DSN Telemetry System Performance With Convolutionally Coded Data Using Operational Maximum-Likelihood Convolutional Decoders

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This article describes the DSN telemetry system performance with convolutionally coded data using the operational maximum-likelihood convolutional decoder (MCD) being implemented in the Network. The report covers data rates from 80 bps to 115.2 kbps and both S- and X-band receivers. The results of both one- and two-way radio losses are included.

I. Introduction

DSN telemetry system performance with convolutionally coded data at low data rates was presented in Ref. 1. In that article, real-time telemetry data obtained from the Compatibility Test Area (CTA 21) were processed by a simulated Viterbi decoding computer program to measure the system performance. The results covered the data rates ranging from 8 to 2048 bps, which will be useful in the design of telecommunication links for future spacecraft such as the Mariner Jupiter-Saturn (MJS), to be launched in 1977. Since such spacecraft will also employ higher data rates, the work described in this article covering data rates from 80 bps to 115.2 kbps was undertaken.

The article has a threefold purpose. The first is to give overall MCD acceptance test data received from the manufacturer. The second and third are to describe the test purposes, test setups, and test results from CTA 21 and from the Telecommunication Development Laboratory (TDL). The tests concentrate mainly on the Block IV receiver, high-data-rate, X-band carrier frequency with some S-band results to allow S- and X-band performance comparison. The effects of using different receiver bandwidths and subcarrier demodulator assembly (SDA) bandwidths are also investigated.

All 32 MCD production units were acceptance-tested, and their required performance was verified at the highest data rate, 250 kbps, before delivery. They were also checked with the telemetry processing assembly (TPA) for proper interface prior to installation.

Since the actual operational software for the TPA was not ready when this project was underway, a special real-time computer program, called MCD Performance Evaluation Program (MCDPEP), was written in assembly language for collecting decoded data and formatting them into an appropriate compressed form on disc. The MCD status and symbol error information from the symbol synchronizer assembly (SSA) was also recorded. The recorded data were then processed by an off-line MCD Data Analysis Program (MDAP), also written in assembly language, to provide bit error rate (BER), symbol error rate (SER), burst error statistics, and MCD normalization rate (NR). The burst error statistics are expressed in terms of error-free runs (EFR) and burst length sample distributions.

The two-way radio losses of the DSN telemetry system were also examined for various values of carrier loop signal-to-noise ratio margin. These latter test results were obtained at TDL.

At present, only certain tests at data rates 44.8, 67.2 and 115.2 kbps are available from CTA 21. However, the test results from TDL cover a larger data range from 80 bps to 115.2 kbps. Additional tests will be accomplished in CTA 21 and in Spain, at DSS 62, by DSN Madrid Engineering. This will allow station-to-station comparison.

II. MCD Acceptance Test Data

Before delivery, each production MCD was verified to satisfy the functional requirements. The telemetry test data used were assumed corrupted by additive white Gaussian noise, and the tests performed at the highest allowable data rate, 250 kbps.

The acceptance tests consisted in part of BER performance, MCD symbol synchronization recovery interval, and channel error rate performance. These were accomplished for both code rates ½ and ⅓. Table 1 summarizes an average performance in terms of bit signal-to-noise ratio (ST_B/N_0), BER, and channel error rate. The table includes the corresponding standard deviation figures which are noticeably small. The functional requirements, lower and upper bounds, are also given in Table 1.

The verification of MCD symbol resynchronization recovery interval was done at ST_B/N_0 = 3 dB. For each MCD, ten observations were made for each code rate. This gives rise to 320 observations in all. The histogram plots of both code rates are depicted in Fig. 1. The figure indicates that the MCD time in symbols to resynchronization remains well below the functional requirements, i.e., 2000 symbols for rate ½ and 3000 symbols for rate ⅓.[1] The corresponding cumulative distribution plots of Fig. 1 are given in Fig. 2.

III. Performance Tests at CTA 21

The purpose of the test investigation at CTA 21 is to obtain telemetry system performance for medium to high data rates under the Mark III-1977 DSN telemetry system configuration. Emphasis is placed on the X-band Block IV receiver with corresponding results for the S-band, Block III receiver. Effects of receiver and SDA bandwidth are also examined. Another objective is to determine an optimum modulation index for each data rate.

The equipment used is a typical telemetry string (receiver, SDA, SSA, MCD, and TPA), along with symbols provided by the SCA via a radio frequency link. The SCA provides a cyclical repetitive 2047-bit pseudo random noise (PN) sequence encoded by a 7:½ (or ⅓) convolutional encoder (with alternate symbols inverted) at the desired symbol rate and modulation index value. The MCD receives the noisy quantized (5-bit parallel) symbols from the SSA, performs its decoding function, and outputs decoded data to the TPA. The SSA, after proper initialization from the TPA via commands transmitted by the 920 emulator, periodically (once every 10^6 symbols) outputs symbol error count (SEC) to the TPA via the SSA/TPA coupler. Thus, MCD decoding performance is obtained from output SSA SER and output MCD BER.

The MCDPEP (resident in the TPA) stores and evaluates all MCD output data in real-time. Data are received in 8-bit bytes and sequentially stored in two alternate memory blocks (200 16-bit words/block), using the external direct memory processor (DMP) in the data chaining mode. Data are processed from one block while the other block is being accumulated. Data processing starts by searching the stored data to find frame synchronization within the known 2047-bit PN sequence, consisting of 11 consecutive 1's. Normal data, and inverted data if necessary, are searched. After finding frame sync, every stored data bit is compared with the corresponding known

[1]This assumes a nominal bit transition density (1/40 - 1/2 at 3 dB and greater). For low bit transition densities, the result may not be valid; see Ref. 2.

PN bit, being done 8 bits (one byte) at a time. Every byte containing one or more erroneous bits is stored in an output error list (OEL), and periodically transferred from core to disc in 50-word blocks, 32 bits/word.

The exclusive-OR byte pattern is stored, with 1's indicating error bits and 0's indicating correct bits. The corresponding good byte count (GBC) is also stored in the same entry, providing the number of consecutive correct bytes since the last previous error byte.

The 32-bit word format used for each OEL entry is shown below.

GBC (16 bits)	XOR (8 bits)	NR (7 bits)	1 bit
Good Byte Count	Byte Error Pattern	MCD Average NR	MCD Sync Change

An entry is made in the OEL whenever one of the following events occurs:

(1) GBC Full Count. An entry is made any time this counter reaches full-scale value, which is 8×2^{16} or 524,288 consecutive correct bits.

(2) MCD BER. Once every DMP block (or 3200 bits) the MCD is commanded to output its 4-bit NR word. This number is derived from the MCD internal normalization rate. It is related to the input SER and consequently the output BER. These NR outputs are stored and averaged (over 31 outputs), and the average value is entered in the OEL in the 7 bits provided (4-bit whole number plus 3-bit fractional number) once every 99,200 data bits. For these NR entries, the GBC value is shown as 0, although the actual value is retained and continues to be accumulated.

(3) MCD Node Sync Change. When a node sync change occurs, the MCD outputs its own status and an entry is made in the OEL, with the least significant bit equal to 1. If the MCD had previously achieved symbol sync, and then a sync change occurs; this means that the MCD output data are temporarily not valid and the program reverts to its frame sync search mode. When frame sync is again found, this implies that the MCD has regained symbol sync and the output data are again valid.

The MCD generates a node sync change when its input symbols are uncorrelated. To resync, the MCD attempts to find an acceptable level of symbol correlation by regrouping the incoming symbols.

The OEL continues to accumulate and is stored on disc for the test duration, nominally 10^7 bits. At the same time, another list is output on the Terminet printer containing every other average NR value, or once every 198,400 bits. When this list has reached the desired length, the test is manually terminated by actuating a switch on the TPA console, after which the stored SEC list is printed on the Terminet, with one entry every 10^6 symbols (or any other power-of-ten number of symbols available).

MDAP is an off-line program for use to complete the MCD data analysis phase. The program converts the OEL entries produced and recorded on disc by MCDPEP into a sequence of EFR's, classifies them, and generates their sample distributions. It also generates average BER and average NR at every 99,200 decoded bits. At the end of each run, the following are printed:

Total number of decoded bits

Total number of bit errors

Average bit error rate

Total number of EFRs

Total number of bit bursts

Total number of normalization rates

Average bit errors per burst

Average burst length in bits

EFR sample distribution

Number of distinct EFRs

Burst length sample distribution

Number of distinct burst lengths

Symbol error rate

When a sync change bit is detected, MDAP outputs the entire data statistics, reinitializes program parameters, and restarts to process the remaining data again.

Figure 3 gives an overall view of the test configuration. (A more detailed configuration is given in Fig. 7 which will be discussed later). The ST_B/N_0 used in describing the system performance is obtained from the average SER accumulated for each run via an uncoded performance curve. The MCD error rate calibration curve (MCD input ST_B/N_0 in dB vs MCD normalization rate indication) for each rate is also obtained from the program printout, as shown in Fig. 4.

A. Optimization of Modulation Index

The signal energy per bit (which determines the bit error probability of a telemetry channel) of any modulation system is related to the total received power P_T as follows:

$$\frac{ST_B}{N_0} = \frac{P_T}{N_0}\frac{P_D}{P_T} T_B \, \eta_{WDL} \, \eta_S \tag{1}$$

where

P_D = sideband power available for data

N_0 = single-sided noise spectral density, W/Hz

T_B = bit time in seconds

η_{WDL} = subcarrier waveform distortion loss

η_S = system efficiency

= $\eta_{RL} + \eta_{SDL} + \eta_{BSDL}$, dB, where

η_{RL} = radio loss, dB

η_{SDL} = subcarrier demodulation loss, dB

η_{BSDL} = bit sync and detection loss, dB

One way to optimize the performance of the telemetry system is to maximize the data rate. To achieve this, the values of P_T/N_0 and ST_B/N_0 must be specified. Then the parameters P_D/P_T and η_S are adjusted to obtain the maximum data rate. Another way is to specify the values of the data rate, ST_B/N_0, and adjust the parameters P_D/P_T and η_S to minimize the required P_T/N_0.

The easiest parameter to adjust in the telemetry system is the modulation index. This parameter determines the allocation of power in the various sidebands and strongly affects the magnitude of the system losses.

For a single channel, a square-wave subcarrier, P_D/P_T, is $\sin^2\theta$, where θ denotes the system modulation index. Since η_{WDL} is usually small ($\eta_{WDL} \simeq 0$ dB), Eq. (1) may be rewritten as

$$\frac{ST_B}{N_0} = \frac{P_T}{N_0}\frac{\eta_S}{BPS}\sin^2\theta, \; BPS = 1/T_B \tag{2}$$

If the values of P_T/N_0, η_S, and BPS are known, the plot of ST_B/N_0 vs θ can be obtained from Eq. (2). Such plots for various values of P_T/N_0 from 51.45 to 54.58 dB are given in Fig. 5. They are for 10- and 30-Hz Block IV receiver and wide bandwidth Block III SDA. From these curves, one can determine the optimum modulation index for each P_T/N_0. To derive this value algebraically, one first expresses Eq. (2) as

$$BPS = \frac{\frac{P_T}{N_0}\,\eta_S}{\frac{ST_B}{N_0}}\sin^2\theta$$

The maximum data rate, BPS_{max}, can now be computed by setting the derivative of BPS with respect to θ equal to zero, yielding

$$\theta_{opt} = \tan^{-1}\left\{\frac{-2\eta_S}{\frac{d\eta_S}{d\theta}}\right\}_{\theta = \theta_{opt}}$$

This indicates that the optimum modulation index for a single-channel system is totally dependent on the proper characterization of the system losses.

B. Test Strategies and Preliminary Results

The end product of the project is to obtain DSN telemetry system performance using convolutionally coded data in terms of bit error probability *(BER)* vs ST_B/N_0 and the corresponding burst characteristics. Toward this end, we first proceed to determine the optimum modulation index. This is to be used to corroborate the theoretical value of the true optimum modulation index. Once this parameter is determined, the telemetry system performance for it is then obtained.

The results obtained so far have been for data rates 44.8, 67.2, 96.8, and 115.2 kbps. Figure 6 describes the telemetry system performance at data rate 67.2 kbps. The test conditions are given in Table 2. The true optimum modulation index for this rate appears in Fig. 6(a) to be about 80 deg, which is in agreement with the theoretical value. The curves *BER* vs ST_B/N_0 corresponding to modulation indices 79 and 80 deg are given in Fig. 6(b). The sample distribution plots of the burst lengths are given in Fig. 6(c)–(f). The average burst length vs modulation index and the average burst error vs modulation index are given in Fig. 6(g). The average burst length and average burst error vs ST_B/N_0 are given in Fig. 6(h). And finally, the MCD error rate calibration for this data is depicted in Fig. 4.

IV. Performance Tests at TDL

One purpose of the tests conducted at TDL is to measure system two-way radio losses using an operational MCD over various data rates for both S- and X-band receiver. Another purpose is to obtain telemetry system performance in terms of BER vs ST_B/N_0.

Equipment used for the tests includes the Block III exciter, Mariner Venus/Mercury transponder, X-band transmitter, Block III receiver (S-band), Block IV receiver (S- and X-band), Block III SDA, Block III SSA, and a production model MCD. Test data patterns include 31-bit, 127-bit, and 2047-bit PN codes. The detailed test equipment setup is shown in Fig. 7.

Figure 8 describes system two-way radio loss curves derived from measurements taken in TDL during January 1976, for code rate 7:½, 3 bit quantization. The figure provides BER vs ST_B/N_0 for various values of the uplink margin, $M_C = P_C/N_0\ 2B_{LO}$, where P_C is the carrier power and B_{LO} is the single-sided design point phase-lock-loop bandwidth. This parameter is selectable for each test from the dial at the receiver panel. Here the theoretically optimum downlink modulation indices, discussed in Section III, were used for all tests. This means that the ground receiver loop SNR was not held constant but was allowed to vary with signal level as it will be in an operational situation. These results are not exactly the same as will be obtained with the MJS'77 transponder, due to differences in receiver loop parameters, but are close enough to provide a basis for prediction of the MJS'77 losses.

The most obvious conclusion to be drawn from the data is that the X-band two-way radio losses are so great that they will impose operational limitations on the MJS'77 mission. In order to limit the loss to about 1 dB, the uplink carrier margin must be 35 dB or greater. This is equivalent to an uplink carrier power of -120 dBm, which is just about what can be achieved at Saturn, range = 10 AU, with a 100-kW, 64-m DSS. Operation at greater distances or with a 26-m DSS will require noncoherent operation of the X-band downlink.

The operational thresholds are also shown in Fig. 8. Further, the X-band telemetry threshold as a function of uplink margin is described in Fig. 9.

The difference between the X-band and S-band performance is believed due entirely to the greater turnaround phase jitter on the X-band signal due to the VCO phase noise being multiplied by a greater ratio (11/3 times). The magnitude of the problem can be reduced by increasing the frequency of the uplink signal (thus reducing the multiplication ratio) or by using a feed-forward technique for removing most of the phase jitter from the downlink. Using a feed-forward system has been demonstrated in the laboratory and resulted in almost no two-way degradation at uplink margins as low as 5 dB.

It is strongly recommended that both of the above solutions be investigated. It is probably too late to do anything about MJS, but the standard transponder should certainly include the feed-forward features.

The TDL MCD error rate calibration curve was previously given in Fig. 4. The telemetry performance curves in terms of BER vs ST_B/N_0 for rates 7.2 and 115.2 kbps are given in Fig. 10. The performance of code rates 1/2 and 1/3 at data rates 115.2 and 76.8 kbps, respectively, is given in Fig. 11. For BER's of 10^{-3} to 10^{-4}, the rate 1/3 code is 0.3 dB better. For a BER of 10^{-5}, the improvement is 0.25 dB.

V. Telemetry Performance for Radio Frequency Subsystem

Telemetry performance for the Radio Frequency Subsystem (RFS) using both the TDL telemetry simulator and the Mark III Data System (MDS) as sources is listed in Table 3 and plotted in Fig. 12. Telemetry performance is similar to that obtained previously during developmental tests and no anomalies were found.

The high rate (115.2 kbps) two-way telemetry loss at X-band was found to be slightly worse than that measured on the MVM'73 RFS. This was expected since the MJS'77 RFS has a wider bandwidth. The measured losses for both transponders are shown in Fig. 13. The effective telemetry loss at a threshold BER of (5.0×10^{-3}) as a function of uplink carrier margin is shown in Fig. 14. This shows that an uplink carrier margin must be at least 35 dB whenever high-rate X-band telemetry is being transmitted in the two-way coherent mode. With the present DSN capability, this characteristic precludes use of the two-way coherent mode with high-rate telemetry for ranges greater than 10.0 AU for a 100-kW, 64-m station or 2.0 AU for a 20-kW, 26-m station.

References

1. Benjauthrit, B., "Final Report on DSN Telemetry System Performance with Convolutionally Coded Data: Maximum Likelihood Decoding," in *The Deep Space Network Progress Report 42-33*, pp. 112–122, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1976.

2. Burow, N. A., "Acquisition of Node Synchronization by a Viterbi Decoder," Interoffice Memorandum 3397-76-15, September 8, 1976. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 8, 1976 (an internal document).

Table 1. JPL MCD acceptance test data (averaged over 32 units)

Code rate		ST_B/N_0	No. bits	Bit error rate		Upper bound	Channel mean	Error rate std. dev.	Lower bound	Upper bound
				Mean	Std. dev.					
MCD-TPA	1/2	3.0	4.096×10^6	7.41×10^{-4}	1.82×10^{-6}	9.0×10^{-4}	11.5	0.51	10	13
		4.0	4.096×10^7	3.95×10^{-5}	6.24×10^{-8}	6.0×10^{-5}	7.9	0.62	7	9
		5.0	6.553×10^7	1.36×10^{-5}	7.95×10^{-9}	2.5×10^{-6}	5.0	0.33	4	6
	1/3	3.0	4.096×10^6	2.90×10^{-4}	2.47×10^{-5}	3.6×10^{-4}	11.1	0.45	10	12
		3.5	4.096×10^7	6.92×10^{-5}	2.77×10^{-6}	1.0×10^{-4}	9.7	0.44	9	11
		4.5	4.096×10^6	2.83×10^{-6}	5.11×10^{-7}	7.0×10^{-6}	7.1	0.24	6	8
MCD-DDA	1/3	3.0	4.096×10^6	2.88×10^{-4}	2.41×10^{-5}	3.6×10^{-4}	–	–	–	–

Table 2. Test conditions and results for 67.2-kbps, Block IV receiver, S-band

Test ID	Total bits ($\times 10^7$)	Mod index, deg	RVC IV BW, Hz	SDA III BW, Hz	AVE BER	AVE SER, %	MCD input ST_B/N_0, dB	AVE MCD NR
DA1	1.51	77	30	Medium	1.24×10^{-4}	5.97	3.85	7.75
2	1.42	78			1.48×10^{-4}	6.07	3.80	8.00
3	1.21	80			1.12×10^{-4}	5.60	4.03	7.75
4	1.38	79			1.25×10^{-4}	6.05	4.81	8.13
5	1.81	79			1.55×10^{-4}	5.96	3.85	7.88
6	1.41	79			8.00×10^{-5}	5.96	3.85	7.50
7	1.08	79			2.70×10^{-7}	3.02	5.48	3.13
8	1.10	79			0	1.46	6.77	1.13
DB1	1.35	77		Narrow	1.31×10^{-4}	5.99	3.84	7.50
2	1.30	78			1.10×10^{-4}	6.03	3.82	7.75
3	1.35	80			6.56×10^{-5}	5.46	4.09	7.25
4	1.33	79			1.39×10^{-4}	6.25	3.72	8.25
5	1.58	79			6.55×10^{-5}	5.76	3.95	7.38
6	1.06	79			1.00×10^{-4}	5.91	3.88	7.75
7	1.00	79			8.10×10^{-7}	2.97	5.51	3.13
8	1.57	79			0	1.44	6.80	1.00
DC1	1.24	77	10	Medium	1.35×10^{-4}	6.42	3.64	8.38
2	1.30	78			1.59×10^{-4}	6.41	3.65	8.38
3	1.37	79			1.53×10^{-4}	6.41	3.65	8.63
4	1.47	80			1.82×10^{-4}	6.42	3.64	9.00
5	1.58	80			4.98×10^{-5}	5.75	3.95	7.13
6	1.04	80			6.48×10^{-5}	5.84	3.91	8.00
7	1.05	80			2.70×10^{-7}	2.95	5.52	3.13
8	1.30	80			0	1.32	6.93	1.00
DD1	1.30	77		Narrow	7.57×10^{-5}	6.20	3.74	8.00
2	1.27	78			1.13×10^{-4}	5.89	3.89	7.00
3	1.33	79			8.72×10^{-5}	5.74	3.96	7.75
4	1.31	80			1.32×10^{-4}	6.03	3.82	8.25
5	1.54	80			6.44×10^{-5}	5.74	3.96	7.75
6	1.12	80			9.82×10^{-5}	5.92	3.87	7.88
7	1.15	80			0	2.97	5.51	3.13
8	1.10	80			0	1.35	6.90	1.00

Table 3. Measured telemetry performance

Band/test	M.I., deg	Bit rate, kbps	ST_B/N_0, dB	BER	Loop SNR, dB
X1	80.0	115.2	3.84	4.7×10^{-4}	15.4
X2	80.0	115.2	2.84	5.0×10^{-3}	14.4
X3	80.0	115.2	5.20	2.1×10^{-5}	15.2
X4	80.0	44.8	4.84	1.8×10^{-5}	13.1
X5[a]	79.5	115.2	3.08	2.0×10^{-3}	15.2
X6[a]	79.5	44.8	3.13	1.1×10^{-3}	12.1
X7[a]	79.5	29.9	3.09	1.5×10^{-3}	11.6
X8[a]	79.5	21.6	3.00	2.0×10^{-3}	10.6
X9[a]	72.0	7.2	3.06	1.4×10^{-3}	9.9
X10[a]	72.5	2.56	3.42	2.2×10^{-3}	8.5
X11[a]	65.0	1.20	2.78	3.5×10^{-3}	8.5
S1	45.8	2.56	3.07	1.1×10^{-3}	16.9

[a]These tests performed with MDS/RFS combined; others performed using TLM simulator for source.

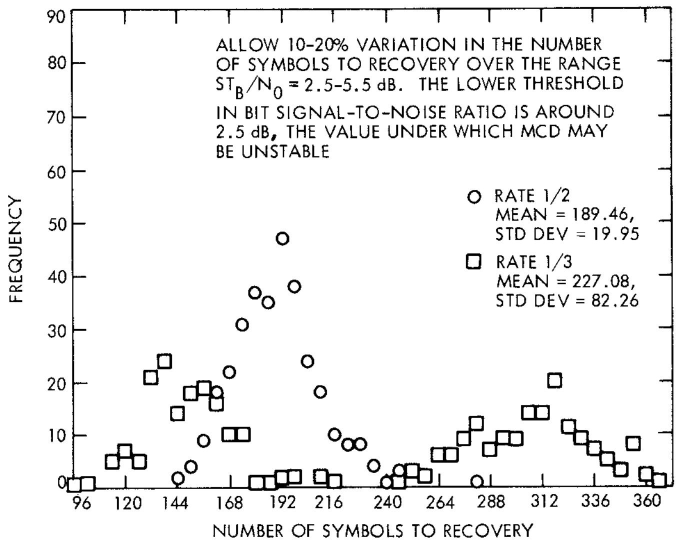


Fig. 1. Sample distribution plots of MCD symbol synchronization recovery for both code rates 1/2 and 1/3, ST_B/N_0 = 3 dB, 250 kbps

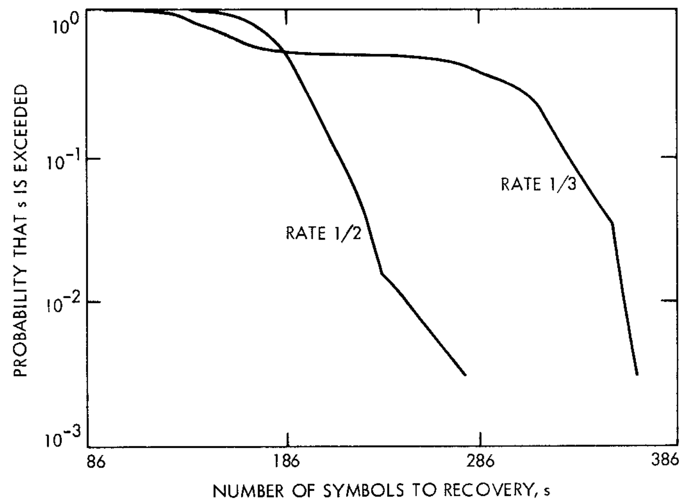


Fig. 2. Number of symbols to recovery S vs probability that S is exceeded for MCD symbol synchronization recovery of code rates 1/2 and 1/3

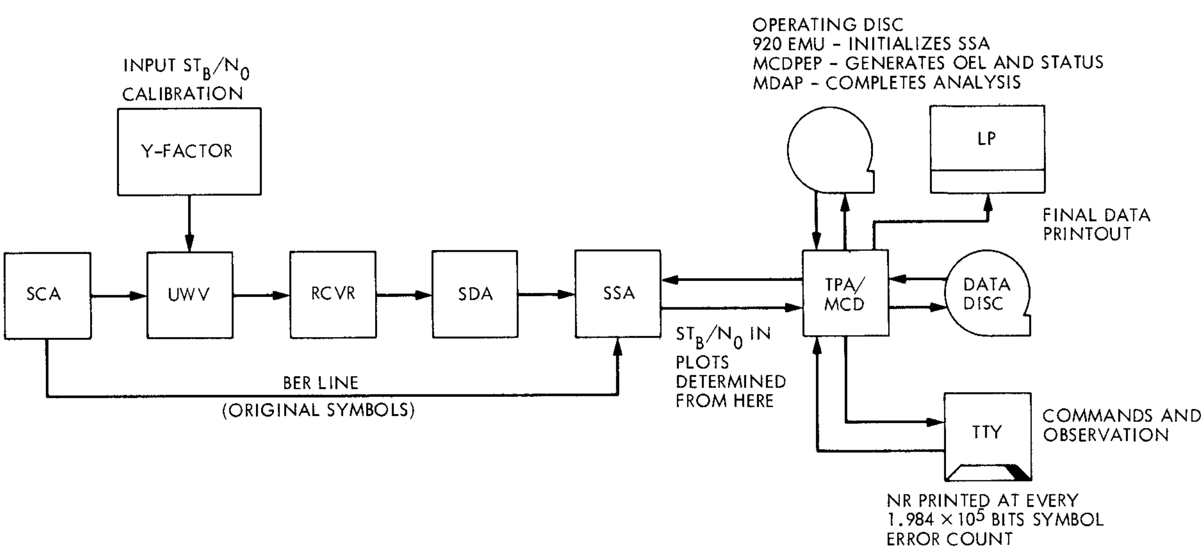


Fig. 3. MJS telemetry system test configuration at CTA 21

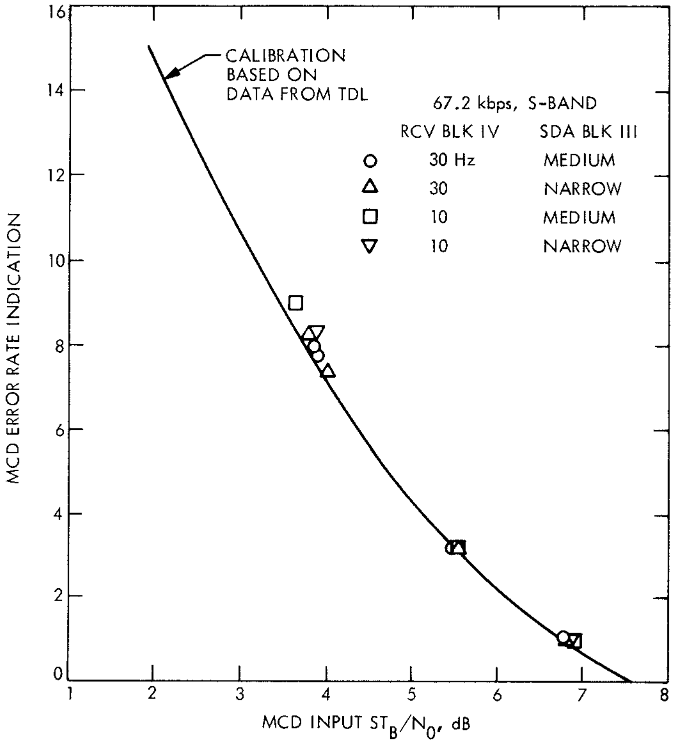


Fig. 4. MCD error rate calibration

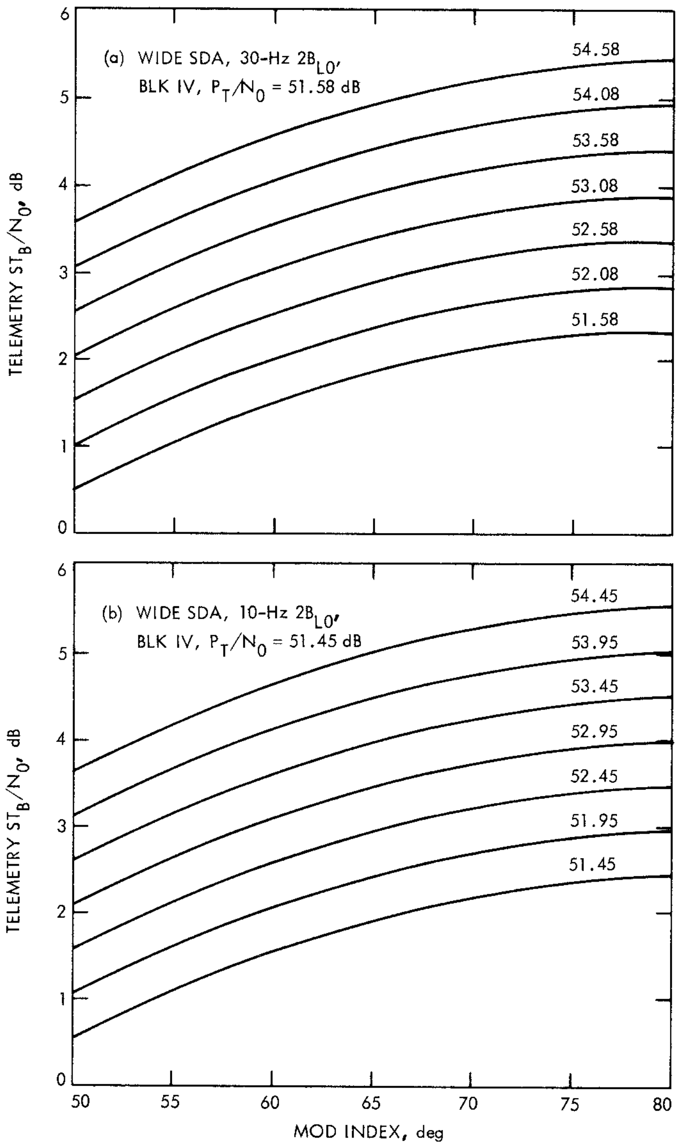


Fig. 5. ST_B/N_0 vs mod index at 67.2 kbps

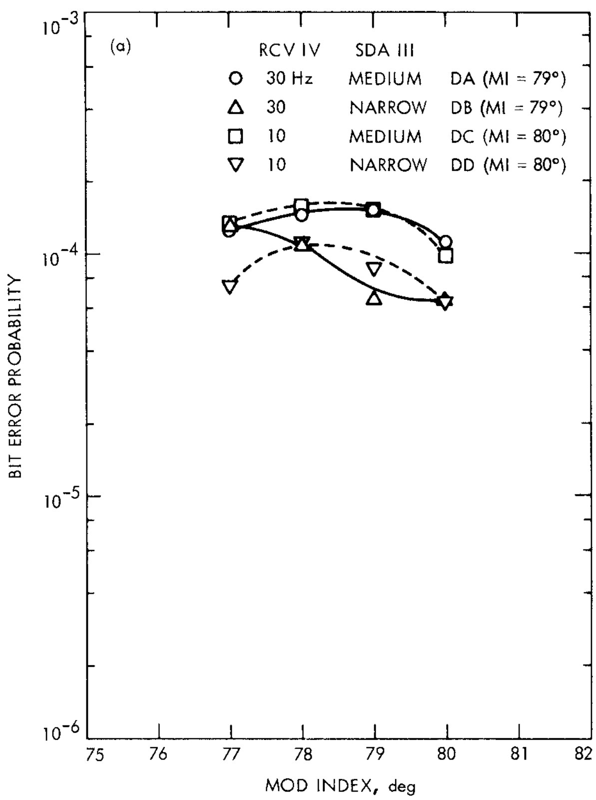


Fig. 6. Telemetry system performance at 67.2 kbps

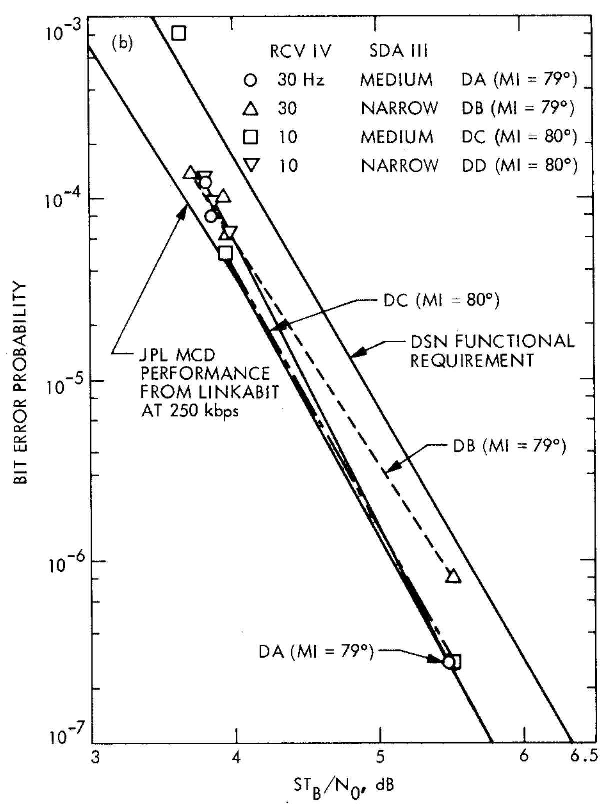


Fig. 6 (contd)

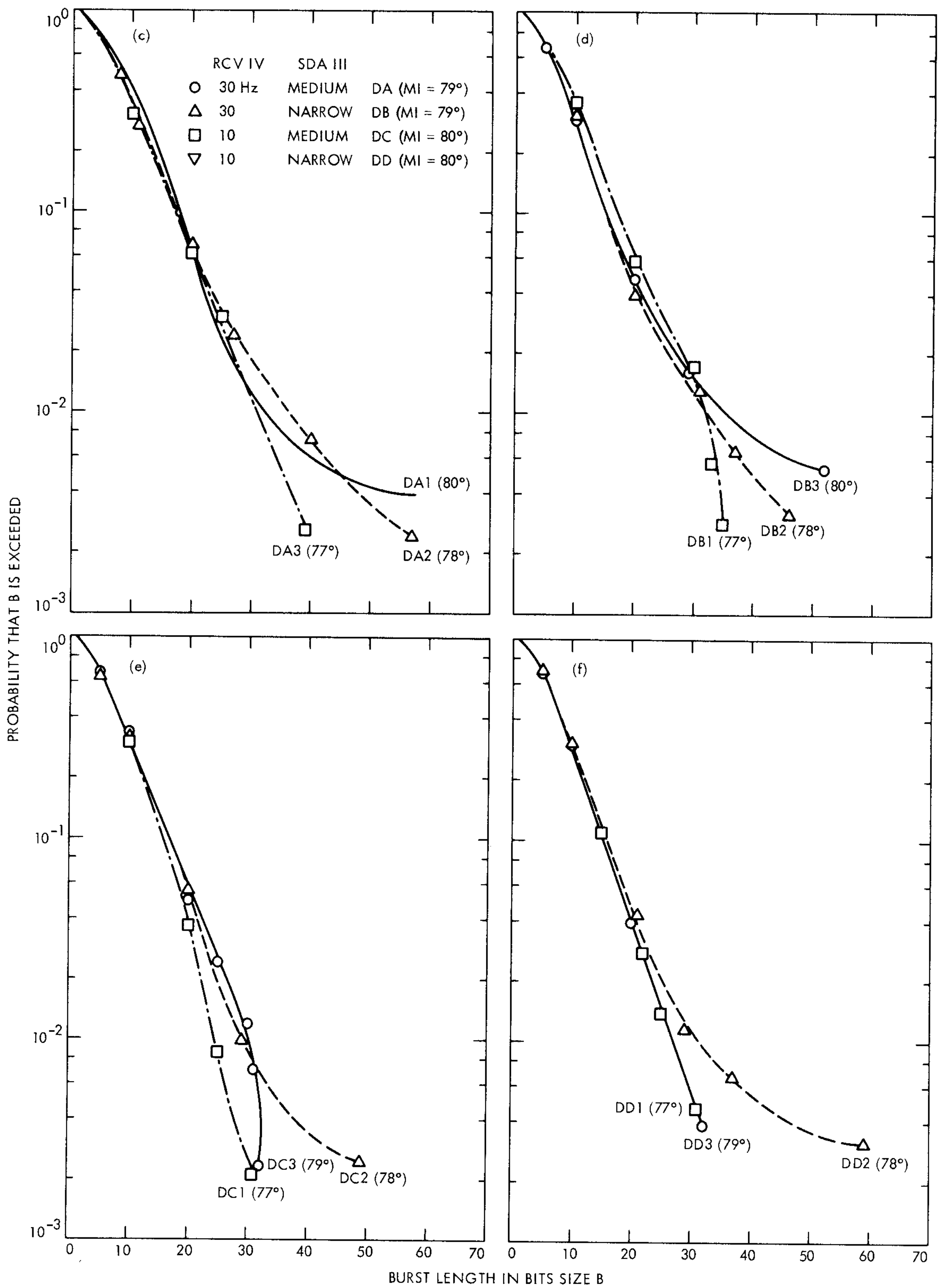
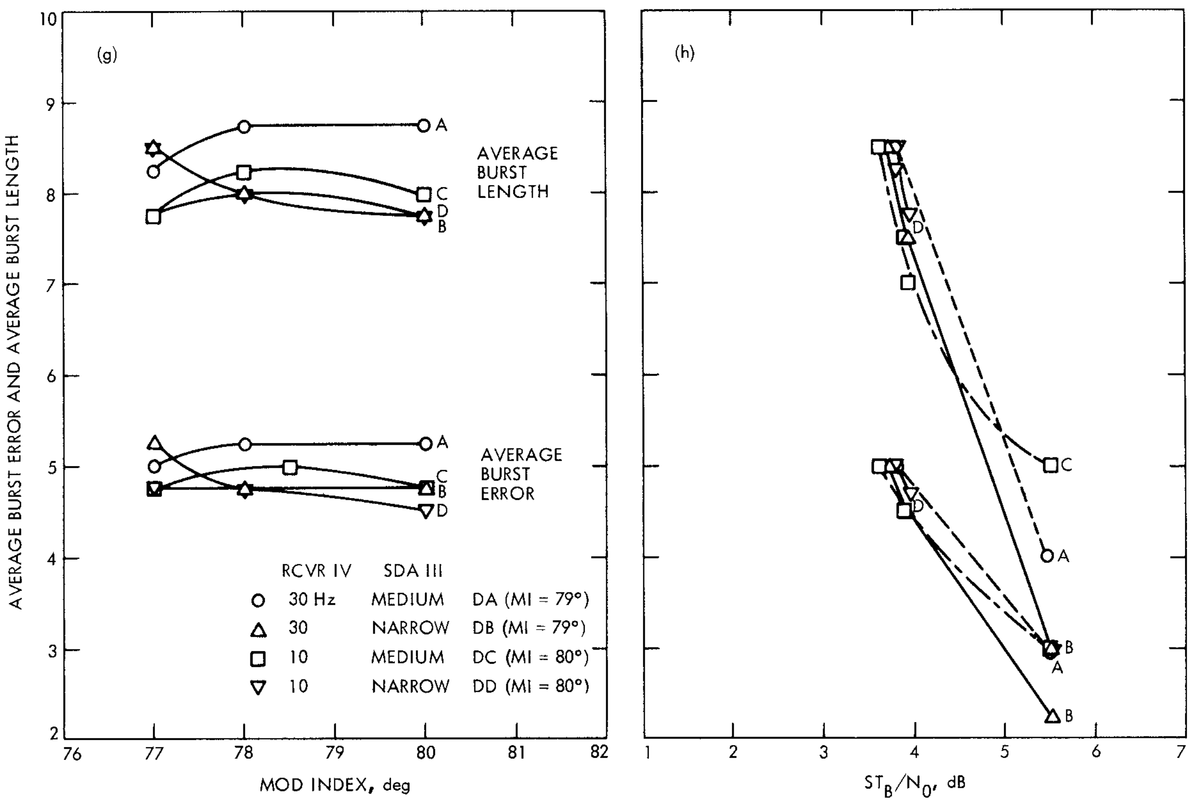

(c)
RCV IV
SDA III
30 Hz
MEDIUM
DA (MI = 79°)
30
NARROW
DB (MI = 79°)
10
MEDIUM
DC (MI = 80°)
10
NARROW
DD (MI = 80°)
DA1 (80°)
DA3 (77°)
DA2 (78°)
(d)
DB3 (80°)
DB1 (77°)
DB2 (78°)
(e)
DC3 (79°)
DC2 (78°)
DC1 (77°)
(f)
DD1 (77°)
DD3 (79°)
DD2 (78°)
PROBABILITY THAT B IS EXCEEDED
BURST LENGTH IN BITS SIZE B
10^0
10^{-1}
10^{-2}
10^{-3}
0
10
20
30
40
50
60
70

Fig. 6 (contd)



(g)
(h)
AVERAGE BURST ERROR AND AVERAGE BURST LENGTH
AVERAGE BURST LENGTH
AVERAGE BURST ERROR
RCVR IV SDA III
30 Hz MEDIUM DA (MI = 79°)
30 NARROW DB (MI = 79°)
10 MEDIUM DC (MI = 80°)
10 NARROW DD (MI = 80°)
MOD INDEX, deg
ST_B/N_0, dB

Fig. 6 (contd)

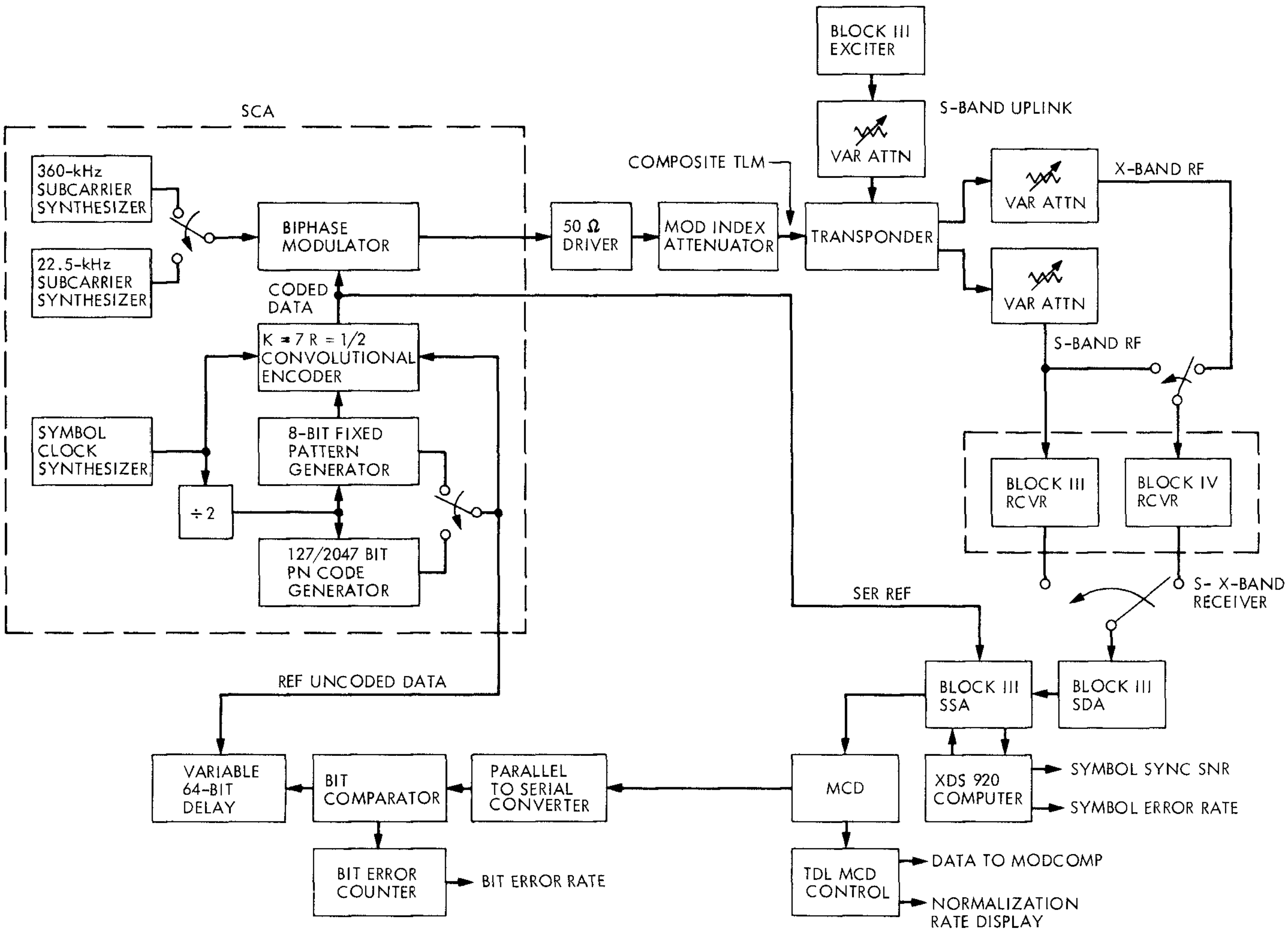


Fig. 7. MJS telemetry system configuration at TDL

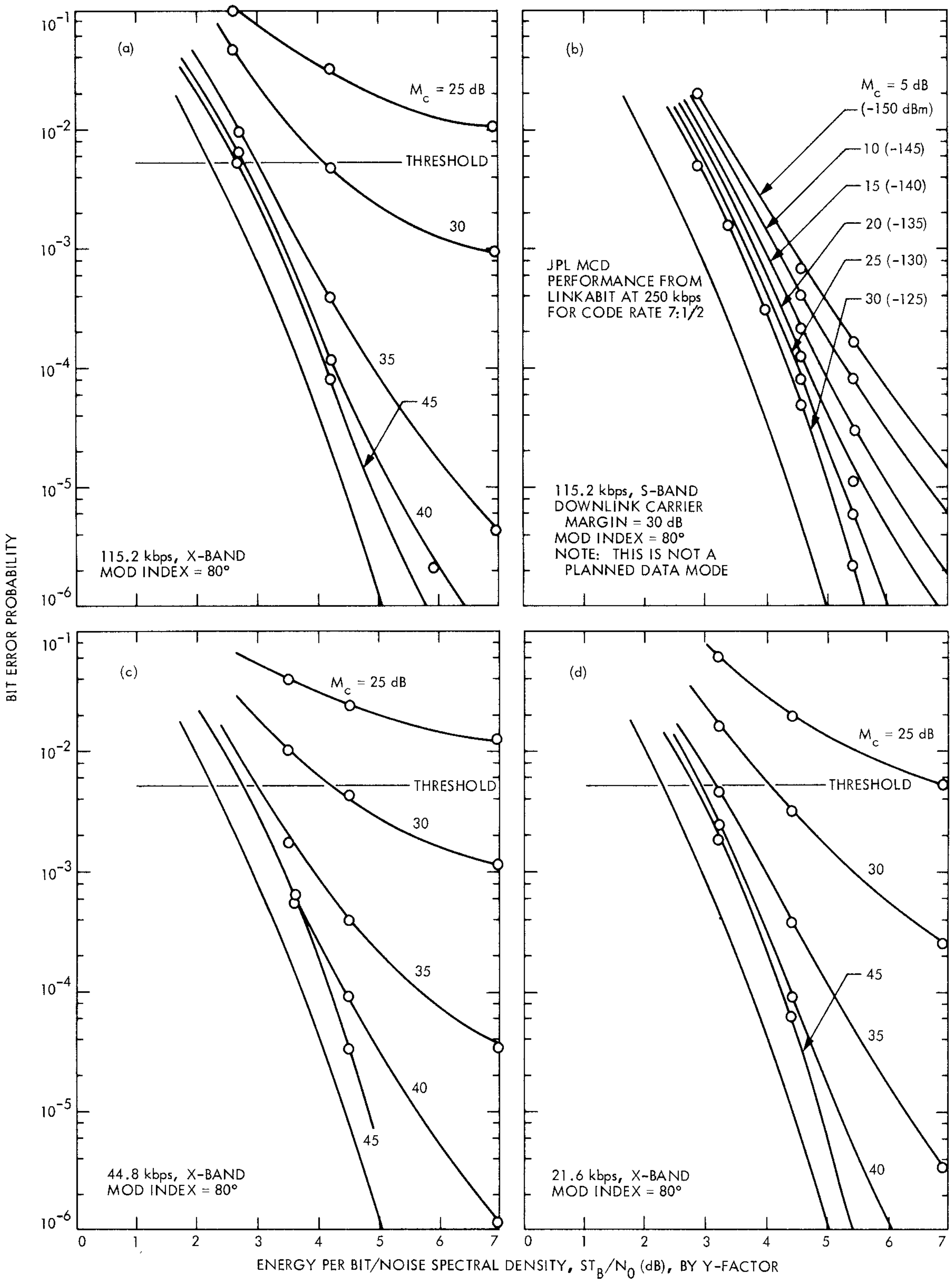
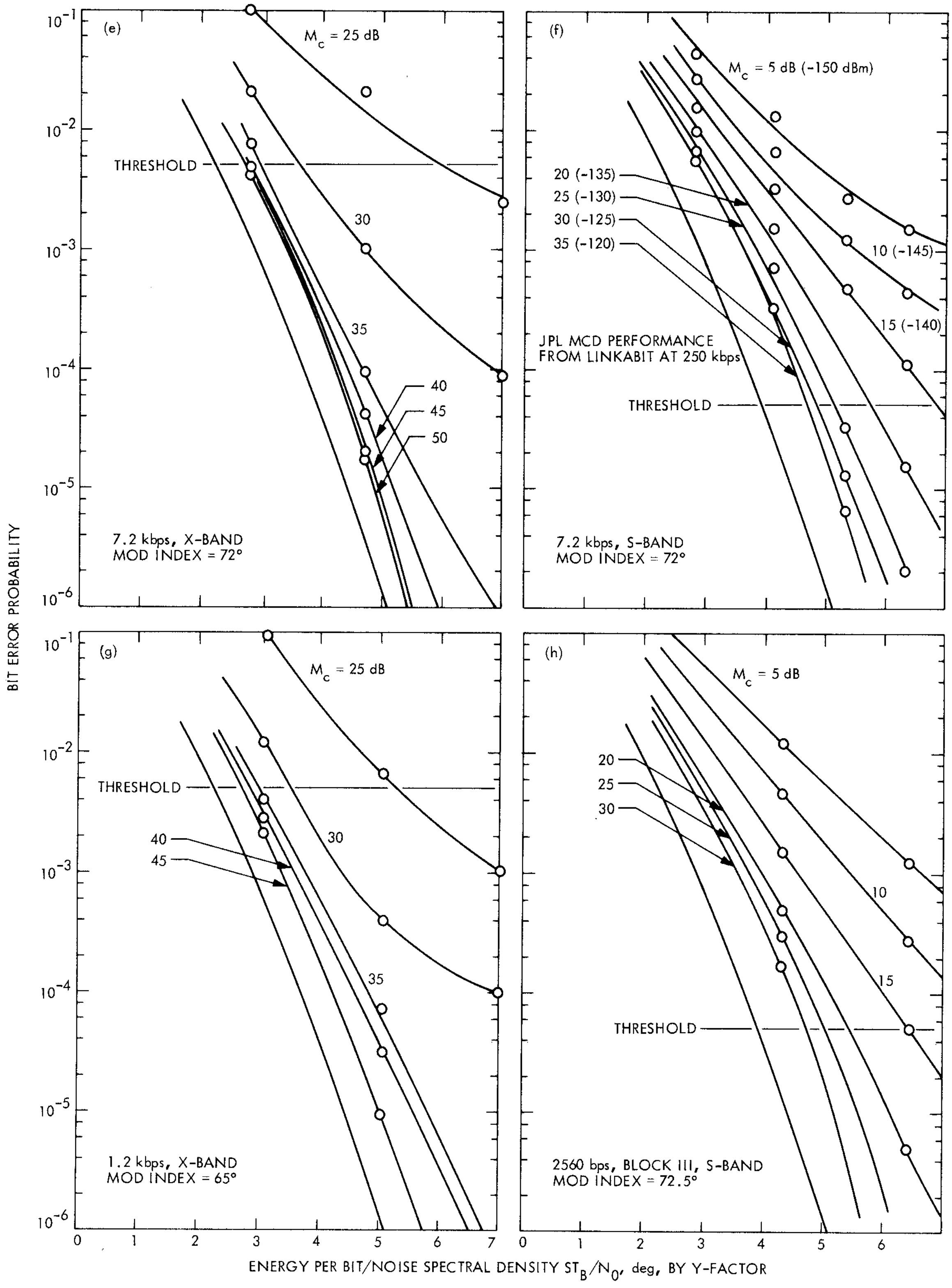
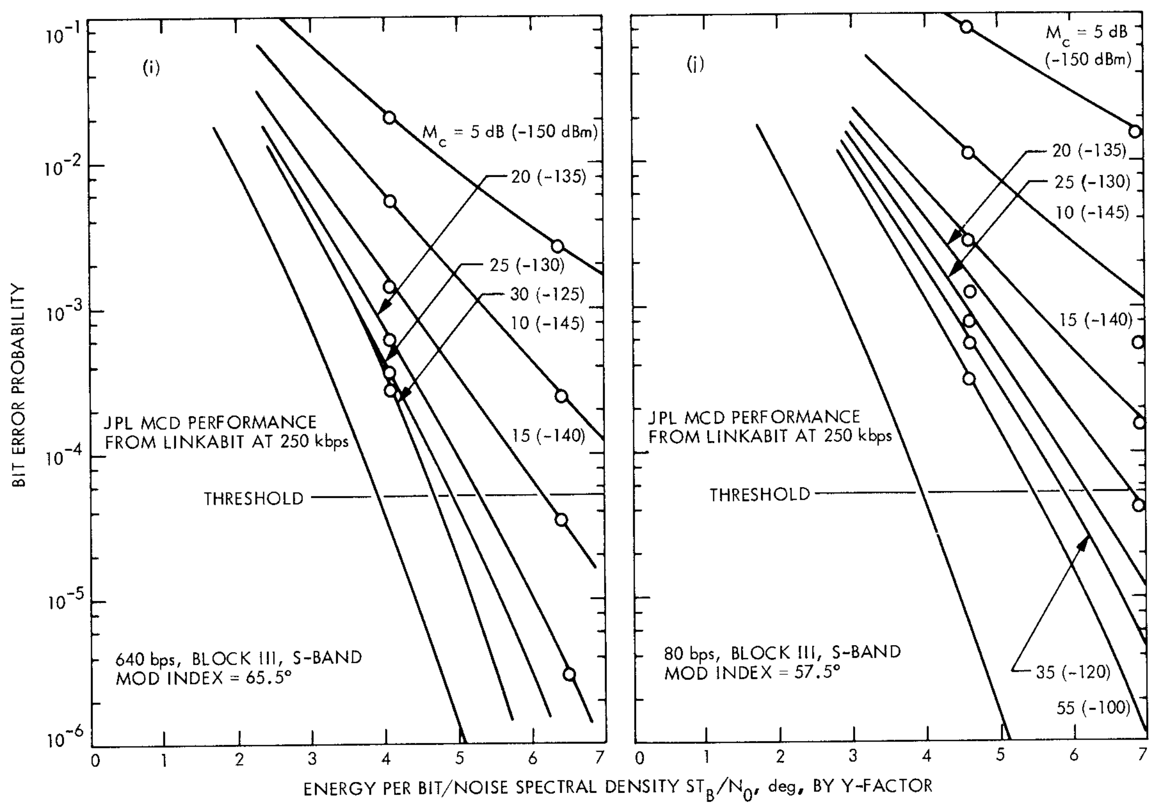


Fig. 8. X- and S-band two-way radio losses with various uplink carrier margins for data rates from 80 bps to 115.2 kbps, Block IV, 30 Hz



BIT ERROR PROBABILITY
(e)
M_c = 25 dB
THRESHOLD
30
35
40
45
50
7.2 kbps, X-BAND
MOD INDEX = 72°
(f)
M_c = 5 dB (-150 dBm)
20 (-135)
25 (-130)
30 (-125)
35 (-120)
10 (-145)
15 (-140)
JPL MCD PERFORMANCE
FROM LINKABIT AT 250 kbps
THRESHOLD
7.2 kbps, S-BAND
MOD INDEX = 72°
(g)
M_c = 25 dB
THRESHOLD
30
40
45
35
1.2 kbps, X-BAND
MOD INDEX = 65°
(h)
M_c = 5 dB
20
25
30
10
15
THRESHOLD
2560 bps, BLOCK III, S-BAND
MOD INDEX = 72.5°
ENERGY PER BIT/NOISE SPECTRAL DENSITY ST_B/N_0, deg, BY Y-FACTOR

Fig. 8 (contd)



BIT ERROR PROBABILITY
ENERGY PER BIT/NOISE SPECTRAL DENSITY ST_B/N_0, deg, BY Y-FACTOR
(i)
M_c = 5 dB (-150 dBm)
20 (-135)
25 (-130)
30 (-125)
10 (-145)
15 (-140)
JPL MCD PERFORMANCE FROM LINKABIT AT 250 kbps
THRESHOLD
640 bps, BLOCK III, S-BAND
MOD INDEX = 65.5°
(j)
M_c = 5 dB (-150 dBm)
20 (-135)
25 (-130)
10 (-145)
15 (-140)
JPL MCD PERFORMANCE FROM LINKABIT AT 250 kbps
THRESHOLD
80 bps, BLOCK III, S-BAND
MOD INDEX = 57.5°
35 (-120)
55 (-100)

Fig. 8 (contd)

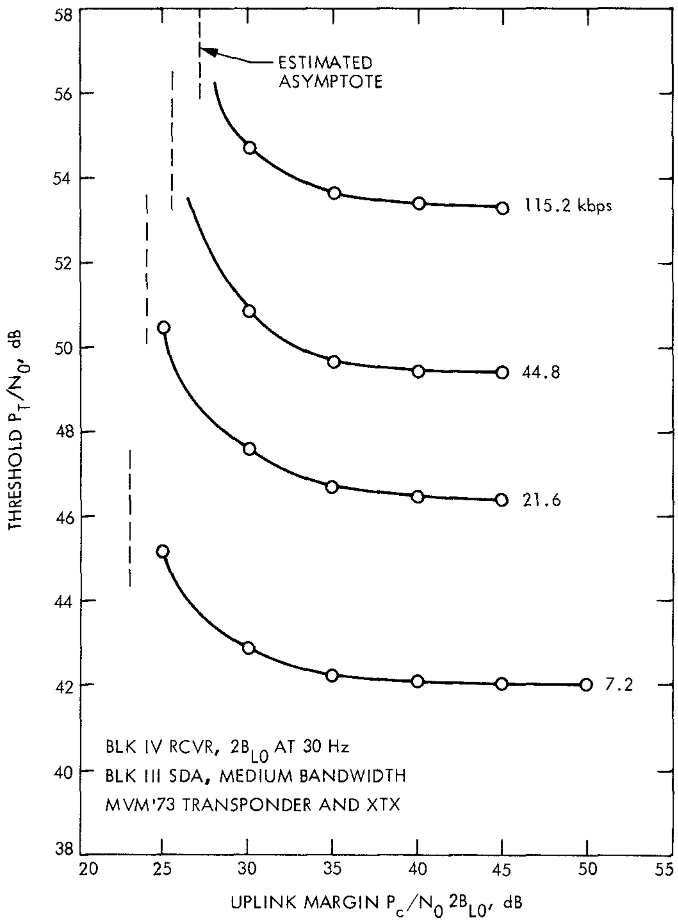


Fig. 9. X-band telemetry threshhold as a function of uplink margin

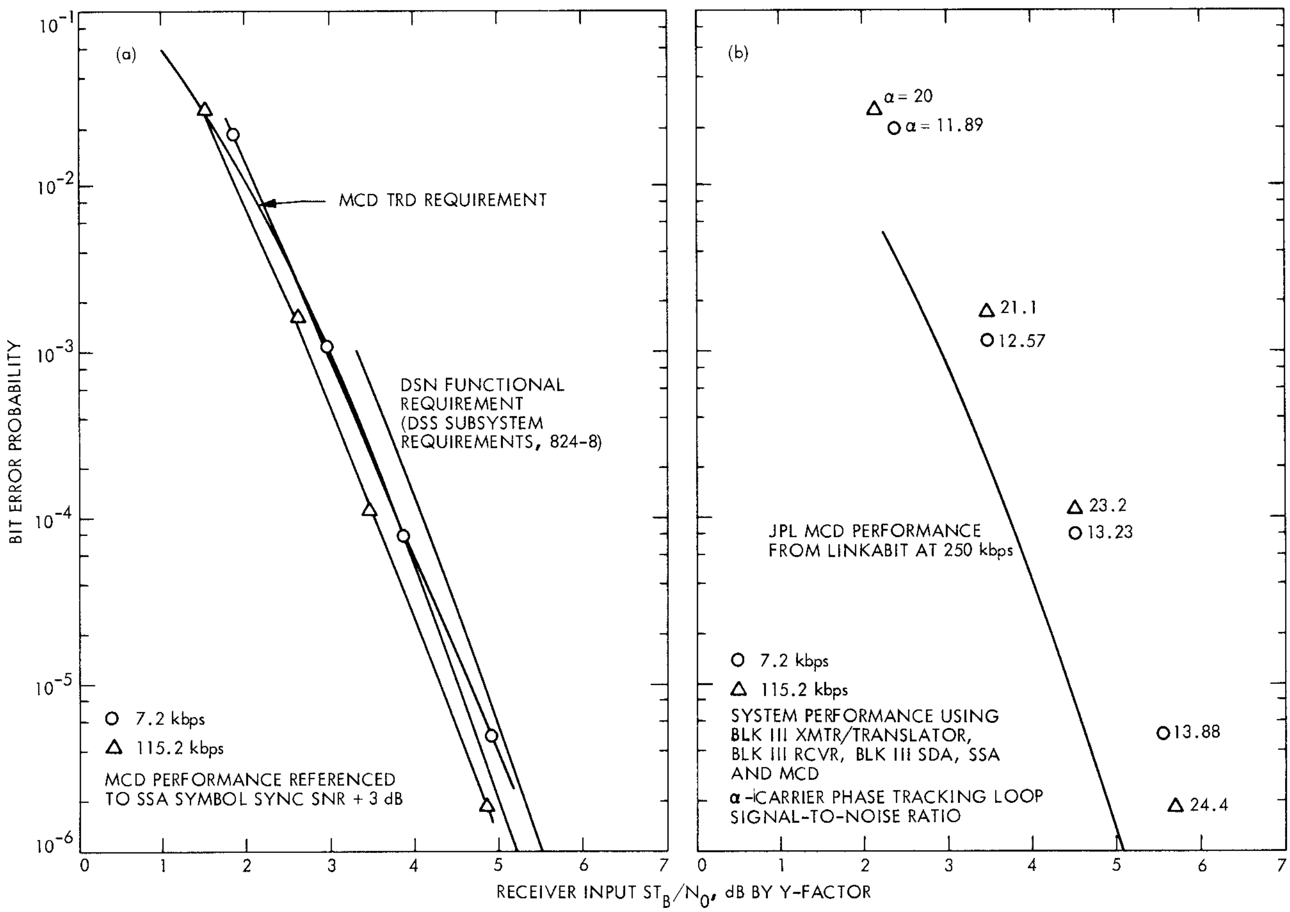


Fig. 10. Bit error probability vs ST_B/N_0 at 7.2 and 115.2 kbps

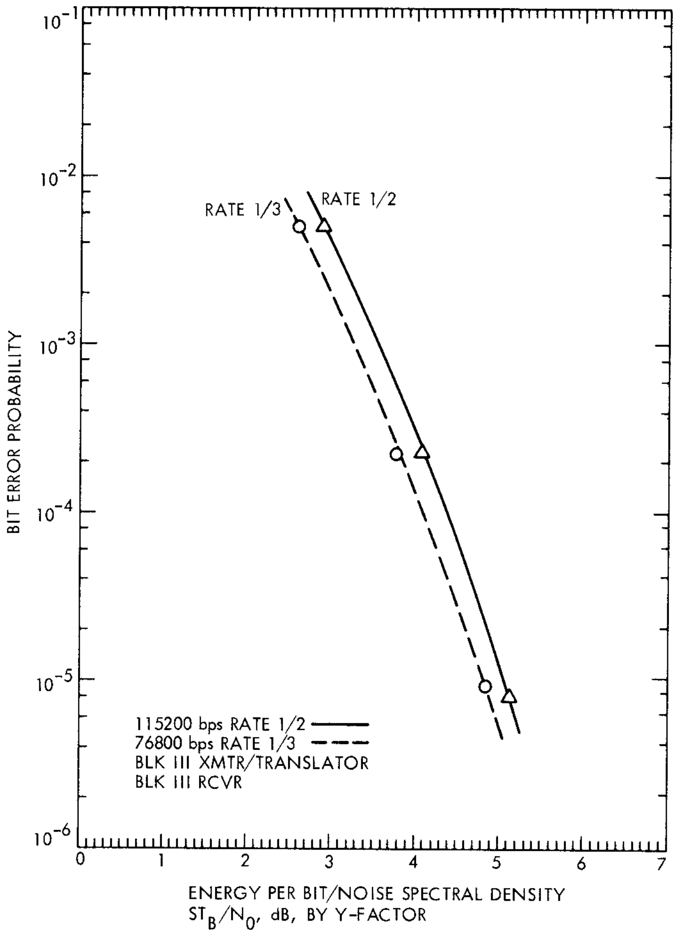


Fig. 11. Bit error probability vs ST_B/N_0 for code rate 1/2 and 1/3

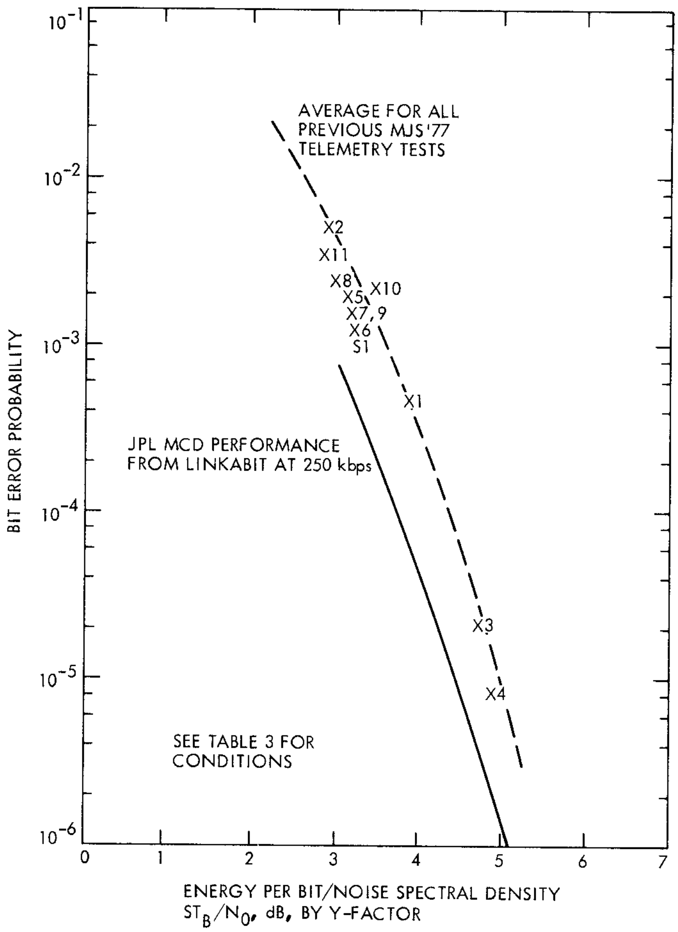


Fig. 12. Measured telemetry performance

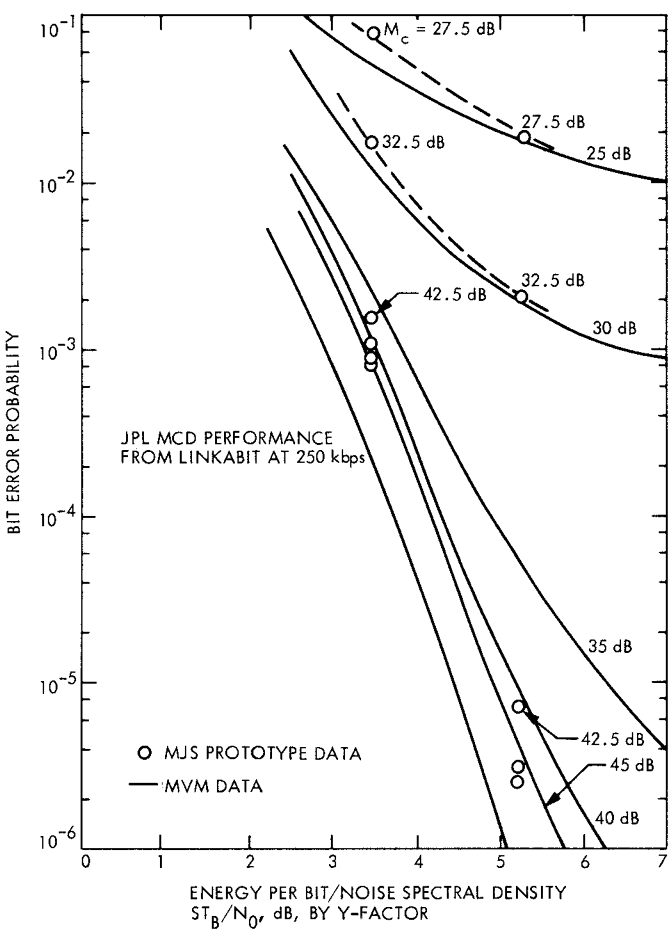


Fig. 13. Bit error probability vs ST_B/N_0 of two-way ratio loss, Block IV, X-band, 30 Hz at 115.2 kbps

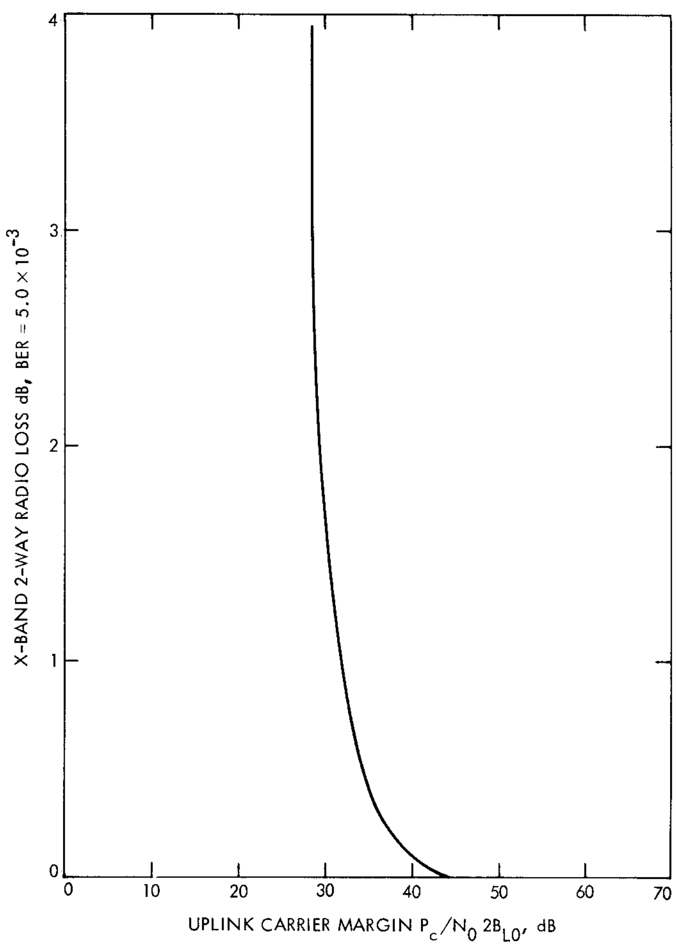


Fig. 14. X-band two-way radio loss vs uplink carrier margin