Pioneer 10 and G Mission Support

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The Deep Space Network (DSN) has already furnished more than four months of continuous data acquisition and command support for Pioneer 10, launched on March 3, 1972. After the description of the new DSN/Flight Project interface, a brief review is given on the qualitative and quantitative performance of DSN's data recovery support.

I. *Pioneer 10* Cruise

The *Pioneer 10* spacecraft has been cruising for over four months toward the Planet Jupiter. It was successfully launched on March 3, 1972.

The DSN has furnished continuous tracking for the *Pioneer 10* mission using 26-m-diam antenna stations. During the midcourse maneuvers, data were obtained from the 64-m antenna at DSS 14 to enhance the telemetry signal-to-noise ratio. Most of the time the spacecraft operated on a telemetry bit rate of 2048 bps. All spacecraft telemetry was processed in real time, and for the Project's Mission Operations Team numerous digital display tables, teletype, and high-speed line printer formats were provided for configuration control and spacecraft health analysis. Based upon the mission plan and the analysis of the real-time telemetry information, the Operations Team has sent to the spacecraft over 5000 commands to obtain the best scientific data return. The Project initiated all commands using the DSN's Mark III-type automatic command system.

The DSN has also supported, via a high-speed data line interface, the *Pioneer* Remote Information Center (RIC), which is located in the *Pioneer* Building at Ames Research Center, Moffett Field, California. This Remote Space Flight Control Facility is processing in real-time synchronized spacecraft telemetry data handled by the Central Processing System of the Space Flight Operations Facility (360/75 IBM computer). In addition, the DSN provided to the RIC the on-site-generated *Pioneer 10* telemetry high-speed data blocks as a backup.

In the non-real-time mode, the DSN generated, within 24 hours, *Pioneer 10* digital System Data Records (SDR) which contain not only all telemetry data received by the Central Processing System in real time, but also fill data obtained postflight from a digital Original Data Record (ODR) generated on-site. The *Pioneer* Project has received in biweekly batches the system data records from the DSN and converted them to experimenter data records (EDR). During June 1972, the DSN finished the software implementation of a master data record (MDR) capability. The MDR data tapes contain filled, time-cued, and merged spacecraft telemetry data.

During the first half of CY 1972, the DSN was engaged in extensive planning activities to modify the DSN/Flight

Project interface configuration. The Office of Space Sciences and the Office of Tracking and Data Acquisition of NASA Headquarters has reviewed the Planetary Mission Operations/DSN interface to bring the program control and budget functions more into line with management responsibilities. The Headquarters guidelines were asking for the development of a reasonably clear Network/Project interface in order to simplify technical management and also to assure that budgeting requirements of the two offices are well understood. Assurance was also sought for the coverage of all technical and operational requirements. In accordance with these guidelines, the Deep Space Network will have the responsibility of network control and monitoring. These functions will include network scheduling and performance monitoring, and will provide clean data streams (bit synchronized and identified) to Mission Operations. In addition, the network will accept commands from Mission Operations and will transmit them to the stations and spacecraft and will have a provision for recording of clean data streams of radio metric, telemetry, and command data. These data can be provided to Mission Operations as required. The network will also participate in the test and training activity of Mission Operations using simulated data streams generated by the missions. The same guidelines shifted all Mission Operations responsibilities to OSS funding and to the Flight Projects.

The funding, planning, and operations of the Space Flight Operations Facility (SFOF) at JPL, which also supports the *Pioneer* Mission Support Area, will be transferred to JPL's Office of Computing and Information Systems (OCIS). The Data System Division, operating under OCIS, will be responsible for taking over the Mission Operations support and computing functions by July 1, 1972. The Space Flight Operations Facility has been renamed the Mission Control and Computing Center (MCCC). The DSN will provide the telemetry, radio metric, and command verification data streams to the MCCC for the support of all planetary and interplanetary projects. Provisions will also be made to transmit automatic commands via high-speed data line to the DSSs. The DSN plans to add to the network a Network Control System (NCS). This system will have a network control area and a data processing area. The DSN started the development of the NCS, which will have the capabilities as recommended by NASA Headquarters guidelines. During the interim, the MCCC's Central Processing System (360/75) will support the Network Control System requirements.

Based upon the actual performance evaluation of the *Pioneer 10* telecommunications downlink, which carries the spacecraft-generated telemetry signals to the Deep Space Stations, it was observed that the performance parameters were correlating well with the design goals established during *Pioneer 10* preflight planning. The actual performance residuals were well within a tolerance range of $\pm 1\frac{1}{2}$ dB. This is the root sum square (RSS) value of all combined favorable and adverse measurement tolerances of the flight and ground equipment operating the downlink telemetry channel.

To assess the actual performance of the *Pioneer 10* telecommunications downlink, the DSN measures regularly the following parameters: system-noise temperature (SNT), received carrier power P_c, symbol energy per bit versus receiver noise spectral density ratio (ST_s/N_0), symbol error rate (SER), and deletion rate (DLR).

Table 1 is a recently updated *Pioneer 10* Telecommunications Downlink Design Table. Figure 1 depicts the design and actual characteristics of the *Pioneer 10* sequential decoding capabilities. Based upon the contents of Table 1 and Fig. 1, downlink performance nomograms were charted which are illustrated in Fig. 2. These nomograms are based upon *Pioneer 10* downlink performance characteristics and represent actual and nominal conditions. If the reader wishes to use these graphic calculation aids, the following procedures can be followed:

(1) Obtain cold sky SNT and antenna elevation readings from the DSS and using correction scales G and H to determine the deviation from the nominal SNT. This will be a positive or negative dB adjustment defining the actual SNT.

(2) Obtain the actual downlink carrier power level from DSN monitoring format 24. Connect on both A scales this actual carrier power value with a horizontal line. At the appropriate telemetry bit rate, read out on the F scale the SNR related to an SNT of 33 K. Mark down this value.

(3) Add or subtract the SNT dB adjustment as calculated in (1) to the 33 K SNR obtained from the F scale. This is the adjusted SNR. Read out the SER and DLR values corresponding with the adjusted SNR.

(4) Obtain the measured signal-to-noise ratio (SNR) from Form 815 (which contains numbers of the digital display forms available from the DSN Network Control Area), and calculate a residual versus the adjusted SNR. The residual of these two values should be within $\pm 1\frac{1}{2}$ dB.

(5) Obtain actual Earth/spacecraft range in kilometers from the RTLT displayed on Form 815.

$$\text{Range in million km} = 9 \times \text{RTLT (in minutes)}$$

or

$$\text{Range in million km} = \frac{3}{20} \times \text{RTLT (in seconds)}$$

The estimated Earth/spacecraft range and the predicted downlink carrier power can be obtained from the *Pioneer 10* and *G* telecommunications calculator.

(6) Determine a residual between predicted P_c (5) and measured P_c (2).

If the reader wants to use the attached graphs for the 64-m DSS, the following corrections should be made:

$$\text{SNT 26 m (nominal)} = 33\ \text{K}$$

$$\text{SNT 64 m (nominal)} = 24\ \text{K}$$

The lower 64-m SNT results in a nominal SNR correction of +1.4 dB. Nominal antenna gain:

64 m: 61.4 dBi

26 m: 53.3 dBi

The 64-m versus 26-m antenna gain improvement factor is 8.1 dB; thus the received spacecraft power level should be increased by this factor. Therefore, the attached curves can be used with 64-m antennas, if one makes the proper SNT correction.

If during the spacecraft's 12-s-long rotational period the amplitude of the downlink power has a CONSCAN-type amplitude variation of more than 1 dB peak-to-peak, the following corrections should be made:

(1) Obtain from the DSS the minimum and maximum downlink carrier power readings. Calculate the arithmetic mean of P_c and use this value. The computer-generated mean values are not always accurate unless several averaged readings are taken.

(2) The signal-to-noise ratio estimator (SNORE) program-generated telemetry SNR as displayed on Format 815 is somewhat higher than the arithmetic mean corresponding with P_c. This reading should be lowered by approximately 0.5 dB at P_c variations of 5 dB peak-to-peak.

(3) The SER and DLR readings are average values. All the symbol errors and deletions are generated only during the low values of the time-varying SNR. For a 10-dB peak-to-peak, divide SER by approximately 3.3; for a 5-dB peak-to-peak, divide by 2.2; for a 3-dB peak-to-peak, divide by 1.5 to obtain correlation between the constant SNR scale F and DLR scale D readings.

To obtain the most accurate performance parameters from the *Pioneer* Form 815, and the DSN Monitoring Format 24 displayed on the digital monitors, it is necessary that the user understand the relationship between quantizing levels and errors, the statistical sampling time periods, and their impact on the displayed values. In other words, it is important to know how the on-site and CPS processors manipulate the raw measurement data.

The following example shows the typical steps of the downlink analysis.

(1) Nominal 26-m SNT = 33 K (charts are based on this value)

Actual cold sky DSS SNT = 24 K, (scale G)

Noise power improvement: +1.4 dB (scale H)

Elevation angle: 10 deg

Noise degradation because of 10 deg elevation: −2.1 dB (scale H)

Resultant noise power correction: −2.1 + 1.4 = −0.7 dB

(2) Actual downlink carrier power, $P_c = -157.4$ dBmW (place straight at this value on both A scales)

CONSCAN amplitude ~1 dB peak-to-peak

Telemetry bit rate: 512 bps

33 K SNR = 1.3 dB (read on scale F)

(3) Adjusted SNR: 1.3 dB − 0.7 dB = 0.6 dB (predicted value of SNR)

SER: 6% (read from scale E and compare with Format 815)

DLR: 0.5% (read from scale D and compare with Format 815)

(4) Actual SNR: 1.0 dB (Format 815) (use I and K scales)

SNR residual: 0.4 dB

(5) RTLT: 46 min

Range: 415 million km

High-gain spacecraft antenna with ELA = 0.3 deg

Calculated downlink carrier power: −157.7 dBmW

(6) Predicted P_c from (5) −157.7 dBmW

Measured P_c from (2) −157.4 dBmW

P_c residual: +0.3 dB

To illustrate the quantitative support performance of *Pioneer 10*, it should be stated that DSN has delivered to the *Pioneer* Project continuous telemetry data packages which contain on a daily basis 98 to 99% of all data acquired by the stations. Our original commitment was to furnish at least 97% of the received data stream.

II. Planning and Preparations for the *Pioneer G* Launch Readiness

The second mission of the third-generation *Pioneers*, *Pioneer G*, will be launched during April 1973. The DSN plans to use the same network configuration and capabilities for *Pioneer G* which are already in operation for the support of *Pioneer 10*. This decision will be based upon the assumption that the *Pioneer G* and *Pioneer 10* telecommunications interfaces will be the same. The planning activities for *Pioneer G* are in progress and regular bi-weekly *Pioneer G* Operational Support and Planning Group meetings are held to identify, issue, or close out *Pioneer G*-oriented action items. The updating of the *Pioneer 10* documentation has been started.

Terms used in this article are defined as follows:

SNT = Cold-sky high-elevation angle system noise temperature measured during *Pioneer 10* prepass calibrations. Obtain from DSS.

P_T = Total transmitted power of *Pioneer 10*, nominal value: 39 dBmW (actual displayed on Format 808).

P_c = Received carrier power. With a nominal modulation index of 1.1, the carrier is 6.9 dB below the received total power P_t. P_c is measured by a DSS and displayed at MCCC in dBmW or in voltages. Use the DIS-generated (DSIF monitoring) value displayed on Format 24 whenever available. The P_c displayed on Format 815 is generated by the DSS/TCP. The engineering conversion of the TCP-generated value is based upon a linear approximation and it has a somewhat lower accuracy.

P_s = Received symbol power. It is 1 dB below P_T. It is not measured or displayed at the MCCC.

$\frac{ST_s}{N_0}$ (or SNR) = Symbol energy per bit versus receiver noise spectral density ratio. The DSS/TCP SNR program calculates this value from statistical values obtained from the symbol synchronizer assembly (SSA). The results of these calculations are displayed on Format 815 as the SNR of the demodulated symbol stream. It should be noted that the telemetry SNR is higher at the input of the DSIF receiver. This SNR degradation is caused by some additive noise originating from the carrier tracking loop, the subcarrier demodulator, and the symbol synchronizer. The measured values of the combined SNR degradations (also called demodulation efficiency) are included in the 810-5 document. The attached graphs are adjusted for this SNR degradation. Below SNR = 6 dB use scales I and K and convert the displayed SNR to an actual SNR.

SER = Symbol error rate. Parameters for this calculation are generated in the DSS/DDA/TCP and calculated and displayed by the SFOF/CPS. Format 815 displays *SER* and it is identified as *BER* (0.10000 = 10% and 0.0100 = 1%).

DLR = Deletion rate. A constraint caused by physical limitations of the sequential decoding processor. This value describes the percentage of the deleted telemetry frames versus the total number of received telemetry frames. Display Format 815 shows the actual DLR (0.10000 = 10% and 0.0100 = 1%). Because of statistical constraints, the DLRs displayed are only meaningful between 1% and 10%. The displayed numbers should be averaged for at least 30 min. The DDA can perform approximately 25,000 computations per second as an upper limit and at SER values >4%; some telemetry frames cannot be decoded and are deleted. The deletion rates displayed on the nomograms show the statistical decoding performance. The actual DDA performance will be somewhat improved when all decoders are equipped with the correct read-only memories (ROMs).

ELA = Earth look angle. Angle between the spacecraft spin axis and the spacecraft/Earth line.

RTLT = Round-trip light time.

ROM = Read-only memory

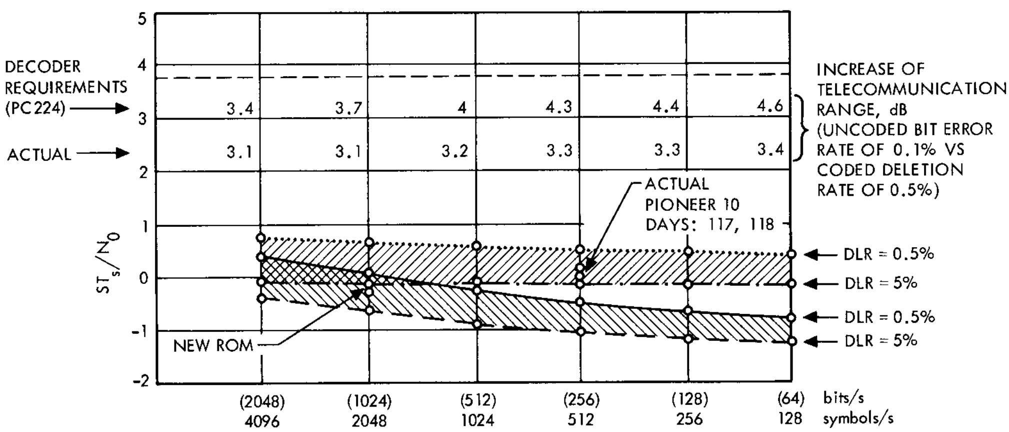
Table 1. *Pioneer 10* typical telecommunications downlink design

DSN/spacecraft range: 300 Mkm; spacecraft antenna: high-gain; DSS antenna: 26-m diam

Item	Source	Parameter	Nominal	Unit	Tolerances Favorable	Tolerances Adverse	Notes
1	ARC	Transmitter power, spacecraft	39.0	dBmW	0.2	0.2	Telemetered value
2	ARC	Transmitting circuit losses	−2.0	dB	0.12	0.12	Includes antenna alignment loss
3	ARC	Transmitting antenna gain	31.8	dBi	0.4	0.4	High-gain antenna, ELA = 0 deg
4	—	Space loss	−268.9	dB	—	—	at 2292 MHz
5	DSN	Receiving antenna gain	53.3	dBi	0.6	0.6	26-m antenna
6	DSN/ARC	Polarization and antenna pointing	−0.5	dB	—	—	Spacecraft, DSN measurements
7	Σ 1–6	Total received power	−147.3	dBmW	0.76	0.76	RSS of tolerances
8	DSN	Receiver noise spectral density	−183.4	dBmW-Hz	0.4	0.4	N_0
		Carrier performance					
9	ARC	Carrier modulation loss	−6.9	dB	—	—	$\theta = 1.1$ rad
10	DSN	Received carrier power	−154.2	dBmW	0.76	0.76	Measured by DSN
11	DSN	Carrier loop threshold bandwidth	10.8	dB	0.5	0.5	$2Bl_0 = 12$ Hz
12	DSN	Required SNR in carrier loop	6.0	dB			Cycle slip constraint
13	8 + 11 + 12	Required minimum carrier power	−166.6	dBmW	0.9	0.9	Calculated
14	13–10	Margin	12.4	dB	0.9	0.9	RSS of tolerances
		Data channel performance					
15	ARC	Data modulation loss	−1.0	dB	—	—	$\theta = 1.1$ rad, measured and calculated
16	7–15	Received symbol power	−148.3	dBmW	0.76	0.76	
17	DSN	Demodulation loss	−0.5	dB	0.2	0.2	810-5, measured and calculated
18	16 + 17	Effective symbol power	−148.8	dBmW	0.78	0.78	Calculated
19	—	Time per symbol	−33.1	dB-s	—	—	2048 symbols/s 1024 bps calculated
20	18 + 19	Effective ST_s (energy per bit	−181.9	dBmW-s	—	—	
21	20–8	Effective ST_s/N_0	1.5	dB	0.4	0.4	Measured by DSN
22	ARC	Required ST_s/N_0	1.5	dB	—	—	24 SER = 4.6% 25 DLR = 0.01%
23	21–22	Margin	0	dB	0.9	0.9	RSS of tolerances

Measured by ARC
Spacecraft transmitter power (1)

Measured by DSN
Received carrier power, P_c (10)
DSN cold sky system noise temperature, SNT (8)
Effective ST_s/N_0 (21)
Symbol error rate, SER (24)
Coded mode deletion rate, DLR (25)
Tolerances are one-sigma values



MODULATION INDEX = 1.1 rad, 25,000 COMPUTATIONS/s

THE PIONEER REQUIREMENTS VERSUS ACTUAL PERFORMANCE RESIDUALS OF ~ 0.3 TO 1.2 dB (2048 TO 64 bps) ARE CAUSED BY THE PHASE JITTER OF THE BEST ESTIMATE OF THE RECEIVED S-BAND CARRIER. THIS PHASE NOISE HAS SOME NON-WHITE GAUSSIAN COMPONENTS (1/F TYPE) AND IT IS A FUNCTION OF THE S/N RATIO IN THE $2BL_0$ = 12-Hz CARRIER LOOP

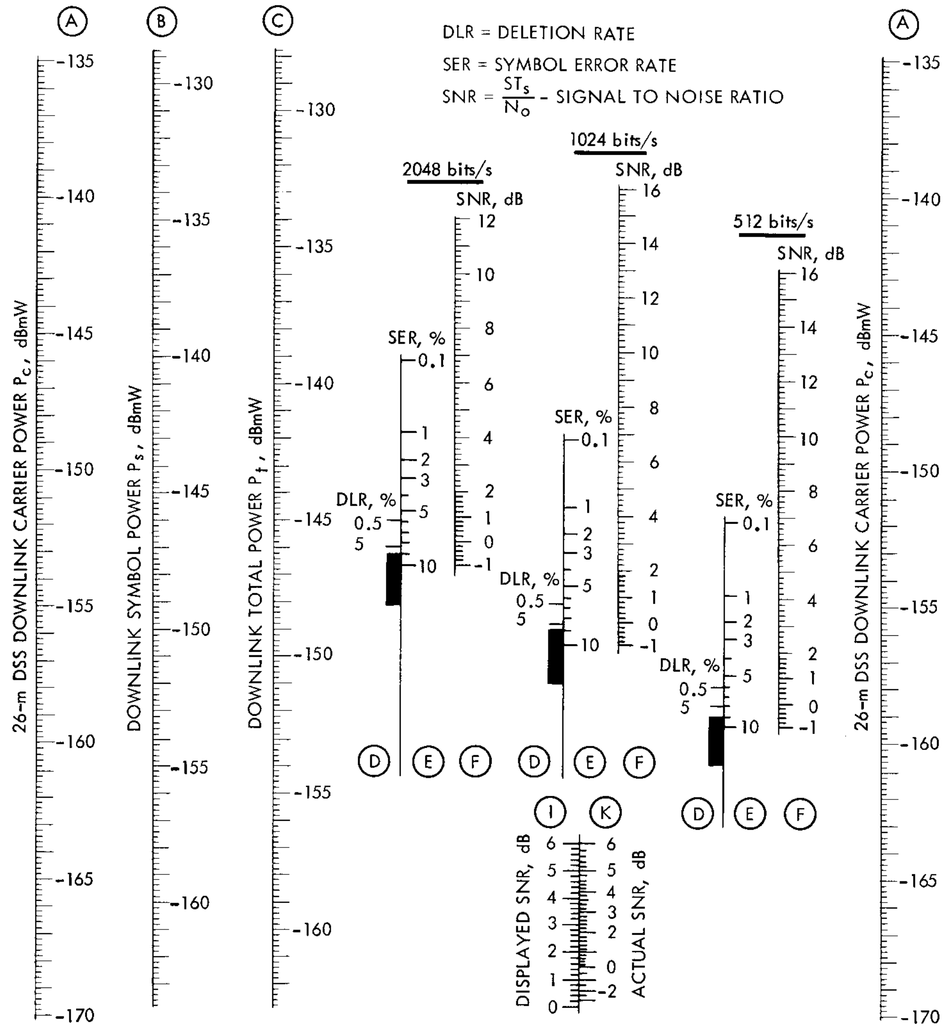
DLR = DELETION RATE

$2BL_0$ = TWO-SIDED NOISE BANDWIDTH OF THE CARRIER TRACKING PHASE-LOCKED LOOP AT THRESHOLD CONDITIONS

SIMULATED AND ACTUAL SYSTEM PERFORMANCE

DECODER REQUIREMENTS, PC224

Fig. 1. *Pioneer 10* sequential decoding

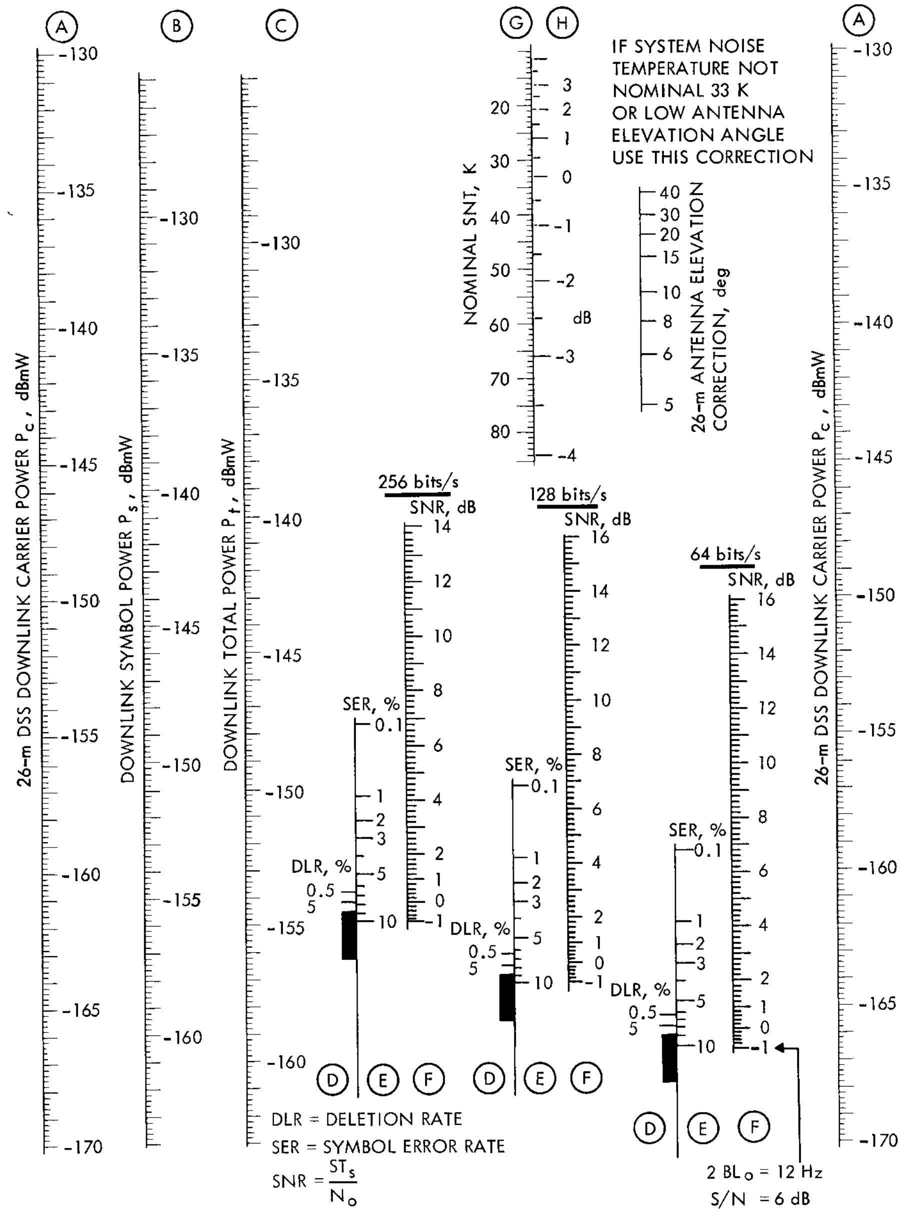


MODULATION INDEX: 1.1, CODED MODE, CARRIER SUPPRESSION: 6.9 dB, SYMBOL POWER SUPPRESSION: 1 dB

26-m DSS SNT: 33 K (NOMINAL)

RECEIVER NOISE SPECTRAL DENSITY: -183.4 dBmW Hz

Fig. 2. *Pioneer 10* downlink performance nomograms: (a) 2048, 1024, and 512 bps; (b) 256, 128, and 64 bps



26-m DSS DOWNLINK CARRIER POWER P_c, dBmW
DOWNLINK SYMBOL POWER P_s, dBmW
DOWNLINK TOTAL POWER P_t, dBmW
NOMINAL SNT, K
IF SYSTEM NOISE TEMPERATURE NOT NOMINAL 33 K OR LOW ANTENNA ELEVATION ANGLE USE THIS CORRECTION
26-m ANTENNA ELEVATION CORRECTION, deg
256 bits/s
128 bits/s
64 bits/s
SNR, dB
SER, %
DLR, %
DLR = DELETION RATE
SER = SYMBOL ERROR RATE
$SNR = \frac{ST_s}{N_o}$
$2 BL_o$ = 12 Hz
S/N = 6 dB

Fig. 2 (contd)