1351

TO:

FOR YOUR	INFO.	COMMENTS	FILE

APR 22

PLS.	HANDLE	RETURN	DISCUSS WITH ME

FROM: D. A. THOMPSON

MAGNETIC RECORDING

OF

DIGITAL DATA

M. K. HAYNES

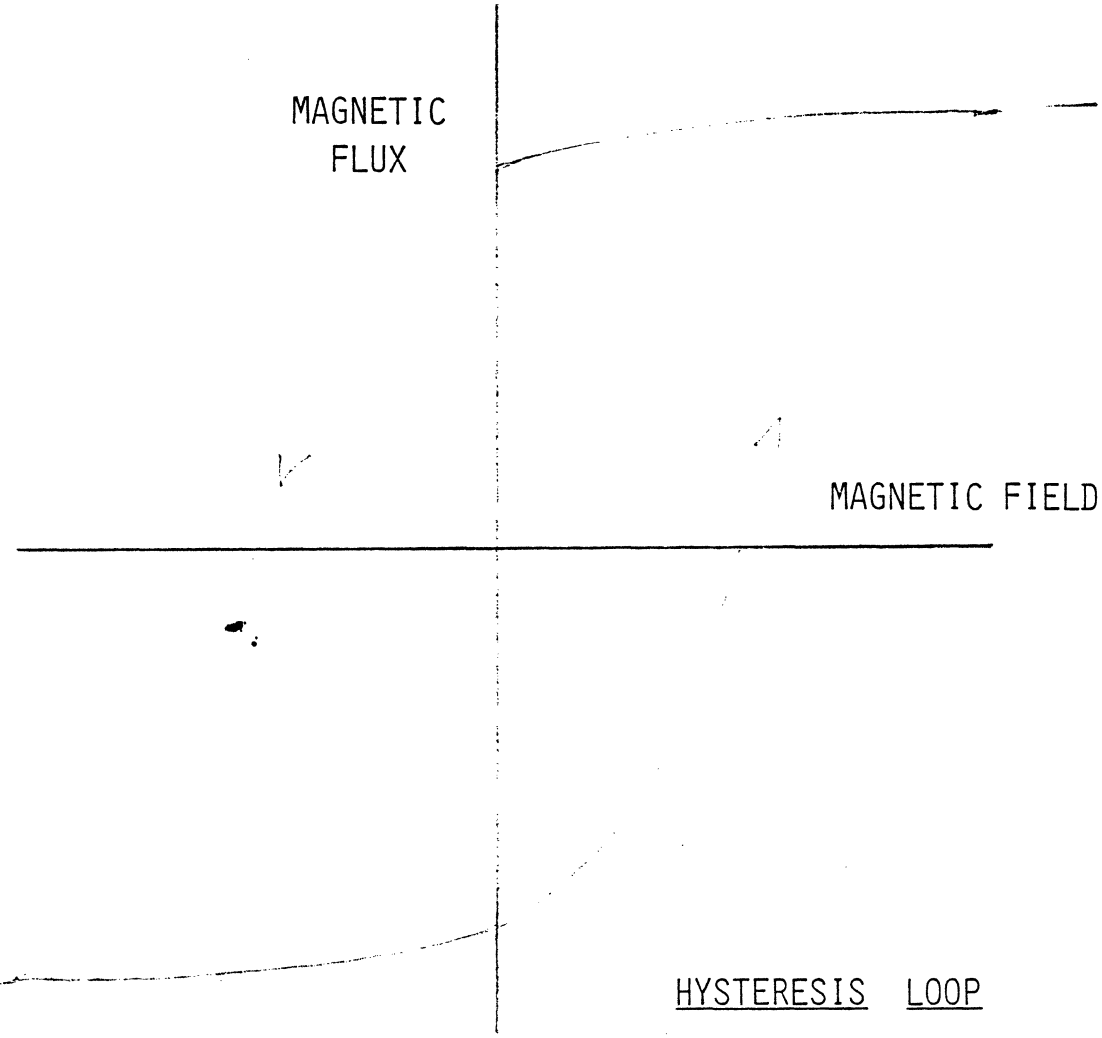
IBM CORP.

TUCSON, ARIZ.

APRIL 1983

SYMBOLS	SOUND	IMAGES
DIGITS		
CLAY TABLETS, PAPYRUS		
TORCHES		
PRINTING PRESS		
SEMAPHORE		
TELEGRAPH		PHOTOGRAPH
SUBMARINE CABLE		
TYPEWRITER	TELEPHONE	
PUNCHED CARD	PHONOGRAPH	MOTION PICTURE
RADIO TELEGRAPH	MAGNETIC WIRE	MICROFILM
TELEPRINTER	RADIO TELEPHONE	FACSIMILE
PUNCHED PAPER TAPE	MAGNETIC TAPE	VIDEO PHONE
MAGNETIC DRUM		TELEVISION
MAGNETIC TAPE	PCM TELEPHONY	VIDEO TAPE
MAGNETIC DISK	MULTILEVEL TRANS.	
RADAR DATA TRANS.		VIDEO DISK
TELEMETRY	DIGITAL AUDIO	DIGITAL VIDEO
SATELLITE DATA	OPTICAL DISK	MAVICA
OPTICAL DISK?		

DEVELOPMENT OF INFORMATION STORAGE AND TRANSMISSION



HYSTERESIS LOOP

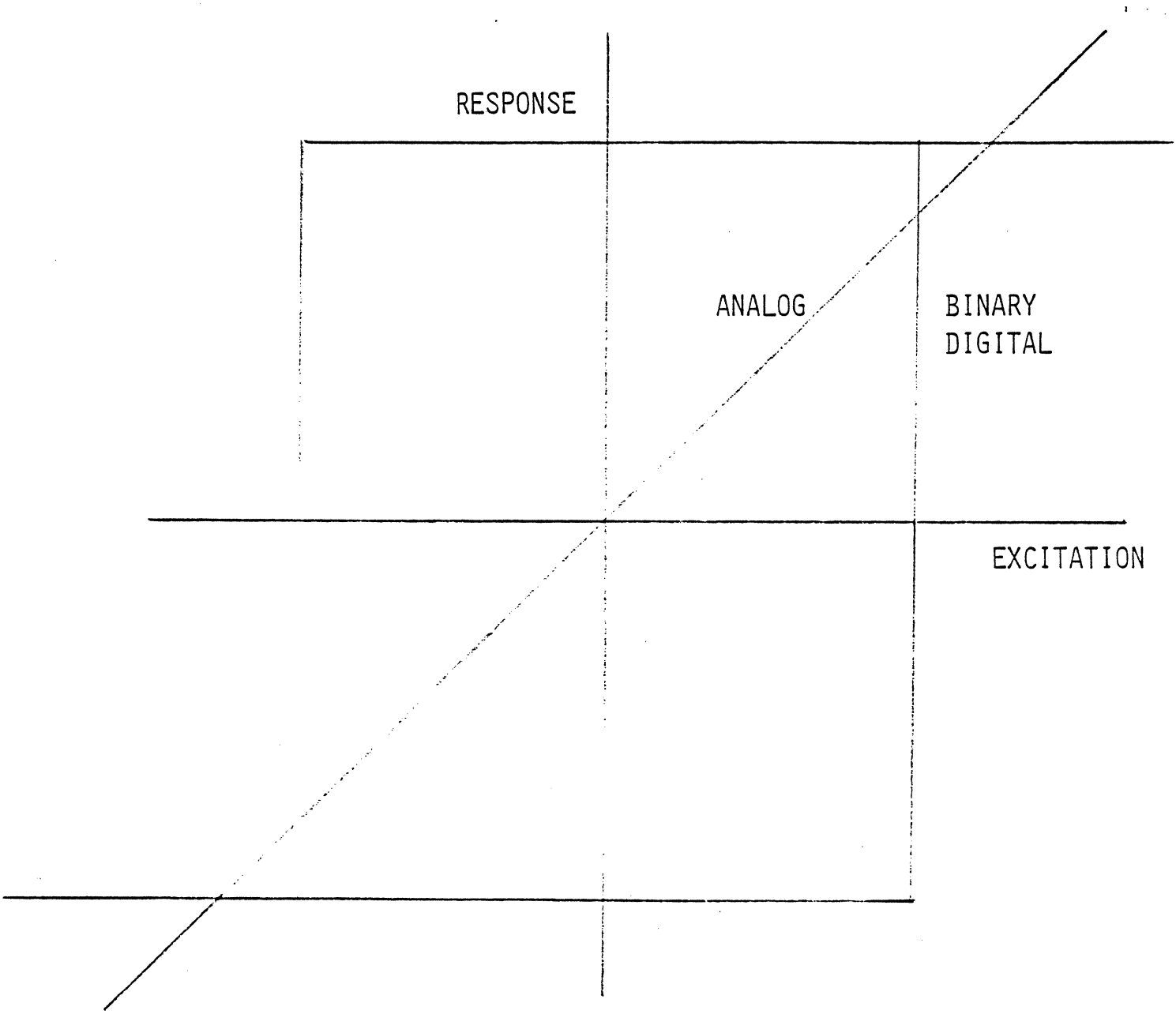
HYSTERESIS -- LAG

NON-LINEAR
SATURATION
ENERGY LOSS
TIME DEPENDENT

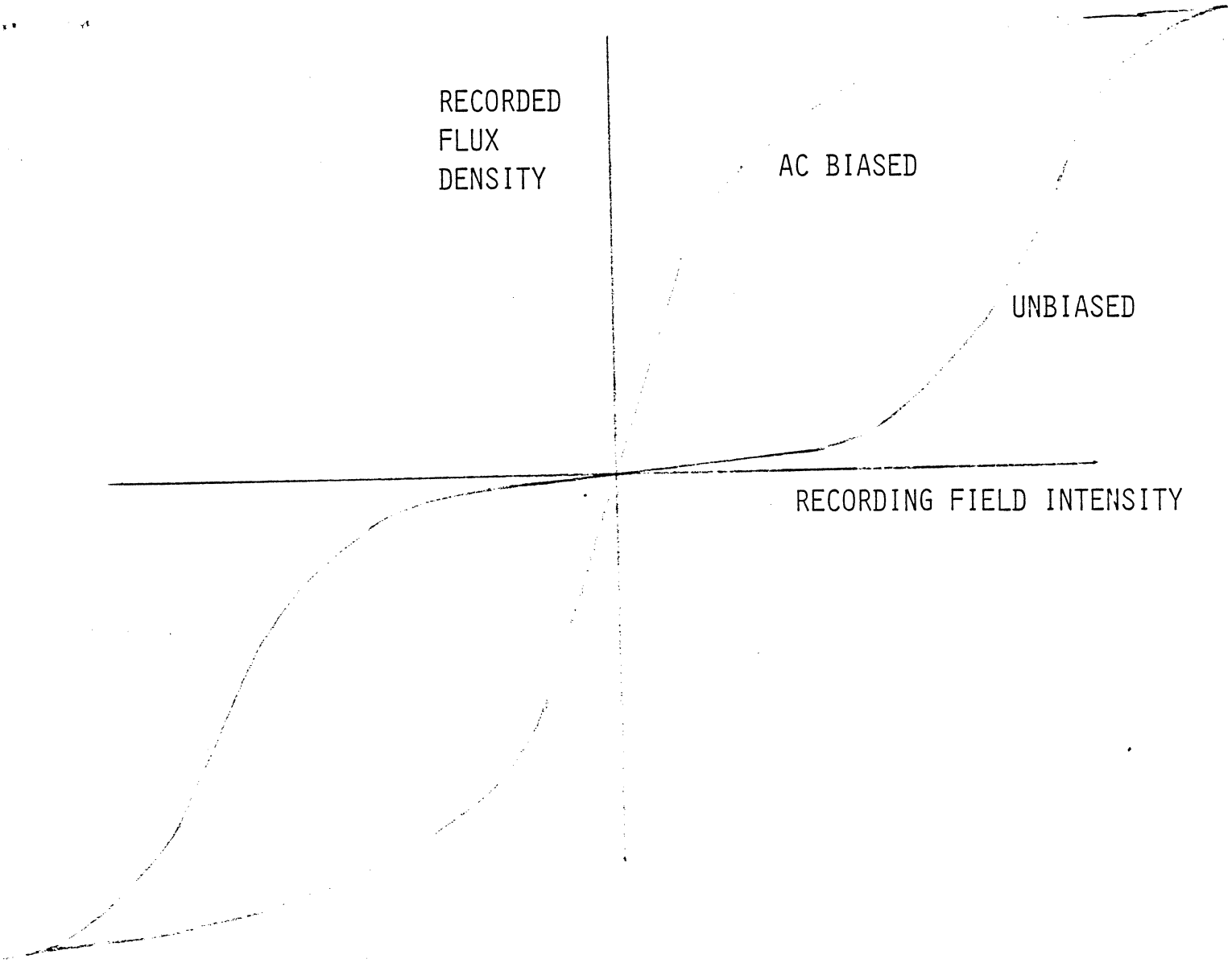
AN ESSENTIAL REQUIREMENT
FOR STORAGE-- MAGNETIC CORES

MAGNETIC RECORDING

HYSTERESIS
MECHANICAL MOTION



IDEAL TRANSFER-RESPONSE CHARACTERISTICS



MAGNETIC RECORDING CHANNEL

TRANSFER RESPONSE CHARACTERISTICS

AN 'ANALOG' CHANNEL
NONLINEARITY
SATURATION
DISTORTION
NOISE

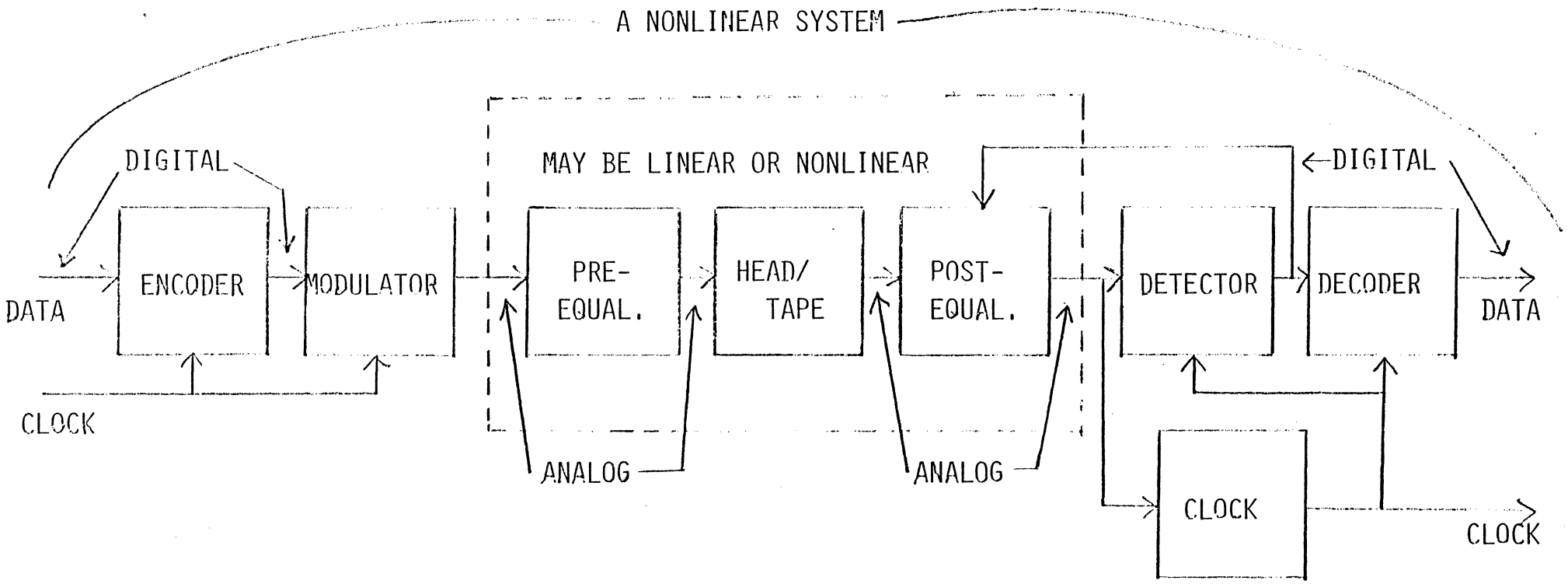
ANALOG RECORDING

- LINEARIZE
  - DC BIAS
  - AC BIAS

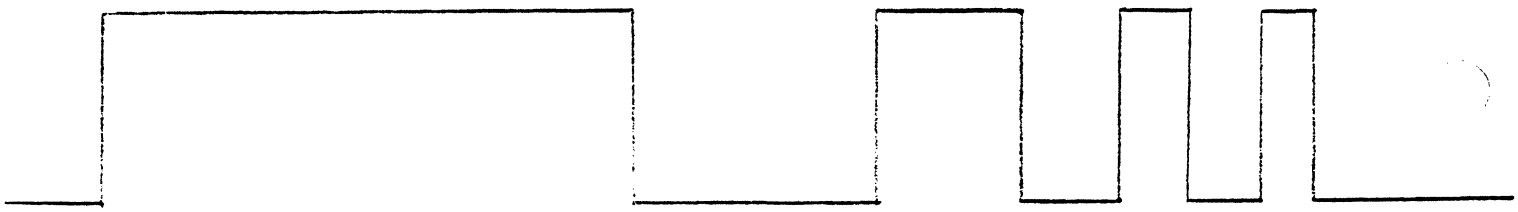
DIGITAL RECORDING

- SATURATE
  - TWO STATES
  - RECORD TRANSITIONS
- QUASI-LINEAR
  - SIGNAL PROCESSING
- LINEARIZE

APPLICATION STRATEGIES FOR MAGNETIC RECORDING CHANNEL



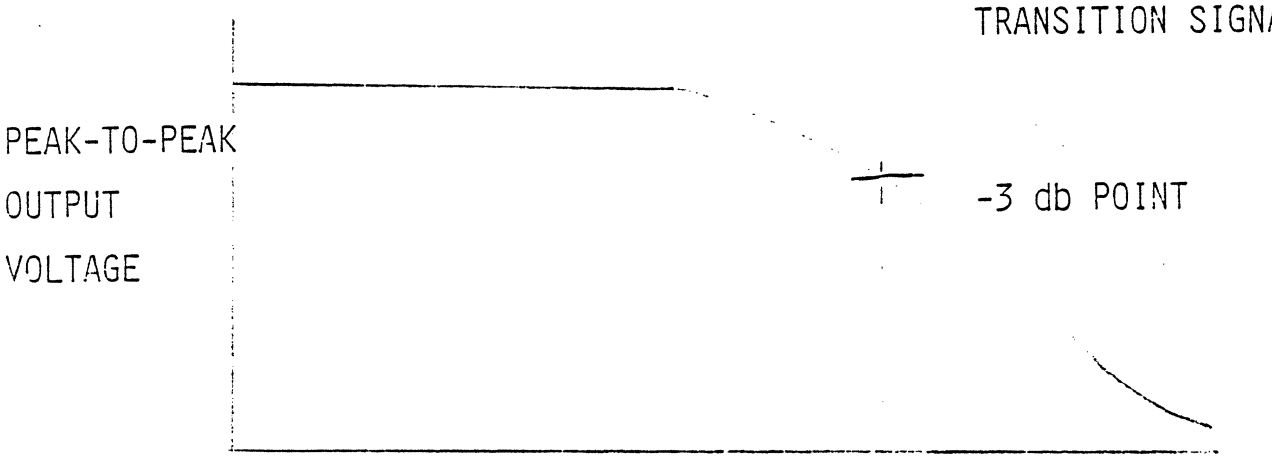
A DIGITAL-DATA RECORDING SYSTEM



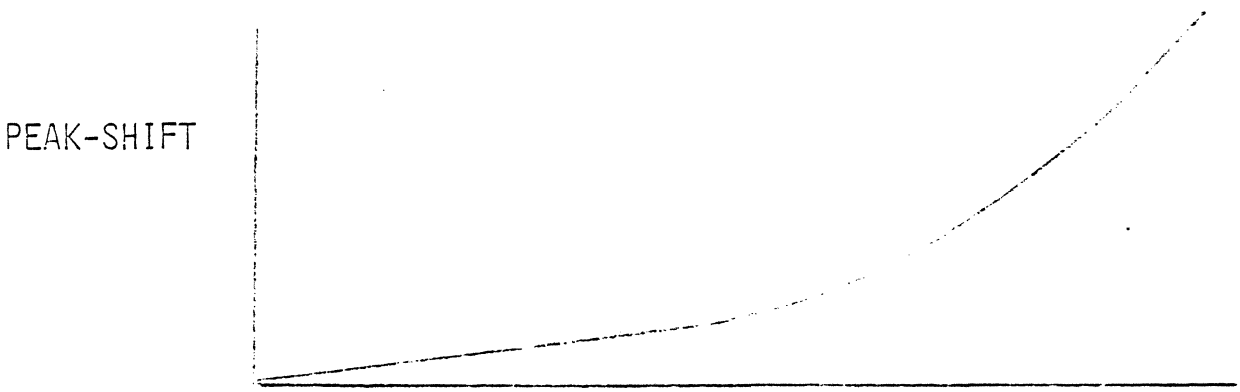
WRITE CURRENT

READ-HEAD OUTPUT VOLTAGE

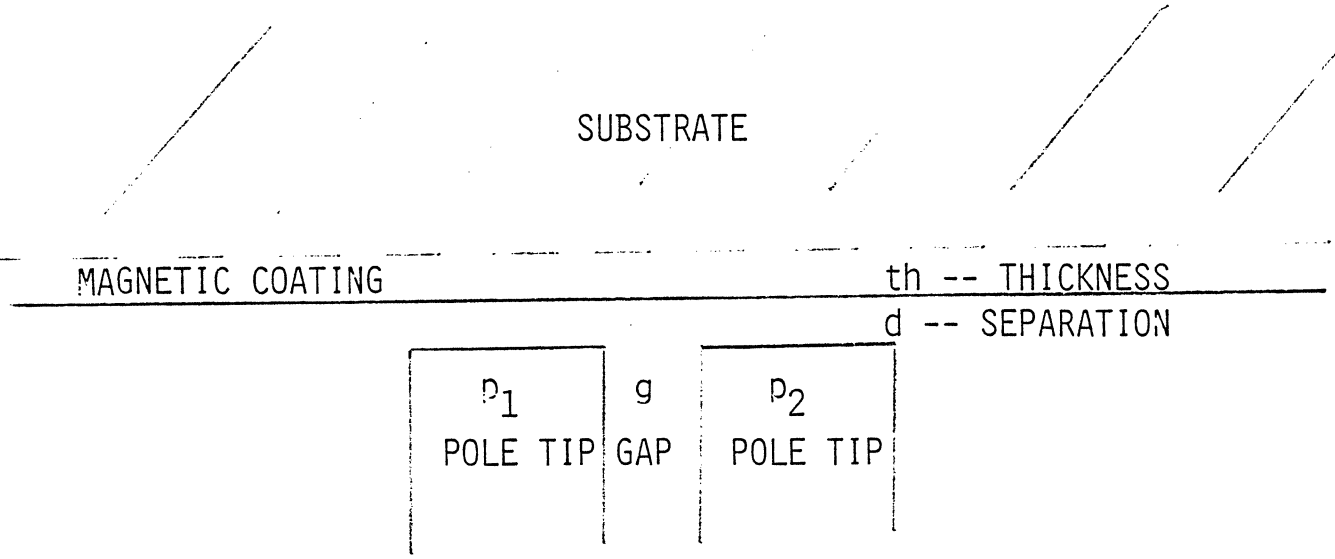
SUPERPOSITION OF
TRANSITION SIGNALS



RECORDING DENSITY (TRANSITIONS PER INCH)



RECORDING DENSITY



RECORDING DENSITY LIMITERS IN SATURATION RECORDING

MEDIA THICKNESS

SEPARATION

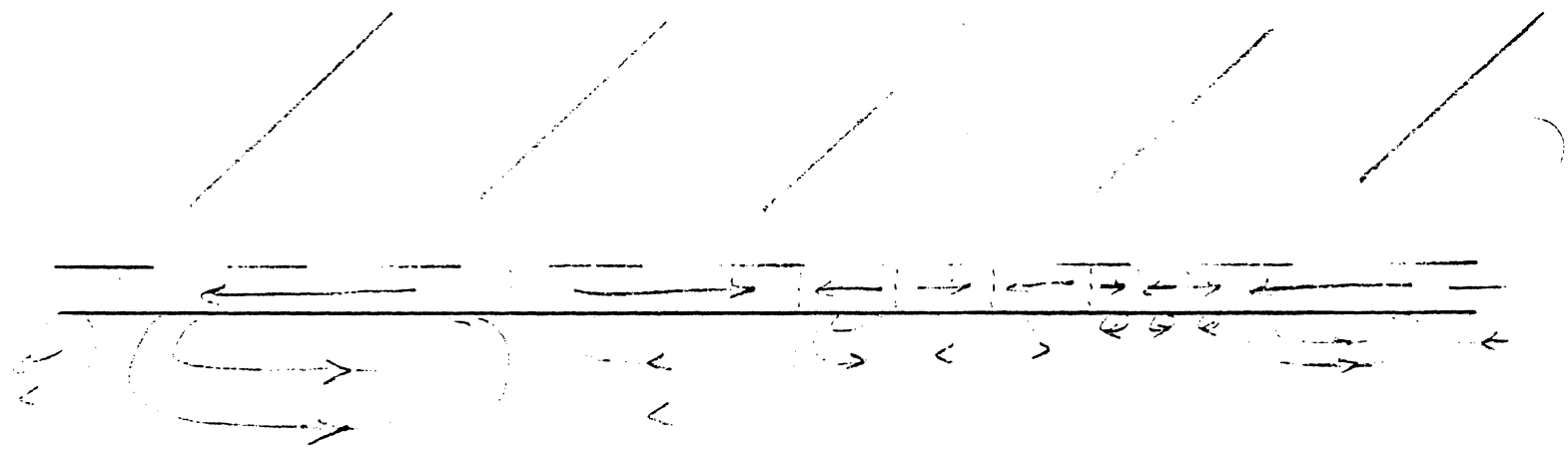
GAP LENGTH

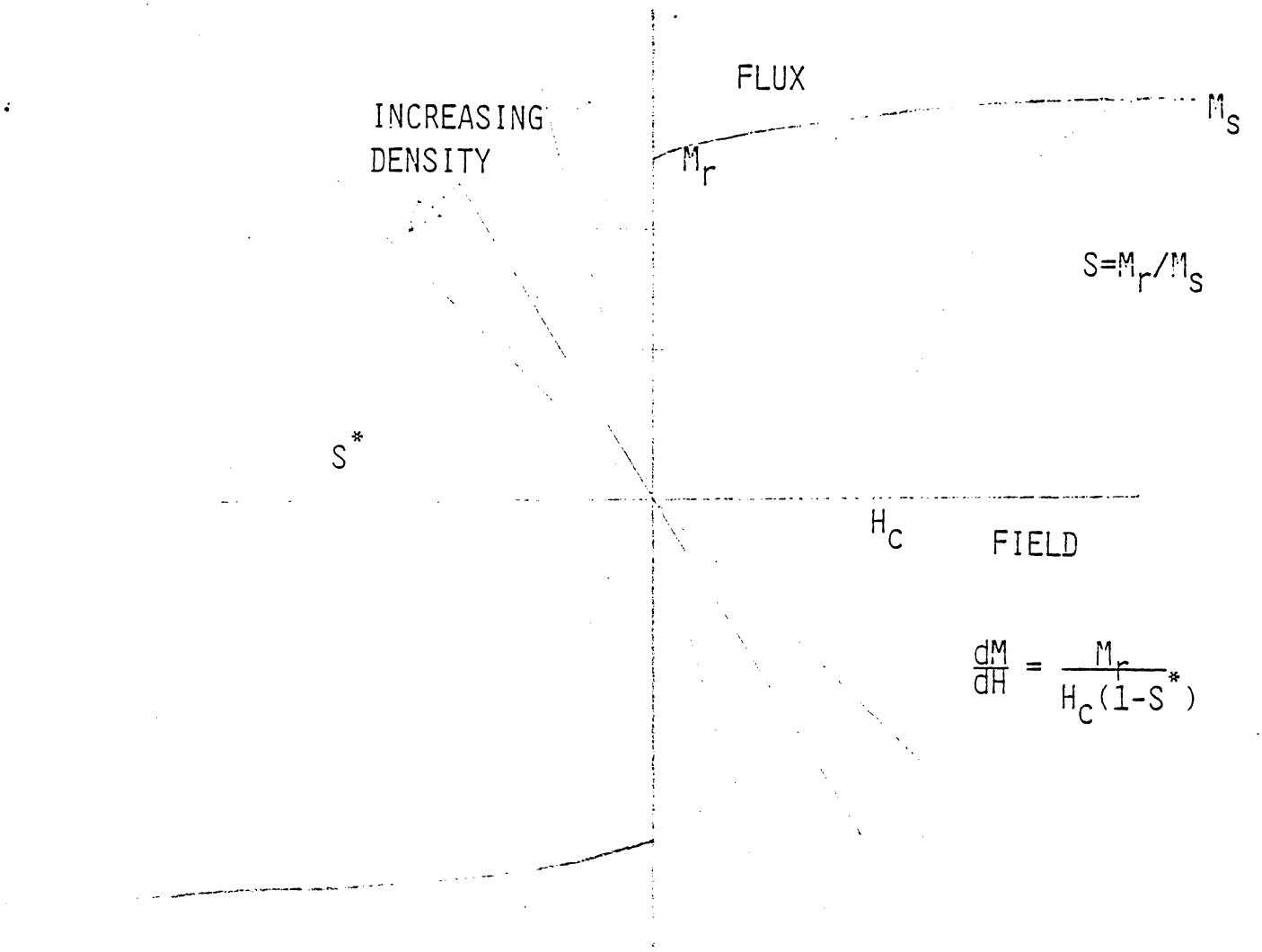
POLE TIP LENGTH

TRANSITION LENGTH

DEMAGNETIZATION

WRITE FIELD GRADIENT





RECORDING DEMAGNETIZATION

SATURATION-RECORDING ANALYSIS

THIN MEDIA

SELF-CONSISTENT FIELD CALCULATIONS

ARCTANGENT TRANSITION SHAPE

$$M_x = \frac{2M_o}{\pi} \arctan x/a \ , \quad a = \text{transition length}$$

LORENZTIAN PULSE RESPONSE

$$e(t) = \frac{1}{1 + (2t/PW_{50})^2}$$

PULSE WIDTH, $PW_{50} = (g^2 + 4(d+a)(d+a+th))^{\frac{1}{2}}$

QUASI-LINEAR ANALYSIS

THICK MEDIA

SUBSTRATE CHARACTERISTICS

NON-SATURATE RECORDING

"PREFERRED DEPTH", UNBIASED OR AC BIAS

FREQUENCY-DOMAIN MEASUREMENT AND ANALYSIS

LINEAR ANALYSIS, FOURIER TRANSFORMS

DATA TRANSMISSION THEORY

EQUALIZATION, OPTIMIZATION

R.O.McCary, "Saturation Magnetic Recording Process," IEEE Trans. Mag. V. MAG-7, March 1971, pp4-16.

CATEGORIES OF SIGNAL DISTORTION

LINEAR

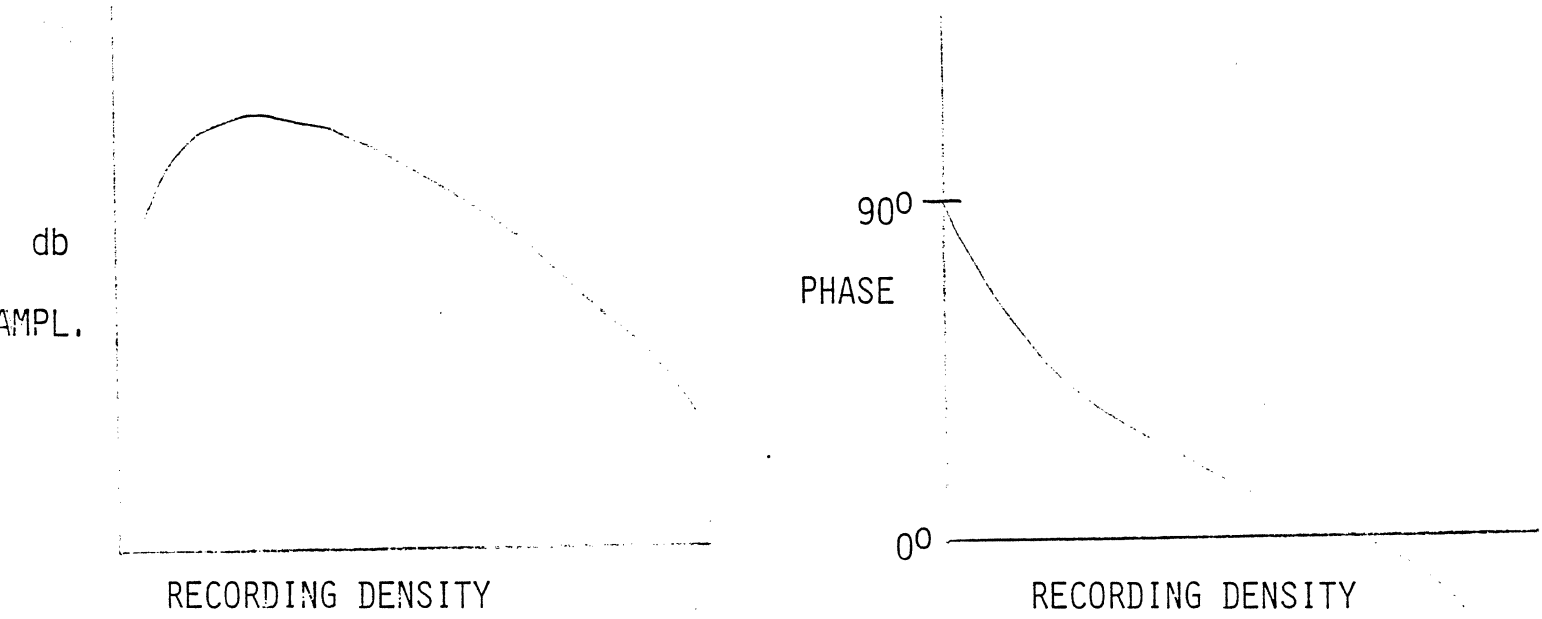
- FREQUENCY DISTORTION
- AMPLITUDE AND PHASE VARIATION VS FREQUENCY

NONLINEAR, NO MEMORY EFFECTS

- HARMONIC DISTORTION
- INTERMODULATION DISTORTION

NONLINEAR WITH MEMORY

- NONLINEAR INTERSYMBOL INTERFERENCE



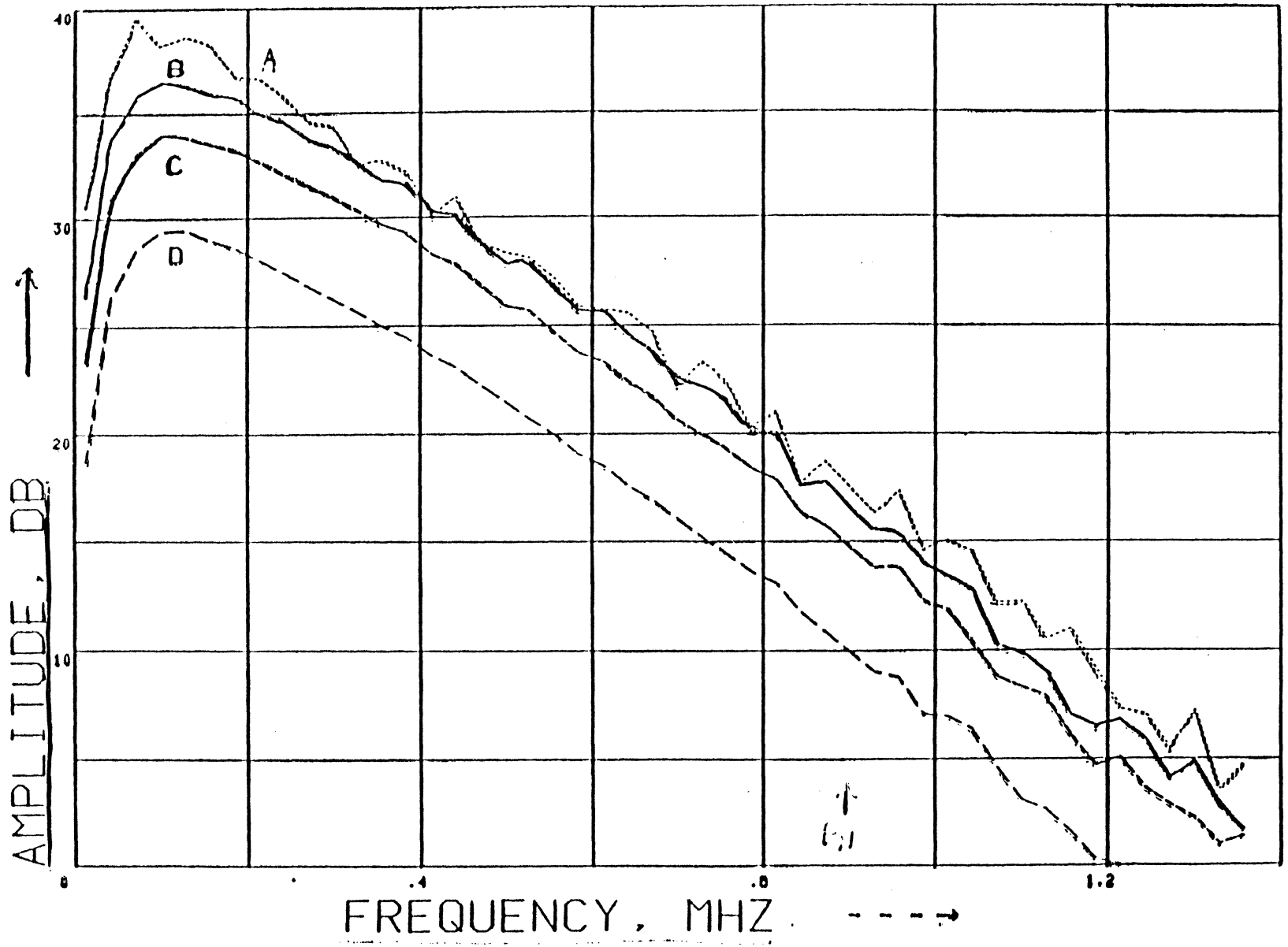
FREQUENCY DISTORTION

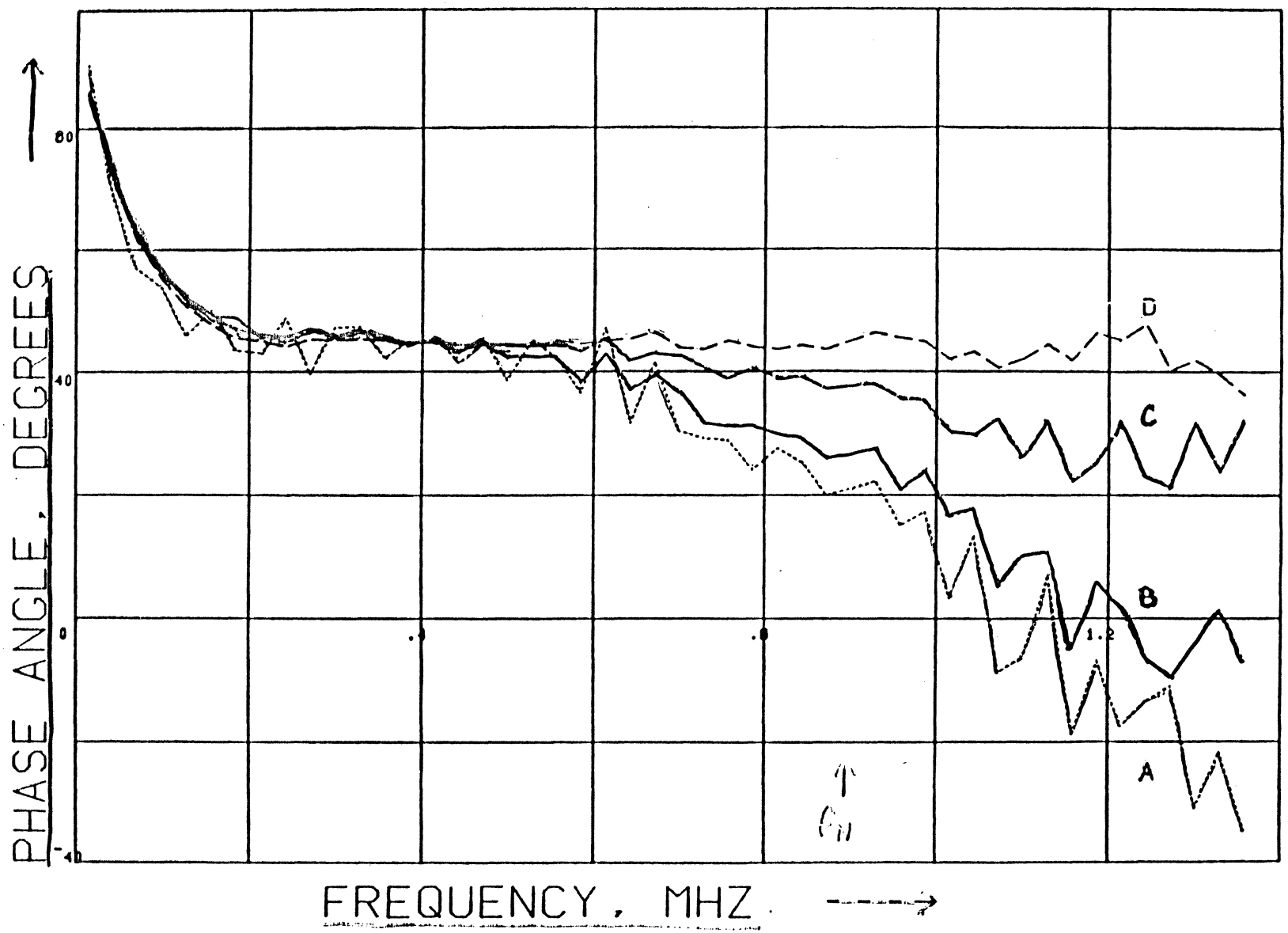
WALLACE'S EQUATIONS
- SEPARATION
- GAP
- THICKNESS

PHASE EFFECT DURING RECORDING

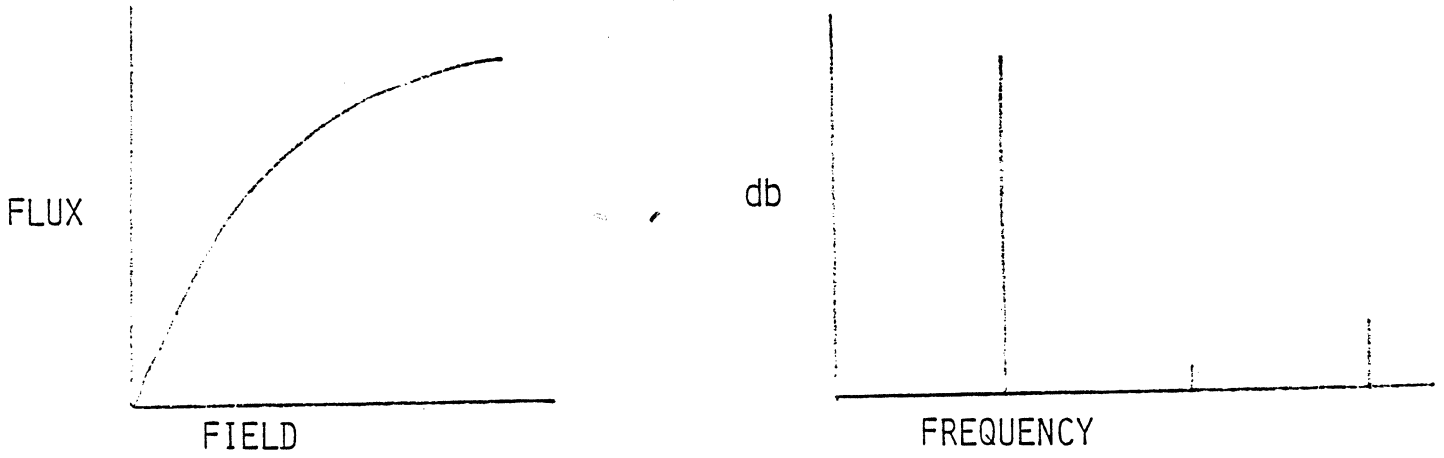
LINEAR EFFECTS

CORRECTABLE BY EQUALIZATION

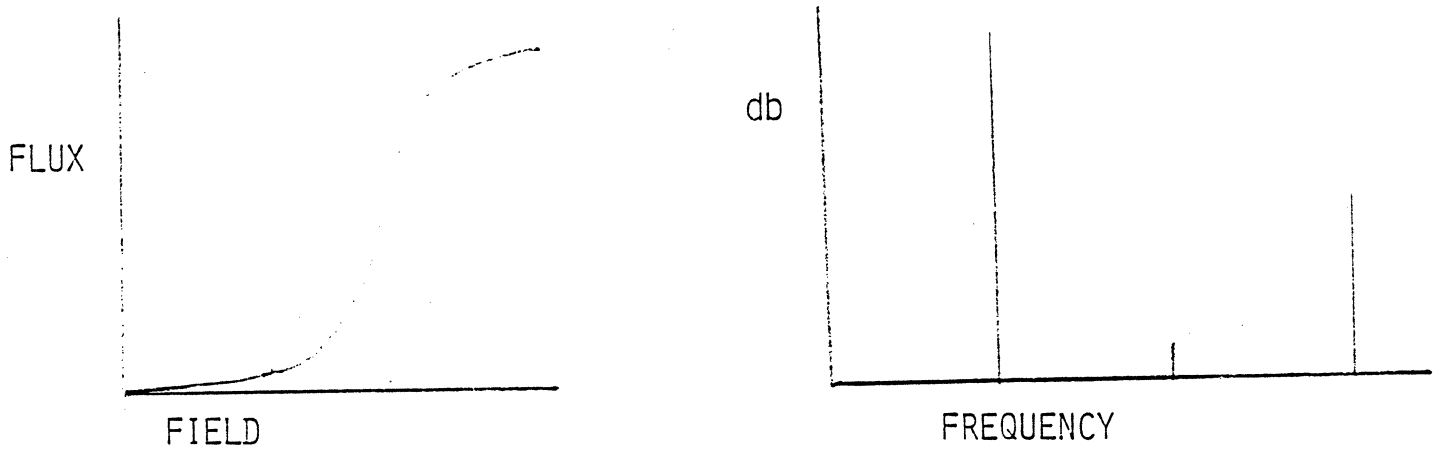

40
30
20
10
0
.4
.8
1.2
A
B
C
D
AMPLITUDE, DB
FREQUENCY, MHZ


80
40
0
-40
PHASE ANGLE, DEGREES
FREQUENCY, MHZ
D
C
B
A
1.2

HARMONIC DISTORTION



AC BIAS RECORDING



UNBIASED RECORDING

NONLINEARITY AS A POWER SERIES

NO EVEN HARMONICS

UNCORRECTABLE BY LINEAR EQUALIZATION

EXTENSION TO INTERMODULATION

NO MEMORY EFFECTS
SUPERPOSITION APPLICABLE

NONLINEAR INTERSYMBOL INTERFERENCE

A HIGH DENSITY PHENOMENON

RELATED TO THE EXTENT OF WRITE-HEAD FIELD, AND THE TRANSITION LENGTH, AS COMPARED TO THE BIT SPACING

DEMAGNETIZATION INTERACTION

DATA PATTERN DEPENDENT

SUPERPOSITION FAILURE

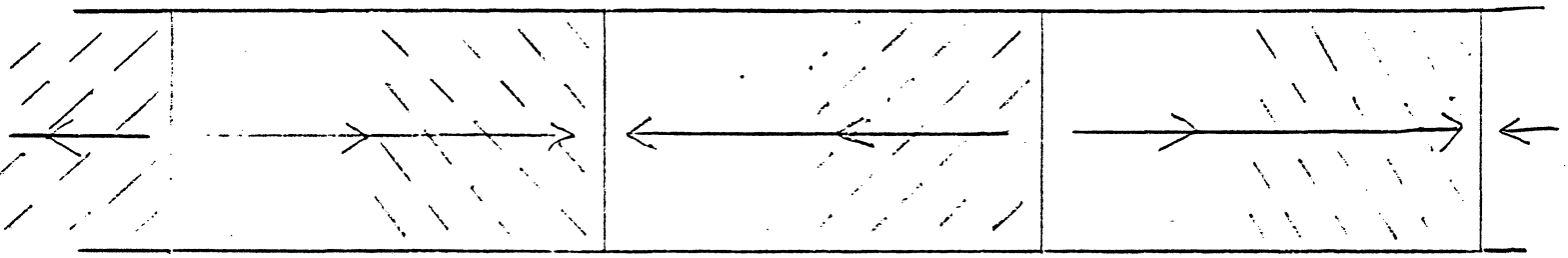
UNCORRECTABLE BY LINEAR EQUALIZATION

SHOWN IN:-

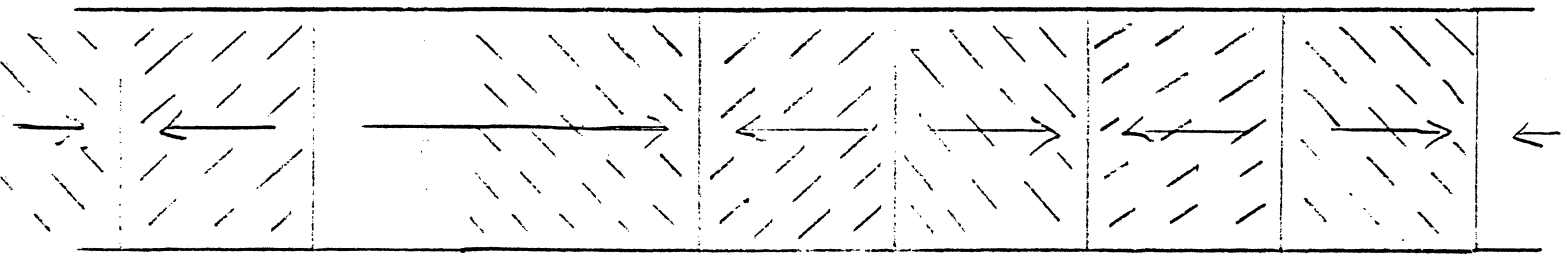
- SELF-CONSISTENT FIELD CALCULATIONS
- SCALE-MODELING EXPERIMENTS
- TIME-DOMAIN MEASUREMENTS
- TRANSFER-FUNCTION MEASUREMENTS

NONLINEAR INTERSYMBOL INTERFERENCE

"SNOWSHOE" EFFECT



LOW RECORDING DENSITY



HIGH RECORDING DENSITY

SHADED AREA = TRANSITION REGION

NOISE SOURCES IN DIGITAL RECORDING

HEAD NOISE

AMPLIFIER NOISE

MEDIA NOISE

- PARTICULATE, DOMAIN, DEFECTS
- MODULATION NOISE

STRAY COUPLING

- FEEDTHROUGH
- MULTI-TRACK HEADS

HEAD FRINGE-FIELDS

- SIDE WRITING
- SIDE READING
- CORNER READING

OVERWRITE NOISE

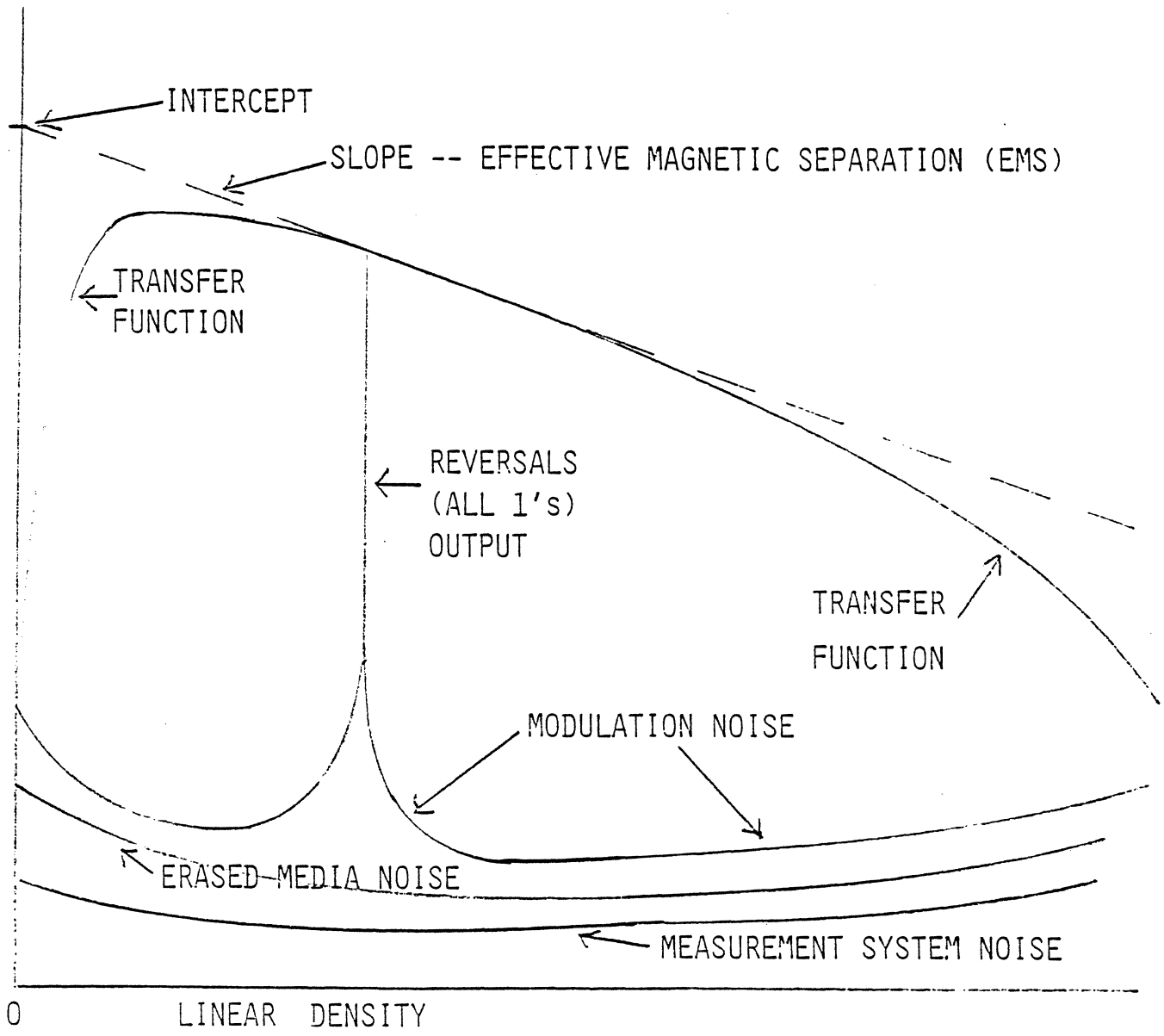
TRACK MISREGISTRATION

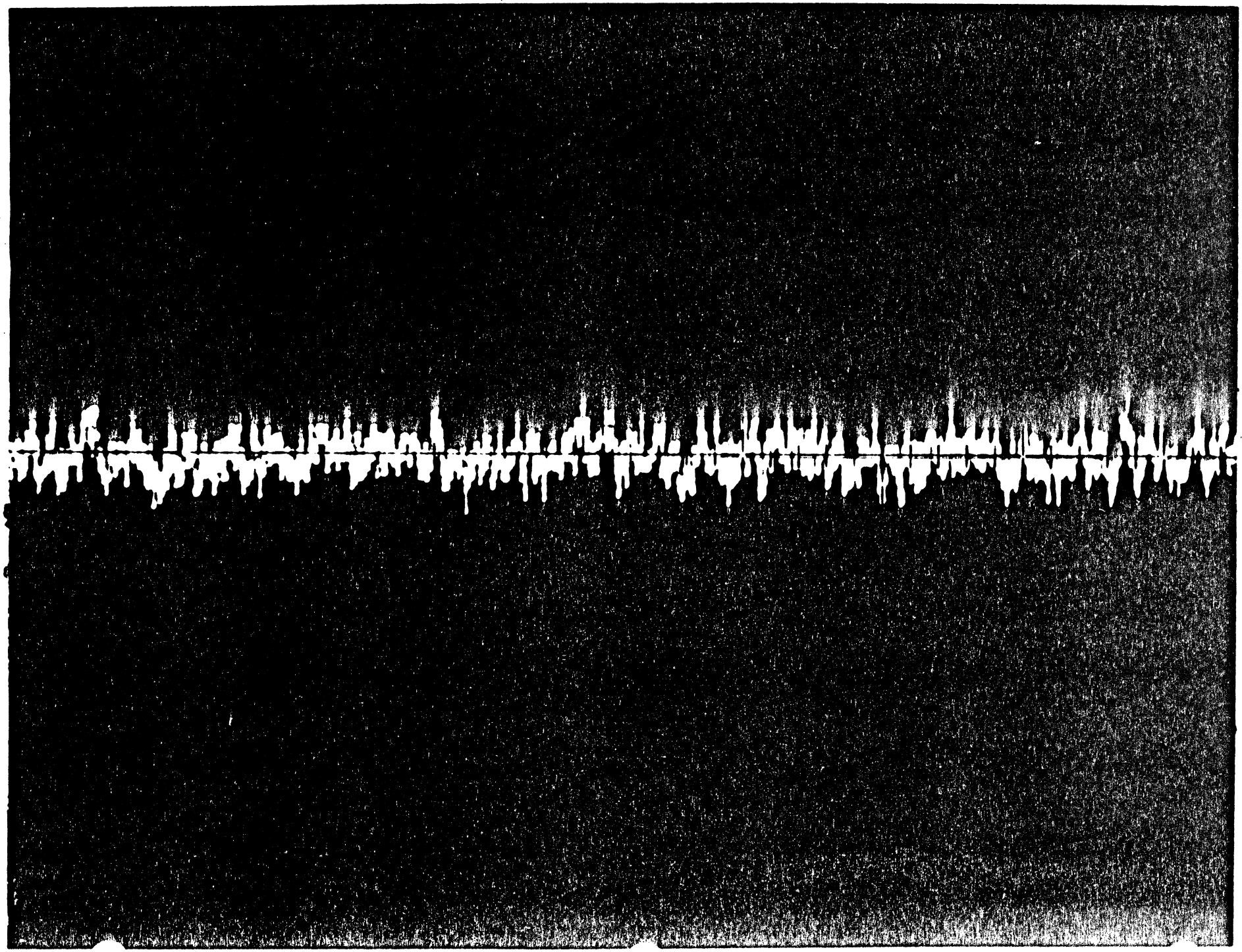
- OFF-TRACK
- ADJACENT TRACK
- OLD INFORMATION

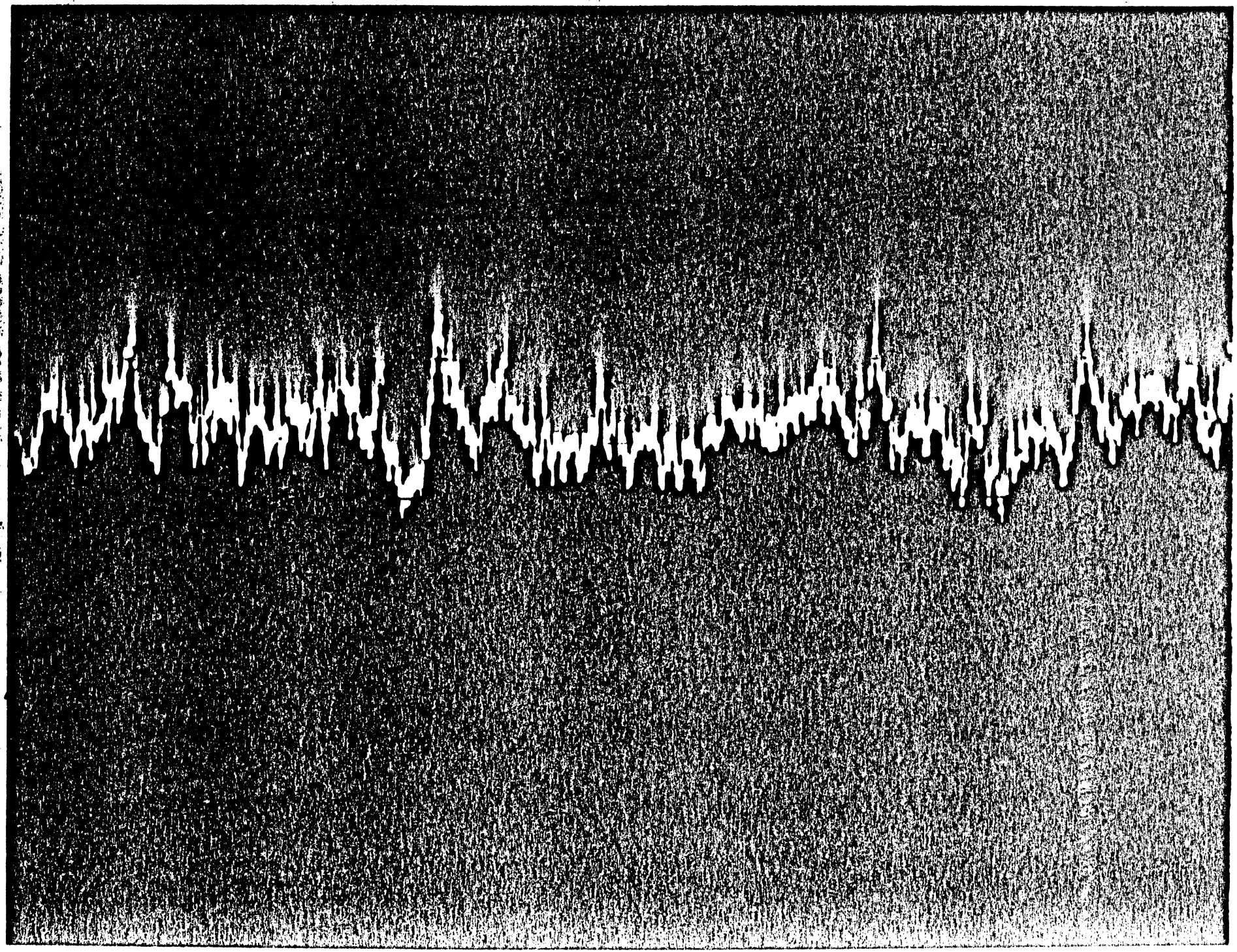
MECHANICAL VIBRATIONS AND VARIATIONS

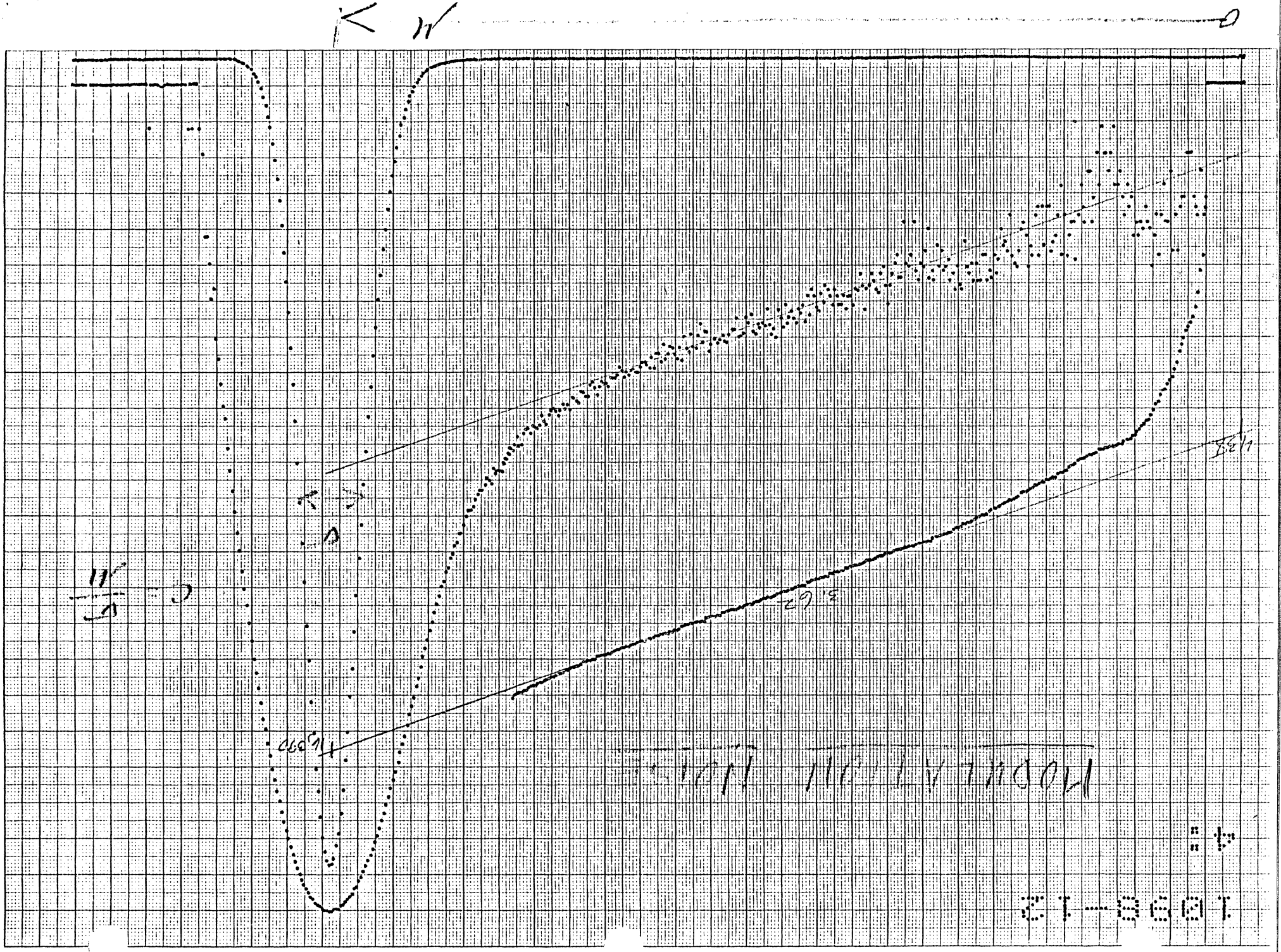
- VELOCITY
- TRACKING

DENSITY RESPONSE AND NOISE

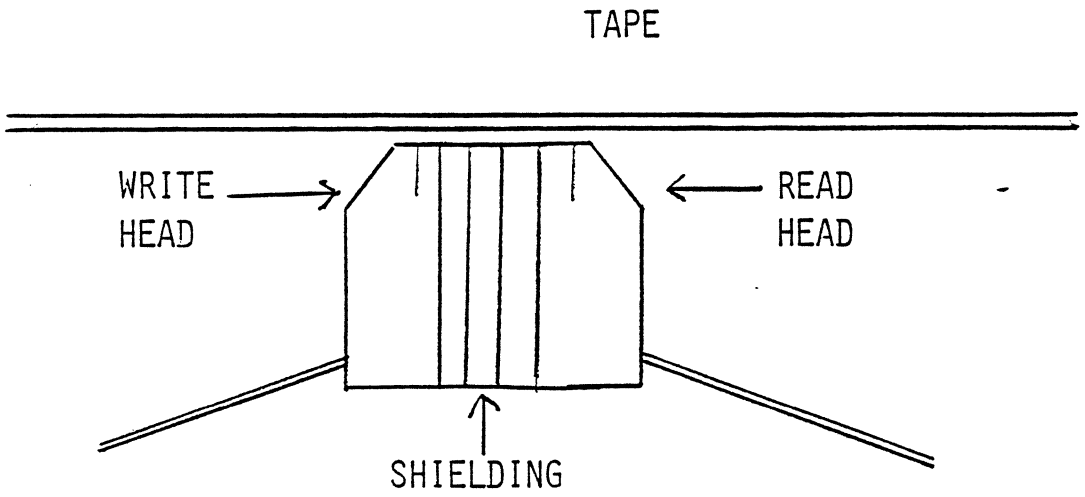




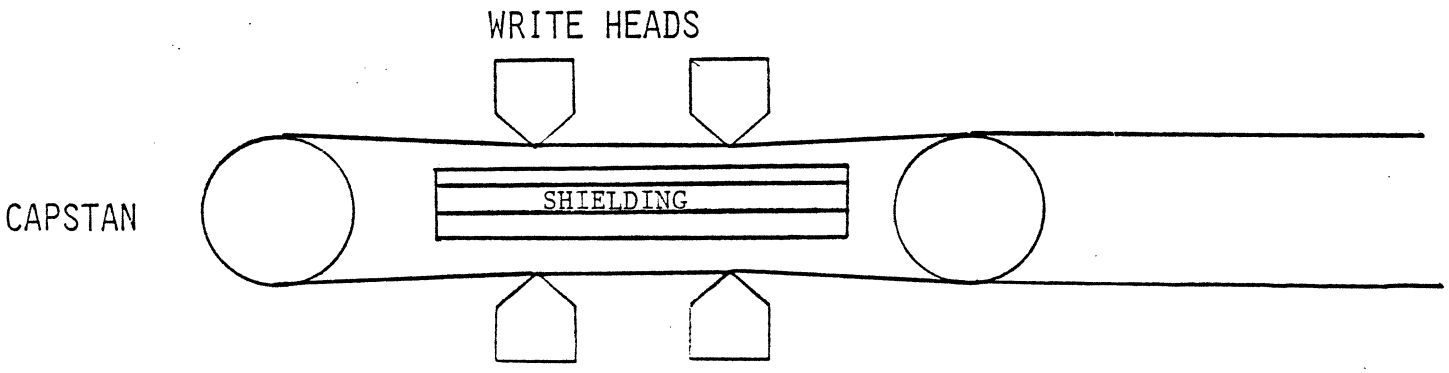




FEEDTHROUGH NOISE



COMBINED READ-WRITE HEAD



SEPARATE READ AND WRITE HEADS

COUPLING FROM WRITE HEAD AND CABLES TO READ HEAD

READ-WHILE-WRITE OPERATION ONLY

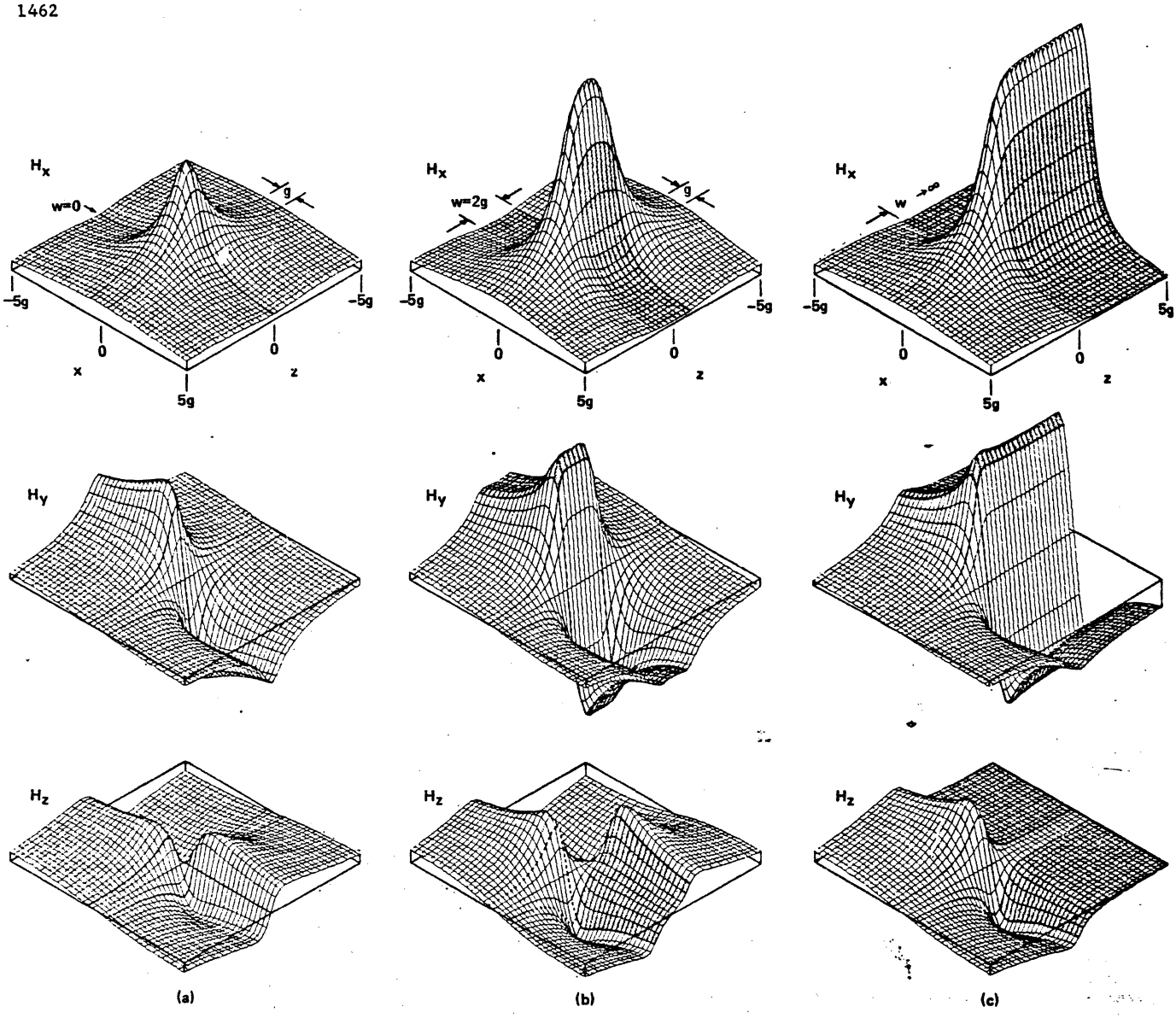


Figure 4. Magnetic fields at y=g/2 for (a) zero width head, (b) finite width head, w=2g, and (c) semi-infinite width head. Components are: longitudinal (H_x), vertical (H_y), and transverse (H_z). Projected onto each field surface are the outlines of the top of the head with edge extensions.

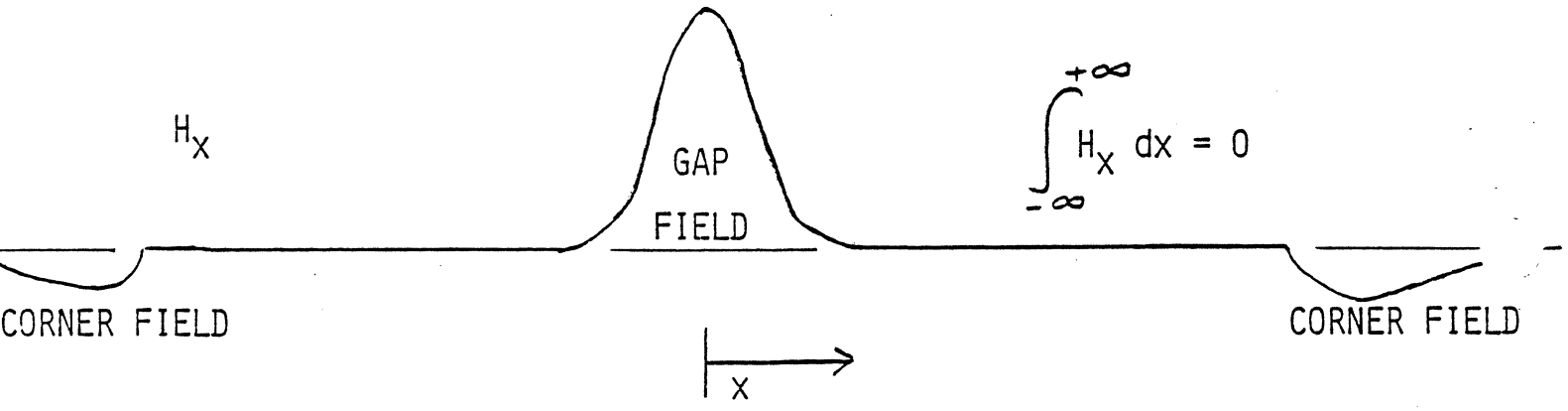
HEAD FIELD DISTRIBUTIONS

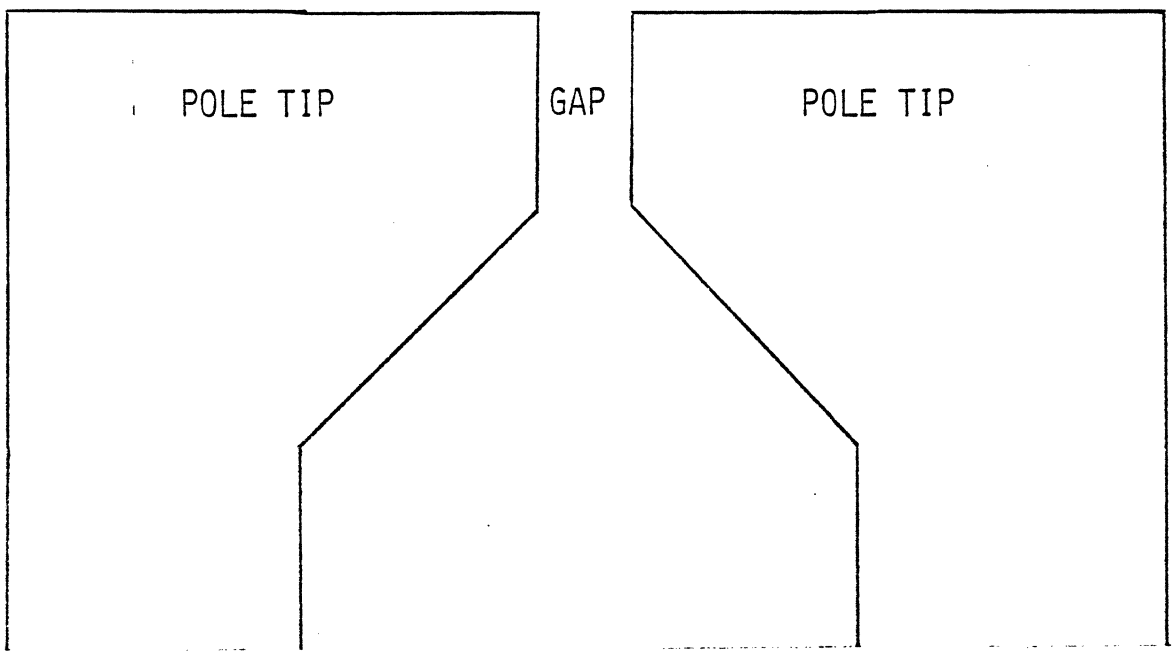
D. A. Lindholm, "Magnetic Fields of Finite Track Width Heads," IEEE Trans. Mag. Vol. MAG-13, Sept. 1977

READ-SEPARATION DEPENDENT

DENSITY DEPENDENT

HEAD-CORNER READING EFFECT





OVERWRITE-ERASURE NOISE

ERASE PROBLEM

DC ERASE, AC ERASE

DENSITY DEPENDENCE

TRANSITION REGION

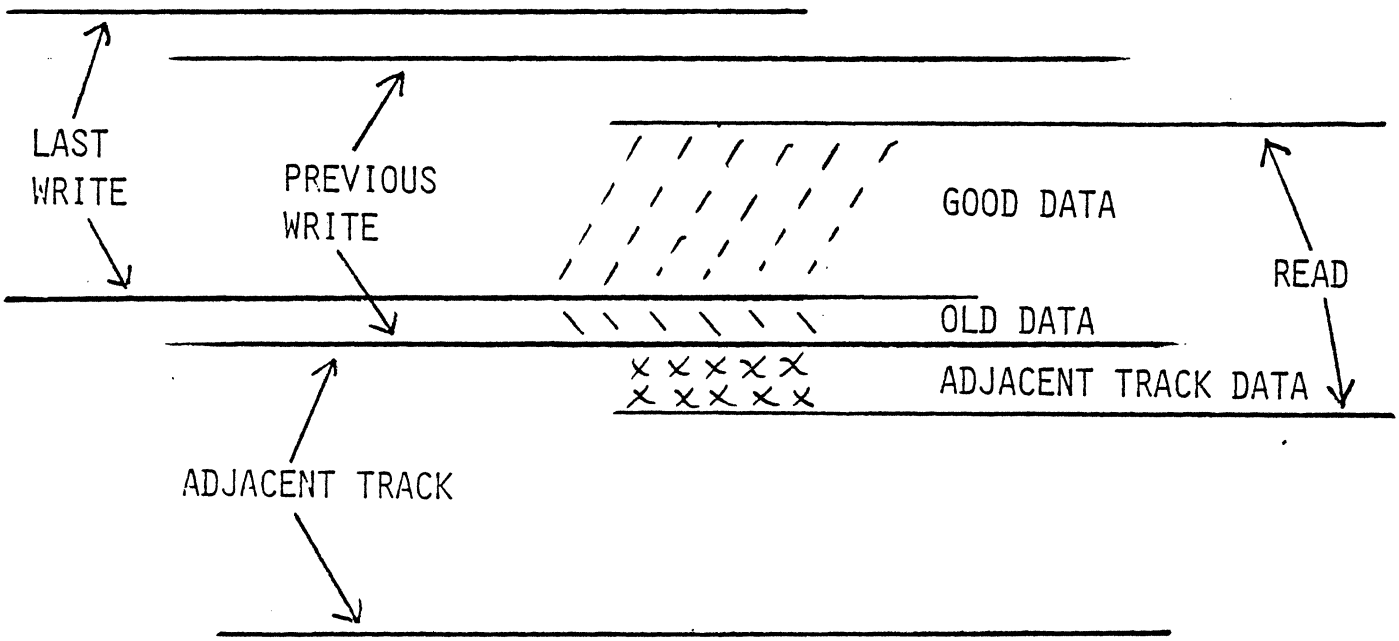
FINITE DEPTH RECORDING

FLYING-HEIGHT VARIATION

UNBIASED, AC BIAS, RECORDING

CODED WRITE-DATA SPECTRUM

TRACK MISREGISTRATION (TMR)



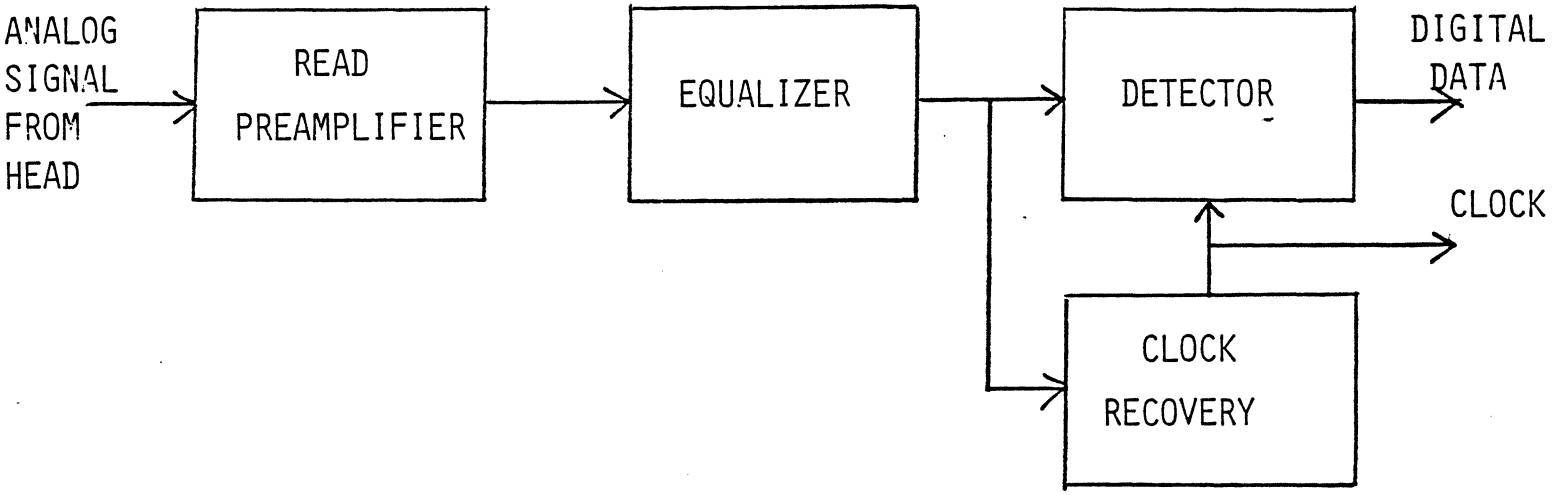
GUARD BAND

TUNNEL ERASE

WRITE WIDE, READ NARROW

SERVO TRACK FOLLOWING

READ-ELECTRONICS CHAIN

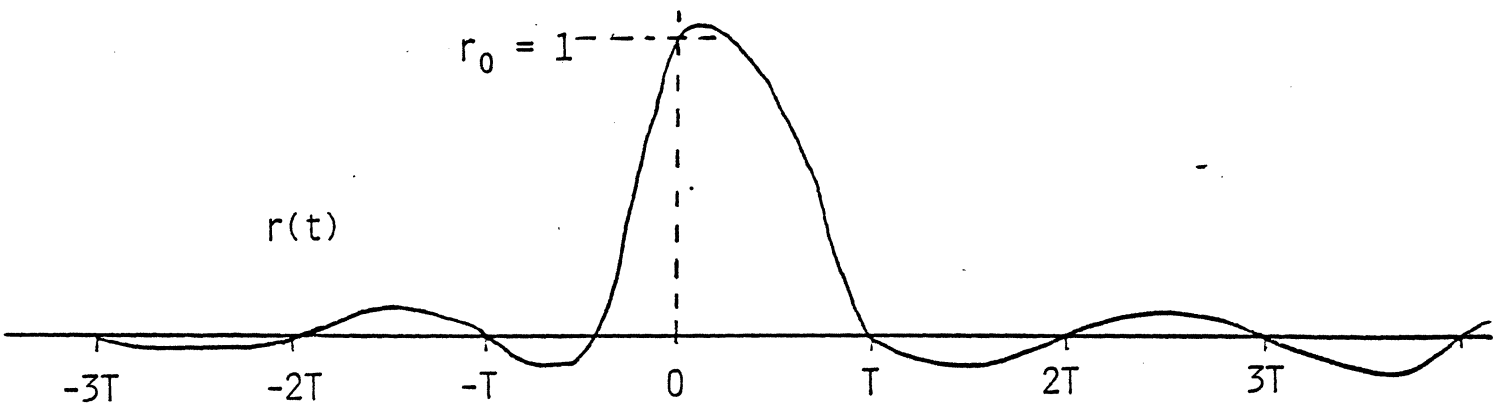


BENNETT & DAVY, DATA TRANSMISSION, NEW YORK: McGRAW-HILL, 1965.

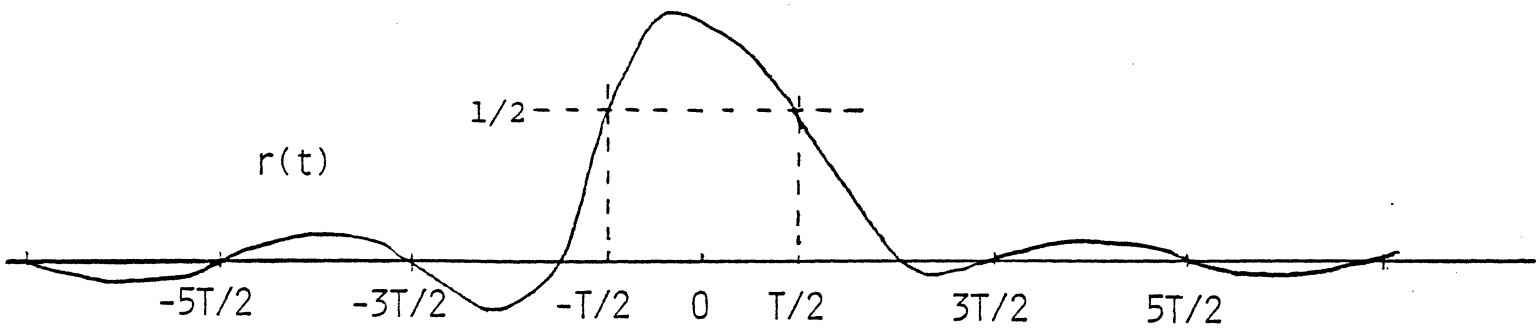
EQUALIZATION:-

GIBBY & SMITH, B.S.T.J., V44, Sept. 1965, pp 1487-1510

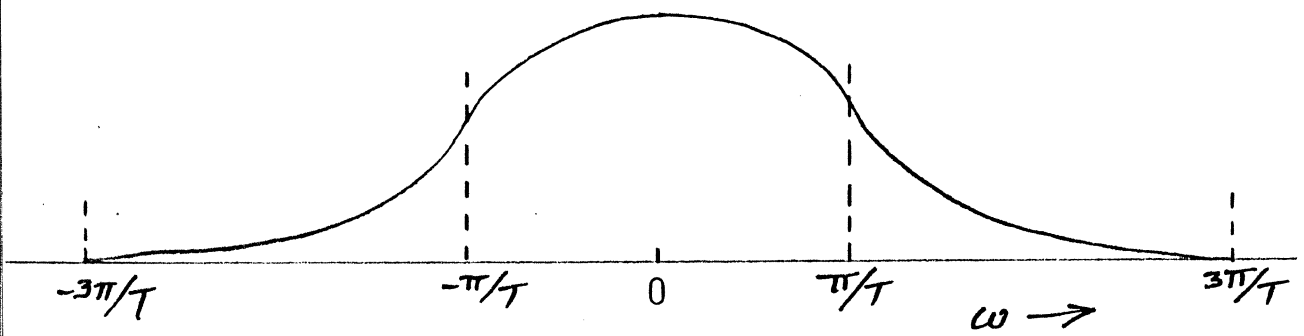
EQUALIZING SAMPLED DATA



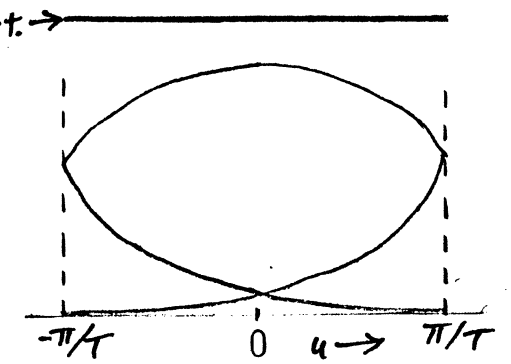
CONTROLLING AMPLITUDE AT SAMPLE POINTS



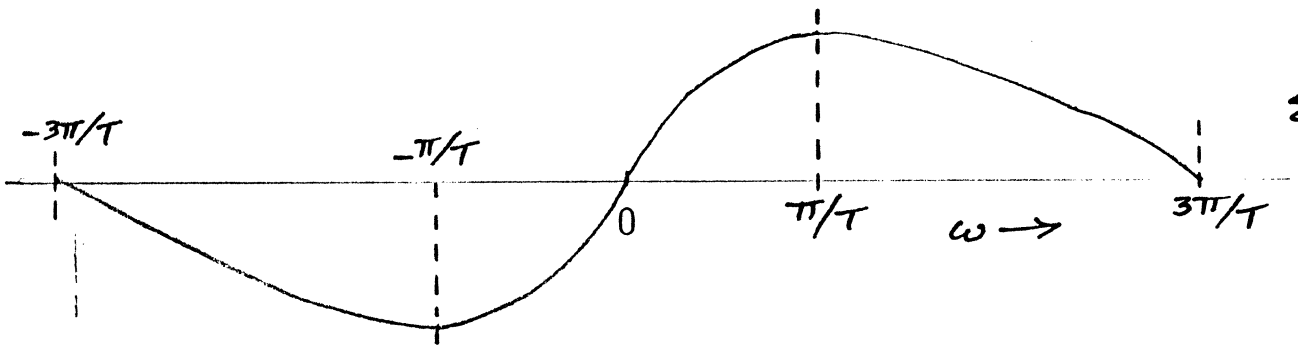
CONTROLLING PULSE WIDTH BETWEEN SAMPLE POINTS



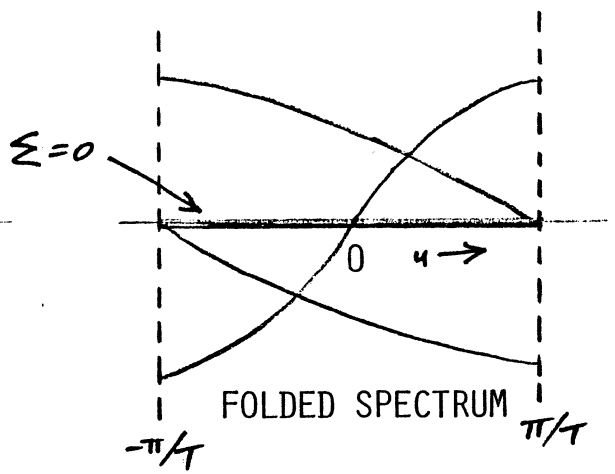
REAL COMPONENT OF SIGNAL SPECTRUM



FOLDED SPECTRUM

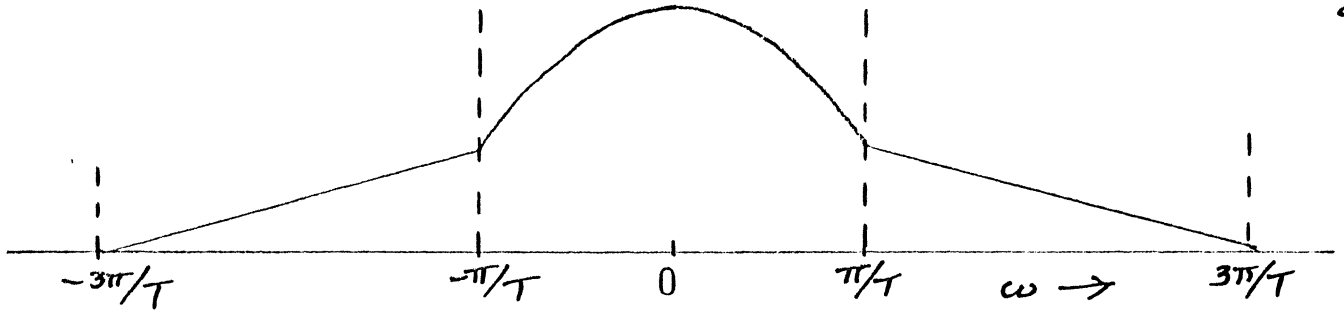


IMAGINARY COMPONENT OF SIGNAL SPECTRUM

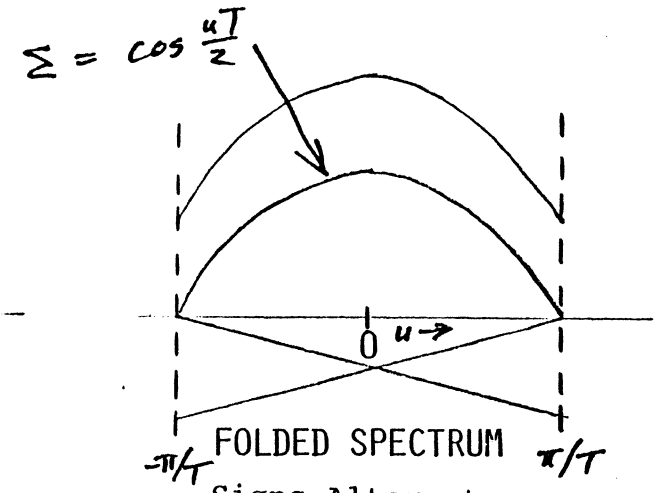


FOLDED SPECTRUM

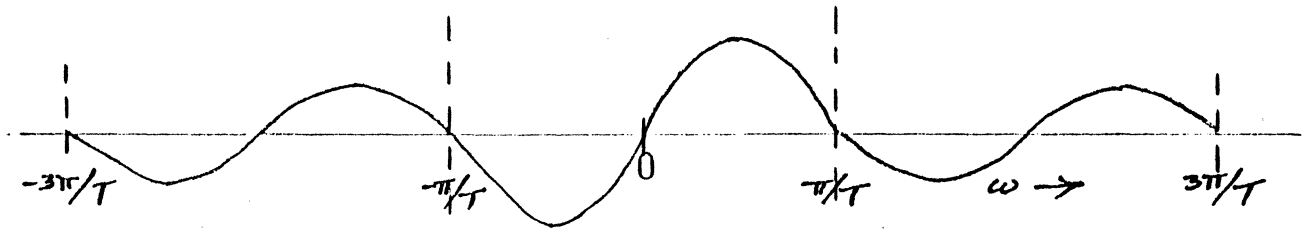
EXAMPLE:-- SPECTRUM THAT CONTROLS AMPLITUDE AT SAMPLE POINTS



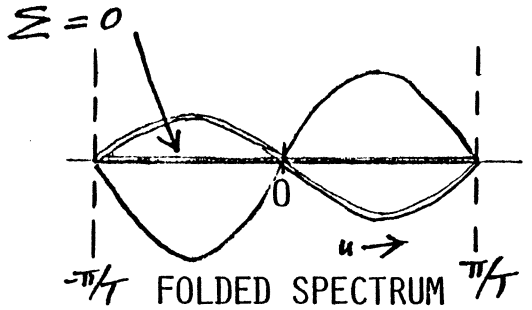
REAL COMPONENT OF SIGNAL SPECTRUM



FOLDED SPECTRUM
Signs Alternate



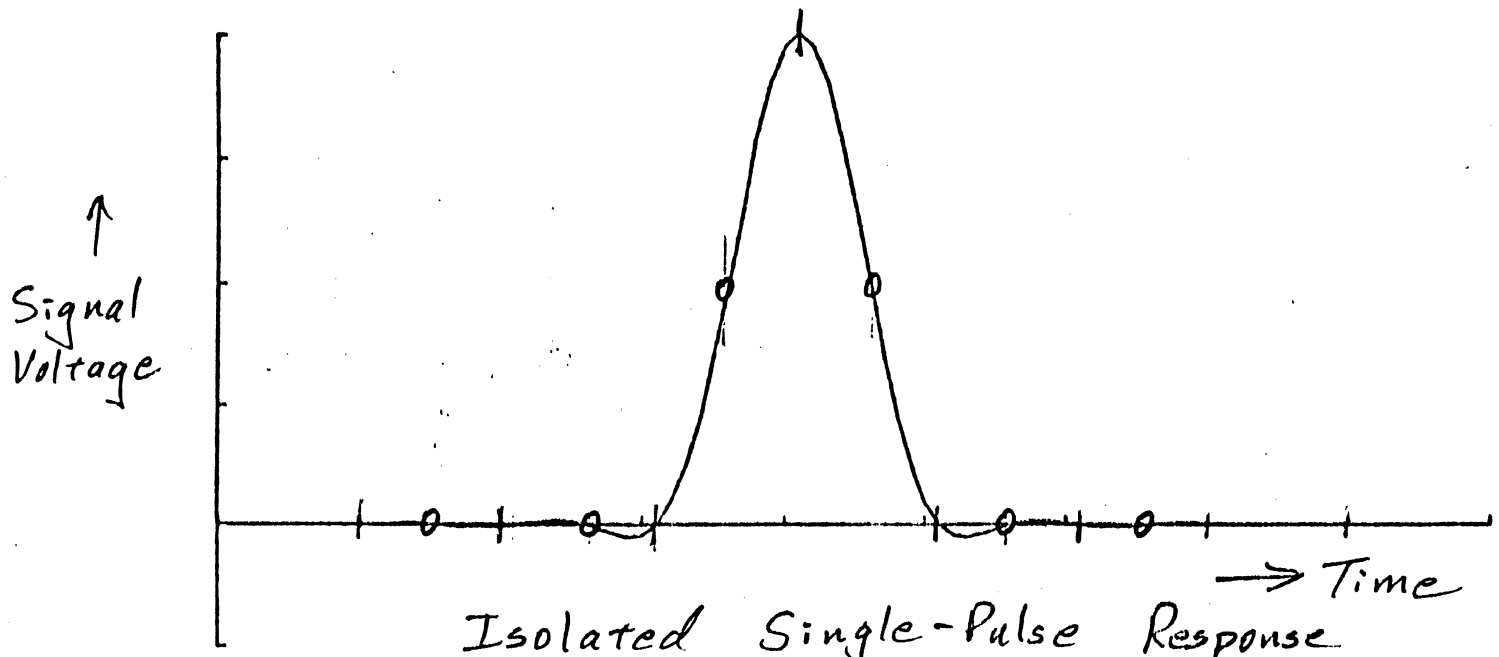
IMAGINARY COMPONENT OF SIGNAL SPECTRUM



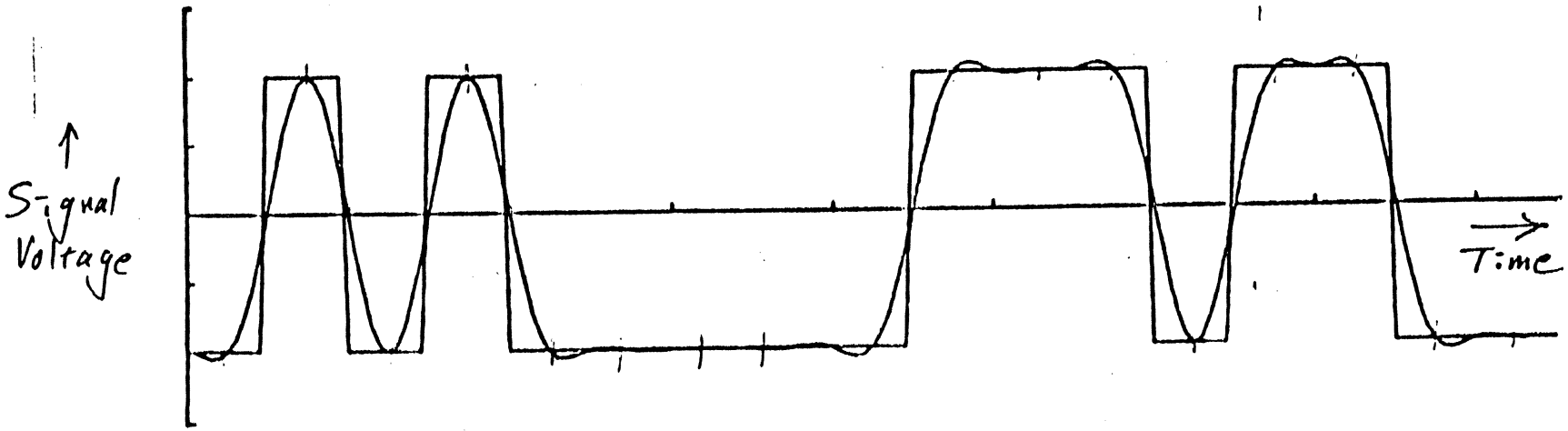
FOLDED SPECTRUM
Signs Alternate

EXAMPLE:-- SPECTRUM THAT CONTROLS PULSE-WIDTH AT SAMPLE POINTS

"RAISED - COSINE" CHANNEL

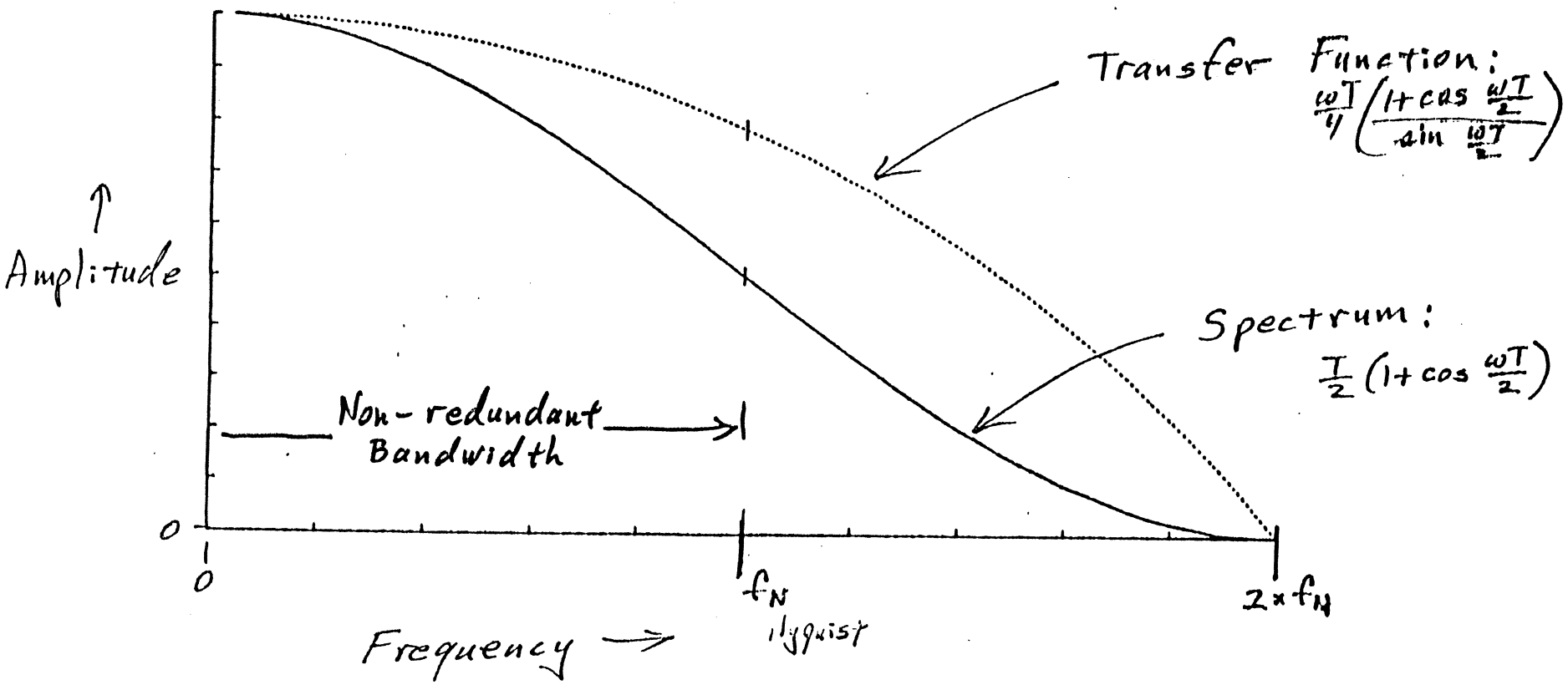


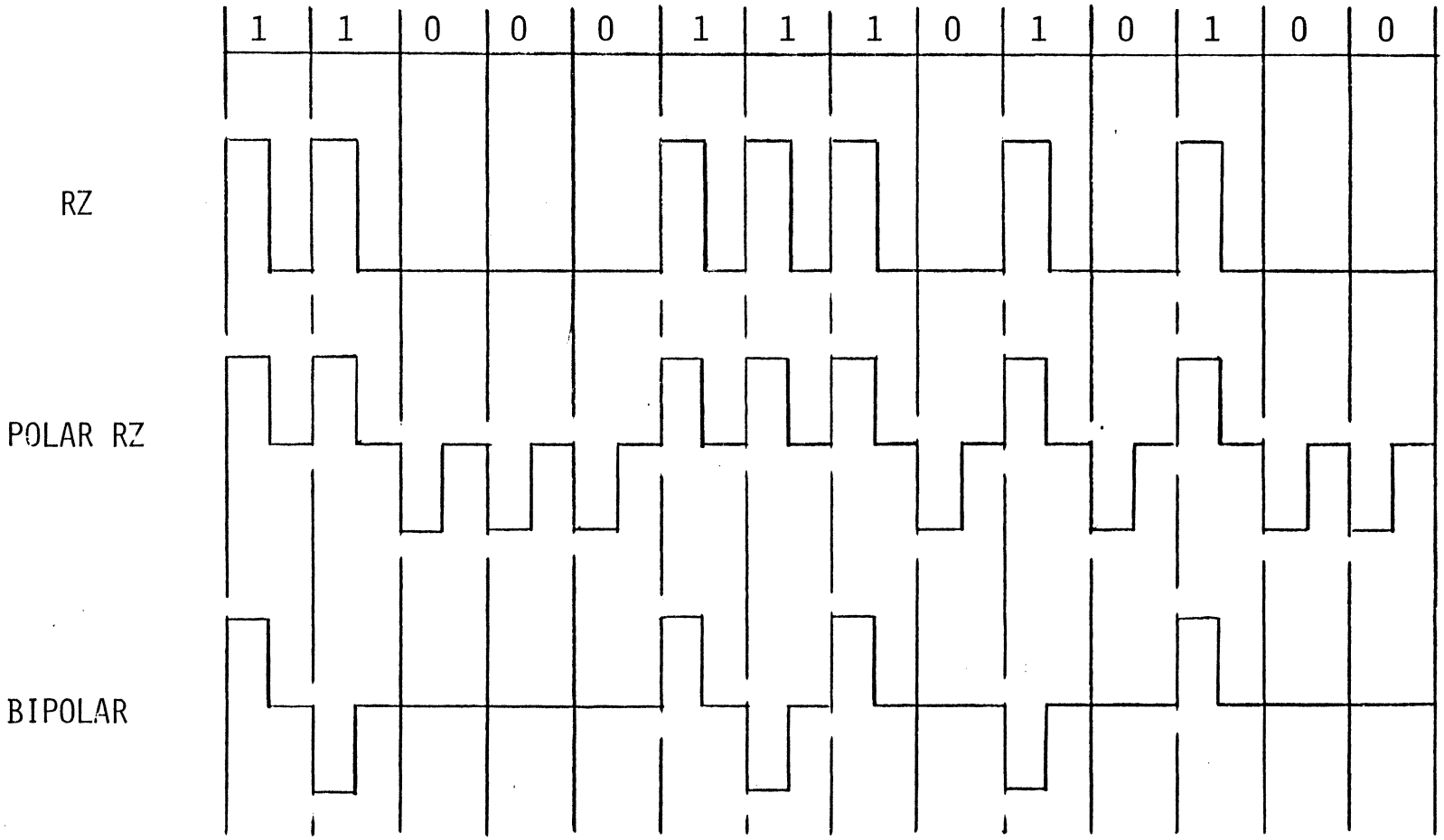
Isolated Single-Pulse Response



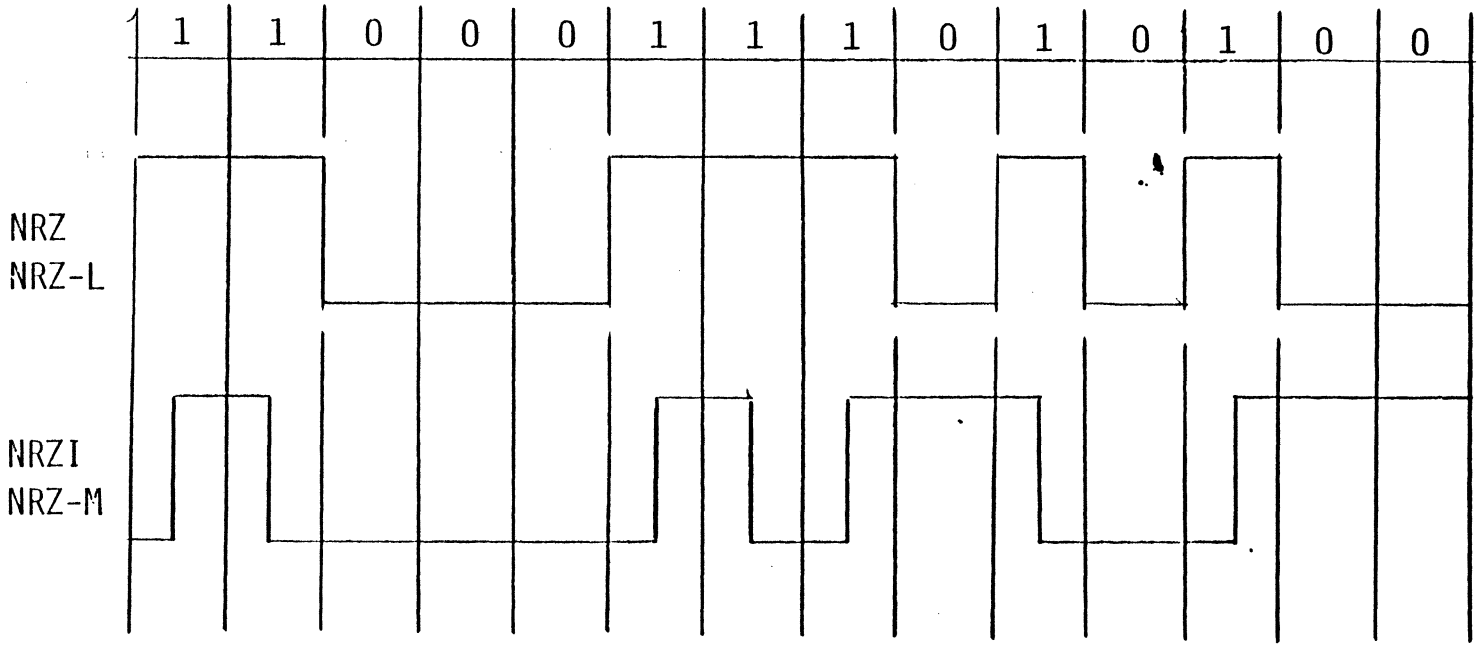
Pulse-Train Response

"RAISED - COSINE" CHANNEL

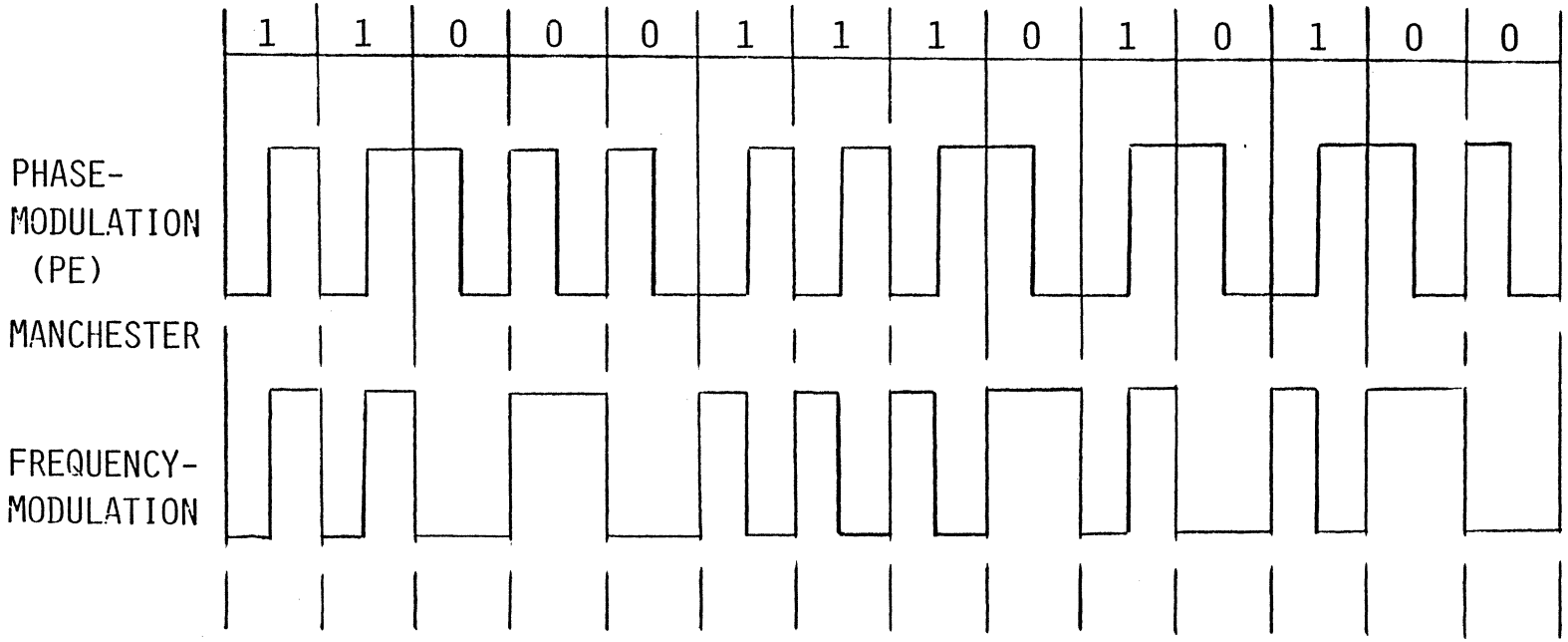




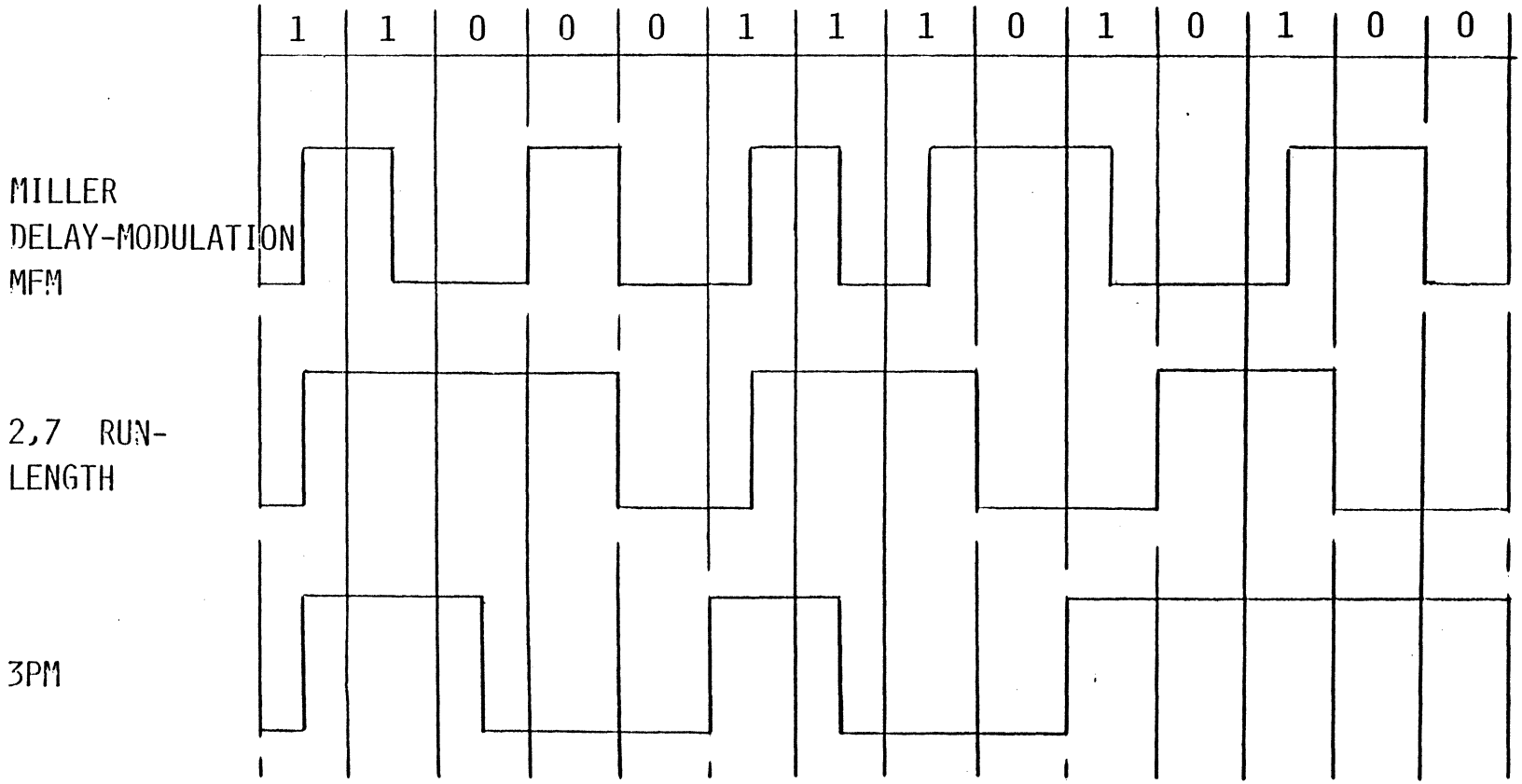
RETURN-TO-ZERO (RZ) CODES



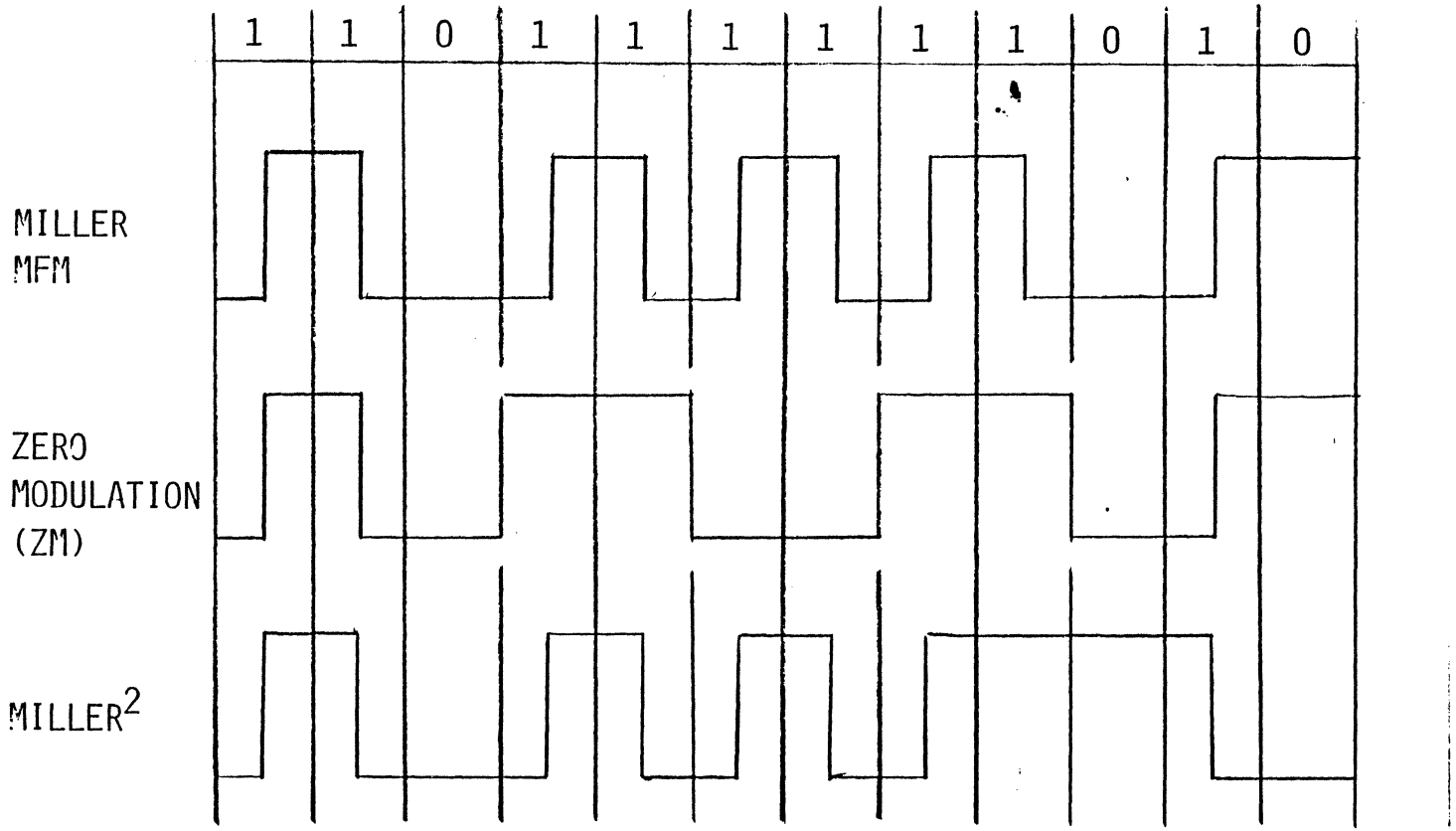
NON-RETURN-TO-ZERO (NRZ) CODES



DOUBLE-FREQUENCY CODES



HALF-WINDOW CODES



DC-FREE MODIFICATIONS OF MILLER-MFM CODE

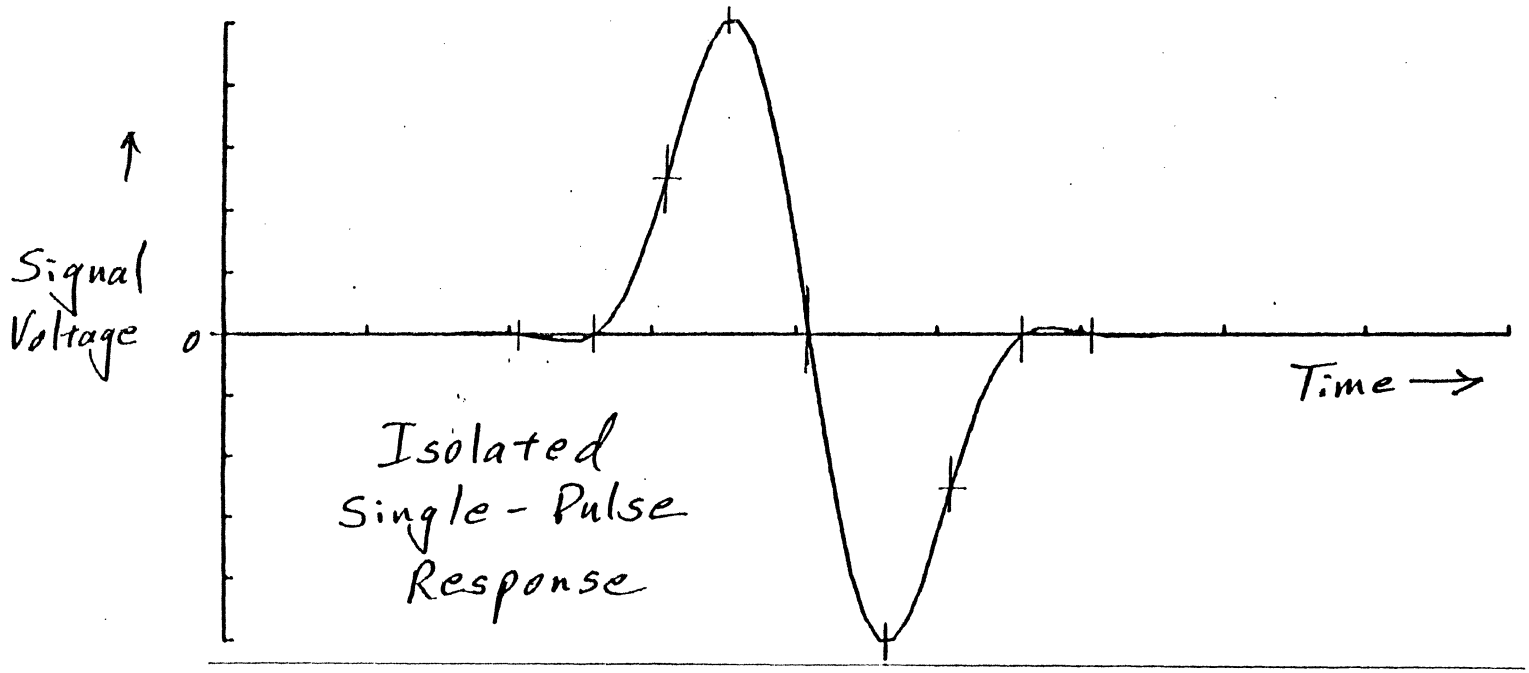
CHANNEL CODE PARAMETERS

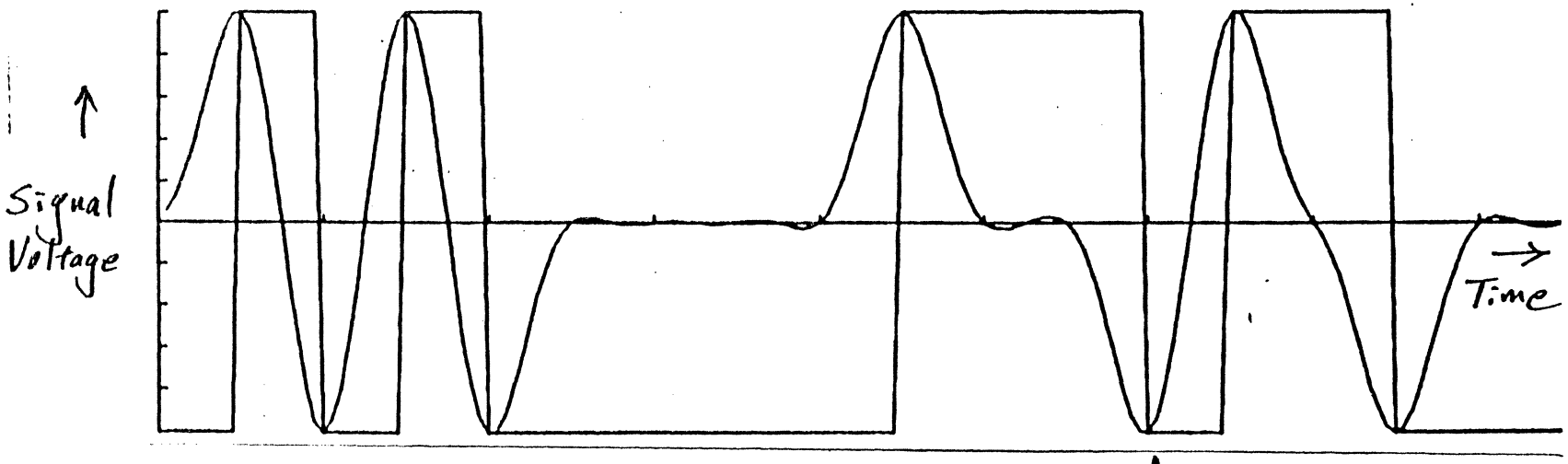
T	DATA BIT TIME INTERVAL
m	# OF DATA BITS GROUPED
n	# OF CODE BITS IN GROUP
m/n	RATE
d	MINIMUM # OF ZEROS BETWEEN ONES
k	MAXIMUM # OF ZEROS BETWEEEN ONES
T_{min}	MINIMUM TIME BETWEEN TRANSITIONS
T_{max}	MAXIMUM TIME BETWEEN TRANSITIONS
DR	DENSITY RATIO = $T_{min}/T = \frac{\text{DATA DENSITY}}{\text{MAX. TRANS. DENSITY}}$
W	WINDOW = (m/n)T
DSV	MAXIMUM DIGITAL SUM VARIATION

	m	n	RATE	d	k	T_{min}	T_{max}	DR	W	CLOCK	DSV
NRZI	1	1	1	0	∞	T	∞	1	T	1/T	∞
DOUBLE FREQUENCY	1	2	1/2	0	1	T/2	T	1/2	T/2	2/T	T
MILLER MFM	1	2	1/2	1	3	T	2T	1	T/2	2/T	∞
ZM	1	2	1/2	1	3	T	2T	1	T/2	2/T	3T/2
MILLER^2	1	2	1/2	1	5	T	3T	1	T/2	2/T	3T/2
3PM	3	6	1/2	2	7	3T/2	4T	3/2	T/2	2/T	∞
2,7 RLL	2 3 4	4 6 8	1/2	2	7	3T/2	4T	3/2	T/2	2/T	∞

CHANNEL CODE COMPARISON

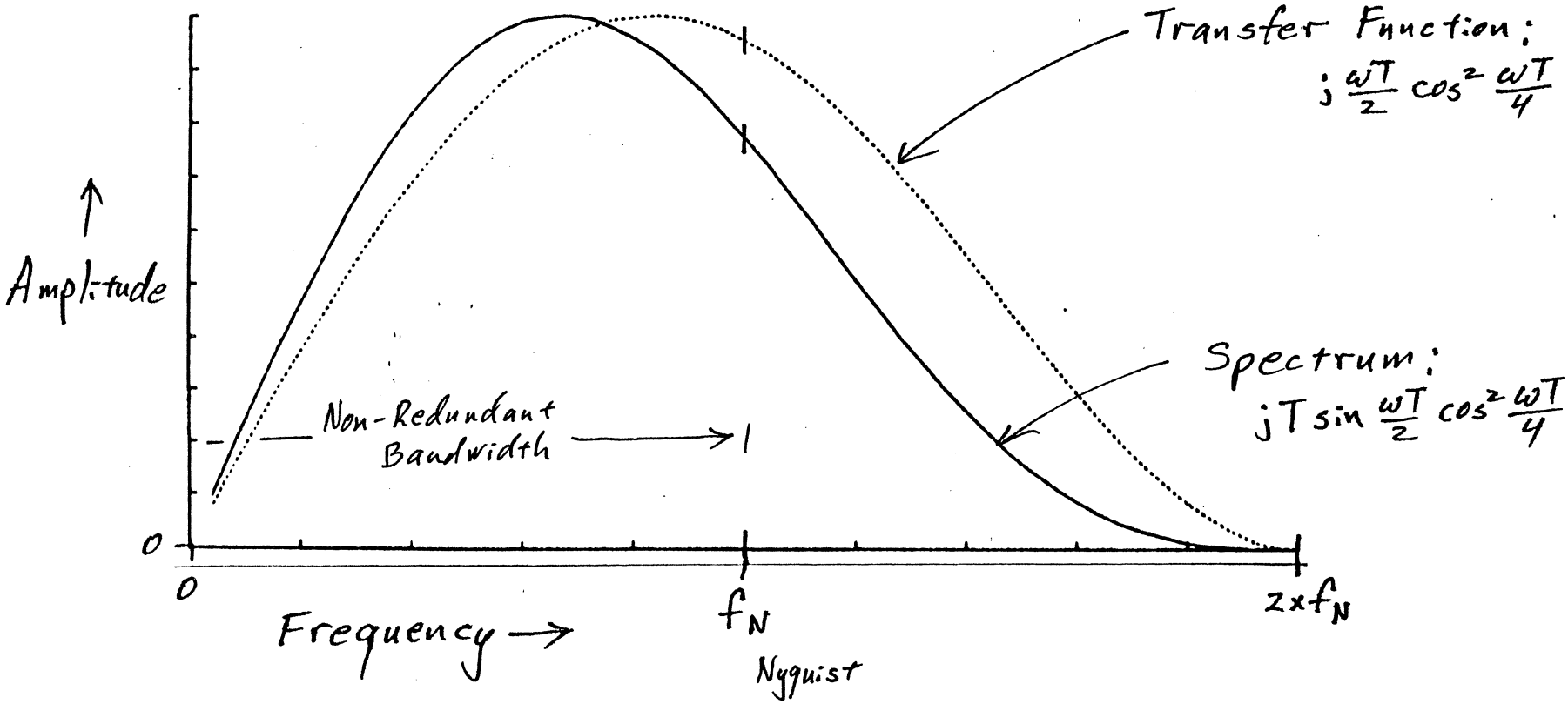
PSEUDO-TERNARY NRZI CHANNEL



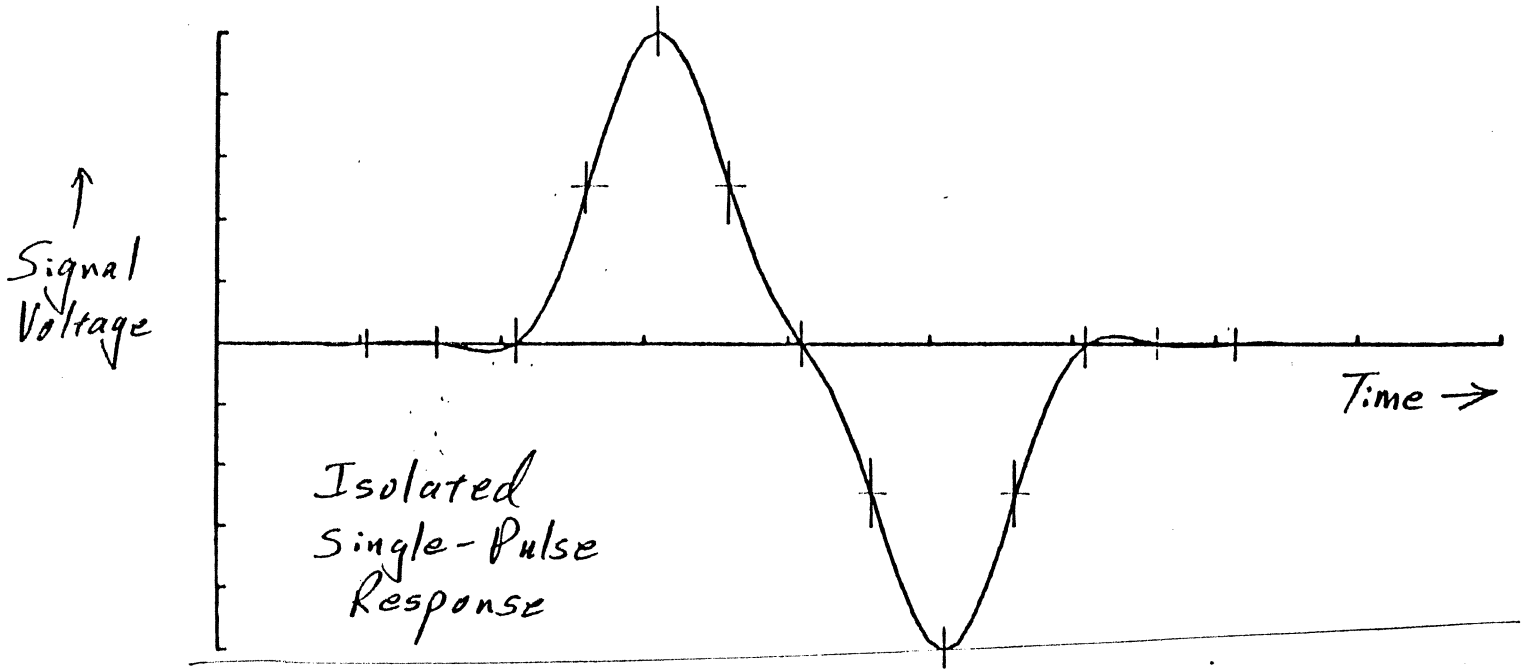


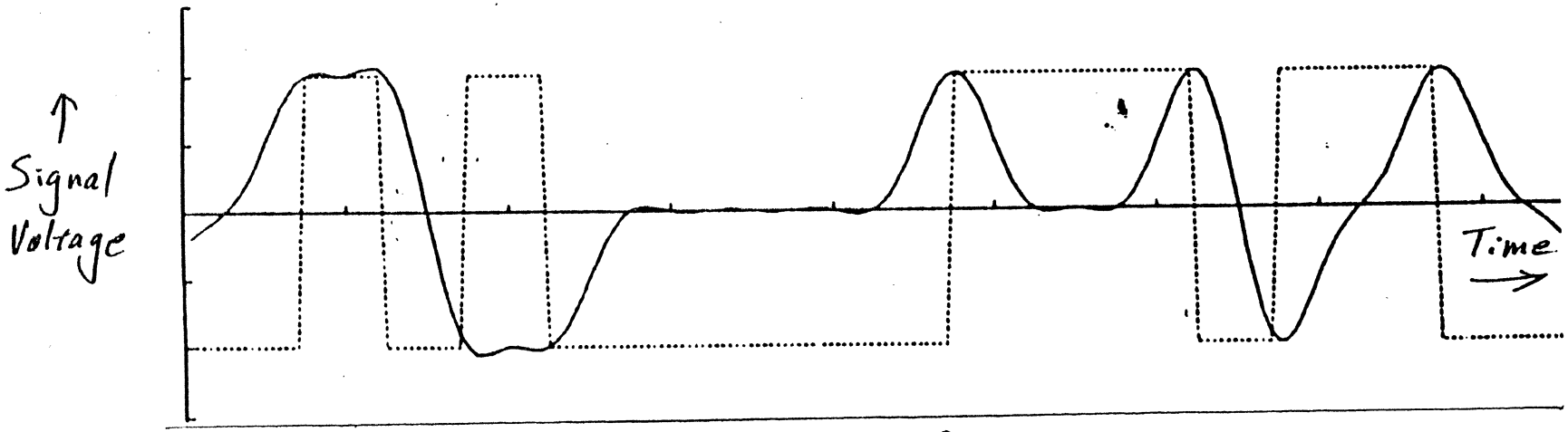
Pulse-Train Response

PSEUDO-TERNARY NRZI CHANNEL



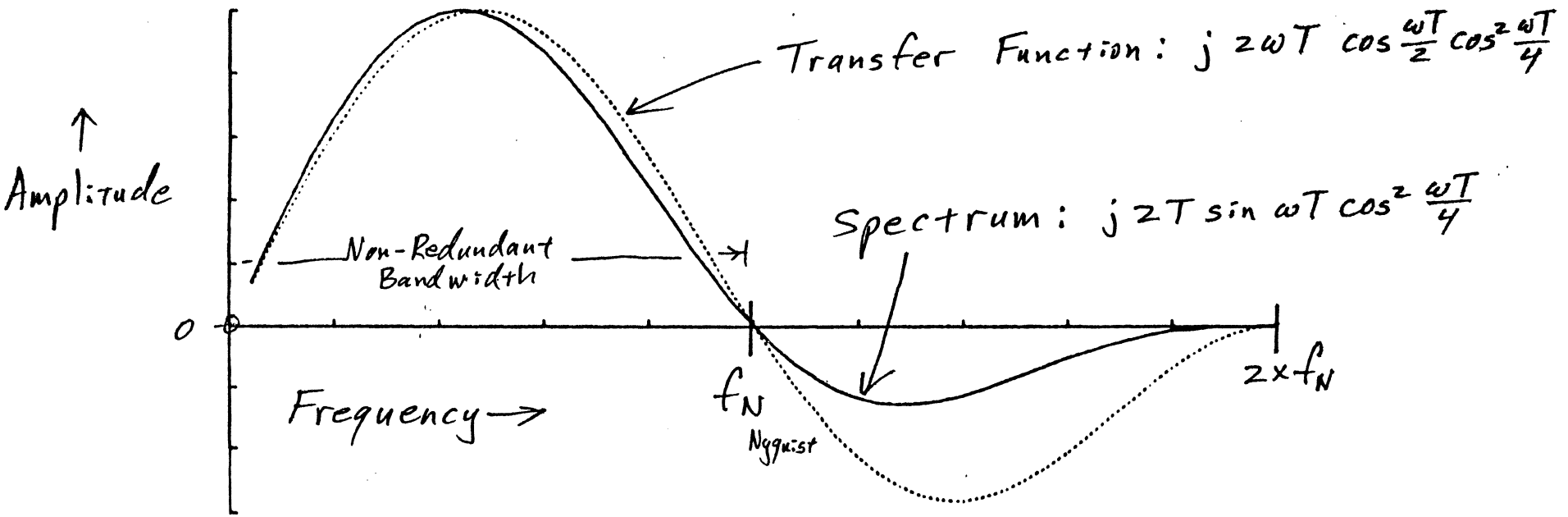
INTERLEAVED NRZI





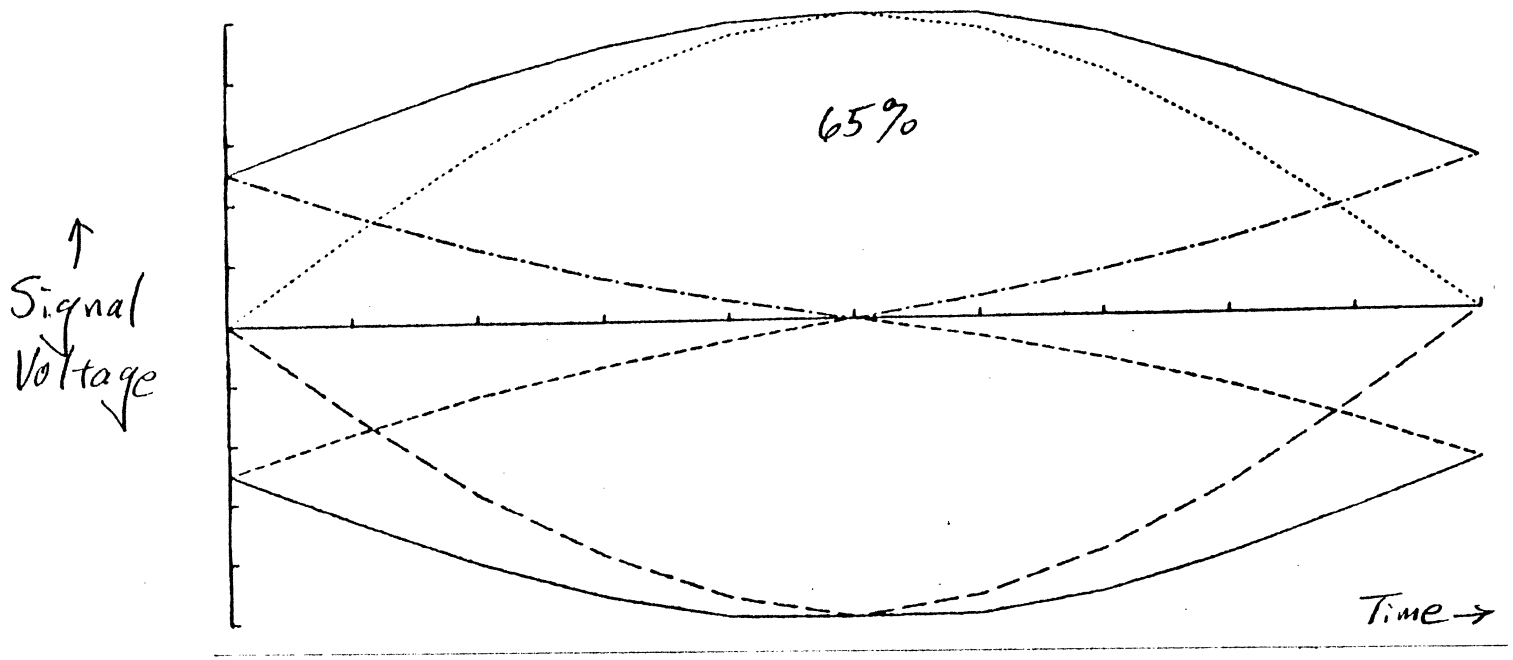
Pulse-Train Response

INTERLEAVED NRZI



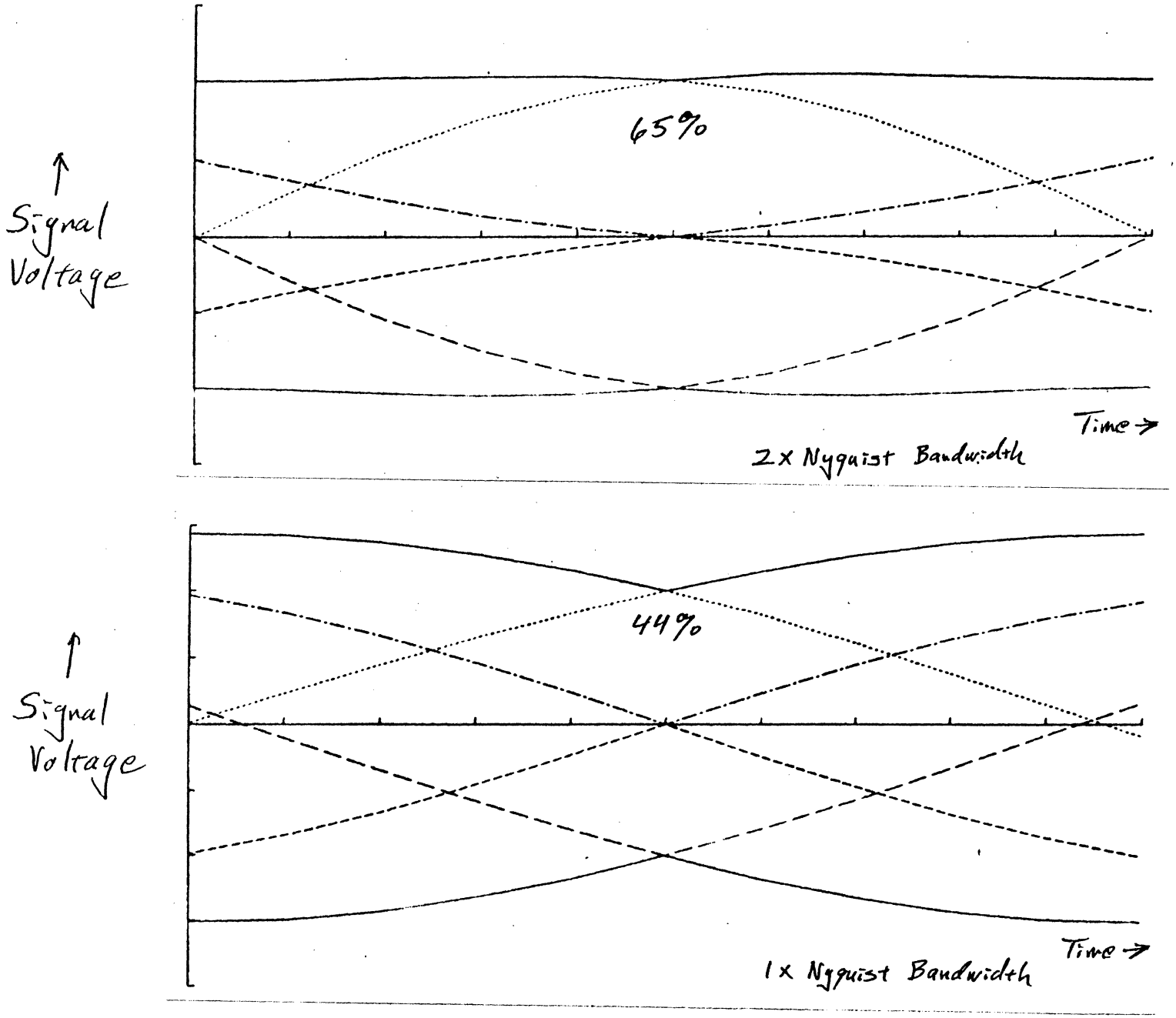
EYE PATTERN

PSEUDO-TERNARY NRZI

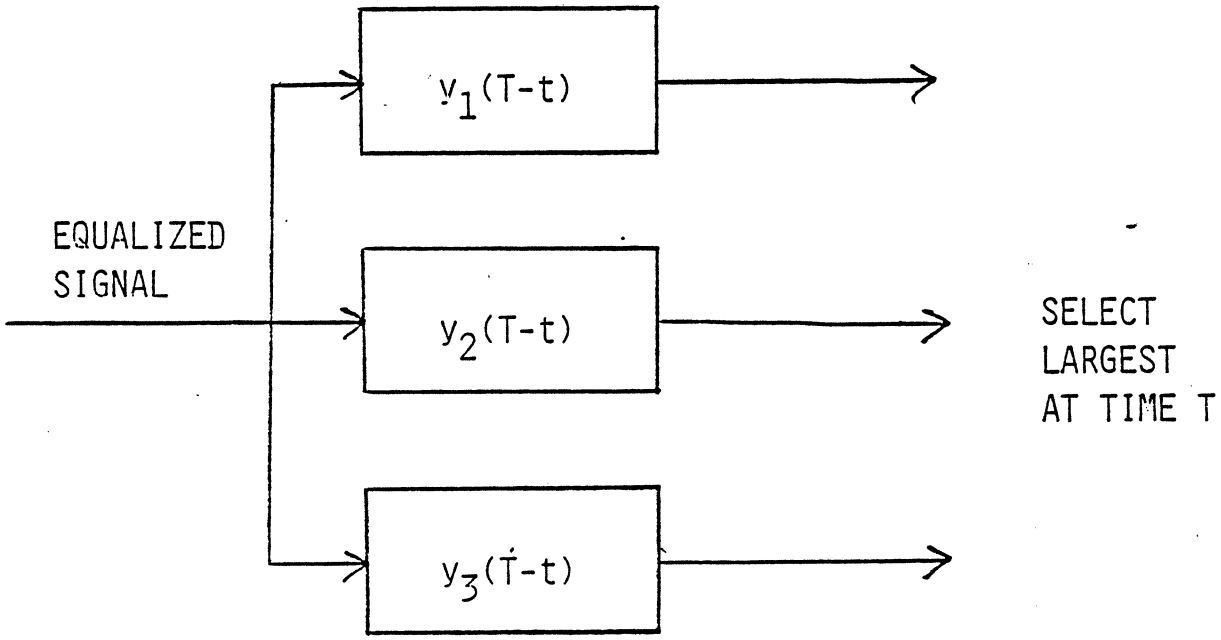


EYE PATTERNS

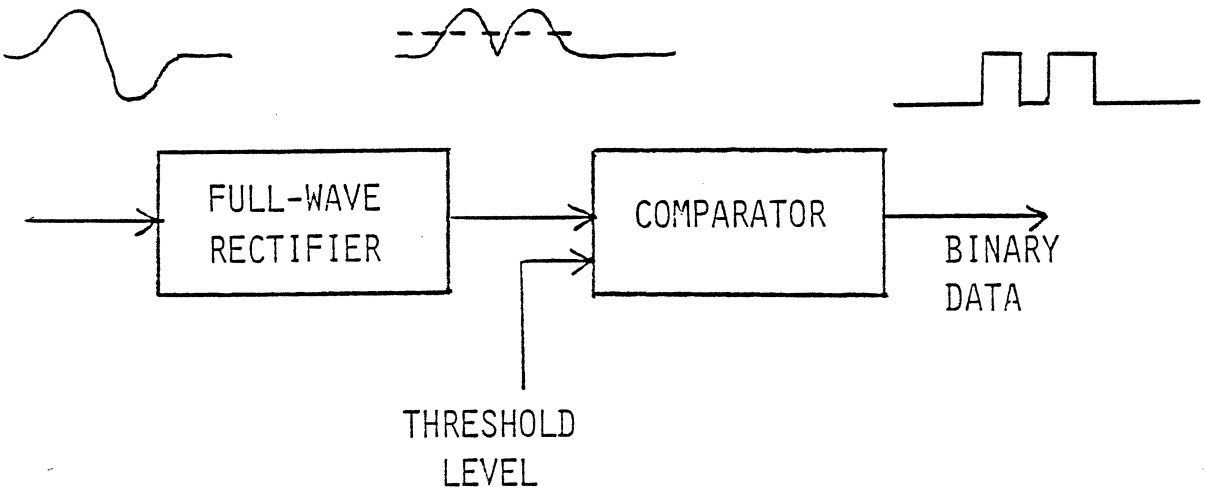
INTERLEAVED NRZI



DATA DETECTORS

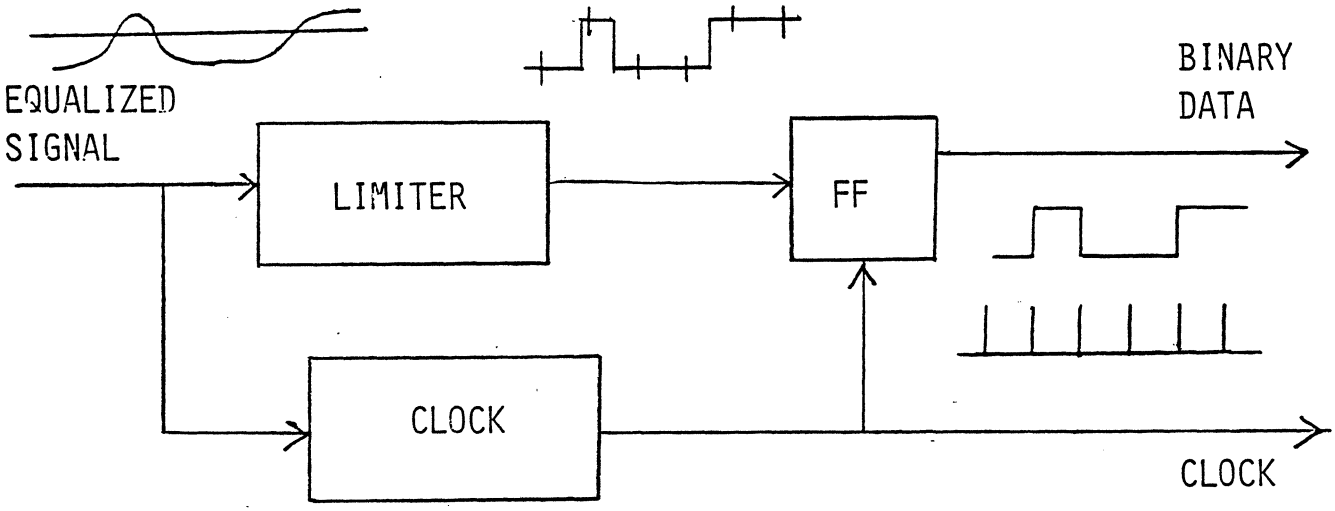


MATCHED FILTER DETECTOR

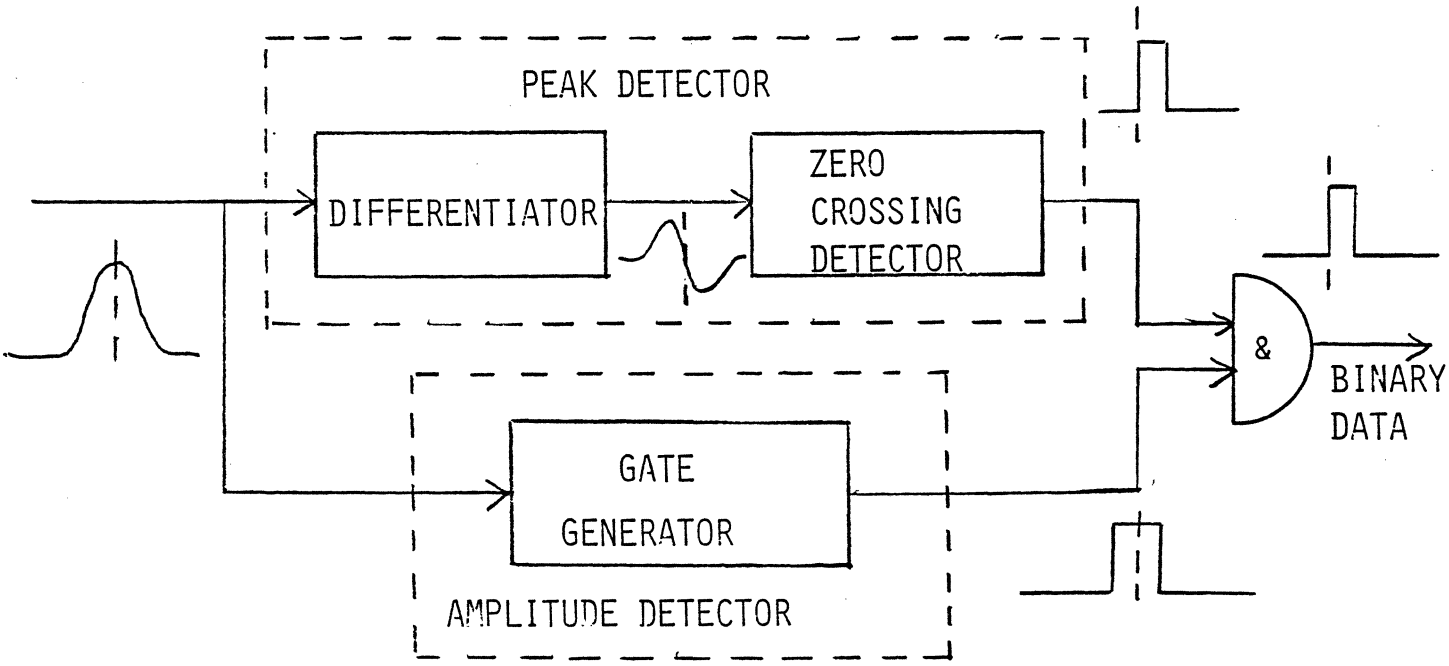


SIMPLE AMPLITUDE DETECTOR

DATA DETECTORS



SAMPLING DETECTOR



GATED PEAK DETECTOR

CLOCK RECOVERY

NRZI

- PARALLEL TRACKS, ODD PARITY
- SYNCHED NRZI, ENRZI

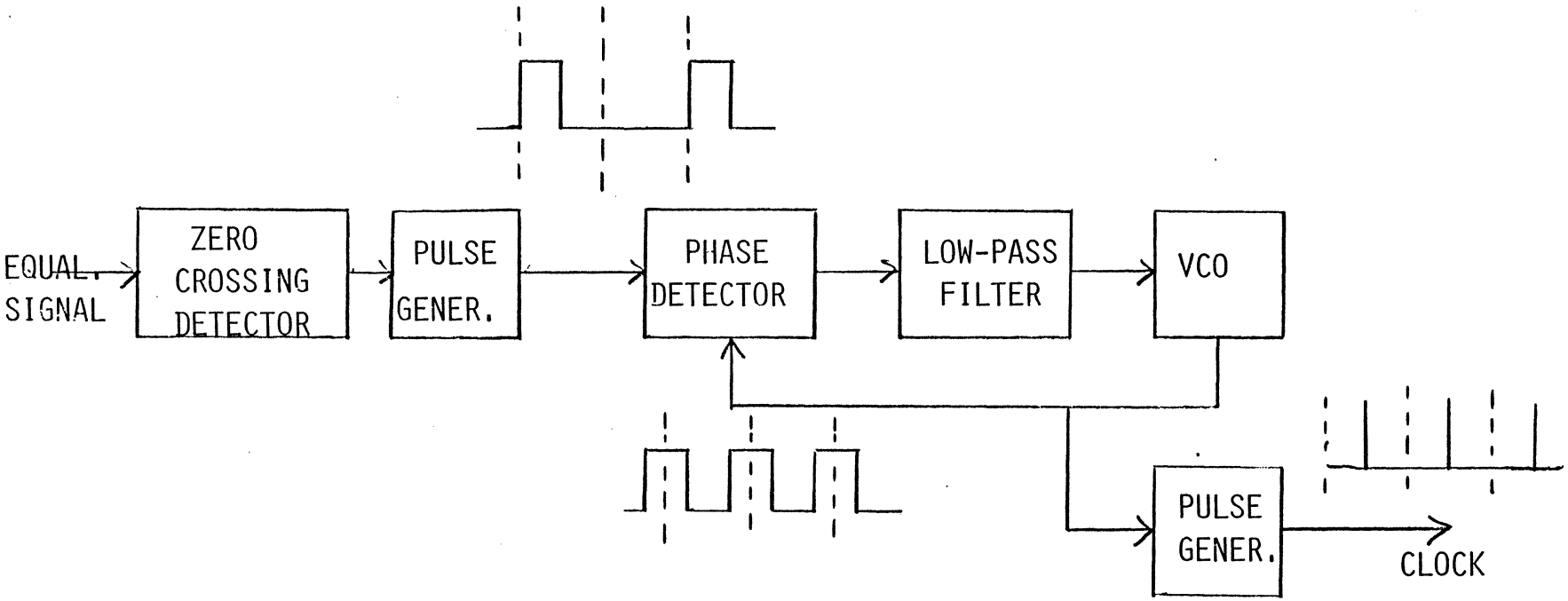
SELF-CLOCKING CODES

- DOUBLE FREQUENCY

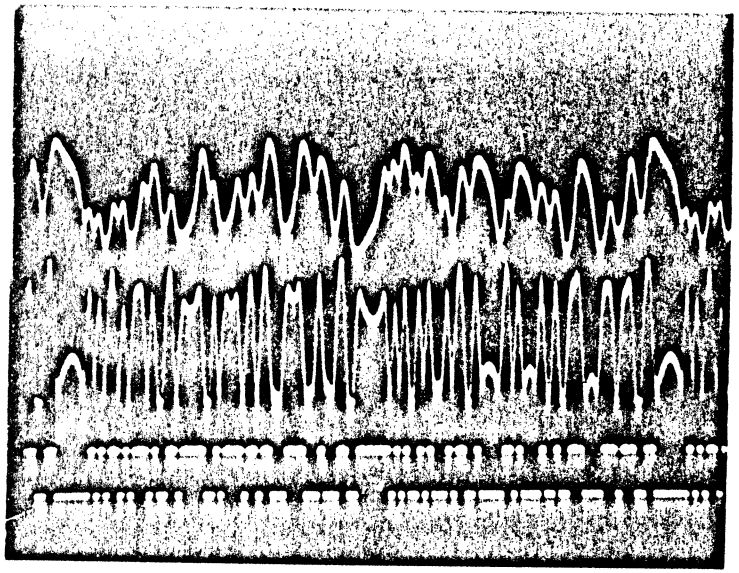
RUN-LENGTH-LIMITED CODES

FILLED CODES

PILOT TONES



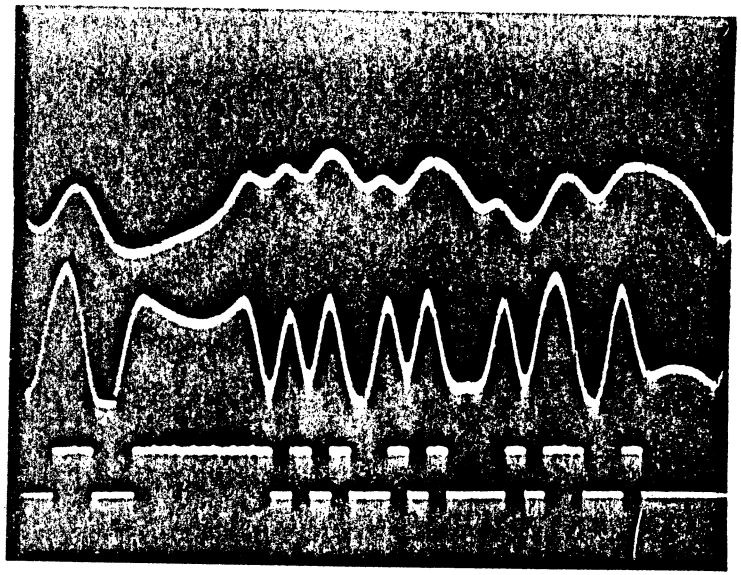
CLOCK EXTRACTION BY PHASE-LOCKED LOOP



PREAMP.

EQUALIZED

DETECTED
DIGITAL
DATA



DIGITAL RECORDING WAVEFORMS AT 60 KFCI

BELL & HOWELL INSTRUMENTATION RECORDER

FERRITE HEADS, 50 MIL TRACK

DUPONT CROLYN VIDEO TAPE