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ATDRSS 300 MB/S MODEM PROGRAM

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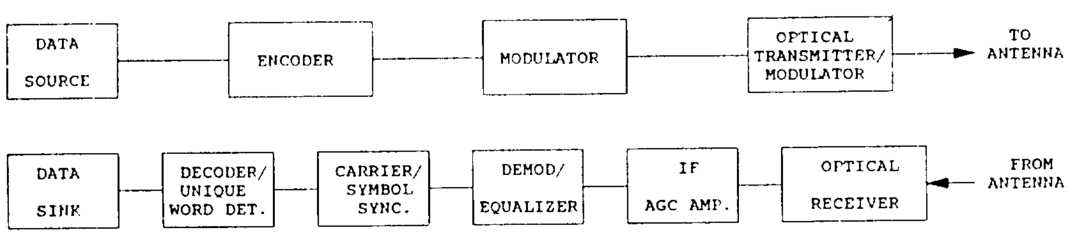
ABSTRACT

The 300 Mbps modem has been developed by Motorola, Government Electronics Group, for direct application to the next generation high data rate TDMA communication system. This Modem utilizes continuous phase modulation combined with a restricted range Reed-Solomon Codec to achieve a bandwidth efficiency of 3 bits/sec/hz. The constant envelope amplitude signal allows one to operate the power amplifier in its saturation mode without significant spectral regrowth or bit error rate degradation.

1.1 INTRODUCTION

The 300 Mbps modem has been developed by Motorola, Government Electronics Group, for direct application to the next generation high data rate TDMA communication system. The 300 Mbps modem functional block diagram is shown in Figure 1.1. NASA envisions using the 300 Mbps modem capability for handling data from the Space Station being transmitted through the TDRSS system. The Space Station will be transmitting either 150 Mbps or 300 Mbps data through TDRSS to the White Sands ground station.



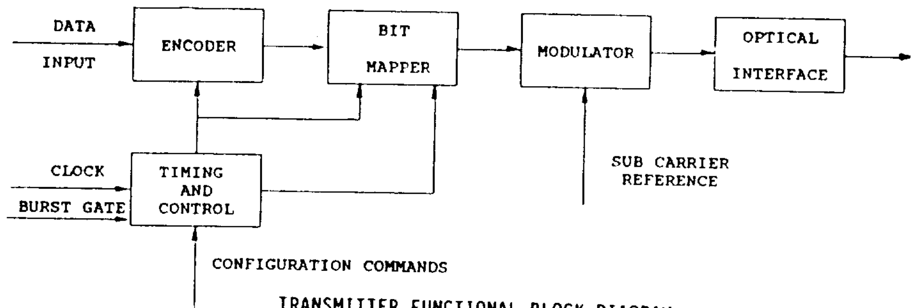
300 Mbps MODEM CONCEPTUAL BLOCK DIAGRAM
Figure 1.1

NASA has the responsibility of relaying this data from the White Sands ground station to Kennedy Space Center, Johnson Space Center and Goddard Space Flight Center for analysis. The 300 Mbps modem will be used to handle this redistribution of data. This system is expected to be deployed in the 1990's.

The 300 Mbps Modem performs all of the necessary functions required to transmit and receive a bandwidth-efficient continuous phase modulated signal. The 300 Mbps Modem consists of a Transmitter, Receiver, Data Source/Error Detector and Channel Simulator. The Data Source/Error Detector and Channel Simulator will be used for test and evaluation purposes only. The modem and STE will be user controlled via an IBM-compatible computer for monitoring and data collection purposes.

2.1 TRANSMITTER

The transmitter subsystem drawer consists of the necessary hardware to generate a bandwidth-efficient CPQPSK/4 modulated signal at an IF frequency of 440 MHz and a required RF bandwidth of 100 MHz. Figure 2.1 shows the functional block diagram of the unit. The transmitter is comprised of the following six functional blocks: Timing Generator, Preamble Generator, System Controller, Encoder, Bit Mapper and Modulator. A description of each of these assemblies is provided in the following sections.



TRANSMITTER FUNCTIONAL BLOCK DIAGRAM
Figure 2.1

2.1.1 Timing Generator
The Timing Generator accepts the Burst Gate control signal and System Clock reference at its input. It generates all the internal control signals and clocks required by all functional blocks of the transmitter.

2.1.2 System Controller
The System Controller is used as the interface between the personal computer and the transmitter. It primarily interfaces with the Encoder and Bit Mapper for fallback transmission selection and down-loading of the Bit Mapper Mapping rule. The System Controller will be a commercially available hardware item.

2.1.3 Encoder
The restricted Reed-Solomon Encoder interlaces a forward error correcting block code into the input PN data stream in such a way that any single phase error in the receiver can be detected. The 5 bit per symbol Reed-Solomon code used has a block length of 130 bits (26 symbols). The restricted encoder effectively encodes the LSB only thereby reducing the hardware complexity required and providing an effective code rate very near one. The data to be encoded is derived from the gray coded phase states by XOR-ing the gray coded bits together to produce a checksum bit. Several checksum bits are used by the encoder to generate parity bits which are added to the data stream.

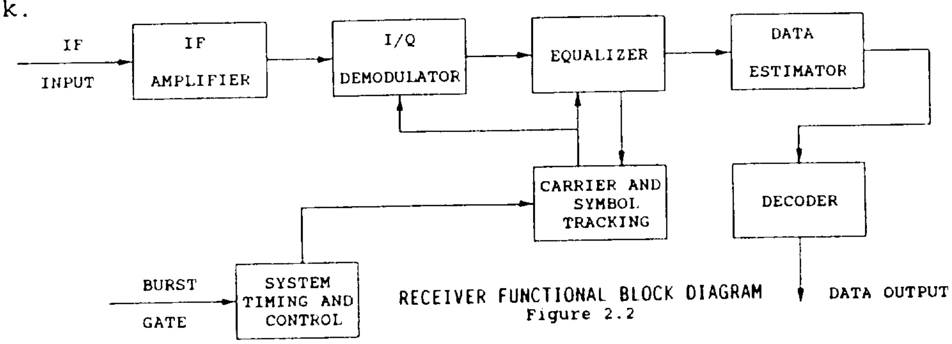
2.2 OPTICAL LINK
The up-link side is to receive a satellite-ready 440 MHz IF signal. It provides the necessary amplification to modulate a laser, and then transmits the modulated lightwave carrier over a 2 km fiber optic cable to the OPTO/IF unit. An optical receiver in the OPTO/IF unit converts the optical signal back to an analog 440 MHz IF signal. Additional amplification will be required to increase the converted signal to a 0 dBm power level for RF transmission.

The down-link side receives a 440 MHz satellite signal and essentially performs the same function as the up-link side.

The ORTEL 3510A optical transmitter and ORTEL 4511A are the major components that comprise the optical link.

2.3 RECEIVER
The receiver subsystem drawer consists of the necessary hardware to amplify, demodulate, equalize, decode and detect a CPQPSK/4 modulated signal. Figure 2.2 shows the functional block diagram of the 300 Mbps Modem receiver. The receiver consists of the

following seven functional blocks: IF Amplifier/AGC, I/Q Demodulator, Decision Feedback Equalizer, Carrier Synchronizer, Symbol Synchronizer, Unique Word Detector and Restricted RS-Decoder. The following paragraphs provide a brief description of each functional block.



RECEIVER FUNCTIONAL BLOCK DIAGRAM
Figure 2.2

2.3.1 <u>IF Amplifier/AGC</u>

The IF Amplifier/AGC accepts the CPQPSK/4 modulated signal at its input. The 440 MHz IF signal is amplified such that the output is maintained at a constant output power. The IF Amplifier/AGC consists of a series of fixed and variable gain amplifiers which maintain a constant output power over a wide range of input power. The gain acquisition characteristics of the AGC circuitry will enable operation in a TDMA environment.

An external control signal will reset the incoming primary AGC loop to its maximum gain prior to each signal burst.

2.3.2 <u>I/Q Demodulator</u>

The Demodulator converts the incoming 440 MHz IF signal from the IF Amplifier/AGC to baseband inphase and quadrature signals. The 440 MHz LO signal is provided by an external fixed crystal reference.

2.3.3 <u>Decision Feedback Equalizer</u>

The equalizer receives a down converted baseband signal from the demodulator. The equalizer shall be 3 taps--1 leading, center, and 1 lagging taps--decision feedback equalizer with preset, manual, and adaptive tap adjustment capability.

The equalizer contains two parts: linear and nonlinear. The linear portion of the DFE is the same as a transversal equalizer. The nonlinear portion of the DFE contains a feedback network as a recursive equalizer. The feedback network of the DFE, however, contains a decision device that makes a hard decision from the output of the DFE. The resulting signal is delayed properly, scaled by the tap weights, and summed at the input junction of the equalizer.

3.1 300 MBPS MODEM OPERATIONS SYSTEM DESCRIPTION

The high data rate modem has been designed to provide for a 3 bits/hz/sec bandwidth efficiency along with various back-off modes to allow for optimizing the bit error rate (BER) and data rate performance for varying channel conditions.

The continuous phase modulation (CPM) format of the modulator provides a near constant envelope amplitude signal with very low side lobes. This constant envelope amplitude signal allows one to operate the down link power amplifier at or near its saturation limit without causing significant BER degradation or spectral side lobe regrowth that is normally observed in phase shift keying schemes like 8PSK. The use of high performance Reed-Solomon Codec optimized for the modulation format allows for efficient signal power utilization with less than 10% coding overhead. Table 2.1 provides the theoretical performance of the modem.

MODEM THEORETICAL PERFORMANCE CHARACTERISTICS
Table 2.1

Data Rate (MB/S)	No of Errors RS CODEC Corrects	Effective Code Rate	Symbol Rate (Mhz)	Modulation Index	Modulator Levels	Spectral Efficiency (Bits/Sec/hertz)	Eb/No for 10^{-6} BER (UNCODED)	Eb/No for 10^{-6} BER (CODED)	Relative Power Required
300	3	12/13	108.3	1/16	8	3	18 dB	13.8 dB	0 dB
200	2	12/13	108.3	1/8	4	2	14.1 dB	10.8 dB	-5.7 dB
100	1	12/13	108.3	1/4	2	1	10.6 dB	9.5 dB	-12.2 dB
250	3	14/15	107.1	1/16	8	2.5	16.5 dB	12 dB	-2.3 dB

3.1.1 Waveform Design and Coding

The range of performance characteristics is very large because of the built in flexibility of the codec/modulator combination. The diagram of Figure 2.1 illustrates the fundamental design approach of the modulator and is helpful in describing the various operating modes of the modem.

Three distinct functions are performed within the transmitter. These functions are:

1. Forward Error Correcting Coding

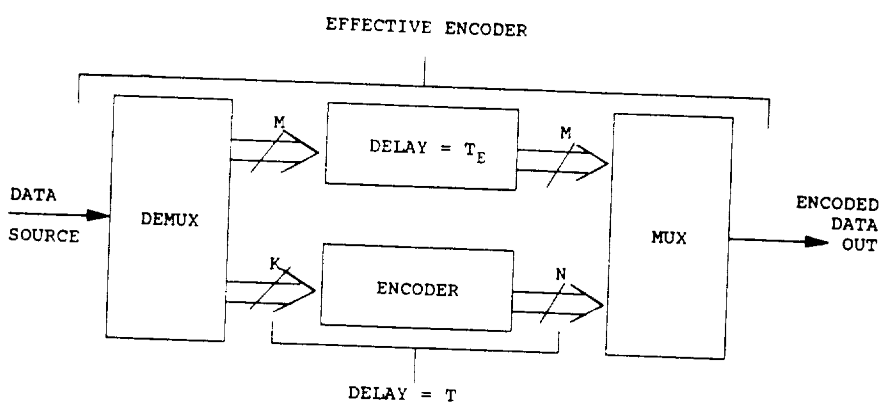
This encoder (illustrated in Figure 3.1) is a Reed-Solomon coder operating at a code rate of approximately 7/8. This coder is capable of correcting 3 bit errors and uses a block length of 32 symbols. Performance optimization is obtained by coding only the least significant data bits in the modulator.

2. Bit Mapper

The bit mapper provides the mapping necessary to convert the encoded data into a format required by the modulator. This bit mapper is the key to the designs flexibility of the modulator and allows one to operate at a variety of modulation indices. (See Figure 3.2 and Table 2.2)

3. CPM Modulator

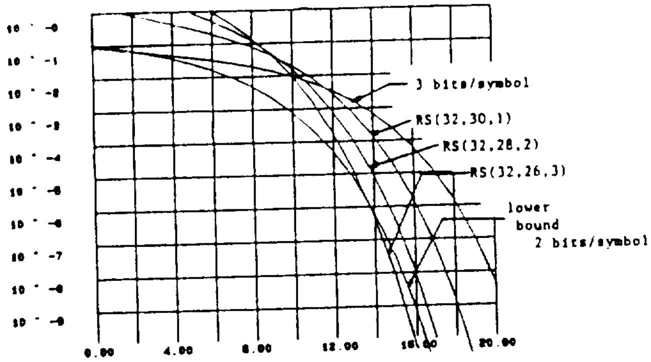
The CPM Modulator is actually an implementation of a four state 22.5° per phase state ($M=4$, $h=1/16$) modulator capable of operating at a rate of 350 mega symbols per second. The phase division and filtering scheme provides for very accurate phase state and phase trajectory control. The high symbol rate requirements are necessary to allow for the necessary phase control of the final output operating at approximately 110 MS/S.

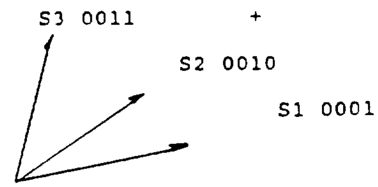


NOTE: ENCODER RATE (K/N) TYPICALLY 3/4, 2/3

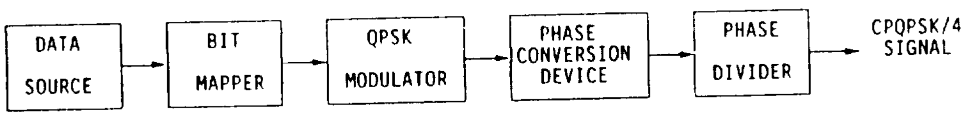
TOTAL EFFECTIVE ENCODER RATE ($\frac{M+K}{M+N}$) TYPICALLY 10/11, 12/13

RESTRICTED RS ENCODER CONCEPTUAL BLOCK DIAGRAM
Figure 3.1



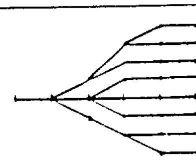


BER PERFORMANCE OF RESTRICTED CODED
3 BITS/SYMBOL SIGNAL
Figure 3.1(a)



BIT MAPPER AND CPQPSK/4 MODULATOR BLOCK DIAGRAM
Figure 3.2

PHASE TREE FOR CPQPSK/4
Table 2.2

input symbol	QPSK equivalent	CPQPSK/4 phase tree	output bit sequence (previous symbol = 2)
6	11 = 135°		1110011111
5	01 = 112.5°		1110010101
4	00 = 90°		1110000000
3	10 = 67.5°		1111101010
2	11 = 45°		1111111111
1	01 = 22.5°		1111010101
0	00 = 0°		1101000000
7	10 = -22.5°		1101001010

3.1.2 Other Operating Modes
Table 2.1 provides an indication of the baseline performance of the modem. The 108.33 MS/S reference was chosen on the basis of the actual channel availability. Operation at symbol rates less than the above values is a practical consideration; however, the optimum bandwidth efficiency will not be achieved and the symbol clock rate of the receiver must be changed accordingly to accommodate this reduced symbol rate operation.

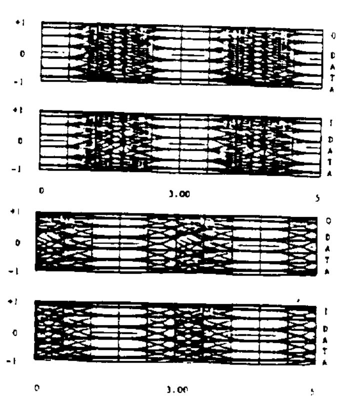
3.2.2 Modulator
The bandwidth efficient continuous phase modulator is realized in hardware using Continuous Phase Quadrature Phase Shift Keyed (CPQPSK) signaling technique, [2] This signaling scheme also allows easy hardware implementation that approximates the ideal CPM signal with little Power Spectral Density (PSD) and Bit Error Rate (BER) probability degradation.

The CPQPSK modulator is derived from a QPSK modulator; however, the discrete phase trajectories of QPSK signal are converted through a phase conversion device to obtain smooth raised cosine phase trajectories and nearly constant envelope amplitude characteristic. CPQPSK signal approximates M=4, h=1/4, RC pulse CPM signals. But, it can be modified by phase dividing and bit mapping, referred to as CPQPSK/4 signaling technique, to obtain a CPM signal with M=8, h=1/16, 3RC pulse shape. The smaller modulation index, h, of 1/16 is obtained by phase dividing the CPQPSK by 4. The modulation level, M, of 8 is obtained from the phase divided CPQPSK signal through the bit mapper.

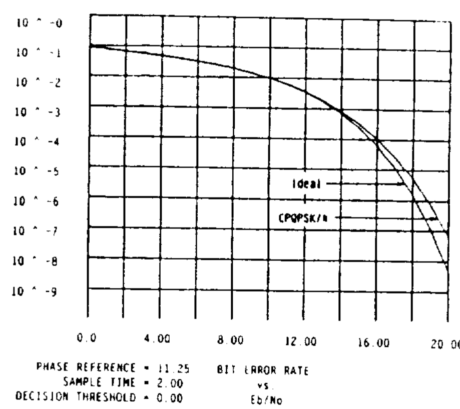
Figure 3.4 shows a block diagram of the CPQPSK/4 modulator. It contains a QPSK modulator, phase conversion device, phase divider, and bit mapper. The bit mapper is responsible for mapping the message data into the phase divided CPQPSK signal constellation in such a way that the correct phase transitions and destination occurs. Thus, with the bit mapper controlling the signal phase paths through the phase divided CPQPSK modulator, M=8, h=1/16, 3RC CPM signal can be obtained.

Figure 3.3, -4, and -5 show eye patterns, BER probabilities, and PSD, respectively, of CPQPSK/4 CPM signal and an ideal M=8, h=1/16, 3RC CPM signal. The eye patterns, Figure 3.3, of CPQPSK/4 show a close approximation to the ideal signal. Figure 3.4 indicates that there is only about 0.7 dB of Eb/No degradation at 10-6 BER probability. There is also a little difference in the power spectral densities between the two signals, as shown in Figure 3.5. The CPQPSK/4 CPM signal generated this way will be referred to as 3 Bits/Symbol (B/S) signal for the rest of this report.
The FCC Bandwidth requirement mask, per reference [3], that specifies frequency attenuation of a signal about an assigned channel bandwidth is also shown in Figure 3.5. The frequency axis is normalized to data bit rate, R, at 300 MBPS. Thus, a channel bandpass bandwidth of (1/3)R indicates a 100 MHz channel and (1/4)R indicates a 125 MHz channel. If a signal transmitting at a data rate of 300 Mbps is transmitted through the 100 MHz and 125 MHz channel while meeting the FCC mask, then it represents 3 b/s/hz and 2.5 b/s/hz, respectively, bandwidth efficiency.

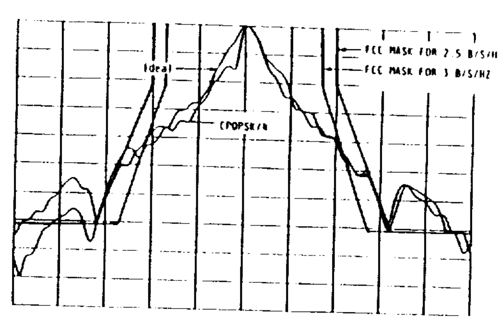
However, Figure 3.5 shows that PSD of 3 B/S signal does not meet the FCC mask for neither the 3 b/s/hz nor the 2.5 b/s/hz bandwidth efficiency. Compliance to the FCC mask is a necessary requirement for the 300 MBPS modem and, thus, the 3 B/S signal requires further processing. This motivates use of a modulator bandlimiting filter in order to meet the FCC mask.



EYE PATTERNS OF CPQPSK/4 AND IDEAL CPM (M=8, h=1/16, 3RC) SIGNAL
Figure 3.3

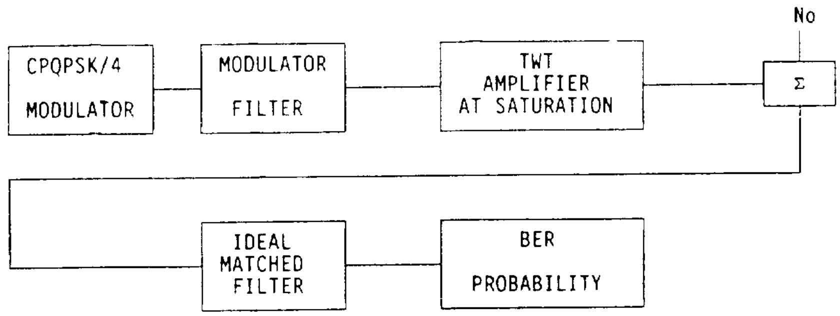


BER PROBABILITY OF CPQPSK/4 AND IDEAL CPM (M=8, h=1/16, 3RC) SIGNAL
Figure 3.4



POWER SPECTRAL DENSITY OF CPQPSK/4 AND IDEAL CPM (M=8, h=1/16, 3RC) SIGNAL
Figure 3.5

The modulator bandlimiting filter can be selected by investigating its effect on the bandlimited 3 B/S signal as it is transmitted through a satellite transponder channel. Figure 3.6 shows a computer simulation set up where the ideal 3 B/S signal is filtered with a modulator filter and operated through a TWT amplifier at saturation. (The nonlinear amplifier is a device often used in a typical satellite channel and performance of the bandlimited 3 B/S signal transmitted through TWT amplifier at saturation must be evaluated.)



COMPUTER SIMULATION SET-UP BLOCK DIAGRAM
Figure 3.6

There are many candidates for selecting the type of modulator filter. Smooth frequency roll-off response filters, such as Butterworth and Chevychev filters, are usually a good choice since they are easily realized in hardware and since the frequency and group delay responses are well characterized. However, in a bandwidth limited channel, a Nyquist filtering is usually chosen in practice. Such ideal filters have sharp frequency attenuation skirts and well equalized group delay responses. They are not easily realized in hardware, however, and subject to careful implementation techniques to approximate the ideal filter responses. Nonetheless, they are readily available through filter vendors and newly emerging filter techniques, such as crystal filters and surface acoustic wave filters, make Nyquist filtering possible.

Therefore, a Nyquist filter with -3dB bandpass bandwidth of (0.35)R, is used in the simulation of modulator bandlimiting filter. The roll-off factor, α, of the filter defines the amount of bandlimiting. With the roll-off factor of the modulator filter varied, one can simulate the effect of the bandlimiting on the 3 B/S CPM signal through the satellite nonlinear channel. The noise is assumed to be White Additive Gaussian Noise (WAGN) and BER probability is measured through the ideal matched filter, which has a noise bandwidth of (0.25)R and does not introduce any intersymbol interference. The resulting PSD bandpass out of band power (OBP) is shown in Figure 3.7. (The MSK signal and FCC mask for 3 and 2.5 b/s/hz channel is also shown as reference.) Figure 3.7 shows that PSD's of the bandlimited 3 B/S signal before the TWT amplifier meet both the 2.5 and 3 b/s/hz bandwidth mask for all roll-off factors of the filter. However, the PSD after the TWT amplifier, operating at saturation, slightly exceeds the masks. The nonlinear device causes spectral regrowth on the signal and , would, nonetheless, require further bandlimiting after the TWT amplifier in order to limit the sideband energy.

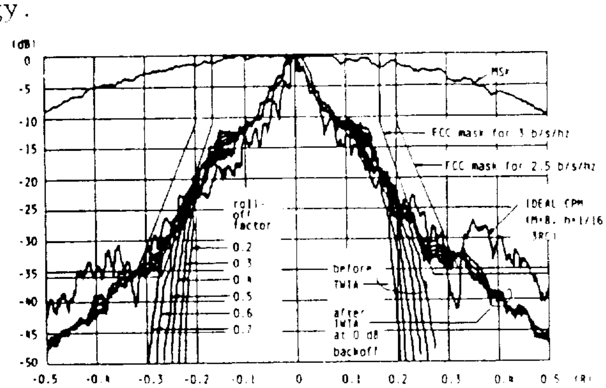
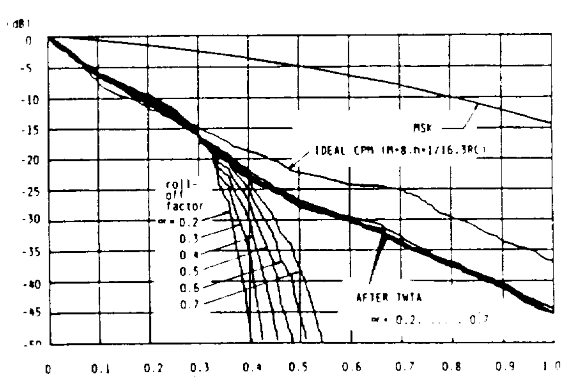


Figure 3.7(a)

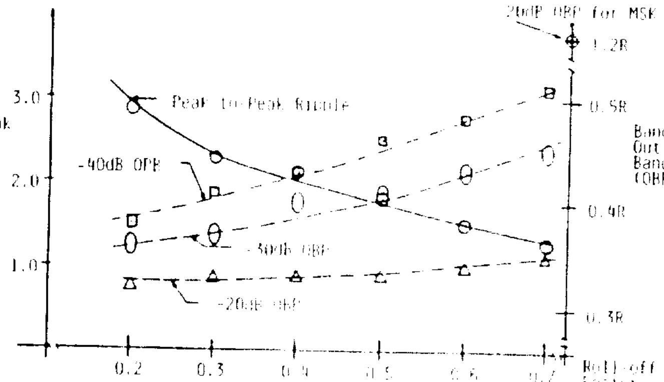


OUTPUT SPECTRAL CHARACTERISTIC

Figure 3.7(b)

The bandpass out of band power (OBP) of the bandlimited 3 B/S signal before and after TWT amplifier, in Figure 3.7, shows that the 3 B/S CPM signal is spectrally much narrower than MSK signal. The OBP after TWT amplifier, although less than that of the ideal CPM signal, is about the same regardless the falloff factors of the modulator bandlimiting filter. However, the effect of the modulator filter is drastic. For example, at frequency of (0.4)R away from (0)R, the OBP is as small as -45dB for a α of 0.2, but it is as large as -24 dB for α of 0.7.

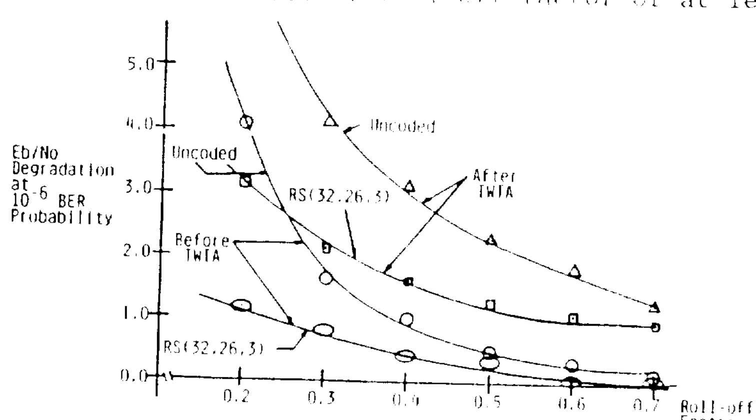
Figure 3.8 shows peak-to-peak ripple, a worse case fluctuation of the power, of the bandlimited 3 B/S signal before TWT amplifier versus roll-off factor of the modulator filter. The bandpass OBP at -20, -30, and -40 dB is also shown. As expected, the ripple on the filtered signal decreases as the amount of bandlimiting decreases. However, the frequency at which the 99%, 99.9%, and 99.99% of the out of band power occur increases as the filter roll-off factor increases. As a reference, -20 dB bandpass OBP for MSK signal occurs at frequency of (1.2)R.



MODULATOR OUTPUT BANDLIMITING FILTER
(NYQUIST @ - 6dB RF_{bw} = 0.35R)

BANDPASS OUT OF BAND POWER (OBP) AND PEAK TO PEAK
RIPPLE BANDLIMITED 3 B/S CPM SIGNAL
(Same filters used as in Figure [illegible])
Figure 3.8

Figure 3.9 shows E_b/N_o degradation of the bandlimited 3 B/S signal at 10^{-6} BER probability versus the roll-off factor of the modulator bandlimiting filter. A restricted Reed-Solomon coder, (discussed in next section), at code rate of 0.92 is used to assess the amount of BER improved against the uncoded BER performance. The performance degradation due to TWT amplifier operating at saturation is also shown. The graph shows that the degradation decrease as the amount of modulator bandlimiting decreases. However, the degradation due to the saturated TWT amplifier is at least 2 dB for the coded case and for the filter roll-off factor of at least 0.3.



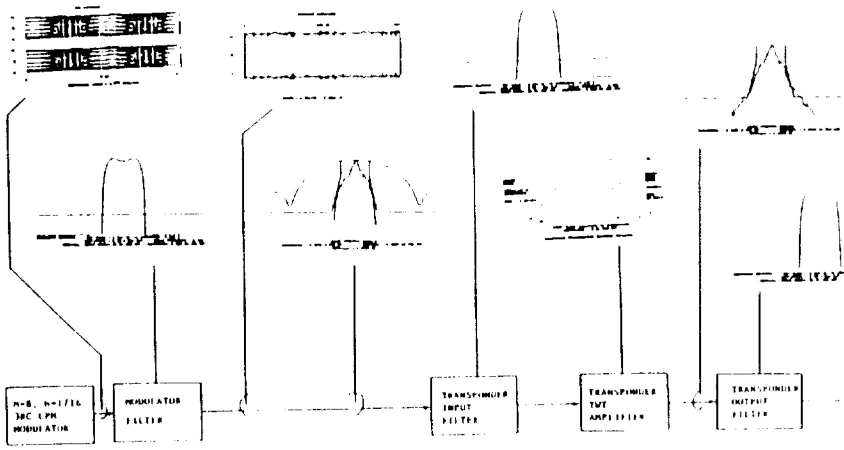
MODULATOR OUTPUT BANDLIMITING FILTER
(Nyquist @ -6dB RF_{bw} = 0.35R)

Eb/No required for 10^{-6} BER, uncoded : 18.2dB
RS(32.26.3) : 13.5dB

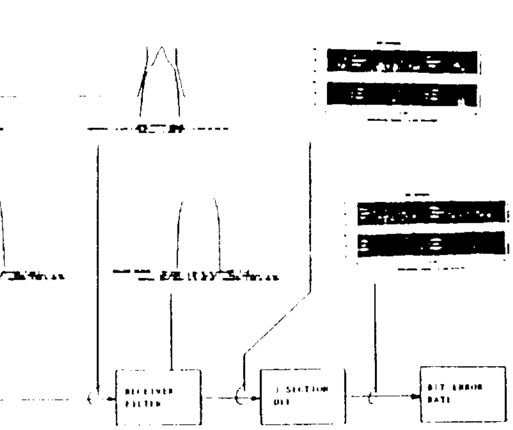
PERFORMANCE DEGRADATION OF BANDLIMITED 3 B/S CPM
SIGNAL BEFORE AND AFTER TWTA AMPLIFIER AT SATURATION
(Restricted RS (32,26,3) coder used)
Figure 3.9

Therefore, the modulator bandlimiting filter degrades BER performance of 3 B/S signal as it is transmitted through TWT amplifier at saturation. The performance degradation can be improved by using error correction coding technique. The performance of 3 B/S signal can also be improved if the TWT amplifier is operated in its linear region. However, as satellites have limited power source, operating TWT amplifier linearly reduces the output power from the satellite drastically. This requires additional Eb/No at the receiver such that the BER performance gained by operating TWT amplifier linearly not enough to justify the linear operation of the amplifier.

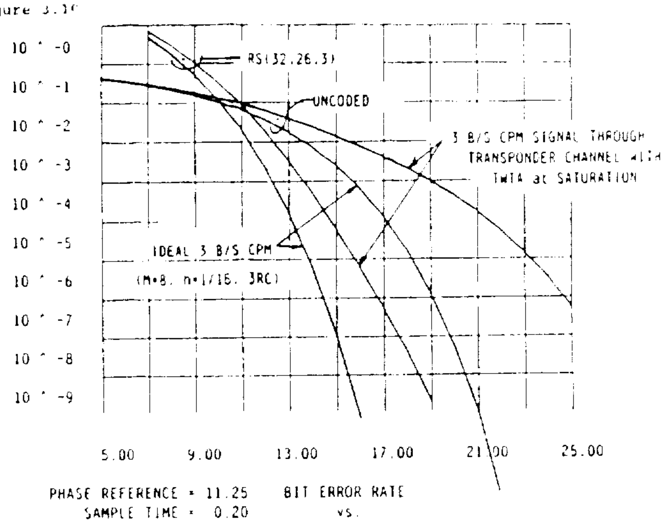
Figure 3.10 and 3.11 show the time and frequency domain plots of the simulation. The BER probability is also evaluated for coded case and Eb/No degradation of about 2 dB is expected from the satellite channel distortion, as shown in Figure 3.12.



TIME AND FREQUENCY PLOTS OF MODULATOR AND TRANSPONDER
Figure 3.10



TIME AND FREQUENCY PLOTS OF RECEIVER
Figure 3.11

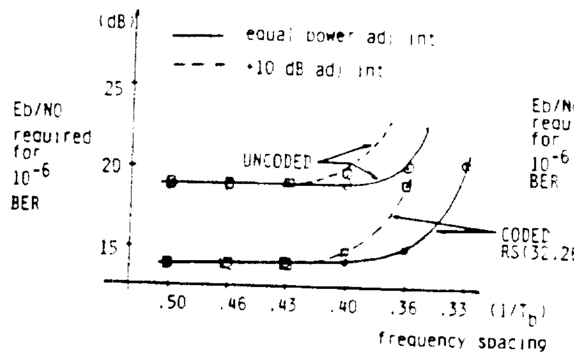


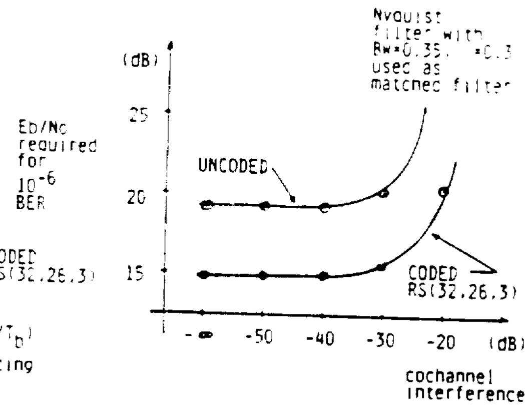
BER PERFORMANCE OF 3 B/S SIGNAL THROUGH CHANNEL DESCRIBED IN FIGURE 3.10 AND 3.11
Figure 3.12

Thus, utilization of TWT amplifier operating at its saturation is possible when using the hardware realizable 3 B/S CPM signal with some modulator bandlimiting. In fact, 3 bits/sec/hz bandwidth efficiency, defined as transmitting 300 Mbps data through a 100 MHz bandwidth channel while meeting FCC mask is achievable with M=8, h=1/16, 3RC CPM signal only if the modulator bandlimiting filter and the transponder output mux filter is used. However, the modulator bandlimiting filter introduces envelope amplitude on the signal, which, inevitably, degrades the BER performance when operated through the nonlinear device at saturation.

Furthermore, the performance of the 3 B/S signal not only depended on the bandwidth requirement of the modulator bandlimiting filter, the FCC mask, and degradation due to TWT amplifier and the transponder filters, but also it depends on the amount of adjacent channel interference allowed. The signal's power spectral density could meet the FCC mask, have small envelope amplitude, and still, cause severe BER degradation when the adjacent channels are placed together closely, i.e. by symbol rate.

The BER performance is measured for various adjacent channel spacing. The result is shown in Figure 3.13. It shows the coded and uncoded Eb/No degradation of 3 B/S CPM signal at 10^{-6} BER probability for equal and unequal power adjacent channel interference. The frequency spacing is also normalized to data rate, R, at 300 Mbps. The frequency spacing of the adjacent channel interference, however, is about 0.36R for the coded case for Eb/No degradation of less than 0.5 dB.





DEGRADATION DUE TO ADJACENT AND COCHANNEL INTERFERENCE

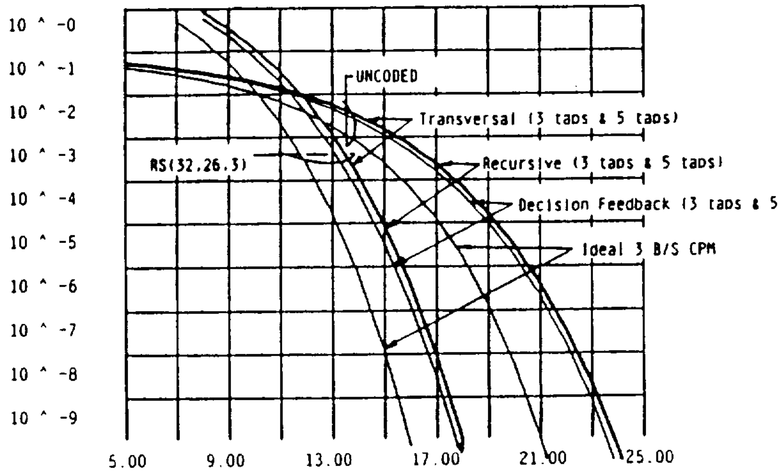
Figure 3.13(a)
Performance of 3 B/S Signal for Adjacent Channel Interference

Figure 3.13(b)
Performance of 3 B/S Signal for Cochannel Interference

Another channel impairment that degrades the BER performance is cochannel interference. Such interference, when large enough, causes a severe BER degradation as Figure 3.13(b) shows. For both the coded and uncoded case, cochannel interference of about 30 dB degrades the system performance by about 0.5 dB at coded BER of 10^{-6}. However, the BER degradation exponentially increases as the amount of the cochannel interference increases.

Another performance improving device to combat the intersymbol interferences is the equalizer. The equalization techniques are based on linear theory and often successful in correcting for multipath distortions as well as the ISI distortions. Typically, equalizers are used together with a receiver filter to not only correct for channel ISI and multipath distortions, but also it is used for desensitization of the critical receiver filter responses.

Transversal, recursive, and decision feedback equalizers are considered for performance improvement on the bandlimited 3 B/S signal. The channel is selected to be linear and the Nyquist filter with α of 0.3 is selected as the receiver filter. The BER performance of both 3 section and 5 section equalizers are shown in Figure 3.14. It can be seen that the 3 section equalizers are adequate and offer nearly the same performance as the 5 section equalizers. The decision feedback equalizer performs slightly better, by about 0.3 dB, than transversal or recursive equalizer. The coded performance is also shown.



BIT ERROR RATE
vs.
Eb/No

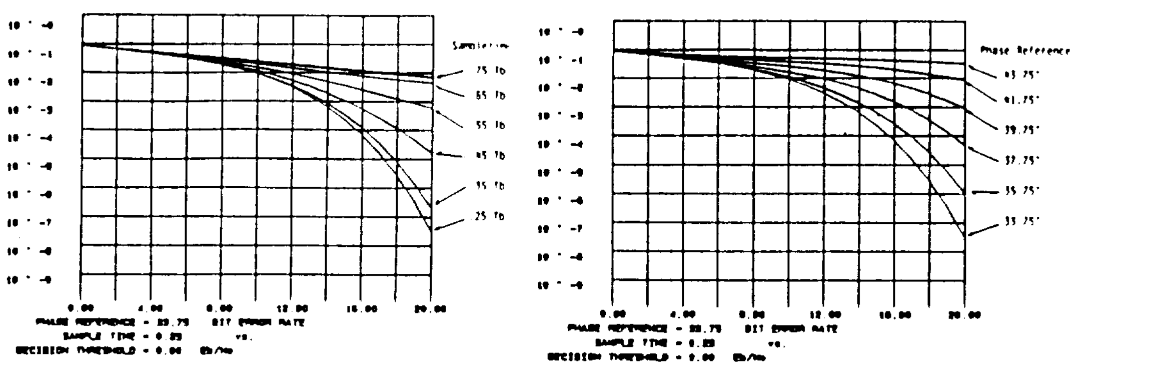
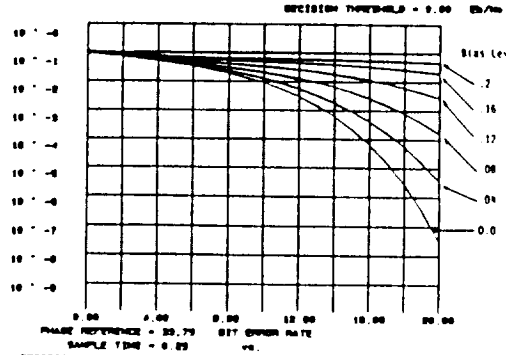
BER PERFORMANCE OF EQUALIZED 3 B/S SIGNAL FOR
TRANSVERSAL, RECURSIVE AND DECISION FEEDBACK EQUALIZER
Figure 3.14

4.1 HARDWARE IMPAIRMENTS

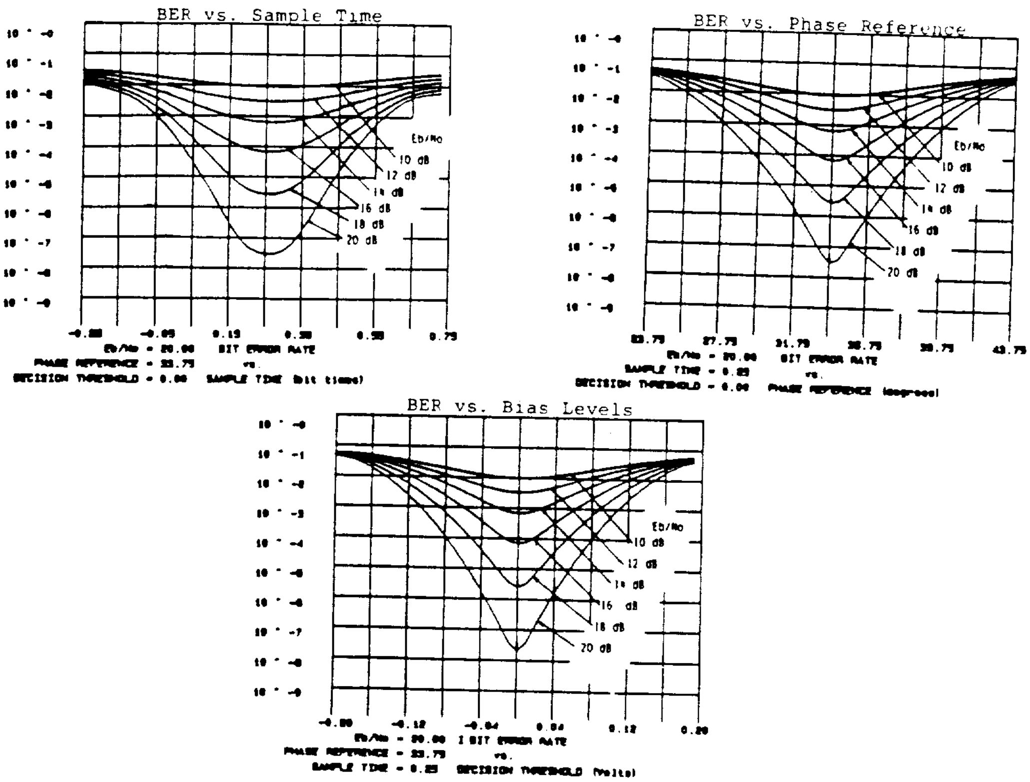
A variety of factors contribute to the overall hardware performance as compared to the theoretical bound presented earlier. Realistic estimates of the hardware performance impairments have been made and presented in this section. These estimates are based on computer simulation, hardware measurements and observed performance characteristics of related equipment.

Figure 4.1 and Figure 4.2 show uncoded BER probability of 3 bits/symbol signal versus Eb/No. Receiver hardware impairment such as phase reference, sample time and bias level errors contribute to overall BER performance. 2° variation in the carrier phase reference, for example, can cause as much as 1.5 dB of degradation at uncoded 10_{-6} BER.

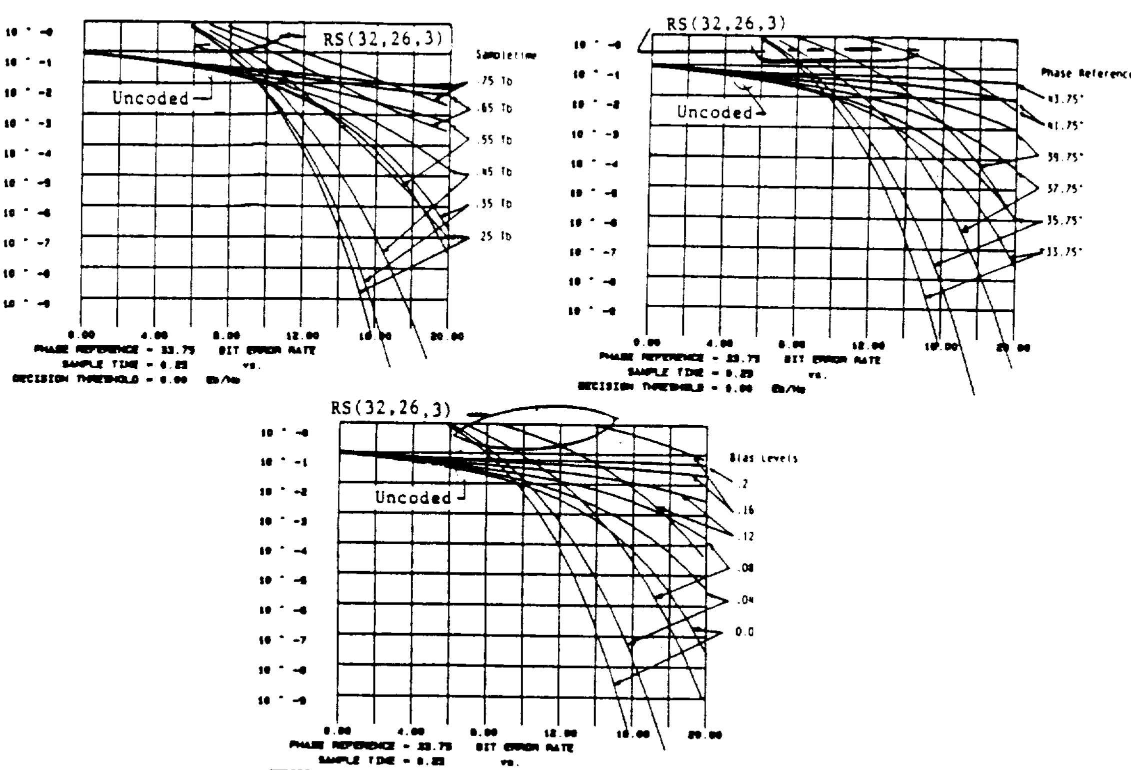
The BER probability degradation can be reduced by the use of error correcting hardware, as Figure 4.3 shows. It indicates that BER probability improvement can be seen as RS (32,30,1) CODEC is used.

UNCODED BER PROBABILITY vs. Eb/No
FOR 3 B/S SIGNAL
Figure 4.1



UNCODED BER PROBABILITY vs. SAMPLE,
PHASE AND BIAS ERRORS FOR 3 B/S SIGNAL
Figure 4.2



RS(32,26,1) CODED BER PROBABILITY
vs. Eb/No FOR 3 B/S SIGNAL
Figure 4.3

Table 4.1 provides the hardware impairment assessment for both the 2.5 bits/sec/hz and the 3 bits/sec/hz systems. The important bottom line on the performance assessment is that for coded 10-6 BER probability an Eb/No of 18.55 dB will be required for 2.5 bits/sec/hz system and 21.65 dB for the 3 bits/sec/hz system.

HARDWARE IMPAIRMENT SUMMARY @ 10^{-6} BER
Table 4.1

PARAMETER	VALUE (comments)	DEGRADATION (dB)	
		2.5 B/s/hz	3 B/s/hz
MODULATOR PHASE ERROR	1°	.3	.3
CARRIER TRACK PHASE ERROR	2°	.75	.75
SYMBOL TIMING ERROR	(0.1)Tb	.2	.2
MATCHED FILTER MISMATCH		.4	.6
QUANTIZATION BIAS ERROR	5 BIT PHASE A/D (1%)	.3	.4
LIMITING IN IF	NON-IDEAL AGC & LIMITER	.1	.1
CHANNEL FILTER	UNEQUALIZED ISI	1.5	1.8
ADJACENT CHANNEL INT.	EQUAL AMPLITUDE, SEPARATED BY Rs	.5	2.0
CHANNEL NONLINEARITY	TWTA AT SATURATION	.5	.5
NET DEGRADATION		4.55	6.65
THEORETICAL Eb/No REQUIRED FOR 10^{-6} BER		17.0	18.0
RESTRICTED CODEC GAIN		-3	-3
TOTAL Eb/No REQUIRED FOR 10^{-6} BER		18.55	21.65

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