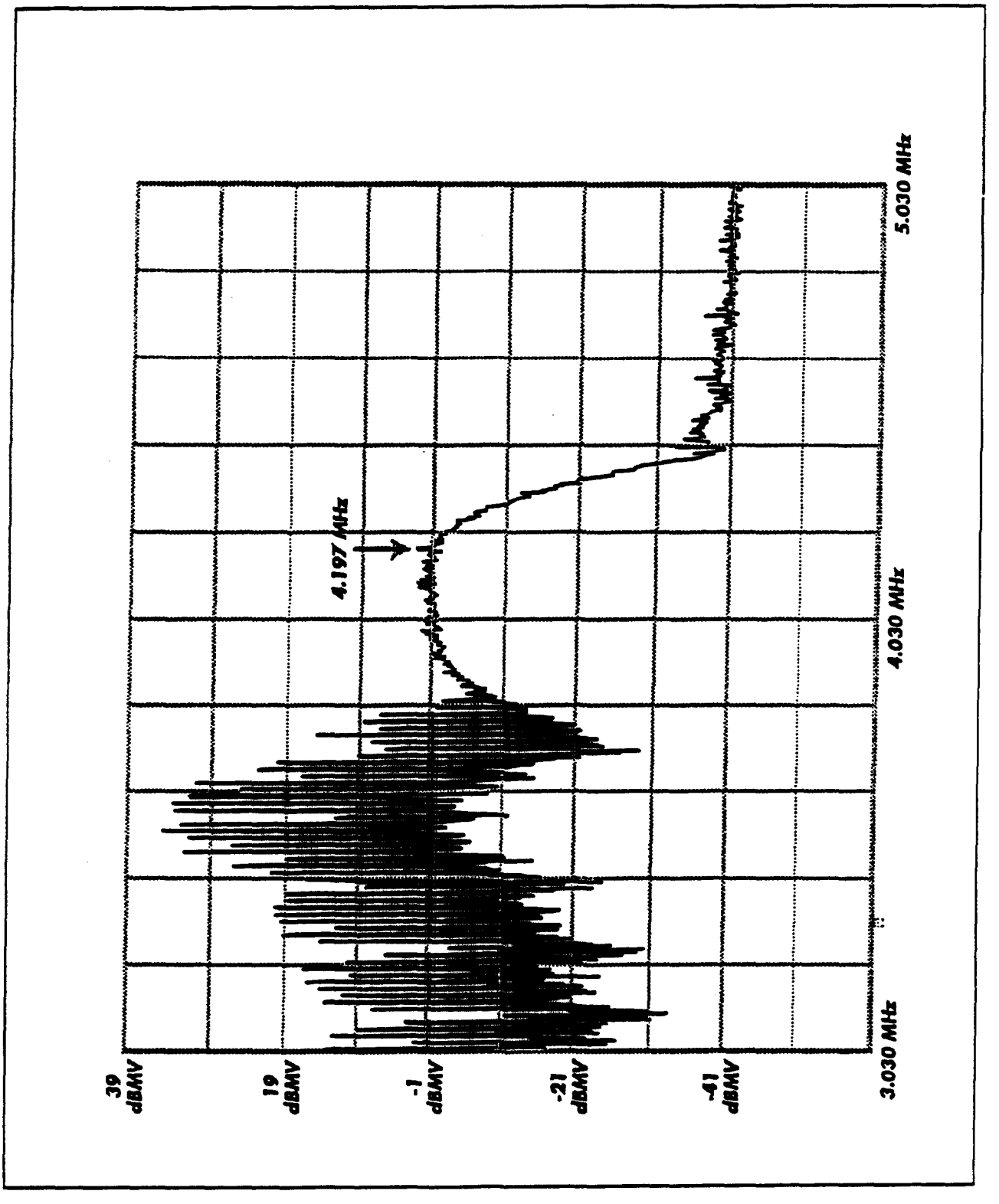

Figure 5
Video Signal with Data Added

3.2.1.2 Data Path, Encoder

The data to be encoded enters the TVT1/4 Encoder through a connector at the rear of the unit labeled, RS-422 DIGITAL, see the Encoder Functional Diagram, Figure 3.

3.2.1.2.1 RS-422/449 Interface

The electrical interface characteristics are defined by RS-422 and the protocol and mechanical interface by RS-449. This data may either be clocked in using a clock from the Encoder (master clock), or from the external source (slave clock), see dotted enclosures in Figure 3. If the slave clock is being used, it may be in the range of 56 Kbits/sec to 393 Kbits/sec. If the master clock is being used, the Encoder generated clock frequency will be:

RS-422 Clock = 4.1975115 MHz / 7
= 599.6445 KHz

3.2.1.2.2 Scrambler

The incoming data and appropriate clock are converted to TTL by a standard RS-422 receiver and then scrambled. The data is scrambled by the Encoder to ensure there are no repeated patterns of ones or zeroes that could cause recognizable patterns on the displayed video. The Decoder descrambles the data to restore the original order of bits. Scrambling and descrambling are based on the simple generating polynomial (GP):

$$GP = 1 + x^{-3} + x^{-5}$$

where x is the input sample and the exponent on x indicates a time delay, e.g., x^{-3} is the third previous sample. The additions are modulus 2 additions, that is, the bitwise exclusive-OR of the data values. The encoder scrambles the input data sequence by dividing the message sequence by the generating polynomial. The Decoder multiplies the scrambled sequence by the same polynomial to descramble and recover the original order of bits.

3.2.1.2.3 FIFO

If an external clock is being used (Slave), the data from the scrambler is clocked into a 2K x 8 FIFO (First In First Out) buffer, a byte at a time, see Figure 6.

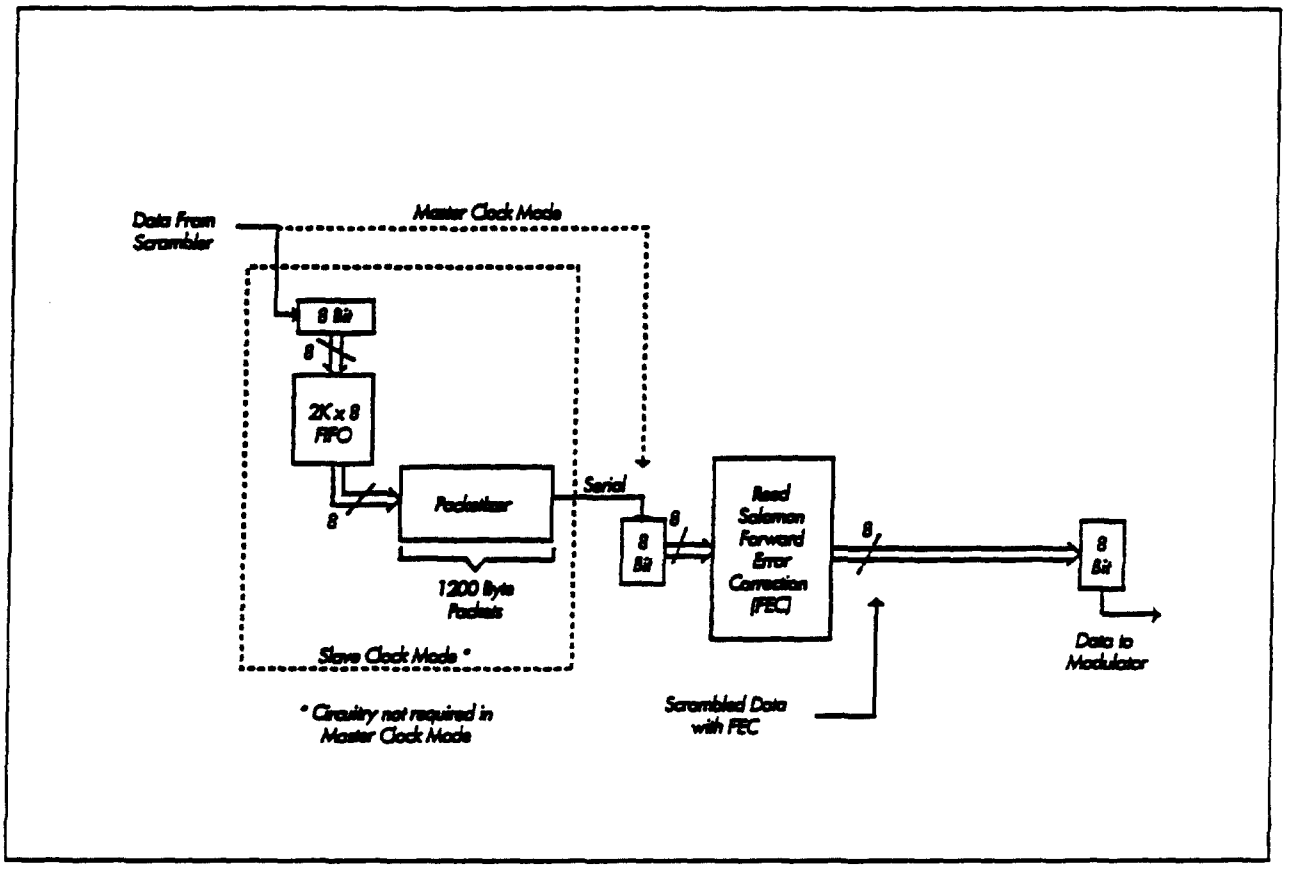

Figure 6
Encoder Input Data Structuring, Slave Clock Mode

3.2.1.2.4 Framing/Packetizer

Data, either from the RS-422/449 Interface circuit in the master mode, or from the packetizer in the slave mode, is accumulated 205 bytes at a time, along with 20 bytes of error correction information added by the Forward Error Correction (FEC) section, to form a 225 byte block, see Figure 7. The external data structure is independent of any specific data pattern or protocol.

In the slave mode, the data is transmitted in HDLC type frames consisting of 1200 byte packets. These packets contain four bytes of overhead as follows:

1 byte for Beginning of Frame (BOF)
1 byte for End of Frame (EOF)
2 bytes for Cyclic Redundancy Checking (CRC)

These packets of data are transmitted totally asynchronous to the video and include a zero bit insertion algorithm that prevents false beginning of frame (BOF) and end of frame (EOF) bytes.

If the internal Encoder clock is being used (Master Mode), the data by-passes the FIFO and Packetizer (Depacketizer) and goes directly to the Forward Error Correction section (FEC), see Figure 7. In this case, the RS-449 data gets loaded into the FEC in the order received from the Scrambler (without packetizing).

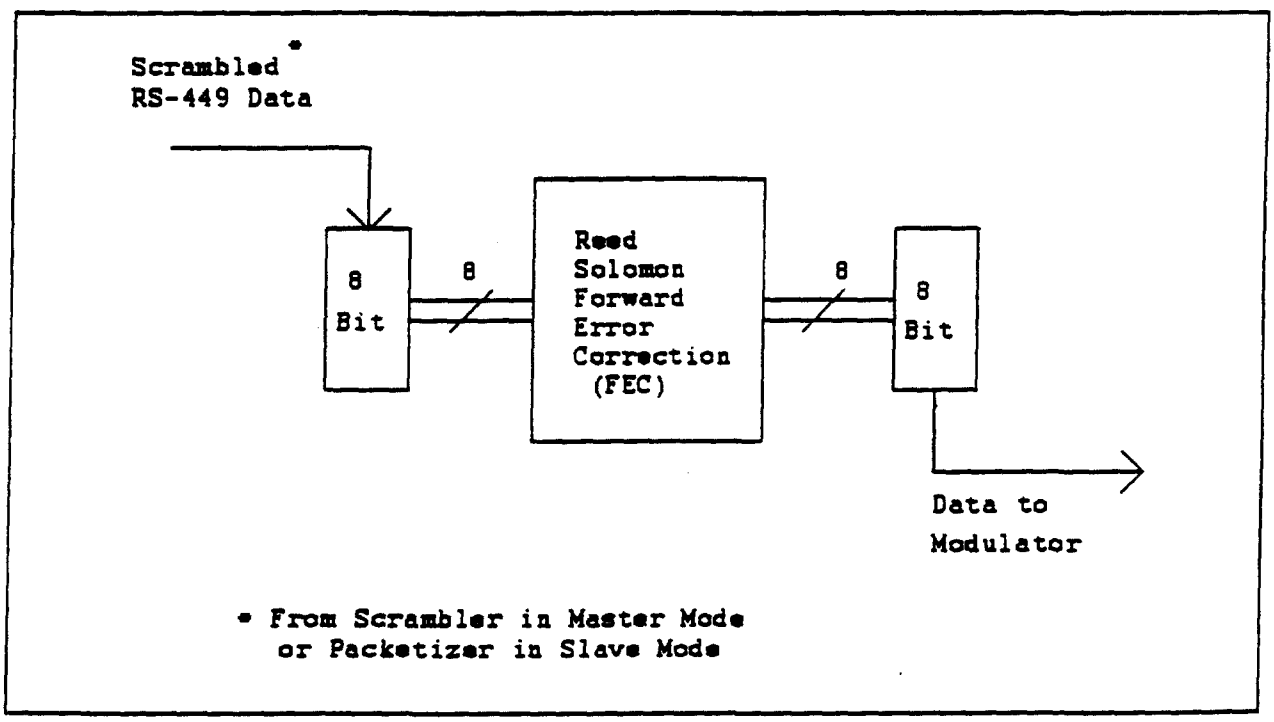

Figure 7
Encoder Input Data Structuring, Master Clock Mode

3.2.1.2.5 Error Correction Performance

The TVT1/4 Decoder uses a Reed Solomon (225,205) algorithm to accomplish forward error correction (FEC), see Figure 7. This technique can correct up to 10 bytes of data in a block of 225 bytes, or 40 bytes out of every four blocks (900 bytes) in a video field.

3.2.1.2.5.1 Reed Solomon Forward Error Correction (FEC)

The Forward Error Correction (FEC) section adds correction information in the Encoder according to Reed Solomon (225,205) algorithm. Data into the FEC is asynchronous to the video timing itself.

3.2.1.2.6 Data Synchronization

3.2.1.2.6.1 Data Sync

The data is clocked out of the Forward Error Correction circuit, receives some shaping and phase correction, and is sent to the Bandpass Data Filter by the Data Sync. It is organized at this point in four blocks of data per video field of 240 lines, with each block containing 225 bytes of data as follows:

225 bytes per block, made up of 205 bytes of data and 20 bytes of correction

The line usage is then:

Lines of data and error correction	240
Unused lines at beginning of each field	22
* 2 fields/frame	
Total	262 lines per field

3.2.1.2.6.2 Transmitted and Received Bit Rate

The peak instantaneous bit rate is 599 Kbps. The average data rate, including error correction and control bits, is 431.568 Kbps, resulting in a net bit rate for pure data of 393.207 Kbps, as determined in the following paragraphs.

The field rate is based on the video burst frequency of 3.579545 MHz and is determined as follows:

Burst Frequency, f_b	3.579545 MHz
Horizontal Scan Frequency (lines/sec), f_{hs} = f_b (cycles/sec) ÷ 455 (cycles/scan) * 2 (scans/line)	15.734 KHz
Frame Rate = f_{hs} (lines/sec) ÷ 525 (lines/frame)	29.970 frames/second
Field Rate (2 fields per frame to generate 2 traces per line)	59.940 fields/second

The data rate, including error correction, is determined from the above and from the density of data per block, also given above, as follows:

225 (bytes/block) * 4 (blocks/field)	900 bytes/field
900 (bytes/field) * 8 (bits/byte)	7.200 Kbits/field
7.20 (Kbits/field) * 59.940 (fields/sec)	431.568 Kbps

This rate can also be determined from the bits per video line as follows:

30 (bits/line) * 240 (lines of data per field) * 59.940 (fields/Sec)
= 431.568 Kbps

The net data rate, not including error correction bits, is:

205 (bytes/block) * 4 (blocks/field) * 8 bits/byte) * 59.940 (fields/sec)
= 393.207 Kbps

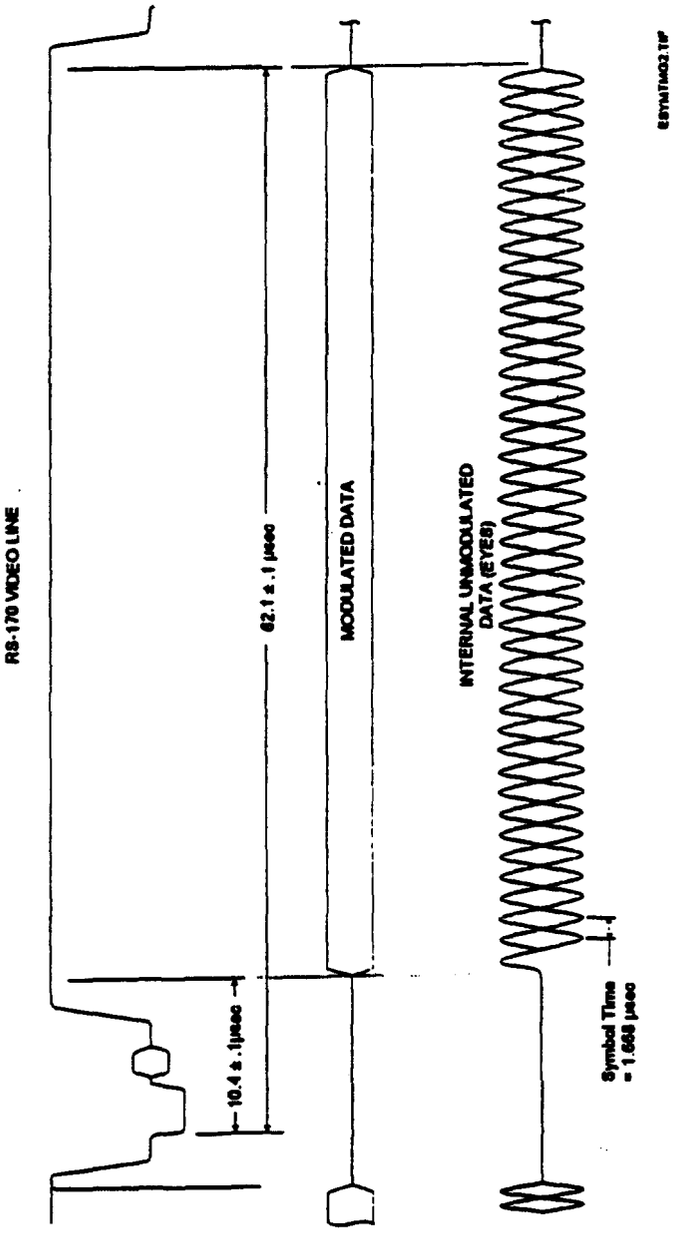

Figure 8
Shows Relationship of Data to Video Signal

3.2.1.2.6.3 Carrier Synchronization

The digital data stream into the PSK Modulator is synchronized with the video lines by the Data Sync using the crystal controlled 4.1975115 MHz Carrier clock from the Carrier Generator. A carrier synchronizing bit is added ahead of the 30 data bits, as bit number one, making a total of 31 bits transmitted per line. This synchronizing bit is always a logical one (1) and is added to ensure carrier phase recovery for demodulation, see Figure 8, earlier.

3.2.1.2.7 PSK Modulator and Modulated Data Band Pass Filter

The data signal is phase shift key (PSK) modulated at 4.197 MHz by the Phase Shift Key (PSK) Modulator, see block Diagram, Figure 3, resulting in a biphase signal similar to that shown in Figure 9. A data logical one and a logical 0 are shown in comparison to the resultant modulated internal data signal.

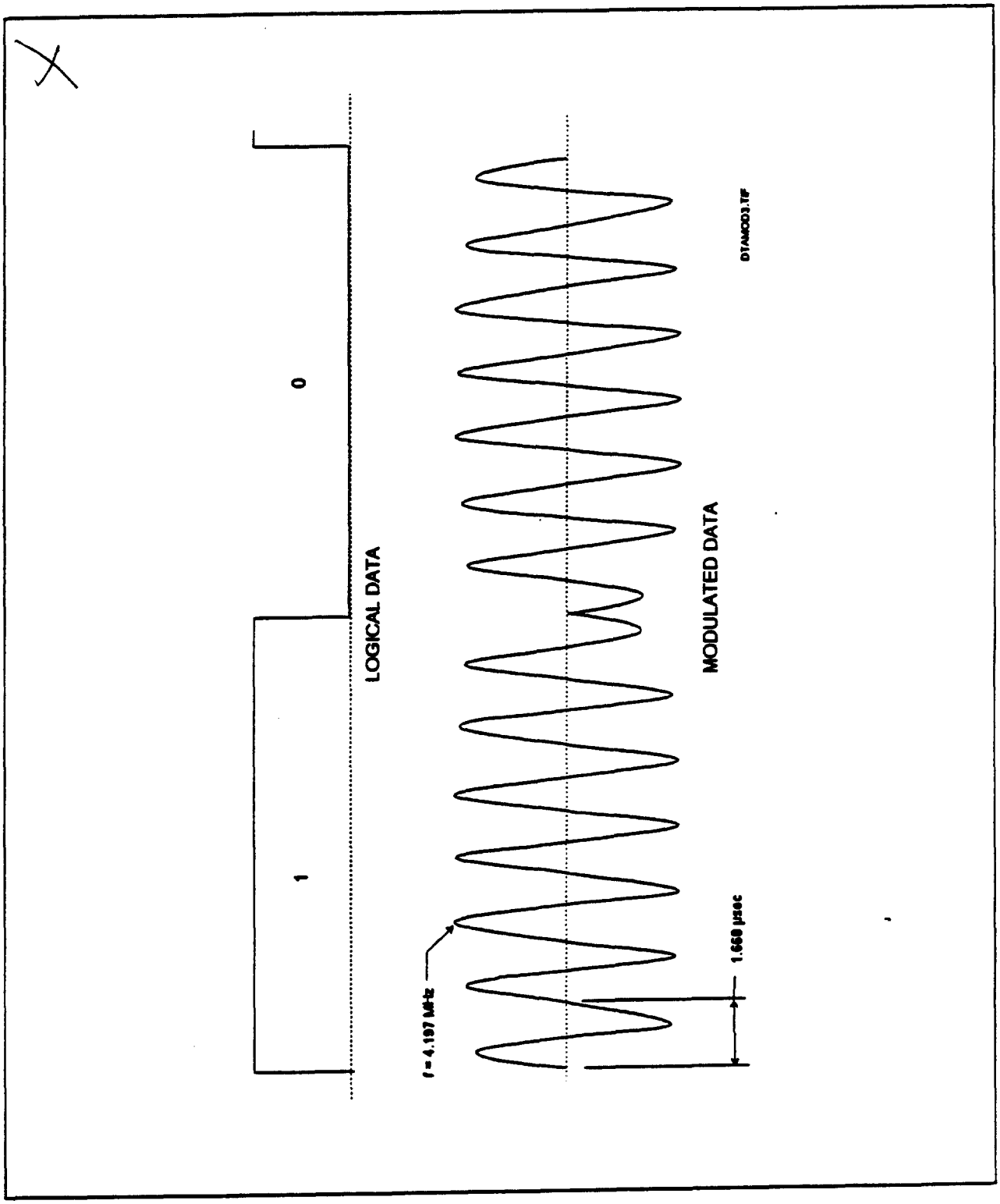

Figure 9
Phase Shift Key (PSK) Modulated Data, Internal

It is then filtered to remove most of its frequencies above 4.197 MHz and of the frequencies below 3.897 MHz, resulting in single sideband (SSB) data, with the data being in a relatively narrow 300 KHz range, primarily below 4.197 MHZ, as illustrated by the spectrum plots in the two figures that follow. Figure 10 is a plot of the peak amplitudes of the spectrum of the modulated data prior to the Modulated Data Band Pass Filter.

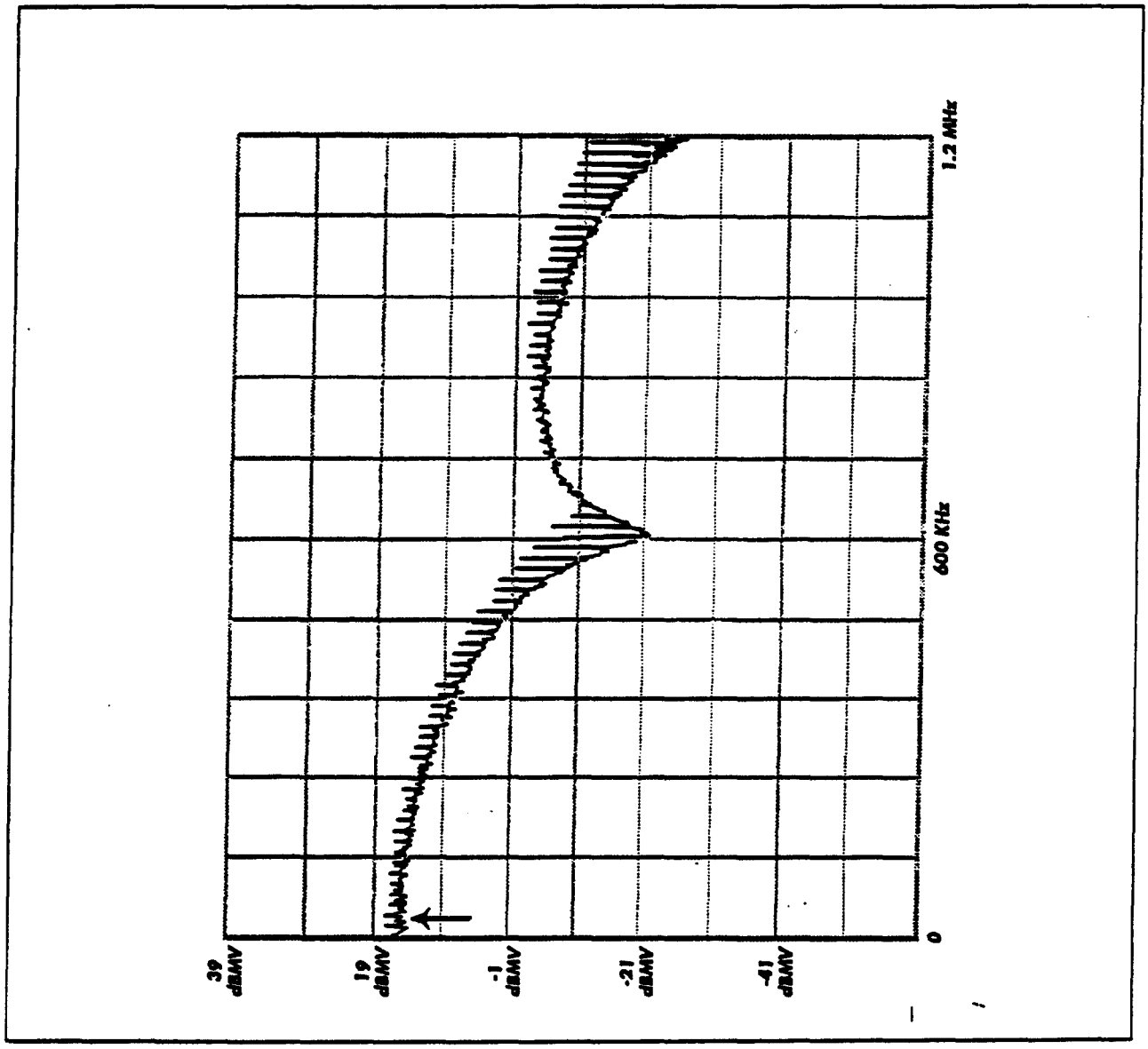

Figure 10
Baseband Data Prior to Filtering

Figure 11 is a plot of the peak amplitudes of the spectrum of modulated data <u>after</u> the **Modulated Data Band** Pass Filter which shows the 300 KHz modulation.

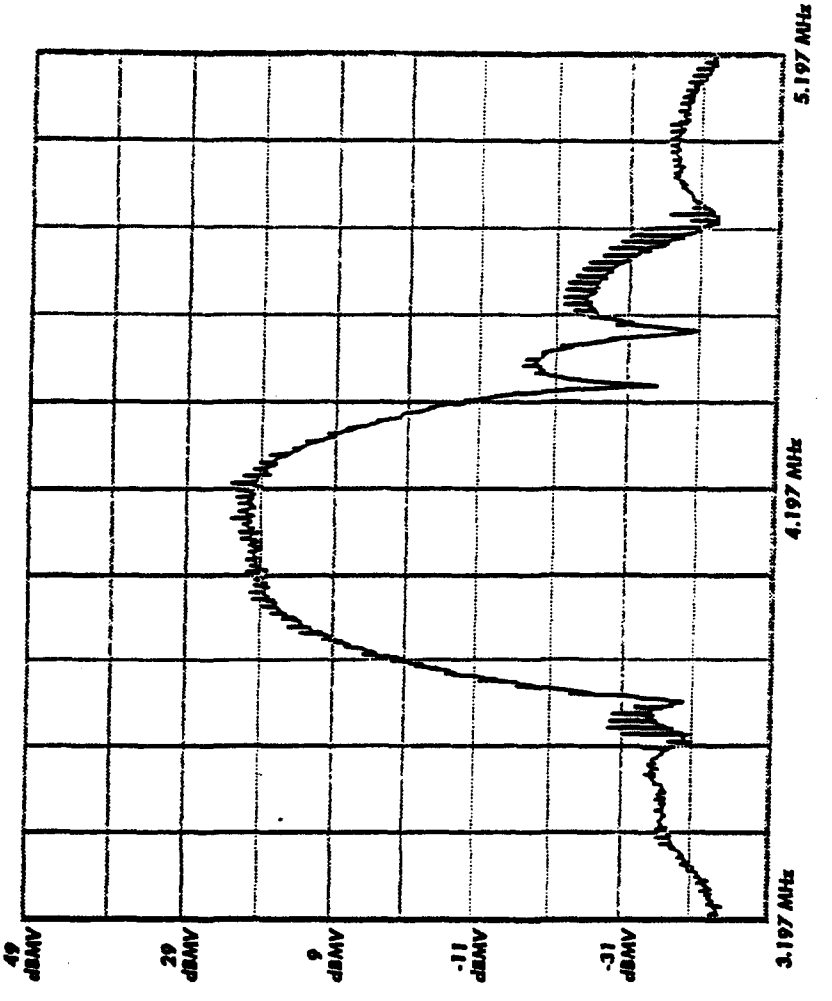

Figure 11
Modulated Data, After Filtering

3.2.1.2.8 Summer/Driver and Output Signal

This phase shift keyed, single sideband data is then sent to the summer/driver where it is summed with the preconditioned video signal and buffered for output and return to the station transmitter.

A plot of peak amplitudes of a video signal, containing color bar information, around 4.2 MHz, is shown in Figure 12. A plot of amplitudes of this same video signal out of the Encoder with the data added, is as shown in Figure 13. An overlay of these two, comparing the video signal with and without data is shown in Figure 14.

The comparison in Figure 14 graphically shows the amplitudes of the video signal containing data to be less than or equal to the amplitudes of the original signal without data. For this reason, WavePhore is confident that transmission of a video signal encoded with data in this manner will introduce no added interference properties.

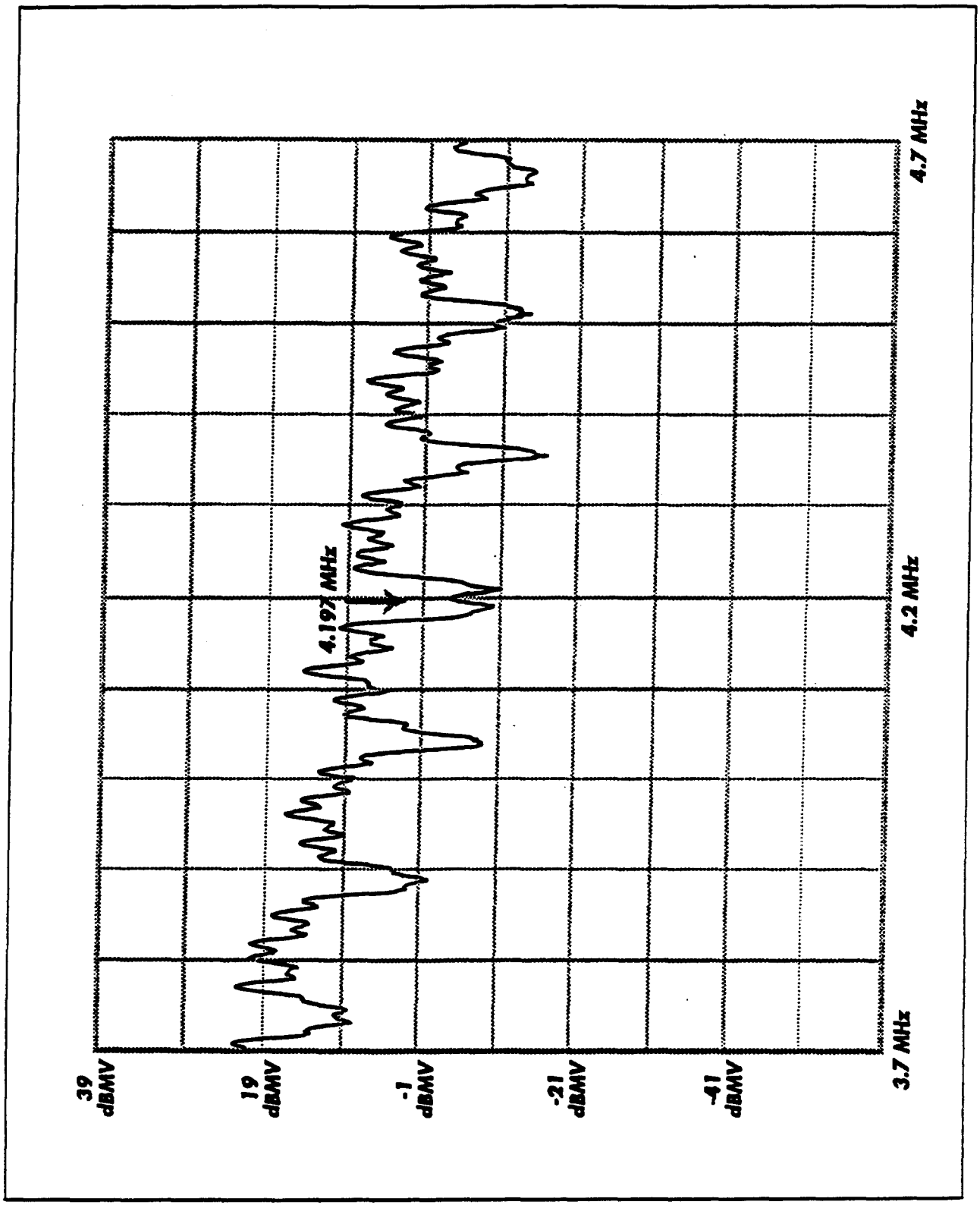

Figure 12
Video Spectrum, Without Data

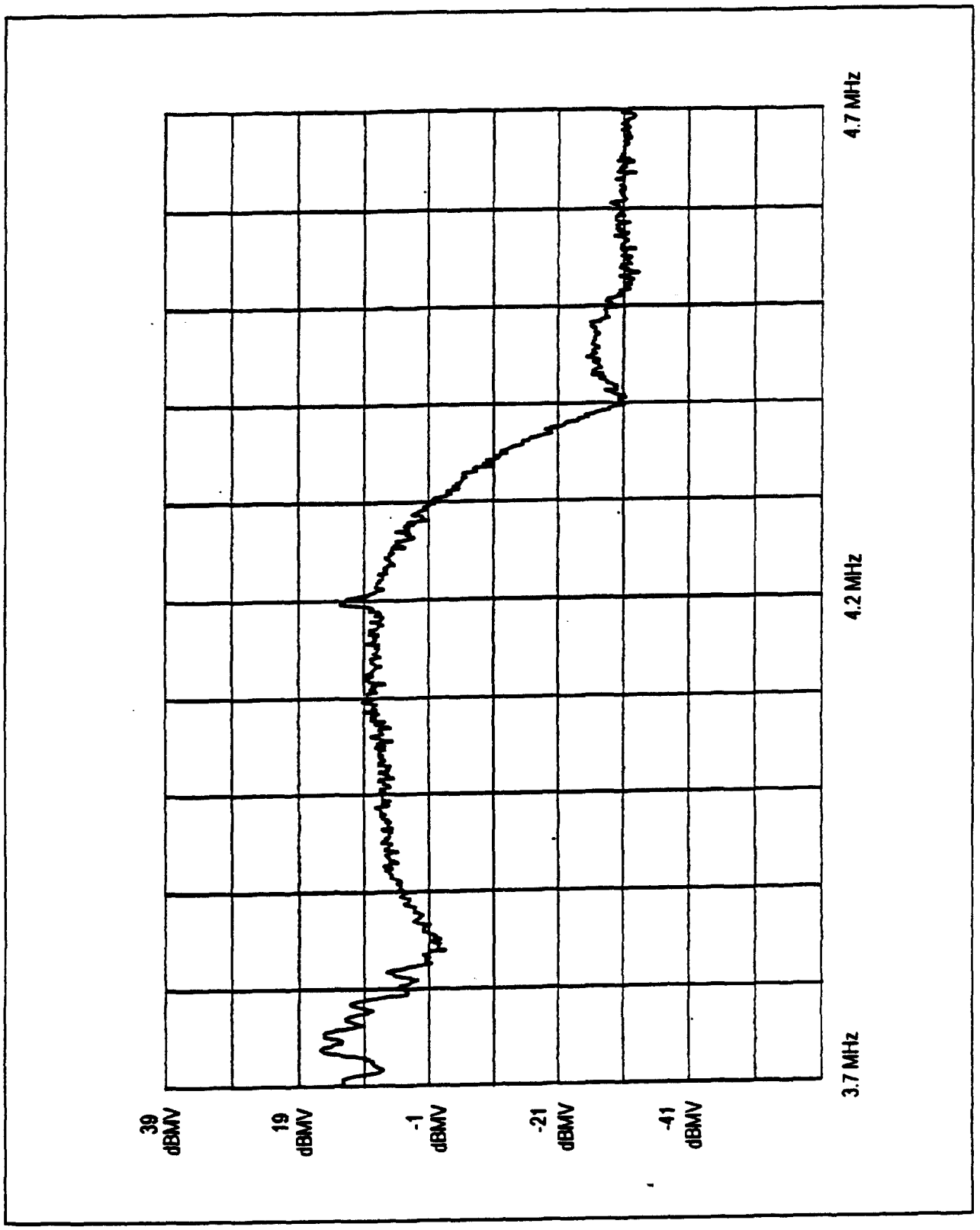

Figure 13
Video Spectrum With Data

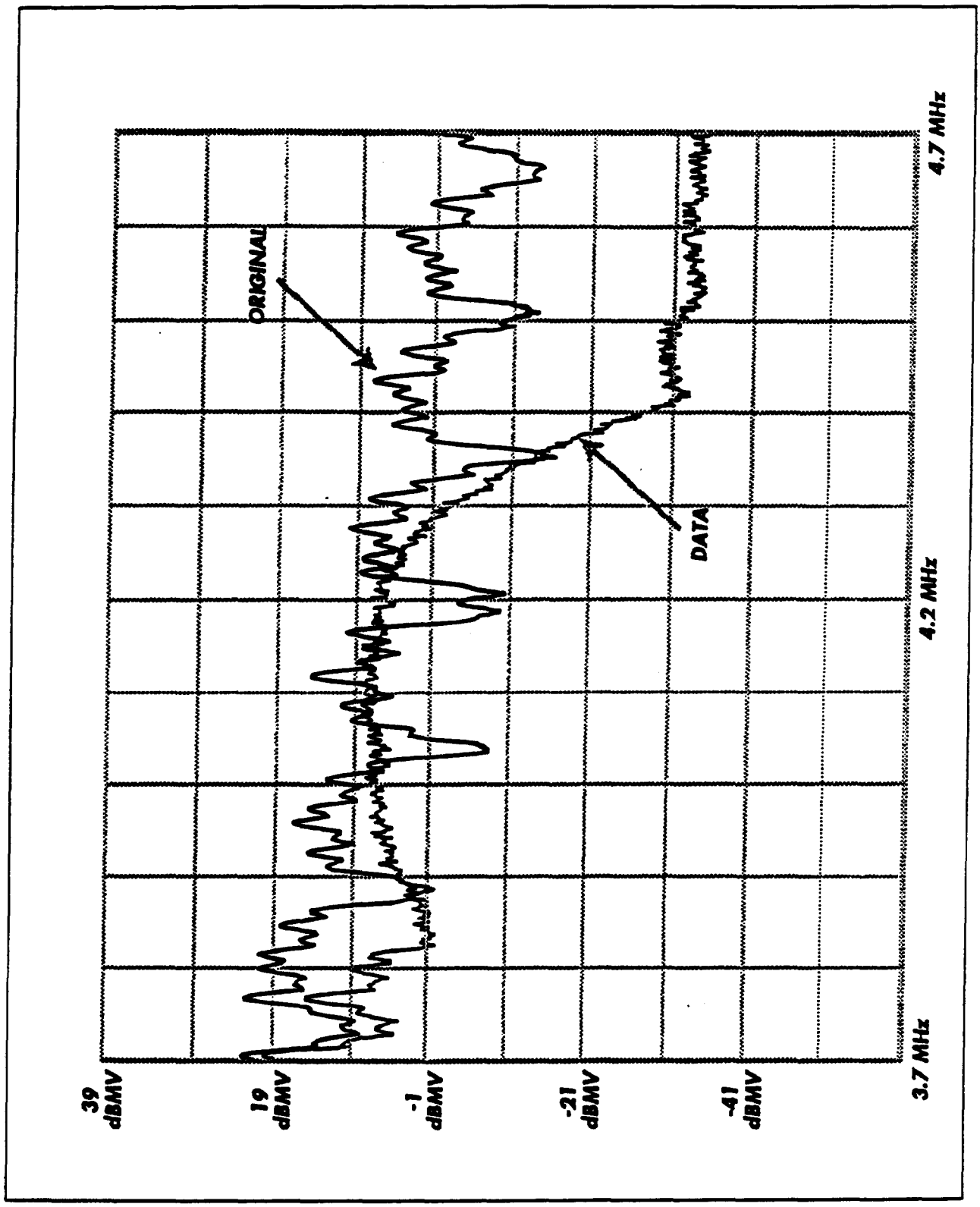

Figure 14
Video Spectrum, With and Without Data

3.2.1.3 Electrical Characteristics, Encoder

3.2.1.3.1 Video Specifications, Encoder

The video shall meet the following specifications with the data off.

Signal to Noise ratio	
w/chroma filter	> 60 dB
w/unified weighting	> 67 dB
Frequency response	flat within 1 db, 15 KHz to 3.6 MHz
Group Delay	< 50 nsec from 15 KHz to 3.6 MHz
Chroma vectors	< ± 2 degrees < ± 0.5 dB amplitude
Differential Phase	< 2 degrees
Differential Gain	< 1%
Input Video Signal Level	1 ± 0.5 V Peak-to-Peak 0 ±.75 V DC level at blanking
Input impedance	75 ohms +/- 2%
Output Video Signal Level	1.00 V sync tip to peak white
Output impedance	75 ohms +/- 2%

3.2.1.3.2 Analog Data Specifications, Encoder

Input Format	Standard RS-422/449
Input Rate	56 Kbps to 393 Kbps
Injection level	Adjustable, 0 to 170 mV peak to peak
Output Data Format	30 symbols per line of video (1bit/symbol)
Output Data Synchronization	
Start	10.4 µsec ± 0.1 µsec after falling edge of horizontal sync
End	60.5 µsec ± 0.1 µsec after falling edge of horizontal sync

3.2.1.3.3 Input Power Requirements, Encoder

Voltage	90 to 132 VAC
Frequency	47 to 63 Hz
Power	70 Watts

3.2.1.3.4 Hardware Interface

LABEL	ITEM	I/O
RS-422 DIGITAL	37 pin connector	Input
INPUT MONITOR	BNC Connector	Output
VIDEO INPUT	BNC Connector	Input
VIDEO OUTPUT	BNC Connector	Output
OUTPUT MONITOR	BNC Connector	Output

3.2.2 TVT1/4 Decoder

Given here is a functional description of the TVT1/4 Decoder and how data is extracted from the TV signal.

The TVT1/4 Decoder is located at the site of the customer receiver site. Its purpose is to select the RF channel from the antenna, bring the selected video and data down to baseband, and extract the data in an RS-422/449 format.

3.2.2.1 Video Path, Decoder

3.2.2.1.1 RF Demodulator

The input RF signal enters at the rear of the TVT1/4 Decoder at the F type connector labeled, RF Input (Video Signal), and is routed to the RF Demodulator where the video signal selected by the Channel Tuner is down converted to baseband video and to 4.197 MHz modulated data, see Figure 15 for functional diagram.

3.2.2.1.2 Sync Separator

The baseband video portion is sent to the Sync Separator which generates signals for video frame synchronization, Vertical Sync and the Composite Sync (CSYNC) used by the Timing Generator to generate other timing signals used by the data detection circuitry.

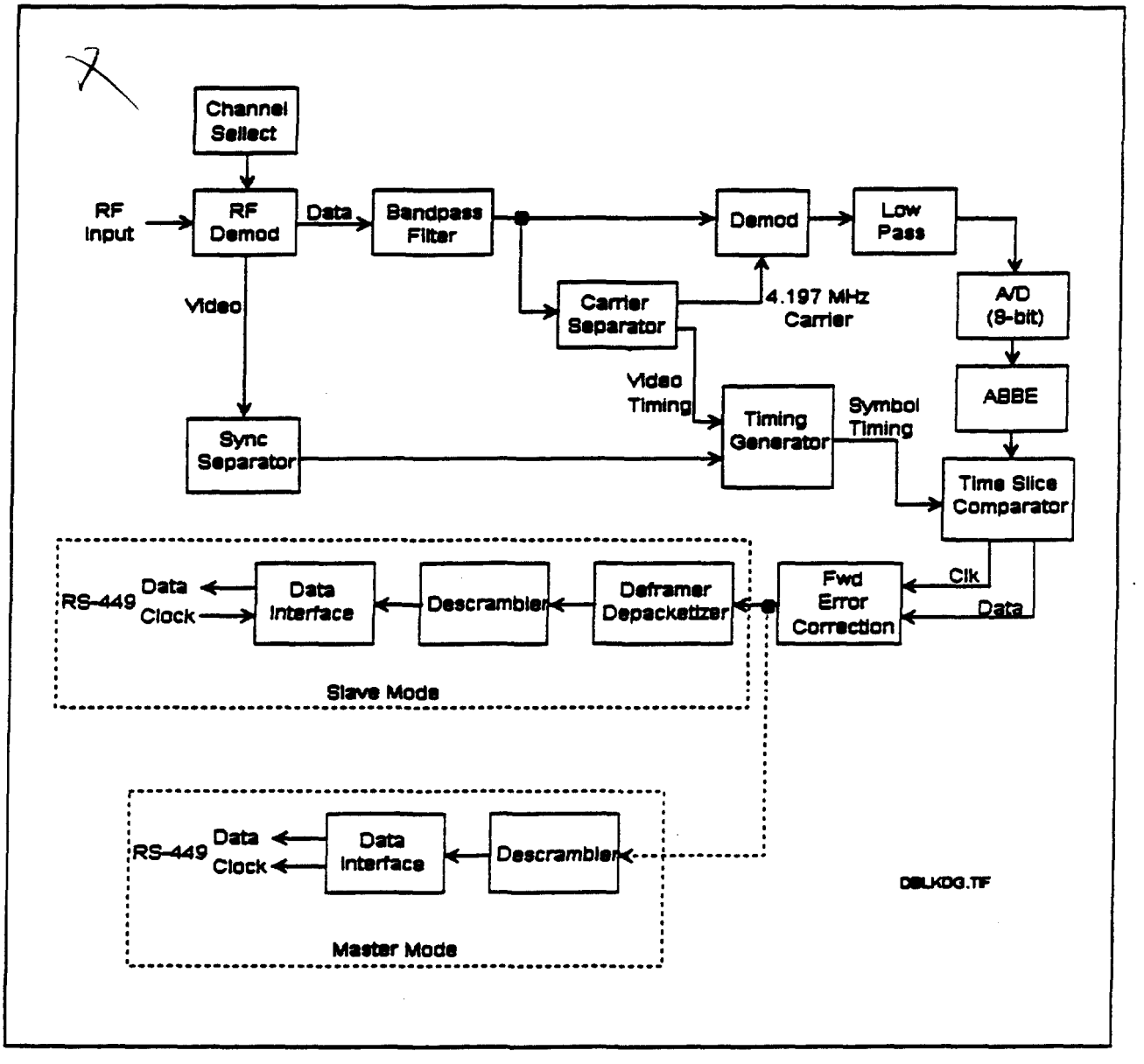

Figure 15
TVT1 Decoder Functional Diagram

3.2.2.2 Data Path, Decoder

3.2.2.2.1 Bandpass Filter

The data from the RF Demodulator is sent to the Bandpass Filter, see Figure 15. The Band Pass Filter removes all frequencies above 4.2 MHz, including the sound carrier, and all frequencies below 3.9 MHz, including chrominance and luminance, leaving the 4.197 MHz modulated data signal. This data signal is then sent to the Demodulator and the Carrier Separator.

3.2.2.2.2 Carrier Separator

The Carrier Separator phase locks with the modulated data signal and recreates the 4.197 MHz carrier clock for the Demodulator.

3.2.2.2.3 Demodulator

The Demodulator converts the 4.197 MHz modulated data to analog baseband data.

3.2.2.2.4 Low Pass Filter

This data signal is then low pass filtered to remove any alienating artifacts above the 300 KHz baseband data signal.

3.2.2.2.5 A/D Converter

It is then converted to digital by an Analog to Digital Converter, see Figure 15.

3.2.2.2.6 ABBE

The digital signal is sent through an Adaptive Baseband Equalizer (ABBE) that maximizes the energy of the data within the 300 KHz spectrum and reduces the Intersymbol Interference (ISI) caused by non-linear characteristics of the channel and to reduce the effect of ghosting.

3.2.2.2.7 Time Slice Comparator

The Time Slice Comparator uses Symbol Timing from the Timing Generator to recover the data.

3.2.2.2.8 Forward Error Correction (FEC)

The Forward Error Correction circuit uses the Reed Solomon (225,205) algorithm to analyzes each block of data to determine if correction is necessary and within its defined capability. If correction is necessary and meets the above criteria, the FEC makes the appropriate corrections, otherwise the data is left unchanged. The data is then sent to the Deframer/Depacketizer.

3.2.2.2.9 Deframer/Depacketizer

The Depacketizer searches the data stream, now of the HDLC and SDLC format, for a Beginning of (data) Frame (BOF) byte which marks the beginning of a packet of data as originally structured by the Encoder and accepts the following packet of data. It removes the BOF and End of Frame (EOF) bytes from the packet of data, and extracts and uses the Cyclic Redundancy Check bytes (CRC).

3.2.2.2.10 Descrambler

The data is then descrambled in a reverse manner to that described for the Scrambler in 3.2.1.2.2, and sent to the RS-422/449 Interface circuit.

3.2.2.2.11 Data Interface

Depending on the data interface mode, Slave or Master clock, the Data Interface circuitry clocks the data out to the user using either the user supplied clock (if in the Slave clock mode) or the internal 599 KHz clock (if in the Master clock mode) in the same format as originally received by the Encoder.

3.2.2.3 Electrical Characteristics, Decoder

3.2.2.3.1 Input and Output Requirements, Decoder

RF input range	0.5 mV to 50 mV, 75 ohm "F" connector (NTSC format)
Tuning Range	Channel 2 through channel 69
Digital Output Format	Standard RS-422/449 Interface
Output Data Rate	56 Kbps to 393 kbps

3.2.2.3.2 Input Power Requirements, Decoder

Voltage	95 to 260 VAC
Frequency	47 to 63 Hz
Power	50 Watts

User Interface

LABEL	ITEM	I/O
RS-422 DIGITAL	37 pin connector	Output
RF Input (Video Signal)	F Type Female connector	Input

The main power is supplied through a grounded, recessed, male power connector and an on/off rocker switch that are part of the AC power module accessible on the rear panel. The front panel contains two STATUS lamps labeled POWER and SYSTEM.

3.2.3 Coverage

The WavePhore TVT1/4 system can successfully operate under A-contour conditions and has proven performance up to the B-contour conditions. Operation under B-contour conditions remains dependant upon the type of antenna used and the terrain. Use of a good directional antenna is important, however, to ensure a good reception and minimize disruptions. WavePhore's Adaptive Baseband Equalizer has proven

effective in minimizing the effect of stationary and mobile multipath signals, and allowing the system to continue to provide good data integrity in the presence of ghosting and at distances up to 60 miles provided the signal-to-noise ratio remains above 45 dB.

3.2.4 NTSC Compatibility

The video, with encoded data, out of the TVT1/4 Encoder is fully compatible with the normal NTSC video signal and requires no changes to the NTSC transmission system. The data signal is within the video bandwidth below the audio frequency and at very low levels, typically less than 20 dB above the normal noise level in the area where data is added, 3.9 MHz to 4.5 MHz. At this location and at this low level, there is no interference with co- or adjacent channel NTSC signals. Likewise, it has no effect on the parent channel video or audio.

WavePhore's TVT1/4 system has been successfully transmitting test data on Channel 3 for a period of 22 months on continuous basis, and 16 months on Channel 45 in the Phoenix area with no complaints from viewers or station operators. The WavePhore system was also in continuous operation on channel 13 in the Las Vegas area during the week of the NAB Conference in March of 1994 with no degradation of television viewing nor any adverse effects upon the host NTSC signal, including closed captioning, VBI or ghost cancelling.

A two day test was performed on Channel 45 at five different locations in the Phoenix area in November, 1993, by COHEN, DIPPELL AND EVERIST, P.C., Radio and Television Consulting Engineers, Washington, D.C., see Appendix A. Critical viewing of the received television signal were made with the data stream being switched on and off, on request, or by automatically being cycled on and off at five second intervals. A careful search was made for artifacts and various effects including: noise patterns, noise increase, color change, ghost/echo, areas of sudden color change, and aural noise and distortion. Monitoring was done visually using various kinds of television receivers as well as studio monitors, and electronically using a Tektronix VM-700A Video Measurement Set, a Tektronix 1450 Precision Demodulator, a Tektronix 2712 Frequency Analyzer, and a Telecommunications Techniques Fireberd 6000 Communications Analyzer to test Bit Error Rate (BER). There was no perceptible degradation of visual or aural signals on any receiver at any site, nor was there any perceivable degradation or artifacts found on the video recorded play-back or on color photos taken of the television display.

3.2.5 Multipath Mitigation

3.2.5.1 Static Multipath

To minimize the effects of static multipath signals on the data signal, a multitap fractionally spaced equalizer is used. It can equalize out ghosts up to 5 µsec prior to the main signal and 25 µsec after the main signal as long as the ghost signals are

more than 10 dB down within the window of 500 nsec before and 60 nsec after the main signal. This is needed to recover a stable video sync signal for the timing recover circuits.

3.2.5.2 Dynamic Multipath

The Reed Solomon error correction method in the system is designed to handle large bursts of error. This minimizes the effects of dynamic multipaths while the ABBE adapts to the changes in the ghosting effects.

3.2.6 Interference Immunity

WavePhore's TVT1/4 tuner is designed to discriminate between adjacent channels having equal signal strength, and co-channel signals that are more than 25 dB down from the primary signal.

3.2.7 Bit Error Rate Performance

The bit error rate will exceed 5E-07 in environments exceeding 40 dB data signal-to-noise ratio at the receiver. A plot of expected error free bits vs. data signal to noise is shown in Figure 16.

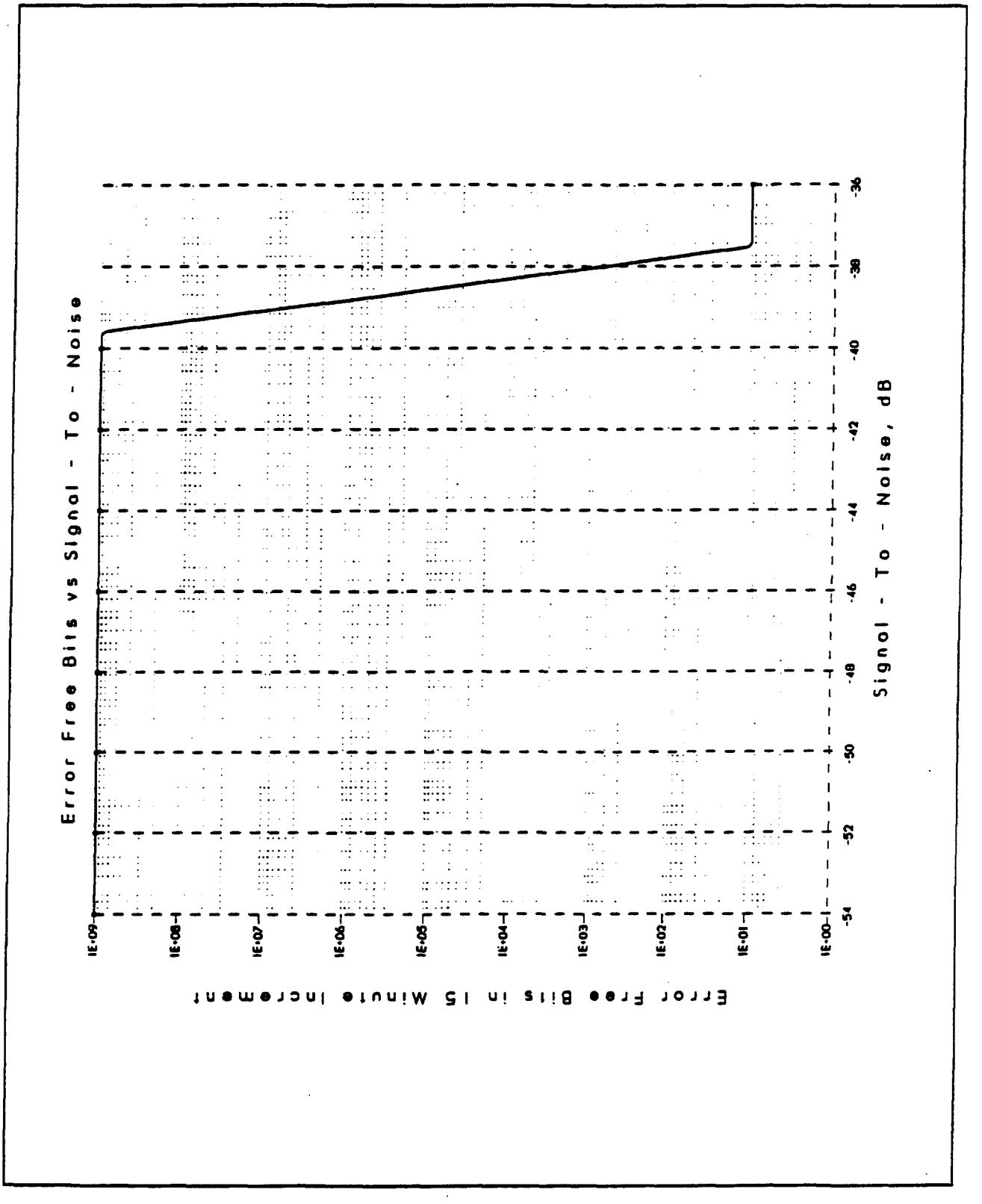

Figure 16
Error Free Bits vs. Signal-to-Noise

3.2.8 Real-Time Delay, Data

The total real-time delay from the time the channel is selected until data has been communicated by the TVT1/4 System will essentially be divided equally between the Encoder and the Decoder. If the data clock is supplied external to the Encoder/Decoder (slave mode) the delay will be dependant upon the clock used for RS-422/449 data, the Forward Error Correction (FEC), and the interleaving of data used, as follows:

<u>Slave Mode</u>

t_{rd} (Encoder) = real time delay
= FIFO delay (t_{FIF})+ FEC delay (t_{FEC}) + Interleaving delay (t_{int})

where:

$t_{FIF} = 2048 * 8 * 1/f_c$

where:

f_c min = 56 Kbps
f_c max = 384 Kbps

therefore:

$1/f_c$ max = 1/56,000 = 17.857 µsec
$1/f_c$ min = 1/384,000 = 2.604 µsec (min)

therefore:

t_{FIF} max = 2048 * 8 * 17.857 µsec
= 292.57 msec

t_{FIF} min = 2048 * 8 * 2.604 µsec
= 42.66 msec

and:

t_{FEC} = 6.71 msec