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Direct Access System User's Guide for the EOS–AM Spacecraft
(ICD–107)

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REVISION LOG

This log identifies those portions of this document which have been revised since the original issue. Revised portions of each page, for the current revision only, are identified by marginal striping.

Revision	Paragraph Number(s) Affected	Rev. Date	Approval
Preliminary 1		Feb. 28 1997	
Preliminary 2		Nov. 20 1998	

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1 SCOPE

This document provides the following:

a. an overview of the types of services which will be provided to the user community by the EOS–AM Spacecraft Direct Access System (DAS)

b. information which provides the user community an understanding of the ground station requirements for accessing the DAS services.

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2 APPLICABLE DOCUMENTS

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

The EOS–AM Spacecraft Communications Subsystem Specification, PS20008580, controls the requirements for the DAS design and operation. This specification shall govern in the event of a conflict between this DAS User's Guide and any of the documents listed below.

2.1 Lockheed Martin Documents

Design Documents:

20054745	EOS–AM–1 Spacecraft Flight Systems Manual, Volume III, Communications Subsystem
EOS–DN–COMM–014B	X–band Design Approach
EOS–DN–COMM–021	Design and Breadboard Report for the KSA and DAS Modulators
EOS–DN–COMM–025	Design and Breadboard Report for the Convolutional Encoder Boards in the EOS KSA and DAS Modulators
EOS–DN–C&DH–052	Command and Data Handling Subsystem Functional Description

Specifications:

PS20005396	EOS–AM Spacecraft Contract End Item Specification (SEP–101)
PS20008506	Critical Item Development Performance Specification: Direct Access System Antenna
PS20008573	Critical Item Development Performance Specification: DAS Upconverter
PS20008575	Critical Item Development Specification: Science Data Formatting Equipment
PS20008580	Performance Specification, Communications Subsystem for EOS–AM Spacecraft
PS20008589	Critical Item Development Performance Specification: DAS Modulator
PS20008590	Critical Item Development Performance Specification: DAS SSPA

PS20008745	Critical Item Development Performance Specification: Command and Data Handling/Communications Equipment Module
IS20008658	Interface Control Document Data Format Control Book for EOS AM Spacecraft (ICD–106)
Source:	Lockheed Martin Missiles and Space P.O. Box 8555 Philadelphia, PA 19101–8555

2.2 NASA Documents

Design Documents:

Memo to J. Deskevich, GSFC Code 502 from J. Hart, STel "EOS AM1 Interference to DSN at X–band," March 20, 1995.

Specifications:

531–RFICD–EOS AM–1/EPGN	X–band Radio Frequency Interface Control Document (RFICD) Between the EOS–AM–1 Spacecraft and the EOS Polar Ground Network (EPGN)
Source:	NASA Goddard Space Flight Center Code 531.1 Greenbelt, MD 20771
CCSDS 101.0–B–2 Jan. 1987	Consulting Consortium of Space Data Systems Telemetry Channel Coding, Issue 2, Blue Book
Source:	CCSDS Secretariat Communications and Data Systems Div. (Code–TS) National Aeronautics and Space Administration Washington, DC 20546

3 OVERVIEW OF THE DIRECT ACCESS SYSTEM (DAS)

The Direct Access System (DAS) provides real–time science data from the EOS–AM–1 Spacecraft Instruments directly to the science community independent of the EOS Data and Information System (EOSDIS). In addition to providing a direct–to–user communications link, the DAS serves as a backup to the TDRSS Ku–band science data return communications path.

The DAS transmits science data via an 8.2125 GHz link directly to user ground stations on the earth at the data rates shown in Table III. The DAS return link is a scheduled service which is available 100% of the time during Spacecraft science mode, and the availability of DAS services does not depend on High Gain Antenna (HGA) operability.

3.1 DAS RF Communication Links

The DAS provides three types of science data return capabilities, including:

a. real–time direct downlink (DDL) of ASTER instrument data

b. real–time direct broadcast (DB) of MODIS instrument data and Spacecraft ancillary data

c. direct playback (DP) for a backup to the Ku–band science data downlink.

> The direct playback service is described here for completeness. The performance requirements for the DAS contingency direct playback service are controlled by the X–band Radio Frequency Control Document (RFICD), 531–RFICD–EOS AM–1/EPGN.

These services are used to downlink data from Spacecraft Instruments as shown in Table I. The Spacecraft Bus will include packetized ancillary data in the DB and DP data streams which are identical to the ancillary data included with the science data for transmission via the Ku-band link. When DP service is used, the C&DH will include Spacecraft housekeeping telemetry in the data sent to the DAS Modulator.

The DB and DDL services will be provided during normal Spacecraft operations. The DP service will be used in contingency conditions only, i.e., when the Spacecraft is incapable of normal recorder playback via the HGA–TDRSS link.

Table I. Science Data Downlink Service Allocations

	ASTER	CERES	MISR	MOPITT	MODIS	Ancillary Data	House-keeping Teleme-try
DDL	✓						
DB					✓	✓	
DP	✓	✓	✓	✓	✓	✓	✓

In addition to these three science data downlinks, the DAS provides a Pseudo–Random Bit Stream (PRBS) downlink for test purposes.

3.2 DAS Functional Description

Figure 1 shows the block diagram of the DAS, and the major components are listed in Table II.

Table II. Major Components

Subsystem Component	Qty	Major Function
DAS Antenna	1	DAS Communications Links
DAS SSPA	2	DAS RF Transmission
DAS Upconverter	2	DAS IF to RF Frequency conversion
DAS Modulator	2	Science Data modulation and coding on the DAS RF link
DAS Band Pass Filter	1	RF Spectrum limiting
DAS Waveguide Switch	1	Select Prime/Redundant SSPA whose output is routed to the antenna
DAS Coaxial Switch	2	Select Prime/Cross–strapping connections of DAS/ Modulator/ Das Upconverter

The DAS is a single antenna system with 2–for–1 redundancy of the modulators, upconverters, and SSPAs. Coaxial switches allow either modulator to provide the modulated carrier to either upconverter/amplifier system. This cross–strapping between the primary and redundant chains of equipment provides 4 paths for X–band transmission through the DAS subsystem, ensuring that no credible single point failure can cause the loss of the DAS communication link.

Upon command, 4–bit wide data is delivered on either or both data channels to the DAS modulator from the Science Formatting Equipment (SFE) which is part of the Command and Data Handling (C&DH) Subsystem. The signal from the SFE is differential emitter–coupled logic (ECL) in a non–return to zero level (NRZ–L) format. The DAS Modulator reclocks the data and differentially encodes it to convert the data to non–return to zero mark (NRZ–M) format. The modulator then encodes the NRZ–M signal using a convolutional encoder at a rate of 1/2 and a constraint length of 7. The output symbol rate from the convolutional encoder is two times the input bit rate. The I– and Q–channel data is Staggered Quadrature Phase Shift Keying (SQPSK) modulated onto the X–band carrier at the intermediate frequency (IF). The Q:I power ratio is either 1:1 or 4:1 depending on the mode, as shown in Table III. The upconverter converts the IF frequency to X–band and delivers this signal to the solid state power amplifier (SSPA). The SSPA provides the final amplification required to provide adequate RF power at X–band to close the communication link. The output of the SSPA is routed to the DAS antenna via a waveguide transfer switch and transmit filter.

3.3 DAS–to–Earth Station Communication Link Interface Description

Contact with the user ground stations is achieved through the DAS antenna. The DAS antenna is composed of a cup and dipole feed with a shaped reflector which transmits in X–band, as shown in Figure 2. The antenna operates with right hand circularly polarized signals. The reflector is shaped to provide approximately constant power density on the earth for a subtended angle of ±63.8° about the Spacecraft earth pointing axis.

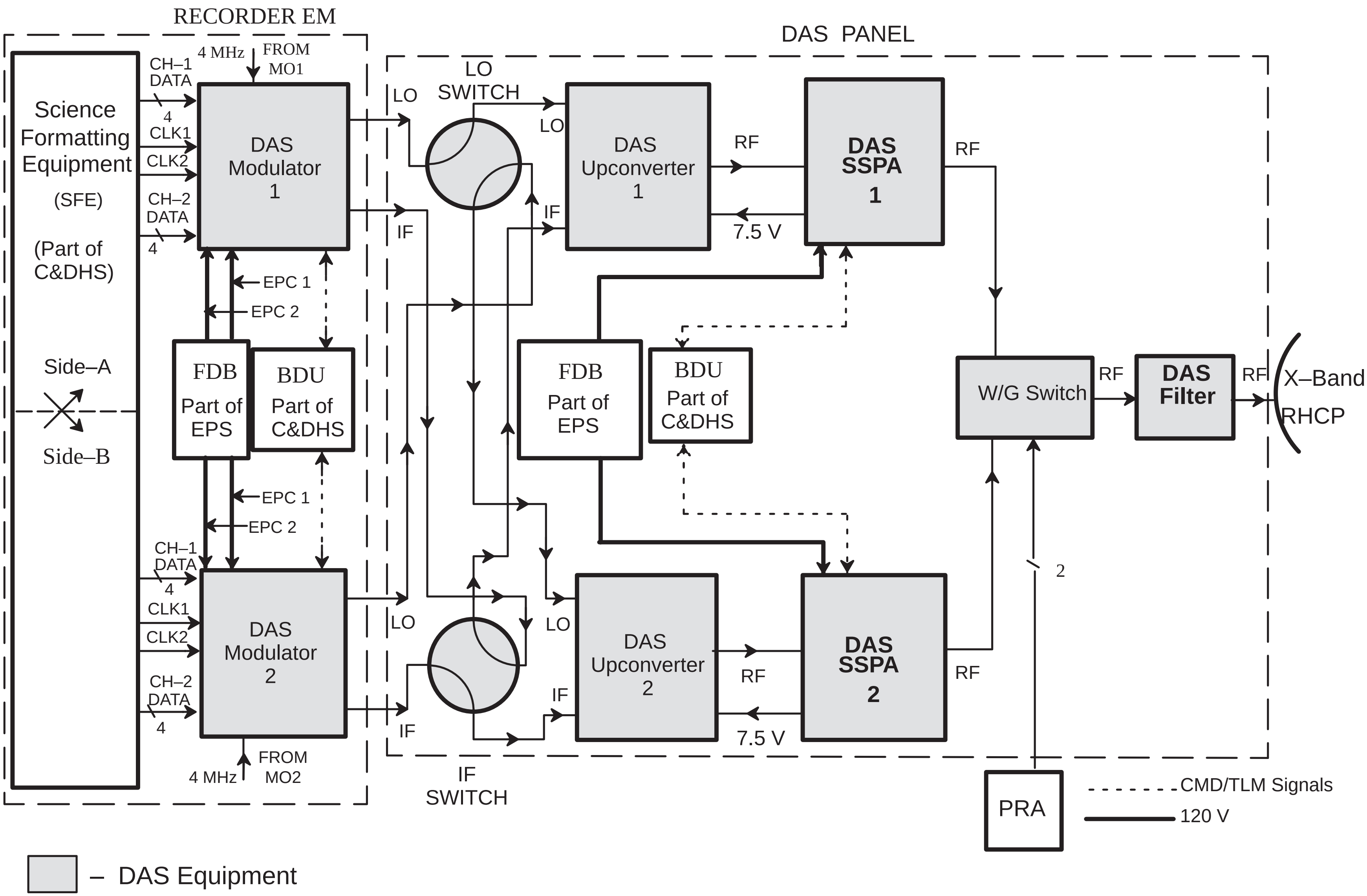


Figure 1. X–band Block Diagram

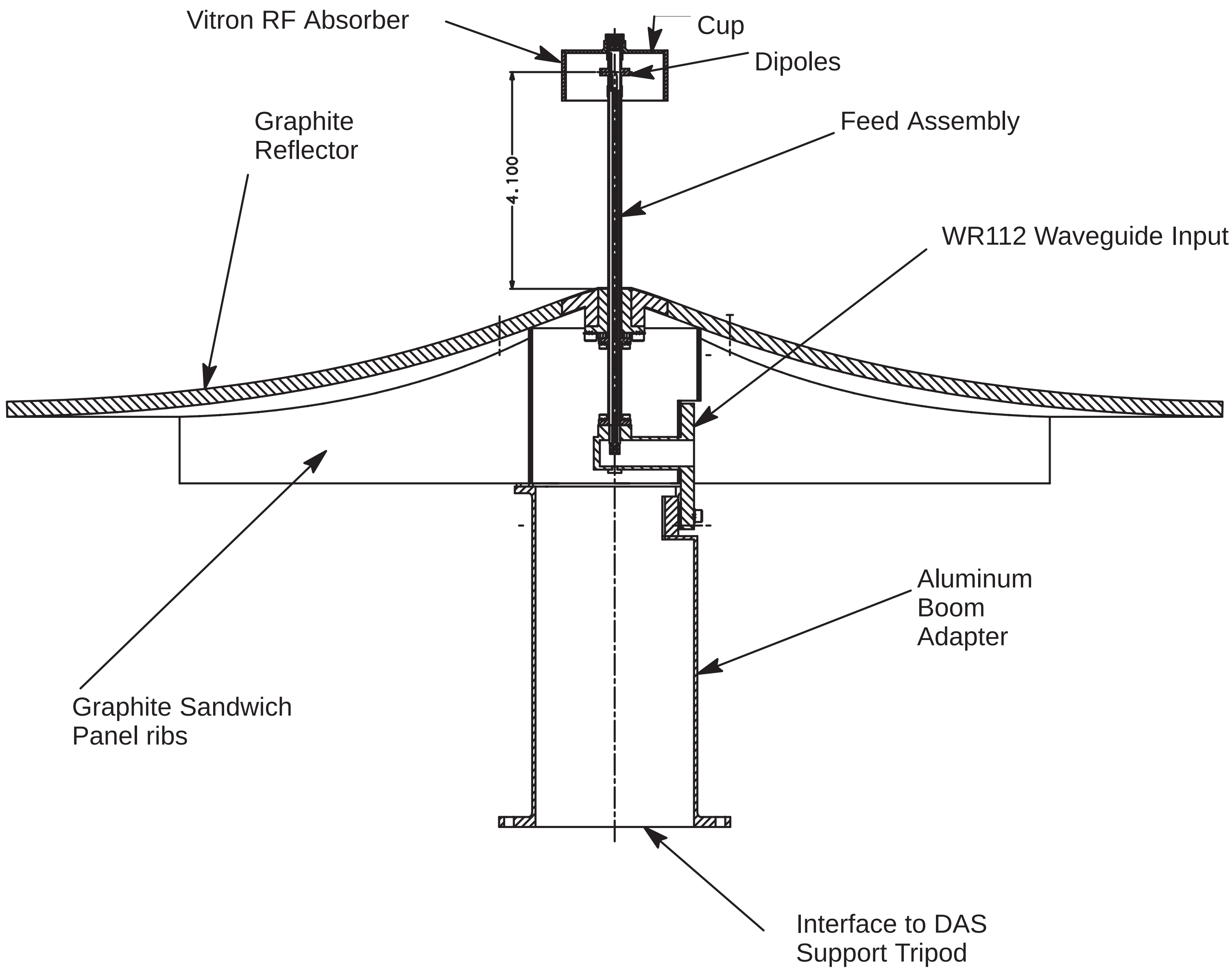


Figure 2. DAS Antenna Configuration

Figure 3 shows the DAS satellite–to–earth station geometry. The boresight of the DAS antenna will continuously point toward the center of the earth. User ground stations, which are assumed to be either 3 meter or 11.3 meter receiver dishes, should be programmed to track in X–band as the satellite passes overhead. The Spacecraft–to–earth station link distance ranges from 2575 km (at a ground station elevation angle of 5 degrees) to 705 km (at a station elevation angle of 90 degrees). Ground antenna support is dependent on favorable radio line–of–sight conditions when the ground antenna angle is greater than 5 degrees (i.e. above the local mask). The ground station location determines the orbits and portions of orbits in which contacts can be made, and the ground station acquisition cone determines the duration of the contact for the given orbit.

The ground antenna will be selected by the user to provide the performance needed for satisfactory link performance. The ground antenna which meets the user's requirements may be different from the antennas assumed in the link budget tables in Section 6.

Note that 3 meter dishes are suitable only for the lower data rates of DB service, not for the high data rates of DDL and DP service which require dishes of approximately 11.3 meters diameter.

The DAS transmits all data at the fixed frequency of 8.2125 GHz. The frequency reference is generated by an Ovenized Crystal Oscillator (OCXO). The center carrier frequency derived from the OCXO is 912.5 MHz ±300 Hz. The frequency stability of the OCXO are as shown in Table IV.

Figure 4 illustrates the overall DAS communications link. Onboard the Spacecraft, instrument data undergoes a concatenated encoding process in which Reed Solomon coding is applied by the SFE and then convolutional encoding is applied within the DAS modulator prior to transmission to the earth station. At the earth station, it is assumed that the demodulator will employ a 3–bit soft–decision Viterbi decoding process (code rate of 1/2 and constraint length of 7) and that the bit stream will be Reed Solomon decoded prior to delivery to the data users.

The specific Spacecraft–to–user downlink configurations for the various DAS services are shown in the following figures:

a. Figure 5 – Direct Broadcast (DB) with Q:I=4:1

b. Figure 6 – Direct Downlink (DDL) or Direct Playback 2 (DP2) with Q:I=4:1

c. Figure 7 – Direct Playback 1 (DP1) or Pseudo–Random Bit Stream (PRBS) Test with Q:I=1:1

The user is encouraged to review the X–band RFICD for a detailed description of NASA's approach to preparing the direct playback data at EPGN.

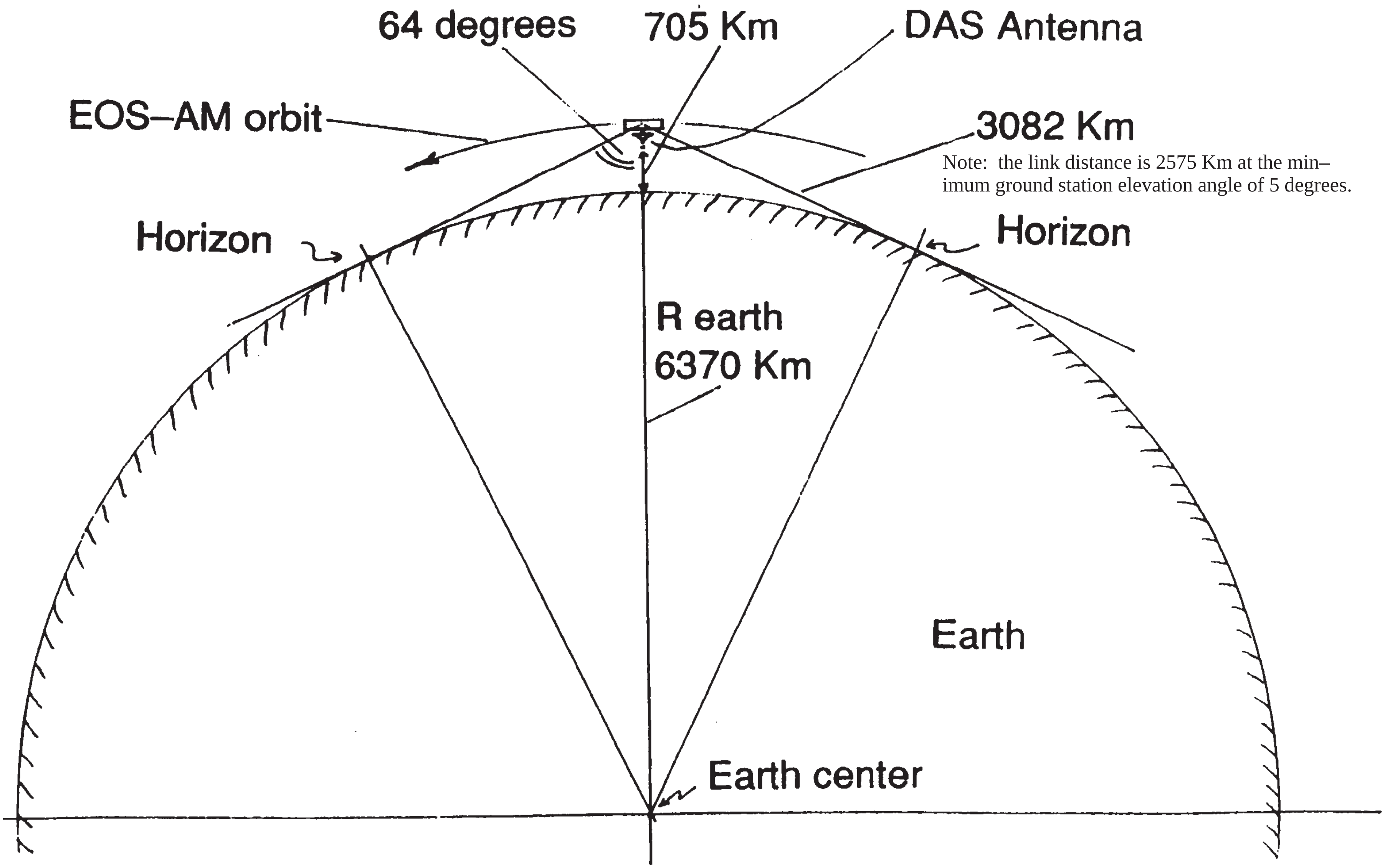


Figure 3. DAS Satellite–to–Earth Station Geometry

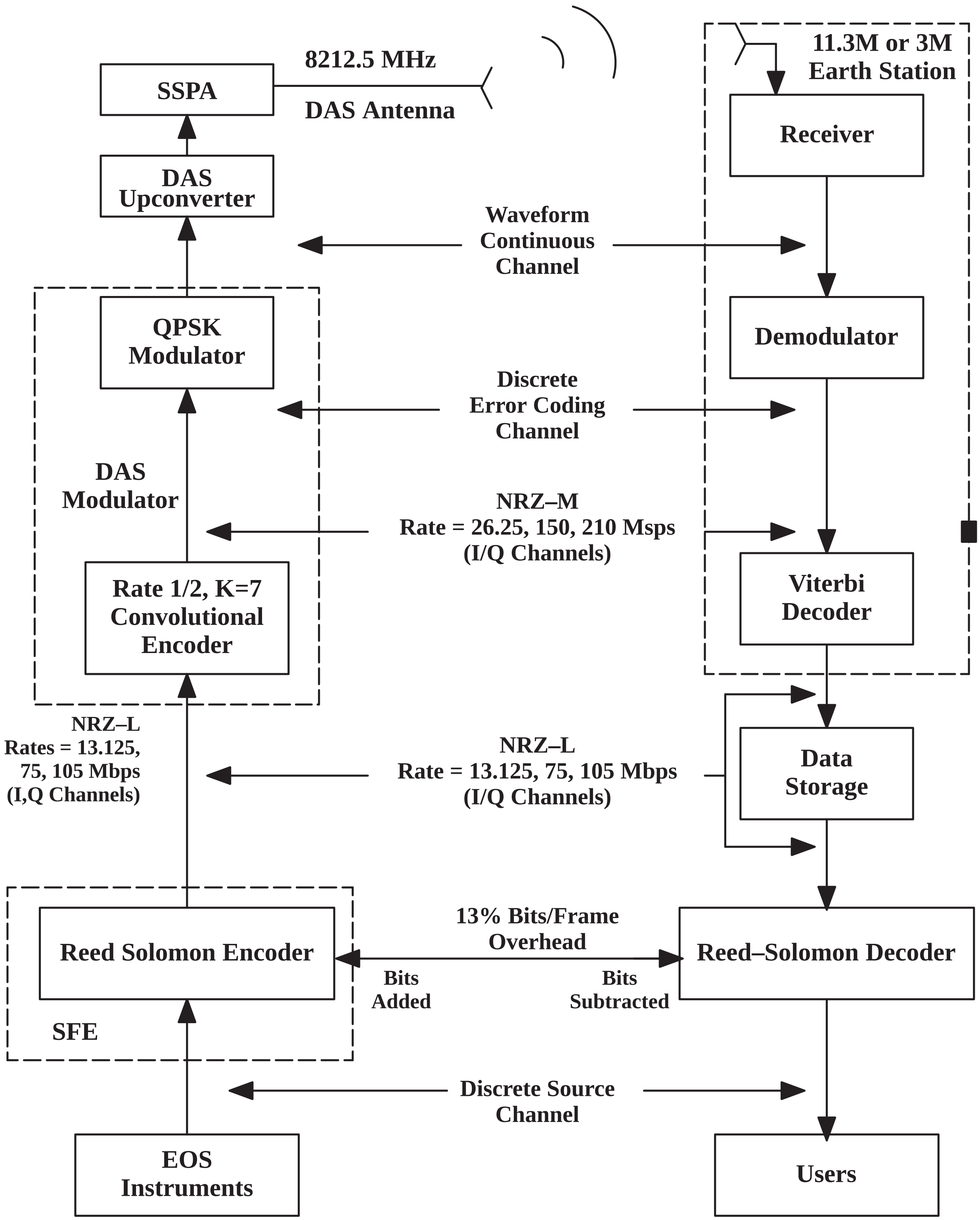


Figure 4. EOS–AM DAS Digital Satellite Communications Link Model

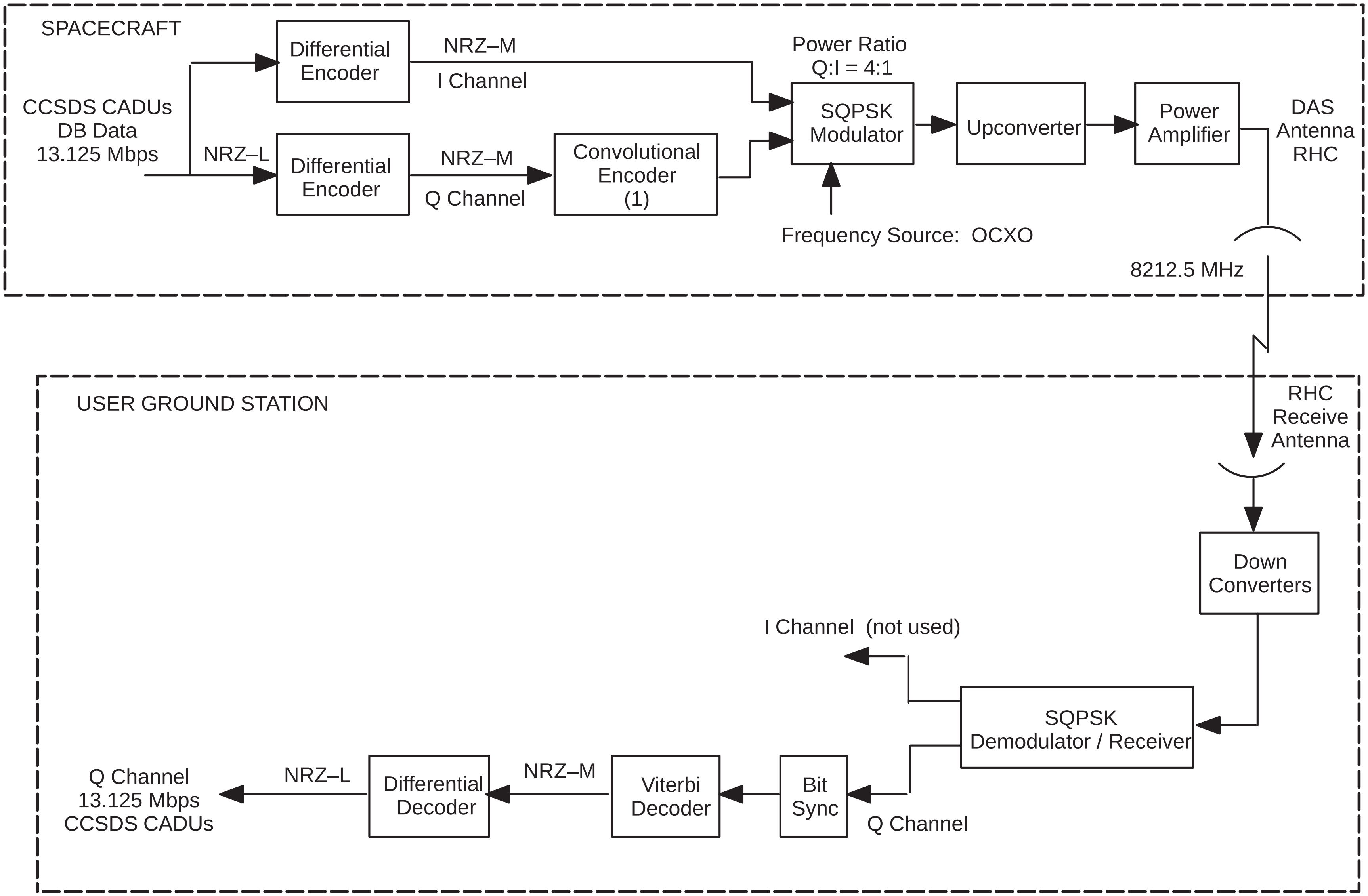


Figure 5. Spacecraft–to–User Downlink Configuration for DAS Direct Broadcast Mode With Q:I=4:1

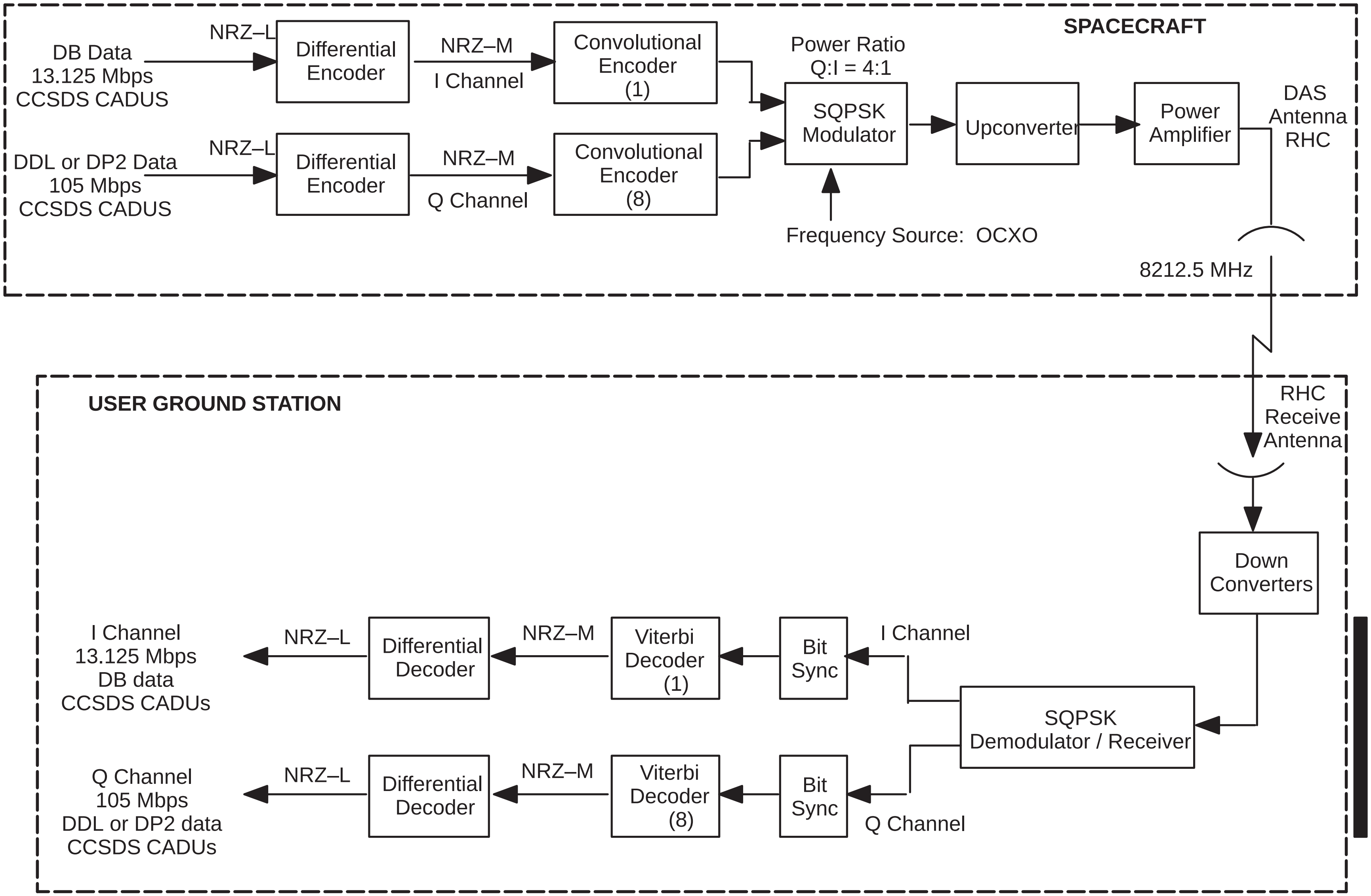


Figure 6. Spacecraft–to–User Downlink Configuration for DAS Direct Downlink (DDL) or Direct Playback 2 (DP2) Modes With Q:I=4:1

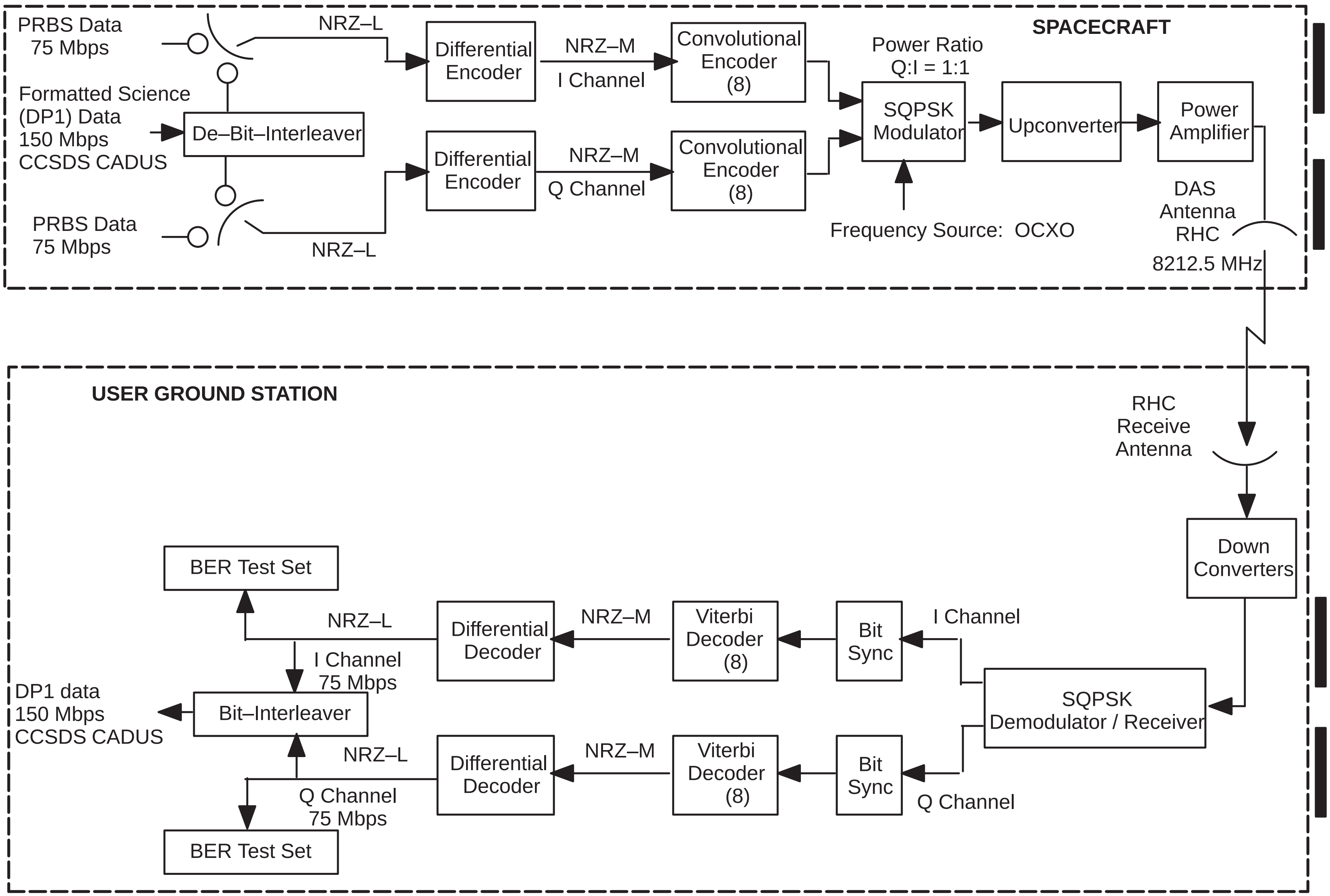


Figure 7. Spacecraft–to–User Downlink Configuration for DAS Direct Playback 1 (DP1) or Pseudo–Random Bit Stream (PRBS) Modes With Q:I=1:1

3.4 Baseband Signal Characteristics

The format of the Channel Access Data Units (CADUs) which are the DAS downlink data is shown in Figure 8. The Spacecraft Science Formatting Equipment (SFE) will use fill data as necessary to maintain constant data rates. The format of the fill CADU is shown in Figure 9.

The VCDU Data Unit Zone for Science Data is randomized to ensure data transition density in the downlink stream. The following CCSDS polynomial is XOR'ed with the data to randomize it.

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

The random sequence generator is initialized to all One's at the beginning of each VCDU. This randomizing is applied to science data and to SFE fill VCDU's. This randomization is as shown in Figure 10.

The DAS downlink data will have a (255,223) Reed Solomon (RS) outer code with interleave depth I=4 to provide improved bit error performance. The RS encoding will achieve a bit error rate (BER) of less than 10^{-7}. RS encoding is performed on the randomized data.

Convolutional encoding and Viterbi decoding with eight levels of quantization (3–bit soft decision) are used to provide a performance gain for each type of DAS service, as explained below.

3.4.1 Convolutional Coding

For the X–band downlink, a non–systematic, transparent convolutional code with a code rate of 1/2 and a constraint length of 7 is used. The I– and Q–channel data signals are differentially formatted separately, and then rate–1/2 convolutionally encoded prior to transmission to the I– and Q–channels.

Each rate 1/2 convolutional encoder is an "n–parallel encoder." An "n–parallel encoder" consists of n–branch encoders in parallel, where the quantity "n" is either 1 (for the DB data) or 8 (for the DDL, DP1, and DP2 data). The composite serial symbol output from the n–parallel encoder consists of the branch encoder output symbols interleaved every nth symbol. Each branch of the n–parallel encoder has the shift register representation shown in Figure 11. The n–parallel encoder and the composite serial n–encoded sequences are shown in Figure 12.

The G2 symbol is inverted to provide an increased symbol transition density when the uncoded data signal has a low transition density. The commutation rate and input data rate are coherent.

3.4.2 Viterbi Decoding

A phase ambiguity will occur in the carrier reference signal in the receiver whenever a suppressed carrier tracking loop is used to synthesize the coherent carrier reference. The incorrect phase of the reference signal will result in an inversion of the baseband data signal at the demodulator output. In addition, a symbol ambiguity exists since the Viterbi decoder has no prior knowledge whether a given symbol is from the G1 or G2 generator. The Viterbi decoder resolves the symbol ambiguity and decodes either the true or inverted symbol. The NRZ–M to NRZ–L converter resolves any phase inversions that might be present in the baseband data resulting in true NRZ–L output.

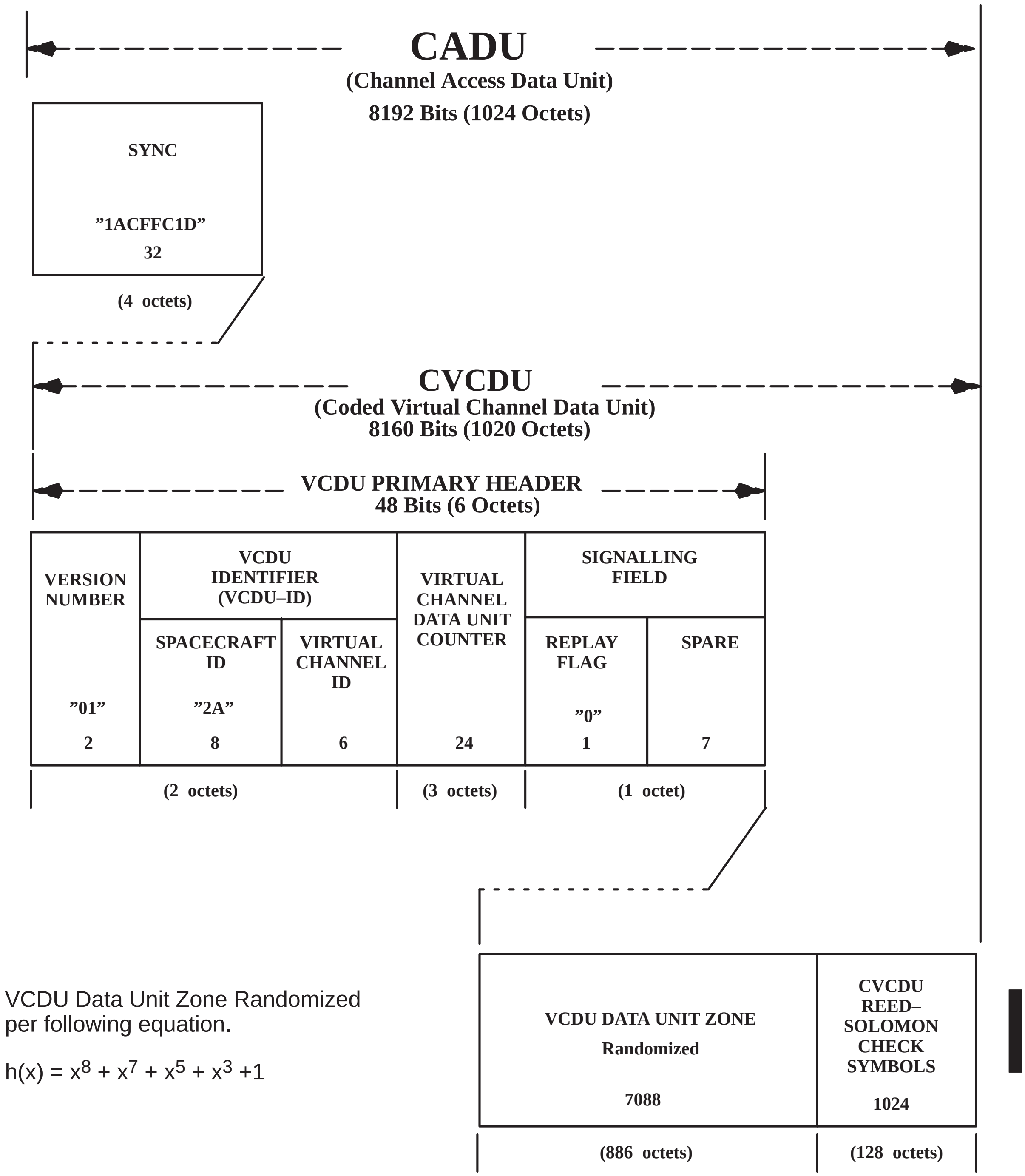
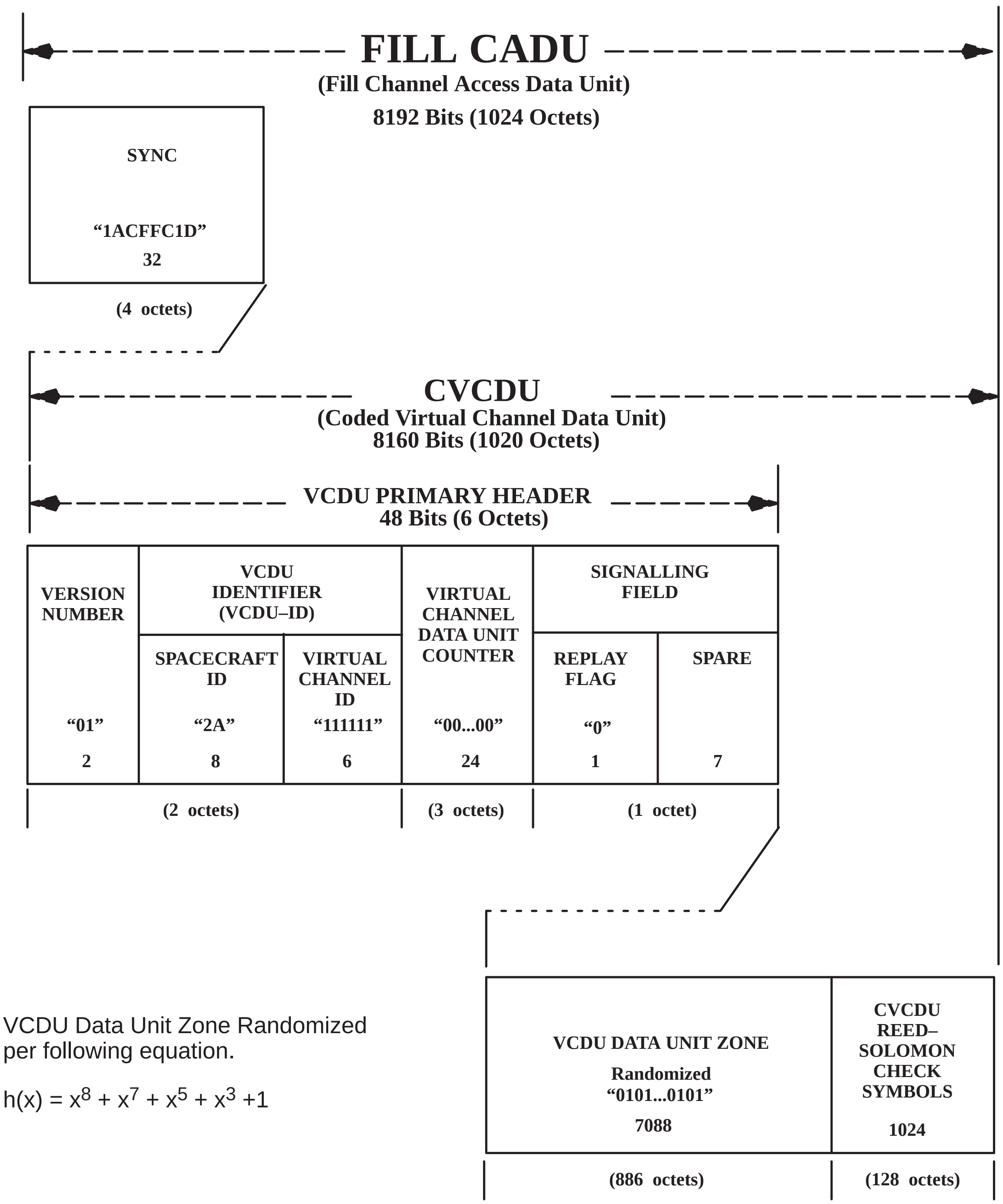


Figure 8. Format of Channel Access Data Unit (CADU) with Science Data



VCDU Data Unit Zone Randomized per following equation.

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

Figure 9. Format of CADU with Fill Data

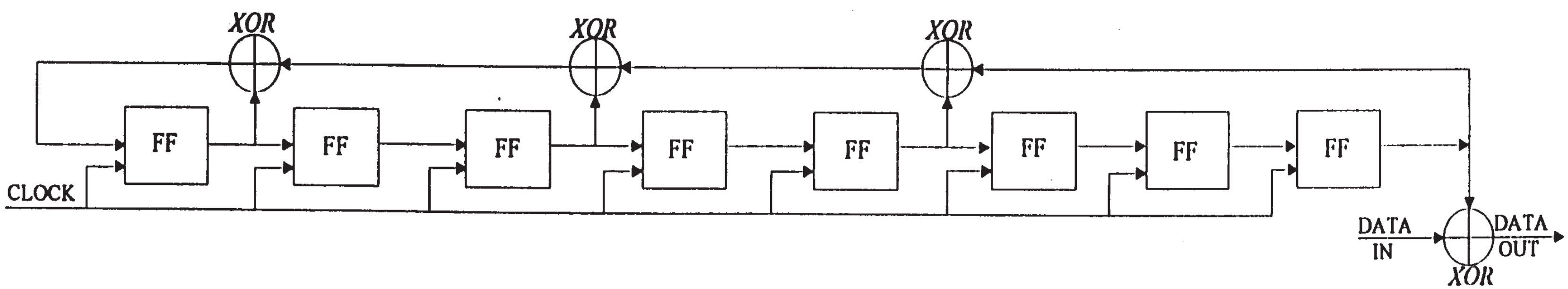
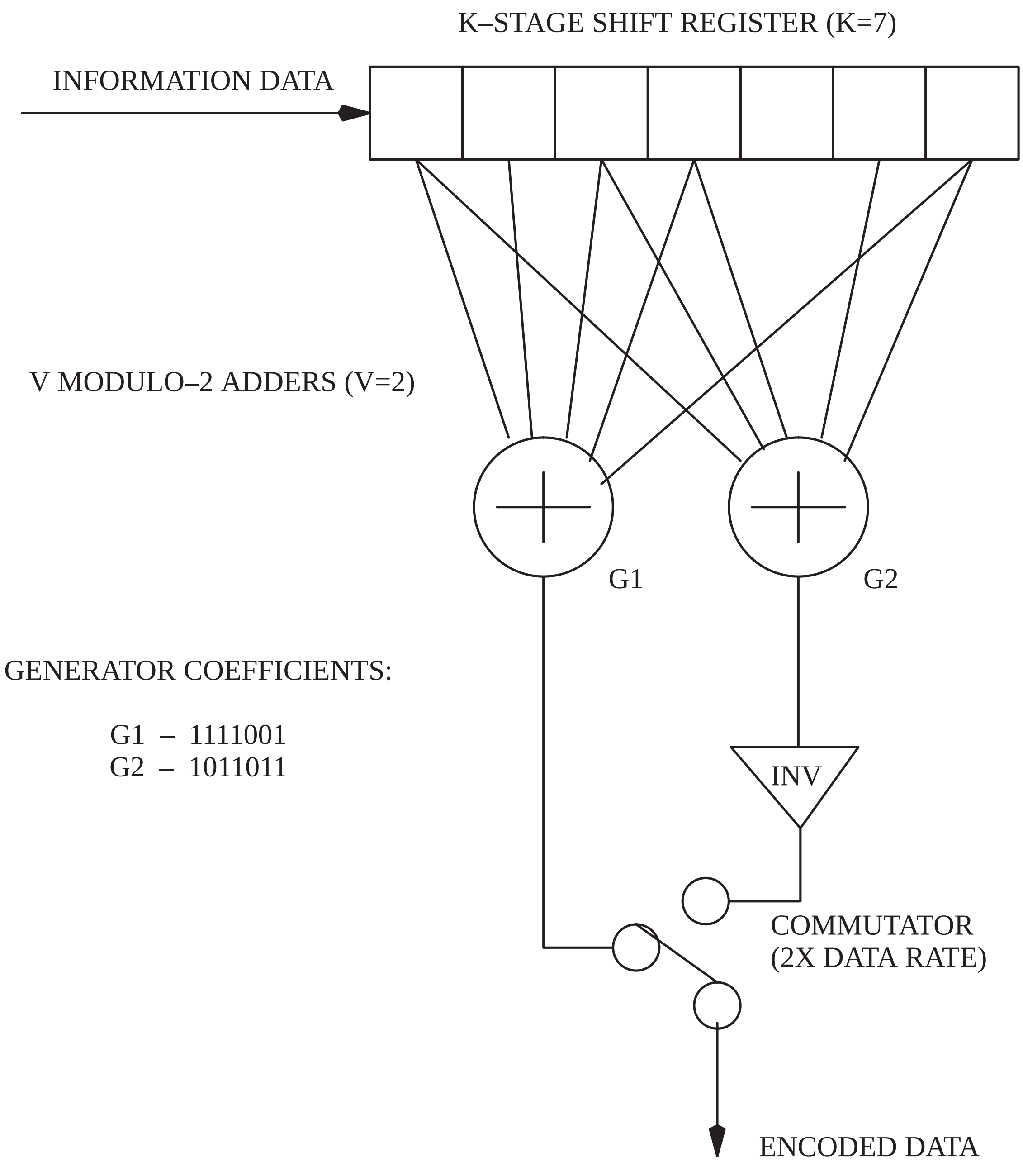


Figure 10. Data Randomization



NOTE: SYMBOL FROM G2 COMPLEMENTED. G1 PRECEDES G2 RELATIVE TO THE INFORMATION DATA BIT PERIOD.

Figure 11. Functional Configuration of the Convolutional Encoder

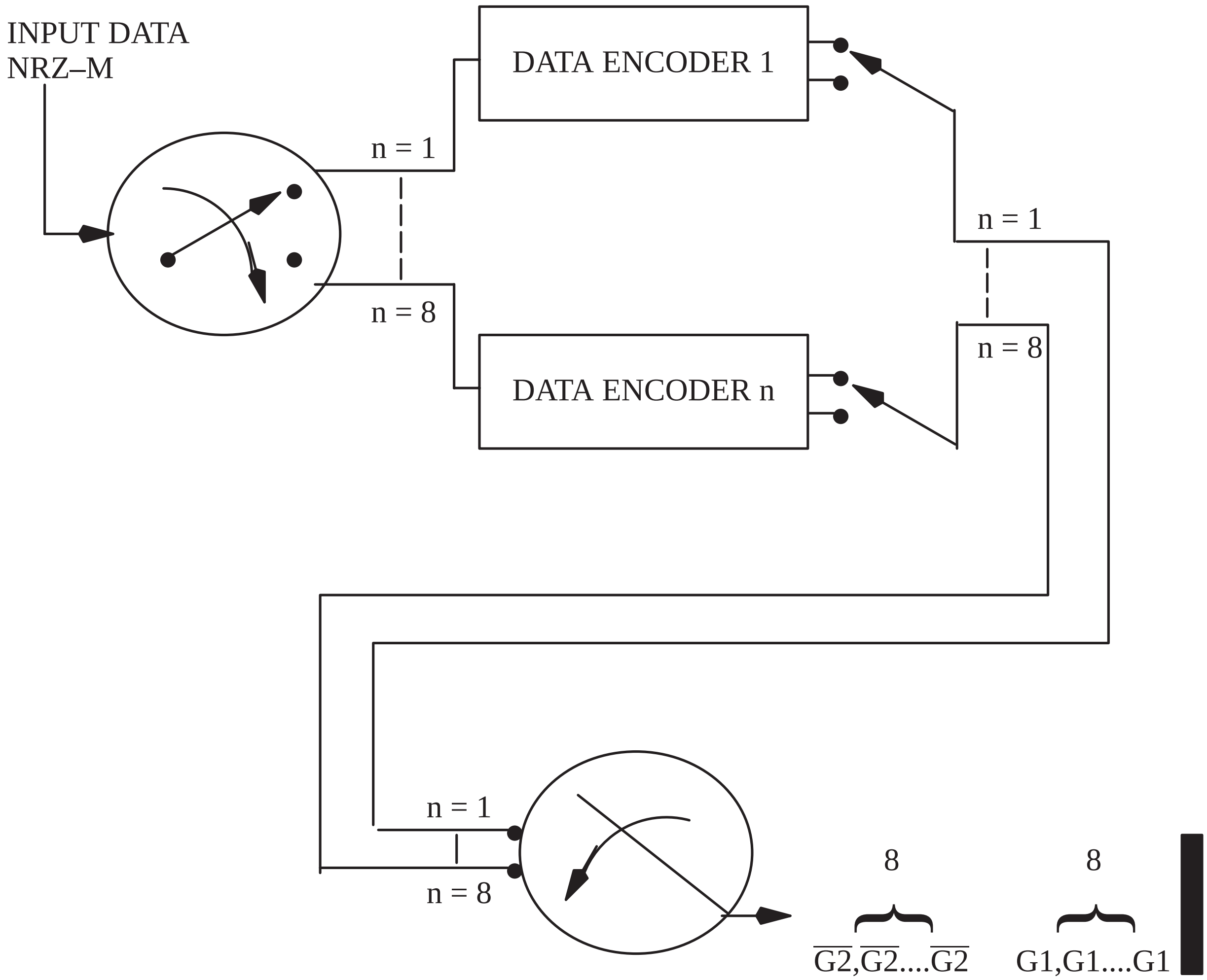


Figure 12. n–Parallel Data Encoder and the n–Encoded Sequences

3.5 DAS Management

3.5.1 Scheduling

The user must schedule DAS services for a time when the Spacecraft passes over the user's ground station. The scheduling of DAS services will be achieved by Relative Time Sequences (RTS) commands uplinked from the EOS Operations Center (EOC). Typically, the DAS commands will be uplinked the day before the scheduled contact. The instrument mode changes and commands will be controlled independently of the DAS commands.

There will be no automatic coordination of the start of DAS transmission with the start of a data packet. That is, data will be transmitted continuously from the moment that the DAS Modulator mode is selected, without regard to synchronization with the beginning of a data set. The user can choose to coordinate instrument operations with a scheduled contact by coordinating the timing requirements in the instrument and DAS command instructions provided to the EOC.

3.5.2 Anomalies

The Flight Operations Team (FOT) at the EOC will not have direct visibility of DAS output performance because the science telemetry transmitted by the DAS will not be routed to the EOC. The Spacecraft does not support any automated Fault Detection, Isolation, and Recovery (FDIR) for the DAS System.

Therefore, the user must notify the EOC of any problems with DAS service in order to start an investigation of the anomaly.

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4 DAS SUBSYSTEM OPERATING MODES

There are seven DAS subsystem operating modes, as shown in Table III. The DAS subsystem can be configured for only one of these seven operating modes at any time, but any combination of operating modes can be used during any orbit. DAS services are available all of the time, and the DAS operational duty cycle can vary from 0% to 100%. During mode transitions, the DB, DDL, and DP services may be interrupted for about 5 sec. If the DAS Modulator is ever turned off, it will require approximately 15 minutes warmup time after turn–on before meeting long–term frequency stability requirements.

The DAS subsystem is only required to be operational during Spacecraft nominal science mode, when the instruments are functioning and are producing science data. It is possible that DAS services may also be available in non–nominal Spacecraft operating modes, such as delta–V mode and the type of safe mode in which the Spacecraft Controls Computer (SCC) continues to function.

During nominal operation, the DAS subsystem will provide Direct Broadcast (DB) service (Mode 3) and for Direct Downlink (DDL) service (Mode 4) at scheduled times when the Spacecraft passes over user earth stations. Typically, both Mode 3 and Mode 4 would be performed using unbalanced SQPSK modulation which provides a Q channel with 4 times the power of the I channel. In between times when DB and DDL science data downlinks are scheduled, the DAS subsystem would operate in standby mode, in which RF transmission is disabled. The other operating modes will be used less frequently, typically during checkout or contingency conditions.

4.1 Pseudo–Random Bit Stream Test

DAS mode 1 provides for PRBS data to be generated internal to the modulator for the purpose of bit error rate (BER) checking. The DAS is designed to achieve positive link margins with a Bit Error Rate (BER) of $\leq 10^{-5}$ prior to Reed Solomon decoding (as required by CCSDS Grade 2 of service) on all direct–to–user communications links.

4.2 Direct Broadcast of MODIS Instrument Data

Direct Broadcast is a service in which real–time MODIS instrument science data and ancillary data is broadcast directly to earth stations. Data for direct broadcast is accepted on DAS Modulator input channel 1 only. The DAS transmits the DB data stream in real time via a QPSK-modulated X-band downlink.

In normal operation, DAS mode 3 will be used for the direct broadcast service. In DAS mode 3, DB data is provided with positive link margin on the higher–powered Q channel (Q:I = 4:1) and is encoded in a single convolutional encoder. DB data is provided on channel I in DAS modes 2, 3, 4, and 6, and the I channel data is uncoded in modes 2 and 3 and is encoded in a single convolutional encoder in modes 4 and 6.

Table III. DAS Subsystem Operating Modes

Mode #	Description	Input Data and Maximum Data Rate [Mbps]		Output Data Rate [Mbps] [1]		Q:I Power Ratio
		Data 1	Data 2	I	Q	
1	Pseudo–Random Bit Stream Test (DB, DDL, and DP off)	N/A	N/A	75	75	1:1
2	DB only – Q:I = 1:1 (not used)	DB 13.125	N/A	13.125 (uncoded)	13.125 (serial encoded)	1:1
3	DB only – Q:I = 4:1	DB 13.125	N/A	13.125 (uncoded)	13.125 (serial encoded)	4:1
4	Direct Downlink, DDL [3]	DB 13.125	DDL 105	13.125 (DB, serial encoded)	105 (DDL, parallel encoded)	4:1
5	DP1 only	N/A	DP1 150	75 (bit interleaved for effective rate of 150 Mbps)	75	1:1
6	Direct Playback 2, DP2 [3]	DB 13.125	DP2 105	13.125 (DB, serial encoded)	105 (DP2, parallel encoded)	4:1
7	Standby [2]	N/A	N/A	0	0	N/A

Notes:
[1] The final output is 1/2 rate encoded data at symbol rates two times the data rates shown.
[2] The IF and LO outputs of the DAS Modulator are switched off in Standby mode, providing a means of disabling RF output while maintaining oscillator stability for operational readiness.
[3] The DB link is not required for modes #4 and #6.

4.3 Direct Downlink of ASTER Instrument Data

DDL service, in which real–time ASTER instrument science data is broadcast to earth stations with 11.3 meter dishes, is provided whenever DAS mode 4 is selected. Data for direct downlink is accepted on channel 2 only. The DAS transmits the DDL data stream in real time via a QPSK-modulated X-band downlink. DDL data appears only on the Q-channel for DAS mode 4, and the Q:I power ratio is 4:1.

The DDL service is dedicated to science data from the ASTER instrument. This service will be activated only when ASTER is in operation and when a target 11.3 meter DAS ground station is within range. The DDL service will be scheduled by the Flight Operations Team (FOT) based on requests for service from user stations, and it will be controlled by the Spacecraft Controls Computer (SCC) per Stored Command Table (SCT) uploads.

4.4 Direct Playback of Recorded Science and Housekeeping Data

Direct Playback (DP) service, in which stored science and ancillary data is broadcast to earth stations with 11.3 meter dishes, is provided whenever DAS modes 5 or 6 is selected. There are two types of DP service, DP1 and DP2:

d. DAS mode 5 provides DP1 service, in which data on the I and Q channels will be bit–interleaved for an effective data rate of 150 Mbps. In this mode, the power of the I and Q channels will be balanced (i.e. Q:I power ratio = 1:1).

e. DAS mode 6 provides DP2 service, in which direct playback data will appear only on the Q–channel at a rate of 105 Mbps. The I–channel will be used to transmit 13.125 Mbps of DB data. In this mode, the Q:I power ratio will be 4:1.

Direct playback data is accepted on modulator input channel 2 only. The DAS transmits the DP data stream via a QPSK-modulated X-band downlink. The DP service can not be provided on a continuous basis since time must be allocated for recording before playback can occur.

The DP service will be utilized only as a backup in case of any interruption of the ability to transmit science data to ground users via the TDRSS Ku-band return link service. The DP service will not be available simultaneously with the TDRSS Ku-band return link service. The ancillary data transmitted in the direct playback data will be identical to that transmitted in the Ku–band services. Users of the DPI service should only use the VCDU data after Reed Solomon decoding due to a small number of bit errors generated in the spacecraft after the Reed Solomon encoding and before the viterbi encoding (DPI mode only).

The anomalous conditions which would warrant DP mode service usage include:

a. HGA pointing problem

b. Tracking and Data Relay Satellite System communication path outage for any length of time greater than Solid State Recorder (SSR) recording capabilities

c. EOS Data Operations System (EDOS) outage for any length of time greater than SSR recording capabilities.

4.5 Standby

The standby mode, DAS mode 7, provides a means for disabling RF output while maintaining oscillator stability for operational readiness. By scheduling DB and DDL services to occur over user ground stations, interference with DSN ground stations is avoided. The standby mode disables the DAS subsystem RF output by switching off the IF and LO outputs from the DAS Modulator.

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5 DAS RF CHARACTERISTICS

The DAS RF signal parameters for all services are listed in Table IV.

Table IV. X–band (DAS) Subsystem Performance Characteristics

Parameter	Capability
Transmit Center Frequency	8212.5 ± 0.01 MHz
Polarization	RHCP
Axial Ratio	Angle from S/C Antenna Boresight [degrees] / Axial Ratio [dB]: 63.8 / <7.4 43.6 / <9.8 29.0 / <13.5 24.0 / <17.0 17.9 / <32.5 0 / <10.1
Coverage	± 63.8, approximates Constant Power Density
Data Modulation	SQPSK, USQPSK (1)
Data Format	NRZ–L: Input; NRZ–M:Output
Data Processing	Reclock, Differential Encoding, Rate 1/2 Convolutional Encoding
Assigned Frequency Range (Bandwidth)	8025 to 8400 MHz (375 MHz)
Gain Slope (10MHz min. interval)	Angle from S/C Antenna Boresight [degrees] / Gain Slope [dB/MHz]: 63.8 / 0.057 43.6 / 0.085 17.9 / 0.23 0 / 0.18
AM/PM	<7.5°/dB
Phase Imbalance with respect to ideal	< 4°
Ideal Phase Angles (2)	90°(1:1 modes), 128°, 52° (1:4 modes)
Gain Imbalance	< 0.2 dBp–p
I/Q Data Skew (with respect to 1/2 symbol offset)	< 0.375 nsec
Data Asymmetry	< 3%
Data Rise Time	< 2.3 nsec

Table IV. X–band (DAS) Subsystem Performance Characteristics (Continued)

Parameter	Capability
Data Bit Jitter	DB and DP mode: < 0.37 Radians for BER (< 0.37 radians for BSR) DDL mode: < 0.85 Radians for BER (<0.37 radians for BSR)
In Band Flux Density $0° < \theta_{EL} < 5°$ $5° < \theta_{EL} < 25°$ $25° < \theta_{EL} < 90°$	 < -150 dBW/m^2/4 kHz $< -150 + (\theta_{EL} - 5)/2$ dBW/m^2/4 kHz < -140 dBW/m^2/4 kHz
Spurious Output Out–of–band	< –39dBm per Hz outside ±5% of transmit freq –72 dBm per Hz, 2106.4 to 2112.5 MHz
Phase Noise 1 – 10 Hz 10 – 100 Hz 100 Hz – 1 kHz 1 kHz – 150 MHz	 1.0° RMS 2.0° RMS 3.0° RMS 2.0° RMS
Frequency Stability 1 Second Average 5 Hour Average 48 Hour Average	 $\pm 5 \times 10^{-12}$ $\pm 3 \times 10^{-11}$ $\pm 3 \times 10^{-10}$
System Bit Error Rate (BER) DAS Space Segment BER	1×10^{-5} (Goal: link margin ≥ 3dB) $\leq 0.5 \times 10^{-7}$ DB, DDL, DP2; $\leq 8 \times 10^{-5}$ DP1
Untracked Spurious PM (1 kHz to 150 mHz)	≤ 2 degrees
Carrier Suppression	> 30 dB
Service Interruption	< 5 seconds during mode transitions
Gain Flatness (dBp–p) over ±112 MHz	Antenna Boresight Angle [degrees] / Gain Flatness [dB p–p] 0 — 5.0 dBp–p 17.9 — 3.7 dBp–p 43.6 — 1.9 dBp–p 63.8 — 2.0 dBp–p

Table IV. X–band (DAS) Subsystem Performance Characteristics (Continued)

Parameter	Capability	
Phase Nonlinearity (degrees p–p) over ±112 MHz	Antenna Boresight Angle [degrees]	Phase Nonlinearity [degrees p–p]
	0	40 degrees p–p
	17.9	38 degrees p–p
	43.6	30 degrees p–p
	63.8	29 degrees p–p

Note 1: SQPSK: Staggered QPSK; USQPSK: Unbalanced Staggered QPSK

Note 2: Resultant (transmitted) phasors

Note 3: Includes ± 0.6 degrees (circular) DAS Antenna pointing error. (total EOS system allocation).

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6 DAS COMMUNICATION LINK BUDGETS

The DAS system is required to achieve positive link margin with a Bit Error Rate (BER) of less than 1 x 10^{-5}, as required by CCSDS Grade 2 level of service. The DAS was designed with a goal of maintaining link margins of more than 3 dB for every link.

The link budgets provided in this section are based on worst case Equivalent Isotropic Radiated Power (EIRP) and axial ratio losses measured in tests of the DAS Engineering Test Model (ETM) antenna on a mockup of the Spacecraft nadir deck. For each DAS operating mode, link budgets are provided for four earth station elevation angles: 5°, 40°, 63°, and 90°. The budget is based on the specified minimum end–of–life (EOL) Solid State Power Amplifier (SSPA) output power of 11.5 dBW (i.e. 14 W) and the minimum DAS antenna gain.

The rationale for estimates of the various losses in the link budget is explained in EOS–DN–COMM–14B.

Antenna performance test data is provided in Appendix 1 in order that the user can revise the following link margins as required for specific operating conditions. The data shows that the DAS system EIRP drops significantly around 20 degrees off boresight. NASA does not plan to use the DAS direct playback service within ±24 degrees of antenna boresight (i.e. above 63.14 degrees of ground station elevation angle).

Information on the impact of data coding to BER and required Eb/No performance is provided in Appendix 2.

Table V. DAS Return Link Performance Summary [1]

Mode	Data Rate [Mbps]	Channel	Link Margin (dB) For Various Ground Elevation Angles (degrees)			
			5	40	63	90
Direct Broadcast with Q:I = 4:1 to 3 meter ground antenna	13.125	Q	5.97	10.54	0.12 3.82	6.26 9.96
Direct Downlink or Direct Playback 2 (DP2) with Q:I = 4:1 to 11.3 meter ground antenna	105	Q	6.99	11.56	4.84	10.98
Direct Playback 1 (DP1) with Q:I=1:1 to 11.3 meter ground antenna	150	I,Q	3.6	8.17	1.45	7.59

[1] For ground system with Reed Solomon decoding.

6.1 Direct Broadcast (DB) Link Budget

The link budget for the DB mode with a Q:I power ratio of 4:1 is provided in Table VI.

6.2 Direct Downlink (DDL) Link Budget

The link budget for the DDL mode (with 80% of the transmit power on the Q channel with the ASTER data) is shown in Table VII.

6.3 Direct Playback Link Budgets

The link budget for the the Direct Playback 1 (DP1) mode is shown in Table VIII.

The link budget for the Direct Playback 2 (DP1) mode (with 80% of the transmit power on the Q channel with the playback data) is shown in Table VII.

Table VI. DAS Return Downlink Budget for Direct Broadcast (DB) Mode with Q:I = 4:1

Service	DB with Q:I = 4:1
Frequency	8.2125 GHz
Polarization / AR of DAS (dB)	RHCP 8dB
Shaped DAS Antenna Pattern for Constant Power Flux Density on Earth	+ / – 63.8 degrees FOV
Ground Station Antenna Size	3 meter
Ground Station Antenna Gain (3m)	45.6 dBi; Eff = 0.55
Range at Ground Elevation Angle of 5 degrees	2574.5 kM

	I Channel	Q Channel
Data Rate [Mbps]	13.125	13.125
Coding	1/2 convolutional	1/2 convolutional
Modulation	QPSK	QPSK
Data Type	NRZ–L/M	NRZ–L/M

	Parameter	Gnd Station Elev Angle / DAS Ant Boresight Angle [degrees]				Units	Comments
		5 / 63.8	**40 / 43.6**	**63 / 24**	**90 / 0**		
1	DAS Antenna Transmitter Output Power	11.5	11.5	11.5	11.5	dBW	14 W RF, per spec, EOL
2	Passive Circuit Loss	–1.89	–1.89	–1.89	–1.89	dB	per spec
3	EOS TX Antenna Gain	6.20	–1.00	–9.80	–6.00	dBi	measured, worst case
4	EOS DAS DB EIRP	15.81	8.61	–0.19	3.61	dB	Sum 1 through 3
5	Antenna Pointing Loss	0.00	0.00	0.00	0.00	dB	Included in Ant spec
6	Polarization Loss	–1.10	–1.28	–2.15	–1.10	dB	TX/RX axial ratio: 8dB or measured worst case/1.50dB
7	Free Space Loss	–178.95	–170.99	–168.17	–167.70	dB	2575,1029,744,705 km
8	Atmospheric Absorption Loss	–0.80	–0.10	–0.10	–0.10	dB	50% humidity, 20°C
9	Rain Attenuation Loss	–1.70	–0.40	–0.20	–0.10	dB	4mm/hr rain rate
10	Ground Station Antenna Gain	45.60	45.60	45.60	45.60	dBi	3m, eff = 55%
11	Received Carrier Power	–121.14	–118.56	–125.62	–119.79	dBW	sum of 4 through 10

Table VI. DAS Return Downlink Budget for Direct Broadcast (DB) Mode with Q:I=4:1 (continued)

	Parameter	Gnd Station Elev Angle / DAS Ant Boresight Angle [degrees]				Units	Comments
		5 / 63.8	40 / 43.6	63 / 24	90 / 0		
12	Ground Station Noise Temperature, K	180.00	155.00	155.00	155.00	deg K	clear sky
13	Noise Temperature Increase Due to Rain, K	116.00	32.00	18.00	6.00	deg K	estimate
14	Total Noise Temp in dB	24.71	22.72	22.38	22.07	dBK	296,187,173,161 deg K
15	Ground Station G/T	20.89	22.88	22.88	23.53	dB/K	G/T degraded by rain
16	Boltzmann’s Constant	–228.60	–228.60	–228.60	–228.60	dB/Hz/K	
17	Received Carrier to Noise Density Ration (C/No)	82.75	87.32	80.60	86.74	dB/Hz	(11–14–16)
18	Convert C to Eb	71.18	71.18	71.18	71.18	dB–bps	10*log(13.125e6)
19	Ground Multipath Degradation	0.00	0.00	0.00	0.00	dB	User to supply (Note [1])
20	Differential Encoder / Decoder Loss	–0.20	–0.20	–0.20	–0.20	dB	
21	I–Q Channel Power Split Loss	–1.20	–1.20	–1.20	–1.20	dB	4:1 power ratio with tolerance
	Link margin Without Reed Solomon Decoding						
22	Received Eb/No	10.37	14.94	8.22	14.36	dB	
23	Implementation Loss	–2.0	–2.0	–2.0	–2.0	dB	Note [2]
24	Required Eb/No (1/2 CONV)	4.20	4.20	4.20	4.20	dB	
25	SYSTEM LINK MARGIN (1/2 CONV)	4.17	8.74	2.02	8.16	dB	(21+22–23)
26	LINK MARGIN ABOVE 3DB GOAL(1/2 CONV)	1.17	5.74	–0.98	5.16	dB	
	Link margin With Reed Solomon Decoding						
27	Required Eb/No (1/2/ CONV + RS)	2.40	2.40	2.40	2.40	dB	
28	SYSTEM LINK MARGIN (1/2 CONV + RS)	5.97	10.54	3.82	9.96	dB	(21+22–26)
29	LINK MARGIN ABOVE 3DB GOAL (1/2 CONV + RS)	2.97	7.54	0.82	6.96	dB	

[1] User should provide a value for the Ground Multipath Degradation because this item in budget depends on the ground station design.
[2] The uncertainty band for the implementation loss is +/– 0.3 dB, based on two analysis methods. The actual value will depend on the ground station as well as the spacecraft segment.

Table VII. DAS Return Downlink Budget for Direct Downlink (DDL) or Direct Playback 2 (DP2) Modes

Service	DDL or DP2
Frequency	8.2125 GHz
Polarization / AR of DAS (dB)	RHCP 8dB
Shaped DAS Antenna Pattern for Constant Power Flux Density on Earth	+ / – 63.8 degrees FOV
Ground Station Antenna Size	11.3 meter
Ground Station Antenna Gain (3m)	56.1 dBi; Eff = 0.55
Range at Ground Elevation Angle of 5 degrees	2574.5 kM

	I Channel	Q Channel
Data Rate [Mbps]	n/a	105
Coding	n/a	1/2 convolutional
Modulation	n/a	QPSK
Data Type	n/a	NRZ–L/M

		Gnd Station Elev Angle / DAS Ant Boresight Angle [degrees]					
	Parameter	**5 / 63.8**	**40 / 43.6**	**63 / 24**	**90 / 0**	**Units**	**Comments**
1	DAS Antenna Transmitter Output Power	11.5	11.5	11.5	11.5	dBW	14 W RF, per spec, EOL
2	Passive Circuit Loss	–2.14	–2.14	–2.14	–2.14	dB	per spec
3	EOS TX Antenna Gain	6.00	–1.20	–10.00	–6.20	dBi	measured, worst case
4	EOS DAS DDL EIRP	15.36	8.16	–0.64	3.16	dB	Sum 1 through 3
5	Antenna Pointing Loss	0.00	0.00	0.00	0.00	dB	Included in Ant spec
6	Polarization Loss	–1.10	–1.28	–2.15	–1.10	dB	TX/RX axial ratio: 8dB or measured worst case/1.50dB
7	Free Space Loss	–178.95	–170.99	–168.58	–167.70	dB	2575,1029,744,705 km
8	Atmospheric Absorption Loss	–0.80	–0.10	–0.10	–0.10	dB	50% humidity, 20°C
9	Rain Attenuation Loss	–1.70	–0.40	–0.20	–0.10	dB	4mm/hr rain rate
10	Ground Station Antenna Gain	57.30	57.30	57.30	57.30	dBi	11.3m, eff = 55%
11	Received Carrier Power	–109.89	–107.31	–114.37	–108.54	dBW	sum of 4 through 10

Table VII. DAS Return Downlink Budget for Direct Downlink (DDL) or Direct Playback 2 (DP2) Modes (continued)

	Parameter	Gnd Station Elev Angle / DAS Ant Boresight Angle [degrees]				Units	Comments
		5 / 63.8	**40 / 43.6**	**63 / 24**	**90 / 0**		
12	Ground Station Noise Temperature, K	180.00	155.00	155.00	155.00	deg K	clear sky
13	Noise Temperature Increase Due to Rain, K	116.00	32.00	18.00	6.00	deg K	estimate
14	Total Noise Temp in dB	24.71	22.72	22.38	22.07	dBK	296,187,173,161 deg K
15	Ground Station G/T	32.59	34.58	34.58	35.23	dB/K	G/T degraded by rain
16	Boltzmann's Constant	–228.60	–228.60	–228.60	–228.60	dB/Hz/K	
17	Received Carrier to Noise Density Ration (C/No)	94.00	98.57	91.85	97.99	dB/Hz	(11–14–16)
18	Convert C to Eb	80.21	80.21	80.21	80.21	dB–bps	10*log(105e6)
19	Ground Multipath Degradation	0.00	0.00	0.00	0.00	dB	User to supply (Note [1])
20	Differential Encoder / Decoder Loss	–0.20	–0.20	–0.20	–0.20	dB	
21	I–Q Channel Power Split Loss	–1.20	–1.20	–1.20	–1.20	dB	1:4 pwr ratio w/ tolerance
	Link margin Without Reed Solomon Decoding						
22	Received Eb/No	12.39	16.96	10.24	16.38	dB	
23	Implementation Loss	–3.0	–3.0	–3.0	–3.0	dB	Note [2]
24	Required Eb/No (1/2 CONV)	4.20	4.20	4.20	4.20	dB	
25	SYSTEM LINK MARGIN (1/2 CONV)	5.19	9.76	3.04	9.18	dB	(22+23–24)
26	LINK MARGIN ABOVE 3DB GOAL(1/2 CONV)	2.19	6.76	0.04	6.18	dB	
	Link margin With Reed Solomon Decoding						
27	Required Eb/No (1/2/ CONV + RS)	2.40	2.40	2.40	2.40	dB	
28	SYSTEM LINK MARGIN (1/2 CONV + RS)	6.99	11.56	4.84	10.98	dB	(22+23–27)
29	LINK MARGIN ABOVE 3DB GOAL (1/2 CONV + RS)	3.99	8.56	1.84	7.98	dB	

[1] User should provide a value for the Ground Multipath Degradation because this item in budget depends on the ground station design.
[2] The uncertainty band for the implementation loss is +/– 1.9 dB, based on two analysis methods. The actual value will depend on the ground station as well as the spacecraft segment.

Table VIII. DAS Return Downlink Budget for Direct Playback 1 (DP1) Mode

Service	DP1
Frequency	8.2125 GHz
Polarization / AR of DAS (dB)	RHCP 8dB
Shaped DAS Antenna Pattern for Constant Power Flux Density on Earth	+ / – 63.8 degrees FOV
Ground Station Antenna Size	11.3 meter
Ground Station Antenna Gain (3m)	56.1 dBi; Eff = 0.55
Range at Ground Elevation Angle of 5 degrees	2574.5 kM

	I Channel	Q Channel
Data Rate [Mbps]	75	75
Coding	1/2 convolutional	1/2 convolutional
Modulation	QPSK	QPSK
Data Type	NRZ–L/M	NRZ–L/M

		Gnd Station Elev Angle / DAS Ant Boresight Angle [degrees]					
	Parameter	**5 / 63.8**	**40 / 43.6**	**63 / 24**	**90 / 0**	**Units**	**Comments**
1	DAS Antenna Transmitter Output Power	11.5	11.5	11.5	11.5	dBW	14 W RF, per spec, EOL
2	Passive Circuit Loss	–2.09	–2.09	–2.09	–2.09	dB	per spec
3	EOS TX Antenna Gain	6.10	–1.10	–9.90	–6.10	dBi	measured, worst case
4	EOS DAS DPI EIRP	15.51	8.31	–0.49	3.31	dB	Sum 1 through 3
5	Antenna Pointing Loss	0.00	0.00	0.00	0.00	dB	Included in Ant spec
6	Polarization Loss	–1.10	–1.28	–2.15	–1.10	dB	TX/RX axial ratio: 8dB/1.50dB
7	Free Space Loss	–178.95	–170.99	–168.17	–167.70	dB	2575,1029,744,705 km
8	Atmospheric Absorption Loss	–0.80	–0.10	–0.10	–0.10	dB	50% humidity, 20°C
9	Rain Attenuation Loss	–1.70	–0.40	–0.20	–0.10	dB	4mm/hr rain rate
10	Ground Station Antenna Gain	57.30	57.30	57.30	57.30	dBi	10m, eff = 55%
11	Received Carrier Power	–109.74	–107.16	–114.22	–108.39	dBW	sum of 4 through 10

Table VIII. DAS Return Downlink Budget for Direct Playback 1 (DP1) Mode (continued)

	Parameter	Gnd Station Elev Angle / DAS Ant Boresight Angle [degrees]				Units	Comments
		5 / 63.8	40 / 43.6	63 / 24	90 / 0		
12	Ground Station Noise Temperature, K	180.00	155.00	155.00	155.00	deg K	clear sky
13	Noise Temperature Increase Due to Rain, K	116.00	32.00	18.00	6.00	deg K	estimate
14	Total Noise Temp in dB	24.71	22.72	22.38	22.07	dBK	296,187,173,161 deg K
15	Ground Station G/T	32.59	34.58	34.58	35.23	dB/K	G/T degraded by rain
16	Boltzmann’s Constant	–228.60	–228.60	–228.60	–228.60	dB/Hz/K	
17	Received Carrier to Noise Density Ration (C/No)	94.15	98.72	92.00	98.14	dB/Hz	(11–14–16)
18	Convert C to Eb	78.75	78.75	78.75	78.75	dB–bps	10*log (75e6)
19	Ground Multipath Degradation	0.00	0.00	0.00	0.00	dB	User to Supply (Note [1])
20	Differential Encoder / Decoder Loss	–0.20	–0.20	–0.20	–0.20	dB	
21	I–Q Channel Power Split Loss	–3.20	–3.20	–3.20	–3.20	dB	1:1 pwr ratio w/ tolerance
	Link margin Without Reed Solomon Decoding						
22	Received Eb/No	12.00	16.57	9.85	15.99	dB	
23	Implementation Loss	6.0	6.0	6.0	–6.0	dB	Note [2]
24	Required Eb/No (1/2 CONV)	4.20	4.20	4.20	4.20	dB	
25	SYSTEM LINK MARGIN (1/2 CONV)	1.8	6.37	–0.35	5.79	dB	(22+23–24)
26	LINK MARGIN ABOVE 3DB GOAL(1/2 CONV)	–1.2	3.37	–3.35	2.79	dB	
	Link margin With Reed Solomon Decoding						
27	Required Eb/No (1/2 CONV + RS)	2.40	2.40	2.40	2.40	dB	
28	SYSTEM LINK MARGIN (1/2 CONV + RS)	3.6	8.17	1.45	7.59	dB	(22+23–27)
29	MARGIN ABOVE 3DB GOAL (1/2 CONV + RS)	0.6	5.17	–1.55	4.59	dB	

[1] User should provide a value for the Ground Multipath Degradation because this item in budget depends on the ground station design.
[2] The uncertainty band for the implementation loss is +/– 1.1 dB, based on two analysis methods. The actual value will depend on the ground station as well as the spacecraft segment. Loss includes allowance for degradation of Reed Solomon decoding from small number of bit errors generated in spacecraft after the Reed Solomon encoding and before viterbi encoding.

APPENDIX 1

ANTENNA PERFORMANCE DATA

This section provides DAS system test data for reference only. The measured variation in the DAS system EIRP, gain, and axial ratio as a function of ground antenna elevation angle are shown in Figures 13, 14, and 15, respectively.

If it is desired to evaluate the link budget for a different ground elevation angle from the ones shown in this document, the EIRP and polarization loss (rows 4 and 6) in the link budgets can be updated using the information in Figure 13.

The DAS system tests were performed using an Engineering Test Model (ETM) antenna mounted on a mockup of the nadir face of the Spacecraft.

The data in these three figures is a weighted average of the ETM antenna measurements at five frequencies, in which the data is integrated with respect to power spectral density occupancy of the DP1 150/150 Mbps (I/Q) signal. The following factors should be used to adjust the data in these figures for other data rates:

Symbol Rate	Correction Factor
26 Mps	+0.3 dB
210 Mps	–0.2 dB

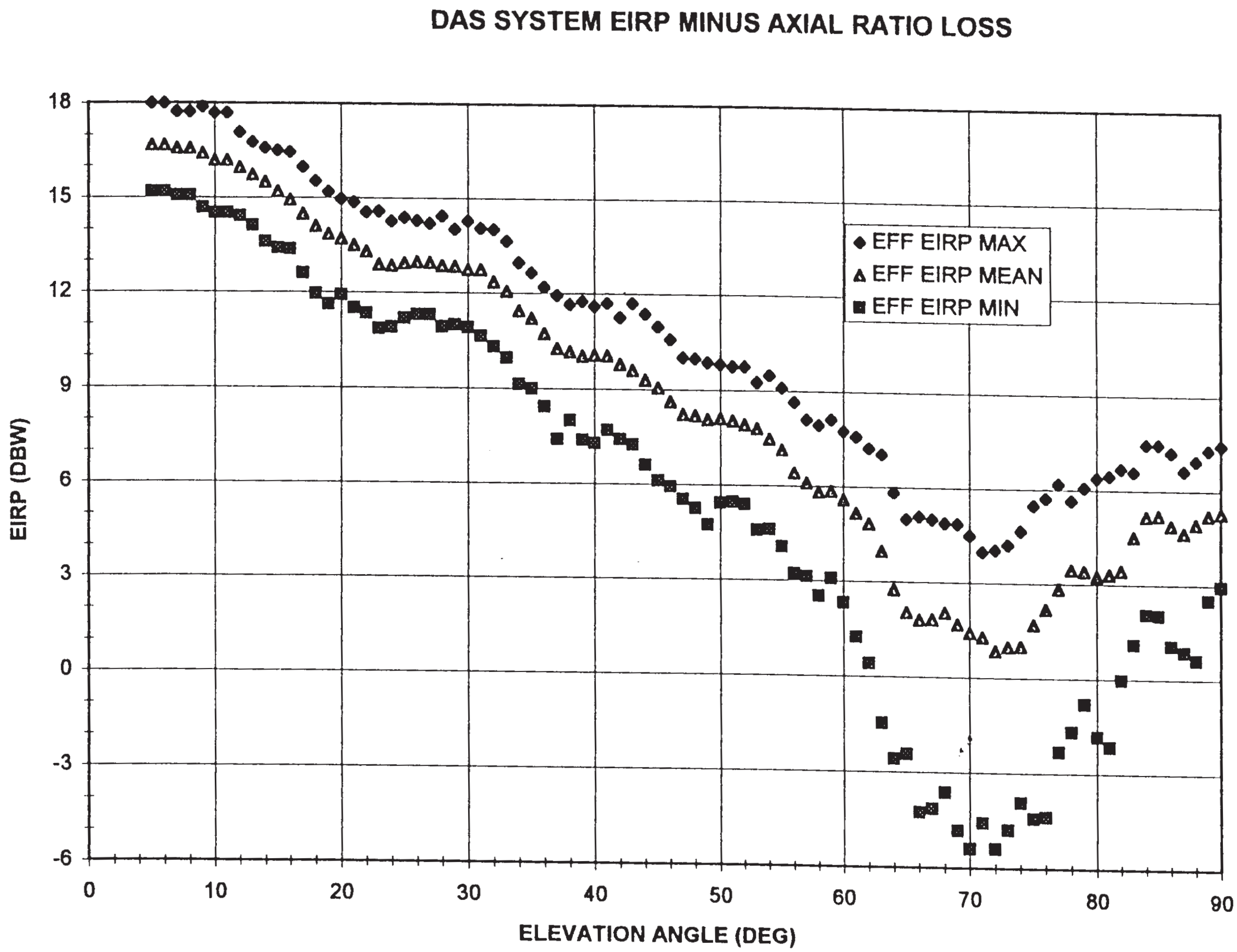

Figure 13. DAS System EIRP Minus Axial Ratio Loss

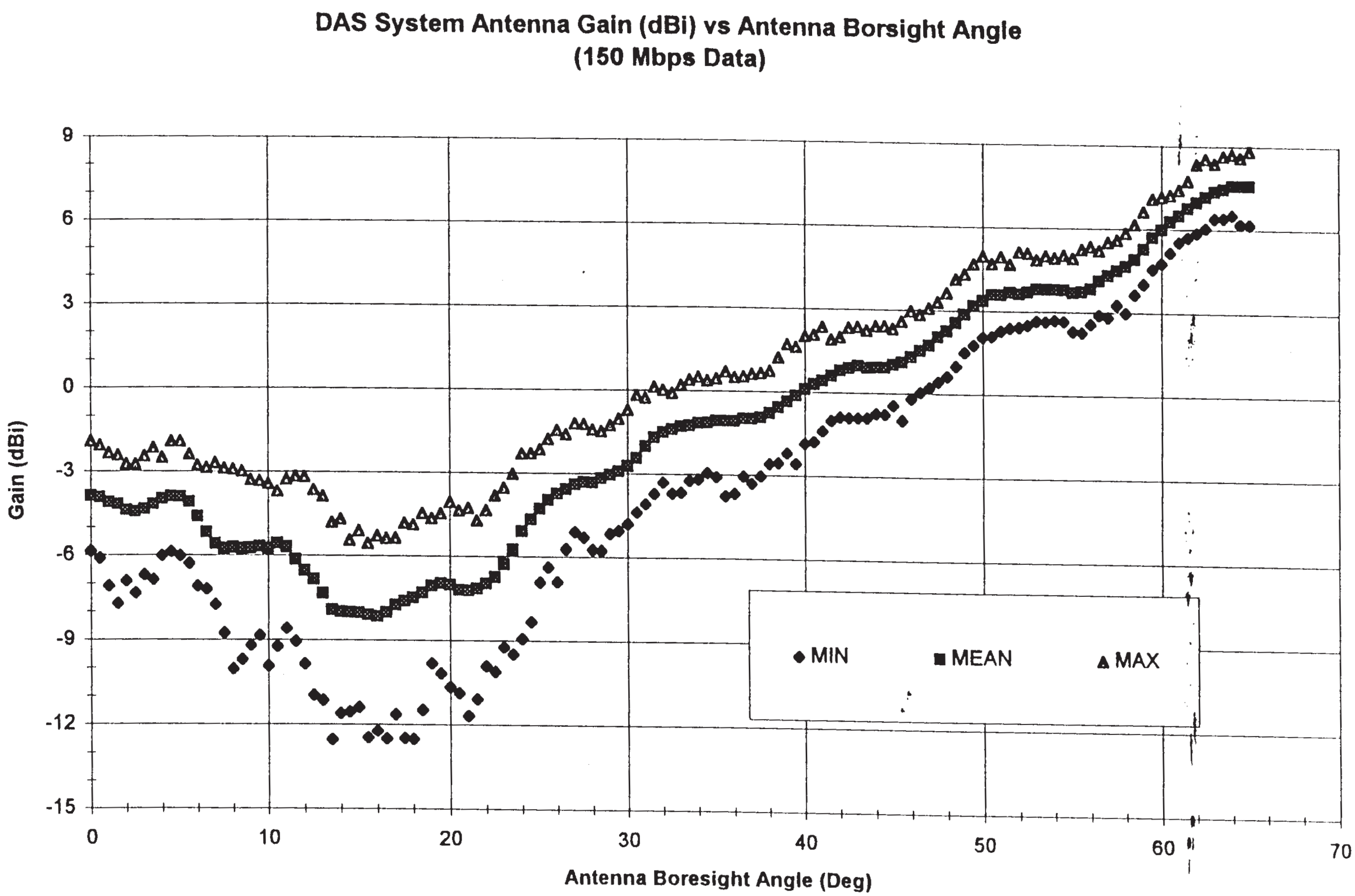

Figure 14. DAS System Antenna Gain (dBi) Versus Antenna Boresight Angle

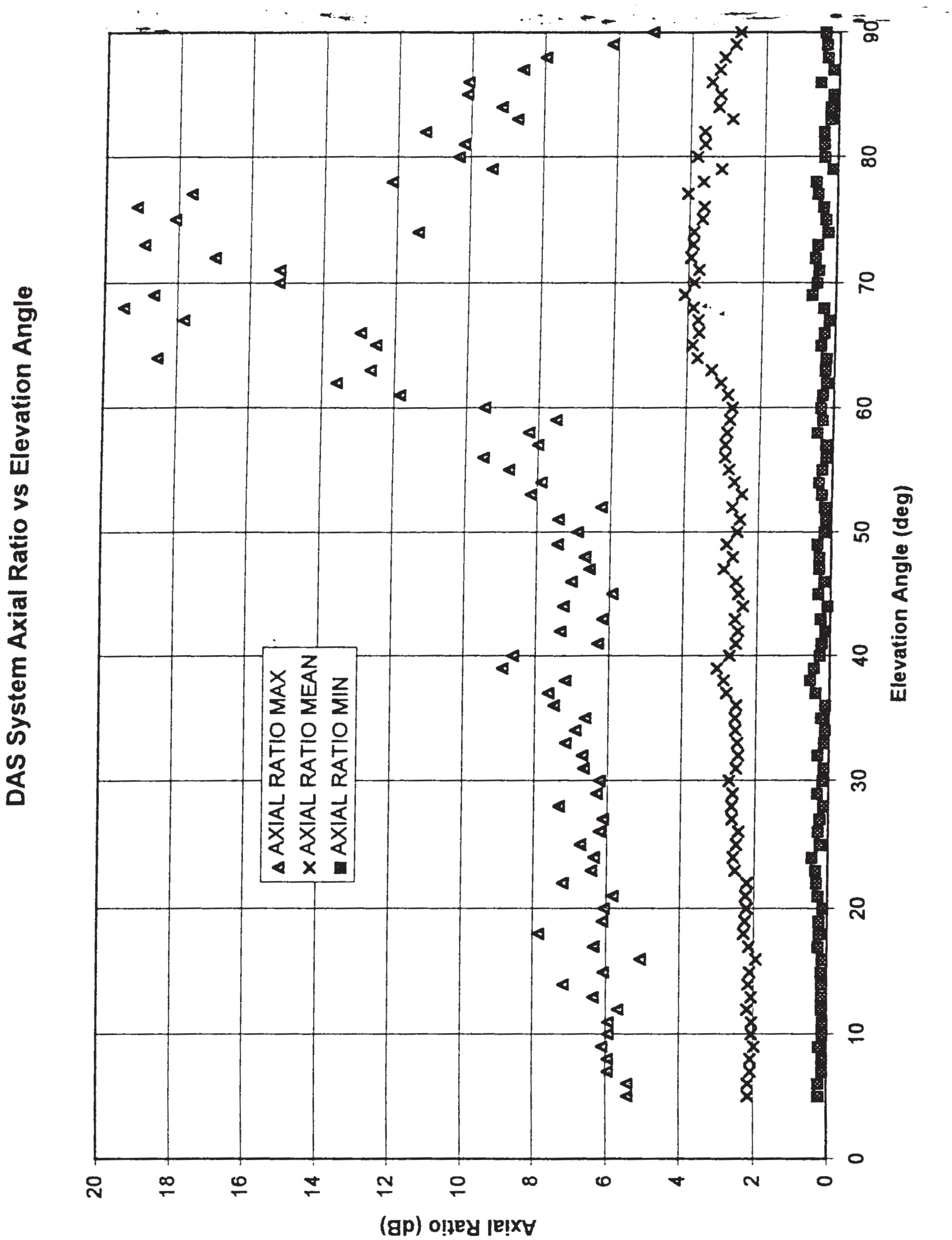

Figure 15. DAS System Axial Ratio Versus Ground Antenna Elevation Angle

APPENDIX 2

IMPACT OF DATA CODING ON REQUIRED EB/NO AND BIT ERROR RATE

This appendix provides information about how the BER and required Eb/No depends on the type of data coding performed by the ground system.

Eb/No is the ratio of received energy–per–bit (i.e. the received power times the bit duration) to the noise spectral density. The receiver noise bandwidth is determined by the data rate and the choice of modulation and coding.

The DAS communications link model shown in Figure 4 illustrates a concatenated coding scheme in which Reed–Solomon (RS) coding and then convolution (CONV) encoding are applied on the Spacecraft prior to transmission to the earth station. At the earth station, it is assumed that a demodulator will employ a 3–bit soft–decision Viterbi (CONV) decoding process and that the subsequent bit stream will be Reed–Solomon decoded prior to delivery to the data users.

Data arrives at the DAS Modulators on the Spacecraft in an NRZ–L format and is converted to an NRZ–M format prior to convolutional encoding. In the NRZ–M format, data values are defined by either a change in value from the Nth to the (N+1st)bit (logic 1) or by no change in value from the Nth to the (N+1st) bit (logic 0). The differential encoding process, in which the format is changed from NRZ–M to NRZ–L, doubles the bit error rate because a single–bit error in the NRZ–M data stream produces two adjacent errors after conversion to the NRZ–L data format.

Figure 16 illustrates the significant benefits of data coding by showing the probability of error, Pe, as a function of Eb/No performance associated with several types of data coding. For a BER of 1 x 10^{-5}, the required Eb/No values range from 9.6 dB for the case of no coding to 4.2 dB for convolution encoding only to greater than 2.4 dB for convolution plus Reed–Solomon coding (with I=4).

The link budgets provided in Section 6 are provided for two points on Figure 16:

a. Point A: Convolutional Encoding (length 7, rate 1/2) Only requires a Eb/No of 4.2 dB to achieve a BER of 1 x 10^{-5}

b. Point B: Reed Solomon plus Convolutional Encoding requires a Eb/No of greater than 2.4 dB to achieve a BER of 1 x 10^{-5}

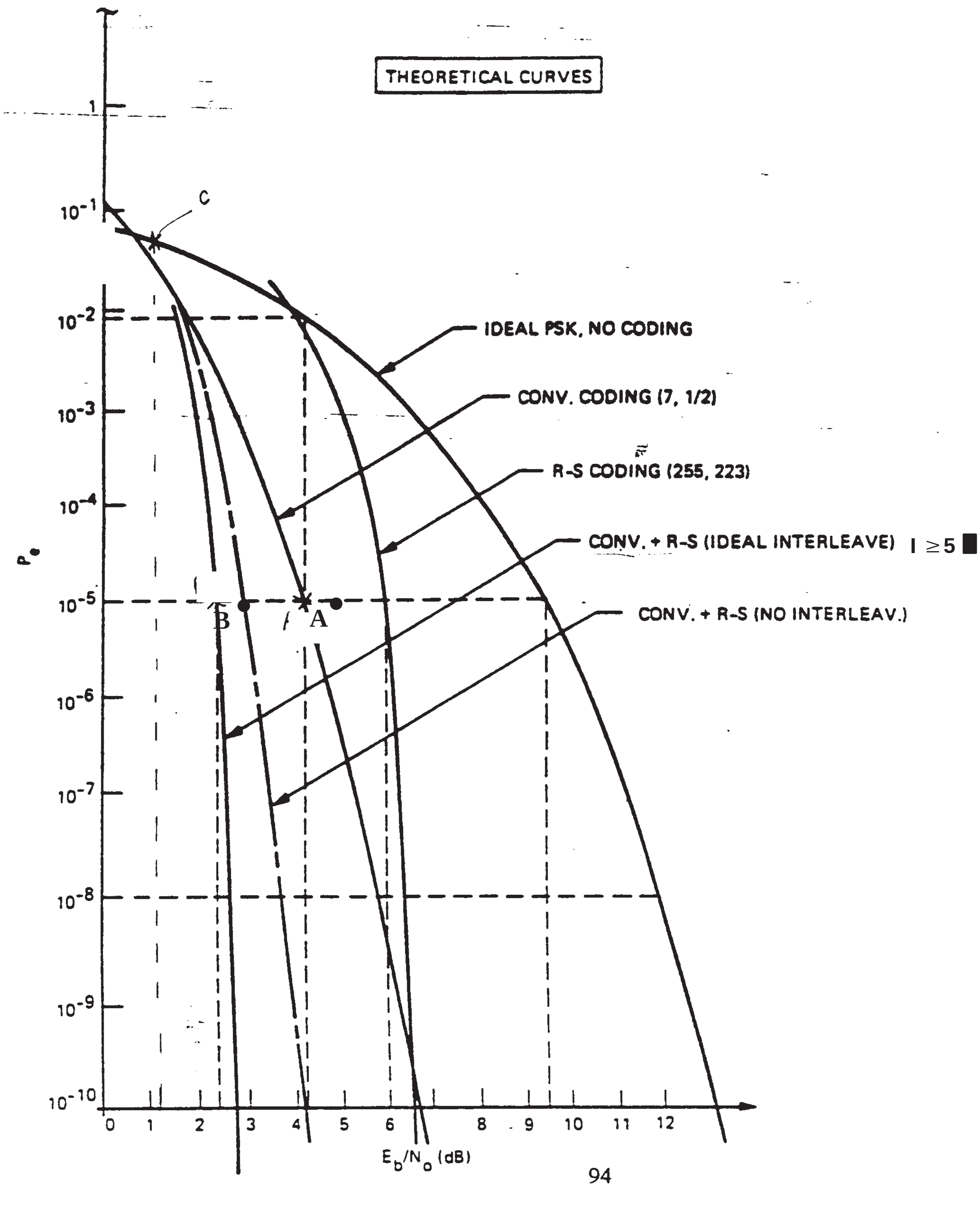

Figure 16. Theoretical Curves of The Probability of Error, Pe, As A Function of Data Coding Methods

APPENDIX 3

ACRONYM LIST

AM	Amplitude Modulation
AZ	Azimuth
BER	Bit Error Rate
Biϕ–S	Biphase Space
BOL	Beginning of Life
bps	bits per second
BPSK	Binary Phase Shift Keyed
BRF	Band Reject Filter
CADU	Channel Access Data Unit
CCSDS	Consulting Consortium of Space Data Systems
C&DH	Command and Data Handling Subsystem
CMD	Command
COMMS	Communications Subsystem
C&T	Command and Telemetry
CTIU	Command/Telemetry Interface Unit
DAS	Direct Access System
dc	Direct Current
DB	Direct Broadcast
dB	decibel
DDL	Direct Downlink
DG	Data Group, as defined in STDN 101.2
DP	Direct Playback
DSN	Deep Space Network
EDAC	Error Detection and Correction
EIRP	Effective Isotropic Radiated Power
EL	Elevation
EOC	EOS Operations Center
EOL	End of Life
EOS	Earth Observation System

EOSDIS	Earth Observation System Data Information System
EPGN	EOS Polar Ground Network
ESD	Electrostatic Discharge
FDIR	Fault Detection, Isolation, and Recovery
FOT	Flight Operations Team
GHz	Giga Hertz
GN	Ground Network
HGA	High Gain Antenna
H/K	Housekeeping Telemetry
H&S	Health and Safety Telemetry
Hz	Hertz
ICD	Interface Control Drawing
IF	Intermediate Frequency
I/O	Input/Output
Kbps	kilobits per second
kHz	Kilohertz
KSA	Ku–band Single Access
LHCP	Left Hand Circularly Polarized
LNA	Low Noise Amplifier
LPC	Load Power Conditioner
M	Mode, as defined in STDN 101.2
Mbps	Megabits per second
Msps	Megasymbols per second
MHz	Megahertz
MO	Master Oscillator
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NCO	Numerically Controlled Oscillator
NRZ–L	Non–Return to Zero Level
NRZ–M	Non–Return to Zero Mark
OCXO	Ovenized Crystal Oscillator
omni	omnidirectional

PCB	Printed Circuit Board
PLL	Phase Lock Loop
PM	Phase Modulation
PN	Pseudorandom Noise
pps	pulses per second
PBSG	Pseudorandom Bit Stream Generator
PRBS	Pseudo Random Bit Stream
PWM	Phase Width Modulated
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RFI	Radio Frequency Interference
RHCP	Right Hand Circularly Polarized
RT	Remote Terminal
SCC	Spacecraft Control Computer
SFE	Science Formatting Equipment
SQPN	Staggered Quadriphase Pseudorandom Noise
SQPSK	Staggered Quadrature Phase Shift Keying
SSR	Solid State Recorder
STDN	Spaceflight Tracking and Data Network
TCXO	Temperature Compensated Drystal Oscillator
TDRSS	Tracking and Data Relay Satellite System
TLM	Telemetry
VCO	Voltage Controlled Oscillator
VSWR	Voltage Standing Wave Ratio
WGS	Waveguide Switch
WPS	Wallops Island Station
WSGT	White Sands Ground Tracking
X–band RFICD	NASA document 5310–RFICD–EOS–AM–1/EPGN