Interface Description Document for EOS-PM1 X-band Direct Broadcast

PREFACE

This EOS-PM1 Spacecraft Radio Frequency (RF) Interface Description Document (IDD) describes the X-band Direct Broadcast link between EOS-PM1 Spacecraft and the Earth Observing System Broadcast Stations (EBS).

A Document Change Notice (DCN) will be issued to update the document for any future approved changes.

Any changes or questions concerning this document should be addressed to:

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1. INTRODUCTION

1.1 PURPOSE

The Interface Description Document (IDD) decribes technical aspects of the Direct Broadcast (DB) communication interface between the EOS-PM1 spacecraft and the Earth Observing System Broadcast Stations (EBS) worldwide within line-of-sight view. The EBS will be used to provide DB science and engineering data service in real time via X-band downlink transmission.

1.2 INTERFACE RESPONSIBILITIES

Interface responsibilities are defined in terms of the Goddard Space Flight Center (GSFC) EOS-PM Project Office. The portion identified as the EOS-PM1 spacecraft is the responsibility of the GSFC EOS-PM Project Office. The design characteristics and parameters in this IDD are subject to the joint control of the GSFC EOS-PM Project Office and the TRW EOS-PM Program Office. The GSFC Operations Manager of the EOS-PM Project and his Designee and the Designee of the TRW EOS-PM Program Office will jointly approve this IDD upon resolution of issues and discrepancies as agreed upon by these parties.

1.3 INTERFACE IDENTIFICATION

1.3.1 RF Link Definition

The communications subsystem interface defined by this IDD is the X-band DB transmission link between the EOS-PM1 spacecraft and the Earth Observing System broadcast ground stations. Figure 1.3-1 depicts the RF downlink between the Spacecraft and an EOS Broadcast Ground Station.

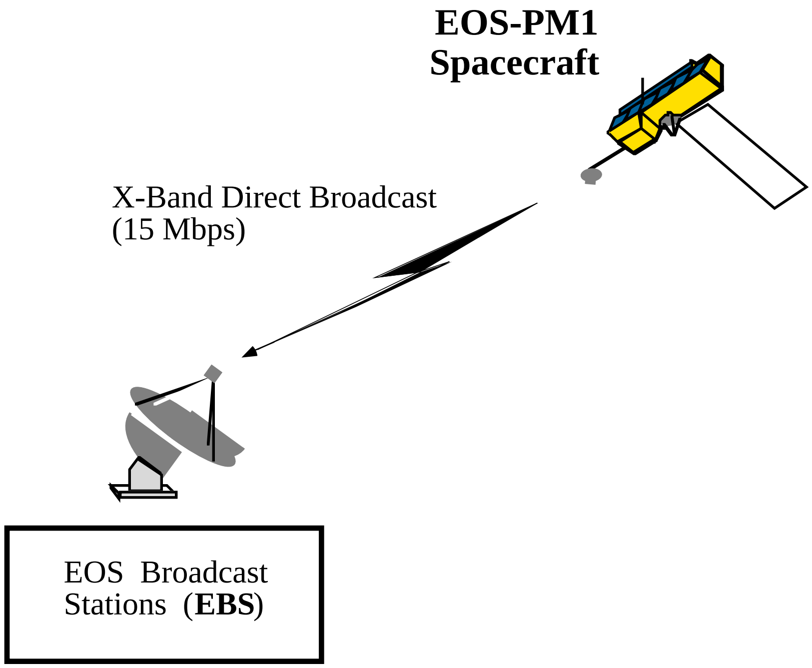

Figure 1.3-1: RF X-band Direct Broadcast Downlink

1.3.2 Functional Description

In the Broadcast mode the spacecraft continuously transmits all real-time instrument science data, real-time spacecraft engineering (housekeeping) data, and instrument engineering (housekeeping) data as it travels in a sun-synchronous near circular orbit at a nominal altitude of 705 km. The data rate is 15 Mbps at a nominal downlink frequency of 8160 MHz. In normal operations the Broadcast mode will be used during most of the orbit. The only time it is not used is during the approximate 8 to 22 minutes of every 99 minute orbit when the Playback or Downlink modes are active in playing back stored or real time data to the two Earth Observing System Polar Ground Stations (EPGS). The RF interfaces between the EOS-PM1 Spacecraft and the EPGS are defined in a separate RF Interface Control Document (ICD) referenced in Section 2.

1.3.3 Link Calculations

The RF link calculations contained in Appendix A for the Spacecraft modes of operation are included only as supporting data and do not constitute a formal part of the IDD agreement. The X-band earth coverage antenna pattern data provided in Appendix B are included for information purposes and are also not part a formal of this IDD.

2. DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents are applicable to the E0S-PM1 Spacecraft. In the event of conflict between this IDD and the documents listed below, the documents below govern.

a. GSFC-422-13-11-01, EOS-Common Spacecraft Specification, August 1994.

b. SS6-0165, TRW EOS Common Spacecraft Communications Subsystem Specification, 23 June, 1997

2.2 REFERENCE DOCUMENTS

The following documents are reference documents applicable to the RF interface. These documents do not form a part of this IDD and are not controlled by their reference herein.

a. GSFC 422-11-12-01, General Interface Requirement Document for EOS Common Spacecraft/Instruments, January 1994.

b. GSFC 422-11-TBD, Interface Control Document Data Format Control Book for EOS-PM Spacecraft, Date (TBD)

c. GSFC EOS Mission Operations Concept Document, March 1993

d. EPGS document, Radio Frequency Interface Control Document between the EOS-PM1 Spacecraft and the EOS Polar Ground Stations (EPGS) and the Wallops Island Station (WPS), April 1997

2.3 OTHER RELATED DOCUMENTS

The following documents are listed for the convenience of the user. These documents do not form a part of this IDD and are not controlled by their reference herein.

a. CCSDS 701.0-B-1 "Advanced Orbiting Systems, Networks and Data Links: Architectural Specification" , Issue 1, Blue Book, Consultative Committee for Space Data Systems, October, 1989.

b. CCSDS 101.0 B-3 "Telemetry Channel Coding" Blue Book, May 1992.

3. COMMUNICATIONS FUNCTIONAL INTERFACE

3.1 GENERAL

3.1.1 Interface RF Links

This section defines the required RF communication downlinks:

1. Spacecraft-to-EBS X-band Direct Broadcast (DB) data link
2. Spacecraft-to EBS X-Band Direct Broadcast Pseudo-Random Bit Stream (PRBS) link

3.1.2 Interface Functional Applicability

The RF communications interface functional and performance capabilities shall be applicable to the following project phases:

a) RF Compatibility Testing

b) End-to End (ETE) Testing: Full X-band capability

c) Pre-launch: Check-out

d) Orbit acquisition initialization and orbit acquisition: X-band communication links

f) Operations Phase - Full X band communications capability

g) End-of-Mission phase: X-band communication links

3.2 SPACECRAFT COMMUNICATIONS SUBSYSTEM OVERVIEW

A block diagram of the X-band section is shown in Figure 3.2-1. It consists of two modulators, a hybrid coupler, two traveling wave tube amplifiers (TWTAs), two isolators, a waveguide switch, a bandpass filter, a lowpass filter, and an X-band earth coverage antenna.

Each of the identical modulators receive broadcast or playback I and Q channel data from the Formatter Multiplexer Unit (FMU) in the Command and Data Handling (C&DH) subsystem. A clock signal is output from the active modulator to the FMU, setting the modulator input data rate. For the PM1 mission, the data rate is 15 Mbps using the Direct Broadcast link. The I& Q channels are balanced so that alternating bits of the data stream are placed on each channel (viz 7.5 Mbps). The incoming data is then directly Staggered Quadriphase Shift Key (SQPSK) modulated onto an 8160 MHz carrier. The resulting RF signal is then sent to the active TWTA via the 3 dB hybrid coupler. The coupler provides cross strapping between the redundant modulators and redundant TWTAs.

Each X-band TWTA consists of a traveling wave tube and power converter. The power converter generates the required traveling wave tube voltages from the spacecraft DC power bus. To prevent TWTA damage and/or performance degradation due to potential voltage reflection an isolator is used at the TWTA output. The active TWTA amplifies the modulated input signal to a nominal saturated output power of 25 Watts (23 Watts EOL minimum). The resulting RF signal from the isolator is routed through a waveguide switch to the filters. This switch provides a two-for-one redundancy of the RF signal path.

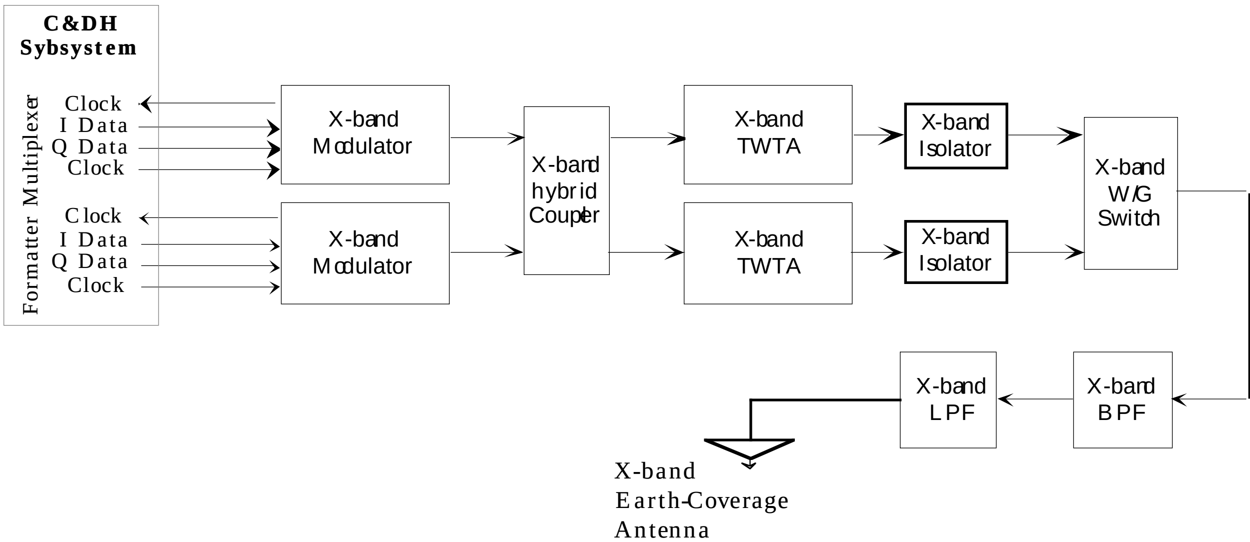

Figure 3.2-1: Communications Subsystem X-band section block diagram

Before transmission through the earth coverage antenna, the TWTA output signal is filtered by two X-band Filters. The purpose of the filters is twofold. First, the bandpass filter reduces the portion of the spectrum falling within the Deep Space Research band (8400 MHz to 8450 MHz) to meet the CCIR recommended power spectral density requirement at the ground. Second, the lowpass filter suppresses harmonic components to comply with on-board instrument noninterference requirements.

After filtering, the signal is radiated with Right Hand Circular Polarization (RHCP) through the X-band earth coverage antenna. The antenna is mounted at the end of a boom that is deployed after launch to obtain a full earth field-of-view. Across a 63.8 degree half angle cone the reflector is shaped to provide approximately constant power density to a fixed earth station as the spacecraft passes overhead. Since a 5 degree ground station elevation angle corresponds to 63.8 degrees from antenna Nadir, the cone represents the nominal operating beamwidth of the antenna.

3.3 COMMUNICATIONS PERFORMANCE CHARACTERISTICS

RF link performance characteristics for the communications functional capability described in Paragraph 3.3 are defined in this section. The EBS communications performance characteristics are based on the presumption that the Spacecraft and EBS each perform in accordance with the X-band performance parameters defined in Section 4

3.3.1 Science Data Channel BER

The maximum X-band downlink information BER for the detected digital science data in the science data channel shall be $\leq 10^{-3}$, referenced to the input of a Reed Solomon Decoder on the ground. This assumes that the downlink signal meets all the characteristics in Section 4.

3.3.2 PRBS Test Channel BER

The maximum X-band downlink information BER for the PRBS test channel shall be $\leq 10^{-3}$ referenced to the input of a Reed-Solomon decoder on the ground. This assumes that the downlink signal meets all the characteristics in Section 4.

3.4 COMMUNICATIONS FUNCTIONAL CHARACTERISTICS

Section 3.4.1 and 3.4.2 describes the Communications functional characteristics which exist between the Spacecraft and the EBS. This is dependent upon favorable radio line of sight conditions and when the station antenna elevation angle is greater than 5 degrees (above the local mask). The Spacecraft X-band downlink Broadcast modes are shown in Table 3.4-1.

3.4.1 Science Data Mode

Transmission from the Spacecraft to EBS of real time science and engineering data on the I and Q channels will be at a total data rate of 15 Mbps. Science data shall be formatted in accordance with the characteristics outlined in Paragraph 4.2.

3.4.2 Pseudo-Random Bit Stream (PRBS) Mode

PRBS test data will be generated in the Formatter Multiplexer Unit (FMU) of the C&DH subsystem and sent to the X-band modulator on the I and Q channels maintaining a total data rate of 15 Mbps. The PRBS test mode is used for the purpose of bit error rate (BER) checking, as required. It is not a normal X-band downlink service

Table 3.4-1: X-band Broadcast downlink modes

Mode	Description	I/Q Data Rate [Mbps]	Data Type
DB	Direct Broadcast (worldwide)	7.5 / 7.5	All real-time S&E data
TB	Test Broadcast	7.5 / 7.5	PRBS

S&E: Science and Engineering
PRBS: Pseudo Random Bit Stream

4. LINK INTERFACE CHARACTERISTICS

This section describes the functional design of the RF X-band Direct Broadcast link. Pertinent Spacecraft and EBS communications signal designs and system performance characteristics are also described.

4.1 LINK FUNCTIONAL DESIGN

4.1.1 Spacecraft to Ground Station Design

The X-band section provides the downlink interface for both the Direct Broadcast and Test Direct Broadcast modes. For EBS support of the EOS-PM1 mission, only Direct Broadcast will be utilized to transmit real time science and engineering data to the ground stations. Therefore, Pseudo-Random Bit Stream (PRBS) test data transmission will be used only for bit error rate performance checking. In other words, when the PRBS test mode is on, the Direct Broadcast mode will be off.

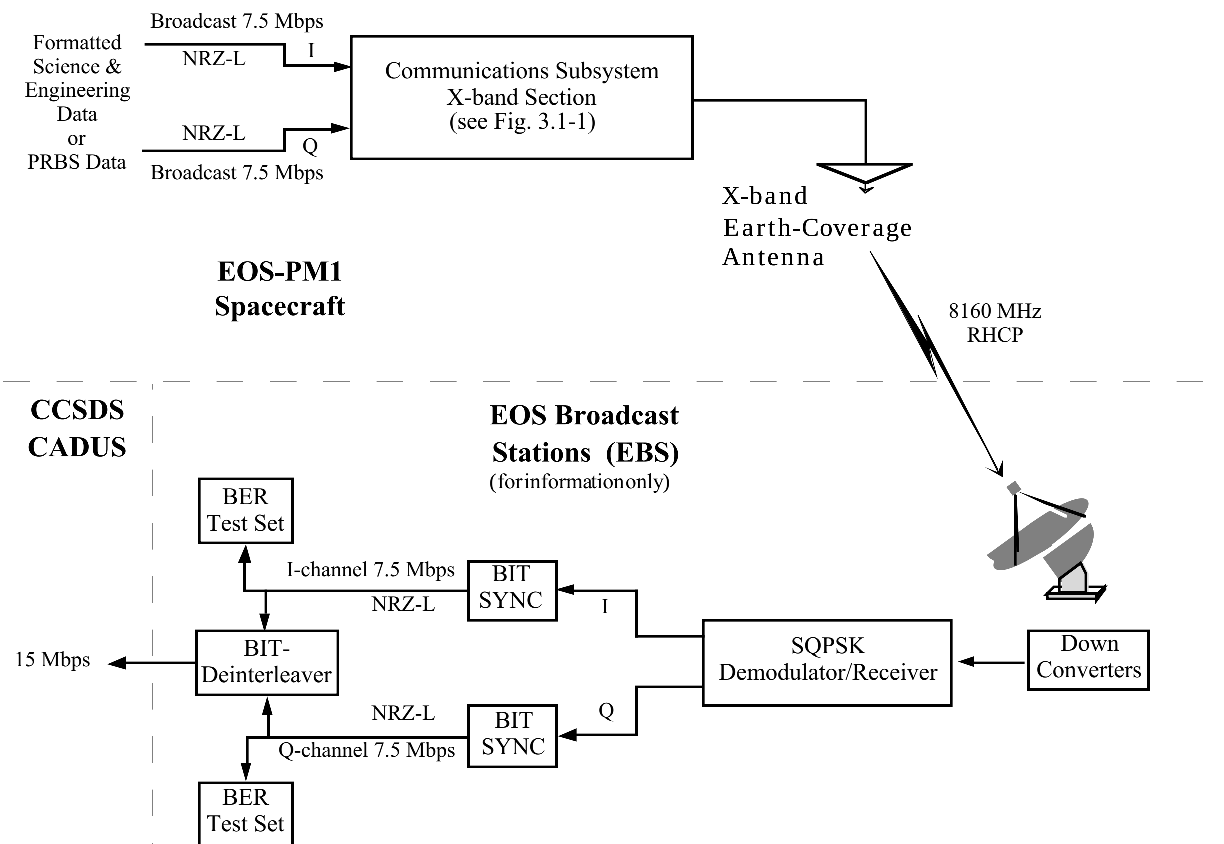

Figure 4.1-1: Spacecraft-to-EBS ground station downlink configuration

4.1.2 Spacecraft to Ground Station Functional Description

The functional interface of this link is shown in Figure 4.1-1. EBS configuration is shown for information purposes only. The Spacecraft data from the Formatter Multiplexer Unit (FMU) in the

C&DH subsystem is processed in real time at 15 Mbps. It is bit interleaved into two streams of 7.5 Mbps (one for the I-channel and one for the Q-channel) and sent to the X-band modulators. This signal is sent using the Non-Return to Zero level (NRZ-L) format. In the PRBS test mode, the data is a PRBS. This is generated in the FMU and sent via NRZ-L format on the I and Q channels at a rate of 7.5 Mbps each.

Irrespective of the transmission mode selected, the I and Q channel data is Staggered Quadrature Phase Shift Keying (SQPSK) modulated onto the X-band carrier with an I/Q channel power ratio of 1-to-1. The X-band carrier at a frequency of 8160 MHz is derived from an internal oscillator in the modulator. The traveling wave tube amplifier (TWTA) performs amplification of the SQPSK signal received from the modulator to the nominal saturated output power of 25 Watts (23 Watts EOL minimum) for data transmission. The X-band filters suppress harmonic components and out-of-band emissions from the TWTAs, and also suppress the portion of the X-band spectrum falling within the Deep Space Research 8.4 to 8.45 GHz frequency band. The link uses the RHC polarized earth coverage antenna to transmit the signal to EBS.

At the EBS, the input signal from the receive antenna is downconverted before being input to the SQPSK receiver/demodulator. A separate tracking receiver may be utilized for antenna auto-tracking purposes. The SQPSK receiver/demodulator demodulates the downconverted signal into separate I and Q channel data stream with NRZ-L format. Following QPSK demodulation, the bit synchronizers recover bit clock. The 7.5 Mbps NRZ-L I and Q channels Broadcast data stream may then be combined into one single stream of 15 Mbps. For the PRBS test mode, the data may be provided to a BER test set for BER performance testing. (Note: Because NRZ-L data format is used, the CCSDS Attached Sync Marker (ASM) is expected to be be used to resolve data inversion ambiguity in the ground station.)

4.2 SIGNAL CHARACTERISTICS AND CONSTRAINTS

This section provides a description of the signal characteristics and constraints of the X-band downlink signal to the EBS.

4.2.1 Science Frame Format

The science and engineering data transmitted via Direct Broadcast will be formatted for transmission at 15 Mbps over the X-band link. With the exception of PRBS data, the delivery service will be equivalent to the Grade 2 service defined in CCSDS 701.00-R-3, Advanced Orbiting Systems, Networks and Data Links: Architectural Specification, will be provided in GSFC 422 (TBD), the EOS Common Spacecraft to the ground system ICD. See Figure 4.2-1 for the downlink transfer frame format.

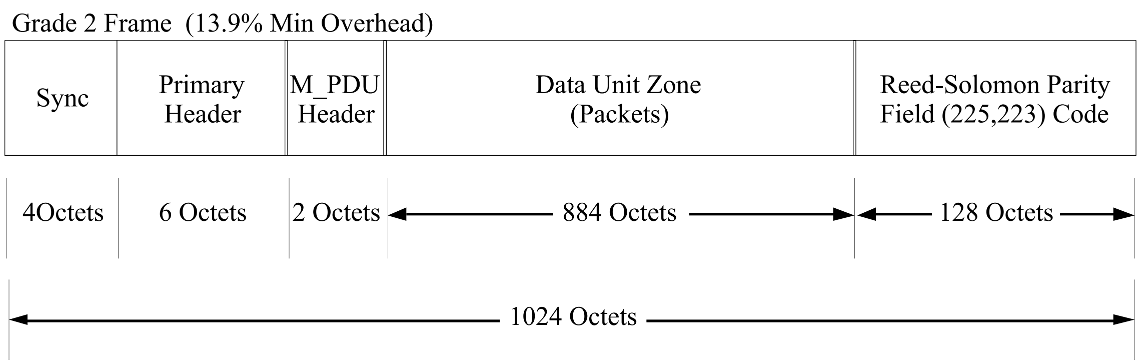

Figure 4.2-1: Channel Access Data Unit (Sync + coded VCDU)

4.2.1.1 Reed-Solomon Coding

To provide improved bit error performance, the downlink data will have a (255,223) Reed-Solomon code with interleave depth I = 4.

4.2.2 Randomizer for Generation of PRBS

a. The pseudo-random bit stream (PRBS) is generated by the Spacecraft using the following bit transition generation function (refer to CCSDS 101.0 B-3 "Telemetry Channel Coding" Blue Book, May 1992, pp. 6-1):

$$h(x) = x^8 + x^7 + x^5 + x^3 + 1$$

b. This bit sequence repeats after 255 bits and the randomizer is reinitialized to an all-ones states during each Synchronization Marker period. The first 40 bits of the pseudo-random bit stream are shown below: the left-most bit is the first bit of the sequence and is exclusively ORed with the first bit of the CVCDU.

1111 1111 0100 1000 0000 1110 1100 0000 1001 1010

4.2.3 Signal Characteristics

The Spacecraft X-band downlink signal characteristics are contained in Table 4.2-1. As noted, Balanced SQPSK modulation (channel power ratio of 1-to-1) is used for the Spacecraft-to-EBS X-band Direct Broadcast link.The X-band downlink uses the RHC polarized earth coverage antenna on the Spacecraft.

Table 4.2-1: X-band Downlink Signal Characteristics

Parameter	Requirement
Center Frequency	8160 MHz
Bandwidth (1st null-to-1st\ null)	15 MHz*
Data Modulation	SQPSK
Data Format	NRZ-L
I/Q Power ratio	1 : 1
Operational Duty Cycle	100%
Antenna Coverage from nadir	±63.8°
Antenna Polarization	RHCP
Data Rate	15 Mbps

* Channel bandwidth ≈150 MHz

4.2.3.1 Data Signal Format

The science data signal output from the FMU of the C&DH subsystem is in NRZ-L signal format prior to the modulator. The format for NRZ-L data shall conform to that shown in Figure 4.2-2.

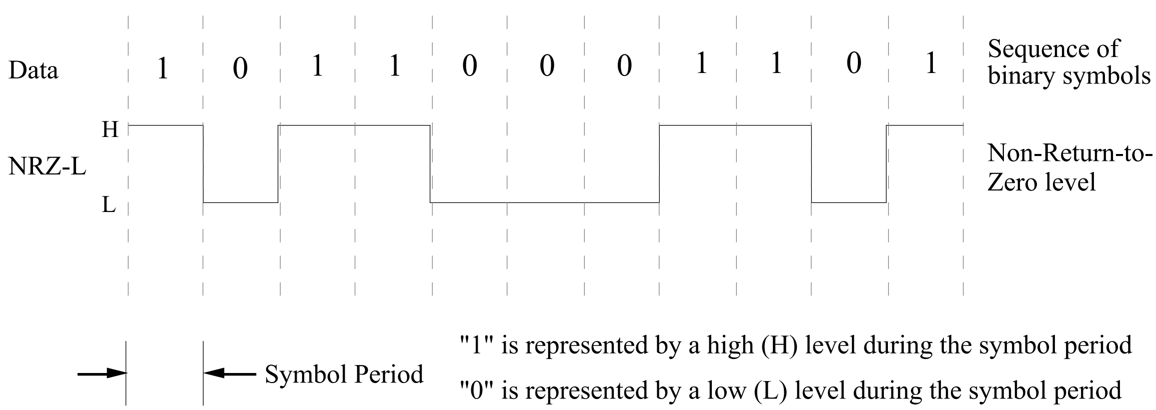

Figure 4.2-2: Digital data Signal Formats

4.2.3.2 Data Rate Accuracy

Accuracy of the Direct Broadcast 15 Mbps data rate is within ±1.8 kbps.

4.2.4 Modulated Signal Constraints

The signal constraints of the X-band Direct Broadcast link are in accordance with Table 4.2-2. The X-band carrier is SQPSK modulated using the I and Q baseband signals

Table 4.2-2: X-band Downlink Signal Constraints

Parameter	Requirement
Frequency Stability a) 1 second average b) 5 hour average	 $\pm 0.003 \times 10^{-6}$ $\pm 0.1 \times 10^{-6}$
Phase Noise 1 to 10 Hz 10 to 100 Hz 100 to 1000 Hz 1000 to 1 MHz	 ≤ 15° RMS ≤ 7.5° RMS ≤ 2.0° RMS ≤ 2.0° RMS
Data Asymmetry @ 15 Mbps	≤ 0.4 %
I/Q Data rise/fall Time	≤ 2.5 nanosec.
Data Bit Jitter	≤ 1 %
I/Q Data Skew (Q delayed 0.5 bit)	0.5 ± 0.1 bit
SQPSK Amplitude Imbalance	≤ 0.5 dB p-p
SQPSK Phase Imbalance	≤ 4°
SQPSK Carrier Suppression	≥ 30 dBc
Gain Slope†	≤ 0.2 dB/MHz
AM/PM	≤ 5°/dB
Spurious PM	< 2° RMS
Gain Flatness†‡	< 4.0 dB p-p
Phase Nonlinearity†‡	< 29° p-p

† Over 150 MHz bandwidth centered at 8160 MHz

‡ At ±17° from antenna boresight

4.2.4.1 Spacecraft Frequency Stability

The Spacecraft X-band downlinks use a single fixed frequency reference for the transmit carrier. The frequency reference source is generated by an internal oscillator. The carrier frequency derived from the oscillator is 8160 MHz within the 8025-8400 MHz. The frequency characteristics of the oscillator are given below.

4.2.4.2 Output Frequency Stability

The frequency stability of the oscillator will be equal to or better than the value specified in Table 4.2-2. Long term stability will be less than $\pm 2\times10^{-6}$/YR and the initial set tolerance will be less than $\pm 2\times10^{-6}$. Over a -20°C to +60°C temperature range the stability will be less than $\pm 6\times10^{-6}$.

4.2.4.3 Phase Noise

The carrier phase noise will be equal or better than the values specified Table 4.2-2.

4.3 DOWNLINK ACQUISITION AND TRACKING

4.3.1 EBS Station Characteristics

The EBS station parameters need to be better than or equal to the G/T values shown in Table 4.3-1 to insure the specified BER performance.

Table 4.3-1: X-band EOS Broadcast Station G/T values

Elevation [deg.]	EBS Ground Station G/T [dB/K]
5°	21.0
40°	22.5
70°	22.7
90°	23.4

4.3.2 Carrier Acquisition and Tracking Threshold

The carrier loop in the ground station X-Band receiver should automatically acquire the modulated or unmodulated carrier signals received within ±800 kHz (TBR) of the nominal carrier frequency.

The Ground station should track the signal provided:

a. The received SNR in the carrier tracking loop bandwidth of ±25 kHz within the nominal carrier is 10 dB (TBR), and
b. the received SNR in the 2nd IF bandwidth of TBD MHz is ≥ TBD dB.

Appendix A

LINK CALCULATIONS

Table A - 1: Broadcast Link Margin Summary

Ground Elevation	Nominal Margin [dB]	Adverse Margin [dB]
5° elevation <=> 63.8° off-Nadir	2.7	1.3
71° elevation <=> 17° off-Nadir	2.0	0.8
90° elevation <=> 0° off-Nadir	7.2	2.2

Table A - 2: Direct Broadcast Mode - 15 Mbps X-band Downlink Budget

	Parameter	Results at off-nadir angles, θ 63.8°	17°	0°	Units	Adverse Tolerance	Items in Table 8.2-4
1.	TWTA Tx Output Power	13.6	13.6	13.6	dBW	+0.0	Item 2
2.	Transmit Circuit loss/gain	-3.9	-3.9	-3.9	dB	+1.1	Item 3
3.	Antenna loss/gain	5.6	-8.0	-4.0	dBi	Fn(θ)	Item 4 a, b, &, c
4.	EOS EIRP	15.4	1.8	5.8	dBWi		∑
6.	Space loss/gain	-178.9	-168.1	-167.6	dB	+0.0	Item 6 a, b, &, c
7.	Atmospheric loss/gain	-0.5	0.0	0.0	dB	+0.0	Item 7 a, b, &, c
9.	Polarization loss/gain	-0.4	-0.4	-0.4	dB	+0.5	Item 9
10.	Received isotropic power	-164.4	-166.7	-162.3	dBWi		∑
11.	User Ground Terminal G/T	21.0	22.7	23.4	dBi/K	+0.0	Item 10 a, b, &, c
12.	1/Boltzmann's constant	228.6	228.6	228.6	dBHzK/W		1.38*10^-23 W s / K
13.	1/Data rate	-71.8	-71.8	-71.8	dB-sec.		Item 11
14.	Received Eb/No	13.5	12.8	18.0	dB		∑
15.	Implementation loss/gain	-4.0	-4.0	-4.0	dB	+0.0	Item 12
16.	Required Eb/No	-6.8	-6.8	-6.8	dB	+0.0	Item 13
17.	**Nominal** link margin	2.7	**2.0**	7.2	dB		
	Adverse tolerance	-1.4	-1.3	-4.9	dB	<<< Fn(θ)	Adverse Tolerance
18.	**Adverse** link margin	**1.3**	**0.8**	2.2	dB		Margin less adv. tol.

Note: End-to-end data rate refers to the 15 Mbps data stream at input to Reed-Solomon decoder

Table A - 3: X-band Downlink Budget - Parameters

	Parameter	Units	Value	Adv.	Comments
1.	Frequency	GHz	8.1600		Selected frequency in 8.025 - 8.400 GHz band
2.	TWTA Transmit Output Power	dBW	13.62	0.0	Based on 23W **end-of-life** from TWTA spec.
3.	Transmit Circuit Losses	dB	3.85	1.1	Current estimate
4.	Antenna Gain				Adverse tol. @ 5° includes 0.6° mispointing
	(a) 5° elev. <=> 63.8° off-Nadir	dBi	5.6	0.7	◊ **Nominal** measurements at **8212.5 MHz**
	(b) 71° elev. <=> 17° off-Nadir	dBi	-8.0	0.4	from 90° cut Landsat D breadboard #2
	(c) 90° elev. <=> 0° off-Nadir	dBi	-4.0	4.8	
6.	Space Loss				From EOS to X-band ground terminal
	(a) 5° elevation angle	dB	178.9		Range at 2574 km. is maximum range
	(b) 71° elevation angle	dB	168.1		Range at 741 km.
	(c) 90° elevation angle	dB	167.6		Range at 705 km.
7.	Atmospheric loss				For Direct Playback and Direct Broadcast
	(c) 5° elevation angle	dB	0.50		Clear air atmospheric using CCIR Specific Model
	(b) 71° elevation angle	dB	0.05		
	(a) 90° elevation angle	dB	0.05		
	Ground temperature	deg C	22.0		CCIR Specific Model: ground station temp.
	Water Vapor Density	g/m^3	7.5		CCIR Specific Model: water vapor density
	Earth Terminal Altitude	km	0.0		CCIR Specific Model: alt. above mean sea level
8.	Rain Loss				For Direct Playback only (Using Crane model)
	(a) 5° elevation angle	dB	0.00		95% avail. & climate A (99.7% => 0.06 dB)
	(b) 71° elevation angle	dB	0.00		95% avail. & climate A
	(c) 90° elevation angle	dB	0.00		95% avail. & climate A
9.	Polarization Loss	dB	0.35	0.5	0.2 assumes 3.2 nominal and 4.3 worst case
	Ground Terminal Rx Axial Ratio	dB	1.8		Est. per C. Wu email 3/10/97
	S/C Transmit Axial Ratio	dB	3.2		◊ **Nominal** Landsat D breadboard #2
10.	User Ground Station G/T				
	(a) 5° elevation angle	dBi/K	21.0		Direct Broadcast (15 Mbps) §4.3.5.10†
	(b) 71° elevation angle	dBi/K	22.7		^Temperature increase due to rain is 0 dB
	(c) 90° elevation angle	dBi/K	23.4		
11.	CCSDS data rate				
	15 Mbps	dB-Hz	71.8		
12.	Other losses				
	Minimum Implementation Loss	dB	3.0		From §4.3.5.11† (DP) and §4.3.5.10† (DB)
	Add'l s/c Signal Distortion	dB	1.0		Est.
	Total	dB	4.0		**TBD**
13.	Required Eb/No				10^-3 BER per §4.3.5.8†
	Ideal required Eb/No	dB	6.8		Ideal PSK (no coding); CCSDS 700.0 G-3 Pg. A-5

† EOS-PM Common Spacecraft Specification: GSFC 422-13-11-01 August, 1994

Appendix B

TYPICAL X-BAND

EARTH COVERAGE ANTENNA PATTERN