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INTERFACE DESCRIPTION DOCUMENT

FOR

EOS AQUA X-BAND DIRECT BROADCAST

EOS AQUA PROJECT

JUNE 2002

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

INTERFACE DESCRIPTION DOCUMENT

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NASA Goddard Space Flight Center
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1. INTRODUCTION

1.1 SCOPE

This Interface Description Document (IDD) describes the Direct Broadcast (DB) radio frequency interface between the EOS AQUA spacecraft and the worldwide Earth Observing System (EOS) Direct Broadcast Ground Stations (DBGS), which receive real time science and engineering data via X-band DB service. Source of information for the DB data content and structure is also provided.

1.2 OVERVIEW

EOS Aqua, formerly known as EOS-PM-1, is the second of the NASA EOS missions. It carries AIRS, AMSR-E, AMSU-A, CERES, HSB and MODIS instruments.

In the Direct Broadcast mode the Aqua spacecraft continuously transmits all real-time instrument science data, real-time spacecraft engineering (housekeeping) data, instrument engineering (housekeeping) data and ground-based attitude determination (GBAD) data as it travels in a sun-synchronous near circular orbit at a nominal altitude of 705 km (Figure 1.2-1). The data rate is 15 Mbps at a nominal downlink frequency of 8160 MHz. In normal operations the Direct Broadcast mode will be on during most of the 99 minute orbit. It is off briefly when the spacecraft is in Playback mode, playing back data stored in the onboard solid state recorder to one of the four Earth Observing System Polar Ground Stations (EPGS) located at Poker Flat, Alaska and Svalbard, Norway.

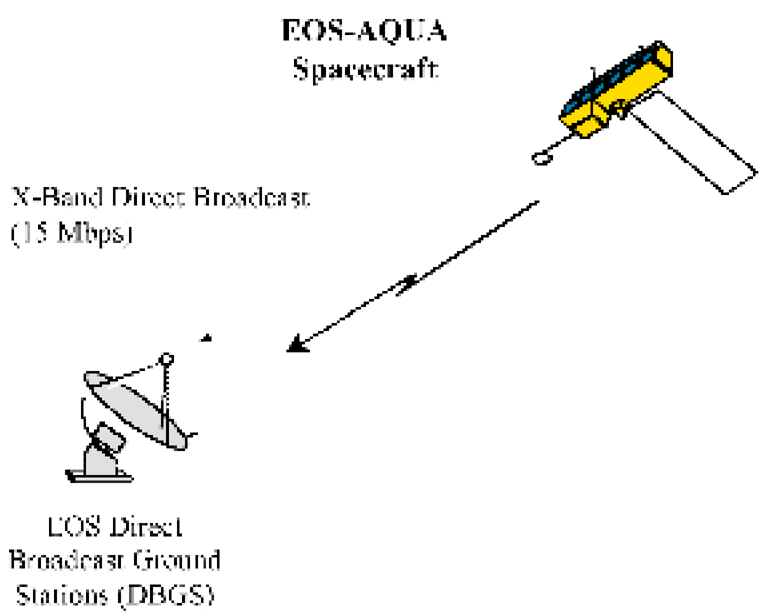


Figure 1.2-1 X-band Direct Broadcast Downlink

1.3 LINK CALCULATIONS

The RF link calculations and the X-band earth coverage antenna pattern data are provided in Appendix A and Appendix B respectively.

1.4 DATA CONTENTS AND FORMATS

The contents and formats of the DB data are described in Section 5 and Appendix B of Reference Document 2a, EOS PM-1 Spacecraft to EOS Ground System Interface Control Document. It should be pointed out that the GBAD data includes not only the data for ground attitude determination but also a selected subset of spacecraft and instrument housekeeping data useful for science data analysis.

2. REFERENCE DOCUMENTS

a. GSFC 422-11-19-03: EOS PM-1 Spacecraft to EOS Ground System Interface Control Document, Revision A, March 2002.

b. CCSDS 701.0-B-2: Advanced Orbiting Systems, Networks and Data Links: Architectural Specification, Issue 1, Blue Book, Consultative Committee for Space Data Systems, November 1992.

c. CCSDS 101.0 B-3: Telemetry Channel Coding, Blue Book, May 1992.

3. LINK INTERFACE CHARACTERISTICS

This section describes the functional design of the RF Direct Broadcast link, spacecraft and DBGS communications system performance and signal characteristics.

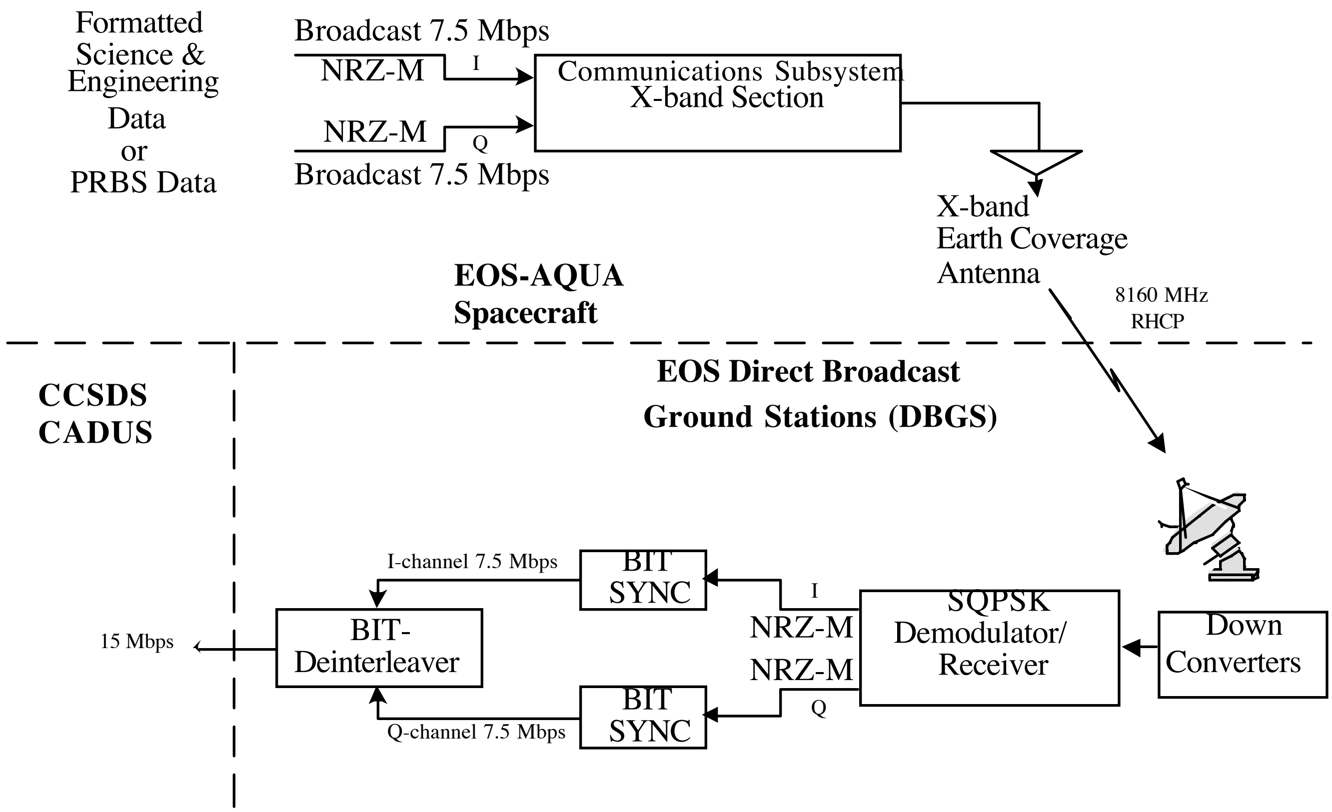
3.1 SPACECRAFT TO GROUND STATION FUNCTIONAL DESIGN

The functional interface of this link is shown in Figure 3.1-1. DBGS configuration is shown for information purposes only. On the Spacecraft, data from the Formatter Multiplexer Unit (FMU) in the

C&DH subsystem is processed in real time at 15 Mbps. The data is Reed-Solomon coded as described in 3.2.1.1 and CCSDS randomized as described in 3.2.1.2. Randomization can be commanded off if desired. The Reed-Solomon coded and randomized data is then 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. Each data stream is sent using the Non-Return to Zero Mark (NRZ-M) format. In the case of a bit error rate (BER) test, the data is a Pseudo-Random Bit Stream (PRBS). This is generated in the FMU and sent also via NRZ-M format on the I and Q channels at a rate of 7.5 Mbps each.

The I and Q channel data is then Staggered Quadrature Phase Shift Keying (SQPSK) modulated onto the X-band carrier with an I/Q channel power ratio of 1-to-1. The Q-channel data is modulated on the Q-carrier which is delayed by 90 degrees with respect to the I-channel data carrier. The I-channel and Q-channel staggered data relationship is such that the Q-channel data is delayed by 0.5 ± 0.1 symbol with respect to the I-channel data. The I-channel bit is the first bit of an I/Q data bit pair. 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 End-of-Life 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 Right Hand Circular Polarization (RHCP) earth coverage antenna to transmit the signal to DBGS. Across a 63.8 degree half cone angle the reflector is shaped to provide approximately constant power density to any DB ground station with line-of-sight view as the spacecraft passes overhead.

As illustrated in Figure 3.1-1, once the input signal at the DBGS antenna is received, it 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 streams. Following SQPSK demodulation, the bit synchronizers recover bit clock. The 7.5 Mbps I and Q channels Broadcast data stream may then be combined into one single stream of 15 Mbps. Again, the I-channel bit leads the Q-channel bit and is the first bit of an I/Q data bit pair. The data must be de-randomized and Reed-Solomon decoded. In the case of a BER test, the data may be provided to a BER test set.



Note:

The 15 Mbps output from the bit deinterleaver needs to be de-randomized and Reed-solomon decoded

Figure 3.1-1 Spacecraft-to-DBGS Ground Station Downlink Configuration

3.2 SIGNAL CHARACTERISTICS AND CONSTRAINTS

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

3.2.1 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 as described in Section 5 of Reference Document 2a, EOS PM-1 Spacecraft to EOS Ground System Interface Control Document. See Figure 3.2-1 for the downlink Channel Access Data Unit format.

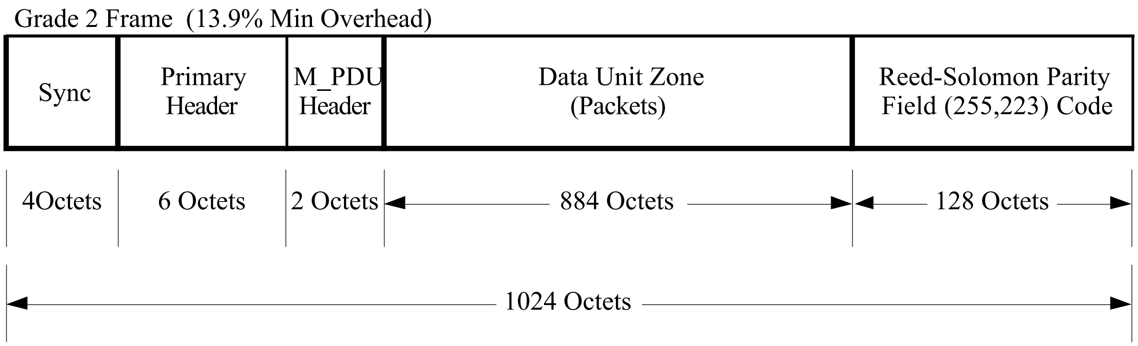


Figure 3.2-1 Channel Access Data Unit (Sync + coded VCDU)

3.2.1.1 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.

3.2.1.2 Data Randomization

a. The pseudo-random bit stream (PRBS) is generated by the Spacecraft using the following bit transition generation function (refer to Reference Document 2c, 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 coded VCDU, i.e. the entire CADU is thus randomized except for the 32-bit Sync Marker,

1111 1111 0100 1000 0000 1110 1100 0000 1001 1010

3.2.2 Signal Characteristics

The Spacecraft X-band downlink signal characteristics are provided in Table 3.2-1. As noted, the Balanced SQPSK modulated signal (channel power ratio of 1-to-1) is radiated using a RHC polarized Earth Coverage antenna on the Spacecraft.

Table 3.2-1 X-band Downlink Signal Characteristics

Parameter	Requirement
Center Frequency Bandwidth (1st null-to-1st null) Data Modulation Data Format	8160 MHz 15 MHz* SQPSK NRZ-M
I/Q Power ratio Operational Duty Cycle Antenna Coverage from nadir	1 : 1 100% ±63.8°
Antenna Polarization	RHCP
Data Rate	15 Mbps
Coding	Reed-Solomon (255-223) (No Convolutional Coding)

* Channel bandwidth □150 MHz

3.2.2.1 Data Format

The science data output from the FMU of the C&DH subsystem is in NRZ-M data format prior to the modulator. The I and Q channels are separately NRZ-M coded. The format for NRZ-M data is shown in Figure 3.2-2.

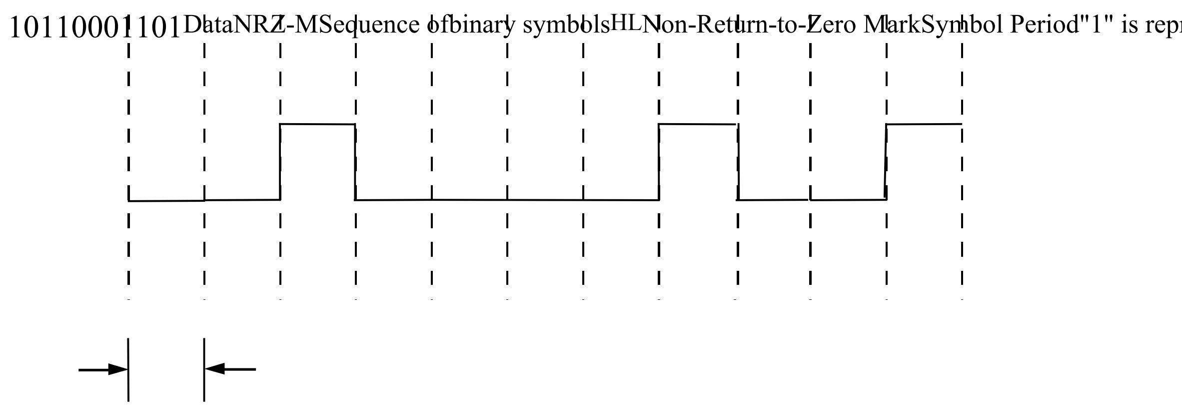


Figure 3.2-2 Digital Data Format

3.2.2.2 Data Rate Accuracy

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

3.2.3 Modulated Signal Constraints

The signal constraints of the X-band Direct Broadcast link are in accordance with Table 3.2-2. The X-band carrier is SQPSK modulated using the I and Q baseband signals.

Table 3.2-2 X-band DB Downlink Signal Constraints

Parameter	Requirement
Frequency Stability	
a) 1 second average	±0.003 × 10^{-6}
b) 5 hour average	±0.1 × 10^{-6}
Phase Noise	
10 to 100 Hz	≤ 7.5° RMS
100 to 1000 Hz	≤ 2.0° RMS
1000 to 1 MHz	≤ 2.0° RMS
Data Asymmetry @ 15 Mbps	≤ 0.4 %
I/Q Data rise/fall Time	≤ 2.5 nanosec.
Data Bit Jitter	≤ 5 %
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‡	< 2.0 dB p-p
Phase Nonlinearity‡	< 12° p-p

† Over 150 MHz bandwidth centered at 8160 MHz

‡ Over 15 MHz centered at 8160 MHz

3.2.3.1 Downlink 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 bandwidth.

The frequency stability of the oscillator will be equal to or better than the value specified in Table 3.2-2. Long term stability will be less than ±2×10^{-6}/YR and the initial set tolerance will be less than ±2×10^{-6}. Over a -20°C to +60°C temperature range the stability will be less than ±6×10^{-6}.

3.2.3.2 Phase Noise

The carrier phase noise will be equal or better than the values specified in Table 3.2-2.

3.2.4 Bit Error Rate

The X-band downlink BER for the detected digital science data in the data channel will be ≤10^{-3}, at the input of a Reed-Solomon Decoder on the ground. 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).

3.3 DBGS Station Characteristics

To ensure the specified BER performance the DBGS station parameters need to be better than or equal to the G/T values shown in Table 3.3-1.

Table 3.3-1 X-band EOS Direct Broadcast Ground Station G/T

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

Appendix A

LINK CALCULATIONS

Table A-1 Direct Broadcast Link Margin Summary

Ground Elevation	Nominal Margin [dB]	Adverse Margin [dB]
5° elevation <=> 63.8° off-Nadir	5.7	4.8
71° elevation <=> 17° off-Nadir	4.6	2.6
90° elevation <=> 0° off-Nadir	8.8	8.1

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

	Parameter	Results at off-nadir angles, □			Units	Adverse Tolerance (dB)	Items in Table A-3
		63.8°	17°	0°			
1.	TWTA Tx Output Power	14.0	14.0	14.0	dBW	0.4	Item 2
2.	Transmit Circuit loss	-3.0	-3.0	-3.0	dB	0.2	Item 3
3.	Antenna loss/gain	6.8	-7.2	-4.1	dBi	0.5,1.6,0.3	Item 4 a, b, &, c
4.	EOS EIRP	17.8	3.8	6.9	dBWi		□
6.	Space loss/gain	-178.9	-168.1	-167.6	dB	-	Item 6 a, b, &, c
7.	Atmospheric loss/gain	-0.5	0.0	0.0	dB	-	Item 7 a, b, &, c
9.	Polarization loss/gain	-0.4	-0.5	-0.6	dB	0.6,1.2,0.4	Item 9
10.	Received isotropic power	-162.0	-164.8	-161.3	dBWi		□
11.	User Ground Terminal G/T	21.0	22.7	23.4	dBi/K	-	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	15.8	14.7	18.9	dB		□
15.	Implementation loss/gain	-3.3	-3.3	-3.3	dB	-	Item 12†
16.	Required Eb/No	-6.8	-6.8	-6.8	dB	-	
17.	Nominal link margin	5.7	4.6	8.8	dB		
	Adverse tolerance	-0.9	-2.0	-0.7	dB	0.9,2.0,0.7	Adverse Tolerance
18.	Adverse link margin	4.8	2.6	8.1	dB		Margin less adv. tol.

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

† Implementation loss is an estimate of spacecraft constraint loss plus ground station signal processing loss, individual user ground station loss could be higher.

Table A-3 X-band DB 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	14.0	0.4	25W nominal, 23W spec.
3.	Transmit Circuit Losses	dB	3.0	0.2	Current measurement
4.	Antenna Gain				
	(a) 5° elev. <=> 63.8° off-Nadir	dBi	6.8	0.5	Measurements, avg. (SN301 Antenna)
	(b) 71° elev. <=> 17° off-Nadir	dBi	-7.2	1.6	
	(c) 90° elev. <=> 0° off-Nadir	dBi	-4.1	0.3	
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/m³	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			
	Ground Terminal Rx Axial Ratio (1.8)	dB			Estimate
	S/C Transmit Axial Ratio:				AR Measurements, avg. (SN 301 Antenna)
	63.8° (4.9)	dB	0.4	0.6	
	17° (5.7)	dB	0.5	1.2	
	0° (6.7)	dB	0.6	0.4	
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				
	Differential Decoding Loss		0.3		NRZ-M
	Minimum Implementation Loss	dB	3.0		From §4.3.5.11† (DP) and §4.3.5.10† (DB)
	Total	dB	3.3		
13.	Required Eb/No				10^-3 BER per §4.3.5.8†
	Ideal required Eb/No	dB	6.8		Ideal PSK (no coding); CCSDS700.0 G-3 Pg. A-5

† EOS AQUA Common Spacecraft Specification: GSFC 422-13-11-01

Appendix B

X-BAND EARTH COVERAGE ANTENNA PATTERN

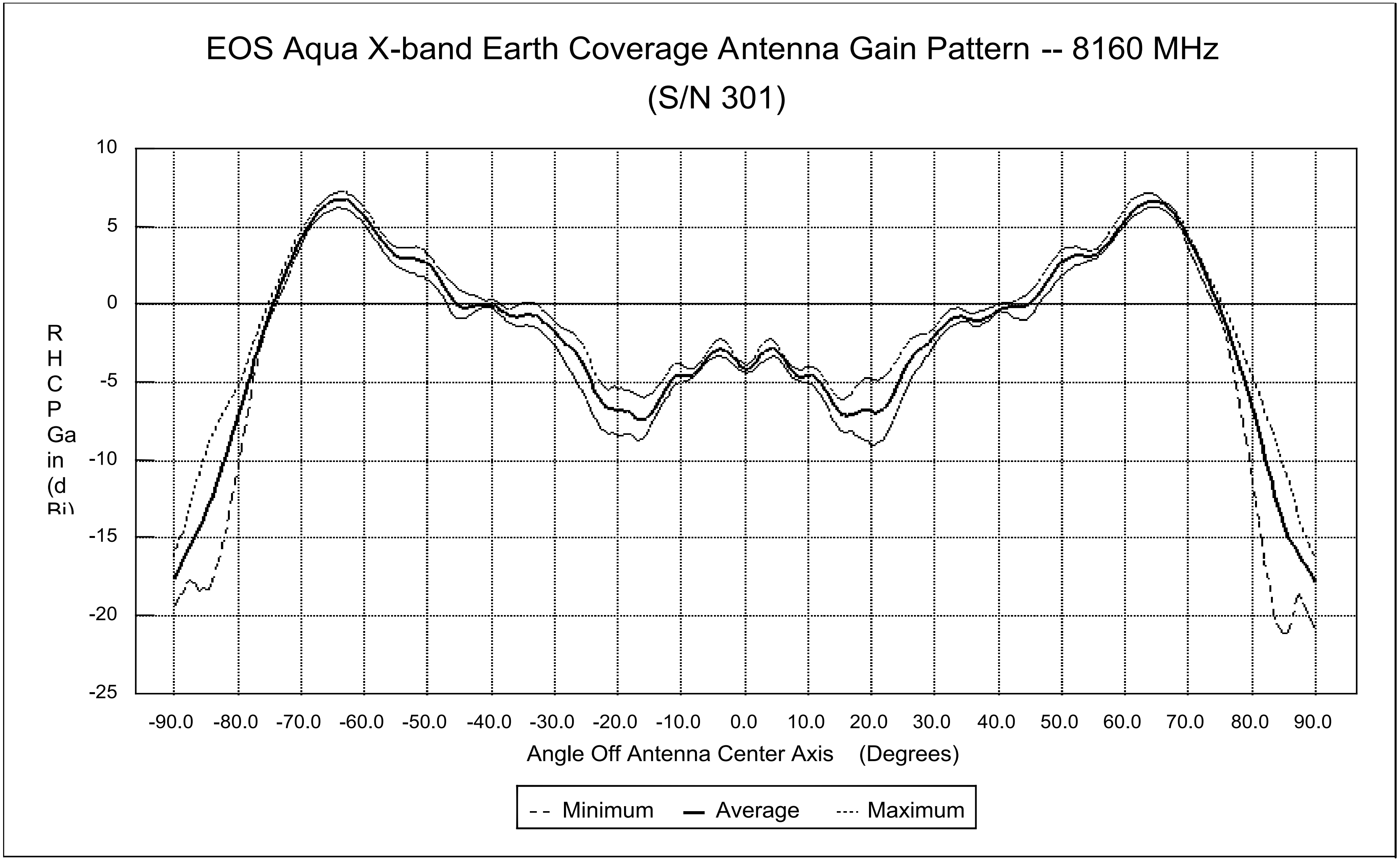


Figure B-1 EOS Aqua X-band Earth Coverage Antenna (S/N 301) Gain Performance