1994 Transient Voltage Suppression Devices HARRIS

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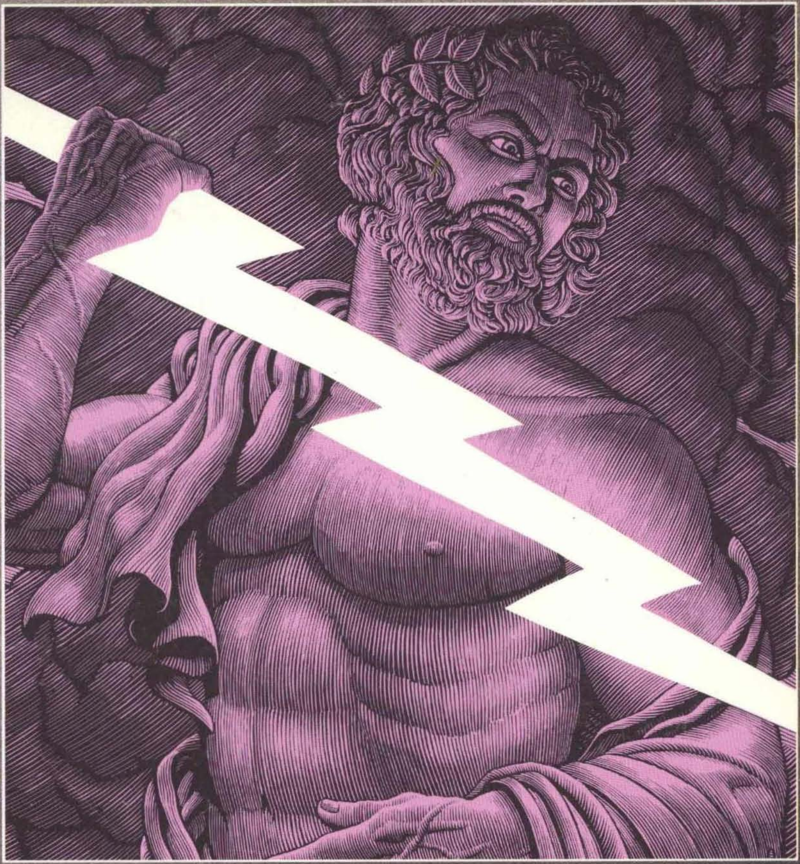

Transient Voltage Suppression Devices

1994

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HARRIS SEMICONDUCTOR TRANSIENT VOLTAGE SUPPRESSION

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TRANSIENT VOLTAGE SUPPRESSION

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MOV Index

MOV Index (Continued)

MOV Index (Continued)

Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

TVS 1

VOLTAGE TRANSIENTS — AN OVERVIEW

To treat any problem, the scope of the problem must first be established. This chapter is an overview of the sources and nature of transient overvoltages, the problems they can cause and the equipment for testing and monitoring them.

Transients in electrical circuits result from the sudden release of previously stored energy. This energy can be stored within the circuit and released by a voluntary or controlled switching action or it can be stored outside the circuit and be injected or coupled into the circuit of interest by some action beyond the control of the circuit designer.

Transients may occur either in repeatable fashion or as random impulses. Repeatable transients, such as commutation voltage spikes, inductive load switching, etc., are more easily observed, defined and suppressed. Random transients are more elusive. They occur at unpredictable times, at remote locations, and require installation of monitoring instruments to detect their occurrence. In fact, a direct corollary of Murphy's law states that the best transient suppressor is a transient monitor! However, enough experience has been accumulated to provide reasonable guidelines of the transient environments in low voltage ac power circuits,[1,2] telecommunications equipment[3] and automotive electrical systems.[4]

Effective transient overvoltage protection requires that the impulse energy be dissipated in the added suppressor at a voltage low enough to ensure the survival of circuit components. The following sections will discuss in detail the two categories of transients, how they occur, their effects and their detection.

1.1 REPEATABLE TRANSIENTS

A sudden change in the electrical conditions of any circuit will cause a transient voltage to be generated from the energy stored in circuit inductance and capacitance. The rate of change in current (di/dt) in an inductor (L) will generate a voltage equal to -L di/dt, and it will be of a polarity that causes current to continue flowing in the same direction.

It is this effect that accounts for most switching-induced transient overvoltages. It occurs as commutating spikes in power conversion circuits, when switching loads and under fault conditions. The effect is brief, since the source is limited to the energy stored in the inductance ($\frac{1}{2}Li^2$), and it is generally dissipated at a high instantaneous power (Energy = power x time). But the simple effect of one switching operation can be repeated several times during a switching sequence (consider arcing in the contact gap of a switch), so that cumulative effects can be significant.

1.1.1 Energizing the Transformer Primary

When a transformer is energized at the peak of the supply voltage, the coupling of this voltage step function to the stray capacitance and inductance of the secondary winding can generate an oscillatory transient voltage with a peak amplitude up to twice the normal peak secondary voltage. (Figure 1.1)

Subsequent oscillations depend on the L and C parameters of the circuit. Another important point to remember is that the secondary side will be part of a capacitive divider network in series with the transformer interwinding capacitance (C_S). This capacitively coupled voltage spike has no direct relationship to the turns ratio of the transformer, so that it is conceivable that the secondary circuit can see a substantial fraction of the peak applied primary voltage.

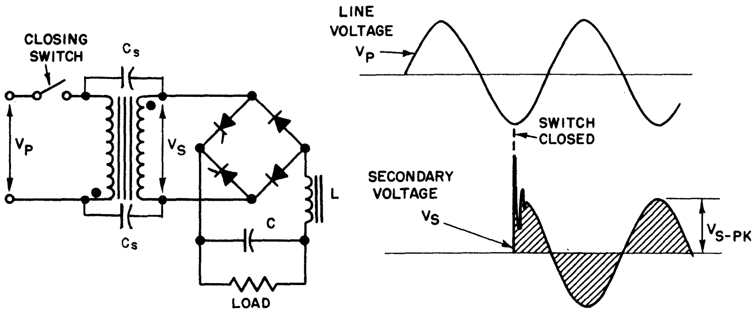


Figure 1.1 — Voltage Transient Caused by Energizing Transformer Primary

1.1.2 De-Energizing the Transformer Primary

The opening of the primary circuit of a transformer generates extreme voltage transients, especially if the transformer drives a high impedance load. Transients in excess of ten times normal voltage have been observed across power semiconductors when this type of switching occurs.

Interrupting the transformer magnetizing current, and the resulting collapse of the magnetic flux in the core, couples a high voltage transient into the transformer secondary winding, as shown in Figure 1.2.

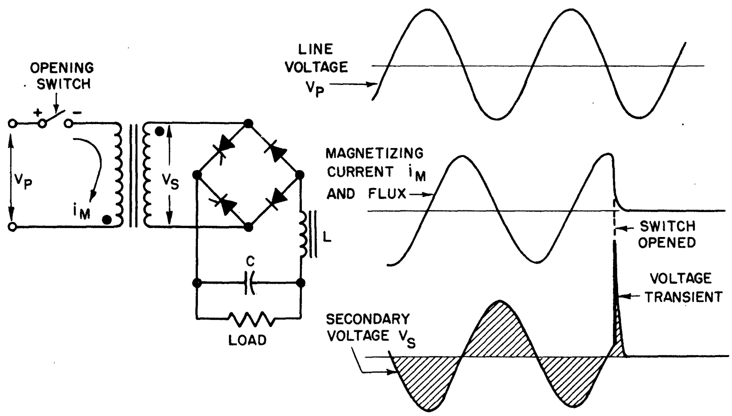


Figure 1.2 — Voltage Transient Caused by Interruption of Transformer Magnetizing Current

Unless a low-impedance discharge path is provided, this burst of transient energy appears across the load. If this load is a semiconductor device or capacitor with limited voltage capabilities, that component may fail. The transients produced by interrupting the magnetizing current are usually quite severe. For example, the stored energy in the magnetizing field of a 150kVA transformer can be 9J.

1.1.3 Fault with Inductive Power Source

If a short develops on any power system, devices parallel to the load may be destroyed as the fuse clears.

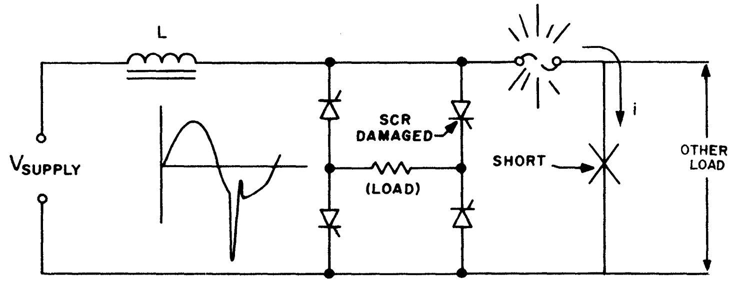


Figure 1.3 — Voltage Transient Cause by Fuse Blowing During Power Fault

When the fuse or circuit breaker of Figure 1.3 opens, it interrupts the fault current, causing the slightly inductive power source to generate a high voltage (-L di/dt), high energy (½Li²) transient across any parallel devices. Suddenly interrupting a high current load will have a similar effect.

1.1.4 Switch Arcing

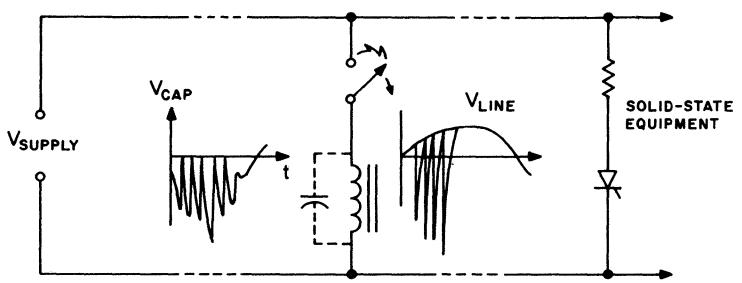


Figure 1.4 — Voltage Transients Caused by Switch Arcing

When current in an inductive circuit, such as a relay coil or a filter reactor, is interrupted by a contractor, the inductance tries to maintain its current by charging the stray capacitance. Similar action can take place during a closing sequence if the contacts bounce open after the initial closing Figure 1.4. The high initial charging current will oscillate in the inductance and capacitance at a high frequency. When the voltage at the contact rises, breakdown of the gap is possible since the distance is still very small during the opening motion of the contact. The contact arc will clear at the current zero of the oscillation but it will restrike as the contact voltage rises again. As the contacts are moving farther apart, each restrike must occur at a higher and higher voltage until the contact succeeds in interrupting the current.

This restrike and escalation effect is particularly apparent in Figure 1.5, where a switch opens a relay coil of 1H, having about 0.001μF of distributed (stray) capacitance in the winding. Starting with an initial dc current of 100mA, the circuit produces hundreds of restrikes (hence, the "white" band on the oscillogram) at high repetition rate, until the circuit clears, but not before having reached a peak of 3kV in contrast to the initial 125V in the circuit.

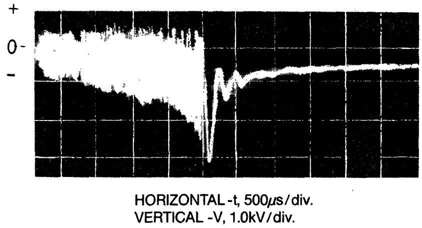


Figure 1.5 — Voltage Escalation During Restrikes

Electromechanical contacts generate transients which they generally can survive. However, in the example just discussed, the 2.5ms long sequence of restrikes and attendant high current may be damaging to the contacts. Also, the transients injected into the power system during the restrike can be damaging to other loads.

In an attempt to eliminate electromechanical switches and their arcing problem, solid-state switches are recommended with good reason! However, if these switches are applied without discrimination in inductive circuits, the very effectiveness of the interruption can lead the solid-state switch to "commit suicide" by generating high transients.

In the example of Figure 1.6, the transistor used for switching 400mA in a 70mH solenoid is exposed to 420V spikes, although the circuit voltage is only 150V.

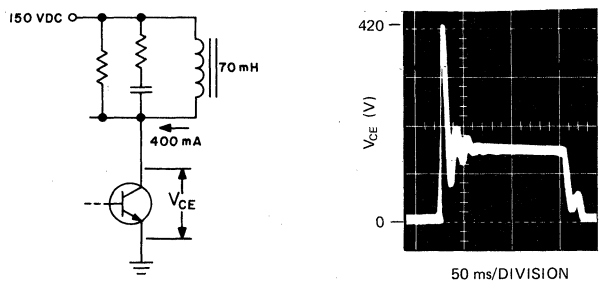


Figure 1.6 — Transistor Switching Transient

Whenever possible, a system should be examined for potential sources of transient overvoltage so they can be eliminated at the source, for one source can affect many components. If the sources are many (or unidentifiable) and the susceptible components few, it may be more practical then to apply suppression at the components.

1.2 RANDOM TRANSIENTS

Frequently, transient problems arise from the power source feeding the circuit. These transients create the most consternation because it is difficult to define their amplitude, duration and energy content. The transients are generally caused by switching parallel loads on the same branch of a distribution system, although they also can be caused by lightning. Communication lines, such as alarm and telephone systems, are also affected by lightning and power system faults.

To deal with random transients, a statistical approach has been taken to identify the nature of line overvoltages. While recordings of transients have been made, one cannot state that on a specific system there is an "X" probability of encountering a transient voltage of "Y" amplitude. Therefore, one is limited to quoting an "average" situation, while being well aware that large deviations from this average can occur, depending on the characteristics of the specific system.

In the following sections, the recorded experiences of three types of systems will be described. These are: 1) ac power lines (up to 1000V); 2) telecommunication systems; and 3) automotive systems.

1.3 TRANSIENTS ON AC POWER LINES

Data collected from various sources has provided the basis for this guide to transient overvoltages.[1,5,6,7,8]

1.3.1 Amplitude and Frequency of Occurrence

The amplitude of transient recordings covers the range from harmless values just above normal voltage to several kilovolts. For 120V ac lines, flashover of the typical wiring spacing produces an upper limit between 6 and 8kV. Ironically, the better the wiring practices, the higher the flashover, allowing higher transients to exist in the wiring system. Studies of the frequency of occurrence and amplitude agree on an upper limit and a *relative* frequency of occurrence. Figure 1.7 shows frequency as a function of amplitude. Experience indicates that devices with less than 2kV withstand capability will have poor service life in the unprotected residential environment. Prudent design will aim for 3kV capability, although, where safety is of the utmost concern, designing for 6kV can cope with these rare but possible occurrences.

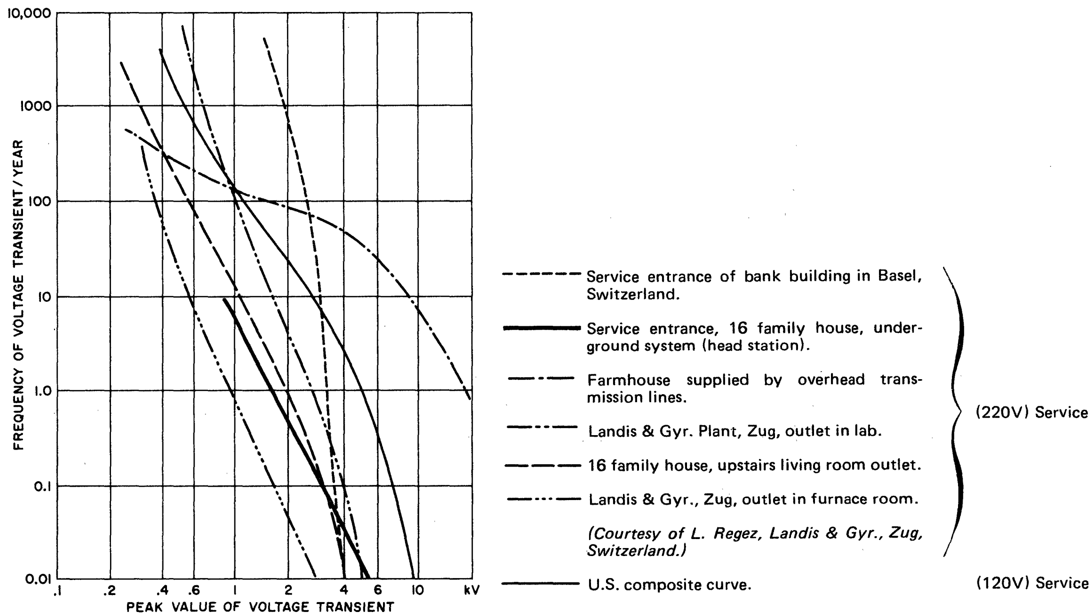


Figure 1.7 — Frequency of Occurrence of Transient Overvoltages in 220V and 120V Systems

For systems of higher voltages (220/240V, 480V), limited data is available for U.S. systems. However, the curves of Figure 1.8 indicate the difference between the two classes, 120V and 220V systems, is smaller than the differences within each class.[8] One can conclude that the amplitude of the transient depends more upon the amount of externally coupled energy and the system impedance than upon the system voltage.

For internal switching transients in the power system, Figure 1.8 shows the relationship (computed and measured) between system voltage and transient peaks.[8] Clearly, there is no direct linear increase of the transient amplitude as the system voltage is increased.

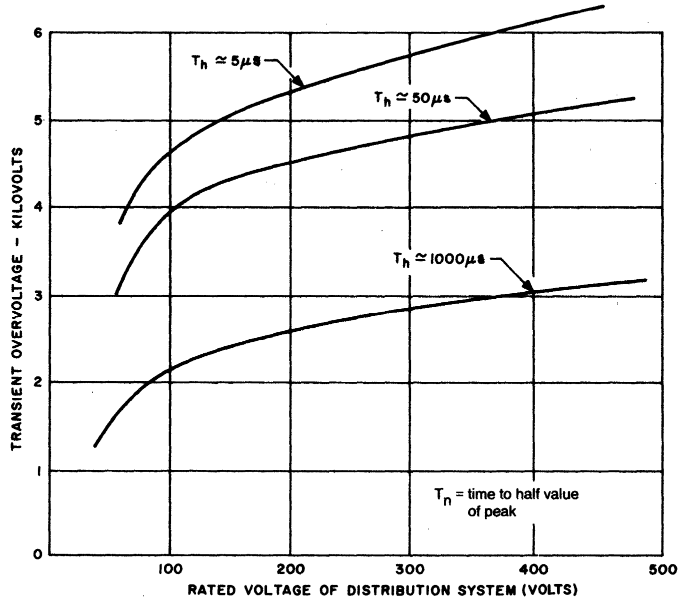


Figure 1.8 — Switching Voltage Transients as a Function of the System Voltage for Three Values of the Transient Tail (Time to Half-Value)

(Data Courtesy of L. Regez, Landis & Gyr., Zug, Switzerland)

Some indication of the uncertainty concerning the expected transient level can be found in the industrial practice of choosing semiconductor ratings. Most industrial users of power semiconductors choose semiconductor voltage ratings from 2.0 to 2.5 times the applied peak steady-state voltage, in conjunction with rudimentary transient suppression, in order to ensure long-term reliability. Whether or not this ratio is realistically related to actual transient levels has not been established; the safety factor is simply chosen by experience. While it is dangerous to argue against successful experience, there are enough cases where this rule of thumb is insufficient and thus a more exact approach is justified. Another objection to the indiscriminate rule of thumb is economic. Specifying 2.5 times the peak system voltage results in a high price penalty for these components. It is normally unrealistic and uneconomical to specify semiconductors that should withstand transients without protection. The optimum situation is a combination of low cost transient protection combined with lower cost semiconductors having lower voltage ratings.

1.3.2 Duration, Waveform and Source Impedance

There is a lack of definitive data on the duration, waveform and source impedance of transient overvoltages in ac power circuits. These three parameters are important for estimating the energy that a transient can deliver to a suppressor. It is desirable to have a means of simulating the environment through a model of the transient overvoltage pulse. Suggestions have been made to use standard impulses initially developed for other applications. For instance, the classical 1.2 x 50μs unidirectional voltage impulse specified in high voltage systems has been proposed.[9] Also the repetitive burst of 1.5 MHz oscillations ("SWC") specified for low-voltage and control systems exposed to transients induced by high-voltage disconnect switches in utility switch yards is another suggestion.[10]

Working Groups of the IEEE and the International Electrotechnical Commission have developed standard test waves and source impedance definitions. These efforts are aiming at moving away from a concept whereby one should *duplicate* environmental conditions and towards a concept of one standard wave or a few standard waves *arbitrarily* specified. The justifications are that equipments built to meet such standards have had satisfactory field experience and provide a relative standard against which different levels of protection can be compared. A condition for acceptance of these standard waves is that they be easy to produce in the laboratory.[11] This is the central idea of the TCL (Transient Control Level) concept which is currently being proposed to users and manufacturers in the electronics industry. Acceptance of this concept will increase the ability to test and evaluate the reliability of devices and systems at acceptable cost.

1.4 TELECOMMUNICATION LINE TRANSIENTS

Transient overvoltages occurring in telephone lines can usually be traced to two main sources: lightning and 50/60 Hz power lines. Lightning overvoltage is caused by a strike to the conductor of an open wire system or to the shield of a telephone cable. Most modern telephone lines are contained in shielded cables. When lighthing or other currents flow on the shield of a cable, voltages are induced between the internal conductors and the shield.[12] The magnitudes of the induced voltages depend on the resistance of the shield material, openings in its construction, and on the dielectric characteristics and surge impedance of the cable.

The close proximity of telephone cables and power distribution systems, often sharing right-of-way-poles and even ground wires, is a source of transient overvoltages for the telephone system. Overvoltages can arise from physical contact of falling wires, electromagnetic induction, and ground potential rise. Chapter 5 of this manual presents a detailed discussion of lightning-induced and power system-induced transients.

1.5 AUTOMOBILE TRANSIENTS

Four principal types of voltage transients are encountered in an automobile. These are "load dump," alternator field decay, inductive switching and mutual coupling.[4] In addition, cold morning "jump starts" with 24V batteries occur in some areas.

The load dump transient is the most severe and occurs when the alternator current loading is abruptly reduced. The most demanding case is often initiated by the disconnection of a partially discharged battery due to defective terminal connections. Transient voltages have been reported over 100V lasting up to 500ms with energy levels in the range of tens to hundreds of joules.

Switching of inductive loads, such as motors and solenoids, will create negative polarity transient voltages with a smaller positive excursion. The voltage waveform has been observed to rise to a level of -210V and +80V and last as long as 320μs. The impedance to the transient is unknown, leading some designers to test with very low impedance, resulting in the use of more expensive components than necessary.

The alternator field decay transient is essentially an inductive load switching transient. When the ignition switch is turned off, the decay of the alternator field produces a negative voltage spike, whose amplitude is dependent on the voltage regulator cycle and load. It varies between -40V to -100V and can last 200ms.

Other unexplained transients have been recorded with peaks of 600V upon engine shutdown. Furthermore, removal of regulation devices, particularly the battery, will raise normally innocuous effects to dangerous levels. For example, ignition pulses up to 75V and 90μs in duration have been observed with the battery disconnected.

Chapter 6 provides a comprehensive review of automotive transients and practical suppression techniques to protect automotive electronics.

1.6 EFFECTS OF VOLTAGE TRANSIENTS

1.6.1 Effects on Semiconductors

Most semiconductor devices are intolerant of voltage transients in excess of their voltage ratings. Even such a short-lived transient as a few microseconds can cause the semiconductor to fail catastrophically or may degrade it so as to shorten its useful life.

Frequently, damage occurs when a high reverse voltage is applied to a non-conducting PN junction. The junction may avalanche at a small point due to the non-uniformity of the electric field. Also, excess leakage current can occur across the passivated junction between the terminations on the pellet surface. The current can create a low resistance channel that degrades the junction blocking voltage capability below the applied steady-state voltage. In the avalanche case, thermal runaway can occur because of localized heating building up to cause a melt-through which destroys the junction.

If the base-emitter junction of a transistor is repetitively "avalanched" or "zenered" by a reverse pulse, the forward current gain may be degraded. The triggering sensitivity of a thyristor will be reduced in the same manner by "zenering" the gate-cathode junction. Thyristors can also be damaged if turned on by a high voltage spike (forward breakover) under bias conditions that allow a rate of current increase (di/dt) beyond device capability. This will occur in virtually all practical circuits because the discharge of the RC dv/dt protection circuits will exceed device capability for di/dt and destroy the thyristor.

1.6.2 Effects on Electromechanical Contacts

The high voltage generated by breaking current to an inductor with a mechanical switch will ultimately cause pitting, welding, material transfer, or erosion of the contacts. The nature of ultimate failure of the contacts depends upon such factors as the type of metal used, rate of opening, contact bounce, atmosphere, temperature, steady-state and inrush currents, and ac or dc operation. Perhaps most important is the amount of energy dissipated in each operation of the contacts.

The actual breaking of current by a set of contacts is a complex operation. The ultimate break occurs at a microscopic bridge of metal which, due to the inductive load, is forced to carry nearly all the original steady-state current. Ohmic heating of this bridge causes it to form a plasma, which will conduct current between the contacts when supplied with a current and voltage above a certain threshold. The inductor, of course, is more than happy to supply adequate voltage ($E_L = -L\,di/dt$). As the contacts separate and the current decreases, a threshold is reached, and the current stops abruptly ("chopping"). Inductor current then charges stray capacitances up to the breakdown voltage of the atmosphere between the contacts. (For air, this occurs at 30kV/in.) The capacitance discharges and recharges repeatedly until all the energy is dissipated. This arc causes sufficient contact heating to melt, oxidize, or "burn" the metal, and when the contacts close again, the contacts may form a poorer connection. If they "bounce," or are closed soon after arcing, the contacts may be sufficiently molten to weld closed. Welding can also occur as a result of high inrush currents passing through the initially formed bridges upon closing.

Good suppression techniques can significantly reduce the amount of energy dissipated at the contacts, with a proportional increase in operating life. Suppression can also reduce the noise generated by this arcing. Voltage-limiting devices are particularly suited to preventing the noisy high-voltage "showering" arc described above and illustrated in Section 1.1.4.

1.6.3 Effects on Insulation

Transient overvoltages can cause breakdown of insulation, resulting in either a temporary disturbance of device operation or instantaneous failure. The insulating level in the former case will be weakened leading to premature failure.

The severity of the breakdown varies with the type of insulation — air, liquid, or solid. The first two tend to be self-healing, while breakdown of solid insulation (generally organic materials) is generally a permanent condition.

Air clearances between metal parts in electrical devices and power wiring constitute air gaps, which behave according to the usual physics of gap breakdown (pressure, humidity, shape of electrodes, spacing). The International Electrotechnical Commission Working Group on Low Voltage Insulation Coordination has developed a table listing the minimum clearances in air for optimum and worst case electric field conditions existing between electrodes.[13] Breakdown of the clearance between metal parts can be viewed as a form of protection, limiting the overvoltage on the rest of the circuit. However, this protection is dependent upon the likelihood of ac line current that may follow during the arc breakdown. Normally, power-follow current should cause the system fuse or breaker to function. If the power-follow current heat is limited by circuit impedance, then the system fusing may not operate. In that case, sufficient heat could be generated to cause a fire. Experience with power wiring has shown that metal clearances can flash-over harmlessly under transient voltage conditions, and power-follow problems are rare, but can occur.

In liquid dielectrics, an impulse breakdown not followed by a high current is normally harmless. However, this type of breakdown is of limited interest in low-voltage systems, where liquid insulation systems are seldom used, except in combination with some degree of solid insulation.

Breakdown of solid insulation generally results in local carbonization of an organic material. Inorganic insulation materials are generally mechanically and permanently damaged. When no power-follow current takes place, the system can recover and continue operating. However, the degraded insulating characteristic of the material leads to breakdown at progressively lower levels until a mild overvoltage, even within ac line overvoltage tolerances, brings about the ultimate permanent short circuit. Since the final failure can occur when no transients are present, the real cause of the problem may be concealed.

Breakdown along surfaces of insulation is the concern of "creepage" specifications. The working group of IEC cited above is also generating recommendations on creepage distances. The behavior of the system where creepage is concerned is less predictable than is breakdown of insulation in the bulk because the environment (dust, humidity) will determine the withstand capability of the creepage surface.

When considering the withstand capabilities of any insulation system, two fundamental facts must be remembered. The first is that breakdown of insulation is not instantaneous but is governed by the statistics of avalanche ionization. Hence there is a "volt-time" characteristic, which challenges the designer to coordinate protection systems as a function of the impinging waveshape. The second is that the distribution of voltage across insulation is rarely linear. For example, a steep wave front produces a piling up of voltage in the first few turns of a motor winding, often with reflections inside the winding. Also, the breakdown in the gap between the electrodes, initiating at the surface, is considerably dependent upon the overall field geometry, as well as on macroscopic surface conditions.

1.6.4 Effects on Power Consumption

As a result of the increasing emphasis on energy conservation, a number of transient voltage suppression devices have been offered for sale as energy savers. The premise seems to be that transient overvoltages would cause degradation of electrical equipment leading to increased losses and thus to a waste of energy. No convincing proof has been offered to support this claim, and injunctions against making such claims have been obtained in several states.[14]

1.6.5 Noise Generation

With sensitive logic gates gaining popularity, noise problems are frequent, especially in environments with electromechanical devices. Noise can upset automatic manufacturing equipment, medical equipment, computers, alarms and thyristor-controlled machinery. Such disruption can cause loss of product, time, money, and even human life.

Noise enters a system either directly on wires or grounds connected to the source or through coupling to adjacent wires. Noise problems are dealt with by suppression at the source, at the receiver, or by isolation. Noise is induced when stray capacitance or mutual inductance links the susceptible system to the noise-generating system. The amplitude of the induced noise is then related to the rate-of-change of either the current or the voltage of the noise source. The low-frequency components of the induced noise (which are hardest to filter out) are a result of the amplitude of the original transient impulses.

Frequently, the source of noise is the arcing of contacts breaking current through an inductor, such as a relay coil. A low-current, high-voltage arc creates a series of brief discharges of a damped oscillatory nature, occurring at kHz to MHz frequencies with amplitudes of from 300 to several thousand volts. These pulses and their reflections from loads and line discontinuities travel along the power wires, easily inducing noise in adjacent wiring. This interference is best eliminated by preventing it at the source (the inductance) with voltage-limiting devices such as varistors.

1.6.6 Rate of Rise vs. Amplitude

Interference coupled into electronic systems, as opposed to damage, is most often associated with the rate of rise of the interfering signal rather than its peak amplitude. Consequently, low-amplitude fast-rise interference which is dealt only by the capacitance of a varistor until the clamping level is reached by the impinging interference may still be a problem with the circuit if attempts are made to suppress it with a retrofit varistor at the location of the victim. A much more effective cure would be to install the appropriate varistor near the source of the offending surge, so that the interference radiated or coupled by the surge would be confined to the immediate vicinity of the offending source.

1.7 TRANSIENT DETECTION

Voltage transients are brief and unpredictable. These two characteristics make it difficult to detect and measure them. Even transients described earlier in this chapter as "repeatable" are subject to variations resulting from the timing of the switching operation, the erratic bouncing of contacts, and other random combinations.

The transient detector *par excellence* is the high-frequency storage oscilloscope, but its cost limits its availability. Custom systems have been built to monitor transients on location,[15, 16] but cost has been a limiting factor in this method of detection as well. A conventional oscilloscope with high-frequency response can be used as a monitor if it is provided with single-sweep controls for monitoring transients occurring at random times but at relatively low frequent rates. The operator sets the trigger controls at some threshold level in single-sweep mode and watches the "ready" light on the oscilloscope panel while a camera with open shutter records the screen display. The film is pulled after the operator notices that sweep occurred and, thus, a record is obtained. While not very efficient for extensive monitoring, this method is very effective for short-term panics - the most frequent situation when transients are suspected. Digital storage oscilloscopes with automatic data transfer to a magnetic disc are now available for unattended monitoring.

In recent years, leading oscilloscope manufacturers have developed improved versions of storage oscilloscopes and high-frequency oscilloscopes, and most laboratories now are equipped with one or another. The experienced engineer can put them to work and obtain satisfactory recordings by the technique described above, using normal safeguards against erroneous recordings (check on noise background, stray ground currents, radiation of noise into preamplifier circuits, high frequency response limitations in differential mode, etc.).

A wide variety of suitable analog or digital test instruments is commercially available. These allow economical monitoring of a remote location by providing various degrees of storage (single-event recording, counting above a threshold, digital memory for playback, etc.).

Trade magazines and engineering papers have also described a number of homemade detectors. While these are undoubtedly performing to the satisfaction of their creators, one can question the economic wisdom of investing time and engineering resources to duplicate, debug, validate and calibrate a homemade device when so many commercial units offering well demonstrated and credible performance are available.

1.8 PREVIOUS AND FUTURE SURGE RECORDINGS

The supporting data cited in the IEEE Guide on Surge Voltages, ANSI/IEEE C62-41-1980, are based on voltage surge recordings made in the 1962-1965 period. In that period, digital instrumentation for surge monitoring was not as readily available as it is now, and, most significantly, the proliferation of surge protective devices, such as metal oxide varistors, had not reached the present level.

Measurements, limited to *voltage,* were conducted with oscilloscope/camera systems or with peak-recording instruments. Voltages were generally recorded between the line(s) and the neutral of a single-phase or polyphase power system. No measurements had been reported as neutral-to-ground; some may have been between line and ground. Of course, that distinction is moot for measurements made at the service entrance where neutral and ground are bonded.

An estimate of the number of low-voltage surge protective devices such as varistors used in the United States since 1972 on ac power circuits is in the order of 500 million. An undefined but substantial portion of that number is installed in permanently connected equipment. Therefore, it is now very likely that a new limitation exists in the recording of voltage surges. A surge recording instrument installed indiscriminately at a random location may have a varistor connected across the line near the point being recorded.[17] This situation will have several implications for the recordings obtained in present and future measurements, as contrasted to those of previous measurement campaigns.

1. Locations where voltage surges were previously identified — assuming no change in the source of surges — are now likely to experience lower *voltage* surges, while *current* surges will occur in the newly installed protective devices.
2. Not only will the *peaks* of the observed voltages be changed, but also their waveforms will be affected by the presence of nearby varistors as follows:
   a. If a varistor is located between the source of the surge and the recording instrument, the instrument will record the clamping voltage of the varistor. This voltage will have lower peaks but longer time to half-peak than the original surge.

b. If the instrument is located between the source of the surge and a varistor, or if a varistor is installed in a parallel branch circuit, the instrument will record the clamping voltage of the varistor, *preceded* by a spike corresponding to the inductive drop in the line supplying surge current into the varistor.

c. If a varistor is connected between line and neutral with a surge impinging between line and neutral at the service entrance, a new situation is created: the line-to-neutral voltage is indeed clamped as intended, but the inductive drop in the neutral conductor between the point of connection of the varistor and the service entrance creates a spike voltage between the neutral and the grounding connector at the point of connection of the varistor and downstream points supplied by the same neutral. Because this spike will have a short duration, it will be enhanced by the open-end transmission line effect between the neutral and grounding conductors.[18]

3. The surge voltage limitation function performed by flashover of clearances is more likely to be assumed by new surge protective devices that are constantly being added to the systems.

4. The considerations discussed in paragraphs 1, 2, and 3 above will produce a significant reduction in the *mean* of recorded voltage surges in a population of different locations. This reduction will continue as more and more varistors are installed. The *upper limit,* however, will remain the same for locations where no varistor has yet been installed. A sense of false security and an incorrect description of the environment might be created by attention given only to the average of voltage surges presently recorded in power systems. Furthermore, the need for adequate surge current handling capability of a new candidate surge suppressor might be underestimated if partial surge diversion is already being performed by a nearby varistor. This risk will be exacerbated if an attempt is made to clamp at lower voltages by the installation of a new protective device with a clamping voltage lower than that of the device already installed.[19]

1.9 TRANSIENT TESTING AND STANDARDS

It is desirable to have test criteria and definitions that provide a common engineering language beneficial to both the user and manufacturer of surge protective devices. Regretfully, different terms have come into use through industry practice over the years. Testing standards have tended to proliferate as the measurement objective defines either the characteristics of the protective device or the environment of the application.

The characteristics of each surge protection device will vary according to its basic construction. Protective devices are diverse, being based on ionized gas breakdown, semiconductor junction breakdown, and "charge hopping" conduction. For this reason, it seems sensible to group devices by physical category and set up pertinent standards that are suitable for characterizing their behavior. The standards would use appropriate stress levels and measure those parameters that are critical to ensuring proper performance.

The application environment has demanded different conditions of transient levels. Standards vary depending on system usage, whether protection is intended for power lines, telecommunications, automotive, or aircraft, to name a few. Each environment also has been defined with less than full precision leading to additional diversity on choice of waveshape, amplitude and duration.

Several organizations such as ANSI/IEEE, IEC, UL, NEMA are currently developing guidelines and standards to describe what the environment is likely to be, on the basis of accumulated recording and field experience. From this, test specifications are being prepared[20, 21, 22, 23] that will allow objectives are realistic evaluation of suppressor applications.

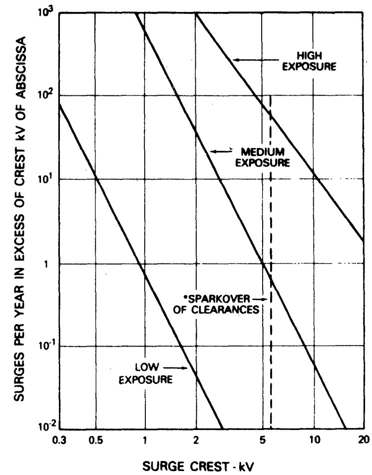
The Development of a Guide* on Surge Voltages in Low-Voltage AC Power Circuits

F.D. MARTZLOFF, FELLOW, IEEE

INTRODUCTION

SURGE VOLTAGES occurring in ac power circuits can be the cause of misoperation or product failure for residential as well as industrial systems. The problem has received increased attention in recent years because miniaturized solid state devices are more sensitive to voltage surges (spikes and transients) than were their predecessors.

Although surge voltage amplitudes and their frequency of occurrence on unprotected circuits are well known, their waveshapes and energy content are less well known. On the basis of measurements, statistics, and theoretical considerations, a practical guide for outlining the environment for use in predicting extreme waveshapes and energy content can nevertheless be established. A Working Group of the Surge Protective Devices Committee has completed such a descriptive Guide.† The Guide proposes two waveforms, one oscillatory, the other unidirectional, depending on the location within the power system. It also includes recommendations for source impedance or short-circuit current. While the major purpose of the Guide is to *describe the environment,* a secondary purpose is to lead toward standard tests.



*In some locations, sparkover of clearances may limit the overvoltages

Fig. 1. Rate of surge occurrence versus voltage level at unprotected locations.

THE ORIGINS OF SURGE VOLTAGES

Surge voltages occurring in low-voltage ac power circuits originate from two major sources: system switching transients and direct or indirect lightning effects on the power system. System switching transients can be divided into transients associated with (1) major power system switching disturbances, such as capacitor bank switching; (2) minor switching near the point of interest, such as an appliance turnoff in a household or the turnoff of other loads in an individual system; (3) resonating circuits associated with switching devices, such as thyristors; and (4) various system faults, such as short circuits and arcing faults.

Measurements and calculations of lightning effects have been made to yield data on what levels can be produced, even if the exact mechanism of any particular surge is unknown. While the data have been recorded primarily on 120, 220/380, or 277/480V systems, the general conclusions should be valid for 600V systems. To the extent that surge voltages are produced by a discrete amount of energy being dumped into a power system, low-impedance, heavy industrial systems can be expected to experience lower peaks from surge voltages than 120V residential systems, but comparable, or greater, amounts of energy potentially available for deposition in a surge suppressor.

RATE OF OCCURRENCE AND VOLTAGE LEVELS IN UNPROTECTED CIRCUITS

The rate of occurrence of surges varies over wide limits, depending on the particular power system. Prediction of the rate for a particular system is always difficult and frequently impossible. Rate is related to the level of the surges; low-level surges are more prevalent than high-level surges.

It is essential to recognize that a surge voltage observed in a power system can be either the driving voltage or the voltage limited by the sparkover of some clearance in the system. Hence, the term *unprotected circuit* must be understood to be a circuit in which no low-voltage protective device has been installed but in which clearance sparkover will eventually limit the maximum voltage. The distribution of surge levels, therefore, is influenced by the surge-producing mechanisms as well as by the sparkover level or clearances in the system. This distinction between actual driving voltage and voltage limited by sparkover is particularly important at the interface between outdoor equipment and indoor equipment. Outdoor equipment has generally higher clearances, hence higher sparkover levels: 10kV may be typical, but 20kV is possible. In contrast, most indoor wiring devices used in 120-240V systems have sparkover levels of about 6kV; this 6kV level, therefore, can be selected as a typical cutoff for the occurrence of surges in indoor power systems.

*Condensed from a paper presented at the 1979 IEEE 14th Electrical/Electronics insulation Conference, Boston, October 9-11 1979. Reprinted with permission of the Institute of Electrical and Electronics Engineers.

†ANSI/IEEE C62.41-1980 Guide on Surge Voltages in Low-Voltage AC Power Circuits.

Data collected from many sources have led to the plot shown in Figure 1. This prediction shows with certainty only a *relative* frequency of occurrence, while the *absolute* number of occurrences can be described only in terms of "low exposure," "medium exposure," or "high exposure." These exposure levels can be defined in general terms as follows:

Low Exposure — Systems in geographical areas known for low lightning activity, with little load switching activity.

Medium Exposure — Systems in geographical areas known for high lightning activity, with frequent and severe switching transients.

High Exposure — Rare but real systems supplied by long overhead lines and subject to reflections at line ends, where the characteristics of the installation produce high sparkover levels of the clearances.

The two lower lines of Figure 1 have been drawn at the same slope, since the data base shows reasonable agreement among several sources on that slope. All lines may be truncated by sparkover of the clearances at levels depending on the withstand voltage of these clearances. The "high-exposure" line needs to be recognized, but it should not be applied indiscriminately to all systems. Such application would penalize the majority of installations, where the exposure is lower.

From the relative values of Figure 1, two typical levels can be cited for practical applications. First, the expectation 3kV transient occurrence on a 120V circuit ranges from 0.01 to 10 per year at a given location — a number sufficiently high to justify the recommendation of a minimum 3kV withstand capability. Second, the sparkover of wiring devices indicates that a 6kV withstand capability may be sufficient to ensure device survival indoors, but a withstand capability of 10kV, or greater, may be required outdoors.

The voltage and current amplitudes presented in the Guide attempt to provide for the vast majority of lightning strikes but should not be considered as "worst case," since this concept cannot be determined realistically. One should think in terms of the statistical distribution of strikes, accepting a reasonable upper limit for most cases. Where the consequences of a failure are not catastrophic but merely represent an annoying economic loss, it is appropriate to make a trade-off of the cost of protection against the likelihood of failure caused by a high but rare surge. For instance, a manufacturer may be concerned with nation-wide failure rates, those at the upper limits of the distribution curve, while the user of a specific system may be concerned with a single failure occurring at a specific location under "worst-case conditions." Rates can be estimated for average systems, however, and even if imprecise, they provide manufacturers and users with guidance. Of equal importance is the observation that surges in the range of 1 to 2kV are fairly common in residential circuits.

Surges occur at random times with respect to the power frequency, and the failure mode of equipment may be affected by the power frequency follow current. Furthermore, the timing of the surge with respect to the power frequency may affect the level at which failure occurs. Consequently, when the failure mode is likely to be affected, surge testing should be done with the line voltage applied to the test piece.

WAVESHAPE OF REPRESENTATIVE SURGE VOLTAGES

Waveshapes in Actual Occurrences

Indoor — Measurements in the field, measurements in the laboratory, and theoretical calculations indicate that most surge voltages in indoor low-voltage systems have oscillatory waveshapes, unlike the well-known and generally accepted unidirectional waves specified in high-voltage insulation standards. A surge impinging on the system excites the natural resonant frequencies of the conductor system. As a result, not only are the surges typically oscillatory, but surges may have different amplitudes and waveshapes at different places in the system. These oscillatory frequencies of surges range from 5kHz to more than 500kHz. A 30 to 100kHz frequency is a realistic measure of a "typical" surge for most residential and light industrial ac line networks.

Outdoor and Service Entrance — Surges encountered in outdoor locations have also been recorded, some oscillatory, other unidirectional. The "classical lightning surge" has been established as 1.2/50μs for a voltage wave and 8/20μs for a current wave, but these waveshapes should not be construed as typical waves for low-voltage circuits. Lightning discharges induce oscillations, reflections, and disturbances that ultimately appear as decaying oscillations in low-voltage systems.

Because the prime concern here is the energy associated with these surges, the waveshape to be selected must involve greater energy than that associated with the indoor environment. Secondary surge arresters have a long history of successful performance, meeting the ANSI C62.1 specification, as detailed below; consequently, these specifications can be adopted as a realistic representation of outdoor waveshapes.

Selection of Representative Waveshapes

The definition of a waveshape to be used as representative of the environment is important for the design of candidate protective devices, since unrealistic requirements, such as excessive duration of the voltage or very low source impedance, place a high energy requirement on the suppressor, with a resulting cost penalty to the end user. The two requirements defined below reflect this trade-off.

Indoor — Based on measurements conducted by several independent organizations in 120 and 240V systems, the waveshape shown in Figure 2 is reasonably representative of surge voltages in these power circuits. Under the proposed description of a "0.5μs - 100kHz ring wave," this waveshape rises in 0.5μs, then decays while oscillating at 100kHz, each peak being about 60% of the preceding peak.

Outdoor — In the outdoor and service entrance environment, as well as in locations close to the service entrance, substantial energy, or current, is still available, in contrast to the indoor environment, where attenuation has taken place. For these locations, the unidirectional impulses long established for secondary arresters are more appropriate than the oscillatory wave.

Accordingly, the recommended waveshape is 1.2/50μs for the open-circuit voltage or voltage applied to a high-impedance device, and 8/20μs for the discharge current or current in a low-impedance device. The numbers used to describe the impulse, 1.2/50 and 8/20, are those defined in IEEE Standard 28 - ANSI

Standard C62.1; Figure 3 presents the waveshape and a graphic description of the numbers.

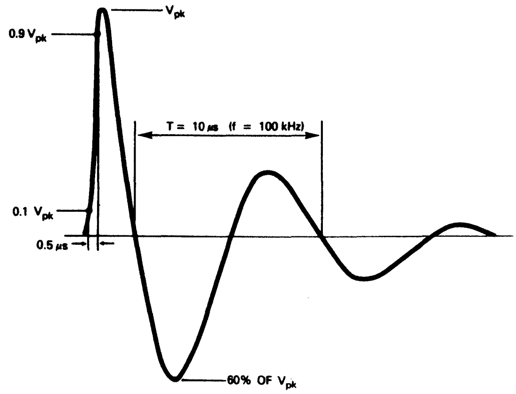


Fig. 2. The proposed 0.5μs - 100kHz ring wave (open-circuit voltage)

ENERGY AND SOURCE IMPEDANCE

General

The energy involved in the interaction of a power system with a surge source and a surge suppressor will divide between the source and the suppressor in accordance with the characteristics of the two impedances. In a gap-type suppressor, the low impedance of the arc after sparkover forces most of the energy to be dissipated elsewhere: for instance, in a resistor added in series with the gap for limiting the power-follow current. In an energy-absorber suppressor, by its very nature, a substantial share of the surge energy is dissipated in the suppressor, but its clamping action does not involve the power-follow energy resulting from the short-circuit action of a gap. It is therefore essential to the effective use of suppression devices that a realistic assumption be made about the source impedance of the surge whose effects are to be duplicated.

The voltage wave shown in Figure 2 is intended to represent the waveshape a surge source would produce across an open circuit. The waveshape will be different when the source is connected to a load having a lower impedance, and the degree to which it is lower is a function of the impedance of the source.

To prevent misunderstanding, a distinction between *source impedance* and *surge impedance* needs to be made. Surge impedance, also called *characteristic impedance,* is a concept relating the parameters of a line to the propogation of traveling waves. For the wiring practices of the ac power circuits discussed here, this characteristic impedance would be in the range of 150 to 300Ω, but because the durations of the waves being discussed (50 to 20μs) are much longer than the travel times in the wiring systems being considered, traveling wave analyses are not useful here.

Source impedance, defined as "the impedance presented by a source energy to the input terminals of a device, or network" (IEEE Standard 100), is a more useful concept here. In the conventional Thevenin's description, the open-circuit voltage (at the terminals of the network or test generator) and the source impedance (of the surge source or test generator) are sufficient to calculate the short-circuit current, as well as any current for a specified suppressor impedance.

The measurements from which Figure 1 was derived were of voltage only. Little was known about the impedance of the circuits upon which the measurements were made. Since then, measurements have been reported on the impedance of power systems. Attempts were made to combine the observed 6kV open-circuit voltage with the assumption of a parallel 50Ω/50μH impedance.

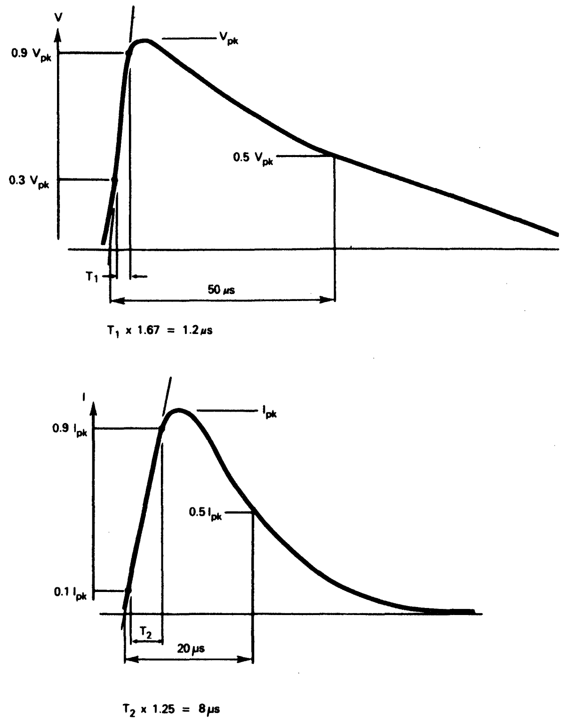


Fig. 3. Unidirectional (ANSI Standard C62.1) waveshapes
(a) open-circuit voltage waveform (b) discharge current waveform

This combination resulted in low energy deposition capability, which was contradicted by field experience of suppressor performance. The problem led to the proposed definition of oscillatory waves as well as high-energy unidirectional waves, in order to produce both the effects of an oscillatory wave and the high-energy deposition capability.

The degree to which source impedance is important depends largely on the type of surge suppressors that are used. The surge suppressors must be able to withstand the current passed through them by the surge source. A test generator of too high an impedance may not subject the device under test to sufficient stresses, while a generator of too low an impedance may subject protective devices to unrealistically severe stresses. A test voltage wave specified without reference to source impedance could imply zero source impedance — one capable of producing that voltage across any impedance, even a short circuit. That would imply an infinite surge current, clearly an unrealistic situation.

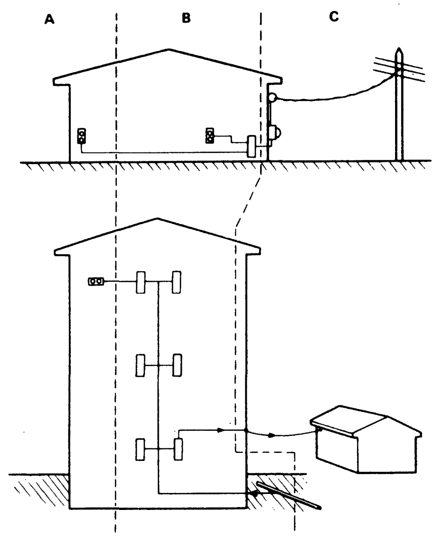
Because of the wide range of possible source impedances and the difficulty of selecting a specific value, three broad categories of building locations are proposed to represent the vast majority of locations, from those near the service entrance to those remote from it. The source impedance of the surge increases from the outside to locations well within the building. Open-circuit voltages, on the other hand, show little variation within a building because the wiring provides little attenuation. Figure 4 illustrates the application of the three categories to the wiring of a building.

For the two most common location categories, Table 1 shows the representative surge voltages and currents, with the waveforms and amplitudes of the surges, and high- or low-impedance specimen. For the discharge current shown, the last two columns show the energy that would be deposited in a suppressor clamping at 500V and 1000V, typical of 120V or 240V applications, respectively. For higher system voltages (assuming the same current values), the energy would increase in proportion to the clamping voltage of a suppressor suitable for that system voltage.

The values shown in Table 1 represent the maximum range and correspond to the "medium exposure" situation of Figure 1. For less exposed systems, or when the prospect of a failure is not highly objectionable, one could specify lower values of open-circuit voltages with corresponding reductions in the discharge currents.

The 6kV open-circuit voltage derives from two facts: the limiting action of wiring device sparkover and the unattenuated propagation of voltages in unloaded systems. The 3kA discharge current in Category B derives from experimental results: field experience in suppressor performance and simulated lightning tests. The two levels of discharge currents from the 0.5μs - 100kHz wave derive from the increasing impedance expected in moving from Category B to Category A.

Location Category C is likely to be exposed to substantially higher voltages than location Category B because the limiting effect of sparkover is not available. The "medium exposure" rates of Figure 1 could apply, with voltage in excess of 10kV and discharge currents of 10kA, or more. Installing unprotected load equipment in location Category C is not recommended; the installation of secondary arresters, however, can provide the necessary protection. Secondary arresters having 10kA ratings have been applied successfully for many years in location Category C (ANSI Standards C62.1 and C62.2).



A. Outlets and Long Branch Circuits
All outlets at more than 10m (30 ft) from Category B with wires #14-10
All outlets at more than 20m (60 ft) from Category C with wires #14-10

B. Major Feeders and Short Branch Circuits
Distribution panel devices
Bus and feeder systems in industrial plants
Heavy appliance outlets with "short" connections to the service entrance
Lighting systems in commercial

C. Outside and Service Entrance
Service drop from pole to building entrance
Run between meter and distribution panel
Overhead line to detached buildings
Underground lines to well pumps

Fig. 4. Location categories

TABLE 1
SURGE VOLTAGES AND CURRENTS DEEMED TO REPRESENT THE INDOOR ENVIRONMENT AND SUGGESTED FOR CONSIDERATION IN DESIGNING PROTECTIVE SYSTEMS

Location Category	Comparable To IEC 664 Category	Impulse: Waveform	Impulse: Medium Exposure Amplitude	Type of Specimen or Load Circuit	Energy (Joules) Deposited in a Suppressor(3) With Clamping Voltage of 500V	Energy (Joules) Deposited in a Suppressor(3) With Clamping Voltage of 1000V
A. Long branch					(120V System)	(240V System)
circuits and	II	0.5μs - 100kHz	6kV	High impedance(1)	—	—
outlets			200A	Low impedance(2)	0.8	1.6
B. Major feeders		1.2/50μs	6kV	High impedance(1)	—	—
short branch	III	8/20μs	3kA	Low impedance(2)	40	80
circuits, and						
load center		0.5μs - 100kHz	6kV	High impedance(1)	—	—
			500A	Low impedance(2)	2	4

Notes: (1) For high-impedance test specimens or load circuits, the voltage shown represents the surge voltage. In making simulation tests, use that value for the open-circuit voltage of the test generator.
(2) For low-impedance test specimens or load circuits, the current shown represents the discharge current of the surge (not the short-circuit current of the power system). In making simulation tests, use that current for the short-circuit current of the test generator.
(3) Other suppressors which have different clamping voltages would receive different energy levels.

REFERENCES

1. Martzloff, F.D., *"The Development of a Guide on Surge Voltages in Low-Voltage AC Power Circuits,"* Report 81CRD047, General Electric, Schenectady, New York 1981.
2. Greenwood, Allan, Electrical Transients in Power Systems, Wiley-Interscience, New York, 1971.
3. Bodle, D.W., A.J. Ghaze, M. Syed and R.L. Woodside, Characterization of the Electrical Environment, Toronto: University of Toronto Press, 1970.
4. Recommended Environmental Practices for Electronic Equipment Design, Publication SAE J1211, Society of Automotive Engineers, Warrendale, Pennsylvania.
5. Hahn, G.J. and F.D. Martzloff, *"Surge Voltages in Residential and Industrial Power Circuits,"* IEEE Trans. PAS-89, No. 6, July-Aug. 1970, pp. 1049-1056.
6. Bull, J.H., *"Voltage Spikes in L.V. Distribution Systems and Their Effects on the Use of Electronic Control Equipment,"* Report No. 5254, Electrical Research Assn., Cleeve Rd., Leatherhead, Surrey, Great Britain, 1968.
7. IEEE Surge Protective Devices Committee, *"Bibliography on Surge Voltages in AC Power Circuits Rated 600 Volts or Less,"* IEEE Trans. PAS-89, No. 6, July-Aug. 1970, pp. 1056-1061.
8. Data contributed by L. Regez (Landis & Gyr. Co., Zug, Switzerland), Swiss representative to IEC Working Group 28A on Low Voltage Insulation Coordination.
9. Surge Arresters for Alternating Current Power Circuits, ANSI Standard C62.1, IEEE Standard 28, 1974.
10. Guide for Surge Withstand Capability (SWC) Test, ANSI Standard C37.90a, 1974, IEEE Standard 472, 1974.
11. Martzloff, F.D. and F.A. Fisher, *"Transient Control Level Philosophy and Implementation — The Reasoning Behind the Philosophy,"* 77CH1224-SEMC, Proceedings of the 2nd Symposium on EMC, Montreux, June 1977.
12. Fisher, F.A., *"A Way to Evaluate the Effects of Changing Magnetic Fields on Shielded Conductors,"* Report 77CRD158, General Electric, Schenectady, New York, July 1977.
13. *"Insulation Co-ordination Within Low-Voltage Systems, including Clearances and Creepage Distances for Equipment,"* IEC Report 664, 1980.
14. *"Evaluation of Transient Voltage Suppressors for Saving Electric Energy,"* EPRI EM-1722, February 1981.
15. Allen, George W., *"Design of Power-Line Monitoring Equipment,"* IEEE Trans. PAS-90, No. 6, Nov-Dec. 1971, pp. 2604-2609.
16. Herzog, R., *"How to Catch a Transient,"* Machine Design Magazine, March 1973, pp. 170-175.
17. Martzloff, F.D., Discussion of paper *"Rural Alaska Electric Power Quality,"* IEEE Transactions on Power Apparatus and Systems PAS-104, No. 3, pp. 618-619, March 1985.
18. Martzloff, F.D. and Gauper, H.A., Surge and High Frequency Propagation in Industrial Power Lines, 85CRD087,General Electric Company, Schenectady, New York, 1985.
19. Martzloff, F.D., *"Varistor versus Environment: Winning the Rematch,"* IEEE/PES Summer Meeting, 1985 — Scheduled for IEEE Transaction on Power Apparatus and System, 1986.
20. IEEE Standard Test Specifications for Gas Tube Surge-Protective Devices, ANSI/IEEE C62.31-1981.
21. IEEE Standard Test Specifications for Low-Voltage Air Gap Surge-Protective Devices (Excluding Valve and Expulsion Type Devices), ANSI/IEEE C62.32-1981.
22. IEEE Standard Test Specifications for Varistor Surge-Protective Devices, ANSI/IEEE C62.33-1982.
23. IEEE Standard Test Specifications for Avalanche Junction Semiconductor Surge-Protective Devices, IEEE C62.34-1984.

TVS 2

TRANSIENT SUPPRESSION — DEVICES AND PRINCIPLES

This chapter presents a brief description of available transient suppressors and their operation, and discusses how these devices can be applied.

2.1 TRANSIENT SUPPRESSION DEVICES

There are two major categories of transient suppressors: a) those that attenuate transients, thus preventing their propagation into the sensitive circuit; and b) those that divert transients away from sensitive loads and so limit the residual voltages.

Attenuating a transient — that is, keeping it from propagating away from its source or keeping it from impinging on a sensitive load — is accomplished with filters inserted in series within a circuit. The filter, generally of the low-pass type, attenuates the transient (high frequency) and allows the signal or power flow (low-frequency) to continue undisturbed.

Diverting a transient can be accomplished with a voltage-clamping type device or with a "crowbar" type device. The designs of these two types, as well as their operation and application, are different enough to warrant a brief discussion of each in general terms. A more detailed description will follow later in this chapter.

A voltage-clamping device is a component having a variable impedance depending on the current flowing through the device or on the voltage across its terminal. These devices exhibit a nonlinear impedance characteristic — that is, Ohm's law is applicable but the equation has a variable R. The variation of the impedance is monotonic; in other words, it does not contain discontinuities in contrast to the crowbar device, which exhibits a turn-on action. The volt-ampere characteristic of these clamping devices is somewhat time-dependent, but they do not involve a time delay as do the sparkover of a gap or the triggering of a thyristor.

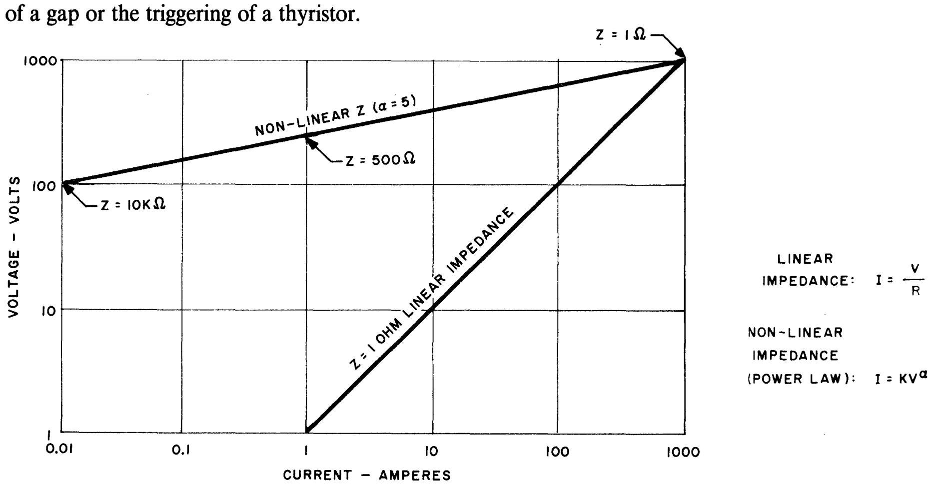


Figure 2.1 — Voltage/Current Characteristic for a Linear 1 Ohm Resistor and Nonlinear Varistor

With a voltage-clamping device, the circuit is unaffected by the presence of the device before and after the transient for any steady-state voltage below the clamping level. The voltage clamping action results from the increased current drawn through the device as the voltage tends to rise. If this current increase is greater than the voltage rise, the impedance of the device is nonlinear (Figure 2.1). The apparent "clamping" of the voltage results from the increased voltage drop (IR) in the source impedance due to the increased current. It should be clearly understood that the device depends on the source impedance to produce the clamping. One is seeing a voltage divider action at work, where the ratio of the divider is not constant but changes. However, if the source impedance is very low, then the ratio is low. The suppressor cannot be effective with zero source impedance (Figure 2.2) and works best when the voltage divider action can be implemented.

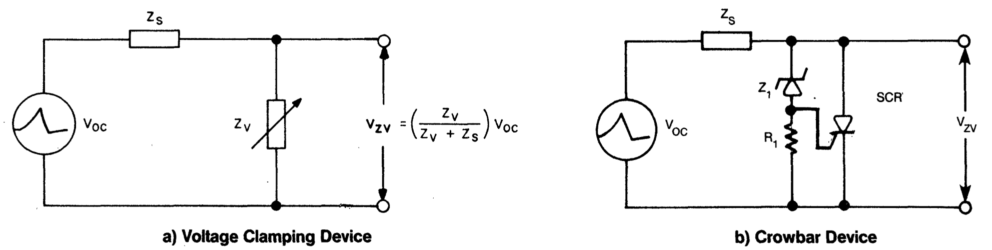


Figure 2.2 — Division of Voltage with Variable Impedance Suppressor

Crowbar-type devices involve a switching action, either the breakdown of a gas between electrodes or the turn-on of a thyristor. After switching on, they offer a very low impedance path which diverts the transient away from the parallel-connected load.

These crowbar devices have two limitations. The first is their delay time, typically microseconds, which leaves the load unprotected during the initial rise. The second limitation is that a power current from the steady-state voltage source will follow the surge discharge (called "follow-current" or "power-follow"). In ac circuits, this power-follow current may or may not be cleared at a natural current zero; in dc circuits the clearing is even more uncertain. Therefore, if the crowbar device is not designed to provide self-clearing action within specified limits of surge energy and system voltage and power-follow current, additional means must be provided to open the power circuit.

2.1.1 Filters

The frequency components of a transient are several orders of magnitude above the power frequency of an ac circuit and, of course, a dc circuit. Therefore, an obvious solution is to install a low-pass filter between the source of transients and the sensitive load.

The simplest form of filter is a capacitor placed across the line. The impedance of the capacitor forms a voltage divider with the source impedance, resulting in attenuation of the transient at high frequencies. This simple approach may have undesirable side effects, such as a) unwanted resonances with inductive components located elsewhere in the circuit leading to high peak voltages; b) high inrush currents during switching, or, c) excessive reactive load on the power system voltage. These undesirable effects can be reduced by adding a series resistor — hence, the very popular use of RC snubbers and suppression networks. However, the price of the added resistance is less effective clamping.

Beyond the simple RC network, conventional filters comprising inductances and capacitors are widely used for interference protection. As a bonus, they also offer an effective transient protection, provided that the filter's front-end components can withstand the high voltage associated with the transient.

There is a fundamental limitation in the use of capacitors and filters for transient protection when the source of transients in unknown. The capacitor response is indeed nonlinear with frequency, but it is still a linear function of current.

In Chapter 1, it was explained that to design a protection scheme against random transients, it is often necessary to make an assumption about the characteristics of the impinging transient. If an error in the source impedance or in the open-circuit voltage is made in that assumption, the consequences for a linear suppressor and a nonlinear suppressor are dramatically different as demonstrated by the following comparison.

A SIMPLIFIED COMPARISON BETWEEN PROTECTION WITH *LINEAR* AND *NONLINEAR* SUPPRESSOR DEVICES

Assume an open-circuit voltage of 3000V (see Figure 2.2):

1. If the source impedance is $Z_S = 50\Omega$
   with a suppressor impedance of $Z_V = 8\Omega$
   the expected current is:

$$I = \frac{3000}{50 + 8} = 51.7\text{A and } V_R = 8 \times 51.7 = 414\text{V}$$

The maximum voltage appearing across the terminals of a typical nonlinear V130LA20A varistor at 51.7A is 330V.

Note that:

$$\begin{aligned} Z_S \times I &= 50 \times 51.7 = 2586\text{V} \\ Z_V \times I &= 8 \times 51.7 = \underline{\ \ 414\text{V}} \\ &= 3000\text{V} \end{aligned}$$

2. If the source impedance is only 5Ω (a 10:1 error in the assumption), the voltage across the same linear 8Ω suppressor is:

$$V_R = 3000 \frac{8}{5 + 8} = 1850\text{V}$$

However, the nonlinear varistor has a much lower impedance; again, by iteration from the characteristic curve, try 400V at 500A, which is correct for the V130LA20A; to prove the correctness of our "educated guess" we calculate I.

$$I = \frac{3000\text{-}400\text{V}}{5} = 520\text{A} \qquad \begin{aligned} Z_S \times I &= 5 \times 520 = 2600\text{V} \\ V_C &= \underline{\ \ 400\text{V}} \\ &= 3000\text{V} \end{aligned}$$

which justifies the "educated guess" of 500A in the circuit.*

Summary

3000V "OPEN-CIRCUIT" TRANSIENT VOLTAGE

Protective Level Achieved	Assumed Source Impedance	
	50Ω	5Ω
Linear 8Ω	414V	1850V
Nonlinear Varistor	330V	400V

Similar calculations can be made, with similar conclusions, for an assumed error in open-circuit voltage at a fixed source impedance. In that case, the linear device is even more sensitive to an error in the assumption. The calculations are left for the interested reader to work out.

*An educated guess, or the result of an iteration — see "Designing with Harris Varistors," Chapter 4.

The example calculated in the box shows that a source impedance change from an assumed 50Ω to 5Ω can produce a change of about 414V to 1850V for the protective voltage of a typical linear suppressor. With a typical nonlinear suppressor, the corresponding change is only 330V to 400V. In other words, a variation of only 21% in the protective level achieved with a nonlinear suppressor occurs for a 10 to 1 error in the assumption made on the transient parameters, in contrast to a 447% variation in the protective level with a linear suppressor for the same error in assumption. Nonlinear voltage-clamping devices give the lowest clamping voltage, resulting in the best protection against transients.

2.1.2 Crowbar Devices

This category of suppressors, primarily gas tubes (also called "spark gaps") or carbon-block protectors, is widely used in the communication field where power-follow current is less of a problem than in power circuits. Another form of these suppressors is the hybrid circuit which uses solid-state or ionic devices where a control circuit causes turn-on of an active component.

In effect, a crowbar device short-circuits a high voltage to ground. This short will continue until the current is brought to a low level. A voltage clamping device will never reduce the line voltage below its steady-state value but the crowbar device often will. Because the voltage (arc or forward-drop) during the discharge is held very low, substantial currents can be carried by the suppressor without dissipating a considerable amount of energy within the suppressor. This capability is the major advantage of these suppressors. However, two limitations must be considered.

Volt-Time Response — When the voltage rises across a spark gap, no significant conduction can take place until transition to the arc mode has occurred by avalanche breakdown of the gas between the electrodes. The delay time, typically microseconds, leaves the load unprotected during the initial rise.

Since the process is statistical in nature, there is a considerable variation in the sparkover voltage obtained in successive operations. For some devices, this sparkover voltage also can be substantially higher after a long period of rest than after a succession of discharges. From the physical nature of the process, it is difficult to produce consistent sparkover voltage for low voltage ratings. The difficulty is compounded by the effect of manufacturing tolerances on very small gap distances. One way to alleviate the difficulty is to fill the tube with a gas having a lower breakdown voltage than that of air. However, this substitution creates a reliability problem if the enclosure seal is lost and the gas is replaced by air. Some applications require providing a second gap in parallel with the first, with slightly higher sparkover voltage for backup against failure of the gas tube.

Power-Follow — The second limitation is that a power current from the steady-state voltage source will follow the surge discharge (called "follow-current" or "power-follow"). In ac circuits, this power-follow current may or may not be cleared at a natural current zero; in dc circuits the clearing is even more uncertain. Therefore, if the crowbar device is not designed to provide self-clearing action within specified limits of surge energy and system voltage and power-follow current, additional means must be provided to open the power circuit.

2.1.3 Voltage-Clamping Devices

To perform the voltage limiting function, voltage-clamping devices at the beginning of the chapter depend on their nonlinear impedance in conjunction with the transient source impedance. Three types of devices have been used: reverse selenium rectifiers, avalanche (zener) diodes and varistors made of different materials, i.e., silicon carbide, zinc oxide, etc.[1]

Selenium Cells — Selenium transient suppressors apply the technology of selenium rectifiers in conjunction with a special process allowing reverse breakdown current at high-energy levels without damage to the polycrystalline structure. These cells are built by developing the rectifier elements on the surface of a metal plate substrate which gives them good thermal mass and energy dissipation performance. Some of these have self-healing characteristics which allows the device to survive energy discharges in excess of the rated values for a limited number of operations — characteristics that are useful, if not "legal" in the unsure world of voltage transients.

The selenium cells, however, do not have the clamping ability of the more modern metal-oxide varistors or avalanche diodes. Consequently, their field of application has been considerably diminished.

Zener Diodes — Silicon rectifier technology has improved the performance of regulator-type zener diodes in the direction of the design of surge-suppression type avalanche diodes. The major advantage of these diodes is their very effective clamping, which comes closest to an ideal constant voltage clamp. They are also available in low-voltage ratings.

Since the diode maintains the avalanche voltage across a thin junction area during surge discharge, substantial heat is generated in a small volume. The major limitation of this type of device is its energy dissipation capability.

Varistors — A *varistor* functions as a nonlinear variable impedance. The relationship between the current in the device, I, and the voltage across the terminals, V, is typically described by a power law: $I = kV^{\alpha}$. While more accurate and more complete equations can be derived to reflect the physics of the device,[2,3] this definition will suffice here. A more detailed discussion will be found in Chapter 3.

The term α (alpha) in the equation represents the degree of nonlinearity of the conduction. A linear resistance has an $\alpha = 1$. The higher the value of α, the better the clamp, which explains why α is sometimes used as a figure of merit. Quite naturally, varistor manufacturers are constantly striving for higher alphas.

Silicon Carbide Varistors — Until the introduction of metal-oxide varistors, the most common type of varistor was made from specially processed silicon carbide. This material was very successfully applied in high-power, high-voltage surge arresters. However, the relatively low α values of this material produce one of two results. Either the protective level is too high for a device capable of withstanding line voltage or, for a device producing an acceptable protective level, excessive stand-by current would be drawn at normal voltage if directly connected across the line. Therefore, a series gap is required to block the normal voltage.

A detailed discussion of series gap/silicon carbide block combinations is beyond the scope of this manual, but many references and standards on the design, testing and application of surge arrestors are available.[4,5]

In lower voltage electronic circuits, silicon carbide varistors have not been widely used because of the need for using a series gap, which increases the total cost and reproduces some of the undesirable characteristics of gaps described earlier. However, this varistor has been used as a current-limiting resistor to assist some gaps in clearing power-follow current.

Metal-Oxide Varistors — This family of transient voltage suppressors are made of sintered metal oxides, primarily zinc oxide with suitable additives. These varistors have α values considerably greater than those of silicon carbide varistors, typically in the range of an effective value of 15 to 30 measured over several decades of surge current. One type of varistor, the Harris Varistor, will be described in greater detail in Chapter 3. For the moment, the description will be limited to what is necessary for understanding the discussion of suppression and application in this chapter.

The high exponent values (α) of the metal-oxide varistors have opened completely new fields of applications by providing a sufficiently low protective level and a low standby current. The opportunities for applications extend from low-power electronics to the largest utility-type surge arresters.

2.2 TRANSIENT SUPPRESSORS COMPARED

Because of diversity of characteristics and nonstandardized manufacturer specifications, transient suppressors are not easy to compare. A graph (Figure 2.3) shows the relative volt-ampere characteristics of the four common devices that are used in 120V ac circuits. A curve for a simple ohmic resistor is included for comparison. It can be seen that as the alpha factor increases, the curve's voltage-current slope becomes less steep and approaches an almost constant voltage. High alphas are desirable for clamping applications that require operation over a wide range of currents.

It also is necessary to know the device energy-absorption and peak-current capabilities when comparisons are made. The table below includes other important parameters of commonly used suppressors.

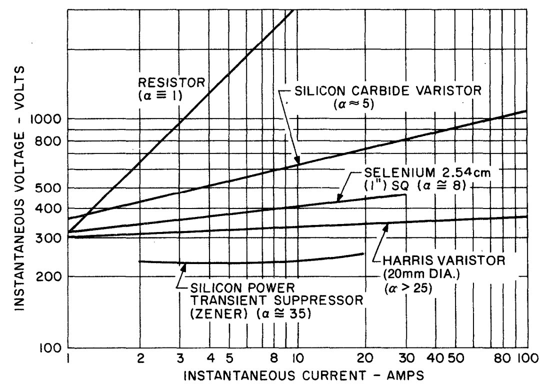
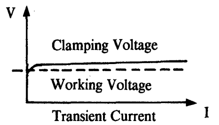
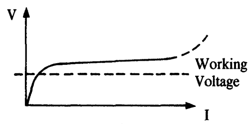
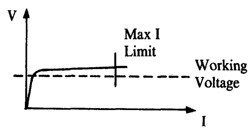
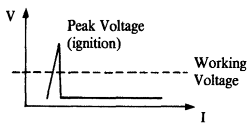
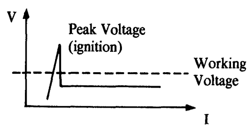
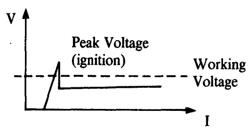
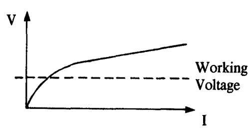
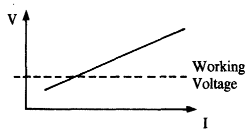


Figure 2.3 — V-I Characteristics of Four Transient Suppressor Devices

Table 2.1 — Characteristics and Features of Transient Voltage Suppressor Technology

V-I Characteristics	Device Type	Leakage	Follow on I	Clamping Voltage	Energy Capability	Capacitance	Response Time	Cost
	Ideal Device	Zero To Low	No	Low	High	Low Or High	Fast	Low
	Zinc Oxide Varistor	Low	No	Moderate To Low	High	Moderate To High	Fast	Low
	Zener	Low	No	Low	Low	Low	Fast	High
	Crowbar (Zener - SCR Combination)	Low	Yes (Latching Holding I)	Low	Medium	Low	Fast	Moderate
	Spark Gap	Zero	Yes	High Ignition Voltage Low Clamp	High	Low	Slow	Low To High
	Triggered Spark Gap	Zero	Yes	Lower Ignition Voltage Low Clamp	High	Low	Moderate	High
	Selenium	Very High	No	Moderate To High	Moderate To High	High	Fast	High
	Silicon Carbide Varistor	High	No	High	High	High	Fast	Relative Low

Standby power — the power consumed by the suppressor unit at normal line voltage — is an important selection criterion. Peak standby current is one factor that determines the standby power of a suppressor. The standby power dissipation depends also on the alpha characteristic of the device.

As an example, a selenium suppressor in Table 2.1 can have a 12mA peak standby current and an alpha of 8 (Figure 2.3). Therefore, it has a standby power dissipation of about 0.5W on a 120V rms line (170V peak). A zener-diode suppressor has standby power dissipation of less than a milliwatt. And a silicon-carbide varistor, in a 0.75″ diameter disc, has standby power in the 200mW range. High standby power in the lower alpha devices is necessary to achieve a reasonable clamping voltage at higher currents.

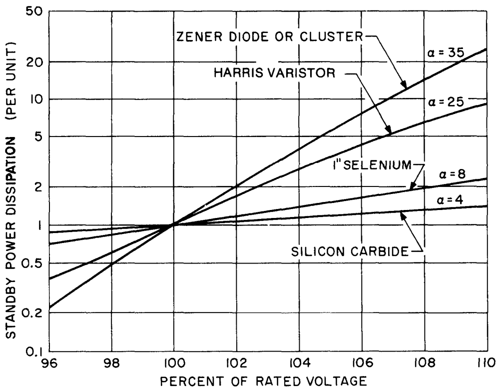


Figure 2.4 — Changes in Standby Power are Considerably Greater when the Suppressor's Alpha is High

The amount of standby power that a circuit can tolerate may be the deciding factor in the choice of a suppressor. Though high-alpha devices have low standby power at the nominal design voltage, a small line-voltage rise would cause a dramatic increase in the standby power. Figure 2.4 shows that for a zener-diode suppressor, a 10% increase above rated voltage increases the standby power dissipation above its rating by a factor of 30. But for a low-alpha device, such as silicon carbide, the standby power increases by only 1.5 times.

Typical volt-time curves of a gas discharge device are shown in Figure 2.5 indicating an initial high clamping voltage. The gas-discharge suppressor does not turn on unless the transient pulse exceeds the impulse sparkover voltage. Two representative surge rates — 1kV/μs and 20kV/μs — are shown in Figure 2.5. When a surge voltage is applied, the device turns on at some point within the indicated limits. At 20kV/μs, the discharge unit will sparkover between 600 and 2500V. At 1kV/μs, it will sparkover between 390 and 1500V.

In use for the protection of ac line surges, the gas discharge device may experience follow-current. As the voltage passes through zero at the end of every half cycle the arc will extinguish, but if the electrodes are hot and the gas is ionized, it may re-ignite on the next cycle. Depending on the power source, this current may be sufficient to cause damage to the electrodes. The follow current can be reduced by placing a limiting resistor in series with the device, reducing its current, but at a penalty of increased clamping voltage.

The gas discharge device is useful for high current surges but it is not effective in protecting low voltage, low impedance circuits. It is often advantageous to provide another suppression device in a combination that allows the added suppressor to protect against the high initial impulse. Several hybrid combinations with a varistor or avalanche diode are possible. Care in design is required to direct the initial portion of the impulse to the solid state device and to divert the high current of the later portion of the pulse to the gas discharge element. Precautions must also be taken against voltages induced in adjacent wiring by the sharp current rise associated with the gap sparkover.

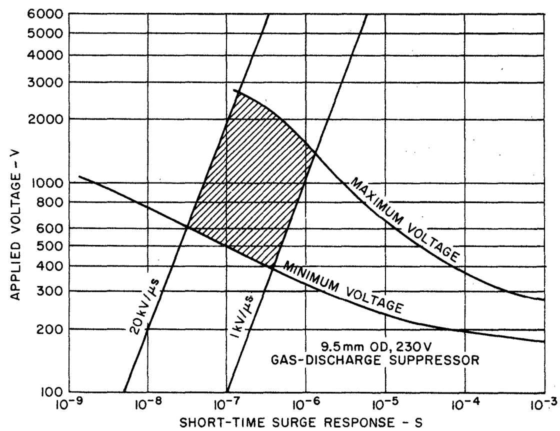


Figure 2.5 — Impulse Breakover of a Gas-Discharge Device Depends Upon the Rate of Voltage Rise as well as the Absolute Voltage Level

2.3 COMPARISON OF ZENER DIODE AND HARRIS VARISTOR TRANSIENT SUPPRESSORS

Many circuit designers ask, "Which device is better, a zener or varistor?" Unfortunately, there is no simple answer.

To make this point clear, different features will be covered to aid in realizing the proper choice among the two device types.

2.3.1 Peak Pulse Power

Transient suppressors have to be optimized to absorb large amounts of power or energy in a short time duration: nanoseconds, microseconds, or milliseconds in some rare instances.

Electrical energy is transformed into heat and has to be distributed instantaneously throughout the device. Transient thermal impedance is much more important than steady state thermal impedance, as it keeps peak junction temperature to a minimum. In other words, heat should be instantly and evenly distributed throughout the device.

The varistor meets these requirements: an extremely reliable device with large overload capability. Zener diodes on the other hand, transform electrical energy into heat in the depletion region, an extremely small area, resulting in high peak temperature. From there the heat will flow through the silicon and solder joint to the copper. Thermal coefficient mismatch and large temperature differentials can result in an unreliable device for transient suppression.

Figure 2.6 shows Peak Pulse Power vs. Pulse width for the V8ZA2 and the P6KE 6.8, the same devices compared for leakage current.

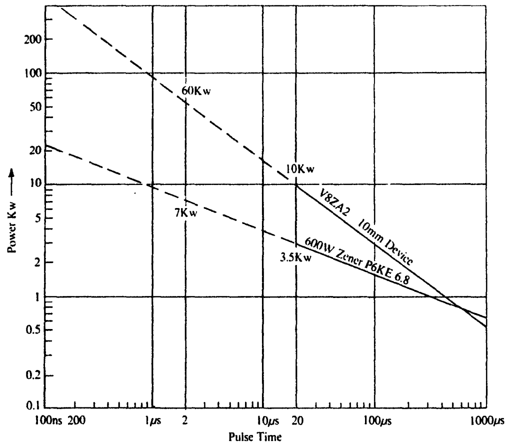


Figure 2.6 — Peak Pulse Power vs. Pulse Time

At 1ms, the two devices are almost the same. At 2μs the varistor is almost 10 times better, 7kW for the P6KE 6.8 Zener vs. 60kW for the varistor V8ZA2.

2.3.2 Clamping Voltage

Clamping voltage is an important feature of a transient suppressor. Zener diode type devices have lower clamping voltages than varistors. Because all protective devices are connected in parallel with the device or system to be protected, a lower clamping voltage will apply less stress to the device protected.

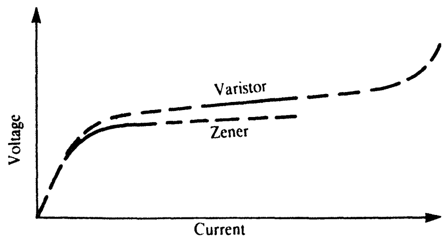


Figure 2.7 — Characteristics of Zener and Varistor

2.3.3 Speed of Response

Response times of less than 1 picosecond are claimed for zener diodes, but these claims are not supported by any data or measurements. For the varistor, measurements were made down to 500 picoseconds with a voltage rise time (dv/dt) of 1 million volts per microsecond. These measurements are described on page 3-12 of this manual. Another consideration is the lead effect. Detailed information on the lead effect can be found in Section 2.5.1. In summary, both devices are fast enough to respond to any practical requirements, including N-EMP type transients.

2.3.4 Leakage Currents

Leakage current and sharpness of the knee are two other areas of misconception about the varistor and zener diode devices. Figure 2.8 shows a P6KE 6.8 and a V8ZA2, both recommended by their manufacturers for protection of integrated circuits having 5V supply voltages.

The zener diode leakage is about 100 times higher at 5V than the varistor, 200 micro amps versus less than 2 micro amps.

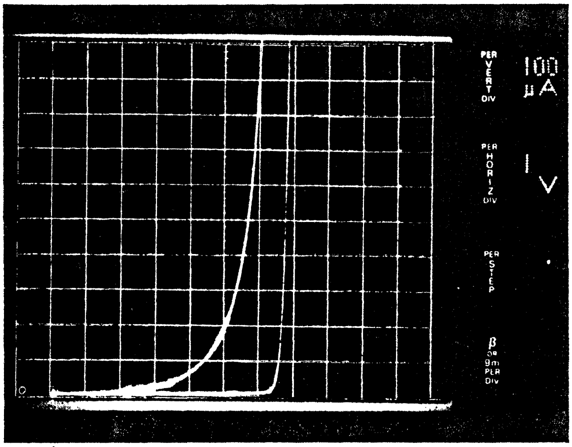


Figure 2.8 — Characteristic of Zener P6KE 6.8 (on left) Versus Harris Varistor V8ZA2 (on right)

For a leakage current comparison, 25 zener diode devices were measured at 25°C. Only 1 device measured 30μA. The rest were 150μA and more. At elevated temperatures, the comparison is even more favorable to the varistor. The zener diode is specified at 1000μA at 5.5V.

The leakage current of a zener can be reduced by specifying a higher voltage device which would have a lower leakage current, but the price is a higher clamping voltage and the advantage of the zener disappears.

2.3.5. "Aging"

What is wrong with "Aging?" It can be a pleasant experience considering the alternative — "Instant Death."

Aging is actually a misnomer; it is believed that a varistor's V-I characteristic changes every time energy is absorbed. That is not the case!

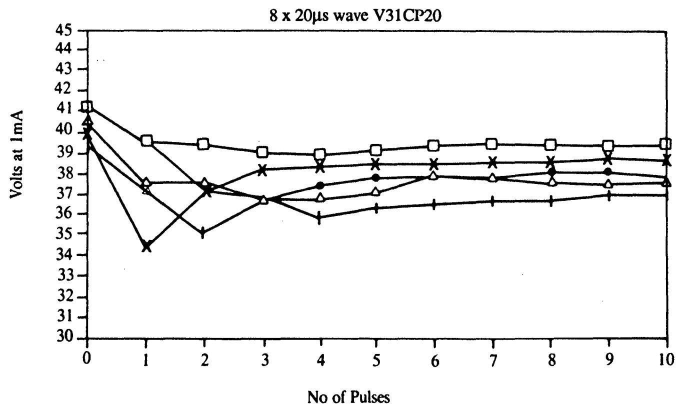


Figure 2.9 — 250A Pulse Withstand Capabilities

As illustrated in Figure 2.9, the V-I characteristic changed on some of the devices, but returned to its original value after applying a second or third pulse. Is this an inversion of the aging process? Time and temperature have very similar effects.

To be conservative, peak pulse limits have been established which, in many cases, have been exceeded many fold without harm to the device. This does not mean that established limits should be ignored, but rather, viewed in perspective of the definition of a failed device. A failed device shows a ±10% change of the V-I characteristic at the 1mA point. Zener diodes, on the other hand, fail suddenly at predictable power and energy levels. See Figure 2.6.

This, along with its superior peak pulse power capability, makes the varistor the device of choice in many applications.

2.3.6 Failure Mode

Varistors fail short, but can explode when energy is excessive, resulting in an open circuit. Because of the large peak pulse capabilities of varistors, these types of failure are quite rare for properly selected devices.

Zeners, on the other hand, can fail either short or open. If the pellet is connected by a wire, it can act as a fuse, disconnecting the device and resulting in an open circuit. Designers must analyze which failure mode, open or short, is preferred for their circuits.

When a device fails during a transient, a short is preferred, as it will provide a current path by-passing and continuing to protect the sensitive components. On the other hand, if a device fails open during a transient the remaining energy ends up in the sensitive components that were supposed to be protected. If the energy was already dissipated, the circuit will now operate without a suppressor and the next transient, or the next few transients, will finish the job.

These are just some of the points to be considered when comparing and using transient suppressors.

Another consideration is a hybrid approach, making use of the best features of both types of transient suppressors (See Figure 2.10).

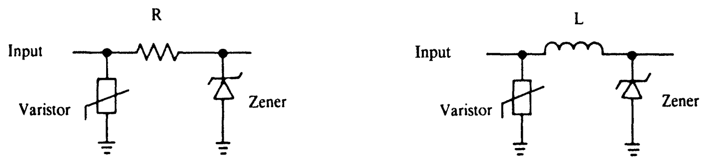


Figure 2.10 — Hybrid Protection Using Varistors, Zeners, R and L

2.3.7 Capacitance

Depending on the application, transient suppressor capacitance can be a very desirable or undesirable feature. Varistors in comparison to zener diodes have a higher capacitance. In dc-circuits capacitance is desirable, the larger the better. Decoupling capacitors are used on IC supply voltage pins and can in many cases be replaced by varistors, providing both the decoupling and transient voltage clamping functions.

The same is true for filter connectors where the varistor can perform the dual functions of providing both filtering and transient suppression.

There are circuits however, where capacitance is less desirable, such as high frequency digital or some analog circuits.

As a rule the source impedance of the signal and the frequency as well as the capacitance of the transient suppressor should be considered.

The current through C_P is a function of dv/dt and the distortion is a function of the signal's source impedance. Each case must be evaluated individually to determine the maximum allowable capacitance.

The structural characteristics of metal-oxide varistors unavoidably result in an appreciable capacitance between the device terminals, depending on area, thickness and material processing. For the majority of power applications, this capacitance is not significant. In high-frequency applications, however, the effect must be taken into consideration in the overall system design.

2.4 PROOF TESTS

To consider protective devices while a system is being designed and to follow with proof tests should be axiomatic, but historical evidence makes it apparent that this is not so. Thus, retrofit of transient suppressors is common practice. Actually, one can view this retrofit as part of the trade-off process, with iterative corrections in a calculated risk approach. It may be justifiable to attempt applying some device with minimal protection in the harsh outside world, and later, when found necessary, to take corrective action. Hence, retrofit should then be the result of informed choice, not an unforeseen need for correction. Even here some form of proof testing will be required to ascertain that the retrofit will do the job.[9]

The nature of the transient environment comes under examination when a retrofit must be applied. There is some factual knowledge on the subject, discussed in Chapter 1, but there are also many tentative "generalizations" that require confirmation. Test standards and specifications, then, become useful guides to the extent that they are not applied or enforced blindly.[8]

Some test specifications emphasize *voltage* tests. This is natural because historically, electrical equipment had dielectric failures as the major consequence of overvoltages. One can, therefore, specify some voltage test wave that the equipment must withstand without breakdown. However, with the inclusion of a protective device within the boundaries of an electronic black box, a simple voltage test is no longer meaningful. What is needed is the two-step approach discussed below, where the voltage allowed by the protector is determined first, then the effects on the downstream components determined. *Coordination* is the key concept.

One point to remember when specifying or performing a test is the difference between a *voltage* and a *current* test.

In testing a device for voltage withstand capability, proper recognition must be given to the impedance of the device being tested and to whether or not it already contains a transient suppressor. It would seem obvious that one does not specify a voltage test and then crank up the generator until that specified steady-state voltage is achieved at the terminals of the black box containing a suppressor. Yet this has been attempted!

Conversely, applying a voltage test to a black box containing a suppressor will be meaningless if the source impedance of the test generator is too high or too low. It is more appropriate, at least in the design stage, to separate the test from the design steps. First, one specifies the test circuit which will exercise the suppressor: open circuit voltage, (amplitude and duration) and source impedance. This determines the clamp voltage that will be developed across the shunt-connected suppressor (Figure 2.11). Second, one designs the protected circuit for this clamp voltage allowing adequate margins. After the design, this two-step approach can also be applied for demonstrating that withstand capability has been achieved.

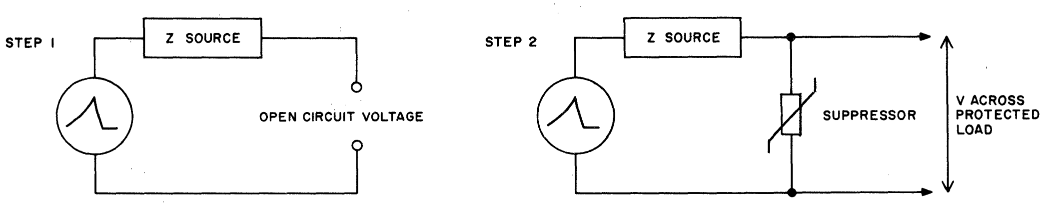


Figure 2.11 — Two Steps for Evaluating Protection Requirements

Chapter 7 provides detailed information on varistor testing, both for evaluating varistor characteristics and for conducting realistic proof tests.

2.5 UPDATE ON NEW DEVICES:

- Radial Varistors
- High Energy Varistors
- Square Varistors
- Connector Pin Varistors
- Surface Mount Varistors
- RA Series Low Profile Varistors

2.5.1 The "C" III Series

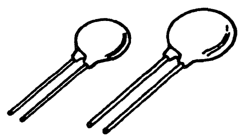


Figure 2.12

The "C" III Series (Figure 2.12) is an expanded version of the LA series of metal-oxide varistors, and consists of AC line voltage rated MOVs with extremely high current and energy handling capabilities. This new "C" III series of MOVs were primarily designed for the transient voltage surge suppressor (TVSS) environment. They provide the increased level of protection now deemed to be necessary for the transients expected in this environment.

This new expanded version of the Harris 14mm and 20mm LA series of metal oxide varistors is also available with 10mm lead spacing, in tape and reel and in a variety of distinctive crimped and trimmed offerings.

2.5.2 The HA Series

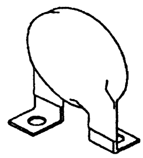


Figure 2.13

The HA Series (Figure 2.13) is an innovation in varistor packaging technology. This new format gives a very high energy/current handling capability in a cost effective package.

They are designed to provide secondary surge protection in the outdoor and service entrance environment (distribution panels), in computers, and also in industrial applications for motor controls and power supplies used in the oil-drilling, mining, and transportation fields.

The HA series of industrial varistors have similar package construction but differ in size, (32 and 40mm), ratings and characteristics. The design of the HA series of metal oxide varistors provide rigid terminals to insure secure mounting. See Page 9-43 for specifications.

2.5.3 The NA Series

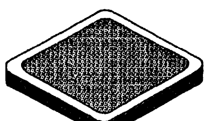


Figure 2.14

The NA Series (Figure 2.14) are industrial high energy square varistors intended for special applications requiring unique contact or packaging considerations. The electrode finish of these devices is solderable and can also be used as pressure contacts for stacking applicaltions.

These NA series industrial square varistor is available as a 34mm device, with thicknesses ranging from 1.8mm minimum for the 130V device to 8.3mm maximum for the 750V device.

2.5.4 The Connector Pin Varistor for Transient Voltage Protection in Connectors

The Connector Pin Varistor represents an entirely new approach to transient supression, forming the active material into a shape which requires no leads or package. The idea was developed many years ago, but only recently have breakthroughs in the manufacturing process allowed cost effective production of such devices.

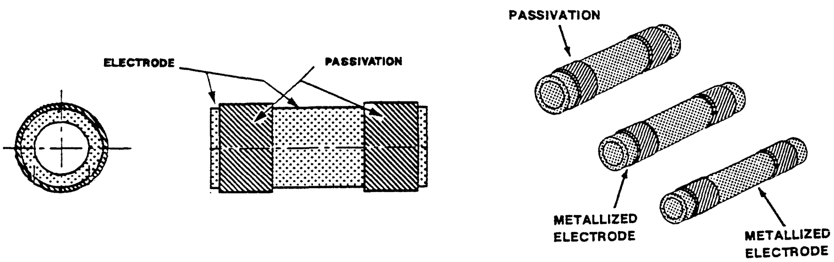


Figure 2.15 Tubular Varistor (Connector Pin Varistor) CP and CS Series

When assembled into a standard connector, adding no space or weight, they allow effective space saving transient suppression. Connector Pin Varistors (CPV's) are available in a wide range of voltage ratings with mechanical dimensions allowing them to be used with 22, 20, or 16 gauge connector pins.

The electrical characteristics are similar to those of traditional varistors and are described in detail on page 9-29 of this manual.

Although electrically similar, there are some important differences in performance between CPV's and leaded varistors such as speed of response.

Tests made on lead mounted devices, even with careful attention to minimize lead length, show that the voltage induced through lead inductance contributes substantially to the voltage appearing across the varistor terminals. These undesirable induced voltages are proportional to lead inductance and di/dt and can be positive or negative.

$$e = \frac{di}{dt} \bullet L \qquad V_C = \text{Clamping Voltage}$$

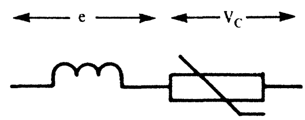


Figure 2.16 Shows the Electrical Equivalent of a Lead Mounted Varistor

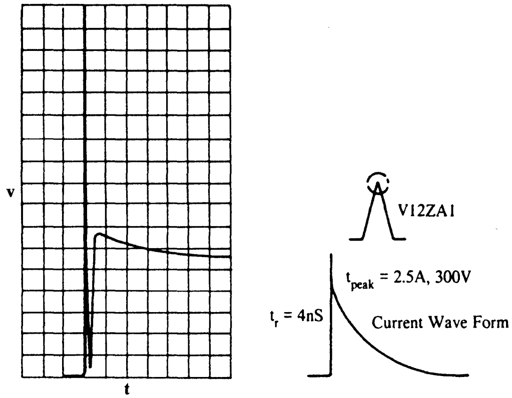


Figure 2.17 Exponential Pulse Applied to a Radial Device (5V/div., 50ns/div.)

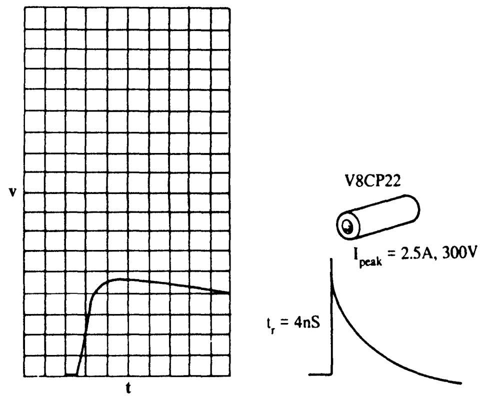


Figure 2.18 Exponential Pulse Applied to a Pin-Varistor (5V/div., 50ns/div.)

Figure 2.17 shows the positive and negative part of the induced voltage, resulting from a pulse with a rise time of 4ns to a peak current of 2.5A.

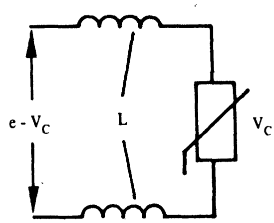
When the above measurement is repeated with a leadless varistor, such as the Connector Pin Varistor, its unique coaxial mounting allows it to become part of the transmission line. This completely eliminates inductive lead effect.

Pursuing the inductive lead effect further; calculation of the induced voltage as a direct result of lead effect for different current rise times provides a better understanding of the di/dt value at which the lead effects become significant.

Assuming a current pulse of 10A, 1 inch of lead wire (which translates into approximately 15nH) and rise times ranging from seconds to femtoseconds, the table below is obtained.

Table 1 — Induced Voltage in 1 Inch Leads. Peak Current 10A, at Different Current Rise Time

	Time	I	L	e
$1 \bullet 10^{0}$	1sec	10A	15nH	$150 \bullet 10^{-9}$
$1 \bullet 10^{-3}$	1ms	10A	15nH	$150 \bullet 10^{-6}$
$1 \bullet 10^{-6}$	1μs	10A	15nH	$150 \bullet 10^{-3}$
$1 \bullet 10^{-9}$	1ns	10A	15nH	150
$1 \bullet 10^{-12}$	1ps	10A	15nH	$150 \bullet 10^{+3}$
$1 \bullet 10^{-18}$	1fs	10A	15nH	$150 \bullet 10^{+6}$



$$e = \frac{di}{dt} \bullet L$$

Figure 2.19 illustrates the lead effect even more dramatically for fast rising pulses ranging in rise time from milliseconds to temtoseconds.

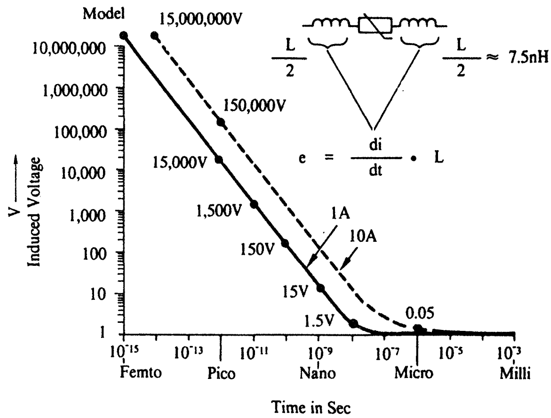


Figure 2.19 Lead Effect of 1 Inch Connection L ≈ 15nH

A short lead length is important when fast rising pulses (below 10ns) must be suppressed. This and other factors led Harris to the development of new varistor form factors like the Pin Varistor.

Figure 2.20 shows the clamping voltage of a Pin Varistor installed in a connector. The result of a 1000V pulse, 10A amplitude, 100nsec. duration with 5nsec. rise time results in a clamping voltage of 29V. The 29V includes the overshoot, dropping at the end of the pulse to 22V, resulting in an average clamping voltage of 25V. For more detailed information on the Connector Pin Varistor an application note is available.

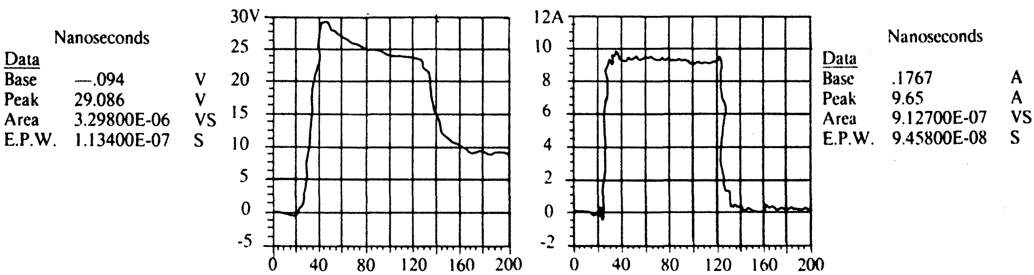
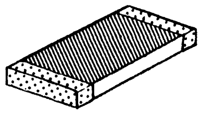


Figure 2.20 Clamping Voltage on Connector Equipped with V8CP22 Pin Varistors (Courtesy of Bendix Connector Operation of Allied, Amphenol Products)

2.5.2 Surface Mount Varistors



CH

Figure 2.21

Electronics manufacturers are turning to surface-mount technology to lower costs, increase reliability, and reduce the size and weight of their products. As a consequence, systems designers are looking for surface-mount solutions to the problem of transient voltage protection.

The increased circuit densities now possible with surface-mount systems have also increased the susceptibility of these tightly-clustered semiconductors to damage or upset by voltage transients. Thus, surface-mount technology demands a reliable transient voltage protection technology, packaged compatibly with other forms of surface-mount semiconductors.

Harris has introduced a series of surface-mount varistors for a wide range of applications. These varistors have significantly lower profiles than traditional radial leaded varistors (Figure 2.22), and are compatible with most surface-mounting assembly equipment.

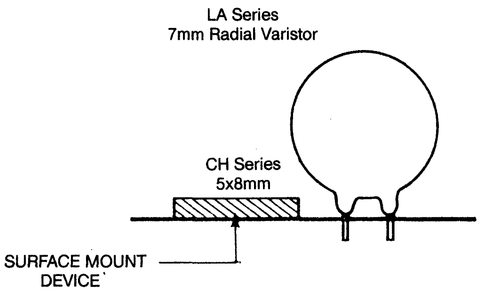


Figure 2.22

CH:
- Direct mount chip
- Available in voltage ratings 14VDC to 369V DC
- Chip size is 5mm x 8mm
- U.L. Approved

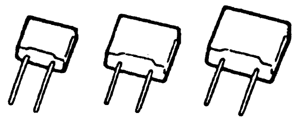


Figure 2.23

2.5.3 The RA Series Low Profile Varistor

The RA Series (Figure 2.23) is an innovation in varistor packaging which has a lower profile than traditional radial varistors. Its precise seating plane increases mechanical stability for secure circuit board mounting - a feature that makes the design well suited to high-vibration applications.

Other applications of the RA Series varistor include automotive, motor control, test equipment, computer, consumer electronics, telecommunications, and military markets.

RA Series varistors can be operated at +125°C, the result of advances in materials technology. They are available in voltage and energy ratings up to 275 volts (RMS), 140 joules. Available on tape and reel for auto-insertion, they feature in-line leads for easier automatic placement. See page 9-67 for specifications.

REFERENCES

1. Sakshaug, E.C., J.S. Kresge and S.A. Miske, *"A New Concept in Station Arrester Design,"* IEEE Trans. PAS-96, No. 2, March-April 1977, pp. 647-656.
2. Philipp, H.R. and L.M. Levinson, *"Low Temperature Electrical Studies in Metal Oxide Varistors — A Clue to Conduction Mechanisms,"* Journal of Applied Physics, Vol. 48, April 1977, pp. 1621-1627.
3. Philipp, H.R. and L.M. Levinson, *"Zinc Oxide for Transient Suppression,"* IEEE Trans. PHP, December 1977.
4. Surge Arresters for Alternating Current Power Circuits, ANSI Standard C62.1, IEEE Standard 28.
5. Lightning Arresters. Part I: Nonlinear Resistor Type Arresters for AC Systems, IEC Recommendation 99-1, 1970.
6. Matsuoka, M., T. Masuyama and Y. Iida, Supplementary Journal of Japanese Society of Applied Physics, Vol. 39, 1970, pp. 94-101.
7. Harnden, J.D., F.D. Martzloff, W.G. Morris and F.B. Golden, *"Metal-Oxide Varistor: A New Way to Suppress Transients,"* Electronics, October 2, 1972.
8. Martzloff, F.D., *"The Development of a Guide on Surge Voltages in Low-Voltage AC Power Circuits,"* Report 81CRD047, General Electric, Schenectady, New York, 1981.
9. Martzloff, F.D., *"Varistor versus Environment: Winning the Rematch,"* Report 85CRD037, General Electric, Schenectady, New York, May 1985.

HARRIS VARISTOR BASIC PROPERTIES, TERMINOLOGY AND THEORY

3.1 WHAT IS A HARRIS VARISTOR?

Varistors are voltage dependent, nonlinear devices which have an electrical behavior similar to back-to-back zener diodes. The symmetrical, sharp breakdown characteristics shown in Figure 3.1 enable the varistor to provide excellent transient suppression performance. When exposed to high voltage transients the varistor impedance changes many orders of magnitude from a near open circuit to a highly conductive level, thus clamping the transient voltage to a safe level. The potentially destructive energy of the incoming transient pulse is absorbed by the varistor, thereby protecting vulnerable circuit components.

The varistor is composed primarily of zinc oxide with small additions of bismuth, cobalt, manganese and other metal oxides. The structure of the body consists of a matrix of conductive zinc oxide grains separated by grain boundaries providing P-N junction semiconductor characteristics. These boundaries are responsible for blocking conduction at low voltages and are the source of the nonlinear electrical conduction at higher voltages.

Since electrical conduction occurs, in effect, between zinc oxide grains distributed thoughout the bulk of the device, the Harris Varistor is inherently more rugged than its single P-N junction counterparts, such as zener diodes. In the varistor, energy is absorbed uniformly throughout the body of the device with the resultant heating spread evenly through its volume. Electrical properties are controlled mainly by the physical dimensions of the varistor body which is sintered in various form factors such as discs, chips and tubes. The energy rating is determined by volume, voltage rating by thickness or current flow path length, and current capability by area measured normal to the direction of current flow.

Harris Varistors are available with ac operating voltages from 4V to 6000V. Higher voltages are limited only by packaging ability. Peak current handling exceeds 70,000A and energy capability extends beyond 10,000J for the larger units. Package styles include the tiny tubular device for use in connectors and progress in size up to the rugged industrial device line.

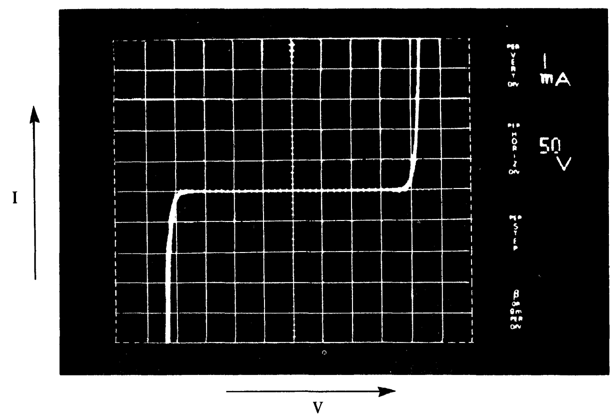


Figure 3.1 — Typical Varistor V-I Characteristic

3.2 PHYSICAL PROPERTIES

3.2.1 Introduction

An attractive property of the metal oxide varistor, fabricated from zinc oxide (ZnO), is that the electrical characteristics are related to the bulk of the device. Each ZnO grain of the ceramic acts as if it has a semiconductor junction at the grain boundry. A cross-section of the material is shown in Figure 3.2, which illustrates the ceramic microstructure. The ZnO grain boundaries can be clearly observed. Since the nonlinear electrical behavior occurs at the boundary of each semiconducting ZnO grain, the varistor can be considered a "multi-junction" device composed of many series and parallel connections of grain boundaries. Device behavior may be analyzed with respect to the details of the ceramic microstructure. Mean grain size and grain size distribution play a major role in electrical behavior.

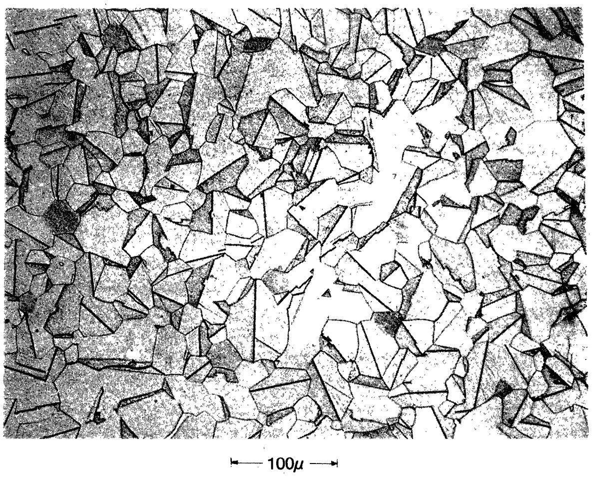


Figure 3.2 — Optical Photomicrograph of a Polished and Etched Section of a Varistor

3.2.2 Varistor Microstructure

Varistors are fabricated by forming and sintering zinc oxide-based powders into ceramic parts. These parts are then electroded with either thick film silver or arc/flame sprayed metal. The bulk of the varistor between contacts is comprised of ZnO grains of an average size "d" as shown in the schematic model of Figure 3.3. Resistivity of the ZnO is < 0.3 ohm-cm.

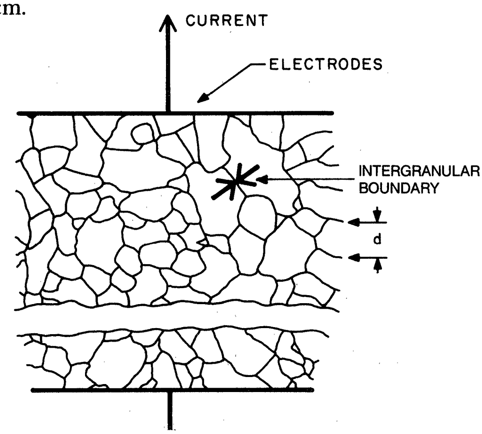


Figure 3.3 — Schematic Depiction of the Microstructure of a Metal-Oxide Varistor. Grains of Conducting ZnO (Average Size d) are Separated by Intergranular Boundaries

Designing a varistor for a given nominal varistor voltage, V_N, is basically a matter of selecting the device thickness such that the appropriate number of grains, n, are in series between electrodes. In practice, the varistor material is characterized by a voltage gradient measured across its thickness by a specific volts/mm value. By controlling composition and manufacturing conditions the gradient remains fixed. Because there are practical limits to the range of thicknesses achievable, more than one voltage gradient value is desired. By altering the composition of the metal oxide additives it is possible to change the grain size "d" and achieve the desired result.

A fundamental property of the ZnO varistor is that the voltage drop across a single interface "junction" between grains is nearly constant. Observations over a range of compositional variations and processing conditions show a fixed voltage drop of about 2-3V per grain boundary junction. Also, the voltage drop does not vary for grains of different sizes.

It follows, then, that the varistor voltage will be determined by the thickness of the material and the size of the ZnO grains. The relationship can be stated very simply as follows:

Varistor voltage, V_N(dc) = (3V)n

where, n = average number of grain boundaries between electrodes

and, varistor thickness, D = (n + 1)d

$$\approx \frac{V_N \times d}{3}$$

where, d = average grain size

The varistor voltage, V_N, is defined as the voltage across a varistor at the point on its V-I characteristic where the transition is complete from the low-level linear region to the highly nonlinear region. For standard measurement purposes, it is arbitrarily defined as the voltage at a current of 1mA.

Some typical values of dimensions for Harris varistors are given in the table below.

Varistor Voltage	Average Grain Size	n	Gradient	Device Thickness
Volts	Microns		V/mm AT 1mA	mm
150V RMS	20	75	150	1.5
25V RMS	80*	12	39	1.0

*Low voltage formulation.

3.2.3 Theory of Operation

Because of the polycrystalline nature of metal-oxide semiconductor varistors, the physical operation of the device is more complex than that of conventional semiconductors. Intensive measurement has determined many of the device's electrical characteristics, and much effort continues to better define the varistor's operation. In this section we will discuss some theories of operation, but from the user's viewpoint this is not nearly as important as understanding the basic electrical properties as they relate to device construction.

The key to explaining metal-oxide varistor operation lies in understanding the electronic phenomena occurring near the grain boundaries, or junctions between the zinc oxide grains. While some of the early theory supposed that electronic tunneling occurred through an insulating second phase layer at the grain boundaries, varistor operation is probably better described by a series-parallel arrangement of semiconducting diodes. In this model, the grain boundaries contain defect states which trap free electrons from the n-type semiconducting zinc oxide grains, thus forming a space charge depletion layer in the ZnO grains in the region adjacent to the grain boundaries.[6]

Evidence for depletion layers in the varistor is shown in Figure 3.4 where the inverse of the capacitance per boundary squared is plotted against the applied voltage per boundary.[7] This is the same type of behavior observed for semiconductor abrupt P-N junction diodes. The relationship is:

$$\frac{1}{C^2} = \frac{2(V_b + V)}{q\varepsilon sN}$$

Where V_b is the barrier voltage, V the applied voltage, q the electron charge, εs the semiconductor permittivity and N is the carrier concentration. From this relationship the ZnO carrier concentration, N, was determined to be about 2×10^{17} per cm^3.[7] In addition, the width of the depletion layer was calculated to be about 1000 Angstrom units. Single junction studies also support the diode model.[9]

It is these depletion layers that block the free flow of carriers and are responsible for the low voltage insulating behavior in the leakage region as depicted in Figure 3.5. The leakage current is due to the free flow of carriers across the field lowered barrier, and is thermally activated, at least above about 25°C.

Figure 3.5 shows an energy band diagram for a ZnO-grain boundary-ZnO junction.[11] The left-hand grain is forward biased, V_L, and the right side is reverse biased to V_R. The depletion layer widths are X_L and X_R, and the respective barrier heights are ϕ_L and ϕ_R. The zero biased barrier height is ϕ_O. As the voltage bias is increased, ϕ_L is decreased and ϕ_R is increased, leading to a lowering of the barrier and an increase in conduction.

The barrier height ϕ_L of a low voltage varistor was measured as a function of applied voltage[11] and is presented in Figure 3.6. The rapid decrease in the barrier at high voltage represents the onset of nonlinear conduction.[12]

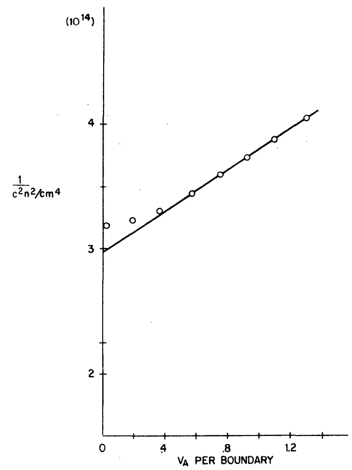


Figure 3.4 — Capacitance-Voltage Behavior of Varistor Resembles a Semiconductor Abrupt-Junction Reversed Biased Diode. $N_d \sim 2 \times 10^{17}/cm^3$

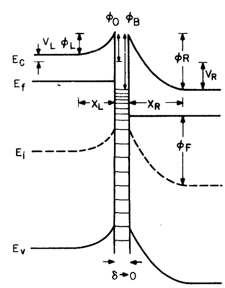


Figure 3.5 — Energy Band Diagram of a ZnO-Grain Boundary-ZnO Junction

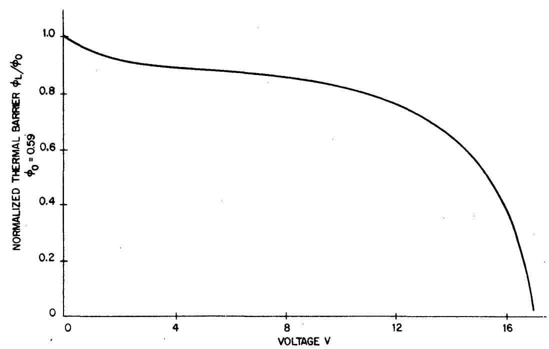


Figure 3.6 — Thermal Barrier as a Function of Applied Voltage

Transport mechanisms in the nonlinear region are very complicated and are still the subject of active research. Most theories draw their inspiration from semiconductor transport theory and the reader is referred to the literature for more information.[3,5,13,14,15]

Turning now to the high current upturn region in Figure 3.10 (see page 3-8), we see that the V-I behavior approaches an ohmic characteristic. The limiting resistance value depends upon the electrical conductivity of the body of the semiconducting ZnO grains, which have carrier concentrations in the range of 10^{17} to 10^{18} per cm^3. This would put the ZnO resistivity below 0.3Ωcm.

3.3 VARISTOR CONSTRUCTION

The process of fabricating a Harris Varistor is illustrated in the flow chart of Figure 3.7. The starting material may differ in the composition of the additive oxides, in order to cover the voltage range of product.

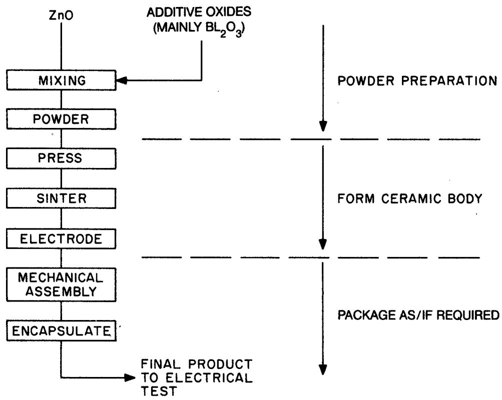


Figure 3.7 — Schematic Flow Diagram of Harris Varistor Fabrication

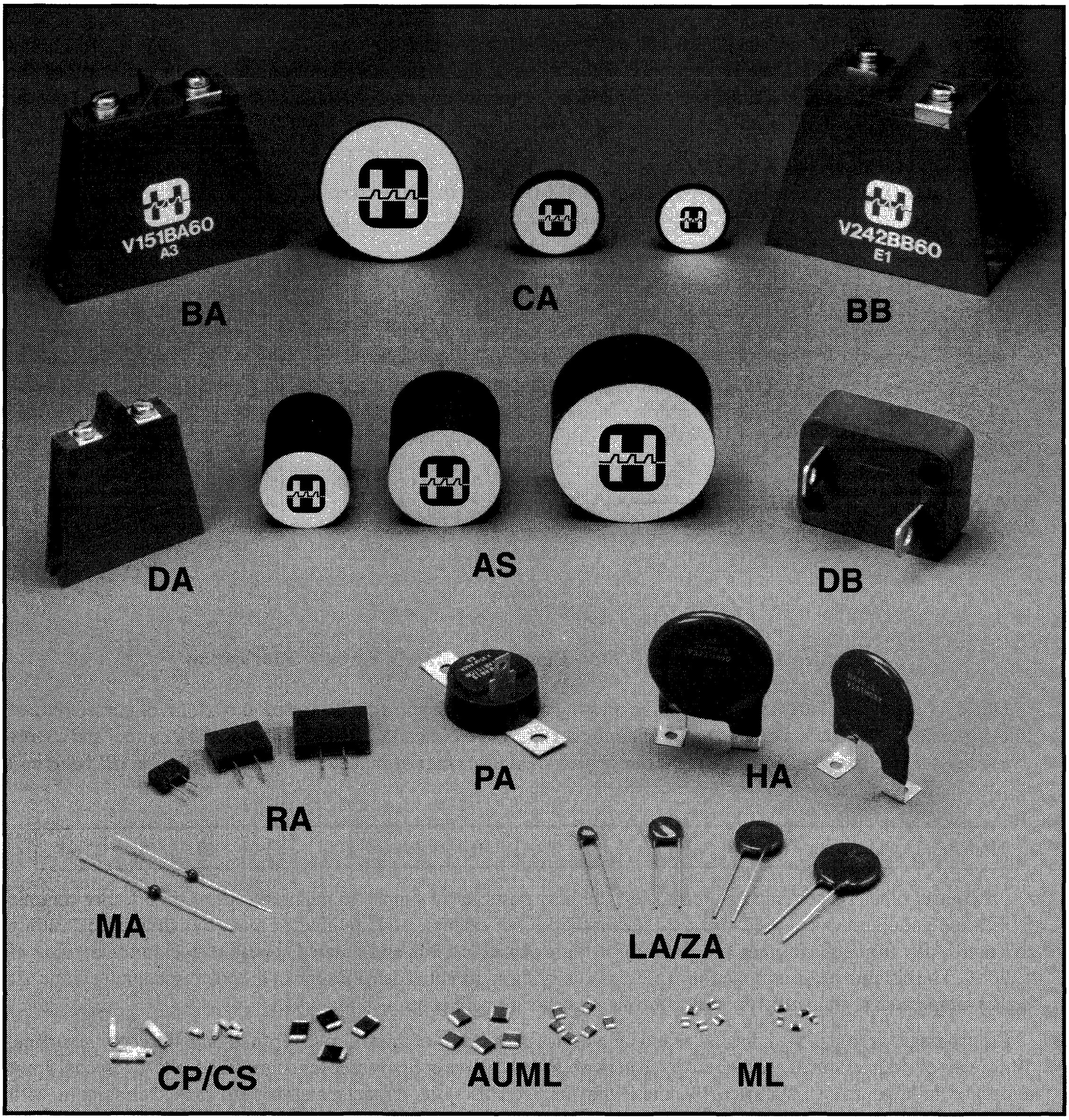
Device characteristics are determined at the pressing operation. The powder is pressed into a form of predetermined thickness in order to obtain a desired value of nominal voltage. To obtain the desired ratings of peak current and energy capability, the electrode area and mass of the device are varied. The range of diameters obtainable in disc product offerings is listed here:

Nominal Disc Diameter - mm	3	5	7	10	14	20	32	40	52	60

Of course, other shapes, such as rectangles, are also possible by simply changing the press dies. Other ceramic fabrication techniques can be used to make different shapes. For example, rods or tubes are made by extruding and cutting to length. After forming, the green (i.e. unfired) parts are placed in a kiln and sintered at peak temperatures in excess of 1200°C. The bismuth oxide is molten above 825°C, assisting in the initial densification of the polycrystalline ceramic. At higher temperatures, grain growth occurs, forming a structure with controlled grain size.

Electroding is accomplished, for radial and chip devices, by means of thick film silver fired onto the ceramic surface. Wire leads or strap terminals are then soldered in place. A conductive epoxy is used for connecting leads to the axial 3mm discs. For the larger industrial devices (40 and 60mm diameter discs) the contact material is arc sprayed aluminum, with an overspray of copper if necessary to give a solderable surface.

Many encapsulation techniques are used in the assembly of the various Harris Varistor packages. Most radials and some industrial devices (HA Series) are epoxy coated in a fluidised bed, whereas epoxy is "spun" onto the axial device. Radials are also available with phenolic coatings applied using a wet process. The PA series package consists of plastic molded around a 20mm disc sub-assembly. The RA, DA, and DB series devices are all similar in that they all are composed of discs or chips, with tabs or leads, encased in a molded plastic shell filled with epoxy. Different package styles allow variation in energy ratings, as well as in mechanical mounting. Figures 3.8 & 3.9 illustrate several package forms.



HARRIS
SEMICONDUCTOR

Dwgs. Not to Scale

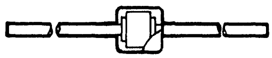


Figure 3.9A
Cross-Section of MA Package

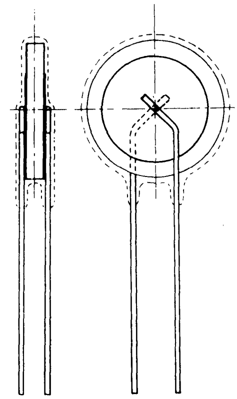
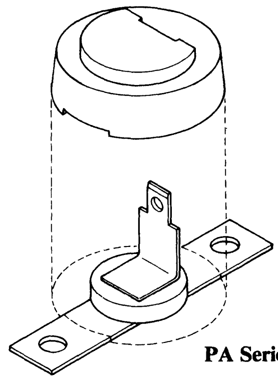
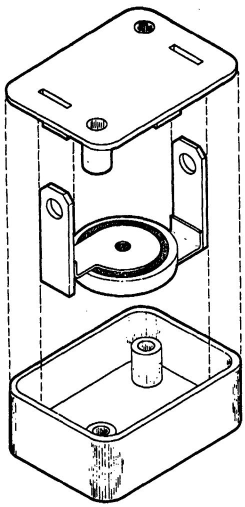


Figure 3.9B
Cross-Section of
Radial Lead Package

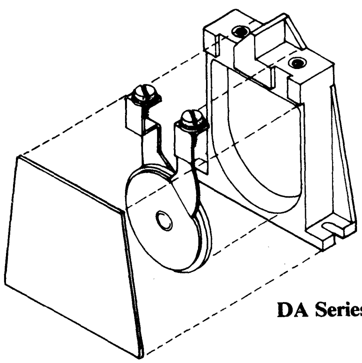


PA Series

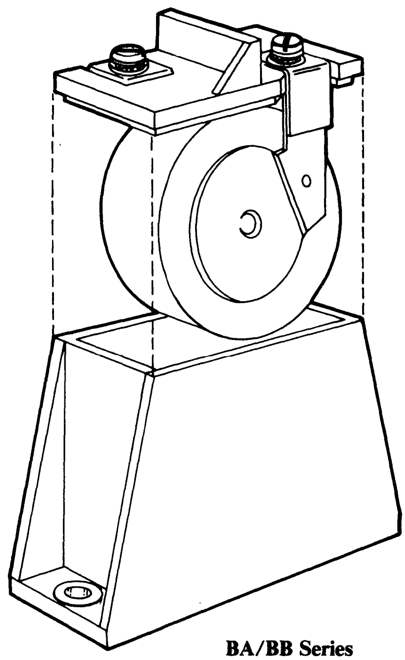
Figure 3.9C
Pictorial View of
Power MOV Package



DB Series



DA Series



BA/BB Series

Figure 3.9D — Pictorial View of High Energy Packages DA, DB and BA/BB Series

Figure 3.9 shows construction details of some packages. Dimensions of the ceramic, by package type, are given below:

Package Type		Ceramic Dimensions
Direct Surface Mount	- CH, AUML, ML Series	5 x 8mm Chip, 1206, 1210, 1812, 2220
Connector Pin	-CP, CS Series	22, 20, 16 Gauge Tube
Axial Leaded	-MA Series	3mm Diameter Disc
Radial Leaded	-ZA, LA, "C"III Series	5, 7,10, 14, 20mm Diameter Discs
Radial Leaded Low Profile	-RA Series	5 x 8mm, 10 x 16mm, 14 x 22 Chips
Power	-PA Series	20mm Diameter Disc
Industrial Packages	-HA Series -DA, DB Series -BA, BB Series	32, 40mm Diameter Disc 40mm Diameter Disc 60mm Diameter Disc
Industrial Discs	-CA, NA Series	32, 40, 60mm Diameter Discs 34mm Square
Arrester	-AS Series	32, 42, 52, 60mm Diameter Discs

3.4 ELECTRICAL CHARACTERIZATION

3.4.1 Varistor V-I Characteristics

Varistor electrical characteristics are conveniently displayed using log-log format in order to show the wide range of the V-I curve. The log format also is clearer than a linear representation which tends to exaggerate the nonlinearity in proportion to the current scale chosen. A typical V-I characteristic curve is shown in Figure 3.10. This plot shows a wider range of current than is normally provided on varistor data sheets in order to illustrate three distinct regions of electrical operation.

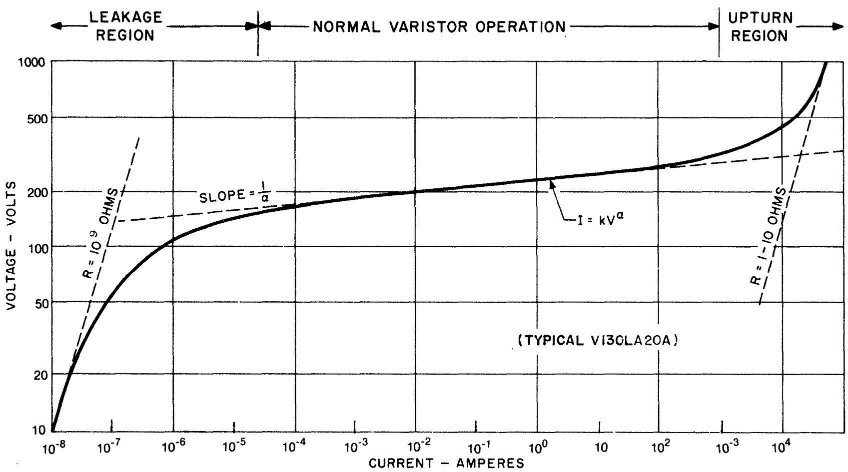


Figure 3.10 — Typical Varistor V-I Curve Plotted on Log-Log Scale

3.4.2 Equivalent Circuit Model

An electrical model for the varistor can be represented by the simplified equivalent circuit of Figure 3.11.

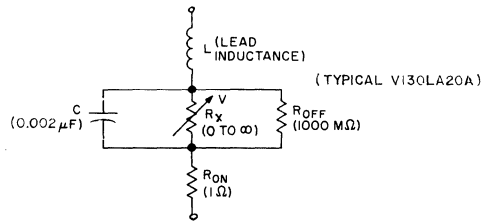


Figure 3.11 — Varistor Equivalent Circuit Model

3.4.3 Leakage Region of Operation

At low current levels, the V-I Curve approaches a linear (ohmic) relationship and shows a significant temperature dependence. The varistor is in a high resistance mode (approaching 10^9 ohms) and appears as an open circuit. The nonlinear resistance component, R_X, can be ignored because R_{OFF} in parallel will predominate. Also, R_{ON} will be insignificant compared to R_{OFF}.

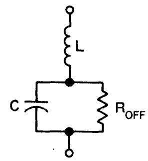


Figure 3.12 — Equivalent Circuit at Low Currents

For a given varistor device, capacitance remains approximately constant over a wide range of voltage and frequency in the leakage region. The value of capacitance drops only slightly as voltage is applied to the varistor. As the voltage approaches the nominal varistor voltage, the capacitance abruptly decreases. Capacitance remains nearly constant with frequency change up to 100kHz. Similarly, the change with temperature is small, the 25°C value of capacitance being well within ± 10% from -40°C to +125°C.

The temperature effect of the V-I characteristic curve in the leakage region is shown in Figure 3.13. A distinct temperature dependence is noted.

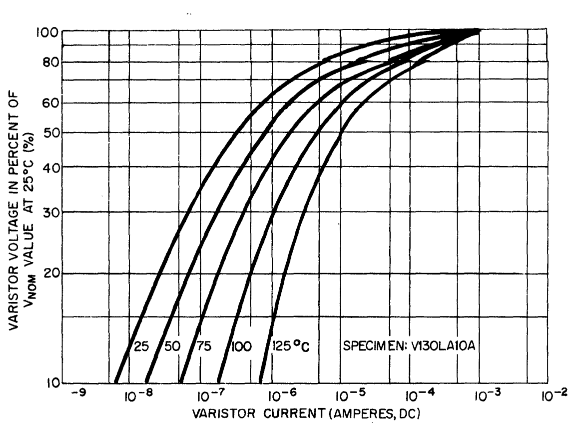


Figure 3.13 — Temperature Dependence of the Characteristic Curve in the Leakage R

The relation between the leakage current, I, and temperature, T, is:

$$I = I_o \, \varepsilon^{-V_B/kT}$$

where: I_o = constant

k = Boltzmann's Constant

V_B = 0.9 eV

The temperature variation, in effect, corresponds to a change in R_{OFF}. However, R_{OFF} remains at a high resistance value even at elevated temperatures. For example, it is still in the range of 10 to 100 megaohms at 125°C.

Although R_{OFF} is a high resistance it varies with frequency. The relationship is approximately linear with inverse frequency.

$$R_{OFF} \sim \frac{1}{f}$$

However, the parallel combination of R_{OFF} and C is predominantly capacitive at any frequency of interest. This is because the capacitive reactance also varies approximately linearly with 1/f.

At higher currents, at and above the milliamp range, temperature variation becomes minimal. The plot of the temperature coefficient (dv/dt) is given in Figure 3.14. It should be noted that the temperature coefficient is negative and decreases as current rises. In the clamping voltage range of the varistor ($I > 1A$), the temperature dependency approaches zero.

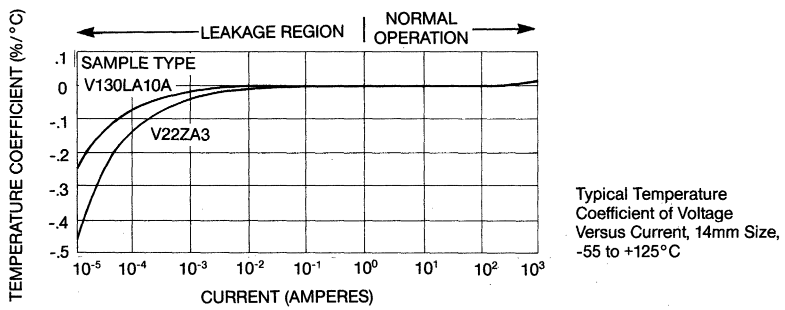


Figure 3.14 — Relation of Temperature Coefficient dv/dt to Varistor Current

3.4.4 Normal Varistor Region of Operation

The varistor characteristic follows the equation $I = kV^{\alpha}$, where k is a constant and the exponent α defines the degree of nonlinearity. Alpha is a figure of merit and can be determined from the slope of the V-I curve or calcuated from the formula:

$$\alpha = \frac{\log (I_2/I_1)}{\log (V_2/V_1)} = \frac{1}{\log (V_2/V_1)} \quad \text{for } I_2/I_1 = 10$$

In this region the varistor is conducting and R_X will predominate over C, R_{ON} and R_{OFF}. R_X becomes many orders of magnitude less than R_{OFF} but remains larger than R_{ON}.

Figure 3.15 — Equivalent Circuit at Varistor Conduction

During conduction the varistor voltage remains relatively constant for a change in current of several orders of magnitude. In effect, the device resistance, R_X, is changing in response to current. This can be observed by examining the static or dynamic resistance as a function of current. The static resistance is defined by;

$$R_X = \frac{V}{I}$$

and the dynamic resistance by:

$$Z_X = \frac{dv}{di} = V/\alpha I = R_X/\alpha$$

Plots of typical resistance values vs. current, I, are given in Figure 3.16.

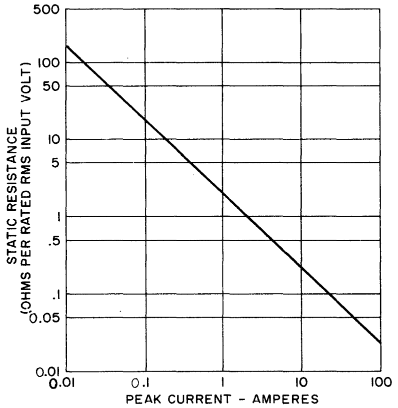


Figure 3.16A — R_X Static Varistor Resistance

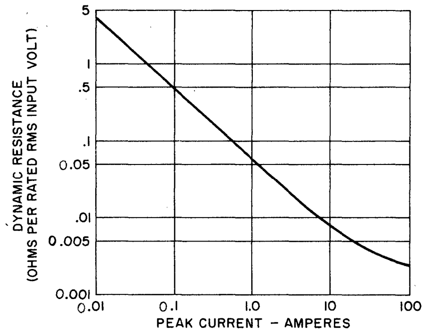


Figure 3.16B — Z_X Dynamic Varistor Resistance

3.4.5 Upturn Region of Operation

At high currents, approaching the maximum rating, the varistor approximates a short-circuit. The curve departs from the nonlinear relation and approaches the value of the material bulk resistance, about 1-10 ohms. The upturn takes place as R_X approaches the value of R_{ON}. Resistor R_{ON} represents the bulk resistance of the zinc oxide grains. This resistance is linear (which appears as a steeper slope on the log plot) and occurs at currents 50 to 50,000A, depending on the varistor size.

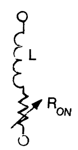


Figure 3.17 — Equivalent Circuit at Varistor Upturn

3.4.6 Speed of Response and Rate Effects

The varistor action depends on a conduction mechanism similar to that of other semiconductor devices. For this reason, conduction occurs very rapidly, with no apparent time lag — even into the nanosecond range. Figure 3.18 shows a composite photograph of two voltage traces with and without a varistor inserted in a very low inductance inpulse generator.The second trace (which is not synchronized with the first, but merely superimposed on the oscilloscope screen) shows that the voltage clamping effect of the varistor occurs in less than one nanosecond.

In the conventional lead-mounted devices, the inductance of the leads would completely mask the fast action of the varistor; therefore, the test circuit for Figure 3.18 required insertion of a small piece of varistor material in a coaxial line to demonstrate the intrinsic varistor response.

Tests made on lead-mounted devices, even with careful attention to minimizing lead length, show that the voltages induced in the loop formed by the leads contribute a substantial part of the voltage appearing across the terminals of a varistor at high current and fast current rise. Fortunately, the currents which can be delivered by a transient source are invariably slower in rise time than the observed voltage transients. The applications most frequently encountered for varistors involve *current* rise times longer than 0.5μs.

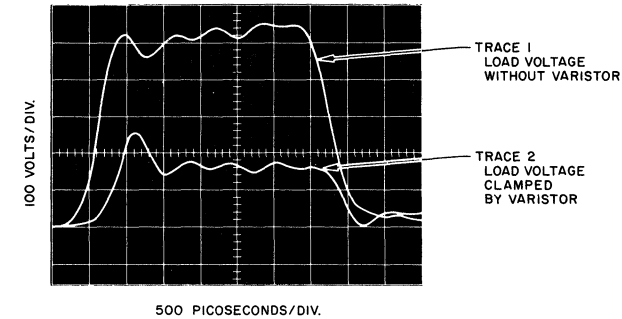
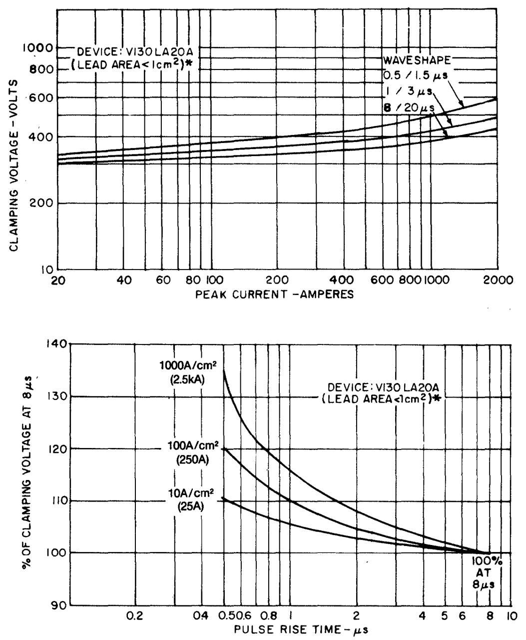


Figure 3.18 — Response of a ZnO Varistor to a Fast Rise Time (500 Picosecond) Pulse

Voltage rate-of-rise is not the best term to use when discussing the response of a varistor to a fast impulse (unlike spark gaps where a finite time is involved in switching from non-conducting to conducting state). The response time of the varistor to the transient current that a circuit can deliver is the appropriate characteristic to consider.



a) V-I Characteristics For Various Current Rise Times

b) Overshoot Defined With Reference To The Basic 8 / 20μs Current Pulse

*Refer to Section 7.3.2.

Figure 3.19a and b — Response of Lead-Mounted Varistors to Current Waveform

The V-I characteristic of Figure 3.19a shows how the response of the varistor is affected by the current waveform. From such data, an "overshoot" effect can be defined as being the relative increase in the maximum voltage appearing across the varistor during a fast current rise, using the conventional 8/20μs current wave as the reference. Figure 3.19b shows typical clamping voltage variation with rise time for various current levels.

3.5 VARISTOR TERMINOLOGY

The following tabulation defines the terminology used in varistor specifications. Existing standards have been followed wherever possible.

3.5.1 Definitions (IEEE Standard C62.33, 1982)

A characteristic is an inherent and measurable property of a device. Such a property may be electrical, mechanical, or thermal, and can be expressed as a value for stated conditions.

A rating is a value which establishes either a limiting capability or a limiting condition (either maximum or minimum) for operation of a device. It is determined for specified values of environment and operation. The ratings indicate a level of stress which may be applied to the device without causing degradation or failure. Varistor symbols are defined on the linear V-I graph illustrated in Figure 3.20.

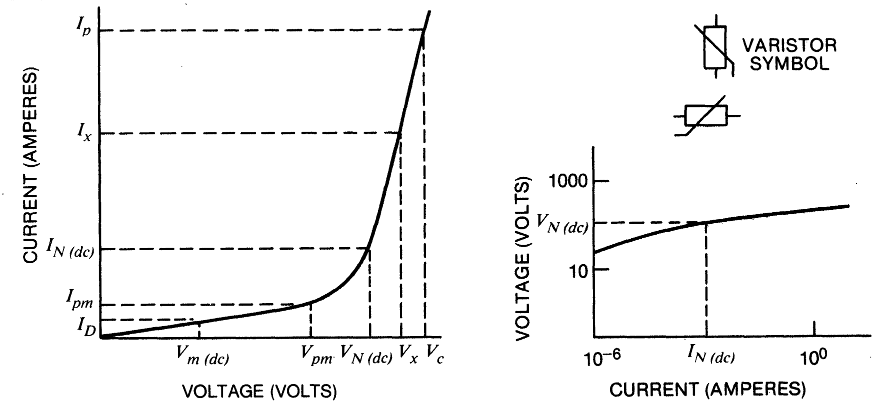


Figure 3.20 — I-V Graph Illustrating Symbols and Definitions

3.5.2 Varistor Characteristics (IEEE Standard C62.33-1982 Subsection 2.3 and 2.4)

Terms and Descriptions	Symbol
2.3.1 Clamping Voltage. Peak voltage across the varistor measured under conditions of a specified peak pulse current and specified waveform. *Note:* Peak voltage and peak currents are not necessarily coincidental in time.	V_c
2.3.2 Rated Peak Single Pulse Transient Currents (Varistor). Maximum peak current which may be applied for a single 8/20μs impulse, with rated line voltage also applied, without causing device failure.	I_{tm}
2.3.3 Lifetime Rated Pulse Currents (Varistor). Derated values of I_{tm} for impulse durations exceeding that of an 8/20μs waveshape, and for multiple pulses which may be applied over device rated lifetime.	—
2.3.4 Rated RMS Voltage (Varistor). Maximum continuous sinusoidal rms voltage which may be applied.	$V_{m(ac)}$
2.3.5 Rated DC Voltage (Varistor). Maximum continuous dc voltage which may be applied.	$V_{m(dc)}$
2.3.6 DC Standby Current (Varistor). Varistor current measured at rated voltage, $V_{m(dc)}$.	I_D
2.4 For certain applications, some of the following terms may be useful.	
2.4.1 Nominal Varistor Voltage. Voltage across the varistor measured at a specified pulsed dc current, $I_{N(dc)}$, of specific duration. $I_{N(dc)}$ of specific duration. $I_{N(dc)}$ is specified by the varistor manufacturer.	$V_{N(dc)}$
2.4.2 Peak Nominal Varistor Voltage. Voltage across the varistor measured at a specified peak ac current, $I_{N(ac)}$, of specific duration. $I_{N(ac)}$ is specified by the varistor manufacturer.	$V_{N(ac)}$
2.4.3 Rated Recurrent Peak Voltage (Varistor). Maximum recurrent peak voltage which may be applied for a specified duty cycle and waveform.	V_{pm}

Terms and Descriptions (cont'd)	Symbol
2.4.4 Rated Single Pulse Transient Energy (Varistor). Energy which may be dissipated for a single impulse of maximum rated current at a specified waveshape, with rated rms voltage or rated dc voltage also applied, without causing device failure.	W_{tm}
2.4.5 Rated Transient Average Power Dissipation (Varistor). Maximum average power which may be dissipated due to a group of pulses occurring within a specified isolated time period, without causing device failure.	$P_{t(AV)m}$
2.4.6 Varistor Voltage. Voltage across the varistor measured at a given current, I_x.	V_x
2.4.7 Voltage Clamping Ratio (Varistor). A figure of merit measure of the varistor clamping effectiveness as defined by the symbols $V_c/V_{m(ac)}$, $V_c/V_{m(dc)}$.	$\frac{V_c}{V_{pm}}$
2.4.8 Nonlinear Exponent. A measure of varistor nonlinearity between two given operating currents, I_1 and I_2, as described by $I = kV^{\alpha}$ where k is a device constant, $I_1 \leq I \leq I_2$, and $\alpha_{12} = \frac{\log I_2/I_1}{\log V_2/V_2}$	α
2.4.9 Dynamic Impedance (Varistor). A measure of small signal impedance at a given operating point as defined by: $Z_x = \frac{dV_x}{dI_x}$	Z_x
2.4.10 Resistance (Varistor). Static resistance of the varistor at a given operating point as defined by: $R_x = \frac{V_x}{I_x}$	R_x
2.4.11 Capacitance (Varistor). Capacitance between the two terminals of the varistor measured at specified frequency and bias.	C
2.4.12 AC Standby Power (Varistor). Varistor ac power dissipation measured at rated rms voltage $V_{m(ac)}$.	P_d
2.4.13 Voltage Overshoot (Varistor). The excess voltage above the clamping voltage of the device for a given current that occurs when current waves of less than 8μs virtual front duration are applied. This value may be expressed as a % of the clamping voltage (V_c) for an 8/20 current wave.	V_{os}
2.4.14 Response Time (Varistor). The time between the point at which the wave exceeds the clamping voltage level (V_c) and the peak of the voltage overshoot. For the purpose of this definition, clamping voltage as defined with an 8/20μs current waveform of the same peak current amplitude as the waveform used for this response time.	—
2.4.15 Overshoot Duration (Varistor). The time between the point at which the wave exceeds the clamping voltage level (V_c) and the point at which the voltage overshoot has decayed to 50% of its peak. For the purpose of this definition, clamping voltage is defined with an 8/20μs current waveform of the same peak current amplitude as the waveform used for this overshoot duration.	—

3.5.3 Test Waveform

At high current and energy levels, varistor characteristics are measured, of necessity, with an impulse waveform. Shown in Figure 3.21 is the ANSI Standard C62.1 waveshape, an exponentially decaying waveform representative of lightning surges and the discharge of stored energy in reactive circuits.

The 8/20μs current wave (8μs rise and 20μs to 50% decay of peak value) is used as a standard, based on industry practices, for the characteristics and ratings described. One exception is the energy rating (W_{tm}), where a longer waveform of 10/1000μs is used. This condition is more representative of the high energy surges usually experienced from inductive discharge of motors and transformers. Varistors are rated for a maximum pulse energy surge that results in a varistor voltage (V_N) shift of less than ±10% from initial value.

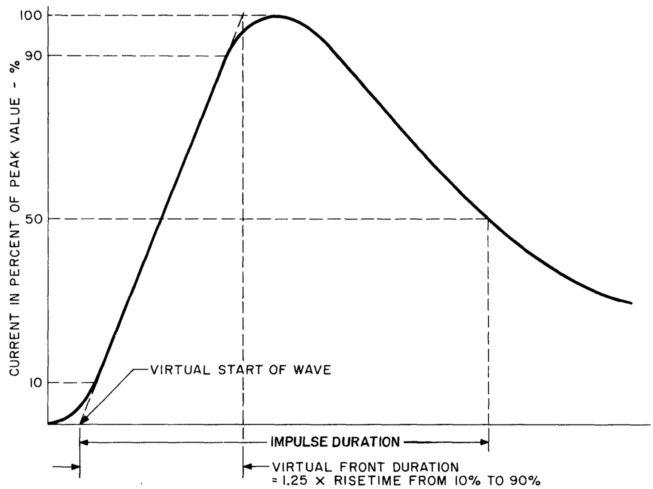


Figure 3.21 — Definition of Pulse Current Waveform

3

PROPERTIES, TERM., THEORY

REFERENCES

1. Harnden, J.D., F.D. Martzloff, W.G. Morris and F.B. Golden, *"The GE-MOV® Varistor — The Super Alpha Varistor,"* Electronics, Vol. 45, No. 21, 1972, p. 91.
2. Morris, W.G., *"Electrical Properties of ZnO-Bi_2O_3 Ceramics,"* Journal of the Am. Ceram. Soc., Vol 56, 1973.
3. Matsuoka, M., *"Non-Ohmic Properties of Zinc Oxide Ceramics,"* Japanese Jnl. Appl. Phys., Vol. 10, 1971, p. 736.
4. Mahan, G., L. Levinson and H. Philipp, *"Single Grain Junction Studies at ZnO Varistors — Theory & Experiment,"* Report #78CRF160, General Electric, Schenectady, N.Y., 1978. Forthcoming in Applied Physics Letters.
5. Mahan, G., L. Levinson and H. Philipp, *"Theory of Conduction in ZnO Varistors,"* Journal of Applied Physics (in press).
6. Levine, J.D., *"Theory of Varistor Electronic Properties,"* Critical Review of Solid State Science, 5, 1975, pp. 597-608.
7. May, J.E., *"Carrier Concentration and Depletion Layer Model of Zinc Oxide Varistors,"* Bulletin of the American Ceramic Society, Vol. 57, No. 3, 1978, p. 335.
8. Sze, S.M., *"Physics of Semiconductor Devices,"* John Wiley & Sons, New York, N.Y., 1969.
9. Einzinger, R., *"Microcontact Measurement of ZnO Varistors,"* Ber. Dt. Keram, Vol. 52, 1975, pp. 244-245.
10. Lou, L.F., *"Current-Voltage Characteristics of ZnO-Bi_2O_3 Heterojunction,"* Journal of Applied Physics, Vol. 50, 1979, p. 555.
11. Lou, L.F. *"Semiconducting Properties of ZnO-Grain Boundary-ZnO Junctions in Ceramic Varistors,"* Appl. Phys. Letters, Vol. 36, 1980, pp. 570-572.
12. Lou, L.F., and J.E. May, Unpublished Research, General Electric, Syracuse, N.Y., 1981.
13. Morris, W., *"Physical Properties of the Electrical Barriers in Varistors,"* J. Vac. Sci. Technol., 13, 1976, pp. 926-931.
14. Bernasconi, J., S. Strassler, B. Knecht, H. Klein and A. Menth, Solid State Communication, Vol. 21, 1977, pp. 867-869.
15. Pike, G. and C. Seager, *"The DC Voltage Dependence of Semiconductor Grain-Boundary Resistance,"* Journal of Appl. Phys., Vol. 50, 1979, pp. 3414-3422.

DESIGNING WITH HARRIS VARISTORS

4.1 SELECTING THE VARISTOR

The varistor must operate under steady-state and transient conditions. Device ratings allow a selection of the proper size device to insure reliable operation. The selection process requires a knowledge of the electrical environment. When the environment is not fully defined, some approximations can be made.

For most applications, selection is a five-step process:

1) Determine the necessary steady-state voltage rating (working voltage)
2) Establish the transient energy absorbed by the varistor
3) Calculate the peak transient current through the varistor
4) Determine power dissipation requirements
5) Select a model to provide the required voltage-clamping characteristic

Refer also to page 9-6 "How to select a Harris Varistor," and page 9-8 "How to connect a Harris Varistor."

4.1.1 Steady-State Voltage Rating

Consider the maximum steady-state voltage applied to the varistor including any high line conditions (i.e., 110% or more of nominal voltage). Ratings are given for sinusoidal ac and constant dc. If a nonsinusoidal waveform is applied, the recurrent peak voltage should be limited to $\sqrt{2} \times V_{m(ac)}$.

Specifications for the LA Series varistor are shown in Figure 4.1 for 130V ac rated devices to illustrate the use of the ratings and characteristics table.

Model Number	Model Size Dia. (mm)	Device Marking	Maximum Ratings (85°C)				Characteristics (25°C)					
			Continuous		Transient							
			RMS Voltage	DC Voltage	Energy (10/1000μs)	Peak Current (8/20μs)	Varistor Voltage @ 1 mA DC Test Current			Maximum Clamping Voltage V_C @ Test Current (8/20μs)		Typical Capacitance
			$V_{m(ac)}$	$V_{m(dc)}$	W_{tm}	I_{tm}	Min.	$V_{N(dc)}$	Max.	V_C	I_P	f = 0.1-1 MHz
			Volts	Volts	Joules	Amperes	Volts	Volts	Volts	Volts	Amps	Picofarads
V130LA1	7	1301	130	175	11	1200	184	200	255	390	10	180
V130LA2	7	1302	130	175	11	1200	184	200	228	340	10	180
V130LA5	10	1305	130	175	20	2500	184	200	228	340	25	450
V130LA10A	14	130L10	130	175	38	4500	184	200	228	340	50	1000
V130LA20A	20	130L20	130	175	70	6500	184	200	228	340	100	1900
V130LA20B	20	130L20B	130	175	70	6500	184	200	220	325	100	1900

Figure 4.1 — Ratings and Characteristics Table

Model Number — Indicates an ac voltage rating of 130V ac RMS for LA Series.

$V_{m(ac)}$ — These models can be operated continuously with up to 130V ac RMS at 50-60 Hz applied. They would be suitable for 117V ac nominal line operation and would allow for a 110% high line condition.

$V_{m(dc)}$ — Operation is allowable with up to 175V dc constant voltage applied continuously.

$V_{N(dc)}$ **Min.** — Indicates the minimum varistor terminal voltage that will be measured with 1mA dc applied. This is a characteristic of the device and is a useful parameter for design or for incoming inspection.

$V_{N(dc)}$ **Max. @ 1mA dc** — Indicates the maximum limit of varistor terminal voltage measured at 1mA dc.

The format for the model number designation is shown below. Note, the model series are grouped in two forms. One group is based on the ac voltage rating for applications primarily across the power line. The second group is based on the $V_{N(dc)}$ characteristic voltage.

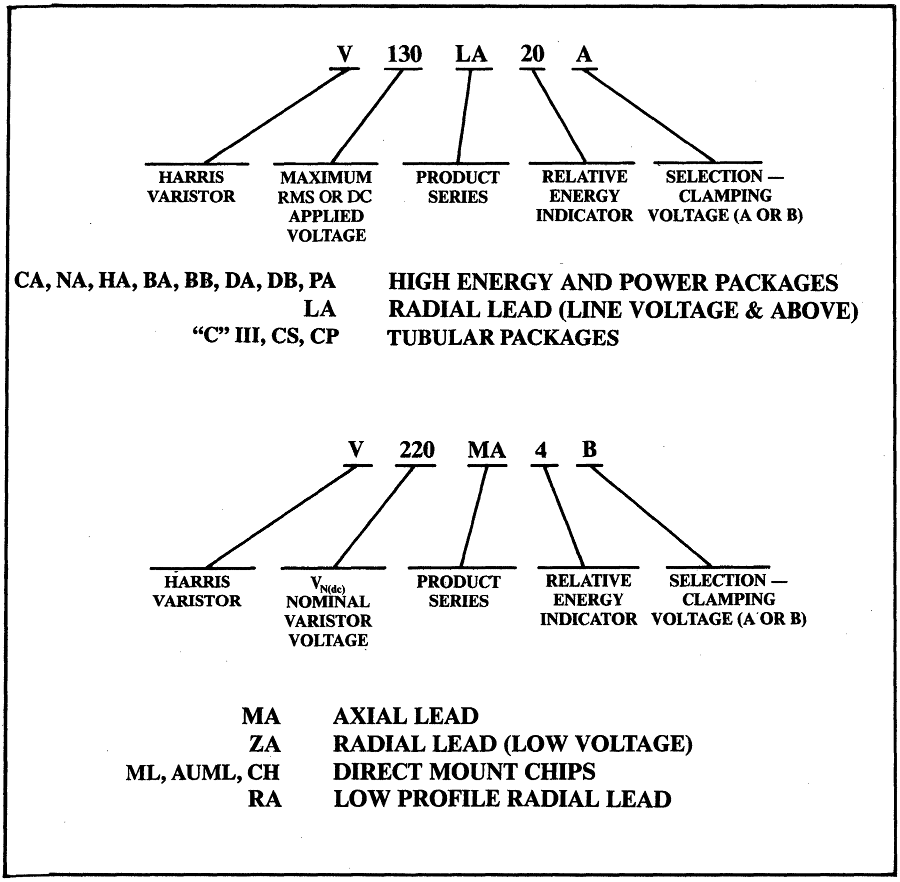


Figure 4.2 — Model Number Nomenclature

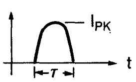
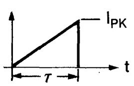
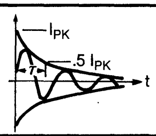
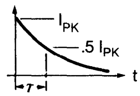
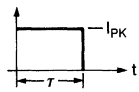
4.1.2 Energy

Transient energy ratings are given in the W_{tm} column of the specifications in joules (watt-second). The rating is the maximum allowable energy for a single impulse of 10/1000µs current waveform with continuous voltage applied. Energy ratings are based on a shift of V_N of less than ±10% of initial value.

When the transient is generated from the discharge of an inductance (i.e., motor, transformer) or a capacitor, the source energy can be calculated readily but, in most cases the transient is from a source external to the equipment and is of unknown magnitude. For this situation an approximation technique can be used to estimate the energy of the transient *absorbed* by the varistor. The method requires finding the transient current and voltage through the varistor. To determine the energy *absorbed* the following equation applies:

$$E = \int_0^{\tau} V_c(t) I(t) \Delta t = K V_c I \tau$$

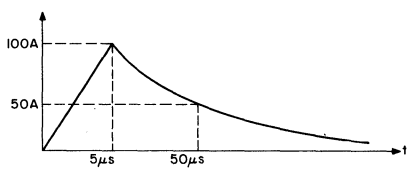
where I is the peak current applied, V_c is the clamp voltage which results, τ is the impulse duration and K is a constant. K values are given in Figure 4.3 for a variety of waveshapes frequently encountered. The K value and pulse width correspond to the current waveform only, assuming the varistor voltage waveform is almost constant during the current impulse. For complex waveforms, this approach also can be used by dividing the shape into segments that can be treated separately.

WAVESHAPE	EQUATION	K*
	$I_{PK} \sin(\frac{\pi}{\tau} t)$	0.637
	$I_{PK} (\frac{t}{\tau})$	0.5
	$I_{PK} \sin(\pi t)\, e^{-t/\tau}$	0.86
	$I_{PK}\, e^{-t/1.44\tau}$	1.4
	I_{PK}	1.0

*Based upon alpha of 25 to 40.

Figure 4.3 — Energy Form Factor Constants

Consider the condition where the exponential waveform shown below is applied to a V130LA1 Harris Varistor.



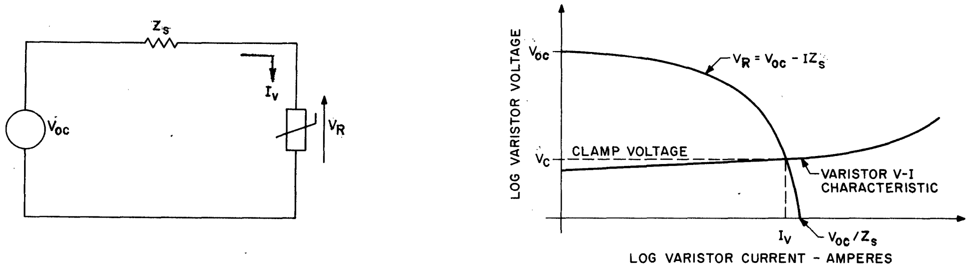
The waveform is divided into two parts that are treated separately using the factors of Figure 4.3: current waveform section (1) 0 to 5µs to infinity. The maximum voltage across the V130LA1 at 100A is found to be 500V from the V-I characteristics of the specification sheet.

Section(1)	$E = KV_C I\tau = (0.5)(500)(100)(5)(10^{-6})$	= 0.13J
Section (2)	$E = KV_C I\tau = (1.4)(500)(100)(50\text{-}5)(10^{-6})$	= 3.15J
		3.28J Total

The specifications of Figure 4.1 indicate a rating of 11J for this device which is adequate for the application.

4.1.3 Peak Current

The peak current rating can be checked against the transient current measured in the circuit. If the transient is generated by an inductor, the peak current will not be more than the inductor current at the time of switching. Another method for finding the transient current is to use a graphical analysis. When the transient voltage and source impedance is known, a Thevenin equivalent circuit can be modeled. Then, a load line can be drawn on the log — log, V-1 characteristic as shown in Figure 4.4. The two curves intersect at the peak current value.



1) Equivalent Circuit **2) Graphics/Analysis to Determine Peak 1**

Figure 4.4 — Determining Varistor Peak Current from a Voltage Source Transient

The rated single pulse current, I_{tm}, is the maximum allowable for a single pulse of 8/20μs exponential waveform (illustrated in Figure 3.21). For longer duration pulses, I_{tm} should be derated to the curves in the varistor specifications. Figure 4.5 shows the derating curves for 7mm size, LA series devices. This curve also provides a guide for derating current as required with repetitive pulsing. The designer must consider the total number of transient pulses expected during the life of the equipment and select the appropriate curve.

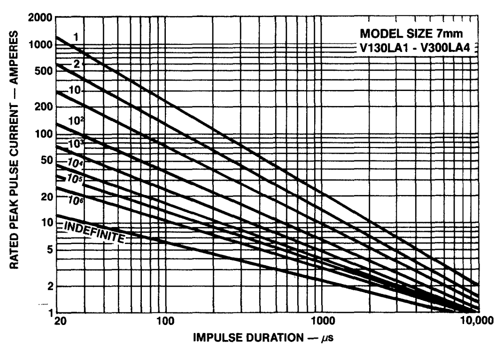


Figure 4.5 — Pulse Ratings

Where the current waveshape is different from the exponential waveform of Figure 3.18, the curves of Figure 4.5 can be used by converting the pulse duration on the basis of equivalent energy. This is easily done using the constants given in Figure 4.3. For example, suppose the actual current measured has a triangular waveform with a peak current of 10A, a peak voltage of 340V and an impulse duration of 500μs.

Then:

$$E = (.5)(10)(340)(500)(10^{-6}) = 850\text{mJ}$$

The equivalent exponential waveform of equal energy is then found from:

$$E_{TRIANGULAR} = E_{EXP}$$

$$850\text{mJ} = 1.4\, V_C\, I\, \tau_{EXP}$$

The exponential waveform is taken to have equal V_C and I values. Then,

$$\tau_{EXP} = \frac{850\text{mJ}}{1.4\,(340)\,(10)} = 179\mu s$$

Or:

$$\tau_{EXP} = \frac{K^* \tau^*}{1.4}$$

Where: K* and τ* are the values for the triangular waveform and τ_{EXP} is the impulse duration for the equivalent exponential waveform.

The pulse rise portion of the waveform can be ignored when the impulse duration is five times or more longer. The pulse life for the above example would exceed 10^4 pulses from the pulse life curves shown in Figure 4.5.

4.1.4 Power Dissipation Requirements

Transients generate heat in a suppressor too quickly to be transferred during the pulse interval. Power dissipation capability is not necessary for a suppressor, unless transients will be occurring in rapid succession. Under this condition, the power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the ratings tables. It is to be noted that varistors can only dissipate a relatively small amount of average power and are, therefore, not suitable for repetitive applications that involve *substantial* amounts of average power dissipation. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 4.6.

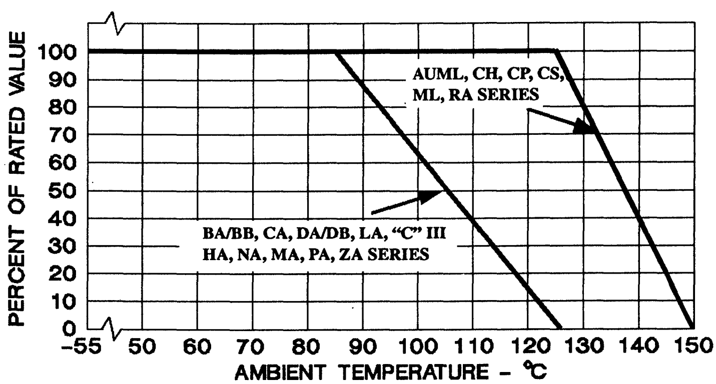


Figure 4.6 — Current, Energy, Power Rating vs. Temperature

4.1.5 Voltage Clamping Selection

Transient V-I characteristics are provided in the specifications for all models of these varistors. Shown below in Figure 4.7 are curves for 130V ac rated models of the LA series. These curves indicate the peak terminal voltage measured with an applied 8/20μs impulse current. For example, if the peak impulse current applied to a V130LA2 is 10A, that model will limit the transient voltage to no higher than 340V.

If the transient current is unknown, the graphical method of Figure 4.4 can be utilized. From a knowledge of the transient voltage and source impedance a load line is plotted on the V-I characteristic. The intersection of the load line with the varistor model curve gives the varistor transient current and the value of clamped peak transient voltage.

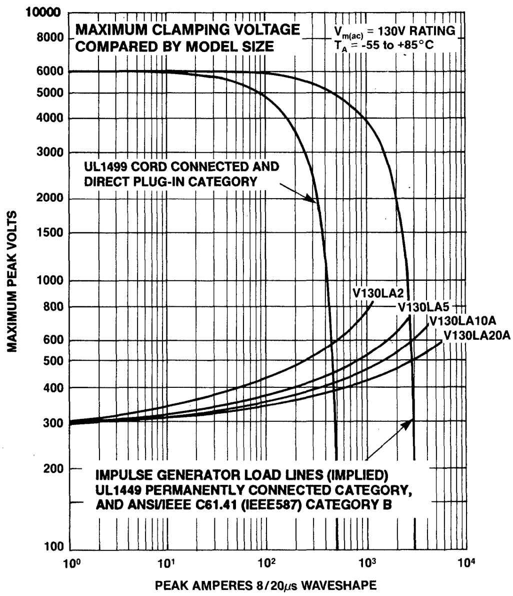


Figure 4.7 — Transient V-I Characteristics of Typical LA Series Models

The ability of the varistor to limit the transient voltage is sometimes expressed in terms of a clamp ratio. For example, consider a varistor applied to protecting the power terminals of electrical equipment. If high line conditions will allow a rise to 130V ac, then 184V peak would be applied. The device selected would require a voltage rating of 130V ac or higher. Assume selection of a V130LA2 model varistor. The V130LA2 will limit transient voltages to 340V at currents of 10A. The clamp ratio is calculated to be,

$$\text{Clamp Ratio} = \frac{V_C \ @ \ 10A}{\text{Peak Voltage Applied}}$$

$$= \frac{340V}{184V} = 1.85$$

The clamp ratio can be found for other currents, of course, by reference to the V-I characteristic. In general, clamping ability will be better as the varistor physical size and energy level increases. This is illustrated in Figure 4.8 which compares the clamping performance of the different Harris Varistor families. It can be seen that the lowest clamping voltages are obtained from the 20mm (LA series) and 60mm (BA series) products. In addition, many varistor models are available with two clamping selections, designated by an A, B, or C at the end of the model number. The A selection is the standard model, with B and C selections providing progressively tighter clamping voltage. For example, the VI30LA20A voltage clamping limit is 340V at 100A, while the VI 30LA20B clamps at not more than 325V.

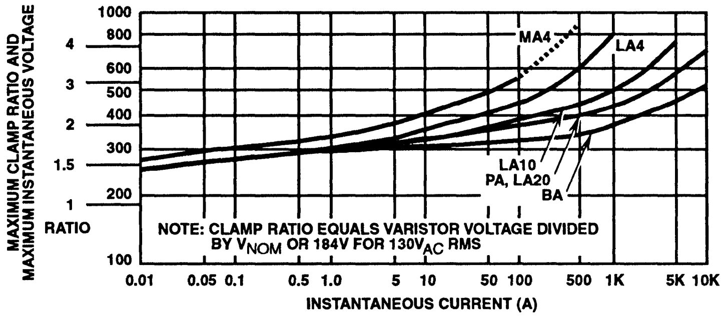


Figure 4.8 — Varistor VI Characteristics for Four Product Families Rated at 130VAC

4.1.6 Summary

The five major considerations for varistor selection have been described. The final choice of model is a balance of these factors with a device cost trade-off. In some applications a priority requirement such as clamp voltage or energy capability may be so important as to force the selection to a particular model. A summary of varistor properties is provided in Figure 4.9 for a quick comparison of operating ranges.

PEAK CURRENT (A)	ENERGY (J)	MAXIMUM STEADY-STATE APPLIED VOLTAGE VOLTS AC RMS: 4 10 25 130 150 250 264 275 460 660 750 1,000 6,000 VOLTS DC: 3.5 14 35 175 200 330 365 369 615 850 970 1,200 7,000	DISC SIZES/ PACKAGES
80 - 500	0.5 - 5.0	CP, CS SERIES	22, 20, 16 GAUGE
150 - 1000	0.2 - 25	AUML, ML, CH SERIES	5 x 8 1206 1210 1812 2220
40 - 100	0.07 - 1.7	MA SERIES	3mm
25 - 4500	0.1 - 35	ZA SERIES	5, 7, 10, 14, 20 (mm)
100 - 6500	0.4 - 160	RA SERIES	5 x 8, 10 x 16, 14 x 22 (mm)
1,200 - 9000	11 - 360	"C" III, LA SERIES	7, 10, 14, 20 (mm)
6500	70 - 250	PA SERIES	20mm
25,000 - 40,000	270 - 1,050	HA, DA/ DB SERIES	32, 40 (mm) 40mm
50,000 - 70,000	450 - 10,000	BA/ BB SERIES	60mm
20,000 - 100,000	200 - 10,000	NA, AS & CA SERIES	32, 40, 42, 52, 60 (mm) 34mm SQ.

Figure 4.9 — Varistor Product Family Selection Guide

4.2 FAILURE MODES AND VARISTOR PROTECTION

Varistors are inherently rugged and are conservatively rated. Therefore, they exhibit a low failure rate. Nevertheless, the careful designer may wish to plan for potential failure modes and the resultant effects on circuitry being protected.

4.2.1 Failure Modes

Varistors initially fail in a short-circuit mode when subjected to surges beyond their peak current/energy ratings. They also short-circuit when operated at steady-state voltages well beyond their voltage ratings. This latter mode of stress may result in the eventual open-circuiting of the device due to melting of the lead solder joint.

When the device fails in the shorted mode the current through the varistor becomes limited mainly by the source impedance. Consequently, a large amount of energy can be introduced, causing mechanical rupture of the package accompanied by expulsion of package material in both solid and gaseous forms. Steps may be taken to minimize this potential hazard by the following techniques: 1) fusing the varistor to limit high fault currents, and, 2) protecting the surrounding circuitry by physical shielding, or by locating the varistor away from other components.

4.2.2 Fusing the Varistor

Varistor fusing should be coordinated to select a fuse that limits current below the level where varistor package damage could occur. The location of the fuse may be in the distribution line to the circuit or it may be in series with the varistor as shown in Figure 4.10. Generally, fuse rather than breaker protection is preferred. Breaker tripping is too slow to prevent excessive fault energy from being applied.

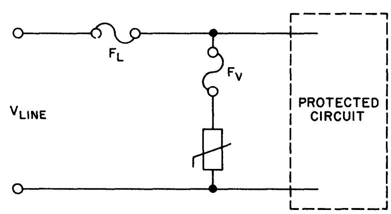


Figure 4.10 — Fuse Placement for Varistor Protection

In high power industrial circuits the line currents are generally so high as to rule out the use of a line fuse for varistor protection. The fuse may not clear under a varistor fault condition and would allow varistor failure. In low power (5-20A) applications it may be feasible to use the line fuse, F_L, only.

Use of a line fuse, F_L, rather than F_V, does not present the problem of having the fuse arc voltage being applied across the circuit. Conversely, with F_V alone, the fuse arc voltage adds to the varistor voltage, increasing the V_C, the transient clamp voltage. Since some fuses can have peak arc voltages in excess of twice peak working voltage, fuse clearing can have a significant effect on protection levels.

Another factor in the choice of location is the consequence of system interruption. Fuse location F_L will cause a shutdown of the circuit while location F_V will not. While the circuit can continue to operate when F_V clears, protection no longer is present. For this reason it is desirable to be able to monitor the condition of F_V.

4.2.3 Fusing Example (Light Industrial Application)

A process control minicomputer is to be protected from transients on a 115V nominal line. The minicomputer draws 7.5A from the line, which is guaranteed to be regulated to ±10% of nominal line voltage. A V130LA20A varistor is chosen on the basis that the worst-case surge current would be a 10/1000μs pulse of 100A peak amplitude. The rationale for this surge requirement is that the incoming plant distribution system is protected with lightning arrestors having a maximum arrestor voltage of 5kV. Assuming a tyical 50Ω characteristic line impedance, the worst-case transient current through the varistor is 100A. The 1ms impulse duration is taken as a worst-case composite wave estimate. While lightning stroke discharges are typically less than 100μs, they can recur in rapid fire order during a 1s duration. From the pulse lifetime rating curves of the L series size 20 models, it is seen that the V130LA20 single pulse withstand capability at 1ms impulse duration is slightly in excess of 100A.

This is adequate for application in areas where lightning activity is medium to light. For heavy lightning activity areas, either a DA or DB series varistor might be desirable to allow a capability of withstanding over 70 transients. In making the choice between the LA series and higher energy series, the designer must decide on the likelihood of a worst-case lightning stroke and the cost of the fuse replacement should the varistor fail.

Assuming a low lightning activity area, the V130LA20A series is a reasonable choice. To coordinate the fuse with the varistor, the single pulse lifetime curve is redrawn as I^2t vs. impulse duration as shown in Figure 4.11. The I^2t of the composite 10/1000μs impulse is found from:[1]

$$I^2t = \frac{1}{3}\hat{I}^2 (10\mu s) + 0.722\,\hat{I}^2 (\tau_{(.5)} - 10\mu s)$$

when: $\tau_{(.5)} \geqslant 200\mu s$ (time for impulse current to decay by 0.5)

$$I^2t \approx 0.722\,\hat{I}^2\,\tau_{(.5)}$$

where: the first term represents the impulse I^2t contributed by the 10μs rise portion of the waveform and the second term is the I^2t contributed by the exponential decay portion.

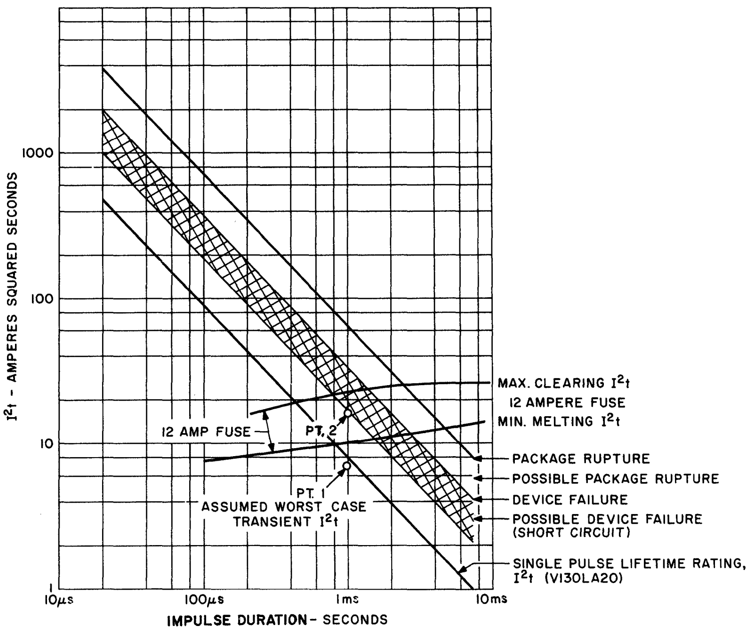


Figure 4.11 — Harris Varistor — Fuse Coordination Chart

Figure 4.11 shows a cross-hatched area which represents the locus of possible failure of the varistor. This area is equal to an I^2 value of from two to four times that derived from the data sheet peak current pulse life curves. The curve extending beyond the cross-hatched area and parallel to it is where package rupture will take place.

The criteria for fuse selection is given below.

A) Fuse melts; i.e., opens, only if worst-case transient is exceeded and/or varistor fails.
B) If varistor fails, fuse clearing limits I^2t applied to varistor values below that required for package rupture.
C) Fuse is rated at 130V RMS.
D) Fuse provides current limiting for solid-state devices.

Based on the above, a Carbone-Ferraz 12A RMS, 130V RMS, Class FA fuse is tentatively selected. The *minimum* melting I^2t and *maximum* clearing I^2t curves for the 12A fuse are shown superimposed on the varistor characteristics.

This fuse is guaranteed to melt at an I^2t of 40% above the estimated worst-case transient. Upon melting, clearing I^2t and clearing time will depend upon available fault current from the 130V RMS line. Figure 4.12 lists clearing times for the selected fuse versus available prospective circuit current.

Prospective Current Amps RMS	Clearing Time Milliseconds
60	8.0
120	5.6
240	3.5
1200	1.3
3600	0.57

Figure 4.12 — 12A Fuse — Prospective Current vs. Clearing Time

As Figure 4.11 shows, a clearing time of less than 1.5ms is desirable. For fault currents in excess of 1.2kA, the fuse will clear at less than $24A^2s$ and 1.3ms. This will prevent varistor package rupturing. However, the distribution line may be "soft," i.e., have a high source impedance at the 60Hz power frequency that limits the fault current to values below 1.2kA. Then, it is possible that the fuse would not protect the varistor package from rupturing, though it would serve to isolate the varistor in any case.

Upon further examination of this example, it is clear that the varistor will be protected from package rupturing even if the transient pulse current is 50% greater than that of the assumed value, resulting in an I^2t of $16A^2s$ (Point 2 on Figure 4.11).

Placement of the fuse for this example application could be in the line or in series with the varistor. If in series with the varistor, the line fuse should be a medium to slow speed, such as a "slow blow" type 15A fuse. That would assure a fault in the varistor would be isolated by the varistor fuse without interrupting the line fuse.

It is desirable to indicate the status of the varistor fuse if one is used in addition to the line fuse. The circuit shown in Figure 4.13 senses the presence of voltage across the varistor by use of a photocoupler. When the fuse interrupts the varistor circuit, the LED of the coupler becomes de-energized, and the coupler output signal can be used to annunciate an unprotected condition. Some fuse manufacturers provide indicating means upon fuse operation that may also be used to trip an alarm.

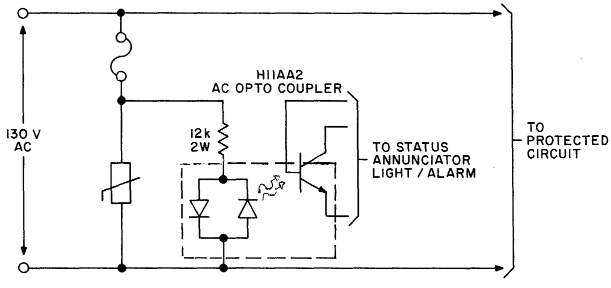


Figure 4.13 — Varistor Fuse Status Sensing Circuit

In selecting a fuse, the reader is advised to avoid data based on average values or data taken at operating conditions that are grossly different from the actual application. For example, dc data does not apply when the fuse will be used on an ac circuit. Also, test data taken in a resistive circuit with unity power factor does not hold for low power factor operation.

4.3 SERIES AND PARALLEL OPERATION OF VARISTORS

In most cases the designer can select a varistor that meets the desired voltage ratings from standard catalog models. Occasionally the standard catalog models do not fit the requirements either due to voltage ratings or energy/current ratings. When this happens, two options are available: varistors can be arranged in series or parallel to make up the desired ratings, or the factory can be asked to produce a "special" to meet the unique application requirement.

4.3.1 Series Operation of Varistors

Varistors are applied in series for one of two reasons: to provide voltage ratings in excess of those available, or to provide a voltage rating between the standard model voltages. As a side benefit, higher energy ratings can be achieved with series connected varistors over an equivalent single device. For instance, assume the application calls for a lead mounted varistor with an RMS voltage rating of 375V ac and having a I_{tm} peak current capability of 6000A. The I_{tm} requirement fixes the varistor size. Examining the LA series voltage ratings near 375V ac, only 320V and 420V units are available. The 320V is too low and the 420V unit (V420LA40B) results in too high a clamp voltage (V_C of 1060V at 100A). For a V130LA20B and a V250LA40B in series, the maximum rated voltage is now the sum of the voltages, or 380V. The clamping voltage, V_C, is now the sum of the individual varistor clamping voltages, or 945V at 100A. The peak current capability is still 6500A but the energy rating is now the sum of the individual energy ratings, or 200J.

In summary, varistors can be connected in series providing they have identical peak current ratings (I_{tm}), i.e., same disc diameter. The composite V-I characteristic, energy rating, and maximum clamp voltages are all determined by summing the respective characteristics and/or ratings of the individual varistors.

4.3.2 Parallel Operation of Varistors

Application requirements may necessitate higher peak currents and energy dissipation than the high energy series of varistors can supply individually. When this occurs, the logical alternative is to examine the possibility of paralleling varistors. Fortunately, all Harris Varistors have a property at high current levels that makes paralleling feasible. This property is the varistor's series-resistance that is prominent during the "up-turn region" of the V-I characteristic. This up-turn is due to the inherent linear resistance component of the varistor characteristic (see Chapter 3). It acts as a series balancing, or ballasting, impedance to force a degree sharing that is not possible at lower current levels. This is depicted in Figure 4.14. At a clamp voltage of 600V, the difference in current between a maximum specified sample unit and a hypothetical 20% lower bound sample would be more than 20 to 1. Thus, there is almost no current sharing and only a single varistor carries the current. Of course, at low current levels in the range of 10-100A, this may well be acceptable.

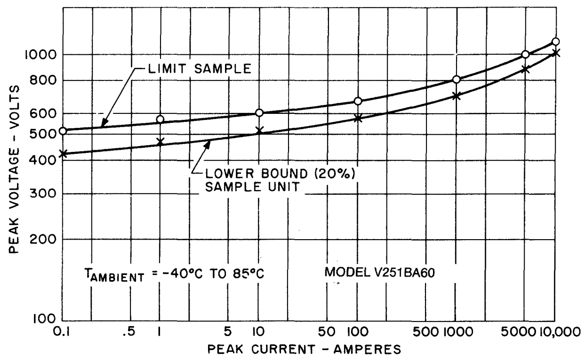


Figure 4.14 — Parallel Operation of Varistors by Graphical Technique

At high current levels exceeding 1000A, the up-turn region is reached and current sharing improves markedly. For instance, at a clamp voltage of 900V, the respective varistor currents (Figure 4.14) are 2500A and 6000A, respectively. While far from ideal sharing, this illustration shows the feasibility of paralleling to achieve higher currents and energy than achievable with a single model varistor.

Practically, varistors must be matched by means of high current pulse tests to make parallel operation feasible. Pulse testing should be in the range of over 1kA, using an 8/20μs, or similar pulse. Peak voltages must be read and recorded. High current characteristics could then be extrapolated in the range of 100-10,000A. This is done by using the measured data points to plot curves parallel to the data sheet curves. With this technique current sharing can be considerable improved from the near worst-case conditions of the hypothetical example given in Figure 4.14.

In summary, varistors can be paralleled, but good current sharing is only possible if the devices are matched over the total range of the voltage-current characteristic. In applications requiring paralleling, Harris should be consulted.

Some guidelines for series and parallel operation of varistors are given in Figure 4.15.

	Series	Parallel
Objective	Higher Voltage Capability Higher Energy Capability Non-standard Voltage Capability	Higher Current Capability Higher Energy Capability
Selection Required	NO	YES
Models Applicable	All, must have same I_{tm} rating.	All models
Application Range	All voltages and currents.	All voltages — only high currents, i.e., > 100 amperes.
Precautions	I_{tm} ratings must be equal.	Must be identical voltage rated models. Must test and select units for similar V-I characteristics.
Effect on Ratings	Clamp voltages additive. Voltage ratings additive. Current ratings that of single device. Energy W_{tm}, ratings additive.	Current ratings function of current sharing as determined graphically. Energy ratings as above in proportion to current sharing. Clamp voltages determined by composite V-I characteristic of matched units. Voltage ratings that of single unit.

Figure 4.15 — Checklist for Series and Parallel Operation of Varistors

4.4 APPLICATIONS

4.4.1 Power Supply Protection Against Line Transient Damage

PROBLEM: It is desired to prevent failure of the power supply shown in Figure 4.16(b) to be used on residential 117V ac lines. A representative transient generator is to be used for testing, as shown in Figure 4.16(a).

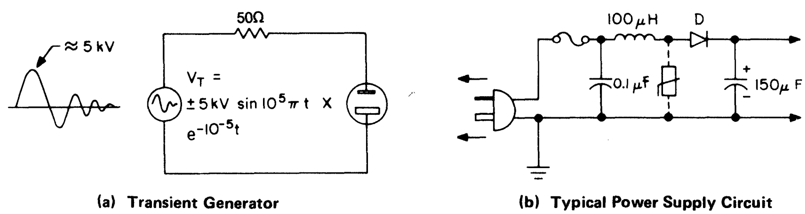


Figure 4.16 — Power Supply Protection

If the transient is applied to the existing circuit, the rectifier will receive high negative voltages, transmitted through the filter capacitor. The LC network is there to prevent RFI from being transmitted into the power line (as in a TV set), but also serves to reduce the transient voltage. An analysis shows that the transient will be reduced approximately by half, resulting in about 2.5kV instead of 5kV at the rectifier.

This is still too high for any practical rectifier, so some suppression must be added. It is desirable to use the built-in impedance of the coil to drop the remaining voltage, so the suppressor would best be applied as shown. A selection process for a Harris Varistor is as follows:

SOLUTION:

Steady-State Voltage

The 117V ac, 110% high line condition is 129V. The closest voltage rating available is 130V.

Energy and Current

The 100μH inductor will appear to be about 30Ω to the transient. The 30Ω is derived from the inductive reactance at the transient generator source frequency of $10^5 \pi$ rad. Taking a first estimate of peak varistor current, 2500V/80Ω = 31A. (This first estimate is high, since it assumes varistor clamping voltage is zero.) With a tentative selection of a 130V Harris Varistor, we find that a current of 31A yields a voltage of from 325V to 430V, depending on the model size, as shown in Figure 4.17.

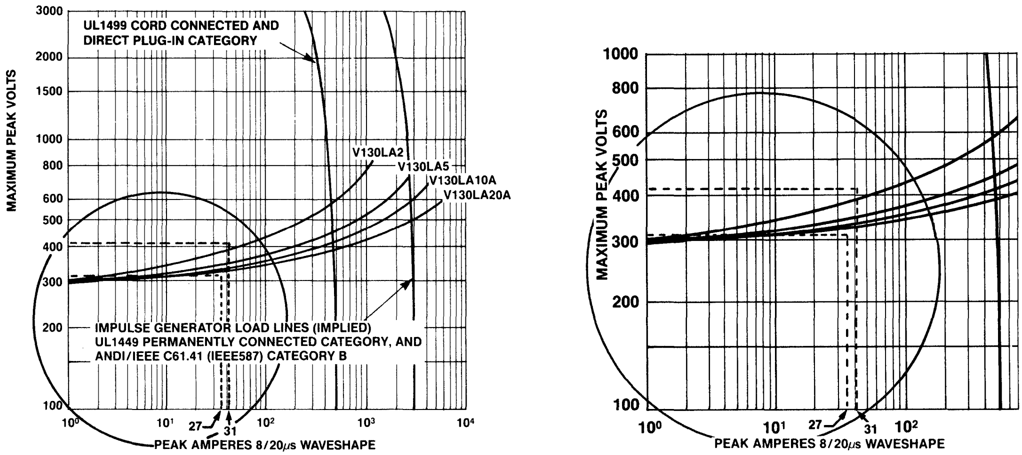


Figure 4.17 — V130LA Varistor V-I Characteristics

Revising the estimate, I ≈ (2500V — 325V)/80Ω = 27.2A. For model V130LA20B, 27.2A coincides closely with a 320V clamping level. There is no need to further refine the estimate of peak current if model B remains the final selection.

To arrive at an energy figure, assume a sawtooth current waveform of 27A peak, dropping to zero in two time constants, or 20μs.

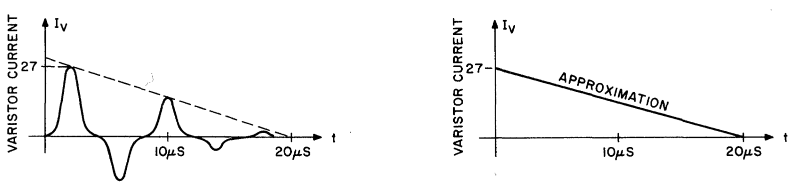


Figure 4.18 — Energy Approximation

Energy is then roughly equal to (27A x 320V x 20μs)/2, the area under the power waveform. The result is 0.086J, well within the capability of the varistor (50J). Peak current is also within the 6000A rating.

Model Selection

The actual varistor selection is a trade-off between the clamping voltage desired and the number of transient current pulses expected in the life of the equipment. A 50J rated varistor will clamp at 315V and be capable of handling over 10^5 such pulses. An 8J unit will clamp to approximately 385V and be capable of handling over 1000 such pulses. Furthermore, the clamping voltage determines the cost of the rectifier by determining the voltage rating required. A smaller, lower cost varistor may result in a more expensive higher voltage rectifier diode.

4.4.2 SCR Motor Control

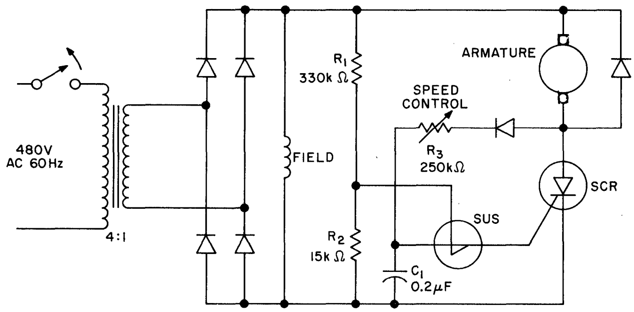


Figure 4.19 — SCR Motor Control

PROBLEM: The circuit shown in Figure 4.19 experiences failures of the rectifiers and SCR when the transformer primary is switched off. The manufacturer has tried 600V components with little improvement.

SOLUTION: Add a varistor to the transformer secondary to clamp the transformer inductive transient voltage spike. Select the lowest voltage Harris Varistor that is equal to or greater than the maximum high line secondary ac voltage. The V130LA series fulfills this requirement.

Determine the peak suppressed transient voltage produced by the transient energy source. This is based on the peak transient current to the suppressor, assuming the worst-case condition of zero load current. Zero load current is normally a valid assumption. Since the dynamic transient impedance of the Harris Varistor is generally quite low, the parallel higher impedance load path can be neglected.

Determination of Peak Transient Current

Since transient current is the result of stored energy in the core of the transformer, the transformer equivalent circuit shown in Figure 4.20 will be helpful for analysis. The stored inductive energy is:

$$E_{L_m} = \frac{1}{2} L_m \hat{I}^2_m$$

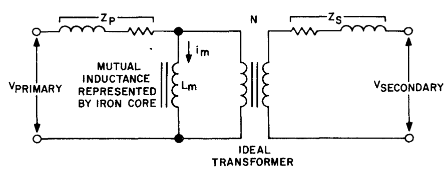


Figure 4.20 — Simplified Equivalent Circuit of a Transformer

The designer needs to know the total energy stored and the peak current transformed in the secondary circuit due to the mutual inductance, L_m. At no load, the magnetizing current, (I_{NL}), is essentially reactive and is equal to i_m. This assumes that the primary copper resistance, leakage reactance and equivalent core resistive loss components are small compared to L_m. This is a valid assumption for all but the smallest control transformers. Since I_{NL} is assumed purely reactive, then:

$$X_{L_M} = \frac{V_{pri}}{I_{NL}}$$

and

$$i_m = I_{NL}$$

I_{NL} can be determined from nameplate data. Where nameplate is not available, Figures 4.21 and 4.22 can guide the designer.

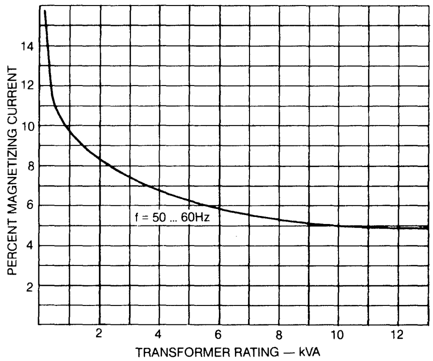


Figure 4.21 — Magnetizing Current of Transformers with Low Silicon Steel Core

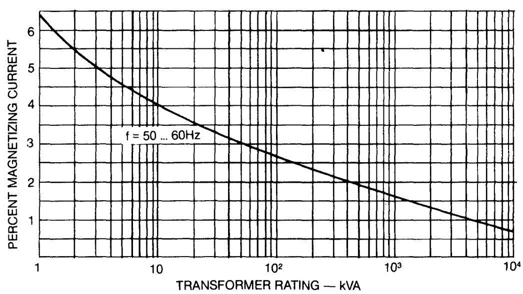


Figure 4.22 — Magnetizing Current of Transformers with High Silicon Steel Core or Square Loop Core

Assuming a 3.5% value of magnetizing current from Figure 4.22 for a 20kVA transformer with 480V ac primary, and 120V ac secondary:

$$i_m = (0.035)\ \frac{20\text{kVA}}{480\text{V}}$$

$$= 1.46\text{A}$$

$$\hat{i}_m = \sqrt{2}\ i_m$$

$$X_{L_m} = 480\text{V}/1.46\text{A}$$

$$= 329\Omega$$

$$L_m = X_{L_m}/\omega$$

$$= 0.872\text{H}$$

$$E_{L_m} = \frac{0.872\ (2.06)^2}{2}$$

$$= 1.85\text{J}$$

With this information one can select the needed semiconductor voltage ratings and required varistor energy rating.

Semiconductor Blocking Voltage Ratings Required

Peak varistor current is equal to transformed secondary magnetizing current, i.e., $\hat{i}_m(N)$, or 8.24A. From Figure 4.17, the peak suppressed transient voltage is 310V with the V130LA10A selection, 295V with the V130LA20B. This allows the use of 300V rated semiconductors. Safety margins exist in the above approach as a result of the following assumptions:

1. All of the energy available in the mutual inductance is transferred to the varistor. Because of core hysteresis and secondary winding capacitance, only a fraction less than two-thirds is available.
2. The exciting current is not purely reactive. There is a 10% to 20% safety margin in the peak current assumption.

After determining voltage and peak current, energy and power dissipation requirements must be checked. For the given example, the single pulse energy is well below the V130LA10A varistor rating of 38J at 85°C maximum ambient temperature. Average power dissipation requirements over idling power are not needed because of the non-repetitive nature of the expected transient. Should the transient be repetitive, then the average power is calculated from the product of the repetition rate times the energy of the transient. If this value exceeds the V130LA20A capability of 1.0W, power varistors of the HA, DA, or DB Series.

Should the ambient temperature exceed 85°C or the surface temperature exceed 85°C, the RA series varistors should be considered because of their higher temperature capabilities. The single pulse energy ratings and the average power ratings must be derated by the appropriate derating factors supplied on the data sheet.

4.4.3 Contact Arcing Due to Inductive Load

When relays or mechanical switches are used to control inductive loads, it is necessary to use the contacts at only about 50% of their resistive load current rating to reduce the wear caused by arcing of the contacts. The energy in the arcing is proportional to the inductance and to the square of the current.

Each time the current in the inductive load is interrupted by the mechanical contacts, the voltage across the contacts builds up as $-L\,di/dt$. When the contacts arc, the voltage across the arc decreases and the current in the coil can increase somewhat. The extinguishing of the arc causes an additional voltage transient which can again cause the contacts to arc. It is not unusual for the restriking to occur several times with the total energy in the arc several times that which was originally stored in the inductive load. It is this repetitive arcing that is so destructive to the contacts.

PROBLEM: To extend the life of the relay contacts shown in Figure 4.23 and reduce radiated noise, it is desired to eliminate the contact arcing.

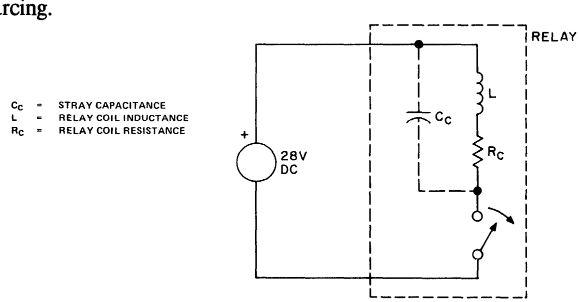


Figure 4.23 — Relay Circuit

In the example, R_C is 30Ω and the relay contacts are conducting nearly 1A. The contacts will draw an arc upon opening with more than approximately 0.4A or 12V. The arc continues until current falls below 0.4A.

SOLUTION: To prevent initiation of the arc, it is necessary to reduce the current and voltage of the contacts below the arc threshold levels at the time of opening, and then keep them below breakdown threshold of the contacts as they open. Two obvious techniques come to mind to accomplish this: 1) use of a large capacitor across the contacts, and 2) a voltage clamp (such as a varistor). The clamp technique can be effective only when the minimum arc voltage exceeds the supply voltage.

In this example a clamping device operating above the supply voltage will not prevent arcing. This is shown in Figure 4.24.

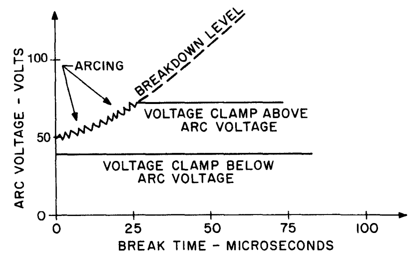
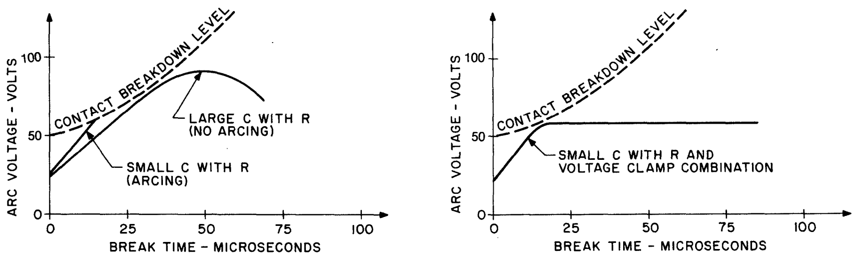


Figure 4.24 — Voltage Clamp Used as Arc Suppressor

The capacitor technique requires the capacitance to be sufficiently large to conduct the inductor current with a voltage rate-of-rise tracking the breakdown voltage rate-of-rise of the contacts as they mechanically move apart. This is shown in Figure 4.25(a).



(a) R-C Arc Suppression **(b) R-C & Clamp Arc Suppression**

Figure 4.25 — Relay Arc Voltage Suppression Techniques

The limitations in using the capacitor approach are size and cost. This is particularly true for those cases involving large amounts of inductive stored energy. Furthermore, the use of a large capacitor alone creates large discharge currents upon contact reclosure during contact bouncing. As a result, the contact material may melt at the point of contact with subsequent welding. To avoid this inrush current, it is customary to add a series resistor to limit the capacitive discharge current. However, this additional component reduces the network effectiveness and adds additional cost to the solution.

A third technique, while not as obvious as the previous two, is to use a combination approach. This technique shown in Figure 4.25(b) parallels a voltage clamp component with an R-C network. This allows the R-C network to prevent the low voltage initial arcing and the clamp to prevent the arcing that would occur later in time as the capacitor voltage builds up. This approach is often more cost effective and reliable then using a large capacitor.

Also, with ac power relays the impedance of a single large R-C suppressor might be so low that it would allow too much current to flow when the contacts are open. The combination technique of a small R-C network in conjunction with a varistor is of advantage here, too.

In this example a 0.22μF capacitor and 10Ω resistor will suppress arcing completely, but by reducing the capacitance to 0.047μF, arcing will start at 70V.

Thus, to use a varistor as a clamp in conjunction with the R-C network, it must suppress the voltage to below 70V at 1A and be capable of operating at a steady-state maximum dc voltage of 28V + 10%, or 30.8V (assumes a $\pm$10% regulated 28V dc supply).

Selecting the Varistor

The three candidates that come closest to meeting the above requirement are the MA series V39MA2B model and the ZA series V39ZA1 and V39ZA05 models, all of which have maximum steady-state dc voltage ratings of 31V. The V39MA2B and V39ZA05 V-I characteristics at 1A shows a maximum voltage of 73V, while the V39ZA1 characteristic at 1A shows a maximum voltage of 67V. Thus, the latter varistor is selected. Use of a 0.068μF capacitor in place of the 0.047μF previously chosen would allow use of the V39MA2B or V39ZA05.

Placing only a Harris Varistor rated for 31V dc across the contacts results in arcing up to the 66V level. By combining the two, the capacitor size and voltage rating are reduced and suppression complete.

Besides checking the varistor voltage and arcing elimination, the designer should review energy and peak current requirements. Varistor energy is determined from a measurement of the coil inductance and the calculation $E = \frac{1}{2} Li^2$. Peak current, of course, is under 1A. Power dissipation is negligible unless the coil is switched often (several times per minute).

In those cases where multiple arcs occur, the varistor energy will be a multiple of the above $\frac{1}{2} Li^2$ value. The peak current is well within the rating of either the MA or ZA series of varistors, but the number of contact operations allowable for either varistor is a function of the impulse duration. This can be estimated by assuming a L/R_C time constant at the 1A or peak current value. Since the voltage across the varistor is 67V at 1A, the varistor static resistance is 67Ω. The coil R_C value is 28V/1A, or 28Ω. The coil inductance was found to be 20mH. Thus, the approximate time constant is:

$$\tau = L/R_C = \frac{20\text{mH}}{95} = 210\mu\text{s}$$

From the pulse lifetime curves of the V39ZA1 model, the number of allowable pulses exceeds 100 million.

4.4.4 Noise Suppression

Noise is an electromechanical system is a commonly experienced result of interrupting current by mechanical contacts. When the switch contacts open, a hot cathode arc may occur if the current is high enough. On the other hand, low current will permit switch opening without an arc, but with ringing of circuit resonances. As a consequence, voltages can exceed the contact gap breakdown resulting in a replica of the old spark gap transmitter. It is the low current case that produces the most serious noise disturbances which can result in malfunctions or damage to electrical equipment. These pulses cause noise problems on adjacent lines, trigger SCR's and triacs, and damage semiconductors. In addition, they can raise havoc with mircroprocessor operation causing memory to be lost and vital instructions to be missed.

PROBLEM: Switching of a small timer motor on 120V, 60Hz, was causing serious malfunctions of an electronic device operating from the same power line. Attempts were made to observe the transient noise on the line with an oscilloscope as the first step in curing the problem. Observed waveforms were "hash," i.e., not readily identifiable.

SOLUTION: A test circuit (Figure 4.26) was set up with lumped elements replacing the measured circuit values. The motor impedance was simulated by R_1, L_1, and C_1, and the ac line impedance by L_2 and C_2. A dc source allowed repeatable observations over the full range of current that could flow through the switch in the normal ac operation. A diode detector was used to observe the RF voltage developed across a 2" length of wire (50nH of inductance).

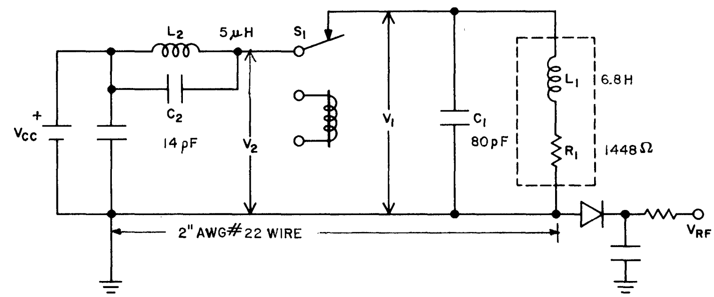
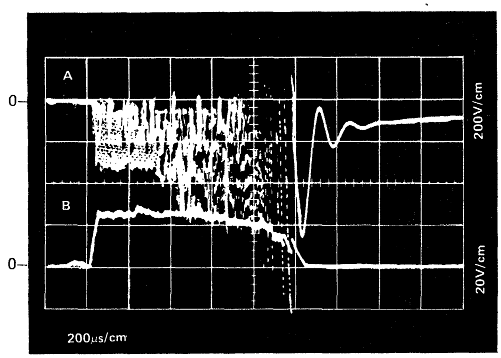


Figure 4.26 — Test Circuit

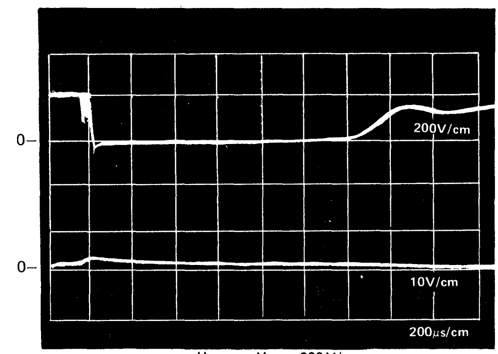
The supply is set at 25mA to represent the peak motor current in normal 120V ac operation. As switch S_1 was opened, the waveform in Figure 4.27 was recorded. Note the "showering arc" effect. The highest breakdown voltage recorded here is 1020V, and the highest RF detector output (shown in the lower trace) is 32V.

Obviously, some corrective action should be taken and the most effective one is that which prevents the repeated breakdown of the gap. Figure 4.28 shows the waveform of V_1 (upper trace) and V_{RF} (lower trace) for the same test conditions with a Harris Varistor, type V130LA10A, connected directly across the switch terminals. The varistor completely eliminates the relaxation oscillations by holding the voltage below the gap breakdown voltage (about 300V) while dissipating the stored energy in the system.



Upper V_1: 200 V/cm
Lower V_{RF}: 20 V/cm
t: 0.2 ms/cm

Figure 4.27 — Unprotected Contacts

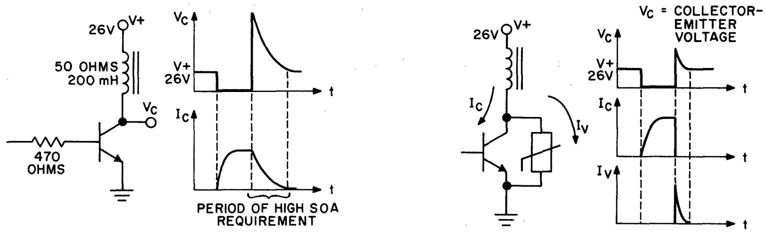


Upper V_1: 200 V/cm
Lower V_{RF}: 20 V/cm
t: 0.2 ms/cm

Figure 4.28 — Varistor Protected Contacts

4.4.5 Protection of Transistors Switching Inductive Loads

PROBLEM: The transistor in Figure 4.29 is to operate a solenoid. It may operate as frequently as once per second. The circuit (without any suppression) consistently damages the transistor.



(a) Basic Solenoid Circuit

(b) Solenoid Circuit with Varistor Protection

Figure 4.29 — Transistor Switching of an Inductive Load

The inductor drives the collector voltage up when the transistor base is grounded (turning "off"). The inductor forces current to flow until the energy stored in its field is dissipated. This energy is dissipated in the reverse bias condition of the transistor and is sufficient to cause breakdown (indicated by a sudden collapse of collector voltage during the pulse).

SOLUTION: This condition can be eliminated either by shunting the transistor with a suppressor or by turning it on with a varistor connected collector-to-base. The first method will considerably reduce the demands upon the safe-operating area (SOA) of the transistor. If the voltage is kept below its breakdown level, all energy will be dissipated in the suppressor. The latter method will cause the transistor to once again dissipate the stored energy, but in the forward-bias state in which the transistor can safely dissipate limited amounts of energy. The choice is determined by economics and reliability. A suppressor connected collector-emitter (C-E) will be more expensive than one connected C-B, since it is required to absorb more energy, but will allow the use of a transistor with reduced SOA.

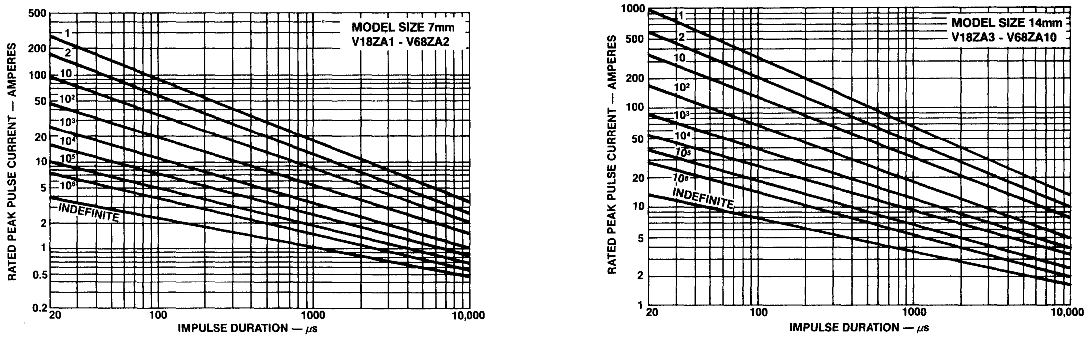
If a collector-emitter varistor is used in the above example, it is required to withstand 28.6V dc worst-case (26 + 10% regulation). The stored energy is $\frac{1}{2} Li^2$ or $\frac{1}{2}(0.20)(0.572)^2 = 0.0327J$. The energy contributed by the power supply is roughly equal to this (coil voltage ≈ supply voltage, since varistor clipping voltage ≈ 2 x supply voltage). Ignoring coil resistance losses for a conservative estimate, varistor energy dissipation is 0.065J per pulse. The peak current will be 0.572A, the same as the coil current when the transistor is switched off.

If the transistor operates once per second, the average power dissipation in the varistor will be 0.065W. This is less than the 0.20W rating of a small 31V dc varistor (V39ZA1). From the data sheet it can be seen that if the device temperature exceeds 85°C, derating is required. The non-recurrent joule rating is 1.2J, well in excess of the recurrent value. To determine the repetitive joule capability, the current pulse rating curves for the ZA series must be consulted. Two are shown in Figure 4.30.

To use Figure 4.30, the impulse duration (to the 50% point) is estimated from the circuit time constants and is found to be 1240μs. From Figure 4.30(a), the pulse rating is estimated to be slightly over 10^8 operations. As this may not be adequate, the designer may wish to go to a larger size varistor (V39ZA6). At 0.572A, the approximate impulse duration is now found to be 1280μs and using Figure 4.30(b), the designer is faced with the problem of extrapolation below 1A. This has been done in Figure 4.31 which is a new plot of the data of Figure 4.30(b) at 1280μs.

We conclude that the life exceeds 10^9 operations. The reader may question the extrapolation of four orders of magnitude. At low currents the relationship is a straight line extrapolation on log-log paper, as seen from Figure 4.30(a), where the pulse rating curves extend to 10^8 pulses.

The clipping characteristics of the V39ZA6 model will provide a 61V maximum peak. The transistor should have a V_{CER} of 65V or greater for this application.



(a) — ZA Series V18ZA1 to V68ZA2
Model Size 7mm

(b) — ZA Series V18ZA3 to V68ZA10
Model Size 14mm

Figure 4.30 — ZA Series Pulse Ratings

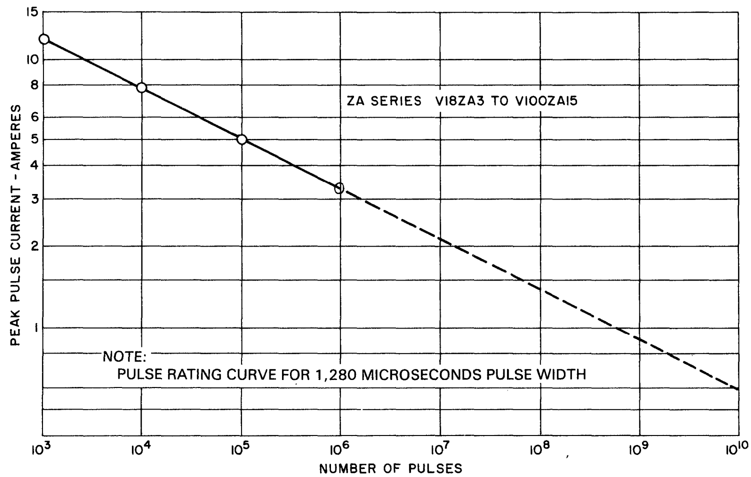


Figure 4.31 — Extrapolated Pulse Rating Curves

4.4.6 Motor Protection

Frequently, the cause of motor failures can be traced to insulation breakdown of the motor windings. The source of the transients causing the breakdown may be from either internal magnetic stored energy or from external sources. This section deals with the self-generated motor transients due to motor starting and circuit breaker operation. Externally-generated transients and their control are covered in Chapter 2.

In the case of dc motors the equivalent circuit consists of a single branch. The magnetic stored energy can be easily calculated in the armature or field circuits using the nameplate motor constants. With ac induction motors the equivalent magnetic motor circuit is more complex and the circuit constants are rarely given on the motor nameplate. To provide a guide for motor protection, Figures 4.32, 4.33 and 4.34 were drawn from typical induction motor data. While the actual stored energy will vary according to motor frame size and construction techniques, these curves provide guidance when specific motor data is lacking. The data is conservative as it assumes maximum motor torque, a condition that is not the typical running condition. Stored energy decreases considerably as the motor loading is reduced. Experience with the suppression of magnetic energy stored in transformers indicates that Harris Varistors may be used at their maximum energy ratings, even when multiple operations are required. This is because of the conservatism in the application requirements, as indicated above, and in the varistor ratings. Thus, no attempt is made to derate the varistor for multiple operation because of the random nature of the transient energy experienced.

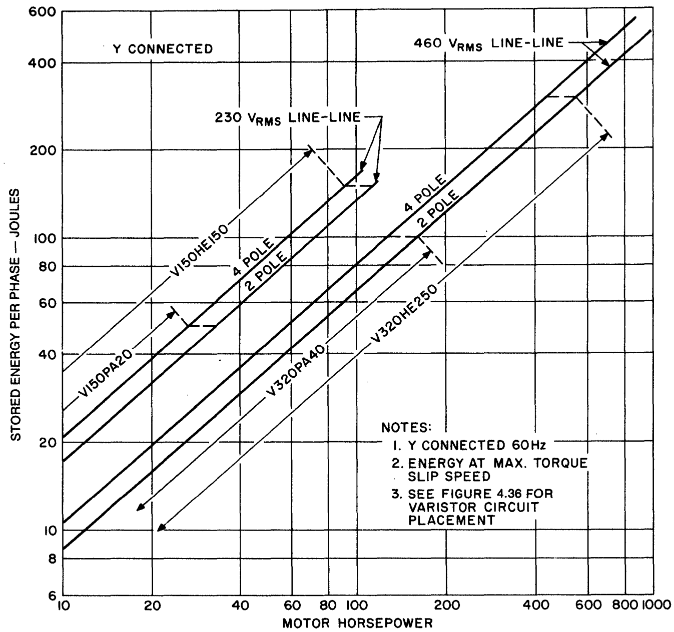


Figure 4.32 — Stored Energy Curves for Typical Wye-Connected Induction Motor

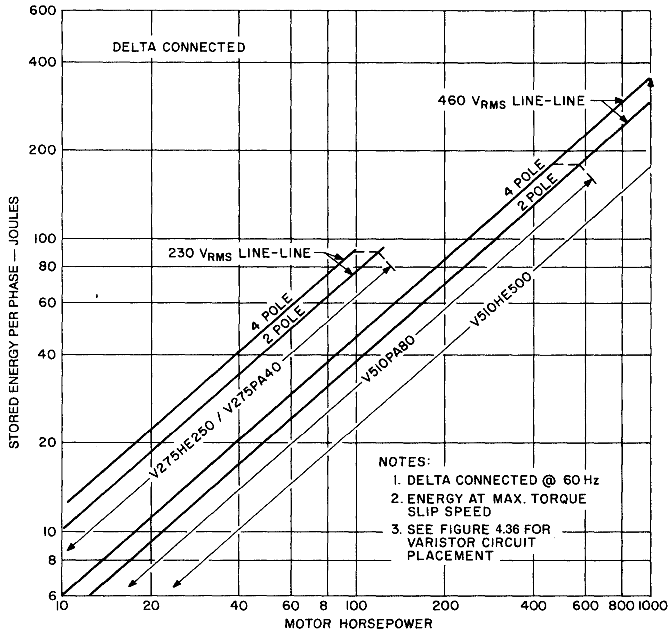


Figure 4.33 — Stored Energy Curves for Typical Delta-Connected Induction Motor

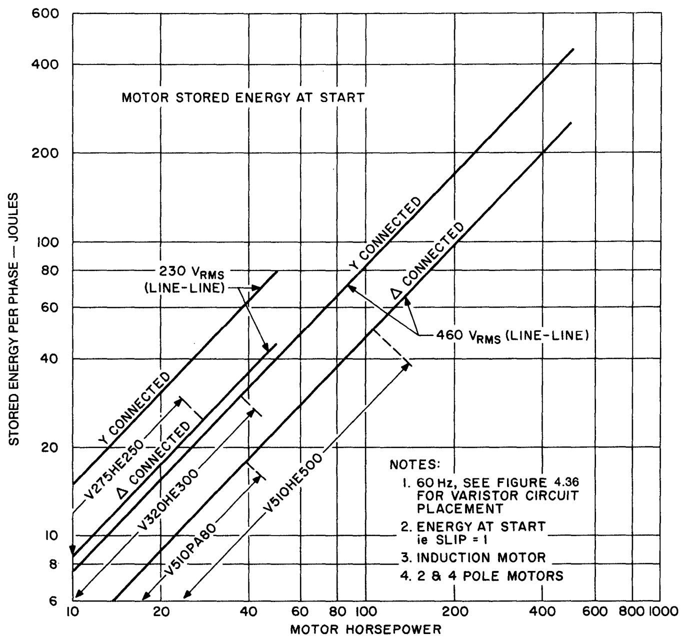


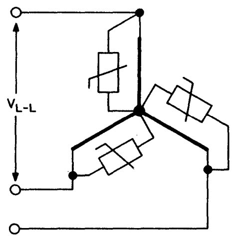
Figure 4.34 — Stored Energy Curves for a Typical Motor with Stalled Rotor

As an aid in selecting the proper operating voltage for Harris Varistors, Figure 4.35 gives guidelines for wye-connected and delta-connected motor circuits at different line-to-line applied voltages. Figure 4.36 provides guidance in proper placement of the varistor.

RMS LINE VOLTAGE (LINE-LINE)	⟹	230	380	460	550	600
DELTA CONNECTED	APPLIED V.	230	380	460	550	600
	VARISTOR RATINGS	250/275	420/480	510/575	575/660	660
Y CONNECTED	APPLIED V.	133	220	266	318	346
	VARISTOR RATINGS	150	250/275	320	420	420

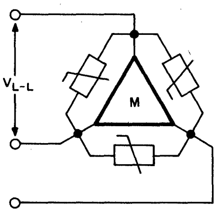
Figure 4.35 — Preferred Varistor Voltage Ratings for Delta- and Wye-Connected Motors

Interruption of motor starting currents presents special problems to the user as shown in Figure 4.34. Since the stored magnetic energy values are approximately 10 times the running values, protection is difficult at the higher horsepower levels. Often the motor is started by use of a reduced voltage which will substantially reduce the stored energy. A reduction in starting current of a factor of two results in a four-fold reduction in stored energy. If a reduced voltage starter is not used, then a decision must be made between protection for the run condition only, and the condition of locked rotor motor current. For most applications, the starting condition can be ignored in favor of selecting the varistor for the worst-case run condition.



$V_{VARISTOR} = \frac{1}{\sqrt{3}} V_{L-L}$

(a) WYE Connected



$V_{VARISTOR} = V_{L-L}$

(b) Delta Connected

Figure 4.36 — Varistor — 3ϕ Induction Motor Circuit Placement

PROBLEM: To protect a two-pole, 75hp, 3ϕ, 460V RMS line-to-line wye-connected motor from interruption of running transients.

Specific motor data is not available.

SOLUTION: Consult Figure 4.32 along with Figure 4.35. Standard varistors having the required voltage ratings are the 320V RMS rated models. This allows a 20% high-line voltage condition on the nominal 460V line-to-line voltage, or 266V line-neutral voltage. Figure 4.32 shows a two-pole 75hp, wye-connected induction motor, at the running condition, has 52J of stored magnetic energy per phase. Either a V320PA40 series or a V321DA40 series varistor will meet this requirement. The DA series Harris Varistor provides a greater margin of safety, although the PA series Harris Varistor fully meets the application requirements. Three varistors are required, connected directly across the motor terminals as shown in Figure 4.36.

4.4.7 Power Supply Crowbar

Occasionally it is possible for a power supply to generate excessively high voltage. An accidental removal of load can cause damage to the rest of the circuit. A simple safeguard is to crowbar or short circuit the supply with an SCR. To provide the triggering to the SCR, a high-voltage detector is needed. High voltage avalanche diodes are effective but expensive. An axial leaded Harris Varistor provides an effective, inexpensive substitute.

PROBLEM: In the circuit below, the voltage, without protection, can exceed twice the normal 240V peaks, damaging components downstream. A simple arrangement to crowbar the supply is shown.

The supply shown can provide 2A RMS of short-circuit current and has a 1A circuit breaker. A C106SCR having a 4A RMS capability is chosen. Triggering will require at least 0.4V gate-to-cathode, and no more than 0.8V at 200μA at 25°C ambient.

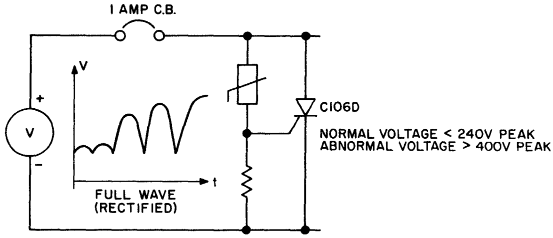


Figure 4.37 — Crowbar Circuit

SOLUTION: Check the MA series Harris Varistor specifications for a device capable of supporting 240V peak. The V270MA4B can handle $\sqrt{2}$ (171V rms) = 242V. According to its specification of 270V $\pm$10%, the V270MA4B will conduct 1mA dc at no less than 243V. The gate-cathode resistor can be chosen to provide 0.4V (the minimum trigger voltage) at 1mA, and the SCR will not trigger below 243V. Therefore, R_{GK} should be less than 400Ω. The highest value 5% tolerance resistor falling below 400Ω is a 360Ω resistor, which is selected. Thus, R_{GK} is 378Ω maximum and 342Ω minimum. Minimum SCR trigger voltage of 0.4V requires a varistor of 0.4V/378Ω, or 1.06mA for a minimum varistor voltage of ≈ 245V. The maximum voltage to trigger the circuit is dependent upon the maximum current the varistor is required to pass to trigger the SCR. For the C106 at 25°C, this is determined by calculating the maximum current required to provide 0.8V across a parallel resistor comprised of the 360Ω R_{GK} selected and the equivalent gate-cathode SCR resistor of 0.8V/200μA, since the C106 requires a maximum of 200μA trigger current. The SCR gate input resistance is 4KΩ and the minimum equivalent gate-cathode resistance is the parallel combination of 4KΩ and $R_{GK(min)}$, or 360Ω -5%, 342Ω. The parallel combination is 325Ω. Thus, $I_{varistor}$ for maximum voltage-to-trigger the C106 is 0.8V/315Ω, or 2.54 mA. According to the specification sheet for the V270MA4B, the varistor will not exceed 330V with this current. The circuit will, therefore, trigger at between 245 and 330V peak, and a 400V rated C106 can be used. The reader is cautioned that SCR gate characteristics are sensitive to junction temperatures, and a value of 25°C for the SCR temperature was merely chosen as a convenient value for demonstrating design procedures.

Figure 4.3 can be used to determine the maximum energy per pulse with this waveform. It will not exceed approximately ½/0.15/I_{pk}/V_{pk}/τ (duration of ½ wave pulse), or 0.52mJ for this example. Since the voltage does not drop to zero in this case, the SCR remains on, and the varistor sees only one pulse; thus, no steady-state power consideration exists.

4.4.8 General Protection of Solid State Circuitry, Against Transients on 117V ac Lines

PROBLEM: Modern electronic equipment and home appliances contain solid state circuitry that is susceptible to malfunction or damage caused by transient voltage spikes. The equipment is used in residential, commercial, and industrial buildings. Some equipment designs are relatively low cost consumer items while others are for commercial/industrial use where an added measure of reliability is needed. Since solid state circuits and the associated transient sensitivity problem are relatively new, the knowledge of design in the transient environment is still incomplete. Some test standards have been adopted by various agencies (see Chapter 7), and further definition of the environment is underway by the Surge Protective Devices Committee of the IEEE.

The transients which may occur on residential and commercial ac lines are of many waveshapes and of varying severity in terms of peak voltage, current, or energy. For suppressor application purposes, these may be reduced to three categories.

First, the most frequent transient might be the one represented by a 30 or 100kHz ring wave. This test surge is defined by an oscillatory exponentially decaying voltage wave with a peak open circuit voltage of 6kV. This wave is considered representative of transients observed and reported by studies in Europe and North America. These transients can be caused by distant lightning strikes or distribution line switching. Due to the relatively high impedance and short duration of these transients, peak current and surge energy are lower than the following categories.

The second category is that of surges produced by nearby lightning strokes. The severity of a lightning stroke is characterized in terms of its peak current. The probability of a direct stroke of a given severity can be determined. However, since the lightning current divides in many paths, the peak current available at an ac outlet within a building is much less than the total current of the stroke. The standard impulse used to represent lightning and to test surge protective devices is an 8/20μs current waveshape as defined by ANSI Standard C68.2, and also described in ANSI/IEEE Standard C62.41-1980.

A third category of surges are those produced by the discharge of energy stored in inductive elements such as motors and transformers. A test current of 10/100μs waveshape is an accepted industry test impulse and can be considered representative of these surges.

Although no hard-and-fast rules can be drawn as to the category and severity of surges which will occur, a helpful guideline can be given to suggest varistors suitable in typical applications.

This guideline recognizes considerations such as equipment cost, equipment duty cycle, effect equipment downtime, and balances the economics of equipment damage risk against surge protection cost.

Harris Varistor Selection Guideline for 117V AC Applications

Application Type	Duty Cycle	Location	Example	Suggested Model
Light Consumer	Very Low	A	Mixer/Blender	V130LA2
Consumer	Low	A	Portable TV	V130LA10A
Consumer	Medium	A	Console TV	V130LA20A
Light Industrial	Medium	B	Copier	V130LA20A or B
Industrial	Medium	B	Small Computer	V130PA20A or C
Industrial	High	B	Large Computer	V131DA40 or DB40
Industrial	High	B	Elevator Control	V151DA40 or DB40

REFERENCE

1. Kaufman, R., *"The Magic of I^2t,"* IEEE Trans. IGA-2, No. 5, Sept.-Oct. 1966.

SUPPRESSION — TELECOMMUNICATIONS SYSTEMS

5.1 INTRODUCTION

Modern telecommunication systems are fast, efficient, and complex. Many improvements have been made in central office equipment and subscriber equipment which involves the use of solid state circuitry. Unfortunately, solid state devices are much more susceptible to malfunction or failure due to transient voltages and noise than are older devices, such as relays, coils, step-switches, and vacuum tubes. To complicate matters further, increased usage of telecommuniation lines for data and video transmissions has produced a further intolerance for transient voltages.

Although telecommunications systems have always employed transient protection devices such as the carbon gap, the gas tube, and the heat coil, these are not always adequate to protect solid state circuitry. Harris offers two distinct technologies to deal with the varied requirements of telecommunications transient protection. The MOV, Metal Oxide Varistor, is a zinc oxide ceramic based technology, and the SURGECTOR, a solid state silicon based process, which integrates a zener diode and the SCR technology on a single chip.

The requirements of the telecommunications industry are varied and unique. Both technologies have advantages and limitations dependent on the specific application. The trade-offs are discussed in Section 5.14.

5.2 SYSTEM TRANSIENTS

A telecommunication system is made up of subscriber stations linked together through the cable plant and a central office switching network. Included in the system are repeater amplifiers, multiplexers, and other electronic circuits. Supplying the electrical energy to run the system is a main power source.

The cable plant and the power supply provide a path by which damaging transients enter the system, to be transmitted to vulnerable electronic circuitry. The cable plant consists of conductors in shielded cables, which are suspended on poles (shared with power lines) or buried in the earth. A single cable is made up of many conductors, arranged in twisted pairs (tip and ring). Some sections of open-wire transmission lines are still used, but most of these are remote from central offices, and transient protectors are usually provided where the open wire enters the shielded cables. All of these cables (even the ones underground) are capable of picking up transient energy from lightning and conducting them to the central office or subscriber equipment.

The power used by a telecommunication system is usually obtained from commercial power lines. These lines, like the telephone cables, are either suspended on poles or buried. Transient energy is frequently picked up by power lines and transmitted to the central office by direct conduction or by induction into the telephone cable plant. The increased used of off-line power supplies in telephone equipment makes power line transients even more hazardous to the electronic circuitry.

5.3 LIGHTNING — INDUCED TRANSIENTS

Lightning is the most common source of over voltage in communication systems. Because of the exposure to lightning strokes, a knowledge of the effects of lightning is important when designing a transient protective system.

Lightning currents may enter the conductive shield of a suspended cable by direct or indirect stroke, or it may enter a cable buried in the ground by ground currents, as shown in Figure 5.1.

In the case of a suspended cable, the lightning current that enters the cable is seeking a ground and will travel in both directions along the cable. Some of the current will leave the shield at each grounded pole along its path. Studies have shown that all of the lightning current has left the cable shield after passing 10 poles grounded in high conductivity soils or 20 poles grounded in high resistivity soil.

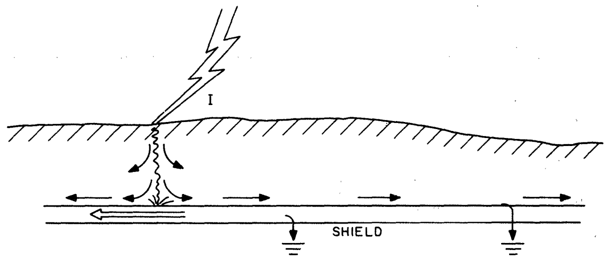


Figure 5.1 — Lightning Current in Buried Cable

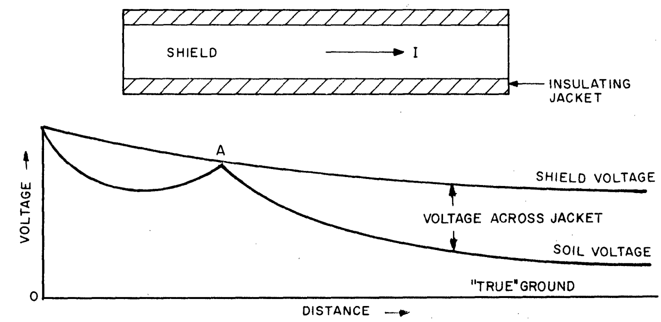


Figure 5.2 — Condition for Puncture of Cable Jacket

Stroke currents leave a buried cable in a similar way but with a different mechanism. Since the cable shield has a finite electrical resistance, the current passing through it will produce a potential gradient along its length. This voltage will produce a potential difference between the cable and the soil, as shown in Figure 5.2.

At some point (Point A) the shield-to-earth potential will exceed the dielectric strength of the jacket, causing it to puncture. Some of the lightning current then flows through the puncture into the soil, thus equalizing the potential at that point. The remaining current continues along the shield until another puncture occurs, providing another path to ground.

Lightning currents are usually not harmful to the shield itself, but they do induce surge voltages on the conductors of the cable which are often harmful to central office equipment. The surge voltage that appears at the ends of the cable depends upon the distance to the disturbance, the type of cable, the shield material, and its thickness and insulation, as well as the amplitude and waveshape of the lightning current in the shield. Since the current-derived potential along the cable shield is capacitively coupled to the cabled conductors, the waveshape of the surge voltage on the eonductors will closely resemble the waveshape of the lightning current.

Quantitative information on lightning has been accumulated from many sources,[2] with research centers in the United States, Western Europe and South Africa. One of the most comprehensive surveys of available data has been compiled by Cianos and Pierce,[3] describing the amplitude, rate-of-rise, duration, etc., in statistical terms.

Using these statistics, one can make numerical calculations of induced voltages in various electrical circuits, such as the cable plant of a communication system. The parameters of interest are the voltages developed as a function of intensity and duration of the lightning impulse. The examples discussed later in this chapter are based on this source of information.

5.4 CALCULATIONS OF CABLE TRANSIENTS

The voltage surge induced into the conductors of a cable will propagate as a traveling wave in both directions along the cable from the region of induction. The cable acts as a transmission line. The surge current and voltage are related to each other by Ohm's law where the ratio of voltage to current is the surge impedance (Z_o) of the cable. Z_o can also be expressed in terms of the inductance (L) and capacitance (C) per unit length of the cable by the equation,

$$Z_o = \sqrt{L/C}\ (\Omega)$$

The velocity of the surge, as it propagates along the conductors, is also a function of L and C, and can be expressed as

$$\text{Velocity} = \sqrt{1/LC}\ \text{(meters/sec.)}$$

The series resistance of the shield and conductors, as well as losses due to corona and arcing, determine the energy lost as the disturbance propagates along the cable.

Tests conducted on telephone cables[4] have measured surge impedances of 80Ω between any of the conductors and the shield. Shield resistances between 5Ω and 6Ω per mile were found to be typical. These values and the applied lightning current waveform of Figure 5.3 were used to compute the worst case transient which would appear at cable terminals in a central office.The computation assumes the lightning current is introduced into a suspended cable shield at a point 2.75 miles from the central office. An average cable span between poles of 165 feet, with a ground connection on every fourth pole, was assumed. It was also assumed that the cable will support the voltage without arcing over.

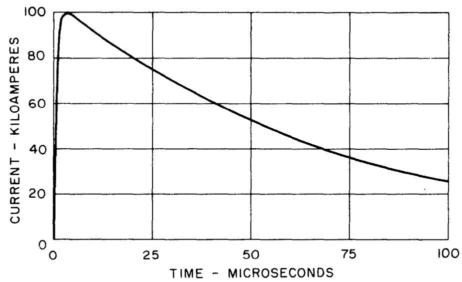


Figure 5.3 — Severe Lightning Current Waveform (2/50μs)

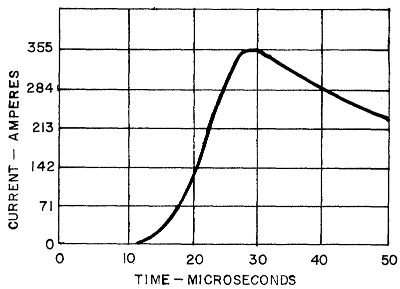


Figure 5.4 — Available Current 2.75 Miles from 100kA Lightning Stroke

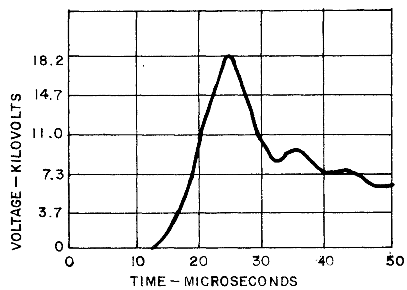


Figure 5.5 — Open Circuit Voltage 2.75 Miles from 100kA Lightning Stroke

The resulting short-circuit current available at the central office is shown in Figure 5.4.

The open-circuit voltage at the cable end is shown in Figure 5.5. This analysis shows that if a severe, 100kA lightning flash strikes a cable at a point 2.75 miles from a central office, a voltage transient reaching a peak of nearly 18kV may appear at the cable end, with about 355A of current available.

Since the cable can be considered to be a linear system, the voltages and currents will bear a linear relation to the lightning stroke amplitude. A tabulation of the open-circuit voltage and available current which would result from stroke currents of various magnitudes is given in Table 5. Included in the table is the probability of occurrence, as given by Cianos and Pierce.[3] It should be realized that voltages in excess of 10kV probably would not be sustained since the cable insulation will break down.

The transient voltage at the central office in any case would be excessive, so that protectors would be required. The protector would conduct up to 213A surge current for most (85%) of the strokes that occur and only up to twice that current on rare occasions.

Table 5.1
Lightning Transients At Cable End 2.75 Miles from Stroke Point

Lightning Stroke, Peak Current	Probability of Occurrence	Terminal Open-Circuit Voltage	Terminal Short-Circuit Current
(kA)	(%)	(Peak V)	(Peak A)
175	1	32,200	621
100	5	18,400	355
60	15	11,040	213
20	50	3,680	71

The values shown in Table 5.1 are based on the assumption of a single conductor cable with the stroke point 2.75 miles from the central station. For closer strokes the peak short-circuit current at the cable end will increase as shown in Table 5.2. These calculations were made assuming a breakdown at the stroke point, which gives the worst case result.

Since telephone cables actually have many pairs of wires rather than a single conductor, the peak currents in each wire will be lower. It is assumed that the stroke voltage will be induced equally in all wires if they are equally loaded. Then, the currents in all wires will be equal if all protectors are identical. To predict the individual wire currents, it is assumed that the wire currents are proportional to sheath curent and the ratio of resistances, and are reduced a constant amount by cable inductance. Worst case calculated values for the shortest distances are shown in Table 5.2.

Table 5.2
Peak Lightning-Induced Currents in Various Lengths of Telephone Cable (100kA Lightning Stroke)

Distance To Stroke (Miles)	Peak Currents (A)			
	At Stroke Point	At Central Office		
		Single Conductor	6 Pair Cable	12 Pair Cable
2.75	630	355	—	—
1.50	630	637	—	—
1.00	734	799	—	—
0.50	1110	1120	712	453
0.25	1480	1480	852	463

An example of the current which a protective device must handle can now be estimated. Assume a cable of six pairs (the smallest available) is struck by lightning, inducing a stroke current of 100kA into the shield, at a distance of 0.25 mile from the protector. The transient current will be divided up among the twelve suppressors at the cable ends. Each protective device must handle up to 852A of peak current in order to clamp the voltage to a protected level.

5.5 POWER SYSTEM-INDUCED TRANSIENTS

Since telephone cables very often share a pole and ground wire with the commercial ac utility power system, the high currents that accompany power system faults can induce over-voltages in the telephone cables. These induced over-voltages will be at the power system frequency and can have long duration (compared to the lightning-induced transients) from a few milliseconds to several cycles of power frequency. Three types of over-voltage can occur in conjunction with power system faults:

Power Contact — (Sometimes called "power cross") The power lines fall and make contact with the telephone cable.

Power Induction — The electromagnetic coupling between the power system experiencing a heavy fault and the telephone cable produces an over-voltage in the cable.

Ground Potential Rise — The heavy ground currents of power system faults flow in the common ground connections and cause substantial differences in potential.

There is little definitive data available on the severity of these over-voltages. However, proposals have been made by telephone protection engineers to define the power contact as the most severe condition. The proposed requirement calls for the suppressor to withstand 10A RMS for a duration of power contact ranging from 10 to 60 cycles of the power system frequency.

5.6 PROTECTORS — VOLTAGE TRANSIENT SUPPRESSORS

5.6.1 Primary Protection

The oldest and most commonly used primary protector for a telephone system is the carbon block spark gap. The device is made up of two carbon block electrodes separated by a small air gap of between 0.003 and 0.004 inch. One electrode is connected to the telephone cable conductor and the other to the system ground. When an over-voltage transient appears, the gap breaks down diverting the transient and dissipating the energy in the arc and the source impedance of the transient. The carbon gap is a low-cost protector but suffers from a relatively short life and exhibits sparkover voltage variations. Nominal 3-mil carbon gaps statistically sparkover as low as 300V and as high as 1000V —this is a serious problem.

Telephone conductors occur in pairs in a cable so that transient voltages induced into the conductors will be common to both tip and ring conductors, as shown in Figure 5.6. This longitudinal voltage produces no current through the load termination. Normally, there is zero difference in the potential between conductors. If protector, PR_1 should break down at 400V, while PR_2 requires 700V to break down, then only PR_1 would breakdown on transient of 600V causing a transient current flow through the load. Even if PR_2 does break down but responds later in time than PR_1 a transient current will flow.

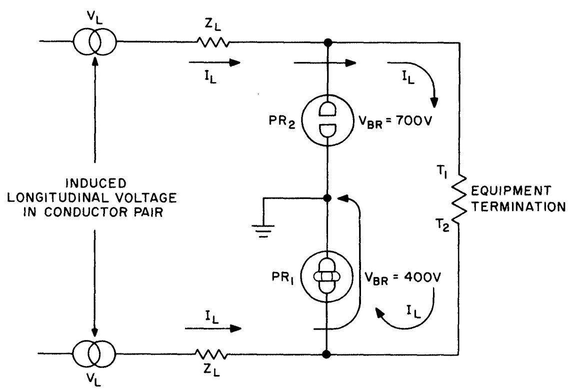


Figure 5.6 — Unbalanced Line Protection

Another common suppressor in telephone systems is the gas tube protector. It consists of two metallic gaps spaced by a distance of 0.010 to 0.015 inch. The electrodes are enclosed in a sealed glass envelope containing a combination of gases at a low pressure. Such gaps offer higher current-carrying capability and longer life than do carbon block devices. However, the possibility of seal leakage and the consequent loss of protection has limited the use of these devices. Dual-gap gas tubes, also called three-electrode gas tubes, have been introduced to alleviate the problem of unbalanced breakdown as described in the preceding paragraph.

Harris Varistors have properties that make them excellent candidates for telephone system protectors. These characteristics include tight tolerance, high reliability, high energy capability, and good clamping characteristics. The V130LA20A Harris Varistor, for instance, is capable of handling a peak transient current of 6500A (8/20μs pulse) and dissipating up to 70J of energy. The 6500A current surge would result in the voltage across the varistor being clamped at a maximum of 600V. A 1000A pulse would be clamped to less than 420V, yet ring voltage peaks of 180V would not be affected by this varistor.

Varistors are often used in telecommunication circuits between tip, ring and ground requiring 1, 2 or sometimes 3 separate varistors. See Figure 5.7.

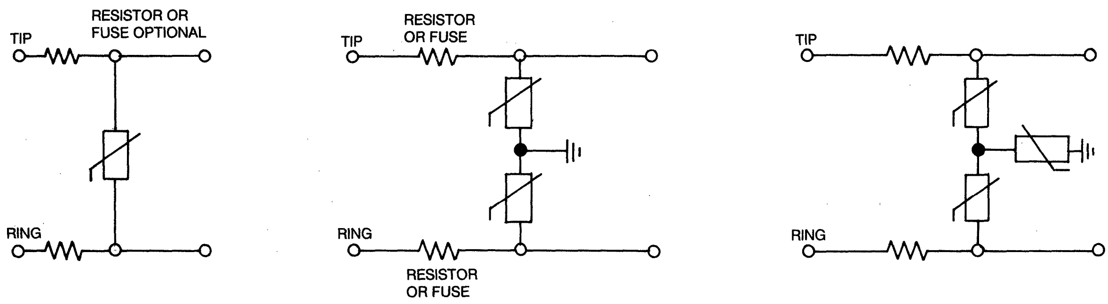


Figure 5.7 — Varistor Connection Between Tip and Ring

The voltage rating of the varistor is determined by the voltage applied between tip and ring. Most telecommunication systems have 52.5V dc with a superimposed ring voltage between 40 to 150V RMS (210V peak), which results in a minimum voltage rating for the varistor of 52.5V + 210V = 262.5V. The proper device would have a minimum DC-voltage rating of greater than 262.5V. For example, a V230LA20A, two V130LA10A devices in series, or two V130LA20A devices in series would be appropriate.

5.6.2 Secondary Protection

Modern solid state communications circuitry can be damaged even if the primary protection is working normally. It is often advisable to provide a secondary protection system to further reduce the voltage transient. As shown in Figure 5.8, the secondary protection removes the over-voltage spike which is passed by the primary protector.

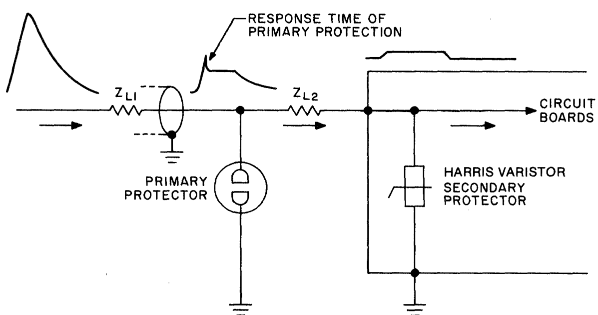


Figure 5.8 — Secondary Protection

In most installations the length of conductor between the primary protector and the telephone circuit boards is greater than 25 feet. The impedance (Z_{L2}) presented by this length of wire to most lightning-induced transient voltages will insure that the primary protector will operate first and the secondary protector will not be exposed to the full surge. In the rare cases where a power cross occurs, the varistor may fail, but it will still perform its assigned task of protecting the circuit board. Because its failure mode is a short circuit it will blow the system fuses. Usually the probability of a power cross if so low that the replacement of a damaged varistor is an acceptable alternative to repairing a damaged circuit board.

The SURGECTOR can also be a desirable transient protector for secondary protection. Its "crowbar" action and fast response time can shunt the transient to ground effectively and prevent damage to the system. The characteristics and forms of SURGECTORS are discussed in Section 5.9 and 10.1.

5.7 POWER LINE TRANSIENTS

For transients introduced into a telecommunications system through the powerlines, the Harris Varistor is a very effective suppressor. Properly selected, the varistor will not effect the normal operation of the line but will clamp heavy transient surges to an acceptable voltage level. Refer to Chapters 2, 4 and 9 for information on the selection of a varistor suppressor.

5.8 RELAY CONTACT PROTECTION

Even the most modern telephone equipment requires the use of relays and other electromechanical switching devices. These device are required to switch currents into inductive loads causing contact arcing, pitting, and noise generation. The Harris Varistor is a useful suppressor for increasing contact life, improving reliability, and reducing noise. Chapters 1 and 4 contain selection information for contact protection applications by means of varistors.

5.9 SURGECTOR™ TRANSIENT SURGE SUPPRESSOR

The Harris SURGECTOR is a new type of surge-suppressor, developed to protect sophisticated electronic circuits from rapid, high-voltage power surges that conventional surge suppressors cannot handle. The need for a new type of surge suppressor stems from the increasing sophistication of today's electronics. In the telecommunications industry, for example, the trend is toward increasing use of medium-scale integrated (MSI) and very large-scale integrated (VLSI) circuits. These circuits are used in equipment that transmits, processes, codes, switches, stores data, and has multifunction capability, but is intolerant of voltage overloads. In addition, a strong shunt device, such as the SURGECTOR, is used to open a series device, such as a fuse, to prevent excessive current overloads of premise wiring and equipment as required by safety agencies (e.g., Underwriters Laboratories).

The SURGECTOR is a monolithic device. It consists of an SCR-type thyristor whose gate region contains a special diffused section that acts as a zener (avalanche) diode. The zener portion of the SURGECTOR provides continuous protection of the circuit.

Because it combines the continuous voltage protection of the zener with the thyristor's ability to handle high current, the SURGECTOR provides instantaneous protection against fast-rising, high-voltage pulses- pulses that are too rapid or too powerful for conventional devices (such as gas tubes, air-gap carbon blocks, or stand-alone zeners) to block. As a result, the SURGECTOR can provide the much-needed secondary surge protection for telecommunications circuitry, data links, and other sensitive electronic circuits that are especially susceptible to damage from transient voltage.

Surge Characteristics

- ***Large voltage and energy variations***
- ***Wide variations in surge durations***
- ***Possible rapid repetition and mixed polarity of surges***
- ***dv/dt of up to 10,000 V/μs***

SURGECTOR Characteristics

- ***High input impedance until breakdown (i.e. low leakage)***
- ***Repeatable breakdown/threshold voltage***
- ***High surge current handling capability***
- ***Withstand and respond to rapidly reoccurring surges***
- ***Fast recovery to high impedance state (turn-off)***
- ***Dual polarity protection***
- ***No degradation of essential characteristics with use***

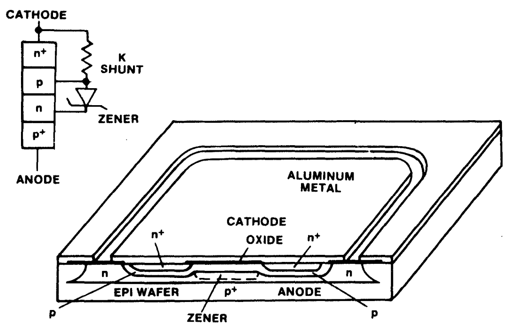
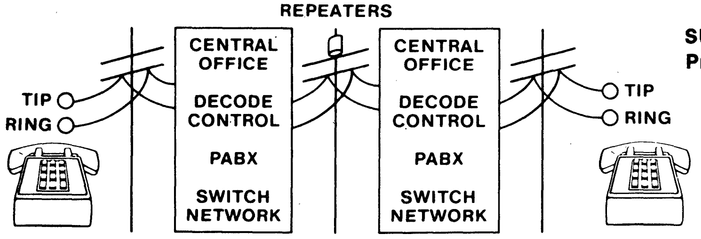


Figure 5.9 - SURGECTOR Vertical Structure



SURGECTORs Provide Transient Protection for:

- ***Central Office Equipment***
- ***Supervisory Equipment***
- ***Switchgear Equipment***
- ***Data Transmission***
- ***Handsets***
- ***EPABX, PABX, PBX***
- ***Repeaters***
- ***Line Concentrator***
- ***Receivers***
- ***Headsets***
- ***Modem***
- ***PCM***

5.10 SURGECTOR OPERATION

The SURGECTOR allows normal operation of the circuit as long as the voltage does not exceed a certain maximum value (VDM). Current SURGECTOR devices are rated at 30, 60, 100, 230, and 270 volts. When a transient pulse hits the line, voltage begins to rise - often as an extremely rapid rate. Lightning, for example, can cause a voltage rise in excess of 1000 volts per microsecond. As soon as the voltage reaches the avalanche breakdown voltage, the zener instantly "clamps the voltage. The voltage can rise above its normal value for the circuit, but only by a small amount; the SURGECTOR ensures that the protected circuit never sees a voltage greater than 110 percent of the zener avalanche operating voltage.

A normal stand alone zener diode maintains a constant voltage for the duration of the pulse and can quickly burn out from this energy overload. But in the SURGECTOR, current flows from the zener region into the thyristor gate, switching on the thyristor in nanoseconds. The thyristor drops to low voltage, creating a low impedance in the circuit, and shunts the excess energy from the circuit to the ground. In effect, the thyristor draws energy away from the zener, allowing it to survive the transient. Because of this, the SURGECTOR can handle about ten times more current than a stand alone zener.

While the transient is on the line, the SURGECTOR remains in the ON state, and the voltage across the circuit is low. Its precise value depends on the type of pulse and the type of SURGECTOR being used. Eventually, the pulse passes, and the current begins to drop. When it reaches a certain minimum value, known as the "holding current," the SURGECTOR automatically shuts off, and normal circuit operation resumes, with the zener section of the SURGECTOR again providing continuous protection.

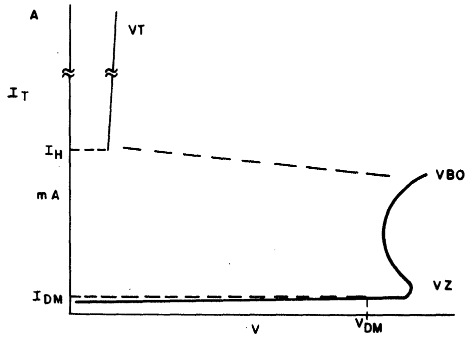


Figure 5.10 - Typical Volt-Ampere Characteristics

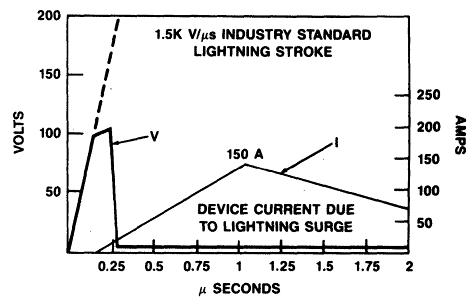


Figure 5.11 - Industry Standard Lightning Stroke

5.11 SURGECTOR TYPES

Harris SURGECTOR devices include SCR types, unidirectional and bidirectional. The SCR SURGECTOR is unidirectional but provides three terminals instead of two. The third terminal gives the user direct access to the SCR gate region, so that the SURGECTOR types are available; the SGT10S10 (100 volts, 100 milliamps), the SGT27S10 (270 volts, 100 milliamps), and the SGT27S23 (270 volts, 230 milliamps). With the external gate control circuitry, any voltage between 5V and 100V or 5V and 270V respectively can trigger the device. This class has high holding current (100 to 270 milliamps) to allow rapid transition to the OFF state.

The unidirectional SURGECTOR is available in voltages of 30, 60, and 230 volts (types SGT03U13, SGT06U13, and SGT23U13 respectively, the holding current is 130 milliamps.

The bidirectional SURGECTOR is capable of handling both positive and negative surges. It has two terminals, and only one SURGECTOR per line is required. Four versions are available at the present time; 230 and 270V, 130 milliamp, surge capability of 10 x 1000μs at 100 amps, and two larger devices rated at 230 and 270 volts respectively with 270 milliamps holding currents and 200 amp surge capability at a pulse of 10 x 1000μs.

5.12 PERFORMANCE CHARACTERISTICS

Currently announced SURGECTOR devices have ratings for transient peak surge current of 300 to 600 amperes for a 1 x 2μs pulse and appropriately scaled currents at 8 x 20, 10 x 560, and 10 x 1000μs. These rated surges can be applied to the SURGECTOR devices repeatedly without degradation. The overshoot ratio of the SURGECTOR is the ratio of the highest voltage encountered by the protected circuit (during a 100V/microsecond pulse) over the zener voltage of the SURGECTOR. The SURGECTOR has the lowest overshoot ratio of any surge-suppression technology on the market today, which means it suppresses transient voltage more effectively than gas tubes, metal oxide semiconductor devices, or carbon blocks.

Many surge-suppression devices are characterized by the speed at which they switch on. A gas discharge tube, in which gas must ionize before the device can function, takes microseconds to become operational. But this specification is meaningless for the SURGECTOR, because the SURGECTOR provides instantaneous and continuous protection. The zener section of the SURGECTOR always clamps voltage when the value reaches a certain minimum zener voltage for which the device is rated.

The SURGECTOR type SGT23U13, which is rated at 230 volts, clamps the transient voltage the instant it reaches the zener voltage. Within nanoseconds, the thyristor switches on and drops the voltage to just a few volts. (The voltage will remain at this low value until the surge passes and the current drops below the holding current.)

As stated, the SURGECTOR can handle peak currents up to 600 amperes, depending on the type of pulse. But, like any solid-state device, the SURGECTOR will eventually fail if pushed beyond its specifications. However, the SURGECTOR is designed not to fail to an open condition on a 1 x 2 pulse below 450A (900A for the SGT27B27). This becomes especially important in new telecom equipment designs which are required to meet UL-1459 requirements. A typical design for secondary protection would use a pair of fuses and SURGECTOR devices to open the line on excessive currents such as a power line cross.

This is an important feature, especially in telecommunication applications. If a device fails to an open condition, the circuit remains unprotected until the device is replaced, and open failures on the line are not easily detected. A short, on the other hand, provides continuous protection against surges (although if prevents operation of the circuit) and is easy to locate for repair or replacements.

Aside from failure due to operating beyond the device's specifications, the SURGECTOR has no inherent wearout mechanism. Performance is consistent and does not degrade with repeated use or time. There is no inherent limit on the SURGECTOR device's operating life. We predict the SURGECTOR will have a life comparable to Harris Power transistors, lasting 20 years or more. By comparison, gas tubes and carbon blocks have wearout mechanisms and trigger voltage changes.

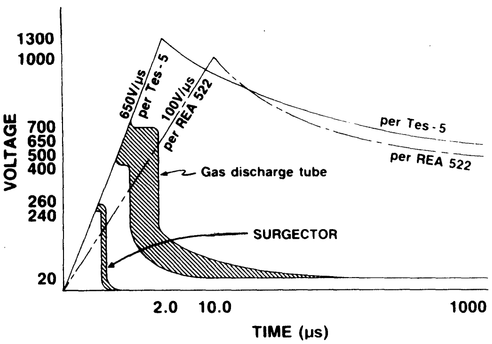


Figure 5.12 - SURGECTOR Devices Clip Voltage Surges and Shunt Energy to Ground

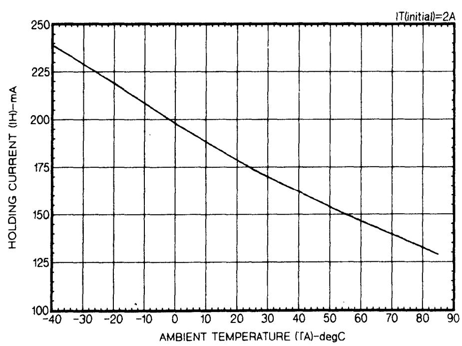


Figure 5.13 - Typical Holding Current vs. Temperature

SURGECTOR devices are usually used in conjunction with primary protection devices, and therefore should rarely see currents exceeding their rated capacities. When operated within their specifications, SURGECTOR devices automatically switch to their off-state once the pulse passes and the current drops below the holding current. The holding current of the SURGECTOR must be greater than the normally available short-circuit current in the circuit to insure that the SURGECTOR will return to the off-state when the transient has passed and allow normal circuit operation to resume. SURGECTOR devices are designed with high holding currents, ranging from 100 to 270 milliamps, depending on the type. These ratings are sufficient to allow proper operation in most telecommunications circuits.

The SURGECTOR device's normal off condition is a state of high impedance, which prevents loading of the line. Leakage is extremely low; the SURGECTOR passes less than 100 nanoamps. The capacitance of SURGECTOR devices is also low, presenting about 100 pF for a bidirectional device in normal telecommunication circuits. This is low enough to allow high-speed data communications.

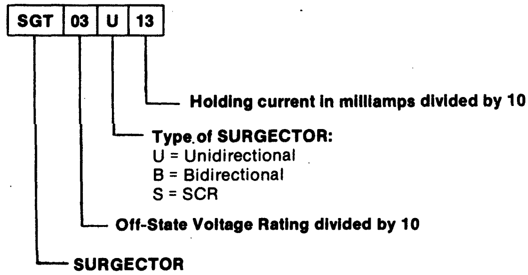
5.13 NOMENCLATURE, PACKAGES, AND SHIPPING

The SURGECTOR type numbers are easy to interpret. The first three characters - the letter "SGT" - stand for SURGECTOR. Next comes two digits, which represent the maximum off-state voltage divided by 10. Following the voltage is a letter indicating either SCR (S), Unidirectional (U), or Bidirectional (B). The next two digits indicate holding current in milliamps divided by 10.

All versions of the SURGECTOR are housed in a modified TO-202 versatab plastic package. This is a single-in-line package, meaning that all leads come out of the same end and are parallel to one another. The advantage of single-in-line packaging is that it makes the SURGECTOR easy to insert into a circuit board or socket by automated methods.

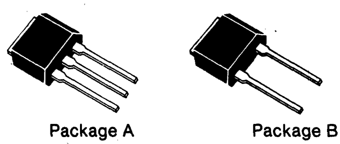
SURGECTOR devices are shipped to the customer either in bulk or on plastic "sticks" designed for automated machinery handling. The sticks are rectangular tubes that hold 50 SURGECTOR devices each.

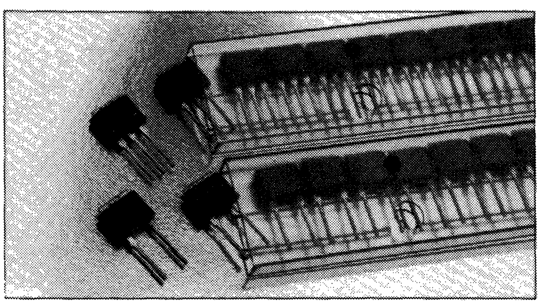
Nomenclature For SCR, Unidirectional and Bidirectional



SURGECTOR Packages

Modified TO-202 Package Style





SURGECTOR devices are shipped to the customer either in bulk or on plastic "sticks" designed for automated machinery handling. The sticks are rectangular tubes that hold 50 SURGECTOR devices each.

Figure 5.14 - Plastic Shipping Tubes

TYPE NO.	FUNCTION	V_2 MIN V	V_{BO} MAX (100V/μs)	I_{TSM} (1 x 2μs)	I_{TSM} (10 x 1000μs)	I_H mA/	PACKAGE STYLE
SGT10S10†	VAR CLAMP	100	†	300	100	> 100	A
SGT27S10†	VAR CLAMP	270	†	300	100	> 100	A
SGT27S23†	VAR CLAMP	270	†	300	100	> 230	A
SGT03U13	UNI-DIRECT	30	< 50	300	100	> 130	B
SGT06U13	UNI-DIRECT	60	< 85	300	100	> 130	B
SGT23U13	UNI-DIRECT	230	< 275	300	100	> 130	B
SGT23B13	BI-DIRECT	230	< 285	300	100	> 130	B
SGT27B13	BI-DIRECT	270	< 345	300	100	> 130	B
SGT23B32*	BI-DIRECT	230	< 290	300	100	> 320	B
SGT27B32*	BI-DIRECT	270	< 350	300	100	> 320	B
SGT23B27	BI-DIRECT	230	< 290	600	200	> 270	B
SGT27B27	BI-DIRECT	270	< 350	600	200	> 270	B

† Dependent on trigger circuit. * Preliminary Data Sheets. All finalized devices UL recognized to 497B – File Number E135010.

5.14 APPLICATIONS

Telecommunications equipment has to operate in extreme transient/surge environments. Transients may originate from power mains, switching sources, lightning and electrostatic discharges. Isolation, grounding, and shielding among others, are methods used to control transients but while these techniques may be used in various telecom applications they are not totally effective.

The Harris line of SURGECTOR devices protects circuits from damage better than Transorb® zeners, gas-discharge tubes, spark-gaps and any other means of protection. SURGECTOR devices offer continuous protection with unique ability to clamp at specific voltages (30V, 60V, 100V, 230V or 270V) which then trigger the SCR on and bypass the energy away from the circuit. The Harris SURGECTOR may be used in many applications to provide transient energy protection at subscriber stations and central offices where other suppression devices do not provide adequate protection for newer more sensitive circuit components. The SURGECTOR combines the protection of crowbar-acting devices and fast voltage-clamping devices. They combine the clamping voltage temperature coefficient and low clamping-voltage ratio of a zener diode with the high current surge capability of a spark gap (gas-discharge tube) device. Bidirectional devices provide this protection in either polarity as in the case of the gas-discharge tube.

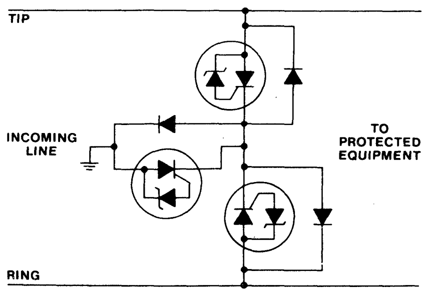


Figure 5.15 - Full balanced protection employing three unidirectional SURGECTOR devices and three diodes.

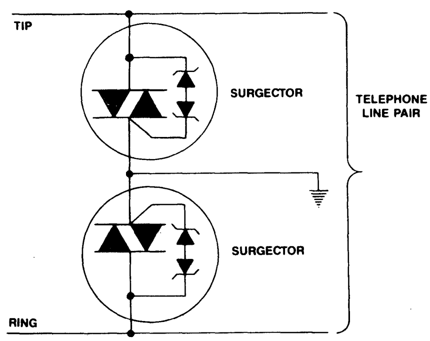


Figure 5.16 - Two bidirectional SURGECTOR devices are placed between the tip and ring lines just after these lines enter the telephone to protect delicate telecommunications.

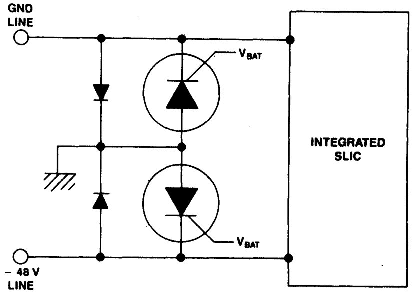


Figure 5.17 - Full balanced protection using three terminal SURGECTOR devices.

Typical Transient Surge Suppressor Applications

Transient Surge Suppression Devices	Data Lines	Telecom (Primary)	Telecom (Secondary)	AC Power Lines	DC Power & Automotive
SURGECTOR	✓	✓	✓		✓
MOV	✓	✓	✓	✓	✓
AVALANCHE DIODE	✓		✓		✓
GAS TUBE		✓			

Comparison of Surge Suppression Devices

Transient Surge Suppression Devices	Major Advantages/Uses	Major Limitations
SURGECTOR	+ Ideal for datacom and telecom + Leakage - <50 nanoamps + Shunt capacitance - <50 pF + Subnanosecond response + Lifetime unlimited @ 200 Amps, 8x20 μS pulse shape + Failure mode - Short circuit	- Cannot be used in DC circuits where available current exceeds holding current - Surge current capability - 200 Amps @ 8x20 μS pulse shape - Limited AC line protection capability
METAL-OXIDE VARISTOR (MOV)	+ Ideal for AC power lines; suitable for low-voltage logic protection + Subnanosecond response + Units available up to 70,000 Amps surge + Lifetime @ 1000 Amps, 8x20 μS pulse shape - 1000 surges + Failure mode - Short circuit	- Shunt capacitance - >500 pF - Leakage - approximately 10 microamps - Clamp voltage goes up with current
AVALANCHE DIODE	+ Ideal for low-voltage logic protection + Subnanosecond response + Lifetime @ 50 Amps, 8x20 μS pulse shape - unlimited + Shunt capacitance - 50 pF + Failure mode - Short circuit	- Low-surge capability - 50 Amps @ 8x20 μS pulse shape - Leakage - approximately 10 microamps - Clamp voltage goes up with current
GAS TUBE	+ Wide use in telecom for primary protection + High surge capability - >20,000 Amps + Leakage - subpicoamps + Shunt capacitance - <1 pF + Lifetime @ 500 Amps, 8x20 μS pulse width - 200 surges	- Response time - <5 microseconds - Failure mode - Open circuit - Follow-on current because of "crowbar" - Trigger voltage changes with time - Limited Life

In order to protect equipment properly, the circuit connected to the input lines must limit the energy delivered through fault conditions on the phone lines. This energy must then be compared to the minimum safety standards of UL and the FCC to see if a proper design has been achieved for the range of expected transients and overvoltages. Note that UL requires AC testing, therefore "U" and "S" types are typically used with shunt or bridge rectifiers.

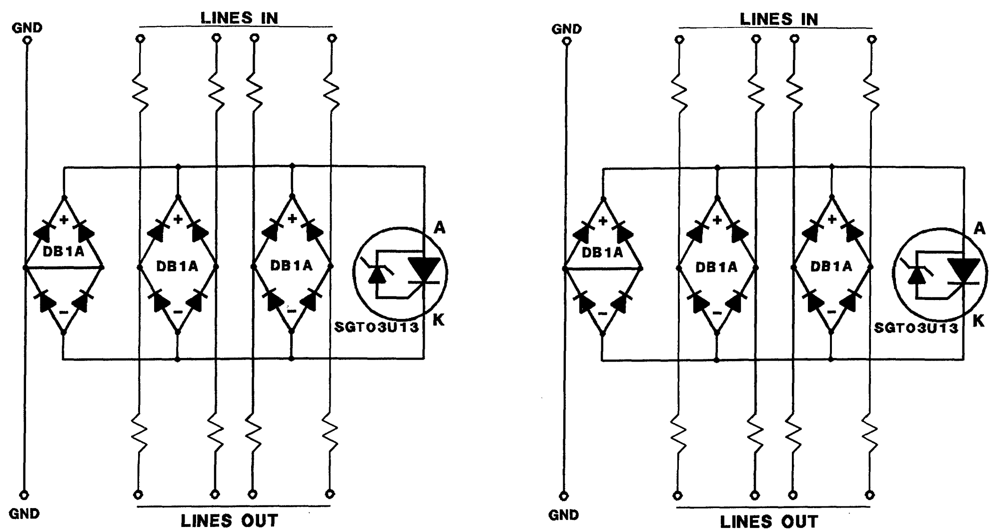
For example the new UL–1459 standard (effective October 1990) requires several overvoltages and currents to be imposed on telephone equipment – such that power lines coming in contact with telephone lines will not cause fires in the equipment or in the house wiring. One test involves a 1.5 second application of 600 volts at 40 amperes. This voltage would certainly turn on a SURGECTOR, protecting the equipment for overvoltage. The resulting 40 ampere current flow must then be interrupted or limited to a safe value.

Using Ohm's Law, E = IR, it can be estimated that 15 ohms will limit 600 volts to 40 amperes of current. This amounts to about 200 feet of 26 gauge telephone wire. Of course, additional resistance can be added to the telecom equipment to provide even more protection than the 600 volt, 40 ampere requirement.

In order to interrupt the current, a fuse may be employed that will open before either the wiring or the SURGECTOR is damaged. A fast acting 1 ampere fuse will readily open the circuit within the time–current curve specified by UL–1459. (All other fuse parameters should be checked with the fuse manufacturer before finalizing a design.)

As a result of either lightning transients or the SURGECTOR turning on, a transient voltage of L times di/dt will appear in the system. Transformer and ringer inductance should be examined for its contribution to the overvoltage condition. In addition, the circuit wiring going to the SURGECTOR should be arranged so that this effect is minimized.

Whereas most telecom applications use either 230 volt or 270 volt SURGECTOR devices to accommodate the 100 volt ring signal plus battery voltage, there are also low voltage SURGECTOR applications for data cables, alarm systems, and control cables. These signals can be ±12 volts, 24 Vac, or 48 Vdc. For these applications the low voltage 30 and 60 volt unidirectional and variable voltage SCR type SURGECTOR types are suitable. Typical applications are shown in Figures 5.15 through 5.20. By using a few extra components these economical general purpose circuits become quite reliable. In some cases these circuits can be simplified to obtain a lower parts count.



One SURGECTOR recommended per each 4 lines.

Figure 5.18 - Data Line Protector

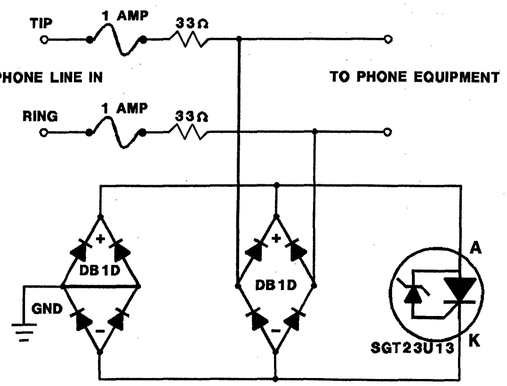
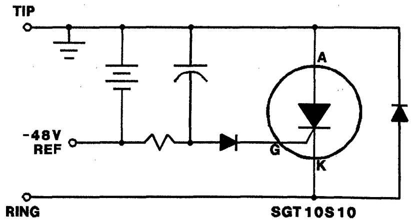
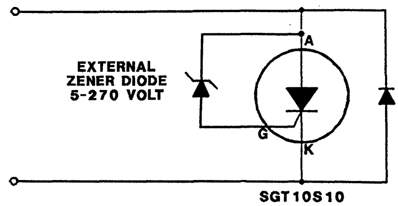


Figure 5.19 - Telecom Protector



a) With -48V Reference



b) With Zener Reference

Figure 5.20 - Using the SCR Type SURGECTOR

REFERENCES

1. Bennison, E., P. Ferland and A.J. Ghazi, *"Lightning Surges in Open-Wire, Coaxial and Paired Cables,"* IEEE International Conference on Communications, June 1972.
2. Golde, R.H., *"Lightning Currents and Related Parameters,"* Lightning, Vol. 1, Physics of Lightning, Chapter 9, ed. R.H. Golde, Academic Press, 1977.
3. Cianos, N. and E.T. Pierce, *"A Ground Lightning Environment for Engineering Usage,"* Report No. 1, Stanford Research Institute, August 1972.
4. Boyce, C.F., *"Protection of Telecommunication Systems,"* Lightning, Vol. 2, Lightning Protection, Chapter 25, ed. R.H. Golde, Academic Press, 1977.
5. *"Connection of Terminal Equipment to the Telephone Network,"* Federal Communications Commission Rules and Regulations, part 68, October 1982.

SUPPRESSION — AUTOMOTIVE TRANSIENTS

6.1 TRANSIENT ENVIRONMENT

The designer of electronic circuits for automotive applications must ensure reliable circuit operation in a severe transient environment. The transients on the automobile power supply range from the severe, high energy, transients generated by the alternator/regulator system to the low-level "noise" generated by the ignition system and various accessories (motors, radios, transceivers, etc.). Transients are also coupled to the input and output terminals of automotive electronics by magnetic and capacitive coupling in the wiring harness, as well as conductive coupling in common conductor circuits (especially the chassis "ground"). Steady state over-voltages may be applied by the circuit power supply due to the voltage regulator failure or the use of 24V battery "jump" starts. The circuits must also be designed against the possibility of the battery being connected in reverse polarity. Figure 6.1a shows a simplified automotive electrical system, illustrating transient sources and how to protect against them. Circuits which drive inductive loads must be protected against the transients resulting from the energy stored in the field of the inductor. These transients can be defined from the load inductance and load current. Figure 6.1b summarizes the automotive power supply transients as documented by the Society of Automotive Engineers (SAE).[1]

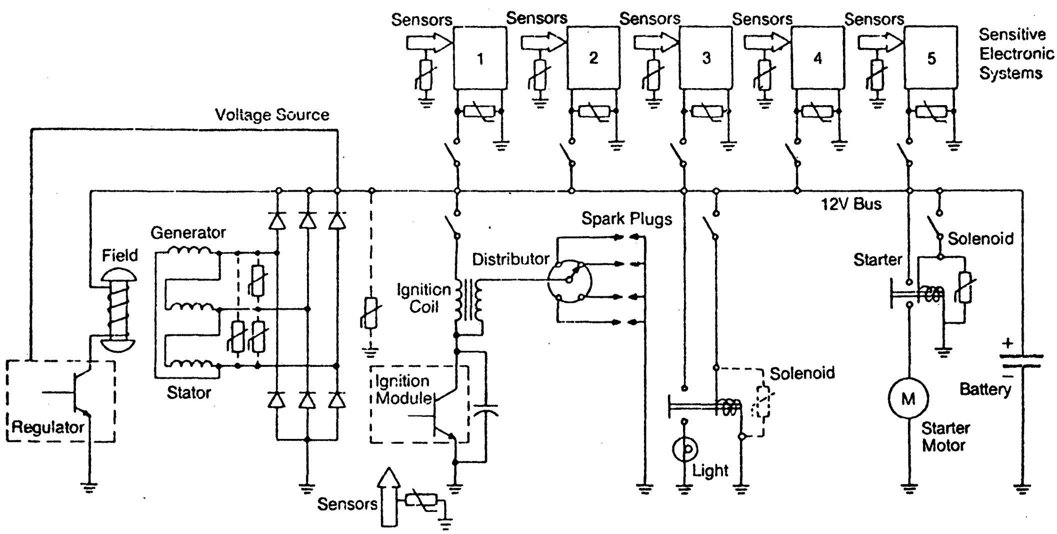


Figure 6.1a — Simplified Electrical Automotive System

Length of Transient	Cause	Energy Capability / Voltage Amplitude	Possible Frequency of Application
Steady State	Failed Voltage Regulator	∞ / +18V	Infrequent
3 - 5 Minutes	Jump start with 24V battery	∞ / ±24V	Infrequent
200ms to 400ms	Load Dump — i.e., disconnection of battery while at high charging rates.	⩾ 10J / ⩽ 125V	Infrequent
⩽ 0.32s	Inductive Load Switching Transient	< 1J / -300V to +80V	Often
⩽ 0.20s	Alternator Field Decay	< 1J / -100V to -40V	Each Turn-Off
90ms	Ignition Pulse, Battery Disconnected	< 0.5J / ⩽ 75V	⩽ 500Hz Several times in vehicle life
1ms	Mutual Coupling in Harness*	< 1J / ⩽ 200V	Often
15μs	Ignition Pulse, Normal	< 0.001J / 3V	⩽ 500Hz Continuous
	Accessory Noise	⩽ 1.5V	50Hz to 10kHz
	Transceiver Feedback	≈ 20mV	R.F.

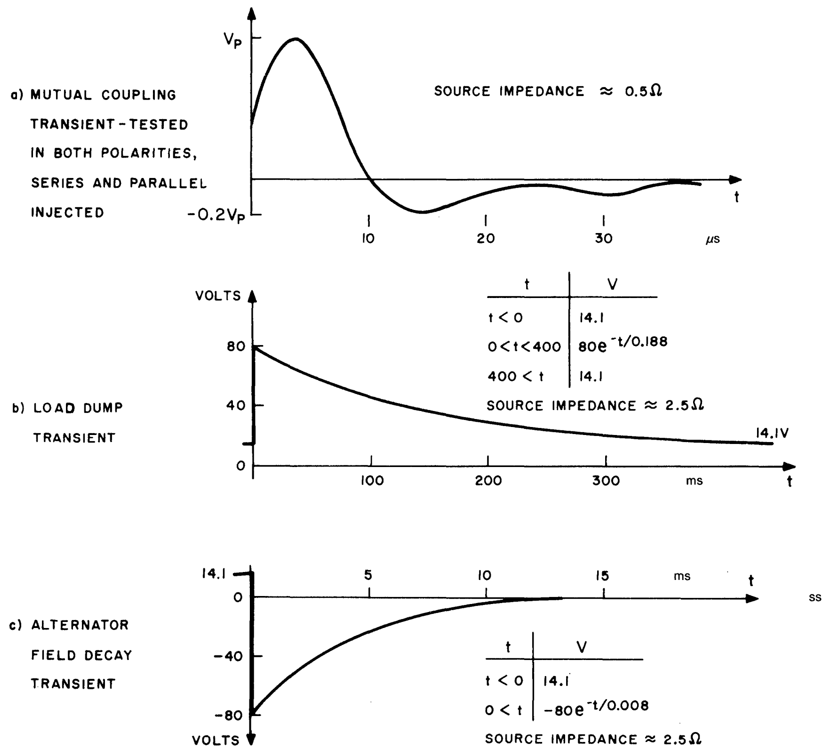
*These transients may be present on any wire in the vehicle.

Figure 6.1b — Typical Automotive Supply Transient Summary

Achieving maximum transient protection involves many factors. First, consequences of a failure should be determined. Current limiting impedances and noise immunity requirements need to be considered. The state of the circuit during the transient (on, off, unknown) and the availability of low-cost components capable of withstanding the transient are other factors. Considerable variation has been noted in the data gathered on automotive transients. Further, the interaction of other parts of the automotive electrical system with the circuit under transient conditions may require definition. The empirical evaluation of transient suppression using SAE-recommended test circuits,[2] is invaluable in many cases. Figure 6.2 illustrates the test waveform for the most common, high energy transients.

6.2 VARISTOR APPLICATIONS

To illustrate the procedures involved in designing transient protection for automotive electronics, two examples are provided. One example illustrates the protection of a solenoid driver circuit consisting of a logic integrated circuit with power transistor buffer; the second is the protection of an ignition circuit output transistor. These examples also illustrate the difference between protecting against random and repetitive transients. For random transients, energy and clamping vs. standby power dissipation are dominant constraints. For repetitive transients, transient power dissipation places an additional constraint on the choice of the suppression device. The solenoid driver protection circuit also illustrates the conflicting constraints placed on automotive transient suppressors by the low maximum voltage ratings of integrated circuits, the 24V jump-start cycle and the load dump transients.



NOTE:
Amplitudes, impedances, and time constants vary, depending on the specific electrical system considered and the system loading.

Figure 6.2 — Severe Transient Test Waveforms (From SAE Proposed Test Procedures[2])

6.2.1 Protection by a Central Suppressor

A central suppressor was the principal transient suppression device in a motor vehicle. As such, it is connected directly across the main power supply line without any intervening load resistance. It must absorb the entire available load dump energy, and withstand the full jump-start voltage. To be cost effective, it usually is best located in the most critical electronic module. In newer applications additional suppressors may be placed at other sites for further suppression and to control locally-generated transients.

The load dump energy available to the central suppressor in the worst case depends on variables such as the alternator size, the response of the sampled-data regulator system, and the loads that share the surge current and energy. Each application therefore tends to be somewhat different. However, by combining several applications, it is possible to construct a representative example. The key fact is the alternator surge power available to be dissipated in the suppressor. Figure 6.3 is suggested as a starting point for analysis. Since a peak surge power of 1600W is available, a suppressor with a clamping voltage of 40V would draw a peak current of 40A. The surge energy rating needed for the suppressor can be found by taking the integral of the surge power over time, resulting in approximately 85 Joules. A jump-start rating of 24V is also needed.

Evaluating central suppressor devices can be simplified with the aid of a load dump simulator as shown in Figure 6.4. The inductor L, which simulates the alternator inductance, slows the surge rise time but does not materially affect the analysis. In the absence of a suppressor or load, the output waveform will be similar to that of Figure 6.2b. If a suppressor is inserted, the operating characteristics can be estimated as follows:

$$\text{Assume } V_C = 40V, \text{ then } I_p = (80 - 40V)/R_1 = 40A$$

The energy W dissipated in the varistor may be estimated by: $W = 1.4V_C I_p \tau$ (see Section 4.1.2). The impulse duration τ of the surge current (see Figure 3.21) can be estimated from the delay time as:

$$\tau = 0.7\ RC_1$$

where R is the series-parallel combination of the effective resistance of the varistor and simulator components R_1 and R_2. To facilitate this calculation, assume that the effective resistance is given by $V_C/0.7\ I_p = 1.4$ohm. The delay time constant with the suppressor in the circuit then becomes:

$$RC_1 = \left(\frac{2.4 \times 7}{2.4 + 7}\right)(0.03) = 0.054\text{sec}$$

and the surge impulse duration:

$$\tau = 0.7\ RC_1 = 0.038\text{sec}$$

The deposited energy now can be estimated by:

$$W = 1.4\ V_C\ I_p \tau = (1.4)(40)(40)(.038) = 85\ \text{Joules}$$

Hence, the simulator produces unprotected and protected circuit conditions similar to those expected in the vehicle itself.

A suppressor with the needed high energy capability has been developed and already is in use. This improved Harris Varistor model V24ZA50 has a load dump rating of 100 Joules. A narrow-tolerance selection can satisfy the clamping requirement of 40V maximum at 40A, with a jump-start rating of 24V. The protective performance of this suppressor can be measured conveniently using the simulator circuit shown in Figure 6.4.

The suppressor's durability has been demonstrated by subjecting test specimens first to 10 load dumps about 30s apart. After readout, additional stresses were applied consisting of a single dump of 200J and a jump-start overvoltage of 24V for 5 minutes. Clamping voltage, which is virtually invariant with temperature, was found to remain nearly unchanged by stress up to the single-surge destruction level of about 250J (see Figure 6.5). Standby current, the most sensitive parameter, remained well within limits as shown in Figure 6.6.

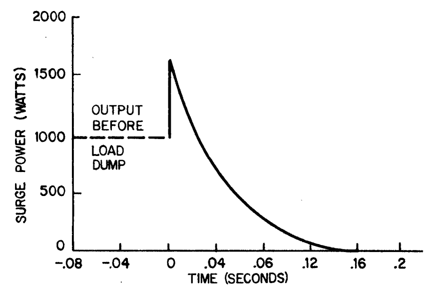


Figure 6.3 — Alternator Power Output into a Central Suppressor

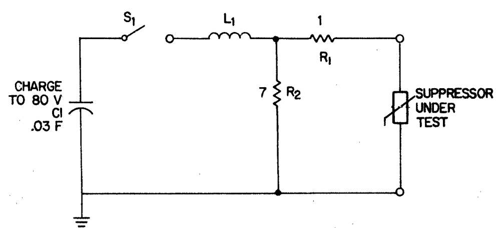


Figure 6.4 — Load Dump Simulator Circuit

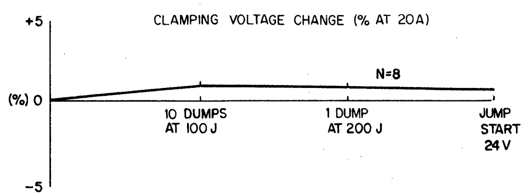


Figure 6.5 — Stability of Clamping Voltage

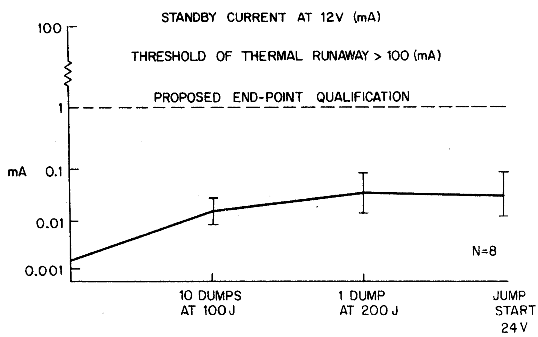
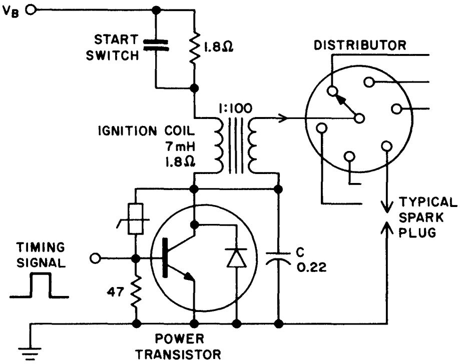


Figure 6.6 — Stability of Standby Current

6.2.2 Protection of Electronic Ignition

In the second example, the protection of the output power transistor in an electronic ignition circuit is analyzed. This power transistor performs the current switching function of mechanical distributor points in the usual Kettering ignition, thus avoiding the pitting, burning, and erosion mechanisms associated with the mechanical points. The ignition circuit is illustrated in Figure 6.7.



SYSTEM CONDITIONS		
CONDITION	V_B	START SWITCH
RUNNING	12V TO 16V	OPEN
STARTING	5V TO 12V	CLOSED

OPERATING TEMPERATURE RANGE -40°C TO +110°C

Figure 6.7 — Typical Electronic Ignition Circuit

In normal operation, the coil primary current builds up when the power transistor is on, storing energy in the coil inductance. The power transistor is then switched off, and the voltage at the collector rises rapidly as the capacitor, C, charges. Transformer action causes the secondary voltage to rise until the spark plug reaches firing voltage, clamping the transistor collector voltage at a safe value. If a spark plug is fouled or disconnected, the collector voltage can rise until either the capacitor contains the stored energy (minus losses), or the transistor breaks down with resulting damage/failure. Since the capacitor is small, transfer of the stored energy of the coil to the capacitor would result in a very high voltage requiring transistor protection. A varistor can be used to turn the transistor on during the period of high voltage, thus dissipating the excess energy safely as heat. The constraints on varistor selection are: clamp voltage must be low enough to protect the transistor; clamp voltage must be high enough to not affect normal spark energy; the power dissipation (with two spark plugs disconnected) must be within varistor ratings for an 8-cylinder, 4-cycle engine at 3300 rpm (misfires at 55Hz, average). The minimum spark voltage output required is 20,000V, which represents 200V at the transistor collector. The transistor has a breakdown voltage rating of 400V with the 47Ω base emitter resistor and a current gain over 20. The base emitter on-state voltage, $V_{BE(ON)}$, is between 1.0 and 1.8V, and the collector to emitter saturation voltage is between 0.9 and 1.5V. The varistor clamp voltage range is determined by the 200V needed to supply minimum spark voltage and the 400V rating of the transistor. At 200V the varistor current must be less than:

$$V_{BE(ON)}/47\Omega = \frac{1V}{47\Omega} = 0.02A$$

to prevent unwanted transistor turn-on. The minimum varistor voltage at the 1mA varistor specification point is found by solving the varistor voltage equation:

$$I = kV^{\alpha},$$

assuming a maximum α of 40. The result is 186V. The peak clamping current (at $400V - V_{BE(MAX)}$) is found from the energy balance equation for the coil, using the peak coil current, I_C. I_C maximum is analyzed under both start and run conditions to determine the worst case:

$$I_{C(start)} \leqslant \frac{12 - 0.9}{1.8\Omega} = 6.17A$$

and,

$$I_{C(run)} \leqslant \frac{16 - 0.9}{3.6\Omega} = 4.2A$$

The worst case coil current occurs with the start switch closed and will be less than 6.2A. The maximum peak coil current, I_p, when clamping is then:

$$\tfrac{1}{2}L\,I_C^2 = \tfrac{1}{2}L\,I_p^2 + \tfrac{1}{2}C\,V_p^2$$

and with a V_p of 400V:

$$I_p^2 = I_C^2 - 400^2\,C/L$$

results in 6.0A starting and 3.6A running. The varistor currents corresponding to this are:

$$I_p/h_{FE} + V_{BE}/47\Omega;$$

which gives 0.34A starting and 0.22A running. Peak varistor voltage must be less than:

$$400V - V_{BE}\ \text{(i.e., 398V at 0.34A)}$$

The varistor power dissipation at 3300 rpm (55pps), assuming a triangular current waveform with constant voltage and no losses, is found from coil energy balance:

$$\tfrac{1}{2}L\,(I_p)^2 = V_{MAX}\,\frac{I_p}{2}\,t$$

solving for t:

$$t = \frac{(7)(10^{-3})\ H\ (3.6A)}{400V} = 63\mu s$$

The varistor power dissipation is found to be:

$$V_{MAX}\,\frac{I_p}{2}\,tf = 398V\left(\frac{0.22A}{2}\right)(63)(10^{-6})s\,(55pps) = 0.15W$$

Observations indicate that the losses in the coil and reflected secondary load will reduce this by half to about 75mW. Using the 110°C ambient temperature derating factor of 0.53, it is found that a varistor of 0.15W dissipation capability is required. The varistor parameters are now defined as V_x of at least 186V at 1mA but less than 398V at 0.34A and capable of at least 0.15W dissipation. The V220MA2A and V270MA4B both fit these requirements.

As these examples have illustrated, the use of the Harris Varistor in automotive circuits for transient protection is both technically and economically sound. Design procedures are identical to the procedures used in the other environments. Experimental verification of the degree of protection can be made using standard waveforms reported by automotive engineering investigators.

REFERENCES

1. Preliminary Recommended Environmental Practices for Electronic Equipment Design, Society of Automotive Engineers, 2 Pennsylvania Plaza, N.Y., N.Y. 10001.
2. Electromagnetic Susceptibility Test Procedures for Vehicle Components (except Aircraft), Society of Automotive Engineers, 2 Pennsylvania Plaza, N.Y., N.Y. 10001.
3. Korn, S.R., *"Transient Voltage Suppression in Automotive Vehicles,"* SS-8766.

VARISTOR TESTING

7.1 INTRODUCTION

As with any device, metal-oxide varistors possess a number of parameters which can be identified and measured in several ways. However, to minimize testing effort, the test parameters should be reduced to the essential few. Also, tests should be conducted in a standard way to assure correlation of measured values between maker and user. The essential varistor parameters are defined in Chapter 3. This chapter will detail the tests of these varistor parameters, describe suitable test methods using simplified test circuits, and list some available test equipment.

It should be noted that all tests are performed at 25°C, unless otherwise specified. Also, the test circuits and methods given herein are intended as a general guide only, and may not be generally applicable to the test equipment available to the user. Since the tests frequently entail high voltages and currents, the user must exercise appropriate safety precautions.

7.2 TEST OBJECTIVES

Varistor testing that would be undertaken by a user will depend considerably on prior knowledge of both the device and the application. Factors are the relative severity of the application (both electrical and environmental), the number of devices to be used, and the possible adverse effect of device misapplication or malfunction. Further considerations are resources available to the user and the economics of alternate uses of those resources versus more extensive varistor testing. Equipment makers designing transient protection into their products will have different objectives in varistor testing than a user simply adding a few varistors to existing equipment as a protective step. Finally, the user may have different test requirements depending on which point in the cycle of system design or component evaluation and procurement the testing is being done.

7.2.1 Engineering Evaluation

For the original equipment maker, the process of evaluating and procuring a new component begins with an initial evaluation of the component itself. Typically, the circuit or systems engineer will obtain a few samples of the candidate component for evaluation in the prototype equipment design. He may seek recommendations from his component engineer in selecting from devices available in the market. It is important to focus on the key characteristics and ratings to determine if the component can perform as expected. Typically, varistor voltage, clamping voltage, standby current, insulation resistance, and capacitance of the samples should be measured according to the methods given in Section 7.3. Assuming that a varistor type has been selected according to the design application examples of Chapter 4, the engineer obviously will verify that the component performs as expected when placed in the breadboard circuit. Also, it should be verified that variation of these parameters within their specification values are consistent with the application requirements. The surge current, or energy, and waveshape available in the circuit together with its frequency of occurrence should be measured or computed. These characteristics of the expected transients should then be checked against the pulse lifetime and the power dissipation ratings of the selected varistor type. Where suitable equipment is available, the rating of the varistor may be verified by injections of transients into the varistor alone or into the prototype circuit. See Section 7.6 and 7.7 of this chapter for a discussion of transient test equipment and test waves.

7.2.2 Product Qualification

In some user organizations, selection and evaluation of the varistor as a component may pass to a specialized group that evaluates component engineering and reliability. The final output of this evaluation will be a purchase specification detailing the mechanical and electrical requirements and ratings of the component, and possible approved sources for the part. A product qualification plan often will be used to detail the electrical and environmental tests to which a sample of the candidate component may be subjected and which it must pass in order to be approved. Frequently the manufacturer will be asked to supply supporting data for his in-house testing to supplement and minimize the qualification testing. The suggested electrical characteristics tests are (with appropriate conditions and limits): nominal varistor voltage, V_N; maximum clamping voltage, V_c; dc standby current, I_D (optional, especially for ac applications); insulation resistance; and capacitance. These characteristics will be measured frequently in the component/equipment cycle thereafter, and care should be exercised that they are neither too many and complex nor too few to be meaningful to the application. Reliability requirements of operating conditions and expected life will sometimes be specified and usually tested for early in the qualification phase of the component. These tests may be performed at special conditions of environment or temperature to stress the component as proof of its intended use or design capability. A test to insure surge current withstand capability may be included in the qualification plan. This test must be carefully performed and specified (by using either 8/20μs or 10/1000μs waveshapes) in line with the recommendations of Chapter 3 and consistent with the pulse lifetime rating chart of the varistor selected. Other qualification tests may be used to ensure mechanical integrity, humidity resistance, solderability, and terminal/lead strength. These tests should be of a standard nature wherever possible to assure reproducibility.

7.2.3 Incoming Inspection

Once the component has been qualified, the equipment maker will wish to verify that shipments received consist of correct parts at the expected quality level. Shipments will be sample-tested to assure correct markings, appearance, finish, and major or critical electrical parameters. It is especially desirable to prevent material with incorrect voltage characteristics from entering assembly operations so as to minimize troubleshooting and rework. For incoming inspection of Harris Varistors,it is recommended that sample testing include nominal varistor voltage, V_N, tested against the minimum and maximum voltages specified on the purchase drawing/specification. Components below specification limits may lead to premature degradation or circuit failure. If above specification, they may not deliver the required protection from transients and may possibly allow other failures. Other electrical sampling tests frequently performed can include insulation resistance and capacitance. Tests such as maximum clamping voltage, V_C, and dc standby current, I_D, are usually checked only on a periodic audit basis.

7.2.4 Field Maintenance

Field maintenance testing is done to verify that the varistor is still providing the intended protection function or, in the case of sensitive circuit applications, that the varistor has not degraded. Since the usual change of Harris Varistor characteristics when over-stressed is toward lower resistance, it is very unlikely that the protection function will deteriorate unless the electrode system is damaged. The varistor should be physically examined for loose leads, charred or broken areas in the encapsulant, solder dribbles on the leads, or other evidence of overheating damage. If physically acceptable, the varistor may be tested electrically.

The nominal varistor voltage should be tested against the minimum limits for the model using the method described in Section 7.3.1. If the varistor is open, short, or more than 10% outside either limit, it should be discarded. The dc standby current also should be measured. If more than twice the specification, the varistor is significantly degraded and should be discarded. If the varistor is physically sound and shows no evidence of degradation in these electrical tests, it is fully functional.

7.3 MEASUREMENT OF VARISTOR CHARACTERISTICS[1]

7.3.1 Nominal Varistor Voltage V_N

This is measured at a dc test current, I_N, of 1mA for product models. A simplified circuit for instrumenting this test, shown in Figure 7.1, is suitable for varistors up through a rating of 300V RMS. Above the 300V RMS rating, a higher supply voltage will be needed. Resistor R1 has a dual purpose. In conjunction with the variable voltage supply, E1, it forms a quasi-current source providing up to 6mA when switch S1 is closed. Also, R1 is used as a current sensor to measure current flowing through the varistor-under-test. To use the circuit, the operator places switch S2 in position I and S3 into position V_N. A test device is then inserted into the socket and S1 is closed. E1 is then adjusted to obtain a reading of 100 $\pm$5V on the digital voltmeter. Approximately 1mA of current will be flowing in R1. When switch S2 is placed in position V, the varistor voltage will be indicated on the voltmeter. The values of R1 and E1 supply voltage can be scaled appropriately for other voltage-current test points.

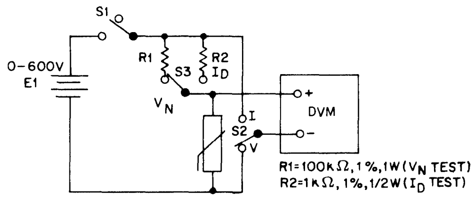


Figure 7.1 — Simplified Circuit for Varistor Voltage and DC Standby Current Tests

If the varistor voltage test is implemented on automatic test equipment, a "soak" time of 20ms minimum should be allowed after application of test current before voltage measurement. This is necessary to allow varistor voltage to settle toward a steady-state value. Figure 7.2 illustrates the time response of a specimen varistor with a constant 1.0mA current applied. As can be seen, the varistor voltage initially may rise to a value up to 6% greater than final. With a 20ms or greater soak time, the measured value will differ by less than 2% from the steady-state value.

For varistor models that are commonly used on 60Hz power lines, the V_N limits may be specified for a 1.0mA peak ac current applied. If an ac test is preferred by the user, a schematic approach similar to that shown in Figure 7.1 is used, except an ac Variac™ is substituted for the dc power supply, and an oscilloscope is substituted for the voltmeter. This circuit is equivalent to that of a typical curve tracer instrument.

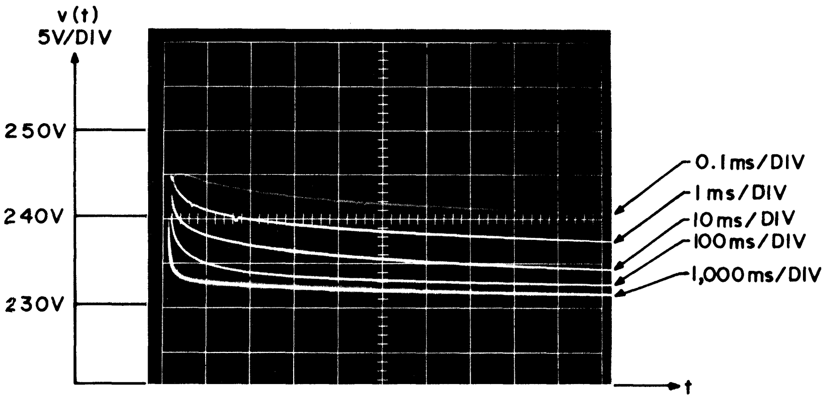


Figure 7.2 — Voltage-Time V(T) Characteristics of a Harris Varistor (V130LA10A) Operating at a Constant DC Current of 1.0mA

To avoid unnecessary concern over minor measurement anomalies, three behavioral phenomena of metal-oxide varistors should be noted. First, it is normal for the peak varistor voltage measured with ac current to be about 2% to 5% higher than the dc value, as illustrated by Figure 7.3. This "ac-dc difference" is to be expected, since the one-quarter cycle period of a 60Hz wave is much less than the 20ms minimum settling time required for dc readout.

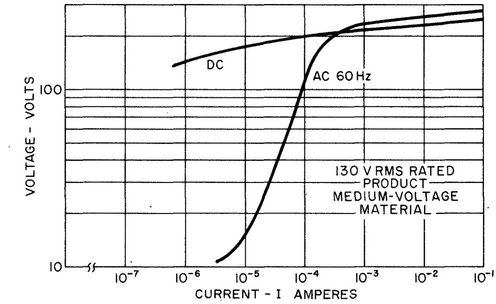


Figure 7.3 — AC and DC Characteristic Curves

Second, it is normal for the varistor voltage to increase slightly when first subjected to electrical current, as shown in Figure 7.4. This might be considered a "break-in" stabilization of the varistor characteristics. During normal measurement the voltage shift typically is less than 1%. This voltage shift is of little consequence for most measurement purposes but might be noticeable when viewing a DVM as in the test method of Figure 7.1. The visual DVM observation should be made shortly after power is applied, with measurement to not more than three significant figures.

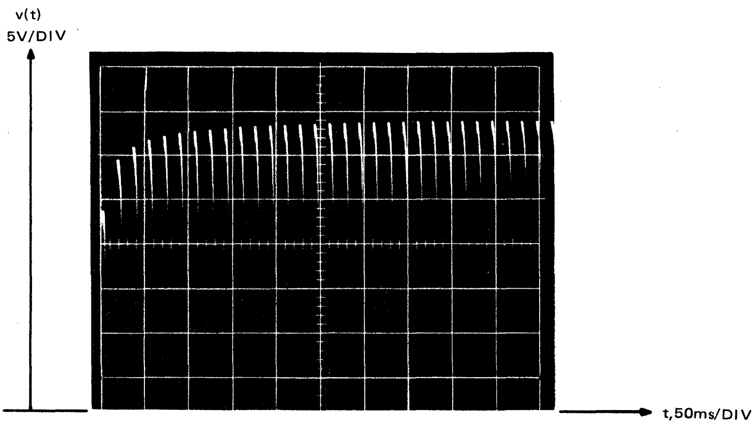


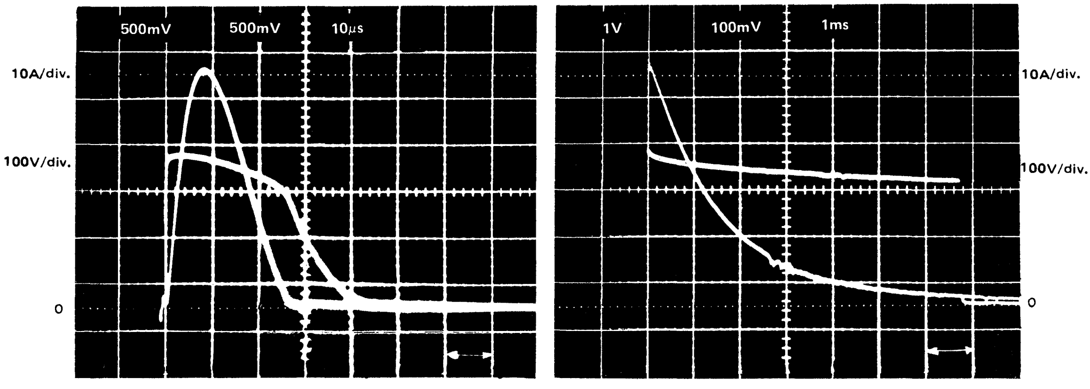
Figure 7.4 — (V130LA10A) Varistor Voltage for the Initial Cycles of 60Hz Operation at a Peak Current of 1.0mA

Third, it is normal for the varistor voltage-current characteristic to become slightly asymmetrical in polarity under application of dc electrical stress over time. The varistor voltage will increase in the same direction as the polarity of stress, while it will be constant or will decrease in the opposite polarity. This effect will be most noticeable for a varistor that has been subjected to unipolar pulse stresses or accelerated dc life tests. Therefore, to obtain consistent results during unipolar pulse or operating life tests, it is essential to provide a polarity identification for the test specimens. However, for initial readout purposes, this effect usually is insignificant.

7.3.2 Maximum Clamping Voltage, V_C

As discussed in Chapter 3, the clamping voltage of a varistor is best defined in terms of the current impulse impressed on the varistor, rather than in terms of applied voltage. Two typical current impulses that may be used to define the varistor clamping voltage are the 8/20μs and the 10/1000μs pulses. Figure 7.5 shows typical varistor test waveforms for these two impulses.

The clamping voltage of a given model varistor at a defined current is related by a factor of the varistor voltage. Therefore, a test of the nominal varistor voltage against specifications may be sufficient to provide reasonable assurance that the maximum clamping voltage specification is also satisfied. When it is necessary to perform the V_C test, special surge generators are required. For shorter impulses than 8/20μs, precautions must be observed to avoid an erroneous "overshoot" in the measurement of the clamping voltage. Section 7.6 gives general information on surge generators; a brief description of the "overshoot" effect follows.



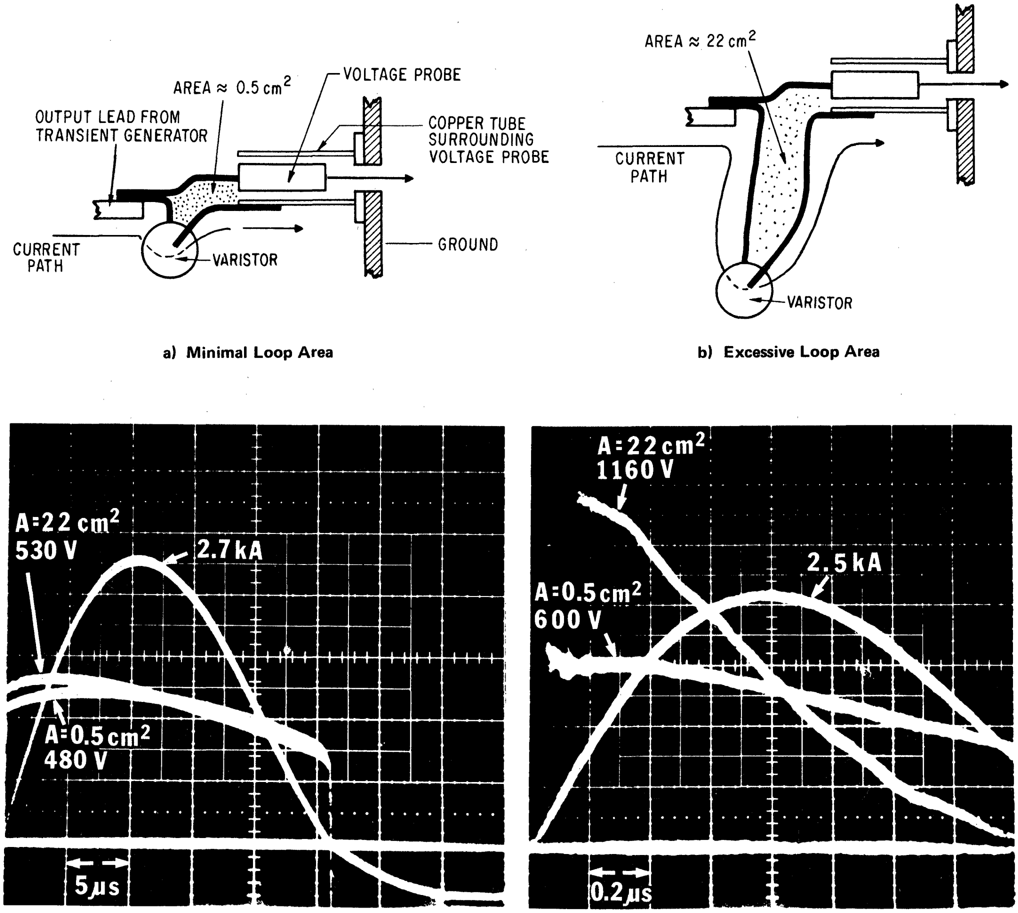
a) 8 / 20μs wave I_P = 50A, V_P = 315V

b) 10 / 1000μs wave I_p = 50A, V_C = 315V

Figure 7.5 — Typical Clamping Voltage Test Waveforms (Harris Varistor Type V130LA10A)

The Harris Varistor specification sheets show the V-I characteristic of the devices on the basis of maximum voltage appearing across the device during a current pulse of 8/20μs. If current impulses of equal magnitude but faster rise are applied to the varistor, higher voltages will appear across the device. These higher voltages, described as "overshoot," are partially the result of an intrinsic increase in the varistor voltage, but mostly of the inductive effect of the unavoidable lead length. Therefore, as some applications may require current impulses of shorter rise time than the conventional 8μs, careful attention is required to recognize the contribution of the voltage associated with lead inductance.[1]

The varistor voltage, because of its nonlinearity, increases only slightly as the current amplitude of the impulse increases. The voltage from the lead inductance is strictly linear and therefore becomes large as high current amplitudes with steep fronts are applied. For that reason, it is impractical to specify clamping voltages achieved by lead-mounted devices with current impulses having rise times shorter than 0.5μs, unless circuit geometry is very accurately controlled and described.



a) Minimal Loop Area **b) Excessive Loop Area**

c) Current Rise of 8μs **d) Current Rise of 0.5 μs**

Figure 7.6 — Effect of Lead Length on "Overshoot"

To illustrate the effect of lead length on the "overshoot," two measurement arrangements were used. As shown in Figures 7.6a and 7.6b, respectively, 0.5cm² and 22cm² of area were enclosed by the leads of the varistor and of the voltage probe.

The corresponding voltage measurements are shown in the oscillograms of Figures 7.6c and 7.6d. With a slow current front of 8μs, there is little difference in the voltages occurring with a small or large loop area, even with a peak current of 2.7kA. With the steep front of 0.5μs, the peak voltage recorded with the large loop is nearly twice the voltage of the small loop. (Note on Figure 7.6d that at the current peak, L di/dt = 0, and the two voltage readings are equal; before the peak, L di/dt is positive, and after, it is negative.)

Hence, when making measurements as well as when designing a circuit for a protection scheme, it is essential to be alert to the effects of lead length (or more accurately of loop area) for connecting the varistors. This is especially important when the currents are in excess of a few amperes with rise times of less than 1μs.

With reasonable care in maintaining short leads, as shown in Figure 7.6a, it is possible to describe the "overshoot" effect as an increase in clamping voltage relative to the value observed with a 8/20μs impulse. Figure 7.7 shows a family of curves indicating the effect between 8 and 0.5μs rise times, at current peaks ranging from 20 to 2000A. Any increase in the lead length, or area enclosed by the leads, would produce an increase in the voltage appearing across the varistor terminals — that is, the voltage applied to the protected load.

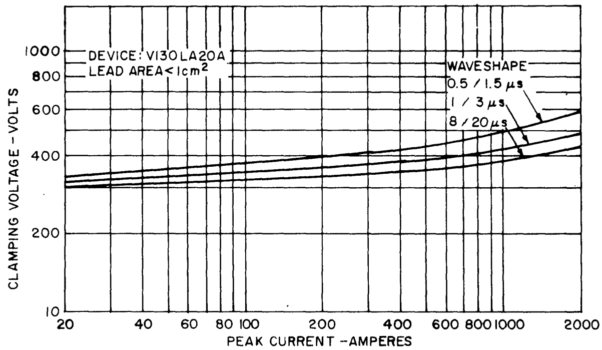


Figure 7.7 — Typical "Overshoot" of Lead-Mounted Varistor with Steep Current Impulses

7.3.3 DC Standby Current, I_D

This current is measured with a voltage equal to the rated continuous dc voltage, V_m(dc), applied across the varistor. The circuit of Figure 7.1 is applicable where current sensing resistor R2 has a value of 1000Ω. The test method is to set the voltage supply, E1, to the specified value with switch S1 closed and S2 in the V position. Then S2 is placed in position I and S3 in position, I_D. S1 is then opened, the test device is inserted in the test socket, and S1 is closed. The DVM reading must be converted into current. For example, if a maximum standby current of 200μA is specified, the maximum acceptable DVM reading would be 0.200V.

The measurement of dc standby current can be sensitive to the device behavioral phenomena of "break-in" stabilization and polarization of the V-I characteristics, as described in Section 7.3.1. If the device under test has prior unipolar electrical history, polarity indicators should be observed and test values interpreted accordingly.

The value of dc standby current also can be sensitive to ambient temperature. This is unlike varistor characteristics measured at currents of 1mA or greater, which are relatively insensitive to ambient temperatures. With V_M(dc) around 85% of V_N, Figure 7.8 shows the typical dc standby current of a model V130LA10A varistor in the order of 10 or 20μA at room temperature. I_D increases to about 80μA at 85°C, the maximum operating temperature without derating.

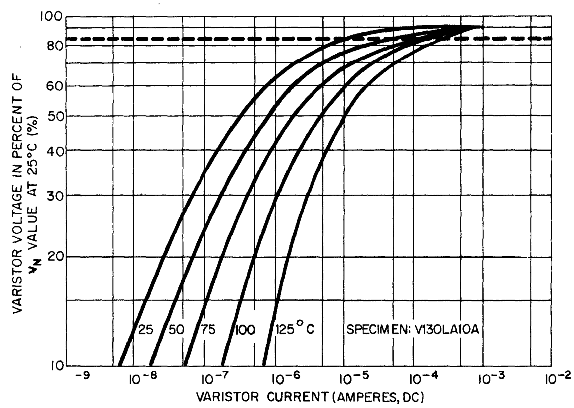


Figure 7.8 — Typical Temperature Dependence of DC Standby Current Varistor Type — V130LA10A

7.3.4 Capacitance

Since the bulk region of a Harris Varistor acts as a dielectric, the device has a capacitance that depends directly on its area and varies inversely with its thickness. Therefore, the capacitance of a Harris Varistor is a function of its voltage and energy ratings. The voltage rating is determined by device thickness, and the energy rating is directly proportional to volume.

Harris Varistor capacitance can be measured through use of a conventional capacitance bridge and is found to vary with frequency, as shown in Figure 7.9. Typically, capacitance measurements are made at 1MHz. Dissipation factor also is frequency-dependent, as shown in Figure 7.10.

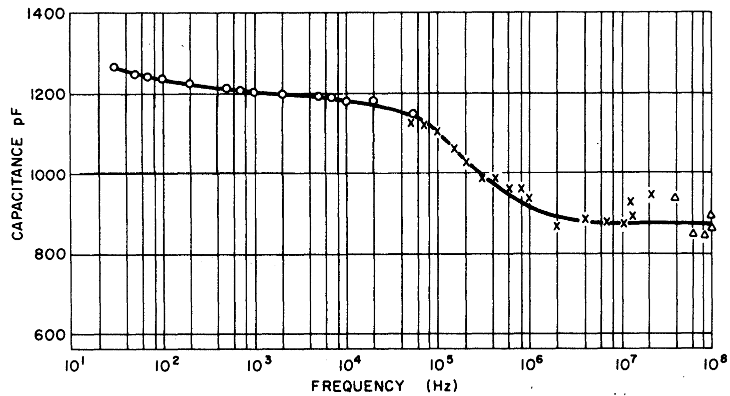


Figure 7.9 — Capacitance Variation with Frequency

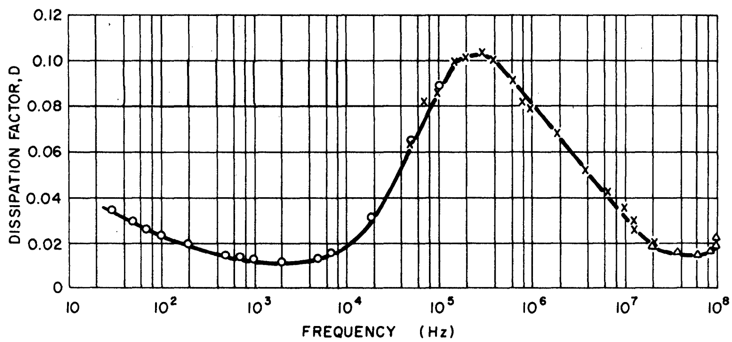


Figure 7.10 — Dissipation Factor Variation with Frequency

When measured with a dc bias, the capacitance and dissipation factor show little change until the bias approaches or exceeds the V_N value. Furthermore, the capacitance change caused by an applied voltage (either dc or ac) may persist when the voltage is removed, with the capacitance gradually returning to the prebias value. Because of this phenomenon, it is important that the electrical history of a Harris Varistor be known when measuring capacitance.

7.3.5 Miscellaneous Characteristics

A number of characteristic measurements can be derived from the basic measurements already described, including the nonlinear exponent (alpha), static resistance, dynamic impedance, and voltage clamping ratio. These characteristics are derived characteristics in the sense that they are found by computation per the defining equations given in Chapter 3. The data, however, may be obtained by measurement methods similar to those already given for nominal varistor voltage and maximum clamping voltage. These miscellaneous characteristics may be useful in some cases to enable comparison of Harris Varistors with other types of nonlinear devices, such as those based on silicon carbide, selenium rectifier or zener diode technologies.

7.4 VARISTOR RATING ASSURANCE TESTS

7.4.1 Continuous Rated RMS and DC Voltage [V_m(ac) and V_m(dc)]

These are established on the basis of operating life tests conducted at the maximum rated voltage for the product model. These tests usually are conducted at the maximum rated ambient operating temperature, or higher, so as to accelerate device aging. Some test results are given in Chapter 8. Unless otherwise specified, end-of-lifetime is defined as a degradation failure equivalent to a V_N shift in excess of ±10% of the initial value. At this point the device is still continuing to function. However, the varistor will no longer meet the original specifications.

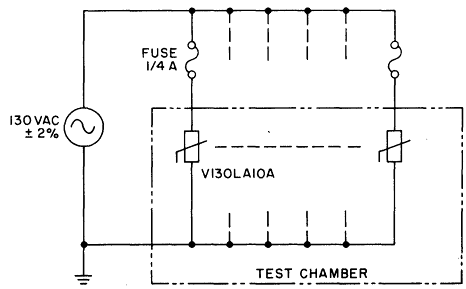


Figure 7.11 — Simplified Operating Life Test Circuit

A typical operating life test circuit is shown in Figure 7.11. If the varistor is intended principally for a dc voltage application, then the ac power source should be changed to dc. It is desirable to fuse the varistors individually so testing is not interrupted on other devices if a fuse should blow. The voltage sources should be regulated to an accuracy of ±2% and the test chamber temperature should be regulated to within ±3 °C. The chamber should contain an air circulation fan to assure a uniform temperature throughout its interior. The varistors should receive an initial readout of characteristics at room ambient temperature — i.e., 25 ±3 °C. They should then be removed from the chamber for subsequent readout at 168, 500, and 1000 hours. A minimum of 20 minutes should be allowed before readout to ensure that the devices have cooled off to the room ambient temperature.

7.4.2 Transient Peak Current, Energy, Pulse Rating, and Power Dissipation Ratings

Special surge generator equipment is required for testing. Data on commercially available equipment is given in Table 7.3, and an example test circuit is described in Section 7.6. Since high energy must be stored at high voltages to perform these tests, especially on larger sizes of Harris Varistors, the equipment is necessarily expensive and must be operated using adequate safety precautions.

The peak current rating, I_{tm}, of Harris Varistors is based on an 8/20μs test impulse waveshape. The specifications include a maximum single value in the ratings table. A pulse rating graph defines the peak current rating for longer impulse duration as well, such as for a 10/1000μs wave. A family of curves defines the rated number of impulses with a given impulse duration and peak current.

Energy rating, W_{tm}, is defined for a 10/1000μs current impulse test wave. This waveshape has been chosen as being the best standard wave for tests where impulse energy, rather than peak current, is of application concern. A direct determination of energy requires that the user integrate over time the product of instantaneous voltage and current. Such integration is cumbersome to perform, and the integration feature is not generally available in surge generation equipment.

However, peak voltage and current are readily measured with available equipment. Therefore, the energy rating can be tested indirectly by applying the rated peak impulse current of a 10/1000μs waveshape to the test specimen. Then, the energy dissipated in the varistor can be estimated from the known pulse waveshape. For a 10/1000μs waveshape the approximate energy is given by the expression $E = 1.4V_C\, I\, \tau$. See Chapter 4 for a discussion of energy dissipation for various waveshapes.

For example, a model V130LA10A varistor has a single pulse rating for a 10/1000μs impulse waveshape of about 75A peak, and a maximum clamping voltage at 75A of about 360V. Thus, the computation of estimated energy dissipation is 38J.

The transient power dissipation rating, P_{tam}, is defined as the maximum average power of test impulses occurring at a specified periodic rate. It is computed as the estimated energy dissipation divided by the test pulse period. Therefore, varistors can be tested against this rating by applying two or more impulses at rated current with a specified period between pulses. For example, a model V130LA10A varistor has a pulse rating of two 10/1000μs test impulses with a peak current of about 65A. The estimated energy dissipation per pulse computed as per the preceding example is about 30J. If a period of 50s is allowed after the first test pulse, the estimated average power dissipation can be computed as about 0.6W, which is the specification rating. It should be noted that Harris Varistors are not rated for continuous operation with high-level transients applied. The transient power dissipation rating is based on a finite number of pulses, and the pulse rating of the varistor must be observed. See Figure 7.12.

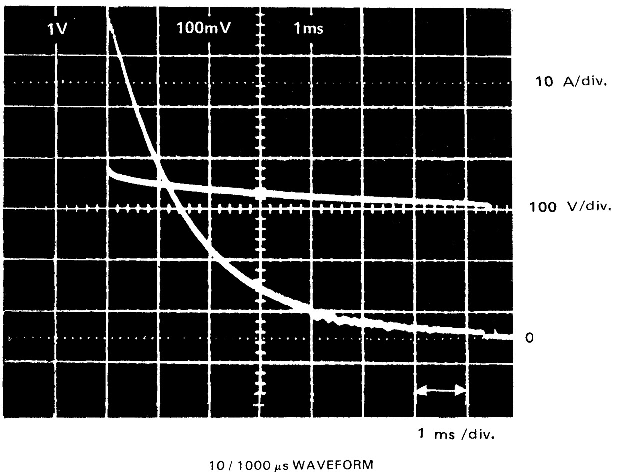


Figure 7.12 — Surge Test Waveforms

Table 7.1 outlines a suggested program of testing to verify varistor transient and pulse ratings with a minimum of expensive, time-consuming testing. New specimens should be used for each test level and failure judged according to the specification criteria.

Table 7.1
Testing of Transient Current, Energy, Pulse Rating, and Power Dissipation Ratings

Test Parameter	No. Pulses @ Rated Current (Alternating Polarity)	Test Waveshape (μs)	Minimum Pulse Period (s)
Maximum Peak Current	1 (same polarity as readout)	8/20	NA
Pulse/Energy Rating, Power Dissipation	2	10/1000	50
Pulse Rating	10	8/20	25
Pulse Rating	100	8/20	12

7.4.3 Continuous Power Dissipation

Since Harris Varistors are used primarily for transient suppression purposes, their power dissipation rating has been defined and tested under transient impulse conditions. If the devices are to be applied as threshold sensors or coarse voltage regulators in low power circuits, then a dissipation test under continuous power is more appropriate. This continuous power test will aid the user in determining if the device is suitable for his specific application.

A circuit for continuous power dissipation testing is shown in Figure 7.13. The dc power supply voltage should be set to a value of approximately twice the nominal varistor voltage of the product model under test. In that case, nearly constant power dissipation is maintained in the varistor. Since the circuit transfers nearly equal power to the series resistor and varistor-under-test, the series resistor value is simply chosen to achieve the test design value of power dissipation. In Figure 7.13 a nearly constant power dissipation of about 0.6W is obtained.

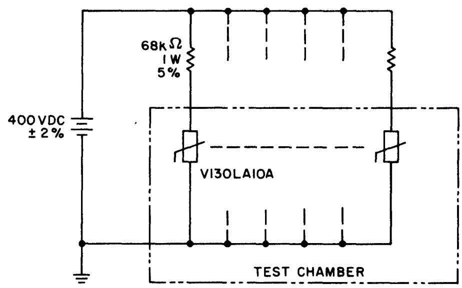


Figure 7.13 — Constant Power Life Test Circuit

7.5 MECHANICAL AND ENVIRONMENTAL TESTING OF VARISTORS

7.5.1 Introduction

Many tests have been devised to check the reliability of electronic components when subjected to mechanical and environmental stresses. Although individual equipment makers may specify their own tests on component purchase documents, these tests are often based on an equivalent MIL-STD specification. Therefore, it is convenient to summarize these tests in MIL-STD terms. Since the ratings of Harris Varistors may vary with product series and model, the test conditions and limits should be as specified on the applicable detail specification.

Harris Varistors are available in a high reliability series. This series incorporated most standard mechanical and environmental tests, including 100% pre-screening and 100% process conditioning. Details are provided in Chapter 9.

7.5.2 UL Recognition Tests

Harris Varistors have been tested by Underwriters Laboratories, Inc. (UL) and have been recognized as varistor type across-the-line components to UL STD1414 per UL File E56529. Harris Varistors are also recognized as suppressor components to UL STD1449 per UL File E75961. The tests were designed by UL and included discharge (withstand of charged capacitor dump), expulsion (of complete materials), life, extended life, and flammability (UL94V0) tests.

7.6 EQUIPMENT FOR VARISTOR ELECTRICAL TESTING

7.6.1 Introduction

Most tests of Harris Varistors can be performed with relatively simple circuits and inexpensive equipment on the laboratory bench. However, large users with versatile automatic test systems available may find it more economical to program these systems for the low-current varistor tests. As noted previously, medium or high-current impulse testing will require specialized test equipment. Table 7.2 is a partial listing of available test equipment and systems that can be used for varistor testing. It is intended as a guide only to illustrate the generic type of equipment offered commercially.

7.6.2 Impulse Generators

A convenient method of generating current or voltage surges consists of slowly storing energy in a capacitor network and abruptly discharging it into the test varistor. Possible energy storage elements that can be used for this purpose include lines (lumped or distributed) and simple capacitors, depending on the waveshape desired for the test. Figure 7.14 shows a simplified schematic for the basic elements of an impulse generator.

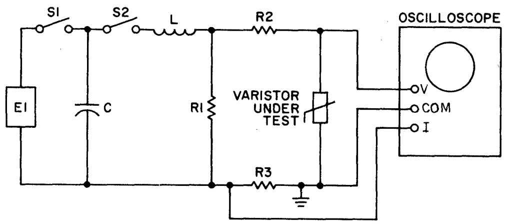


Figure 7.14 — Simplified Circuit of Surge Impulse Generator

The circuit is representative of the type used to generate exponentially decaying waves. The voltage supply, E1, is used to charge the energy storage capacitor, C, to the specified open-circuit voltage when switch S1 is closed. When switch S2 (an ignitron or a triggered gap) is closed, the capacitor, C, discharges through the waveshaping elements of the circuit into the suppressor device under test. With capacitances in the order of $1\mu F$ to $10\mu F$ and charging voltages of 10kV to 20kV, the typical $8/20\mu s$ or $10/1000\mu s$ impulses can be obtained by suitable adjustment to the waveshaping components L, R_1, and R_2, according to conventional surge generator design.[2,3,4,5]

7.6.3 Measurement Instrumentation

Transient measurements include two aspects of varistor application: (1) detection of transients to determine the need for protection, and (2) laboratory measurements to evaluate varistor performance. Transient detection can be limited to recording the occurrence of transient overvoltages in a particular system or involve comprehensive measurements of all the parameters which can be identified. Simple detection can be performed with peak-indicating or peak-recording instruments, either commercial or custom-made. Table 7.3 gives a partial listing of such instruments.

Laboratory instruments and field detection with comprehensive instrumentation can involve substantial investment, primarily associated with oscilloscopes, cameras, and calibrated sensors. A detailed discussion of these systems is beyond the scope of this manual; rather, the major oscilloscope manufacturers should be consulted, as well as the available literature.

Table 7.2 — Avaliable Equipment for Varistor Testing*

Type & Manufacturer	Model	Features
Storage Curve Tracer Tektronix, Inc. P.O. Box 500 Beaverton, OR 97077 503-627-7111	577/177 (Also can use 576)	ac & dc tests up to 1600V peak, with safety interlock, storage display mode.
Auto Capacitance Bridge Genrad Inc. 300 Baker Ave. Concord, MA 01742 617-369-4400	1687	1MHz test frequency, 3 measurements/sec, .01% accuracy, digital display, programmable control, IEEE testing.
Varistor Test System Mastech, Inc. 478 E. Brighton Ave. Syracuse, NY 13210 315-478-3133	222F 342	0-2000V, up to 10mA dc, 100mA pulse, digital readout, front panel programming 0-100kV at 10A. Front panel programming. IEEE Standard 4888
Semiconductor Test Systems Teradyne, Inc. 183 Essex St. Boston, MA 02111 617-482-2700	T57 or Z27	0-1200V, up to 10mA, computer operated, line printer output, multiple test stations, data analysis software, tape cartridge.
Pulse Generator Cober Electronics, Inc. 102 Hamilton Ave. Stamford, CT 06904 203-327-0003	605P	2.2kV, 20kW peak power, pulses 0.3μs — 10ms, variable PRF or can amplify external input.
Velonex 560 Robert Ave. Santa Clara, CA 95050 408-727-7370	360 587 510 515	2.5kV, 10A, pulses, up to 300μs wide, variable PRF, variable rise-fall available, plug-ins for higher peak I.
Surge Generator Systems KeyTek Instrument Corp. 260 Fordham Rd. Wilmington, MA 617-272-5170	System 1000, including Models 424, 711 and 587	6kV, up to 10kA, further expandable, selectable waveshapes (8/20, 10/1000, etc.), measures & displays peak V & I across test device. Peak biased differential high voltage probe. IEEE testing.
Joslyn Corp P.O. Box 817 Santa Barbara Research Park 6868 Cortona Drive Goleta, CA 93116 805-968-3551	4020-01	• 5 pin telephone module tester • Tests Gas Tube and Solid State modules • Battery operation
	4010-01	• Test set for surge protection devices • Tests breakdown at 1mA and clamping voltage • Tests MOVs, Zener, etc.

*Inclusion of any manufacturer in this listing does not constitute an endorsement nor does exclusion imply any judgment upon same.

7

VARISTOR TESTING

Table 7.3 — Avaliable Equipment for Varistor Testing*

Type & Manufacturer	Model	Features
Storage Oscilloscopes		
Tektronix P.O. Box 500 Beaverton,OR 97077 503-627-7111	466 7834	100MHz, 3000div/μs speed, portable Multimode storage, 400MHz, 5500div/μs
Peak Recording Instruments		
Micro-Instrument P.O. Box 1565 2250 Micro Place Escondido, CA 92025 619-746-2010	Memory Voltmeter Model 5203	20MHz, records, displays voltage levels up to 2kV
Bermar P.O. Box 12844 Research Triangle Park North Carolina 27709 919-489-4316	Memory Voltmeter MVM-108	Displays peak voltage, >0.5μs pulses up to 8kV
Dranetz Technologies 1000 New Durham Rd. Edison, NJ 08818 201-287-3680	Model 606 626	Prints out peak voltages, >0.5μs duration pulse
Industrionics 54 Holliston St. Medway, MA 02053 617-533-6736	Zap Trap	Measures peak voltages, >2μs duration
Trott Electronics Inc. 9020 Wehrle Dr. Clarence, NY 14031 716-634-8500	TR745A	Detects 0.3μs pulses, up to 3000V

*Inclusion of any manufacturer in this listing does not constitute an endorsement nor does exclusion imply any judgment upon same.

7.7 TEST WAVES AND STANDARDS

The varistor test procedures described in this chapter have been established to ensure conformity with applicable standards,[6] as well as to reflect the electromagnetic environment of actual circuits[7] which need transient protection. Chapter 1 presented an overview of the transient environment; some additional background is presented in this section concerning generally accepted assumptions about this environment.

7.7.1 Test Waves

A number of test waves have been proposed, to be applied to various electronic "black boxes," in order to demonstrate capability of survival or unimpeded performance in the environment. Table 7.4 is a partial listing of these test waves presented to illustrate the variety of proposals rather than to be an exhaustive listing.

Table 7.4 — Partial Listing of Existing or Proposed Test Waves

Origin	Description		Typical Application
	Waveshapes	Amplitude	
ANSI, IEC	• 1.2/50μs • 8/20μs	Specified voltage Specified Current	Power apparatus
IEEE Std. 472 Guide for Surge Withstand Capability (SWC)	• 1.25MH repetitive at 60Hz • 6μs decay to 50% • 150Ω source impedance	2.5kV Peak	Low-voltage ac circuits and control lines in.substation equipment.
ANSI/IEEE Std. C62.41-1980 Guide on Surge Voltage in Low Voltage ac Power Circuits	• .5μs - 100kHz • 1.2/50μs voltage • 8/20μs current	Dependent on location	Low-voltage ac circuits and signal lines.
Ground Fault Interrupters	• 0.5μs rise • 100kHz ring • 2nd peak ≥ 60% first • 50Ω source impedance	3kV and 6kV	High impedance circuit of ground fault interrupters.
ANSI/IEEE C62.31-1982 Test Specifications for Gas Tube Surge Protective Devices	Three requirements: • 10/1000μs current • 8/20μs current • Linear voltage ramp of 100, 500, 5000, 10,000V/μs until sparkover	 50 to 500A 5 to 20kA	 Telephone protectors
FCC Docket 19528	• Metallic — 10/560μs — 100A short-circuit current • Longitudinal — 10/160μs — 200A short-circuit current	 800V Peak 1500V Peak	Communications equipment
FCC Section 68.302 Title 47, Telecommunications	• 2/10μs — 1000A short-circuit capability	2500V Peak	Line-powered communication equipment
Rural Electrification Administration Spec. PE-60	• 10/1000μs voltage • 100V/μs rise	3σ of Protector level	Telephone electronics
Nuclear Electromagnetic Pulse (NEMP)	• Rectangular pulse 3ns to 10μs • Damped sinewave 10^1 to 10^3Hz	0.1 to 1000A 1.0 to 100A	Evaluation of components
NASA Space Shuttle	• Damped sinewave 125kHz • Unidirectional — 2/100μs — 300/600μs	E_{OC} — 50V I_{SC} — 10A E_{OC} — 50V I_{SC} — 10A E_{OC} — 0.5V I_{SC} — 5A	Space Shuttle electronics

Table 7.4 — Partial Listing of Existing or Proposed Test Waves (Cont'd)

Origin	Description		Typical Application
	Waveshapes	Amplitude	
MIL-STD-704	• Envelope specified, max. duration 50μs	600V Peak	Military aircraft power
ANSI/IEEE Std. C62.33-1982 Test Specification for Varistor Surge—Protective Devices	• 8/20μs current • 10/1000μs current	From Manufacturer's specifications	Suppresors for low voltage ac circuits, electronic equipment
IEEE Std. P465.4/FD Test Specifications for Avalanche Junction Semiconductor Surge—Protective Devices	• 8/20μs current • 10/1000μs current	From Manufacturer's specifications	Suppresors for electronic equipment
UL1449 Transient Voltage Surge Suppressors	• 1.2/50μs voltage • 8/20μs current	6kV 125A to 3kA dependent on location	Suppresors for low voltage ac circuits

A proposal also has been made to promote a transient control level concept[7] whereby a *few* selected test waves could be chosen by common agreement between users and manufacturers. The intent being that standard test waves would establish certain performance criteria for electronic circuits, without resorting to a multiplicity of test waves, each attempting to simulate a particular environment.

7.7.2 Source Impedance

The effective impedance of the circuit which introduces the transient is an extremely important parameter in designing a protective scheme. Impedance determines the energy and current-handling requirements of the protective device.

Historically, the approach to transient withstand capability was to apply a voltage wave to a device and to ascertain that no breakdown occurred. Typically, the device offered high impedance to the impulse, so that no significant current would flow (unless breakdown occurred), and the source impedance was unimportant. But if a transient suppressor is applied, especially a suppressor of the energy-absorbing type, the transient energy is then shared by the suppressor and the rest of the circuit, which can be described as the "source".

As in the case of waveshapes, various proposals have been made for standardizing source impedances. The following list summarizes the various proposals intended for ac power lines:

1. The Surge Withstand Capability (SWC) standard specified a 150Ω source.
2. The Ground Fault (UL-GFCI) standard is 50Ω source.[8]
3. The Transient Control Level (TCL) proposals of Martzloff et al[7] include a 50Ω resistor in parallel with a 50μH inductor.
4. The installation category concept of ANSI/IEEE Standard C62.41-1980 implies a range of impedances from 1 to 50Ω as the location goes from outside to inside.
5. The FCC regulation for line-connected telecommunication equipment implies a 2.5Ω source impedance.[9] However, the requirement of the FCC is aimed at ensuring a permanent "burning" of a dielectric puncture and does not necessarily imply that the actual source impedance in the real circuits is 2.5Ω.
6. Reported measurements[10] indicate the preponderance of the inductance in branch circuits. Typical values are μH per meter of conductors.

7. There is no agreement among the above proposals on a specific source impedance. Examining the numbers closer, one can observe that there is a variance between 2.5ohms to about 50ohms. Going back to ANSI/IEEE Standard C62.41-1980 — by using the OCV (open circuit voltage) and SCI (short circuit current) for the different location categories, one can calculate a source impedance.

Any practical power circuit will always have some finite impedance due to the resistance and inductance of the power line and distribution transformer. Figure 7.15 shows representations of the surge source impedance implied in the environment description of ANSI/IEEE C62.41-1980.

The impedance of industrial or commercial systems generally supplied by underground entrances, or a separate substation of relatively large kVA rating, tends to be low, and the injection of any lightning transients occurs at a remote point. This results in lower transient peaks than those that can be expected in residential circuits, but the energy involved may be, in fact, greater. Therefore, transient suppressors intended for industrial use should have greater energy-handling capability than the suppressors recommended for line-cord-powered appliances.

Clearly, the industry standards have not been able to agree on a single value of the source impedance, for several reasons. When a transient suppressor is being selected for a particular application, there is a need for engineering judgment based on a knowledge of the function, and the capability of the device.

CATEGORY A RING WAVE	6kV/200A = 30Ω
CATEGORY B RING WAVE	6kV/500A = 12Ω
CATEGORY B IMPULSE	6kV/3kA = 2Ω
CATEGORY C IMPULSE	10kV/10kA = 1Ω

Figure 7.15 — Source Impedance at Different Location Categories in Low Voltage AC Systems (up to 1000V)

Note: IEEE categories A, B & C defined on page 9-7.

7

VARISTOR TESTING

REFERENCES

1. Fisher, F.A., *"Overshoot — A Lead Effect in Varistor Characteristics,"* Report 78CRD, General Electric, Schenactady, N.Y., 1978.
2. Heller, B. and A. Veverka, *Surge Phenomena in Electrical Machine,* ILIFFE Books Ltd., London, 1968.
3. Greenwood, Allen, *Electrical Transients in Power Systems,* Wiley Interscience, New York, 1971.
4. Craggs, J.D. and J.M. Meek, *High Voltage Laboratory Techniques,* Buttersworth Scientific Publications, London, 1954.
5. Martzloff, F.D., *"Transient Control Level Test Generators,"* Report 77CRD241, General Electric, Schenectady, N.Y., 1977.
6. Test Specifications for Varistor Surge-Protective Devices, ANSI/IEEE Std. C62.33, 1982.
7. Martzloff, F.D., and F.A. Fisher, *"Transient Control Level Philosophy and Implementation — The Reasoning Behind the Philosophy,"* 77CHI224-5EMC, Proceedings of the 2nd Symposium on EMC, Montreux, June 1977.
8. *"Standard for Safety: Ground Fault Circuit Interrupters,"* UL943, Underwriters Laboratories, May 12, 1976.
9. *"Longitudinal Voltage Surge Test #3,"* Code of Federal Regulations, Section 68.302(e), Title 47, Telecommunications.
10. F.D. Martzloff, *"The Propagation and Attenuation of Surge Voltages and Surge Currents in Low-Voltage AC Circuits,"* IEEE Transactions on Power Apparatus and Systems, PAS-102, pp. 1163-1170, May 1983.

HARRIS MOV QUALITY & RELIABILITY

QUALITY STATEMENT

"Harris is committed to being a company
of the highest quality in every aspect
of its business activity"

John T. Hartley
Chairman, Harris Corporation

INTRODUCTION

Success in the metal oxide varistor (MOV) industry means more than simply meeting or exceeding the demands of today's market. It also includes anticipating and accepting the challenges of the future. It results from a process of continuing improvement and evolution, with perfection as the constant goal.

Harris Semiconductor's commitment to supply only top value varistors has made quality improvement a mandate for every person in our work force – from designer to manufacturing operator, from hourly employee to corporate executive. Price is no longer the only determinant in marketplace competition. Quality, reliability, and performance enjoy significantly increased importance as measures of value in MOVs.

Quality in varistors cannot be added on or considered after the fact. It begins with the development of capable process technology and product design. It continues in manufacturing, through effective controls at each process or step. It culminates in the delivery of products which meet or exceed the expectations of the customer.

VISION

Total Quality, every minute of every day, for everyone who depends on our performance.

CHARTER

To be the preferred supplier of high performance semiconductors for analog, digital signal processing and power applications.

Throughout the 80's the pace of change of what has been considered 'acceptable' quality has been breathtaking. It has been a transition from percentage defective, to under 100 ppm, undertaken only by those who are still in business. The forces of change have been those of customer expectation and natural selection. Harris varistors have followed a path of strong and steady continuous improvement which today results in world-class end-product quality and reliability.

The Total Quality Management principles used to create the Quality System, within which Harris varistors are made, are based on five principles. Emanating from the top of the Corporation, they are evident throughout the Semiconductor Sector, and affect the conduct of business in a profound way.

HARRIS TOTAL QUALITY MANAGEMENT PRINCIPLES

Customer Focus

Customer satisfaction is the paramount purpose of all company activities. Meeting the requirements and value expectations of our internal and external customers is the primary task of every employee.

Continuous Improvement

Our planning activities will recognize continuous improvement as a primary business objective. Our products and services, together with the processes and systems which produce them, will be world class.

Employee Involvement

We will provide an environment and related value system in which all Harris people are personally involved, individually and as team members, in establishing and achieving quality goals.

Supplier Partnerships

We will develop and maintain mutually beneficial partnerships with suppliers who share our commitment to achieving increased levels of customer satisfaction through continuing improvements in quality, service, timelines and cost.

Highest Standards of Conduct, Ethics and Integrity

We will conduct our business in strict compliance with applicable laws, rules and regulations; with honesty and integrity; and with a strong commitment to the highest standards of business ethics.

ISO 9000

Preparing for ISO 9000 certification means that a company as a whole looks at its total system; operational waste is eliminated and quality procedures are firmly put in place from the grass roots level all the way to the board room. This certification focuses on the concept of stating what you do, documenting what you do and then doing what you say. Simply put, this means it is necessary to document the operation from when raw material is purchased right through to the finished product. This quality management system begins with the management responsibility, including the policy statement and explanation. It also requires that the authority and responsibility be clearly defined for all functions. ISO 9000 assures a system approach to quality control. It represents a basic look at the business that is a very good way to view manufacturing and operations. (Figure 1)

Obtaining ISO certification really stresses the quality concepts of supplier quality, supplier partnership, and manufacturing control. The pursuit of this international certification clearly focuses on process and as a result empowers all company employees through the documentation and understanding that is necessary in becoming certified.

The IS0 9000 series of standards are generic in nature. The United States has adopted the ISO series word for word as the ANSI/ ASQC Q90 series. ISO 9000 and ISO 9004 are basically glossary documents. A company can really only be certified to ISO 9001, ISO 9002 and ISO 9003.

The Harris MOV facility has been a registered ISO 9001 company since 1989. ISO 9001 is a model for quality assurance in the design/development, production, installation and servicing. This certification requires the demonstration of a supplier's capability to design, produce, install and service a product. ISO 9001 certification requires verification by independent auditors four times a year to ensure compliance.

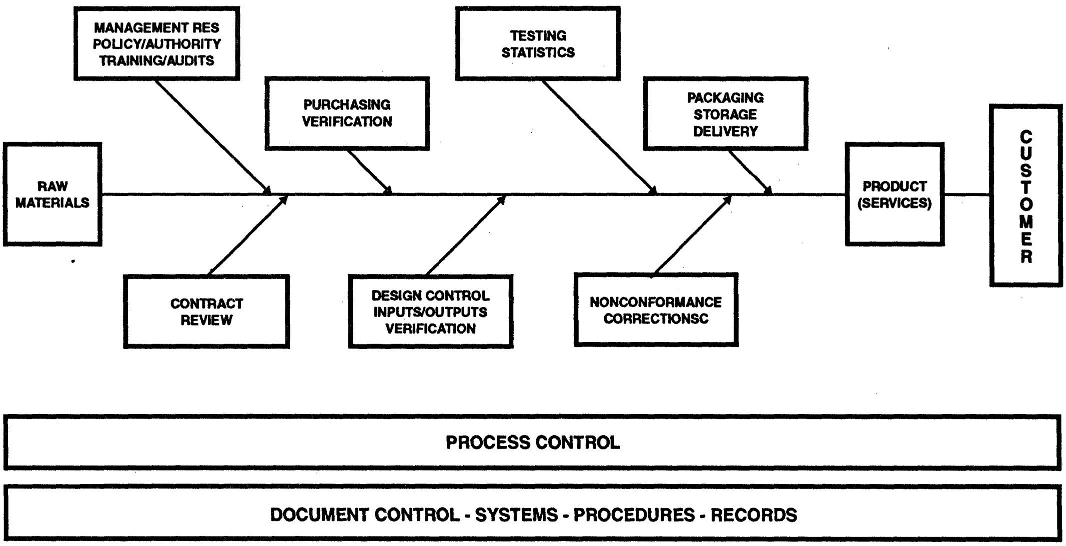


Figure 1. ISO 9000 Logic

THE ROLE OF THE QUALITY ORGANIZATION

The emphasis on building quality into the design and manufacturing processes of a product has resulted in a significant refocus of the role of the Quality organization. In addition to facilitating the development of SPC and DOX programs and working with manufacturing to establish control charts, Quality professionals are involved in the measurement of equipment capability, standardization of inspection equipment and processes, analysis of inspection data and feedback to the manufacturing areas, coordination of efforts for process and product improvement, optimization of raw materials quality, and the development of quality improvement programs with vendors.

At critical manufacturing operations, process and product quality is analyzed through random statistical sampling and product monitors. The Quality organization's role is changing from policing quality to leadership and coordination of quality programs or procedures through auditing, sampling, consulting, and managing Quality Improvement projects.

To support specific market requirements, or to ensure conformance to military or customer specifications, the Quality organization still performs many of the conventional quality functions. But, true to the philosophy that quality is everyone's job, much of the traditional on-line measurement and control of quality characteristics is where it belongs – with the people who make the product. The Quality organization is there to provide leadership and assistance in the deployment of quality techniques, and to monitor progress.

THE IMPROVEMENT PROCESS

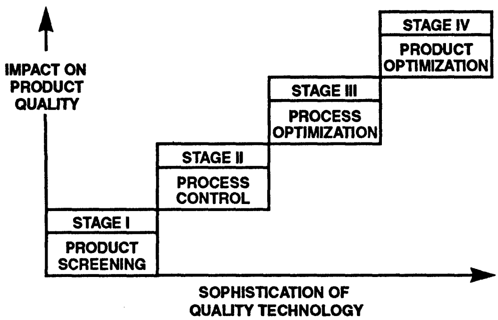


Figure 2. Stages of Statistical Quality Technology

Harris Semiconductor's quality methodology is evolving through the stages shown in Figure 2. In 1985 we embarked on a program to move beyond Stage I, and we are currently in the transition from Stage II to Stage III, as more and more of our people become involved in quality activities. The traditional "quality" tasks of screening, inspection, and testing are being replaced by more effective and efficient methods, putting new tools into the hands of all employees.

HARRIS STANDARD FLOWS

Harris Semiconductor offers a variety of standard product flows which cover the myriad of application environments our customers experience. All of these grades have one thing in common. They result from meticulous attention to quality, starting with design decisions made during product development and ending with the labeling of shipping containers for delivery to our customers.

Wherever feasible, and in accordance with good value engineering practice, the MOV user should specify device grades based on the standard Harris manufacturing flow. These are more than adequate for the overwhelming majority of applications and may be utilized quite effectively if the user engineer bases designs on the standard data sheet, military drawing or slash sheet (as applicable) electrical limits.

Some of the more important advantages gained by using standard as opposed to custom flows are as follows:

- Lower cost than the same or an equivalent flow executed on a custom basis. This results from the higher efficiency achieved with a constant product flow and the elimination of such extra cost items as special fixturing, test programs, additional handling and added documentation.

- Faster delivery. The manufacturer often can supply many items from inventory and, in any case, can establish and maintain a better product flow when there is no need to restructure process and/or test procedures.
- Increased confidence in the devices. A continuing flow of a given product permits the manufacturer to monitor trends which may bear on end-product performance or reliability and to implement corrective action, if necessary.

Reduction of risk. Since each product is processed independent of specific customer orders, the manufacturer absorbs production variability within its scheduling framework without major impact on deliveries. In a custom flow, a lot failure late in the production cycle can result in significant delays in delivery due to the required recycling time.

Despite the advantages of using standard flows, there are cases where a special or custom flow is mandatory to meet design or other requirements. In such cases, the Harris Marketing groups stand ready to discuss individual customer needs and, where indicated, to accommodate appropriate custom flows.

DESIGNING FOR MANUFACTURABILITY

Assuring quality and reliability in MOVs begins with good product and process design. This has always been a strength in Harris Semiconductor's quality approach. We have a very long lineage of high reliability, high performance products that have resulted from our commitment to design excellence. All Harris products are designed to meet the stringent quality and reliability requirements of the most demanding end equipment applications, from military and space to industrial and automotive. The application of new tools and methods has allowed us to continuously upgrade the design process.

Each new design is evaluated throughout the development cycle to validate the capability of the new product to meet the end market performance, quality, and reliability objectives.

The validation process has four major components:

1. Design simulation/optimization
2. Layout verification
3. Product demonstration
4. Reliability assessment.

CONTROLLING AND IMPROVING THE MANUFACTURING PROCESS SPC/DOX

Statistical process control (SPC) is the basis for quality control and improvement at Harris Semiconductor. Harris manufacturing people use Shewhart control charts to determine the normal variabilities in processes, materials, and products. Critical process variables are measured and control limits are plotted on the control charts. Appropriate action is taken if the charts show that an operation is outside the process control limits or indicates a trend toward the limit. These same control charts are powerful tools for use in reducing variations in processing, materials, and products.

SPC is important, but still considered only part of the solution. Processes which operate in statistical control are not always capable of meeting engineering requirements. The conventional way of dealing with this in the semiconductor industry has been to implement 100% screening or inspection steps to remove defects, but these techniques are insufficient to meet today's demands for the highest reliability and perfect quality performance.

Harris still uses screening and inspection to "grade" products and to satisfy specific customer requirements. However, inspection and screening are limited in their ability to reduce product defects to the levels expected by today's buyers. In addition, screening and inspection have an associated expense, which raises product cost.

Harris engineers are, instead, using Design of Experiments (DOX), a scientifically disciplined mechanism for evaluating and implementing improvements in product processes, materials, equipment, and facilities. These improvements are aimed at reducing the number of defects by studying the key variables controlling the process, and optimizing the procedures or design to yield the best result. This approach is a more time-consuming method of achieving quality perfection, but a better product results from the efforts, and the basic causes of product nonconformance can be eliminated.

SPC, DOX, and design for manufacturability, coupled with our 100% test flows, combine in a product assurance program that delivers the quality and reliability performance demanded for today and for the future.

MEASUREMENT

Harris facilities, engineering, manufacturing, and product assurance are supported by the Analytical Services Laboratory. Organized into chemical or microbeam analysis methodology, staff and instrumentation from both labs cooperate in fully integrated approaches necessary to complete analytical studies. The capabilities of each area are shown below.

SPECTROSCOPIC METHODS: Colorimetry, Optical Emission, Ultraviolet Visible, Fourier Transform-Infrared, Flame Atomic Absorption, Furnace Organic Carbon Analyzer, Mass Spectrometer.

CHROMATOGRAPHIC METHODS: Gas Chromatography, Ion Chromatography.

THERMAL METHODS: Differential Scanning Colorimetry, Thermogravimetric Analysis, Thermomechanical Analysis.

PHYSICAL METHODS: Profilometry, Microhardness, Rheometry.

CHEMICAL METHODS: Volumetric, Gravimetric, Specific Ion Electrodes.

ELECTRON MICROSCOPE: Transmission Electron Microscopy, Scanning Electron Microscope.

X-RAY METHODS: Energy Dispersive X-ray Analysis (SEM), Wavelength Dispersive X-ray Analysis (SEM), X-ray Fluorescence Spectrometry, X-ray Diffraction Spectrometry.

SURFACE ANALYSIS METHODS: Scanning Auger Microprobe, Electron Spectroscope/Chemical Analysis, Secondary Ion Mass Spectrometry, Ion Scattering Spectrometry, Ion Microprobe.

The department also maintains ongoing working arrangements with commercial, university, and equipment manufacturers' technical service laboratories, and can obtain any materials analysis in cases where instrumental capabilities are not available in our own facility.

FIELD RETURN PRODUCT ANALYSIS SYSTEM

The purpose of this system is to enable Harris' Field Sales and Quality operations to properly route, track and respond to our customers' needs as they relate to product analysis. The Product Failure Analysis Solution Team (PFAST) consists of the group of people who must act together to provide timely, accurate and meaningful results to customers on units returned for analysis. This team includes the salesman or applications engineer who gets the parts from the customer, the PFAST controller who coordinates the response, the Product or Test Engineering people who obtain characterization and/or test data, the analysts who failure analyze the units, and the people who provide the ultimate corrective action. It is the coordinated effort of this team, through the system described in this document that will drive the Customer responsiveness and continuous improvement that will keep Harris on the forefront of the semiconductor business.

The system and procedures define the processing of product being returned by the customer for analysis performed by Product Engineering, Reliability Failure Analysis and/or Quality Engineering. This system is designed for processing "sample" returns, not entire lot returns or lot replacements.

The philosophy is that each site analyzes its own product. This applies the local expertise to the solutions and helps toward the goal of quick turn time.

Goals: quick, accurate response, uniform deliverable (consistent quality) from each site, traceability.

The PFAST system is summarized in the following steps:

1) Customer calls the sales rep about the unit(s) to return.
2) Fill out PFAST Action Request see the PFAST form in this section. This form is all that is required to process a Field Return of samples for failure analysis. This form contains essential information necessary to perform root cause analysis. (See Figure 5).
3) The units must be packaged in a manner that prevents physical damage. Send the units and PFAST form to the appropriate PFAST controller. This location can be determined at the field sales office or rep using "look-up" tables in the PFAST document.
4) The PFAST controller will log the units and route them to ATE testing for data log.
5) Test results will be reviewed and compared to customer complaint and a decision will be made to route the failure to the appropriate analytical group.
6) The customer will be contacted with the ATE test results and interim findings on the analysis. This may relieve a line down situation or provide a rapid disposition of material. The customer contact is valuable in analytical process to insure root cause is found.

7) A report will be written and sent directly to the customer with copies to sales, rep, responsible individuals with corrective actions and to the PFAST controller so that the records will capture the closure of the cycle.

8) Each report will contain a feedback form (stamped and preaddressed) so that the PFAST team can assess their performance based on the customers assessment of quality and cycle time.

9) The PFAST team objectives are to have a report in the customers hands in 28 days, or 14 days based on agreements. Interim results are given realtime.

Failure Analysis Laboratory

The Failure Analysis Laboratory's capabilities encompass the isolation and identification of all failure modes/failure mechanisms, preparing comprehensive technical reports, and assigning appropriate corrective actions.

Failure analysis is a method of enhancing product reliability and determining corrective action. It is the final and crucial step used to isolate potential reliability problems that may have occurred during reliability stressing. Accurate analysis results are imperative to assess effective corrective actions. To ensure the integrity of the analysis, correlation of the failure mechanism to the initial electrical failure is essential.

A general failure analysis procedure has been established. The analysis procedure was designed on the premise that each step should provide information on the failure without destroying information to be obtained from subsequent steps. The exact steps for an analysis are determined as the situation dictates. (See Figures 3 and 4). Records are maintained by laboratory personnel and contain data, the failure analyst's notes, and the formal Product Analysis Report.

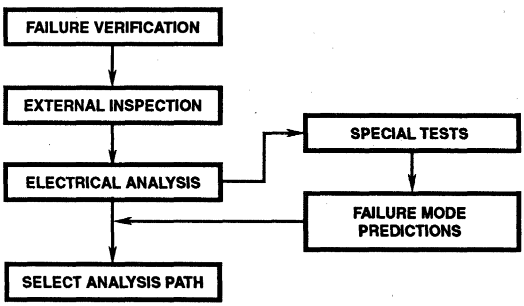


Figure 3. Non-Destructive

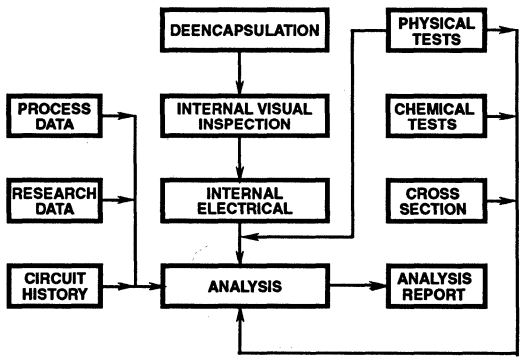


Figure 4. Destructive

HARRIS SEMICONDUCTOR

Request # ____________
Customer Analysis # ____________

PFAST ACTION REQUEST

Date: ____________

ORIGINATOR ____________	CUSTOMER ____________
LOCATION/PHONE NO. ____________	LOCATION ____________
DEVICE TYPE/PART NO. ____________	PURCHASE ORDER NO. ____________
NO. SAMPLES RETURNED ____________	QUANTITY RECEIVED ____________

THE COMPLETENESS AND TIMELY RESPONSE OF THE EVALUATION IS DIRECTLY RELATED TO THE COMPLETENESS OF THE DATA PROVIDED. PLEASE PROVIDE ALL PERTINENT DATA. ATTACH ADDITIONAL SHEETS IF NECESSARY.

TYPE OF PROBLEM

1. ☐ INCOMING INSPECTION
   - ☐ 100% SCREEN ☐ SAMPLE INSPECTION
   - NO. TESTED _____ NO. OF REJECTS _____
   - ARE RESULTS REPRESENTATIVE OF PREVIOUS LOTS? ☐ YES ☐ NO
   - ☐ BRIEF DESCRIPTION OF EVALUATION AND RESULTS ATTACHED
2. ☐ IN PROCESS/MANUFACTURING FAILURE
   - ☐ BOARD CHECKOUT ☐ SYSTEM CHECKOUT
   - ☐ FAILED ON TURN-ON
   - ☐ FAILED AFTER _____ HOURS OPERATION
   - WAS UNIT RETESTED UNDER INCOMING INSPECTION CONDITIONS? ☐ YES ☐ NO
   - ☐ BRIEF DESCRIPTION OF HOW FAILURE WAS ISOLATED TO COMPONENT ATTACHED
3. ☐ FIELD FAILURE
   - FAILED AFTER _____ HOURS OPERATION
   - ESTIMATED FAILURE RATE _____% PER 1000 HOURS
   - END USER ____________ LOCATION ____________
   - AMBIENT TEMPERATURE ____________ C
   - MIN. _____ C MAX. _____ C
   - REL. HUMIDITY ____________%
   - ☐ END USER FAILURE CORRESPONDENCE ATTACHED

ACTION REQUESTED BY CUSTOMER

SPECIFIC ACTION REQUESTED ____________

____

IMPACT OF FAILED UNITS ON CUSTOMER'S SITUATION: ____________

____

CUSTOMER CONTACTS WITH SPECIFIC KNOWLEDGE OF REJECTS

NAME ____________

POSITION ____________ PHONE ____________

DETAILS OF REJECT

(Where appropriate serialize units and specify for each)

TEST CONDITIONS RELATING TO FAILURE
- ☐ TESTER USED (MFGR/MODEL) ____________
- ☐ TEST TEMPERATURE ____________
- ☐ TEST TIME: ☐ CONTINUOUS TEST ☐ ONE SHOT (T = _____ SEC)
- ☐ DESCRIPTION OF ANY OBSERVED CONDITION TO WHICH FAILURE APPEARS SENSITIVE: ____________

1. ☐ DC FAILURES
   - ☐ OPENS ☐ SHORTS ☐ LEAKAGE ☐ STRESS
   - ☐ POWER DRAIN ☐ INPUT LEVEL ☐ OUTPUT LEVEL
   - ☐ LIST OF FORCING CONDITIONS AND MEASURED RESULTS FOR EACH PIN IS ATTACHED
   - ☐ POWER SUPPLY SEQUENCING ATTACHED
2. ☐ AC FAILURES
   - LIST FAILING CHARACTERISTICS ____________
   - ADDRESS OF FAILING LOCATION (IF APPLICABLE) ____________
   - ATTACHED:
     - ☐ LIST OF POWER SUPPLY AND DRIVER LEVELS (Include pictures of waveforms).
     - ☐ LIST OF OUTPUT LEVELS AND LOADING CONDITIONS
     - ☐ INPUT AND OUTPUT TIMING DIAGRAMS
     - ☐ DESCRIPTION OF PATTERNS USED (If not standard patterns, give very complete description including address sequence).
3. ☐ PROM PROGRAMMING FAILURES
   - ADDRESS OF FAILURES ____________
   - PROGRAMMER USED (MFG/MODEL/REV. NO.) ____________
4. ☐ PHYSICAL/ASSEMBLY RELATED FAILURES
   - ☐ SEE COMMENTS BELOW ☐ SEE ATTACHED

Additional Comments:

Figure 5. PFAST Action Request

ACCREDIATIONS

The Harris quality system meets or exceeds a wide range of standards, which indicates, together with the knowledge that each standard involves surveillance audits, up to four times per year, that the quality system is complete, and its integrity is being maintained.

CECC 00 100	The European Standard harmonization agency, CENELEC Electronic Component Committee, awarded Harris their "Certificate of Approval of Manufacture". Rej'n #M010, in 1986.
ISO 9000 Part 1	The quality system meets all of the requirements of ISO 9000 Part 1(ISO 9001).
MilQ9858A, Mil-I-45208	Harris is a Mil-R-83530 QPL supplier and conforms to these standards, as well as those referenced by them.

Certain product certifications with UL, CSA, VDE, IEC, JEDEC, DESC and the CECC QPL system also exist.

Training

The basis of a successful transition from conventional quality programs to more effective, total involvement is training. Extensive training of personnel involved in product manufacturing began in 1984 at Harris, with a comprehensive development program in statistical methods. Using the resources of the private consultants, and internally developed programs, training of over engineers, supervisors, and operators/technicians has been completed.

Nearly 200 operators, 10 supervisors, and more than 25 engineers have been trained in SPC methods, providing them with tools to improve the overall level of uniformity of Harris products. 25 engineers have received training in DOX methods: learning to evaluate changes in process operations, set up new processes, select or accept new equipment, evaluate materials, select vendors, compare two or more pieces of equipment, and compare two or more process techniques.

Over the past four years, Harris has also deployed a comprehensive training program for hourly operators and supervisors in job requirements and functional skills. All hourly manufacturing employees participate (see Table 1).

Table 1. Summary of Training Programs

COURSE	AUDIENCE	LENGTH	TOPICS COVERED
SPC	Manufacturing Operators	8 Hours	Basic Philosophy, Statistical Calculations Graphing Techniques, Pareto Charts, Control Charts
SPC	Manufacturing Supervisors	21 Hours	Basic Philosophy, Statistical Calculations Graphing Techniques, Pareto Charts, Control Charts, Testing for Inspector Agreement, Cause & Effect Diagrams, 1 & 2 Sample Methods
SPC	Engineers and Managers	48 Hours	Basic Philosophy, Graphical Methods, Control Charts, Rational Subgrouping, Variance Components, 1 & 2 Sample Methods, Pareto Charts, Cause & Effect Diagrams
DOX (Design of Experiments)	Engineers and Managers	88 Hours	Factorial Designs, Fractional Factorial Designs, Blocking Designs, Variance Components, Computer Usage, Normal Probability Plotting
Continuous Improvement Methods	Manufacturing Supervisors	12 Hours	Basic Philosophy, Pareto Analysis, Imagineering, Run Charts, Cause & Effect Diagrams, Histograms, Ideas of Control Charts
SPC-The Essentials	Department-Level Work Groups	20 Hours	Basic Philosophy, of Continuous Improvement, Imagineering Pareto Charts, Cause & Effect Diagrams, Flow Charts, Graphical Display, Control Charts, Ideas of Experiment

In addition to the already widespread use of statistics, SPC and DOX the following tools are now being widely distributed throughout the whole workforce.

- P.M. Preventative Maintenance
- T.P.M. Total Productive Maintenance
- F.M.E.A. Failure Mode Effect Analysis
- A.C.T. P.T.M. Applying Concurrent Teams to Product to Market
- A.F.E. Agreement for Excellence
- Process Characterization Skills
- Project Management
- Concurrent Engineering

RELIABILITY

The Harris Varistor is a rugged, reliable voltage transient suppressor designed to improve the reliability of electronic systems. Proper system design with this varistor, as detailed in other parts of this manual, will clamp transient voltages to a level compatible with long-life of the electronic system. To assure Harris Varistor reliability, Harris performs extensive process and quality control monitoring. This is accomplished via a combination of 100%, periodic, and lot testing. Both parametric and reliability characteristics are controlled in this manner.

For example, Harris Varistors are classified into two categories; a "line voltage" type (above 115V RMS) and a "low voltage" type (below 115V RMS). Reliability evaluation has been conducted on both types under the conditions summarized below:

Table 2. Reliability Evaluation

TEST CONDITION	STRESS
Voltage	AC Bias, DC Power
Temperature	85°C, 125°C
Energy	Pulse
Storage	125° C, 150° C
Humidity	85°C, 85% RH
Mechanical	Solderability, Terminal Strength, Drop Shock, Vibration

As improved products, processes, and test procedures evolve, the applicability of past data to reliability assessment changes. Thus, the data presented in this chapter represents a "snapshot in time" of data applicable to the Harris Varistors being manufactured now and for the anticipated future. The test data has been generated at very high stress levels, at or beyond maximum ratings, to confirm the product's ability to meet these ratings and to obtain the most information in the shortest time period. Results of ac voltage and dc power bias tests are used in the generation of models from which the expected life as a function of stress can be obtained.

A general "High Reliability" series of Harris Varistors is also available. These are specially stress-screened devices for high reliability applications.

High Reliability Harris Varistors are the latest step in increased product performance, and are available for applications requiring quality and reliability levels consistent with military test methods.

Reliability Assessment and Enhancement

At Harris Semiconductor, reliability is built into every product by emphasizing quality throughout manufacturing. This starts by ensuring the excellence of the design, layout, and manufacturing process. The quality of the raw materials and workmanship is monitored using statistical process control (SPC) to preserve the reliability of the product. The primary and ultimate goal of these efforts is to provide full performance to the product specification throughout its useful life. Product reliability is maintained through the following sources: Qualifications, In-Line Reliability Monitors, Failure Analysis.

Qualifications

Qualifications at Harris de-emphasize the sole dependence on production product which is only available late in the development cycle. The focus is primarily on the use of test vehicles to establish design ground rules for the product and the process that will eliminate any wear-out mechanisms during the useful life of the product. However, to comply with the military requirements concerning reliability, product qualifications are performed.

In-line Reliability Monitors

In-line reliability monitors provide immediate feedback to manufacturing regarding the quality of workmanship, quality of raw materials, and the ultimate reliability implications. The rudimentary implementation of this monitoring is the "First Line of Defense," which is a pass/ fail acceptance procedure based on control charts and trend analysis. The second level of monitoring is referred to as the "Early Warning System" and incorporates wafer level reliability concepts for extensive diagnostic and characterization capabilities of various components that may impact the device reliability or stability. The quick feedback from these schemes allows more accurate correlation to process steps and corrective actions.

Product/Package Reliability Monitors

Reliability of finished product is monitored extensively under a program called Matrix II, III monitor. All major technologies are monitored.

Matrix II Longer duration test, much like requalification. The sample sizes are reduced in number and frequency, yet meet or exceed the JEDEC Standard 29. Stresses Operating Life, Storage, THB, Autoclave, Temp Cycle, and Thermal Shock.

Matrix III Package specific test. Tests Solderability, Lead Fatigue, Physical Dimensions, Brand Adhesion, Flammability, and Constant Acceleration. Data from these Monitor Stress Test provides the following information:

- Routine reliability monitoring of products by technology and package styles.
- Data base for determining FIT Rates and Failures Mode trends used drive Continuous Improvement.
- Major source of reliability data for customers.
- Customers have used this data to qualify Harris products.

RELIABILITY FUNDAMENTALS

Reliability, by its nature, is a mixture of engineering and probability statistics. This combination has derived a vocabulary of terms essential for describing the reliability of a device or system. Since reliability involves a measurement of time, it is necessary to accelerate the failures which may occur. This, then, introduces terms like “activation energy” and “acceleration factor,” which are needed to relate results of stressing to normal operating conditions (see Table 3). Also, to assess product reliability requires failures. Therefore, only a statistical sample can be used to determine the model of the failure distribution for the entire population of product.

Failure Rate Calculations

Reliability data for products may be composed of several different failure mechanisms and requires careful combining of diverse failure rates into one comprehensive failure rate. Calculating the failure rate is further complicated because failure mechanisms are thermally accelerated at varying rates and thereby have differing accelerating factors. Additionally, this data is usually obtained a variety of life tests at unique stress temperatures. The equation below accounts for these considerations and then inserts a statistical factor to obtain the confidence interval for the failure rate.

$$FIT = \left(\sum_{i=1}^{B} \frac{X_i}{\sum_{j=1}^{k} TDH_J \; AF_{IJ}} \right) \times 10^9 \times M$$

B = # of distinct possible failure mechanisms

K = # of life tests being combined

X_I = # of failures for a given failure mechanism i = 1, 2, . . . B

TDG_J = Total device hours of test time (unaccelerated) for Life Testj

AF_{IJ} = Acceleration factor for appropriate failure mechanism i = 1, 2, . . . K

M = Statistical factor for calculating the upper confidence limit (M is a function of the total number of failures and an estimate of the standard deviation of the failure rates)

In the failure rate calculation, Acceleration Factors (AF_{IJ}) are used to derate the failure rate from thermally accelerated Life Test conditions to a failure rate indicative of use temperatures. Though no standards exist, a temperature of +55°C has been popular and allows some comparison of product failure rates.

Acceleration Factors

The Acceleration Factors (AF) are determined from the Arrhenius Equation. This equation is used to describe physiochemical reaction rates and is an appropriate model for expressing the thermal acceleration of semiconductor failure mechanisms.

$$AF = EXP\left[\frac{E_A}{K}\left(\frac{1}{T_{use}} - \frac{1}{T_{stress}}\right)\right]$$

AF = Acceleration Factor

E_A = Thermal Activation Energy in eV

K = Boltzmann's Constant (8.62×10^{-5} eV/°K)

Both Tuse and Tstress (in degrees Kelvin) include the internal temperature rise of the device and therefore represent the junction temperature. With the use of the Arrhenius Equation, the thermal Activation Energy (E_A) term is a major influence on the result. This term is usually empirically derived and can vary widely.

Activation Energy

To determine the Activation Energy (E_A) of a mechanism you must run at least two (preferably more) tests at different stresses (temperature and/or voltage). The stresses will provide the time to failure (Tf) for the populations which will allow the simultaneous solution for the Activation Energy by putting the experimental results into the following equations.

$$\ln (t_{f1}) = C + \frac{E_A}{KT_1} \qquad \ln (tf_2) = C + \frac{E_A}{KT_2}$$

Then, by subtracting the two equations, the Activation Energy becomes the only variable, as shown.

$\ln(t_{f1}) - \ln(t_{f2}) = E_A/k(1/T1-1/T2)$

$E_A = K^* ((\ln(t_{f1}) - \ln(t_{f2}))/(1/T1 - 1/T2))$

The Activation Energy may be estimated by graphical analysis plots. Plotting ln time and ln temperature then provides a convenient nomogram that solves (estimates) the Activation Energy.

All Harris Reliability Reports from qualifications and Group C1 (all high temperature operating life tests) will provide the data on all factors necessary to calculate and verify the reported failure rate (in FITs) using the methods outlined in this primer.

Table 3. Glossary of Terms

TERMS/DEFINITIONS	UNITS/DESCRIPTION
FAILURE RATE λ For Semiconductors, usually expressed in FITs. Represents useful life failure rate (which implies a constant failure rate). FITs are not applicable for infant mortality or wearout failure rate expressions.	FIT - Failure In Time 1 FIT - 1 failure in 10^9 device hours. Equivalent to 0.0001%/1000 hours FITs = $\frac{\text{\# Failures}}{\text{\# Devices x \# hours stress x AF}} \times 10^9 \times m$ m - Factor to establish Confidence Interval 10^9 - Establishes in terms of FITs AF - Acceleration Factor at temperature for a given failure mechanism
MTTF - Mean Time To Failure For semiconductors, MTTF is the average or mean life expectancy of a device. If an exponential distribution is assumed then the mean time to fail of the population will be when 63% of the parts have failed.	Mean Time is measured usually in hours or years. 1 Year = 8760 hours When working with a constant failure rate the MTTF can be calculated by taking the reciprocal of the failure rate. MTTF = $1/\lambda$ (exponential model) Example: =10 FITs at +55°C The MTTF is: MTTF $= 1/\lambda = 0.1 \times 10^9$ hours = 100M hours
CONFIDENCE INTERVAL (C. I.) Establishes a Confidence Interval for failure rate predictions. Usually the upper limit is most significant in expressing failure rates.	Example: "10 FITs @ a 95% C. I. @ 55°C" means *only* that you are 95% certain the FITs <10 at +55°C use conditions.

AC BIAS RELIABILITY

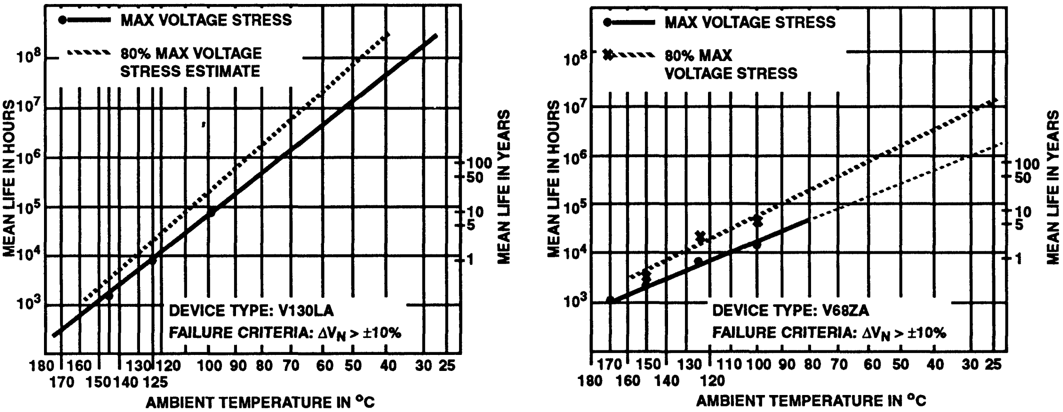
Many applications of Harris Varistors are as transient suppressors on an ac line. The varistor is connected across the ac line voltage and is biased with a constant amplitude sinusoidal voltage. If the varistor current increases with time, the power dissipation will also increase, with the ultimate possibility of thermal runaway and varistor failure. Because of this possibility, an extensive series of statistically designed tests were performed to determine the reliability of this type of varistor under ac bias combined with high levels of temperature stress. This test series contained over one million device hours of operation at temperatures up to 150°C. The average duration of testing ranged from 7000 hours at low stress to 495 hours at high stress. The definition of failure is a shift in V_N exceeding ±10%. Although this type of varistor is still functioning normally after this magnitude of shift, devices at the lower extreme of V_N tolerance will begin to dissipate more power. As previously explained, this could ultimately lead to failure. This choice of failure definition, in combination with the lower stresses found in applications, will provide life estimates adequate for most design requirements.

The results of these accelerated high level tests showed that the response of the Harris Varistor is an excellent fit to the Arrhenius model, i.e., the expected mean life is logarithmically related to the inverse of the absolute temperature. This type of Arrhenius model response is shown in Figure 6 for the line voltage and the low voltage types of varistors. As shown in the illustrations this response can be described in the following general equation.

$$A_b = A.\exp\left(\frac{E}{KT}\right)$$

Where:

A_b = Mean Time to Failure
E = Activation Energy (eV)
K = Boltzmann's Constant (8.63 x 10-5 eV/K)
T = Absolute Temperature (K)
A = Constant



(a) Line Voltage Harris Varistor

(b) Low Voltage Harris Varistor

Figure 6. Arrhenius Models of Varistor Mean Life vs Temperature

This type of statistical model also allows a prediction of the mean life that can be expected at normal operating temperatures. The usual ambients are well below the temperature levels chosen for accelerated testing. For example, a V130LA10A operating at 130V ac in a 55°C environment has a mean life, from figure 6(a), of about 9,152,824 hours (1045 years). Note at the lower bias voltage an even longer mean life is expected. Although the V13OLA and V68ZA type devices are specifically described, the results are representative of other types of Harris Varistors. Additional evidence of the conservative ratings of the Harris Varistor is the absence of systematic or repeated field failures during over fifteen years of product use.

It is noted that the mean life curves have a steep slope. This indicates a high activation energy. As operating temperature is decreased, the mean life increases rapidly. Also, as the voltage stress is lowered, life expectancy will also increase. The maximum stress curve represents the worst-case condition of a device at its lowest voltage limit operated at the maximum allowable rating. In usual practice, the median of a population of devices will operate close to the 80% voltage stress curve.

For some applications the circuit designer requires other stability information to assess the effects of time on circuit performance. Figures 7, 8, and 9 illustrate the stability of additional Harris Varistor parameters when operated at maximum rated voltage and 100°C for 10,000 hours (~1.15 years). The graphs indicate upper decile, median and lower decile response, furnishing useful design information on the stability of V_N, standby power drain, and the nonlinear exponent (a).

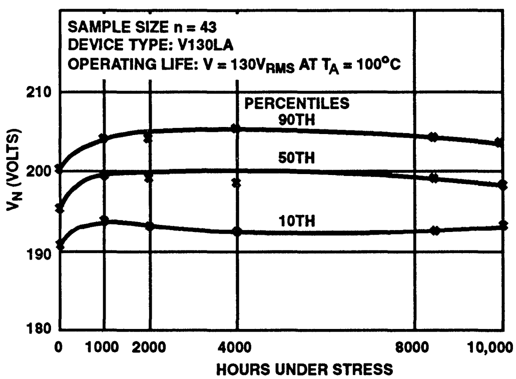


Figure 7. Voltage Stability

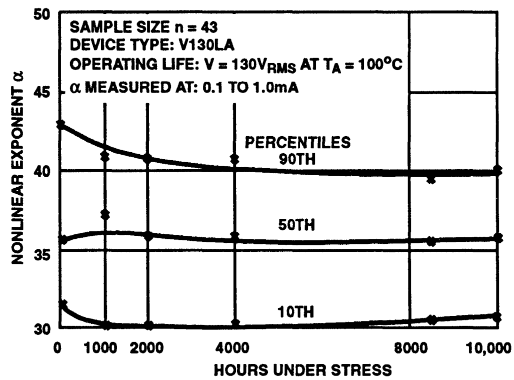


Figure 8. Nonlinear Exponent Stability

8

QUALITY AND RELIABILITY

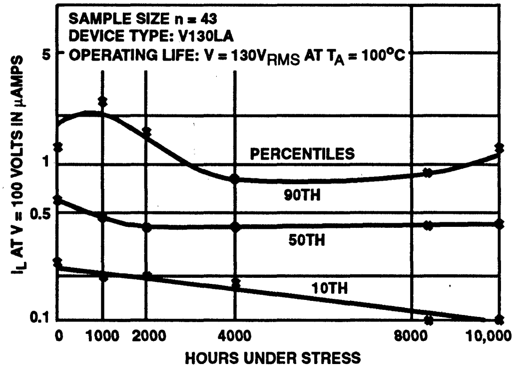


Figure 9. Leakage Stability

DC BIAS RELIABILITY

Harris Varistors are also applied across dc power lines where transient impulses may occur. This application more frequently uses the low voltage type of device. The varistor is designed to have high reliability when the dc bias voltage is below V_N, where the current is of the order of microamperes and little average power is dissipated. This operation is analogous to the ac bias condition.

Varistors can operate reliably under power dissipation from intermittent transient pulses. Ratings are provided in the specifications for this type of service. Operation is not characterized for continuous power dissipation since transient applications generally do not require this capability. The stress under continuous power dissipation can be severe and its effects are shown below for design guidance.

DC Bias Voltage Tests

The application of a constant dc voltage within device ratings to the Harris Varistor results in a low stress. A high degree of stability is desired, as in the ac voltage case, as the danger of increasing power dissipation with time exists. Life tests of Harris Varistors on constant dc voltage bias at accelerated test conditions were conducted. Measurements indicate stability is at least comparable to the results of ac voltage tests. The data is illustrated in Figure 10.

Failure criteria on this test is defined as a ±10% shift in V_N. No units exceeded this failure limit during the 3000-hour accelerated test. It should be noted that the polarity of parameter readout is the same as the polarity of the stress.

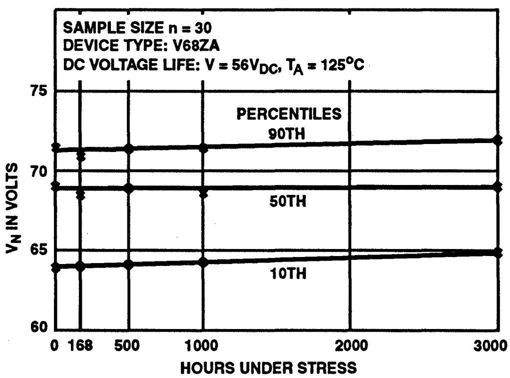


Figure 10. Accelerated DC Voltage Life

DC Power Tests

Application of a constant current to the varistor results in nearly a constant power condition. In practice, a constant power life test can be implemented easily, using a current limiting resistor and a voltage source about twice V_N for significant power levels that are above the rating. The long-term response is characterized by a continuing increase in leakage current, especially noticeable at low voltages. This is illustrated in Figure 11. This test is at a high stress compared to the normal application levels. The change in leakage causes V_N to fall gradually with time. This is illustrated by Figures 12 and 14 showing V_N vs. time.

The response to dc power life may be put into further perspective with an analysis of a series of accelerated temperature tests. These tests were run on low voltage products at stress temperatures of 55°C, 100°C, 125°C, and 145°C. The change in low voltage leakage current was selected as the most sensitive indicator of degradation and was plotted against time. The device end-of-life was defined at a leakage current limit of 100μA. The mean life results were found to be a good fit to the Arrhenius model as shown in Figure 13. The self-heating caused by device power dissipation was added to the ambient temperature of the test. This Arrhenius model can be used to predict mean life at normal operating temperatures by extrapolation. For example, at 55°C operating ambient, a mean life of 2,400,000 hours (271 years) continuous operation is projected. This is equivalent to a constant average failure rate of 0.42 Parts Per Million or 0.042% per 1,000 hours.

With judicious derating to a modest power level, the varistor may be used at continuous power dissipation on a dc line. These applications are limited and highly specialized as the device is intended primarily for intermittent, transient service.

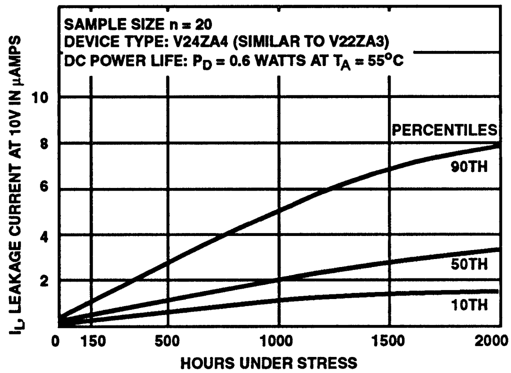
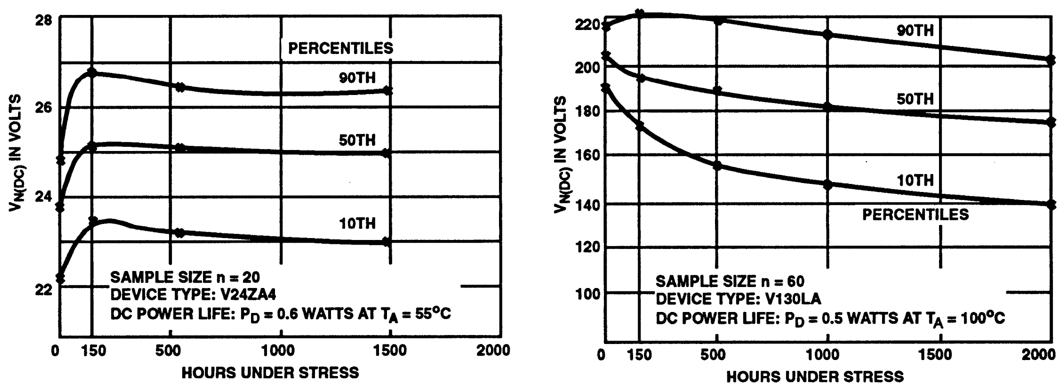


Figure 11. Accelerated DC Power Life, Leakage Current Variation for Low Voltage Varistor



(a) Low Voltage Varistor **(b) Line Voltage Varistor**

Figure 12. Accelerated DC Power Life, $V_{N(DC)}$ Variation

8

QUALITY AND RELIABILITY

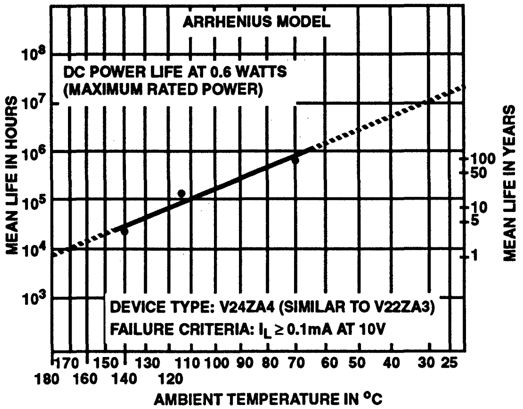
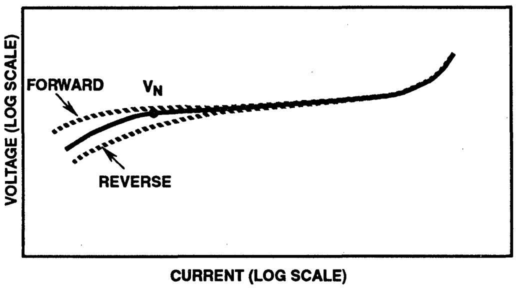


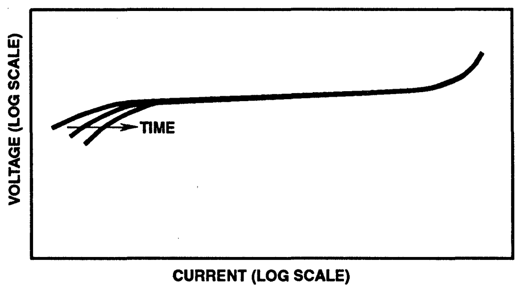
Figure 13. Reliability Model DC Power Life

PULSE ENERGY CAPABILITY

The ability of the Harris Varistor to absorb large amounts of transient energy is the key to its utility. No other suppressor device combines equal performance with the same economic advantage. Pulse energy is absorbed throughout the bulk of the device. The effect of pulse stress is to shift the low current end of the V-I characteristic as illustrated in Figure 14. With sufficient stress (unipolar) the curve will become asymmetrical as shown in Figure 14(a). Other forms of electrical or temperature stress affect the low current region as well. The general response to most stress is a shift of the low current V-I segment to the right. That is the main reason for the consistent use of the failure definition as a change in $V_{N(DC)}$ of ±10%.



(a) Unipolar Pulse and DC Stress Response

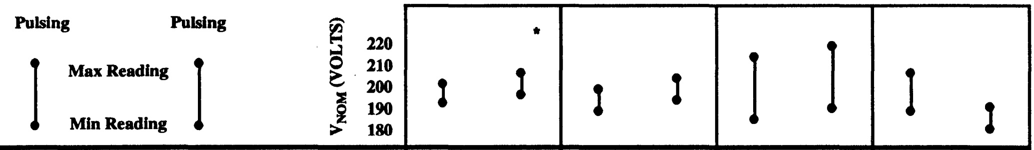


(b) General Response to Stress with Time

Figure 14. Effect of Stress with Time on V-I Characteristic

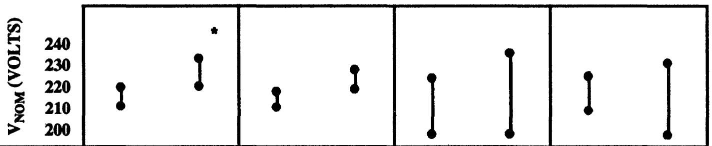
At voltages above $V_{N(dc)}$, little change is observed in response to pulsing or other types of stress. The varistor will continue to provide adequate clamping protection after stressing, up to the point of catastrophic failure. At catastrophic failure the device exhibits a short-circuit punch-through. It takes an extremely high energy pulse to cause this type of failure which is a melting of the ceramic body. More frequently, it is ac current from the power line that causes the pulse-weakened device to go into thermal runaway.

Voltage stability at several conditions of peak current, impulse duration, and temperature is summarized in Figure 15 for the V130LA2 model. These results are typical of the excellent pulse capability observed in a number of sizes of devices. No significant difference is noted between 25°C and 85°C testing.



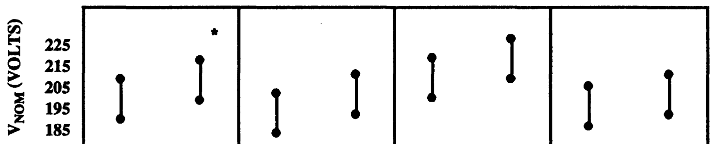
No. of Alternating Pulses	2 + 24		2 + 24		50	1
Peak Current (Amperes)	500	125	500	125	5	1200
Pulse Duration (μs)	8 x 20	8 x 20	8 x 20	8 x 20	10 x 1000	8 x 20
Test Temperature (°C)	25		85		25	85
With 130V RMS Applied	Yes		Yes		No	Yes
Catastrophic Failures vs Sample Size	0/3		0/3		0/10	0/10

Figure 15. Voltage Type: V130LA2 (7mm)



No. of Alternating Pulses	2 + 24		2 + 24		50	1
Peak Current (Amperes)	3000	750	3000	750	25	4500
Pulse Duration (μs)	8 x 20	8 x 20	8 x 20	8 x 20	10 x 1000	8 x 20
Test Temperature (°C)	25		85		25	85
With 130V RMS Applied	Yes		Yes		No	No
Catastrophic Failures vs Sample Size	0/3		0/3		0/10	0/10

Figure 16(A). Voltage Type: V130LA10A (14mm)



No. of Alternating Pulses	2 + 24		2 + 24		50	1
Peak Current (Amperes)	3000	750	3000	750	50	6500
Pulse Duration (μs)	8 x 20	8 x 20	8 x 20	8 x 20	10 x 1000	8 x 20
Test Temperature (°C)	25		85		25	85
With 130V RMS Applied	Yes		Yes		No	No
Catastrophic Failures vs Sample Size	0/3		0/3		0/10	0/10

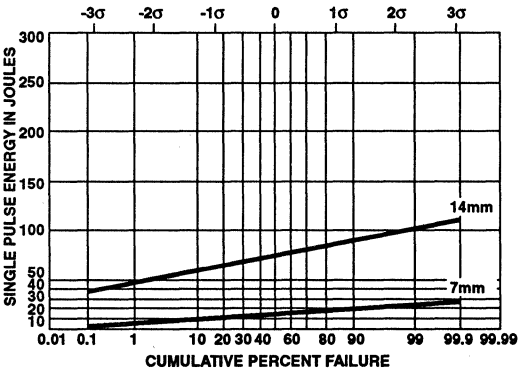
Figure 16(B). Voltage Type: V130LA20A (20mm)

* These test conditions simulate very closely those called for in the transient voltage suppression test and the duty cycle test of UL1449.

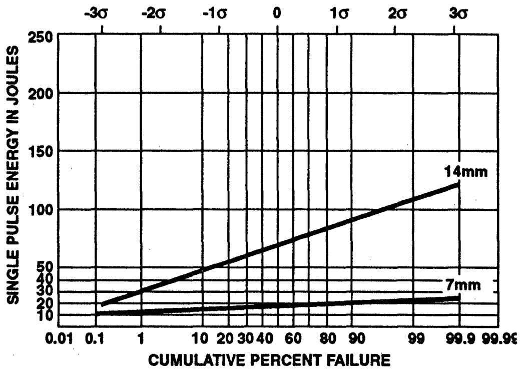
The results of pulse testing on the V130LA10A and the V130LA20A are shown in Figures 16(a) and 16(b). The results of these tests on the V130LA series are typical of the excellent response obtained on other Harris Varistors.

The first pulse test in the series simulates very closely the conditions required in the transient voltage suppression test and the duty cycle test of UL1449. The second test is identical to the first except that it was conducted at 85°C instead of 25°C. This illustrates the high temperature capability of the Harris Varistor. The ability to perform under high energy conditions is indicated by the stability of the devices when they are subjected to repeated long duration (10 x 1000μsec) pulses. The ability to perform under high current conditions is indicated by the stability of the devices when they are subjected to peak current waveforms up to and above rated conditions.

Data for defining energy withstand capability are presented in Figure 17 for the low voltage varistor (V68ZA types) and for the line voltage varistor (V130LA types). These curves show a statistical estimate of the energy to failure distribution. The distributions are shown on normal probability paper where the estimated percentiles of failure can be obtained. The surge test method uses a quasi-current source to apply a single surge of 8/20 energy stress after which the rated continuous voltage is applied, 130V RMS for line voltage units and 40V RMS for low voltage devices. The failure mode was a catastrophic punchthrough of the ceramic body occurring after the surge stress and during application of rated voltage. Thus, the immediate cause was thermal runaway on rated voltage, induced by overheating from surge energy absorption. A post-test readout of nonfailed devices showed no significant degradation of V-I characteristics.



(a) Low Voltage Varistor (Type V68ZA)

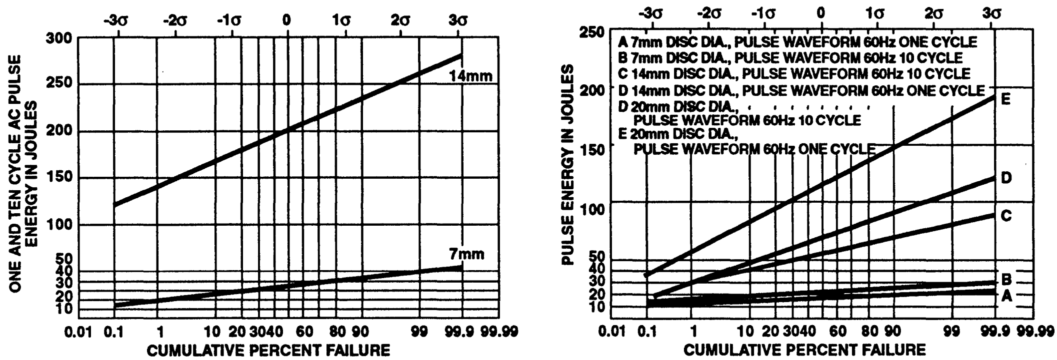


(b) Line Voltage Varistor (Type V130LA)

Figure 17. Pulse Energy Capability to Single Pulse of 8 x 20μs

The distribution curves reflect the conservatism of the Harris Varistor energy ratings. For example, 7mm and 14mm line voltage devices (V130LA types) are rated at 8J and 30J respectively. Figure 17 indicates a statistical estimate at these energy levels of 1% or less of the population failing.

Pulse energy testing also has been performed at 60Hz for single cycle and ten cycle surges. This test simulates conditions possible in ac line applications, especially in crowbar circuits and when used in conjunction with spark gaps to enhance turnoff. In these tests the pulse energy application is immediately followed by maximum rated ac voltage. The results also are presented on a normal probability graph as distributions of energy vs. percent failure. Figure 18 illustrates low voltage and line voltage varistor performance.



(a) Low Voltage Varistor (Type V68ZA)

(b) Line Voltage Varistor (Type V130LA)

Figure 18. 60Hz Surge Energy Capability

MECHANICAL RELIABILITY

The Harris Varistor is constructed by encapsulating a solid piece of ceramic in a rugged plastic body. This rugged construction, when subjected to the normal military standard mechanical tests, illustrates a conservative design philosophy. An example of the mechanical testing performed and typical results obtained, under Test Matrix III, are shown in Table 4. No significant differences are noted between various packaged devices or low voltage and line voltage types. Also note that the plastic encapsulant complies with the flammability requirement of Underwriters Laboratories Standards UL 492 and UL 1410, superseded by UL 1414.

Table 4. Mechanical Test Results on Varistor Packages

MILITARY TEST	METHOD	CONDITION	TEST (FAILURES/SAMPLE) PACKAGE TYPE			
			RADIAL LA/ZA	INDUSTRIAL DA/DB	LOW-PROFILE RADIAL RA	CONNECTOR PIN CP
Solderability	Mil-Std-750 Method 2026.2	230°C, 5 sec. dip 95% wetting	0/60	0/20	0/60	0/20
Terminal Strength	Mil-Std-750 Method 2036.3	3 bends, 90 deg. Arc 8oz. Weight	0/30	N/A	0/20	N/A
Mechanical Shock	Mil-Std-750 Method 2016.2	1500 g's, 0.5 msec 5 Pulses, X1, Y1, Z1.	0/60	0/10	0/40	0/42
Vibration	Mil-Std-750 Method 2056	20 g's, 100-2000Hz X1, Y1, Z1	0/50	0/10	0/50	0/40
Flammability	Mil-Std-202 Method 111A	15 sec. Torching 10 sec. to Flame-out	0/80	0/50	0/60	N/A
Constant Acceleration	Mil-Std-750 Method 2006	Y2, 20,000 g's Min.	0/60	N/A	0/60	0/40

ENVIRONMENTAL AND STORAGE RELIABILITY

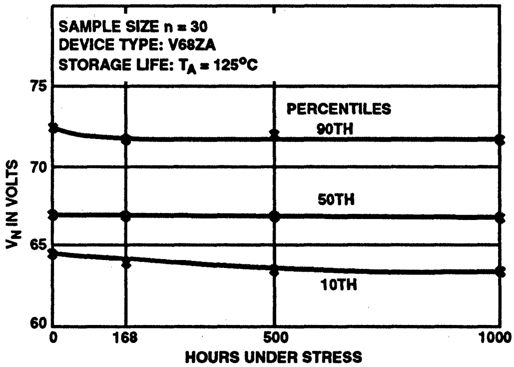
The construction of the Harris Varistor ensures stable characteristics over the wide variety of environments in which electronic equipment is operated, stored, and shipped. Testing of the Harris Varistor confirms the stability of low-voltage and line-voltage types when subjected to accelerated high-temperature storage and humidity stresses. The 1000-hour stability life data at 125°C storage conditions are shown in Figure 19 for two types of varistors.

An example of the electrical and environmental tests performed and typical results obtained, under Test Matrix II, are shown in Table 5.

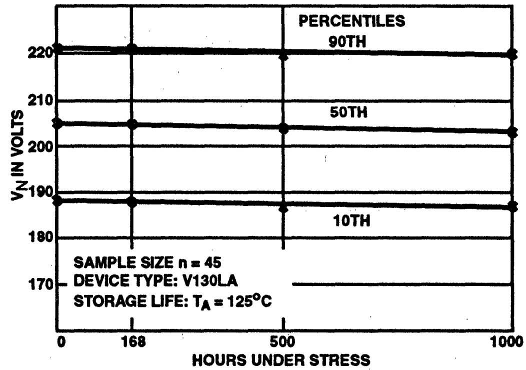
Table 5. Electrical and Environmental Test Results on Varistor Packages

MILITARY TEST	METHOD	CONDITION	TEST (FAILURES/SAMPLE) PACKAGE TYPE RADIAL LA/ZA	INDUSTRIAL DA/DB	LOW-PROFILE RADIAL RA	CONNECTOR PIN CP
Operating Life	N/A	125°C, 1000 hrs. Bias Voltage	0/200	0/50	0/150	0/100
High-Temperature Storage	Mil-Std-750 Method 1032	150°C, 1000 hrs.	0/300	0/50	0/120	0/100
Thermal Shock	Mil-Std-750 Method 1051	-55°C to +125°C 5 Cycles	0/200	0/40	0/140	0/42
Humidity	N/A	85°C; 85% R.H.	0/150	0/50	0/100	0/80

The 1000-hour stability life during accelerated humidity testing is shown in Figure 19. Note that the low voltage varistor type has been subjected to two tests sequentially. The normal 40°C, 95% R.H., 1000-hour test was followed by the very severe 85°C, 95% R.H. test. Excellent stability is observed through this combined testing sequence.



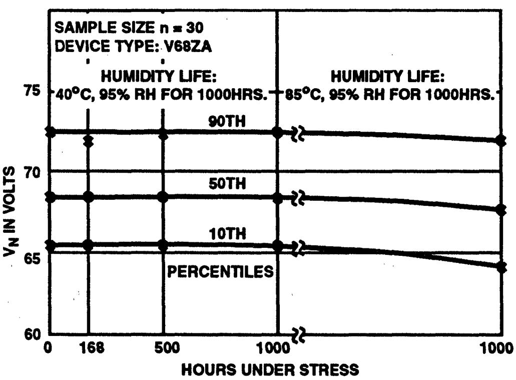
(a) Low Voltage Varistors



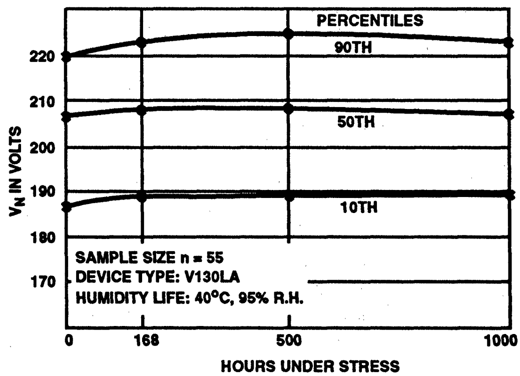
(b) Line Voltage Varistors

Figure 19. Accelerated Storage Life

The 1000-hour stability life during accelerated humidity testing is shown in Figure 20. Note that the low voltage varistor type has been subjected to two tests sequentially. The normal 40°C, 95% R.H., 1000-hour test was followed by the very severe 85° C, 95% R.H. test. Excellent stability is observed through this combined testing sequence.



(a) Low Voltage Varistors



(b) Line Voltage Varistors

Figure 20. Accelerated Humidity Life

QUALIFICATION PROCEDURES

New products are reliably introduced to market by the proper use of design techniques and strict adherence to process layout ground rules. Each design is reviewed from its conception through early production to ensure compliance to minimum failure rate standards.

New process/product qualifications have two major requirements imposed. First is a check to verify the proper use of process methodology, design techniques, and ground rules. Second is a series of stress tests designed to accelerate failure mechanisms and demonstrate its reliability.

From the earliest stages of a new product's life, the design phase, through layout, and in every step of the manufacturing process, reliability is an integral part of every Harris Semiconductor product. This kind of attention to detail "from the ground up" is the reason why our customers can expect the highest quality for any application.

RADIATION HARDNESS

For space applications, an extremely important property of a protection device is its response to imposed radiation effects.

Electron Irradiation

A Harris MOV and a silicon transient suppression diode were exposed to electron irradiation. The V-I Curves, before and after test, are shown in Figure 21.

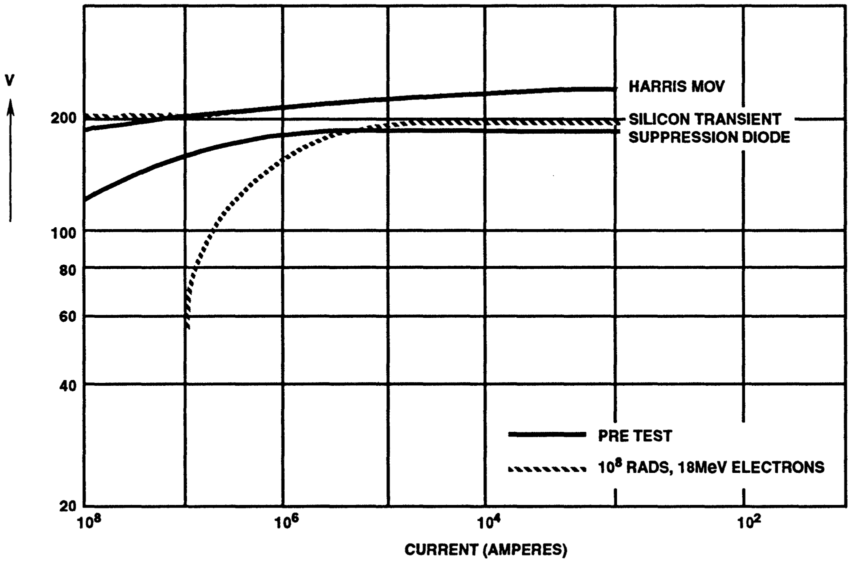


Figure 21. Radiation Sensitivity of Harris V130LA1 and Silicon Transient Suppression Diode

It is apparent that the Harris MOV was virtually unaffected, even at the extremely high dose of 10^8 rads, while the silicon transient suppression diode showed a dramatic increase in leakage current.

Neutron Effects

A second MOV-Zener comparison was made in response to neutron fluence. The selected devices were equal in area.

Figure 22 shows the clamping voltage response of the MOV and the zener to neutron irradiation to as high as 10^{15} N/cm^2. It is apparent that in contrast to the large change in the zener, the MOV is unaltered. At higher currents where the MOV's clamping voltage is again unchanged, the zener device clamping voltage increases by as much as 36%.

Counterclockwise rotation of the V-I characteristics is observed in silicon devices at high neutron irradiation levels; in other words, increasing leakage at low current levels and increasing clamping voltage at higher current levels.

The solid and open circles for a given fluence represent the high and low breakdown currents for the sample of devices tested.

8

QUALITY AND RELIABILITY

Note that there is a marked decrease in current (or energy) handling capability with increased neutron fluence.

Failure threshold of silicon semiconductor junctions is further reduced when high or rapidly increasing currents are applied. Junctions develop hot spots, which enlarge until a short occurs if current is not limited or quickly removed.

The characteristic voltage current relationship of a PN-Junction is shown in Figure 23.

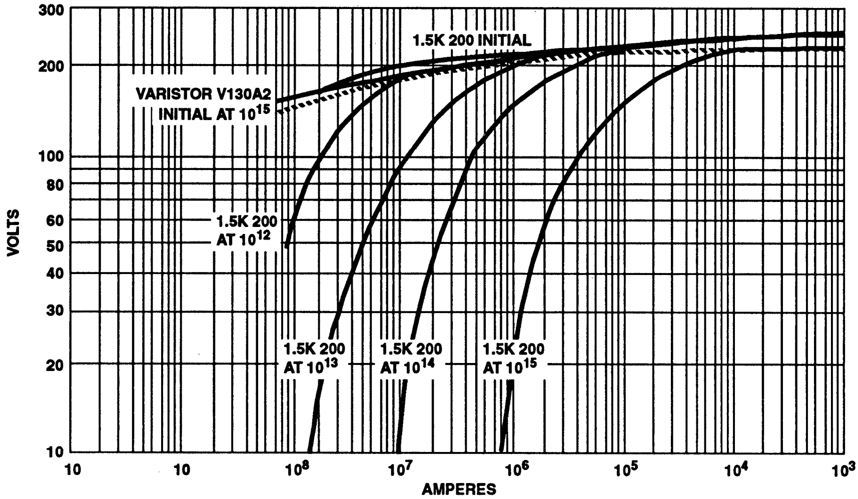


Figure 22. V-I Characteristic Response to Neutron Irradiation for MOV and Zener Diode Devices

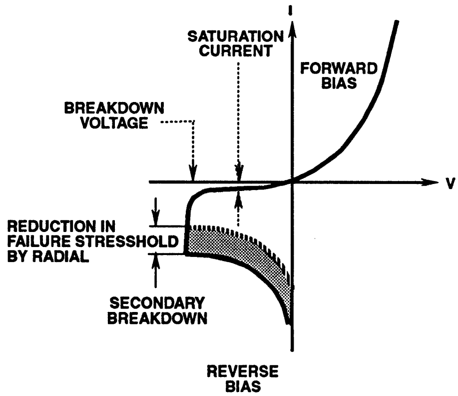


Figure 23. V-I Characteristic of PN-Junction

At low reverse voltage, the device will conduct very little current (the saturation current). At higher reverse voltage V_{BO} (breakdown voltage), the current increases rapidly as the electrons are either pulled by the electric field (Zener effect) or knocked out by other electrons (avalanching). A further increase in voltage causes the device to exhibit a negative resistance characteristic leading to secondary breakdown.

This manifests itself through the formation of hotspots, and irreversible damage occurs. This failure threshold decreases under neutron irradiation for zeners, but not for Zinc Oxide Varistors.

Gamma Radiation

Radiation damage studies were performed on type V130LA2 varistors. Emission spectra and V-I characteristics were collected before and after irradiation with 10^6 rads Co^{60} gamma radiation.

Both show no change, within experimental error, after irradiation.

SAFETY

The Harris Varistor may be used in systems where personnel safety or equipment hazard is involved. All components, including this semiconductor device, have the potential of failing or degrading in ways which could impair the proper operation of such systems. Well-known circuit techniques are available to protect against the effects of such occurrences. Examples of these techniques include fusing and self-checking. Fault analysis of any systems where safety is in question is recommended. Potential device reaction to various environmental factors has been discussed throughout this section. These and any other environmental factors should be analyzed in all circuit designs.

Should the varistor be subjected to surge currents and energy levels substantially above its maximum ratings, it may physically fail by package rupture or expulsion of material. It is recommended that protective fusing be used as described in Chapter 4. If not fused, the varistor should be located away from other components or be physically shielded from them.

Harris Varistors have received listing under an Underwriters Laboratories standard for "Across-The-Line Components", E56 529(N), and "Component — Transient Voltage Surge Suppressors", E75961(M).

If the system analysis indicates the need for a maximum degree of reliability, it is recommended that Harris be contacted for a customized reliability program.

It is stressed that most Harris Varistor parameter and reliability testing requires the use of voltages of a magnitude that is hazardous. When Harris Varistor testing is contemplated, provisions must be made to insure personnel safety.

REFERENCES

1. Erwin A. Herr, Alfred Poe and Albert Fox, *"Reliability Evaluation and Prediction for Discrete Semiconductors," EEE* Transactions on Reliability, Volume R-29 No. 3, August, 1980, GE Pub. No. 300.1.
2. A.V. Fiegenbaum, Total Quality Control, New York; McGraw Hill, Third Edition, 1983.

TVS 9

VARISTOR PRODUCTS

9.1 INTRODUCTION

Harris Varistors represent the state-of-the-art in metal-oxide varistor technology, offering high energy capabilities and excellent voltage clamping characteristics.

Harris Varistors are voltage dependent, symmetrical, metal-oxide semiconductor devices. Their characteristics enable them to protect against high transient voltage spikes (when properly selected) to meet anticipated loads. When the protected equipment or circuit encounters high voltage spikes, the varistor impedance changes from a very high standby value to a very low conducting value, thus clamping the transient voltage to a protective level. The excess energy of the incoming high voltage pulse is absorbed by the Harris Varistor, protecting voltage sensitive components against damage.

The protection afforded by the Harris Varistors not only guards expensive and voltage sensitive equipment from physical damage, but also improves functional reliability in components that can encounter temporary upset due to transient voltages of lower amplitudes.

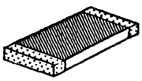
A BROAD RANGE OF PRODUCTS TO FIT EVERY TRANSIENT VOLTAGE SUPPRESSION NEED

Features

- Wide Voltage/Energy Range
- Excellent Clamp Ratio
- Fast Response Time
- Low Standby Power
- ISO 9000 Approved
- IEC Conformance
- No Follow-On Current
- DESC (QPL) Parts
- UL Recognized
- Rad Hard
- CSA Recognized
- CECC Approved

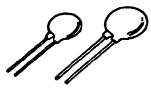
Special Products for Special Applications

CH Series Surface-Mount Varistors



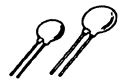
- UL/CSA Recognized
- Higher Reliability
- Save on Board Real Estate
- Increases Circuit Density

ZA Series



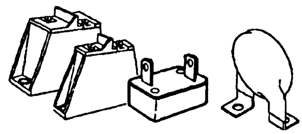
- Radial Package
- Low Voltage Operation
- UL/CSA Recognized
- CECC Approved

"C"III/LA Series



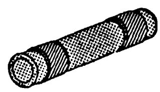
- Radial Package
- Line Voltage Operation
- UL/CSA Recognized
- CECC Approved

BB, BA, DA, DB, HA Series



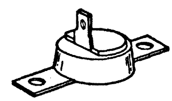
- High Energy Capability
- Rigid Terminals
- Isolated
- Low Inductance
- Improved Creep and Strike
- UL/CSA Recognized

CS/CP Series Connector Pin Varistors



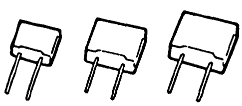
- Provides Protection in Connectors
- 22, 20 and 16 Pin Gauge Size
- Rad Hard
- Compact Size
- Solderable

PA Series



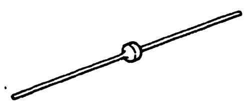
- Rigid Mountdown
- NEMA Creep and Strike Distance
- Quick Connect Terminal
- UL/CSA Recognized

RA Series



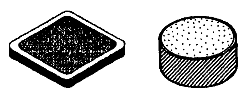
- Low Profile
- High Temperature Capability
- In-Line Leads
- Precise Seating Plane
- UL/CSA Recognized

MA Series



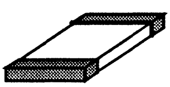
- Axial Package
- Wide Voltage
- Automatic Insertion

NA, CA Series



- Industrial Discs
- Solderable Contacts
- Edge Passivation

AUML/ML Series

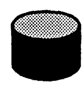


- Surface Mount
- Significant Size Reduction
- High Reliability

High-Reliability Series

- 100% Prescreened
- 100% Process Conditioning
- Meets Military Specifications
- DESC (QPL) Parts
- Rad Hard
- CECC

AS Series



- Arrester Discs

9.2 CONCEPTS OF TRANSIENT VOLTAGE PROTECTION

Varistor characteristics are measured at high current and energy levels of necessity with an impulse waveform. Shown below is the ANSI STD C62.1 waveshape, an exponentially decaying waveform representative of lightning surges, and the discharge of stored energy in reactive circuits. See Figures 9.1 and 9.2.

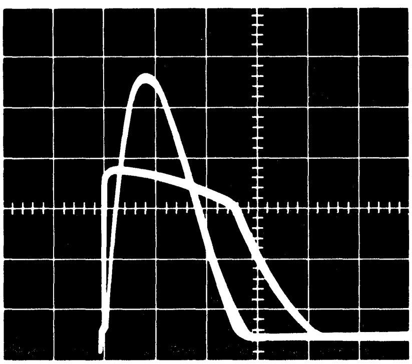
Based on industry practices, the 8/20μs current wave (8μs rise and 20μs to 50% decay of peak value) is used as a standard for current (I_{tm}) and clamp voltage (V_C) ratings shown in the specification tables and curves. Ratings for other waves of different decay times are shown specifically on the pulse life derating curves.

For the energy rating (W_{tm}), a longer duration waveform of 10/1000μs is used. This condition is more representative of the high energy surges usually experienced from inductive discharge of motors and transformers. Harris Varistors are rated for a maximum pulse energy surge that results in a varistor voltage ($V_{N(dc)}$) shift of less than ±(10% + 1V) of initial value.

To determine the energy absorbed in a varistor the following equation applies:

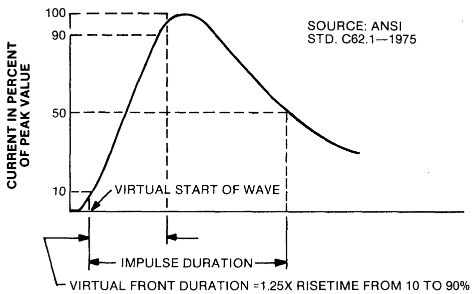
$$E = KV_C I \tau$$

where I is the peak current applied, V_C is the clamp voltage which results, τ is the pulse width and K is a constant. K values are 1.0 for a rectangular wave, 1.4 for a 10/1000μs wave and for a 8/20μs wave.



8/20μs Test Wave, I_p-315V
V130LA10A

Figure 9.1



Peak Current Test Impulse Wave
8μs front duration / 20μs impulse duration except as noted.

Figure 9.2

Note that the rated energy (W_{tm}) and the energy absorbed in a varistor may not be identical. A specimen with lower clamping voltage will absorb less energy. This effect tends to be greatest at rated peak current (I_{tm}) with an 8/20μs wave.

It is important to note, as demonstrated by the above equation, that poorer varistors must absorb higher energy levels than the better performance varistors with lower clamp voltages, yet they actually provide less over-voltage protection. For that reason, energy ratings based on an 8/20μs pulse tend to overstate varistor capability. The 10/1000μs waveform consequently gives a more realistic energy rating value.

9.3 SPEED OF RESPONSE

The measured response time of a varistor is influenced by lead configuration and length. In a typical application, the response time is shorter than the inductive lead effect. In a coaxial configuration, one could show response times of less than a few nanoseconds. See Figure 3.18 page 3-12.

Table 9.2 Term Definitions

Term	Definition
DC Voltage, $V_{m(dc)}$	Maximum allowable steady state dc applied voltage, DC standby current, I_D = 20μA typical, 200μA maximum at T_A = 25°C, except V18ZA to V36ZA 20mm size: I_D = 200µA (TYP), 3mA max and U24RA22 to V36RA22.
RMS Voltage, $V_{m(ac)}$	Maximum allowable steady state sinusoidal voltage (RMS) at 50-60Hz. If a nonsinusoidal waveform is applied, the recurrent peak voltage should be limited to $\sqrt{2} x V_{m(ac)}$.
Energy, W_{tm}	Maximum allowable energy for a single impulse of 10/1000μs current waveform. Energy rating based on a V_N shift of less than ±10%.
Peak Current, I_{tm}	Maximum allowable peak current for a single impulse of 8/20μs waveform with rated continuous voltage applied. See pulse lifetime rating curves for other conditions.
Varistor Voltage, $V_{N(dc)}$	Varistor peak terminal voltage measured with a specified current applied. For dc conditions, 1mA is applied for a duration of 20ms to 1s. For ac conditions 1mA peak 60Hz wave is applied.
Clamping Voltage, V_C	Maximum terminal voltage measured with an applied 8/20μs impulse of a given peak current. See V-I curves and table for product ratings of clamping voltage over the allowable range of peak impulse current.
Capacitance	Typical values measured at a test frequency of 1.0 MHz. Maximum capacitance can be 100% higher than the typical value measured at 1.0 MHz.

9.4 VARISTOR SAFETY PRECAUTIONS

Should the varistor be subjected to surge currents and energy levels substantially above maximum ratings, it may physically fail by package rupture or expulsion of material. It is recommended that protective fusing be used as described in Chapter 4. If not fused, the varistor should be located away from other components or be physically shielded from them.

Harris Varistor encapsulant complies with flammability requirements of Underwriters Laboratories Standard UL1414 and has a flammability rating of 94V-O.

Table 9.3 — Varistor Product Family Selection Guide

MAXIMUM STEADY-STATE APPLIED VOLTAGE

VOLTS AC RMS: 4, 10, 25, 130, 150, 250, 264, 275, 460, 660, 750, 1,000, 6,000

VOLTS DC: 3.5, 14, 35, 175, 200, 330, 365, 369, 615, 850, 970, 1,200, 7,000

PEAK CURRENT (A)	ENERGY (J)	SERIES	DISC SIZES/ PACKAGES
80 - 500	0.5 - 5.0	CP, CS SERIES	22, 20, 16 GAUGE
150 - 1000	0.2 - 25	AUML, ML, CH SERIES	5 x 8; 1206, 1210, 1812, 2220
40 - 100	0.07 - 1.7	MA SERIES	3mm
25 - 4500	0.1 - 35	ZA SERIES	5, 7, 10, 14, 20 (mm)
100 - 6500	0.4 - 160	RA SERIES	5 x 8, 10 x 16, 14 x 22 (mm)
1,200 - 9000	11 - 360	"C" III, LA SERIES	7, 10, 14, 20 (mm)
6500	70 - 250	PA SERIES	20mm
25,000 - 40,000	270 - 1,050	HA, DA/ DB SERIES	32, 40 (mm); 40mm
50,000 - 70,000	450 - 10,000	BA/ BB SERIES	60mm
20,000 - 100,000	200 - 10,000	NA, AS & CA SERIES	32, 40, 42, 52, 60 (mm); 34mm SQ.

Table 9.4

SERIES	RA	AUML, ML, CH, CP, CS	LA, ZA	MA	PA (Note 1)	DA, DB & HA	BA, BB	CA, NA	AS
Operating Ambient Temperature (w/out derating)	-55 to +125°C	-55 to +125°C	-55 to +85°C	-55 to +85°C	-55 to +85°C	-55 to +85°C	-55 to +85°C	-55 to +85°C	-55 to +60°C
Storage Temperature	-55 to +150°C	-55 to +150°C	-55 to +125°C	-55 to +125°C	-55 to +125°C	-55 to +125°C	-55 to +125°C	-55 to +125°C	-55 to +80°C
HiPot Encapsulation (Note 2)	2500	NA	2500	1000	NA	5000	5000	NA	NA
Voltage Temperature Coefficient (V_C at Specified Test Current)	<.01%/°C	<.01%/°C	<.01%/°C	<.01%/°C	<.01%/°C	<.01%/°C	<.01%/°C	<.01%/°C	<.01%/°C
Insulation Resistance (MΩ)	>1000	NA	>1000	>1000	NA	>1000	>1000	NA	NA

NOTES:

1. Base Plate Temperature.
   Solderability: Per MIL STD 202, Method 208C.
2. Dielectric withstand per MIL STD 202, Method 301, 2500 Vdc, for 1 minute.

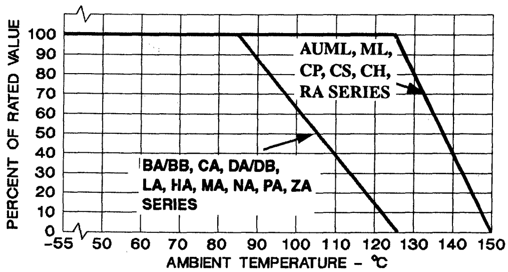


Figure 9.3 — Current Power, Energy Rating vs. Temperature

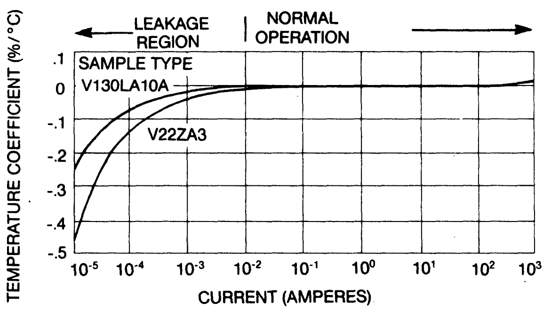


Figure 9.4 — Typical Temperature Coefficient of Voltage Versus Current, 14mm Size, -55 to +125°C

9.5 HOW TO SELECT A HARRIS VARISTOR

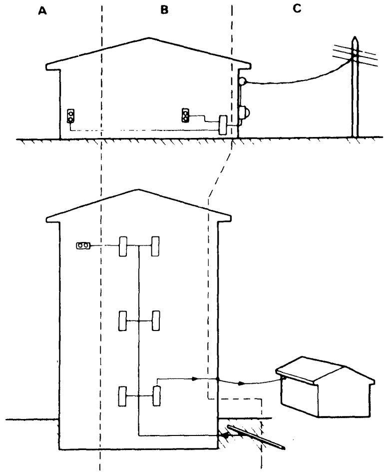
To select the correct Harris Varistor for a specific application, determine the following information:

1. What is system RMS or dc voltage?
   A. Phase to Ground ________________.
   B. Phase to Phase ________________.
2. How will the Harris Varistor be connected?
   A. Phase to Ground ________________.
   B. Phase to Phase ________________.
3. Calculate required varistor voltage at 10-25% above system RMS or dc voltage.
   A. $V_{Phase\ to\ Ground}$ x 1.1 = ________________.
   B. $V_{Phase\ to\ Phase}$ x 1.1 = ________________.

   The maximum continuous RMS or dc varistor voltage should be equal to or greater than either 3A or 3B. This maximum continuous RMS or dc varistor voltage can be found in the rating and characteristic tables $V_{m(ac)}$ or $V_{m(dc)}$.
4. Selecting the correct varistor voltage is reasonably straightforward, but selecting the proper energy rating is more difficult and normally presents a certain degree of uncertainty. Choosing the highest energy rating available is expedient, but usually not cost effective.

   As economic considerations enter the selection process, the worst case size of the transient, the frequency of occurrence, and the life expectancy of the equipment to be protected cannot be ignored.

   ANSI/IEEE C62.41-1980 addresses these considerations, and the reprint in Chapter 1 gives the background and the environment description of this standard. From ANSI/IEEE C62.41-1980 it becomes evident that the equipment or component to be protected is not as important as the location in the electrical system. ANSI/IEEE C62.41-1980 divides the electrical distribution system into 3 location categories. Figure 9.5 defines these location categories in detail.



A. Outlets and Long Branch Circuits
All outlets at more than 10m (30 ft) from Category B with wires #14-10
All outlets at more than 20m (60 ft) from Category C with wires #14-10

B. Major Feeders and Short Branch Circuits
Distribution panel devices
Bus and feeder systems in industrial plants
Heavy appliance outlets with "short" connections to the service entrance
Lighting systems in commercial buildings

C. Outside and Service Entrance
Service drop from pole to building entrance
Run between meter and distribution panel
Overhead line to detached buildings
Underground lines to well pumps

Figure 9.5 — Location Categories

Table 9.5 — Surge Voltages and Currents Deemed to Represent the Indoor Environment and Recommended for Use in Designing Protective Systems

Location Category Center	Comparable To IEC 664 Category	Impulse		Type of Specimen or Load Circuit	Energy (Joules) Deposited in a Suppressor(3) With Clamping Voltage of	
		Waveform	Medium Exposure Amplitude		500V	1000V
					(120V System)	(240V System)
A. Long branch circuits and outlets	II	0.5μs - 100kHz	6kV	High impedance(1)	—	—
			200A	Low impedance(2)	0.8	1.6
B. Major feeders short branch circuits, and load center	III	1.2/50μs	6kV	High impedance(1)	—	—
		8/20μs	3kA	Low impedance(2)	40	80
		0.5μs - 100kHz	6kV	High impedance(1)	—	—
			500A	Low impedance(2)	2	4

Notes: (1) For high-impedance test specimens or load circuits, the voltage shown represents the surge voltage. In making simulation tests, use that value for the open-circuit voltage of the test generator.
(2) For low-impedance test specimens or load circuits, the current shown represents the discharge current of the surge (not the short-circuit current of the power system). In making simulation tests, use that current for the short-circuit current of the test generator.
(3) Other suppressors which have different clamping voltages would receive different energy levels.

Table 9.5 shows the open-circuit voltage and short-circuit current of the transients which can be expected at location A and B.

The Harris Varistor selected must first survive the worst case transient (see "Medium Exposure Amplitude" in Table 9.5) and, secondly, clamp the maximum open-circuit voltages to levels which will not damage equipment or components in the system to be protected.

5. Select proper location category, A or B.
6. Determine worst case transient current and voltage from Table 9.5.

7. Knowing the maximum continuous RMS or dc varistor voltage (from 3), determine maximum clamping voltage from V-I curve for the device selected using the worst case transient current found in 6.
8. Does this clamping voltage provide the required protection level? If not, repeat Step 7 using a higher energy-rated device. If this process proves to be ineffective, consult your local Harris sales office for assistance.
9. In many cases the source of the transient is known. The transient energy can be calculated, and maximum clamping voltage can be determined from the V-I characteristic since the maximum pulse current or source impedance is known. Examples of these calculations can be found in chapter 4.

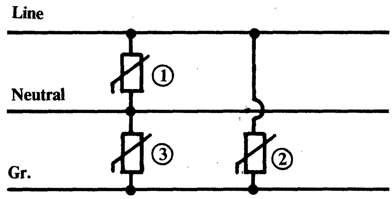
9.6 HOW TO CONNECT A HARRIS VARISTOR

Transient suppressors can be exposed to high currents for short durations in the nanoseconds to millisecond time frame.

Harris Varistors are connected in parallel to the load, and any voltage drop in the leads to the varistor will reduce its effectiveness. Best results are obtained by using short leads that are close together to reduce induced voltages and a low ohmic resistance to reduce I • R drops.

9.7 ELECTRICAL CONNECTIONS

9.7.1 Single Phase:

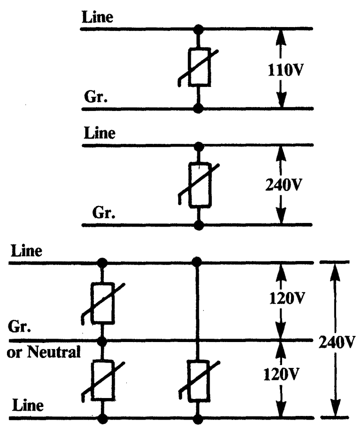


This is the most complete protection one can select, but in many cases only Varistor 1 or Varistor 1 and 2 are selected.

Single Phase 2 Wire 110V

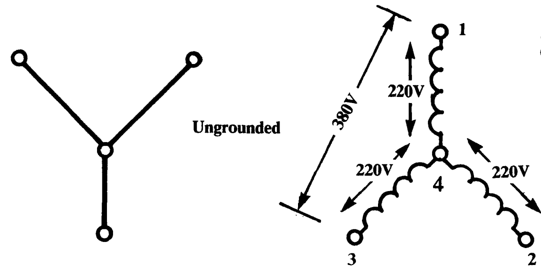
Single Phase 2 Wire 240V

Single Phase 3 Wire 120/240V



9.7.2 3 Phase:

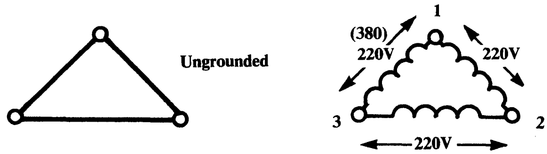
3 Phase 220/380V



Suppressor Connection

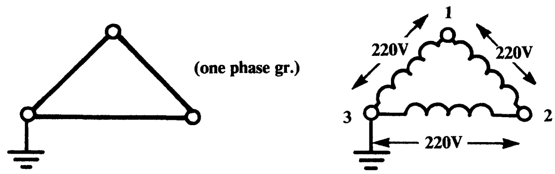
1-4
2-4
3-4

3 Phase 220V or 380V



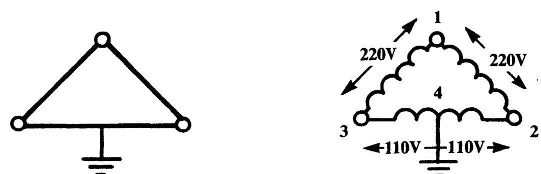
1-2
2-3
3-1

3 Phase 220V



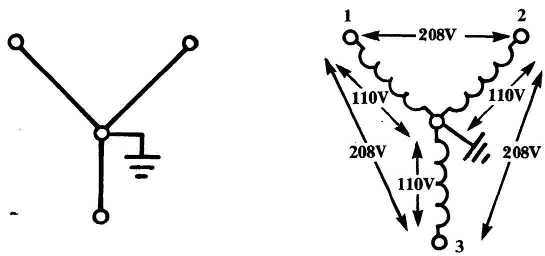
1-2
2-3
1-3

3 Phase 220V



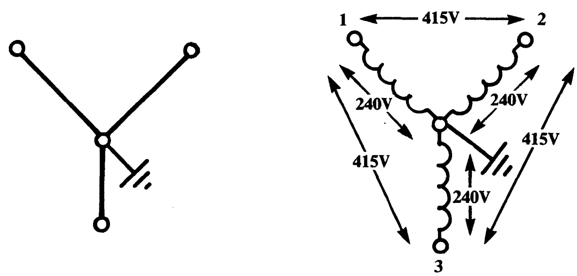
1-3
1-2
2-4 } Lower Voltage
3-4

3 Phase 120/208V
(4 Wire)
(If only 3 suppressor use 1-Gr, 2-Gr, 3-Gr)



1-2
1-3
3-2
1-Gr.
2-Gr.
3-Gr.

3 Phase 240/415V
(If only 3 suppressor use 1-Gr, 2-GR, 3-Gr)



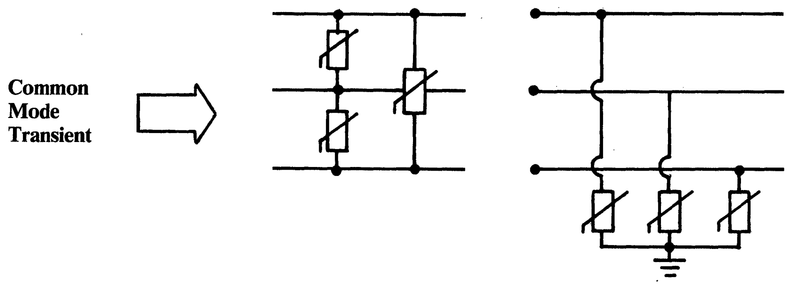
1-2
1-3
3-2
1-Gr.
2-Gr.
3-Gr.

For higher voltages use same connections, but select varistors for the appropriate voltage rating.

9.7.3 DC Applications:

DC applications require connection between plus and minus or plus and ground and minus and ground.

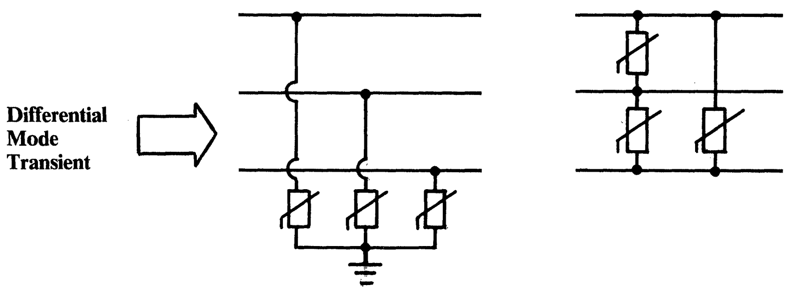
For example, if a transient towards ground exists on all 3 phases (common mode transients) only transient suppressors connected phase to ground would absorb energy. Transient suppressors connected phase to phase would do absolutely nothing.



a) Incorrect b) Correct

Figure 9.6 — Common Mode Transient and Correct Solution

On the other hand if a differential mode of transient (phase to phase) exists then transient suppressors connected phase to phase would be the correct solution.



a) Incorrect b) Correct

Figure 9.7 — Differential Mode Transient and Correct Solution

This is just a selection of some of the more important variations in connecting transient suppressors.

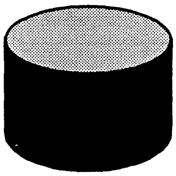
The logical approach is to connect the transient suppressor between the points of the potential difference created by the transient. The suppressor will then equalize or reduce these potentials to lower and harmless levels.

HARRIS SEMICONDUCTOR

AS Series

High Energy Metal-Oxide Varistor for Arrester Applications

August 1993



AS SERIES

Features

- Provided in Disc Form for Unique Packaging by Customer
- Electrode Finish Enables Pressure Contact for Stacking Application
- Available Disc Sizes: 32mm, 42mm, 52mm and 60mm Diameter
- No Follow Current
- Large Surge Current Capability
- Designed for Lightning Protection of Distribution Transformers

Description

AS series arresters are designed for protection from lightning and switching surges in high-power distribution equipment.

Discs are designed to provide high-energy handling capability and long term stability in stressful applications.

Typical applications include porcelain, polymeric, under oil, and metal-clad arresters.

Applications

- **Arrester Discs should be stored in a moisture free environment at all times**
- **Mechanical handling should be avoided to prevent chipping of edges**

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	AS SERIES	UNITS
Rated Voltage:		
AC Voltage Range	3.00 to 6.00	KV
Steady State Applied Voltage:		
AC Voltage (MCOV)	2.55 to 5.10	KV
Transient:		
Peak Pulse Current (I_{TM}) for 4/10 µs Current Wave	65 to 100	KA
Single-Pulse Energy Rating for 2ms Current Wave	2.6 to 10	KJ
Operating Ambient Temperature (T_A)	60	°C

9 VARISTOR PRODUCTS

File Number 2492.2

Device Ratings and Characteristics

MODEL NUMBER	PART SIZE	RATED VOLTAGE	MAXIMUM RATINGS (+60°C)			CHARACTERISTICS (+25°C)	
			CONTINUOUS	TRANSIENT		MAXIMUM DISCHARGE VOLTAGE (V_C) AT TEST CURRENT (I_P) (8/20μs)	
			RMS VOLTAGE	ENERGY (2ms)	PEAK CURRENT (4/10μs)		
			MCOV	W_{TM}	I_{TM}	V_C	I_P
	(mm)	(KV)	(KV)	(KJ)	(KA)	(KV)	(KA)
V452AS32	32	4.50	3.83	3.2	65	14.3	5
V502AS32	32	5.00	4.25	3.5	65	16.0	5
V602AS32	32	6.00	5.10	3.50	65	19.0	5
V452AS42	42	4.50	3.83	5.4	100	15.0	10
V502AS42	42	5.00	4.25	6.00	100	16.7	10
V602AS42	42	6.00	5.10	6.00	100	20.0	10
V452AS52	52	4.50	3.83	7.50	100	14.3	10
V502AS52	52	5.00	4.25	8.20	100	16.0	10
V602AS52	52	6.00	5.10	9.50	100	19.0	10
V302AS60	60	3.00	2.55	8.00	100	9.0	10
V332AS60	60	3.30	2.81	8.50	100	10.0	10
V402AS60	60	4.00	3.40	10.00	100	12.0	10

Other Electrical Ratings, Per unit of Rated Voltage (T_A = 60°C Maximum):

System Line to Neutral Maximum. 0.60

Maximum System Line to Line Voltage 1.00

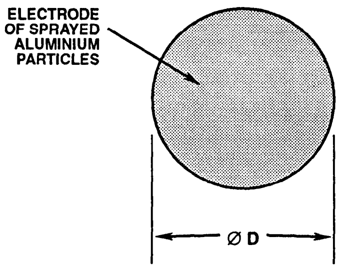
Maximum Temporary Overvoltage, duration:

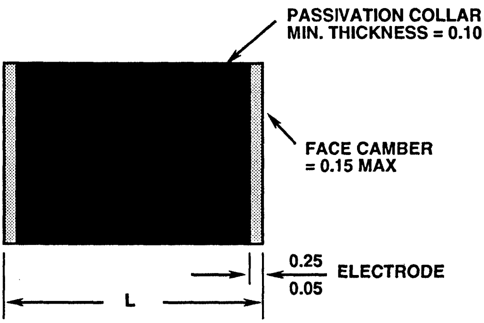
- 1800s 1.05
- 10s 1.15
- 0.1s 1.25

Discharge Current, 8/20 μs Wave, 20 Discharges, 50s to 60s apart:

- 32 size. 5KA
- 42 size. 10KA
- 52 size. 10KA
- 60 size. 10/20KA

Packaging





Dimensions in Millimeters

PART SIZE	DISC DIAMETER (Ø D)
AS32	31.75 ± 0.75
AS42	41.25 ± 0.75
AS52	52.50 ± 0.75
AS60	60.75 ±1.25

VOLTAGE FAMILY	LENGTH OF ARRESTER (L)
V302	25.40 ± 0.75
V332	28.00 ± 0.75
V402	33.75 ± 0.75
V452	39 ± 1.00
V502	43 ± 1.00
V602	43 ± 1.00

Dimensions are in millimeters.

9

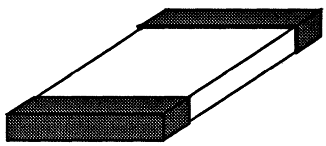
VARISTOR PRODUCTS

HARRIS SEMICONDUCTOR

Automotive AUML Series

Multilayer Transient Surface Mount Surge Suppressors

August 1993



AUML SERIES

Features

- Leadless Chip form Surface Mount
- Zero Lead Inductance
- Variety of Energy Ratings Available; (1210, 1812 and 2220 Sizes)
- 125°C Continuous Operating Temperature
- Load Dump Energy Handling Capability per SAE Specification J1113
- Low Profile, Compact Chip Size
- Inherently Bidirectional
- No Plastic or Epoxy Packaging Guarantees Better than 94V-0 Flammability Rating

Description

The Automotive multilayer (AUML) series of transient surge suppressors was specifically designed to protect the sensitive electronic equipment of an automobile, from destructive transient voltages. The most common transient conditions result either from a large energy discharge or a steady state overvoltage. Almost all the electronic systems in the automobile, e.g. antilock brake systems, direct ignition systems, airbag control systems, wiper motors, etc., are susceptible to damage from voltage transients and thus require protection. The AUML transient suppressors have temperature independent protection characteristics and afford protection from -55°C to +125°C. Multilayer suppressors are designed to fail short when overstressed and, thus protect the associated equipment. The AUML suppressor is manufactured from semiconducting ceramics which offer rugged protection, excellent transient energy absorption and increased internal heat dissipation in an exceedingly small package. The devices are in chip form, eliminating lead inductance and guaranteeing the fastest speed of response to transient surges. The AUML surge suppressors require significantly smaller space envelopes and land pads than traditional silicon TVS diodes or surface mount metal oxide varistors (MOVs), thus allowing designers to reduce size and weight while increasing system reliability.

Absolute Maximum Ratings For ratings of individual members of a series, see Device Ratings and Characteristics chart

	AUML SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
DC Voltage Range ($V_{M(DC)}$)	16	V
Transient:		
Load Dump Energy, (W_{LD})	3.0 to 25	J
Jump Start Capability (5 minutes), (V_{JUMP})	24.5	V
Operating Ambient Temperature Range (T_A)	-55 to +125	°C
Storage Temperature Range (T_{STG})	-55 to +150	°C
Temperature Coefficient (αv) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

Device Ratings and Characteristics

MODEL NUMBER	MAXIMUM RATINGS (125°C)			CHARACTERISTICS (25°C)				
	MAXIMUM CONTINUOUS DC VOLTAGE	JUMP START VOLTAGE (5 MIN)	LOAD DUMP ENERGY (10 PULSES)	NOMINAL VARISTOR VOLTAGE AT 10mA DC TEST CURRENT		MAXIMUM STANDBY LEAKAGE (AT 13V DC)	MAXIMUM CLAMPING VOLTAGE (V_C) AT TEST CURRENT (8/20μs)	
	$V_{M(DC)}$	V_{JUMP}	W_{LD}	$V_{N(DC)}$ MIN	$V_{N(DC)}$ MAX	I_L	V_C	I_P
	(V)	(V)	(J)	(V)	(V)	(μA)	(V)	(A)
V18AUMLA1210	16	24.5	3	23	32	50	40	1.5
V18AUMLA1812	16	24.5	6	23	32	100	40	5
V18AUMLA2220	16	24.5	25	23	32	200	40	40

NOTES:

1. Average power dissipation of transients not to exceed 0.15, 0.3 and 1 watt for model sizes 1210, 1812 and 2220 respectively.
2. Load dump energy rating (into the suppressor) of a voltage transient with a time constant of 115 milliseconds to 230 milliseconds.
3. Thermal shock capability per Mil-Std-750, Method 1051: -55°C to +125°C, 5 minutes at 25°C, 25 Cycles: 15 minutes at each extreme.
4. For application specific requirements, please contact Harris sales office.

Power Dissipation Requirements

Transients in a suppressor may generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore is not a necessary requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1.

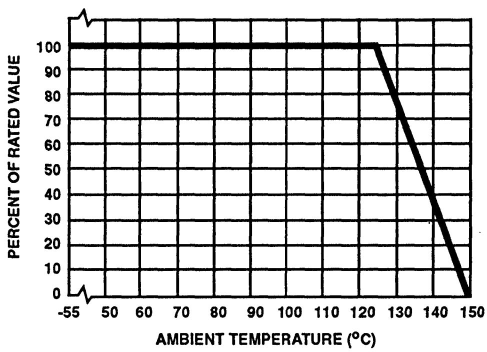
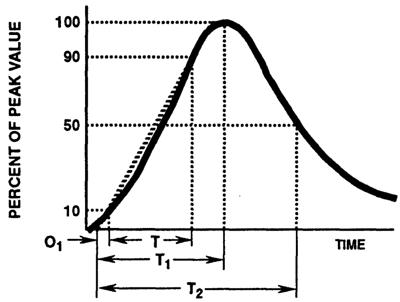


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = VIRTUAL ORIGIN OF WAVE
T = TIME FROM 10% TO 90% OF PEAK
T_1 = VIRTUAL FRONT TIME = 1.25 x t
T_2 = VIRTUAL TIME TO HALF VALUE (IMPULSE DURATION)

EXAMPLE:
FOR AN 8/20μs CURRENT WAVEFORM:
8μs = T_1 = VIRTUAL FRONT TIME
20μs = T_2 = VIRTUAL TIME TO HALF VALUE

FIGURE 2. PEAK PULSE CURRENT WAVEFORM

9

VARISTOR PRODUCTS

Maximum V-I Characteristic Curve

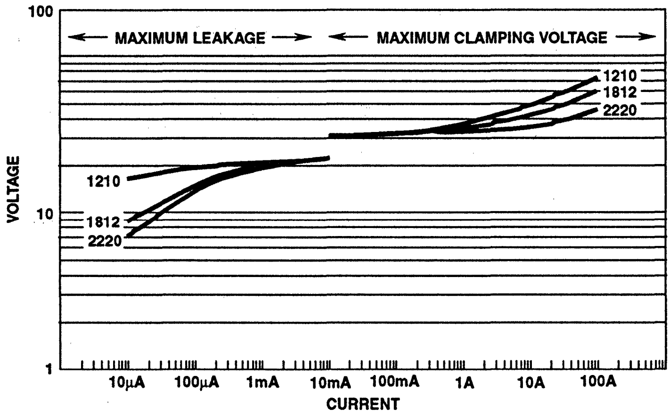


FIGURE 3. WORST CASE LEAKAGE CURRENT/CLAMPING VOLTAGE CURVE FOR AUML SERIES

Soldering Recommendations

The principal techniques used for the soldering of components in surface mount technology are Infra Red (IR) Reflow, Vapour Phase Reflow and Wave Soldering. When wave soldering, the AUML suppressor is attached to the substrate by means of an adhesive. The assembly is then placed on a conveyor and run through the soldering process. With IR and Vapour Phase reflow the device is placed in a solder paste on the substrate. As the solder paste is heated it reflows, and solders the unit to the board.

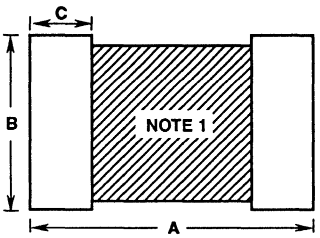
With the AUML suppressor, the recommended solder is a 62/36/2 (Sn/Pb/Ag) silver solder paste. While this configuration is best, a 60/40 (Sn/Pb) or a 63/37 (Sn/Pb) solder paste can also be used. In soldering applications, the AUML suppressor is held at elevated temperatures for a relatively long period of time, with the wave soldering operation the most strenuous of the processes. To avoid the possibility of generating stresses due to thermal shock, a preheat stage in the soldering process is recommended, and the peak temperature of the solder process should be rigidly controlled.

When using a reflow process, care should be taken to ensure that the AUML chip is not subjected to a thermal gradient steeper than 4 degrees per second; the ideal gradient being 2 degrees per second. During the soldering process, preheating to within 100 degrees of the solders peak temperature is essential to minimize thermal shock. Examples of the soldering conditions for the AUML series of suppressors are given in the table below.

Once the soldering process has been completed, it is still necessary to ensure that any further thermal shocks are avoided. One possible cause of thermal shock is hot printed circuit boards being removed from the solder process and subjected to cleaning solvents at room temperature. The boards must be allowed to cool to less than 50 degree Celsius before cleaning.

SOLDERING OPERATION	TIME (SECONDS)	PEAK TEMPERATURE (°C)
IR Reflow	5 - 10	220
Vapour Phase Reflow	5 - 10	222
Wave Solder	3 - 5	260

Recommended Pad Outline



NOTE: Avoid metal runs in this area.

SYMBOL	CHIP SIZE					
	1210		1812		2220	
	IN	MM	IN	MM	IN	MM
A	0.219	5.51	0.272	6.91	0.315	8.00
B	0.147	3.73	0.172	4.36	0.240	6.19
C	0.073	1.85	0.073	1.85	0.073	1.85

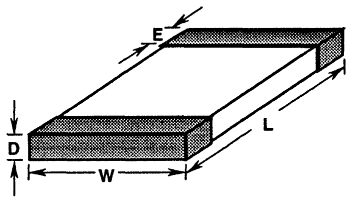
Soldering Recommendations

Material - 62/36/2 Sn/Pb/Ag or equivalent

Temperature - 230°C, 5 seconds max

Flux - Non activated

Packaging



SYMBOL	CHIP SIZE					
	1210		1812		2220	
	IN	MM	IN	MM	IN	MM
D MAX	0.070	1.80	0.07	1.8	0.118	3.00
E	0.02 ±0.01	0.50 ±0.25	0.02 ±0.01	0.5 ±0.25	0.03 ±0.01	0.75 ±0.25
L	0.125 ±0.012	3.20 ±0.30	0.18 ±0.014	4.5 ±0.35	0.225 ±0.016	5.7 ±0.4
W	0.10 ±0.012	2.54 ±0.30	0.125 ±0.012	3.2 ±0.30	0.197 ±0.016	5 ±0.4

Load Dump Energy Capability

A Load dump transient occurs when the alternator load in the automobile is abruptly reduced. The worst case scenario of this transient occurs when the battery is disconnected while operating at full rated load. There are a number of different load dump specifications in existence in the automotive industry, with the most common one being that recommended by the society of automotive engineers, specification #SAE J1113. Because of the diversity of these load dump specifications Harris defines the load dump energy capability of the AUML suppressor range as that energy dissipated by the device itself, independent of the test circuit setup. The resultant load dump energy handling capability serves as an excellent figure of merit for the AUML suppressor.

Standard load dump specifications require a device capability of 10 pulses at rated energy, across a temperature range of -40°C to + 125°C. This capability requirement is well within the ratings of all of the AUML series (Figure 4).

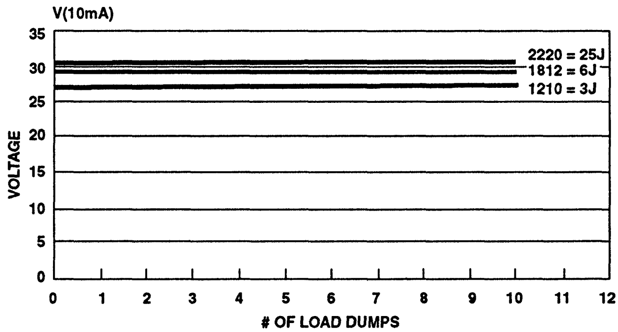


FIGURE 4. AUML LOAD DUMP PULSING OVER A TEMPERATURE RANGE OF -55°C TO +125°C

9 VARISTOR PRODUCTS

Further testing on the AUML series has concentrated on extending the number of load dump pulses, at rated energy, which are applied to the devices. The reliability information thus generated gives an indication of the inherent capability of these devices. To date the 1210 series of device has been subjected to over 2000 pulses at its rated energy of 3 joules; the 1812 series have been pulsed over 1000 times at 6 joules and 2220 series has been pulsed at its rated energy of 25 joules over 300 times. In all cases there has been little or no change in the device characteristics (Figure 5).

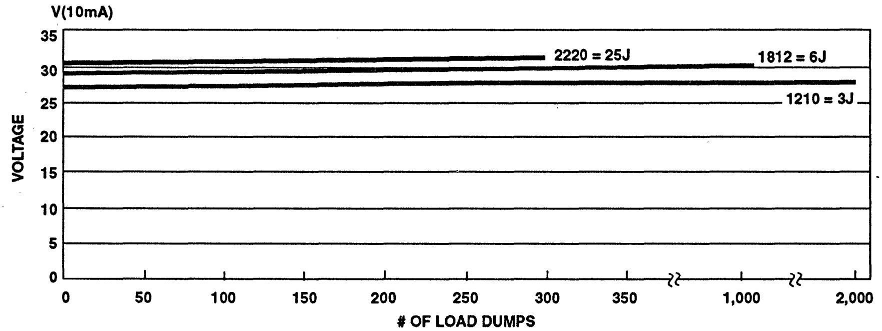


FIGURE 5. REPETITIVE LOAD DUMP PULSING AT RATED ENERGY

The very high energy absorption capability of the AUML suppressor is achieved by means of a new, highly controlled manufacturing process. This new technology ensures that a large volume of suppressor material, with an interdigitated layer construction, is available for energy absorption in an extremely small package. Unlike equivalent rated silicon TVS diodes, all of the AUML device package is available to act as an effective, uniform heat sink. Hence, the peak temperatures generated by the load dump transient are significantly lower and evenly dissipated throughout the complete device (Figure 6). This even energy dissipation ensures that there are lower peak temperatures generated at the P-N grain boundaries of the AUML suppressor.

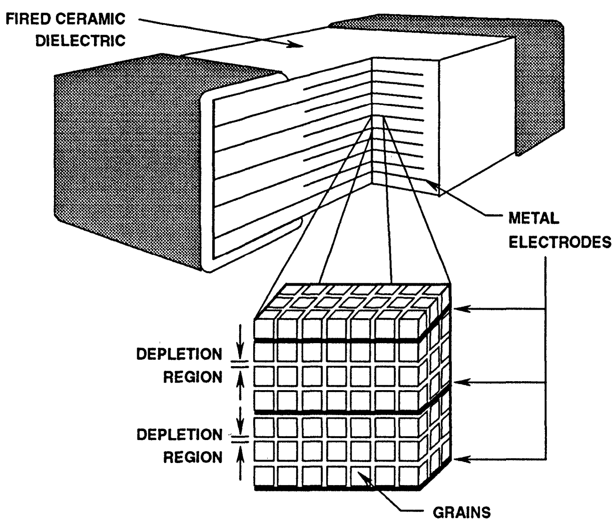


FIGURE 6. INTERDIGITATED CONSTRUCTION OF AUML SUPPRESSOR

There are a number of different size devices available in the AUML series, each one with a load dump energy rating, which is size dependent.

Experience has shown that while the effects of a load dump transient is of real concern, its frequency of occurrence is much less than those of low energy inductive spikes. Such low energy inductive spikes may be generated as a result of motors switching on and off, from ESD occurrences, fuse blowing, etc. It is essential that the suppression technology selected also has the capability to suppress such transients. Testing on the V18AUMLA2220 has shown that after being subjected to a repetitive energy pulse of 2 joules, over 6000 times, no characteristic changes have occurred (Figure 7.)

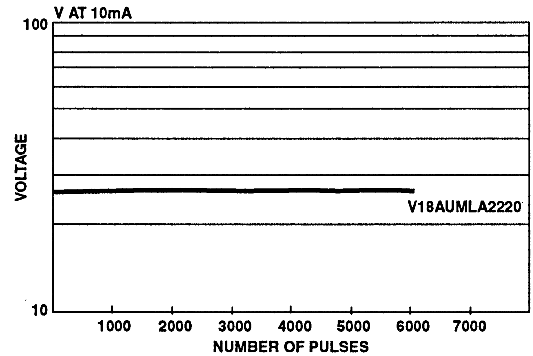


FIGURE 7. REPETITIVE ENERGY TESTING OF THE V18AUMLA2220 AT AN ENERGY LEVEL OF 2 JOULES

Temperature Effects

In the leakage region of the AUML suppressor, the device characteristics approaches a linear (ohmic) relationship and shows a temperature dependent affect. In this region the suppressor is in a high resistance mode (approaching 10^9 ohms) and appears as a near open-circuit. Leakage currents at maximum rated voltage are in the microamp range. With clamping transients at higher currents (at and above the ten milliamp range), the AUML suppressor approaches a 1-10Ω characteristic. In this region the characteristics of the AUML are virtually temperature independent. Figure 8 shows the typical effect of temperature on the V-I characteristics of the AUML suppressor.

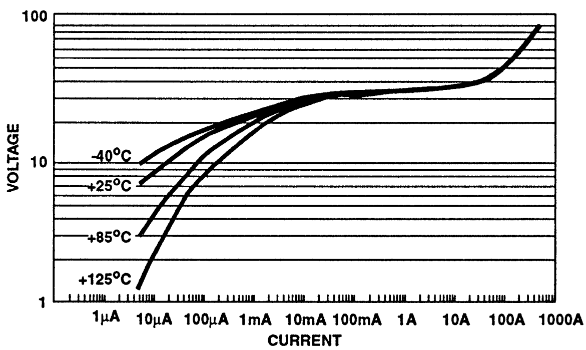


FIGURE 8. TYPICAL V-I CHARACTERISTICS OF THE V18AUMLA2220 at -40°C, +25°C, +85°C AND +125°C

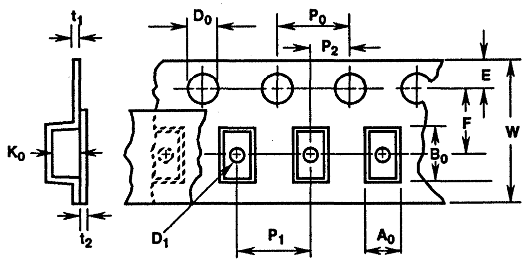
Speed of Response

The clamping action of the AUML suppressor depends on a conduction mechanism similar to that of other semiconductor devices (i.e. P-N Junctions). The apparent slow response time often associated with transient voltage suppressors (Zeners, MOVs) is often due to parasitic inductance in the package and leads of the device and is independent of the basic material (silicon, zinc oxide). Thus, the single most critical element affecting the response time of any suppressor is its lead length and, hence, the inductance in the leads. The AUML suppressor is a pure surface mount device, with no leads or external packaging, and thus, it has virtually zero inductance. The actual response time of a AUML surge suppressor is in the 1 to 5 nanosecond range and this response time is more than sufficient for the transients which are likely to be encountered in an automotive environment.

Tape and Reel Specifications

- **Conforms to EIA - 481, Revision A**
- **Can be Supplied to IEC Publication 286 - 3**

TAPE	8mm WIDE TAPE	12mm WIDE TAPE	
Chip Size	1210	1812	2220
Quantity Per 178mm Reel	2000	1000	1000
Quantity Per 330mm Reel	8000	4000	4000

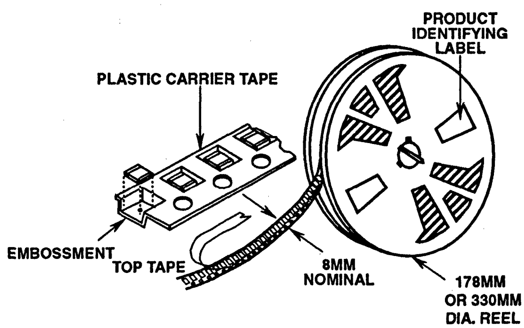


SYMBOL	DESCRIPTION	TAPE WIDTH	
		8mm	12mm
A_0	Width of Cavity	Dependent on Chip Size to Minimize Rotation.	
B_0	Length of Cavity	Dependent on Chip Size to Minimize Rotation.	
K_0	Depth of Cavity	Dependent on Chip Size to Minimize Rotation.	
W	Width of Tape	8 ± 0.2	12 ± 0.2
F	Distance Between Drive Hole Centers and Cavity Centers	3.5 ± 0.5	5.4 ± 0.5
E	Distance Between Drive Hole Centers and Tape Edge	1.75 ± 0.1	
P_1	Distance Between Cavity Center	4 ± 0.1	8 ± 0.1
P_2	Axial Distance Between Drive Hole Centers and Cavity Centers	2 ± 0.1	
P_0	Axial Distance Between Drive Hole Centers	8 ± 0.1	
D_0	Drive Hole Diameter	1.55 ± 0.05	
D_1	Diameter of Cavity Piercing	1.05 ± 0.05	1.55 ± 0.05
t_1	Embossed Tape Thickness	0.3 max	0.4 max
t_2	Top Tape Thickness	0.1 max	

NOTE: Dimensions in millimeters.

Standard Packaging

Tape and reel is the standard packaging method of the AUML series. The standard 330 millimeter (13 inch) reel utilized contains 4000 pieces for the 2220 and 1812 chips, and 8000 pieces for the 1210 chip. To order add "T23" to the standard part number, eg.V18AUMLA2220T23.



Special Packaging

Option 1: 178 millimeter (7 inch) reels containing 1000 (2220, 1812) or 2000 (1210), pieces are available. To order add "H23" to the standard part number, e.g. V18AUMLA2220H23.

Option 2: For small sample quantities (less than 100 pieces) the units are shipped bulk pack. To order add "A23" to the standard part number, e.g. V18AUMLA2220A23.

Part Nomenclature

The part numbering system of the AUML surge suppressor series gives the following information:

e.g. Part Number: V18AUMLA2220T23

where:

V = Harris Transient Voltage Suppressor
18 = Recognized Automotive Suppressor Rating
AUML = Automotive Series
A = Load Dump Energy Indicator
2220 (or 1812 or 1210) = Device Size
T23 (or H23 or A23) = Quantity Designator

Description of AUML Ratings and Characteristics

Maximum Continuous DC Working Voltage ($V_{M(DC)}$)

This is the maximum continuous DC voltage which may be applied, up to the maximum operating temperature (+125°C), to the ML suppressor. This voltage is used as the reference test point for leakage current and is always less than the breakdown voltage of the device.

Load Dump Energy Rating (W_{LD})

This is the actual energy the part can dissipate under load dump conditions.

Maximum Clamping Voltage (V_C)

This is the peak voltage appearing across the suppressor when measured at conditions of specified pulse current and specified waveform (8/20μs). It is important to note that the peak current and peak voltage may not necessarily be coincidental in time.

Leakage Current (I_L)

In the non-conducting mode, the device is at a very high impedance (approaching $10^9\Omega$) and appears as an almost open circuit in the system. The leakage current drawn at this level is very low (<50μA at ambient temperature) and, unlike the zener diode, the multilayer TVS has the added advantage that, when operated up to its maximum temperature, its leakage current will not increase above 500μA.

Nominal Voltage ($V_{N(DC)}$)

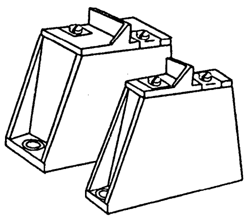
This is the voltage at which the AUML enters its conduction state and begins to suppress transients. In the automotive environment this voltage is defined at the 10 milliamp point and has a minimum ($V_{N(DC)\ MIN}$) and maximum ($V_{N(DC)\ MAX}$) voltage specified.

HARRIS SEMICONDUCTOR

BA/BB Series

August 1993

Industrial High Energy Metal-Oxide Varistors



BB SERIES BA SERIES

Features

- Recognized as "Transient Voltage Surge Suppressors", UL File #E75961 to Std. 1449
- High Energy Absorption Capability W_{TM}
  BA Series 3200J
  BB Series 10,000J
- Wide Operating Voltage Range $V_{M(AC)RMS}$
  BA Series .... 130V to 880V
  BB Series .... 1100V to 2800V
- Rigid Terminals for Secure Wire Contact
- Case Design Provides Complete Electrical Isolation of Disc SubAssembly
- Large Diameter Disc 60mm

Description

BA and BB series transient surge suppressors are heavy-duty industrial metal-oxide varistors designed to provide surge protection for motor controls and power supplies used in oil-drilling, mining, and transportation equipment. Possible voltage surges in their ac power supplies could cause product failure and the subsequent faulty operation of these systems.

These UL-recognized varistors have similar package construction but differ in size, ratings and electrical characteristics.

Both the BA and BB series feature improved creep and strike capability to minimize breakdown along the package surface, a package design that provides complete electrical isolation of the disc subassembly, and rigid terminals to insure secure wire contacts.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	BA SERIES	BB SERIES	UNITS
Continuous:			
Steady State Applied Voltage:			
AC Voltage Range ($V_{M(AC)RMS}$)	130 to 880	1100 to 2800	V
DC Voltage Range ($V_{M(DC)}$)	175 to 1150	1400 to 3500	V
Transient:			
Peak Pulse Current (I_{TM}) For 8/20μs Current Wave (See Figure 2)	50,000 to 70,000	70,000	A
Single Pulse Energy Range For 10/1000μs Current Wave (W_{TM})	450 to 3200	3800 to 10,000	J
Operating Ambient Temperature Range (T_A)	-55 to +85	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	<0.01	%/°C
Hi-Pot Encapsulation (Isolation Voltage Capability) (Dielectric must withstand indicated dc voltage for one minute per MIL-STD 202, Method 301)	5000	5000	V
Insulation Resistance	1000	1000	MΩ

File Number 2183.2

Device Ratings and Characteristics

Series BA and BB Varistors are listed under UL file #E75961 as a UL recognized component.

MODEL NUMBER	MAXIMUM RATINGS (+85°C) CONTINUOUS RMS VOLTAGE $V_{M(AC)}$ (V)	CONTINUOUS DC VOLTAGE $V_{M(DC)}$ (V)	TRANSIENT ENERGY (10/1000μs) W_{TM} (J)	TRANSIENT PEAK CURRENT (8/20μs) I_{TM} (A)	CHARACTERISTICS (+25°C) VARISTOR VOLTAGE AT 1mA DC TEST CURRENT MIN (V)	$V_{N(DC)}$ (V)	MAX (V)	MAX CLAMPING VOLT V_C AT 200A CURRENT (8/20μs) V_C (V)	TYPICAL CAPACITANCE f = 1MHz (pF)
VI 31 BA60	130	175	450	50000	184	200	228	340	20000
V151BA60	150	200	530	50000	212	240	268	400	16000
V251BA60	250	330	880	50000	354	390	429	620	10000
V271BA60	275	369	950	50000	389	430	473	680	9000
V321BA60	320	420	1100	50000	462	510	539	760	7500
V421BA60	420	560	1500	70000	610	680	748	1060	6000
V481BA60	480	640	1600	70000	670	750	825	1160	5500
V511BA80	510	675	1800	70000	735	820	910	1300	5000
V571BA60	575	730	2100	70000	805	910	1000	1420	4500
V661BA60	660	850	2300	70000	940	1050	1160	1640	4000
V751BA60	750	970	2600	70000	1080	1200	1320	1880	3500
V881BA60	880	1150	3200	70000	1290	1500	1650	2340	2700
V112BB60	1100	1400	3800	70000	1620	1800	2060	2940	2200
V142BB60	1400	1750	5000	70000	2020	2200	2550	3600	1800
V172BB60	1700	2150	6000	70000	2500	2700	3030	4300	1500
V202BB60	2000	2500	7500	70000	2970	3300	3630	5200	1200
V242BB60	2400	3000	8600	70000	3510	3900	4290	6200	1000
V282BB60	2800	3500	10000	70000	4230	4700	5170	7400	800

NOTE: Average power dissipation of transients not to exceed 2.5W. See Figures 3 and 4 for more information on power dissipation.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

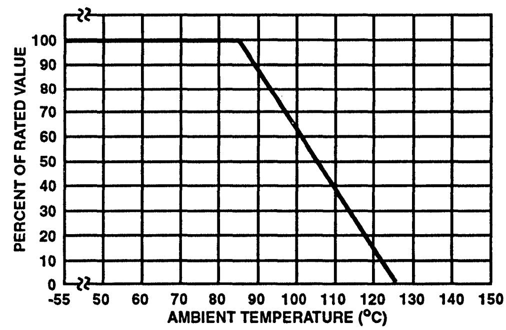
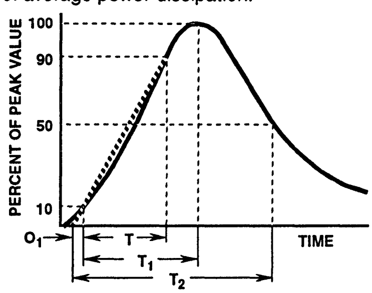


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

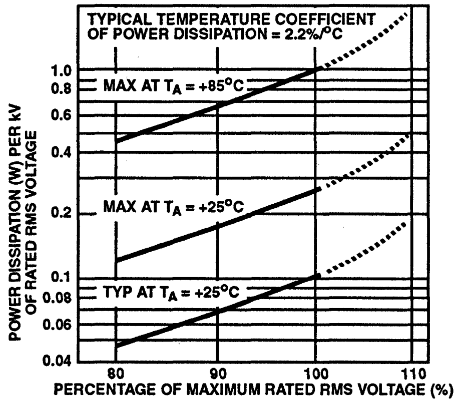


FIGURE 3. STANDBY POWER DISSIPATION vs APPLIED RMS VOLTAGE AT VARIED TEMPERATURES

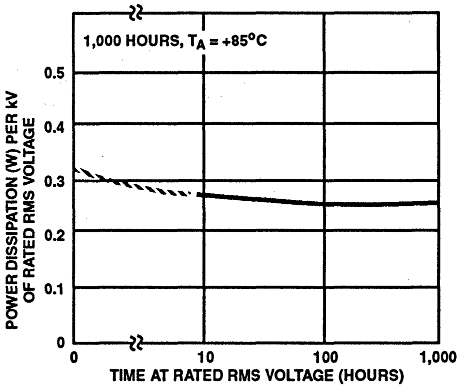


FIGURE 4. TYPICAL STABILITY OF STANDBY POWER DISSIPATION AT RATED RMS VOLTAGE vs TIME

Transient V-I Characteristics Curves

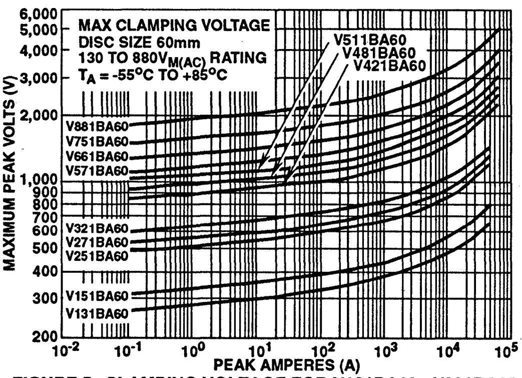


FIGURE 5. CLAMPING VOLTAGE FOR V131BA60 - V881BA60

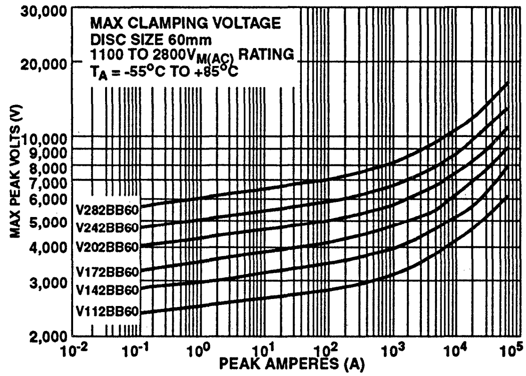


FIGURE 6. CLAMPING VOLTAGE FOR V112BB60 - V282BB60

Pulse Rating Curves

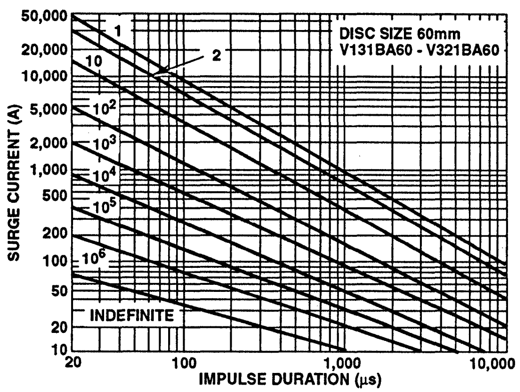


FIGURE 7. SURGE CURRENT RATING CURVES FOR V131BA60 - V3210A60

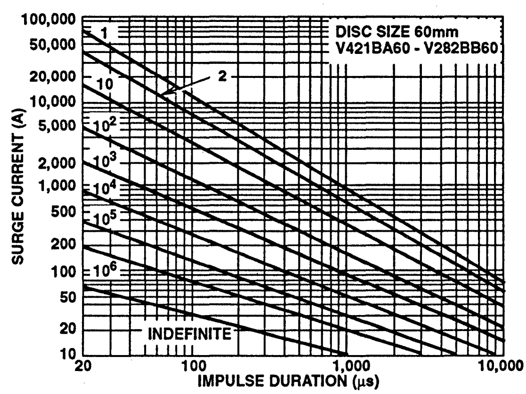
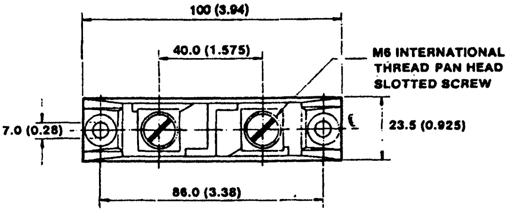


FIGURE 8. SURGE CURRENT RATING CURVES FOR V421BA60 - V282BB60

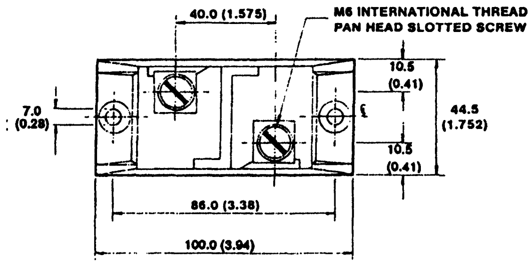
NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

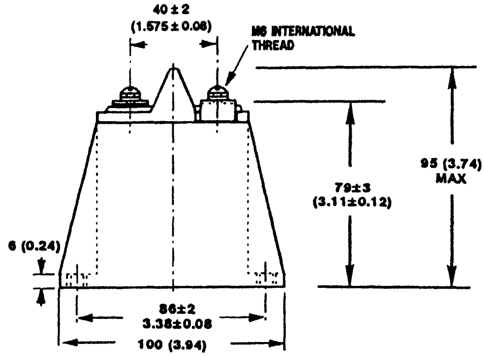
Packaging

BA SERIES



BB SERIES





NOTES:

1. Typical Weight:
   BA 250g
   BB 600g

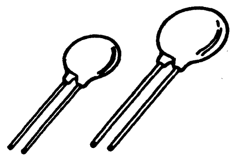
Dimensions are in mm; inches in parentheses for reference only.

HARRIS SEMICONDUCTOR

"C" III Series

Radial Lead Metal-Oxide Varistors for the TVSS Environment

August 1993



"C" III SERIES

Features

- **Recognized as "Transient Voltage Surge Suppressors" to UL 1449; File # E75961**
- **Recognized as "Transient Voltage Surge Suppressors" to CSA C22.2, No. 1; File # LR91788**
- **High Energy Absorption Capability W_{TM} .... 45J to 240J (2ms)**
- **High Peak Pulse Current Capability I_{TM} .... 6000A to 9000A (8/20µs)**
- **Wide Operating Voltage Range $V_{M(AC)RMS}$ .... 130V to 300V**
- **Available in Tape and Reel for Automatic Insertion; Also Available Crimped and/or Trimmed**

Description

The expanded version of the LA series of metal-oxide varistors, designation "C" III series, consists of AC line voltage rated MOVs with extremely high current and energy handling capabilities. This new "C" III series of MOVs were primarily designed for the transient voltage surge suppressor (TVSS) environment. They provide the increased level of protection now deemed to be necessary for the transients expected in this environment. The occurrence of high voltage transients in the ac power network can be detrimental to the associated line equipment. Such transient occurrences may cause product failure and the subsequent faulty operation of the electrical systems. This new expanded version of the Harris 20mm LA series of metal oxide varistors is also available with 10mm lead spacing, in tape and reel and in a variety of distinctive crimped and trimmed offerings.

Absolute Maximum Ratings For ratings of individual members of a series, see Device Ratings and Characteristics chart

	"C" III SERIES	UNITS
Continuous:		
Steady State AC Voltage Range ($V_{M(AC)RMS}$)	130 to 300	V
Transients:		
Single-Pulse Peak Current (I_{TM}) 8/20µs Wave (See Figure 2)	6000 to 9000	A
Single-Pulse Energy Range (W_{TM}) 2ms Rectangular Wave	45 to 240	J
Maximum Temporary Overvoltage of $V_{M(AC)}$, (5 Minutes Duration)	120	%
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

File Number **3540.1**

Specifications "C" III Series

MODEL NUMBER	DEVICE MARKING	MAXIMUM RATINGS (+85°C)			
		CONTINUOUS	TRANSIENT		
		MAXIMUM RMS VOLTAGE $V_{M(AC)}$ (V)	WITHSTANDING ENERGY (2ms) W_{TM} (⎍) (J)	PEAK CURRENT (8/20µs)	
				I_{TM1} 1 PULSE (A)	I_{TM2} 2 PULSES (A)
V130LA10C	130L10C	130	45	6000	5000
V130LA20C	130L20C	130	90	9000	7000
V130LA20CX325	130LA20CX325	130	90	9000	7000
V140LA10C	140L10C	140	50	6000	5000
V140LA20C	140L20C	140	100	9000	7000
V140LA20CX340	140L20CX340	140	100	9000	7000
V150LA10C	150L10C	150	55	6000	5000
V150LA20C	150L20C	150	110	9000	7000
V150LA20CX360	150L20CX360	150	110	9000	7000
V175LA10C	175L10C	175	60	6000	5000
V175LA20C	175L20C	175	120	9000	7000
V175LA20CX425	175L20CX425	175	120	9000	7000
V230LA20C	230L20C	230	80	6000	5000
V230LA40C	230L40C	230	160	9000	7000
V230LA40CX570	230L40X570	230	160	9000	7000
V250LA20C	250L20C	250	100	6000	5000
V250LA40C	250L40C	250	200	9000	7000
V250LA40CX620	250L40CX620	250	200	9000	7000
V275LA20C	275L20C	275	110	6000	5000
V275LA40C	275L40C	275	220	9000	7000
V275LA40CX680	275L40CX680	275	220	9000	7000
V300LA20C	300L20C	300	120	6000	5000
V300LA40C	300L40C	300	240	9000	7000
V300LA40CX745	300L40CX745	300	240	9000	7000

MODEL NUMBER	MODEL SIZE DISC DIAMETER (mm)	CHARACTERISTICS (+25°C)					
		VARISTOR VOLTAGE AT 1MA DC TEST CURRENT		MAXIMUM CLAMPING VOLTAGE (8/20µs)		DUTY CYCLE SURGE RATING	
		V_N MIN (V)	V_N MAX (V)	V_C (V)	I_P (A)	3KA (8/20µs) # PULSES	750A (8/20µs) # PULSES
V130LA10C	14	184	228	340	50	10	80
V130LA20C	20	184	228	340	100	20	120
V130LA20CX325	20	184	220	325	100	20	120
V140LA10C	14	198	242	360	50	10	80
V140LA20C	20	198	242	360	100	20	120
V140LA20CX340	20	198	230	340	100	20	120
V150LA10C	14	212	268	395	50	10	80
V150LA20C	20	212	268	395	100	20	120
V150LA20CX360	20	212	243	360	100	20	120
V175LA10C	14	247	303	455	50	10	80
V175LA20C	20	247	303	455	100	20	120
V175LA20CX425	20	247	285	425	100	20	120
V230LA20C	14	324	396	595	50	10	80
V230LA40C	20	324	396	595	100	20	120
V230LA40CX570	20	324	384	570	100	20	120
V250LA20C	14	354	429	650	50	10	80
V250LA40C	20	354	429	650	100	20	120
V250LA40CX620	20	354	413	620	100	20	120
V275LA20C	14	389	473	710	50	10	80
V275LA40C	20	389	473	710	100	20	120
V275LA40CX680	20	389	453	680	100	20	120
V300LA20C	14	400	540	775	50	10	80
V300LA40C	20	400	540	775	100	20	120
V300LA40CX745	20	400	520	745	100	20	120

NOTE: Average power dissipation of transients not to exceed 0.6W and 1W for model sizes 14mm and 20mm, respectively

Power Dissipation Requirements

The metal oxide varistor is designed to absorb voltage spikes of relatively short durations, not continuous voltage overloads. Therefore, unless transients occur in rapid succession, a continuous power dissipation capability is not a necessary design requirement for a varistor . Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. The operating values of a MOV need to be derated at high temperatures as shown in Figure 1. Because varistors only dissipate a relatively small amount of average power they are not suitable for repetitive applications that involve substantial amounts of average power dissipation.

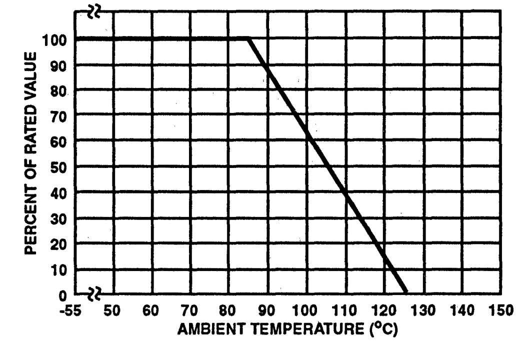
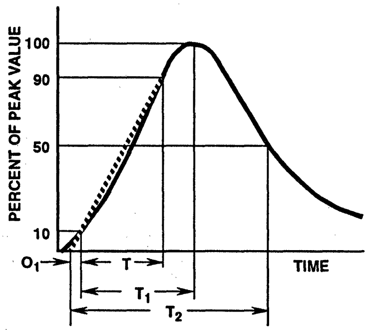


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)
Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

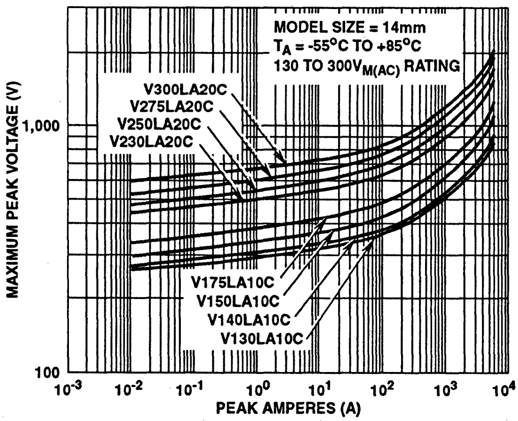


FIGURE 3. MAXIMUM CLAMPING VOLTAGE FOR V130LA10C TO V300LA20C

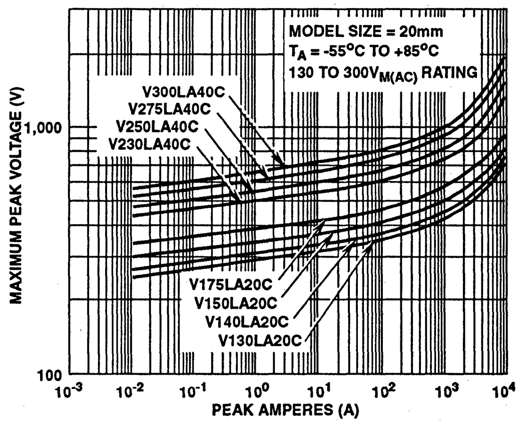


FIGURE 4. MAXIMUM CLAMPING VOLTAGE FOR V130LA20C TO V200LA40C

Pulse Rating Curves

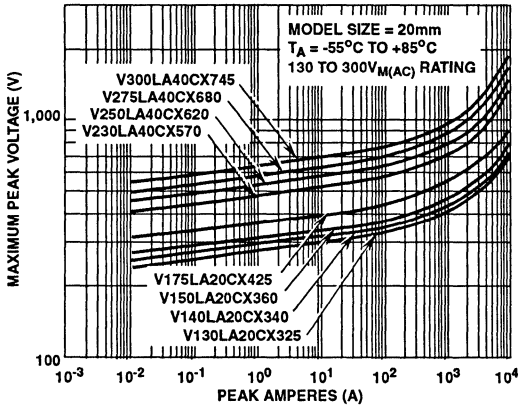


FIGURE 5. REPETITIVE SURGE CAPABILITY FOR V130LA20CX325 TO V300LACX745

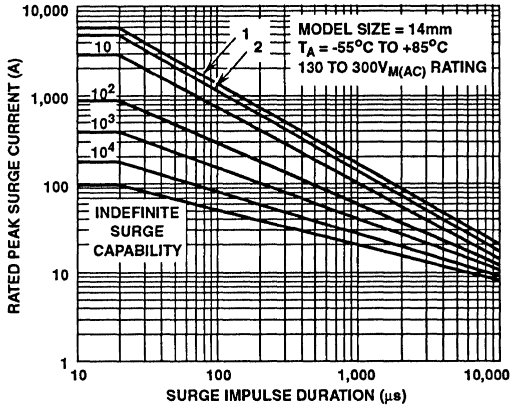


FIGURE 6. REPETITIVE SURGE CAPABILITY FOR V130LA10C TO V300LA20C

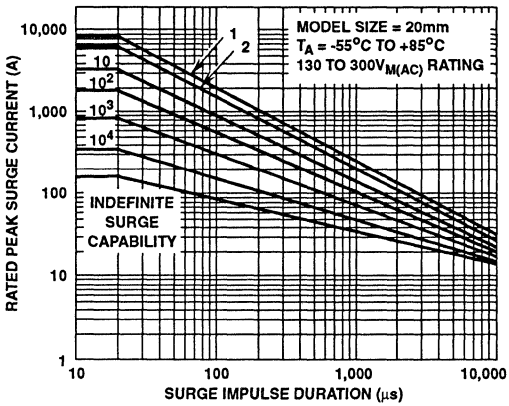
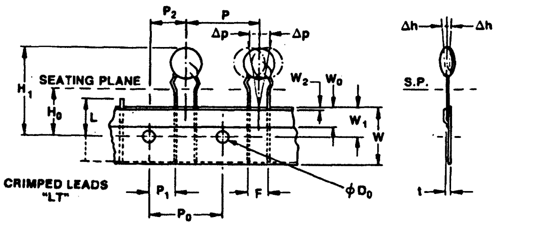
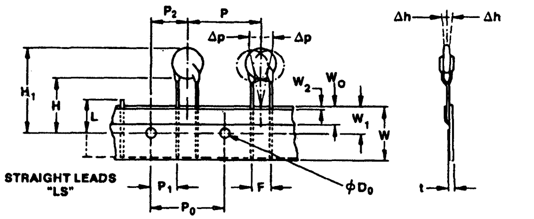
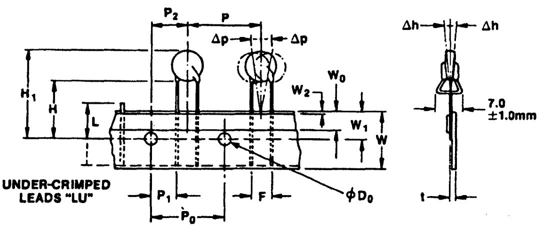


FIGURE 7. REPETITIVE SURGE CAPABILITY FOR V130LA20C TO V300LA40C

Tape and Reel Specification







SYMBOL	DESCRIPTION	MODEL SIZE 14mm	MODEL SIZE 20mm
P	Pitch of Component	25.4 ± 1.0	
P_0	Feed Hole Pitch	12.7 ± 0.2	
P_1	Feed Hole Center to Pitch	2.60 ± 0.7	
P_2	Hole Center to Component Center	6.35 ± 1.0	
F	Lead to Lead Distance	7.50 ± 0.8	
h	Component Alignment	2.00 Max	
W	Tape Width	18.25 ± 0.75	
W_0	Hold Down Tape Width	6.00 ± 0.3	12.0 ± 0.3
W_1	Hole Position	9.125 ± 0.625	
W_2	Hold Down Tape Position	0.5 Max	
H	Height From Tape Center To Component Base	19.0 ± 1.0	
H_0	Seating Plane Height	16.0 ± 0.5	
H_1	Component Height	40 Max	46.5 Max
D_0	Feed Hole Diameter	4.0 ± 0.2	
t	Total Tape Thickness	0.7 ± 0.2	
L	Length of Clipped Lead	12.0 Max	
p	Component Alignment	3° Max	

Tape and Reel Data

- Conforms to ANSI and EIA Specifications
- Can be supplied to IC publication 286-2
- Radial devices on tape and reel are supplied with crimped leads, straight leads, or under-crimped leads.

Shipping Quantity

DEVICE SIZE	QUANTITY PER REEL "T" REEL	"S" REEL	"U" REEL
14mm	500	500	500
20mm	500	500	500

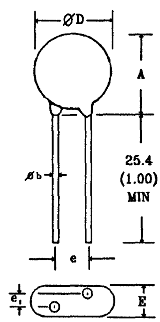
Tape and Reel Ordering Information

- Crimped leads are standard on LA types supplied in tape and reel and are denoted by the model letter "T". Also, in tape and reel, model letter "S" denotes straight leads and letter "U" denotes special under-crimped leads.

Example:

STANDARD MODEL	CRIMPED LEADS	STRAIGHT LEADS	UNDER CRIMP LEADS
V130LA20C	V130LT20C	V130LS20C	V130LU20C

Packaging



SYMBOL	VARISTOR MODEL SIZE 14mm MIN	14mm MAX	20mm MIN	20mm MAX
A	13.5 (0.531)	20 (0.787)	17.5 (0.689)	26.5 (1.043)
ØD	13.5 (0.531)	17 (0.669)	17.5 (0.689)	23 (0.906)
e	6.5 (0.256)	8.5 (0.335)	6.5 (0.256)	8.5 (0.335)
e1	1.5 (0.059)	3.5 (0.138)	1.5 (0.059)	3.5 (0.138)
E	- -	5.6 (0.220)	- -	5.6 (0.220)
Øb	0.76 (0.030)	0.86 (0.034)	0.76 (0.030)	0.86 (0.034)

Dimensions are in millimeters (inches)

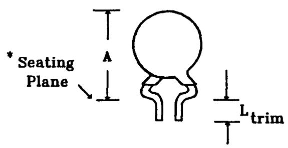
NOTE: 10mm lead spacing also available. See ordering information.

Available Lead Style

Radial lead types can be supplied with a preformed crimp in the leads. This is available in both 14mm and 20mm model sizes. The lead trim option (L_{TRIM}) is supplied to the dimensions shown below.

SYMBOL	VARISTOR MODEL SIZE			
	14mm		20mm	
	MIN	MAX	MIN	MAX
A	-	24.5 (0.96)	-	31 (1.22)
L_{TRIM}	2.41 (0.095)	4.69 (0.185)	2.41 (0.095)	4.69 (0.185)

NOTE: Dimensions are in millimeters (inches)



Crimped and Trimmed Lead

*Seating plan interpretation per IEC-717

Ordering Information

- To order crimped and trimmed lead styles, the standard radial type model number "LA" is changed to the model number "LC".

Example:

STANDARD MODEL	ORDER AS
V130LA20C	V130LC20C

- For 10 ± 1mm lead spacing on 20mm units only; append standard model numbers by adding "X10".

Example:

STANDARD MODEL	ORDER AS
V130LA20C	V130LA20CX10

- For crimped leads without trimming and other variations to the above, please contact Harris Semiconductor Power Marketing

The Origins of Surge Overvoltages

There are a wide variety of transient overvoltage environments, each with radically different levels of exposure. Transients may be caused by lightning, which can inject very high currents into the electrical system, or by switching transients. Lightning strikes usually occur to the primary transmission lines with resulting coupling to the secondary line through mutual inductive or capacitive coupling. Even a lightning hit that misses the primary AC line can induce substantial voltage onto the primary conductors, triggering lightning arresters and thus creating transients.

Switching transients, while of a lower magnitude than lightning, occur more frequently and thus are of a greater threat to the AC system. Switching transients may result from fuse blowing, capacitor bank switching, fault clearing or grid switching.

Field studies and laboratory investigation of residential and industrial low power AC voltage systems have shown that the amplitude of a transient is proportional to the rate of its occurrence, i.e. lower magnitude transients occur most often. Governing bodies, in particular IEC, UL, IEEE and ANSI have established guidelines on the transient environment one may expect to encounter in a low voltage AC power system. Table 1 reflects the surge voltages and currents deemed to represent the indoor environment.

LOCATION CATEGORY		TRANSIENT WAVEFORM/ MAGNITUDE	
A	Long Branch Circuits and Outlets	0.5μs 100kHz	6kV 200A
B	Major Feeders and Short Branch Circuits	1.2/50μs 8/20μs	6kV 3kA
		0.5μs 100kHz	6kV 500A

"C" III MOV Series

The new "C" III series of Harris radial MOVs represent the third generation of improvements in device performance and characteristics. The technology effort involved in the development of this new series concentrated on extending the existing performance and capability of the Harris second generation of metal oxide varistors.

The characteristics of greatest importance for a metal oxide varistor in an AC surge environment are the peak current, energy handling, repetitive surge and temporary over-voltage capabilities. The focus of the design effort was on improving these characteristics and therefore offering the maximum protection presently available to the end user.

The new "C" III series are designed to survive the harsh environments of the AC low-power indoor environment. Their much improved surge withstand capability is well in excess of the transients expected in the AC mains environment. Further design rules for the development of the "C" III series included considerations of the expected steady state operating conditions and the repetitive surge environment.

Investigation of the AC low-power indoor environment show that most transients occur where the power enters the building and at major feeders and short branch circuits. Surges recorded at this service entrance, location Category B from C62.41-1992, may be both oscillatory and unidirectional in nature. The typical "lightning surge" has been established as a 1.2/50µs voltage wave and a 8/20µs current wave. A short circuit current of 3000A and open circuit voltage 6000V are the expected worst case transients at this location.

TEST	REFERENCE STANDARD	TEST CONDITIONS	TEST RESULTS
Surge Current	UL 1449 IEEE/ANSI C62.41	9000A (8/20µs) 1 Pulse	0/165
	IEC 1051	7000A (8/20µs) 2 Pulses	0/105
		3000A (8/20µs) 20 Pulses	0/75
		750A (8/20µs) 120 Pulses	0/65
Surge Energy	UL 1449 IEEE/ANSI C62.41 IEC 1051	90J (2ms) 1 Pulse	0/125
Operating Life	Mil-Std-202 Method 204D	125°C, 1000 Hours, Rated Bias Voltage	0/180
Temporary Overvoltage	N/A	120% Maximum Rated Varistor Voltage For 5 minutes	0/70

The further into the facility one goes, the lower the magnitude of the transients encountered. ANSI/IEEE C62.41 differentiates between the service entrance and the interior of a facility. Per this specification, the internal location or long branch circuits and outlets are classified as Location Category A. The transients encountered here have oscillatory waveshapes with frequency ranges from 5kHz to 500kHz; with 100kHz deemed most common. Transients of the magnitude of 500A are expected in this location.

Reliability Performance of "C" III Series

The electrical ratings of the "C" III series of MOVs are conservatively stated. Samples of these devices have been tested under additional stresses, over and above those called out in the datasheet. The results of this testing show an enhanced device performance.

The series of stress tests to which the units were subjected are a combination of electrical, environmental and mechanical tests. A summary of the reliability tests performed on the "C" III series are described in Table 2

AC Bias Reliability

The "C" III series of metal oxide varistors was designed for use on the ac line. The varistor is connected across the ac line and is biased with a constant amplitude sinusoidal voltage. It should be noted that the definition of failure is a shift in the nominal varistor voltage (V_N) exceeding ± 10%. Although this type of varistor is still functioning normally after this magnitude of shift, devices at the lower extremities of V_N tolerance will begin to dissipate more power.

Because of this possibility, an extensive series of statistically designed tests were performed to determine the reliability of the "C" III type of varistor under ac bias combined with high levels of temperature stress. To date, this test has generated over 50,000 device hours of operation at a temperature of +125°C, although only rated at +85°C. Changes in the nominal varistor voltage, measured at 1mA, of less than 2% have been recorded (Figure 8).

Transient Surge Current/Energy Capability

The transient surge rating serves as an excellent figure of merit for the "C" III suppressor. This inherent surge handling capability is one of the new "C" III suppressor's best features. The enhanced surge absorption capability results from improved process uniformity and enhanced construction. The homogeneity of the raw material powder and improved control over the sintering and assembly processes are contributing factors to this improvement.

In the low power AC mains environment, industry governing bodies (UL, IEC, NEMA and IEEE) all suggest that the worst case surge occurrence will be 3kA. Such a transient event may occur up to five times over the equipment life time (approximately 10 years). While the occurrences of five 3 kiloamps transients is the required capability, the conservatively rated, repetitive surge current for the "C" III series is 20 pulses for the 20mm units and 10 pulses for the 14mm series.

As a measure of the inherent device capability, samples of the 20mm V130LA20C devices were subjected to a worst case repetitive transient surges test. After 100 pulses, each of 3kA, there was negligible change in the device characteristics. Changes in the clamping voltage, measured at 100 amps, of less than 3% were recorded (Figure 9). Samples of the 14mm Series V175LA20C were subjected to repetitive surge occurrences of 750A. Again, there was negligible changes in any of the device characteristics after 250 pulses (Figure 10). In both cases the inherent device capability is far in excess of the expected worst case scenario.

Terms and Descriptions

Rated AC Voltage ($V_{M(AC)RMS}$)

This is the maximum continuous sinusoidal voltage which may be applied to the MOV. This voltage may be applied at any temperature up to the maximum operating temperature of +85°C.

Maximum Non-Repetitive Surge Current (I_{TM})

This is the maximum peak current which may be applied for an 8/20μs impulse, with rated line voltage also applied, without causing device failure. (See Figure 2)

Maximum Non-Repetitive Surge Energy (W_{TM})

This is the maximum rated transient energy which may be dissipated for a single current pulse at a specified impulse and duration (2ms), with the rated rms voltage applied, without causing device failure.

Nominal Voltage ($V_{N(DC)}$)

This is the voltage at which the device changes from the off state to the on state and enters its conduction mode of operation. This voltage is characterized at the 1mA point and has specified minimum and maximum voltage levels.

Clamping Voltage (V_C)

This is the peak voltage appearing across the MOV when measured at conditions of specified pulse current amplitude and specified waveform (8/20μs)

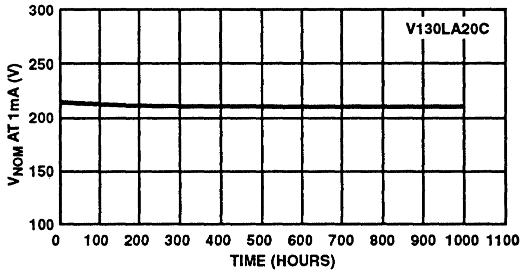


FIGURE 8. HIGH TEMPERATURE OPERATING LIFE 125°C FOR 1000 HOURS AT RATED BIAS

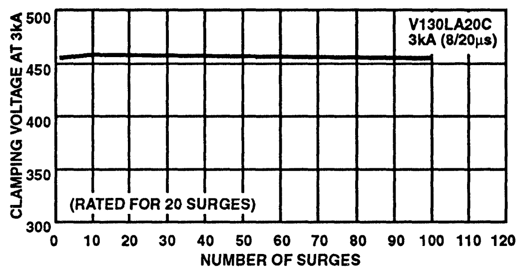


FIGURE 9. TYPICAL REPETITIVE SURGE CURRENT CAPABILITY OF "C" III SERIES MOVs

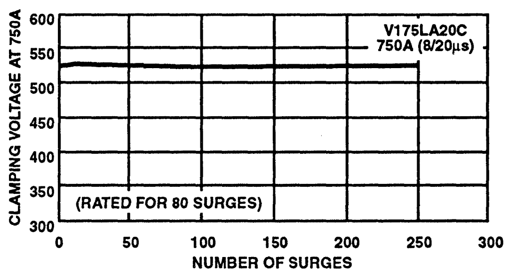


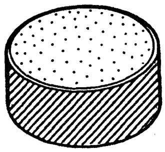
FIGURE 10. TYPICAL REPETITIVE SURGE CURRENT CAPABILITY OF "C" III SERIES MOVs

HARRIS SEMICONDUCTOR

CA Series

Industrial High Energy Metal-Oxide Disc Varistors

August 1993



CA SERIES

Features

- Provided Unpackaged For Unique Packaging By Customer
- Solderable Electrode Finish Also Provides Pressure Contacts for Stacking Applications
- Available Disc Sizes . . . . 32mm, 40mm, and 60mm Diameter
- Wide Operating Voltage Range $V_{M(AC)RMS}$ . . . . 130V to 2800V
- Wide Peak Pulse Current Range I_{TM} . . . . 20,000A to 70,000A
- Very High Energy Capability W_{TM} . . . . 200J to 10,000J

Description

CA series transient surge suppressors are industrial high-energy disc varistors intended for special applications requiring unique contact or packaging considerations. The electrode finish of these devices is solderable and can also be used as pressure contacts for stacking applications.

These CA series industrial disc varistors are available in three diameter sizes: 32, 40, and 60mm, with disc thicknesses ranging from 1.8mm minimum to 32mm maximum. They offer a wide voltage range of from 130 to 2800 $V_{M(AC)RMS}$.

For information on mounting considerations refer to Applications Brief AB-8820.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	CA SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	130 to 2800	V
DC Voltage Range ($V_{M(DC)}$)	175 to 3500	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20µs Current Wave (See Figure 2)	20,000 to 70,000	A
Single Pulse Energy Range		
For 10/1000µs Current Wave (W_{TM})	200 to 10,000	J
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

File Number **2187.2**

Device Ratings and Characteristics

MODEL NUMBER	SIZE (mm)	MAXIMUM RATINGS (+85°C) CONTINUOUS RMS VOLTAGE $V_{M(AC)}$ (V)	CONTINUOUS DC VOLTAGE $V_{M(DC)}$ (V)	TRANSIENT ENERGY (10/1000μs) W_{TM} (J)	TRANSIENT PEAK CURRENT (8/20μs) I_{TM} (A)	CHARACTERISTICS (+25°C) VARISTOR VOLTAGE AT 1mA DC TEST CURRENT MIN (V)	VARISTOR VOLTAGE AT 1mA DC TEST CURRENT $V_{N(DC)}$ (V)	VARISTOR VOLTAGE AT 1mA DC TEST CURRENT MAX (V)	MAX CLAMPING VOLT V_C AT 200A CURRENT (8/20μs) V_C (V)	TYPICAL CAPACITANCE f = 1MHz (pF)
V131CA32	32	130	175	200	20000	184	200	228	350	4700
V131CA40	40			270	30000				345	10000
V151CA32	32	150	200	220	20000	212	240	268	410	4000
V151CA40	40			300	30000				405	8000
V251CA32	32	250	330	330	20000	354	390	429	680	2500
V251CA40	40			370	30000				650	5000
V251CA60	60			880	50000				620	10000
V271CA32	32	275	369	360	20000	389	430	473	750	2200
V271CA40	40			400	30000				730	4500
V271CA60	60			950	50000				680	9000
V321CA32	32	320	420	390	20000	462	510	539	850	1900
V321CA40	40			460	30000				830	3800
V321CA60	60			1100	50000				760	7500
V421CA32	32	420	560	400	25000	610	680	748	1200	1500
V421CA40	40			600	40000				1130	3000
V421CA60	60			1500	70000				1060	6000
V481CA32	32	480	640	450	25000	670	750	825	1300	1300
V481CA40	40			650	40000				1240	2700
V481CA60	60			1600	70000				1160	5500
V511CA32	32	510	675	500	25000	735	820	910	1440	1200
V511CA40	40			700	40000				1350	2500
V511CA60	60			1800	70000				1300	5000
V571 CA32	32	575	730	550	25000	805	910	1000	1600	1100
V571CA40	40			770	40000				1480	2200
V571CA60	60			2100	70000				1420	4500
V661 CA32	32	660	850	600	25000	940	1050	1160	1820	1000
V661CA40	40			900	40000				1720	2000
V661CA60	60			2300	70000				1640	4000
V751CA32	32	750	970	700	25000	1080	1200	1320	2050	800
V751CA40	40			1050	40000				2000	1800
V751CA60	60			2600	70000				1880	3500
V881CA60	60	880	1150	3200	70000	1290	1500	1650	2340	2700
V112CA60	60	1100	1400	3200	70000	1620	1800	2060	2940	2200
V142CA60	60	1400	1750	5000	70000	2020	2200	2550	3600	1800
V172CA60	60	1700	2150	6000	70000	2500	2700	3030	4300	1500
V202CA60	60	2000	2500	7500	70000	2970	3300	3630	5200	1200
V242CA60	60	2400	3000	8600	70000	3510	3900	4290	6200	1000
V282CA60	60	2800	3500	10000	70000	4230	4700	5170	7400	800

NOTE: Average power dissipation of transients not exceed 1.5W, 2.0W and 2.5W for model 32mm, 40mm and 60mm, respectively.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

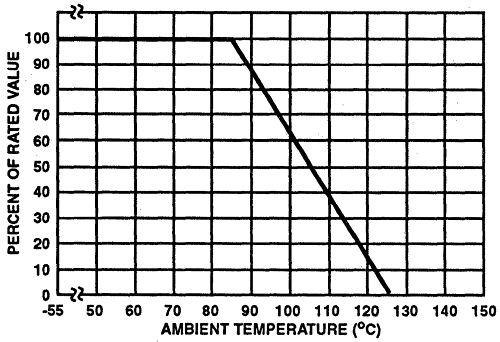
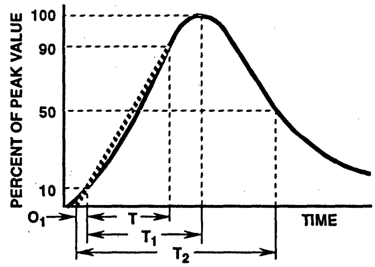


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

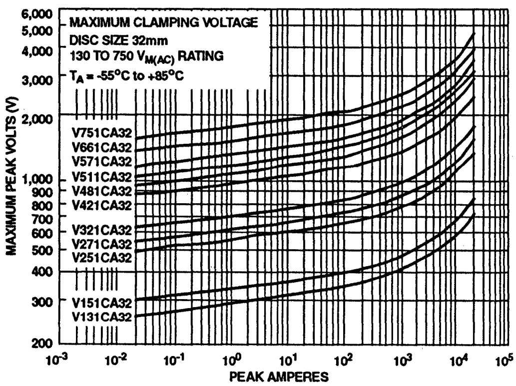


FIGURE 3. CLAMPING VOLTAGE FOR V131CA32 - C751CA32

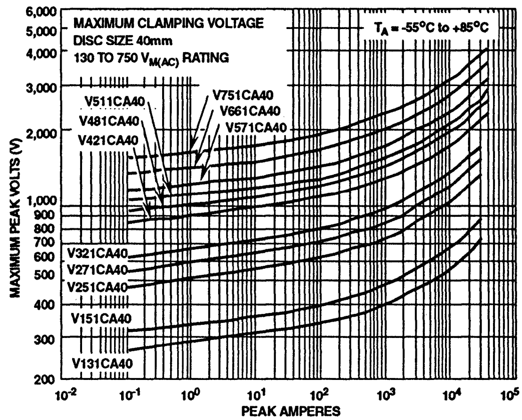


FIGURE 4. CLAMPING VOLTAGE FOR V131CA40 - V751CA40

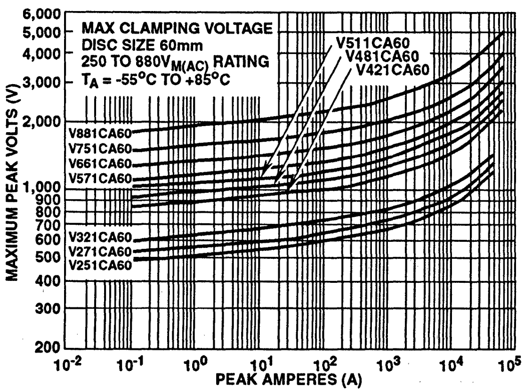


FIGURE 5. CLAMPING VOLTAGE FOR V251CA60 - V881CA60

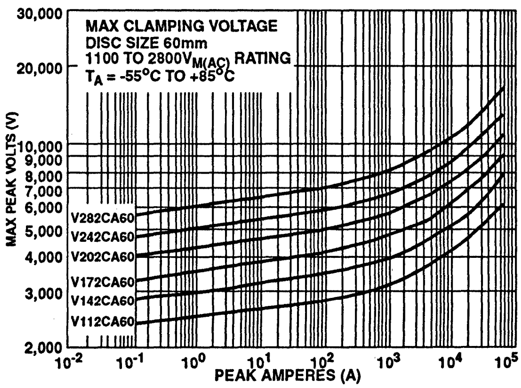


FIGURE 6. CLAMPING VOLTAGE FOR V112CA60 - V282CA60

Pulse Rating Curves

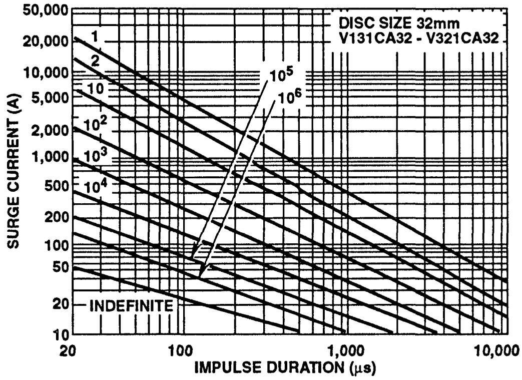


FIGURE 7. SURGE CURRENT RATING CURVES FOR V131CA32 - V321CA32

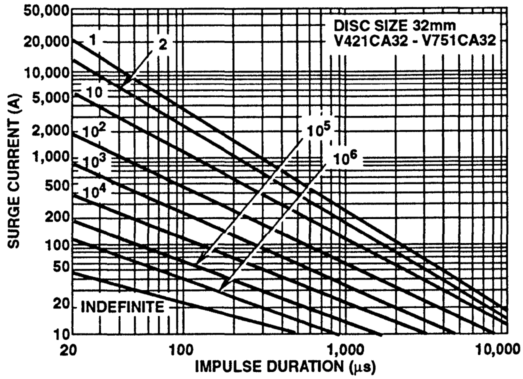


FIGURE 8. SURGE CURRENT RATING CURVES FOR V421CA32 - V751CA32

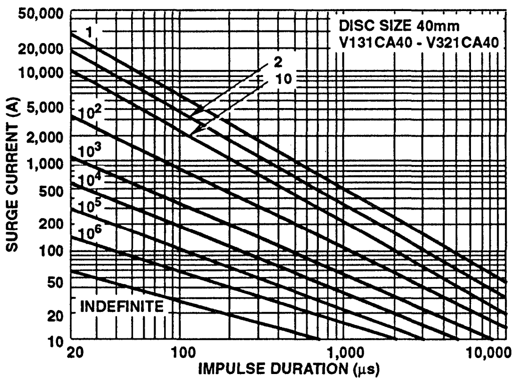


FIGURE 9. SURGE CURRENT RATING CURVES FOR V131CA40 - V321CA40

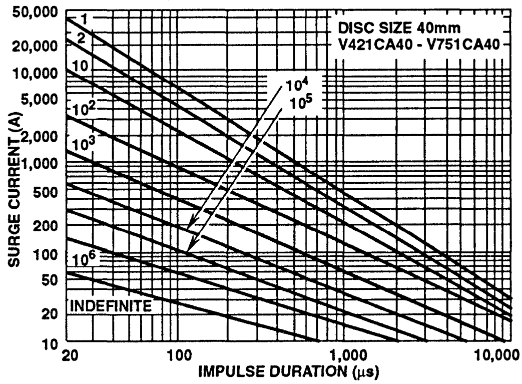


FIGURE 10. SURGE CURRENT RATING CURVES FOR V421CA40 - V751CA40

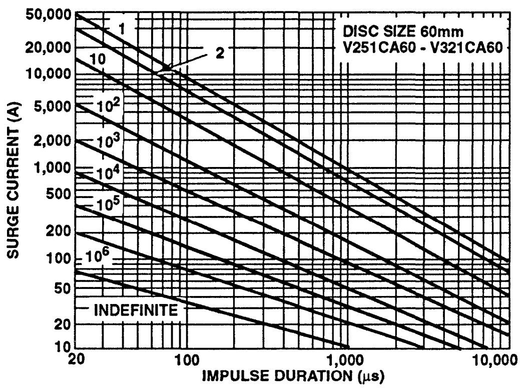


FIGURE 11. SURGE CURRENT RATING CURVES FOR V251CA60 - V321CA60

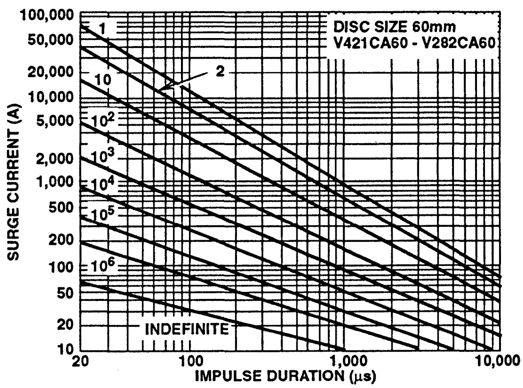
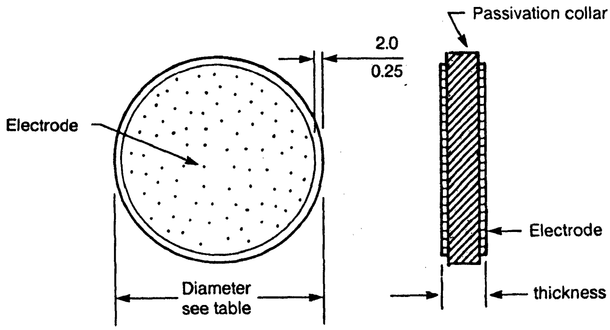


FIGURE 12. SURGE CURRENT RATING CURVES FOR V421CA60 - V282CA60

NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but does not prevent the device from continuing to function, and to provide ample protection.

Packaging



DISC DIAMETER				
NOMINAL SIZE	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
32	31.0	33.0	1.220	1.299
40	38.0	40.0	1.496	1.575
60	58.0	62.0	2.283	2.441

RMS VOLTS $V_{M(ac)}$	32mm DISC THICKNESS				40 AND 60mm DISC THICKNESS			
	MILLIMETERS		INCHES		MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
130+	1.8	2.4	0.071	0.094	2.5	3.4	0.098	0.134
150+	2.1	2.8	0.083	0.110	2.8	3.8	0.110	0.150
250	1.6	2.2	0.063	0.087	2.0	2.7	0.079	0.106
275	1.8	2.5	0.071	0.098	2.2	3.0	0.087	0.118
320	2.1	2.9	0.083	0.114	2.6	3.5	0.102	0.138
420	2.9	3.9	0.114	0.154	3.5	4.7	0.138	0.185
480	3.1	4.3	0.122	0.169	3.8	5.2	0.150	0.205
510	3.5	4.7	0.138	0.185	4.2	5.7	0.165	0.224
575	3.8	5.1	0.150	0.201	4.6	6.3	0.181	0.248
660	4.4	6.0	0.173	0.236	5.3	7.2	0.209	0.283
750	5.1	6.9	0.240	0.327	6.1	8.3	0.240	0.327
880*	—	—	—	—	7.3	10.3	0.287	0.406
1100*	—	—	—	—	9.2	13.0	0.362	0.512
1400*	—	—	—	—	11.5	16.0	0.453	0.630
1700*	—	—	—	—	14.0	19.0	0.551	0.748
2000*	—	—	—	—	17.0	22.5	0.669	0.886
2400*	—	—	—	—	20.0	27.0	0.787	1.063
2800*	—	—	—	—	24.0	32.0	0.945	1.260

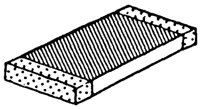
*** Available in 60mm size only.**
+ Available in 32 and 40mm only.
Note: Parts available with soldered tabs, to customer specific requirements or standard design.

HARRIS SEMICONDUCTOR

CH Series

August 1993

Surface Mount Metal-Oxide Varistors



CH SERIES

Features

- Recognized as "Transient Voltage Surge Suppressors", UL File #E75961 to Std. 1449
- Recognized as "Protectors for Data Communication and Fire Alarm Circuits", UL File #E135010 to Std. 497B
- Surface Mount Chip Intended for Hybrid-Circuit Applications
- Voltage Ratings $V_{M(AC)RMS}$ .... 10V to 275V
- Available in Tape and Reel for Use With Automatic Pick and Place Equipment
- Compatible with Most Surface-Mounting Assembly Equipment and Techniques

Description

CH series transient surge suppressors are small, very compact metal-oxide varistors. They are intended for use in hybrid circuit applications in commercial and industrial equipment utilizing direct surface-mounting techniques.

These devices, which have significantly lower profiles than traditional radial-lead varistors, permit designers to reduce the size and weight and increase the reliability of their equipment designs.

CH series varistors are available in a voltage range from 10 to 275V $V_{M(AC)RMS}$, and energy ratings up to 23J.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	CH SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		V
AC Voltage Range ($V_{M(AC)RMS}$)	10 to 275	V
DC Voltage Range ($V_{M(DC)}$)	14 to 369	
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20μs Current Wave (See Figure 2)	250 to 500	A
Single Pulse Energy Range		
For 10/1000μs Current Wave (W_{TM})	0.8 to 23	J
Operating Ambient Temperature Range (T_A)	-55 to +125	°C
Storage Temperature Range (T_{STG})	-55 to +150	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

Device Ratings and Characteristics

V82 - V240 CH Varistors are listed under UL file #E75961 as a recognized component.
Series CH Varistors are listed under UL file #E135010 as a recognized component.

	MAXIMUM RATINGS (+125°C)				CHARACTERISTICS (+25°C)					
	CONTINUOUS		TRANSIENT							
	RMS VOLTAGE	DC VOLTAGE	ENERGY (10/1000μs)	PEAK CURRENT (8/20μs)	VARISTOR VOLTAGE AT 1mA DC TEST CURRENT			MAX CLAMPING VOLT V_C AT TEST CURRENT (8/20μs)		TYPICAL CAPACITANCE
MODEL NUMBER	$V_{M(AC)}$ (V)	$V_{M(DC)}$ (V)	W_{TM} (J)	I_{TM} (A)	MIN (V)	$V_{N(DC)}$ (V)	MAX (V)	V_C (V)	I_P (A)	f = 1MHz (pF)
V18CH8	10	14	0.80	250	14.4	18.0	21.6	42	5	2000
V22CH8	14	18 (Note 3)	10.0 (Note 2)	250	18.7	22.0	26.0	47	5	1600
V27CH8	17	22	1.0	250	23.0	27.0	31.1	57	5	1300
V33CH8	20	26	1.2	250	29.5	33.0	36.5	68	5	1100
V39CH8	25	31	1.5	250	35.0	39.0	43.0	79	5	900
V47CH8	30	38	1.8	250	42.0	47.0	52.0	92	5	800
V56CH8	35	45	2.3	250	50.0	56.0	62.0	107	5	700
V68CH8	40	56	3.0	250	61.0	68.0	75.0	127	5	600
V82CH8	50	66	4.0	500	74.0	82.0	91.0	135	10	500
V100CH8	60	81	5.0	500	90.0	100.0	110.0	165	10	400
V120CH8	75	102	6.0	500	108.0	120.0	132.0	200	10	300
V150CH8	95	127	8.0	500	135.0	150.0	165.0	250	10	250
V180CH8	115	153	10.0	500	162.0	180.0	198.0	295	10	200
V200CH8	130	175	11.0	500	184.0	200.0	228.0	340	10	180
V220CH8	140	180	12.0	500	198.0	220.0	242.0	360	10	160
V240CH8	150	200	13.0	500	212.0	240.0	268.0	395	10	150
V360CH8	230	300	20.0	500	324.0	360.0	396.0	595	10	100
V390CH8	250	330	21.0	500	354.0	390.0	429.0	650	10	90
V430CH8	275	369	23.0	500	389.0	430.0	473.0	710	10	80

NOTES:

1. Power dissipation of transients not to exceed 0.25 watt.
2. Energy rating for impulse duration of 30 milliseconds minimum to one half of peak current value.
3. Also rated to withstand 24 volts for 5 minutes.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

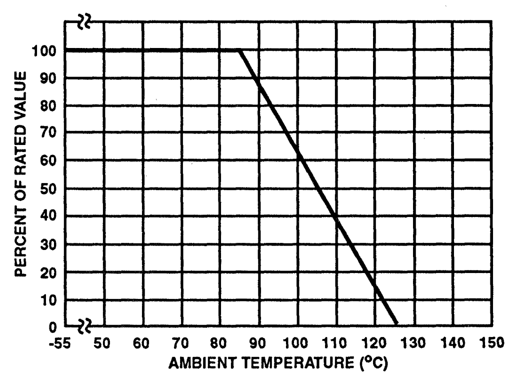
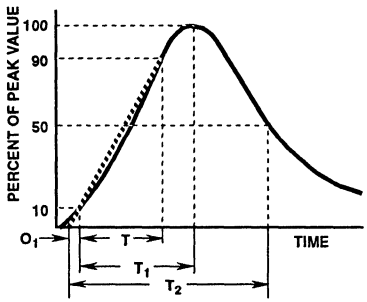


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

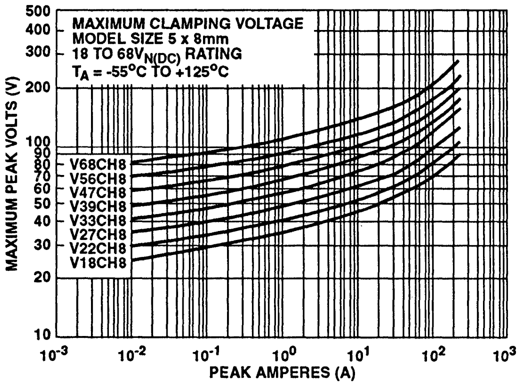


FIGURE 3. CLAMPING VOLTAGE FOR V18CH8 - V68CH8

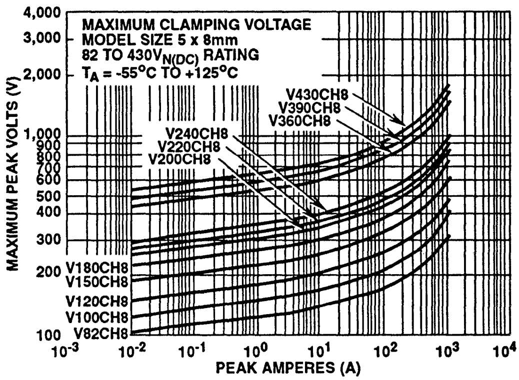


FIGURE 4. CLAMPING VOLTAGE FOR V82CH8 - V430CH8

Pulse Rating Curves

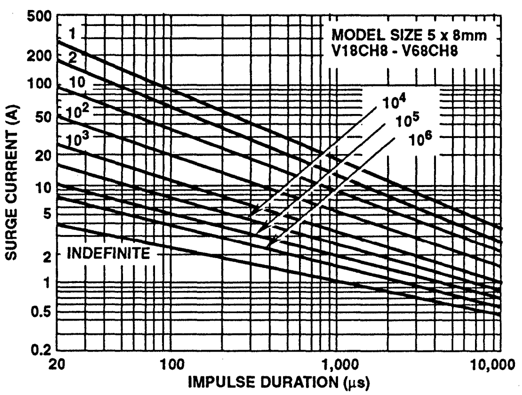


FIGURE 5. SURGE CURRENT RATING CURVES FOR V18CH8 - V68CH8

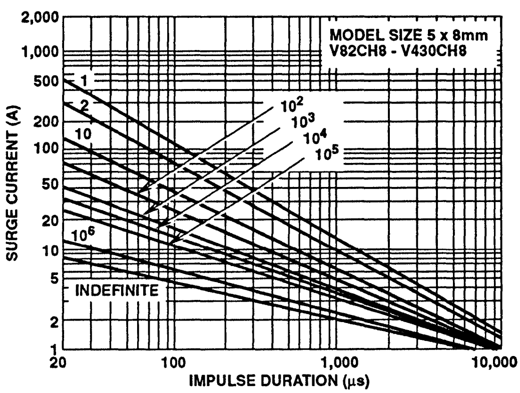
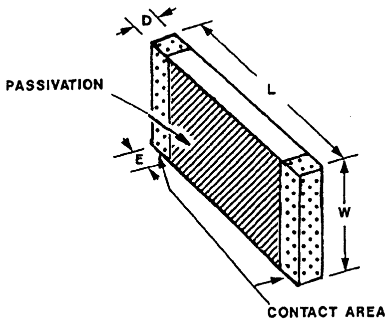


FIGURE 6. SURGE CURRENT RATING CURVES FOR V82CH8 - V430CH8

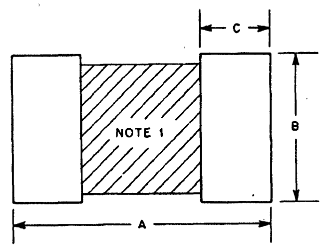
NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

Packaging



SYMBOL	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
D	—	0.080	—	2.03
E	0.016	0.050	0.41	1.27
L	0.311	0.335	7.90	8.51
W	0.185	0.207	4.70	5.26

SUGGESTED MOUNTING PAD OUTLINE



SYMBOL	INCHES	MILLIMETERS
A	0.402	10.21
B	0.216	5.50
C	0.087	2.21

NOTE 1: Avoid metal runs in this area.
Soldering recommendations:
Material - 62/36/2 Sn/Pb/Ag or equivalent
Temperature - 230°C max., 5 sec. max.
Flux - R.M.A.

Standard Packaging:
CH-series varistors are always shipped in tape and reel, therefore, the part number need not be changed; e.g., V47CH8. The standard 13-inch reel utilized contains 4000 pieces.

TAPE AND REEL SPECIFICATIONS

- Conforms to EIA-481, revision A
- Can be supplied to IEC publication 286-3

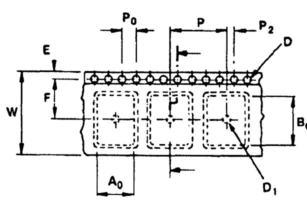
Special Packaging:

Option 1

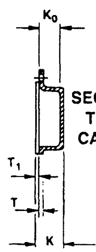
7-inch reels containing 1000 pieces are available. To order 7-inch reels add a T suffix to the part number; e.g., V47CH8T.

Option 2

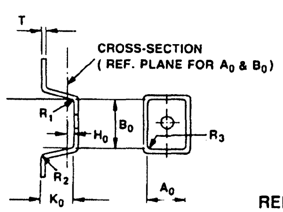
For small quantities (less than 100 pieces) the units are shipped bulk pack. To order, add a S suffix to the part number; e.g., V47CH8S.



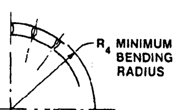
PLAN VIEW OF STRIP



SECTION THRU CAVITY



CAVITY DETAILS



REELED RADIUS DETAILS

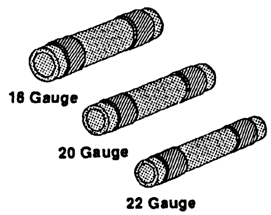
SYMBOL	PARAMETER	SIZE (mm)
B_0	CAVITY LENGTH	8.5 ± 0.1
A_0	CAVITY WIDTH	5.5 ± 0.1
K_0	CAVITY DEPTH	2.0 MIN.
H_0	REF. PLANE FOR A_0 AND B_0	$0.3^{+0.10}_{-0.05}$
R_1, R_2, R_3	TAPE CAVITY RADII	0.5 MAX.
T	CARRIER TAPE THICKNESS	1.0 MAX.
T_1	COVER TAPE THICKNESS	0.1 MAX.
E	SPROCKET HOLE FROM EDGE	1.75 ± 0.1
P_0	SPROCKET HOLE PITCH	4.0 ± 0.1
D	SPROCKET HOLE DIAMETER	$1.5^{+0.1}_{-0.0}$
P_2	HOLE CENTRE TO COMPONENT CENTRE	2.0 ± 0.15
R_4	MIN. BENDING RADIUS	40.0 MIN.
D_1	EJECTION HOLE DIA.	1.5 MIN.
K	OVERALL THICKNESS	3.0 MAX.
P	PITCH OF COMPONENT	8.0 ± 0.1
F	SPROCKET HOLE TO EJECTION HOLE	7.5 ± 0.1
W	CARRIER TAPE WIDTH	16.0 ± 0.3

HARRIS SEMICONDUCTOR

CP Series

August 1993

Connector Pin Metal-Oxide Varistors



CP SERIES

Features

- Unique Coaxial Design and Mounting Arrangement
- Self Contained Tubular Construction Requires No Leads or Packages
- Adds Negligible Weight and Space When Assembled Into Standard Connectors
- Wide Operating Voltage Range $V_{M(AC)RMS}$ .... 6V to 150V
- Can be Used with 16, 20, or 22 Gauge Connector Pins

Description

CP series transient surge suppressors are connector pin metal-oxide varistors that utilize a self contained tubular construction requiring no leads or packages. These varistors are available in a wide range of voltage ratings from 6 to 150 volts $V_{M(AC)RMS}$, and have dimensions allowing them to be used with 16, 20, or 22 gauge connector pins. The unique coaxial mounting arrangement of these tubular varistors allow them to become part of a transmission line; thus, inductive lead effects are eliminated.

Absolute Maximum Ratings For ratings of individual members of a series, see Device Ratings and Characteristics chart

	CP SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	6 to 150	V
DC Voltage Range ($V_{M(DC)}$)	8 to 150	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20µs Current Wave (See Figure 2)	250 to 500	A
Single Pulse Energy Range		
For 10/1000µs Current Wave (W_{TM})	1.5 to 5	J
Operating Ambient Temperature Range (T_A)	-55 to +125	°C
Storage Temperature Range (T_{STG})	-55 to +150	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

MODEL NUMBER	PART SIZE	MAXIMUM RATINGS (+125°C) CONTINUOUS RMS VOLT. $V_{M(AC)}$ (V)	DC VOLT. $V_{M(DC)}$ (V)	TRANSIENT ENERGY (10/1000ms) W_{TM} (J)	PEAK CURRENT (8/20µs) I_{TM} (A)	CHARACTERISTICS (+25°C) VARISTOR VOLTAGE AT 1mA DC TEST CURRENT MIN (V)	$V_{N(DC)}$ (V)	MAX (V)	MAX. CLAMPING VOLTAGE V_C AT TEST CURRENT (8/20µs) V_C (V)	I_P (A)	CAPACITANCE AT f = 1MHz MIN (pF)	MAX (pF)
V8CP22	22B	6.0	8.0	1.5	250	12.5	16.0	19.5	34.0	10	1600	2750
V14CP22	22B	10.0	14.0	1.5	250	18.5	22.0	25.5	42.0	10	1600	2750
V31CP22	22B	25.0	31.0	1.5	250	35.0	39.0	48.0	85.0	5	450	1350
V38CP22	22B	30.0	38.0	1.5	250	42.0	47.0	58.0	100.0	5	450	1250
V130CP22	22A	130.0	130.0	2.4	300	184.0	200.0	228.0	375.0	5	150	350
V150CP22	22A	150.0	150.0	2.4	300	212.0	240.0	268.0	430.0	5	100	300
V31CP20	20B	25.0	31.0	2.0	300	35.0	39.0	48.0	85.0	10	700	2000
V38CP20	20B	30.0	38.0	2.0	300	42.0	47.0	58.0	100.0	10	650	1800
V130CP20	20A	130.0	130.0	3.0	400	184.0	200.0	228.0	375.0	10	150	400
V150CP20	20A	150.0	150.0	3.0	400	212.0	240.0	268.0	430.0	10	100	350
V38CP16	16A	30.0	38.0	3.0	350	42.0	47.0	58.0	100.0	20	1000	2500
V130CP16	16A	130.0	130.0	5.0	500	184.0	200.0	228.0	375.0	20	250	700
V150CP16	16A	150.0	150.0	5.0	500	212.0	240.0	268.0	430.0	20	200	650

Average power dissipation of transients not to exceed 250mW, 300mW and 350mW for sizes 22AWG, 20AWG and 16AWG, respectively.

MODEL NUMBER	PART SIZE	LEAKAGE CURRENT AT $V_{T(DC)}$ +25°C I_L TYP (µA)	I_L MAX (µA)	+125°C I_L TYP (µA)	I_L MAX (µA)	$V_{T(DC)}$ (V)
V8CP22	22B	0.5	5.0	5.0	50	8
V14CP22	22B	0.5	5.0	5.0	50	14
V31CP22	22B	0.5	5.0	5.0	50	28
V38CP22	22B	0.5	5.0	5.0	50	36
V130CP22	22A	0.5	5.0	25.0	100	130
V150CP22	22A	0.5	5.0	25.0	100	150
V31CP20	20B	0.5	5.0	5.0	50	28
V38CP20	20B	0.5	5.0	5.0	50	36
V130CP20	20A	0.5	5.0	25.0	100	130
V150CP20	20A	0.5	5.0	25.0	100	150
V38CP16	16A	0.5	5.0	5.0	50	36
V130CP16	16A	0.5	5.0	25.0	100	130
V150CP16	16A	0.5	5.0	25.0	100	150

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

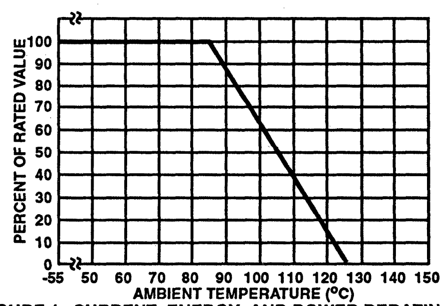
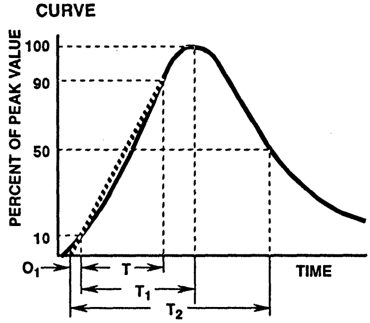


FIGURE 1. CURRENT, ENERGY, AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave

T = Time From 10% to 90% of Peak

T_1 = Virtual Front Time = 1.25 • t

T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20µs Current Waveform:

8µs = T_1 = Virtual Front Time

20µs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

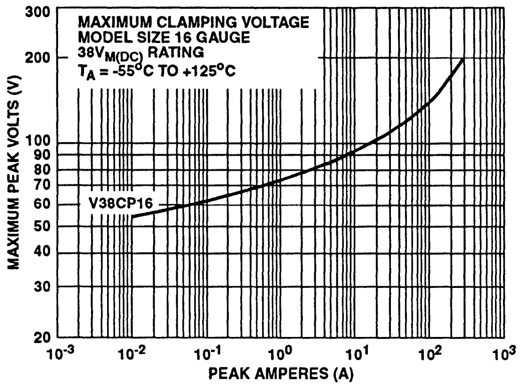


FIGURE 3. CLAMPING VOLTAGE FOR V38CP16

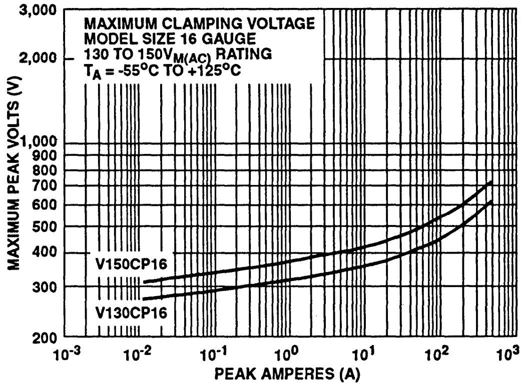


FIGURE 4. CLAMPING VOLTAGE FOR V130CP16 - V150CP16

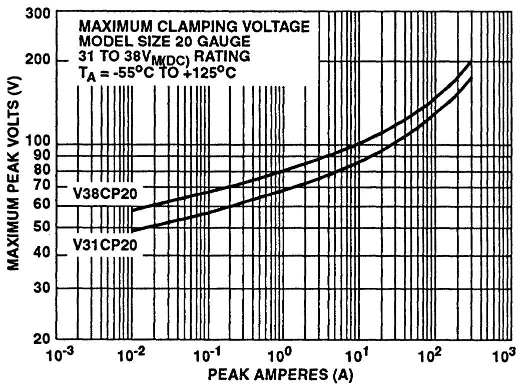


FIGURE 5. CLAMPING VOLTAGE FOR V31CP20 - C38CP20

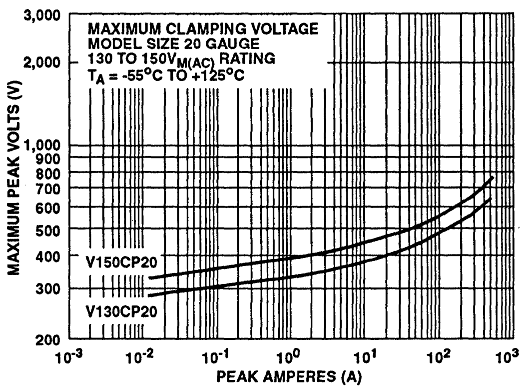


FIGURE 6. CLAMPING VOLTAGE FOR V130CP20 - V150CP20

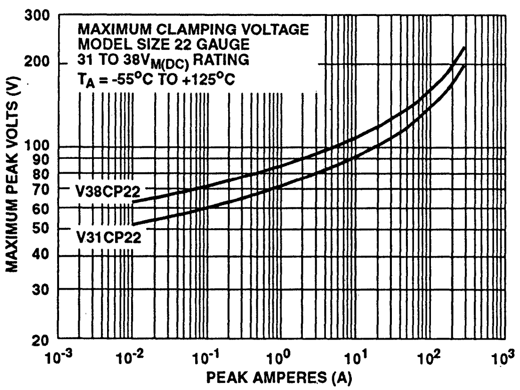


FIGURE 7. CLAMPING VOLTAGE FOR V31CP22 - V38CP22

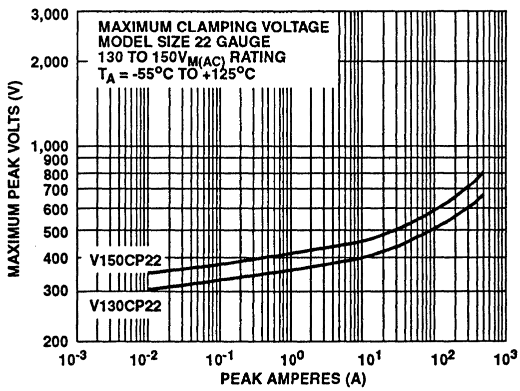


FIGURE 8. CLAMPING VOLTAGE FOR V130CP22 - V150CP22

Transient V-I Characteristics Curves (Continued)

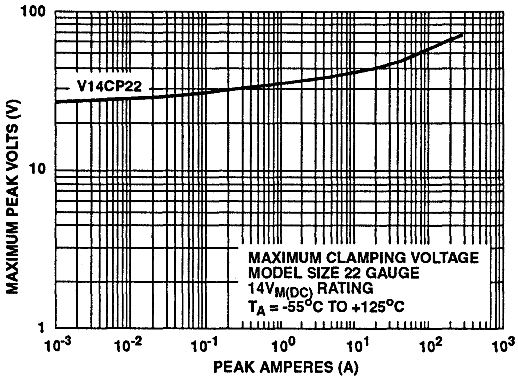


FIGURE 9. CLAMPING VOLTAGE FOR V14CP22

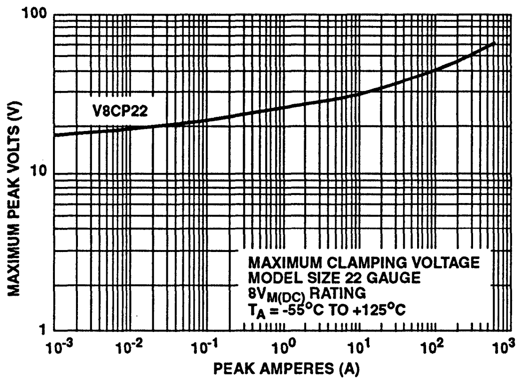


FIGURE 10. CLAMPING VOLTAGE FOR V8CP22

Pulse Rating Curves

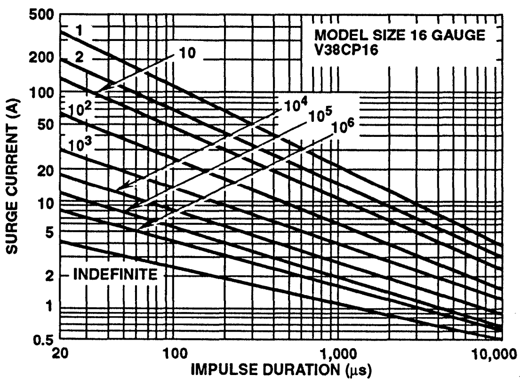


FIGURE 11. SURGE CURRENT RATING CURVES FOR V38CP16

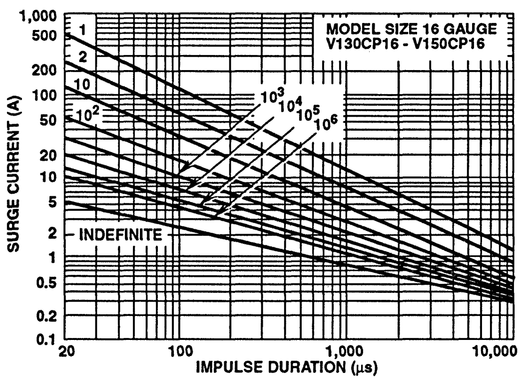


FIGURE 12. SURGE CURRENT RATING CURVES FOR V130CP16 - V150CP16

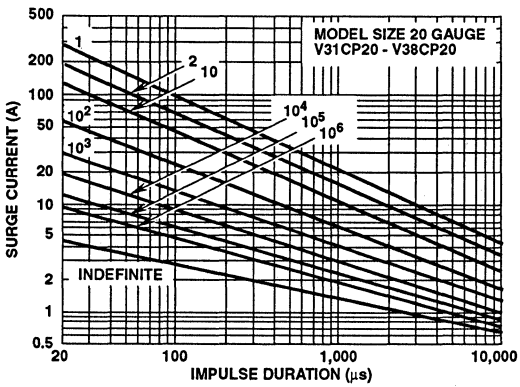


FIGURE 13. SURGE CURRENT RATING CURVES FOR V31CP20 - V38CP20

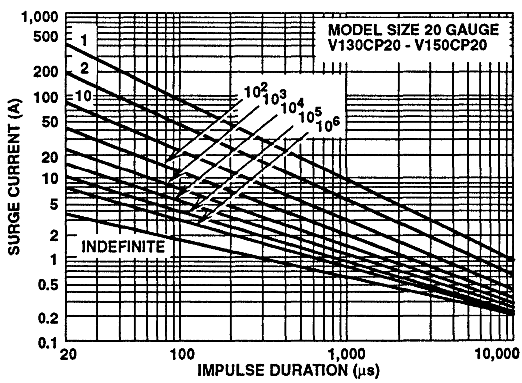


FIGURE 14. SURGE CURRENT RATING CURVES FOR V130CP20 - V150CP20

Pulse Rating Curves (Continued)

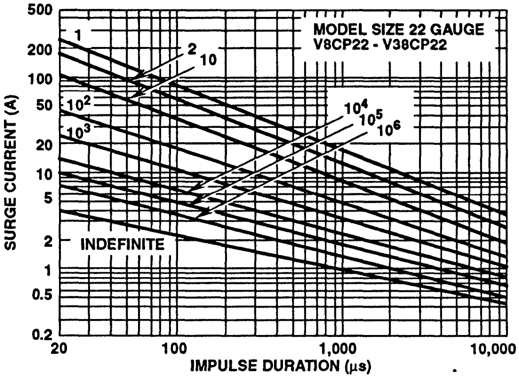


FIGURE 15. SURGE CURRENT RATING CURVES FOR V8CP22 - V38CP22

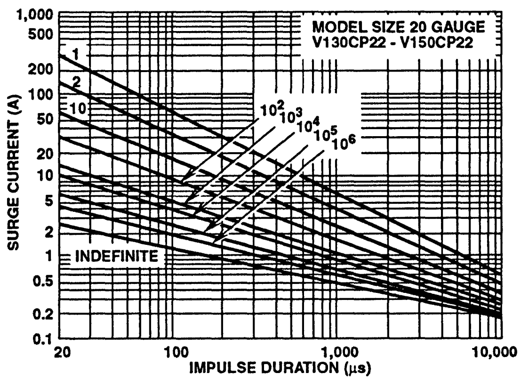
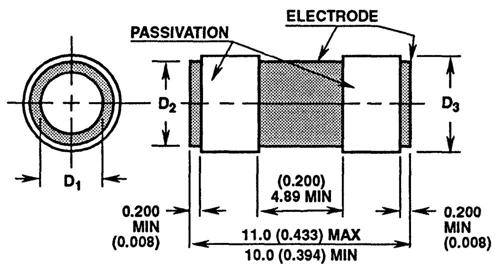


FIGURE 16. SURGE CURRENT RATING CURVES FOR V130CP22 - V150CP22

NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

Packaging



DIMENSIONS

PART SIZE	INTERNAL DIAMETER (D_1) MIN	INTERNAL DIAMETER (D_1) MAX	EXTERNAL DIAMETER (D_2) MIN	EXTERNAL DIAMETER (D_2) MAX	PASSIVATION DIAMETER (D_3) MIN	PASSIVATION DIAMETER (D_3) MAX
22A	0.86 (0.034)	1.02 (0.040)	1.73 (0.068)	1.88 (0.074)	1.83 (0.072)	1.98 (0.078)
22B	0.86 (0.034)	1.25 (0.049)	1.73 (0.068)	1.88 (0.074)	1.83 (0.072)	1.98 (0.078)
20A	1.09 (0.043)	1.25 (0.049)	2.08 (0.082)	2.39 (0.094)	2.18 (0.086)	2.54 (0.100)
20B	1.09 (0.043)	1.83 (0.072)	2.08 (0.082)	2.39 (0.094)	2.18 (0.086)	2.54 (0.100)
16A	2.27 (0.090)	2.41 (0.095)	3.40 (0.134)	3.56 (0.140)	3.50 (0.138)	3.56 (0.144)

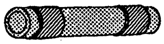
NOTE: Dimensions in millimeters and (inches)

HARRIS SEMICONDUCTOR

CS Series

August 1993

Connector Pin Metal-Oxide Varistors



CS SERIES

Features

- **Unique Coaxial Design and Mounting Arrangement**
- **Wide Operating Voltage Range $V_{M(DC)}$ .... 8V to 38V**
- **Self Contained Tubular Construction; Requires No Leads or Packages**
- **New Reduced Length; Less Than Half the Length of Standard CP Series**

Description

CS series transient surge suppressors are connector pin metal-oxide varistors that utilize a self contained tubular construction requiring no leads or packages. They are designed to provide transient surge protection in connector/filter applications in aerospace, automotive, computer and associated industries. These varistors are available in a wide range of voltage rating from $8V_{DC}$ to $38V_{DC}$.

The CS series of connector suppressors are of similar package construction to the Harris CP series, but differ in size, ratings and characteristics. They offer the advantage of small size and light weight; key benefits in connector assemblies. The unique coaxial mounting arrangement of the CS series allows them to become an integral part of a transmission line; thus, inductive lead effects are eliminated.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	CS SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
DC Voltage Range ($V_{M(DC)}$)	8 to 38	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20μs Current Wave (See Figure 2)	80 to 100	A
Single Pulse Energy Range (W_{TM})		
For 10/1000μs Current Wave	0.5	J
Operating Ambient Temperature Range (T_A)	-55 to +125	°C
Storage Temperature Range (T_{STG})	-55 to +150	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

File Number **2972.1**

Device Ratings and Characteristics

MODEL NUMBER	PART SIZE	MAXIMUM RATINGS (+125°C) CONTINUOUS DC VOLTAGE $V_{M(DC)}$ (V)	TRANSIENT ENERGY (10/1000µs) W_{TM} (V)	TRANSIENT PEAK CURRENT (8/20µs) I_{TM} (A)	CHARACTERISTICS (+25°C) VARISTOR VOLTAGE AT 1mA DC TEST CURRENT $V_{N(DC)}$ MIN (V)	$V_{N(DC)}$ MAX (V)	MAXIMUM CLAMPING VOLTAGE V_C AT 10A (8/20µs) V_C (V)	CAPACITANCE AT f = 1MHz C MIN (pF)	C MAX (pF)
V8CS22	22B	8	0.5	80	13.5	19.5	36	830	1400
V14CS22	22B	14	0.5	80	18.5	25.5	44	675	1125
V18CS22	22B	18	0.5	80	22.5	27.9	47	600	1100
V22CS22	22B	22	0.5	100	27.5	34.5	57	540	950
V26CS22	22B	26	0.5	100	29.5	36.5	68	510	870
V31CS22	22B	31	0.5	100	35.0	48.0	85	450	800
V38CS22	22B	38	0.5	100	42.0	58.0	100	350	700

NOTE: Average power dissipation of transients not to exceed 200mW

MODEL NUMBER	LEAKAGE CURRENT AT $V_{M(DC)}$ +25°C I_L TYP (µA)	+25°C I_L MAX (µA)	+125°C I_L TYP (µA)	+125°C I_L MAX (µA)
V8CS22	0.5	5.0	5.0	50
V14CS22	0.5	5.0	5.0	50
V18CS22	0.5	5.0	5.0	50
V22CS22	0.5	5.0	5.0	50
V26CS22	0.5	5.0	5.0	50
V31CS22	0.5	5.0	5.0	50
V38CS22	0.5	5.0	5.0	50

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore is not a necessary requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts for average power dissipation.

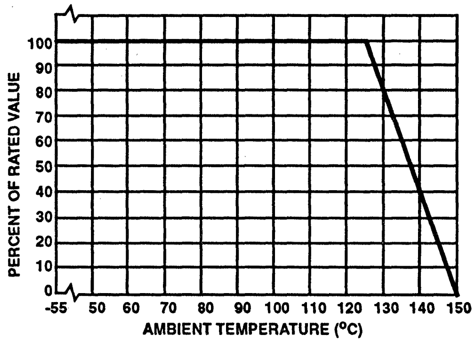
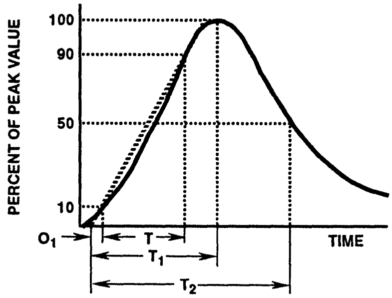


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin Of Wave
T = Time From 10% To 90% Of Peak
T_1 = Virtual Front Time = 1.25 x T
T_2 = Virtual Time To Half Value (Impulse Duration)

EXAMPLE:
For an 8/20µs Current Waveform:
8µs = T_1 = Virtual Front Time
20µs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

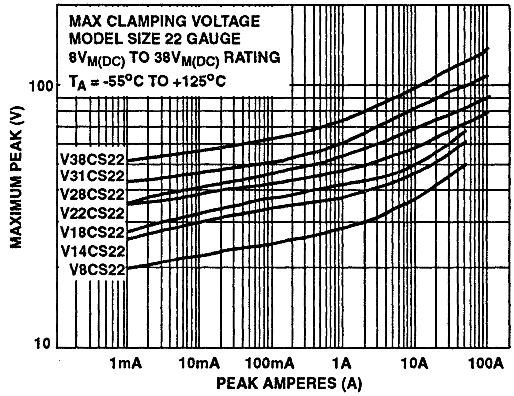
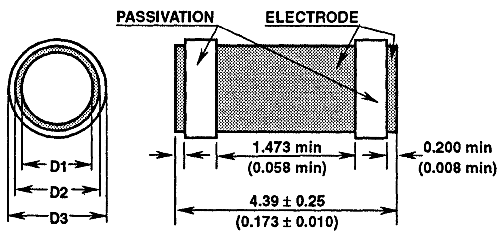


FIGURE 4. CLAMPING VOLTAGE FOR V8CS22 - V38CS22

Packaging



"CS" DIMENSION OUTLINE

DIMENSIONS

PART SIZE	INTERNAL DIAMETER (D1)		EXTERNAL DIAMETER (D2)		PASSIVATION DIAMETER (D3)	
	MIN	MAX	MIN	MAX	MIN	MAX
22B	0.86 (0.034)	1.25 (0.049)	1.73 (0.068)	1.88 (0.074)	1.83 (0.072)	1.98 (0.078)

NOTE: Dimensions in millimeters and (inches)

NOTE:

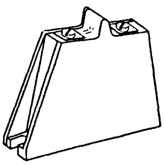
1. The CS series of connector pin varistors may also be obtained in gauge sizes 16A, 20A, 20B, and 22A AWG, and with continuous operating voltages of up to 100 volts dc. For information on availability of different voltages and sizes, please contact Harris Semiconductor Power Marketing.

HARRIS SEMICONDUCTOR

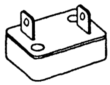
DA/DB Series

August 1993

Industrial High Energy Metal-Oxide Varistors



DA SERIES



DB SERIES

Features

- Recognized as "Transient Voltage Surge Suppressors", UL File #E75961 to Std. 1449
- High Energy Absorption Capability W_{TM} .... Up To 1050J
- Wide Operating Voltage Range $V_{M(AC)RMS}$ .... 130V to 750V
- Rigid Terminals for Secure Wire Contact (DA Series)
- Case Design Provides Complete Electrical Isolation of Disc Subassembly
- Large Diameter Disc 40mm

Description

DA and DB series transient surge suppressors are heavy-duty industrial metal-oxide varistors designed to provide surge protection for motor controls and power supplies used in oil-drilling, mining, and transportation equipment. Possible voltage surges in their ac power supplies could cause product failure and the subsequent faulty operation of these systems.

These UL-recognized varistors have identical ratings and characteristics but differ in case construction to provide flexibility in equipment designs.

DA series devices feature rigid terminals to insure secure wire contacts. Both the DA and DB series feature improved creep and strike distance capability to minimize breakdown along the package surface design that provides complete electrical isolation of the disc subassembly.

Absolute Maximum Ratings For ratings of individual members of a series, see Device Ratings and Characteristics chart

	DA/DB SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	130 to 750	V
DC Voltage Range ($V_{M(DC)}$)	175 to 970	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20μs Current Wave (See Figure 2)	30,000 to 40,000	A
Single Pulse Energy Range		
For 10/1000μs Current Wave (W_{TM})	270 to 1050	J
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C
Hi-Pot Encapsulation (Isolation Voltage Capability) (Dielectric must withstand indicated DC voltage for one minute per MIL-STD 202, Method 301)	5000	V
Insulation Resistance	1000	MΩ

File Number 2189.2

Device Ratings and Characteristics

Series DA and DB Varistors are listed under UL file #E75961 as a UL recognized component.

MODEL NUMBER		MAXIMUM RATINGS (+85°C)				CHARACTERISTICS (+25°C)				
		CONTINUOUS		TRANSIENT		VARISTOR VOLTAGE AT 1mA DC TEST CURRENT			MAX CLAMPING VOLT V_C AT 200A CURRENT (8/20µs)	TYPICAL CAPACI-TANCE
		RMS VOLT-AGE	DC VOLT-AGE	ENERGY (10/1000µs)	PEAK CURRENT (8/20µs)					
		$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM}	MIN	$V_{N(DC)}$	MAX	V_C	f = 1MHz
DA	DB	(V)	(V)	(J)	(A)	(V)	(V)	(V)	(V)	(pF)
V131DA40	V131DB40	130	175	270	30000	184	200	228	345	10000
V151DA40	V151DB40	150	200	300	30000	212	240	268	405	8000
V251DA40	V251DB40	250	330	370	30000	354	390	429	650	5000
V271DA40	V271DB40	275	369	400	30000	389	430	473	730	4500
V321DA40	V321DB40	320	420	460	30000	462	510	539	830	3800
V421DA40	V421DB40	420	560	600	40000	610	680	748	1130	3000
V481DA40	V481DB40	480	640	650	40000	670	750	825	1240	2700
V511DA40	V511DB40	510	675	700	40000	735	820	910	1350	2500
V571DA40	V571DB40	575	730	770	40000	805	910	1000	1480	2200
V661DA40	V661DB40	660	850	900	40000	940	1050	1160	1720	2000
V751DA40	V751DB40	750	970	1050	40000	1080	1200	1320	2000	1800

NOTE: Average power dissipation of transients not to exceed 2.0W.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

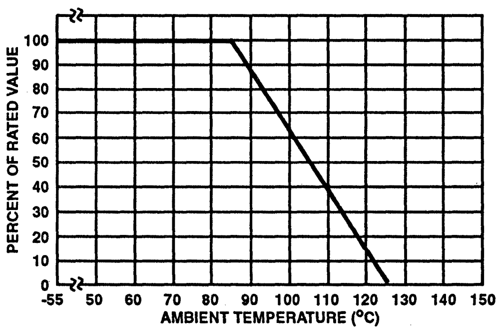
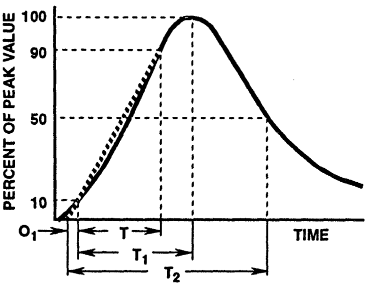


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20µs Current Waveform:
8µs = T_1 = Virtual Front Time
20µs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

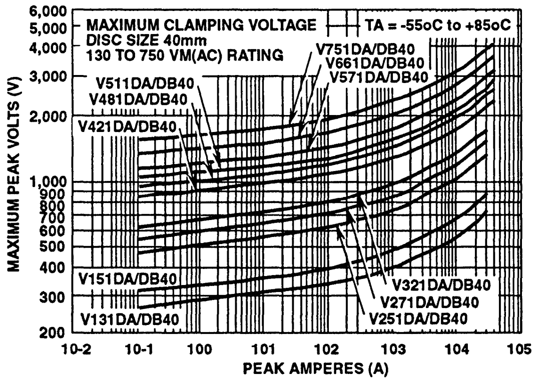


FIGURE 3. CLAMPING VOLTAGE FOR V131DA40, V131DB40 - V751DA40, V751DB40

Pulse Rating Curves

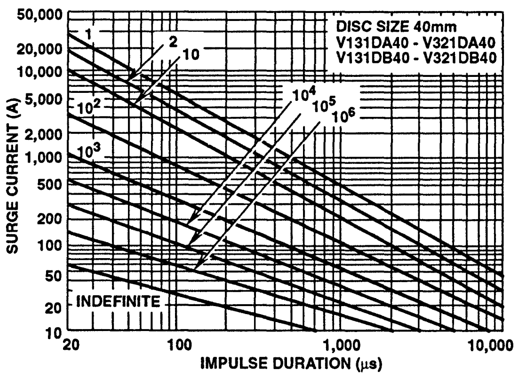


FIGURE 4. SURGE CURRENT RATING CURVES FOR V131DA40, V131DB40 - V321DA40, V321DB40

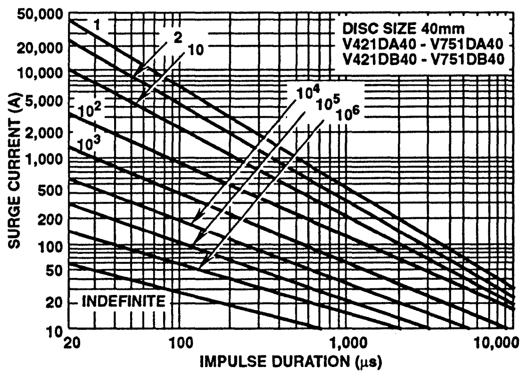
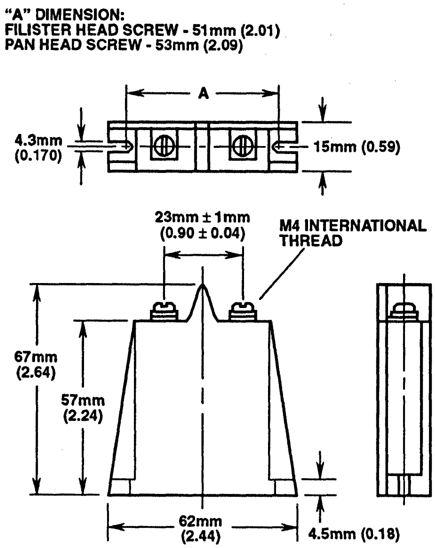


FIGURE 5. SURGE CURRENT RATING CURVES FOR V421DA40, V421DB40 - V751DA40

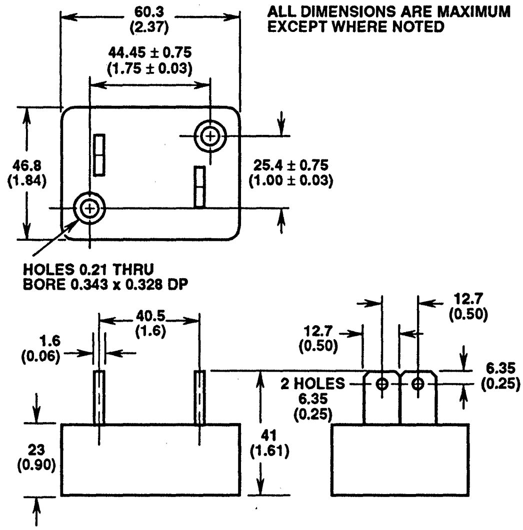
NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

Packaging

DA SERIES



DB SERIES

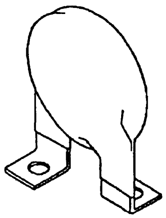


Dimensions in millimeters and (inches).

HA Series

August 1993

Industrial High Energy Metal-Oxide Varistors



HA SERIES

Features

- Recognized as "Transient Voltage Surge Suppressors", UL File #E75961 to Std. 1449
- Recognised as "Transient Voltage Surge Suppressors", CSA File #LR91788 to Standard C22.2 No. 1-M1981
- Wide Operating Voltage Range $V_{M(AC)RMS}$ . . . . 130V to 750V
- Two Model Sizes Available . . . . 32mm and 40mm
- High Energy Absorption Capability . . . . W_{TM} = 200J to 1050J
- High Peak Pulse Current Capability . . . . . . I_{TM} = 25,000A to 40,000A
- Rigid Terminals for Secure Mounting
- Available in Clipped Version for Through Hole Board Mounting - Designation "HC"

Description

HA series transient surge suppressors are industrial high energy metal-oxide varistors. They are designed to provide secondary surge protection in the outdoor and service entrance environment (distribution panels), in computers, and also in industrial applications for motor controls and power supplies used in the oil-drilling, mining, and transportation fields. Possible voltage transients in the ac power network could cause product failure and the subsequent faulty operation of these systems.

The HA series of industrial varistors have similar package construction but differ in size, (32mm and 40mm), ratings and characteristics. The design of the HA series of metal oxide varistors provide rigid terminals to insure secure mounting. Also available in a clipped version for through hole board placement - designation "HC".

Absolute Maximum Ratings For ratings of individual members of a series, see Device Ratings and Characteristics chart

	HA SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	130 to 750	V
DC Voltage Range ($V_{M(DC)}$)	175 to 970	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20μs Current Wave (See Figure 2)	25,000 to 40,000	A
Single Pulse Energy Range		
For 10/1000μs Current Wave (W_{TM})	200 to 1050	J
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C
Hi-Pot Encapsulation (Isolation Voltage Capability) (Dielectric must withstand indicated DC voltage for one minute per MIL-STD 202, Method 301)	2500	V
Insulation Resistance	1000	MΩ

Device Ratings and Characteristics

HA Series varistors are listed under CSA File #LR91788 as a recognized component.
HA Series varistors are listed under U.L. File #E75961 as a recognized component.

MODEL NUMBER	MAXIMUM RATINGS (+85°C)				CHARACTERISTICS (+25°C)				
	CONTINUOUS		TRANSIENT						
	RMS VOLTAGE	DC VOLTAGE	ENERGY (10/1000μs)	PEAK CURRENT (8/20μs)	VARISTOR VOLTAGE AT 1 mA DC TEST CURRENT			MAXIMUM CLAMPING VOLTAGE (V_C) AT 200 Amps (8/20μs)	TYPICAL CAPACITANCE AT f = 1MHz
	$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM}	MIN	$V_{N(DC)}$	MAX	V_C	C
	(V)	(V)	ENERGY	(A)	(V)	(V)	(V)	(V)	(pF)
V131HA32	130	175	200	25000	184	200	228	350	4700
V131HA40	130	175	270	30000	184	200	228	345	10000
V151HA32	150	200	220	25000	212	240	268	410	4000
V151HA40	150	200	300	30000	212	240	268	405	8000
V251HA32	250	330	330	25000	354	390	429	650	2500
V251HA40	250	330	370	40000	354	390	429	630	5000
V271HA32	275	369	360	25000	389	430	473	710	2200
V271HA40	275	369	400	40000	389	430	473	690	4500
V321HA32	320	420	390	25000	462	510	539	845	1900
V321HA40	320	420	460	40000	462	510	539	825	3800
V421HA32	420	560	400	25000	610	680	748	1120	1500
V421HA40	420	560	600	40000	610	680	748	1100	3000
V481HA32	480	640	450	25000	670	750	825	1290	1300
V481HA40	480	640	650	40000	670	750	825	1230	2700
V511HA32	510	675	500	25000	735	820	910	1355	1200
V511HA40	510	675	700	40000	735	820	910	1295	2500
V571HA32	575	730	550	25000	805	910	1000	1570	1100
V571HA40	575	730	770	40000	805	910	1000	1480	2200
V661HA32	660	850	600	25000	940	1050	1160	1820	1000
V661HA40	660	850	900	40000	940	1050	1160	1720	2000
V751HA32	750	970	700	25000	1080	1200	1320	2050	800
V751HA40	750	970	1050	40000	1080	1200	1320	2000	1800

NOTE: Average power dissipation of transients not to exceed 1.5W and 2.0W for model sizes 32mm and 40mm, respectively.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore is not a necessary requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts for average power dissipation.

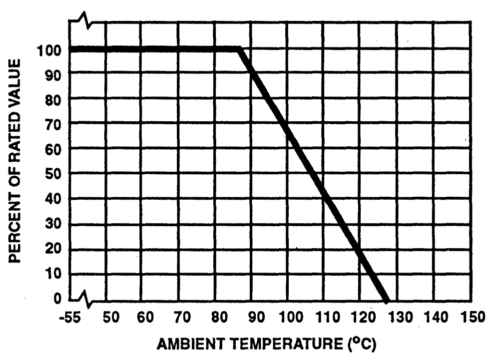
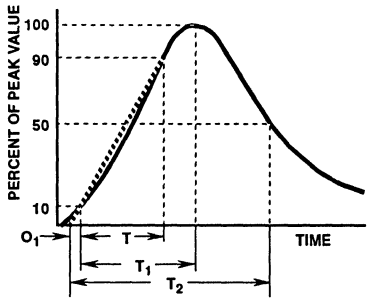


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20µs Current Waveform:
8µs = T_1 = Virtual Front Time
20µs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT WAVEFORM

Transient V-I Characteristics Curves

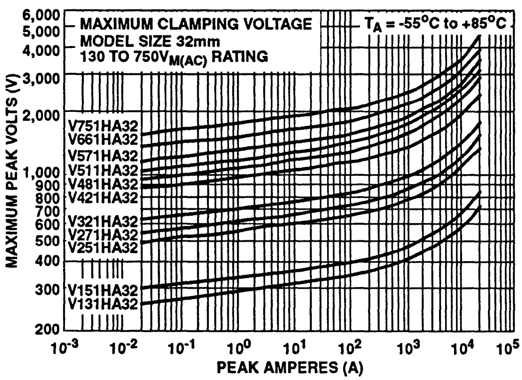


FIGURE 3. CLAMPING VOLTAGE FOR V131HA32 - V751HA32

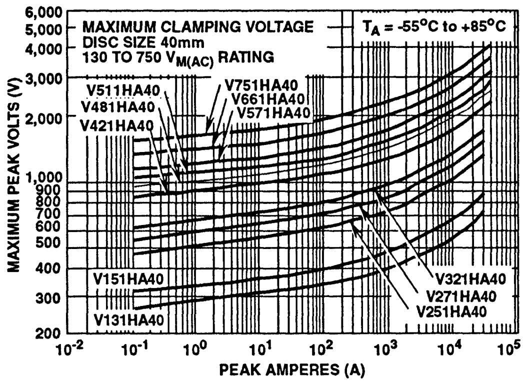


FIGURE 4. CLAMPING VOLTAGE FOR V131HA40 - V751HA40

Pulse Rating Curves

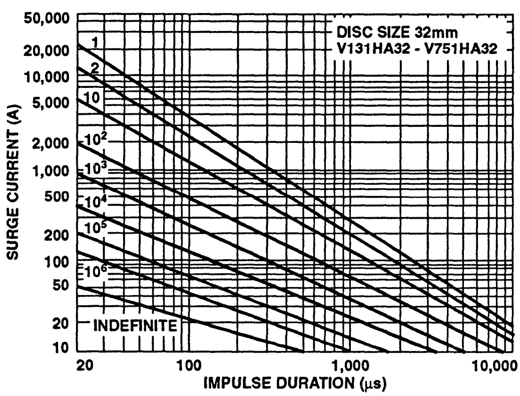


FIGURE 5. SURGE CURRENT RATING CURVES FOR V131HA32 - V751HA32

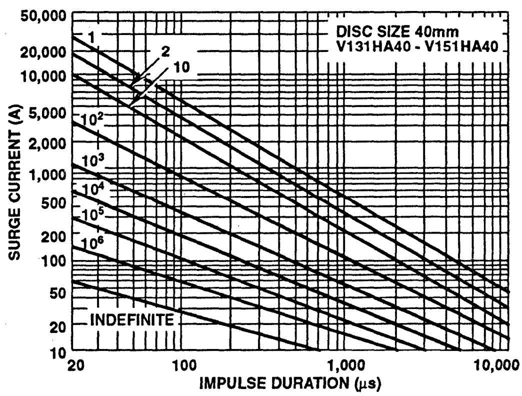


FIGURE 6. SURGE CURRENT RATING CURVES FOR V131HA40 - V151HA40

Pulse Rating Curves (Continued)

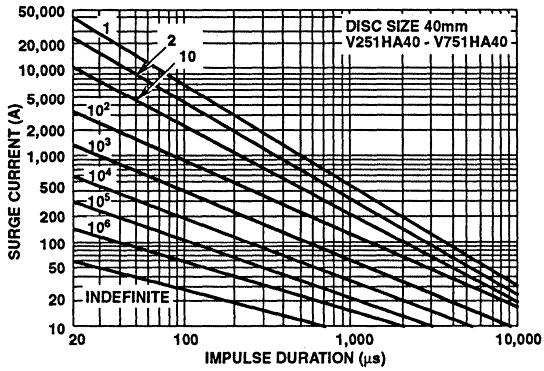
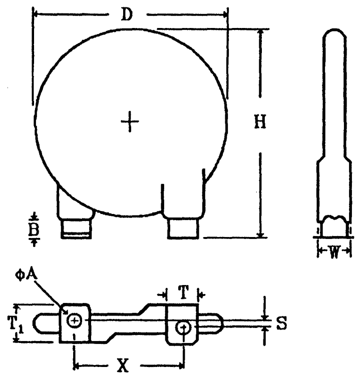


FIGURE 7. SURGE CURRENT RATING CURVES FOR V251HA40 - V751HA40

Packaging



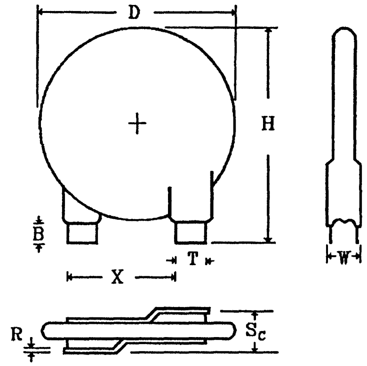


TABLE 1. HA SERIES OUTLINE SPECIFICATIONS (Dimensions in Millimeters)

	D	H	B	X	ØA	T	T1	S
	MAX	MAX	MIN	NOM	MAX	NOM	NOM	OFFSET
HA32	35.5	52.00	5.0	25	4.20	9.30	10.4	Depends on Device Voltage (See Table 2)
HA40	42.5	57.00	5.0	25	4.20	9.30	10.4	

TABLE 3. HC SERIES OUTLINE SPECIFICATIONS (Dimensions in Millimeters)

	D	H	B	X	T	S_C
	MAX	MAX	MIN	NOM	NOM	OFFSET
HC32	35.5	52.00	5.0	25	9.30	Depends on Device Voltage (See Table 4)
HC40	42.5	57.00	5.0	25	9.30	

TABLE 2. HA SERIES MAXIMUM THICKNESS AND TERMINAL OFFSETS (Dimensions in Millimeters)

VOLTAGE	THICKNESS "W"		DIMENSION "S" (±1mm)	
	HA32	HA40	HA32	HA40
V131 - V321	9.00	9.00	3.90	3.90
V421 - V511	10.30	11.10	2.60	1.80
V571 - V751	12.00	13.00	1.00	0.00

TABLE 4. HC SERIES MAXIMUM THICKNESS AND TERMINAL OFFSETS (Dimensions in Millimeters)

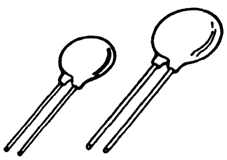
VOLTAGE	THICKNESS "W"		DIMENSION "S_C" (±1mm)	
	HC32	HC40	HC32	HC40
V131 - V321	9.00	9.00	6.00	6.00
V421 - V511	10.30	11.10	7.30	8.10
V571 - V751	12.00	13.00	8.90	10.00

HARRIS SEMICONDUCTOR

LA Series

UL Recognized Radial Lead Metal-Oxide Varistors for Line Voltage Operation

August 1993



7mm, 10mm, 14mm, 20mm
LA SERIES

Features

- **Recognized as "Transient Voltage Surge Suppressors", UL File #E75961 to Standard 1449**
- **Recognized as "Across-The-Line Components", UL File #E56529 to Standard 1414**
- **Recognized as "Transient Voltage Surge Suppressors", CSA File #LR91788 to Standard C22.2 No. 1 - M1981**
- **High Energy Absorption Capability W_{TM} .... Up to 360J**
- **Wide Operating Voltage Range $V_{M(AC)RMS}$ .... 130V to 750V**
- **Line-Voltage Operation - Can be Operated Directly Across 120V, 240V, etc., AC Power Lines**
- **Available in Tape and Reel for Automatic Insertion Equipment**

Description

LA series transient surge suppressors are radial-lead varistors that can be operated continuously across AC power lines. These UL recognized varistors "across-the-line" components, because of their radial lead construction, require very little mounting space. This feature is particularly important in compact, hard wired system designs.

LA series varistors are available in four model sizes: 7mm, 10mm, 14mm and 20mm; and have a $V_{M(AC)RMS}$ voltage range from 130V to 1000V, and an energy absorption capability up to 360J. Some LA series model numbers are available with two clamping voltage selections, designated by a model number prefix of either A or B. The "A" selection is the standard model; the "B" selection provides a tighter clamping voltage.

Absolute Maximum Ratings
For ratings of individual members of a series, see Device Ratings and Characteristics chart

	"C" SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	130 to 1000	V
DC Voltage Range ($V_{M(DC)}$)	175 to 1200	V
Transients:		
Peak Pulse Current (I_{TM})		
For 8/20µs Current Wave (See Figure 2)	1200 to 6500	A
Single Pulse Energy Range		
For 10/1000µs Current Wave (W_{TM})	11 to 360	J
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C
Hi-Pot Encapsulation (Isolation Voltage Capability) (Dielectric must withstand indicated DC voltage for one minute per MIL-STD 202, Method 301)	2500	V
Insulation Resistance	1000	MΩ

Device Ratings and Characteristics

Series LA Varistors are listed under UL file #E75961 and E56529 as a recognized component.
Series LA Varistors are listed under CSA file #LR91788 as a recognized component.

MODEL NUMBER	MODEL SIZE DISC DIA. (mm)	DEVICE MARKING	MAXIMUM RATINGS (+85°C) CONTINUOUS RMS VOLTAGE $V_{M(AC)}$ (V)	CONTINUOUS DC VOLTAGE $V_{M(DC)}$ (V)	TRANSIENT ENERGY (10/1000µs) W_{TM} (J)	TRANSIENT PEAK CURRENT (8/20µs) I_{TM} (A)	CHARACTERISTICS (+25°C) VARISTOR VOLTAGE AT 1mA DC TEST CURRENT MIN (V)	$V_{N(DC)}$ (V)	MAX (V)	MAXIMUM CLAMPING VOLTAGE V_C AT TEST CURRENT (8/20µs) V_C (V)	I_P (A)	TYPICAL CAPACITANCE f = 1MHz (pF)
V130LA1	7	1301	130	175	11	1200	184	200	255	390	10	180
V130LA2	7	1302	130	175	11	1200	184	200	228	340	10	180
V130LA5	10	1305	130	175	20	2500	184	200	228	340	25	450
V130LA10A	14	130L10	130	175	38	4500	184	200	228	340	50	1000
V130LA20A	20	130L20	130	175	70	6500	184	200	228	340	100	1900
V130LA20B	20	130L20B	130	175	70	6500	184	200	220	325	100	1900
V140LA2	7	1402	140	180	12	1200	198	220	242	360	10	160
V140LA5	10	1405	140	180	22	2500	198	220	242	360	25	400
V140LA10A	14	140L10	140	180	42	4500	198	220	242	360	50	900
V150LA1	7	1501	150	200	13	1200	212	240	284	430	10	150
V150LA2	7	1502	150	200	13	1200	212	240	268	395	10	150
V150LA5	10	1505	150	200	25	2500	212	240	268	395	25	360
V150LA10A	14	150L10	150	200	45	4500	212	240	268	395	50	800
V150LA20A	20	150L20	150	200	80	6500	212	240	268	395	100	1600
V150LA20B	20	150L20B	150	200	80	6500	212	240	243	360	100	1600
V175LA2	7	1752	175	225	15	1200	247	270	303	455	10	130
V175LA5	10	1755	175	225	30	2500	247	270	303	455	25	350
V175LA10A	14	175L10	175	225	55	4500	247	270	303	455	50	700
V175LA20A	20	175L20	175	225	90	6500	247	270	303	455	100	1400
V230LA4	7	2304	230	300	20	1200	324	360	396	595	10	100
V230LA10	10	230L	230	300	35	2500	324	360	396	595	25	250
V230LA20A	14	230L20	230	300	70	4500	324	360	396	595	50	550
V250LA2	7	2502	250	330	21	1200	354	390	473	730	10	90
V250LA4	7	2504	250	330	21	1200	354	390	429	650	10	90
V250LA10	10	250L	250	330	40	2500	354	390	429	650	25	220
V250LA20A	14	250L20	250	330	72	4500	354	390	429	650	50	500
V250LA40A	20	250L40	250	330	130	6500	354	390	429	650	100	1000
V250LA40B	20	250L40B	250	330	130	6500	354	390	413	620	100	1000
V275LA2	7	2752	275	369	23	1200	389	430	515	775	10	80
V275LA4	7	2754	275	369	23	1200	389	430	473	710	10	80
V275LA10	10	275L	275	369	45	2500	389	430	473	710	25	200
V275LA20A	14	275L20	275	369	75	4500	389	430	473	710	50	450
V275LA40A	20	275L40	275	369	140	6500	389	430	473	710	100	900
V275LA40B	20	275L40B	275	369	140	6500	389	430	453	680	100	900
V300LA2	7	3002	300	405	25	1200	420	470	565	870	10	70
V300LA4	7	3004	300	405	25	1200	420	470	517	775	10	70
V320LA20A	14	320L20	320	420	90	4500	462	510	565	850	50	380
V320LA40B	20	320L40	320	420	160	6500	462	510	540	810	100	750
V420LA10	10	420L	420	560	45	2500	610	680	748	1120	25	140
V420LA20A	14	420L20	420	560	90	4500	610	680	748	1120	50	300
V420LA40B	20	420L40	420	560	160	6500	610	680	720	1060	100	600
V480LA40A	14	480L40	480	640	105	4500	670	750	825	1240	50	270
V480LA80B	20	480L80	480	640	180	6500	670	750	790	1160	100	550
V510LA40A	14	510L40	510	675	110	4500	735	820	910	1350	50	250
V510LA80B	20	510L80	510	675	190	6500	735	820	860	1280	100	500
V575LA40A	14	575L40	575	730	120	4500	805	910	1000	1500	50	220
V575LA80B	20	575L80	575	730	220	6500	805	910	960	1410	100	450
V660LA50A	14	660L50	660	850	140	4500	940	1050	1210	1820	50	200
V660LA100B	20	660L100	660	850	250	6500	940	1050	1100	1650	100	400
V1000LA80A	14	1000L80	1000	1200	220	4500	1425	1600	1800	2700	50	130
V1000LA160B	20	1000L160	1000	1200	360	6500	1425	1600	1600	2420	100	250

NOTE: Average power dissipation of transients not to exceed 0.25W, 0.4W, 0.6W or 1W for model sizes 7mm, 10mm, 14mm and 20mm, respectively.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

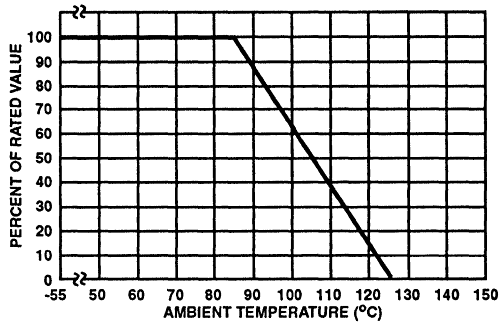
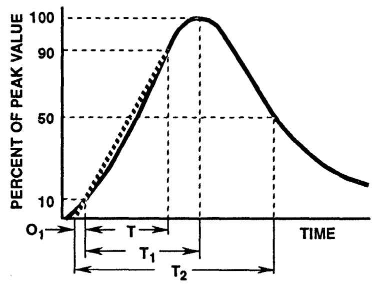


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

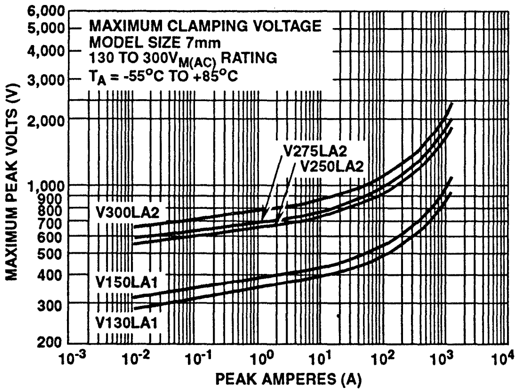


FIGURE 3. CLAMPING VOLTAGE FOR V130LA1 - V300LA2

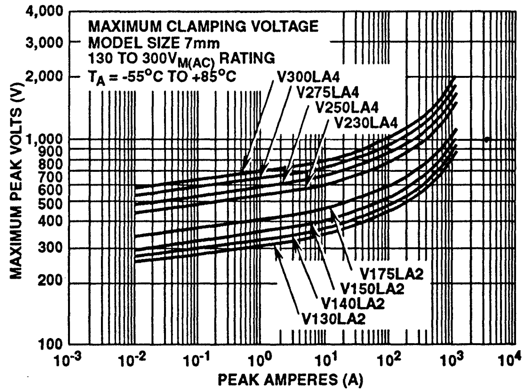


FIGURE 4. CLAMPING VOLTAGE FOR V130LA2 - V300LA4

Transient V-I Characteristics Curves (Continued)

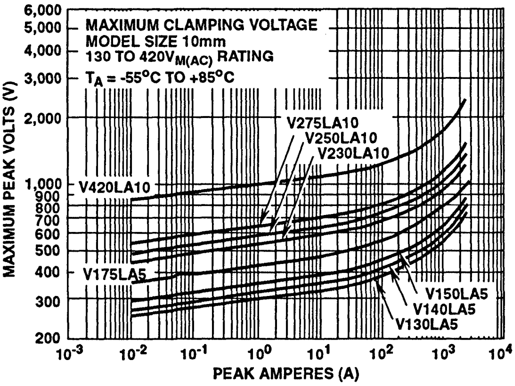


FIGURE 5. CLAMPING VOLTAGE FOR V130LA5 - V420LA10

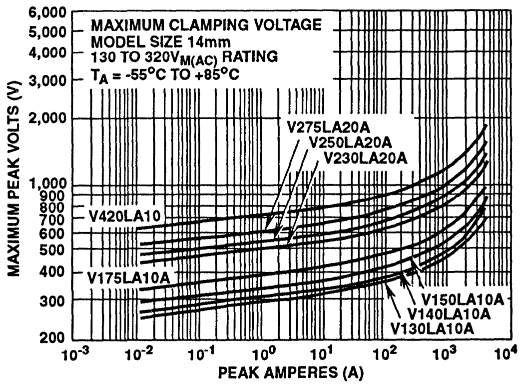


FIGURE 6. CLAMPING VOLTAGE FOR V130LA10A - V320LA20A

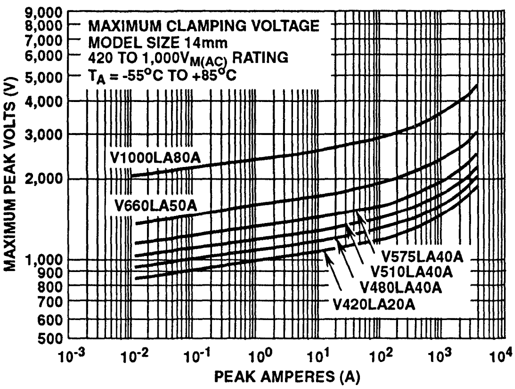


FIGURE 7. CLAMPING VOLTAGE FOR V420LA20A - V1000LA80A

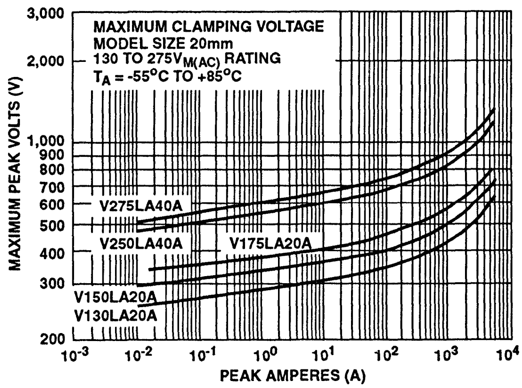


FIGURE 8. CLAMPING VOLTAGE FOR V130LA20A - V275LA40A

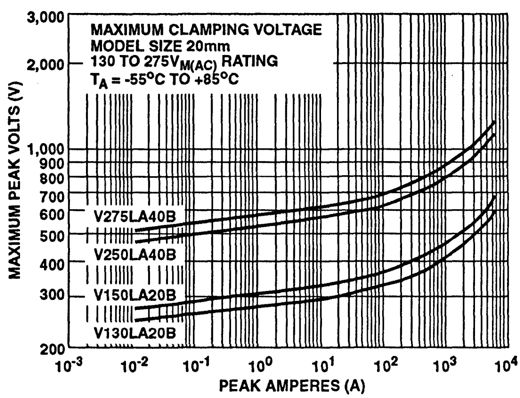


FIGURE 9. CLAMPING VOLTAGE FOR V130LA20B - V275LA40B

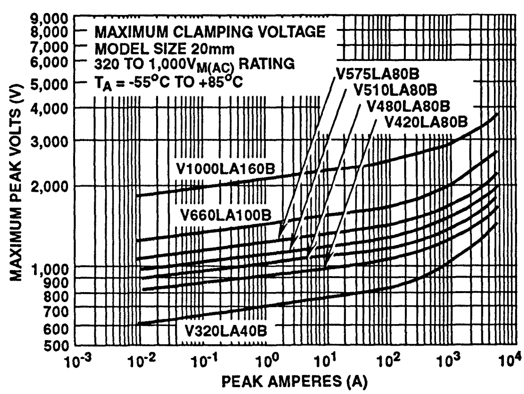


FIGURE 10. CLAMPING VOLTAGE FOR V320LA40B - V1000LA160B

Pulse Rating Curves

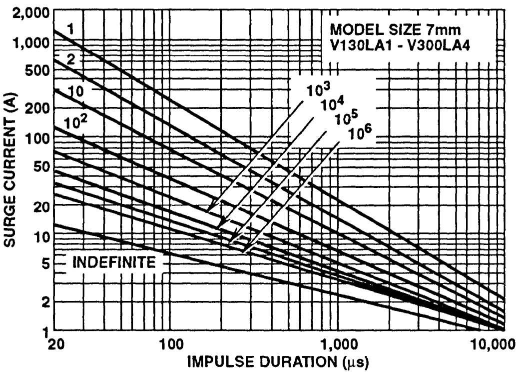


FIGURE 11. SURGE CURRENT RATING CURVES FOR V130LA1 - V300LA4

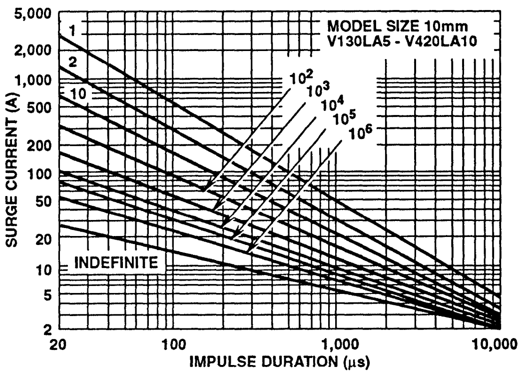


FIGURE 12. SURGE CURRENT RATING CURVES FOR V130LA5 - V420LA10

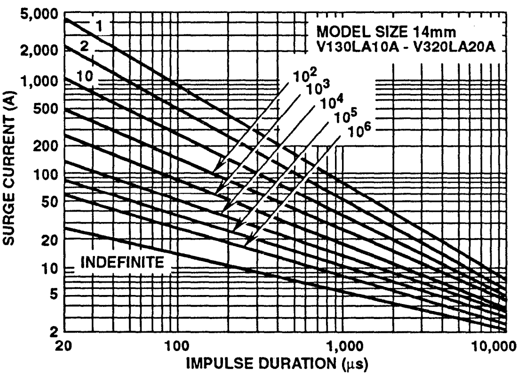


FIGURE 13. SURGE CURRENT RATING CURVES FOR V130LA10A - V320LA20A

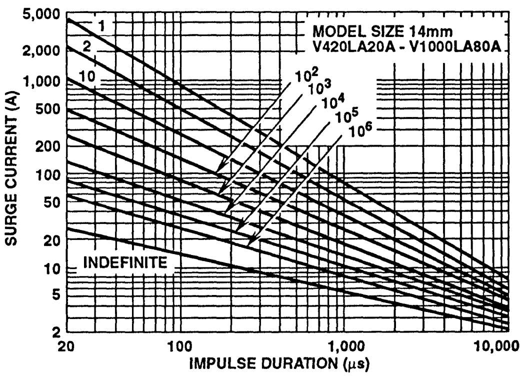


FIGURE 14. SURGE CURRENT RATING CURVES FOR V420LA20A - V1000LA80A

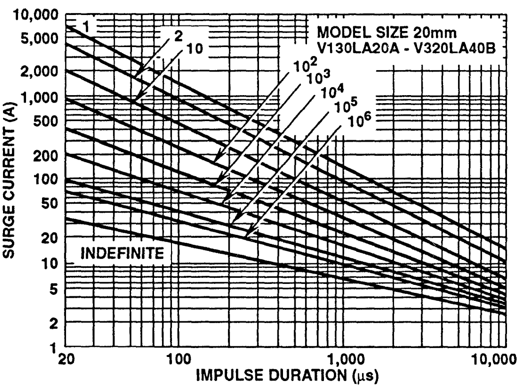


FIGURE 15. SURGE CURRENT RATING CURVES FOR V130LA20A - V320LA40B

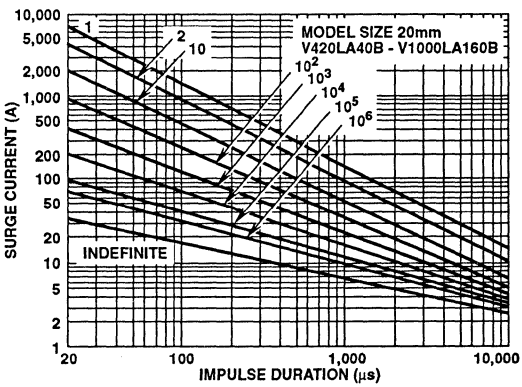
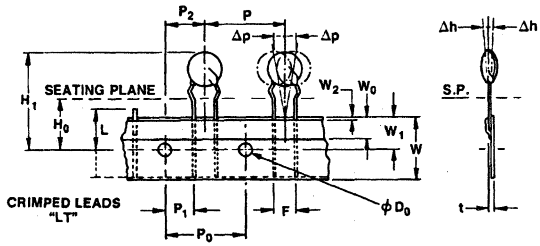
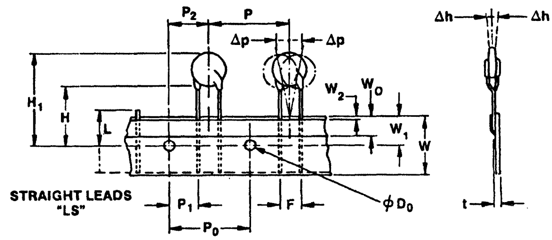


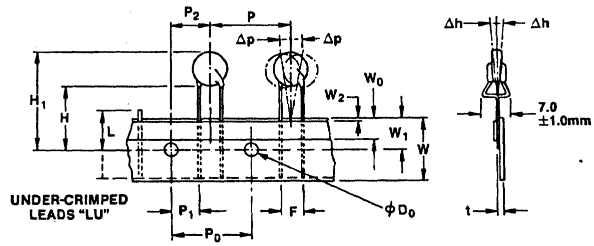
FIGURE 16. SURGE CURRENT RATING CURVES FOR V420LA40B - V1000LA160B

NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but does not prevent the device from continuing to function, and to provide ample protection.

Tape and Reel Specifications







Tape And Reel Data

- Conforms to ANSI and EIA specifications
- Can be supplied to IEC Publication 286-2
- Radial devices on tape are supplied with crimped leads, straight leads, or under-crimped leads

SYMBOL	PARAMETER	MODEL SIZE			
		7mm	10mm	14mm	20mm
P	Pitch of Component	12.7 ± 1.0	25.4 ± 1.0	25.4 ± 1.0	25.4 ± 1.0
P_0	Feed Hole Pitch	12.7 ± 0.2	12.7 ± 0.2	12.7 ± 0.2	12.7 ± 0.2
P_1	Feed Hole Center to Pitch	3.85 ± 0.7	2.6 ± 0.7	2.6 ± 0.7	2.6 ± 0.7
P_2	Hole Center to Component Center	6.35 ± 0.7	6.35 ± 0.7	6.35 ± 0.7	6.35 ± 0.7
F	Lead to Lead Distance	5.0 ± 0.8	7.5 ± 0.8	7.5 ± 0.8	7.5 ± 0.8
Δh	Component Alignment	2.0 Max	2.0 Max	2.0 Max	2.0 Max
W	Tape Width	18.0 + 1.0 18.0 - 0.5	18.0 + 1.0 18.0 - 0.5	18.0 + 1.0 18.0 - 0.5	18.0 + 1.0 18.0 - 0.5
W_0	Hold Down Tape Width	6.0 ± 0.3	6.0 ± 0.3	6.0 ± 0.3	12.0 ± 0.3
W_1	Hole Position	9.0 + 0.75 9.0 - 0.50	9.0 + 0.75 9.0 - 0.50	9.0 + 0.75 9.0 - 0.50	9.0 + 0.75 9.0 - 0.50
W_2	Hold Down Tape Position	0.5 Max	0.5 Max	0.5 Max	0.5 Max
H	Height from Tape Center to Component Base	18.0 + 2.0 18.0 - 0.0	18.0 + 2.0 18.0 - 0.0	18.0 + 2.0 18.0 - 0.0	18.0 + 2.0 18.0 - 0.0
H_0	Seating Plane Height	16.0 ± 0.5	16.0 ± 0.5	16.0 ± 0.5	16.0 ± 0.5
H_1	Component Height	32.0 Max	36.0 Max	40.0 Max	46.5 Max
D_0	Feed Hole Diameter	4.0 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	4.0 ± 0.2
t	Total Tape Thickness	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2
L	Length of Clipped Lead	11.0 Max	11.0 Max	11.0 Max	11.0 Max
Δp	Component Alignment	3° Max 1.00mm	3° Max 1.00mm	3° Max 1.00mm	3° Max

NOTE: Dimensions are in mm.

Tape and Reel Ordering Information

Crimped leads are standard on LA types supplied in tape and reel and are denoted by the model letter "T". Model letter "S" denotes straight leads and letter "U" denotes special under-crimped leads.

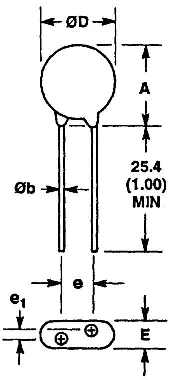
Example:

STANDARD MODEL	CRIMPED LEADS	STRAIGHT LEADS	UNDER-CRIMPED LEADS
V130LA2	V130LT2	V130LS2	V130LU2

SHIPPING QUANTITY

SIZE	RMS (MAX) VOLTAGE	QUANTITY PER REEL		
		"T" REEL	"S" REEL	"U" REEL
7mm	All	1000	1000	1000
10mm	All	1000	1000	1000
14mm	< 300V	500	500	500
14mm	≥ 300V	500	500	500
20mm	<300V	500	500	500
20mm	≤ 300V	500	500	500

Packaging



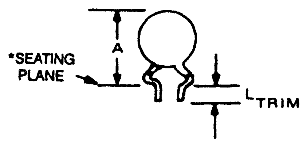
SYMBOL	VOLTAGE MODEL	VARISTOR MODEL SIZE							
		7mm		10mm		14mm		20mm	
		MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
A	V130LA- V320LA	7.5 (0.295)	12 (0.472)	10 (0.394)	16 (0.630)	13.5 (0.531)	20 (0.787)	17.5 (0.689)	26.5 (1.043)
	V420LA- V1000LA	- -	- -	10 (0.394)	17 (0.689)	13.5 (0.531)	20.5 (0.807)	17.5 (0.689)	28 (1.102)
ØD	All	7.5 (0.295)	9 (0.354)	10 (0.394)	12.5 (0.492)	13.5 (0.531)	17 (0.669)	17.5 (0.689)	23 (0.906)
e (Note 1)	All	4 (0.157)	6 (0.236)	6.5 (0.256)	8.5 (0.335)	6.5 (0.256)	8.5 (0.335)	6.5 (0.256) (Note 1)	8.5 (0.335) (Note 1)
e_1	V130LA- V320LA	1.5 (0.059)	3.5 (0.138)	1.5 (0.059)	3.5 (0.138)	1.5 (0.059)	3.5 (0.138)	1.5 (0.059)	3.5 (0.138)
	V420LA- V1000LA	- -	- -	2.5 (0.098)	5.5 (0.217)	2.5 (0.098)	5.5 (0.217)	2.5 (0.098)	5.5 (0.217)
E	V130LA- V320LA	- -	5.6 (0.220)	- -	5.6 (0.220)	- -	5.6 (0.220)	- -	5.6 (0.220)
	V68ZA- V100ZA	- -	7.3 (0.287)	- -	7.3 (0.287)	- -	7.3 (0.287)	- -	7.3 (0.287)
	V100LA	- -	- -	- -	- -	- -	10.8 (0.425)	- -	10.8 (0.425)
Øb (Note 2)	All	0.585 (0.023)	0.685 (0.027)	0.76 (0.030)	0.86 (0.034)	0.76 (0.030)	0.86 (0.034)	0.76 (0.030) (Note 1)	0.86 (0.034) (Note 1)

NOTE: Dimensions in millimeters, inches in parentheses.

1. 10mm ALSO AVAILABLE; See Ordering Information.
2. 1000V parts only supplied with lead wire of diameter 1.00 ± 0.05 (0.039 ± 0.002).

Available Lead Style

Radial lead types can be supplied with a preformed crimp in the leads, and are available in all model sizes. Lead trim (L_{TRIM}) is supplied to the dimensions shown.



*Seating plane interpretation per IEC-717

CRIMPED AND TRIMMED LEAD

SYMBOL	VARISTOR MODEL SIZE							
	7mm		10mm		14mm		20mm	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
A	- -	15 (0.591)	- -	19.5 (0.768)	- -	22.5 (0.886)	- -	29.0 (1.142)
L_{TRIM}	2.41 (0.095)	4.69 (0.185)	2.41 (0.095)	4.69 (0.185)	2.41 (0.095)	4.69 (0.185)	2.41 (0.095)	4.69 (0.185)

NOTE: Dimensions in millimeters, inches in parentheses.

Ordering Information

- For crimped and trimmed lead styles, standard radial type model numbers are changed by replacing the model letter "A" with "C".

Example:

STANDARD CATALOG MODEL	ORDER AS:
V130LA2	V130LC2

- For 10/±1mm lead spacing on 20mm diameter models only; append standard model numbers by adding "X10".

Example:

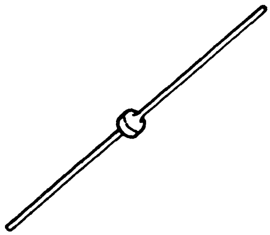
STANDARD CATALOG MODEL	ORDER AS:
V130LA20A	V130LA20AX10

- For crimped leads without trimming and any variations to the above, contact Harris Semiconductor Power Marketing.

MA Series

August 1993

Axial Lead Metal-Oxide Varistors



MA SERIES

Features

- 3mm Diameter Disc Size
- Wide Operating Voltage Range $V_{M(AC)RMS}$ .... 9V to 264V
- Available in Tape and Reel Packaging for Use With Automatic Insertion Equipment

Description

MA series transient surge suppressors are axial-lead metal-oxide varistors for use in a wide variety of industrial and commercial electronic equipment. The construction of these 3mm diameter disc-type axial lead varistors make them particularly useful in automatic insertion equipment.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	MA SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	9 to 264	V
DC Voltage Range ($V_{M(DC)}$)	13 to 365	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20μs Current Wave (See Figure 2)	40 to 100	A
Single Pulse Energy Range		
For 10/1000μs Current Wave (W_{TM})	0.06 to 1.7	J
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C
Hi-Pot Encapsulation (Isolation Voltage Capability) (Dielectric must withstand indicated DC voltage for one minute per MIL-STD 202, Method 301)	1000	V
Insulation Resistance	1000	MΩ

Device Ratings and Characteristics

MODEL NUMBER	DEVICE MARKING	MAXIMUM RATINGS (+85°C) CONTINUOUS RMS VOLTAGE $V_{M(AC)}$ (V)	DC VOLTAGE $V_{M(DC)}$ (V)	TRANSIENT ENERGY (10/1000μs) W_{TM} (J)	PEAK CURRENT (8/20μs) I_{TM} (A)	CHARACTERISTICS (+25°C) VARISTOR VOLTAGE AT 1mA DC TEST CURRENT MIN (V)	$V_{N(DC)}$ (V)	MAX (V)	MAX CLAMPING VOLT AT I_P VALUE CURRENT (8/20μs) I_P = 2.0A (V)	TYPICAL CAPACITANCE f = 1MHz (pF)
V18MA1A	18A	9	13	0.06	40	14	18	23	49	550
V18MA1B	18B	10	14	0.07	40	15	18	21	44	550
V18MA1S	18S	10	14	0.06	40	15	18	21	49	550
V22MA1A	22A	10	15	0.09	40	16	22	28	55	410
V22MA1B	22B	14	18	0.10	40	19	22	26	51	410
V22MA1S	22S	14	18	0.09	40	19	22	26	55	410
V27MA1A	27A	13	19	0.10	40	21	27	34	67	370
V27MA1B	27B	17	22	0.11	40	24	27	31	59	370
V27MA1S	27S	17	22	0.10	40	24	27	31	67	370
V33MA1A	33A	18	23	0.13	40	26	33	40	73	300
V33MA1B	33B	20	26	0.15	40	29.5	33	36.5	67	300
V33MA1S	33S	20	26	0.14	40	29.5	33	36.5	73	300
V39MA2A	39A	22	28	0.16	40	31	39	47	86	250
V39MA2B	39B	25	31	0.18	40	35	39	43	79	250
V39MA2S	39S	25	31	0.17	40	35	39	43	86	250
V47MA2A	47A	27	34	0.19	40	37	47	57	99	210
V47MA2B	47B	30	38	0.21	40	42	47	52	90	210
V47MA2S	47S	30	38	0.19	40	42	47	52	99	210
V56MA2A	56A	32	40	0.23	40	44	56	68	117	180
V56MA2B	56B	35	45	0.25	40	50	56	62	108	180
V56MA2S	56S	35	45	0.23	40	50	56	62	117	180
V68MA3A	68A	38	48	0.26	40	54	68	82	138	150
V68MA3B	68B	40	56	0.30	40	61	68	75	127	150
V68MA3S	68S	40	56	0.27	40	61	68	75	138	150
V82MA3A	82A	45	60	0.33	40	65	82	99	163	120
V82MA3B	82B	50	66	0.37	40	73	82	91	150	120
V82MA3S	82S	50	66	0.34	40	73	82	91	163	120
V100MA4A	100	57	72	0.40	40	80	100	120	200	100
V100MA4B	101	60	81	0.45	40	90	100	110	185	100
V100MA4S	102	60	81	0.42	40	90	100	110	200	100
V120MA1A	120	72	97	0.40	100	102	120	138	220	40
V120MA2B	121	75	101	0.50	100	108	120	132	205	40
V120MA2S	122	75	101	0.46	100	108	120	132	220	40
V150MA1A	150	88	121	0.50	100	127	150	173	255	32
V150MA2B	151	92	127	0.60	100	135	150	165	240	32
V180MA1A	180	105	144	0.60	100	153	180	207	310	27
V180MA3B	181	110	152	0.70	100	162	180	198	290	27
V220MA2A	220	132	181	0.80	100	187	220	253	380	21
V220MA4B	221	138	191	0.90	100	198	220	242	360	21
V270MA2A	270	163	224	0.90	100	229	270	311	460	17
V270MA4B	271	171	235	1.00	100	243	270	297	440	17
V330MA2A	330	188	257	1.00	100	280	330	380	570	14
V330MA5B	331	200	274	1.10	100	297	330	363	540	14
V390MA3A	390	234	322	1.20	100	331	390	449	670	12
V390MA6B	391	242	334	1.30	100	351	390	429	640	12
V430MA3A	430	253	349	1.50	100	365	430	495	740	11
V430MA7B	431	264	365	1.70	100	387	430	473	700	11

NOTE: Average power dissipation of transients not to exceed 200mW.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

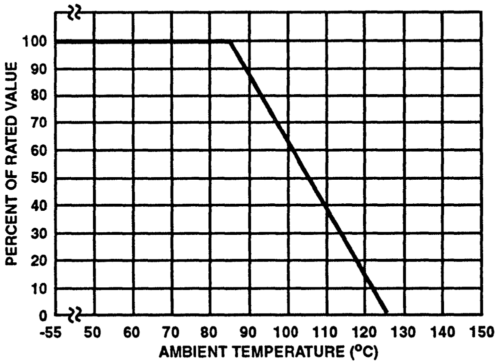
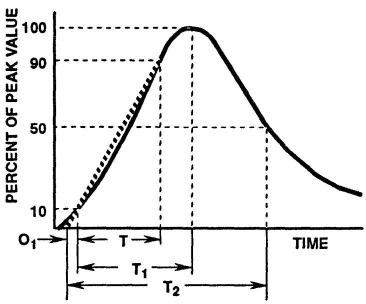


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

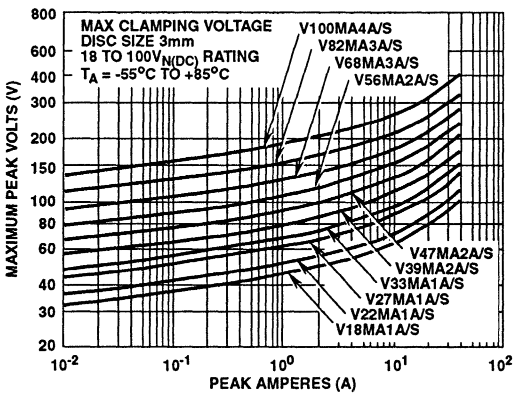


FIGURE 3. CLAMPING VOLTAGE FOR V18MA1A/S - V100MA4A/S

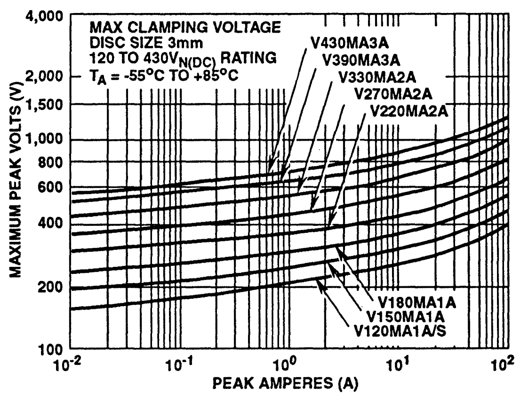


FIGURE 4. CLAMPING VOLTAGE FOR V120MA1A/S - V430MA3A

Transient V-I Characteristics Curves (Continued)

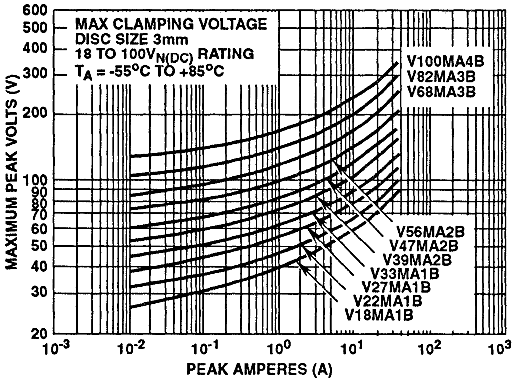


FIGURE 5. CLAMPING VOLTAGE FOR V18MA1B - V100MA4B

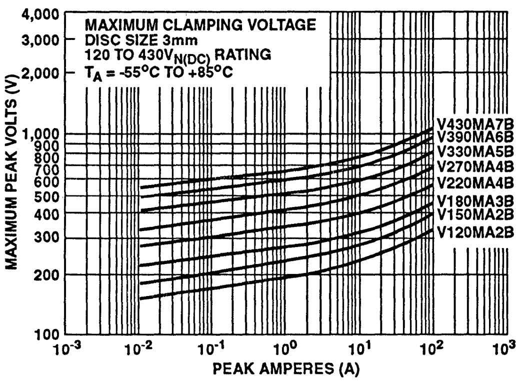


FIGURE 6. CLAMPING VOLTAGE FOR V120MA2B - V430MA7B

Pulse Rating Curves

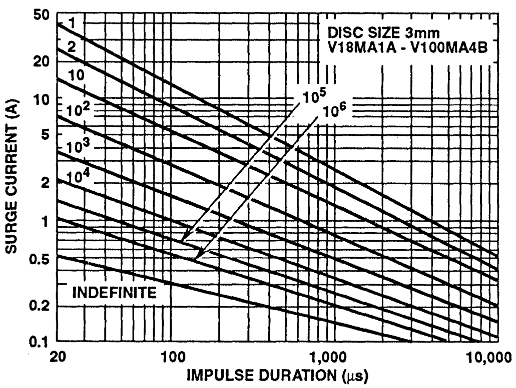


FIGURE 7. SURGE CURRENT RATING CURVES FOR V18MA SERIES - V100MA SERIES

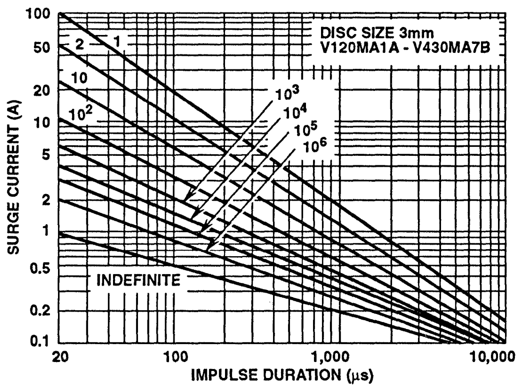
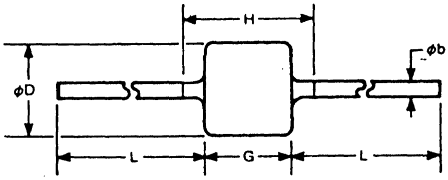


FIGURE 8. SURGE CURRENT RATING CURVES FOR V120MA SERIES - V430MA SERIES

NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

Packaging



SYMBOL	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
Øb	0.024	0.026	0.61	0.66
ØD	0.135	0.177	3.43	4.5
G	0.098	0.177	3.43	4.5
H	0.118	0.236	3.0	6.0
L	1.130	1.220	28.70	31.0
Typical Weight = 25g				

Tape And Reel Data

- Conforms to EIA Standard RS-296E

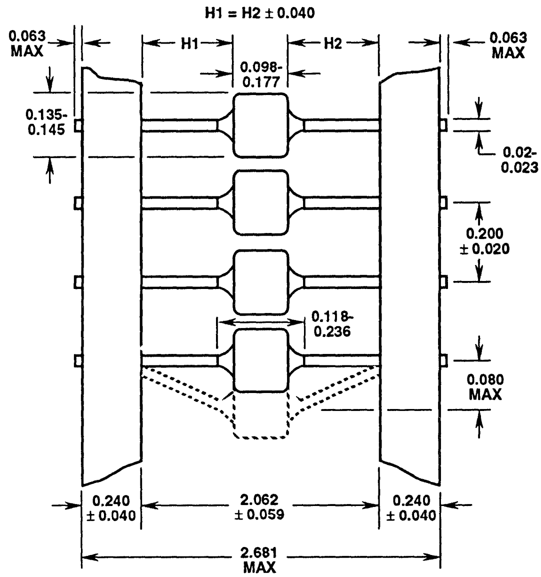
Ordering Information

- Standard model numbers are changed by replacing the model leter "A" with "T".

Example:

STD. CAT. MODEL	ORDER AS
V18MA1A	V18MT1A
Quantity Per Reel: 5,000	

Tape and Reel Specification

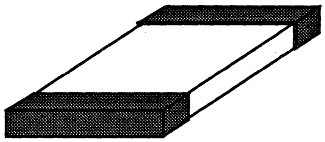


9
VARISTOR PRODUCTS

ML Series

Multilayer Transient Surface Mount Surge Suppressors

August 1993



ML SERIES

Features

- Leadless Chip Form - Zero Lead Inductance
- Multilayer Surface Mount Surge Suppressor
- +125°C Continuous Operating Temperature
- Available In Tape and Reel for Automatic Pick and Place
- Wide Operating Voltage Range $V_{M(DC)}$ . . . . 3.5V to 68V
- Broad Range of Energy Handling Capabilities
- Low Profile, Compact Chip Size
- Inherently Bi-directional
- No Plastic or Epoxy Packaging Guarantees Better than 94V-0 Flammability Rating

Description

ML series transient surge suppressors are designed to protect sensitive electronic devices from destruction by high voltage transients. These suppressors are designed to fail short when overstressed and protect the associated equipment. The ML suppressor is manufactured from semiconducting ceramics which offer rugged protection, excellent transient energy absorption and increased internal heat dissipation.

The devices are in chip form, eliminating lead inductance and guaranteeing the fastest speed of response to transient surges. These transient suppression devices have significantly smaller footprints and lower profiles than traditional TVS diodes or radial MOV's (metal oxide varistors), thus allowing designers to reduce size and weight while increasing system reliability.

Absolute Maximum Ratings For Ratings of Individual members of a series, see device ratings and Characteristics chart

	ML SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
DC Voltage Range ($V_{M(DC)}$)	3.5 to 68	V
AC Voltage Range ($V_{M(AC)RMS}$)	2.5 to 50	V
Transient:		
Non-Repetitive Surge Current, 8/20 µs Waveform, (I_{TM})	100 to 250	A
Non-Repetitive Surge Energy, 10/1000 µs Waveform, (W_{TM})	0.3 to 1.2	J
Operating Ambient Temperature Range (T_A)	-55 to +125	°C
Storage Temperature Range (T_{STG})	-55 to +150	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

Device Ratings and Characteristics

MODEL NUMBER	MAXIMUM RATINGS (+125°C)						CHARACTERISTICS (+25°C)		
	MAXIMUM CONTINUOUS WORKING VOLTAGE		MAXIMUM NON-REPETITIVE SURGE CURRENT (8/20μs)	MAXIMUM NON-REPETITIVE SURGE ENERGY (10/1000μs)	MAXIMUM CLAMPING VOLTAGE AT 10AMP (8/20μs)		NOMINAL VOLTAGE AT 1mA DC TEST CURRENT		TYPICAL CAPACITANCE
	$V_{M(DC)}$	$V_{M(AC)}$	I_{TM}	W_{TM}	V_C		$V_{N(DC)}$ MIN	$V_{N(DC)}$ MAX	f = 1MHz
	(V)	(V)	(A)	(J)	(V)		(V)	(V)	(pF)
V3.5MLA1206	3.5	2.5	100	0.3	14		5.0	7.0	6000
V5.5MLA1206	5.5	4	150	0.4	15.5		7.1	8.7	4500
V14MLA1206	14	10	150	0.4	30		16.4	20	2100
V18MLA1206	18	14	150	0.4	40		22	27	1700
V18MLA1210	18	14	250	0.8	40		22	27	1900
V26MLA1206	26	20	150	0.6	56		29.5	38.5	800
V26MLA1210	26	20	250	1.2	54		29.5	38.5	1000
V33MLA1206	33	26	180	0.8	72		38	45	500
V42MLA1206	42	30	180	0.8	86		46	56	450
V56MLA1206	56	40	180	1.0	110		61	76	350
V68MLA1206	68	50	180	1.0	130		76	90	150

NOTES:

1. Typical leakage at +25°C < 50μA, maximum leakage 100μA.
2. Average power dissipation of transients for 1206 and 1210 sizes not to exceed 0.10W and 0.15W, respectively.
3. Devices specifically for automotive application also available.

Power Dissipation Requirements

Transients in a suppressor may generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore is not a necessary requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1.

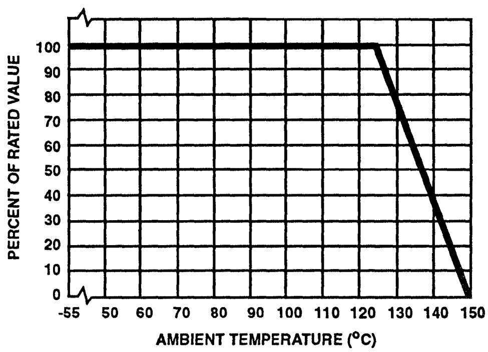
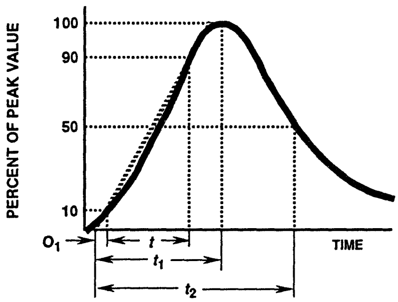


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = VIRTUAL ORIGIN OF WAVE
t = TIME FROM 10% TO 90% OF PEAK
t_1 = VIRTUAL FRONT TIME = 1.25 x t
t_2 = VIRTUAL TIME TO HALF VALUE (IMPULSE DURATION)

EXAMPLE:
FOR AN 8/20μs CURRENT WAVEFORM:
8μs = t_1 = VIRTUAL FRONT TIME
20μs = t_2 = VIRTUAL TIME TO HALF VALUE

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Maximum Transient V-I Characteristic Curves

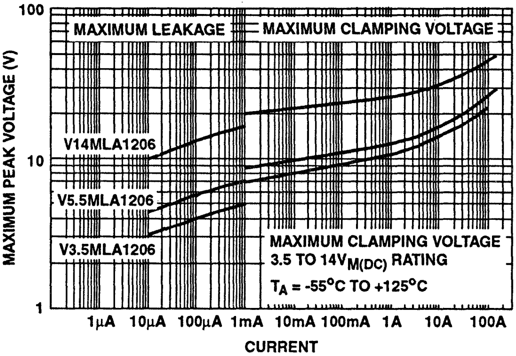


FIGURE 3. V3.5MLA1206 TO V14MLA1206 MAXIMUM V-I CHARACTERISTIC CURVES

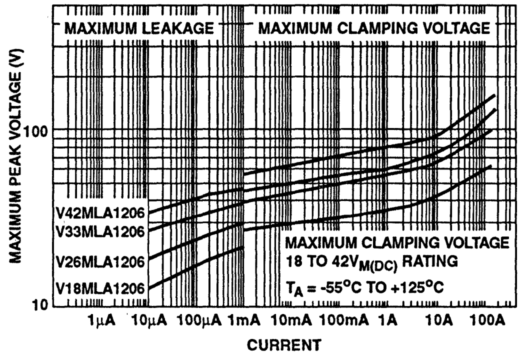


FIGURE 4. V18MLA1206 TO V42MLA1206 MAXIMUM V-I CHARACTERISTIC CURVES

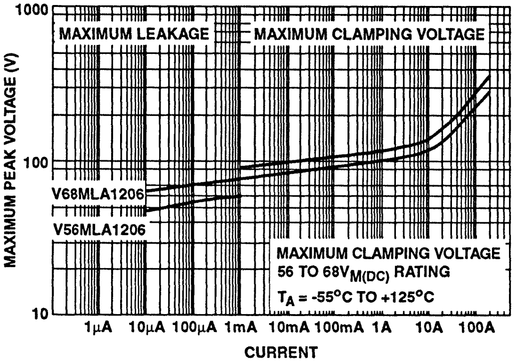


FIGURE 5. V56MLA1206 TO V68MLA1206 MAXIMUM V-I CHARACTERISTIC CURVE

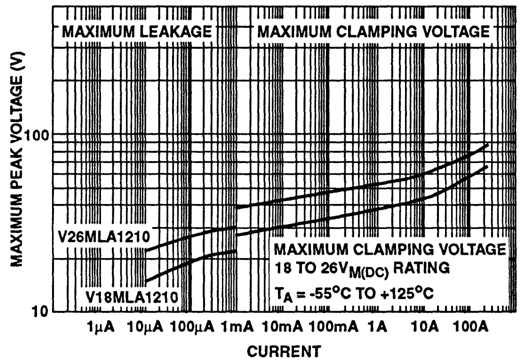


FIGURE 6. V18MLA1210 TO V26MLA1210 MAXIMUM V-I CHARACTERISTIC CURVES

Device Characteristics

At low current levels, the V-I curve of the multilayer transient voltage suppressor approaches a linear (ohmic) relationship and shows a temperature dependent affect (Figure 7). The suppressor is in a high resistance mode (approaching 10^9 ohms) and appears as a near open circuit. This is equivalent to the leakage region in a traditional zener diode. Leakage currents at maximum rated voltage are in the microamp range and in most cases below 50μA.

When clamping transients at higher currents, at and above the 10μA range, the multilayer suppressor approaches a 1-10Ω characteristic. Here, the multilayer becomes virtually temperature independent (Figure 8).

Speed of Response

Traditional transient suppressors, e.g. metal oxide varistors and zener diode type devices, have finite lead inductance, device capacitance and resistance. Thus these suppressors have their response times limited (slowed) by parasitic lead impedances. These difficulties have been recognized by the IEEE committees on transient suppressors concluding that response time of a suppressor is influenced by lead configuration and length. Unlike the leaded packages offered for surface mounting (Gull-wing and J-bend) the multilayer suppressor is a true surface mount device. As the multilayer has no leads it therefore has virtually zero inductance and the major factor controlling response time is eliminated.

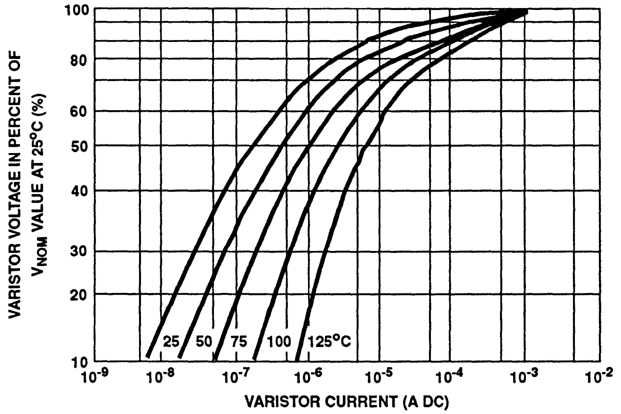


FIGURE 7. TYPICAL TEMPERATURE DEPENDENCE OF THE CHARACTERISTIC CURVE IN THE LEAKAGE REGION

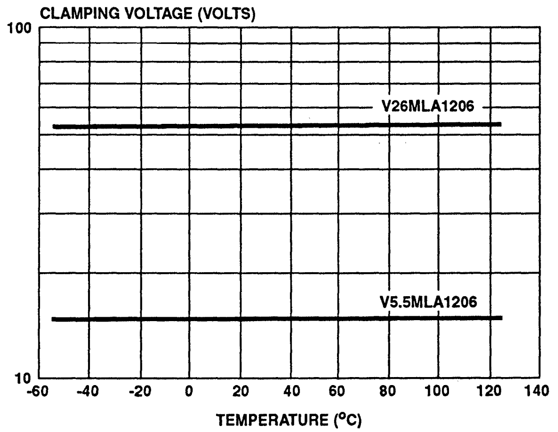


FIGURE 8. CLAMPING VOLTAGE OVER TEMPERATURE (V_C AT 10AMPS)

9

VARISTOR PRODUCTS

Energy Absorption/Peak Current Capability

This rating serves as a figure of merit for the ML suppressor. Energy is calculated by multiplying the clamping voltage, transient current and transient duration. An important advantage of the multilayer TVS interdigitated construction is its mass of transient suppressor material available to absorb energy. As a result, the peak temperature per energy absorbed is very low. The matrix of semiconducting grains combine to absorb and distribute transient energy (heat) (Figure 9). This dramatically reduces peak temperature, thermal stresses and enhances device reliability.

As a measure of the device capability in energy handling and peak current, the V26MLA1206A23 part was tested with multiple pulses at its peak current rating (150A, 8/20 microseconds). As this level of current is far in excess of anything the device is exposed to in an IC protection application it is taken as measure of the ruggedness and inherent capability. At the end of the test, 10,000 pulses later, the device voltage characteristics are still well within specification (Figure 10).

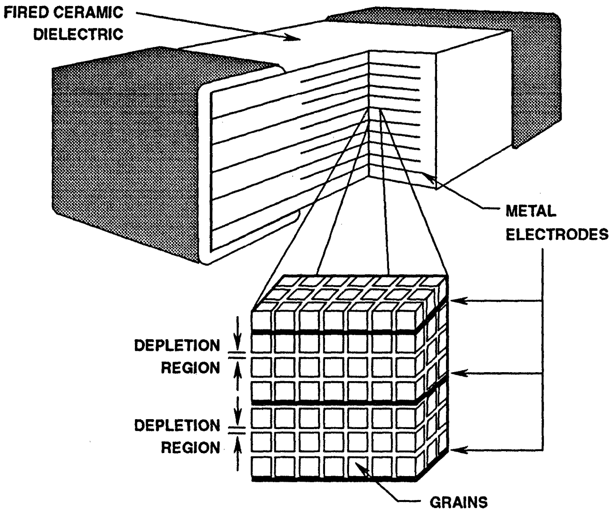


FIGURE 9. MULTILAYER TVS INTERNAL CONSTRUCTION

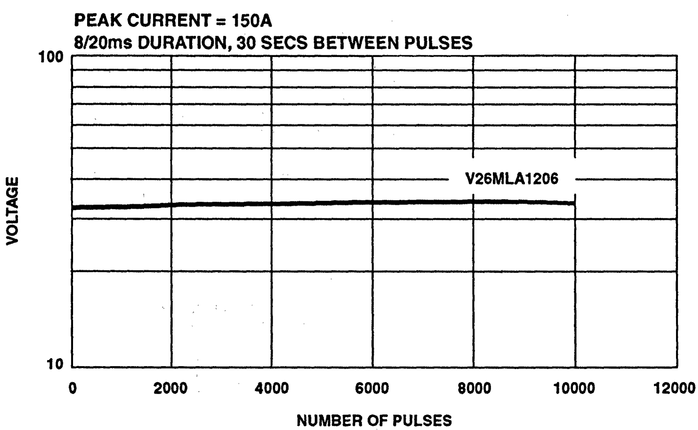


FIGURE 10. REPETITIVE PULSE CAPABILITY

Soldering Recommendations

The principal techniques used for the soldering of components in surface mount technology are Infra Red (IR) Reflow, Vapour Phase Reflow and Wave Soldering. When wave soldering, the ML suppressor is attached to the substrate by means of an adhesive. The assembly is then placed on a conveyor and run through the soldering process. With IR and Vapour Phase reflow the device is placed in a solder paste on the substrate. As the solder paste is heated it reflows, and solders the unit to the board.

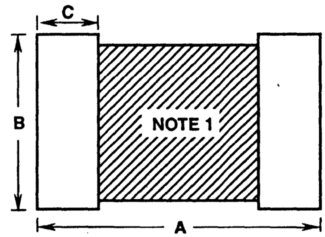
With the ML suppressor, the recommended solder is a 62/36/2 (Sn/Pb/Ag) silver solder paste. While this configuration is best, a 60/40 (Sn/Pb) or a 63/37 (Sn/Pb) solder paste can also be used. In soldering applications, the ML suppressor is held at elevated temperatures for a relatively long period of time. With the wave soldering operation is the most strenuous of the processes. To avoid the possibility of generating stresses due to thermal shock, a preheat stage in the soldering process is recommended, and the peak temperature of the solder process should be rigidly controlled.

When using a reflow process, care should be taken to ensure that the ML chip is not subjected to a thermal gradient steeper than 4 degrees per second; the ideal gradient being 2 degrees per second. During the soldering process, preheating to within 100 degrees of the solders peak temperature is essential to minimize thermal shock. Examples of the soldering conditions for the ML series of suppressors are given in the table below.

Once the soldering process has been completed, it is still necessary to ensure that any further thermal shocks are avoided. One possible cause of thermal shock is hot printed circuit boards being removed from the solder process and subjected to cleaning solvents at room temperature. The boards must be allowed to cool to less than 50 degree celsius before cleaning.

SOLDERING OPERATION	TIME (SECONDS)	PEAK TEMPERATURE (°C)
IR Reflow	5 - 10	220
Vapour Phase Reflow	5 - 10	222
Wave Solder	3 - 5	260

Recommended Pad Outline



NOTE 1: Avoid metal runs in this area.

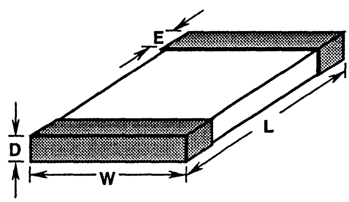
SYMBOL	CHIP SIZE			
	1210		1206	
	IN	MM	IN	MM
A	0.219	5.53	0.203	5.15
B	0.147	3.73	0.103	2.62
C	0.073	1.85	0.065	1.65

Soldering Recommendations

Material - 62/36/2 Sn/Pb/Ag or equivalent

Temperature - 230°C, 5 seconds max
Flux - nonactivated

Dimensional Outline



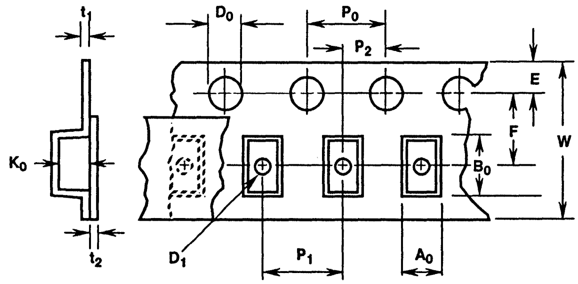
SYMBOL	CHIP SIZE			
	1210		1206	
	INCHES	mm	INCHES	mm
D Max.	0.113	2.87	0.071	1.80
E	0.02 ±0.01	0.50 ±0.25	0.02 ±0.01	0.50 ±0.25
L	0.125 ±0.012	3.20 ±0.30	0.125 ±0.012	3.20 ±0.30
W	0.10 ±0.012	2.54 ±0.30	0.06 ±0.011	1.60 ±0.28

Tape and Reel Specifications

- **Conforms to EIA - 481, Revision A**
- **Can be Supplied to IEC Publication 286 - 3**

SYMBOL	DESCRIPTION	MILLIMETERS
A_0	Width of Cavity	Dependent on Chip Size to Minimize Rotation.
B_0	Length of Cavity	Dependent on Chip Size to Minimize Rotation.
K_0	Depth of Cavity	Dependent on Chip Size to Minimize Rotation.
W	Width of Tape	8 ± 0.2
F	Distance Between Drive Hole Centers and Cavity Centers	3.5 ± 0.5
E	Distance Between Drive Hole Centers and Tape Edge	1.75 ± 0.1
P_1	Distance Between Cavity Center	4 ± 0.1
P_2	Axial Distance Between Drive Hole Centers and Cavity Centers	2 ± 0.1
P_0	Axial Distance Between Drive Hole Centers	4 ± 0.1
D_0	Drive Hole Diameter	1.55 ± 0.05
D_1	Diameter of Cavity Piercing	1.05 ± 0.05
t_1	Embossed Tape Thickness	0.3 max
t_2	Top Tape Thickness	0.1 max

NOTE: Dimensions in millimeters.



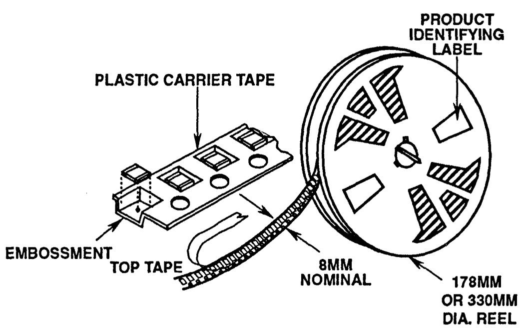
Standard Packaging

The ML Series of transient suppressors are always shipped in tape and reel. The standard 330 millimeter (13 inch) reel utilized contains 8000 pieces for the 1210 and 10000 pieces for the 1206 chip. To order add "T23" to the standard part number, e.g. V5.5MLA1206T23 or V68MLA1206T23.

Special Packaging

Option 1: 178 millimeter (7 inch) reels containing 2000 or 2500, depending on chip size, pieces are available. To order add "H23" to the standard part number, e.g. V5.5MLA1206H23 or V68MLA1206H23.

Option 2: For small sample quantities (less than 100 pieces) the units are shipped bulk pack. To order add "A23" to the standard part number, e.g. V5.5MLA1206A23 or V68MLA1206A23.



Terms and Descriptions

Rated DC Voltage ($V_{M(DC)}$)

This is the maximum continuous DC voltage which may be applied up to the maximum operating temperature of the device. The rated DC operating voltage (working voltage) is also used as the reference point for leakage current. This voltage is always less than the breakdown voltage of the device. Unlike the zener diode all multilayer TVS devices have a maximum leakage current of less than 100µA.

Rated AC Voltage ($V_{M(AC)RMS}$)

This is the maximum continuous sinusoidal rms voltage which may be applied. This voltage may be applied at any temperature up to the maximum operating temperature of the device.

Maximum Non-Repetitive Surge Current (I_{TM})

This is the maximum peak current which may be applied for an 8/20µs impulse, with rated line voltage also applied, without causing device failure. The pulse can be applied to the device in either polarity with the same confidence factor. See Figure 2 for waveform description.

Maximum Non-Repetitive Surge Energy (W_{TM})

This is the maximum rated transient energy which may be dissipated for a single current pulse at a specified impulse duration (10/1000µs), with the rated DC or RMS voltage applied, without causing device failure.

Leakage (I_L) at Rated DC Voltage

In the non-conducting mode, the device is at a very high impedance (approaching $10^9\Omega$) and appears as an almost open circuit in the system. The leakage current drawn at this level is very low (<50µA at ambient temperature) and, unlike the zener diode, the multilayer TVS has the added advantage that, when operated up to its maximum temperature, its leakage current will not increase above 500µA.

Nominal Voltage ($V_{N(DC)}$)

This is the voltage at which the device changes from the off state to the on state and enters its conduction mode of operation. The voltage is usually characterized at the 1mA point and has a specified minimum and maximum voltage listed.

Clamping Voltage (V_C)

This is the peak voltage appearing across the suppressor when measured at conditions of specified pulse current and specified waveform (8/20µs). It is important to note that the peak current and peak voltage may not necessarily be coincidental in time.

Capacitance (C)

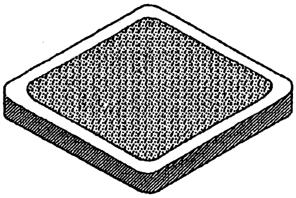
This is the capacitance of the device at a specified frequency (1MHz) and bias ($1V_{P-P}$).

HARRIS SEMICONDUCTOR

NA Series

Industrial High Energy Metal-Oxide Square Varistors

August 1993



NA SERIES

Features

- **Provided Unpackaged For Unique Packaging By Customer**
- **Solderable Electrode Finish Also Provides Pressure Contacts for Stacking Applications**
- **Wide Operating Voltage Range $V_{M(AC)RMS}$ .... 130V to 750V**
- **Peak Pulse Current Capability I_{TM} 40,000A**
- **High Energy Capability W_{TM} .... 270J to 1050J**

Description

NA series transient surge suppressors are industrial high-energy square varistors intended for special applications requiring unique contact or packaging considerations. The electrode finish of these devices is solderable and can also be used as pressure contacts for stacking applications.

These NA series industrial square varistor is available as a 34mm device, with thicknesses ranging from 1.8mm minimum for the 130V device to 8.3mm maximum for the 750V device. For information on mounting considerations refer to Application Note AN8820.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	NA SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	130 to 750	V
DC Voltage Range ($V_{M(DC)}$)	175 to 970	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20µs Current Wave (See Figure 2)	40,000	A
Single Pulse Energy Range		
For 10/1000µs Current Wave (W_{TM})	270 to 1050	J
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

File Number **2825.2**

Device Ratings and Characteristics

MODEL NUMBER	SIZE	MAXIMUM RATINGS (+85°C) CONTINUOUS RMS VOLTAGE	DC VOLTAGE	TRANSIENT ENERGY (10/1000μs)	PEAK CURRENT (8/20μs)	CHARACTERISTICS (+25°C) VARISTOR VOLTAGE AT 1 mA DC TEST CURRENT			MAXIMUM CLAMPING VOLTAGE (Vc) AT 200A (8/20μs)	TYPICAL CAPACITANCE
		$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM}	MIN	$V_{N(DC)}$	MAX	V_C	f = 1MHz
	(mm)	(V)	(V)	(V)	(A)	(V)	(V)	(V)	(V)	(pF)
V131NA34	34	130	175	270	30,000	184	200	228	345	10,000
V151NA34	34	150	200	300	30,000	212	240	268	405	8,000
V251NA34	34	250	330	370	40,000	354	390	429	650	5,000
V271NA34	34	275	369	400	40,000	389	430	473	730	4,500
V321NA34	34	320	420	460	40,000	462	510	539	830	3,800
V421NA34	34	420	560	600	40,000	610	680	748	1,130	3,000
V481NA34	34	480	640	650	40,000	670	750	825	1,240	2,700
V511NA34	34	510	675	700	40,000	735	820	910	1,350	2,500
V571NA34	34	575	730	770	40,000	805	910	1000	1,480	2,200
V661NA34	34	660	850	900	40,000	940	1050	1160	1,720	2,000
V751NA34	34	750	970	1050	40,000	1080	1200	1320	2,000	1,800

Average power dissipation of transients not to exceed 2.0W.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore is not a necessary requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device.

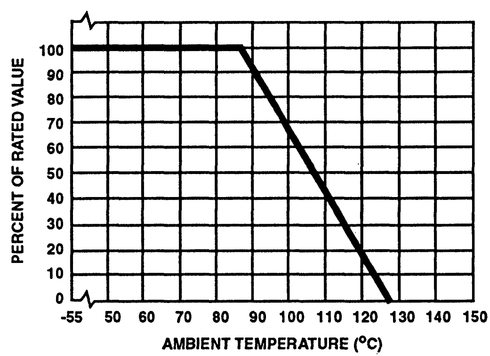
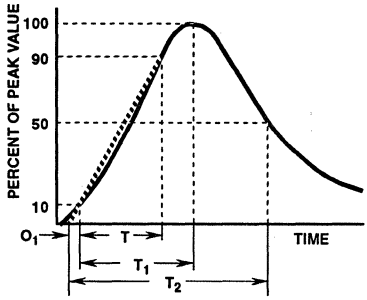


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curve

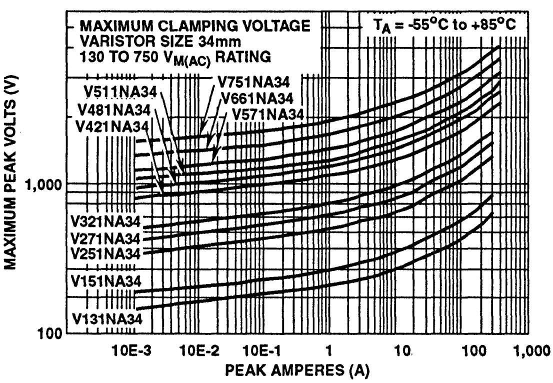


FIGURE 3. CLAMPING VOLTAGE FOR V131NA34 - V751NA34

Pulse Rating Curves

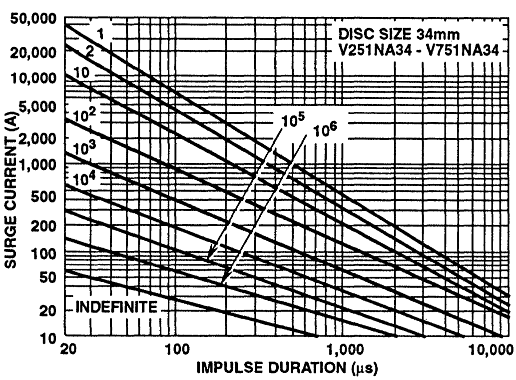


FIGURE 4. SURGE CURRENT RATING CURVES FOR V251NA34 - V751NA34

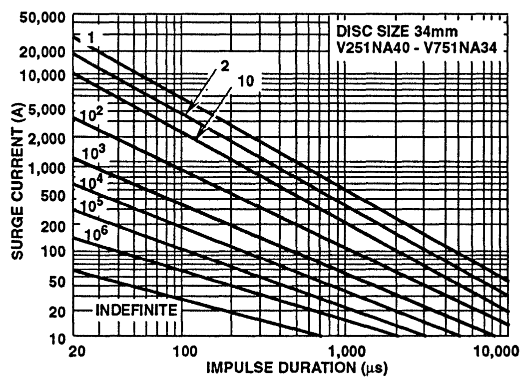
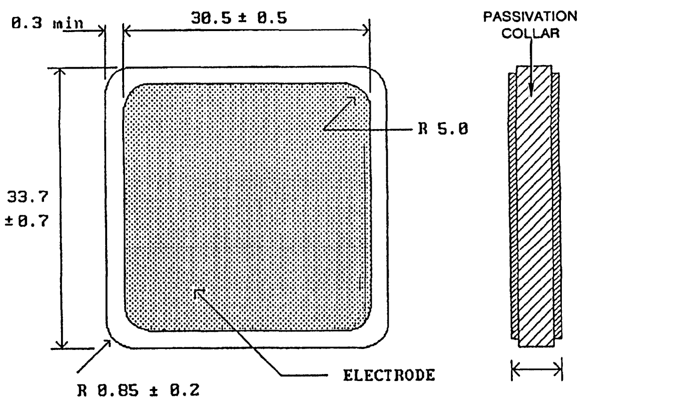


FIGURE 5. SURGE CURRENT RATING CURVES FOR V131NA34 - V751NA34

NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

Packaging

OUTLINE DIMENSIONS: Millimeters



MODEL NUMBER	NA SERIES VARISTOR THICKNESS			
	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
V131NA34	1.40	2.30	0.055	0.090
V151NA34	1.70	2.80	0.067	0.011
V251NA34	2.00	2.70	0.079	0.106
V271NA34	2.20	3.00	0.087	0.118
V321NA34	2.60	3.50	0.102	0.138
V421NA34	3.50	4.70	0.138	0.185
V481NA34	3.80	5.20	0.150	0.205
V511NA34	4.20	5.70	0.165	0.225
V571NA34	4.60	6.30	0.181	0.248
V661NA34	5.30	7.20	0.209	0.284
V751NA34	6.10	8.30	0.240	0.327

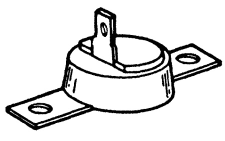
NOTE: Parts available encapsulated with soldered tabs, to standard design or customer specific requirements.

HARRIS SEMICONDUCTOR

PA Series

August 1993

Base Mount Metal-Oxide Varistors



PA SERIES

Features

- Recognized as "Transient Voltage Surge Suppressors", UL File #E75961 to Std. 1449
- Recognized as "Transient Voltage Surge Suppressors", CSA File #LR91788 to Std. C22.2 No. 1-M1981
- Wide Operating Voltage Range $V_{M(AC)RMS}$ .... 130V to 660V
- Creep and Strike Distance Capability Meets Rigid NEMA Standards
- Base Mount Construction for Rigid Mounting Applications
- Quick Connect Tab Terminal

Description

PA series transient surge suppressors are base mount metal-oxide varistors featuring rigid mountdown construction, and are useful in applications which are critical to vibration.

These UL and CSA recognized varistors are available in a wide range of operating voltages, from 130V to 660V $V_{M(AC)RMS}$. The base-mount package has a quick connect tab terminal that provides a fast secure lead mount. Meeting rigid NEMA standards, PA series varistors have a creep and strike distance capability that minimizes breakdown along the package surface.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	PA SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	130 to 660	V
DC Voltage Range ($V_{M(DC)}$)	175 to 850	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20μs Current Wave (See Figure 2)	6500	A
Single Pulse Energy Range		
For 10/1000μs Current Wave (W_{TM})	70 to 250	J
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C

File Number 2192.2

Device Ratings and Characteristics

Series PA Varistors are listed under UL file #E75961 and under CSA file #LR91788, as a UL recognized component.

MODEL NUMBER	MAXIMUM RATINGS (+85°C)				CHARACTERISTICS (+25°C)					
	CONTINUOUS		TRANSIENT		VARISTOR VOLTAGE AT 1mA DC TEST CURRENT			MAX CLAMPING VOLT V_C AT TEST CURRENT (8/20μs)		TYPICAL CAPACITANCE
	RMS VOLTAGE	DC VOLTAGE	ENERGY (10/1000μs)	PEAK CURRENT (8/20μs)						
	$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM}	MIN	$V_{N(DC)}$	MAX	V_C	I_P	f = 1MHz
	(V)	(V)	(J)	(A)	(V)	(V)	(V)	(V)	(A)	(pF)
V130PA20A	130	175	70	6500	184	200	243	360	100	1900
V130PA20C	130	175	70	6500	184	200	220	325	100	1900
V150PA20A	150	200	80	6500	212	240	284	420	100	1600
V150PA20C	150	200	80	6500	212	240	243	360	100	1600
V250PA40A	250	330	130	6500	354	390	453	675	100	1000
V250PA40C	250	330	130	6500	354	390	413	620	100	1000
V275PA40A	275	369	140	6500	389	430	494	740	100	900
V275PA40C	275	369	140	6500	389	430	453	680	100	900
V320PA40A	320	420	160	6500	462	510	565	850	100	750
V320PA40C	320	420	160	6500	462	510	540	800	100	750
V420PA40A	420	560	170	6500	610	680	790	1160	100	600
V420PA40C	420	560	170	6500	610	680	690	1050	100	600
V480PA80A	480	640	180	6500	670	750	860	1280	100	550
V480PA80C	480	640	180	6500	670	750	790	1160	100	550
V510PA80A	510	675	190	6500	735	820	963	1410	100	500
V510PA80C	510	675	190	6500	735	820	860	1280	100	500
V575PA80A	575	730	220	6500	805	910	1050	1560	100	450
V575PA80A	575	730	220	6500	805	910	960	1410	100	450
V660PA100A	660	850	250	6500	940	1050	1210	1820	100	400
V660PA100C	660	850	250	6500	940	1050	1100	1650	100	400

NOTE: Average power dissipation of transients not to exceed 1W.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

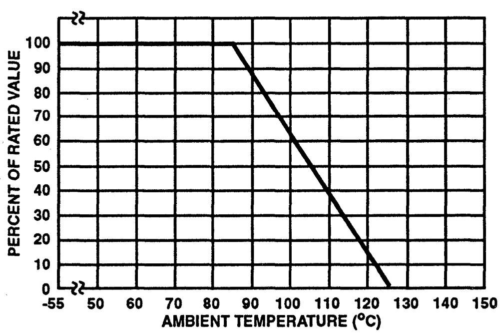
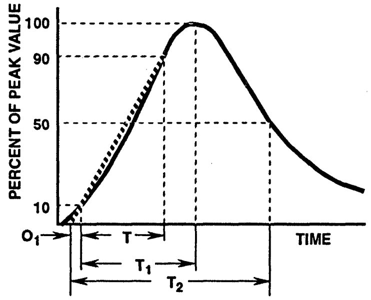


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE

9
VARISTOR PRODUCTS



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front Time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20µs Current Waveform:
8µs = T_1 = Virtual Front Time
20µs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

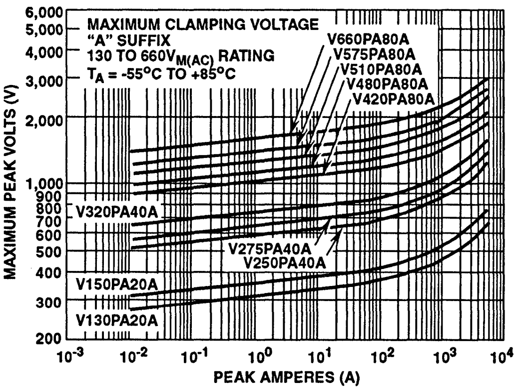


FIGURE 3. CLAMPING VOLTAGE FOR V130PA20A - V660PA100A

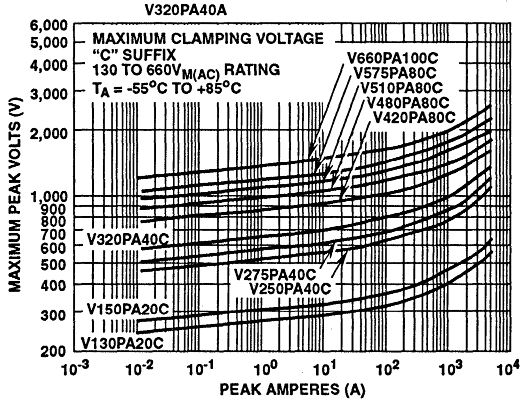


FIGURE 4. CLAMPING VOLTAGE FOR V130PA20C - V660PA100C

Pulse Rating Curves

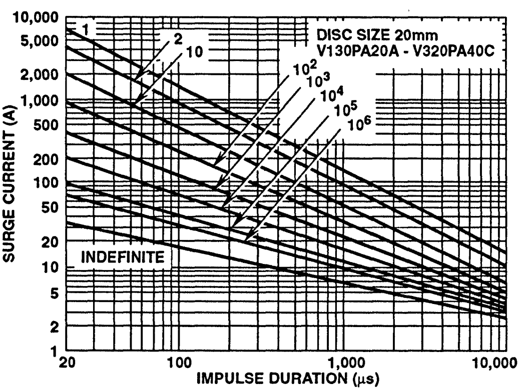


FIGURE 5. SURGE CURRENT RATING CURVES FOR V130PA20A - V320PA40C

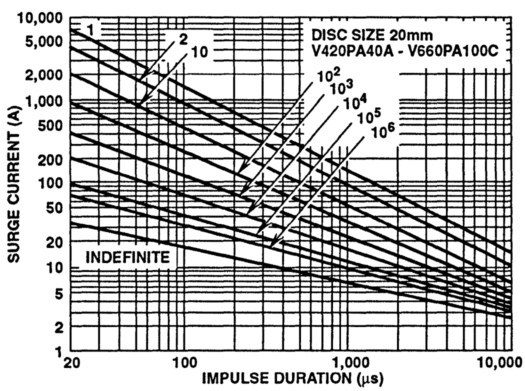
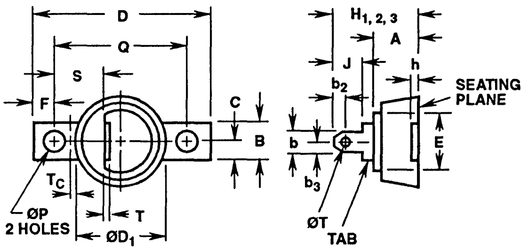


FIGURE 6. SURGE CURRENT RATING CURVES FOR V420PA40A - V660PA100C

NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

Packaging

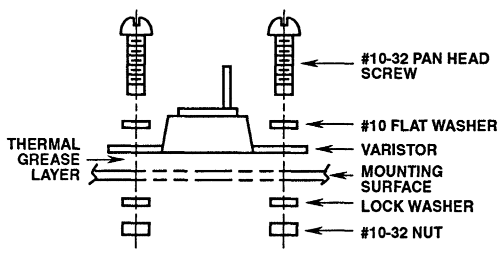


SYMBOL	MILLIMETERS MIN	MILLIMETERS NOM	MILLIMETERS MAX	INCHES MIN	INCHES NOM	INCHES MAX	NOTES
A	-	-	14.3	-	-	0.570	-
b	-	-	6.6	-	-	0.260	1
b2	3.94	4.06	4.18	0.155	0.160	0.165	-
b3	3.05	3.17	3.29	0.120	0.125	0.130	-
B	-	-	12.9	-	-	0.510	-
C	-	-	6.6	-	-	0.260	-
D	-	-	66.3	-	-	2.610	-
ØD1	-	-	33.5	-	-	1.320	-
E	-	11.2	-	-	0.440	-	-
F	7.50	7.62	7.75	0.295	0.300	0.305	-
h	-	0.8	1.0	-	0.030	0.040	-
H_1	-	-	25.6	-	-	1.010	3
H_2	-	-	28.3	-	-	1.120	3
H_3	-	-	32.8	-	-	1.290	3
J	-	-	8.1	-	-	0.320	-
ØP	5.6	-	6.0	0.220	-	0.240	-
Q	50.6	50.8	51.0	1.990	2.000	2.010	-
S	18.4	19.2	20.0	0.72	0.75	0.78	-
T	-	-	1.0	-	-	0.040	-
ØT	2.8	-	-	0.110	-	-	-
T_C	-	3.2	-	-	0.126	-	2

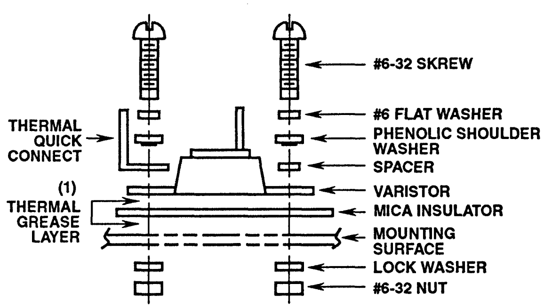
NOTES:

1. Tab is designed to fit 1/4" quick-connect terminal.
2. Case temperature is measured at T_C on top surface of base plate.
3. H_1 (130-150V_{RMS} devices)
   H_2 (250-320V_{RMS} devices)
   H_3 (420-660V_{RMS} devices)
4. Electrical connection: top terminal and base plate.
5. Typical weight: 30g

Suggested Hardware and Mounting Arrangements



Typical Non-Isolated Mounting



Typical Isolated Mounting

NOTES:

1. GE G623, Dow Corning, DC3, 4, 340, or 640 Thermal Grease recommended for best heat transfer.
2. 1,000V isolation kit containing the following parts can be ordered by part #A7811055.

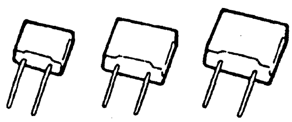
1. MICA insulation 1"/3.1"/0.005" thick	2. Phenolic shoulder washer	2. #6-32/$^3/_4$ screw	2. #6 internal tooth lock washer
1. $^1/_4$" quick-connect terminal	1. Spacer	2. #6-32 nut	2. #6 flat washer

HARRIS SEMICONDUCTOR

RA Series

Low Profile Radial Lead Metal-Oxide Varistors

August 1993



RA SERIES

Features

- **Recognized as "Transient Voltage Surge Suppressors", UL File #E75961 to Std. 1449**
- **Recognized as "Transient Voltage Surge Suppressors", CSA File #LR91788 to Std. C22.2 No. 1-M1981**
- **Low Profile Outline with Precise Seating Plane**
- **Continuous Temperature Operation .... +125°C**
- **Wide Operating Voltage Range $V_{M(AC)RMS}$ 275V**
- **High Energy Absorption Capability W_{TM} .... up to 140J**
- **3 Model Sizes Available .... RA8, RA16, and RA22**
- **In-Line Leads for Ease in Automatic Placement**

Description

RA series transient surge suppressors are low profile radial lead varistors that feature a precise seating plane to increase mechanical stability for secure circuit-board mounting. This feature makes these devices suitable for industrial applications critical to vibration.

The RA series are available in voltage ratings up to 275V $V_{M(AC)RMS}$, and energy levels up to 140J. Supplied in tape and reel for use with automatic insertion equipment, these varistors are also used in automotive, motor-control, telecommunication, and military applications.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	RA8 SERIES	RA16 SERIES	RA22 SERIES	UNITS
Continuous:				
Steady State Applied Voltage:				
AC Voltage Range ($V_{M(AC)RMS}$)	4 to 275	10 to 275	4 to 275	V
DC Voltage Range ($V_{M(DC)}$)	5.5 to 369	14 to 369	18 to 369	V
Transient:				
Peak Pulse Current (I_{TM})				
For 8/20μsec Current Wave (See Figure 2)	100 to 1200	1000 to 4500	2000 to 6500	A
Single Pulse Energy Range (Note 1)				
For 10/1000μsec Current Wave (W_{TM})	0.4 to 23	3.5 to 75	70 to 160	J
Operating Ambient Temperature Range (T_A)	-55 to +125	-55 to +125	-55 to +125	°C
Storage Temperature Range (T_{STG})	-55 to +150	-55 to +150	-55 to +150	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	<0.01	<0.01	%/°C
Hi-Pot Encapsulation (Isolation Voltage Capability) (Dielectric must withstand indicated DC voltage for one minute per MIL-STD 202, Method 301)	5000	5000	5000	V
Insulation Resistance	1000	1000	1000	MΩ

Device Ratings and Characteristics (Note 1)

RA8 Series

Series RA8 Varistors of $130V_{RMS}$ or greater are listed under UL File No. E75961 as a recognized component. CSA approved File No. LR91788.

MODEL NUMBER	DEVICE MARK-ING	MAXIMUM RATINGS (+125°C)				CHARACTERISTICS (+25°C)					
		CONTINUOUS		TRANSIENT		VARISTOR VOLTAGE AT 1mA DC TEST CURRENT			MAX CLAMPING VOLTAGE V_C AT TEST CURRENT (8/20μs)		TYPICAL CAPACI-TANCE
		RMS VOLT-AGE	DC VOLT-AGE	ENERGY (10/1000μs)	PEAK CURRENT (8/20μs)						
		$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM}	MIN	$V_{N(DC)}$	MAX	V_C	I_P	f = 1MHz
		(V)	(V)	(J)	(A)	(V)	(V)	(V)	(V)	(A)	(pF)
V8RA8	8R	4	5.5	0.4	150	6	8.2	11.2	22	5	3000
V12RA8	12R	6	8	0.6	150	9	12	16	34	5	2500
V18RA8	18R	10	14	0.8	250	14.4	18	21.6	42	5	2000
V22RA8	22R	14	18 (Note 3)	10 (Note 2)	250	18.7	22	26	47	5	1600
V27RA8	27R	17	22	1.0	250	23	27	31.1	57	5	1300
V33RA8	33R	20	26	1.2	250	29.5	33	36.5	68	5	1100
V39RA8	39R	25	31	1.5	250	35	39	43	79	5	900
V47RA8	47R	30	38	1.8	250	42	47	52	92	5	800
V56RA8	56R	35	45	2.3	250	50	56	62	107	5	700
V68RA8	68R	40	56	3.0	250	61	68	75	127	5	600
V82RA8	82R	50	66	4.0	1200	74	82	91	135	10	500
V100RA8	100R	60	81	5.0	1200	90	100	110	165	10	400
V120RA8	120R	75	102	6.0	1200	108	120	132	205	10	300
V150RA8	150R	95	127	8.0	1200	135	150	165	250	10	250
V80RA8	180R	115	153	10.0	1200	162	180	198	295	10	200
V200RA8	200R	130	175	11.0	1200	184	200	228	340	10	180
V220RA8	220R	140	180	12.0	1200	198	220	242	360	10	160
V240RA8	240R	150	200	13.0	1200	212	240	268	395	10	150
V270RA8	270R	175	225	15.0	1200	247	270	303	455	10	130
V360RA8	360R	230	300	20.0	1200	324	360	396	595	10	100
V390RA8	390R	250	330	21.0	1200	354	390	429	650	10	90
V430RA8	430R	275	369	23.0	1200	389	430	473	710	10	80

NOTES:

1. Average power dissipation of transients not to exceed 0.25W for RA8 Series.
2. Energy ratings for impulse duration of 30ms minimum to one half of peak current value.
3. Also rated to withstand 24V for 5 minutes.

Device Ratings and Characteristics (Note 1) (Continued)

RA16 Series

Series RA16 and RA22 Varistors of 130V_{RMS} or greater are listed under UL File No. E75961 as a recognized component.
CSA approved File No. LR91788.

MODEL NUMBER	DEVICE MARKING	MAXIMUM RATINGS (+125°C)				CHARACTERISTICS (+25°C)					
		CONTINUOUS		TRANSIENT							
		RMS VOLTAGE	DC VOLTAGE	ENERGY (10/1000μs)	PEAK CURRENT (8/20μs)	VARISTOR VOLTAGE AT 1mA DC TEST CURRENT			MAX CLAMPING VOLTAGE V_C AT TEST CURRENT (8/20μs)		TYPICAL CAPACITANCE
		$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM}	MIN	$V_{N(DC)}$	MAX	V_C	I_P	f = 1MHz
		(V)	(V)	(J)	(A)	(V)	(V)	(V)	(V)	(A)	(pF)
V18RA16	18R16	10	14	3.5	1000	14.4	18	21.6	39	10	11000
V22RA16	22R16	14	18 (Note 3)	50 (Note 2)	1000	18.7	22	26	43	10	9000
V27RA16	27R16	17	22	5.0	1000	23	27	31.1	53	10	7000
V33RA16	33R16	20	26	6.0	1000	29.5	33	36.5	64	10	6000
V39RA16	39R16	25	31	7.2	1000	35	39	43	76	10	5000
V47RA16	47R16	30	38	8.8	1000	42	47	52	89	10	4500
V56RA16	56R16	35	45	10.0	1000	50	56	62	103	10	3900
V68RA16	68R16	40	56	13.0	1000	61	68	75	123	10	3300
V82RA16	82R16	50	66	15.0	4500	74	82	90	145	50	2500
V100RA16	100R16	60	81	20.0	4500	90	100	110	175	50	2000
V120RA16	120R16	75	102	22.0	4500	108	120	132	205	50	1700
V150RA16	150R16	95	127	30.0	4500	135	150	165	255	50	1400
V180RA16	180R16	115	153	35.0	4500	162	180	198	300	50	1100
V200RA16	200R16	130	175	38.0	4500	184	200	228	340	50	1000
V220RA16	220R16	140	180	42.0	4500	198	220	242	360	50	900
V240RA16	240R16	150	200	45.0	4500	212	240	268	395	50	800
V270RA16	270R16	175	225	55.0	4500	247	270	303	455	50	700
V360RA16	360R16	230	300	70.0	4500	324	360	396	595	50	550
V390RA16	390R16	250	330	72.0	4500	354	390	429	650	50	500
V430RA16	430R16	275	369	75.0	4500	389	430	473	710	50	450
RA22 Series											
V24RA22	24R22	14	18 (Note 3)	100.0 (Note 2)	2000	19.2	24 (Note 4)	26	43	20	18000
V36RA22	36R22	23	31	160.0 (Note 2)	2000	32	36 (Note 4)	40	63	20	12000
V200RA22	200R22	130	175	70.0	6500	184	200	2288	340	100	1900
V240RA22	240R22	150	200	80.0	6500	212	240	268	395	100	1600
V270RA22	270R22	175	225	90.0	6500	247	270	303	455	100	1400
V390RA22	390R22	250	330	130.0	6500	354	390	429	650	100	1000
V430RA22	430R22	275	369	140.0	6500	389	430	473	710	100	900

NOTES:

1. Average power dissipation of transients not to exceed 0.60W for RA16 Series, or 1.0W for RA22 Series.
2. Energy ratings for impulse duration of 30ms minimum to one half of peak current value.
3. Also rated to withstand 24V for 5 minutes.
4. 10mA DC Test Current.

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

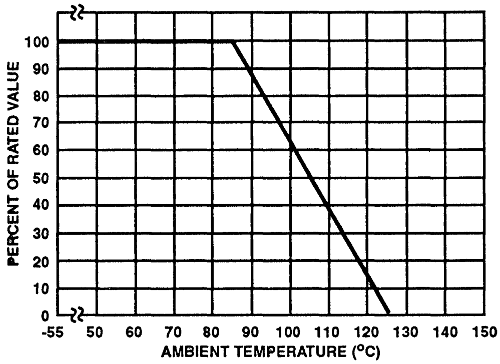
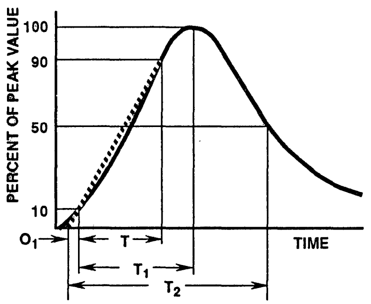


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

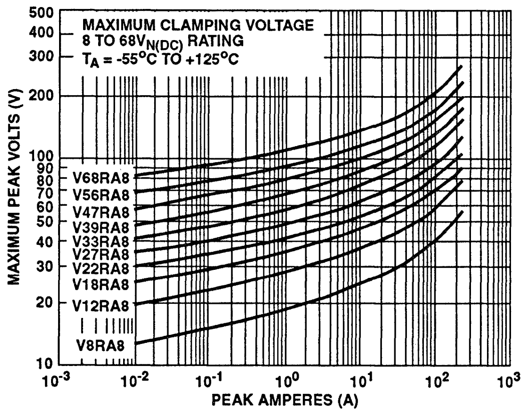


FIGURE 3. CLAMPING VOLTAGE FOR V8RA8 - V68RA8

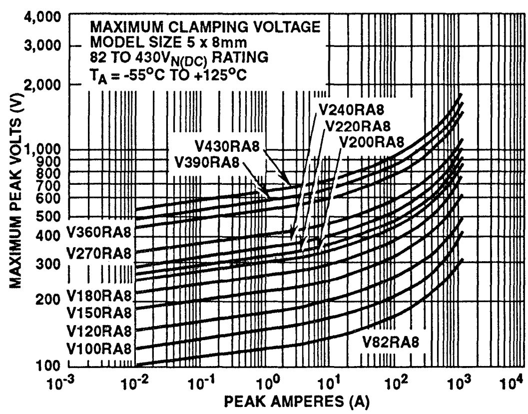


FIGURE 4. CLAMPING VOLTAGE FOR V82RA8 - V430RA8

9 VARISTOR PRODUCTS

Transient V-I Characteristics Curves (Continued)

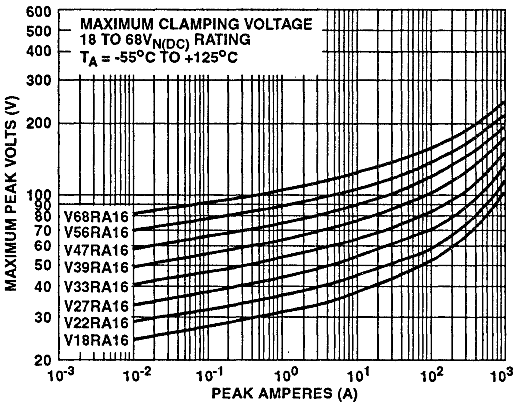


FIGURE 5. CLAMPING VOLTAGE FOR V18RA16 - V68RA16

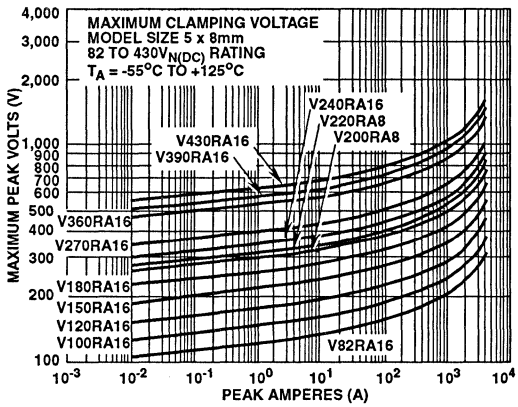


FIGURE 6. CLAMPING VOLTAGE FOR V82RA16 - V430RA16

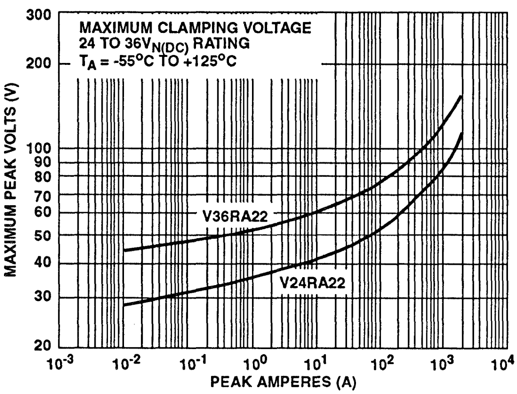


FIGURE 7. CLAMPIING VOLTAGE FOR V24RA22 - V36RA22

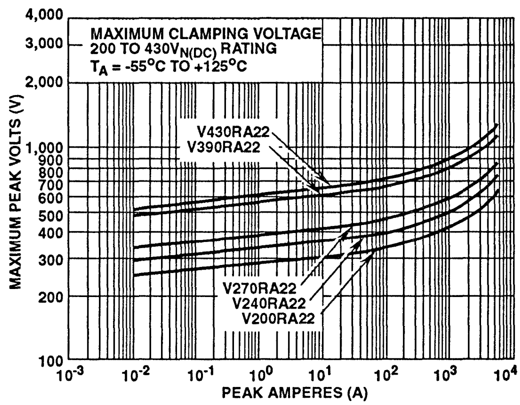


FIGURE 8. CLAMPING VOLTAGE FOR V200RA22 - V430RA22

Pulse Rating Curves

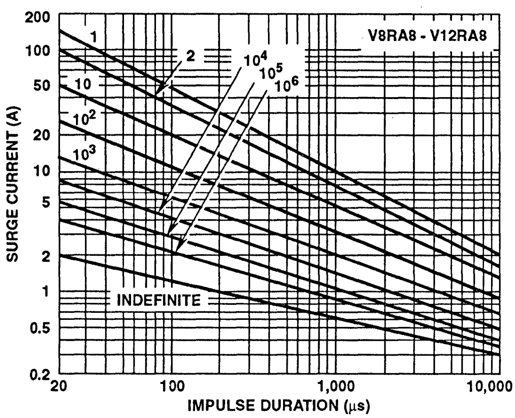


FIGURE 9. SURGE CURRENT RATING CURVES FOR V8RA8 - V12RA8

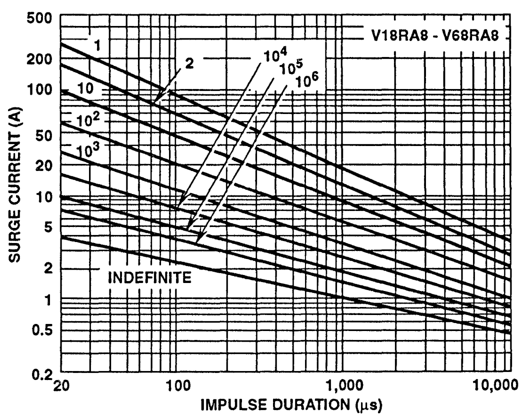


FIGURE 10. SURGE CURRENT RATING CURVES FOR V18RA8 - V68RA8

Pulse Rating Curves (Continued)

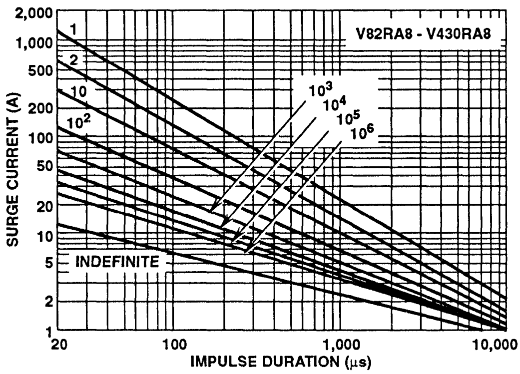


FIGURE 11. SURGE CURRENT RATING CURVES FOR V82RA8 - V430RA8

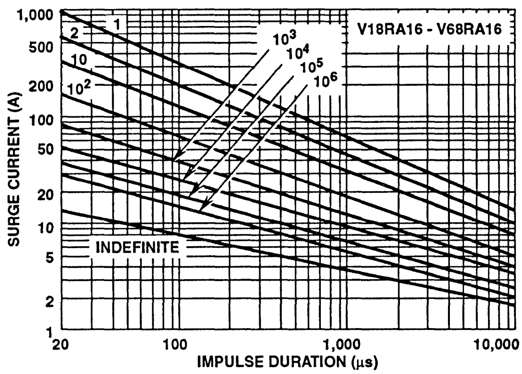


FIGURE 12. SURGE CURRENT RATING CURVES FOR V18RA16 - V68RA16

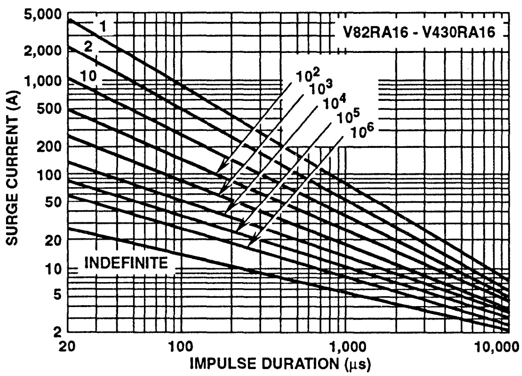


FIGURE 13. SURGE CURREENT RATING CURVES FOR V82RA16 - V430RA16

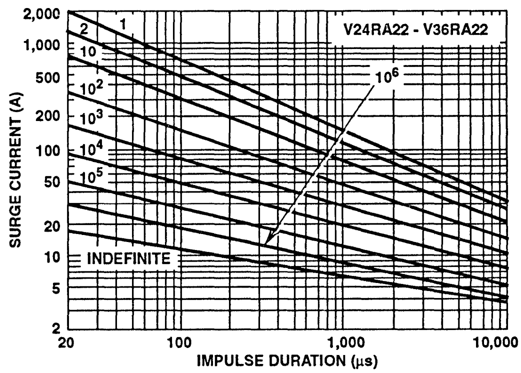


FIGURE 14. SURGE CURRENT RATING CURVES FOR V24RA22 - V36RA22

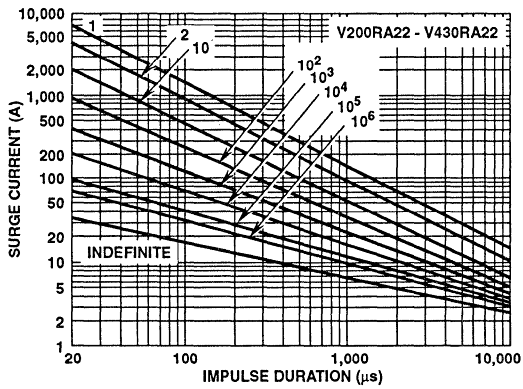
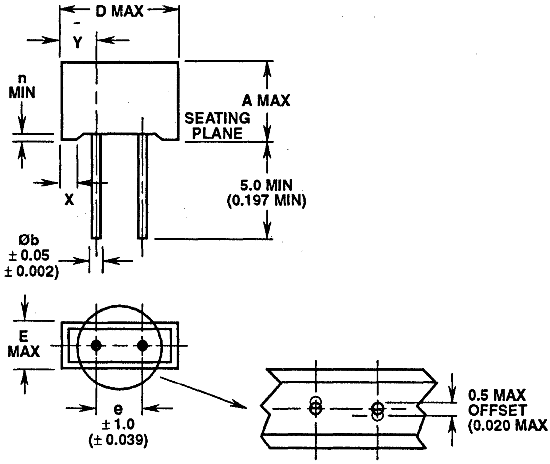


FIGURE 15. SURGE CURRENT CURVES FOR V200RA22 - V430RA22

NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

Packaging



SYMBOL	RA8 SERIES	RA16 SERIES	RA22 SERIES
A MAX	8.85 (0.348)	15.1 (0.594)	19.1 (0.752)
D MAX	11.45 (0.450)	19.7 (0.776)	25.5 (1.004)
e	5 (0.197)	7.5 (0.295)	7.5 (0.295)
E MAX	5.2 (0.205)	6.3 (0.248)	6.3 (0.248)
n MAX	0.7 (0.027)	0.7 (0.027)	0.7 (0.027)
Øb	0.635 (0.025)	0.81 (0.032)	0.81 (0.032)
WEIGHT TYP	1 Gram	3.4 Grams	4.4 Grams
X	2.2 (0.087)	2.2 (0.087)	4.4 (0.173)
Y	3.1 ± 0.5 (0.122 ± 0.02)	6 ± 1 (0.236 ± 0.04)	8.9 ± 1 (0.35 ± 0.04)

NOTES:

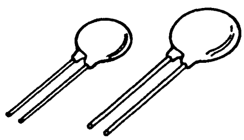
1. Dimensions in mm, dimensions in inches in parentheses.
2. Inches for reference only.

HARRIS SEMICONDUCTOR

ZA Series

Radial Lead Metal-Oxide Varistors for Low-to-Medium Voltage Operation

August 1993



5, 7, 10, 14, 20mm
ZA SERIES

Features

- **Recognized as "Transient Voltage Surge Suppressors", UL File #E135010 to Std. 497B**
- **Wide Operating Voltage Range $V_{M(AC)RMS}$ .... 4V to 460V**
- **DC Voltage Ratings ....5.5V to 615V**
- **5 Model Sizes Available .... 5, 7, 10, 14, and 20mm**
- **Radial-Lead Package for Compact Hard-Wired Printed Circuit Board Designs**
- **Available in Tape and Reel for Use With Automatic Insertion Equipment**

Description

ZA series transient surge suppressors are radial-lead varistors designed for use in the protection of low and medium-voltage circuits (5V or less) of electronic systems. These systems, whose components because of smaller geometries, faster switching times, and less power consumption, are becoming more sensitive to failure and malfunction due to voltage transients. Because of their radial-lead construction, ZA series devices require very little mounting space, a feature of importance in compact, hard-wired printed circuit board systems.

These devices are available in five model sizes: 5mm, 7mm, 10mm, 14mm and 20mm, and feature a wide $V_{M(AC)RMS}$ voltage of 4V to 460V.

Absolute Maximum Ratings

For ratings of individual members of a series, see Device Ratings and Characteristics chart

	ZA SERIES	UNITS
Continuous:		
Steady State Applied Voltage:		
AC Voltage Range ($V_{M(AC)RMS}$)	4 to 460	V
DC Voltage Range ($V_{M(DC)}$)	5.5 to 615	V
Transient:		
Peak Pulse Current (I_{TM})		
For 8/20μs Current Wave (See Figure 2)	25 to 4500	A
Single Pulse Energy Range (Note 1)		
For 10/133000μs Current Wave (W_{TM})	0.1 to 35	J
Operating Ambient Temperature Range (T_A)	-55 to +85	°C
Storage Temperature Range (T_{STG})	-55 to +125	°C
Temperature Coefficient (αV) of Clamping Voltage (V_C) at Specified Test Current	<0.01	%/°C
Hi-Pot Encapsulation (Isolation Voltage Capability)	2500	V
(Dielectric must withstand indicated DC voltage for one minute per MIL-STD 202, Method 301)		
Insulation Resistance	1000	MΩ

NOTE:

1. Ratings on specific types can be as high as 160J for an impulse duration of 30ms minimum to 1/2 of peak current value.

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

Device Ratings and Characteristics (Note 1)

ZA Series Varistors are listed under UL File No. E135010 as a UL recognized component.

			MAXIMUM RATINGS (+85°C)				CHARACTERISTICS (+25°C)					
			CONTINUOUS		TRANSIENT							
	MODEL SIZE DISC DIA.	DEVICE MARK-ING	RMS VOLT-AGE	DC VOLTAGE	ENERGY (10/1000μs)	PEAK CURRENT (8/20μs)	VARISTOR VOLTAGE AT 1mA DC TEST CURRENT			MAX CLAMPING VOLTAGE V_C AT TEST CURRENT (8/20μs)		TYPICAL CAPACITANCE
MODEL			$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM}	MIN	$V_{N(DC)}$	MAX	V_C	I_P	f = 1MHz
NUMBER	(mm)		(V)	(V)	(J)	(A)	(V)	(V)	(V)	(V)	(A)	(pF)
V8ZA05	5	Z08	4	5.5	0.1	50	6.0	8.2	11.0	30	2	1400
V8ZA1	7	08Z1	4	5.5	0.4	100	6.0	8.2	11.0	22	5	3000
V8ZA2	10	08Z2	4	5.5	0.8	250	6.0	8.2	11.0	20	5	7500
V12ZA05	5	Z12	6	8	0.14	100	9.0	12	16.0	37	2	1200
V12ZA1	7	12Z1	6	8	0.6	250	9.0	12	16.0	34	5	2500
V12ZA2	10	12Z2	6	8	1.2	250	9.0	12	16.0	30	5	6000
V18ZA05	5	Z18	10	14	0.17	100	14.4	18	21.6	44	2	1000
V18ZA1	7	18Z1	10	14	0.8	250	14.4	18	21.6	42	5	2000
V18ZA2	10	18Z2	10	14	1.5	500	14.4	18	21.6	39	5	5000
V18ZA3	14	18Z3	10	14	3.5	1000	14.4	18	21.6	39	10	11000
V18ZA40	20	18Z40	10	14	80.0 (Note 2)	2000	14.4	18 (Note 3)	21.6	37	20	22000
V22ZA05	5	Z22	14	18 (Note 4)	0.2	100	18.7	22	26.0	51	2	800
V22ZA1	7	22Z1	14	18 (Note 4)	0.9	250	18.7	22	26.0	47	5	1600
V22ZA2	10	22Z2	14	18 (Note 4)	2.0	500	18.7	22	26.0	43	5	4000
V22ZA3	14	22Z3	14	18 (Note 4)	4.0	1000	18.7	22	26.0	43	10	9000
V24ZA50	20	24Z50	14	18 (Note 4)	100.0 (Note 2)	2000	19.2	24 (Note 3)	26.0	43	20	18000
V27ZA05	5	Z27	17	22	0.25	100	23.0	27	31.1	59	2	600
V27ZA1	7	27Z1	17	22	1.0	250	23.0	27	31.1	57	5	1300
V27ZA2	10	27Z2	17	22	2.5	500	23.0	27	31.1	53	5	3000
V27ZA4	14	27Z4	17	22	5.0	1000	23.0	27	31.1	53	10	7000
V27ZA60	20	27Z60	17	22	120.0 (Note 2)	2000	23.0	27 (Note 3)	31.1	50	20	15000
V33ZA05	5	Z33	20	26	0.3	100	29.5	33	38.0	67	2	500
V33ZA1	7	33Z1	20	26	1.2	250	29.5	33	36.5	68	5	1100
V33ZA2	10	33Z2	20	26	3.0	500	29.5	33	36.5	64	5	2700
V33ZA5	14	33Z5	20	26	6.0	1000	29.5	33	36.5	64	10	6000
V33ZA70	20	33Z70	21	27	150.0 (Note 2)	2000	29.5	33 (Note 3)	36.5	58	20	13000
V26ZA80	20	36Z80	23	31	160.0 (Note 2)	2000	32.0	36 (Note 3)	40.0	63	20	12000
V39ZA05	5	Z39	25	31	0.35	100	35.0	39	46.0	79	2	440
V39ZA1	7	39Z1	25	31	1.5	250	35.0	39	43.0	79	5	900
V39ZA3	10	39Z3	25	31	3.5	500	35.0	39	43.0	76	5	2200
V39ZA6	14	39Z6	25	31	7.2	1000	35.0	39	43.0	76	10	5000

NOTES:

1. Average power dissipation of transients not to exceed 0.2W, 0.25W, 0.4W, 0.6W or 1W for model sizes 5mm, 7mm, 10mm, 14mm and 20mm, respectively.
2. Energy rating for impulse duration of 30ms minimum to one half of peak current.
3. 10mA DC test current.
4. Also rated to withstand 24V for 5 minutes.

Device Ratings and Characteristics (Notes 1, 2)

ZA Series Varistors are listed under UL File No. E135010 as a UL recognized component.

MODEL NUMBER	MODEL SIZE DISC DIA.	DEVICE MARK-ING	MAXIMUM RATINGS (+85°C)				CHARACTERISTICS (+25°C)					
			CONTINUOUS		TRANSIENT		VARISTOR VOLTAGE AT 1mA DC TEST CURRENT			MAX CLAMPING VOLTAGE V_C AT TEST CURRENT (8/20µs)		TYPICAL CAPACITANCE
			RMS VOLTAGE	DC VOLTAGE	ENERGY (10/1000µs)	PEAK CURRENT (8/20µs)						
			$V_{M(AC)}$	$V_{M(DC)}$	W_{TM}	I_{TM}	MIN	$V_{N(DC)}$	MAX	V_C	I_P	f = 1MHz
	(mm)		(V)	(V)	(J)	(A)	(V)	(V)	(V)	(V)	(A)	(pF)
V47ZA05	5	Z47	30	38	0.4	100	42	47	55	90	2	400
V47ZA1	7	47Z1	30	38	1.8	250	42	47	52	92	5	800
V47ZA3	10	47Z3	30	38	4.5	500	42	47	52	89	5	2000
V47ZA7	14	47Z7	30	38	8.8	1000	42	47	52	89	10	4500
V56ZA05	5	Z56	35	45	0.5	00	50	56	66	108	2	360
V56ZA2	7	56Z2	35	45	2.3	250	50	56	62	107	5	700
V56ZA3	10	56Z3	35	45	5.5	500	50	56	62	103	5	1800
V56ZA8	14	56Z8	35	45	10.0	1000	50	56	62	103	10	3900
V68ZA05	5	Z68	40	56	0.6	100	61	68	80	127	2	300
V68ZA2	7	68Z2	40	56	3.0	250	61	68	75	127	5	600
V68ZA3	10	68Z3	40	56	6.5	500	61	68	75	123	5	1500
V68ZA10	14	68Z10	40	56	13.0	1000	61	68	75	123	10	3300
V82ZA05	5	Z82	50	66	2.0	400	73	82	97	135	5	240
V82ZA2	7	82Z2	50	66	4.0	1200	73	82	91	135	10	500
V82ZA4	10	82Z4	50	66	8.0	2500	73	82	91	135	25	1100
V82ZA12	14	82Z12	50	66	15.0	4500	73	82	91	145	50	2500
V100ZA05	5	Z100	60	81	2.5	400	90	100	117	165	5	180
V100ZA3	7	100Z	60	81	5.0	1200	90	100	110	165	10	400
V100ZA4	10	100Z4	60	81	10.0	2500	90	100	110	165	25	900
V100ZA15	14	100Z15	60	81	20.0	4500	90	100	110	175	50	2000
V120ZA05	5	Z120	75	102	3.0	400	108	120	138	205	5	140
V120ZA1	7	120Z	75	102	6.0	1200	108	120	132	205	10	300
V120ZA4	10	120Z4	75	102	12.0	2500	108	120	132	200	25	750
V120ZA6	14	120Z6	75	102	22.0	4500	108	120	132	210	50	1700
V150ZA05	5	Z150	92	127	4.0	400	135	150	173	250	5	120
V150ZA1	7	Z051	95	127	8.0	1200	135	150	165	250	10	250
V150ZA5	10	150Z4	95	127	15.0	2500	135	150	165	250	25	600
V150ZA10	14	150Z10	95	127	30.0	4500	135	150	165	255	50	1400
V180ZA05	5	Z180	110	153	5.0	400	162	180	207	295	5	100
V180ZA1	7	180Z	115	153	10.0	1200	162	180	198	295	10	200
V180ZA5	10	180Z5	115	153	18.0	2500	162	180	198	300	25	500
V180ZA10	14	180Z10	115	153	35.0	4500	162	180	198	300	50	1100
V220ZA05	5	Z220	140	180	6.0	400	198	220	253	360	5	90
V270ZA05	5	Z270	175	225	7.5	400	243	270	311	440	5	70
V330ZA05	5	Z330	210	275	9.0	400	297	330	380	540	5	60
V390ZA05	5	Z390	250	330	10.0	400	351	390	449	640	5	50
V430ZA05	5	Z430	275	369	11.0	400	387	430	495	700	5	45
V470ZA05	5	Z470	300	385	12.0	400	420	470	517	775	5	35
V680ZA05	5	Z680	420	560	14.0	400	610	680	748	1120	5	32
V750ZA05	5	Z750	460	615	17.0	400	675	750	825	1240	5	30
V910ZA05	5	Z910	-	-	-	-	-	910	-	-	5	28

NOTES:

1. Average power dissipation of transients not to exceed 0.2W, 0.25W, 0.4W, 0.6W or 1W for model sizes 5mm, 7mm, 10mm, 14mm and 20mm, respectively.
2. Higher voltages a vailable, contact Harris Semiconductor Power Marketing

Power Dissipation Requirements

Transients in a suppressor generate heat too quickly for it to be transferred to the surroundings during the pulse interval. Continuous power dissipation capability, therefore, is not a necessary design requirement for a suppressor, unless transients occur in rapid succession. Under this condition, the average power dissipation required is simply the energy (watt-seconds) per pulse times the number of pulses per second. The power so developed must be within the specifications shown on the Device Ratings and Characteristics table for the specific device. Furthermore, the operating values need to be derated at high temperatures as shown in Figure 1. Because varistors can only dissipate a relatively small amount of average power they are, therefore, not suitable for repetitive applications that involve substantial amounts of average power dissipation.

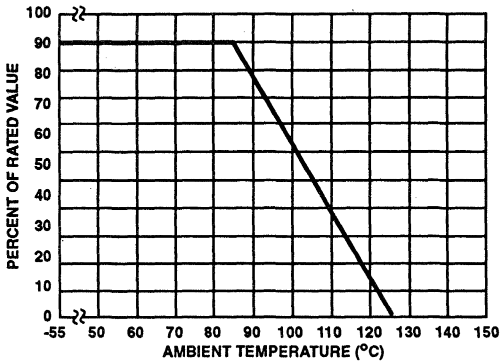
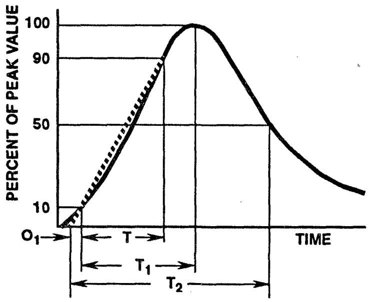


FIGURE 1. CURRENT, ENERGY AND POWER DERATING CURVE



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20μs Current Waveform:
8μs = T_1 = Virtual Front Time
20μs = T_2 = Virtual Time to Half Value

FIGURE 2. PEAK PULSE CURRENT TEST WAVEFORM

Transient V-I Characteristics Curves

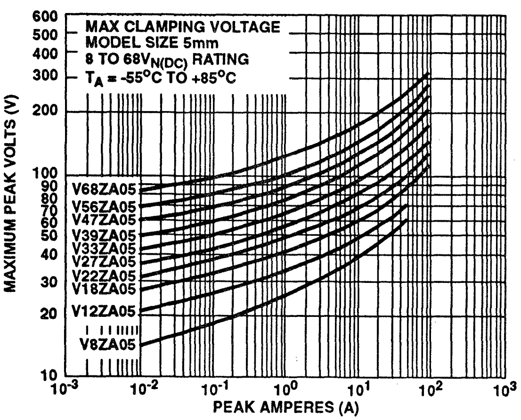


FIGURE 3. CLAMPING VOLTAGE FOR V8ZA05 - V68ZA05

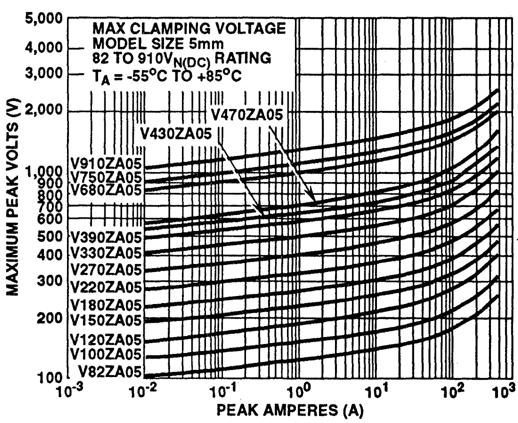


FIGURE 4. CLAMPING VOLTAGE FOR V82ZA05 - V910ZA05

Transient V-I Characteristics Curves (Continued)

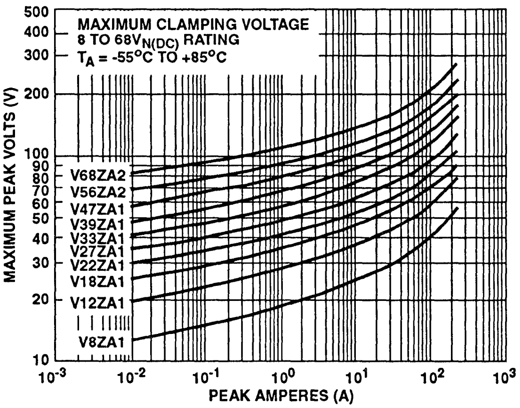


FIGURE 5. PULSE RATING CURVES FOR V8ZA1 - V68ZA2

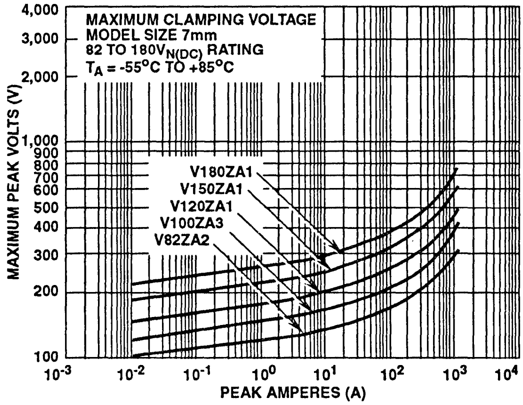


FIGURE 6. PULSE RATING CURVES FOR V82ZA2 - V180ZA1

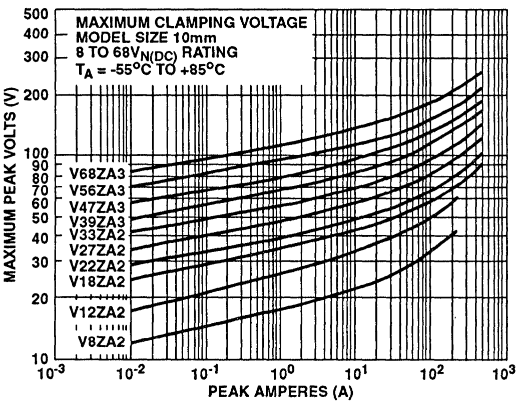


FIGURE 7. CLAMPING VOLTAGE FOR V8ZA2 - V68ZA3

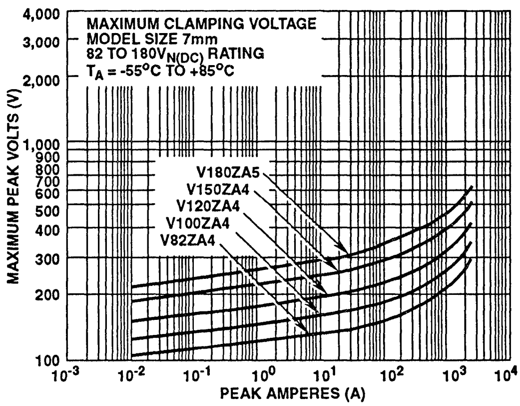


FIGURE 8. CLAMPING VOLTAGE FOR V82ZA4 - V180ZA5

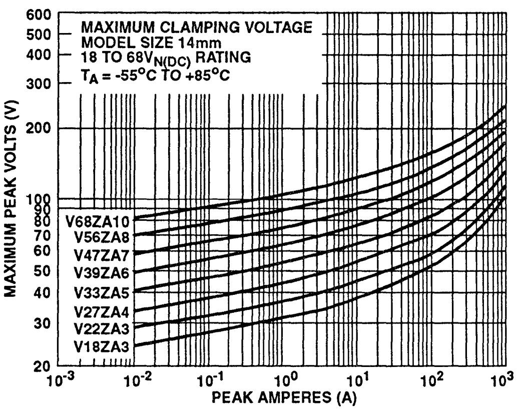


FIGURE 9. CLAMPING VOLTAGE FOR V18ZA3 - V68ZA10

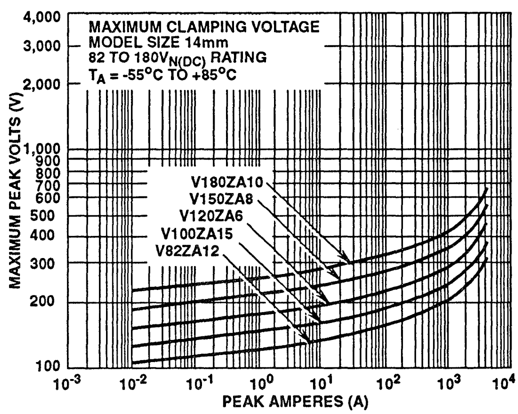


FIGURE 10. CLAMPING VOLTAGE FOR V82ZA12 - V180ZA10

Transient V-I Characteristics Curves (Continued)

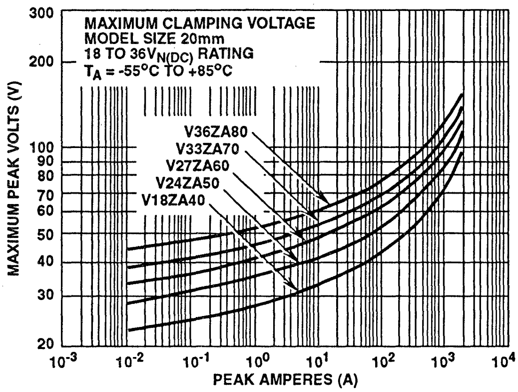


FIGURE 11. CLAMPING VOLTAGE FOR V18ZA40 - V36ZA80

Pulse Rating Curves

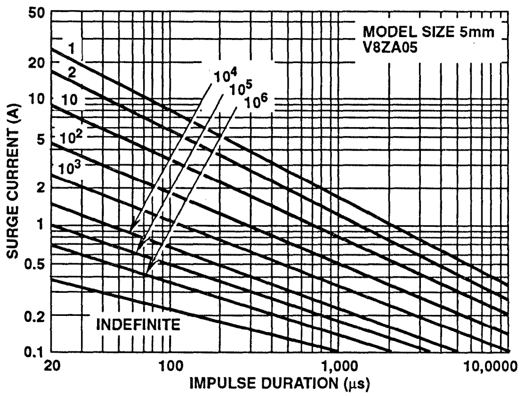


FIGURE 12. SURGE CURRENT RATING CURVES FOR V8ZA05

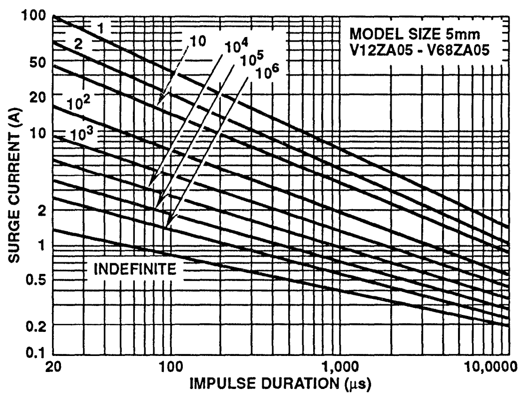


FIGURE 13. SURGE CURRENT RATING CURVES FOR V12ZA05 - V68ZA05

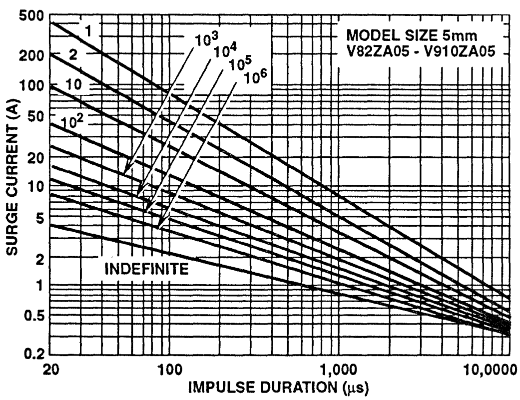


FIGURE 14. SURGE CURRENT RATING CURVES FOR V82ZA05 - V910ZA05

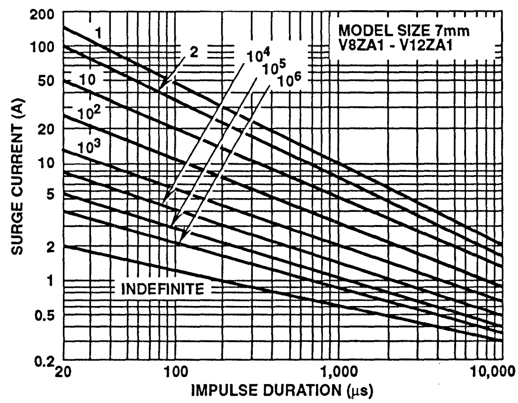


FIGURE 15. SURGE CURRENT RATING CURVES FOR V8ZA1 - V12ZA1

Pulse Rating Curves (Continued)

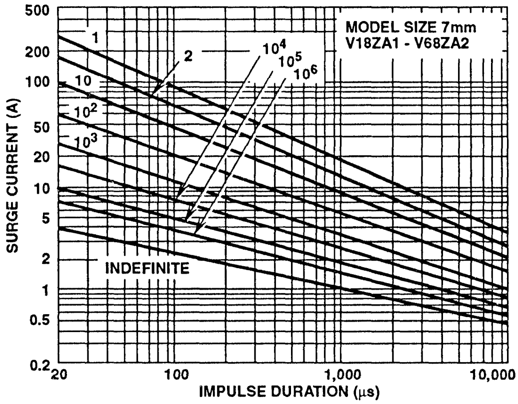


FIGURE 16. SURGE CURRENT RATING CURVES FOR V18ZA1 - V68ZA2

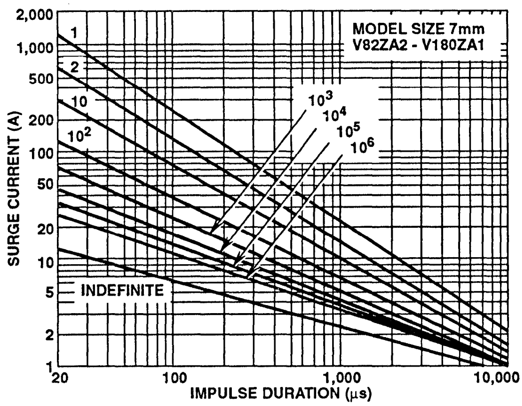


FIGURE 17. SURGE CURRENT RATING CURVES FOR V82ZA2 - V180ZA1

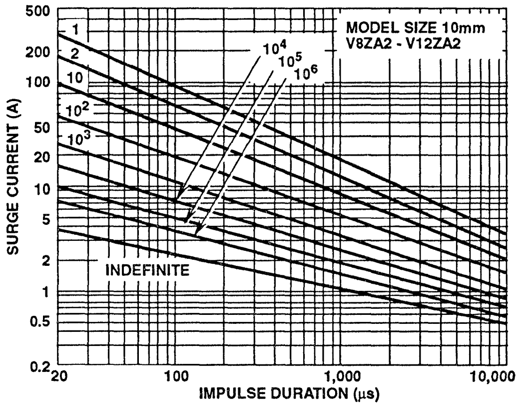


FIGURE 18. SURGE CURRENT RATING CURVES FOR V8ZA2 - V127ZA2

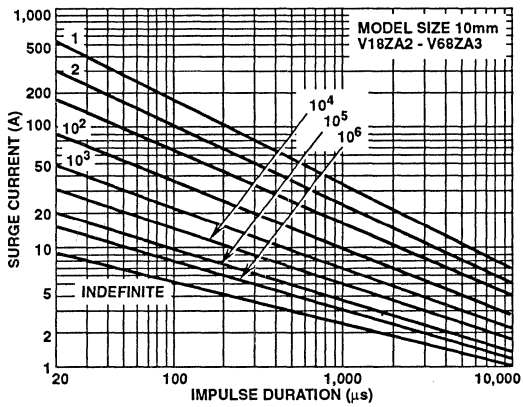


FIGURE 19. SURGE CURRENT RATING CURVES FOR V18ZA2 - V68ZA3

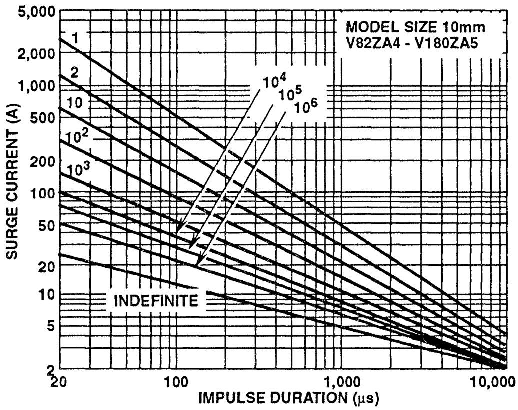


FIGURE 20. SURGE CURRENT RATING CURVES FOR V82ZA4 - V180ZA5

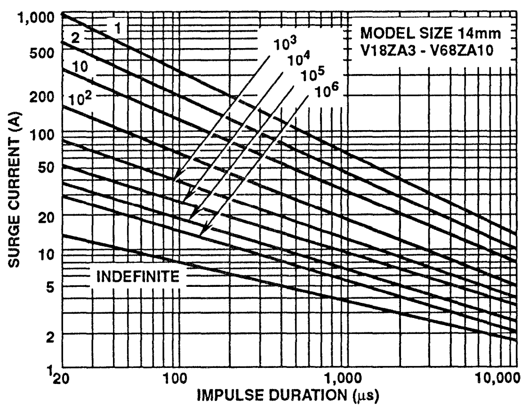


FIGURE 21. SURGE CURRENT RATING CURVES FOR V18ZA3 - V68ZA10

9

VARISTOR PRODUCTS

Pulse Rating Curves (Continued)

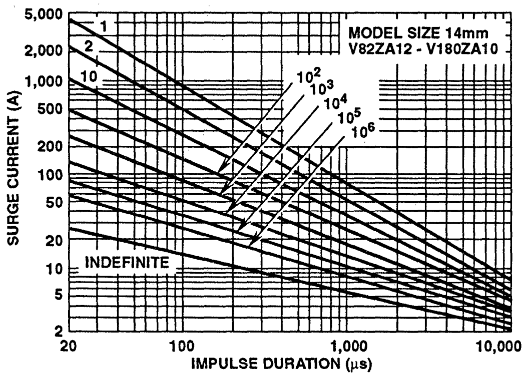


FIGURE 22. SURGE CURRENT RATING CURVES FOR V82ZA12 - V180ZA10

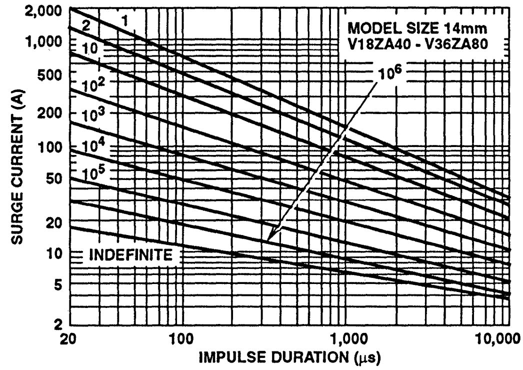
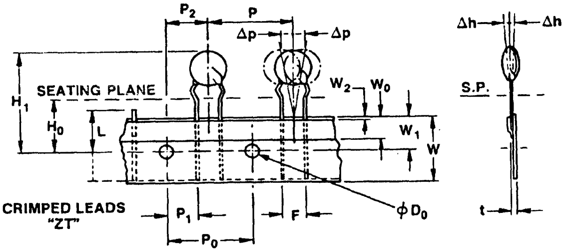
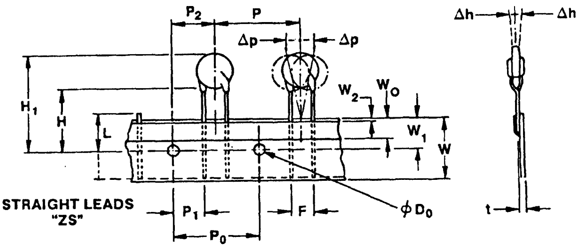


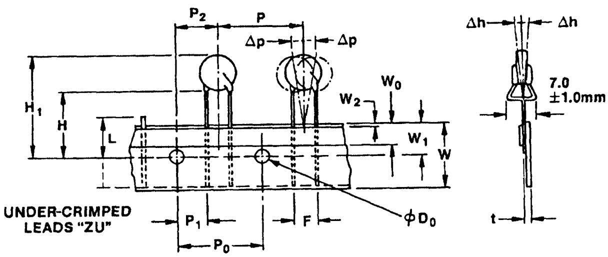
FIGURE 23. SURGE CURRENT RATING CURRENT FOR V18ZA40 - V36ZA80

NOTE: If pulse ratings are exceeded, a shift of $V_{N(DC)}$ (at specified current) of more than ±10% could result. This type of shift, which normally results in a decrease of $V_{N(DC)}$, may result in the device not meeting the original published specifications, but it does not prevent the device from continuing to function, and to provide ample protection.

Tape and Reel Specifications







Tape And Reel Data

- Conforms to ANSI and EIA specifications
- Can be supplied to IEC Publication 286-2
- Radial devices on tape are supplied with crimped leads, straight leads, or under-crimped leads

SYMBOL	PARAMETER	MODEL SIZE				
		5mm	7mm	10mm	14mm	20mm
P	Pitch of Component	12.7 ± 1.0	12.7 ± 1.0	25.4 ± 1.0	25.4 ± 1.0	25.4 ± 1.0
P_0	Feed Hole Pitch	12.7 ± 0.2	12.7 ± 0.2	12.7 ± 0.2	12.7 ± 0.2	12.7 ± 0.2
P_1	Feed Hole Center to Pitch	3.85 ± 0.7	3.85 ± 0.7	2.6 ± 0.7	2.6 ± 0.7	2.6 ± 0.7
P_2	Hole Center to Component Center	6.35 ± 1.0	6.35 ± 1.0	6.35 ± 1.0	6.35 ± 1.0	6.35 ± 1.0
F	Lead to Lead Distance	5.0 ± 1.0	5.0 ± 1.0	7.5 ± 1.0	7.5 ± 1.0	7.5 ± 1.0
Δh	Component Alignment	2.0 Max	2.0 Max	2.0 Max	2.0 Max	2.0 Max
W	Tape Width	18.0 + 1.0 18.0 - 0.5	18.0 + 1.0 18.0 - 0.5	18.0 + 1.0 18.0 - 0.5	18.0 + 1.0 18.0 - 0.5	18.0 + 1.0 18.0 - 0.5
W_0	Hold Down Tape Width	6.0 ± 0.3	6.0 ± 0.3	6.0 ± 0.3	6.0 ± 0.3	12.0 ± 0.3
W_1	Hole Position	9.0 + 0.75 9.0 - 0.50	9.0 + 0.75 9.0 - 0.50	9.0 + 0.75 9.0 - 0.50	9.0 + 0.75 9.0 - 0.50	9.0 + 0.75 9.0 - 0.50
W_2	Hold Down Tape Position	0.5 Max	0.5 Max	0.5 Max	0.5 Max	0.5 Max
H	Height from Tape Center to Component Base	18.0 + 2.0 18.0 - 0.0	18.0 + 2.0 18.0 - 0.0	18.0 + 2.0 18.0 - 0.0	18.0 + 2.0 18.0 - 0.0	18.0 + 2.0 18.0 - 0.0
H_0	Seating Plane Height	16.0 ± 0.5	16.0 ± 0.5	16.0 ± 0.5	16.0 ± 0.5	16.0 ± 0.5
H_1	Component Height	29.0 Max	29.0 Max	29.0 Max	29.0 Max	29.0 Max
D_0	Feed Hole Diameter	4.0 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	4.0 ± 0.2
t	Total Tape Thickness	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2
L	Length of Clipped Lead	11.0 Max	11.0 Max	11.0 Max	11.0 Max	12.0 Max
Δp	Component Alignment	3° Max	3° Max	3° Max	3° Max	3° Max

NOTE: Dimensions are in mm.

Tape and Reel Ordering Information

Crimped leads are standard on ZA types supplied in tape and reel and are denoted by the model letter "T". Model letter "S" denotes straight leads and letter "U" denotes special under-crimped leads.

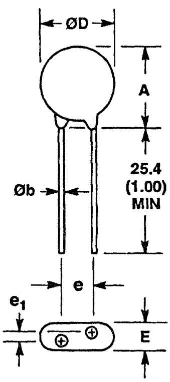
Example:

STANDARD MODEL	CRIMPED LEADS	STRAIGHT LEADS	UNDER-CRIMPED LEADS
V18ZA3	V18ZT3	V18ZS3	V18ZU3

SHIPPING QUANTITY

SIZE	RMS (MAX) VOLTAGE	QUANTITY PER REEL		
		"T" REEL	"S" REEL	"U" REEL
5mm	All	1000	1000	1000
7mm	All	1000	1000	1000
10mm	All	1000	1000	1000
14mm	< 300V	500	500	500
14mm	≥ 300V	500	500	500
20mm	< 300V	500	500	500
20mm	≥ 300V	500	500	500

Packaging



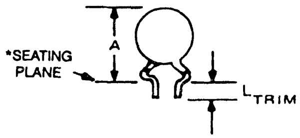
SYMBOL	VOLTAGE MODEL	VARISTOR MODEL SIZE									
		5mm		7mm		10mm		14mm		20mm	
		MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
A	All	6 (0.236)	10 (0.394)	7.5 (0.295)	12 (0.472)	10 (0.394)	16 (0.630)	13.5 (0.531)	20 (0.787)	17.5 (0.689)	26.5 (1.043)
ØD	All	6 (0.236)	7 (0.276)	7.5 (0.295)	9 (0.354)	10 (0.394)	12.5 (0.492)	13.5 (0.531)	17 (0.669)	17.5 (0.689)	23 (0.906)
e (Note 1)	All	4 (0.157)	6 (0.236)	4 (0.157)	6 (0.236)	6.5 (0.256)	8.5 (0.335)	6.5 (0.256)	8.5 (0.335)	6.5 (0.256) (Note 1)	8.5 (0.335) (Note 1)
e_1	V8ZA-V56ZA	1 (0.039)	3 (0.118)	1 (0.039)	3 (0.118)	1 (0.039)	3 (0.118)	1 (0.039)	3 (0.118)	1 (0.039)	3 (0.118)
	V68ZA-V100ZA	1.5 (0.059)	3.5 (0.138)	1.5 (0.059)	3.5 (0.138)	1.5 (0.059)	3.5 (0.138)	1.5 (0.059)	3.5 (0.138)	NA (NA)	NA (NA)
	V120ZA-V180ZA	1 (0.039)	3 (0.118)	1 (0.039)	3 (0.118)	1 (0.039)	3 (0.118)	1 (0.038)	1 (0.118)	NA (NA)	NA (NA)
	V220ZA-V910ZA	1.5 (0.059)	3.5 (0.138)	- -	- -	- -	- -	- -	- -	- -	- -
E	V8ZA-V56ZA	- -	5 (0.197)	- -	5 (0.197)	- -	5 (0.197)	- -	5 (0.197)	- -	5 (0.197)
	V68ZA-V100ZA	- -	5.6 (0.220)	- -	5.6 (0.220)	- -	5.6 (0.220)	- -	5.6 (0.220)	- -	5.6 (0.220)
	V120ZA-V180ZA	- -	5 (0.197)	- -	5 (0.197)	- -	5 (0.197)	- -	5 (0.197)	- -	5 (0.197)
	V220ZA-V910ZA	- -	5.6 (0.220)	- -	5.6 (0.220)	- -	5.6 (0.220)	- -	5.6 (0.220)	- -	5.6 (0.220)
Øb	All	0.585 (0.023)	0.685 (0.027)	0.585 (0.023)	0.685 (0.027)	0.76 (0.030)	0.86 (0.034)	0.76 (0.030)	0.86 (0.034)	0.76 (0.030)	0.86 (0.034)

NOTE: Dimensions in millimeters, inches in parentheses.

1. 10mm ALSO AVAILABLE; See Ordering Information.
   V24ZA50 only supplied with lead spacing of 6.35mm ± 0.5mm (0.25 ± 0.197)

Available Lead Style

Radial lead types can be supplied with a preformed crimp in the leads, and are available in all model sizes. Lead trim (L_{TRIM}) is supplied to the dimensions shown.



*Seating plane interpretation per IEC-717

CRIMPED AND TRIMMED LEAD

SYMBOL	VARISTOR MODEL SIZE									
	5mm		7mm		10mm		14mm		20mm	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
A	- -	13.0 (0.512)	- -	15 (0.591)	- -	19.5 (0.768)	- -	22.5 (0.886)	- -	29.0 (1.142)
L_{TRIM}	2.41 (0.095)	4.69 (0.185)	2.41 (0.095)	4.69 (0.185)	2.41 (0.095)	4.69 (0.185)	2.41 (0.095)	4.69 (0.185)	2.41 (0.095)	4.69 (0.185)

NOTE: Dimensions in millimeters, inches in parentheses.

Ordering Information

- For crimped and trimmed lead styles, standard radial type model numbers are changed by replacing the model letter "A" with "C".

Example:

STANDARD CATALOG MODEL	ORDER AS:
V18ZA3	V18ZC3

- For crimped leads without trimming and any variations to the above, contact Harris Semiconductor Power Marketing.

- For 10/±1mm lead spacing on 20mm diameter models only; append standard model numbers by adding "X10".

Example:

STANDARD CATALOG MODEL	ORDER AS:
V18ZA40	V18ZA40X10

TVS 10

SURGECTOR PRODUCTS

SURGECTOR™ is a trademark of Harris Semiconductor

Surgector Product Selection Guide

PART NUMBER	FUNCTION	V_2 MIN (V)	V_{BO} MAX (100V/µs)	I_{TSM} (1 x 2µs)	I_{TSM} (10 x 1000µs)	I_H (mA)	PACKAGE STYLE
SGT10S10 (Note 1)	VAR CLAMP	100	Note 1	300	100	> 100	A
SGT27S10 (Note 1)	VAR CLAMP	270	Note 1	300	100	> 100	A
SGT27S23 (Note 1)	VAR CLAMP	270	Note 1	300	100	> 230	A
SGT03U13	UNI-DIRECTIONAL	30	< 50	300	100	> 130	B
SGT06U13	UNI-DIRECTIONAL	60	< 85	300	100	> 130	B
SGT23U13	UNI-DIRECTIONAL	230	< 275	300	100	> 130	B
SGT21B13	BI-DIRECTIONAL	210	270	300	100	>130	B
SGT21B13A	BI-DIRECTIONAL	210	290	300	100	>130	B
SGT22B13	BI-DIRECTIONAL	220	280	300	100	>130	B
SGT22B13A	BI-DIRECTIONAL	220	290	300	100	>130	B
SGT23B13	BI-DIRECTIONAL	230	290	300	100	>130	B
SGT23B13A	BI-DIRECTIONAL	230	315	300	100	>130	B
SGT27B13	BI-DIRECTIONAL	270	345	300	100	>130	B
SGT27B13A	BI-DIRECTIONAL	270	360	300	100	>130	B
SGT27B13B	BI-DIRECTIONAL	270	375	300	100	>130	B
SGT23B27	BI-DIRECTIONAL	230	290	600	200	>270	B
SGT27B27	BI-DIRECTIONAL	270	345	600	200	>270	B
SGT27B27A	BI-DIRECTIONAL	270	360	600	200	>270	B
SGT27B27B	BI-DIRECTIONAL	270	375	600	200	>270	B

NOTES:

1. Dependent on trigger circuit.

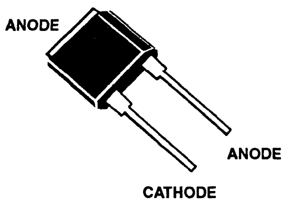
   All finalized devices UL recognized to 497B - File Number E135010.

HARRIS SEMICONDUCTOR

SGT03U13, SGT06U13 SGT23U13

Unidirectional Transient Surge Suppressors (SURGECTOR™)

August 1993



MODIFIED TO-202

Features

- Clamping Voltages: 33V, 60V, or 230V
- Peak Transient Surge Current: 300A
- Minimum Holding Current: 130mA
- Subnanosecond Clamping Action
- Low On-State Voltage
- UL Recognized File #E135010 to STD 497B

Applications

- Telecommunications Equipment
- Data and Communication Links
- Computer Modems
- Alarm Systems

Description

These SURGECTOR devices are designed to protect telecommunication equipment, data links, alarm systems, power supplies and other sensitive electrical circuits from damage by switching transients, lightning strikes, load changes, commutation spikes and line crosses.

These SURGECTOR devices are monolithic compound structures consisting of a thyristor whose gate region contains a special diffused section which acts as a zener diode. This zener diode section permits anode voltage turn-on of the structure. Initial clamping by the zener diode section and fast turn-on by the thyristor, provide excellent voltage limiting even on very fast rise time transients. The thyristor also features very high holding current allowing the SURGECTOR to recover to its high impedance off state after a transient. The SURGECTOR device's normal off-state condition in the forward blocking mode is a high impedance, low leakage state that prevents loading of the line.

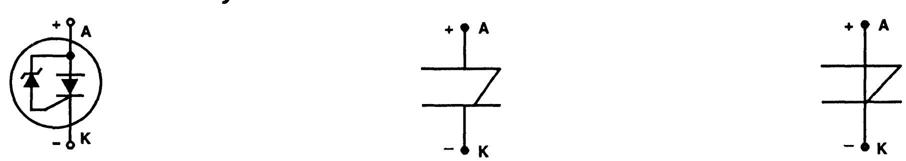
Absolute Maximum Ratings (T_C = +25°C)

	SGT03U13	SGT06U13	SGT23U13	UNITS
Continuous Off State Voltage:				
V_{DM}	30	58	225	V
V_{RM}	1	1	1	V
Transient Peak Surge Current: I_{TSM}				
1µs x 2µs (Note 1)	300	300	300	A
8µs x 20µs	200	200	200	A
10µs x 560µs	125	125	125	A
10µs x 1000µs	100	100	100	A
One Half Cycle 50 - 60Hz (Note 2)	60	60	60	A
One Second 50 - 60Hz, Halfwave	30	30	30	A
Operating Temperature (T_A)		-40°C to +85°C		°C
Storage Temperature Range (T_{STG})		-40°C to +150°C		°C

NOTES:

1. Unit designed not to fail open below: 450A
2. One every 30 seconds maximum.

Equivalent Schematic Symbols



SURGECTOR™ is a trademark of Harris Semiconductor.

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

Electrical Characteristics At Case Temperature (T_C = +25°C), Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	SGT10S10 MIN	SGT10S10 TYP	SGT10S10 MAX	UNITS
Off-State Current	I_{DM}	Maximum Rated V_{DM}				
		T_A = +25°C	-	-	50	nA
		T_A = +85°C	-	-	10	µA
Reverse Current	I_{RM}	V_{RM} = 1V				
		T_A = +25°C	-	-	1	mA
		T_A = +85°C	-	-	10	mA
Clamping Voltage	V_Z	I_Z = 100µA				
SGT03U13			33	-	-	V
SGT06U13			60	-	-	V
SGT23U13			230	-	-	V
Breakover Voltage	V_{BO}	dv/dt = 100V/µs				
SGT03U13			-	-	50	V
SGT06U13			-	-	85	V
SGT23U13			-	-	275	V
Holding Current	I_H		130	-	-	mA
On-State Voltage	V_T	I_T = 10A	-	-	2	V
Main Terminal Capacitance	C_O		-	90	-	pF

Performance Curves

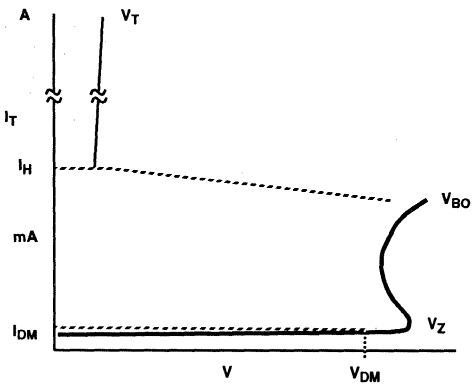


FIGURE 1. TYPICAL VOLT-AMPERE CHARACTERISTICS

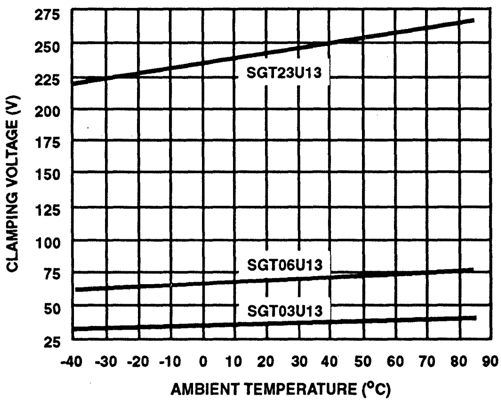


FIGURE 2. TYPICAL CLAMPING VOLTAGE vs TEMPERATURE

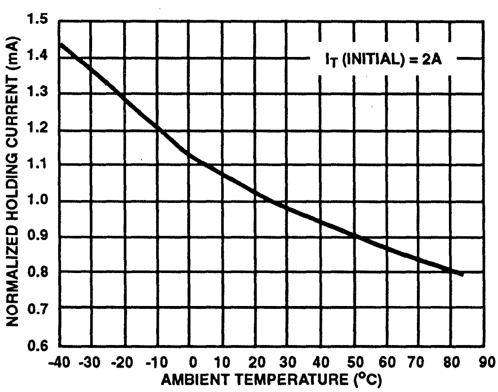


FIGURE 3. TYPICAL HOLDING CURRENT vs TEMPERATURE

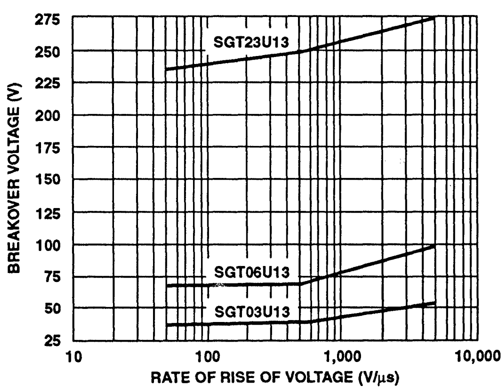


FIGURE 4. TYPICAL V_{BO} vs dv/dt

Terms and Symbols

V_{DM} (Maximum Off-State Voltage) - Maximum off-state voltage (DC or peak) which may be applied continuously.

V_{RM} (Maximum Reverse Voltage) - Maximum reverse- blocking voltage (DC or peak) which may be applied.

I_{TSM} (Maximum Peak Surge Current) - Maximum nonrepetitive current which may be allowed to flow for the time state.

T_A (Ambient Operating Temperature) - Ambient temperature range permitted during operation in a circuit.

T_{STG} (Storage Temperature) - Temperature range permitted during storage.

I_{DM} (Off-State Current) - Maximum value of off-state current that results from the application of the maximum off-state voltage (V_{DM}).

I_{RM} (Reverse Current) - Maximum value of reverse current that results from the application of the maximum reverse voltage (V_{RM}).

V_Z (Clamping Voltage) - off-state voltage at a specified current.

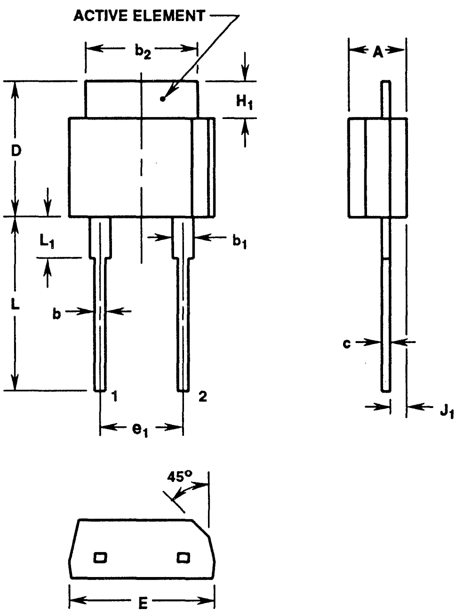
V_{BO} (Breakdown Voltage) - voltage at which the device switches from the off-state to the on-state.

I_H (Holding Current) - Minimum on-state current that will hold the device in the on-state after it has been latched on.

V_T (On-State Voltage) - Voltage across the main terminals for a specified on-state current.

C_O (Main Terminal Capacitance) - Capacitance between the main terminals at a specified off-state voltage.

Packaging



TO-202 Modified

2 LEAD JEDEC STYLE TO-202 SHORT TAB PLASTIC PACKAGE

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN	MAX	MIN	MAX	
A	0.130	0.150	3.31	3.81	-
b	0.024	0.028	0.61	0.71	2, 3
b_1	0.045	0.055	1.15	1.39	1, 2, 3
b_2	0.270	0.280	6.86	7.11	-
c	0.018	0.022	0.46	0.55	1, 2, 3
D	0.320	0.340	8.13	8.63	-
E	0.340	0.360	8.64	9.14	-
e_1	0.200 BSC		5.08 BSC		4
H_1	0.080	0.100	2.04	2.54	-
J_1	0.035	0.045	0.89	1.14	5
L	0.410	0.440	10.42	11.17	-
L_1	-	0.110	-	2.79	1

NOTES:

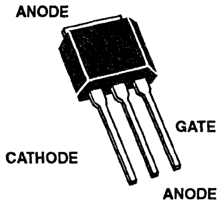
1. Lead dimension and finish uncontrolled in L_1.
2. Lead dimension (without solder).
3. Add typically 0.002 inches (0.05mm) for solder coating.
4. Position of lead to be measured 0.250 inches (6.35mm) from bottom of dimension D.
5. Position of lead to be measured 0.100 inches (2.54mm) from bottom of dimension D.
6. Controlling dimension: Inch
7. Revision 1 dated 1-93.

HARRIS SEMICONDUCTOR

SGT10S10
SGT27S10

Gate Controlled Unidirectional Transient Surge Suppressors

August 1993



MODIFIED TO-202

Description

- Blocking Voltage 100V and 270V
- Peak Transient Surge Current 300A
- Minimum Holding Current 100mA
- Subnanosecond Clamping Action
- Low On-State Voltage
- UL Recognized File # E135010 to STD 497B

Applications

- Telecommunications Equipment
- Data and Voice Lines
- Computer Modems
- Alarm Systems

Description

SURGECTOR transient surge protectors are designed to protect telecommunication equipment, data links, alarm systems, power supplies, and other sensitive electrical circuits from damage that could be caused by switching transients, lightning strikes, load changes, commutation spikes, and line crosses.

These devices are fast turn-on, high holding current thyristors. When coupled with a user supplied voltage level detector, they provide excellent voltage limiting even on very fast rise time transients. The high holding current allows this SURGECTOR to return to its high impedance off state after a transient.

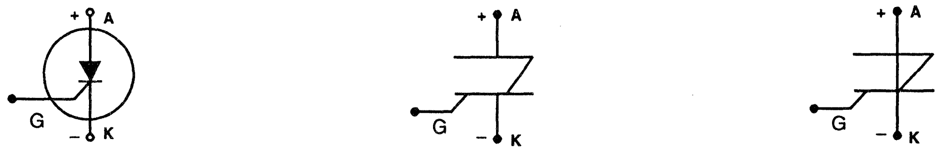
The SURGECTOR device's normal off-state condition in the forward blocking mode is a high impedance, low leakage state that prevents loading of the line.

Absolute Maximum Ratings (T_C = +25°C)

	SGT10S10	SGT27S10	UNITS
Continuous Off State Voltage:			
V_{DM}	100	270	V
V_{RM}	1	1	V
Transient Peak Surge Current: I_{TSM}			
1µs x 2µs (Note 1)	300	300	A
8µs x 20µs	200	200	A
10µs x 560µs	125	125	A
10µs x 1000µs	100	100	A
One Half Cycle, 1 every 30 seconds .50 - 60Hz	60	60	A
One Second, Halfwave .50 - 60Hz	30	30	A
Operating Temperature (T_A)	-40°C to +85°C		°C
Storage Temperature Range (T_{STG})	-40°C to +150°C		°C

NOTE: 1. Unit designed not to fail open below 450A.

Equivalent Schematic Symbols



SURGECTOR™ is a trademark of Harris Semiconductor.

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

Electrical Characteristics At Case Temperature (T_C = +25°C), Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	SGT10S10 MIN	SGT10S10 TYP	SGT10S10 MAX	SGT27S10 MIN	SGT27S10 TYP	SGT27S10 MAX	UNITS
Off-State Current	I_{DM}	V_{DM} = 100V T_A = +25°C T_A = +85°C	- -	- -	50 10	- -	- -	- -	nA μA
	I_{DM}	V_{DM} = 270V T_A = +25°C T_A = +85°C	- -	- -	- -	- -	- -	100 50	nA μA
Off-State Current	I_{RM}	V_{RM} = 1V T_A = +25°C T_A = +85°C	- -	- -	1 10	- -	- -	1 10	mA mA
Breakover Voltage	V_{BO}	dv/dt = 100V/μs (Note 1)	-	-	100	-	-	285	V
Holding Current	I_H		100	-	-	100	-	-	mA
On-State Voltage	V_T	I_T = 10A	-	-	2	-	-	2	V
Gate-Trigger Current	I_{GT}		-	-	150	-	-	150	mA
Main Terminal Capacitance	C_O	V_{DM} = 0V V_{DM} = 50V at 1MHz	- -	90 -	- -	- -	- 50	- -	pF pF

NOTE:

1. External zener diode from anode to gate: 60V (SGT10S10); 270V (SGT27S10).

Performance Curves

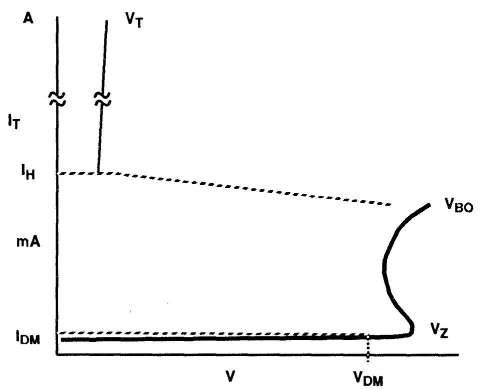


FIGURE 1. TYPICAL VOLT-AMPERE CHARACTERISTICS

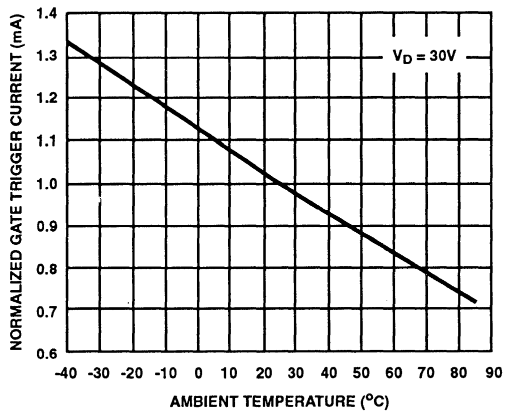


FIGURE 2. NORMALIZED GATE-TRIGGER CURRENT vs TEMPERATURE

Performance Curves (Continued)

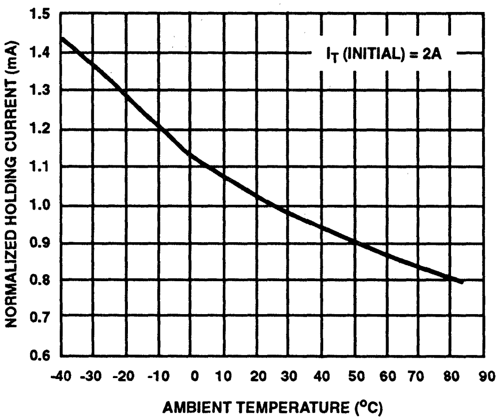


FIGURE 3. NORMALIZED HOLDING CURRENT vs TEMPERATURE

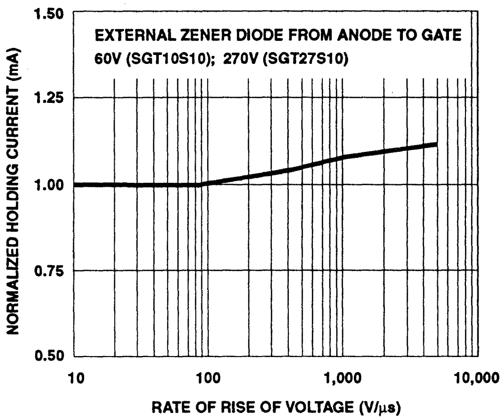


FIGURE 4. NORMALIZED V_{BO} vs dv/dt

Terms and Symbols

V_{DM} (Maximum Off-State Voltage) - Maximum off-state voltage (DC or peak) which may be applied continuously.

V_{RM} (Maximum Reverse Voltage) - Maximum reverse-blocking voltage (DC or peak) which may be applied.

I_{TSM} (Maximum Peak Surge Current) - Maximum nonrepetitive current which may be allowed to flow for the time state.

T_A (Ambient Operating Temperature) - Ambient temperature range permitted during operation in a circuit.

T_{STG} (Storage Temperature) - Temperature range permitted during storage.

I_{DM} (Off-State Current) - Maximum value of off-state current that results from the application of the maximum off-state voltage (V_{DM}).

I_{RM} (Reverse Current) - Maximum value of reverse current that results from the application of the maximum reverse voltage (V_{RM}).

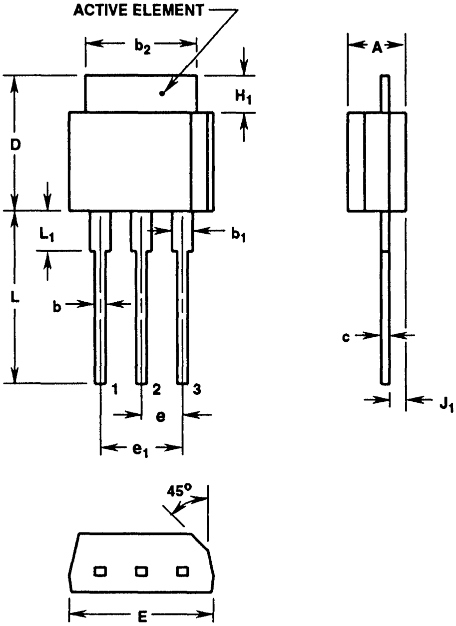
I_H (Holding Current) - Minimum on-state current that will hold the device in the on-state after it has been latched on.

V_T (On-State Voltage) - Voltage across the main terminals for a specified on-state current.

I_{GT} (Gate-Trigger Current) - Minimum gate current which will cause the device to switch from the off-state to the on-state.

C_O (Main Terminal Capacitance) - Capacitance between the main terminals at a specified off-state voltage.

Packaging



TO-202 Modified

3 LEAD JEDEC STYLE TO-202 SHORT TAB PLASTIC PACKAGE

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN	MAX	MIN	MAX	
A	0.130	0.150	3.31	3.81	-
b	0.024	0.028	0.61	0.71	2, 3
b_1	0.045	0.055	1.15	1.39	1, 2, 3
b_2	0.270	0.280	6.86	7.11	-
c	0.018	0.022	0.46	0.55	1, 2, 3
D	0.320	0.340	8.13	8.63	-
E	0.340	0.360	8.64	9.14	-
e	0.100 TYP		2.54 TYP		4
e_1	0.200 BSC		5.08 BSC		4
H_1	0.080	0.100	2.04	2.54	-
J_1	0.035	0.045	0.89	1.14	5
L	0.410	0.440	10.42	11.17	-
L_1	-	0.110	-	2.79	1

NOTES:

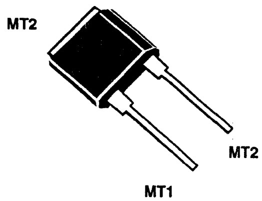
1. Lead dimension and finish uncontrolled in L_1.
2. Lead dimension (without solder).
3. Add typically 0.002 inches (0.05mm) for solder coating.
4. Position of lead to be measured 0.250 inches (6.35mm) from bottom of dimension D.
5. Position of lead to be measured 0.100 inches (2.54mm) from bottom of dimension D.
6. Controlling dimension: Inch
7. Revision 1 dated 1-93.

SGT21B13, SGT21B13A, SGT22B13, SGT22B13A, SGT23B13, SGT23B13A, SGT27B13, SGT27B13A, SGT27B13B

HARRIS SEMICONDUCTOR

Bidirectional Transient Surge Suppressors (SURGECTOR™)

August 1993



MODIFIED TO-202

Features

- Clamping Voltage . . . . . . .210V, 220V, 230V and 270V
- Peak Transient Surge Current . . 300A
- Minimum Holding Current . . . 130mA
- Continuous Protection
- Low On State Voltage
- UL Recognized File #E135010 to STD 497B

Applications

- Data and Communication Links
- Computer Modems
- Alarm Systems

Description

These SURGECTOR devices are designed to protect telecommunication equipment, data links, alarm systems, power supplies and other sensitive electrical circuits from damage by switching transients, lightning strikes, load changes, commutation spikes and line crosses.

Bidirectional SURGECTOR devices are constructed using two monolithic compound chips each consisting of a thyristor whose gate region contains a special diffused section which acts as a zener diode. This chips are connected in anti parallel, providing bidirectional protection. This zener diode section permits anode voltage turn on of the structure.

Initial clamping by the zener diode section, and fast turn on by the thyristor, provide excellent voltage limiting even on very fast rise time transients. The thyristor also features very high holding current, which allows the SURGECTOR to recover to its high impedance off state after a transient.

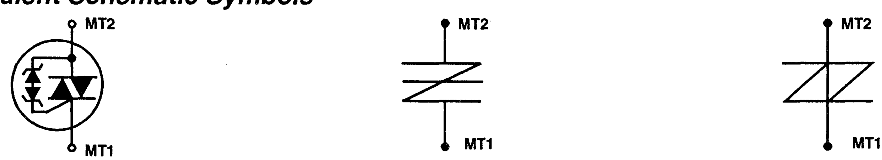
All these devices are supplied in a 2 lead, modified TO-202 VERSATAB package.

Absolute Maximum Ratings (T_C = +25°C)

	SGT21B13 SGT21B13A	SGT22B13 SGT22B13A	SGT23B13 SGT23B13A	SGT27B13 SGT27B13A SGT27B13B	UNITS
Continuous Off State Voltage:					
V_{DM}	185	190	200	235	V
V_{RM}	185	190	200	235	V
Transient Peak Surge Current . . . I_{TSM}					
1μs x 2μs (Note 1)	300	300	300	300	A
8μs x 20μs	200	200	200	200	A
10μs x 560μs	125	125	125	125	A
10μs x 1000μs	100	100	100	100	A
One Half Cycle . . . 50 - 60Hz (Note 2)	60	60	60	60	A
One Second . . . 50 - 60Hz, Halfwave	30	30	30	30	A
Operating Temperature (T_A)	-40°C to +85°C		-40°C to +85°C		°C
Storage Temperature Range (T_{STG})	-40°C to +150°C		-40°C to +150°C		°C

NOTES:
1. Unit designed not to fail open below: 450A.
2. One every 30 seconds maximum.

Equivalent Schematic Symbols



SURGECTOR™ is a trademark of Harris Semiconductor

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

File Number 1895.2

Electrical Characteristics At Case Temperature (T_C = +25°C), Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	LIMITS			UNITS
			MIN	TYP	MAX	
Off-State Current	I_{DM}, I_{RM}	Maximum Rated V_{DM}, V_{RM}				
		T_A = +25°C	-	-	200	nA
		T_A = +85°C	-	-	100	μA
Clamping Voltage	V_Z	I_Z < 200μA				
SGT21B13			210	-	250	V
SGT21B13A			210	-	270	V
SGT22B13			220	-	260	V
SGT22B13A			220	-	270	V
SGT23B13			230	-	270	V
SGT23B13A			230	-	295	V
SGT27B13			270	-	325	V
SGT27B13A			270	-	340	V
SGT27B13B			270	-	355	V
Breakover Voltage	V_{BO}	dv/dt = 100V/μs				
SGT21B13			-	-	270	V
SGT21B13A			-	-	290	V
SGT22B13			-	-	280	V
SGT22B13A			-	-	290	V
SGT23B13			-	-	290	V
SGT23B13A			-	-	315	V
SGT27B13			-	-	345	V
SGT27B13A			-	-	360	V
SGT27B13B			-	-	375	V
Holding Current	I_H		130	-	-	mA
On-State Voltage	V_T	I_T = 10A	-	-	2	V
Main Terminal Capacitance	C_O	V_{DM} = V_{RM} = 50V, Frequency = 1MHz	-	50	-	pF

Terms and Symbols

V_{DM} (Maximum Off-State Voltage) - Maximum off-state voltage (DC or peak) which may be applied continuously.

V_{RM} (Maximum Reverse Voltage) - Maximum reverse-blocking voltage (DC or peak) which may be applied.

I_{TSM} (Maximum Peak Surge Current) - Maximum nonrepetitive current which may be allowed to flow for the time state.

T_A (Ambient Operating Temperature) - Ambient temperature range permitted during operation in a circuit.

T_{STG} (Storage Temperature) - Temperature range permitted during storage.

I_{DM} (Off-State Current) - Maximum value of off-state current that results from the application of the maximum off-state voltage (V_{DM}).

I_{RM} (Reverse Current) - Maximum value of reverse current that results from the application of the maximum reverse voltage (V_{RM}).

V_Z (Clamping Voltage) - off-state voltage at a specified current.

V_{OB} (Breakdown Voltage) - voltage at which the device switches from the off-state to the on-state.

I_H (Holding Current) - Minimum on-state current that will hold the device in the on-state after it has been latched on.

V_T (On-State Voltage) - Voltage across the main terminals for a specified on-state current.

C_O (Main Terminal Capacitance) - Capacitance between the main terminals at a specified off-state voltage.

Performance Curves

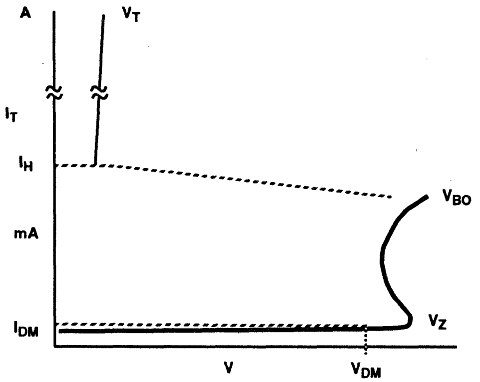


FIGURE 1. TYPICAL VOLT-AMPERE CHARACTERISTICS FOR ALL TYPES

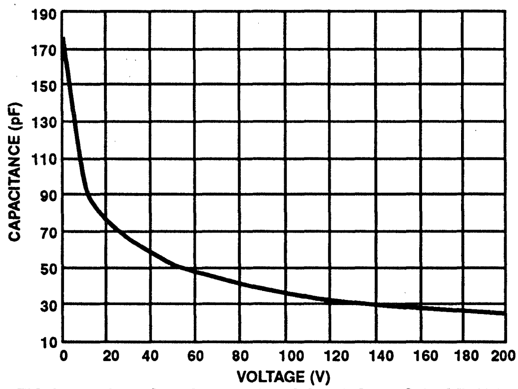


FIGURE 2. TYPICAL CAPACITANCE vs VOLTAGE FOR ALL TYPES

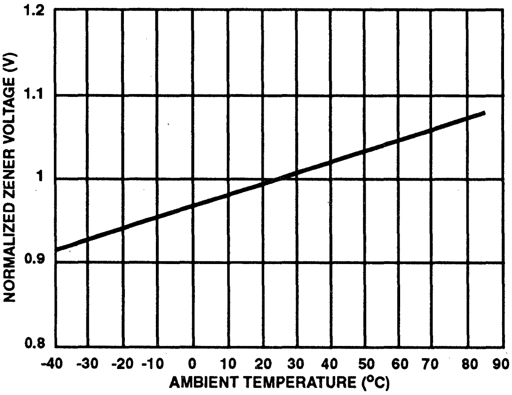


FIGURE 3. NORMALIZED ZENER VOLTAGE vs TEMPERATURE FOR ALL TYPES

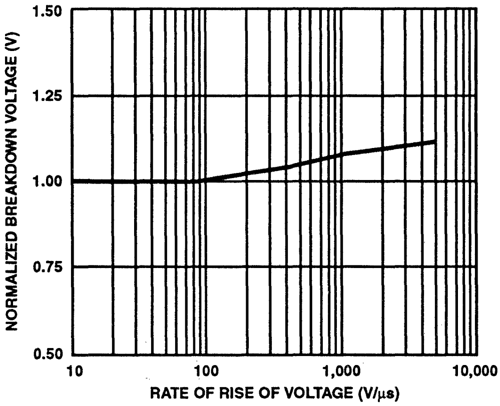


FIGURE 4. NORMALIZED V_{BO} vs dv/dt FOR ALL TYPES

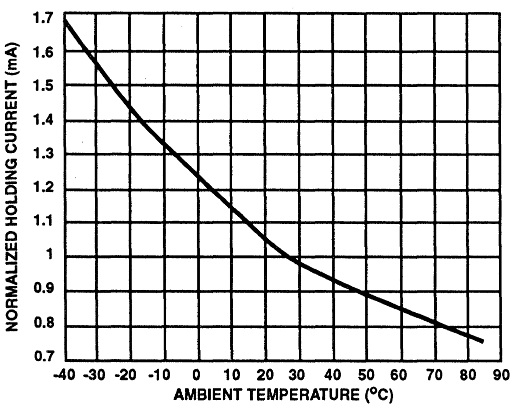
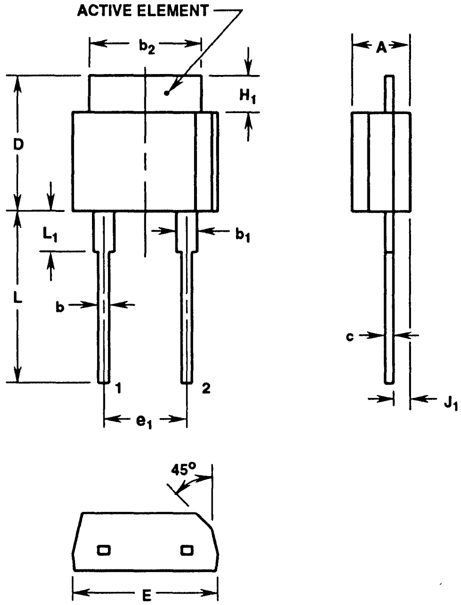


FIGURE 5. NORMALIZED HOLDING CURRENT vs TEMPERATURE FOR ALL TYPES

Packaging



TO-202 Modified

2 LEAD JEDEC STYLE TO-202 SHORT TAB PLASTIC PACKAGE

SYMBOL	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX	NOTES
A	0.130	0.150	3.31	3.81	-
b	0.024	0.028	0.61	0.71	2, 3
b_1	0.045	0.055	1.15	1.39	1, 2, 3
b_2	0.270	0.280	6.86	7.11	-
c	0.018	0.022	0.46	0.55	1, 2, 3
D	0.320	0.340	8.13	8.63	-
E	0.340	0.360	8.64	9.14	-
e_1	0.200 BSC		5.08 BSC		4
H_1	0.080	0.100	2.04	2.54	-
J_1	0.035	0.045	0.89	1.14	5
L	0.410	0.440	10.42	11.17	-
L_1	-	0.110	-	2.79	1

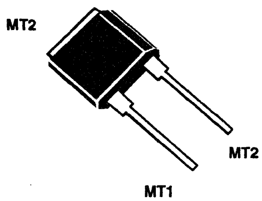
NOTES:

1. Lead dimension and finish uncontrolled in L_1.
2. Lead dimension (without solder).
3. Add typically 0.002 inches (0.05mm) for solder coating.
4. Position of lead to be measured 0.250 inches (6.35mm) from bottom of dimension D.
5. Position of lead to be measured 0.100 inches (2.54mm) from bottom of dimension D.
6. Controlling dimension: Inch
7. Revision 1 dated 1-93.

SGT23B27, SGT27B27 SGT27B27A, SGT27B27B

Bidirectional Transient Surge Suppressors (SURGECTOR™)

August 1993



MODIFIED TO-202

Features

- Clamping Voltage .....230V or 270V,
- Peak Transient Surge Current...600A
- Minimum Holding Current ... 270mA
- Continuous Protection
- Low On State Voltage
- UL Recognized File #E135010 to STD 497B

Applications

- Data and Communication Links
- Computer Modems
- Alarm Systems

Description

These SURGECTOR devices are designed to protect telecommunication equipment, data links, alarm systems, power supplies and other sensitive electrical circuits from damage by switching transients, lightning strikes, load changes, commutation spikes and line crosses.

Bidirectional SURGECTOR devices are constructed using two monolithic compound chips each consisting of a thyristor whose gate region contains a special diffused section which acts as a zener diode. This chips are connected in anti parallel, providing bidirectional protection. This zener diode section permits anode voltage turn on of the structure.

Initial clamping by the zener diode section, and fast turn on by the thyristor, provide excellent voltage limiting even on very fast rise time transients. The thyristor also features very high holding current, which allows the SURGECTOR to recover to its high impedance off state after a transient.

All these devices are supplied in a 2 lead, modified TO-202 VERSATAB package.

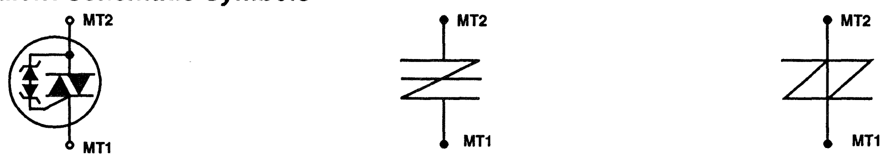
Absolute Maximum Ratings (T_C = +25°C)

	SGT23B27	SGT27B27 SGT27B27A SGT27B27B	UNITS
Continuous Off State Voltage:			
V_{DM}	200	235	V
V_{RM}	200	235	V
Transient Peak Surge Current ... I_{TSM}			
1µs x 2µs (Note 1)	600	600	A
8µs x 20µs	400	400	A
10µs x 560µs	250	250	A
10µs x 1000µs	200	200	A
One Half Cycle ... 50 - 60Hz (Note 2)	60	60	A
One Second ... 50 - 60Hz, Halfwave	30	30	A
Operating Temperature (T_A)	-40°C to +85°C		°C
Storage Temperature Range (T_{STG})	-40°C to +150°C		°C

NOTES:

1. Unit designed not to fail open below: 900A.
2. One every 30 seconds maximum.

Equivalent Schematic Symbols



SURGECTOR™ is a trademark of Harris Semiconductor

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

File Number 3603

Electrical Characteristics At Case Temperature (T_C = +25°C), Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	LIMITS MIN	TYP	MAX	UNITS
Off-State Current	I_{DM}, I_{RM}	Maximum Rated V_{DM}, V_{RM}				
		T_A = +25°C	-	-	200	nA
		T_A = +85°C	-	-	100	µA
Clamping Voltage	V_Z	I_Z < 200µA				
SGT23B27			230	-	-	V
SGT27B27			270	-	325	V
SGT27B27A			270	-	340	V
SGT27B27B			270	-	355	V
Breakover Voltage	V_{BO}	dv/dt = 100V/µs				
SGT23B27			-	-	290	V
SGT27B27			-	-	345	V
SGT27B27A			-	-	360	V
SGT27B27B			-	-	375	V
Holding Current	I_H		270	-	-	mA
On-State Voltage	V_T	I_T = 10A	-	-	2	V
Main Terminal Capacitance	C_O	V_{DM} = V_{RM} = 50V, Frequency = 1MHz	-	80	-	pF

Terms and Symbols

V_{DM} (Maximum Off-State Voltage) - Maximum off-state voltage (DC or peak) which may be applied continuously.

V_{RM} (Maximum Reverse Voltage) - Maximum reverse-blocking voltage (DC or peak) which may be applied.

I_{TSM} (Maximum Peak Surge Current) - Maximum nonrepetitive current which may be allowed to flow for the time state.

T_A (Ambient Operating Temperature) - Ambient temperature range permitted during operation in a circuit.

T_{STG} (Storage Temperature) - Temperature range permitted during storage.

I_{DM} (Off-State Current) - Maximum value of off-state current that results from the application of the maximum off-state voltage (V_{DM}).

I_{RM} (Reverse Current) - Maximum value of reverse current that results from the application of the maximum reverse voltage (V_{RM}).

V_Z (Clamping Voltage) - off-state voltage at a specified current.

V_{OB} (Breakdown Voltage) - voltage at which the device switches from the off-state to the on-state.

I_H (Holding Current) - Minimum on-state current that will hold the device in the on-state after it has been latched on.

V_T (On-State Voltage) - Voltage across the main terminals for a specified on-state current.

C_O (Main Terminal Capacitance) - Capacitance between the main terminals at a specified off-state voltage.

Performance Curves

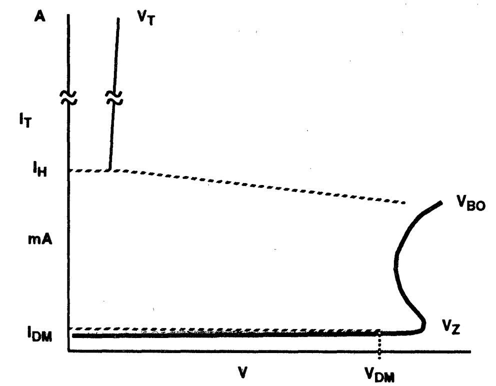


FIGURE 1. TYPICAL VOLT-AMPERE CHARACTERISTICS FOR ALL TYPES

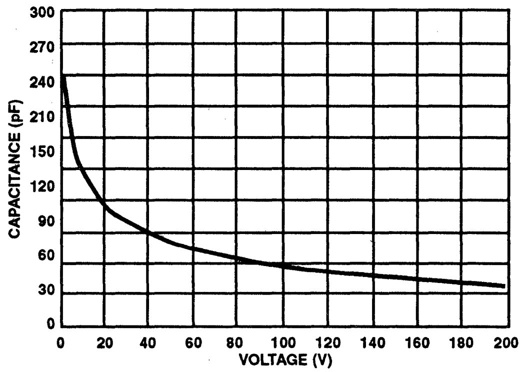


FIGURE 2. TYPICAL CAPACITANCE vs VOLTAGE FOR ALL TYPES

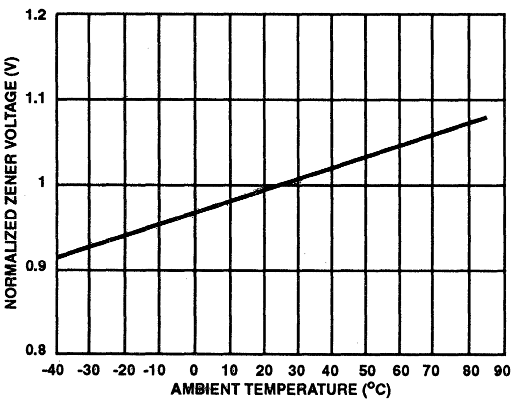


FIGURE 3. NORMALIZED ZENER VOLTAGE vs TEMPERATURE FOR ALL TYPES

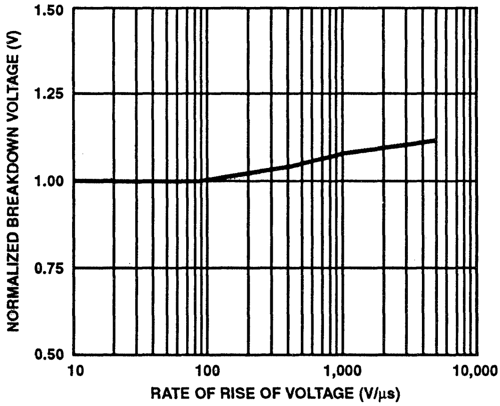


FIGURE 4. NORMALIZED V_{BO} vs dv/dt FOR ALL TYPES

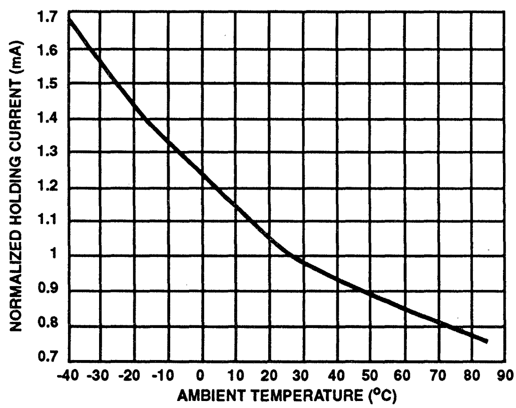
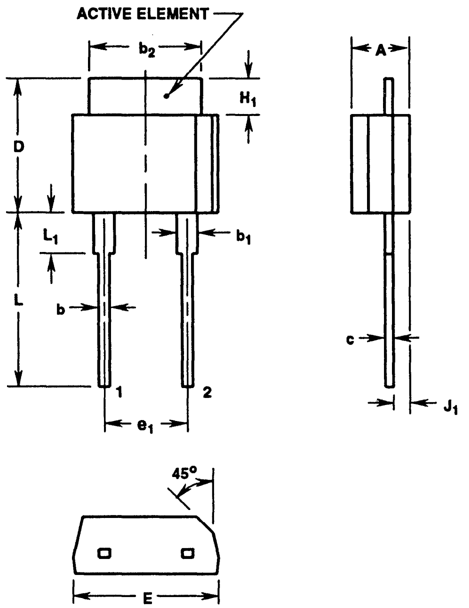


FIGURE 5. NORMALIZED HOLDING CURRENT vs TEMPERATURE FOR ALL TYPES

Packaging



TO-202 Modified

2 LEAD JEDEC STYLE TO-202 SHORT TAB PLASTIC PACKAGE

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN	MAX	MIN	MAX	
A	0.130	0.150	3.31	3.81	-
b	0.024	0.028	0.61	0.71	2, 3
b_1	0.045	0.055	1.15	1.39	1, 2, 3
b_2	0.270	0.280	6.86	7.11	-
c	0.018	0.022	0.46	0.55	1, 2, 3
D	0.320	0.340	8.13	8.63	-
E	0.340	0.360	8.64	9.14	-
e_1	0.200 BSC		5.08 BSC		4
H_1	0.080	0.100	2.04	2.54	-
J_1	0.035	0.045	0.89	1.14	5
L	0.410	0.440	10.42	11.17	-
L_1	-	0.110	-	2.79	1

NOTES:

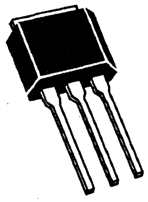
1. Lead dimension and finish uncontrolled in L_1.
2. Lead dimension (without solder).
3. Add typically 0.002 inches (0.05mm) for solder coating.
4. Position of lead to be measured 0.250 inches (6.35mm) from bottom of dimension D.
5. Position of lead to be measured 0.100 inches (2.54mm) from bottom of dimension D.
6. Controlling dimension: Inch
7. Revision 1 dated 1-93.

HARRIS SEMICONDUCTOR

SGT27S23

Gate Controlled Unidirectional Transient Surge Suppressor (SURGECTOR™)

August 1993



MODIFIED TO-202

Description

- **Blocking Voltage 270V**
- **Peak Transient Surge Current 300A**
- **Minimum Holding Current 230mA**
- **Subnanosecond Clamping Action**
- **Low On-State Voltage**
- **UL Recognize File # E135010 to STD 497B**

Applications

- **Telecommunications Equipment**
- **Data and Voice Lines**
- **Computer Modems**
- **Alarm Systems**

Description

SURGECTOR transient surge protectors are designed to protect telecommunication equipment, data links, alarm systems, power supplies, and other sensitive electrical circuits from damage that could be caused by switching transients, lightning strikes, load changes, commutation spikes, and line crosses.

These devices are fast turn-on, high holding current thyristors. When coupled with a user supplied voltage level detector, they provide excellent voltage limiting even on very fast rise time transients. The high holding current allows this SURGECTOR to return to its high-impedance off state after a transient.

The SURGECTOR device's normal off state condition in the forward blocking mode is a high impedance, low leakage state that prevents loading of the line.

The SGT27S23 is supplied in a 3 lead, modified, TO-202 package.

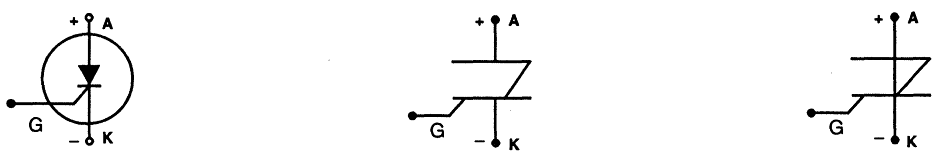
Absolute Maximum Ratings ($T_C = +25^\circ C$)

	SGT27S23	UNITS
Continuous Off State Voltage:		
V_{DM}	270	V
V_{RM}	1	V
Transient Peak Surge Current: I_{TSM}		
1µs x 2µs (Note 1)	300	A
8µs x 20µs	200	A
10µs x 560µs	125	A
10µs x 1000µs	100	A
One Half Cycle 50 - 60Hz (Note 2)	60	A
One Second 50 - 60Hz, Halfwave	30	A
Operating Temperature (T_A)	-40°C to +85°C	°C
Storage Temperature Range (T_{STG})	-40°C to +150°C	°C

NOTES:

1. Unit designed not to fail open below 450A.
2. One every 30 seconds maximum.

Equivalent Schematic Symbols



CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

Electrical Specifications At Case Temperature (T_C = +25°C), Unless Otherwise Specified

PARAMETERS	SYMBOL	TEST CONDITIONS	LIMITS			UNITS
			MIN	TYP	MAX	
Off-State Current	I_{DM}	V_{DM} = 270V at T_C = +85°C	- -	- -	100 50	nA µA
	I_{RM}	V_{RM} = 1V at T_C = +85°C	- -	- -	1 10	mA mA
Holding Current	I_H		230	-	-	mA
On-State Voltage	V_T	I_T = 10A	-	-	2	V
Gate Trigger Current	I_{GT}		-	-	175	mA
Main Terminal Capacitance	C_O	V_{DM} = 0V, Freq = 1MHz V_{DM} = 50V	- -	90 50	- -	pF pF

Performance Curves

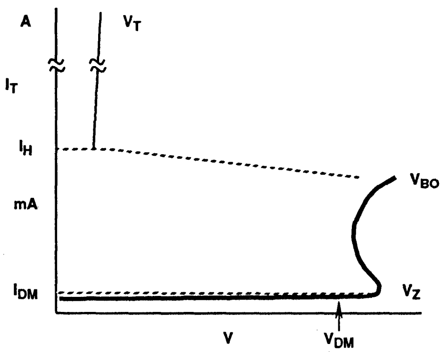


FIGURE 1. TYPICAL VOLT-AMPERE CHARACTERISTICS

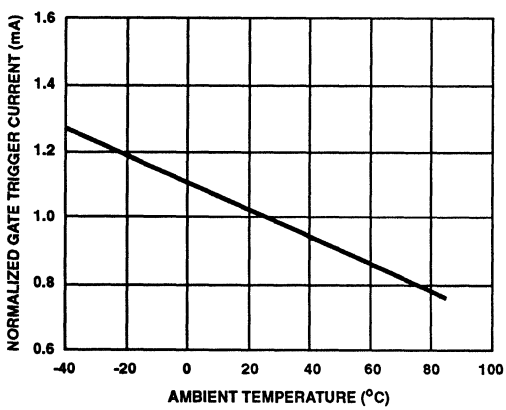


FIGURE 2. NORMALIZED GATE TRIGGER CURRENT vs TEMPERATURE

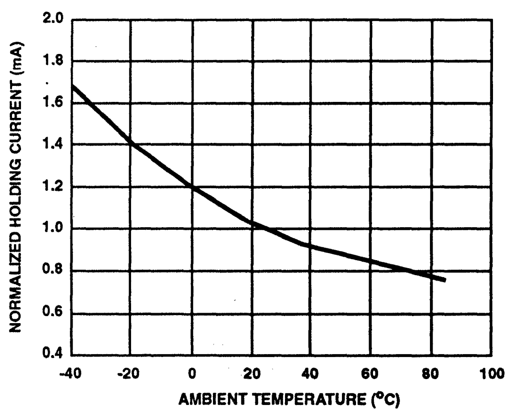


FIGURE 3. NORMALIZED HOLDING CURRENT vs TEMPERATURE

Terms and Symbols

V_{DM} (Maximum Off-State Voltage) - Maximum off-state voltage (DC or peak) which may be applied continuously.

V_{RM} (Maximum Reverse Voltage) - Maximum reverse- blocking voltage (DC or peak) which may be applied.

I_{TSM} (Maximum Peak Surge Current) - Maximum nonrepetitive current which may be allowed to flow for the time state.

T_A (Ambient Operating Temperature) - Ambient temperature range permitted during operation in a circuit.

T_{STG} (Storage Temperature) - Temperature range permitted during storage.

I_{DM} (Off-State Current) - Maximum value of off-state current that results from the application of the maximum off-state voltage (V_{DM}).

I_{RM} (Reverse Current) - Maximum value of reverse current that results from the application of the maximum reverse voltage (V_{RM}).

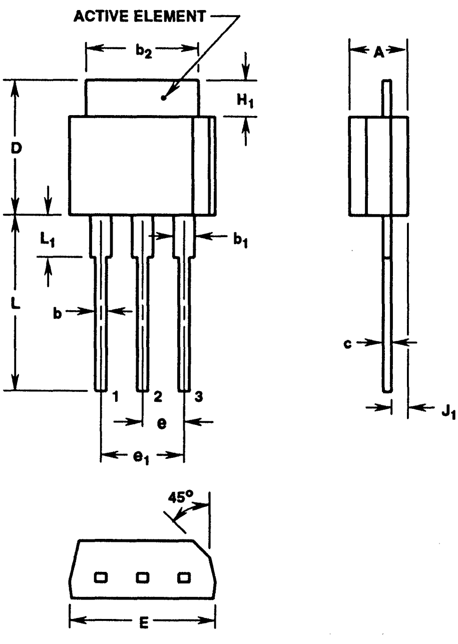
I_H (Holding Current) - Minimum on-state current that will hold the device in the on-state after it has been latched on.

V_T (On-State Voltage) - Voltage across the main terminals for a specified on-state current.

I_{GT} (Gate-Trigger Current) - Minimum gate current which will cause the device to switch from the off-state to the on-state.

C_O (Main Terminal Capacitance) - Capacitance between the main terminals at a specified off-state voltage.

Packaging



TO-202 Modified

3 LEAD JEDEC STYLE TO-202 SHORT TAB PLASTIC PACKAGE

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN	MAX	MIN	MAX	
A	0.130	0.150	3.31	3.81	-
b	0.024	0.028	0.61	0.71	2, 3
b_1	0.045	0.055	1.15	1.39	1, 2, 3
b_2	0.270	0.280	6.86	7.11	-
c	0.018	0.022	0.46	0.55	1, 2, 3
D	0.320	0.340	8.13	8.63	-
E	0.340	0.360	8.64	9.14	-
e	0.100 TYP		2.54 TYP		4
e_1	0.200 BSC		5.08 BSC		4
H_1	0.080	0.100	2.04	2.54	-
J_1	0.035	0.045	0.89	1.14	5
L	0.410	0.440	10.42	11.17	-
L_1	-	0.110	-	2.79	1

NOTES:

1. Lead dimension and finish uncontrolled in L_1.
2. Lead dimension (without solder).
3. Add typically 0.002 inches (0.05mm) for solder coating.
4. Position of lead to be measured 0.250 inches (6.35mm) from bottom of dimension D.
5. Position of lead to be measured 0.100 inches (2.54mm) from bottom of dimension D.
6. Controlling dimension: Inch
7. Revision 1 dated 1-93.

TVS 11

PROTECTION CIRCUITS

11 PROTECTION CIRCUITS

Protection Circuits Selection Guide

PART NUMBER	DESCRIPTION	VCC	TURN-ON VOLTAGE PROTECTION THRESHOLD	TEMPERATURE RANGE
SP710	Protected Power Switch With Transient Suppression	4V to 16V	16V to 18.5V	-40°C to +105°C
HIP1090	Protected High Side Power Switch with Transient Suppression	4V to16V (Expandable)	16V to 19V	-40°C to +105°C
SP720	Electronic Protection Array for ESD and Overvoltage Protection, 14 Inputs	4.5V to 30V	$+V_{BE}$ Above V_{CC} or $-V_{BE}$ Below GND	-40°C to +105°C
SP721	Electronic Protection Array for ESD and Overvoltage Protection, 6 Inputs	4.5V to 30V	$+V_{BE}$ Above V_{CC} or $-V_{BE}$ Below GND	-40°C to +105°C

HARRIS SEMICONDUCTOR

SP710

Protected Power Switch with Transient Suppression

August 1993

Features

- ±90V Transient Suppression
- 4V to 16V Operating Voltage
- 0.8A Current Load Capability
- Over-Voltage Shutdown Protected
- Short-Circuit Current Limiting
- Over-Temperature Protected Thermal Limiting at 150°C (Tj)
- -40°C to +105°C Operating Temperature Range

Applications

- Electronic Circuit Breaker
- Transient Suppressor
- Overvoltage Monitor

Description

The SP710 is a Power Integrated Circuit designed to suppress potentially damaging overvoltage transients up to ±90V in amplitude. The device is designed to be operated in a pass-thru mode which allows the current to flow through the IC with minimal voltage drop. The protected load circuit is connected to the output of the SP710. As such, the protected power switch IC is designed to operate as a transient suppressor which is capable of driving resistive, inductive or lamp loads with minimum risk of damage under stress conditions of over voltage or over current. The SP710 is supplied in a 3 lead TO-220AB package.

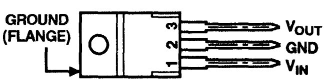
"The SP710 was formerly Harris Developmental No. TA13349"

Ordering Information

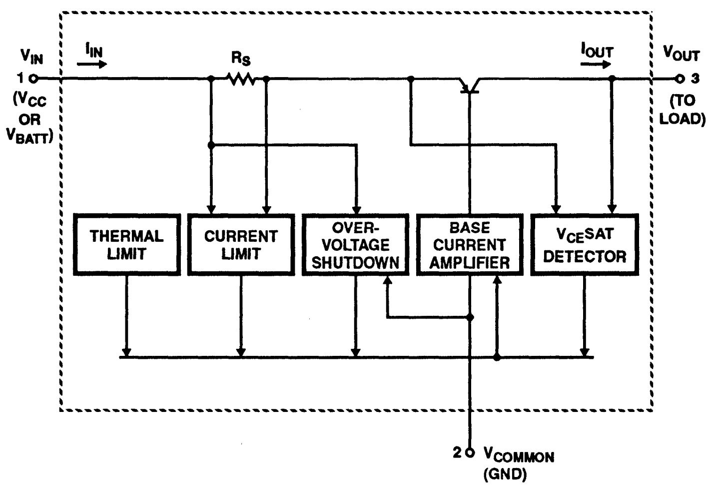
PART NUMBER	TEMPERATURE RANGE	PACKAGE
SP710AS	-40°C to +105°C	TO-220AB

Pinout

TO-220AB
TOP VIEW



Functional Block Diagram



File Number 2789.5

Absolute Maximum Ratings

Input Voltage, V_{IN} 24V
Load Current, I_{OUT} 800mA
Transient Max Voltage, V_{IN} (15ms) . . . . ±90V

NOTE: $Pd = (V_{IN} - V_O)(I_O) + (V_{IN})(I_{COMMON})$
$T_J = T_A + (Pd)$ (Thermal Resistance)

Power Dissipation and Thermal Ratings

Thermal Resistance, θ_{JC} . . . . 4°C/W
Junction Temperature . . . . 150°C
Ambient Operating Temperature . . . . -40°C to +105°C
Storage Temperature . . . . -40°C to +150°C
Lead Temperature (During Solder) . . . . 265°C
$^1/_{16} \pm {}^1/_{32}$" (1.59 ± 0.79mm) from case for 10s maximum

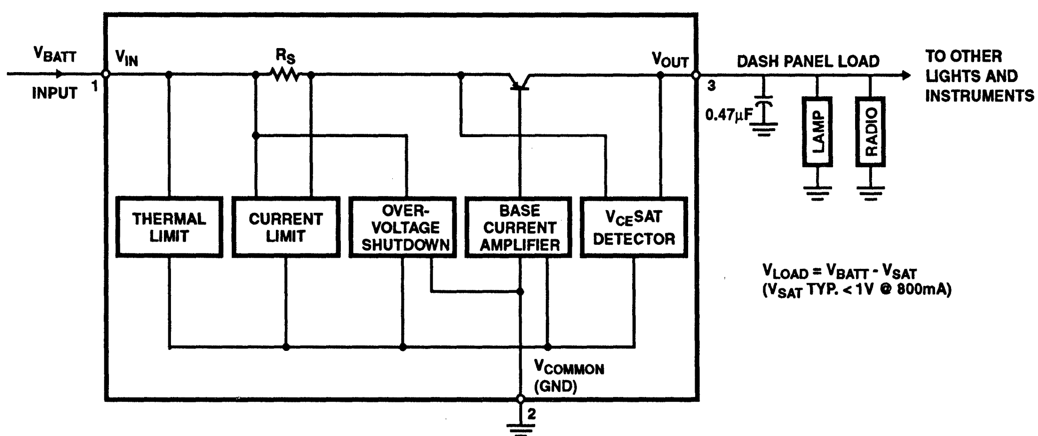
CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

Electrical Specifications

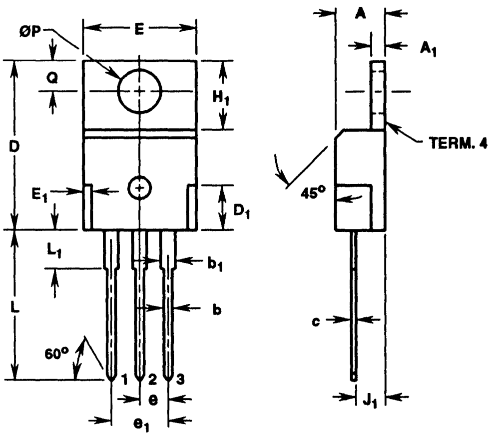
(T_A = -40°C to +105°C, V_{IN} = 4V to 16V), Unless Otherwise Specified

PARAMETER	SYMBOL	CONDITIONS	LIMITS MIN	LIMITS TYP	LIMITS MAX	UNITS
Input Operating Voltage	V_{IN}		4	-	16	V
Shutdown Voltage	V_{SHSD}		16	-	18.5	V
Shutdown Temperature			-	150	-	°C
Transient Pulse	I_{OUT}	V_{IN} = ±90V for 15ms Pin 3 = 14V, Pin 2 = GND	-20	-	+20	mA
Short Circuit Current			1	-	2	A
V_{SAT} (Input-to-Output)		V_{IN} = 4V, I_{OUT} = 175mA	-	-	0.25	V
		V_{IN} = 9V, I_{OUT} = 500mA	-	-	0.65	V
		V_{IN} = 16V, I_{OUT} = 800mA	-	-	1.05	V
Common Current	I_{COM}	V_{IN} = 16V, I_{OUT} = 100mA	-	-	25	mA
		V_{IN} = 16V, I_{OUT} = 800mA	-	-	50	mA

Typical Application



Packaging



Lead No. 1	-	Gate
Lead No. 2	-	Collector
Lead No. 3	-	Emitter
Mounting Flange	-	Collector

TO-220AB

3 LEAD JEDEC TO-220AB PLASTIC PACKAGE

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN	MAX	MIN	MAX	
A	0.170	0.180	4.32	4.57	-
A_1	0.048	0.052	1.22	1.32	-
b	0.030	0.034	0.77	0.86	3, 4
b_1	0.045	0.055	1.15	1.39	2, 3
c	0.014	0.019	0.36	0.48	2, 3, 4
D	0.590	0.610	14.99	15.49	-
D_1	-	0.160	-	4.06	-
E	0.395	0.410	10.04	10.41	-
E_1	-	0.030	-	0.76	-
e	0.100 TYP		2.54 TYP		5
e_1	0.200 BSC		5.08 BSC		5
H_1	0.235	0.255	5.97	6.47	-
J_1	0.100	0.110	2.54	2.79	6
L	0.530	0.550	13.47	13.97	-
L_1	0.130	0.150	3.31	3.81	2
ØP	0.149	0.153	3.79	3.88	-
Q	0.102	0.112	2.60	2.84	-

NOTES:

1. These dimensions are within allowable dimensions of Rev. J of JEDEC TO-220AB outline dated 3-24-87.
2. Lead dimension and finish uncontrolled in L_1.
3. Lead dimension (without solder).
4. Add typically 0.002 inches (0.05mm) for solder coating.
5. Position of lead to be measured 0.250 inches (6.35mm) from bottom of dimension D.
6. Position of lead to be measured 0.100 inches (2.54mm) from bottom of dimension D.
7. Controlling dimension: Inch.
8. Revision 1 dated 1-93.

HARRIS SEMICONDUCTOR

SP720

Electronic Protection Array for ESD and Overvoltage Protection

August 1993

Features

- ±2A Peak Current Capability
- Single-Ended Voltage Range to .... +35V
- Differential Voltage Range to ....+17.5V
- Designed to Provide Over-Voltage Protection
- Fast Switching ....6ns Risetime
- Low Input Leakages of 1nA at +25°C Typical
- Low Input Capacitance of 3pF Typical
- An Array of 14 SCR/Diode Pairs
- Proven Interface for ESD
- Operating Temperature Range...... -40°C to +105°C

Applications

- Microprocessor/Logic Input Protection
- Data Bus Protection
- Analog Device Input Protection
- Voltage Clamp

Description

The SP720 is an array of SCR/Diode bipolar structures for ESD and over-voltage protection to sensitive input circuits. The SP720 has 2 protection SCR/Diode device structures per input. A total of 14 available inputs can be used to protect up to 14 external signal or bus lines. Over voltage protection is from the IN (pins 1-7 & 9-15) to V+ or V-. The SCR structures are designed for fast triggering at a threshold of one $+V_{BE}$ diode threshold above V+ (Pin 16) or a $-V_{BE}$ diode threshold below V- (Pin 8). From an IN input, a clamp to V+ is activated if a transient pulse causes the input to be increased to a voltage level greater than one V_{BE} above V+. A similar clamp to V- is activated if a negative pulse, one V_{BE} less than V-, is applied to an IN input.

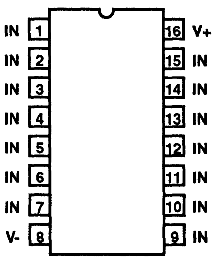
Refer to Application Note AN9304 for further information

Ordering Information

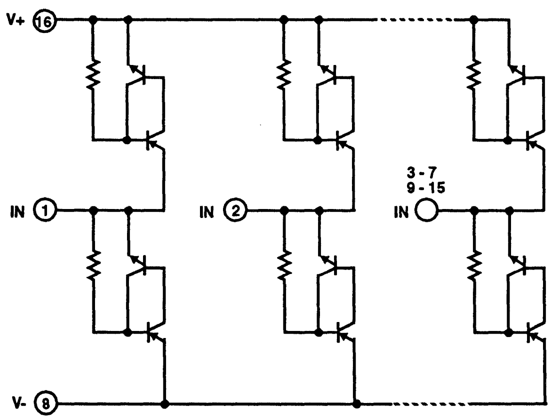
PART NUMBER	TEMPERATURE	PACKAGE
SP720AP	-40°C to +105°C	16 Lead Plastic DIP
SP720AB	-40°C to +105°C	16 Lead Plastic SOIC
SP720ABT	-40°C to +105°C	16 Lead Plastic SOIC Tape and Reel

Pinout

16 LEAD PLASTIC DIP
16 LEAD PLASTIC SOIC
TOP VIEW



Functional Block Diagram



CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

Absolute Maximum Ratings

Continuous Supply Voltage, (V+) - (V-). . . . . +35V
Input Peak Current, I_{IN} . . . . ±2A
Transient Ratings - See Note 2, Figure 1, Table 1
Maximum Package Power Dissipation at +105°C:
Plastic DIP Package 500mW
Plastic SOIC Package. 270mW

Thermal Resistance, θ_{JA}:
16 Lead DIP Package . . . . 90°C/W
16 Lead SOIC Package. . . . . 170°C/W
Storage Temperature Range. . . . . -65°C to +150°C
Junction Temperature . . . . +150°C
Lead Temperature (Soldering 10s) . . . . +265°C

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

Electrical Specifications

T_A = -40°C to +105°C; V_{IN} = 0.5V_{CC} Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	LIMITS			UNITS
			MIN	TYP	MAX	
Operating Voltage Range, V_{SUPPLY} = [(V+) - (V-)]	V_{SUPPLY}		-	4.5 to 30	-	V
Forward Voltage Drop:		I_{IN} = 1A (Peak Pulse)				
IN to V-	V_{FWDL}		-	2	-	V
IN to V+	V_{FWDH}		-	2	-	V
Input Leakage Current	I_{IN}		-20	5	20	nA
Quiescent Supply Current	$I_{QUIESCENT}$		-	50	200	nA
Equivalent SCR ON Threshold		Note 3	-	1.1	-	V
Equivalent SCR ON Resistance		V_{FWD}/I_{FWD}: Note 3	-	1	-	Ω
Input Capacitance	C_{IN}		-	3	-	pF
Input Switching Speed	t_{ON}		-	6	-	ns

NOTES:

1. In automotive and battery operated systems, the power supply lines should be externally protected for load dump and reverse battery. When the V+ and V- pins are connected to the same supply voltage source as the device or control line under protection, a current limiting resistor should be connected in series between the supply and the SP720 pins to limit reverse battery current to within the rated maximum limits. Bypass capacitors of typically 0.01µF or larger from the V+ and V- pins to ground are recommended.
2. For ESD testing of the SP720 to Mil-Std-3015.7 Human Body Model (HBM), the results are typically better than 6KV (Condfition 1) (Figure 1, Table 1). Transient and ESD testing capability is highly dependent on the application. For conditions that are defined as an in-circuit method of ESD testing where the V+ and V- pins have a return path to ground, the ESD capability is typically greater than 15KV from 100pF through 1.5KΩ (Condition 2). For ESD testing of the SP720 to EIAJIC121 Machine Model (MM) standard, the results are typically better than 1KV (Condition 4). These values were measured by AT&T ESD Lab using the component testing procedures of both standards., Additional ESD testing for 200pF through 1.5KΩ with 6ns risetime was done with results better than 9KV (Condition 3).
3. Refer to the Figure 3 graph for definitions of equivalent "SCR ON Threshold" and "SCR ON Resistance." These characteristics are given here for thumb-rule information to determine peak current and dissipation under EOS conditions.

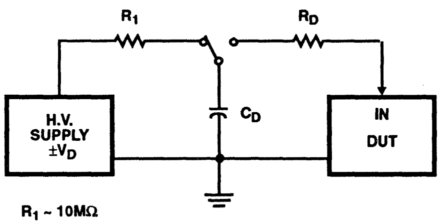


FIGURE 1. ELECTROSTATIC DISCHARGE TEST MIL-STD-883D, METHOD 3015.7

TABLE 1. ESD TEST CONDITIONS

TEST	±V_D	R_D	C_D	
Condition 1	6KV	1.5KΩ	100pF	(HBM)
Condition 2	15KV	1.5KΩ	100pF	(Mod. HBM)
Condition 3	9KV	1.5KΩ	200pF	(Mod. HBM)
Condition 4	1KV	0KΩ	200pF	(MM)

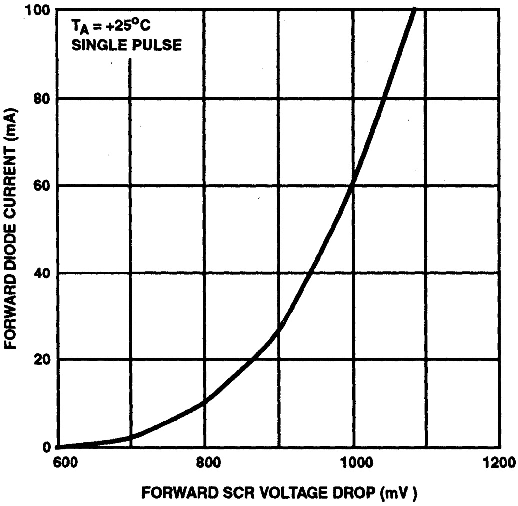


FIGURE 2. LOW CURRENT SCR FORWARD VOLTAGE DROP CHARACTERISTIC

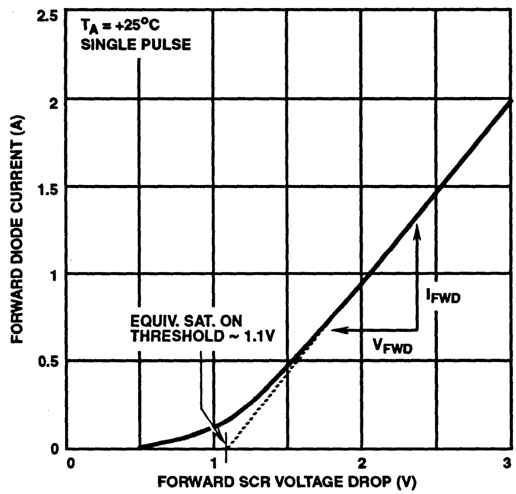


FIGURE 3. HIGH CURRENT SCR FORWARD VOLTAGE DROP CHARACTERISTIC

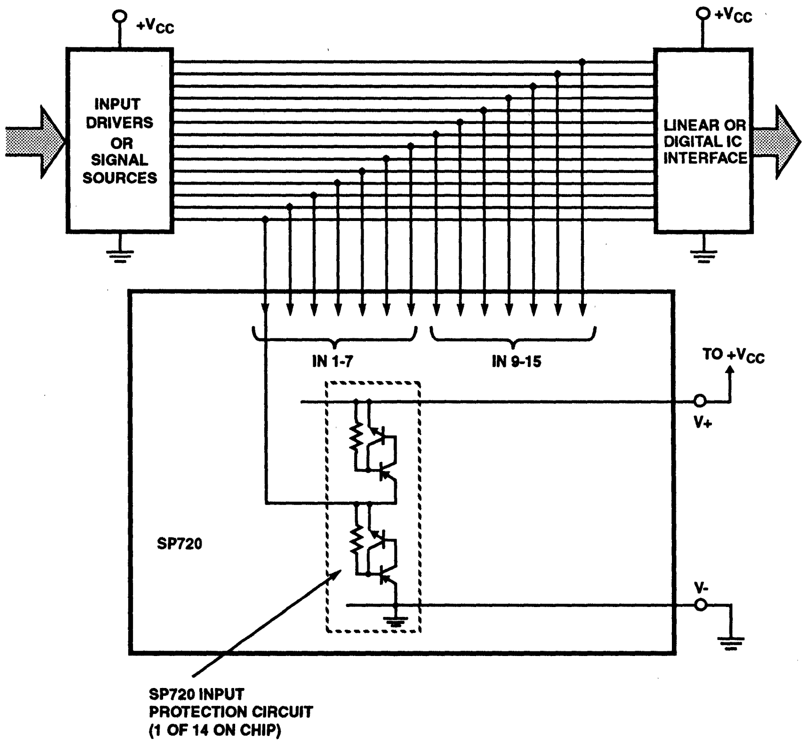


FIGURE 4. TYPICAL APPLICATION OF THE SP720 AS AN INPUT CLAMP FOR OVER-VOLTAGE, GREATER THAN 1 V_{BE} ABOVE V+ OR LESS THAN -1 V_{BE} BELOW V-

Packaging

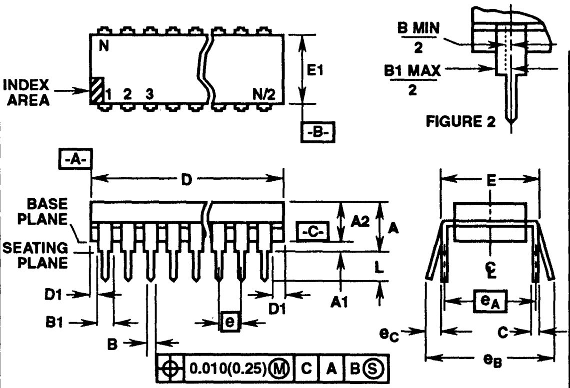


FIGURE 2

FIGURE 1

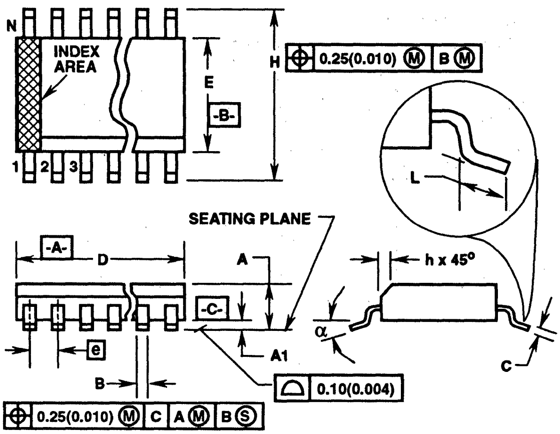
E16.3 (JEDEC MS-001-AA)
16 LEAD DUAL-IN-LINE PLASTIC PACKAGE

SYMBOL	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX	NOTES
A	-	0.210	-	5.33	4
A1	0.015	-	0.39	-	4
A2	0.115	0.195	2.93	4.95	-
B	0.014	0.022	0.356	0.558	-
B1	0.045	0.070	1.15	1.77	9
C	0.008	0.015	0.204	0.381	-
D	0.745	0.840	18.93	21.33	5
D1	0.005	-	0.13	-	-
E	0.300	0.325	7.62	8.25	6
E1	0.240	0.280	6.10	7.11	5
e	0.100 BSC		2.54 BSC		-
e_A	0.300 BSC		7.62 BSC		6
e_B	-	0.430	-	10.92	7
L	0.115	0.160	2.93	4.06	4
N	16		16		8

NOTES:

1. Controlling Dimensions: Inch. In case of conflict between English and Metric dimensions, the inch dimensions control.
2. Dimensioning and tolerancing per ANSI Y14.5M-1982.
3. Symbols are defined in the "MO Series Symbol List" in Section 2.2 of Publication No. 95.
4. Dimensions A, A1 and L are measured with the package seated in JEDEC seating plane gauge GS-3.
5. D and E1 dimensions do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.010 inch (0.25mm).
6. E and e_A are measured with the leads constrained to be perpendicular to plane C.
7. e_B and e_C are measured at the lead tips with the leads unconstrained. e_C must be zero or greater.
8. N is the maximum number of terminal positions.
9. Corner leads (1, N, N/2 and N/2 + 1) may be configured as shown in Figure 2.

Packaging (Continued)



M16.15 (JEDEC MS-012-AC)

16 LEAD NARROW BODY SMALL OUTLINE PLASTIC PACKAGE

SYMBOL	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX	NOTES
A	0.0532	0.0688	1.35	1.75	-
A1	0.0040	0.0098	0.10	0.25	-
B	0.013	0.020	0.33	0.51	9
C	0.0075	0.0098	0.19	0.25	-
D	0.3859	0.3937	9.80	10.00	3
E	0.1497	0.1574	3.80	4.00	4
e	0.050 BSC		1.27 BSC		-
H	0.2284	0.2440	5.80	6.20	-
h	0.0099	0.0196	0.25	0.50	5
L	0.016	0.050	0.40	1.27	6
N	16		16		7
α	0°	8°	0°	8°	-

NOTES:

1. Refer to applicable symbol list.
2. Dimensioning and tolerancing per ANSI Y14.5M-1982.
3. Dimension "D" does not include mold flash, protrusions or gate burrs. Mold flash, protrusion and gate burrs shall not exceed 0.15mm (0.006 inch) per side.
4. Dimension "E" does not include interlead flash or protrusions. Interlead flash and protrusions shall not exceed 0.25mm (0.010 inch) per side.
5. The chamfer on the body is optional. If it is not present, a visual index feature must be located within the crosshatched area.
6. "L" is the length of terminal for soldering to a substrate.
7. "N" is the number of terminal positions.
8. Terminal numbers are shown for reference only.
9. The lead width "B", as measured 0.36mm (0.014 inch) or greater above the seating plane, shall not exceed a maximum value of 0.61mm (0.024 inch)
10. Controlling dimension: MILLIMETER. Converted inch dimensions are not necessarily exact.

HARRIS SEMICONDUCTOR

SP721

PRELIMINARY

August 1993

Electronic Protection Array for ESD and Overvoltage Protection

Features

- ±2A Peak Current Capability
- Single-ended Voltage Range. . . . . to +35V
- Differential Voltage Range: . . . . to ±17.5V
- Designed to Provide Over-Voltage Protection
- Fast Switching - 6ns Risetime
- Low Input Leakages of 1nA at +25°C Typical
- Low Input Capacitance of 3pF Typical
- An Array of 6 SCR/Diode Pairs
- Proven Interface for ESD
- Operating Temperature Range . . . . . . -40°C to +105°C

Applications

- Microprocessor/Logic Input Protection
- Data Bus Protection
- Analog Device Input Protection
- Voltage Clamp

Description

The SP721 is an array of SCR/Diode biploar structures for ESD and over-voltage protection to sensitive input circuits. The SP721 has 2 protection SCR/Diode device structures per input. There are a total of 6 available inputs that can be used to protect up to 6 external signal or bus lines. Over voltage protection is from the IN (pins 1 - 3 & 5 - 7) to V+ or V-.

The SCR structures are designed for fast triggering at a threshold of one $+V_{BE}$ diode threshold above V+ (Pin 8) or a $-V_{BE}$ diode threshold below V- (Pin 4). From an IN input, a clamp to V+ is activated if a transient pulse causes the input to be increased to a voltage level greater than one V_{BE} above V+. A similiar clamp to V- is activated if a negative pulse, one V_{BE} less than V-, is applied to an IN input.

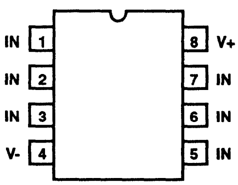
Further information is available in Application Note 9304. AN9304 applies to both the SP720 and SP721

Ordering Information

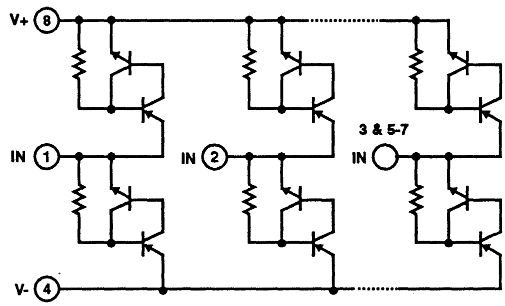
PART NUMBER	TEMPERATURE RANGE	PACKAGE
SP721AP	-40°C to +105°C	8 Lead Plastic DIP
SP721AB	-40°C to +105°C	8 Lead Plastic SOIC
SP721ABT	-40°C to +105°C	8 Lead Plastic SOIC Tape and Reel

Pinout

8 LEAD PLASTIC DIP
8 LEAD PLASTIC SOIC
TOP VIEW



Functional Block Diagram



CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

File Number **3590**

Absolute Maximum Ratings

Continuous Supply Voltage, (V+) - (V-). . . . . +35V
Input Peak Current, I_{IN} . . . . ±2A
ESD Transient Ratings - See Note 2, Figure 1, Table 1
Maximum Package Power Dissipation :
8 Lead Plastic DIP Package, Up to +105°C : 350mW
8 Lead Plastic SOIC Package, Up to +105°C : 270mW

Thermal Resistance, θ_{JA} :
8 Lead DIP Package . . . . 130°C/W
8 Lead SOIC Package. . . . . 170°C/W
Storage Temperature Range. . . . . -65°C to +150°C
Junction Temperature . . . . +150°C
Lead Temperature (Soldering 10s) . . . . +265°C

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

Electrical Specifications

T_A = -40°C to +105°C, V_{IN} = 0.5V_{CC} Unless Otherwise Specified

PARAMETERS	SYMBOL	TEST CONDITIONS	LIMITS			UNITS
			MIN	TYP	MAX	
Operating Voltage Range, V_{SUPPLY} = [(V+) - (V-)]	V_{SUPPLY}			4.5 to 30		V
Forward Voltage Drop IN to V- IN to V+	 V_{FWDL} V_{FWDH}	 I_{IN} = 1A (Peak Pulse)		 2 2		V
Input Leakage Current	I_{IN}		-20	5	+20	nA
Quiescent SupplyCurrent	$I_{QUIESCENT}$			50	200	nA
Equivalent SCR ON Threshold		Note 3		1.1		V
Equivalent SCR ON Resistance		V_{FWD}/I_{FWD} ; Note 3		1		Ω
Input Capacitance	C_{IN}			3		pF
Input Switching Speed	t_{ON}			6		nS

NOTES:

1. In automotive and battery operated systems, the power supply lines should be externally protected for load dump and reverse battery. When the V+ and V- pins are connected to the same supply voltage source as the device or control line under protection, a current limiting resistor should be connected in series between the external supply and the SP721 supply pins to limit reverse battery current to within the rated maximum limits. Bypass capacitors of typically 0.01µF or larger from the V+ and V- pins to ground are recommended.
2. For ESD testing of the SP721 to MIL-STD 883, Method 3015.7, Human Body Model (HBM), the results are typically better than 6kV (Condition 1) (Figure 1, Table 1). Transient and ESD capability is highly dependent on the application. For conditions that are defined as an in-circuit method of ESD testing where the V+ and V- pins have a return path to ground, the ESD capability is typically greater than 15kV from 100pF through 1.5kΩ (Condition 2) or 9kV from 200pF through 1.5kΩ (Condition 3). For ESD testing of the SP721 to EIAJ IC121 Machine Model (MM), the results are typically better than 1kV (Condition 4).
3. Refer to the Figure 3 graph for definitions of equivalent "SCR ON Threshold" and "SCR ON Resistance". These characteristics are given here for thumb-rule information to determine peak current and dissipation under EOS conditions.

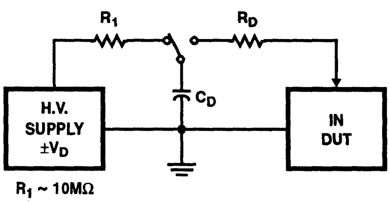


FIGURE 1. ELECTROSTATIC DISCHARGE TEST MIL-STD-883D, METHOD 3015.7

TABLE 1. ESD TEST CONDITIONS

TEST	$\pm V_D$	R_D	C_D	
Condition 1	6kV	1.5kΩ	100pF	(HBM)
Condition 2	15kV	1.5kΩ	100pF	(Mod. HBM)
Condition 3	9kV	1.5kΩ	200pF	(Mod. HBM)
Condition 4	1kV	0kΩ	200pF	(MM)

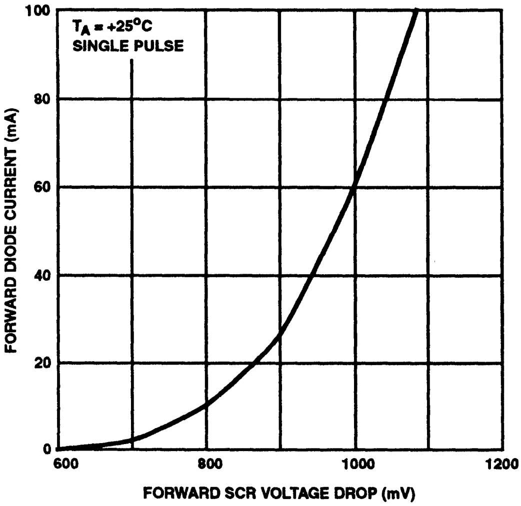


FIGURE 2. LOW CURRENT SCR FORWARD VOLTAGE DROP CHARACTERISTIC

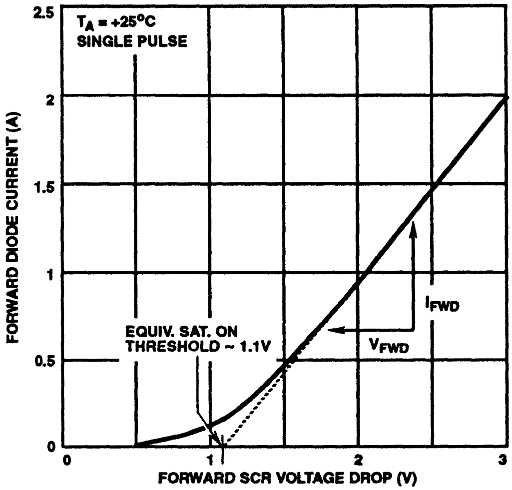


FIGURE 3. HIGH CURRENT SCR FORWARD VOLTAGE DROP CHARACTERISTIC

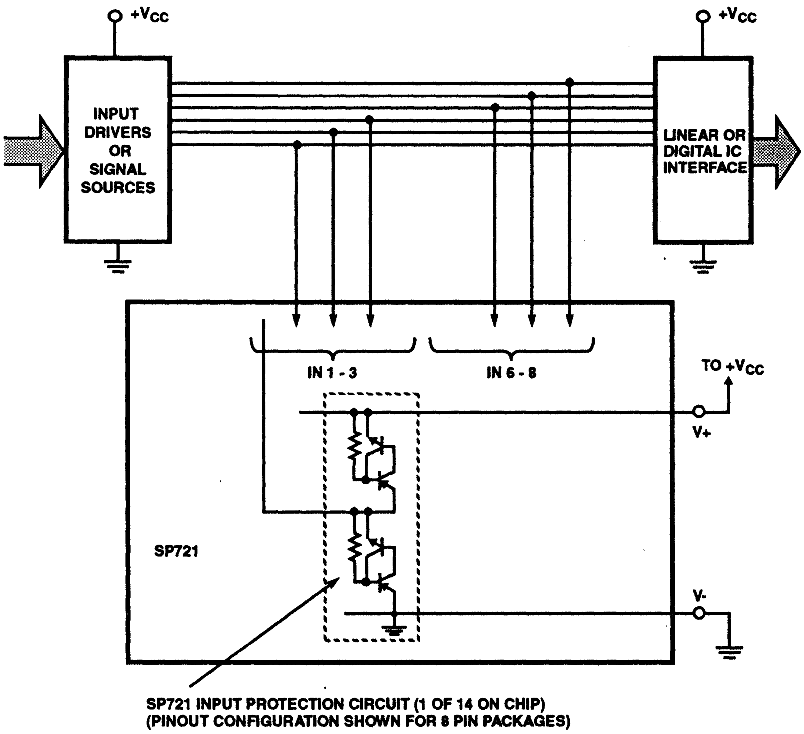


FIGURE 4. TYPICAL APPLICATION OF THE SP720 AS AN INPUT CLAMP FOR OVER-VOLTAGE, GREATER THAN 1 V_{BE} ABOVE V+ OR LESS THAN -1 V_{BE} BELOW V-

Packaging

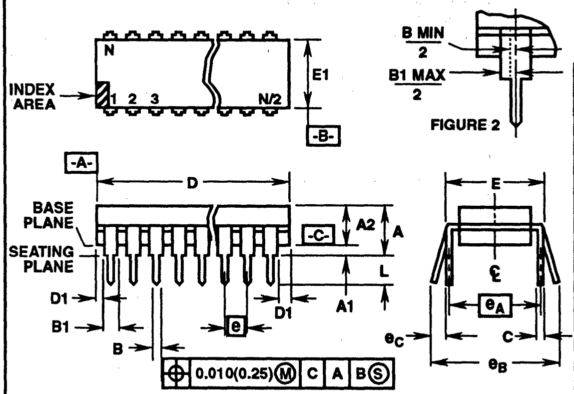


FIGURE 1

FIGURE 2

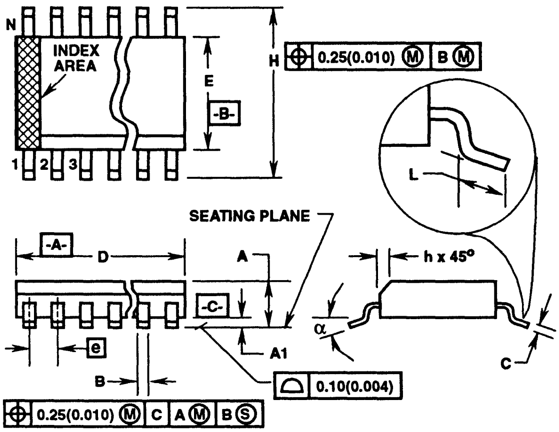
E8.3 (JEDEC MS-001-AB)
8 LEAD DUAL-IN-LINE PLASTIC PACKAGE

SYMBOL	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX	NOTES
A	-	0.210	-	5.33	4
A1	0.015	-	0.39	-	4
A2	0.115	0.195	2.93	4.95	-
B	0.014	0.022	0.356	0.558	-
B1	0.045	0.070	1.15	1.77	9
C	0.008	0.015	0.204	0.381	-
D	0.348	0.430	8.84	10.92	5
D1	0.005	-	0.13	-	-
E	0.300	0.325	7.62	8.25	6
E1	0.240	0.280	6.10	7.11	5
e	0.100 BSC		2.54 BSC		-
e_A	0.300 BSC		7.62 BSC		6
e_B	-	0.430	-	10.92	7
L	0.115	0.160	2.93	4.06	4
N	8		8		8

NOTES:

1. Controlling Dimensions: Inch. In case of conflict between English and Metric dimensions, the inch dimensions control.
2. Dimensioning and tolerancing per ANSI Y14.5M-1982.
3. Symbols are defined in the "MO Series Symbol List" in Section 2.2 of Publication No. 95.
4. Dimensions A, A1 and L are measured with the package seated in JEDEC seating plane gauge GS-3.
5. D and E1 dimensions do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.010 inch (0.25mm).
6. E and e_A are measured with the leads constrained to be perpendicular to plane C.
7. e_B and e_C are measured at the lead tips with the leads unconstrained. e_C must be zero or greater.
8. N is the maximum number of terminal positions.
9. Corner leads (1, N, N/2 and N/2 + 1) may be configured as shown in Figure 2.

Packaging (Continued)



M8.15 (JEDEC MS-012-AA)
8 LEAD NARROW BODY SMALL OUTLINE PLASTIC PACKAGE

	INCHES		MILLIMETERS		
SYMBOL	MIN	MAX	MIN	MAX	NOTES
A	0.0532	0.0688	1.35	1.75	-
A1	0.0040	0.0098	0.10	0.25	-
B	0.013	0.020	0.33	0.51	9
C	0.0075	0.0098	0.19	0.25	-
D	0.1890	0.1968	4.80	5.00	3
E	0.1497	0.1574	3.80	4.00	4
e	0.050 BSC		1.27 BSC		-
H	0.2284	0.2440	5.80	6.20	-
h	0.0099	0.0196	0.25	0.50	5
L	0.016	0.050	0.40	1.27	6
N	8		8		7
α	0°	8°	0°	8°	-

NOTES:

1. Refer to applicable symbol list.
2. Dimensioning and tolerancing per ANSI Y14.5M-1982.
3. Dimension "D" does not include mold flash, protrusions or gate burrs. Mold flash, protrusion and gate burrs shall not exceed 0.15mm (0.006 inch) per side.
4. Dimension "E" does not include interlead flash or protrusions. Interlead flash and protrusions shall not exceed 0.25mm (0.010 inch) per side.
5. The chamfer on the body is optional. If it is not present, a visual index feature must be located within the crosshatched area.
6. "L" is the length of terminal for soldering to a substrate.
7. "N" is the number of terminal positions.
8. Terminal numbers are shown for reference only.
9. The lead width "B", as measured 0.36mm (0.014 inch) or greater above the seating plane, shall not exceed a maximum value of 0.61mm (0.024 inch)
10. Controlling dimension: MILLIMETER. Converted inch dimensions are not necessarily exact.

Harris Semiconductor

TechBrief

No. TB320 August 1993

Harris Intelligent Power

SP720/SP721 CMOS PROTECTION MODEL AND OTHER DATA

(A Supplement to Application Note, AN9304)

by W. Austin

Where the need to provide ESD protection for CMOS circuits is the primary interest for the application of the SP720, interface characteristics of the device to be protected may lead to some specific problems. Application related issues and precautions are discussed here to assist the circuit designer in achieving maximum success in EOS/ESD protection.

CMOS Input Protection

CMOS logic has limited on-chip protection and may contain circuit elements that add difficulty to the task of providing external protection. Consider the case where the input structure of a CMOS device has on-chip protection but only to the extent that it will withstand Human Body Model minimum requirement for ESD when tested under the Mil-Std 883, Method 3015.7. This is normally ±2KV where the charged capacitor is 100pF and the series resistor to the device under test is 1500Ω. The circuit of Figure 1 shows the typical network for an HC logic circuit where the input polysilicon resistor, R_P is typically 120Ω.

When there is a surge or ESD voltage applied to the input structure, the diodes shunt current to V_{CC} or GND to protect the logic circuits on the chip. The on-chip series resistors limit peak currents. If there is a positive transient voltage, $V_{CS}(t)$, applied to the input of the CMOS device, the diode, D_1 will conduct when the forward voltage threshold exceeds the power supply voltage, V_{CC} plus the forward diode voltage drop of D_1, V_{FWD1}. As the voltage at the input is further increased, the CMOS current, I_{CS} is shunted through R_P and D_1 to V_{CC} such that the transient input voltage is

(1) $V_{CS}(t) = I_{CS}(t) \cdot R_P + V_{FWD1} + V_{CC}$ [for Pos. $V_{CS}(t)$]

or

(1a) $I_{CS}(t) = [V_{CS}(t) - (V_{FWD1} + V_{CC})]/R_P$

Similarly, when there is a negative transient, current initially conducts at the negative threshold of diode D_2, V_{FWD2} to shunt negative current at the input, i.e.

(2) $V_{CS}(t) = I_{CS}(t) \cdot R_P + V_{FWD2}$ [for Neg. $V_{CS}(t)$]

or

(2a) $I_{CS}(t) = [V_{CS}(t) - V_{FWD2}]/R_P$

While the circuit of Figure 1 is specifically that of the HC logic family (one cell of the Hex Inverter, 74HCU04), many CMOS devices have a similar or an equivalent internal protection circuit. When compared to the SCR structure of the SP720, the on-chip diodes of the protection network in Figure 1 have lower conduction thresholds.

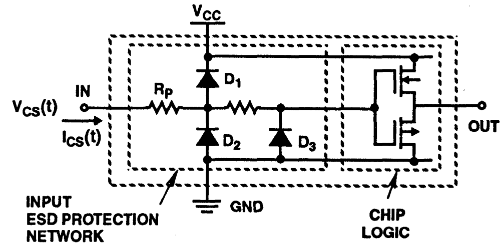


FIGURE 1. TYPICAL CMOS IC INPUT PROTECTION CIRCUIT

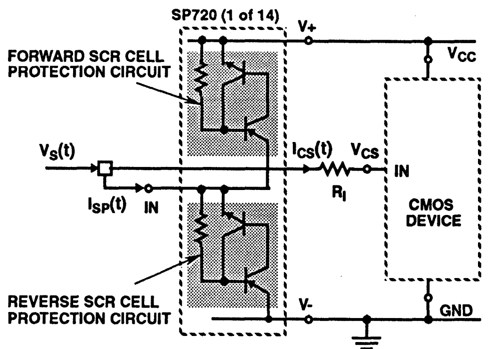


FIGURE 2. SP720 SCR INTERFACE TO A CMOS INPUT WITH R_I ADDED TO ILLUSTRATE MORE EFFECTIVE ESD PROTECTION FOR CMOS DEVICES

SP720 to CMOS Interface

Figure 2 shows the SCR cell structures of one protection pair in the SP720. In this example, the V+ of the SP720 is connected to the V_{CC} logic supply and the V- is connected to logic GND. The IN terminal of the SP720 is connected to the CMOS logic device input through a resistor R_I. When a negative transient voltage is applied to the input circuit of Figure 2, the Reverse SCR Protection Circuit turns on when voltage reaches the forward threshold of the PNP device and current conducts through the SCR resistor to forward bias the PNP transistor. The PNP device then supplies base current to forward bias and turn on the NPN device. Together, the PNP and NPN transistors form an SCR which is latched on to shunt transient current from IN to V-. The Forward SCR Protection Circuit has the same sequence for turn on when a positive transient voltage is applied to the input and conducts to shunt transient current from IN to V+ (V_{CC}).

The Voltage-Current characteristic of the SCR is similar to a diode at low currents but changes to low saturated on resistance at high currents. As shown in the SP720 data sheet, the forward SCR (latched on) voltage is ~1V at 60mA which is ~0.2V higher than a typically junction diode. The fully saturated turn on approaches 0.5A at 1.5V. When the SCR is paralleled with the a CMOS device input having an on-chip protection circuit equivalent to Figure 1, some of the current necessary to latch the SCR is shunted into the CMOS input. For some devices this may be sufficient for an ESD discharge to damage the CMOS input structure before the SP720 is latched on.

The trade-off for achieving a safe level of ESD protection is switching speed. The most effective method is the addition of the series resistor, R_I as shown in Figure 2. The series input resistor, as shown, is a practical method to limit current into the CMOS chip during the latch turn on of the SP720 SCR network. The value of R_I is dependent on the safe level of current that would be allowed to flow into the CMOS input and the loss of switching speed that can be tolerated. The level of transient current, I_{CS} that is shunted into the CMOS device is determined by the series resistor, R_I and the voltage developed across the CMOS protection devices, R_P and D_1 or D_2, plus some contribution from the path of diode, D_3 for negative transients.

As shown in Figure 3, the voltage across the SP720 SCR element is determined by its turn on threshold, V_{TH} and the saturated resistance, R_S when latched. The empirically derived equation for the voltage drop across the SP720 voltage is

(3) $V_{SP}(t) = I_{SP}(t) \bullet R_S + V_{TH}$

or

(3a) $I_{SP}(t) = [V_{SP}(t) - V_{TH}]/(R_S)$

where $V_{TH} \sim \pm 1.1V$ and $R_S \sim 1\Omega$.

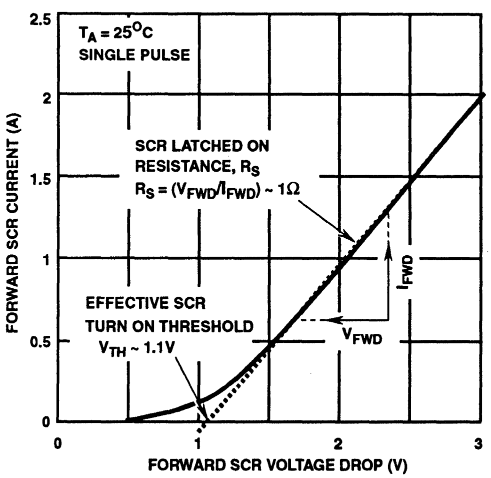


FIGURE 3. FORWARD TURN ON CHARACTERISTIC OF AN SP720 SCR CELL

where current conduction in the SP720 may be positive or negative, depending on the polarity of the transient. For the circuit of Figure 2, $V_S(t)$ is also the input voltage to the resistor, R_I in series to the input of the CMOS device. When latched on, the impedance of the SP720 is much less than the input impedance of either R_I or the CMOS input protection circuit. Therefore, the CMOS loop current can be determined by the voltage, $V_S(t)$ and the known conditions from equation (3).

For a **negative** transient input to the CMOS HCU04, the loop equation is

(4) $V_S(t) = I_{CS}(t) \bullet (R_I + R_P) + V_{FWD2}$

or

(4a) $I_{CS}(t) = [V_S(t) - V_{FWD2}]/(R_I + R_P)$

An equation solution for an input transient may be more directly solved by empirical methods because of the non-linear characteristics. Given a transient voltage, $V_S(t)$ at the input, a value for R_I can be determined for a safe level of peak current into a CMOS device. The input Voltage-Current characteristic of CMOS device should be known. As a first order approximation, the CMOS V-I curve tracer input characteristics of the 74HCU04 are shown in Figure 4. As indicated in Figure 4, the voltage drop across R_P and R_I in series (R_P~120Ω) will be significantly larger than the delta changes in the forward voltage drop of the D_1 or D_2 diodes over a wide range of current. As such, we can effectively assume V_{FWD} ~ 0.75V for moderate levels of current.

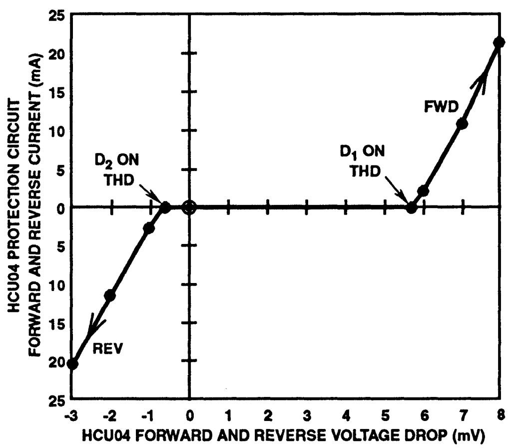


FIGURE 4. FORWARD AND REVERSE PROTECTION CIRCUIT INPUT VOLTAGE-CURRENT CHARACTERISTIC OF THE HCU04 SHOWN FOR V_{CC} = 5V, (i.e. D_1 THD ~ 5V + 0.7V)

Example Transient Solution

Based on the circuit of Figure 2, negative and positive ESD discharge circuit models of the SP720 and HCU04 are shown in Figure 5A and 5B. The negative ESD voltage is taken as the worse case condition because a positive ESD voltage will discharge to the V_{CC} power supply and the positive offset voltage will reduce the forward current. Using the negative model, a peak current value for I_{SP} can be determined by the transient conditions of the applied voltage, $V_S(t)$ at the input.

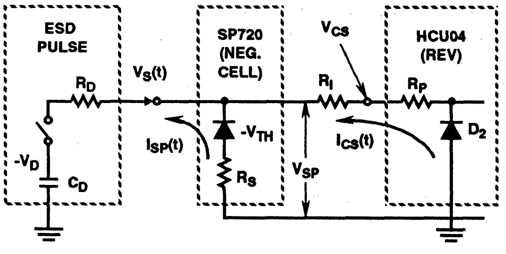


FIGURE 5A. NEGATIVE ESD DISCHARGE MODEL

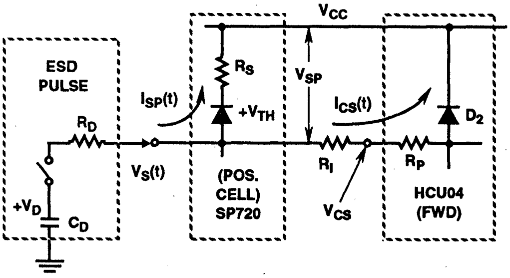


FIGURE 5B. POSITIVE ESD DISCHARGE MODEL

Given Mil-Std ESD HBM test conditions (C_D = 100pF and R_D = 1500Ω), equation (3) with the resistors R_D and R_S in series, we can calculate the peak current for a specified voltage, V_D on the capacitor, C_D.

(5) $I_{SP}(t) = [V_D(t) - V_{TH}]/(R_D + R_S) \sim V_D(t)/R_D$

Here, V_D replaces V_S as the driving voltage; and assumes that (1) R_S is much less than R_D; (2) R_S is much less than (R_I+R_P); and (3) V_{TH} is much less than V_D. This may or may not be the general case but is true for the values indicated here. As such,

$$[I_{SP}]_{t=0} \sim V_D/1500.$$

Given an ESD discharge of -15KV, neglecting inductive effects and distributed capacitance, the peak current at time t = 0 will be ~10A. And, with the SP720 latched on as shown in Equation (3), the 10A peak current will result in an ESD pulse at the input of the SP720 of ~11V. For the HCU04 to withstand this surge of voltage, it is required that the dropping resistor, R_I attenuate the peak voltage, V_{CS} at the HCU04 input to within acceptable ratings.

The negative reverse current path is through R_I, R_P and D_2; where R_P and D_2 are part of the HCU04. For a negative ESD discharge voltage, V_D from capacitor C_D, the equation for the peak voltage, V_{CS} at the input to the HCU04 is derived as follows:

Substituting Equation (5) into Equation (3), we have

(6) $V_S \sim (V_D/R_D)\bullet R_S - 1.1$

and from equation (2) and (4a), a general solution for the V_{CS} voltage is

(7) $V_{CS} = [(V_S - V_{FWD2})/(R_I + R_P)]\bullet R_P + V_{FWD2}$

For a simpler approach, one can work backwards to arrive at he correct solution. The reverse CMOS voltage vs current curve of Figure 3 indicates that a peak voltage, V_{CS} of -3V will produce a negative current of approximately -20mA which is the rated absolute maximum limit. For a -15KV ESD discharge and from Equation (6), the peak voltage, V_S is

$$V_S = (V_D/R_D)\bullet R_S - 1.1 = (-15/1500)-1.1 = -11.1V$$

The peak current, I_{CS} from equation (4a) is

$$I_{CS} = [(V_S - V_{FWD2})/(R_I + R_P)]$$
$$= [(-11.1 -(-0.7))]/(R_I + 120\Omega)$$

Given the I_{CS} current of -20mA and solving for R_I,

$$R_I = 397.5\Omega$$

The same result can be derived from equation (7) but is more susceptible to rounding errors and the assumed voltage drop of V_{FWD2} due to the $(V_{CS} - V_{FWD2})$ difference that appears in the equation.

The approximation solution given here is based on a ±20mA current rating for the HCU04 device; although, input voltage ratings are exceeded at this level of current. As such, the solution is intended to apply only to short duration pulse conditions similar to the Mil-Std 883, Method 3015.7 specifications for ESD discharge conditions. For long periods of sustained dissipation, the SP720 is limited by the rated capability of its package.

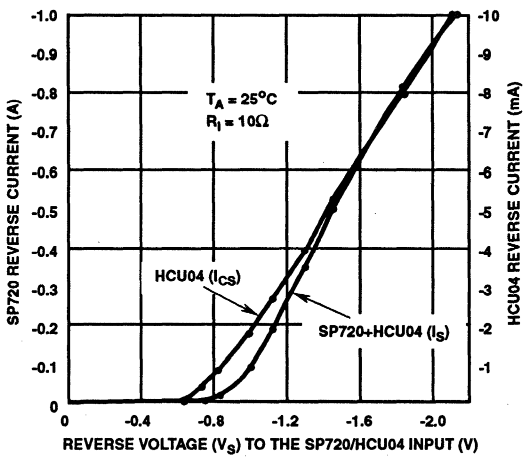


FIGURE 6. MEASURED REVERSE CURRENT vs VOLTAGE CHARACTERISTIC OF THE SP720/HCU04 FOR THE FIGURE 2 CIRCUIT PROTECTION MODE

Figure 6 shows the distribution of currents for the circuit of Figure 2 given a specific value of R_I. Curves are shown for both I_S (HCU04 + SP720) and I_{SP} (SP720) versus a negative input voltage, V_S. The resistor, R_I value of 10Ω is used here primarily to sense the current flow into the HCU04. (This data was taken with the unused inputs to the HCU04 connected to ground and the unused inputs to the SP720 biased to $V_{CC}/2$ on a resistive divider.) The Figure 6 curves verify the model condition of Figure 5A with the exception that resistive heating at higher currents increases the resistance in the latched on SCR. This curve explains the ESD protection of the Harris High Speed Logic "HC" family and, in particular, demonstrates the value of the R_P internal resistor as protection for the HCU04 gate input. Added series resistance external to a signal input is always recommended for maximum ESD protection.

Range of Capability

While the SP720 has substantially greater ESD self protection capability than small signal or logics circuits such as the HCU04, it should be understood that it is not intended for interface protection beyond the limits implied in the data sheet or the application note. The Mil-Std 883, Method 3015.7 condition noted here defines a human body model of 100pF and 1500Ω where the capacitor is charged to a specified level and discharged through the series resistor into the circuit being tested. The capability of the SP720 under this condition has been noted as ±15KV. And, for a machine model where no resistance is specified, a 200pF capacitor is discharged into the input under test. For the machine model the level of capability is ±1KV; again demonstrating that the series resistor used in the test or as part of the application circuit has pronounced effect for improving the level of ESD protection.

While a series resistor at the input to a signal device can greatly extend the level of ESD protection, a circuit application, for speed or other restrictions, may not be tolerant to added series resistance. However, even a few ohms of resistance can substantially improve ESD protection levels. Where an ESD sensitive signal device to be protected has no internal input series resistance and interfaces to a potentially damaging environment, added resistance between the SP720 and the device is essential for added ESD protection. Circuits often contain substrate or pocket diodes at the input to GND or V_{CC}. and will shunt very high peak currents during an ESD discharge. For example, if the HCU04 of Figure 6 is replaced with device having a protection diode to ground and no series resistor, the anticipated increase in input current is 10 times.

Shunt capacitance is sometimes added to a signal input for added ESD protection but, for practical values of capacitance, is much less effective in suppressing transients. For most applications, added series resistance can substantially improve ESD transient protection with less signal degradation.

A further concern for devices to be protected is forward or reverse conduction thresholds within the power supply range (not uncommon in analog circuits). Depending on the cost considerations, the power supply V+ and V- levels for the SP720 could be adjusted to match specific requirements. This may not be practical unless the levels are also common to an existing power supply. The solution of this problem goes beyond added series resistance for improved protection. Each case must be treated with respect to the precise V-I input characteristics of the device to be protected.

Interface and Power Supply Switching

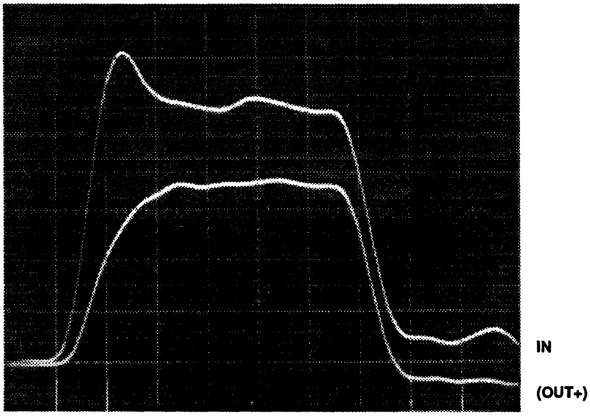
Where separate system components with different power supplies are used for the source signal output and the receiving signal input, additional interface protection circuitry maybe needed. The SP720 would normally have the same power supply levels as the receiving (input) device it is intended to protect. When the SP720 with its receiving interface circuit is powered off, a remote source signal may be activated from a separate supply (i.e., remote bus connected systems). The user should be aware that the SP720 remains active when powered down and may conduct current from the IN input to the V+ (or V-) supply.

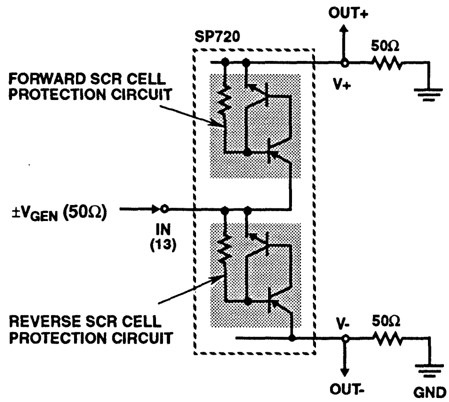
Within its own structure, **any** IN input of the SP720 will forward conduct to V+ when the input voltage increases to a level greater than a Vbe threshold above the V+ supply. Similarly, the SP720 will reverse conduct to V- when the input voltage decreases to a level less than a Vbe threshold below the V- supply. Either condition will exist as the V+ or V- level changes and will continue to exist as the V+ collapses to ground (or V-) when the SP720 supply is switched off. If a transient or power surge is provided from the source input to the IN terminal of the SP720, after the V+ has been switched off, forward current will be conducted to the $V+/V_{CC}$ power supply line. Without a power supply to clamp or limit the rising voltage, a power surge on the input line may damage other signal devices common to the V_{CC} power supply. Bypassing the V_{CC} line may not be adequate to protect for large energy surges. The best choice for protection against this type of damage is to add a zener diode clamp to the V_{CC} line. The zener voltage level should be greater than V_{CC} but within the absolute maximum ratings of all devices powered from the V_{CC} supply line.

Power Supply Off Protection, Rise/Fall Speed

To illustrate the active switching of the SP720 and the speed of the SCR for both turn on and turn off, oscilloscope traces were taken for the circuit conditions of Figure 7. A pulse input signal is applied with **NO** supply voltage applied to the SP720. Figure 7 shows the positive and negative pulse conditions to V+ and V- respectively. The trace scales for Figure 7 are 10ns/division horizontal and 1V/division vertical. Input and output pulses are shown on each trace with the smaller pulse being the output. The smaller output trace is due to an offset resulting from the voltage dropped across the SCR in forward conduction. The OUT+ and OUT- pulses quickly respond to the rising edge of the input pulse, following within ~2ns delay from the start of the IN pulse and tracking the input signal. The output falls with approximately the same delay.

POSITIVE/FORWARD CONDUCTION
HIGH SPEED ON/OFF PULSE (OUT+)





NEGATIVE/REVERSE CONDUCTION
HIGH SPEED ON/OFF PULSE (OUT-)

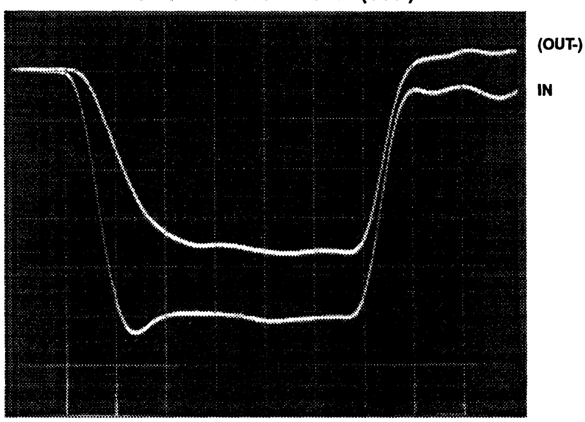


FIGURE 7. SP720 CIRCUIT WITH NO POWER SUPPLY INPUT PULSE TEST WITH 50Ω, (0V TO ±5V) INPUT. THE TRACE SCALES FOR OUT+ AND OUT- ARE 1V/DIV VERTICAL AND 10ns/DIV HORIZONTAL

HARRIS SEMICONDUCTOR

HIP1090

Protected High Side Power Switch with Transient Suppression

August 1993

Features

- ±90V Transient Suppression
- 4V to 16V Operating Voltage
- 1A Current Load Capability
- Low Input-Output Voltage Drop With Controlled Saturation Detector for
  - Fast Low Current Turn-OFF
  - Reduced No-Load Idle Current
- Over-Voltage Shutdown Protection
- Short Circuit Current Limiting
- Over-Temperature Limiting Protected
- Thermal Limiting at T_J = +150°C
- -40°C to +105°C Operating Temperature Range

Applications

- Electronic Circuit Breaker
- Transient Suppressor
- Overvoltage Monitor
- High Side Driver Switch for
  - Relays
  - Solenoids
  - Heaters
  - Motors
  - Lamps

Ordering Information

PART NUMBER	TEMPERATURE RANGE	PACKAGE AND LEAD FORM
HIP1090AS	-40°C to +105°C	TO-220AB

Description

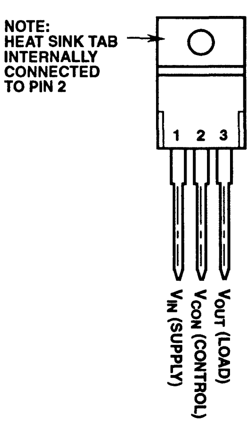
The HIP1090 is a Protected Power Interface Switch designed to suppress potentially damaging overvoltage transients with peak voltage source inputs ranging up to ±90V in amplitude. It is designed to be operated in a 'hard-wired' pass-thru mode or as a high side power switch which controls the current flow through a PNP pass transistor of the IC. In either mode The HIP1090 has a low saturated forward voltage drop. The protected load circuit is connected to the output of the IC. As such, the HIP1090 operates as a transient suppressor where the PNP drive transistor is switched off when V_{IN} is greater than the Overvoltage Shutdown range of 16V to 19V. Shutdown also occurs when V_{IN} is less than the forward turn-on threshold of approximately 2.5V, including the negative voltage range.

The merits of transient suppression depend on the required integrity of the applications load elements. Instrument panel signal warning lights for critical functions such as over temperature or low fluid levels can be protected by the HIP1090 against high level transient voltages and double battery conditions that may potentially cause bulb burnouts. The HIP1090 may be used to protect the power supplies of small signal or logic circuits with voltages ranging from 4V to 16V, effectively blocking higher peak voltages.

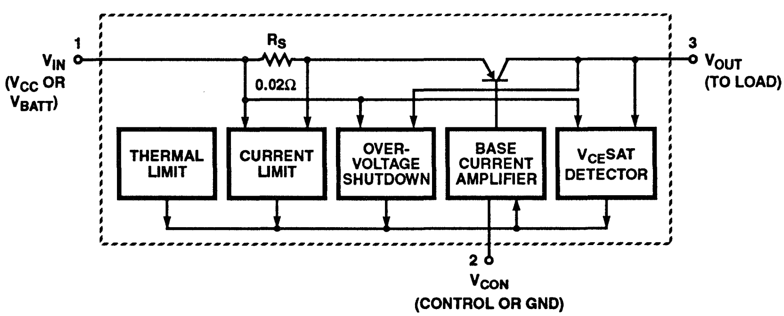
The HIP1090 has internal current limiting protection in the range of 1A to 2A for short circuit to ground conditions and thermal shutdown protection when the junction temperature is greater than 150° C It is capable of driving resistive, inductive or lamp loads (such as lamps No. 168 or 194) with minimum risk of damage under harsh environmental stress conditions. The HIP1090 is supplied in a 3 lead TO-220AB package.

Pinout

TO-220AB
TOP VIEW



Functional Block Diagram



11
PROTECTION CIRCUITS

CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

File Number **3398.1**

Absolute Maximum Ratings

Input (Supply) Voltage, V_{IN} (Control Pin Reference) . . . . ±24V
Transient Max Voltage, V_{IN} (15ms) . . . . ± 90V
Load Current, I_{OUT} . . . . Short Circuit Protected

NOTE: $Pd = (V_{IN} - V_{OUT})(I_{OUT}) + (V_{IN})(I_{CON})$
$T_J = T_A + (Pd)(\theta_{JA})$

Thermal Resistance, θ_{JC} . . . . 4°C/W
Junction Temperature . . . . +150°C
Ambient Temperature Range . . . . -40°C to +105°C
Storage Temperature Range . . . . -40°C to +150°C
Lead Temperature (Soldering During) . . . . +265°C
1/16±1/32"(1.59 ± 0.79mm) from case for 10s maximum

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

Electrical Characteristics T_A = -40°C to +105°C; V_{IN} = 4V to 16V; V_{CON} = GND or 0V, Unless Otherwise Specified

CHARACTERISTICS	SYMBOL	TEST CONDITIONS	LIMITS MIN	LIMITS TYP	LIMITS MAX	UNITS
Input (Supply) Voltage Operating Range	V_{IN}	(Note 1); Also, see Figure 4 for Expanding V_{IN} Range	4	-	16	V
Input Voltage Threshold for Forward Turn-On to Load	V_{THD}	Load = 1KΩ	-	2.5	-	V
Input Voltage for Output Shutdown	V_{SHSD}	(Note 2)	16	-	19	V
Output Shutdown Leakage	I_{LEAK1}	V_{IN} = 19V and 24V; Load = 1KΩ	-	-	100	µA
Output Cutoff Leakage	I_{LEAK2}	V_{IN} = 16V; Control Open; Load=1KΩ	-	1	-	µA
Thermal Shutdown Temperature	T_{SD}		-	150	-	°C
Maximum Output Transient Pulse Current	I_{OUT}(Tran)	V_{IN} = ±90V for 15ms, V_{OUT} = 14V	-20	-	+20	mA
Maximum Control Transient Pulse Current	I_{CON}(Tran)	V_{IN} = ±90V for 15ms, V_{OUT} = 14V	-50	-	+50	mA
Short Circuit Current	I_{SC}		1	-	2	A
Input-to-Output Voltage Drop		V_{IN} = 4V, I_{OUT} = 175mA	-	-	0.25	V
		V_{IN} = 9V, I_{OUT} = 500mA	-	-	0.65	V
		V_{IN} = 16V, I_{OUT} = 800mA	-	-	1.05	V
		V_{IN} = 16V, I_{OUT} = 1A	-	0.8	-	V
Control Current	I_{CON}	V_{IN} = 16V, I_{OUT} = 100mA	-	-	25	mA
		V_{IN} = 16V, I_{OUT} = 800mA	-	-	50	mA
		V_{IN} = 16V, I_{OUT} = 1A	-	50	-	mA
Turn ON (Rise Time); "Pass-Thru" mode	t_{ON}	Switch V_{IN} 0V(GND) to 5.5V; Measure V_{OUT} (to 90%); Load=1KΩ (Note 3)	-	-	20	µs
Turn OFF (Fall Time); "Pass-Thru" mode	t_{OFF}	Switch V_{IN} 5.5V to 0V(GND); Measure V_{OUT} (to 90%); Load=1KΩ (Note 3)	-	-	20	µs
Turn ON (Rise Time); High Pass Switch mode	t_{ON}	See Figures 3 and 4 (Note 3)	-	15	-	µs
Turn OFF (Fall Time); High Pass Switch mode	t_{OFF}	See Figures 3 and 4 (Note 3)	-	15	-	µs

NOTES:

1. The Input Operating Voltage is not limited by the threshold of Shutdown. The V_{IN} voltage may range to ±24V while the normal functional switching range is typically +2.5V to +17.5V (reference to V_{CON}).
2. The Output Drive is switched-off when the Input voltage(Supply pin), referenced to the Control pin exceeds the threshold shutdown VSHSD or the input voltage is less than the forward turn-on threshold (Including negative voltages within the transient peak ratings).
3. T_{ON} and T_{OFF} times include Prop Delay and Rise/Fall time.

Applications

The HIP1090 may be used as a "hard-wired pass-thru" device to protect the load from source voltage transients or may be used as an active high side power interface switch with up to 1A of Load current capability. An ON state condition of $(V_{IN} - 4V) \leq V_{CON} \leq (V_{IN} - 16V)$ is the normal range required to activate the high pass switch, allowing the supply source to conduct through the PNP to the load. When the control terminal, V_{CON} is open, the high pass switch is open (no conduction). Figure 2 shows an HIP1090 application example with a switch in the V_{CON} terminal. In comparison to the hard wired circuit of Figure 1 where pin 2 is fixed at ground, pin 2 in the circuit of Figure 2 is switched from open to ground to turn-ON the high pass switch. Used in this mode, the HIP1090 is both an effective transient suppressor and a high pass switch. The switch in the V_{CON} terminal may be active or passive and conducts typically less than 50mA of current. The HIP1090 used in the controlled switching mode retains all of the protected features of the device. In either circuit the output capacitor may be increased in size to hold charge longer during transient interruptions at the input. The charge duration for larger capacitors or for lamp loads is tolerated because of the internal short circuit current limiting protection. Sustained short circuits may cause the junction temperature to reach the thermal shutdown temperature (150° C).

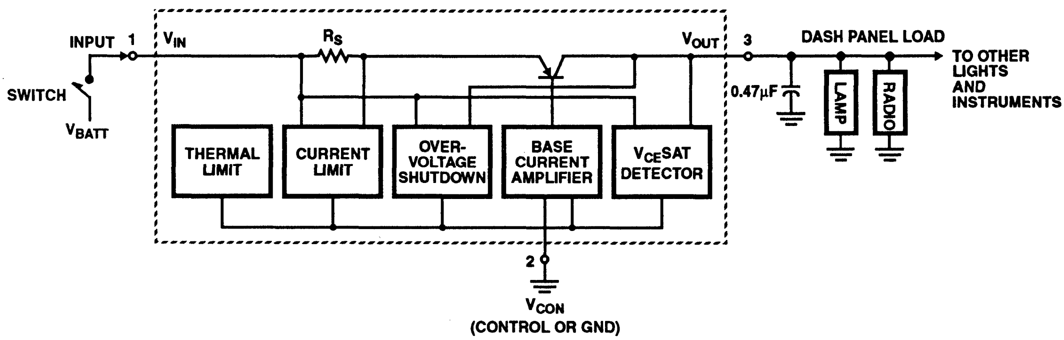
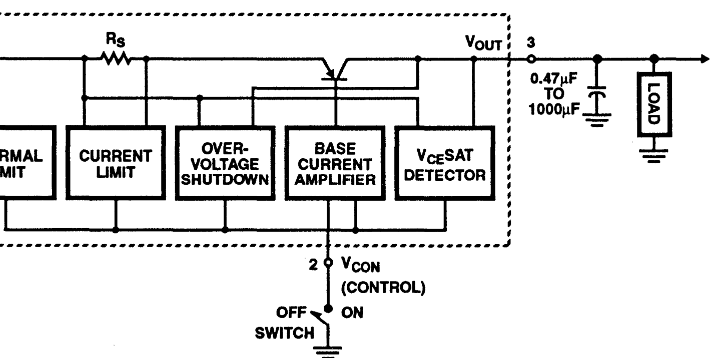


FIGURE 1. TYPICAL APPLICATION OF THE HIP1090 AS A TRANSIENT SUPPRESSOR IN A "PASS-THRU" MODE



NOTE:

$V_{LOAD} = V_{BATT} - V_{SAT}$

V_{SAT} TYP < 0.8V at 1A

FIGURE 2. TYPICAL APPLICATIONS OF THE HIP1090 AS A TRANSIENT SUPPRESSOR IN A HIGH PASS SWITCH MODE

Figure 3 shows the pulsed output switching characteristics of the HIP1090 as a high side driver. A small delay step is noted on the rising edge due to the hold-off of a $V_{CE}SAT$ detector circuit. The $V_{CE}SAT$ circuit senses the saturation level of the PNP pass transistor and controls the drive as a ratio of load current. As the load current is reduced, the drive current to the output transistor is reduced. Under low current operation, the saturation level is controlled and the turn-OFF switching time is much faster. The control switching element is shown as a 2N5320 NPN transistor but may be any open collector or MOS gate. A pull-up resistor of 2kΩ is used for a slight improvement in the turnoff fall time but is not an essential requirement. The V_{CON} terminal may be controlled with a mechanical switch or may be controlled from any driver output that can sink the worst case condition of pin 2 current, I_{CON} when the output load current is increased to 1A (typically 50mA).

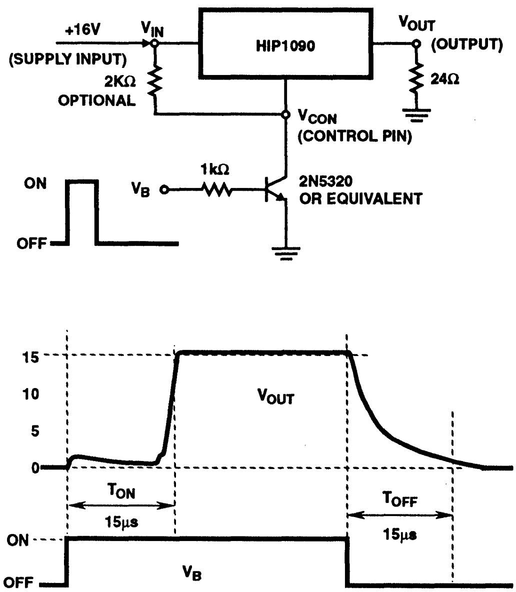


FIGURE 3. TYPICAL ON-OFF SWITCHING CHARACTERISTIC OF THE HIP1090 USING AN NPN TRANSISTOR TO SWITCH THE V_{CON} INPUT TERMINAL

The circuit of Figure 4 shows how the HIP1090 transient suppression voltage shutdown threshold may be increased by using a zener diode from the V_{CON} terminal to the collector terminal of the transistor switch. The preferred method is to use a zener diode for a fixed level shift. While a resistor in place of the zener diode having the same voltage drop will work well, the parametric variation of the I_{CON} current will cause variations of the Over-Voltage Shutdown Threshold. In this circuit, a 10V zener provides a typical overvoltage threshold shift to ~27V. The threshold for overvoltage shutdown is referenced to the (V_{IN} - V_{CON}) voltage difference.

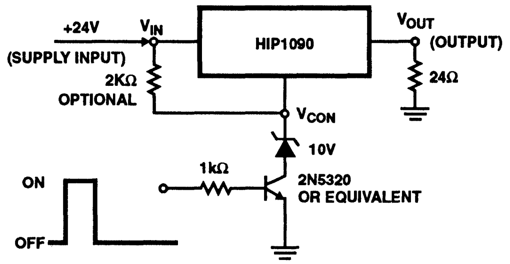


FIGURE 4. A TYPICAL APPLICATION CIRCUIT THAT USES A ZENER TO THE V_{CON} TRANSISTOR SWITCH TO RAISE THE OVERVOLTAGE SHUTDOWN THRESHOLD

Also, it is important to note that high peak current values may be reached when driving nonlinear and inductive loads. The peak output current of the HIP1090 is self limiting in the 1A to 2A range to protect against short circuit conditions. Sustained high peak current may increase the junction temperature to 150°C and cause thermal shutdown. When this happens, the output current will fall off briefly before recovering, unless the over-temperature condition is sustained. Internally, both input and output overvoltage conditions are sensed to protect the circuit, making the high levels of transient voltage ratings possible. Sustained voltage ratings of ±24V DC with transient ratings to ±90V allow a wide variety of applications in high stress environments.

Except for the $V_{CE}SAT$ detector circuit, the HIP1090 is a higher current version of the CA3273 high side driver, which turns-on without the delayed step on the leading edge of the output pulse; switching with a typical T_{ON} time of ~0.5µs. The CA3273 has a higher transient suppression threshold.

Typical Performance Curves

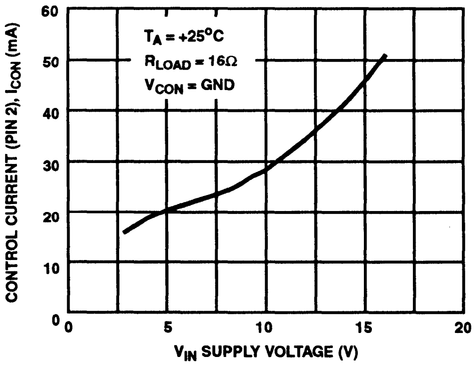


FIGURE 5. CONTROL (QUIESCENT) CURRENT CHARACTERISTIC WITH LOAD

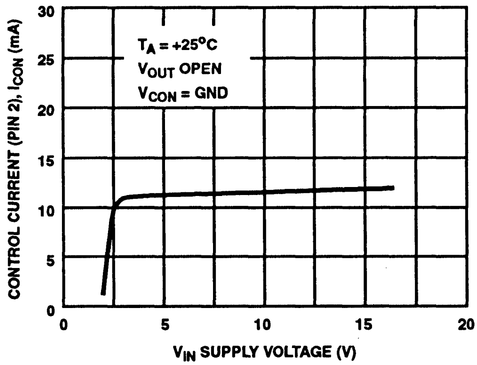


FIGURE 6. CONTROL (QUIESCENT) CURRENT CHARACTERISTIC WITH NO LOAD

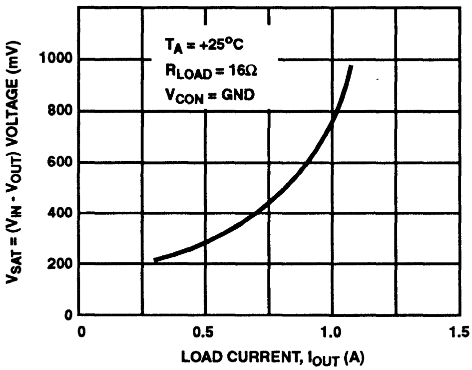
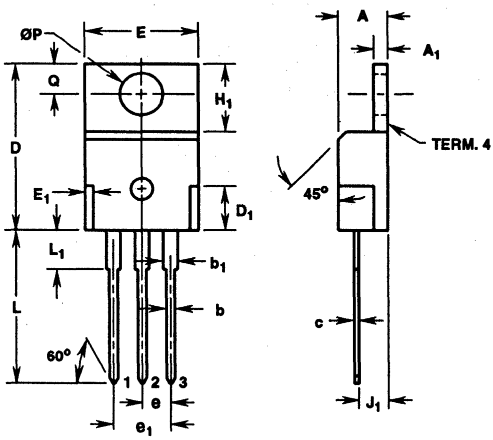


FIGURE 7. SATURATION (V_{IN} - V_{OUT}) CHARACTERISTIC

Packaging



Lead No. 1 - Gate
Lead No. 2 - Collector
Lead No. 3 - Emitter
Mounting Flange - Collector

TO-220AB

3 LEAD JEDEC TO-220AB PLASTIC PACKAGE

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN	MAX	MIN	MAX	
A	0.170	0.180	4.32	4.57	-
A_1	0.048	0.052	1.22	1.32	-
b	0.030	0.034	0.77	0.86	3, 4
b_1	0.045	0.055	1.15	1.39	2, 3
c	0.014	0.019	0.36	0.48	2, 3, 4
D	0.590	0.610	14.99	15.49	-
D_1	-	0.160	-	4.06	-
E	0.395	0.410	10.04	10.41	-
E_1	-	0.030	-	0.76	-
e	0.100 TYP		2.54 TYP		5
e_1	0.200 BSC		5.08 BSC		5
H_1	0.235	0.255	5.97	6.47	-
J_1	0.100	0.110	2.54	2.79	6
L	0.530	0.550	13.47	13.97	-
L_1	0.130	0.150	3.31	3.81	2
ØP	0.149	0.153	3.79	3.88	-
Q	0.102	0.112	2.60	2.84	-

NOTES:

1. These dimensions are within allowable dimensions of Rev. J of JEDEC TO-220AB outline dated 3-24-87.
2. Lead dimension and finish uncontrolled in L_1.
3. Lead dimension (without solder).
4. Add typically 0.002 inches (0.05mm) for solder coating.
5. Position of lead to be measured 0.250 inches (6.35mm) from bottom of dimension D.
6. Position of lead to be measured 0.100 inches (2.54mm) from bottom of dimension D.
7. Controlling dimension: Inch.
8. Revision 1 dated 1-93.

TVS 12

APPLICATION NOTES

No. AN8820.2 April 1993

RECOMMENDATIONS FOR SOLDERING TERMINAL LEADS TO MOV VARISTOR DISCS

Introduction

The CA series of MOV varistor discs with silver electrodes are specifically designed for custom assembly and packaging. To take advantage of the excellent performance and reliability of Harris varistor technology, it is important that the correct materials and processes be used to solder on the terminal leads.

Solder Fixtures

Where varistor discs are custom assembled and packaged, fixturing is normally employed to maintain disc and terminal alignment during solder reflow. Soldering fixtures should be of lightweight design to reduce their thermal mass and, hence, the time necessary to bring them to reflow temperature.

Disc and terminal lead should be pressed together lightly during the whole soldering process to help expel flux residues and excess solder from the interface. Trapped flux residue can result in bubbling of the solder, which leaves voids between silver electrode and terminal. Excess solder will enhance the tendency of the silver electrode to leach.

Soldering Ovens

Box, convection, and conveyor belt ovens are suitable for reflow solder processes using fixtures.

Box ovens should have forced air circulation with sufficient ventilation to remove flux vapors. It is important that every fixture position in the oven be subjected to the same heating conditions. Therefore, fixture positions should be limited to locations within the oven where uniform air flow and temperature can be maintained.

Convection ovens employ carefully designed exit baffles to facilitate close control of the soldering environment. Air is the best environment for soldering varistors. An inert gas (nitrogen) or reducing atmosphere is sometimes employed to reduce oxidation in these ovens, but neither of these is recommended for the processing of unpassivated varistors.

A very repeatable temperature profile can be achieved with a conveyor belt oven. The profile is determined by the temperature of the heated zone(s) and the speed of the belt. A fixed loading pattern also helps in achieving uniform results.

Fluxes

Fluxes are used for chemical cleaning of disc and terminal surfaces. There are three basic types:

R - These unactivated fluxes are less effective than the others in reducing oxides of copper, nickel, or palladium/silver metallizations, but are the ones recommended for MOV varistors. All other fluxes increase leakage, reduce long term reliability, and can promote leaching of the silver electrode. Non-charring, non-activated R type fluxes such as Alpha 100 or its equivalent are best.

RMA - These are mildly activated fluxes, and the most commonly used in the mounting of electronic components. They may be used with varistors, but are not recommended.

RA - These fully activated fluxes are corrosive, difficult to remove, and can lead to varistor failure. They must not be used to flux varistor discs.

Solders and Solder Temperature

Solders in the form of pastes or preforms can be used with varistors. Preforms are solder shapes premanufactured to specific sizes. Upon melting, they provide highly reproducible volumes of solder for joining. Preforms can be prefluxed, eliminating the need for any additional fluxing.

Heat should not be applied to a varistor too quickly, as the flux will not have sufficient time to activate and clean the joining surfaces. The result will be poor solderability. On the other hand, no varistor should be held longer than necessary at an elevated temperature. If heat is applied too slowly or maintained above reflow temperature for too long, leaching of the silver electrode into the solder will occur, reducing the disc to terminal bond strength. To avoid leaching, only solders with at least 2% silver content (e.g., 62Sn/36Pb/2Ag or equivalent) should be used; see Table 1.

It is equally important to observe processing time and temperature limits. Failure to do so can result in excessive leakage and alterations of the varistor's VI characteristic.

Cleaning and Cleaning Fluids

Cleaning is an important step in the soldering process. It prevents electrical faults such as the high current leakage caused by ionic contamination, absorbed organic material, dirt films, and resins.

A wide variety of cleaning processes can be applied to varistors, including water based, solvent based or a mixture of both, tailored to specific applications. Harris recommends 1.1.1 trichloroethane for the removal of flux residues after soldering.

Defluxing in a solvent bath with ultrasonic agitation, followed by a solvent vapor wash, is a very effective cleaning process. After cleaning, the low boiling point solvent completely evaporates from the disc, and will not harm solder joints.

TABLE 1. SILVER BEARING SOLDERS (ALPHA METALS)

ALLOY	MELTING TEMPERATURE
62Sn/36Pb/2AG	179°C
96.5Sn/3.5Ag	221°C
96Sn/5 Ag	221°C - 245°C
10Sn/88Pb/2Ag	268°C - 302°C
5Sn/92.5Pb/2.5Ag	280°C
97.5Pb/2.5Ag	305°C

Harris Semiconductor

APPNOTE

No. AN9108.1 August 1993 **Harris Suppression Technology**

HARRIS MULTILAYER SURFACE MOUNT SURGE SUPPRESSORS

Author: Martin Corbett

Introduction

Sensitivity of Components

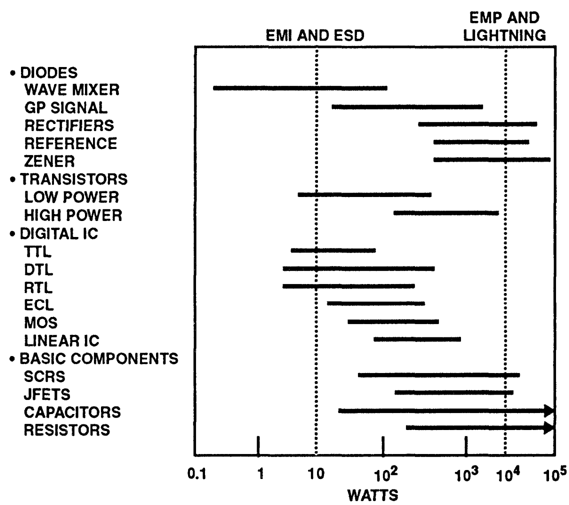
Modern electronic circuits are much more vulnerable to damage from transient overstresses than earlier circuits, which made use of relays and vacuum tubes. The progress in the development of faster and denser integrated circuits has been accompanied by an increase in system vulnerability. As the use of such systems has increased so to has the need for their protection. Figure 1 shows damage susceptibility of some commonly used components, including discrete semiconductors and integrated circuits [1, 2].

As many semiconductor devices can be damaged by potential differences that exceed 10 volts, the survivability of modern electronics is limited when exposed to transient overvoltages. The advent of smaller faster technologies, such as high speed logic and MOSFETs, has led to an increased vulnerability of electronic circuits to damage from overstresses. The voltage, current, or power seen by a device must be below the failure threshold of the device. The value of this threshold is a function of the magnitude and duration of a transient overvoltage occurrence. The magnitude of the transient is determined by the nature of the source, the characteristic impedance of the circuit and the resistance and inductance between the source of the transient and the device.

Integrated circuits are sensitive components, and their threshold for damage is difficult to increase. Therefore, transient protection of these sensitive circuits is highly desirable to assure system survival.

Digital integrated circuits produced with TTL technology are fairly rugged devices and are relatively insensitive to high speed transients. However, ICs designed with new technologies, that have thinner gate oxides and higher cell densities, are more susceptible to voltage transients.

When looking at the gate oxide cross section of devices using existing and new technologies, it is realized that the susceptibility to transients is continuously increasing due to the potential of damage with "punch-through". In order to



EMI - ELECTROMAGNETIC INTERFERENCE
ESD - ELECTROSTATIC DISCHARGE
EMP - ELECTROMAGNETIC PULSE

FIGURE 1. RELATIVE DAMAGE SUSCEPTIBILITY OF ELECTRONIC COMPONENTS (FOR 1μs PULSE)

work with these devices successfully, the sensitivity of such devices must be fully understood, and adequate precautions taken to ensure reliable operation, as well as survival in harsh environments. Table 1 shows a comparison of the feature size, supply voltages, and typical gate count of various IC technologies.

TABLE 1. CURRENT INTEGRATED CIRCUIT TECHNOLOGY

PROPERTIES	BIPOLAR	MOS	BiMOS	POWER BiMOS
Feature Size (μM)	5.0	1.0	1.5	3.0
Typical Gate Count	500	6	16	80
Typical Supply Voltage (Volts)	+60	+6	+16	+80

When designing to protect systems, it is desirable to ensure that worst cases stresses are below the failure threshold of the circuit. In the situation where information on the failure threshold is unknown, it is permissible to use a factor of 2 above the device/system steady state ratings and specify a brief duration at this over stress level (usually a few microseconds). Such an approach has been endorsed by the U.S. Department of Defense Military Handbook 419[3].

When sensitive devices are specified in a circuit, transient protection must not be treated as an afterthought. If no transient suppressor is used, the weakest device absorbs most of the transient energy, with a high probability of a failure. If the failed device is replaced by one having higher breakdown ratings, the next weakest device will take over the unintended roll of transient suppressor, and system failure could still result. Simply replacing failed devices with higher capability parts does not guarantee system reliability.

The Transient Threat

Transients exist in every AC or DC system, or any wire connecting two pieces of equipment or components. The sources of the transient can be lightning, nuclear electromagnetic pulse, high energy switching and high voltage sparkover, or electrostatic discharge. These transients may be found wherever the energy stored in inductances, capacitors, or mechanical devices, such as motors and generators, is returned to a circuit. Stray capacitance and inductance may also set off oscillations, making the problem even worse.

While a direct hit from lightning is not of real concern for a printed circuit board user, what may be of concern is the level of the transient which is "let through" by the primary suppressor. This "follow on current" may be up to 50 amps and it will last for a number of microseconds. If this current is above the failure threshold of a device in the circuit, it will be destroyed.

Hopefully, the threat of transients generated from nuclear electromagnetic pulses (NEMP) will not be a real concern. However specific requirements do exist to ensure that systems are protected from the fast rise pulses of NEMP. These transients have a rise time of approximately 5 nanoseconds and are of a magnitude similar to that encountered from lightning.

The two most likely types of transients from which a circuit must be protected are electrostatic discharge (ESD), and the switching of reactive loads. ESD will result when two conducting materials are brought close to one another and a voltage discharge occurs. The resulting voltage discharge can be as high as 25KV and will last up to 50 nanoseconds. One of the most common methods of "zapping" circuits is walking across a carpeted floor, building up an electrical charge, and touching a device without being properly grounded. Transients can also be generated when an inductive load is disconnected and the existing energy is discharged back into the circuit. The arc generated from the opening of mechanical relay switches is another common source of switching transients.

Whatever the cause of the transient, natural or man-made, the damage potential is real and cannot be casually dismissed if reliable operation of equipment is to be expected. To properly select a transient suppressor, the frequency of occurrence of transients, the open-circuit voltage, the short circuit-current, and the source impedance of the circuit must be known.

To date, designers have used resistors, capacitors, inductors, metal-oxide varistors, zener diodes, silicon carbide varistors, spark gaps, carbon blocks, or combinations of these to suppress transients and protect sensitive components. The new Harris series of Multilayer (ML) surge suppressors represents a unique and effective solution for transient suppression.

Multilayer Surge Suppressor Description

The Harris multilayer (ML) series of transient voltage surge suppressors represents a recent breakthrough in the area of semiconducting ceramic processing. The ML suppressor is a compact, surface mountable chip that is voltage dependent, non-linear, and bi-directional. It has an electrical behavior similar to that of a back-to-back diode, i.e. it is inherently fully symmetrical, offering protection in both forward and reverse directions. The sharp, symmetrical breakdown characteristics of the device provides excellent protection from damaging voltage transients (Figure 2). When exposed to high voltage transients, the ML impedance changes many orders of magnitude from a near open circuit to a highly conductive state.

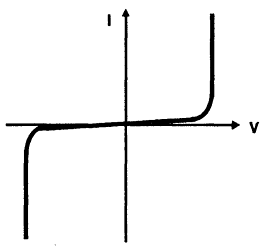


FIGURE 2. SHARP SYMMETRICAL BREAKDOWN OF MULTI-LAYER SUPPRESSOR

Construction

The ML is constructed by forming a combination of alternating electrode plates and semiconducting ceramic layers into a block. Each alternate layer of electrode is connected to opposite end terminations (Figure 3). The interdigitated block formation greatly enhances the available cross-sectional area for active conduction of transients. This paralleled arrangement of the inner electrode layers represents significantly more active surface area than the small outline of the package may suggest. This increased active surface area results in proportionally higher peak energy capability.

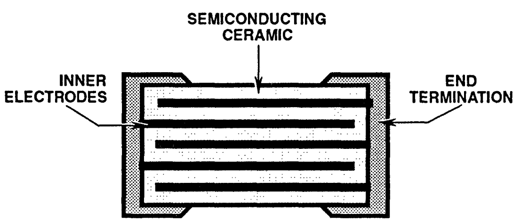


FIGURE 3. MULTILAYER INNER ELECTRODES & SEMICONDUCTING CERAMIC (CROSS-SECTION)

Another advantage of this type of construction is that the breakdown voltage of the device is dependent on the dielectric thickness between the electrode layers and not the overall thickness of the device. Increasing or decreasing the dielectric thickness will change the breakdown voltage of the device.

Energy handling capability can be significantly increased with a larger overall package outline. The energy handling capability doubles from 0.6 Joules (10/1000ms waveform) for a 0.120 inch by 0.06 inch device to 1.2 Joules for a 0.120 inch by 0.100 inch device.

The crystalline structure of the ML transient voltage suppressor (TVS) consists of a matrix of fine, conductive grains separated by uniform grain boundaries, forming many P-N junctions (Figure 4). These boundaries are responsible for blocking conduction at low voltages, and are the source of the nonlinear electrical conduction at higher voltages. Conduction of the transient energy takes place between these P-N junctions. The uniform crystalline grains act as heat sinks for the energy absorbed by the device in a transient condition, and ensures an even distribution of the transient energy (heat) throughout the device. This even distribution results in enhanced transient energy capability and long term reliability.

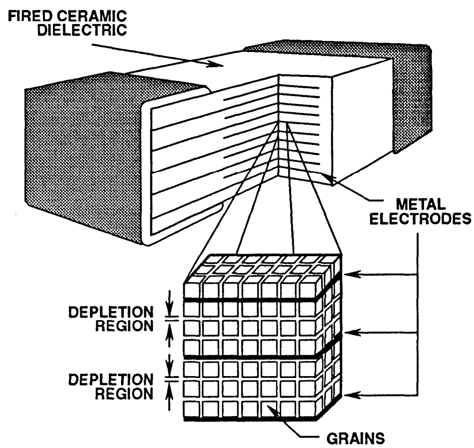


FIGURE 4. MULTILAYER TRANSIENT VOLTAGE SUPPRESSOR

Package Outline

The ML surge suppressor is a surface mountable device that is much smaller in size than the components it is designed to protect. The present size offerings are a "1210" form factor (0.120 inches x 0.100 inches) and a "1206" form factor (0.120 inches x 0.060 inches). Since the device is inherently bi-directional, symmetrical orientation for placement on a printed circuit board is not a concern. Its robust construction makes it ideally suitable to endure the thermal stresses encountered in the soldering, assembling and manufacturing steps involved in surface mount applications. As the device is inherently passivated by the fired ceramic material, it will not support combustion and is thus immune to any risk of flammability which may be present in the plastic or epoxy molded parts used in industry standard packages.

Characteristics

Speed of Response

The clamping action of the ML suppressor depends on a conduction mechanism similar to that of other semiconductor devices. The response time of the zinc oxide material itself has been shown to be less than 500 picoseconds[3, 4, 5]. The apparent slow response time often associated with zinc oxide is due to parasitic inductance in the package and leads. Thus, the single most critical element affecting the response time of any suppressor is its lead length and, hence, the inductance in the leads. As the ML suppressor is a true surface mount device, with no leads or external packaging, it has virtually zero inductance. In actual applications, the estimation of voltage overshoot is of more practical relevance than that of speed of response. As a multilayer suppressor has essentially zero inductance it has little or no voltage overshoot. The actual response time of a ML surge suppressor is 1 to 5 nanosecond. This response time is more than sufficient for the transients which are likely to be encountered by a component on a printed circuit board.

Clamping Voltage

The clamping voltage of a suppressor is the peak voltage appearing across the device when measured under the conditions of a specified pulse current and specified waveform. The industry recommended waveform for clamping voltage is the 8/20 microsecond pulse which has been endorsed by UL, IEEE and ANSI. The clamping voltage of the ML should be the level at which a transient must be suppressed to ensure that system or component failure does no occur. Shunt-type suppressors like the ML are used in parallel to the systems they protect. The effectiveness of shunt suppressors can be increased by understanding the important influence that source and line impedance play in a system, such as is shown in Figure 5.

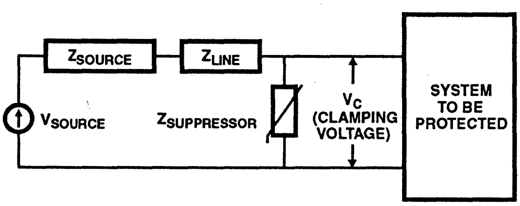


FIGURE 5. VOLTAGE DIVISION BETWEEN SOURCE, LINE AND SUPPRESSOR IMPEDANCE

To obtain the lowest clamping voltage (V_C) possible, it is desirable to use the lowest suppressor impedance ($Z_{SUPPRESSOR}$) and the highest line impedance (Z_{LINE}). The suppressor impedance is an inherent feature of the device, but the line impedance can become an important factor, by selecting location of the suppressor, or by adding resistances or inductances in series.

$$V_C = \frac{V_{SUPPRESSOR} \times V_{SOURCE}}{Z_{SUPPRESSOR} + Z_{LINE} + Z_{SOURCE}}$$

Temperature Dependence

In the off state, the V-I characteristics of the ML suppressor approaches a linear (ohmic) relationship and shows a temperature dependent affect (Figure 6). The suppressor is in a high resistance mode (approaching 109 ohms) and appears as a near open circuit. This is equivalent to the leakage region in a traditional zener diode. Leakage currents at maximum rated voltage are in the microamp range. When clamping transients at higher currents (at and above the milliamp range), the ML suppressor approaches a near short circuit. Here the temperature variation in the characteristics of the ML becomes minimal throughout the full peak current and energy range (Figure 7). The clamping voltage of a multilayer transient voltage suppressor is the same at +25°C and at +125°C.

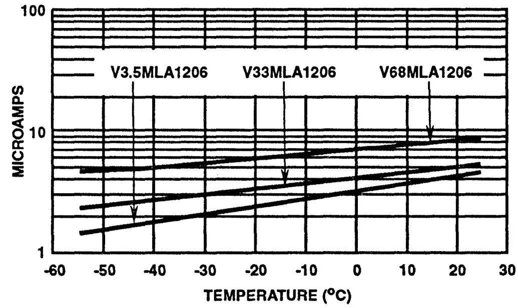


FIGURE 6. TEMPERATURE DEPENDENCE AT LOWER VOLTAGE

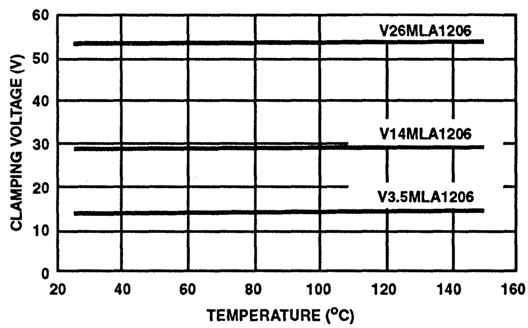


FIGURE 7. CLAMPING VOLTAGE VARIATION OVER TEMPERATURE

Peak Current Capability

The peak current handling capability, and hence its ability to dissipate transient energy, is one of the ML suppressor's best features. This is achieved by the interdigitated construction of the ML, which ensures that a large volume of suppressor material is available to absorb the transient energy. This structure ensures that the peak temperatures generated by the transient is kept low, because all of the package is available to act as an effective, uniform heat sink and absorb all the energy.

(Figure 8). Because of the low peak temperatures, the ML will experience very low thermal stress, both during heating and cooling.

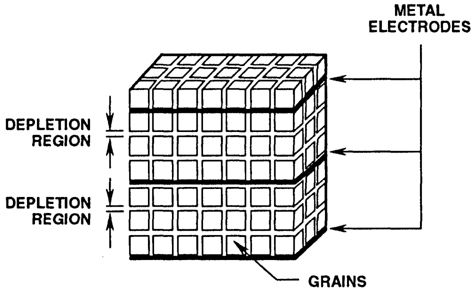


FIGURE 8. INTERDIGITATED CONSTRUCTION

Repetitive pulsing on the ML suppressors (Figure 9) show negligible shift in the nominal voltage at one milliamp (less than 3%). There was also a minimal change in the leakage current of these devices. The Harris ML suppressor can also operate up to +125°C without any need for derating.

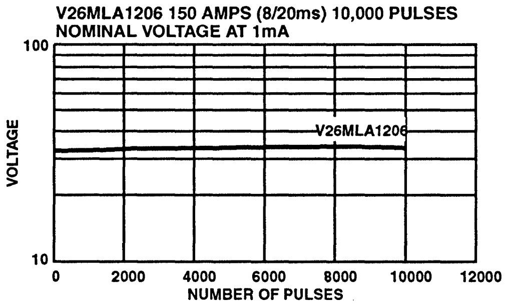


FIGURE 9. REPETITIVE PEAK PULSE CAPABILITY

Capacitance

The ML suppressor is constructed by building up a composite assembly of alternate layers of ceramic material and metal electrode. Since capacitance is proportional to area, and inversely proportional to thickness, the lower voltage ML's have a relatively high capacitance. Typical values of capacitance are shown in Table 2.

TABLE 2. TYPICAL CAPACITANCE VALUES FOR 1206 MULTILAYER FAMILY

	CAPACITANCE (pF)			
	FREQUENCY (AT BIAS = $1V_{P-P}$)			
DEVICE TYPE	1KHz	10KHz	100KHz	1MHz
V5.5MLA1206	6250	5680	5350	5000
V14MLA1206	2750	2500	2360	2200
V18MLA1206	2100	1930	1830	1700
V26MLA1206	1000	910	860	800
V33MLA1206	600	550	520	500
V42MLA1206	550	520	480	450
V56MLA1206	410	380	360	350
V68MLA1206	190	170	160	150

Size

A principal benefit of the new ML suppressor is their compact size in comparison to other surface mount components. The ML suppressor could be up to 50 times smaller than the components they are protecting. The small size of the ML offers an advantage in the saving of circuit board real estate and an ease in handling. Additionally, the solder mounting pads required for ML are much smaller, resulting in even more circuit board area savings.

The present offering of multilayer suppressor sizes is 1206 (0.120 x 0.060 inches) and 1210 (0.120 x 0.100 inches).

Comparison to Other Transient Suppressors

Peak Current and Energy Capability

There are many design trade-offs involved in selecting the best transient suppression device for a given application. As previously mentioned, the large active electrode area available to the ML ensures that it's peak current handling capability is one of it's best features. Thus, by virtue of its construction, the ML is capable of dissipating significant amounts of energy over a small volume. The interdigitated construction of the ML means that the very high temperatures resulting from a transient occurrence will be dissipated through millions of P-N junctions. This is unlike a silicon suppressor, which has only one P-N junction available to handle a peak transient. Additionally, because many different materials with varying thermal coefficients of expansion are employed in the construction of a zener TVS, more extreme thermal stresses are created in transient energy dissipation and in the resulting temperature cycling. In an attempt to overcome this shortcoming, a number of silicon die are placed in series in a sandwich construction, with a metal header to act as a heat sink and solder pellets for bonding (Figure 10). This construction is designed to distribute the transient energy in more than one P-N junction, and will somewhat reduce the steep temperature build up. The reliability of such an approach is questionable. The metal sandwich is not completely effective in increasing the thermal capacity for transient pulses below 50 microseconds, because of the thermal time constant involved in transporting the energy (heat) from where it is generated (the silicon die) to the metal heat sink. Though high energy transients are much less frequent than low energy ones, it takes only one transient to completely damage the transient protector, and hence the component or circuit being protected. A device with no other function than to keep dangerous transients away from components may become the source of the problem if it shorts or opens, and leaves the circuit without protection. In the ML TVS, millions of P-N junctions are an integral part of the device structure, and it is this inherent advantage which gives excellent thermal properties.

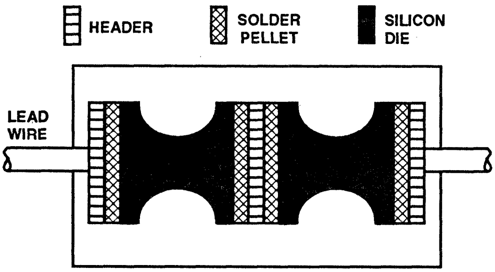


FIGURE 10. DIFFERING THERMAL COEFFICIENT MATERIALS

Comparing the typical peak current/power derating curves of the Harris multilayer to an equivalent silicon suppressor at +125°C, the ML has 100% of rated value while the zener diode has only 35% (Figure 11).

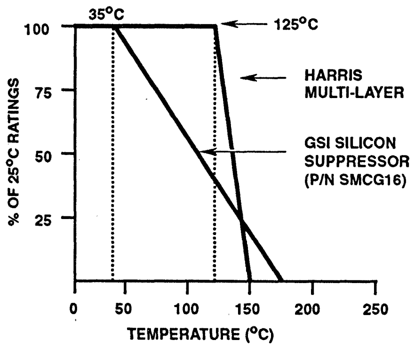


FIGURE 11. ML AND ZENER DIODE POWER DERATING CURVES

Clamping Voltage

A well defined voltage avalanche characteristic is the best feature of a low voltage zener diode device, although it requires a high leakage current rating to achieve this. These diodes, recommended for the protection of 5V logic, have elevated temperature leakage specifications of 1000µA at their rated voltage. The leakage current of a zener diode can be reduced by specifying a higher voltage rated device, but this results in a higher clamping voltage and reduces the advantages of the zener diode.

The V-I characteristic for a zener diode is defined over a small current range (1 decade). The ML current range is extended over a few more decades, which illustrates it's large peak current and energy handling capability.

Temperature Effects

Both the ML and the zener diode have a temperature dependance with respect to off state leakage current, with leakage current increasing as temperature increases. However, beyond the breakdown point, the clamping voltage of the ML will remain constant between +25°C and +125°C, while the clamping voltage for the zener diode at +125°C is higher than that specified at +25°C.

Speed of Response

Unfortunately, speed of response ratings do not represent the realizable response times of the transient suppressor in a typical system application. Traditional transient suppressors, zener diode and metal oxide varistors, for example, have finite lead inductance, and their response time is limited (slowed) by these parasitic lead inductances. This limitation has been recognized by the IEEE committees on transient suppressors, with the conclusion that the response time of a suppressor is influenced by lead configuration and length. Unlike the leaded surface mount packages used in zener diodes, the ML suppressor is a true surface mount device. Since the ML has no leads, it has virtually no inductance and the principal factor contributing to response times is eliminated.

Up to now, the only surface mounted surge suppressors available are leaded gull-wing and j-bend zener diodes or a relatively large surface mount metal oxide varistor. In such cases a large area of the PC board is needed for mount down. Electrically equivalent ML suppressors are as much as three to four times as small than their silicon counterparts, resulting in significant surface mount PC board area savings (Figure 12). The compact size of the ML TVS is driven by the advantages of paralleled stacking, resulting in a high density energy absorber where the device volume is not taken up by lead frames, headers, external leads, and epoxy. Additional board area savings are realized with the smaller solder mounting area required by the ML as compared to the gull-wing or j-bend packages (Figure 13).

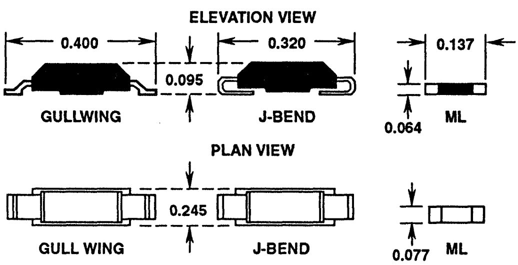
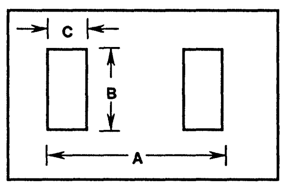


FIGURE 12. COMPARATIVE SURFACE MOUNT SURGE SUPPRESSORS



	DIMENSIONS		
	A	B	C
ML1206	0.203	0.103	0.065
Gull Wing	0.410	0.125	0.050
J-Bend	0.330	0.125	0.070

FIGURE 13. SOLDERING LAND PAD REQUIREMENTS

Applications

Protection of Integrated Circuits and Low Voltage Circuits

Protection against the coupling of transients are mainly required at two locations on the printed circuit board. The first is at the input/output port which affords protection of sensitive inputs to line drivers and receivers. The second location is at the power input to the integrated circuits at the input side of the board. This location will serve to keep the transient threat from transmitting throughout the rest of the board.

In the past, IC's have been protected by means of decoupling capacitors across the input power supply lines. The capacitors suppressed transients and supplied peak current for high speed switching operations. Unfortunately, the energy stored in the capacitor, and with it it's suppression capability, is very small: $E = 1/2 * C * V^2$.

Large electrolytic capacitors are usually placed on the output of the 5 volt supply. These capacitors are bulky and somewhat ineffective because of their poor high frequency response. Crowbars are also used to sense overvoltages. The crowbar functions such that an overvoltage shorts the output until the input fuse or circuit breaker opens, thereby turning the system off. Other concerns to consider as well as the power supplies and supply circuitry, are the input and output terminals carrying information. As long as the interconnections are short, transients do not seem to be a problem. However, when connections from board-to-board, system-to-system, or system-to-sensor are considered transients must be controlled (see Figure 14).[7]

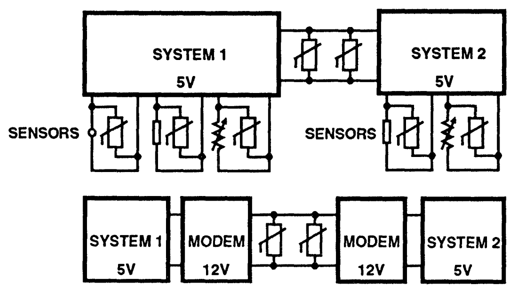


FIGURE 14. SYSTEM-TO-SYSTEM AND SYSTEM-TO-SENSOR PROTECTION

If the distances become long or interconnections between systems result in transient pick-up, then transient suppression is a pre-requisite. Devices that are more effective than resistors and capacitors are needed to provide the necessary protection. Small spark gaps and silicon suppressors have been used quite effectively, but spark gaps still need a zener diode to reduce the initial voltage rise that triggers the spark gaps.

Silicon suppressors, with their almost ideal V-I characteristics, are used quite extensively. However, zeners have low current-surge capabilities and are of limited value as a transient suppressor when a relatively high magnitude transient is encountered. Surge capability is low because the thermal mass of the silicon chip, where all the energy of the transients is to be converted into heat, is so small. Peak temperatures can become so high that part of the silicon will melt, and the device will fail. On the other hand, there are zener diodes specifically designed for transient suppression. The thermal mass of these devices is increased by attaching more copper to the silicon pellet. This approach helps, but it does not eliminate the basic problem. The transient energy is still converted into heat in the silicon pellet. The heat travels somewhat faster to the surrounding mass of copper. However, the large temperature differentials still exist. The mismatch of the thermal coefficient of expansion between the silicon and copper will create shearing forces that may lead to failures due to thermal fatigue.

The low voltage V5.5MLA1206 may be used to protect integrated circuits requiring 5 volts on the input, e.g. all integrated circuits, systems containing low voltage IC's, memories, test equipment, data processing equipment, etc. The suppressor should be connected upstream form the IC to be protected. The maximum clamping voltage of the sup- pressor depends on the maximum transient current. If the clamping voltage is too high and the signal currents are low, a hybrid arrangement of a multilayer suppressor and a series impedance (an inductor or resistor) may be an effective and low cost solution. The series impedance should be as large as possible without distorting or attenuating the signal appreciably. The clamping voltage of the suppressor should be low, but high enough to prevent attenuation or distortion of the signal.

CMOS Protection

Latch-up is a phenomenon inherent in the basic CMOS structure. It is initiated by external conditions, is present only momentarily, and once induced is difficult to reverse, except by complete removal of power to the chip. Latch-up results in large current flow from V_{CC} to ground. It can be triggered by an increasing voltage across the power terminal, such as an excessive voltage at the V_{CC} pin (normally well above the maximum V_{CC} rating of the device). This can be prevented by connecting a low voltage ML transient suppressor across V_{CC}.

Unfortunately, even if the systems power supply variations are kept small, individual inputs can still vary widely. Latch-up is also known to occur in CMOS systems when voltage supplied to an inlet exceeds the supply voltage. Again, transients can be the culprit; the wrong sequence in power-up or power-down may have the same effect. A ML suppressor connected from V_{CC} to ground will eliminate most of the latch-up problems caused by input over voltage. Additionally a ML suppressor connected from input to ground will help to protect the input from damaging transients such as electrostatic discharge (Figure 15).

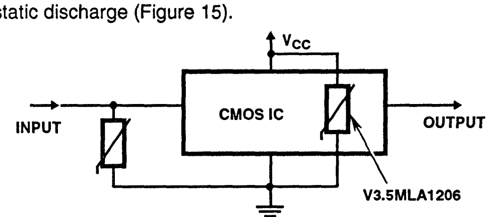


FIGURE 15. PROTECTION OF CMOS DEVICES

The new Harris V3.5MLA1206 represents a new method of protecting next generation 3.5 volt CMOS logic. New generations of high density, high speed logic are more suspectable to overvoltage stress. No equivalent transient protection device currently available in a surface mount package can provide this level of protection.

Discrete MOSFET Protection

Over the years there has been an increasing migration from bipolar technology to MOSFET technology. This has resulted in an increase in the need for transient protection, for the system using the MOSFET. One reason for this is that a MOSFET is more susceptible to damage from electrostatic discharges than a bipolar transistor. Additionally, to take full advantage of the MOSFET, the voltage margins needed in a design should be minimized. This is because the incremental voltage increase for a MOSFET is more expensive than an equivalent incremental voltage increase for a bipolar transistor.

When protecting the MOSFET transistor, its exceptionally fast switching times (50ns to 100ns) must also be considered. The consequences of this fast switching time is a "ringing" in the wiring inductances connecting the MOSFET to the other components, resulting in the MOSFET being subjected to short duration transient voltages. By clamping these transients to a safe low level it may be possible to use a lower cost MOSFET in the application. It is important when using a ML suppressor to connect it as close as possible to the drain and source leads of the MOSFET, in order to minimize the loop inductance. As the ML suppressor is a true surface mount package and has no lead inductance, this ensures that the MOSFET does not to suffer the additional transient voltage overshoot associated with leaded suppressors.

To protect the output of the MOSFET, the ML suppressor is connected between the drain and source (Figure 16). This ML must have a steady state voltage capability ($V_{M(DC)}$) which exceeds the worst case possible maximum supply voltage. Its clamping voltage at a peak transient current must be less than the minimum breakdown voltage of the MOSFET. For example, to protect against transients on a 28 volt ±10% supply, the V33MLA1206 ML suppressor with $V_{M(DC)}$ of 33 volts can be used. According to the transient V-I curves of the ML data sheet, this will protect a MOSFET with a 60 volt minimum breakdown from an approximate 10 amp transient pulse.

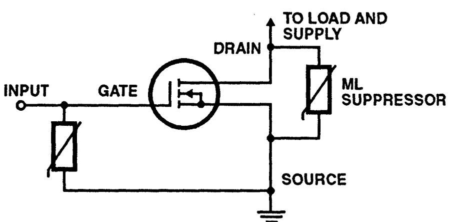


FIGURE 16. DISCRETE MOSFET PROTECTION

Additionally a ML suppressor can be used to protect the input of a discrete MOSFET from the threat of an ESD transient. In the protection of a MOSFET driven with a 10 volt gate drive, the V14MLA1206 or V14MLA1210 suppressor should be connected from gate to source. These devices will protect against ESD pulses of 2kV to 25kV.

The ML can also be used to protect MOSFETs (and bipolar transistors) from the transients generated when switching inductive loads. In this case, the ML selected must be able to dissipate the energy generated by the repetitive nature of these inductive load transient pulses (the average power of these transients must not exceed 0.25 watts).

Automotive System Protection

The increased use of surface mount technology in the automotive industry has resulted in the need for smaller, more densely packed boards with devices which have the performance capabilities of traditional through hole components.

The transient conditions which may occur in the automobile is one of the best documented, and best understood transient environments. A load dump transient will develop when an alternator charging a flat battery is suddenly removed from the system. Peak voltages up to 125 volts may develop and can last for 200-400 milliseconds. Another common transient phenomena is a jump start which is generated when using a 24 volt truck battery to start a car. This overvoltage may be applied for up to 3 to 5 minutes. Other transients result from relays and solenoids switching on and off, and from fuses blowing.

Table 3 shows some sources, amplitudes, polarity, and energy levels of generated transients in the automotive electrical system[8].

TABLE 3. TYPICAL AUTOMOTIVE SUPPLY TRANSIENT SUMMARY

LENGTH OF TRANSIENT	CAUSE	ENERGY CAPABILITY	VOLTAGE AMPLITUDE	FREQUENCY OF OCCURRENCE
Steady State	Failed Voltage Regulator	∞	+18V	Infrequent
3-5 Minutes	Jump Starts with 24V Battery	∞	±24V	Infrequent
200ms to 400ms	Load Dump; Disconnection to Battery While at High Charging	> 10 Joules	< 125V	Infrequent
< 320ms	Inductive-Load Switching Transient	< 1 Joules	-300V to +80V	Often
200ms	Alternator Field Decay	< 1 Joule	-100V to -40V	Each Turn-Off
90ms	Ignition Pulse, Battery Disconnected	< 0.5 Joules	< 75V	< 500Hz Several Times in Vehicle Life
1ms	Mutual Coupling in Harness	< 1 Joules	< 200V	Often
15μs	Ignition Pulse, Normal	< 0.001 Joules	3V	< 500Hz Continuous
	Accessory Noise		< 1.5V	50Hz to 10kHz
	Transceiver Feedback		≅ 20mV	R.F.

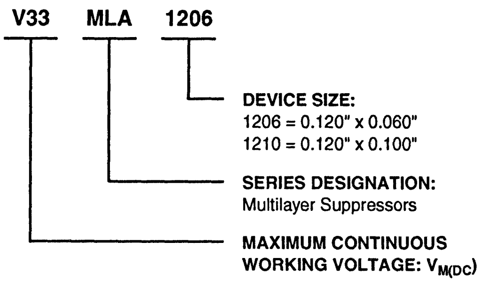
Extension of Contact Life

When relays or mechanical switches are used to control inductive loads, it is often necessary to derate the contacts to 50% of their resistive load rating due to the wear caused by the arcing of the contents. This arcing is caused by the stored energy in the inductive load. Each time the current in the inductive coil is interrupted by the mechanical contacts, the voltage across the contacts increases until the contacts arc. When the contacts arc, the voltage across the arc decreases and the current in the coil can increase somewhat. The extinguishing of the arc causes an additional voltage transient which can again cause the contacts to arc. It is not unusual for restriking to occur several times with the total energy in the arc several times that which was originally stored in the inductive load. It is this repetitive arcing that is so destructive to the contacts. A ML can be used to prevent initiation of the arc.

Knowing the energy absorbed per pulse, the pulse repetition rate and the maximum operating voltage is sufficient to select the correct size ML suppressor. It is necessary to ensure that the device selected is capable of dissipating the power generated in the coil[9].

Part Number Nomenclature

The part number of the ML device gives the following basic information:



Description of ML Ratings and Characteristics

Maximum Continuous DC Working Voltage ($V_{M(DC)}$): This is the maximum continuous dc voltage which may be applied up to the maximum operating temperature (+125°C) of the ML. This voltage is also used as the reference test point for leakage current. This voltage is always less than the breakdown voltage of the device.

Maximum Continuous AC RMS Working Voltage ($V_{M(AC)}$): This is the maximum continuous sinusoidal rms voltage which may be applied. This voltage may be applied at any temperature up to +125°C.

Maximum Non-Repetitive Surge Current (I_{TM}): This is the maximum peak current which may be applied for an 8/20µs impulse (Figure 17), with the $V_{M(DC)}$ or $V_{M(AC)}$ voltage also applied, without causing device failure. This pulse can be applied to the ML suppressor in either polarity.

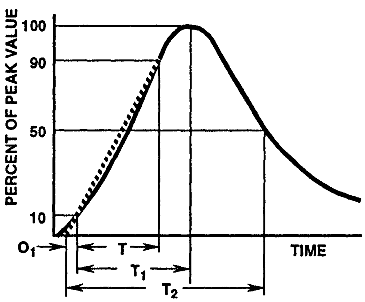
Maximum Non-Repetitive Surge Energy (W_{TM}): This is the maximum rated transient energy which may be dissipated for a single current pulse of 10/1000µs, with the rated $V_{M(DC)}$ or $V_{M(AC)}$ voltage applied, without causing device failure.

Maximum Clamping Voltage (V_C): This is the peak voltage appearing across the ML suppressor when measured for an 8/20µs impulse and specified pulse current. The clamping voltage is shown for a current range of 1 milliamp to 50 amps in the maximum transient V-I characteristic curves.

Leakage Current (I_L): This is the amount of current drawn by the ML in its non-operational mode, i.e. when the voltage applied across the ML does not exceed the rated $V_{M(DC)}$ or $V_{M(AC)}$ voltage.

Nominal Voltage ($V_{N(DC)}$): This is the voltage at which the ML begins to enter its conduction state and suppress transients. This is the voltage defined at the 1 milliamp point and has a minimum and maximum voltage specified.

Capacitance (C): This is the capacitance of the ML when measured at a frequency of 1MHz with 1 volt peak-to-peak voltage bias applied.



O_1 = Virtual Origin of Wave
T = Time From 10% to 90% of Peak
T_1 = Virtual Front time = 1.25 • t
T_2 = Virtual Time to Half Value (Impulse Duration)

Example: For an 8/20µs Current Waveform:
8µs = T_1 = Virtual Front Time
20µs = T_2 = Virtual Time to Half Value

FIGURE 17. CURRENT TEST WAVEFORM

Mountdown Recommendations

Soldering

The principal techniques used for the soldering of components in surface mount technology are Infra Red (IR) Reflow, Vapour Phase Reflow and Wave Soldering. Before soldering, the board and components must first be cleaned. A I, I, I, trichloroethane cleaning solvent in an ultrasonic bath, with a cleaning time of 2-5 minutes, is recommended for this operation. When wave soldering, the ML suppressor is attached to the substrate by means of an epoxy resin. When the epoxy adhesive is cured, the assembly is placed on a conveyor and run through the soldering process. With IR and vapour phase reflow the device is placed in a solder paste on the substrate. As the solder paste is heated it reflows and solders the unit to the board.

With the ML suppressor, the recommended solder paste to use is a 60/40 Tin/Lead (Sn/Pb). While this configuration is best a solder paste a 62/36/2 (Sn/Pb/Ag) or a 63/37 (Sn/ Pb) can also be used with excellent results.

In soldering applications, the ML suppressor is held at elevated temperatures for a relatively long period of time. The wave soldering operation is the most strenuous process, as the components are immersed in the molten solder for several seconds. To avoid the possibility of stresses due to thermal shock occurring, a pre-heat stage in the soldering process is recommended, and the peak temperature of the solder bath should be rigidly controlled. When using the reflow process, care should be taken to ensure that the ML chip is never subjected to a thermal gradient steeper than 4 degrees per second; the ideal gradient being 2 degrees per second. When soldering preheating to within 100 degrees of the peak temperature is essential to minimize thermal shock. Some examples of typical soldering conditions are given in Table 4.

TABLE 4. SOLDERING RECOMMENDATIONS

SOLDERING OPERATION	TIME (SECONDS)	TEMPERATURE (°C)
IR Reflow	5 - 10	220
Wave Solder	3 - 5	260
Vapour Phase	5 - 10	222

Once the soldering process has been completed, it is still necessary to ensure that any further thermal shocks are avoided. One possible cause of thermal shock is hot printed circuit boards being removed from the solder bath and subjected to cleaning solvents at room temperature. The boards must be allowed to cool to less than 50 degree celsius before final cleaning.

References

(1) "An Overview of Electrical Overstress Effects on Semiconductor Devices," D.G. Pierce and D.L. Durgin, Booz-Allen & Hamilton, Inc. Albuquerque, NM.

(2) "Harris Semiconductor Application Note AN9003"

(3) "Protection of Electronic Circuits From Overvoltages", Ronald B. Standler, 1989

(4) "ZnO Varistors for Transient Protection," L.M. Levinson, and H.R. Phillip, IEEE Trans. Parts, Hybrids and Packaging, 13:338-343, 1977

(5) "ZnO Varistors for Protection Against Nuclear Electromagnetic Pulses," H.R Phillip, and L.M. Levinson 1981

(6) "Overshoot: A Lead Effect in Varistor Characteristics," Fisher, F.A., G.E. Company, Schnectady, NY. 1978

(7) "Harris Semiconductor Application Note AN9003"

(8) "Harris Semiconductor Application Note AN9002"

(9) "Transient Voltage Suppression Devices", Harris Semiconductor DB450C

SOLDERING RECOMMENDATIONS FOR SURFACE MOUNT METAL OXIDE VARISTORS AND MULTILAYER TRANSIENT VOLTAGE SUPPRESSORS

Authors: Marty Corbett and Neil McLoughlin

Introduction

In recent years, electronic systems have migrated towards the manufacture of increased density circuits, with the same capability obtainable in a smaller package or increased capability in the same package. The accommodation of these higher density systems has been achieved by the use of surface mount technology (SMT). Surface mount technology has the advantages of lower costs, increased reliability and the reduction in the size and weight of components used. With these advantages, surface mount technology is fast becoming the norm in circuit design.

The increased circuit densities of modern electronic systems are much more vulnerable to damage from transient overvoltages than were the earlier circuits, which used relays and vacuum tubes. Thus, the progress in the development of faster and denser integrated circuits has been accompanied by an increase in system vulnerability. Transient protection of these sensitive circuits is highly desirable to assure system survival. Surface mount technology demands a reliable transient voltage protection technology, packaged compatibly with other forms of components used in surface mount technology.

Harris Semiconductor has led the field in the introduction of surface mount transient voltage suppressors. These devices encompass voltages from 3.5V DC to 275V AC and have a wide variety of applications. Their size, weight and inherent protection capability make them ideal for use on surface mount printed circuit boards.

There are two standard series of Harris surface mount surge suppressors. The *CH SERIES* metal oxide varistors which encompass voltages from 14V DC to 275V AC and the new *ML SERIES* which covers a voltage range from 3.5V DC to 68V DC.

Metal Oxide Varistors

A metal oxide varistor (MOV) is a non-linear device which has the property of maintaining are relatively small voltage change across its terminals while a disproportionately large surge current flows through it (Figure 1). When the MOV is connected in parallel across a line its non-linear action serves to divert the current of the surge and hold the voltage to a value that protects the equipment connected to the line. Since the voltage across the MOV is held at some level higher than the normal line voltage while surge current flows, there is energy deposited in the varistor during its surge diversion function.

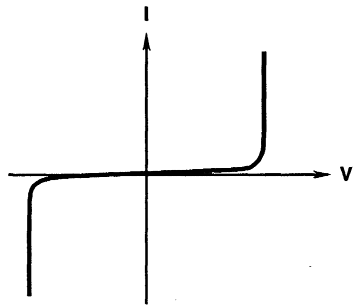


FIGURE 1. V-I CHARACTERISTICS OF A MOV

The basic conduction mechanism of a MOV results from semiconductor junctions (P-N junctions) at the boundaries of the zinc oxide grains. A MOV is a multi junction device with millions of grains acting as a series parallel combination between the electrical terminals. The voltage drop across a single grain in nearly constant and is independent of grain size.

The CH series of surface mount metal oxide varistors are of a monolayer construction in a 5mm by 8mm package size. They are fully symmetrical and are passivated both top and bottom (Figure 2). The main advantage of this technology is its high operating voltage capability (68V DC to 275V AC). The *CH SERIES* of metal oxide varistors are supplied in both 7" and 13" tape and reels.

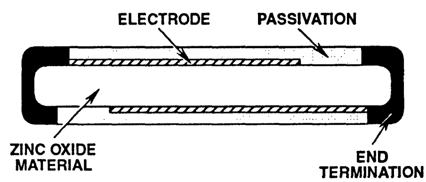


FIGURE 2. CROSS-SECTION OF THE "CH" SERIES OF METAL OXIDE VARISTORS

12 APPLICATION NOTES

Multilayer Transient Voltage Suppressors

The Harris multilayer (ML) series of surface mount surge suppressors are of a multilayer construction. This technology, represents a recent breakthrough in its application to transient voltage suppression.

The ML varistor is constructed by forming a combination of alternating electrode plates and semiconducting ceramic layers into a block. Each alternate layer of electrode is connected to opposite end terminations (Figure 3). The interdigitated block formation greatly enhances the available cross-sectional area for active conduction of transients. This paralleled arrangement of the inner electrode layers represents significantly more active surface area than the small outline of the package may suggest. The increased active surface area results in proportionally higher peak energy capability.

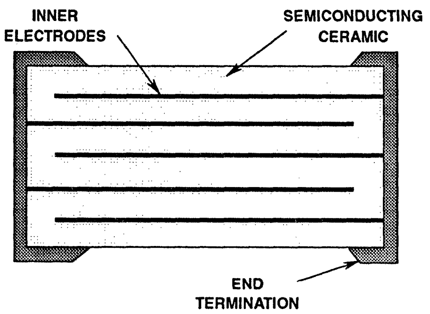


FIGURE 3. INTERNAL CONSTRUCTION OF THE HARRIS MULTILAYER TRANSIENT VOLTAGE SUPPRESSOR

A further advantage of this type of construction is that the breakdown voltage of the device is dependent on the thickness between the electrode layers (dielectric thickness) and not the overall thickness of the device.

The ML suppressor is a surface mountable device that is much smaller in size than the components it is designed to protect. The present size offerings are 1206, 1210, 1812 and 2220, with voltage ranges form 3.5V DC to 68V DC. Its robust construction makes it ideally suitable to endure the thermal stresses involved in the soldering, assembling and manufacturing steps involved in surface mount technology. As the device is inherently passivated by the fired ceramic material, it will not support combustion and is thus immune to any risk of flammability which may be present in the plastic or epoxy molded parts used in industry standard packages.

Substrates

There are a wide choice of substrate materials available for use as printed circuit boards in a surface mount application. The main factors which determine the choice of material to use are:

1. Electrical Performance
2. Size and Weight Limitations
3. Thermal Characteristics
4. Mechanical Characteristics
5. Cost

When choosing a substrate material, the coefficient of thermal expansion of a Harris surface mountable suppressor of 6ppm/°C is an important consideration. Non-organic materials (ceramic based substrates), like aluminum or berillia, which have coefficients of thermal expansion of 5-7ppm°C, are a good match for the CH and ML series devices. Table 1 outlines some of the other materials used, and also their more important properties pertinent to surface mounting.

While the choice of substrate material should take note of the coefficient of expansion of the devices. This may not be the determining factor in whether a device can be used or not. Obviously the environment of the finished circuit board will determine what level of temperature cycling will occur. It is this which will dictate the criticality of the match between device and PCB. Currently for most applications, both the CH and ML series use FR4 boards without issue.

TABLE 1. SUBSTRATE MATERIAL PROPERTIES

SUBSTRATE STRUCTURE	MATERIAL PROPERTIES		
	GLASS TRANSITION TEMPERATURE (°C)	XY COEFFICIENT OF THERMAL EXPANSION (ppm/°C)	THERMAL CONDUCTIVITY (W/M°C)
Epoxy Fiberglass-FR4	125	14-18	0.16
Polyamide Fiberglass	250	12-16	0.35
Epoxy Aramid Fiber	125	6-8	0.12
Fiber/Teflon Laminates	75	20	0.26
Aluminium-beryillia (Ceramic)	Not Available	5-7	21.0

Fluxes

Fluxes are used for the chemical cleaning of the substrate surface. They will completely remove any surface oxides, and will prevent re-oxidation. They contain active ingredients such as solvents for removing soils and greases. Nonactivated fluxes ("R" type) are relatively effective in reducing oxides of copper, nickel or palladium/silver metallizations and are recommended for use with the Harris surface mount range.

Mildly activated fluxes ("RMA" type) have natural and synthetic resins, which reduce oxides to metal or soluble salts. These "RMA" fluxes are generally not conductive nor corrosive at room temperature and are the most commonly used in the mounting of electronic components.

The "RA" type (fully activated) fluxes are corrosive, difficult to remove, and can lead to circuit failures and other problems. Other non-resin fluxes depend on organic acids to reduce oxides. They are also corrosive after soldering and also can damage sensitive components. Water soluble types in particular must be thoroughly cleaned from the assembly.

Environmental concerns, and the associated legislation, has led to a growing interest in fluxes with residues that can be removed with water or water and detergents (semi-aqueous cleaning). Many RMA fluxes can be converted to water soluble forms by adding saponifiers. There are detergents and semi-aqueous cleaning apparatus available that effectively remove most RMA type fluxes. Semi-aqueous cleaning also tends to be less expensive than solvent cleaning in operations where large amounts of cleaning are needed.

For the Harris Semiconductor range of surface mount varistors, nonactivated "R" type fluxes such as Alpha 100 or equivalent are recommended.

Land Pad Patterns

Land pad size and patterns are one of the most important aspects of surface mounting. They influence thermal, humidity, power and vibration cycling test results. Minimal changes (even as small as 0.005 inches) in the land pad pattern have proven to make substantial differences in reliability.

This design/reliability relationship has been shown to exist for all types of designs such as in J lead, quadpacks, chip resistors, capacitors and small outline integrated circuit (SOIC) packages. Recommended land pad dimensions are provided for some surface mounted devices along with formulae which can be applied to different size varistors. Figure 4 gives recommended land patterns for the direct mount ML and CH series devices.

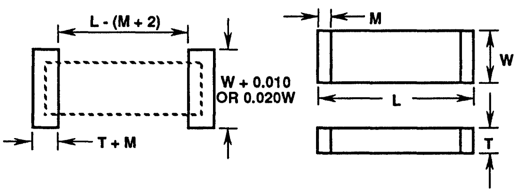


FIGURE 4. FORMULA FOR SURFACE MOUNTABLE VARISTOR FOOTPRINTS

TABLE 2. RECOMMENDED MOUNTING PAD OUTLINE

SUPPRESSOR FAMILY	DIMENSION		
	T + M	L-(M X 2)	0.020W (W + 0.010)
5 X 8 CH Series	2.21 (0.087)	5.79 (0.228)	5.50 (0.216)
1206 ML Series	1.65 (0.065)	1.85 (0.073)	2.62 (0.103)
1210 ML Series	1.85 (0.073)	1.85 (0.073)	3.73 (0.147)
1812 ML Series	1.85 (0.073)	3.20 (0.126)	4.36 (0.172)
2220 ML Series	1.84 (0.073)	4.29 (0.169)	6.19 (0.240)

Solder Materials and Soldering Temperatures

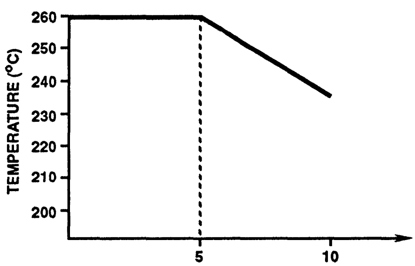


FIGURE 5. RECOMMENDED MAXIMUM TIME AND SOLDER TEMPERATURE RELATIONSHIP OF HARRIS MOVs

No varistor should be held longer than necessary at an elevated temperature. The termination materials used in both the CH and ML series devices are enhanced silver based materials. These materials are sensitive to exposure time and peak temperature conditions during the soldering process (Figure 5). The enhanced silver formulation contains either platinum, palladium or a mixture of both, which have the benefit of significantly reducing any leaching effects during soldering. To further ensure that there is no leeching of the silver electrode on the varistor, solders with at least 2% silver content are recommended (62 Sn / 36 Pb / 2 Ag). Examples of silver bearing solders and their associated melting temperatures are as follows:

TABLE 3. SILVER BEARING SOLDERS (ALPHA METALS)

ALLOY	MELTING TEMPERATURE	
	°F	°C
62 Sn / 36 Pb / 2 Ag	355	179
96.5 Sn / 3.5 Ag	430	221
95 Sn / 5 Ag	430-473	221-245
20 Sn / 88 Pb / 2 Ag	514-576	268-302
5 Sn / 92.5 Pb / 2.5 Ag	536	280

Soldering Methods

There are a number of different soldering techniques used in the surface mount process. The most common soldering processes are infra red reflow, vapor phase reflow and wave soldering.

With the Harris surface mount range, the solder paste recommended is a 62/36/2 silver solder. While this configuration is best, other silver solder pastes can also be used. In all soldering applications, the time at peak temperature should be kept to a minimum. Any temperature steps employed in the solder process must, in broad terms, not exceed 70°C to 80°C. In the preheat stage of the reflow process, care should be taken to ensure that the chip is not subjected to a thermal gradient of greater than 4 degrees per second; the ideal gradient being 2 degrees per second. For optimum soldering, preheating to within 100 degrees of the peak soldering temperature is recommended; with a short dwell at the preheat temperature to help minimize the possibility of thermal shock. The dwell time at this preheat temperature should be for a time greater than $10T^2$ seconds, where T is the chip thickness in millimeters. Once the soldering process has been completed, it is still necessary to protect against further effects of thermal shocks. One possible cause of thermal shock at the post solder stage is when the hot printed circuit boards are removed from the solder and immediately subjected to cleaning solvents at room temperature. To avoid this thermal shock affect, the boards must first be allowed to cool to less than 50°C prior to cleaning.

Two different resistance to solder heat tests are routinely performed by Harris Semiconductor to simulate any possible effects that the high temperatures of the solder processes may have on the surface mount chip. These tests consist of the complete immersion of the chip in to a solder bath at 260°C for 5 seconds and also in to a solder bath at 220°C for 10 seconds. These soldering conditions were chosen to replicate the peak temperatures expected in a typical wave soldering operation and a typical reflow operation.

Reflow Soldering

There are two major reflow soldering techniques used in SMT today:

1. Infra Red Reflow
2. Vapor Phase Reflow

The only difference between these two methods is the process of applying heat to melt the solder. In each of these methods precise amounts of solder paste are applied to the circuit board at points where the component terminals will be located. Screen or stencil printing, allowing simultaneous application of paste on all required points, is the most commonly used method for applying solder for a reflow process. Components are then placed in the solder paste. The solder pastes are a viscous mixture of spherical solder powder, thixotropic vehicle, flux and in some cases, flux activators.

During the reflow process, the completed assembly is heated to cause the flux to activate, then heated further, causing the solder to melt and bond the components to the board. As reflow occurs, components whose terminations displace more weight, in solder, than the components weight will float in the molten solder. Surface tension forces work toward establishing the smallest possible surface area for the molten solder. Solder surface area is minimized when the component termination is in the center of the land pad and the solder forms an even fillet up the end termination. Provided the boards pads are properly designed and good wetting occurs, solder surface tension works to center component terminations on the boards connection pads. This centering action is directly proportional to the solder surface tension. Therefore, it is often advantageous to engineer reflow processes to achieve the highest possible solder surface tension, in direct contrast to the desire of minimizing surface tension in wave soldering.

In designing a reflow temperature profile, it is important that the temperature be raised at least 20°C above the melting or liquidus temperature to ensure complete solder melting, flux activation, joint formation and the avoidance of cold melts. The time the parts are held above the melting point must belong enough to alloy the alloy to wet, to become homogenous and to level, but not enough to cause leaching of solder, metallization or flux charring.

A fast heating rate may not always be advantageous. The parts or components may act as heat sinks, decreasing the rate of rise. If the coefficients of expansion of the substrate and components are too diverse or if the application of heat is uneven, fast breaking or cooling rates may result in poor solder joints or board strengths and loss of electrical conductivity. As stated previously, thermal shock can also damage components. Very rapid heating may evaporate low boiling point organic solvents in the flux so quickly that it causes solder spattering or displacement of devices. If this occurs, removal of these solvents before reflow may be required. A slower heating rate can have similar beneficial effects.

Infra Red Reflow

Infra Red (IR) reflow is the method used for the reflowing of solder paste by the medium of a focused or unfocused infra red light. Its primary advantage is its ability to heat very localized areas.

The IR process consists of a conveyor belt passing through a tunnel, with the substrate to be soldered sitting on the belt.

The tunnel consists of three main zones; a non-focused preheat, a focused reflow area and a cooling area. The unfocused infrared areas generally use two or more emitter zones, thereby providing a wide range of heating profiles for solder reflow. As the assembly passes through the oven on the belt, the time/temperature profile is controlled by the speed of the belt, the energy levels of the infrared sources, the distance of the substrate from the emitters and the absorptive qualities of the components on the assembly.

The peak temperature of the infrared soldering operation should not exceed 220°C. The rate of temperature rise from the ambient condition to the peak temperature must be carefully controlled. It is recommended that no individual temperature step is greater than 80°C. A preheat dwell at approximately 150°C for 60 seconds will help to alleviate potential stresses resulting from sudden temperature changes. The temperature ramp up rate from the ambient condition to the peak temperature should not exceed 4°C per second; the ideal gradient being 2°C per second. The dwell time that the chip encounters at the peak temperature should not exceed 10 seconds. Any longer exposure to the peak temperature may result in deterioration of the device protection properties. Cooling of the substrate assembly after solder reflow is complete should be by natural cooling and not by forced air.

The advantages of IR Reflow are its ease of setup and that double sided substrates can easily be assembled. Its biggest disadvantage is that temperature control is indirect and is dependent on the IR absorption characteristics of the component and substrate materials.

On emergence from the solder chamber, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the IR reflow soldering process is as Table 4 and Figure 6.

TABLE 4. RECOMMENDED TEMPERATURE PROFILE FOR IR REFLOW SOLDER PROCESS

INFRA RED REFLOW	
TEMPERATURE (°C)	TIME (SECONDS)
25-60	60
60-120	60
120-155	30
155-155	60
155-220	60
220-220	10
220-50	60

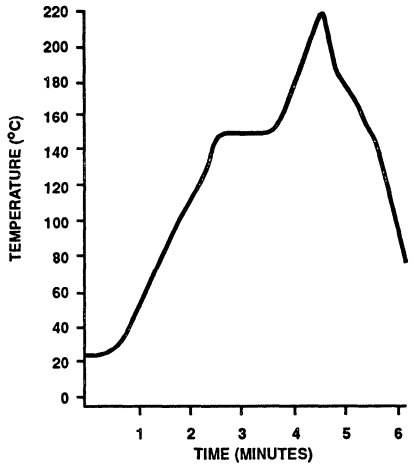


FIGURE 6. TYPICAL TEMPERATURE PROFILE

Vapor Phase Reflow

Vapor phase reflow soldering involves exposing the assembly and joints to be soldered to a vapor atmosphere of an inert heated solvent. The solvent is vaporized by heating coils or a molten alloy, in the sump or bath. Heat is released and transferred to the assembly where the vapor comes in contact with the colder parts of the substrate and then condenses. In this process all cold areas are heated evenly and no areas can be heated higher than the boiling point of the solvent, thus preventing charring of the flux. This method gives a very rapid and even heating affect. Further advantages of vapor phase soldering is the excellent control of temperature and that the soldering operation is performed in an inert atmosphere.

The liquids used in this process are relatively expensive and so, to overcome this a secondary less expensive solvent is often used. This solvent has a boiling temperature below 50°C. Assemblies are passed through the secondary vapor and into the primary vapor. The rate of flow through the vapors is determined by the mass of the substrate. As in the case of all soldering operations, the time the components sit at the peak temperature should be kept to a minimum. The dwell time is a function of the circuit board mass but should be kept to a minimum.

On emergence from the solder system, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the vapor phase soldering process is as Table 5 and Figure 7.

TABLE 5. RECOMMENDED TEMPERATURE PROFILE FOR VAPOR PHASE REFLOW PROCESS

VAPOR PHASE REFLOW	
TEMPERATURE (°C)	TIME (SECONDS)
25-90	8
90-150	13
150-222	3
222-222	10
222-80	7
80-25	10

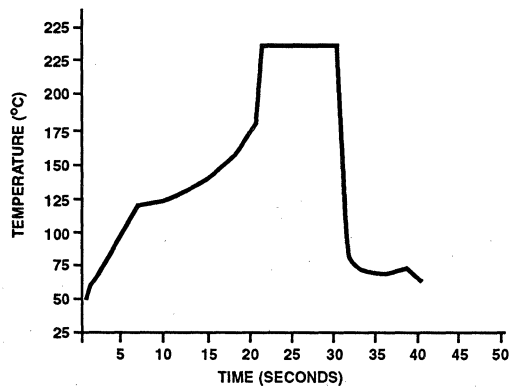


FIGURE 7. TYPICAL TEMPERATURE PROFILE

Wave Solder

This technique, while primarily used for soldering thru hole or leaded devices inserted into printed circuit boards, has also been successfully adapted to accommodate a hybrid technology where leaded, inserted components and adhesive bonded surface mount components populate the same circuit board.

The components to be soldered are first bonded to the substrate by means of a temporary adhesive. The board is then fluxed, preheated and dipped or dragged through two waves of solder. The preheating stage serves many functions. It evaporates most of the flux solvent, increases the activity of the flux and accelerates the solder wetting. It also reduces the magnitude of the temperature change experienced by the substrate and components.

The first wave in the solder process is a high velocity turbulent wave that deposits large quantities of solder on all wettable surfaces it contacts. This turbulent wave is aimed at solving one of the two problems inherent in wave soldering surface mount components, a defect called voiding (i.e. skipped areas). One disadvantage of the high velocity turbulent wave is that it gives rise to a second defect known as bridging, where the excess solder thrown at the board by the turbulent wave spans between adjacent pads or circuit elements thus creating unwanted interconnects and shorts.

The second, smooth wave accomplishes a clean up operation, melting and removing any bridges created by the turbulent wave. The smooth wave also subjects all previous soldered and wetted surfaces to a sufficiently high temperature to ensure good solder bonding to the circuit and component metallizations.

In wave soldering, it is important that the solder have low surface tension to improve its surface wetting characteristics. Therefore, the molten solder bath is maintained at temperatures above its liquid point.

On emergence from the solder wave, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the wave soldering process is as Table 6:

TABLE 6. RECOMMENDED TEMPERATURE PROFILE FOR WAVE SOLDER PROCESS

WAVE SOLDER	
TEMPERATURE (°C)	TIME (SECONDS)
25-125	60
125-180	60
180-260	60
260-260	5
260-180	60
180-80	60
80-25	60

Cleaning Methods and Cleaning Fluids

The objective of the cleaning process is to remove any contamination from the board, which may affect the chemical, physical or electrical performance of the circuit in its working environment.

There are a wide variety of cleaning processes which can be used, including aqueous based, solvent based or a mixture of both, tailored to meet specific applications. After the soldering of surface mount components there is less residue to remove than in conventional through hole soldering. The cleaning process selected must be capable of removing any contaminants from beneath the surface mount assemblies. Optimum cleaning is achieved by avoiding undue delays between the cleaning and soldering operations; by a minimum substrate to component clearance of 0.15mm and by avoiding the high temperatures at which oxidation occurs.

Harris recommends 1, 1, 1 trichloroethane solvent in an ultrasonic bath, with a cleaning time of between two and five minutes. Other solvents which may be better suited to a particular application and can also be used may include one or more of the following:

TABLE 7. CLEANING FLUIDS

Water	Acetone
Isopropyl Alcohol	Fluorocarbon 113
Fluorocarbon 113 Alcohol Blend	N-Butyl
1, 1, 1 Trichloroethane Alcohol Blend	Trichloroethane
Toluene	Methane

Solder Defects

Non-Wetting:

This defect is caused by the formation of oxides on the termination of the components. The end termination has been exposed to the molten solder material but the solder has not adhered to the surface; base metal remains exposed. The accepted criterion is that no more than 5% of the terminated area should remain exposed after an immersion of 5 seconds in a static solder bath at 220°C, using a nonactive flux.

Leaching:

This is the dissolving of the chip termination into the molten solder. It commences at the chip corners, where metal coverage is at a minimum. The result of leaching is a weaker solder joint. The termination on the Harris surface mount suppressors consist of a precious metal alloy which increases the leach resistance capability of the component. Leach resistance defined as the immersion time at which a specified proportion of the termination material is visibly lost, under a given set of soldering conditions.

De-Wetting:

This condition results when the molten solder has coated the termination and then receded, leaving irregularly shaped mounds of solder separated by areas covered with a thin solder film. The base metal is not exposed.

References

1. Transient Voltage Suppression Devices Manual (DB450.2), Harris Semiconductor
2. CANE SMT 2588, Syfer Technology Limited, UK.

Harris Semiconductor

APPNOTE

No. AN9304.1 August 1993

Harris Intelligent Power

ESD AND TRANSIENT PROTECTION USING THE SP720

Author: Wayne Austin

The need for transient protection in integrated circuits is driven by the quest for improved reliability at lower cost. The primary efforts for improvement are generally directed toward the lowest possible incidence of over-voltage related stresses. While electrical over-stress (EOS) is always a potential cause for failure; a discipline of proper handling, grounding and attention to environmental causes can reduce EOS causes for failure to a very low level. However, the nature of hostile environments cannot always be predicted. Electrostatic Discharge (ESD) in some measure, is always present and the best possible ESD interface protection may still be insufficient. As the technology of solid state progresses, the occurrence of ESD related IC failures is not uncommon. There is a continuing tendency for both ESD and EOS failures, due in part, to the smaller geometries of today's VLSI circuits.

The solid state industry has generally acknowledged a standard for the level of capability in LSI designs of ±2000V for the Human Body Model where the defined capacitance is 100pF and the series resistance is 1500Ω. However, this level of protection may not be adequate in many applications and can be difficult to achieve in some VLSI technologies. Normal precautions against ESD in the environment of broad based manufacturing are often inadequate. The need for a more rugged IC interface protection will continue to be an established goal.

Historically, it should be recognized that early IC development began to address the ESD problem when standards for handling precautions did not exist. High energy discharges were a common phenomena associated with monitor and picture tube (CRT) applications and could damage or destroy a solid state device without direct contact. It was recognized that all efforts to safe-guard sensitive devices were not totally sufficient. Small geometry signal processing circuits continued to sustain varying levels of damage through induced circulating currents and direct or indirect exposure in handling. These energy levels could be substantially higher than the current standard referenced in Mil-Std-3015.7; also referred to as the Human Body Model.

The recognized need for improved ESD protection was first precipitated under harsh handling conditions; particularly in applications that interfaced to human contact or from the interaction of mechanical parts in motion. The popular features of component and modular electronic equipment have continued to generate susceptibility to IC damage while in continuing use. These market items include computers and peripherals, telecommunication equipment and consumer electronic systems. While some IC's may only see the need for ESD protection while in manufacturing assembly or during service in the field, the most common cause for ESD failures can still be related to a human contact. Moreover, educational efforts have improved today's manufacturing environment substantially reduce failures that relate to the mechanical handling. The ESD failure causes that relate to mechanical handling now have a test standard referred to as a Machine Model which relates to the source of the generated energy.

While the electrical model for an energy source is generally accepted as a capacitor with stored charge and a series resistance to represent the charge flow impedance, the best means to handle the high energy discharge is not so clearly evident. The circuit of Figure 1 illustrates the basic concept that is applied as a method of ESD testing for the Human Body Model. The ESD energy source is shown as a charged capacitor C_D and series connected, source impedance, resistor R_D. The point of contact or energy discharge is shown, for test purposes, as a switch external to the IC. A protection structure is often included on an IC to prevent damage from an ESD energy source. To properly protect the circuit on the IC the on-chip switch, S_S, is closed when a discharge is sensed and shunts the discharge energy through a low impedance resistor (R_S) to ground. It is imperative that the resistance of the discharge path be as low as practical to limit dissipation in the protection structure. It is not essential that the ground be the chip substrate or the package frame. The energy may be shunted via the shortest path external to the chip to an AC or DC ground.

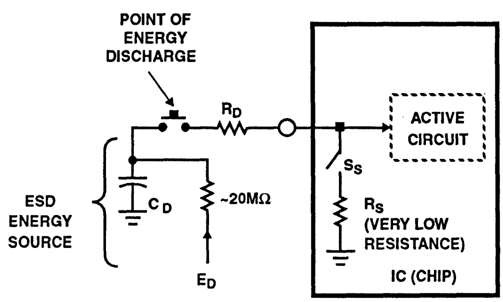


FIGURE 1. ESD TEST FOR AN ON-CHIP PROTECTION CIRCUIT USING THE MIL-STD-883, METHOD 3015.7 (HUMAN BODY MODEL)

This conceptual method has been used in many IC designs employing a wide variation of structures, depending the IC technology and degree of protection needed. The switch, S_S is generally a threshold sensitive turn-ON at some voltage level above or below the normal signal range; however, it must be within the a safe operating range of the device being protected. The resistance, R_S is shown as the inherent series resistance of the protection structure when it is discharging (dumping) the ESD energy. In its simplest forms, the protection structures may be diodes and zeners, where the sensing threshold is the forward turn-ON or zener threshold of the device. The inherent resistance becomes the bulk resistance of the diode structure when it is conducting. Successful examples of two such protection structures that have been used to protect sensitive inputs to MOS devices are shown in Figure 2. The back-to-back zener structure shown for the dual-gate MOSFET was employed in the 3N - dual gate MOS devices before IC technology was firmly established. The series poly and stacked diode structure used to shunt ESD energy followed several variations for use in CMOS technology and was employ in the CD74HC/HCT - High Speed CMOS family of logic devices. This CMOS protection structure is capable of meeting the 2000V requirements of Mil-Std-883, Method 3015.7; where the R_D in Figure 1 is 1500Ω and C_D is 100pF.

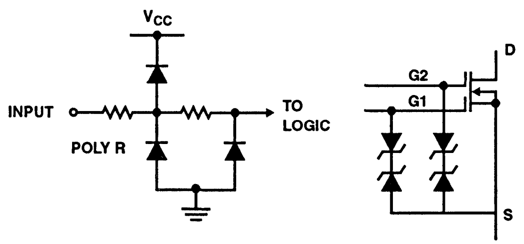


FIGURE 2. ESD AND TRANSIENT PROTECTION EFFECTIVELY USED IN MOS AND CMOS DEVICES

Due to greater emphasis on Reliability under harsh application conditions, more ruggedized protection structure have been developed. A variety of circuit configurations have been evaluated and applied to use in production circuits. A limited introduction to this work was published in various papers by L. Avery (See Bibliography). To provide the best protection possible within economic constraints, it was determined that SCR latching structures could provide very fast turn-ON, a low forward on resistance and a reliable threshold of switching. Both positive and negative protection structures were readily adapted to bipolar technology. Other defining aspects of the protection network included the capability to be self-protecting to a much higher level than the signal input line being protected. Ideally, when a protection circuit is not otherwise needed, it should have no significant loading effect on the operating circuit. As such, it should have very little shunt capacitance and require minimal series resistance to be added to the signal line of the active circuit. Also, where minimal capacitance loading is essential for a fast turn-ON speed, the need for a simpler structure is indicated.

The switching arrangement for a basic and simple protection structure is shown in Figure 3. Each high side and low side protection structure (R_S and S_S) is an embedded device, taking advantage of the P substrate and epitaxial N material used in bipolar technology. Each cell contains an SCR with a series dropping resistor to sense an over-voltage turn-ON condition and trip the SCR (Switch S_S) into latch. The ON-resistance (R_S) of the latched SCR is much lower than R_D and, depending on the polarity of the ESD voltage, dumps energy from the input signal line through the positive or negative switch to ground. The return to ground for either ESD polarity is not limited by voltage supply definition, but may be to positive or negative supply lines, if this suits the needs of the application. When the energy is dissipated and forward current no longer flows, the SCR automatically turns-OFF.

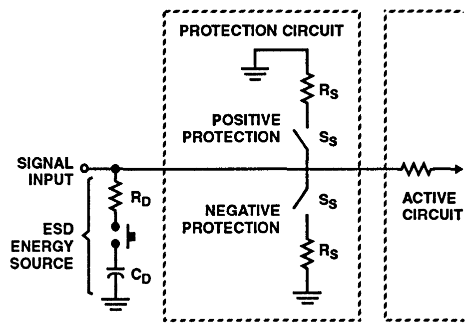


FIGURE 3. ESD AND TRANSIENT PROTECTION CIRCUIT

Figure 4 shows the diagram of a positive and negative cell protection circuit as it applies to the SP720. The PNP and NPN transistor pairs are used as the equivalent SCR structures. Protection in this structure allows forward turn-ON to go marginally above the +V supply to turn-ON the high-side SCR or marginally below the -V supply to turn-ON the low-side SCR. The signal line to the active device is protected in both directions and does not add series impedance to the signal input line. A shunt resistance is used to forward bias the PNP device for turn-ON but is not directly connected to the signal line. As an on-chip protection cell, this structure may be next to the input pad of the active circuit; which is the best location for a protection device. However, for many applications, the technology of the active chip may not be compatible to structures of the type indicated in Figure 4. This is particularly true in the high speed CMOS where the substrates are commonly N type and connected to the positive supply of the chip. The protection cell structure shown in Figure 4 is not required to be on the active chip because it does not sense series input current to the active device. The sense mechanism is voltage threshold referenced to the V+ and V- bias voltages.

The cell structure of the SCR pair of Figure 4 are shown in the layout sketch and profile cutouts of Figure 5. It should be noted that the layout and profiles shown here are equivalent structures intended for tutorial information. The structures are shown on opposite sides of the 'IN" chip bonding pad, as is the case for the SP720. As needed for a preferred layout, the structures are adjacent to the pad and as close to the positive and negative supply lines as possible. The common and best choice for effective layout is to provide a ground ring (V-) around the chip and to layout with minimum distance paths to the positive supply (V+). In the SP720 the V- line is common to the substrate and frame ground of the IC.

The equivalent circuit diagram of the SP720 is shown in Figure 6. Each switch element is an equivalent SCR structure where 14 positive and negative pairs as shown in Figure 4 are provided on a single chip. Each positive switching structure has a threshold reference to the V+ terminal, plus one V_{BE} (based-to-emitter voltage equal to one diode

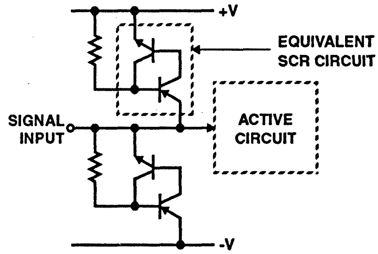


FIGURE 4. PROTECTION CELLS OF THE SP720 SCR ARRAY

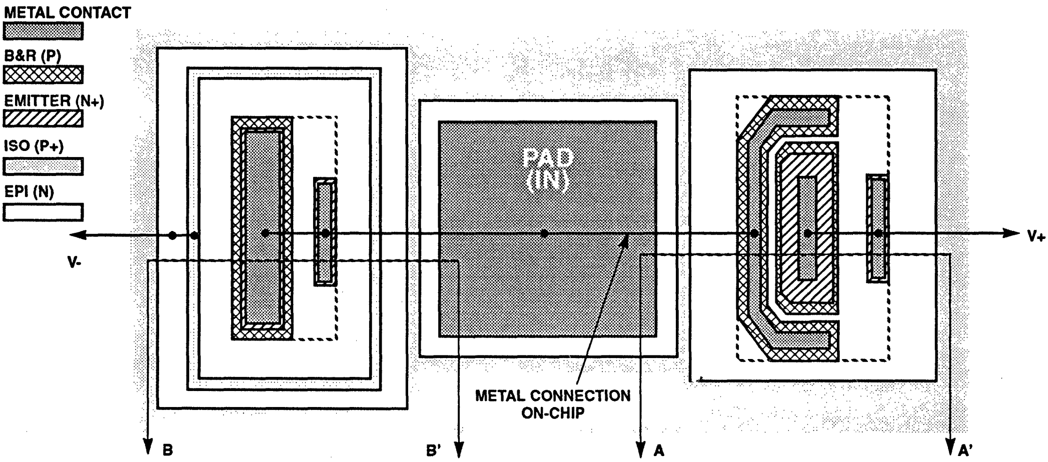


FIGURE 5A. HIGH AND LOW CELL PAIR LAYOUT; SHOWN WITHOUT PROTECT, METAL AND FIELD OXIDE LEVELS (NOT TO SCALE)

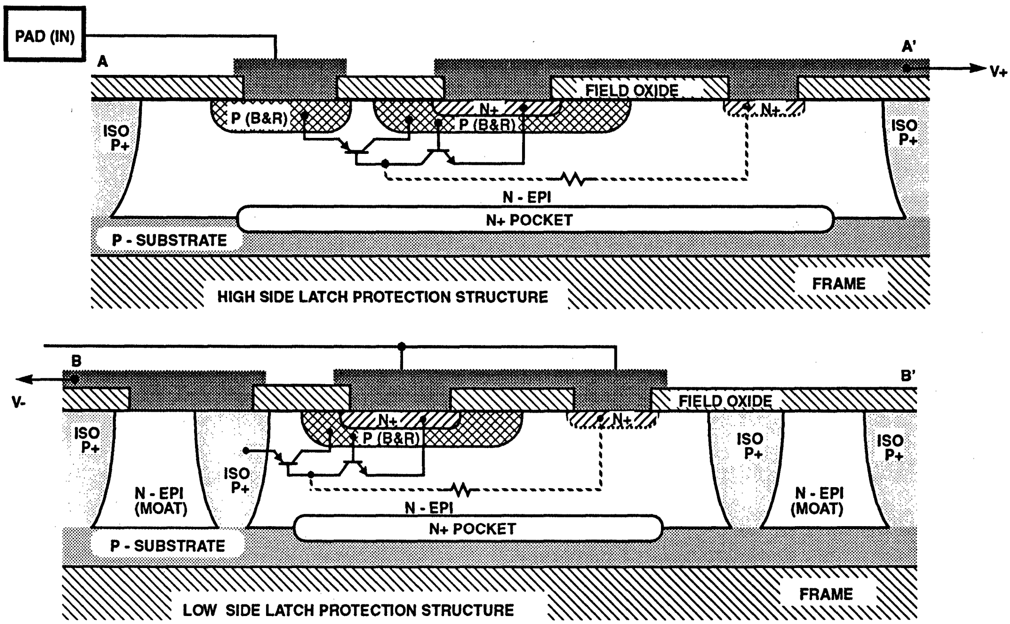


FIGURE 5B. PROFILES OF THE HIGH AND LOW SIDE SP720 SCR PROTECTION PAIR (NOT TO SCALE) forward voltage drop). Similarly, each negative switching pair is referenced to the V- terminal minus one V_{BE}.

The internal protection cells of the SP720 are directly connect to the on-chip power supply line (+V) and the negative supply line (-V), which are substantial in surface metal content to provide low dropping resistance for the high peak currents encountered. Since both positive or negative transients can be expected, the SCR switches direct the positive voltage energy to V+ and the negative voltage sourced energy to V- (substrate) potential to provide fast turn-ON with low ON resistance to protect the active circuit.

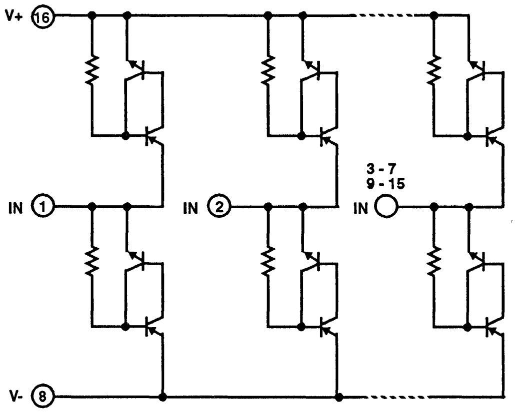


FIGURE 6. EQUIVALENT CIRCUIT DIAGRAM OF THE SP720

The V+ and V- supply lines of the SP720 are not required to be the same as those of the circuit to be protected. However, over-voltage protection is referenced to the V+ and V- supply voltages for all of the signal input terminals, IN1-IN7 and IN9-IN15. The V+ and V- supply voltages to the SP720 may be changed to suite the needs of the circuit under protection. The range of voltage may be power supply levels ranging from 4.5V up to the 35V maximum rating of the SP720. Lower levels of voltage are possible but with some degradation of the switching speed which is nominally 6ns. Also, the input capacitance which is nominally 3pF can be expected to increase. There is no significant quiescent current in the SP720 other than reverse diode junction current which nominally less than 50nA over the rated -40°C to +105°C operating temperature. At room temperatures, this may be as low as a few nanoamperes. Because of the low dissipation of the SP720, the chip temperature can be expected to be close to the environment of the physical location where it is applied to use.

Protection Levels of the SP720

For a given level of voltage or power, there is a defined degree of protection compatible to that need. For the SP720, the protection circuits are designed to clamp over-voltage within a range of peak current that will substantially improve the survival input expectancy of average monolithic silicon circuits used for small signal and digital processing applications. Within itself, the SP720 should be expected to survival peak current and voltage surges within the maximum ratings defined in the data sheet. For voltage, the static DC and short duration transient capability is essentially the same. The process capability is typically better than 45 volts, allowing maximum continuous DC supply ratings to be conservatively rated at 35 volts. The current capability of any one SCR section is rated at 2A peak but is duration limited by the transient heating effect on the chip. As shown in Figure 7, the resistance of the SCR, when it is latched, is approximately 0.96Ω and the SCR latch threshold has 1.08V of offset. For EOS, the peak dissipation can be calculated as follows:

For: 2A Peak Current, R_D = 1500Ω,

Then: $V_{IN(PK)}$ = 1.08V (Offset) + (0.96Ω x 2A) = 3V

The peak dissipation is P_D = 3V x 2A = 6 Watts

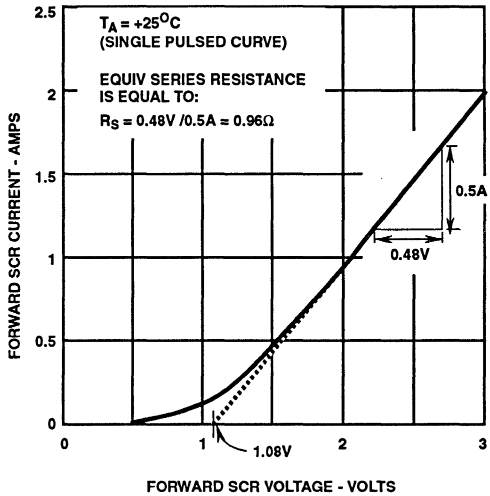


FIGURE 7. SCR FORWARD CURRENT vs VOLTAGE CHARACTERISTICS

While 2A through 1500 ohms is 3000V, which is not an exceptionally high ESD level of voltage, it does represent the EOS capability, provided the time duration for the 6 Watts of dissipation is limited to a few milliseconds. The dissipation of the 16 pin DIP and 16 pin SOIC packages are typically less than 1 Watt for steady state conditions. The thermal capacity of the chip will allow discharge levels several times higher than this because ESD normally has a much shorter duration. The actual results for ESD tests on the SP720 as an isolated device are as follows:

1. Human Body Model using a modified version of the Mil-Std-883, Method 3015.7; with V+ and V- grounded and ESD discharge applied to each individual IN pin - Passed all test levels from ±9KV to ±16KV (1KV steps).
2. Human Body Model using the Mil-Std-883, Method 3015.7 (with V- only grounded) and ESD discharge applied to each individual IN pin - Passed all test levels to ±6KV, failed ±7KV (1KV steps).

3. Machine Model using EIAJ IC121 (R_D = 0Ω); discharge applied to IN pins with all others grounded - Passed all test levels to ±1KV, failed ±1.2KV; (200V steps).

4. While there are many potential uses for the SP720, the circuit of Figure 8 shows a normal configuration for protecting input lines to a sensitive digital IC. Each line is connected to an IN- Input of the SP720 in a shunt connection. As a test model a 2µ digital ASIC CMOS IC was used to evaluate the ESD level of capability provided by the SP720. Without external protection, the ESD level of capability of the CMOS process was typically no better than ±2.5KV. When the SP720 was applied to use as shown in Figure 8, the ESD resistance to damage was better than ±10.2KV. (Higher levels were not evaluated at the time due to high voltage limitations.)

It should be noted that the Mil-Std-883, Method 3015.7 test allows for one pin as a reference when testing. While this cannot be disputed as handling limitation, it is not a test for all aspects of applied use. To properly apply the SP720 to use in the application specifically requires that the V- pin be connected to a negative supply or ground and the V+ pin be connected to a positive supply. The SP720 was designed to be used with the supply terminals bias and, as such, has better than ±16KV of ESD capability. For this reason, the modified test method as described, with the V+ pin connected via a ground return, is correct when the circuit is assembled for use.

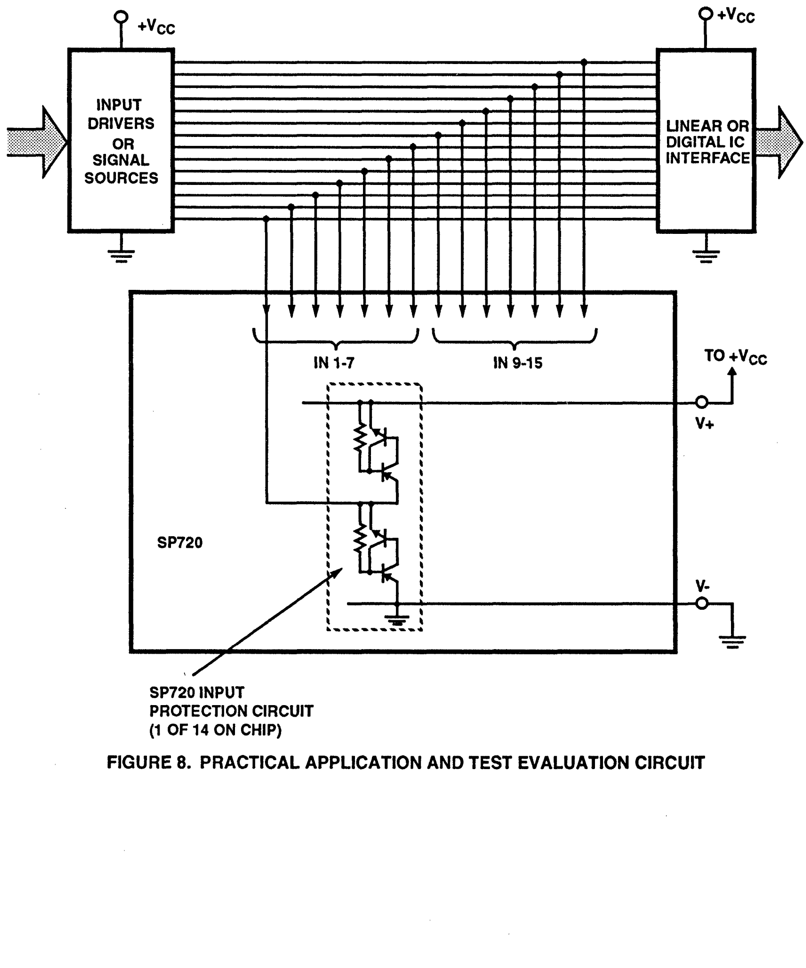


FIGURE 8. PRACTICAL APPLICATION AND TEST EVALUATION CIRCUIT

THE NEW “C” III SERIES OF METAL OXIDE VARISTORS

Authors: Martin Corbett and Paul Durnin

Introduction

The development of more sophisticated and less expensive semiconductors over the last 5 - 10 years has resulted in a dramatic increase in the consumer electronics market. It is not uncommon to see thousands of dollars worth of TV, VCR, music equipment, and computers in todays home. Accompanying this boom in the consumer market there has been an increased awareness, by the user, about system reliability. This is a result of the fact that solid state devices are very susceptible to stray electrical transients which may be present in the AC distribution system.

Transient voltages can result from the sudden release of previously stored energy. Transients are sudden short term variations in the AC power and can be characterized by three things; they are undesirable, unpredictable and potentially destructive. Transients may be generated by lightning, inductive load switching, electromagnetic pulses or electrostatic discharges. They occur randomly throughout the AC wave, generally lasting from a few microseconds to a number of milliseconds. Even for this very short time, they can do incalculable damage. The severity of the damage caused by the transient depends on, the magnitude of the transient, its waveshape duration and its frequency of occurrence. Electrical overvoltages on AC mains can cause both permanent deterioration, or temporary malfunctions, of electronic components and systems.

To be as effective as possible, the optimum transient suppressor must take into account transients that may be bidirectional in nature, that may appear at any point on the AC wave, and that may be of almost any duration. The suppressor selected needs to address all of the conditions to be effective.

Not all original equipment manufacturers (OEMs) in the consumer market design transient protection into their equipment. It is, therefore, left to the end user to provide their own protection. A wide variety of off-the-shelf protectors are available, the most common types being known as a "Transient Voltage Surge Suppressor" (TVSS). All major TVSS manufacturers use metal oxide varistors (MOVs) as the primary suppression technique in their systems. The use of correctly selected and installed MOVs have a long and proven history of successful field performance. Transient voltage surge suppressors can be obtained as either permanently connected fixtures or as cord and plug connected units. Permanently connected surge suppressors are an integral part of the electrical outlet and will protect any equipment which is plugged into that particular outlet. Permanently connected suppressors give continuous protection. Cord and plug connected suppressors are transportable protectors and will only protect from transients if they are plugged into an outlet at the time of the transient occurrence.

The Transient Environment[1,2,3,4,5]

The environment in which transient overvoltages occurs varies dramatically from region to region. Primarily the problem is that of the enigmatic presence of overvoltage surges, above the normal system voltage. Overvoltages are sometimes explainable or sometimes they just suddenly appear in the electrical system; they may take the form of disturbances, notches, swells, sags, brownouts, outages or combinations of the above and are generically known as transients.

Transients can be divided into two types; normal mode and common mode. A **normal mode** transient, sometimes referred to as a differential or transverse mode, is defined as a transient which occurs from line to line. Investigatory studies have shown that approximately 90% of all transients are normal mode occurrences. A **common mode** transient occurs between either line, and ground.

The causes of the surges in an indoor AC electrical system can be attributed to one of the following causes:

- Lightning
- Opening or closing of switch contacts under load
- Propagation of surges through transformers
- Severe load changes in adjacent systems
- Power line fluctuations and pulses
- Short circuits or blown fuses.

Transients caused by lightning can inject very high currents into the system. These lightning strikes, usually to the primary transmission lines, may result in coupling to the secondary line through mutual inductive or capacitive coupling. A direct strike is not the only damage lightning can do. The sudden change in an electrical field that occur during a cloud-to-cloud discharge can induce substantial voltages onto primary conductors, triggering lightning arresters and creating transients.

Man-made switching transients can be of a lesser, but more frequent threat. Such transients may be unpredictable and unrepeatable. Switching transients result from the rapid release of energy, e.g. switching of the power grid can cause transients which may damage equipment further along the electrical system.

Studies and laboratory investigation of residential and industrial low voltage AC power systems have shown that the amplitude of the transient is proportional to the rate of its occurrence, i.e. lower magnitude transients occur most often. Governing standards bodies, in particular UL, IEEE and ANSI, have established standards which give practical guidelines to the transient environment one may expect to encounter in a low voltage AC power system. Typical examples are the ANSI/IEEE standard C62.41 and UL 1449.

Rate of Occurrence

The rate of occurrence of surges varies quite a lot and is dependent upon a particular power system. Rate of occurrence is related to the level of surges; low magnitude surges are more common than high level surges. An area described as a "low exposure" area would have very little lightning activity and few switching loads on the AC power system. A "medium exposure" area is known for high lightning activity, with frequent and severe switching transients. When designing equipment for the global environment it is expedient that it be, at least, designed for use in an area with "medium exposure" transient occurrences. "High exposure" areas are rare but real systems supplied by long overhead transmission lines and subject to reflections at line ends, where the characteristics of the installation produce high sparkover levels of the clearances.

Lightning and switching transients generate overvoltages up to 10kV on the AC power lines. While this is the case, electronic equipment virtually never sees anything larger than 6kV. This is because the wiring systems used in indoor applications "flash over" at this 6kV level. Therefore, this is the maximum level that the aforementioned standards organizations have selected as the upper limit that electrical equipment is expected to be able to survive. The transient generated by this "flash over" creates a high energy, low impedance pulse. The further away from the source of the transient the protected equipment is located, the more the energy is absorbed in the wiring impedance and the more the equipment is protected.

Representative Transients

Table 1 reflects the surge voltages and currents deemed to represent the indoor transient environment in a low voltage AC power system. When deciding on the type of device to use as a transient voltage surge suppressor, it is generally recommended that the device selected have as a minimum the capability to handle the conditions called out in location Category B of Table 1.

TABLE 1. SURGE VOLTAGES AND CURRENTS DEEMED TO REPRESENT THE INDOOR ENVIRONMENT

LOCATION CATEGORY		IMPULSE	
		WAVEFORM	MEDIUM EXPOSURE
A	Long Branch Circuits and Outlets	0.5μs 100kHz	6kV 200A
B	Major Feeders and Short Branch Circuits	1.2/50μs 8/20ms	6kV 3kA
		0.5μs 100kHz	6kV 500A

Transient Protection

Once the decision to include transient suppression has been made, the next stage in the process is to decide on what protection technology to use and on how to use it. The transient suppressor selected must be able to suppress surges to levels which are below the failure threshold of the equipment being protected, and the suppressor must survive a definite number of worst case transients. When comparing the various devices available considerations must be given to characteristics such as protection levels required, component survivability, cost, and size.

"C" III Metal Oxide Varistor Series[6]

The new "C" III series of Harris radial metal oxide varistors represent the third generation of improvements in device performance and characteristics. The technology effort involved in the development of this new series concentrated on extending the existing performance and capability of the Harris second generation of metal oxide varistors.

A metal oxide varistor (MOV) is a non-linear device which has the property of maintaining a relatively small voltage change across its terminals while a disproportionately large surge current flows through it. This non-linear action allows the MOV to divert the current of a surge when connected in parallel across a line and hold the voltage to a value that protects the equipment connected to that line. Since the voltage across the MOV is held at some level higher than the normal line voltage while surge current flows, there is energy deposited in the varistor during its surge diversion function.

The basic conduction mechanism of a MOV results from semiconductor junctions (P-N junctions) at the boundaries of the zinc oxide grains. A MOV is a multi junction device with millions of grains acting as a series - parallel combination between the electrical terminals. The voltage drop across a single grain in nearly constant and is independent of grain size. The material of a metal oxide varistor is primarily zinc oxide with small additions of bismuth, cobalt, manganese and other metal oxides. The structure of the body consists of a matrix of conductive zinc oxide grains separated by grain boundaries, which provide the P-N junction semiconductor characteristics. When the MOV is exposed to surges, the zinc oxide exhibits a "bulk action" characteristic permitting it to conduct large amounts of current without damage.

The MOV has many advantages which make it ideal for use as a suppressor on the low voltage AC power line. The bulk nature of its construction gives it the required energy handling capability to handle the secondary level transients resulting from indirect lightning hits. MOV's are both cost and size effective, are widely available and do not have a significant amounts of voltage overshoot. The flexibility of their manufacture means that a variety of different sizes and packages are available for transient suppression in the indoor application.

The characteristics of greatest importance for a metal oxide varistor in an AC surge environment are the peak current, energy handling, repetitive surge and temporary over-voltage capabilities. The focus of the design effort was on improving these characteristics and therefore offering the maximum protection presently available to the end user.

The new "C" III series are designed to survive the harsh environments of the AC low-power indoor environment. Their much improved surge withstand capability is well in excess of the transients expected in the AC mains environment. Further design rules for the development of the "C" III series included considerations of the expected steady state operating conditions and the repetitive surge environment.

Transient Surge Withstand Capabilities

The worst case transients encountered in the indoor AC environment may be represented by the combination wave of 6kV (1.2/50µs) and 3kA (8/20µs). This combination wave has been selected by Underwriters Laboratories (UL) for certification of all transient voltage surge suppressors to UL standard 1449. This standard calls out for a maximum surge transient withstand capability and also for duty-cycle withstand capability.

The maximum surge withstand capability of 6kV, 3kA is proposed for cord and plug connected, direct plug in and permanently wired receptacle outlet type transient voltage surge suppressors. These peak transients are applied to the suppressor a total of three times, with normal line voltage also applied.

The peak surge current rating of the new 20mm "C" III series of Harris metal oxide varistors is 9000 amps. This series of varistors are generally used for the permanently wired receptacle suppressors. Under the surge current withstand test requirements of UL Standard 1449 (3 pulses of 3kA) these devices have a conservative rating of 20 such pulses. Continued stress testing at this level has shown an inherent device capability which commonly in excess of 100 pulses. See Figure 1.

The peak surge current rating of the new 14mm series of Harris metal oxide varistors is 6000 amps. This series of varistors are generally used for both the cord and plug connected and direct plug in types of suppressors. Under the surge current withstand test requirements of UL Standard 1449 (3 pulses of 3kA) these devices have a conservative rating of 10 such pulses. Continued stress testing of these components at this level has shown an inherent device capability commonly is in excess of 40 pulses.

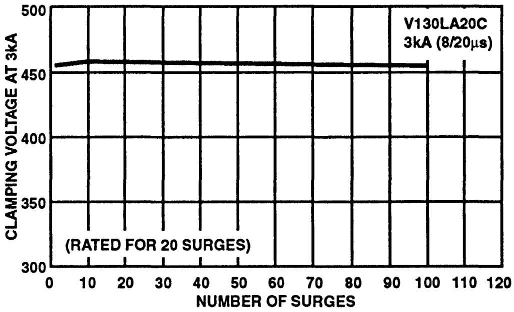


FIGURE 1. TYPICAL REPETITIVE SURGE CURRENT CAPABILITY OF "C" III SERIES MOVs

As well as the surge current withstand test, UL Standard 1449 also has requirements for suppressor performance in a repetitive surge environment. The duty-cycle transient withstand test capability peak voltage and current levels are 6kV and 500A for both the cord and plug connected and direct plug in suppressors. For the permanently wired receptacle outlet the test levels are 6kV and 750A. In all cases the duty-cycle test requirements are for a total of 24 pulses, 12 in alternating directions.

In the case of the 20mm size varistors, used for the permanently wired receptacle suppressors, their repetitive surge capability at 750A is 120 times. For the 14mm series of devices, used in cord and plug connected and direct plug in suppressors, the repetitive surge withstand capability is 80 pulses at 750 amps and 150 pulses at 500 amps. As in the previous case, this rating is conservative. Continued stress testing at the 750A level has shown an inherent device capability which commonly is in excess of 250 pulses. See Figure 2.

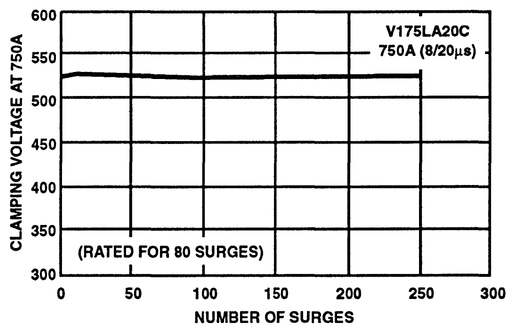


FIGURE 2. TYPICAL REPETITIVE SURGE CURRENT CAPABILITY OF "C" III SERIES MOVs

The transient surge rating serves as an excellent figure of merit for the "C" III suppressor. This extremely high, inherent surge handling capability is one of the new "C" III suppressor's best features. The enhanced surge absorption capability results from improved process uniformity and enhanced construction. The homogeneity of the raw material powder and improved control over the sintering and assembly processes are contributing factors to this improvement.

AC Bias Reliability

The "C" III series of metal oxide varistors were designed for use on the AC power line. The varistor is connected across the line and is biased with a constant amplitude sinusoidal voltage. If the varistor let through/leakage current increases with time, the power dissipation will also increase, with the ultimate possibility of thermal runaway and varistor failure. It should be noted that the definition of failure is a change in the nominal varistor voltage (V_N) exceeding ± 10%, with an associated increase in the leakage current drawn by the MOV. Although this type of varistor is still functioning normally after this magnitude of change, devices at the lower extremities of V_N tolerance may begin to dissipate more power.

To guard against this possibility, an extensive series of statistically designed tests were performed to determine the reliability of the "C" III type of varistor under AC bias combined with high levels of temperature stress. To date, this test has generated over 50,000 device hours of operation at a temperature of 125°C. This temperature was selected in order to accelerate the stress testing, although the "C" III series are only rated at 85°C. Changes in the nominal varistor voltage, measured at 1 milliamp, of less than 2% have been recorded. See Figure 3.

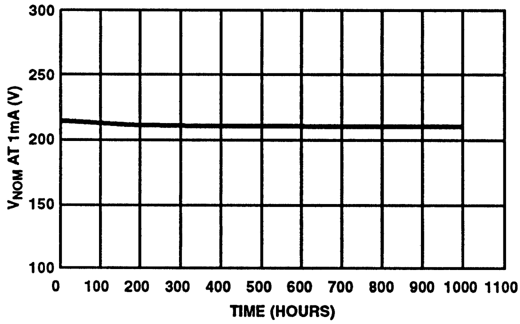


FIGURE 3. HIGH TEMPERATURE OPERATING LIFE +125°C FOR 1000 HOURS AT RATED BIAS

Device Comparisons[7, 8]

A range of standard varistors, avalanche diodes, gas tube arresters and filter capacitors were evaluated under a 6kV, 0.5µs x 100kHz ring wave. This transient replicates that called out in location Category A of the ANSI/IEEE C62.41, where most cord and plug connected and direct plug in suppressors are used, and is the most benign condition expected in this location. All of the selected devices are rated for use on a 120V AC line. The results obtained from this evaluation are per Table 2. The conclusions from this evaluation were: a) the silicon avalanche diode had the lowest level of performance; b) since location Category A is the location requiring the smallest sized suppressor, how can a device which does not survive this testing be considered an adequate suppressor?

Not only does the avalanche diode fail, but it is also very expensive when compared with an equivalently rated metal oxide varistor. There are avalanche diodes available, in the 15kW family, which absorb large amounts of energy and it is assumed that these devices will meet the transient requirements of this test. From a cost comparisons, these devices may be 15 - 20 times more expensive than an equivalent MOV.

TABLE 2. COMPARATIVE PERFORMANCE DATA8 (NOTE: THE LOWER THE PROTECTION LEVEL IS THE BETTER)

PROTECTION TECHNOLOGY	DEVICE PART #	AVERAGE PROTECTION LEVEL (kV)	FAILS / SAMPLE SIZE
Metal Oxide Varistor	V130LA1 V130LA5 V130LA10A	0.51 0.50 0.47	0/10 0/10 0/10
Silicon Avalanche Diode	1.5KE200C	0.48	2/10
Gas Tube Surge Arrester	CG2230	0.67	0/10
Filter Capacitor	C280A - EA4K7	1.30	0/10

One of the primary requirements for a device rated for suppression of transients on the AC mains is its ability to handle large amounts of energy. In order for a device to have a high energy handling capability, it requires a large amount of bulk material with a high specific heat value in the immediate vicinity of the P-N junctions. The primary material in a metal oxide varistor is zinc oxide and the average grain size for a MOV used in an AC application is 20 microns. Observations over a range of compositional variations and processing conditions show a fixed voltage drop of between 2-3 volts per grain with boundary junctions evenly distributed along their edges. In the case of a 14mm varistor, part V130LA10C, it would have an approximate volume of $220mm^3$ of material in the immediate vicinity of the PN grain junctions. An equivalent silicon avalanche diode would have approximately $0.106mm^3$ in their single P-N junction vicinity. Comparing the volume of the varistor and the diode in the immediate vicinity of the junction, the varistor has more than 2000 times a larger mass available. Thus, the peak temperature in the bulk material of the varistor per energy absorbed is much lower than that for the single silicon avalanche diode junction. It is the millions of P-N junctions, which are an integral part of the mov structure, that gives it excellent thermal and energy handling properties.

Reliability Performance of "C" III Series MOVs

While the electrical ratings and characteristics of the "C" III series of MOVs are conservatively rated, samples of these devices have been subjected to a number of additional electrical and environmental stresses, over and above those specified. The results of this testing show an enhanced device performance. A summary of the reliability tests performed on the "C" III series are shown in Table 3.

TABLE 3. RELIABILITY TEST PERFORMANCE OF "C" III SERIES MOVS

TEST	REFERENCE STANDARD	TEST CONDITIONS	TEST RESULTS
Surge Current	UL 1449 IEEE/ ANSI C62.41 IEC 1051	9000 Amps (8/20μs) 1 Pulse	0/165
		6500 Amps (8/20μs) 2 Pulses	0/105
		3000 Amps (8/20μs) 20 Pulses	0/75
		750 Amps (8/20μs) 120 Pulses	0/65
Surge Energy	UL 1449 IEEE/ ANSI C62.41 IEC 1051	90 Joules (2ms) 1 Pulse	0/1258
Operating Life	Mil-Std-202 Method 204D	125°C, 1000 Hours, Rated Bias Voltage	0/180
Temporary Overvoltage	N/A	120% Maximum Rated Varistor Voltage For 300s	0/70

Device Selection

After evaluating the advantages and disadvantages of the various suppression technologies available, the device of choice is clearly the metal oxide varistor. Once the decision has been made as to which technology to use, it is now necessary to decide on the actual device to select for a particular application. To select the correct varistor for a specific application, determine the following information:

1. The maximum system RMS voltage
2. How the MOV is to be connected?
3. The MOV rating with a voltage 10-25% above system voltage
4. The worst-case transient energy that will need to be absorbed by the MOV. (Use the guidelines called out in ANSI/IEEE C62.411992)
5. The clamping voltage required for system protection

Device Features

- Recognized as "Transient Voltage Surge Suppressors" to UL 1449; File E75961
- Recognized as "Transient Voltage Surge Suppressors" to CSA C22.2, No. 1; File LR91788
- High energy absorption capability: W_{TM} = 45 to 120 joules (2ms).
- High peak pulse current capability: I_{TM} = 6000 to 9000 amps (8/20μs)
- Wide operating voltage range: $V_{M(AC)RMS}$ = 130 to 175 volts

Available in tape and reel for automatic insertion; also available with trimmed and/or crimped leads.

"C" III MOV Terms and Descriptions

Rated AC Voltage ($V_{M(AC)RMS}$) - This is the maximum continuous sinusoidal voltage which may be applied to the MOV. This voltage may be applied at any temperature up to the maximum operating temperature of +85°C.

Maximum Non-Repetitive Surge Current (I_{TM}) - This is the maximum peak current which may be applied for an 8/20μs impulse, with rated line voltage also applied, without causing device failure.

Maximum Non-Repetitive Surge Energy (W_{TM}) - This is the maximum rated transient energy which may be dissipated for a single current pulse at a specified impulse and duration (2ms), with the rated rms voltage applied, without causing device failure.

Nominal Voltage ($V_{N(DC)}$) - This is the voltage at which the device changes from the off state to the on state and enters its conduction mode of operation. This voltage is characterized at the 1 milliamp point and has specified minimum and maximum voltage levels.

Clamping Voltage (V_C) - This is the peak voltage appearing across the MOV when measured at conditions of specified pulse current amplitude and specified waveform (8/20μs).

References

1. "ANSI/IEEE C62.411992 Guide On Surge Voltages In Low Voltage AC Power Circuits".
2. "Voltage Transients and Their Suppression", Corbett, M.,
3. "Understanding AC Line Transient Immunity", Dash, G. and Straus, I.,
4. "Suppression Of Voltage Transients Is An Art Trying To Be A Science", GE 660.33
5. "The Propagation and Attenuation of Surge Voltages and Currents in Low Voltage AC Circuits", Martzloff, F.D., 1984
6. "Transient Voltage Suppression Devices", Harris Semiconductor DB450.2
7. "Protective Level Comparison of Voltage Transient Suppressors", Hopkins, D.C.
8. "Comparison of Transient Suppressors!", Korn, S.

No. AN9307 April 1993

THE CONNECTOR PIN VARISTOR FOR TRANSIENT VOLTAGE PROTECTION IN CONNECTORS

Authors: Paul McCambridge and Martin Corbett

Introduction

Nonlinear devices have long been used for transient voltage protection and have bee available in conventional package configurations - axial, radial, and power packages (Figure 1) The connector pin varistor represents a new approach to transient suppression by forming the active material into a shape which requires no leads or package (Figure 2) The idea was developed many years ago, but only recently have breakthroughs in the manufacturing process allowed cost-effective production of such devices.

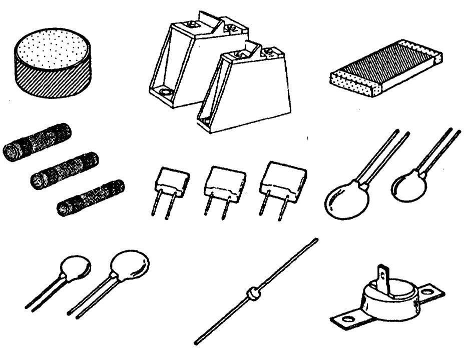


FIGURE 1. CONVENTIONAL PACKAGE CONFIGURATIONS

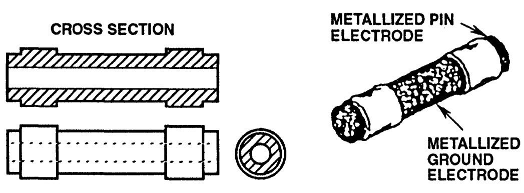


FIGURE 2. TUBULAR VARISTOR (CONNECTOR PIN VARISTOR)

Connector pin varistors are voltage dependent nonlinear semiconducting devices having electrical behavior similar to back-to-back zener diodes. The symmetrical sharp break-down characteristic enables the varistor to provide excellent transient suppression. As the voltage of a transient rises, the impedance of the varistor changes from a very high value to an extremely low value, limiting the voltage rise across the varistor (Figure 3). The destructive energy is absorbed by circuit impedance and varistor impedance. Energy is converted into hear and, if the varistor is properly rated, no components are harmed.

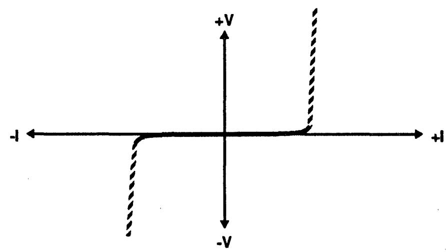
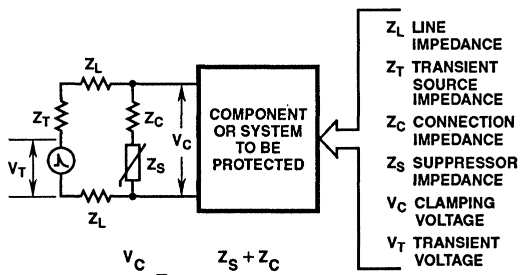


FIGURE 3. VOLTAGE IMPEDANCE CHARACTERISTICS OF A TYPICAL VARISTOR

To obtain the lowest clamping voltage, the impedance of the varistor (Z_S) and the impedance of the varistor leads (Z_C), should be as low as possible, but the impedance of the line (Z_L) and the transient source (Z_T) should be as high as possible (Figure 4). The part of Z_L which is contributed by the ground return also reduces Z_L, but at the same time lifts the ground above true ground and therefore should be small. Unfortunately, the impedance of the transient source (Z_T) cannot be controlled and is unknown in most instances.[1]



$$\frac{V_C}{V_T} = \frac{Z_S + Z_C}{Z_S + Z_C + Z_L + Z_T}$$

FIGURE 4. IMPEDANCE RELATIONSHIP IN A TRANSIENT SUPPRESSOR CIRCUIT

Varistors contain zinc oxide, bismuth, cobalt, manganese and other metal oxides. The structure of the body consists of conductive zinc oxide grains surrounded by a glassy layer (the grain boundary) which provides the 2.5V PN-junction semiconductor characteristics. Figure 5 shows a simplified cross section of the varistor material.

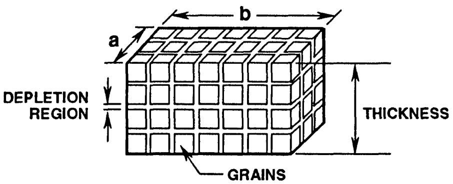


FIGURE 5. SIMPLIFIED MICROSTRUCTURE OF A VARISTOR MATERIAL

The varistor is a multi-junction device with many junctions in parallel and series. Each junction is heat sunk by zinc oxide grains resulting in low junction temperatures and large overload capabilities.

As shown in Figure 5, the more junctions that are connected in series, the higher the voltage rating and as more junctions are connected in parallel, the higher the current rating. Energy rating, on the other hand, is related to both voltage and current and is proportional to the volume of the varistor. In summary:

- Thickness is proportional to voltage
- Area is proportional to current (a x b) or [(d2 • π)/4] or (d • π • length).
- Volume is proportional to energy (area x thickness)

Electrical Characteristics

An electrical model for a varistor is represented by the equivalent circuit shown in Figure 6.

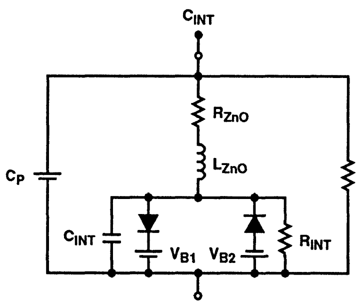


FIGURE 6. VARISTOR EQUIVALENT CIRCUIT

Pulse Response

The pulse response of a varistor is best understood by using the equivalent circuit representation consisting of a pure capacitor (C_P), two batteries, the grain resistance (R_{ZnO}) and the intergrain capacitance (C_{INT}). The off-resistance (R_{OFF}) is not applicable in this discussion.

Due to the varistor capacitance (C_P), the varistor is initially a short circuit to any applied pulse. Varistor breakdown conduction through (V_{B1}) and (V_{B2}), as illustrated in Figure 6 does not occur until this capacitor is charged to the varistor breakdown voltage (V_B). The time is calculated by:

$$t_C = C_P \bullet (V_{B1}/\bar{I}) \text{ or } (2)$$

Where $\bar{I}$ is the average pulse current (capacitor charging current) for $0 \leq t \leq t_C$. The value of the peak current is controlled by $\hat{I} = (di/dt) \bullet C_P$, the source impedance voltage of the transient, and the varistor's dimensions (area proportional to C).

For longer duration pulses $t > t_C$, V_{B1} and V_{B2} will participate on the current conduction process, as the voltage on C_P rises above the breakover voltage (V_B).

Speed of Response

The conduction mechanism is that of a II - VI polycrystalline semiconductor. Conduction occurs rapidly, with no apparent time lag even in the picosecond range.

Figure 7 shows a composite photograph of two voltage traces with and without a varistor connected to a low-inductance high speed pulse generator having a rise time of 500 picosecond. The second trace is not synchronized with the first, but merely superimposed on the oscilloscope screen, showing the instantaneous voltage clamping effect of the varistor. There is no delay or any indication which would justify concern about response time.

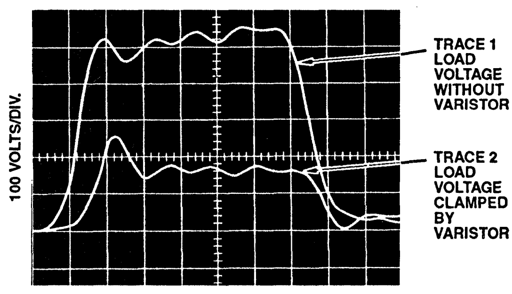


FIGURE 7. RESPONSE OF A VARISTOR TO A FAST RISING PULSE (dv/dt = 1 MILLION VOLTS/μs)

Using conventional lead-mounted varistors, the inductance of the leads completely masks the fast action of the varistor; therefore, the test results as shown in Figure 7 required the insertion of a small piece of varistor material in a coaxial line to demonstrate the intrinsic varistor response.

Tests made on lead-mounted devices, even with careful attention to minimize lead length, show that the voltage induced through lead inductance contributes substantially to the voltage appearing across the varistor terminals (Figure 8). These undesirable induced voltage are proportional to lead inductance and di/dt and can be positive or negative.

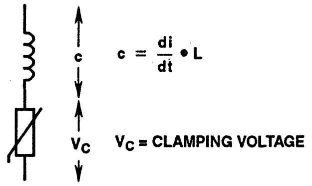


FIGURE 8. THE ELECTRICAL EQUIVALENT OF A LEAD-MOUNTED VARISTOR

Figure 9 shows the positive and negative part of the induced voltage, resulting from a pulse with a rise time of 4ns to a peak current of 2.5A. When the measurement is repeated with a leadless varistor, such as the connector pin varistor, its unique coaxial mounting allows it to become part of the transmission line. This completely eliminates inductive lead effect (Figure 10)

Calculations of the induced voltage as a direct result of lead effect for different current rise times provides a better understanding of the di/dt value at which the lead effect become significant. Table 1 is based on an assumption of a current pulse of 10A, 1 inch of lead wire (which translates into approximately 15nH) and rise times ranging from seconds to femtoseconds..

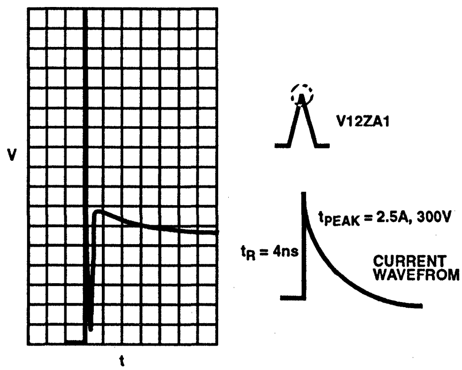


FIGURE 9. EXPONENTIAL PULSE APPLIED TO A RADIAL DEVICE (5V/DIV., 50s/DIV)

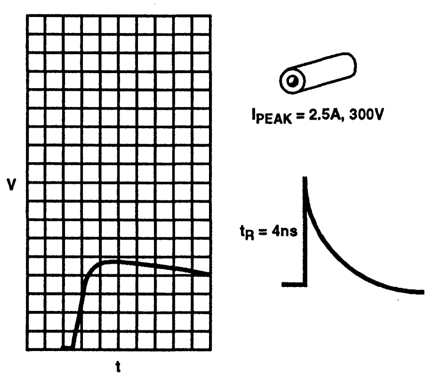


FIGURE 10. EXPONENTIAL PULSE APPLIED TO A PIN-VARISTOR (5V/DIV., 50nS/DIV.)

TABLE 1. INDUCED VOLTAGE IN 1 IN. LEADS. PEAK CURRENT 10A, AT DIFFERENT CURRENT RISE TIMES.

	TIME	I	L	e
1×10^{0}	1 sec.	10A	15nH	150×10^{-9}
1×10^{-3}	1ms	10A	15nH	150×10^{-5}
1×10^{-5}	1µs	10A	15nH	150×10^{-3}
1×10^{-9}	1ns	10A	15nH	150
1×10^{-12}	1ps	10A	15nH	150×10^{-3}
1×10^{-18}	1fs	10A	15nH	150×10^{-6}

Figure 11 illustrates the lead effect even more dramatically for fast rising pulses ranging in rise time from milliseconds to femtoseconds.

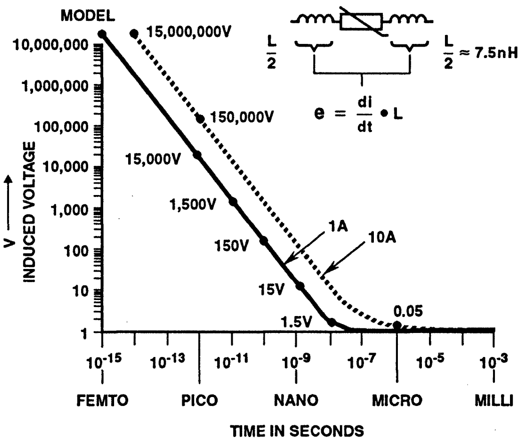


FIGURE 11. LEAD EFFECT OF 1 INCH CONNECTION (L ≈ 15nH)

Temperature Coefficient (Electrical)

The temperature coefficient is usually of little importance. It is most pronounced at low voltage and current levels and decreases to practically zero at the upper end of the V-I characteristics (Figure 12).

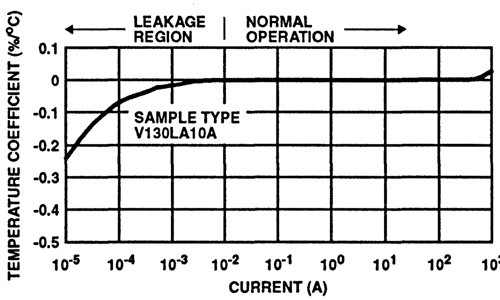


FIGURE 12. TYPICAL TEMPERATURE COEFFICIENT OF VOLTAGE vs CURRENT (-55°C to +125°C)

Connector Pins vs Circuit Board Suppressors

Circuit designers may ask, "Why use connector pin varistors when suppressors could be located on the printed circuit board of the electronic control module (ECM)?" Reasons include saving space and avoiding side effects of circuit board suppressor action.

A simplified schematic of an ECM is illustrated in Figure 13. Suppressors usually would be installed across the power analog and digital signal lines entering the ECM. These would divert surges to ground to avoid upset or damage of the ICs fed by those lines. However, side effects could occur if the suppressors are located internally. The paths of circulating current for diverting surges to ground could be of significant length and impedance. If the suppressor current paths share some impedance, then a surge current in one suppressor could cause a surge voltage on the ground line of another circuit. Also, surges can be coupled from one line to another within the ECM by radiation or by capacitive means. These problems are even more likely with surges that have fast fronts causing high V = LdI/dt voltages, such as when has tubes are activated.

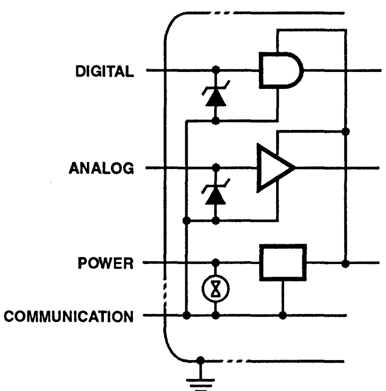


FIGURE 13. CIRCUIT BOARD SUPPRESSOR INSTALLATION

The above concerns are avoided when connector pin varistors are used as shown in Figure 14. Currents then can be diverted directly to a grounding plate within the connector which, in turn, terminates to the exterior of the ECM shielded housing. Surge currents stay outside of the "black box," and sensitive circuits are not exposed to the side effects of suppressor operation. Even if the ICs have on-chip suppressors for ESD protection, or the PC board has local suppressors, the connector pin varistors are desirable because they can divert some of the surge. This permits the local devices, in combination with line impedances and filter chokes, if present, to become secondary protectors. The local surge currents will be less, surge coupling side effects will be reduced, and lower clamping voltages can be attained.

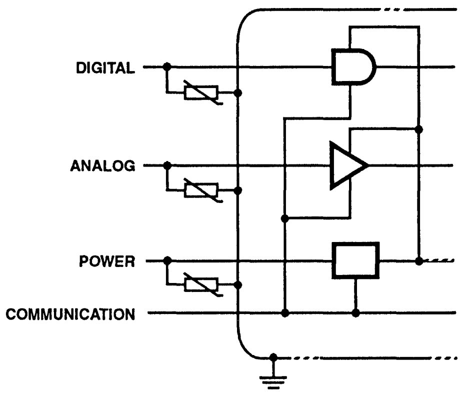


FIGURE 14. CONNECTOR PIN VARISTOR INSTALLATION

Connector Pins vs Zener Diodes

Clamping Voltage

Clamping voltage is an important feature of a transient suppressor. Zener diode type devices have lower clamping voltage than varistors (Figure 15). Because all protective devices are connected in parallel with the device or system to be protected, a lower clamping voltage will apply less stress to the device protected.

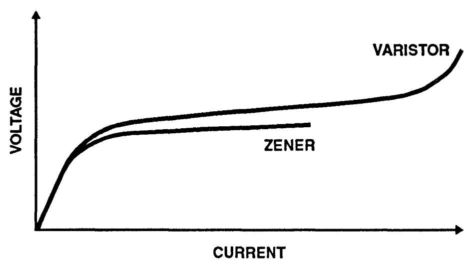


FIGURE 15. CHARACTERISTICS OF ZENER AND VARISTOR

Speeds Compared

Response times of less than 1 picosecond are claimed for zener diodes. For varistors, measurements were made down to 500 picoseconds with a voltage rise time (dv/dt) of 1 million volts per microsecond. Another consideration is the lead effect, previously discussed. Both devices are fast enough to respond to any practical requirements, including NEMP type transients.

Leakage Currents

Leakage current and sharpness of the knee are two areas of misconception about the varistor and zener diode devices. Figure 16 shows a zener diode and a varistor, both recommended by their manufacturers for protection of integrated circuits having 5V supply voltages.

The zener diode leakage is about 100 times higher at 5V than the varistor, 200μA versus less than 2μA.

For a leakage current comparison, 25 zener diode devices were measured at +25°C. Only 1 device measured 30mA. The rest were 150mA and more. At elevated temperatures, the comparison is even more favorable to the varistor. The zener diode is specified at 1000mA at 5.5V.

The leakage current of a zener can be reduced by specifying a higher voltage device which would have a lower leakage current, but the price is a higher clamping voltage and the advantage of the zener disappears.

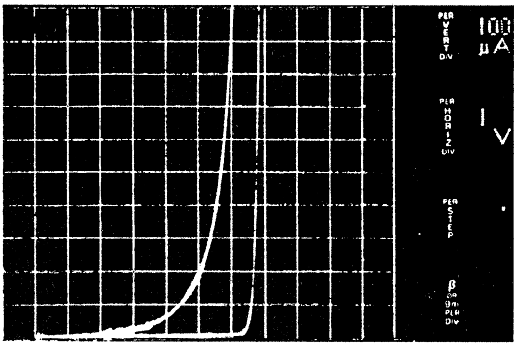


FIGURE 16. CHARACTERISTICS OF A ZENER DIODE (ON LEFT) vs A VARISTOR (ON RIGHT)

Peak Pulse Power

Transient suppressors have to be optimized to absorb large amounts of power or energy in a short time duration: nanoseconds, microseconds or, in some rare instances, milliseconds.

Electrical energy is transformed into heat and has to be distributed instantaneously throughout the device. Transient thermal impedance is much more important than steady-state thermal impedance, as it keeps peak junction temperature to a minimum. In other words, head should be instantly and evenly distributed throughout the device.

The varistor meets these requirements: an extremely reliable device with large overload capability. Zener diodes on the other hand, transform electrical energy into hear in the depletion region, an extremely small area, resulting in high peak temperature. From there the hear will flow through the silicon and solder joint to the copper. Thermal coefficient mismatch and large temperature differentials can result in an unreliable device for transient suppression.

Figure 17 shows peak pulse power versus pulse width for the varistor and the zener diode, the same devices compared for leakage current.

At 1ms, the two devices are almost the same. At 2μs the varistor is almost 10 times better, 7kW for the zener versus 60kW for the varistor.

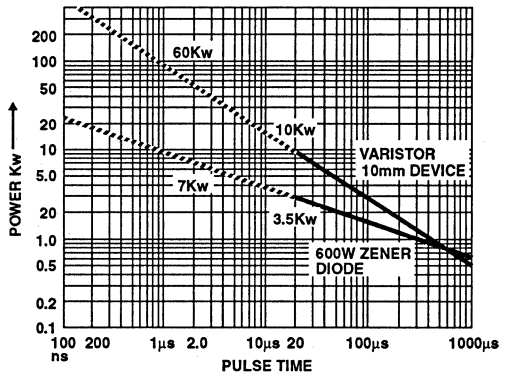


FIGURE 17. PEAK PULSE POWER vs PULSE TIME

Aging

A common misconception is that a varistor's V-I characteristics changes every time energy is absorbed. As illustrated in Figure 18, the V-I characteristic changed on some of the devices, but returned to its original value after applying a second or third pulse. Is this an inversion of the aging process? Time and temperature have very similar effects.

To be conservative, peak pulse limits have been established which, in many cases, have been exceeded manyfold without harm to the device. This does not mean that established limits should be ignored, but rather, viewed in perspective of the definition of a failed device. A failed device shows a ±10 percent change of the V-I characteristic at the 1mA point. Zener diodes, on the other hand, fail suddenly at predictable power and energy levels.

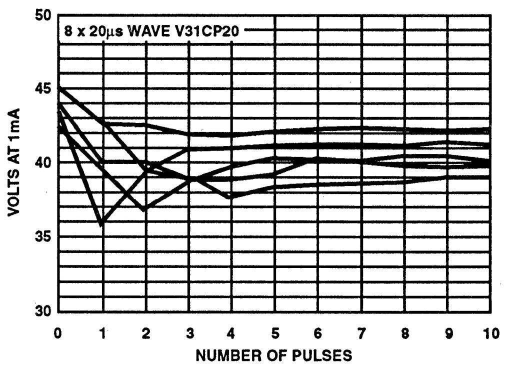


FIGURE 18. 250A PULSE-WITHSTAND CAPABILITIES

Failure Mode

Varistors fail short, but can also explode when energy is excessive, resulting in an open circuit. Because of the large peak pulse capabilities of varistors, these types of failure are quite rare for properly selected devices.

Zeners, on the other hand, can fail either short or open. If the pellet is connected by a wire, it can act as a fuse, disconnecting the device and resulting in an open circuit. Designers must analyze which failure mode, open or short, is preferred for their circuits.

When a device fails during a transient, a short is preferred, since it will provide a current path bypass and continued to protect the sensitive components. On the other hand, if a device fails open during a transient, the remaining energy ends up in the sensitive components that were supposed to be protected. If the energy is already dissipated, the circuit will now operate without a suppressor and the next transient, or the next few transients, will denigrate the equipment.

Another consideration is a hybrid approach, making use of the best features of both types of transient suppressors (Figure 19).

FIGURE 19. HYBRID PROTECTION USING VARISTORS, ZENERS, R AND L

Capacitance

Depending on the application, transient suppressor capacitance can be a very desirable or undesirable feature compared to zener diodes. Varistors have a higher capacitance. In DC circuits, capacitance is desirable: the larger the better. Decoupling capacitors are used on IC supply voltage pins and can in any cases be replaced by varistors, providing both the decoupling and transient voltage clamping functions.

The same is true for filter connectors where the varistor can perform the dual functions of providing both filtering and transient suppression.

There are circuits, however, where capacitance is less desirable, such as high frequency digital or some analog circuits.

As a rule, the source impedance of the signal and the frequency as well as the capacitance of the transient suppressor should be considered (Figure 20).

The current through C_P is a function of dv/dt and the distortion is a function of the signal's source impedance. Each case must be evaluated individually to determine the maximum allowable capacitance.

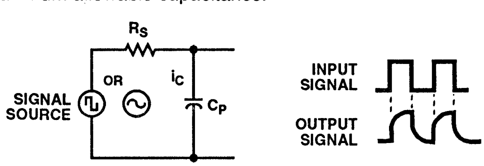


FIGURE 20. SOURCE IMPEDANCE (R_S) AND PARASITIC CAPACITANCE (C_P)

Response to Radiation

For space applications, an extremely important property of a protection device is its response to imposed radiation effects.

Electron Irradiation

Figure 21 represents MOV and zener devices exposed to electron irradiation. The V-I curves, before and after test, are shown. The MOV is virtually unaffected, even at the extremely high dose of 10^8 rads, while the zener shows a dramatic increase in leakage current.

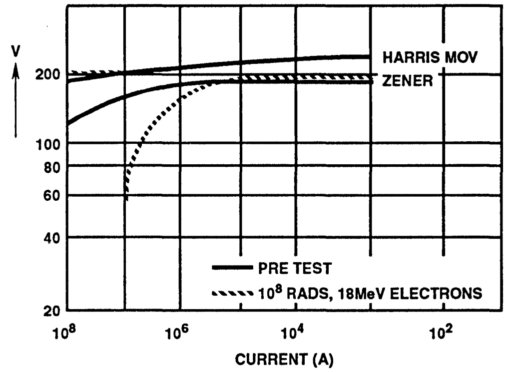


FIGURE 21. RADIATION SENSITIVITY OF MOV AND ZENER DEVICES

Neutron Effects

A second MOV-zener comparison was made with respect to neutron fluence. The selected devices were equal in area.

Figure 22 shows the clamping voltage response of the MOV and the zener to neutron irradiation as high as 10^{15}N/cm^2. In contrast to the large change in the zener, the MOV is unaltered. At higher currents where the MOVs clamping voltage is again unchanged, the zener device clamping voltage increases by as much as 36 percent.

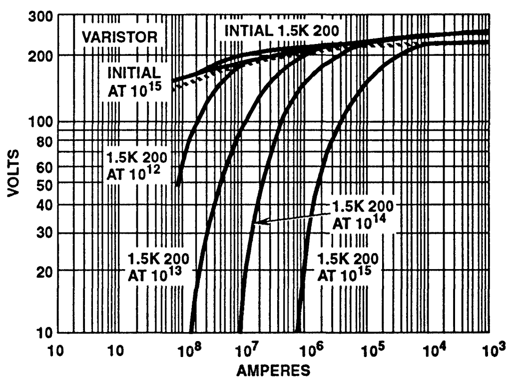


FIGURE 22. VOLTAGE CURRENTS CHARACTERISTIC RESPONSE TO NEUTRON IRRADIATION FOR MOV AND ZENER DIODE DEVICES

Counterclockwise rotation of the V-I characteristics is observed in silicon devices at high neutron irradiation levels. In other words, leakage increases at low current levels and clamping voltage increases at higher current levels.

The solid and open circles for a given fluence represent the high and low breakdown currents for the sample of devices tested. A marked decrease in current (or energy) handling capability with increased neutron fluence should be noted.

The failure threshold level of silicon semiconductor junctions is further reduced when high or rapidly increasing currents are applied. Junctions develop hot spots, which enlarge until a short occurs if current is not limited or quickly removed.

The characteristic voltage current relationship of a PN-Junction is shown in Figure 23.

At low reverse voltage, the device will conduct very little current (the saturation current). At higher reverse voltage V_{BO} (breakdown voltage), the current increases rapidly as the electrons are either pulled by the electric field (zener effect) or knocked out by other electrons (avalanching). A further increase in voltage causes the device to exhibit a negative resistance characteristic leading to a secondary breakdown. This manifests itself through the formation of hotspots, and irreversible damage decreases under neutron irradiation for zeners, but not for zinc oxide varistors.

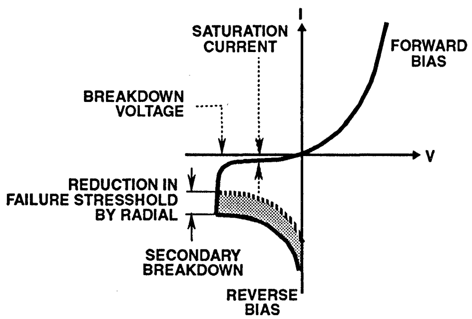


FIGURE 23. VOLTAGE CURRENTS CHARACTERISTIC OF PN-JUNCTION

Gamma Radiation[7]

Radiation damage studies were performed on specified varistors. Emission spectra and V-I characteristics were collected before and after irradiation with 10^6 rads Co^{60} gamma radiation. Both show no change, within experimental error, after irradiation.

Mechanical Strength

After sintering, the varistor becomes a strong, rugged ceramic material. As with all ceramic materials, it has high compressive strength and lower tensile or shear strength. An experiment was performed to demonstrate the strength of the varistor material when used in the tubular form. Results are shown in Table 2. P1 and P2 represent maximum pressures applied before fracture. Directions of applied stresses are shown in Figure 24.

TABLE 2. VARISTOR MATERIAL STRENGTH

PART SIZE	P1	P2
20A	100 lbs	30 lbs
20B	100 lbs	14 lbs
22B	100 lbs	14 lbs

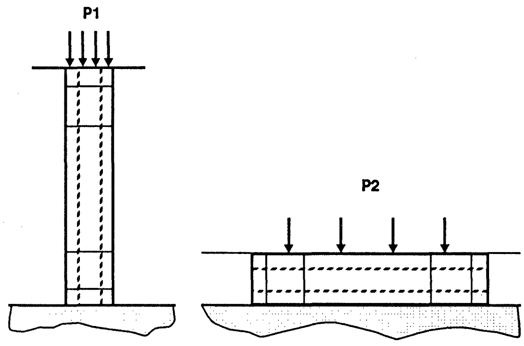


FIGURE 24. APPLIED STRESSES

Conclusions

Connector pin varistors provide a unique way to install surge protection in electronic systems without the bulkiness of some approaches. The tubular form of this varistor gives a relatively large area for conducting surge current, with an inherent mass for dissipating electrical heat energy. The rugged body physically resembles passive components; but, because it is a semiconductor device, response time is very fast. The leadless form reduces the voltage overshoot that can be caused by lead inductance. Also, the device has a high degree of inherent radiation hardness. Connector pin varistors divert surge currents to the outside surface of the "black box" housing, not to printed board runs feeding sensitive circuits, thereby helping to avoid or reduce surge coupling side effects.

References

1. Harris Corporation, "Transient Voltage Suppression Devices," Fifth Edition, 400.3, September 1989.
2. Sebald R. Korn, The New Low Voltage GE-MOV Varistor (for protection of 5 Vdc and below). Application Note No. 200.91 by General Electric Application Engineering.
3. D. M. Tasca and J. C. Peden, Technical Information Series No. 73SD252 EMT/Power Transient Suppression, General Electric Re-entry & Environmental Systems Division.
4. D. M. Tasca and J. C. Peden, Technical Information Series No.73SD23G Subnanosecond Rise Time Pulse Response and Clamping Voltage Characteristics of GE-MOV and Transzorb, General Electric Space Division.
5. Lionel M. Levinson and H. R. Philipp, "AC-Properties of Metal Oxide Varistors," Journal of Applied Physics, Vol. 47, No. 3, March 1976.
6. Lionel M. Levinson and H. R. Philipp, "High-Frequency and High-Current Studies of Metal Oxide Varistors," Journal of Applied Physics, Vol. 47, No. 3 March 1976.
7. Low Temperature Admittance Spectroscopy of Zinc Oxide Varistors (internal GE report).
8. EMP Engineering and Design Principles, Sixth Printing October 1984, Bell Telephone Laboratories, Inc.
9. Data Book 1980 - 1981. General Semiconductor Industries, Inc.

No. AN9308 April 1993

VOLTAGE TRANSIENTS AND THEIR SUPPRESSION

Author: Martin P. Corbett

Introduction

The increasing usage of sensitive solid state devices in modem electrical systems, particularly computers, communications systems and military equipment, has given rise to concerns about system reliability. These concerns stem from the fact that the solid state devices are very susceptible to stray electrical transients which may be present in the distribution system.

The initial use of semiconductor devices resulted in a number of unexplained failures. Investigation into these failures revealed that they were caused by transients, which were present In many different forms in the system. Transients in an electrical circuit result from tile sudden release of previously stored energy. The severity of, and hence the damage caused by transients depends on their frequency of occurrence, the peak transient currents and voltages present and their waveshapes.

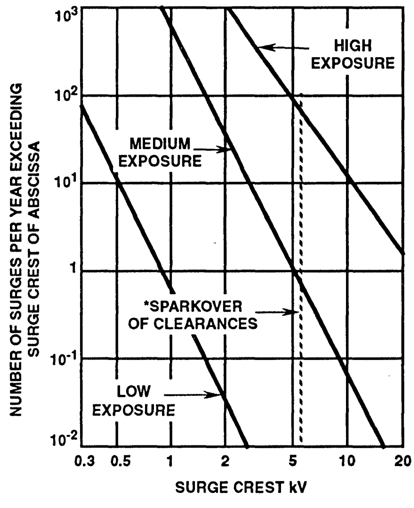
In order to adequately protect sensitive electrical systems, thereby assuring reliable operation, transient voltage suppression must be part of the initial design process and not simply included as an afterthought. To ensure effective transient suppression, the device chosen must have the capability to dissipate the impulse energy of the transient at a sufficiently low voltage so that the capabilities of the circuit being protected are not affected. The most successful type of supppression device used is the metal oxide varistor. Other devices which are also used are the zener diode and the gas-tube arrestor.

The Transient Environment

The occurrence rate of surges varies over wide limits, depending on the particular power system. These transients are difiicult to deal with, due to their random occurrences and the problems in defining their amplitude, duration and energy content. Data collected from many independent sources have led to the data shown In Figure 1. This prediction shows with certainty only a relative frequency of occurrence, while the absolute number of occurrences can be described only in terms of low, medium or high exposure. This data was taken from unprotected circuits with no surge suppression devices.

The low exposure portion of the graph Is derived from data collected in geographical areas known for low lightning activity, with little load switching activity. Medium exposure systems are geographical areas known for high lightning activity, with frequent and severe switching transients. High exposure areas are rare, but real systems, supplied by long overhead lines and subject to reflections at line ends, where the characteristics of the installation produce high sparkover levels of the clearances.

Investigations into the two most common exposure levels, low and medium, have shown that the majority of surges occurring here can be represented by typical waveform shapes (per ANSI/IEEE C62.41-1980). The majority of surges which occur in indoor low voltage power systems can



*In Some Locations, Sparkover of Clearances May Limit the Overvoltages.

FIGURE 1. RATE OF SURGE OCCURENCES vs VOLTAGE LEVEL AT UNPROTECTED LOCATIONS

be modeled to an oscillatory waveform (see Figure 2). A surge impinging on the system excites the natural resonant frequencies of the conductor system. As a result, not only are the surges oscillatory but surges may have different amplitudes and waveshapes at different locations in the system. These oscillatory frequencies range from 5kHz to 500kHz with 100kHz being a realistic choice.

In outdoor situations the surge waveforms recorded have been categorized by virtue of the energy content associated wlth them. These waveshapes involve greater energy than those associated with the indoor environment. These waveforms were found to be unidirectional in nature (see Figure 3).

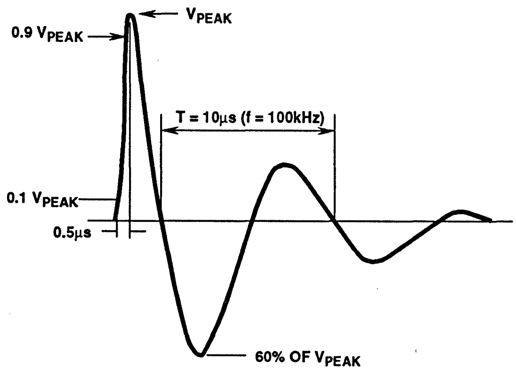
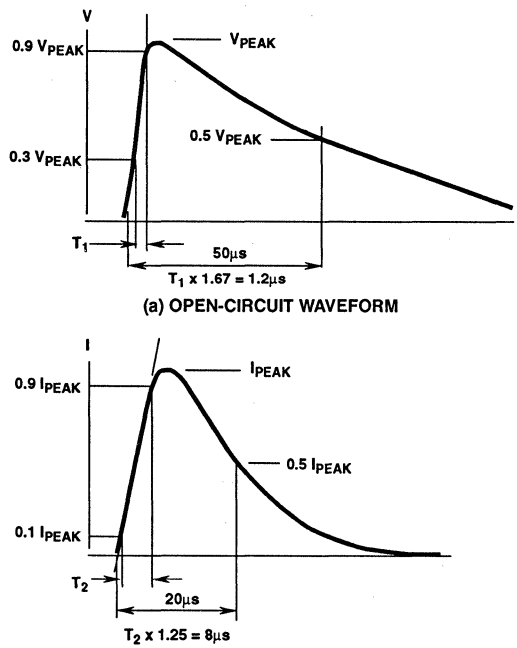


FIGURE 2. 0.5ms - 100kHz RING WAVE (OPEN CIRCUIT VOLTAGE)



(a) OPEN-CIRCUIT WAVEFORM

(b) DISCHARGE CURRENT WAVEFORM

FIGURE 3. UNIDIRECTIONAL WAVESHAPES (OUTDOOR LOCATIONS)

Transient Energy and Source Impedance

Some transients may be intentionally created in the circuit due to inductive load switching, commutation voltage spikes, etc. These transients are easy to suppress since their energy content is known. It is the transients which are generated external to the circuit and coupled into it which cause problems. These can be caused by the discharge of electromagnetic energy, e.g., lightning or electrostatic discharge. These transients are more difficult to identify, measure and suppress. Regardless of their source, transients have one thing in common - they are destructive. The destruction potential of transients is defilned by their peak voltage, the follow-on current and the time duration of the current flow, that is:

$$E = \int_{0}^{\tau} Vc(t) - I(t)\,dt$$

where:

E = Transient energy

I = Peak transient current

Vc = Resulting clamping voltage

t = Time

τ = Impulse duration of the transient

It should be noted that considering the very small possibilities of a direct lightning hit it may be deemed economically unfeasibie to protect against such transients. However, to protect against transients generated by line switching, ESD, EMP and other such causes is essential, and if ignored will lead to expensive component and/or system losses.

The energy contained in a transient will be divided between the transient suppressor and the line upon which it is travelling in a way which is determined by their two impedances. It is essential to make a realistic assumption of the transient's source impedance in order to ensure that the device selected for protection has adequate surge handling capability. In a gas-tube arrestor, the low impedance of the arc after sparkover forces most of the energy to be dissipated elsewhere - for instance in a power- follow current-limiting resistor that has to be added in series with the gap. This is one of tile disadvantages of the gas-tube arrestor. A voltage clamping suppressor (e.g., a metal oxide varistor) must be capable of absorbing a large amount of transient surge energy. Its clamping action does not involve the power-follow energy resulting from the short-circuit action of the gap.

The degree to which source impedance is important depends largely on the type of suppressor used. The surge suppressor must be able to handle the current passed through them by the surge source. An assumption of too high an impedlnoe (when testing the suppressor) may not subject it to sufficient stresses, while the assumption of too low an impedance may subject it to unrealistically large stress; there is a trade off between the size/cost of the suppressor and the amount of protection required.

In a building, the source impedance and the load impedance increases from the outside to locations well within the inside of the building, i.e., as one gets further from the service entrance, the impedance increases. Since the wire in a structure does not provide much attention, the open circuit voltages show little variation. Figure 4 illustrates the application of three categories to the wiring of a power system.

These three categories represent the majority of locations from the electrical service entrance to the most remote wall outlet. Table 1 is intended as an aid in the selection of surge suppressors devices, since it is very difficult to select a specific value of source impedance.

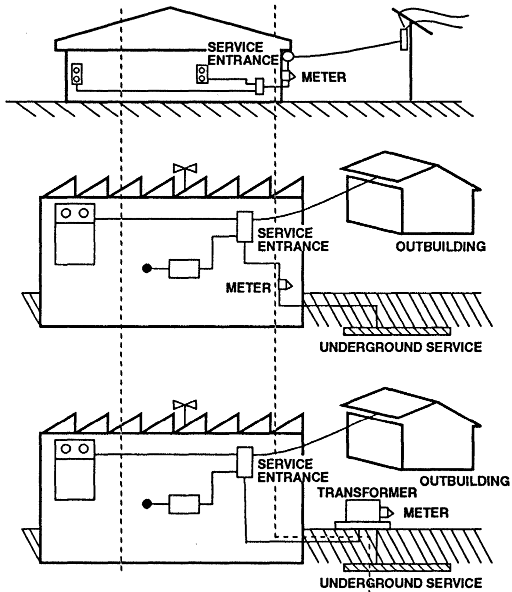
Category A covers outlets and long branch circuits over 30 feet from category B and those over 60 feet from category C. Category B is for major feeders and short branch circuits from the electrical entrance. Examples at this location are bus and feeder systems in industrial plants, distribution panel devices, and lightning systems in commercial buildings. Category C applies to outdoor locations and the electrical service entrance. It covers the service drop from pole to building entrance, the run between meter and the distribution panel, the overhead line to detached buildings and underground lines to well pumps.

TABLE 1. SURGE VOLTAGES AND CURRENTS DEEMED TO REPRESENT THE INDOOR ENVIRONMENT AND RECOMMENDED FOR USE IN DESIGNING PROTECTIVE SYSTEMS.

LOCATION CATEGORY CENTER	COMPARABLE TO IEC 664 CATEGORY	IMPULSE		TYPE OF SPECIMEN OR LOAD CIRCUIT CIRCUIT	ENERGY (JOULES) DEPOSITED IN A SUPPRESSOR WITH CLAMPING VOLTAGE	
		WAVEFORM	MEDIUM EXPOSURE AMPLITUDE		500V	1000V
					(120V Sys.)	(240V Sys.)
A. Long branch circuits and outlets	II	0.5μs - 100kHz	6kV	High Impedance (Note 1)	-	-
			200A	Low Impedance (Note 2)	0.8	1.6
B. Major feeders short branch circuits, and load center	III	1.2/50μs	6kV	High Impedance (Note 1)	-	-
		8/20μs	3kA	Low Impedance (Note 2)	40	80
		0.5μs - 100kHz	6kV	High Impedance (Note 1)	-	-
			500A	Low Impedance	2	4

NOTES:

1. For high-impedance test specimens or load circuits, the voltage shown represents the surge voltage. In making simulation tests, use that value for the open-circuit voltage of the test generator.
2. For low-impedance test specimens or load circuits, the current shown represents the discharge current of the surge (not the short-circuit current of the power system). In making simulation tests, use that current for the short-circuit current of the test generator.
3. Other suppressors which have different clamping voltages would receive different energy levels.



A

Outlets and long branch circuits.
All outlets at more than 10m (30ft.) from Category B. All outlets at more than 20m (60ft.) from Category C.

B

Feeders and short branch circuits
Distribution Panel Devices
Bus and feeder in industrial plants
Heavy appliance outlets with "short" connections to service entrance
Lighting systems in large buildings

C

Outside and service entrance
Service drop from pole to building.
Run between meter and panel.
Overhead line to detached building.
Underground line to well pump.

FIGURE 4. LOCATION CATEGORIES

Transient Suppression

The best type of transient suppressor to use depends on the intended application, bearing in mind that in some cases both primary and secondary protection may be required. It is the function of tile transient suppressor to, in one way or another, limit the maximum instantaneous voltage that can develop across the protected load. The choice depends on several factors, but the decision is ultimately a tradeoff between the cost of the suppressor and the amount of protection needed.

The time required for a transient suppressor to begin functioning is extremely important when it is used to protect sensitive components. If the suppressor is slow acting and a fast-rise transient spike appears on the system the voltage across the protected load can rise to damaging levels before suppression begins. On ac power lines the best type of suppression to use is a metal oxide varistor. Other devices occasionally used are the zener diode and the gas-tube arrestor.

Gas-Tube Arrestors

This is a suppression device which finds most of its applications in telecommunication systems. It is made of two metallic conductors usually separated by 10 to 15mils encapsulated in a glass envelope. This glass envelope is pressurized and contains a number of different gases. One disadvantage of this device arises from the possibility of seal leakage and the resulting loss of protection. Also, in a gas-tube arrestor, the low impedance of the arc after sparkover forces most of the energy to be dissipated elsewhere. This requires additional components in the system, for instance a power-follow current-limiting resistor that has to be added in series with the gap.

Zener Diodes

One type of clamp-action device used in transient suppression is the zener diode. When a voltage of sufficient amplitude is applied in the reverse direction, the zener diode is said to break down, and will conduct current in this direction. This phenomenon is called avalanche. The voltage appearing across the diode is therefore called the reverse avalanche or zener voltage.

When a transient propagates along the line with a voltage exceeding the reverse-based voltage rating of the diode, the diode will conduct and the transient will be clamped at the zener voltage. This clamping voltage is lower than that of an equivalent varistor. Some manufacturers have claimed that the response time of a zener diode is 1 to 2 picoseconds. This is impossible according to the laws of physics, since a signal traveling at the speed of light in vacuum, the fastest speed in the universe, would require about 50 picoseconds to transverse the length of the plastic package of the diode. In practice, the speed of response is determined by the parasitic inductance of the package and the manner in which the device is connected via its leads. Although zener diodes can provide transient protection, they cannot survive significant instantaneous power surges. Larger diodes can be used to increase the power rating, but this is oniy at the expense of increased costs. Also, the maximum tolerable surge current for a zener diode in reverse breakdown is small when compared to tolerable surge currents for varistors. Due to the fact that there is only the p-n junction in a zener diode, it will need to have some additional heat sinking in order to facilitate the rapid build-up of heat which occurs in the junction after it has encountered a transient.

Metal Oxide Varistor

As the name suggests, metal oxide varistors (MOV) are variable resistors. Unlike a potentiometer, which is manually adjusted, the resistance of a varistor varies automatlcally in response to changes in voltages appearing across it. Varistors are a monolithic device consisting of many grains of zinc oxide, mixed with other materials, and compressed into a single form. The boundaries between individual grains can be equated to p-n junctions with the entire mass represented as a series-parallel diode network.

When a MOV is biased, some grains are forward biased and some are reverse biased. As the voltage is increased, a growing number of the reversed biased gralns exhiblt reverse avalanche and begin to conduct. Through careful control in manufacturing, most of the nonconducting p-n junctions can be made to avalanche at the same voltage. MOVs respond to changes in voltages almost instantaneously. The actual reaction time of a given MOV depends on physical characteristics of the MOV and the wave shape of the current pulse driven through it by the voltage spike. Experimental work has shown the response time to be in the 500 picosecond range.

One misconception about varistors is that they are slow to respond to rapid rise transients. This "slow" response is due to parasitic inductance in the package and leads when the varistor is not connected with minimal lead length. If due consideration is given to these effects in its installation, the MOV will be more than capable of suppressing any voltage transients found in the low voltage ac power system.

The MOV has many advantages over the zener diode, the greatest of which is its ability to handle transients of much larger energy content. Because it consists of many p-n junctions, power is dissipated throughout its entire bulk, and unlike the zener, no single hot spot will develop. Another advantage of the MOV is its ability to survive much higher instantaneous power.

Summary

When designing circuits of the complex nature seen in todays electrical environment, the initial design must incorporate some form of transient voltage surge suppression. The expense of incorporating a surge protection device in a system is very low when compared with the cost of equipment downtime, maintenance and lost productivity which may result as a consequence of not having protection. When selecting surge suppressors for retrofit to an existing design, one important point to remember is that the location of the load to be protected relative to the service entrance is as important as the transient entrance which may be present in an overvoltage situation.

Bibliography

An American National Standard/IEEE Guide for Surge Voltages in Low Voltage AC Power Circuits, C62.41-1980.

Harris Semiconductor, Transient Voltage Suppression Devices, SSD-450

Korn, Sebald, Voltage Transients and Power Conversion Equipment, GE.

SURGE SUPPRESSION TECHNOLOGIES ADVANTAGES AND DISADVANTAGES (MOVs, SADs, Gas Tubes, Filters & Transformers)

Author: Martin P. Corbett

Synopsis

Protection on the low voltage AC mains system from transient overvoltages is now a fundamental power quality concern. The use of correctly selected and installed surge protectors have a long and proven history of successful field performance. The expected transient environment is addressed, along with various types of surge suppression components which are available. Advantages and disadvantages of isolator, crowbar and clamping type surge suppressors are discussed. Competitive evaluations are reported and some recommendations and guidelines for the selection of the correct type of device to be used are given.

Introduction

The increasing use of semiconductors and other solid state components in modern electrical systems has resulted in a growing awareness about system reliability. This is a consequence of the fact that solid state devices are very susceptible to stray electrical transients which may be present in the low voltage AC distribution system. The initial use of semiconductors resulted in a large number of unexplained failures. Investigation into these failures revealed that they were caused by a number of diverse overvoltage conditions which were present in the distribution system. Transient voltages result from the sudden release of previously stored energy from overstress conditions such as lightning, inductive load switching, electromagnetic pulses or electrostatic discharges. The severity of, and hence the damage caused, by the transient depends on their frequency of occurrence, their peak values and their waveshapes.

Electrical overvoltages on AC mains can cause either permanent deterioration, or temporary malfunctions in electronic components and systems. Protection from transients can be obtained by using specially designed components which will, either limit the magnitude of the transient using a large series impedance or by diverting the transient using a low value shunt impedance.

A prudent designer will consider the need for transient protection in the early stages of the design. Too many times it has been necessary to retrofit existing equipment with transient suppressors. This is expensive in terms of field failures, customer downtime and potential loss of business. In some systems retrofitting becomes cumbersome, as the space required was not planned for in the initial design. The device selected as the system protector must have the capability to dissipate the impulse energy of the transient at a sufficiently low voltage so that the capabilities of the system being protected are not affected.

Problem Definition (The Transient Environment)[1, 2, 3, 4]

Primarily the problem is that of the enigmatic presence of overvoltage surges, above the normal system voltage. Overvoltages are sometimes explainable or sometimes they just mysteriously appear in the electrical system; they take the form of disturbances, notches, swells, sags, brownouts, outages or combinations of the above and are generically known as transients. A common result of encountering these overvoltages is the early failure of semiconductor components and other sensitive electrical components. An equally serious effect is the loss of control in solid-state logic systems that may think surges are legitimate signals and thus endeavor to react to them.

Numerous studies have been performed which indicate that the causes of the surges in an electrical system can be attributed to one of the following causes:

- Lightning
- Opening or closing of switch contacts under load
- Propagation of surges through transformers
- Severe load changes in adjacent systems
- Power line fluctuations and pulses
- Short circuits or blown fuses

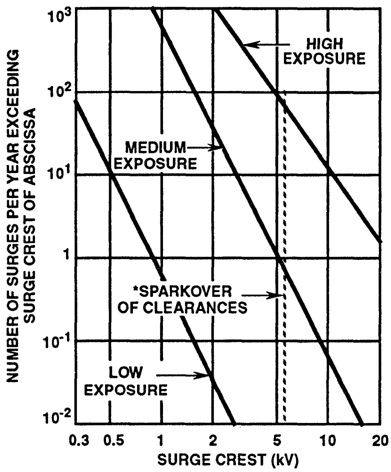
The power system is made up of a large network of cross connected transmission lines. This power system is often interfered with by transients originating from one of the aforementioned sources.

Transients caused by lightning can inject very high currents into the system. These lightning strikes, usually to the primary transmission lines, may result in coupling to the secondary line through mutual inductive or capacitive coupling. Even a lightning hit that misses the line can induce substantial voltage onto the primary conductors, triggering lightning arresters and creating transients. Man-made switching transients can be of a lesser, but more frequent threat. Switching of the power grid can cause transients which may damage down line equipment. The use of thyristors in switching circuits or power control can also create such transients.

Studies and laboratory investigation of residential and industrial low voltage AC power systems have shown that the amplitude of the transient is proportional to the rate of its occurrence, i.e. lower magnitude transients occur most often. Governing standards bodies, in particular IEEE and ANSI, have established a document which gives practical guidelines of the transient environment one may expect to encounter in a low voltage AC power system. This document is called the ANSI/IEEE standard C62.41 and was developed in 1980. Since its inception, more accurate information has become available on the transient environment and this has led to the generation of an updated standard, which should be available later this year.

Rate of Occurrence

The rate of occurrence of surges varies quite a lot and is dependent upon the particular power system. Rate is related to the level of surges and low magnitude surges are more common than high level surges. Data from many sources have shown that surges of 1kV or less are relatively common, while surges of 3kV are more rare. The data generated from the studies was used to generate the curve shown in Figure 1. This curve shows with certainty only a relative frequency of occurrence, while the absolute number of occurrences can be described in terms of "low exposure", "medium exposure" and "high exposure".



*In Some Locations, Sparkover of Clearances May Limit the Overvoltages.

FIGURE 1. RATE OF SURGE OCCURRENCES vs VOLTAGE LEVEL AT UNPROTECTED LOCATIONS

An area described as a "low exposure" area would have very little lightning activity and few switching loads on the AC power system. A "medium exposure" area is known for high lightning activity, with frequent and severe switching transients. When designing equipment for the global environment it is expedient that it be, at least, designed for use in an area with "medium exposure" transient occurrences. "High exposure" areas are rare but real systems supplied by long overhead transmission lines and subject to reflections at line ends, where the characteristics of the installation produce high sparkover levels of the clearances.

All indoor low-voltage AC power systems have an inherent protection system built into the wiring of the building. Wiring systems used in 120V - 240V systems have a natural spark-over level of 6000V. This 6kV level has therefore been selected as the worst case cutoff for the occurrence of transients in the indoor power system. The transient generated by spark-over creates a high energy, low impedance pulse. The further away from the source of the transient the protected equipment is located, the more the energy is absorbed in the wiring impedance and the more the equipment is protected. This, therefore, allows different size suppressors to be used at different locations in the system.

Representative Transients

Table 1 reflects the surge voltages and currents deemed to represent the indoor transient environment in a low-voltage AC power system. When deciding on the type of device to use as a transient voltage surge suppressor, it is recommended that the device selected have, as a minimum, the capability to handle the conditions called out in location Category A of Table 1. The optimum device would preferably have a minimum capability of surviving the transient occurrences called out in location Category B.

TABLE 1. SURGE VOLTAGES AND CURRENTS DEEMED TO REPRESENT THE INDOOR ENVIRONMENT

LOCATION CATEGORY		IMPULSE	
		WAVEFORM	MEDIUM EXPOSURE
A	Long Branch Circuits and Outlets	0.5µs 100kHz	6kV 200A
B	Major Feeders and Short Branch Circuits	1.2/50µs 8/20µs	6kV 3kA
		0.5µs 100kHz	6kV 500A

The investigation into the indoor low voltage system revealed that location Category A encounters transients with oscillatory waveshapes with frequency ranges from 5kHz to more than 500kHz; the 100kHz being deemed most common (Figure 2). Surges recorded at the service entrance, location Category B, are both oscillatory and unidirectional in nature. The typical "lightning surge" has been established as 1.2/50µs voltage wave and 8/20µs current wave (Figure 3).

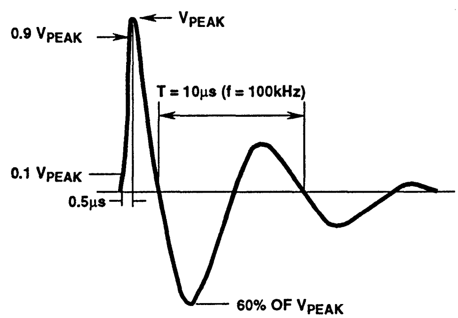
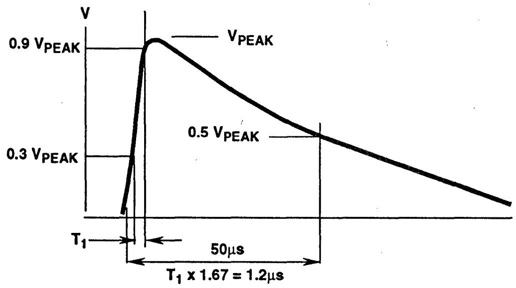
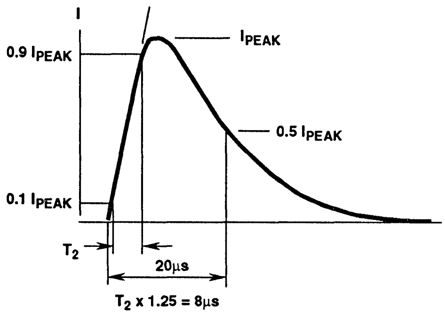


FIGURE 2. 0.5µs - 100kHz RING WAVE (OPEN CIRCUIT VOLTAGE)



(a) OPEN-CIRCUIT WAVEFORM



(b) DISCHARGE CURRENT WAVEFORM

FIGURE 3. UNIDIRECTIONAL WAVESHAPES (OUTDOOR LOCATIONS)

Transient Protection

Once it has been decided to include transient suppression in the design of equipment, the next stage in the process is to decide on what protection technology to use and on how to use it. The transient suppressor selected must be able to suppress surges to levels which are below the failure threshold of the equipment being protected, and the suppressor must survive a definite number of worst case transients. When comparing the various devices available considerations must be given to characteristics such as protection levels required, component survivability, cost, and size.

There are a number of different technologies available for use as a transient suppressor in the low voltage AC mains system. Generally speaking, these can be grouped into two major categories of suppressors: a) those that attenuate transients, thus preventing their propagation into the sensitive circuit; and b) those that divert transients away from sensitive loads and so limit the residual voltage.

Attenuating a transient - that is, keeping it from propagating away from its source or keeping it from impinging on a sensitive load - is accomplished with by placing either filters or isolating transformers in series within a circuit. The *isolator* attenuates the transient (high frequency) and allows the signal or power flow (low frequency) to continue undisturbed.

Diverting the transient can be accomplished with a crowbar type device or with a voltage clamping device. *Crowbar* device types involve a switching action, either the breakdown of a gas between electrodes or the turn on of a thyristor. After switching on, they offer a very low impedance path which diverts the transient away form the parallel-connected load. *Clamping* devices have a varying impedance which depends, either, on the current flowing through the device or on the voltage across the terminals. These devices exhibit a nonlinear impedance characteristic. The variation of the impedance is monotonic; that is, it does not contain discontinuities in contrast to the crowbar device, which exhibits a turn on action.

Filters

The installation of a filter in series with the equipment seems an obvious solution to overvoltage conditions. The impedance of a low pass filter, e.g. a capacitor, forms a voltage divider with the source impedance. As the frequency components of a transient are several orders of magnitude above the power frequency of the AC circuit, the inclusion of the filter will result in attenuation of the transient at high frequencies. Unfortunately, this simple approach may have some undesirable side affects; a) unwanted resonances with inductive components located elsewhere in the system leading to high voltage peaks, b) high inrush currents during switching and c) excessive reactive load on the power system voltage. These undesirable effects can be reduced by adding a series resistor, hence the popular use of RC snubber networks. However, the price of the added resistance is less effective clamping.

There is a fundamental limitation to the use of a filter for transient suppression. Filter components have a response which is a linear function of current. This is a big disadvantage in a situation where the source of the transient is unknown and it is necessary to assume a source impedance or an open-circuit voltage. If the assumption of the characteristics of the impinging transient are incorrect the consequences for a linear suppressor is dramatic. A slight change in the source impedance can result in a disproportionately increase in clamping voltage[6].

Isolation Transformers

Isolation transformers generally consist of a primary and secondary windings with an electrostatic shield between the windings. The isolation transformer is placed between the source and the equipment requiring protection. As its name suggests, there is no conduction path between the primary and secondary windings. A widely held belief is that "isolation transformers attenuate voltage spikes" and "that transients do not pass through the windings of the transformer". When properly applied, the isolation transformers is useful to break ground loops, i. e. block common-mode voltages.

Unfortunately, a simple isolation transformer provides no differential-mode attenuation[7]. Thus, a differential-mode transient will be transmitted through the windings of the device. Also, an isolation transformer will not provide any voltage regulation.

Spark Gaps and Gas Tubes

Spark gap suppression is a crowbar suppression technology. During an overvoltage condition, a crowbar device changes from being an insulator to an almost ideal conductor. Crowbars suppress transients by brute force, (they have the effect of dropping a metal crowbar across the system). The main type of crowbar device is the gas tube surge arrester.

The original offering in the spark gap surge suppression family was a carbon blocks. The carbon block suppressor used the principle of a voltage arcing across an air gap. The air gap breaks down at approximately 150V per thousands of an inch. The minimum size gap was used to provide the lowest level of protection without disturbing regular system operation. When a transient overvoltage occurred in the system, the air gap in the carbon block would ionize and break down. The breakdown of the gap forms a very low impedance path to ground thus diverting the surge away from the equipment. As soon as the overvoltage condition was removed, the air gap is restored and system operation is continued.

The disadvantage of carbon block spark gap technology was that short duration pulses "pitted" the surface of the carbon blocks, thus removing small pieces of the face material. This material builds up after a number of surges, eventually causing a permanently shortened gap resulting in the need for protector replacement. This had a very adverse effect on the maintenance and replacement costs of the protection circuit. Another disadvantage of this technology was the difficulty in exactly controlling the breakdown characteristics over a wide variety of operating conditions.

In an effort to overcome the disadvantages of the carbon block, a sealed spark gap was developed which uses an inert gas in a sealed ceramic envelope. This technology is known as a gas tube surge arrester. In a non conducting mode the impedance of the gas is in the gigiohms region. The gas is set to ionize at a predetermined voltage and offers an extremely low impedance path to ground. Once the overvoltage condition is removed the gas deionizes and the circuit restores itself to its normal operating condition.

The gas tube arrester is an inherently bidirectional device and is comprised of either two or three electrodes lying opposite each other in the sealed chamber. When the voltage across the arrester terminals exceeds a certain limit, known as the firing or breakdown voltage, it triggers an electric arc. This arc limits the voltages applied to the connected equipment. Gas tubes have typical DC firing voltages between 150V and 1000V. They have the smallest shunt resistance of all nonlinear transient suppressors, typically in the milliohm range. Their capacitance is low, between 1pF and 5pF, and they are commonly found in high frequency transmission applications, such as telephone systems. Another advantage of this technology is its ability to handle large currents (up to 20kA).

Gas tubes are transient duration dependent and do not operate very successfully in a fast rising transient environment. In the case of a 120V AC line, one would expect to use a gas tube with a firing voltage of approximately 200V DC. Under a transient condition of 100V per microsecond, the actual firing voltage of the gas tube turns out to be over 500V[5]. This slow response, resulting from the finite time required for the gas to ionize, means that a transient will be allowed to get through to the equipment. Also, when faced with repeated surges, gas tubes tend to wear out over time.

In applications where there is a normal operating voltage, as in the AC mains, there is a possibility that the gas tube will not reset itself once it has fired and suppressed the transient. This condition is known as follow on current and is defined by ANSI "as the current that passes through a device from the connected power source following the passage of discharge current". Follow on current will maintain conduction of the ionized gas after the transient has disappeared and the concern is that the follow on current may not clear itself at a natural current zero and will result in a permanently destroyed gas tube. In an AC mains application, it is not sufficient to rely solely on the crossings of the sinusoidal voltage to extinguish the follow current. If a gas tube is to be used in this type of application, then a current limiting device must be inserted in series between the gas tube and the source of the follow current.

Silicon Avalanche Diodes

Although rarely used on AC mains application, due to their very low transient surge capability, silicon avalanche diodes are an excellent surge suppressor in low voltage DC applications. Avalanche diodes are designed with a wider junction than a standard zener diode. This wide junction gives them a greater ability than a zener to dissipate energy. Avalanche diodes offer the tightest clamping voltage of available devices. When a voltage greater than the device breakdown is applied, the diode will conduct in the reverse direction.

A peak pulse power rating is usually given on diode datasheets. Common values are 600W and 1500W. This peak pulse power is the product of the maximum peak pulse current, I_{PP}, and the maximum clamping voltage, V_C, at a current of I_{PP} during a 10/1000μs transient duration. Use of peak power ratings may be confusing when transients of other than 10/1000μs are to be considered. A maximum energy rating for non-repetitive, short duration transients, similar to that supplied with MOVs, may be of more benefit to design engineers.

The V-I characteristics are the best features of the avalanche diode. Low voltage devices look extremely good. The avalanche diodes has an excellent clamping voltage capability, but only over a small range of current (1 decade). The biggest disadvantage to using the avalanche diode as a transient suppressor on an AC mains line is its low peak current handling capability. Due to their being, at most, only two P-N junctions in a device their is very little material available for the dissipation of the peak power generated during high energy pulses.

Metal Oxide Varistor (MOV)[6]

A metal oxide varistor (MOV) is a nonlinear device which has the property of maintaining a relatively small voltage change across its terminals while a disproportionately large surge current flows through it. This nonlinear action allows the MOV to divert the current of a surge when connected in parallel across a line and hold the voltage to a value that protects the equipment connected to that line. Since the voltage across the MOV is held at some level higher than the normal line voltage while surge current flows, there is energy deposited in the varistor during its surge diversion function.

The basic conduction mechanism of a MOV results from semiconductor junctions (P-N junctions) at the boundaries of the zinc oxide grains. A MOV is a multi junction device with millions of grains acting as a series-parallel combination between the electrical terminals. The voltage drop across a single grain in nearly constant and is independent of grain size.

The material of a metal oxide varistor is primarily zinc oxide with small additions of bismuth, cobalt, manganese and other metal oxides. The structure of the body consists of a matrix of conductive zinc oxide grains separated by grain boundaries, which provide the P-N junction semiconductor characteristics. When the MOV is exposed to surges, the zinc oxide exhibits a "bulk action" characteristic permitting it to conduct large amounts of current without damage. The bulk action is easily explained by imagining this material to be made up of an array of semiconducting P-N junctions arranged electrically in series and parallel so that the surge is shared among all of the grains. Because of the finite resistance of the grains, they act as current limiting resistors and, consequently current flow is distributed throughout the bulk of the material in a manner which reduces the current concentration at each junction.

The MOV has many advantages which make it ideal for use as a suppressor on the low voltage AC power line. The bulk nature of its construction gives it the required energy handling capability to handle the secondary level transients resulting from indirect lightning hits.

MOVs are both cost and size effective, are widely available and do not have a significant amount of overshoot. The flexibility available in the manufacturing of these devices means that different size varistors are available for transient suppression in all categories of the ANSI/IEEE C62.41 standard. They have no follow on current and their response time is more than sufficient for the types of transients encountered in the AC mains environment.

One perceived disadvantage of a MOV is the degradation which is perceived to be suffered by the varistor under a long period of repetitive transient overvoltages. A common misconception is that the device is irreversibly damaged every time it has to suppress a transient. *This is not the case!*

Under high energy transient conditions in excess of the device ratings, the V-I characteristics of the varistor are seen to change. This change is reflected in a decrease in the nominal varistor voltage. After applying a second or third pulse the nominal varistor voltage can be seen to return to its original value (Figure 4). To be conservative, peak pulse limits have been established which, in many cases, have been exceeded many fold without causing harm to the device. Field studies and laboratory tests have shown that the degradation which may result, after a number of pulses outside the ratings of the device, is safe for the equipment being protected. This does not mean that the established limits should be ignored but rather viewed in the perspective of the definition of a failed device. A failed device shows a ± 10% change in the nominal varistor voltage at the 1mA point. This does not imply a non-protecting device, but rather a device whose clamping voltage has been slightly altered.

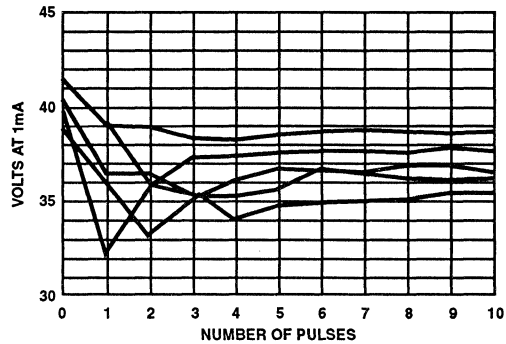


FIGURE 4. REPETITIVE PULSE WITHSTAND CAPABILITIES

The avoidance of this form of failure mode is extremely simple. Harris Semiconductor, the leading manufacturer of varistors in this country, recommends that the way to ensure the degradation failure mode is avoided is to follow the simple rule; "Select the correct size of varistor". Time and again it has been proven that this type of failure mode only occurs when an incorrect sized/rated device is used.

Device Comparisons

A range of standard varistors, avalanche diodes, gas tube arresters and filter capacitors were evaluated under a 6kV, 0.5µs x 100kHz ring wave. This transient replicates that called out in location Category A of the ANSI/IEEE C62.41 and is the most benign condition expected in this location. All of the selected devices are rated for use on a 120V AC line. The results obtained from this evaluation are per Table 2.

TABLE 2. COMPARATIVE PERFORMANCE DATA[8]

PROTECTION TECHNOLOGY	DEVICE PART NUMBER	AVERAGE PROTECTION LEVEL (kV)	FAILS/ SAMPLE SIZE
Metal Oxide Varistor	V130LA1	0.51	0/10
	V130LA5	0.50	0/10
	V130LA10A	0.49	0/10
Silicon Avalanche Diode	1.5KE200C	0.48	2/10
Gas Tube Surge Arrester	CG2-230	0.67	0/10
Filter Capacitor	C280A-EA4K7	1.30	0/10

The conclusions from this evaluation were: a) the silicon avalanche diode had the lowest level of performance; b) since location Category A is the location requiring the smallest sized suppressor, how can a device which does not survive this testing be considered an adequate suppressor?

Not only does the avalanche diode fail, but it is also very expensive when compared with an equivalently rated metal oxide varistor. There are avalanche diodes available, in the 15kW family, which absorb large amounts of energy and it is assumed that these devices will meet the transient requirements of this test. From a cost comparisons, these devices are 15 - 20 times more expensive than an equivalent MOV.

This test further verifies that avalanche diodes become less effective at higher voltages - that is as the voltage rating increases their current capability decreases. Just the opposite is true for the metal oxide varistor. To overcome the avalanche diode's weaknesses, devices are connected in series. In this situation its best feature - clamping voltage - now becomes its downfall. Even with extremely close matching of the VI characteristics, there can be large differences in current distribution when the devices are paralleled. Metal oxide varistors are not generally recommended for parallel operation, since they must also be matched, but the matching is to a lesser degree than in diodes.

One of the primary requirements for a device rated for suppression of transients on the AC mains is its ability to handle large amounts of energy. In order for a device to have a high energy handling capability, it requires a large amount of bulk material with a high specific heat value in the immediate vicinity of the P-N junctions. The primary material in a metal oxide varistor is zinc oxide and the average grain size for a MOV used in an AC application is 20 microns. Observations over a range of compositional variations and processing conditions show a fixed voltage drop of between 2V - 3V per grain with boundary junctions evenly distributed along their edges. In the case of a 14mm varistor, part number V130LA10A, which is commonly used in protection of equipment in Category B locations, it would have an approximate volume of 220mm^3 of material in the immediate vicinity of the P-N grain junctions. An equivalent silicon avalanche diode would have approximately 0.106mm^3 in their single P-N junction vicinity. Comparing the volume of the varistor and the diode in the immediate vicinity of the junction, the varistor has more than 2000 times a larger mass available. Thus, the peak temperature in the bulk material of the varistor per energy absorbed is much lower than that for the single silicon avalanche diode junction. It is the millions of P-N junctions, which are an integral part of the MOV structure, that gives it excellent thermal and energy handling properties.

Device Selection

After evaluating the advantages and disadvantages of the various suppression technologies available, the device of choice is clearly the metal oxide varistor. Once the decision has been made as to which technology to use, it is now necessary to decide on the actual device to select for a particular application.

Metal oxide varistors have a wide variety of options available in each voltage family. These offerings cover the large number of different applications in the low voltage AC environment, plus they address the different prevailing trains of thought on the correct device to use. Device rating is dependent on device size and within each voltage family are a number of different rated parts. Common sizes of varistor are 7, 10, 14, 20, 32, 40 and 60mm, with a number of different package options also available in each size. This advantage of the flexibility in the manufacturing of the MOV also, unfortunately, tends to confuse the user as to how select the correct device for a particular application.

To select the correct varistor for a specific application, determine the following information:

1. The maximum system RMS voltage.
2. How is the MOV to be connected?
3. The MOV with a voltage 10% - 25% above system voltage.
4. The worst-case transient energy that will need to be absorbed by the MOV. (Use the guidelines called out in ANSI/IEEE C62.41 -1980).
5. The clamping voltage required for system protection (As device size increases, for a given voltage family, the clamping voltage gets better).

References

1. "ANSI/IEEE C62.41 -1980 Guide On Surge Voltages In Low-Voltage AC Power Circuits"
2. "Voltage Transients and Their Suppression", Corbett, M.,
3. "Understanding AC Line Transient Immunity", Dash, G. and Straus, I.,
4. "Suppression Of Voltage Transients Is An Art Trying To Be A Science", GE # 660.33
5. "Surge Protection of Electronics", Haskell, Jr., N.H., P.E.
6. "Transient Voltage Suppression Devices", Harris Semiconductor DB450.2
7. "The Propagation and Attenuation of Surge Voltages and Currents in Low Voltage AC Circuits", Martzloff, F.D., - 1984
8. "Protective Level Comparison of Voltage Transient Suppressors", Hopkins, D.C.
9. "Comparison of Transient Suppressors!", Korn, S.

THE ABCs OF MOVs

Author: Martin Corbett

The ABCs of MOVs

The material in this guide has been arranged in 3 parts for easy reference; Section A, Section B and Section C.

"A" is for Applications

This section provides general guidelines on what types of MOV products are best suited for particular environments.

B" is for Basics

This section explains what Metal Oxide Varistors are, and the basic function they perform.

"C" is for Common Questions

This section helps clarify important information about MOVs for the design engineer, and answers questions that are asked most often.

Want to know more? For a copy of the latest Harris MOV data book, please contact your local Harris sales representative, or call 908-685-6000 and ask for Power/MOV Applications.

Applications

To properly match the right MOV with a particular application, it is desirable to know:

1. The maximum system RMS or DC voltage.
2. The MOV voltage at 10 - 25% above maximum system voltage.
3. The worst-case transient energy that will need to be absorbed by the MOV.

When the above information is available, these charts offer basic application guidelines:

AC VOLTAGE (V)	ENERGY (J)	PACKAGING & OTHER CONSIDERATIONS	PREFERRED MOV FAMILY
AC APPLICATIONS			
130-1000	11-360	Through-Hole Board Mounting Low/Medium AC Power Lines	LA Series "C" III Series
130-660	70-250	Shock/Vibration Environment Quick Connect Terminal	PA Series
130-275	11-23	Surface Mount	CH Series
130-750	270-1050	High-Energy Applications Shock/Vibration Environment	DA Series HA Series NA Series DB Series
130-880	450-3200	Primary Power Line Protection	BA Series
1100-2800	3800-10000	Rigid Terminal for Secure Wire Contact	BB Series
DC APPLICATIONS			
4-460	0.1-35	Through-Hole Board Mounting Automotive Applications	ZA Series
10-115	08-10	Surface Mount	CH Series
9-431	0.06 - 1.70	Axial Leaded	MA Series

APPLICATION	PREFERRED MOV FAMILY
TV/VCR/White Goods	ZA, LA, "C" III, CH and MA Series
Motor Control	ZA, LA, "C" III, PA, HA, NA, BA, BB, DA and DB Series
Transformer (Primary Protection)	ZA, LA, "C" III, PA, BA, BB, DA, DB, HA and NA Series
Instrumentation	MA, ZA and CH Series
Automotive (Primary/Secondary Protection)	ZA and CH Series
Noise Suppression	MA, CH, ZA and LA, "C" III Series
Power Supply	PA, LA, "C" III, ZA, HA, NA, BA, BB, DA and DB Series
Transient Voltage Suppressor Strip	LA, "C" III, HA and NA Series

Basics

What is a Harris MOV?

A Harris MOV is a Metal Oxide Varistor. Varistors are voltage dependent, nonlinear devices which have an electrical behavior similar to back-to-back zener diodes. The varistor's symmetrical, sharp breakdown characteristics enable it to provide excellent transient suppression performance. When exposed to high voltage transients, the varistor impedance changes many orders of magnitude from a near open circuit to a highly conductive level and clamps the transient voltage to a safe level. The potentially destructive energy of the incoming transient pulse is absorbed by the varistor, thereby protecting vulnerable circuit components and preventing potentially costly system damage.

What is a Harris MOV Made Of?

The Harris varistor is composed primarily of zinc oxide with small additions of bismuth, cobalt, manganese and other metal oxides. The structure of the body consists of a matrix of conductive zinc oxide grains separated by grain boundaries which provide P-N junction semiconductor characteristics.

What is the Scope of the Harris MOV Product Line?

Standard Harris varistors are available with AC operating voltages from 4V to 3200V. Higher voltages are limited only by packaging ability. Peak current handling exceeds 70,000 amps, and energy capability extends beyond 10,000 joules for the larger units. Package styles include the tiny tubular device used in connectors, and progress in size up to the rugged industrial blocks.

Common Questions

Approvals

Q. Are MOVs subject to UL listing or CSA approval?

A. Yes. All Harris MOVs rated at 1 30V_{RMS} or higher are UL-listed under file number E75961 and/or E56529. (These include all BA/BB, DA/DB, LA and PA series devices as well as ZA devices.) The epoxy encapsulant complies with UL flammability code UL94-VO. Under UL Standard 497B, all ZA and LA series devices are UL approved to file number E135010. Many Harris MOVs are CSA- approved, including LA and PA series types. Check the latest copy of the Harris MOV data book for complete, up-to-date approvals.

Automotive Environment

Q. How can a radial MOV meet the automotive requirements for temperature cycle and 125°C operating temperatures?

A. On request. Harris MOVs can be coated with a special phenolic material that withstands these harsh conditions. Special part number designations will be assigned.

Connecting MOVs for Added Protection

Q. Can MOVs be connected in parallel?

A. Yes. The paralleling of MOVs provides increased peak current and energy-handling capabilities for a given application. The determination of which MOVs to use is a critical one in order to ensure that uniform current sharing occurs at high transient levels. It is recommended that Harris performs this screening and selection process.

Q. Can MOVs be connected in series to provide greater protection?

A. Yes. MOVs can be connected in series to provide voltage ratings higher than those normally available, or to provide ratings between the standard offerings.

Q. How are MOVs connected for single-phase and three-phase protection?

A. FOR SINGLE-PHASE AC: The optimum protection is to connect evenly rated MOVs from hot-neutral, hot-ground and neutral-ground. If this configuration is not possible, connection between hot-neutral and hot-ground is best.
FOR THREE-PHASE AC: Please refer to the Harris MOV data book.

Current, Steering or Directing

Q. Does an MOV simply steer current?

A. No. It is incorrect to believe that an MOV device merely re-directs energy. In fact, the MOV dissipates heat energy within the device by actually absorbing this energy. The degree or level to which this absorption can take place is dependent on the energy rating of the device.

Date Codes

Q. Can you explain the date codes on a Harris MOV?

A. The date code tells you when the device was manufactured. It consists of a letter (which represents the month) followed by a number (which represents the year). Here is the code: A = January, C = February, E = March, G = April, J = May, L = June, N = July, P = August, S = September, U = October, W = November, Y = December; 9 = 1989, 0 = 1990,1 = 1991, 2 = 1992. For example: Using this system, a date code of "A1" tells you the product was manufactured in January 1991.

Failure of Device and Fuse Selection

Q. How does an MOV fail?

A. An MOV is designed to fail as a short circuit. If applied conditions significantly exceed the energy rating of the device, the MOV may be completely destroyed. For this reason, the use of current-limiting fuses is suggested.

Q. How do you select a fuse to prevent failure of an MOV?

A. Fuses should be chosen to limit current below the level where damage to the MOV package could occur. Specific guidance is provided in the Harris MOV data book. Generally, the fuse should be placed in series with either the varistor or the line.

Heavy Metals

Q. Are heavy metals such as cadmium or mercury used in the manufacture of Harris MOVs?

A. No. There are no heavy metals used in the manufacture of Harris MOVs.

Lead Inductance/Lead Forms/Lead Coating

Q. Does lead inductance/capacitance affect MOV performance?

A. Yes. Transient wave forms with steep fronts (≤1μs) and in excess of several amps produce an increase in voltage across the varistor. This phenomenon, a characteristic of all leaded devices including zeners, is known as overshoot. Unlike zeners, however. MOVs are available without leads. Our CH and CPV/CS series, for example, consist of leadless components which do not exhibit overshoot.

Q. What standard lead forms are available an Harris radial MOVs?

A. Radial lead types include outcrimp, undercrimp and inline configurations. This broad offering helps meet several criteria for circuit board components (e.g., mechanical stability, lead length and solder ability). Harris radial MOVs are also available in tape-and-reel packaging to accommodate auto-insertion equipment.

Q. Are MOV leads coated or tinned?

A. Yes. All leads are electroplated to provide a uniform surface. This process ensures that a subsequent solder coat may be evenly applied.

Part Numbering

Q. What information does an MOV part number provide?

A. MOV part numbers were created to impart product data. Each designation follows the pattern: LETTER/NUMBER/LETTER/NUMBER/LETTER.

Letter.... The prefix "V" stands for Varistor.

Number.. Depending on the product family. this number indicates either a) the maximum $AC_{(RMS)}$ continuous voltage the device can handle. or b) the nominal DC voltage (measured with a 1 mA test current through the varistor).

Letter ....These two letters (LA, DB, PA, etc.) correspond to a specific product series and package configuration.

Number...This number represents the relative energy rating.

Letter ....This final letter indicates the voltage selection of the device.

Q. Why isn't the entire part number branded on the device?

A. The small size of some components cannot accommodate the relatively lengthy part number. Consequently, abbreviated brands are used. The Harris MOV data book lists these abbreviated brands (along with their corresponding factory part numbers) in the device ratings and characteristics tables of each series.

Sensitivity

Q. Are MOVs sensitive to polarity?

A. No. MOVs can be used in a bi-directional mode, and provide equal protection in both directions.

Q. Are MOVs sensitive to electrostatic discharge?

A. No. In fact, MOVs are specifically designed to protect sensitive integrated circuits from ESD spikes.

Q. Generally speaking, are MOVs sensitive to chemical/ pressure when potted?

A. No.

Speed of Response, Compared to Zeners

Q. Are zeners significantly faster than MOVs?

A. No, not to the extent of the claims made by many zener manufacturers. The intrinsic response time of MOV material is 500 picoseconds. As the vast majority of transients have a slower rise time than this, it is of little or no significance to compare speeds of response. The response time of a leaded MOV or zener is affected by circuit configuration and lead inductance.

Voltage Regulation, Voltage Limits

Q. Can an MOV be used as a voltage regulator?

A. No. MOVs function as nonlinear impedance devices. They are exceptional at dissipating transient voltage spikes, but they cannot dissipate continuous low level power.

Q. Is it possible to get MOVs with voltages other than those listed in the data book?

A. Yes. The Harris MOV data book discusses standard voltages only. Application-specific MOVs with voltages tailored to customer requirements can be manufactured upon request. Contact your Harris sales representative to discuss your individual needs.

Harris Semiconductor

APPNOTE

No. AN9312.1 August 1993

Harris MOVs

SUPPRESSION OF TRANSIENTS IN AN AUTOMOTIVE ENVIRONMENT

Author: Martin Corbett

Introduction

Market surveys have shown that, while the automotive market is growing about 2% a year in terms of new cars, the actual content of electronics in the car is growing much faster. The initial stage of the introduction of electronics into the automobile began with discrete power devices and IC components. These were to be found in the alternator rectifier, the electronic ignition system and the voltage regulator. This was followed by digital ICs and microprocessors, which are common in engine controls and trip computers. As semiconductor capability continues to expand, the usage of smart power devices and massive memories will become common. The benefits of this smart power will be found in improved electronic controls and shared visual displays. To completely benefit from these advances, protection from transient overvoltages must be supplied.

Transient Environment

As the control circuitry in the automobile continues to develop, there is a greater need to consider the capability of new technology in terms of survivability to the commonly encountered transients in the automotive environment. The circuit designer must ensure reliable circuit operation in this severe transient environment. The transients on the automobile power supply range form the severe, high energy, transients generated by the alternator/regulator system to the low-level "noise" generated by the ignition system and various accessories. A standard automotive electrical system has all of these elements necessary to generate undesirable transients (Figure 1).

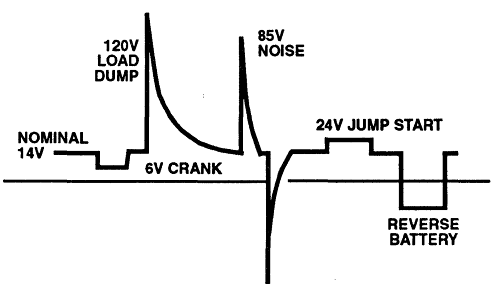


FIGURE 1. TYPICAL AUTOMOTIVE TRANSIENTS

Unlike other transient environments where external influences have the greatest impact, the transient environment of the automobile is one of the best understood. The severest transients result from either a load dump condition or a jump start overvoltage condition. Other transients may also result from relays and solenoids switching on and off, and from fuses opening.

Load Dump

The load dump overvoltage is the most formidable transient encountered in the automotive environment. It is an exponentially decaying positive voltage which occurs in the event of a battery disconnect while the alternator is still generating charging current with other loads remaining on the alternator circuit at the time of battery disconnect. The load dump amplitude depends on the alternator speed and the level of the alternator field excitation at the moment of battery disconnection. A load dump may result from a battery disconnect resulting from cable corrosion, poor connection or an intentional battery disconnect while the car is still running.

Independent studies by the Society of Automotive Engineers (SAE) have shown that voltage spikes from 25V to 125V can easily be generated[1], and they may last anywhere from 40ms to 400ms. The internal resistance of an alternator is mainly a function of the alternator rotational speed and excitation current. This resistance is typically between 0.5Ω and 4Ω (Figure 2).

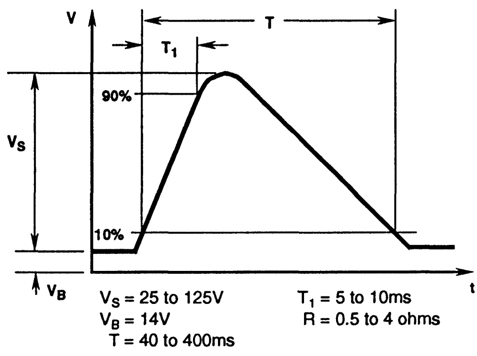


FIGURE 2. LOAD DUMP TRANSIENT

Jump Start

The jump start transient results from the temporary application of an overvoltage in excess of the rated battery voltage. The circuit power supply may be subjected to a temporary overvoltage condition due to the voltage regulator failing or it may be deliberately generated when it becomes necessary to boost start the car. Unfortunately, under such an application, the majority of repair vehicles use 24V "battery" jump to start the car. Automotive specifications call out an extreme condition of jump start overvoltage application of up to 5 minutes.

The Society of Automotive Engineers(SAE) has defined the automotive power supply transients which are present in the system.

Table 1 shows some sources, amplitudes, polarity, and energy levels of the generated transients found in the automotive electrical system[2].

TABLE 1. TYPICAL AUTOMOTIVE TRANSIENTS

LENGTH OF TRANSIENT	CAUSE	ENERGY CAPABILITY / VOLTAGE AMPLITUDE	FREQUENCY OF OCCURRENCE
Steady State	Failed voltage regulator	•	Infrequent
		+18V	
5 minutes	Jump starts with 24V battery	•	Infrequent
		±24V	
200ms to 400ms	Load dump; disconnection of battery while at high charging	> 10J	Infrequent
		< 125V	
< 320µs	Inductive-load switching transient	< 1J	Often
		300V to +80V	
200ms	Alternator field decay	< 1J	Each Turn-Off
		-100V to -40V	
90ms	Ignition pulse, battery disconnected	< 0.5J	< 500Hz Several Times in Vehicle Life
		< 75V	
1ms	Mutual coupling in harness	< 1J	Often
		< 200V	
15µs	Ignition pulse, normal	< 0.001J	< 500Hz Continuous
		3V	
	Accessory noise	< 1.5V	50Hz to 10kHz
	Transceiver feedback	≈20mV	R.F.

The achievement of maximum transient protection involves many factors. First, consequences of a failure should be determined. Current limiting impedances and noise immunities need to be considered. The state of the circuit under transient conditions (on, off, unknown) and the availability of low cost components capable of withstanding the transients are other factors. Furthermore, the interaction of other parts of the automotive electrical system with the circuit under transient conditions may require definition.

Suppressor Applications[3]

The sensitive electronics of the automobile need to be protected from both repetitive and random transients. In an environment of random transients, the dominating constraints are energy and clamping voltage vs standby power dissipation. For repetitive transients, transient power dissipation places an additional constraint on the choice of suppression device.

It must also be noted that the worst case transient scenarios, load dump and jump start, place conflicting constraints on the automotive suppressor. The high energy content of the load dump transient must be clamped to a worst case voltage of 40V, while the leakage current/power dissipation drawn under a jump start condition must also be kept to a minimum.

A centrally located suppressor is the principal transient suppression device used in most automobiles. It is connected directly across the main power supply line without any intervening load resistance. It must be capable of absorbing the entire available load dump energy, and must also withstand the full jump start voltage. To be cost effective, it is usually located in the most critical electronic module. Additional secondary suppression is also employed at other locations in the system for further suppression and to control locally generated transients.

As previously mentioned, the maximum load dump energy available to the central suppressor depends on a combination of the alternator size and the loads that share the surge current and energy which are thus generated. It must be remembered that there are many different automotive electronic configurations which result in a variety of diverse load dumps.

MultiLayer Transient Voltage Surge Suppressor (AUML)[4,5]

The new automotive multilayer (AUML) transient voltage suppressor is a voltage dependent, nonlinear device. It has an electrical behavior similar to that of a back-to-back zener diodes and it is inherently bidirectional. It offers protection from transients in both the forward and reverse directions. When exposed to high voltage transients, the AUML undergoes a nonlinear impedance change which is many orders of magnitude, from approximately 10^9 to 10Ω.

The crystalline structure of the AUML transient voltage suppressor consists of a matrix of fine, conductive grains separated by uniform grain boundaries, forming P-N junctions (Figure 3). These boundaries are responsible for blocking conduction at low voltages, and are the source of the nonlinear electrical conduction at higher voltages. Conduction of the transient energy takes place between the millions of P-N junctions present in the device. The uniform crystalline grains act as heat sinks for the energy absorbed by the device under a transient condition, and ensures an even distribution of the transient energy (heat) throughout the device. This even distribution results in enhanced transient energy capability and long term reliability.

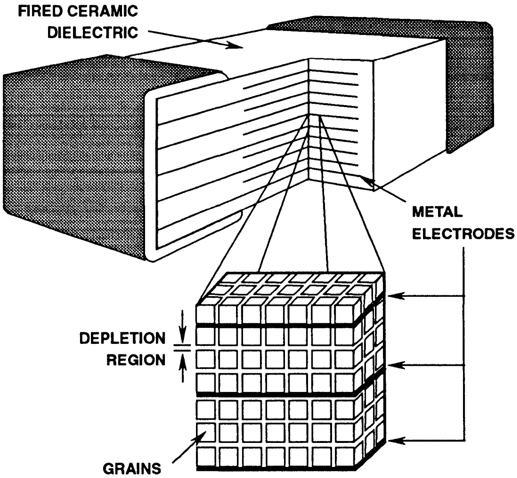


FIGURE 3. AUML TRANSIENT VOLTAGE SUPPRESSOR

The AUML is constructed by forming a combination of alternating electrode layers and semiconducting ceramic layers into a rectangular block. Each alternate layer of electrode material, separated by ceramic semiconducting material, is connected to opposite end terminations of the device.

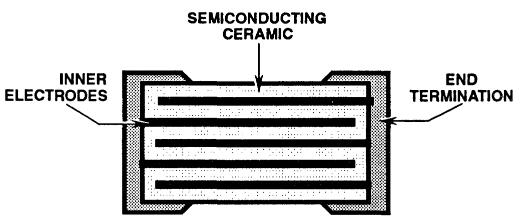


FIGURE 4. AUML INNER CONSTRUCTION

The paralleled arrangement of the inner electrode layers represents significantly more active surface area than the small outline of the package may suggest (Figure 4). This increased active surface area, combined with an interdigitated block formation, results in proportionally higher peak energy capability.

The AUML surge suppressor is a surface mountable device that is much smaller in size than the components it is designed to protect. The present size offerings for suppression in the automotive environment are "1210" (0.120 x 0.100 inches), "1812" (0.180 x 0.120 inches) and "2220" (0.220 x 0.200 inches). The correct device to use depends on the location of the suppressor in the overall electronics system.

Device Ratings and Characteristics

Package Outline

The present size offerings of the AUML series are the industry 2220, 1812 and 1210 standard form factors. Since the AUML device is inherently bidirectional, symmetrical orientation for placement on a printed circuit board is not a concern. Its robust construction makes it ideally suitable to endure the thermal stresses involved in the soldering, assembling and manufacturing steps involved in surface mount technology. The AUML device is inherently passivated by means of the fired ceramic material. They will not support combustion and are thus immune to the risk of flammability which may be present in the plastic or epoxy molded diode devices.

Load Dump Energy Capability

The most damaging classification of transients an automobile must survive is a load dump discharge occurrence. A load dump transient occurs when the alternator load in the automobile is abruptly reduced and the battery clamping effect is thus removed. The worst case scenario of the load dump occurs when the battery is disconnected while operating at full rated load. The resultant load dump energy handling capability serves as an excellent figure of merit for the AUML suppressor.

Standard load dump specifications require a device capability of 10 pulses at rated energy, across a temperature range of -40°C to +125°C. This capability requirement is well within the ratings of all of the AUML series.

Due to the assortment of electronic applications in an automotive circuit, there is a need for a wide range of surge suppressors. The transient environment can generally be divided into three distinct sections and there will be a need for a different type of suppressor within each section. The 2220 size was designed for operation in the primary transient area, i.e. directly across the alternator. The 1812 size for secondary protection and the 1210 size for tertiary protection. A typically load dump transient results in an energy discharge of approximately 100J (depending on the size of the alternator). The deciding factor in the selection of the correct size suppressor is the amount of energy which is dissipated in the series and parallel loads in the circuit. The higher the impedance between the battery and the system requiring suppression, the smaller is the suppressor required.

Random samples of the 1210, 1812 and 2220 devices were subjected to repetitive load dump pulses at their rated energy level. This testing was performed across a temperature spectrum from -40°C to +125°C. This temperature range simulates both passenger compartment and under the hood operation. There was virtually no change in the device characteristics of any of the units tested (Figure 5).

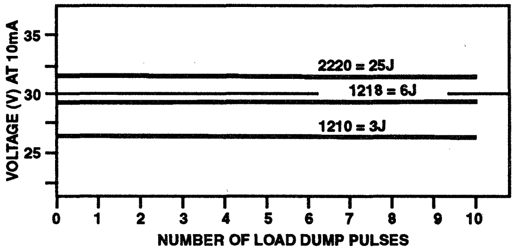


FIGURE 5. LOAD DUMP PULSING OVER A TEMPERATURE RANGE OF - 55°C to +125°C

Further testing on the AUML series has resulted in the extension the number of load dump pulses, at rated energy, which are applied to the devices. The reliability information thus generated gives an indication of the inherent capability of the series of devices. The V18AUMLA1210 sample has been subjected to over 2000 pulses at its rated energy of 3J; the V18AUMLA1812 sample over 1000 times at 6J. The V18AUMLA2220 sample has been pulsed at 25J over 300 times (Figure 6). In all cases there has been little or no change in the device characteristics.

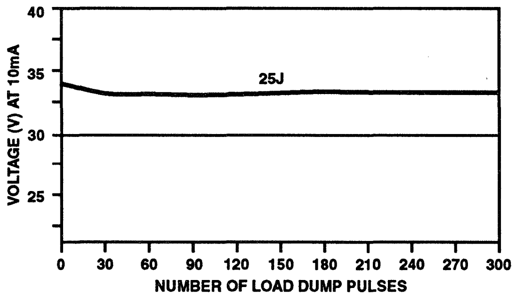


FIGURE 6. REPETITIVE LOAD DUMP PULSING AT RATED LOAD DUMP ENERGY

As previously discussed, the very high energy absorption capability of the AUML suppressor series is achieved by means of a new, highly controlled manufacturing process. This new multilayer technology ensures that a large volume of suppressor material, with an interdigitated layer construction, is available in an extremely small package. Unlike equivalent rated silicon TVS diodes, all of the AUML device package is available to act as an effective, uniform heat sink. Hence, the peak temperatures generated by the load dump transient are evenly dissipated throughout the complete device. This even energy dissipation ensures that there are lower peak temperatures generated at the P-N grain boundaries of the AUML suppressor.

Experience has shown that while the effects of a load dump transient are of real concern, its frequency of occurrence is much less than that of localized low energy inductive spikes. Such low energy spikes may be generated as a result of motors turning on and off, from ESD occurrences, or from any number of other sources. It is essential that the suppression technology selected also has the capability to suppress such transients. Testing on the V18AUMLA2220 has shown that after being subjected to a repetitive energy pulse of 2J, over 6000 times, no characteristic changes have occurred (Figure 7).

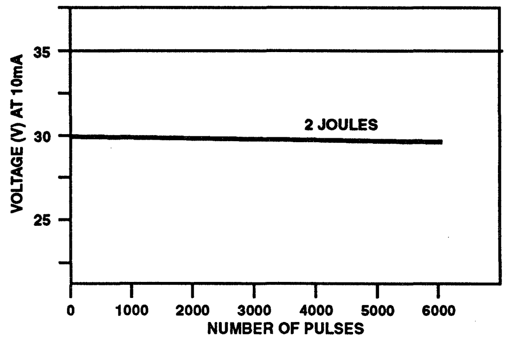


FIGURE 7. REPETITIVE ENERGY TESTING OF THE V18AUMLA2220 AT LOW ENERGY LEVELS

Clamping Voltage

The clamping voltage of a suppressor is the peak voltage appearing across the device when measured under conditions of a specified current pulse waveform. The industry recommended waveform for clamping voltage is the 8/20 microsecond pulse which has been endorsed by UL, IEEE and ANSI. The maximum clamping voltage of the AUML should be below the system or component failure level. Shunt type suppressors like the AUML are used in parallel to the systems they protect. Their effectiveness can be increased by understanding the important influence that source and line impedance play in the overall system (Figure 8).

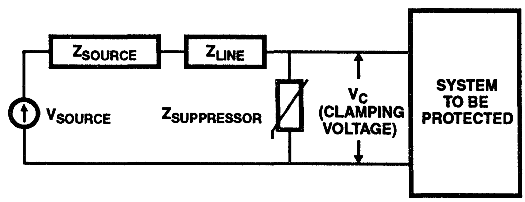


FIGURE 8. VOLTAGE DIVISIONS BETWEEN SOURCE, LINE AND SUPPRESSOR IMPEDANCE

To obtain the lowest clamping voltage (V_C) possible, it is desirable to use the lowest suppressor impedance ($Z_{SUPPRESSOR}$) and the highest line impedance (Z_{LINE}). The suppressor impedance is an inherent feature used to select the device, but the line impedance can become an important factor in selecting the location of the suppressor by adding resistances or inductances in series.

$$V_C = \frac{V_{SUPPRESSOR} \times V_{SOURCE}}{Z_{SUPPRESSOR} + Z_{LINE} + Z_{SOURCE}}$$

Speed of Response

The clamping action of the AUML suppressor depends on a conduction mechanism similar to that of other semiconductor devices (i.e. the P-N Junction). The apparent slow response time often associated with transient suppressors is due to parasitic inductance in the package and leads of the device, and is independent of the conducting material. The most critical element affecting the response time of a suppressor is the inductance of the lead material and hence the lead length.

The AUML suppressor is a surface mount device with no leads or external packaging, and thus, virtually zero inductance. The response time of a AUML surge suppressor is in the 1ns to 5ns range, which is more than sufficient for the transients which are encountered in the automotive environment.

Temperature Effects

In the off-state (leakage) region of the multilayer suppressor, the device characteristics approach a linear (ohmic) relationship and shows a temperature dependent affect. In this region the suppressor is in a very high resistance mode (approaching $10^9\Omega$) and appears as a near open circuit. Leakage currents at maximum rated voltage are in the low microamp range. When suppressing transients at higher currents (at and above the ten milliamp range), the AUML suppressor approaches a near short-circuit. In this region the characteristics of the AUML are virtually temperature independent. The clamping voltage of a multilayer transient voltage suppressor are the same at -55°C and +125°C (Figure 9).

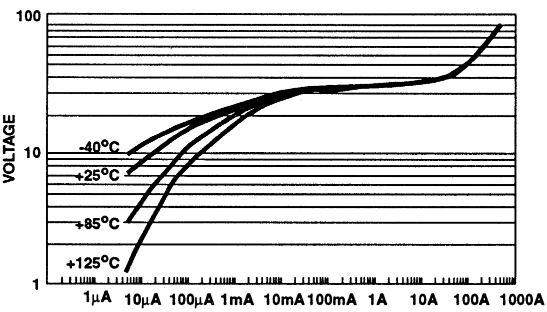


FIGURE 9. TYPICAL V - I CHARACTERISTICS OF THE V18AUMLA2220 AT -40°C, +25°C, +85°C AND +125°C

Soldering Recommendations for Multilayer Surge Suppressors[6]

When soldering all surface mount components onto printed circuit boards there are certain materials, parameters and processes which must be considered. These include:

1. Printed Circuit Board Material
2. Flux used
3. Land Pad Size
4. Soldering Methods
   - 4.1 Infrared Reflow Solder
   - 4.2 Vapor Phase Solder
   - 4.3 Wave Solder
5. Cleaning Methods and Fluids Employed

Substrates

There are a wide choice of substrate materials available for use as printed circuit boards in a surface mount application. The main factors which determine the choice of material to use are:

1. Electrical performance
2. Size and weight limitations
3. Thermal characteristics
4. Mechanical characteristics
5. Cost

When choosing a substrate material, the coefficient of thermal expansion for the ML surface mountable suppressor of 6ppm/°C is an important consideration. Non-organic materials (ceramic based substrates), like aluminum or berillia, which have coefficients of thermal expansion of 5 - 7 ppm/°C, are a good match. Table 2 below outlines some of the other materials used, and also there more important properties pertinent to surface mounting.

While the choice of substrate material should take note of the coefficient of expansion of the devices, this may not be the determining factor in whether a device can be used or not. Obviously the environment of the finished circuit board will determine what level of temperature cycling will occur. It is this which will dictate the criticality of the match between device and printed circuit board. Currently for most applications the ML series use FR4 boards without issue.

TABLE 2. SUBSTRATE MATERIAL PROPERTIES

SUBSTRATE STRUCTURE	MATERIAL PROPERTIES		
	GLASS TRANSITION TEMPERATURE (°C)	XY COEFFICIENT OF THERMAL EXPANSION (PPM/°C)	THERMAL CONDUCTIVITY (W/M°C)
Epoxy Fiberglass FR4	125	14 - 18	0.16
Polyamide Fiberglass	250	12 - 16	0.35
Epoxy Aramid Fiber	125	6 - 8	0.12
Fiber/Teflon Laminates	75	20	0.26
Aluminum-Beryillia (Ceramic)	Not Available	5 - 7	21.0

Fluxes

Fluxes are used for the chemical cleaning of a substrate surface. They will remove any surface oxides, and will also prevent reoxidation. They can contain active ingredients such as solvents for removing soils and greases. Nonactivated fluxes ("R" type) are relatively effective in reducing oxides of copper, nickel or palladium/silver metallizations and are recommended for use with the Harris surface mount suppressor range.

Mildly activated fluxes ("RMA" type) have natural and synthetic resins, which reduce oxides to metal or soluble salts. These "RMA" fluxes are generally not conductive nor corrosive at room temperature and are the most commonly used in the mounting of electronic components.

The "RA" type (fully activated) fluxes are corrosive, difficult to remove, and can lead to circuit failures and other problems. Other nonresin fluxes depend on organic acids to reduce oxides. They are also corrosive after soldering and also can damage sensitive components. Water soluble types in particular must be thoroughly cleaned from the assembly.

Environmental concerns, and associated legislation, has led to a growing interest in fluxes with residues that can be removed with water or water and detergents (semiaqueous cleaning). Many RMA fluxes can be converted to water soluble forms by adding saponifers. There are detergents and semiaqueous cleaning apparatus available that effectively remove most RMA type fluxes. Semiaqueous cleaning also tends to be less expensive than solvent cleaning in operations where large amounts of cleaning are needed.

For the Harris Semiconductor range of surface mount varistors, nonactivated "R" type fluxes such as Alpha 100 or equivalent are recommended.

Land Pad Patterns

Land pad size and patterns are one of the most important aspects of surface mounting. They influence thermal, humidity, power and vibration cycling test results. Minimal changes (even as small as 0.005 inches) in the land pad pattern have proven to make substantial differences in reliability.

This design /reliability relationship has been shown to exist for all types of designs such as in J-lead, quadpacks, chip resistors, capacitors and small outline integrated circuit (SOIC) packages. Optimum and tested land pad dimensions are provided for some surface mounted devices along with formulas which can be applied to different size varistors. Figure 10 gives optimum land patterns for the direct mount multilayer devices, while Table 3 outlines the optimum size of the land pad for each device size.

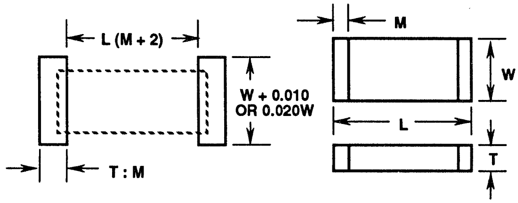


FIGURE 10. LAND PAD PATTERNS FOR MULTILAYER SUPPRESSORS

TABLE 3. RECOMMENDED MOUNTING PAD OUTLINE

SUPPRESSOR SIZE	DIMENSION		
	T + M	L - 2M	W+0.01 OR 0.02*W
1206	1.65	1.85	2.62
1210	1.85	1.85	3.73
1812	1.85	3.20	4.36
2220	1.84	4.29	6.19

Solder Materials and Soldering Temperatures

No varistor should be held longer than necessary at an elevated temperature. Exceeding the temperature and time limits can result in excessive leakage and alterations of the I - V characteristics.

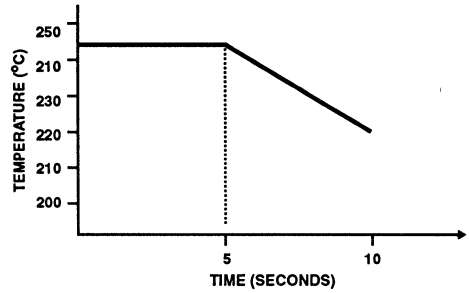


FIGURE 11. RECOMMENDED TIME AND SOLDER TEMPERATURE

To ensure that there is no leeching of the silver electrode on the varistor, solders with at least 2% silver content are recommended (62 Sn / 36 Pb / 2 Ag). Examples of silver bearing solders and their associated melting temperatures are per Table 4.

TABLE 4. SILVER BEARING SOLDERS (ALPHA METALS)

ALLOY	MELTING TEMPERATURE	
	°F	°C
62Sn/36Pb/2Ag	355	179
96.5Sn/3.5Ag	430	221
95Sn/5Ag	430 - 473	221 - 245
20Sn/88Pb/2Ag	514 - 576	268 - 302

Soldering Methods

There are a number of different soldering techniques used in the surface mount process. The most common soldering processes are infra red reflow, vapor phase reflow and wave soldering.

For the Harris surface mount suppressor range, the solder paste recommended is a 62/36/2 silver solder. While this configuration is best, other silver solder pastes can also be used. In all soldering applications, the time at peak temperature should be kept to a minimum. Any temperature steps employed in the solder process must, in broad terms, not exceed +70°C to +80°C. In the preheat stage of the reflow process, care should be taken to ensure that the chip is never subjected to a thermal gradient of greater than +4°C per second; the ideal gradient being +2°C per second. For optimum soldering, preheating to within +100°C of the peak soldering temperature is recommended; with a short dwell at the preheat temperature to help minimize the possibility of thermal shock. The dwell time at this preheat temperature should be for a time greater than $10T^2$ seconds, where T is the chip thickness in millimeters. Once the soldering process has been completed, it is still necessary to protect against further effects of thermal shocks. One possible cause of thermal shock at the post solder stage is when the hot printed circuit boards are removed from the solder bath and immediately subjected to cleaning solvents at room temperature. To avoid this thermal shock affect, the boards must first be allowed to cool to less than +50°C prior to cleaning.

Two different resistance to solder heat tests are routinely performed by Harris Semiconductor to simulate any possible effects that the high temperatures of the solder processes may have on the surface mount chip. These tests consist of the complete immersion of the chip in to a solder bath at +260°C for 5 seconds and also in to a solder bath at +220°C for 10 seconds. These soldering conditions were chosen to replicate the peak temperatures expected in a typical wave soldering operation and a typical reflow operation.

Reflow Soldering

There are two major reflow soldering techniques used in SMT today:

1. Infra-Red Reflow
2. Vapor Phase Reflow

The only difference between these two methods is the process of applying heat to melt the solder. In each of these methods precise amounts of solder paste are applied to the circuit board at points where the component terminals will be located. Screen or stencil printing, allowing simultaneous application of paste on all required points, is the most commonly used method for applying solder for a reflow process. Components are then placed in the solder paste. The solder pastes are a viscous mixture of spherical solder powder, thixotropic vehicle, flux and in some cases, flux activators.

During the reflow process, the completed assembly is heated to cause the flux to activate, then heated further, causing the solder to melt and bond the components to the board. As reflow occurs, components whose terminations displace more weight, in solder, than the components weight will float in the molten solder. Surface tension forces work toward establishing the smallest possible surface area for the molten solder. Solder surface area is minimized when the component termination is in the center of the land pad and the solder forms an even fillet up the end termination. Provided the boards pads are properly designed and good wetting occurs, solder surface tension works to center component terminations on the boards connection pads. This centering action is directly proportional to the solder surface tension. Therefore, it is often advantageous to engineer reflow processes to achieve the highest possible solder surface tension, in direct contrast to the desire of minimizing surface tension in wave soldering.

In designing a reflow temperature profile, it is important that the temperature be raised at least 20°C above the melting or liquidus temperature to ensure complete solder melting, flux activation, joint formation and the avoidance of cold melts. The time the parts are held above the melting point must be long enough to alloy the alloy to wet, to become homogenous and to level, but not enough to cause leaching of solder, metallization or flux charring.

A fast heating rate may not always be advantageous. The parts or components may act as heat sinks, decreasing the rate of rise. If the coefficients of expansion of the substrate and components are too diverse or if the application of heat is uneven, fast breaking or cooling rates may result in poor solder joints or board strengths and loss of electrical conductivity. As stated previously, thermal shock can also damage components. Very rapid heating may evaporate low boiling point organic solvents in the flux so quickly that it causes solder spattering or displacement of devices. If this occurs, removal of these solvents before reflow may be required. A slower heating rate can have similar beneficial effects.

Infra-Red Reflow

Infra-Red (IR) reflow is the method used for the reflowing of solder paste by the medium of a focused or unfocused infra red light. Its primary advantage is its ability to heat very localized areas.

The IR process consists of a conveyor belt passing through a tunnel, with the substrate to be soldered sitting on the belt. The tunnel consists of three main zones; a non-focused preheat, a focused reflow area and a cooling area. The unfocused infrared areas generally use two or more emitter zones, thereby providing a wide range of heating profiles for solder reflow. As the assembly passes through the oven on the belt, the time/temperature profile is controlled by the speed of the belt, the energy levels of the infrared sources, the distance of the substrate from the emitters and the absorptive qualities of the components on the assembly.

The peak temperature of the infrared soldering operation should not exceed 220°C. The rate of temperature rise from the ambient condition to the peak temperature must be carefully controlled. It is recommended that no individual temperature step is greater than 80°C. A preheat dwell at approximately 150°C for 60 seconds will help to alleviate potential stresses resulting from sudden temperature changes. The temperature ramp up rate from the ambient condition to the peak temperature should not exceed 4°C per second; the ideal gradient being 2°C per second. The dwell time that the chip encounters at the peak temperature should not exceed 10 seconds. Any longer exposure to the peak temperature may result in deterioration of the device protection properties. Cooling of the substrate assembly after solder reflow is complete should be by natural cooling and not by forced air.

The advantages of IR Reflow are its ease of setup and that double sided substrates can easily be assembled. Its biggest disadvantage is that temperature control is indirect and is dependent on the IR absorption characteristics of the component and substrate materials.

On emergence from the solder chamber, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the IR reflow soldering process is as Figure 12 and Table 5.

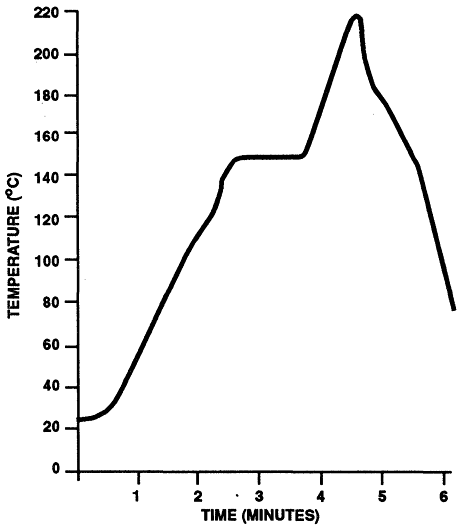


FIGURE 12. TYPICAL TEMPERATURE PROFILE FOR IR REFLOW SOLDER PROCESS

TABLE 5. RECOMMENDED TEMPERATURE PROFILE

INFRARED REFLOW	
TEMPERATURE (°C)	TIME (SECONDS)
25-60	60
60-120	60
120-155	30
155-155	60
155-220	60
220-220	10
220-50	60

Vapor Phase Reflow

Vapor phase reflow soldering involves exposing the assembly and joints to be soldered to a vapor atmosphere of an inert heated solvent. The solvent is vaporized by heating coils or a molten alloy, in the sump or bath. Heat is released and transferred to the assembly where the vapor comes in contact with the colder parts of the substrate and then condenses. In this process all cold areas are heated evenly and no areas can be heated higher than the boiling point of the solvent, thus preventing charring of the flux. This method gives a very rapid and even heating affect. Further advantages of vapor phase soldering is the excellent control of temperature and that the soldering operation is performed in an inert atmosphere.

The liquids used in this process are relatively expensive and so, to overcome this a secondary less expensive solvent is often used. This solvent has a boiling temperature below 50°C. Assemblies are passed through the secondary vapor and into the primary vapor. The rate of flow through the vapors is determined by the mass of the substrate. As in the case of all soldering operations, the time the components sit at the peak temperature should be kept to a minimum. In the case of Harris surface mount suppressors a dwell of no more than 10 seconds at 222°C is recommended.

On emergence from the solder system, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the vapor phase soldering process is as Figure 13 and Table 6.

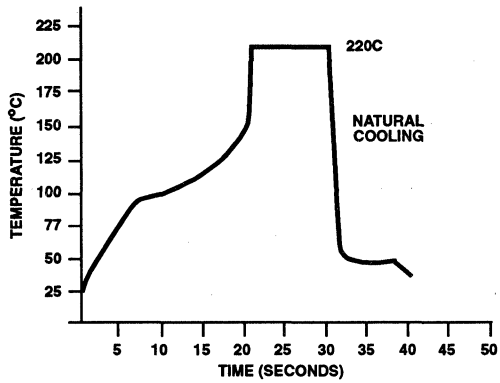


FIGURE 13. TYPICAL TEMPERATURE PROFILE FOR VAPOR PHASE REFLOW SOLDERING

TABLE 6. RECOMMENDED TEMPERATURE PROFILE

INFRARED REFLOW	
TEMPERATURE (°C)	TIME (SECONDS)
25-90	8
90-150	13
150-222	3
222-222	10
222-80	7
80-25	10

Wave Solder

This technique, while primarily used for soldering thru hole or leaded devices inserted into printed circuit boards, has also been successfully adapted to accommodate a hybrid technology where leaded, inserted components and adhesive bonded surface mount components populate the same circuit board.

The components to be soldered are first bonded to the substrate by means of a temporary adhesive. The board is then fluxed, preheated and dipped or dragged through two waves of solder. The preheating stage serves many functions. It evaporates most of the flux solvent, increases the activity of the flux and accelerates the solder wetting. It also reduces the magnitude of the temperature change experienced by the substrate and components.

The first wave in the solder process is a high velocity turbulent wave that deposits large quantities of solder on all wettable surfaces it contacts. This turbulent wave is aimed at solving one of the two problems inherent in wave soldering surface mount components, a defect called voiding (i.e. skipped areas). One disadvantage of the high velocity turbulent wave is that it gives rise to a second defect known as bridging, where the excess solder thrown at the board by the turbulent wave spans between adjacent pads or circuit elements thus creating unwanted interconnects and shorts.

The second, smooth wave accomplishes a clean up operation, melting and removing any bridges created by the turbulent wave. The smooth wave also subjects all previous soldered and wetted surfaces to a sufficiently high temperature to ensure good solder bonding to the circuit and component metallizations. In wave soldering, it is important that the solder have low surface tension to improve its surface wetting characteristics. Therefore, the molten solder bath is maintained at temperatures above its liquid point.

On emergence from the solder wave, cooling to ambient should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Forced air cooling should be avoided as it can induce thermal breakage.

The recommended temperature profile for the wave soldering process is as Table 7.

TABLE 7. RECOMMENDED TEMPERATURE PROFILE

WAVE SOLDER	
TEMPERATURE (°C)	**TIME (SECONDS)**
25-125	60
125-180	60
180-260	60
260-260	5
260-180	60
180-80	60
80-25	60

Cleaning Methods and Cleaning Fluids

The objective of the cleaning process is to remove any contamination, from the board, which may affect the chemical, physical or electrical performance of the circuit in its working environment.

There are a wide variety of cleaning processes which can be used, including aqueous based, solvent based or a mixture of both, tailored to meet specific applications. After the soldering of surface mount components there is less residue to remove than in conventional through hole soldering. The cleaning process selected must be capable of removing any contaminants from beneath the surface mount assemblies. Optimum cleaning is achieved by avoiding undue delays between the cleaning and soldering operations; by a minimum substrate to component clearance of 0.15mm and by avoiding the high temperatures at which oxidation occurs.

Harris recommends 1,1,1 trichloroethane solvent in an ultrasonic bath, with a cleaning time of between two and five minutes. Other solvents which may be better suited to a particular application and can also be used may include those outlined in Table 8.

TABLE 8. CLEANING FLUIDS

Water	Acetone
Isopropyl Alcohol	Fluorocarbon 113
Fluorocarbon 113 Alcohol	N-Butyl
1,1,1, Trichloroethane	Trichloroethane
Toluene	Methane

Comparison to Other Device Technologies

There are many design considerations involved when selecting the correct transient suppressor for an automotive application. One obvious consideration is cost. Other factors such as load dump energy capability, clamping voltage, temperature dependance, and size must also be weighed. Each of these factors will now be discussed.

Energy Capability

The large active electrode area available to the AUML suppressor ensures that load dump energy handling capability is one of it's best features. By virtue of its interdigitated construction, the AUML suppressor is capable of dissipating significant amounts of energy over a very small volume of material. The interdigitated construction also ensures that the very high temperatures resulting from a load dump transient will be evenly dissipated through millions of P-N junctions.

Silicon surge suppressors may also be used for the suppression of transients in an automotive environment. In the case of a silicon suppressor, only one P-N junction is available to handle the energy of the load transient. It should be noted that many different materials, with varying thermal coefficients of expansion, are employed in the construction of a silicon suppressor. This may result in extreme thermal stresses being created in the body of the suppressor during a load dump condition. In an attempt to overcome this weakness, a number of silicon die are placed in series in a sandwich construction, with a metal header to act as a heat sink and solder pellets for bonding (Figure 14).

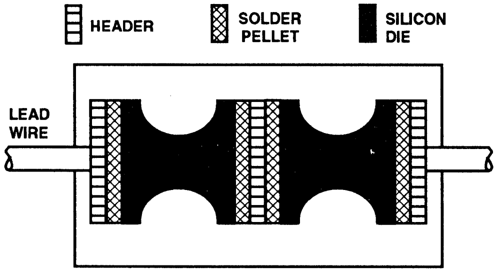


FIGURE 14. TYPICAL INTERNAL CONSTRUCTION OF A SILICON SUPPRESSOR

This construction is designed to distribute the transient energy through more than one P-N junction, and somewhat helps to alleviate the steep temperature build up during the transient. Even with this metal sandwich, the silicon suppressor is not completely effective in handling transient pulses. This is because of the thermal time constant involved in transporting the energy (heat) from where it is generated (the silicon die) to the metal heat sink.

Even though high energy load dump transients are much less frequent than low energy ones, it takes only one such transient to completely damage the transient suppressor and hence the component or circuit being protected.

Comparing the typical peak current, energy and power derating curves of the Harris multilayer to an equivalent silicon suppressor at +125°C, the AUML has 100% of rated value while the zener diode has only 35% (Figure 15).

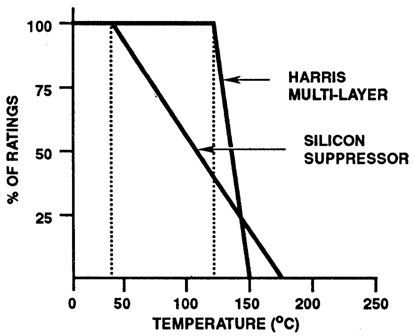


FIGURE 15. AUML AND SILICON SUPPRESSORS CURRENT, ENERGY AND POWER DERATING CURVE

Clamping Voltage

In the majority of automotive applications, the maximum clamping voltage requirement for the primary surge suppressor is 40V at 40A (8/20µs current waveform). Both the AUML and silicon suppressors easily meet this requirement.

The V-I characteristic for a silicon diode is defined over a small current range (1 decade). The AUML current range is extended over a few more decades, which illustrates it's large peak current and energy handling capability.

Temperature Effects

Both the AUML and the silicon diode have a temperature dependance with respect to off state leakage current - leakage current increases as temperature increases. However, beyond the breakdown point, the clamping voltage of the AUML will remain constant between +25°C and +125°C, while the clamping voltage for the zener diode at +125°C is higher than that specified at +25°C.

Size

Up to now, the only surface mounted surge suppressors available are leaded gull-wing and j-bend silicon diodes or a relatively large surface mount metal oxide varistor. In both of these cases a large area of the PC board is needed for mount down. As previously mentioned, electrically equivalent AUML suppressors are as much as three to four times as small than their silicon counterparts, resulting in significant surface mount PC board area savings (Figure 16).

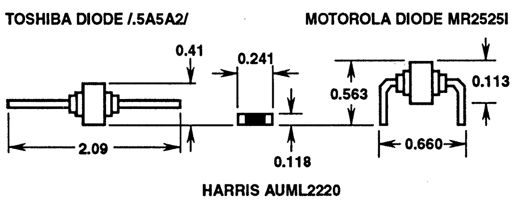


FIGURE 16. SIZE COMPARISONS OF AUTOMOTIVE SURGE SUPPRESSORS

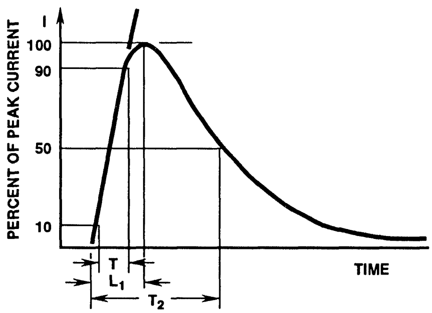
The compact size of the AUML suppressor is obtained by the paralleled stacking manufacturing process. This results in a high density energy absorber where the device volume is not taken up by lead frames, headers, external leads, and epoxy. Additional board area savings are also realized with the smaller solder mounting area required by the AUML.

Description of AUML Ratings and Characteristics

Maximum Continuous DC Working Voltage ($V_{M(DC)}$): This is the maximum continuous dc voltage which may be applied, up to the maximum operating temperature (+125°C), to the AUML suppressor. This voltage is used as the reference test point for leakage current and is always less than the breakdown voltage of the device.

Load Dump Energy Rating (W_{ld}): A load dump occurs when the alternator load is suddenly reduced. The worst case load dump is caused by disconnecting a discharged battery when the alternator is running at full load. The load dump energy discharge occurs with the rated battery voltage also applied and must not cause device failure. This pulse can be applied to the AUML suppressor in either polarity.

Maximum Clamping Voltage (V_C): This is the peak voltage appearing across the AUML suppressor when measured with an 8/20μs pulse current (Figure 17).



0μs - T_1 - FRONT TIME
20μs - LΣ TIME TO HALF VALUE

Leakage Current (I_L): This is the amount of current drawn by the AUML suppressor in its non-operational mode, i.e. when the voltage applied across the AUML does not exceed the rated $V_{M(DC)}$ voltage of the device.

Nominal Voltage ($V_{N(DC)}$): This is the voltage at which the AUML enters its conduction state and begins to suppress transients. In the automotive environment this voltage is defined at the 10 milliamp point and has a minimum and maximum voltage specified.

References

(1) Electromagnetic Susceptibility Measurement Procedures for Vehicle Components - SAE J1113 Aug 1987.

(2) Harris Semiconductor Application Note AN9002.

(3) Transient Voltage Suppression Devices, Harris Semiconductor DB450.2.

(4) "Transient Suppression in the Automotive Environment", Corbett, M. and McCambridge, P., Automotive Electronic Design 10/91.

(5) Harris Semiconductor Application Note AN9108.

(6) CANE SMT 2588, Syfer Technology Limited, UK.

HIGH RELIABILITY SERIES MECHANICAL AND ENVIRONMENTAL TESTING FOR AEROSPACE, MILITARY, AND HIGH RELIABILITY APPLICATIONS

The high-reliability Harris varistor is the latest step in increased product performance, and is available for applications requiring quality and reliability assurance levels consistent with military or other standards. (Mil-Std-19500, Mil-S-750, Method 202)

This series of high-reliability varistors involves five categories:

13.1 DESC Qualified Parts List (QPL) Mil-R-83536.
4 types presently available.

13.2 DESC Source Control Drawings based on Mil-R-83530.
83 types presently available:
ZA Series - Drawing #87063
DB Series - Drawing #90065
PA Series - Drawing #88063

13.3 Harris high reliability series offers TX equivalents.
29 types presently available.

13.4 Custom types processed to customer-specific requirements - (SCD) or to standard military flow.

13.5 Radiation hardened varistors.

Credentials

Harris varistors and quality management systems are:

- DESC approved
- QPL listed
- CECC approved
- ISO approved
- UL approved
- CSA approved.

13.1 DESC QUALIFIED PARTS LIST (QPL) MIL-R-83530

Table 13.1. MIL-R-83530/1 Ratings and Characteristics

PART NUMBER M83530/	NOMINAL VARISTOR VOLTAGE (V)	TOLERANCE (%)	VOLTAGE RATING (V) (RMS)	VOLTAGE RATING (V) (DC)	ENERGY RATING (J)	CLAMPING VOLTAGE AT 100A (V)	CAPACITANCE AT 1MHz (pF)	CLAMPING VOLTAGE AT PEAK CURRENT RATING (V)	I_{TM} (A)	NEAREST COMMERCIAL EQUIVALENT
1-2000B	200	±10	130	175	50	325	3800	570	6000	V130LA20B
1-2200D	220	+10, -5	150	200	55	360	3200	650	6000	V150LA20B
1-4300E	430	+5, -10	275	369	100	680	1800	1200	6000	V275LA40B
1-5100E	510	+5, -10	320	420	120	810	1500	1450	6000	V320LA40B

This series of varistors are screened and conditioned in accordance with MIL-R-83530 as outlined in Table 13.2. Manufactur-

Table 13.2. MIL-R-83530 Group A, B, and C Inspections

Group A Inspection

INSPECTION	AQL (PERCENT DEFECTIVE)	
SUBGROUP 1		
High Temperature Life (stabilization bake)	100%	
Thermal Shock	100%	
Power Burn-In	100%	
Clamping Voltage	100%	
Nominal Varistor Voltage	100%	
SUBGROUP 2	MAJOR	MINOR
Visual and Mechanical Examination		
Body Dimensions		-
Diameter and Length of	1.0% AQL	-
Leads	7.6% LQ	-
Marking		
Workmanship		25% AQL 13.0% LQ

Group B Inspection

INSPECTION
SUBGROUP I
Dielectric Withstanding Voltage
SUBGROUP II
Solderability
Resistance to Solvents
SUBGROUP III
Terminal Strength (lead fatigue)
Moisture Resistance
Peak Current
Energy

Group C Inspection

INSPECTION	NUMBER OF SAMPLE UNITS	FAILURES ALLOWED
EVERY 3 MONTHS		
High Temperature Storage	10	0
Operating Life (steady state)	10	0
Pulse Life	10	0
Shock	10	0
Vibration	10	0
Constant Acceleration	10	0
Energy	10	0

13.2 DESC SOURCE CONTROLLED DRAWING # 87063

Based on MIL-R-83530 ZA Package Series

Table 13.3 Ratings and Characteristics

87063 DASH NO.	NEAREST COMM. NO.	SIZE*	MAXIMUM RATINGS (+85°C) CONTINUOUS RMS $V_{M(AC)}$ (V)	CONTINUOUS DC $V_{M(DC)}$ (V)	TRANSIENT ENERGY (10/1000µs) W_{TM} (J)	TRANSIENT PEAK CURRENT (8/20µs) I_{TM} (A)	CHARACTERISTICS (+25°C) VARISTOR VOLTAGE @ 1mA DC TEST CURRENT MIN (V)	$V_{N(DC)}$ (V)	MAX (V)	MAXIMUM CLAMPING VOLTAGE V_C @ TEST CURRENT (8/20µs) V_C (V)	I_C (A)	TYPICAL CAPACITANCE f = 1MHz (pF)
001	V22ZA05	1	14	18	0.2	35	18.7	22	26	51	2	400
002	V22ZA1	2	14	18	0.9	150	18.7	22	26	47	5	1600
003	V22ZA2	3	14	18	2.0	350	18.7	22	26	43	5	4000
004	V22ZA3	4	14	18	4.0	750	18.7	22	26	43	10	9000
005	V24ZA50	5	14	18	6.5	1500	19.2	24†	26	43	20	18000
006	V27ZA05	1	17	22	0.25	35	23	27	31.1	59	2	300
007	V27ZA1	2	17	22	1.0	150	23	27	31.1	57	5	1300
008	V27ZA2	3	17	22	2.5	350	23	27	31.1	53	5	3000
009	V27ZA4	4	17	22	5.0	750	23	27	31.1	53	10	7000
010	V27ZA60	5	17	22	8.0	1500	23	27†	31.1	50	20	15000
011	V33ZA05	1	20	26	0.3	35	29.5	33	38	67	2	250
012	V33ZA1	2	20	26	1.2	150	29.5	33	36.5	68	5	1100
013	V33ZA2	3	20	26	3.0	350	29.5	33	36.5	64	5	2700
014	V33ZA5	4	20	26	6.0	750	29.5	33	36.5	64	10	6000
015	V33ZA70	5	21	27	9.0	1500	29.5	33†	36.5	58	20	13000
016	V36ZA80	5	23	31	10.0	1500	32	36†	40	63	20	12000
017	V39ZA05	1	25	31	0.35	35	35	39	46	79	2	220
018	V39ZA1	2	25	31	1.5	150	35	39	43	79	5	900
019	V39ZA3	3	25	31	3.5	350	35	39	43	76	5	2200
020	V39ZA6	4	25	31	7.2	750	35	39	43	76	10	5000
021	V47ZA05	1	30	38	0.4	35	42	47	55	90	2	200
022	V47ZA1	2	30	38	1.8	150	42	47	52	92	5	800
023	V47ZA3	3	30	38	4.5	350	42	47	52	89	5	2000
024	V47ZA7	4	30	38	8.8	750	42	47	52	89	10	4500
025	V56ZA05	1	35	45	0.5	35	50	56	66	108	2	180
026	V56ZA2	2	35	45	2.3	150	50	56	62	107	5	700
027	V56ZA3	3	35	45	5.5	350	50	56	62	103	5	1800
028	V56ZA8	4	35	45	10.0	750	50	56	62	103	10	3900
029	V68ZA05	1	40	56	0.6	35	61	68	80	127	2	150
030	V68ZA2	2	40	56	3.0	150	61	68	75	127	5	600
031	V68ZA3	3	40	56	6.5	350	61	68	75	123	5	1500
032	V68ZA10	4	40	56	13.0	750	61	68	75	123	10	3300
033	V82ZA05	1	50	66	1.2	70	73	82	97	145	2	120
034	V82ZA2	2	50	66	3.5	300	73	82	91	135	10	500
035	V82ZA4	3	50	66	7.3	750	73	82	91	135	25	1100
036	V82ZA12	4	50	66	13.0	1500	73	82	91	145	50	2500
037	V100ZA05	1	60	81	1.5	70	90	100	117	175	2	90
038	V100ZA3	2	60	81	4.3	300	90	100	110	165	10	400
039	V100ZA4	3	60	81	8.9	750	90	100	110	165	25	900
040	V100ZA15	4	60	81	16.0	1500	90	100	110	175	50	2000
041	V120ZA05	1	75	102	1.8	100	108	120	138	205	2	70
042	V120ZA1	2	75	102	5.3	400	108	120	132	205	10	300
043	V120ZA4	3	75	102	11.0	1000	108	120	132	200	25	750
044	V120ZA6	4	75	102	19.0	2000	108	120	132	210	50	1700
045	V150ZA05	1	92	127	2.3	100	135	150	173	240	2	60
046	V150ZA1	2	95	127	6.5	400	135	150	165	250	10	250
047	V150ZA4	3	95	127	13.0	1000	135	150	165	250	25	600
048	V150ZA8	4	95	127	23.0	2000	135	150	165	255	50	1400
049	V180ZA05	1	110	153	2.7	150	162	180	207	290	2	50
050	V180ZA1	2	115	153	7.7	500	162	180	198	295	10	200
051	V180ZA5	3	115	153	16.0	1500	162	180	198	300	25	500
052	V180ZA10	4	115	153	27.0	3000	162	180	198	300	50	1100

* Size 1-5mm, 2-7mm, 3-10mm, 4-14mm, 5-20mm   † Denotes 10mA DC test current.

13.2 DESC STANDARD MILITARY DRAWING # 90065

Based on MIL-R-83530 DB Package Series

Table 13.4 Ratings and Characteristics

90065 DASH NO.	VOLTAGE RATING MAX. (RMS)	ENERGY MAX (J)	PEAK CURRENT (A)	NOMINAL VARISTOR VOLTAGE (V)		MAX CLAMPING VOLTAGE AT TEST CURRENT (V)	(I)	TYPICAL CAPACITANCE (pF)
012	130	170	22500	200	+28, -16	345	200	10000
013	150	200	22500	240	±28	405	200	8000
014	250	270	22500	390	+39, -36	650	200	5000
015	275	300	22500	430	±43	730	200	4500
016	320	350	22500	510	+29, -48	830	200	3800
017	420	460	28800	680	+68, -70	1130	200	3000
018	480	510	28800	750	+74, -80	1240	200	2700
019	510	550	28800	820	+91, -85	1350	200	2500
020	575	600	28800	910	+95, -105	1480	200	2200
021	660	690	28800	1050	±110	1720	200	2000
022	750	810	28800	1200	±120	2000	200	1800

13.2 DESC STANDARD MILITARY DRAWING # 88063

Based on MIL-R-83530 PA Package Series

Table 13.5 Ratings and Characteristics

80063 DASH NO.	VOLTAGE RATING MAX. (RMS)	(DC)	ENERGY MAX (J)	PEAK CURRENT (A)	NOMINAL VARISTOR VOLTAGE (V)		MAX CLAMPING VOLTAGE AT TEST CURRENT (V)	(I)	TYPICAL CAPACITANCE (pF)
001	130	175	70	6500	200	+43, -16	360	100	1900
002	130	175	70	6500	200	+20, -16	325	100	1900
003	150	200	80	6500	240	+44, -28	420	100	1600
004	150	200	80	6500	240	+3, -28	360	100	1600
005	250	330	130	6500	390	+63, -36	675	100	1000
006	250	330	130	6500	390	+23, -36	620	100	1000
007	275	369	140	6500	430	+64, -41	740	100	900
008	275	369	140	6500	430	+23, -41	680	100	900
009	320	420	160	6500	510	+55, -48	850	100	750
010	320	420	160	6500	510	+30, -48	800	100	750
011	420	560	160	6500	680	+110, -70	1160	100	600
012	420	560	160	6500	680	+10, -70	1050	100	600
013	480	640	180	6500	750	+110, -80	1280	100	550
014	480	640	180	6500	750	+40, -80	1160	100	550
015	510	675	190	6500	820	+143, -85	1410	100	500
016	510	675	190	6500	820	+40, -85	1280	100	500
017	575	730	220	6500	910	+140, -105	1560	100	450
018	575	730	220	6500	910	+50, -105	1410	100	450
019	660	850	250	6500	1050	+160, -110	1820	100	400
020	660	850	250	6500	1050	+50, -110	1650	100	400

13.3 HARRIS HIGH RELIABILITY SERIES TX EQUIVALENTS

Table 13.6. Available TX Model Types

TX MODEL	MODEL SIZE	DEVICE MARK	NEAREST COMMERCIAL EQUIVALENT
V8ZTX1	7mm	8TX1	V8ZA1
V8ZTX2	10mm	8TX2	V8ZA2
V12ZTX1	7mm	12TX1	V12ZA1
V12ZTX2	10mm	12TX2	V12ZA2
V22ZTX1	7mm	22TX1	V22ZA1
V22ZTX3	14mm	22TX3	V22ZA3
V24ZTX50	20mm	24TX50	V24ZA50
V33ZTX1	7mm	33TX1	V33ZA1
V33ZTX5	14mm	33TX5	V33ZA5
V33ZTX70	20mm	33TX70	V33ZA70
V68ZTX2	7mm	68TX2	V68ZA2
V68ZTX10	14mm	68TX10	V68ZA10
V82ZTX2	7mm	82TX2	V82ZA2
V82ZTX12	14mm	82TX12	V82ZA12

TX MODEL	MODEL SIZE	DEVICE MARK	NEAREST COMMERCIAL EQUIVALENT
V130LTX2	7mm	130TX	V130LA2
V130LTX10A	14mm	130TX10	V130LA10A
V130LTX20B	20mm	130TX20	V130LA20A
V150LTX2	7mm	150TX	V150LA2
V150LTX10A	14mm	150TX10	V150LA10A
V150LTX20B	20mm	150TX20	V150LA20B
V250LTX4	7mm	250TX	V250LA4
V250LTX20A	14mm	250TX20	V250LA20A
V250LTX40B	20mm	250TX40	V250LA40B
V420LTX20A	14mm	420TX20	V420LA20A
V420LTX40B	20mm	420TX40	V420LA40B
V480LTX40A	1 4mm	480TX40	V480LA40A
V480LTX80B	20mm	480TX80	V480LA80B
V510LTX40A	14mm	510TX40	V510LA40A
V510LTX80B	20mm	510TX80	V510LA80B

This series of varistors are 100% screened and conditioned in accordance with MIL-STD-750. Tests are as outlined in Table 13.7.

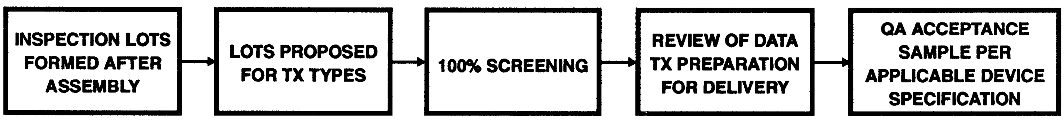


Table 13.7. TX Equivalents Series 100% Screening

SCREEN	MIL-STD-750 METHOD	CONDITION	TX REQUIREMENTS
High Temperature Life (stabilization bake)	1032	24 hours min. at max. rated storage temperature.	100%
Thermal Shock (temperature cycling)	1051	No dwell is required at 25°C. Test condition A1, 5 cycles - 55° C to +125°C (extremes). > 10 minutes	100%
Humidity Life		85°C, 85% R.H., 168 hours.	100%
Interim Electrical $V_{N(DC)}$ V_C (Note 1)		As specified, but including delta parameter as a minimum.	100% Screen
Power Burn-In	1038	Condition B, 85°C, Rated $V_{M(AC)}$, 72 hours mmin	100%
Final Electrical +$V_{N(DC)}$ V_C (Note 1)		As specified — All parameter measurements must be completed within 96 hours after removal from burn-in conditions.	100% Screen
External Visual Examination	2071	To be performed after complete marking.	100%

NOTE:

1. Delta Parameter - $V_{N(DC)}$
   Maximum allowable shift ±10% Max.
   Applicable lot PDA - 10% Max.
   Peak current and energy ratings are derated by 10% and 30%, respectively, from standard parts.

13.3 HARRIS HIGH RELIABILITY SERIES TX EQUIVALENTS (Continued)

Table 13.8. Quality Assurance Acceptance Test

	MIL-STD-105		LTPD
	LEVEL	AQL	
Electrical (Bi-directional) $V_{N(DC)}$, V_C (Per characteristics table)	II	0.1	-
Dielectric Withstand Voltage MIL-STD-202, Method 301, 2500V min. at 1.0μAdc	-	-	15
Solderability MIL-STD-202, Method 208, no aging, non-activated	-	-	15

13.4 CUSTOM TYPES

In addition to our comprehensive high-reliability series as referenced above, Harris can screen and condition to customer-specific requirements.

Additional mechanical and environmental capabilities are defined in Table 13.9.

Table 13.9. Mechanical and Environmental Capabilities (Typical Conditions)

TEST NAME	TEST METHOD	DESCRIPTION
Terminal Strength	MIL-STD-750-2036	3 bends, 90° arc, 16 oz. weight
Drop Shock	MIL-STD-750-2016	1500 g's, 0.5ms, 5 pulses, X_1, V_1, Z_1
Variable Frequency Vibration	MIL-STD-750-2056	20 g's, 100-2000Hz, X_1, V_1, Z_1
Constant Acceleration	MIL-STD-750-2006	V_2, 20,000 g's min
Salt Atmosphere	MIL-STD-750-1041	35° C, 24 hrs, 10-50 g/m^2 day
Soldering Heat/Solderability	MIL-STD-750-2031/2026	260° C, 10s, 3 cycles, test marking
Resistance to Solvents	MIL-STD-202-215	permanence, 3 solvents
Flammability	MIL-STD-202-111	15s torching, 10s to flameout
Flammability	UL1414	3 x 15s torching
Cyclical Moisture Resistance	MIL-STD-202-106	10 days
Steady-State Moisture Resistance		85/85 96 hrs.
Biased Moisture Resistance		Not recommended for high-voltage types
Temperature Cycle	MIL-STD-202-107	-55 to +125°C, 5 cycles
High-Temperature Life (Nonoperating)	MIL-STD-750-1032	125° C, 24 hrs.
Burn-In	MIL-STD-750-1038	Rated temperature and V_{RMS}
Hermetic Seal	MIL-STD-750-1071	Condition D

13.5 RADIATION HARDNESS

For space applications, an extremely important property of a protection device is its response to imposed radiation effects.

Electron Irradiation

A Harris MOV and a silicon transient suppression diode were exposed to electron irradiation. The V-I Curves, before and after test, are shown in Figure 13.1.

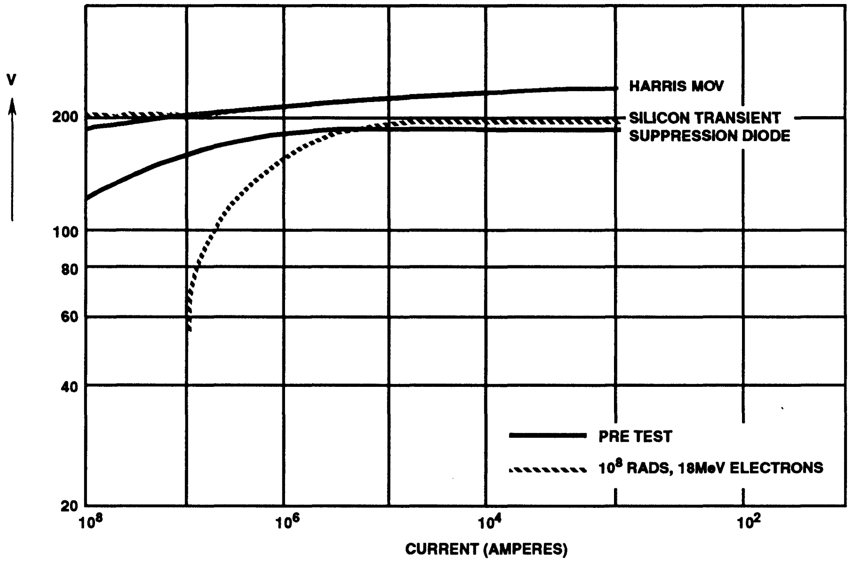


Figure 13.1. Radiation Sensitivity of Harris V130LA1 and Silicon Transient Suppression Diode

It is apparent that the Harris MOV was virtually unaffected, even at the extremely high dose of 10^8 rads, while the silicon transient suppression diode showed a dramatic increase in leakage current.

Neutron Effects

A second MOV-Zener comparison was made in response to neutron fluence. The selected devices were equal in area.

Figure 13.2 shows the clamping voltage response of the MOV and the zener to neutron irradiation to as high as 10^{15} N/cm^2. It is apparent that in contrast to the large change in the zener, the MOV is unaltered. At higher currents where the MOV's clamping voltage is again unchanged, the zener device clamping voltage increases by as much as 36%.

Counterclockwise rotation of the V-I characteristics is observed in silicon devices at high neutron irradiation levels; in other words, increasing leakage at low current levels and increasing clamping voltage at higher current levels.

The solid and open circles for a given fluence represent the high and low breakdown currents for the sample of devices tested. Note that there is a marked decrease in current (or energy) handling capability with increased neutron fluence.

Failure threshold of silicon semiconductor junctions is further reduced when high or rapidly increasing currents are applied. Junctions develop hot spots, which enlarge until a short occurs if current is not limited or quickly removed.

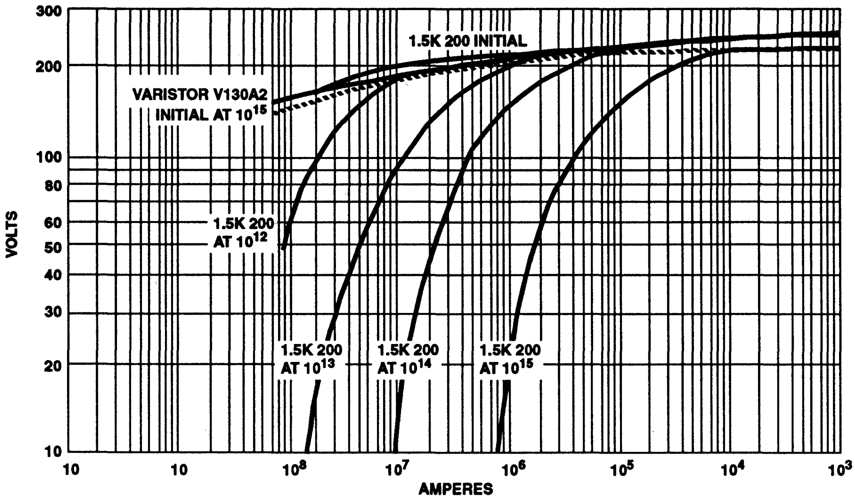


Figure 13.2. V-I Characteristic Response to Neutron Irradiation for MOV and Zener Diode Devices

The characteristic voltage current relationship of a PN-Junction is shown in Figure 13.3.

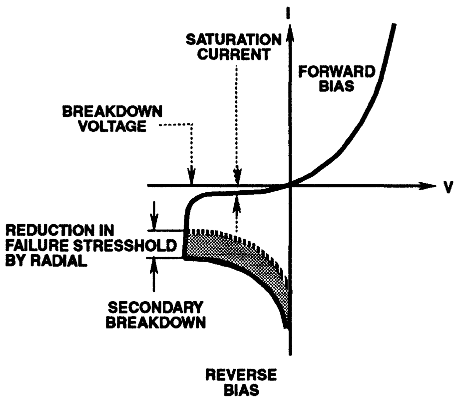


Figure 13.3. V-I Characteristic of PN-Junction

At low reverse voltage, the device will conduct very little current (the saturation current). At higher reverse voltage V_{BO} (breakdown voltage), the current increases rapidly as the electrons are either pulled by the electric field (Zener effect) or knocked out by other electrons (avalanching). A further increase in voltage causes the device to exhibit a negative resistance characteristic leading to secondary breakdown.

This manifests itself through the formation of hotspots, and irreversible damage occurs. This failure threshold decreases under neutron irradiation for zeners, but not for Zinc Oxide Varistors.

Gamma Radiation

Radiation damage studies were performed on type V-I 30LA2 varistors. Emission spectra and V-I characteristics were collected before and after irradiation with 10^6 rads Co^{60} gamma radiation.

Both show no change, within experimental error, after irradiation.

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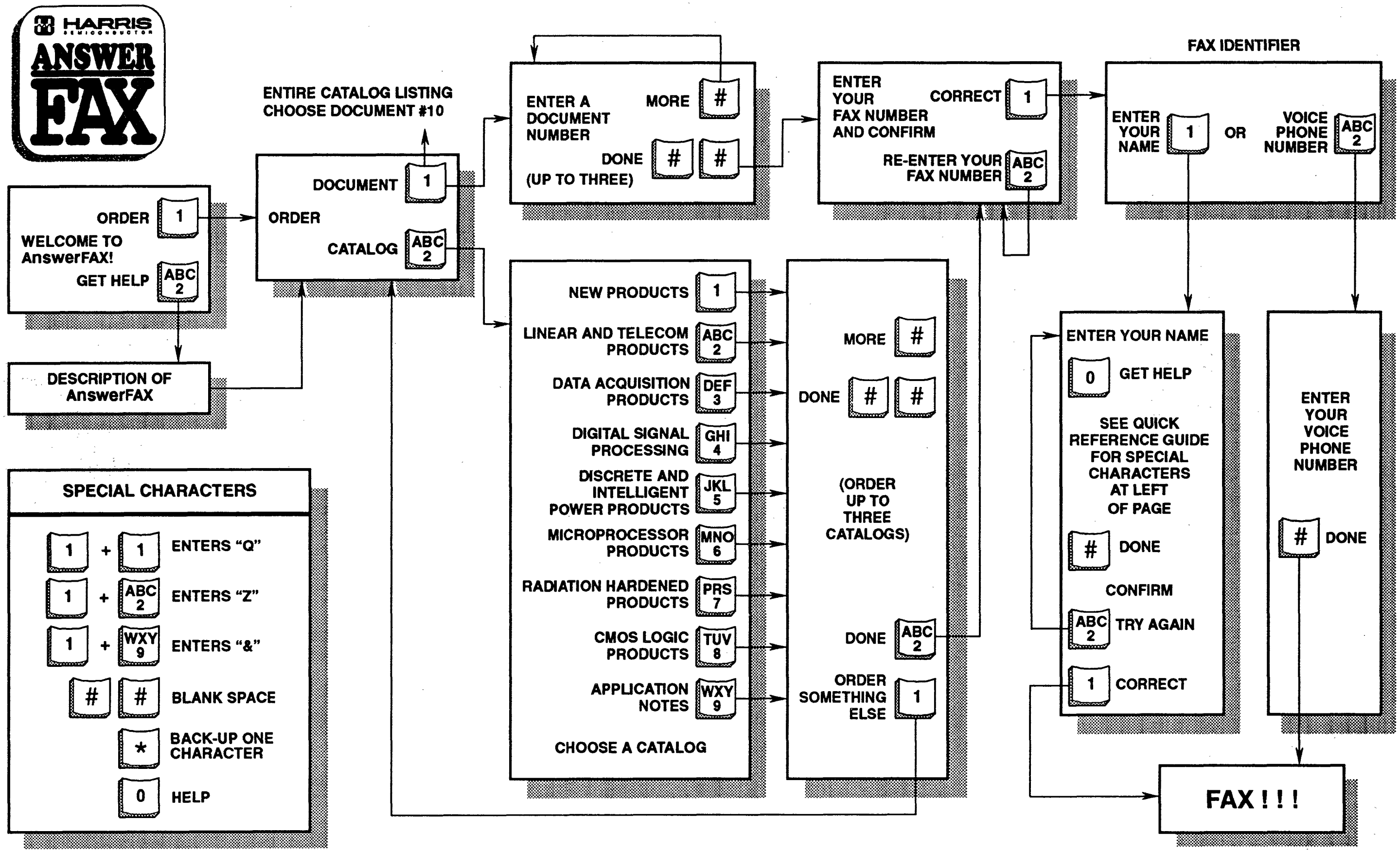

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