THE OMV DATA COMPRESSION SYSTEM
SCIENCE DATA COMPRESSION WORKSHOP

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Fairchild Weston Systems

ORBITAL MANEUVERING VECHICLE (OMV)

COMPRESSION SYSTEM

PRESENTATION SUMMARY

* OVERVIEW VIDEO COMPRESSION UNIT – VCU
* OVERVIEW VIDEO RECONSTRUCTION UNIT – VRU
* THEORY AND ALGORITHMS FOR IMPLEMENTATION OF OMV SOURCE CODING
* DOCKING MODE – 2 – 510 X 488 CCD CAMERAS INTERLEAVED INTO 972 KBPS CHANNEL
* CHANNEL CODING – FORWARD ERROR DETECTION AND CORRECTION
* ERROR CONTAINMENT – RFI ENVIRONMENT
* VIDEO TAPE PROCESSED SPACE IMAGERY

PROGRAM OBJECTIVE

* PROVIDE REMOTE OMV PILOT WITH MONOCHROME VIDEO ADEQUATE FOR –
* TARGET VIEWING
* MANEUVERING OMV THROUGH FINAL 200 FT. DOCKING SEQUENCE
* DIGITAL COMPRESSION SYSTEM ALLOWS FOR FORWARD ERROR CORRECTION AND DETECTION
* OPERATION IN MODERATE RFI

DIGITAL COMPRESSION

* PROVIDE REDUNDANT CAMERA OUTPUTS IN ONE 972 KBPS – SSA CHANNEL

* PROVIDE FULL RESOLUTION MODE OVER 1/4 PIXELS –

* PROVIDE VERTICAL PIXEL PAIRED MODE

* PROVIDE FORWARD ERROR DETECTION AND CORRECTION – OPERATION MODERATE RFI

* ERROR CONTAINMENT – FOR ENTROPY ENCODING

* ENCRYPTION

ORIGINAL SOURCE CODING

* BASED ON INADEQUATE SOURCE MATERIAL
* BLACK RUN LENGTH CODING
* SIMPLE DPCM
* INEFFICIENT MARKER CODE
* HAMMING CODE
* ERROR CONTAINMENT – BASED ON FULL FRAME REPLACEMENT

UPDATED SOURCE CODING

* APPROXIMATELY 130:1 COMPRESSION
* 2–D FILTERING
* 3–D DECIMATION
* 2–D DPCM ADAPTIVE
* ADAPTIVE PREDICTOR–LOCAL–GLOBAL
* 16 NON – UNIFORM QUANTIZERS
* DUAL–TIER VECTOR QUANTIZATION ERROR SIGNAL
* HUFFMAN CODING
* REED – SOLOMON EDAC
* SUB – FRAME ERROR CONTAINMENT

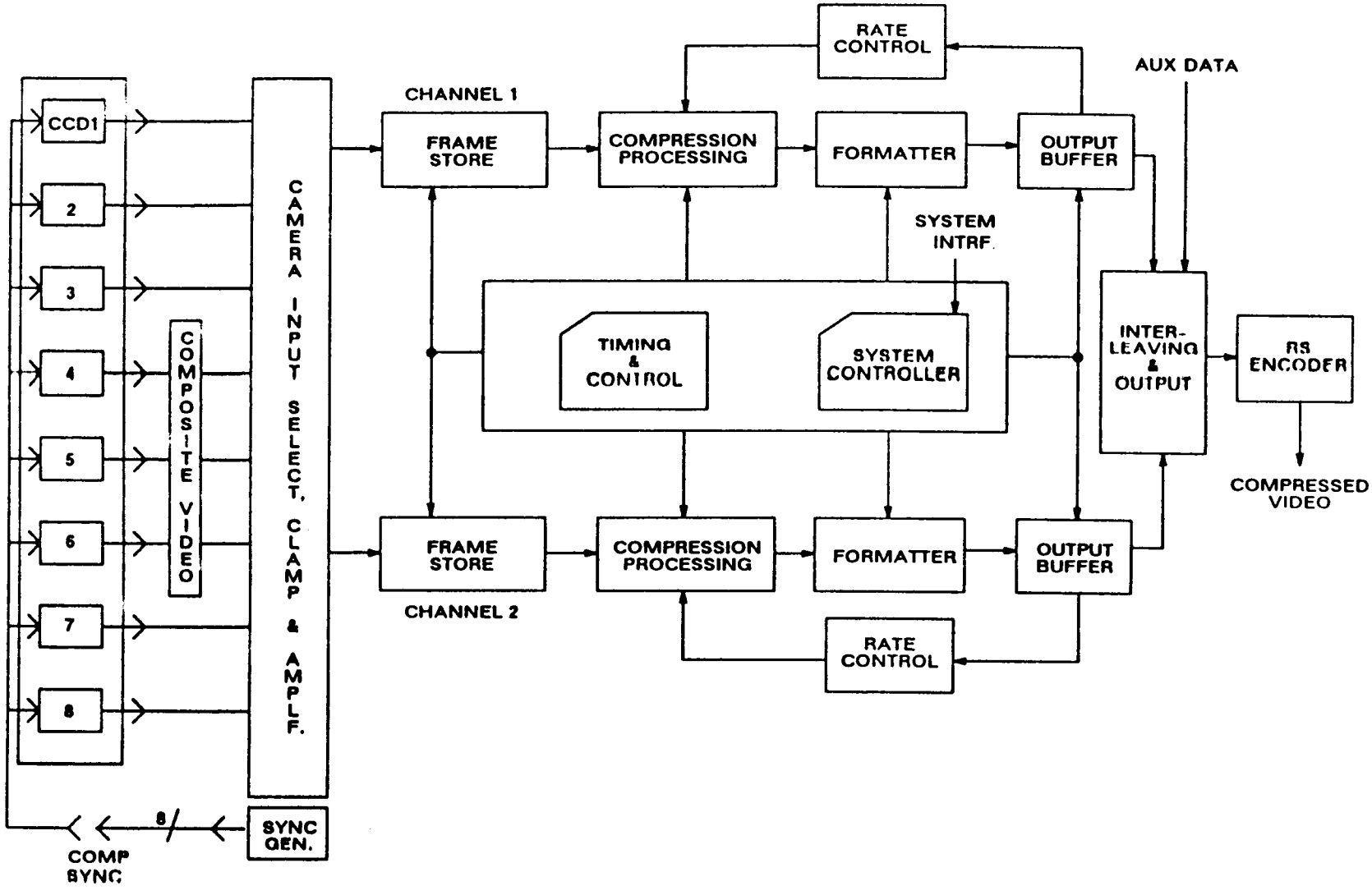
ALGORITHM CONSTRAINTS

1- LIMITED ACCEPTANCE OF VLSI-FLIGHT UNITS

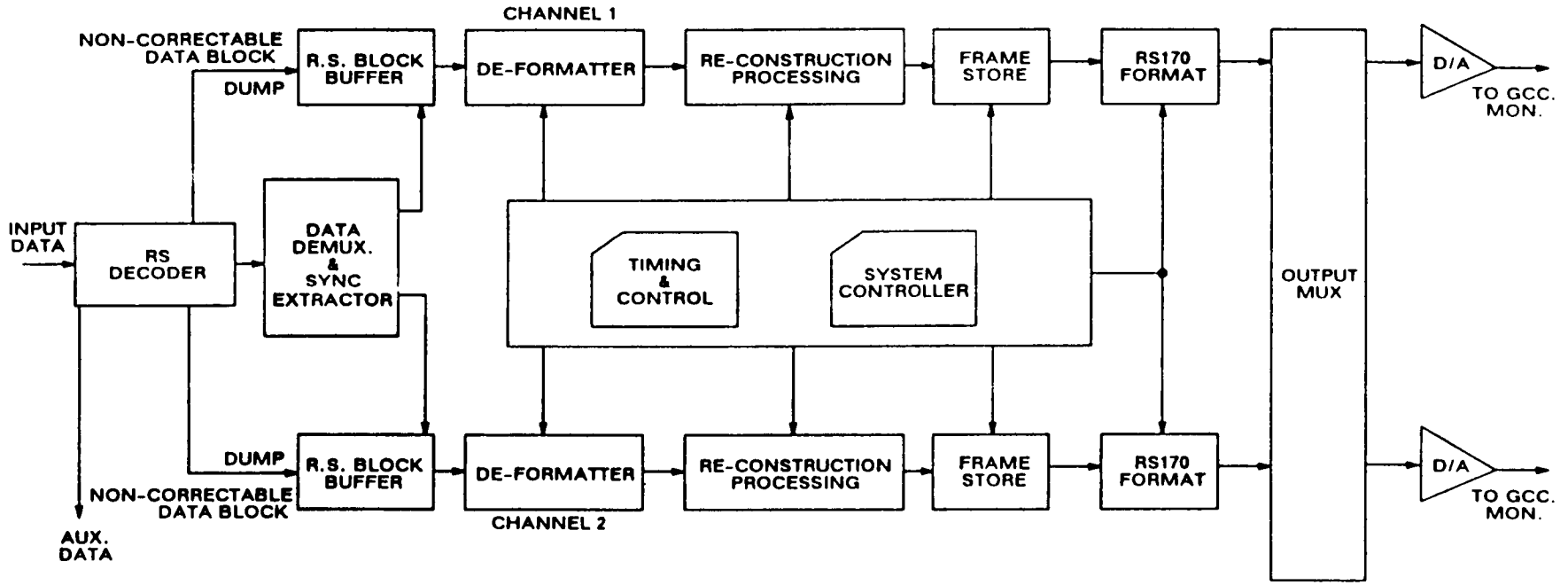
2- S-LEVEL PARTS

3- D.C. POWER BUDGET

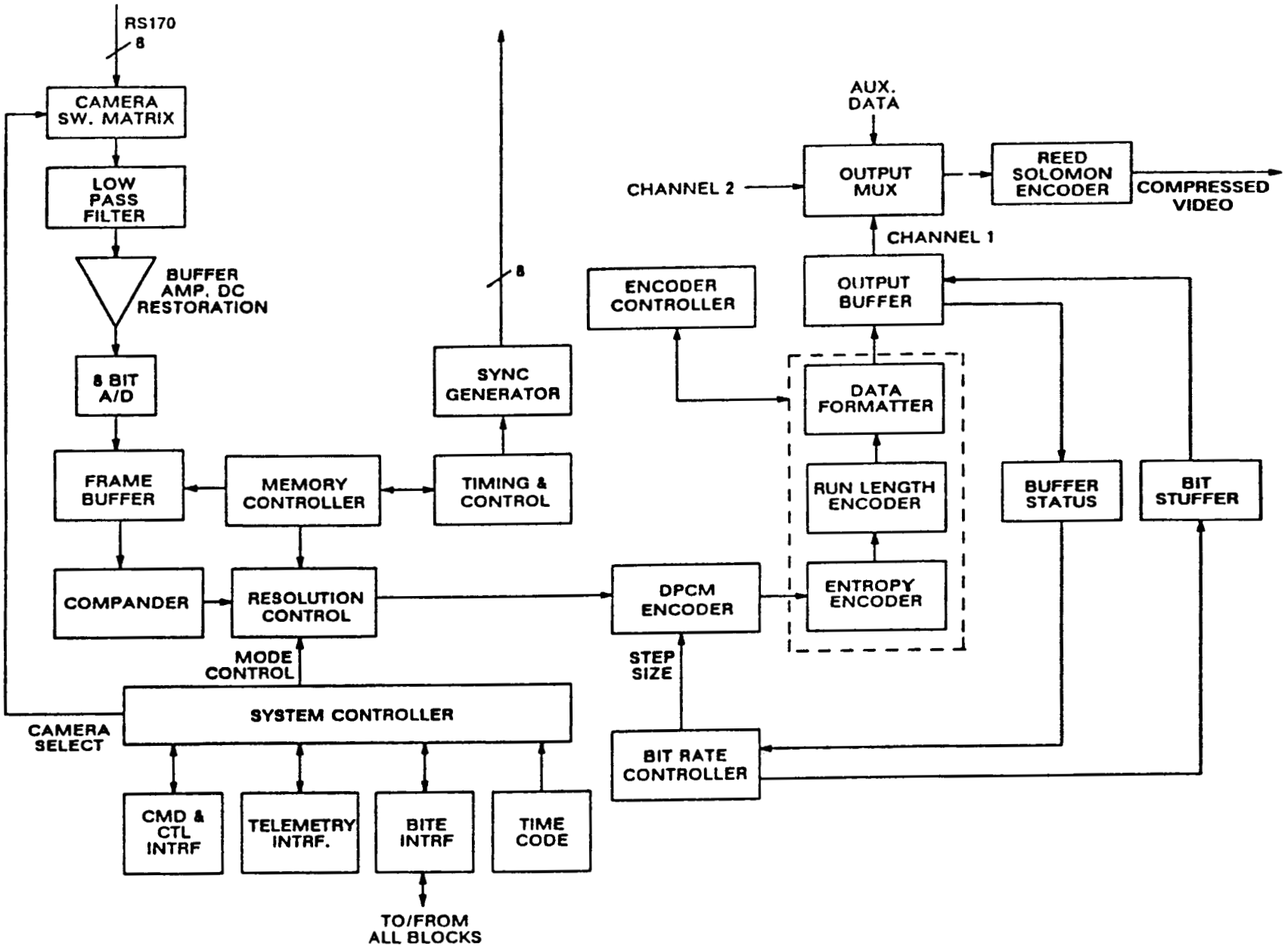
4- RFI CHANNEL ENVIRONMENT



VCU TOP-LEVEL BLOCK DIAGRAM



VRU TOP-LEVEL BLOCK DIAGRAM



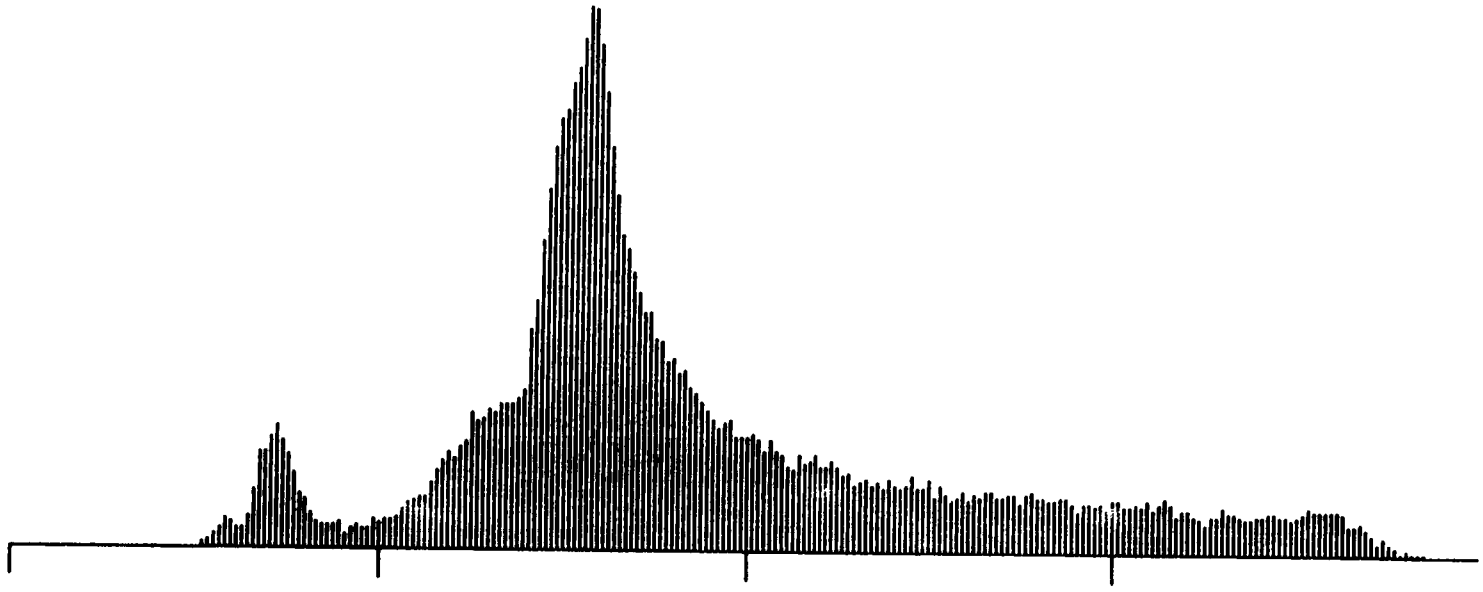
VCU BASELINE FUNCTIONAL BLOCK DIAGRAM (1 Channel)

ARITHMETIC FORMAT

- HARDWARE IMPLEMENTATION 2'S COMPLEMENT FIXED POINT
- FIXED POINT BINARY WHERE REQUIRED
- 2'S COMPLEMENT ROUNDING
  - POSITIVE NUMBERS ROUND UP
  - NEGATIVE NUMBERS TRUNCATE
- + 127
  0
  – 127 SIGNAL CLIPPED AND CLAMPED TO EITHER +127 or –128 TO PREVENT OVERFLOW

OPERATION AT LOW LIGHT LEVELS

* INITIAL ACQUISITION AT 200 FT.
* 50 MM LENS
* LIGHT ON SUBJECT 0.03 FT. LAMBERTS
* LIGHT ON CCD 0.0015 FT. CANDLES
* INTEGRATE CCD CAMERA 1/5 SEC.
* INCREASE S/N IN ANALOG DOMAIN



BLACK SATELLITE: ORIGINAL IMAGE

2-DIMENSIONAL PIXEL PAIRING

LINE	510 X 488 ARRAY			
1	P1,1	P1,2 • • • • • •	P1,509	P1,510
2	P2,1	P2,2 • • • • • •	P2,509	P2,510
3	P3,1	P3,2 • • • • • •	P3,509	P3,510
4	P4,1	P4,2 • • • • • •	P4,509	P4,510
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
488	P488,1	P488,2 • • • • •	P488,509	P488,510

1* P*1,1 = 1/2 P1,1 + 1/2 P1,2 HORIZONTAL PIXEL PAIRING

2* P*2,1 = 1/2 P2,1 + 1/2 P2,2

1** P**1,1 = 1/2 P*1,1 + 1/2 P*2,1 VERTICAL PIXEL PAIRING

PIXEL PAIRING AT 5 FRAMES / SECOND

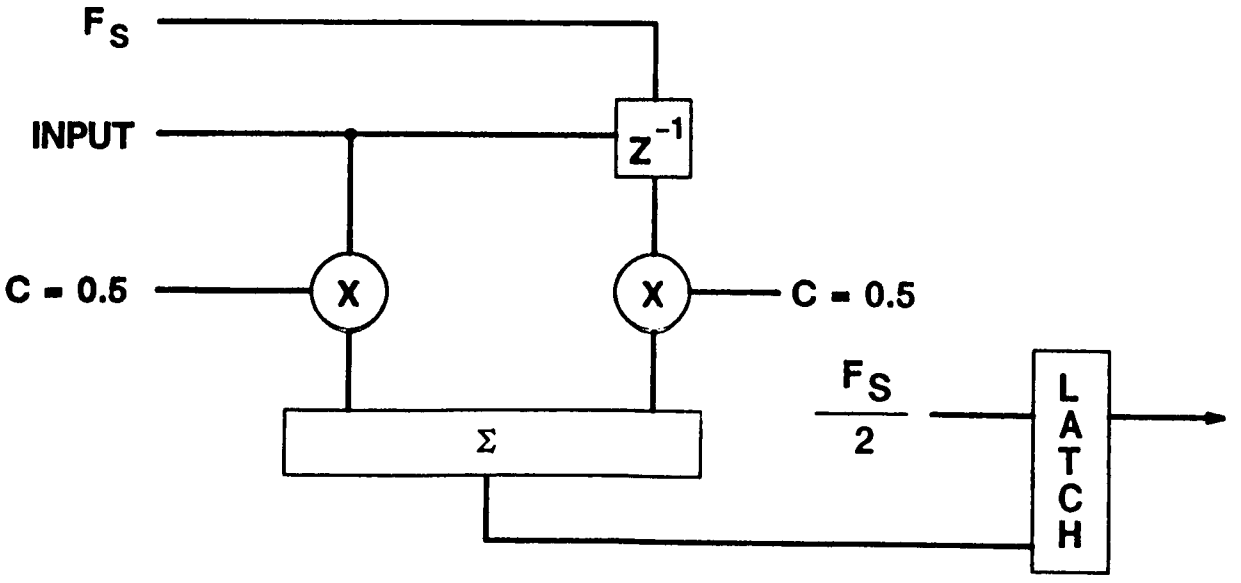
2 – DIMENSIONAL FILTERING RS–170 INPUT

HORIZONTAL Hz = $0.5 + 0.5Z^{-1}$ DECIMATED 2:1

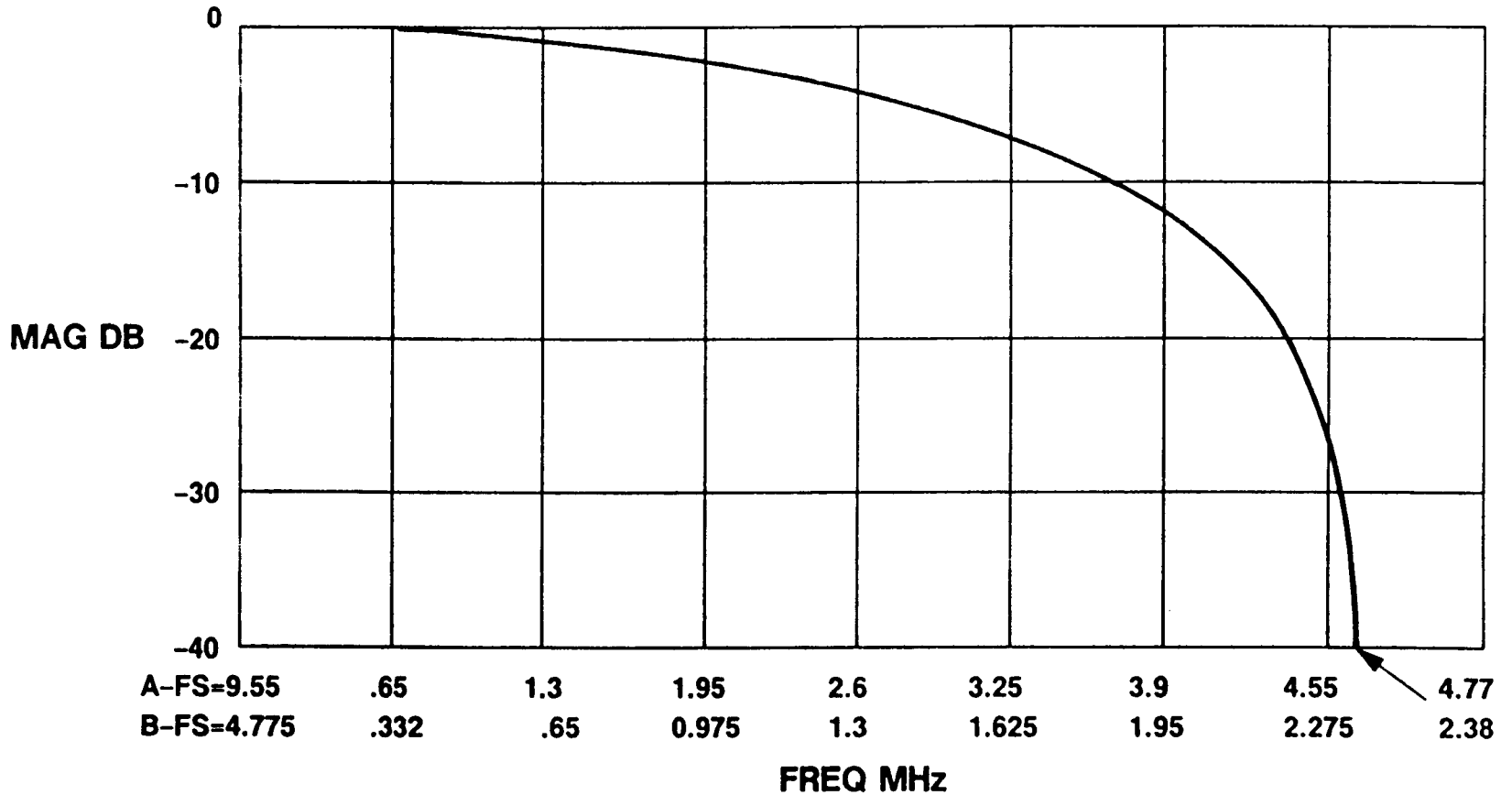
VERTICAL Hz = $0.5 + 0.5Z^{-510}$ DECIMATED 2:1

TEMPORAL Hz = $Z^{-1}, Z^{-7}, Z^{-13}, Z^{-19}, Z^{-25}$ DECIMATED 6:1

FIR Hz = $0.5 + 0.5Z^{-1}$



HORIZONTAL FILTER

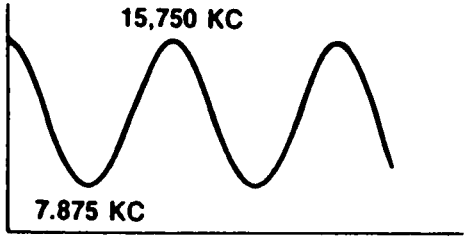


A – RESPONSE Hz = $0.5 + 0.5Z^{-1}$

B – RESPONSE Hz = $0.5 + 0.5Z^{-1}$ DECIMATED 2:1

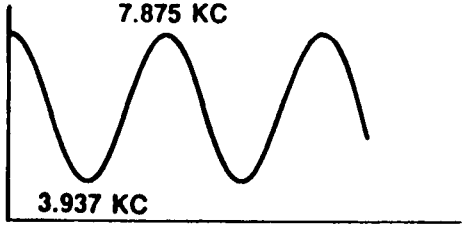
VERTICAL AND TEMPORAL FILTERS

$Hz = 0.5 + 0.5Z^{-H}$
H = LINE 607

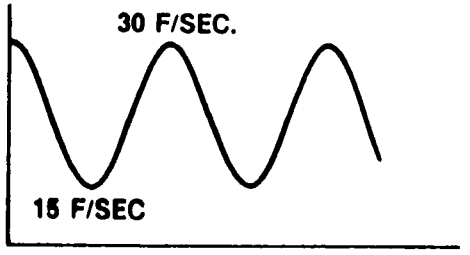


VERTICAL FILTER

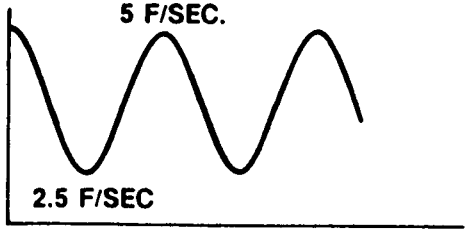
$Hz = 0.5 + 0.5Z^{-H}$
DECIMATED 2:1



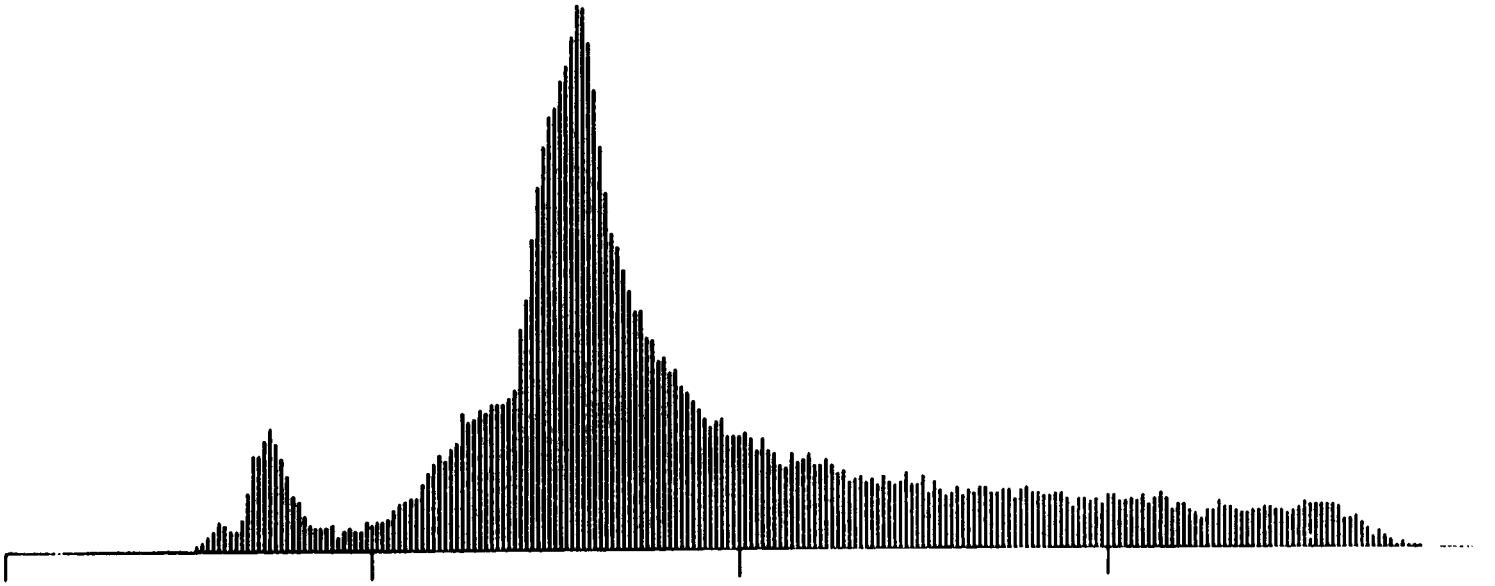
2:1 DECIMATION



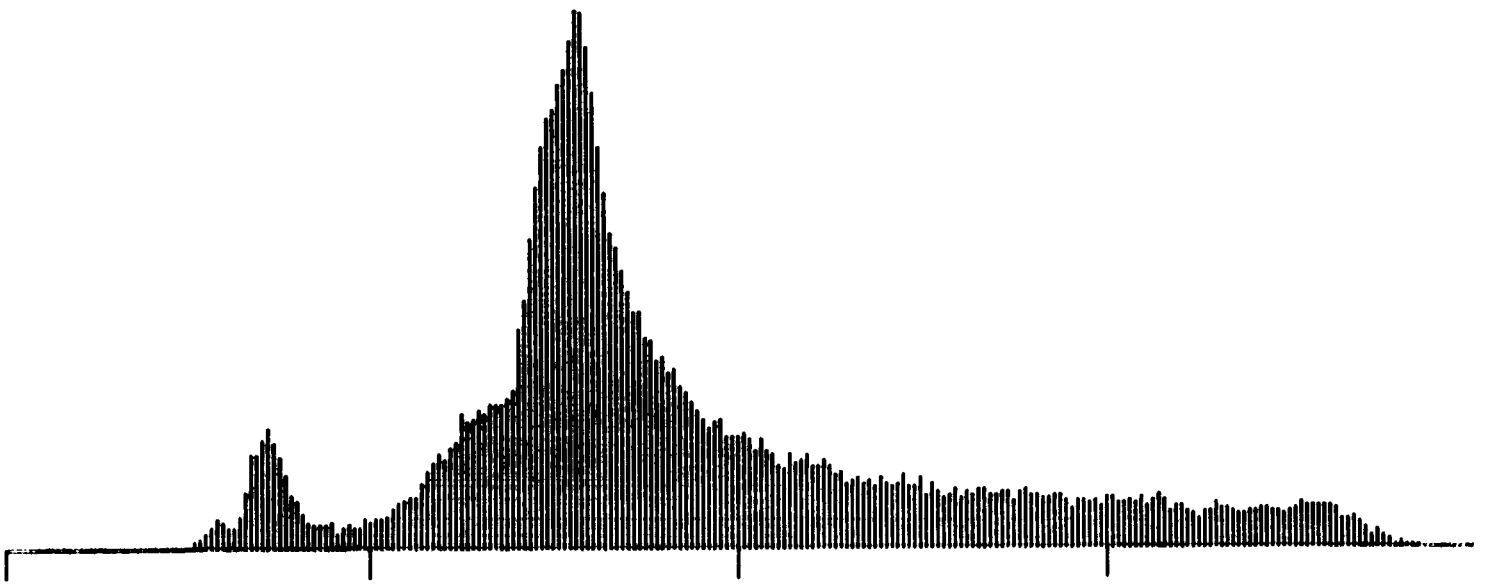
RS-170 TEMPORAL AXIS



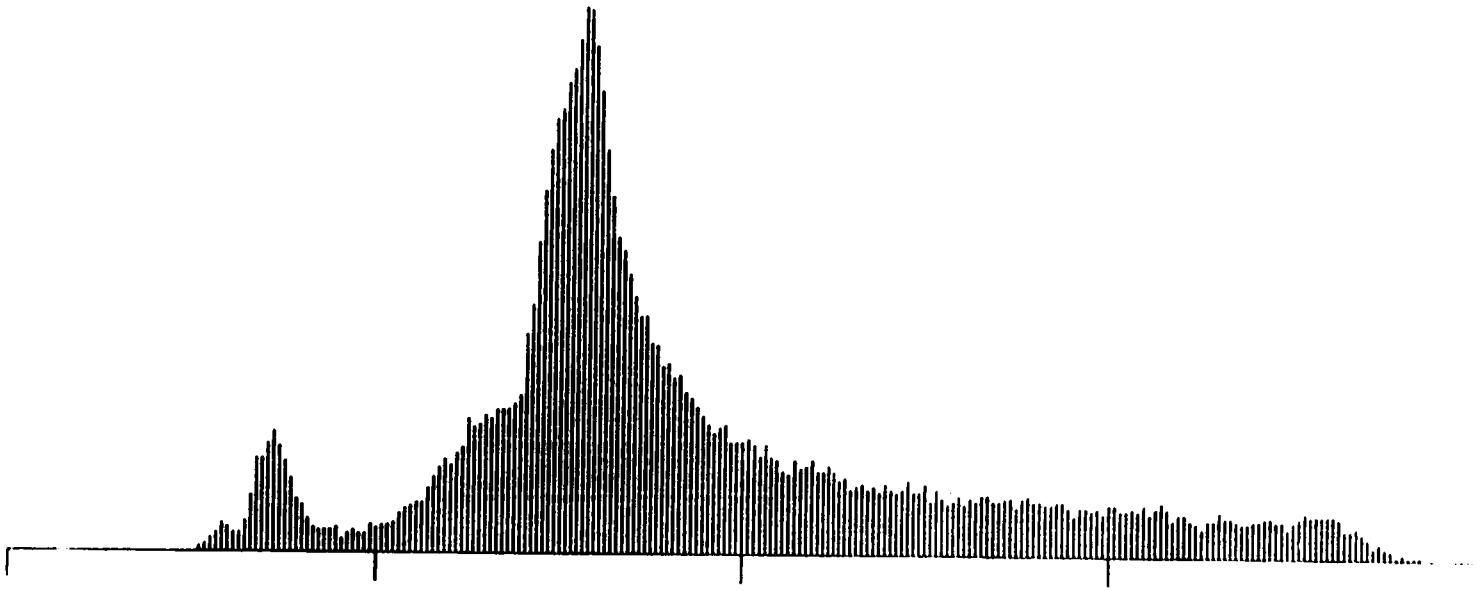
RS-170 6:1 DECIMATION



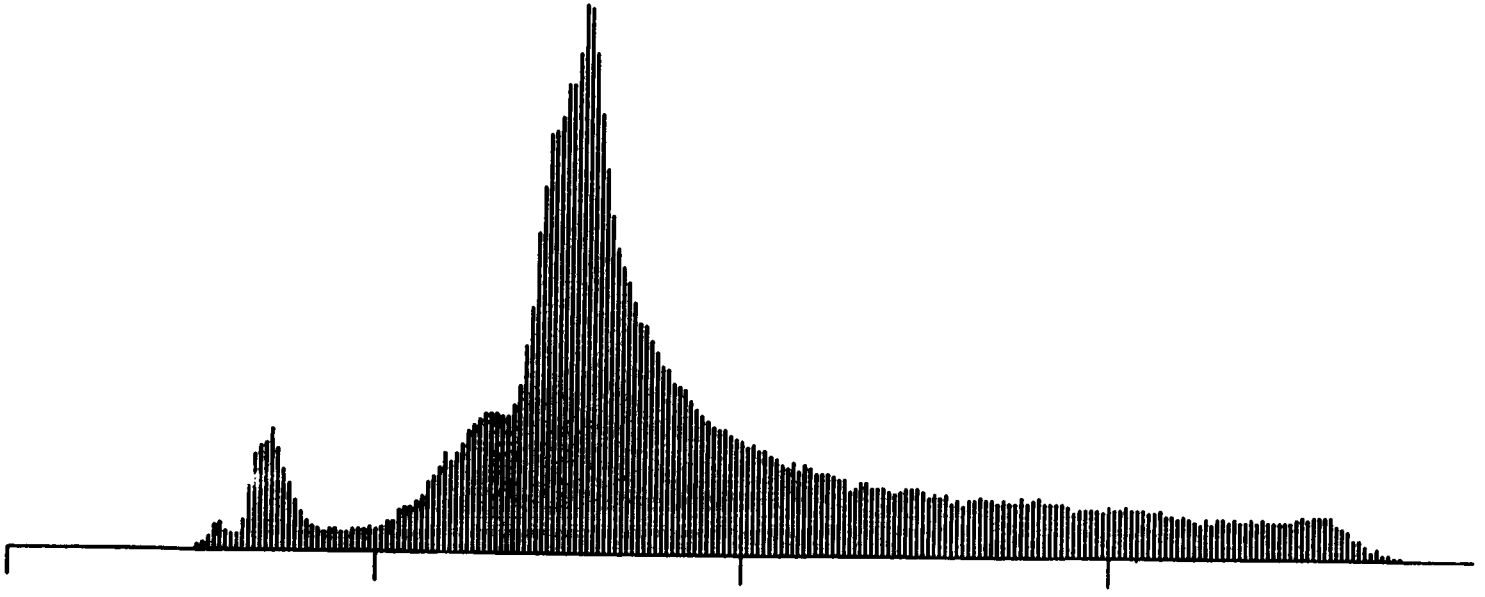
BLACK SATELLITE: ORIGINAL IMAGE



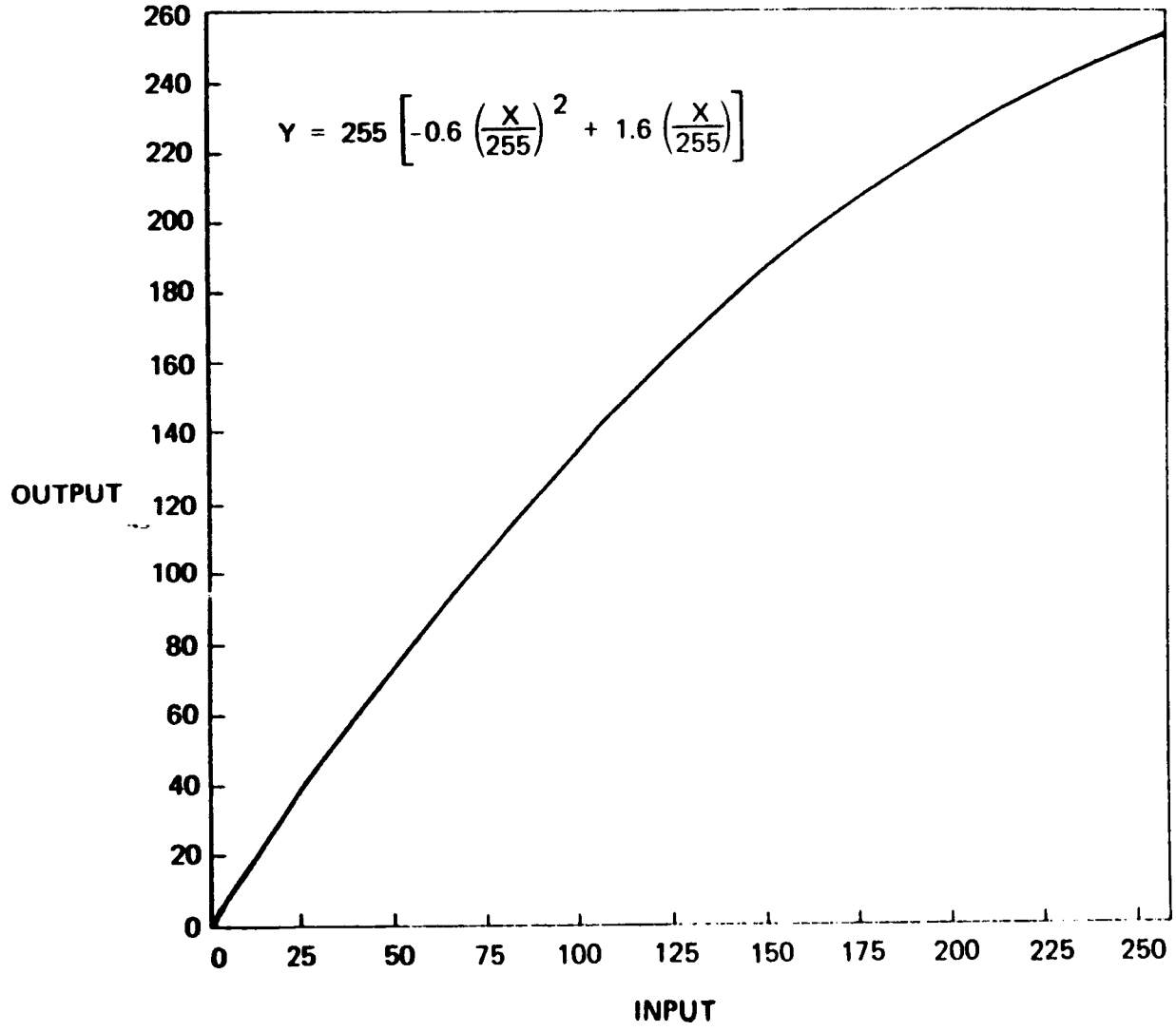
BLACK SATELLITE: EFFECT OF PIXEL PAIRING



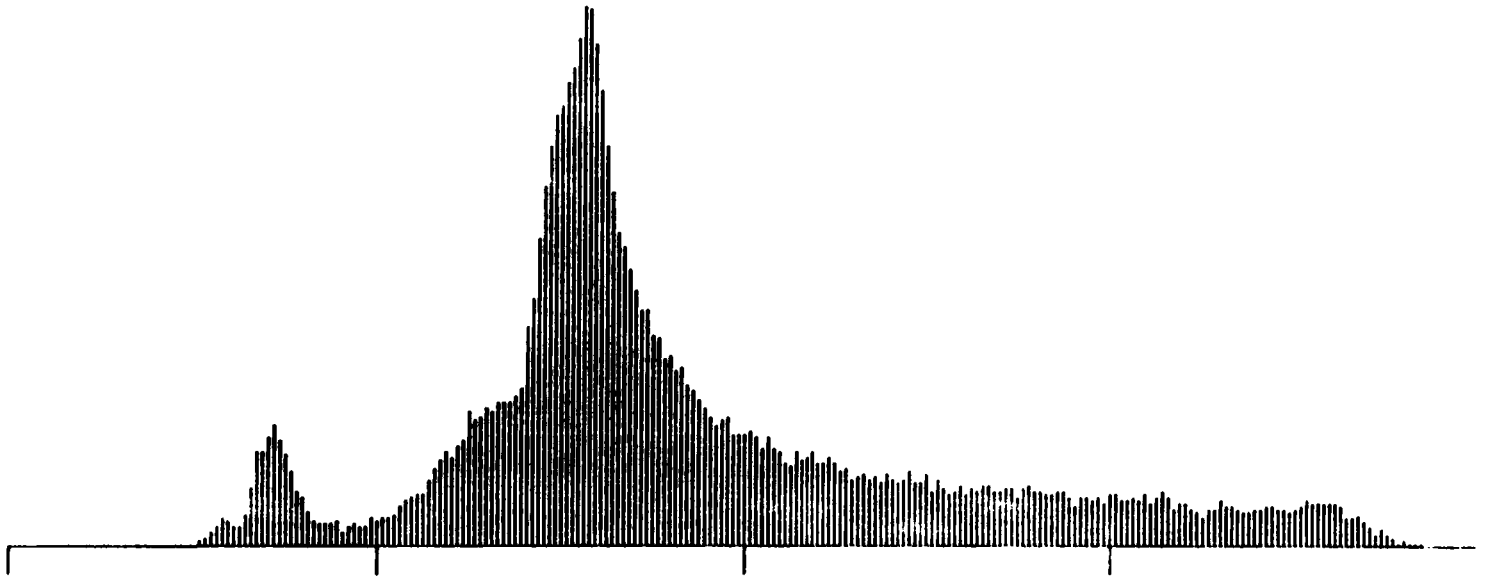
BLACK SATELLITE: ORIGINAL IMAGE



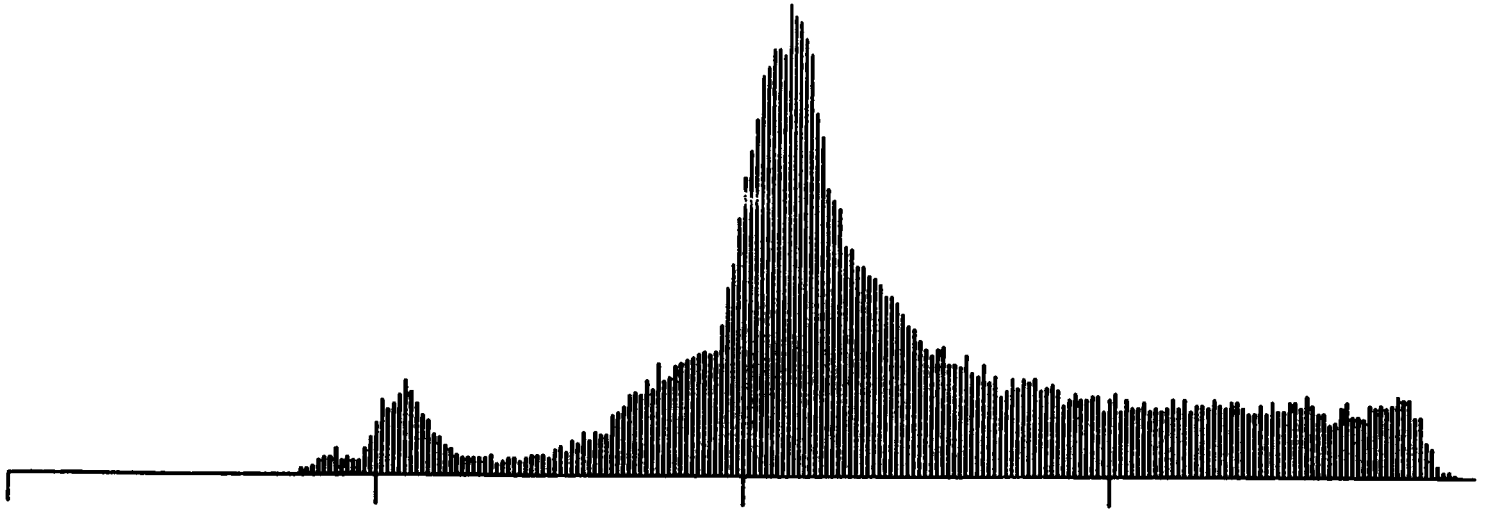
BLACK SATELLITE: PIXEL PAIRING AND INTERPOLATION


$Y = 255\left[-0.6\left(\frac{X}{255}\right)^2 + 1.6\left(\frac{X}{255}\right)\right]$
OUTPUT
INPUT
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
25
50
75
100
125
150
175
200
225
250

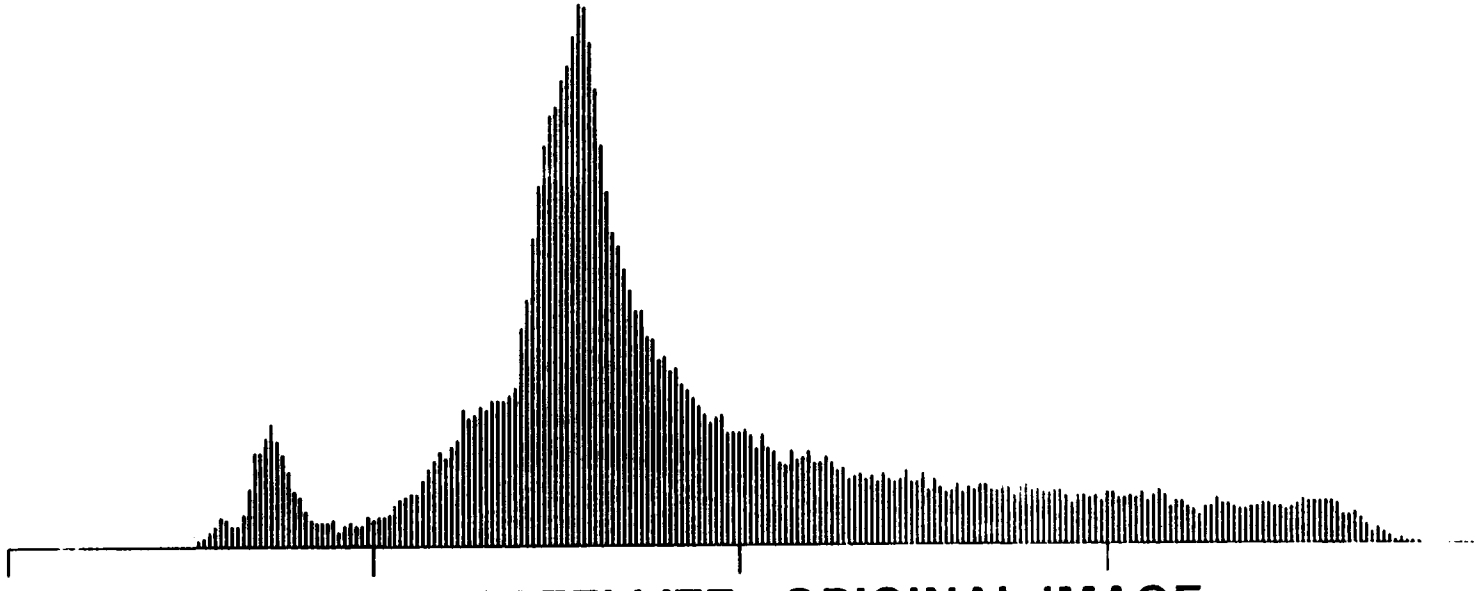
COMPANDER



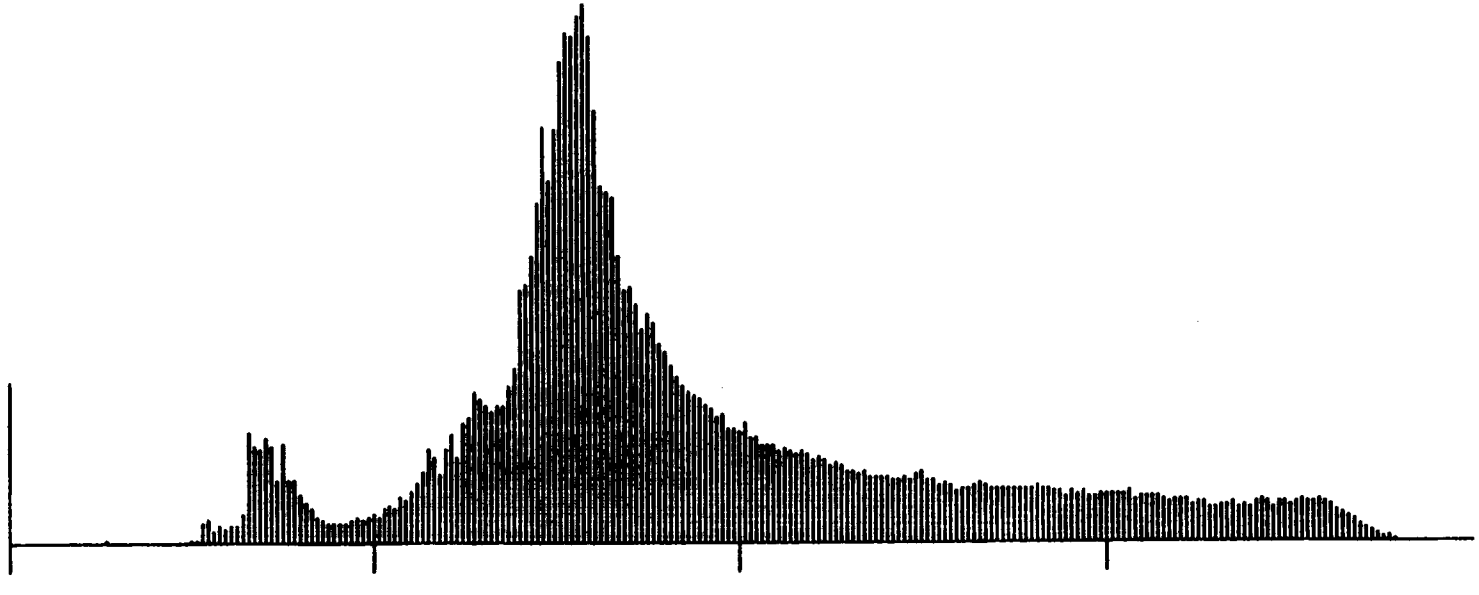
BLACK SATELLITE: ORIGINAL IMAGE



BLACK SATELLITE: COMPANDED AND PIXEL PAIRED

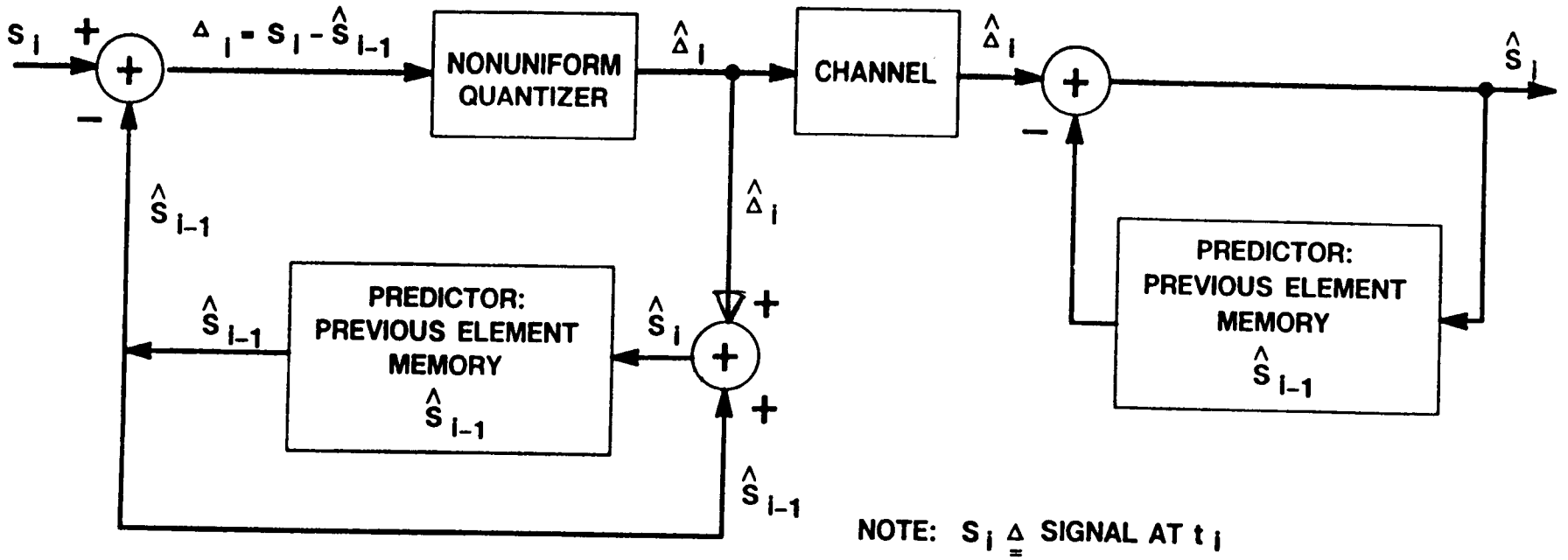


BLACK SATELLITE: ORIGINAL IMAGE



BLACK SATELLITE: COMPLETE ALGORITHM

BASIC DPCM ENCODER / DECODER



NOTE: $s_i \triangleq$ SIGNAL AT t_i

DPCM OPTIMIZATION – GLOBAL STATISTICS

* MEASURE CORRELATION COEFFICIENTS OF TYPICAL IMAGES
* OPTIMIZE PREDICTORS – MIN. LEAST SQUARE ERROR
* OPTIMIZE NON – UNIFORM QUANTIZER
* DESIGN HUFFMAN ENTROPY CODE

MEASUREMENTS CORRELATION COEFFICIENTS

–1,1	0,1	1,1
–1,0	0,0	1,0
–1,–1	0,–1	1,–1

–1,1	0,1	1,1
–1,0	X	

–1/2	+3/4	
+3/4	X	

POSSIBLE PREDICTORS

0	+1/2	
+1/2	X	

OMV – DPCM PREDICTOR MODES

B C

A X

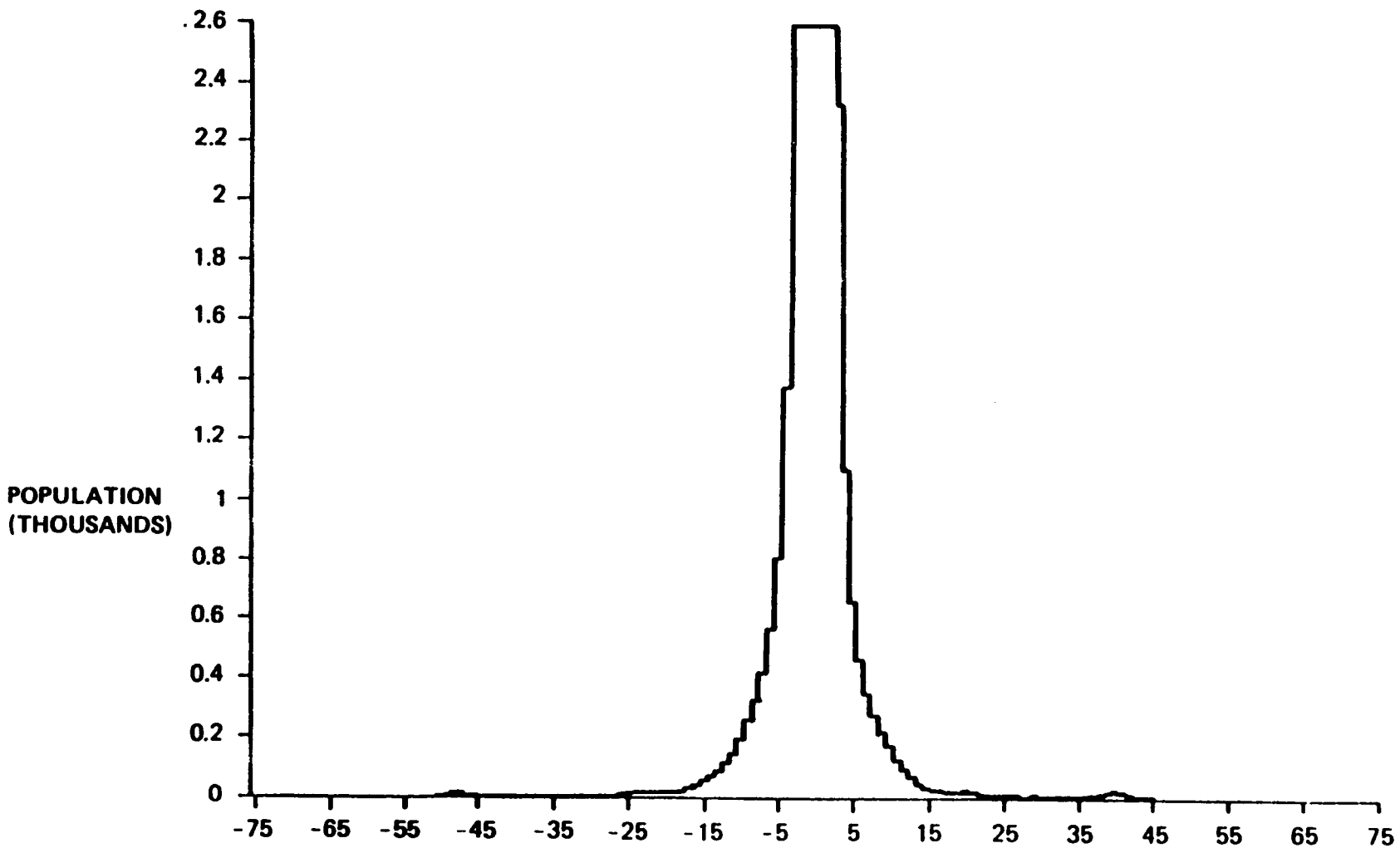
2–D NORMAL OPERATION ADAPTIVE

1–D NORMAL HORIZONTAL REFRESH 1 x A

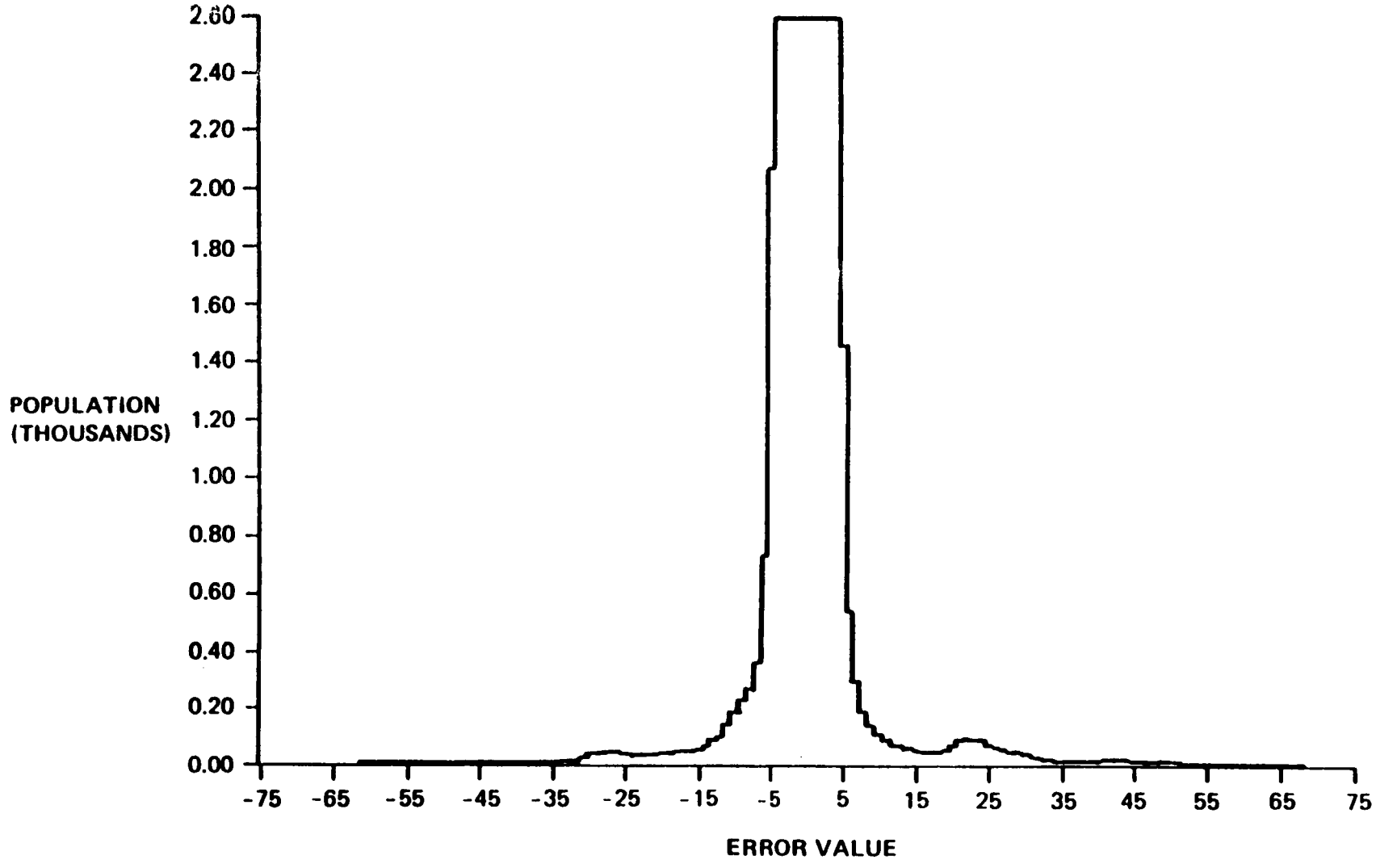
1–D START OF REMAINING LINES SUBFRAME 1 x C

ADAPTIVE DPCM BASED ON GLOBAL AND LOCAL CORRELATION

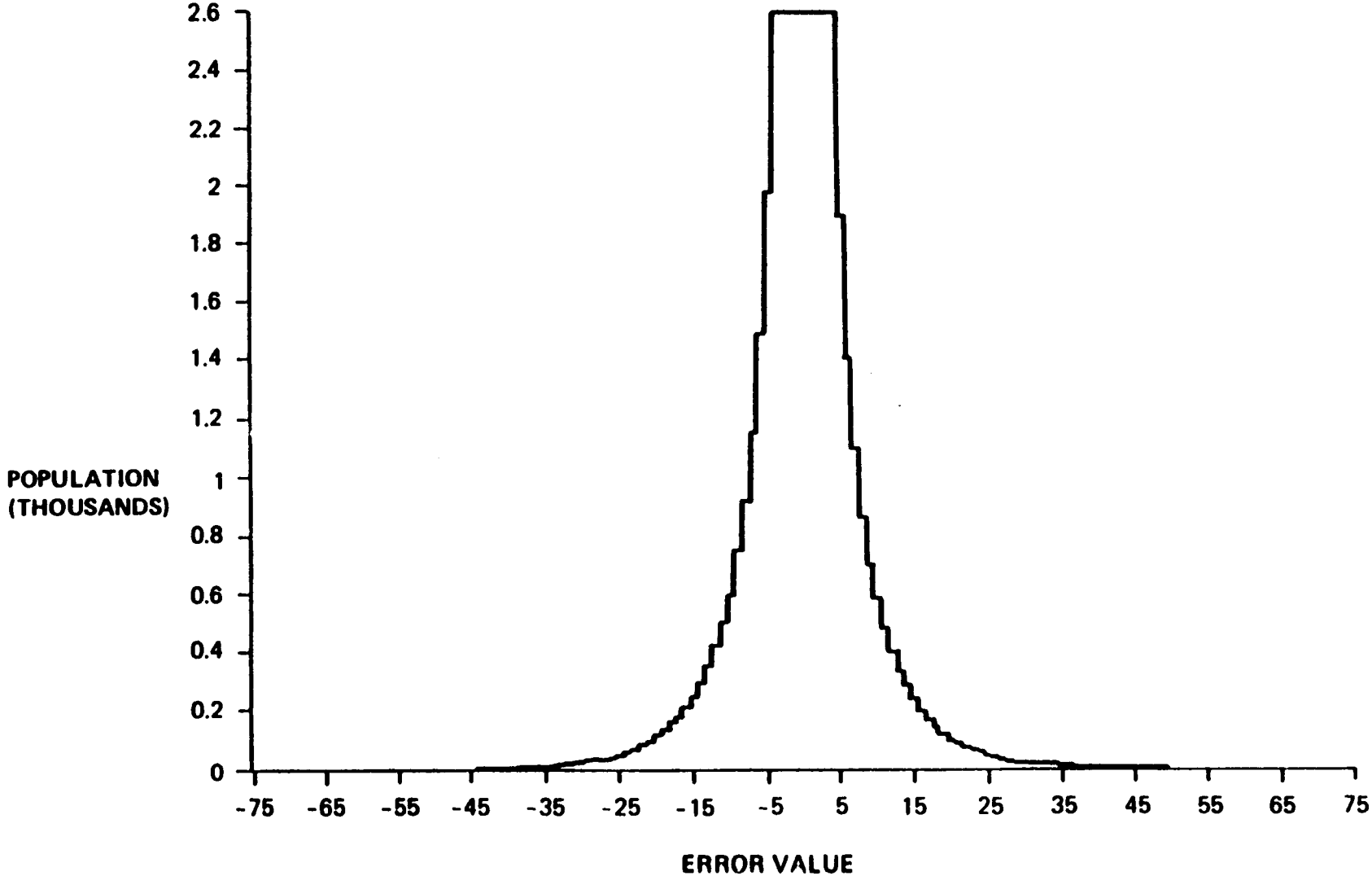
* TEST LOCAL CORRELATION
* $\geq$ THRESHOLD LOCAL PREDICTOR
* ALL OTHER CASES GLOBAL PREDICTOR



DOCKING TARGET WITH PIXEL PAIRING

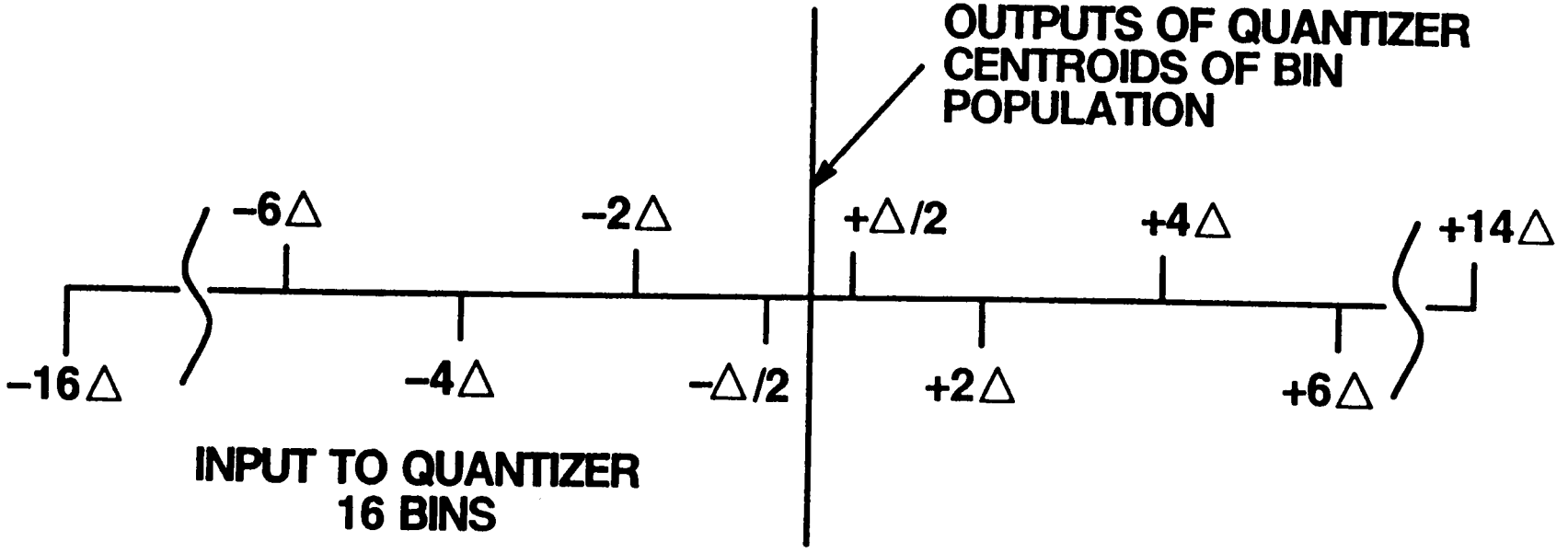


SPIN-SAT WITH PIXEL PAIRING



BLACK-SAT WITH PIXEL PAIRING

NON – UNIFORM QUANTIZER



NON – UNIFORM QUANTIZER OPTIMIZATION

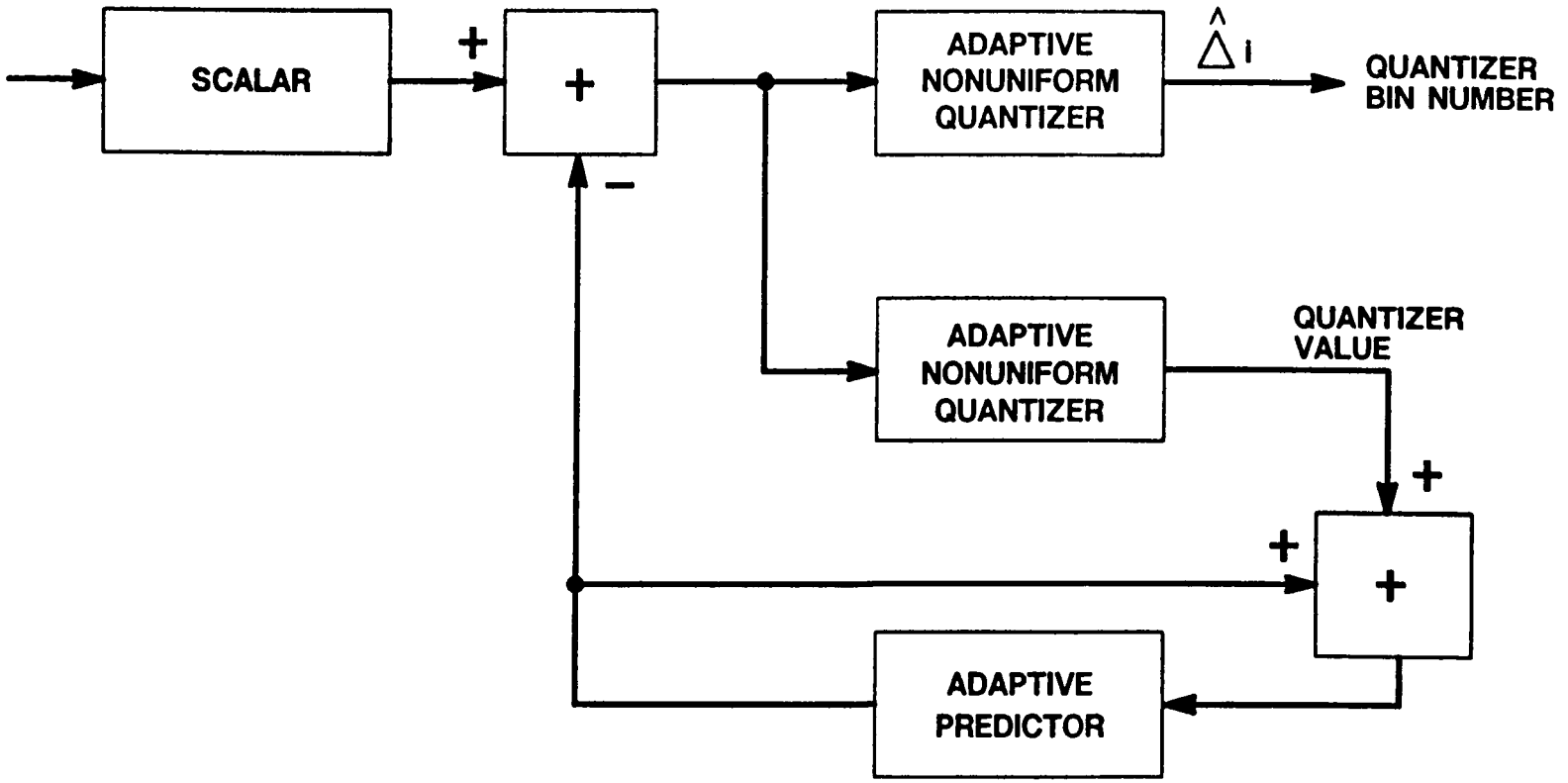
* SPACE IMAGERY ANALYZED – SCALAR VALUE VERSUS 1.3 BITS PER PIXEL

* STATISTICS TAKEN ON ERROR SIGNAL INTO NON-UNIFORM QUANTIZER

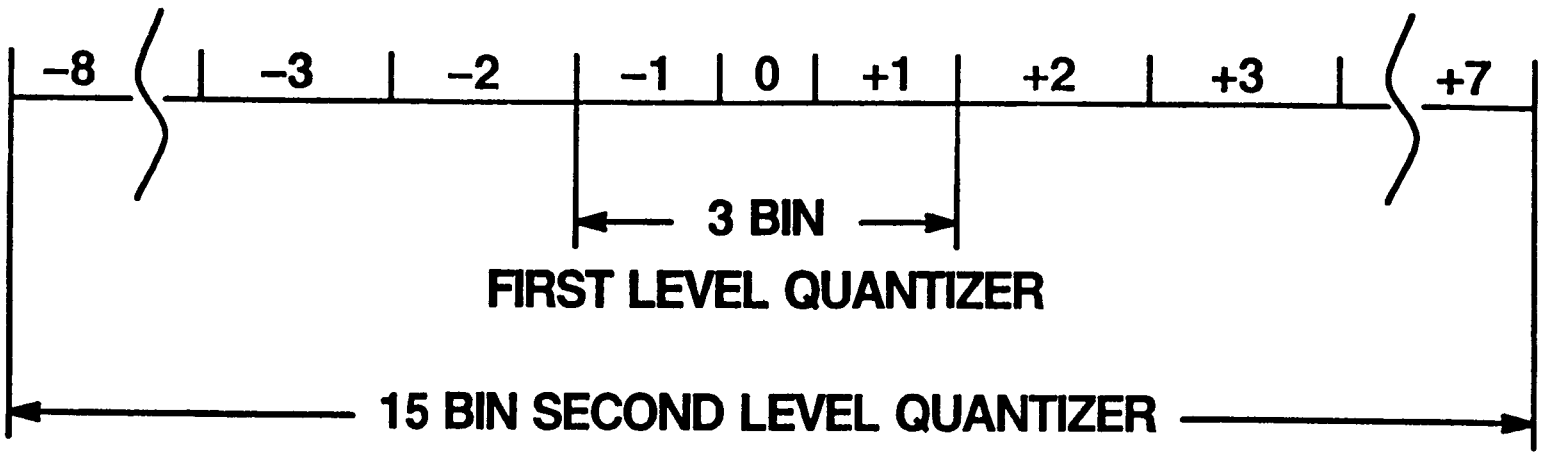
* ENSEMBLE AVERAGE OF MANY SCENES

* 16 NON-UNIFORM QUANTIZER TABLES DEVELOPED BY COMPUTING THE CENTROIDS OF QUANTIZER BINS

OMV – DPCM LOOP



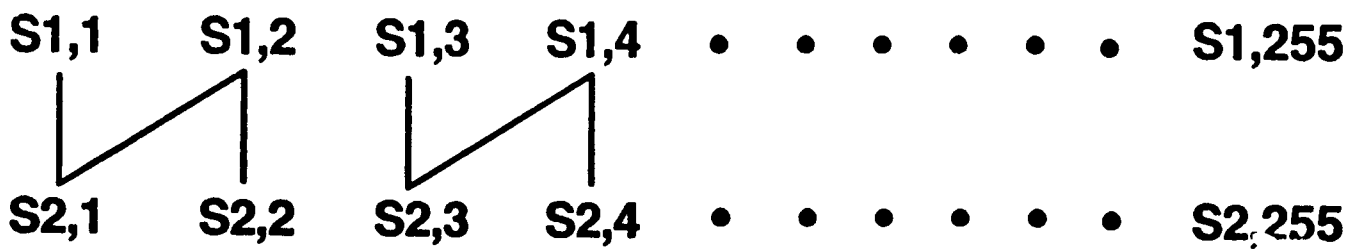
DUAL – TIER QUANTIZATION ERROR SIGNAL



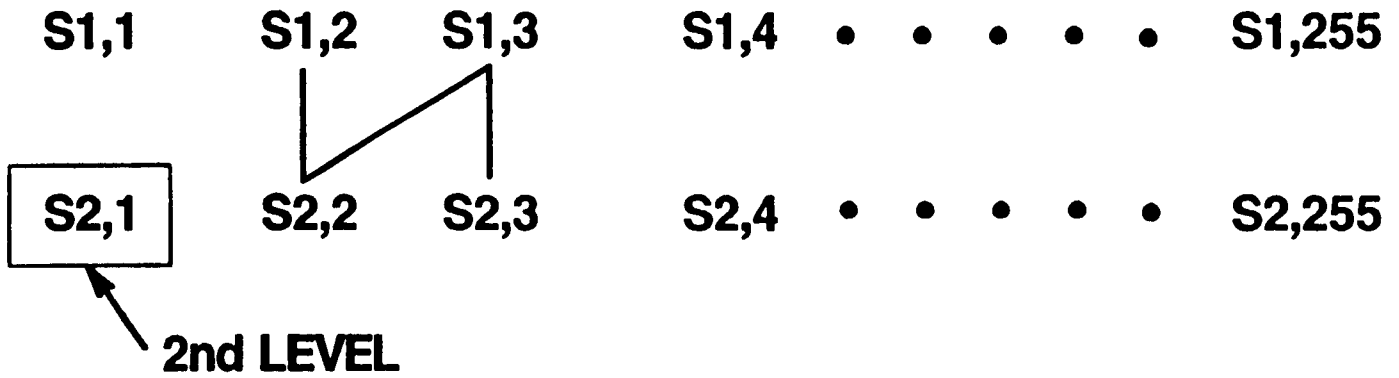
VECTOR QUANTIZATION

* TEST 2x2 ARRAY OF SCALARS LIE WITHIN –1, 0, +1
* QUANTIZER BINS REPRESENT 3 VALUES
* 4 – SCALARS REPRESENT 4 DIMENSIONS
* THUS 3^4 OR 81 VECTORS MAPPED INTO M–1 CODE BOOK

VECTOR QUANTIZATION FOUR SCALARS WITHIN INNER QUANTIZER



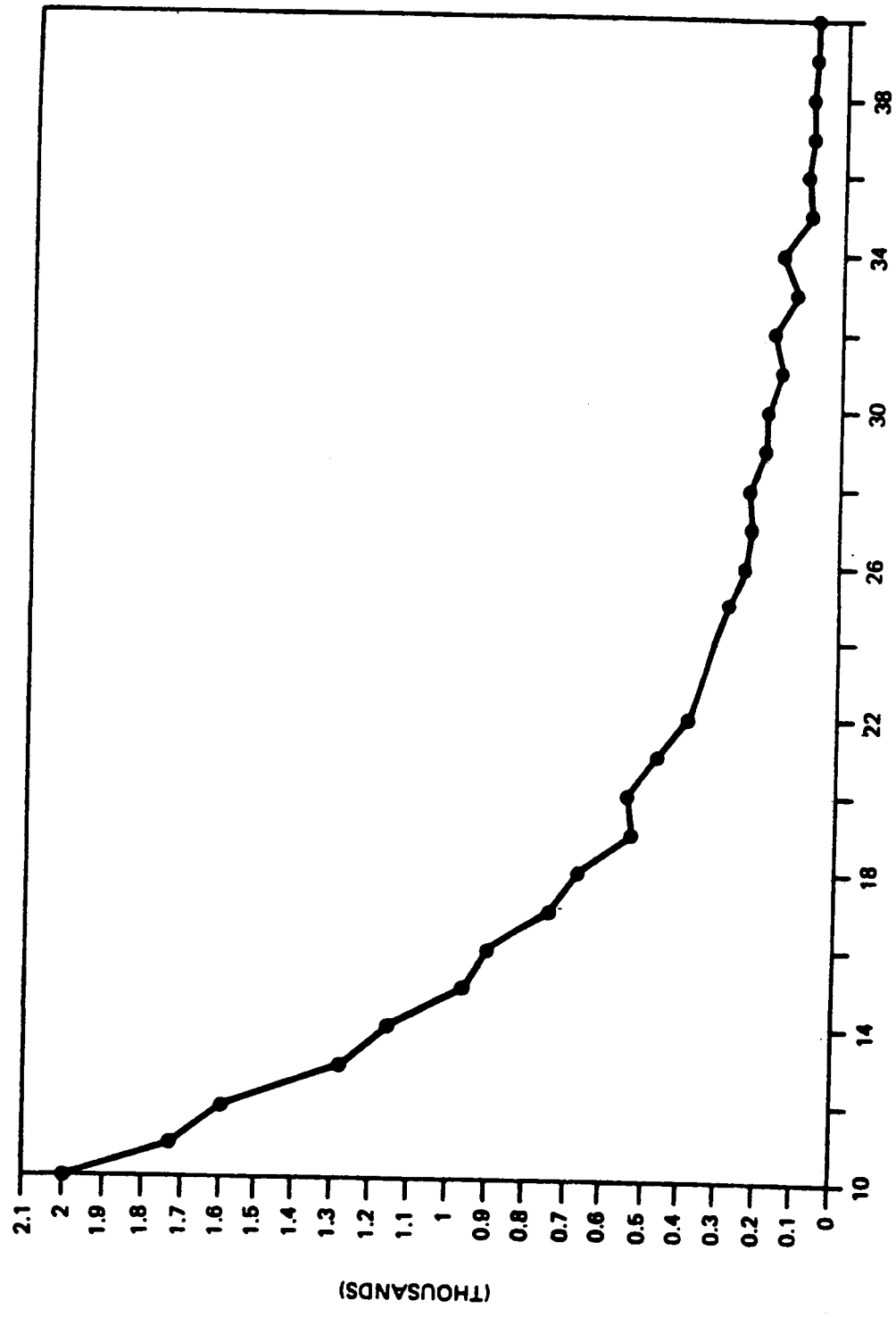
INDIVIDUAL QUANTIZATION WHEN SCALARS HIT INTO SECOND LEVEL QUANTIZER



* CODE S1,1	SCALAR	CODE BOOK M–2
* CODE S2,1	SCALAR	CODE BOOK M–2
* S1,2; S2,2;	S1,3; S2,3	VECTOR CODE BOOK M–1

RUN LENGTH CODING

* RUN ≥ 10 BIN NUMBERS = 0
* RUN LENGTH ENCODE CODE BOOK M–3
* RUNS >74 CODE – 64
* START RUN LENGTH COUNTER AT 10


(THOUSANDS)
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
14
18
22
26
30
34
38
RUN LENGTH

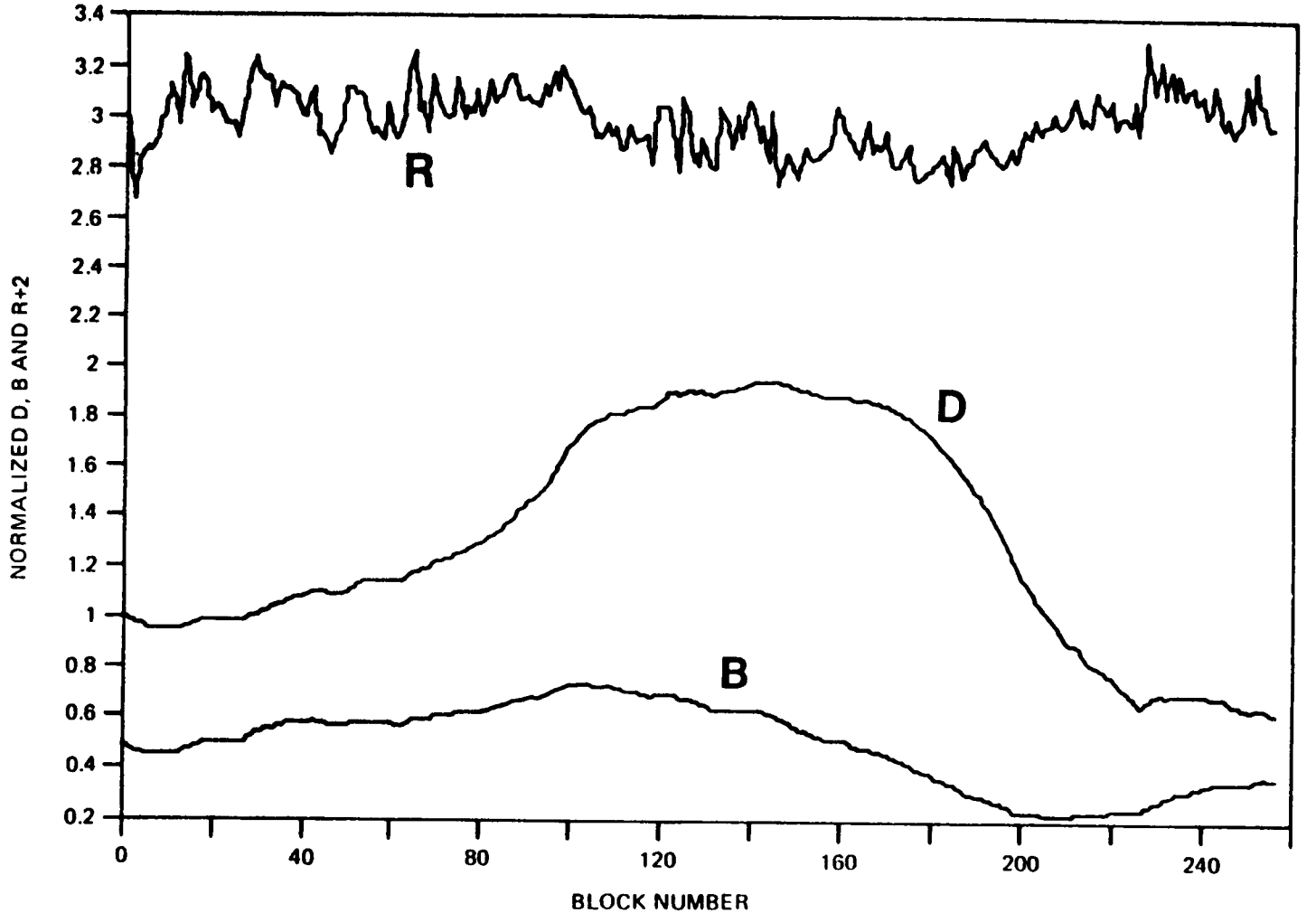
SCALAR = 8

ENTROPY ENCODER

* ENSEMBLE AVERAGING OF MANY SPACE SCENES
* CODE BOOKS M–1, M–2, M–3
* FREQUENCY OF OCCURRENCE USED TO DERIVE ONE HUFFMAN TABLE
* 4 – HUFFMAN TABLES ADAPTIVELY SWITCHED BASED ON SCALAR VALUES

RATE CONTROL ALGORITHM

* ELASTIC BUFFER MIDPOINT NORMALIZED TO ONE
* EMPTY – 0.5 FULL + 0.5
* SCALAR CHANGED EVERY N – LINES
* MODULATE BUFFER OCCUPANCY ABOUT ONE
* SCALAR INCREASED REDUCES BITS / PIXEL
* UNDER FLOW AVOIDED BY BIT STUFFING WITH 64 BIT UNIQUE WORD



GENERIC RATE CONTROL ALGORITHM

D, B AND R HISTORY

CHANNEL REQUIREMENTS FOR 10^{-5} BIT ERROR RATE OF 1/2 RATE VITERBI DECODER

- CARRIER TRACKING LOOP 12.4 dB
- COSTAS LOOP – PHASE ERROR 1.9 dB – JITTER .3 dB
- E_b / N_o INTO DEMODULATOR 6.8 dB
- VITERBI INPUT 4.6 dB

RS – 254,238 CODE
EXTENDED TO
255,238 WITH SYNC

	SYMBOLS	BITS/SYMBOL	TOTAL BITS
MESSAGE	238	X 8 =	1,904
PARITY	16	X 8 =	128
SYNC	1	X 8 =	8
	ONE RS CODE WORD= 2,040 BITS		

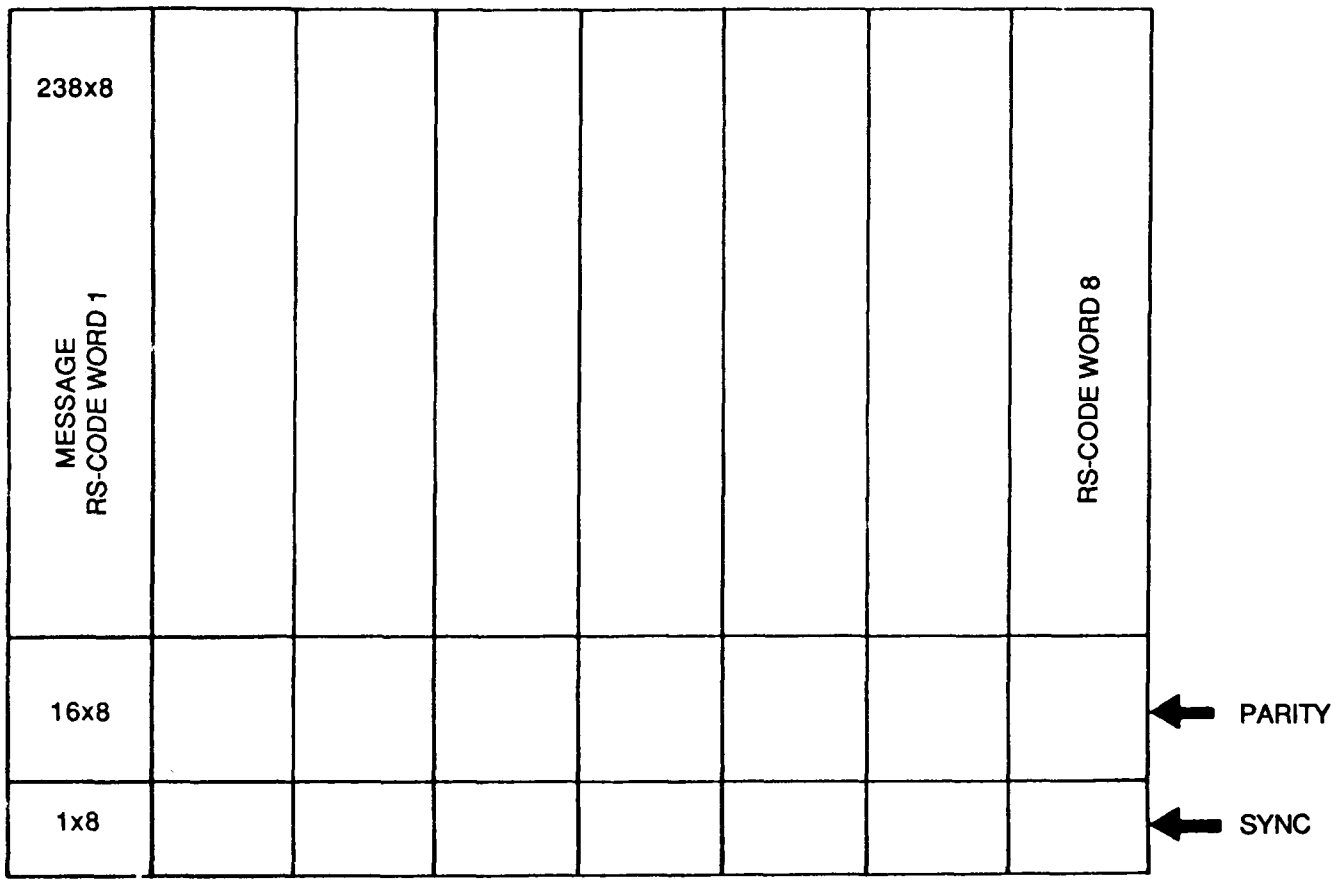
INTERLEAVED TO A DEPTH OF 8

2,040 X 8 = 16,320 BITS IN ONE CODE BLOCK

CHANNEL STATISTICS

* STUDY BY LIN COM FOR GODDARD

* INTERLEAVING TO DEPTH 8 SUFFICIENT

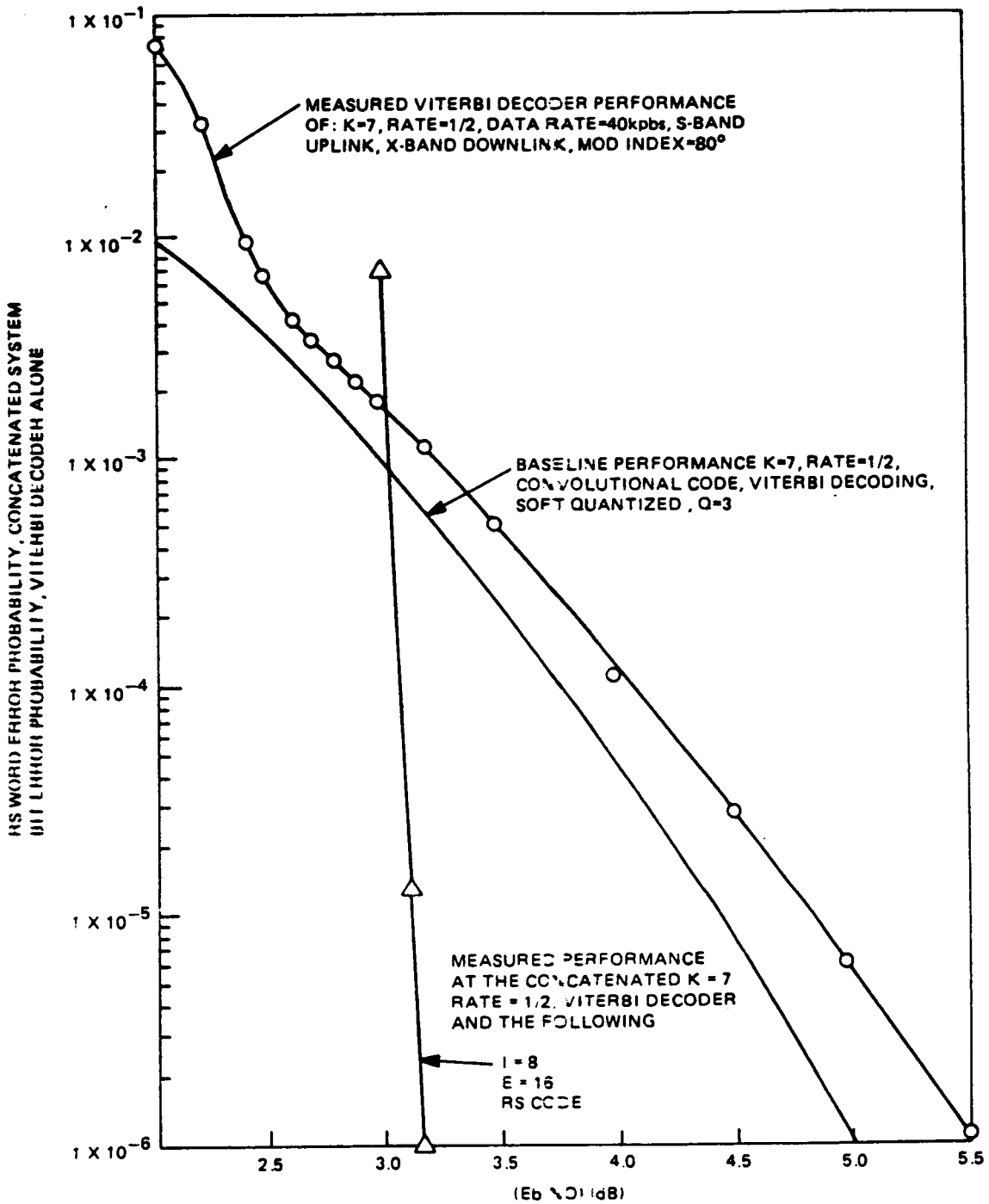


RS–255,238 CODE BLOCK, STANDARD BLOCK INTERLEAVE

- IF THE ACTUAL NUMBER OF ERRORS, s, AND THE ACTUAL NUMBER OF ERASURES, t, IN THE CODE WORD IS SUCH THAT $t, \leq 16$, BUT $2s + t > 16$ THERE CAN BE A MISDETECTION; THE CONDITIONAL PROBABILITY OF THIS MISDETECTION IS;

$$P\left[t \leq 16\ ,\ \text{BUT}\ 2S + t > 16 \Big/ \frac{1}{\left[\frac{(16-t)}{2}\right]!}\right]$$

MISDETECTIONS



PERFORMANCE OF THE RS / VITERBI CONCATENATED CODING SYSTEM (WORD ERROR PROBABILITY VERSES Eb/No)

ERROR CONTAINMENT

* COUNT NUMBER OF DECODED HUFFMAN CODE WORD IN SUB – FRAME

* COUNT CORRECT – USE NEW SUB – FRAME DATA

* COUNT INCORRECT – REPEAT OLD SUB – FRAME

* SUB – FRAME SIZE ADJUSTABLE BY GCC

* BIT ERROR MONITOR FOR OPERATOR