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Performance and Design Requirements and Specification for the Fourth Generation TDRSS User Transponder

February 1996

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National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

Performance and Design Requirements and Specification for the Fourth Generation TDRSS User Transponder

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Preface

This document contains the functional and performance requirements and specifications for the NASA Tracking and Data Relay Satellite System (TDRSS) user transponder.

This document defines and controls the configuration of the NASA standard TDRSS user transponder. Once approved by the Chief, Networks Division, and the Chairman, Space Network (SN) Configuration Control Board (CCB), the TDRSS user transponder capabilities must not be altered without prior approval of the SN CCB.

Any approved changes to the TDRSS user transponder will be noted in this document. Changes to the document will be made by Documentation Change Notice (DCN) or by complete revision.

The Networks Division, Code 530, is responsible for processing all changes to this document and presenting the proposed changes to the SN CCB for review and approval. After the proposed change is approved by the CCB, Code 530 will coordinate the printing and distribution of the DCN.

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Appendix A. TDRSS S-band Forward Link Signal Parameters

Appendix B. TDRSS S-band Return Link Signal Parameters

Appendix C. TDRSS KSA Return Link Signal Parameters

Appendix D. Amplitude and Phase Conventions for TDRSS Services

Appendix E. S-band Diplexer Performance Requirements

Appendix F. Standard Digital Interface Using RS-422

Appendix G. MIL-STD-1773 Interface

Appendix H. Essential Services Node: GSFC's MIL-STD-1773 Interface

Abbreviations and Acronyms

Section 1. Introduction

1.1 Scope

1.1.1
This document defines the design, performance, interface, and environmental requirements for a Tracking and Data Relay Satellite System (TDRSS) user transponder which will provide Multiple Access (MA), S-band Single Access (SSA) and Ku-band Single Access (KSA) TDRSS capability.

1.1.2
The requirements for a backup command and telemetry mode are also provided for a Spaceflight Tracking and Data Network (STDN) ground station link.

1.1.3
The transponder described in this specification is intended to be a fourth generation replacement for the National Aeronautics and Space Administration (NASA)-standard TDRSS user transponder.

1.2 Applicable Documents

The following documents provide additional information about the TDRSS user transponder or are the source of many of the requirements contained in this document. However, applicable requirements of these reference documents have, in general, been extracted and included in this document. Thus, the specification is intended to stand alone except where specific documents are referenced in the body of the specification.

	Control Number	Title
a.	S-805-1	*Performance Specification for Services via the Tracking and Data Relay Satellite System*, Revision B, April 4, 1983
b.	STDN No. 101.2	*Space Network User's Guide* (Revision 6)
c.	GSFC X-560-63-2	*Aerospace Data Systems Standards*
d.	STDN No. 108	*PN Codes for use with the Tracking and Data Relay System (TDRSS)*

	Control Number	Title
e.	MIL-STD-461C (Notice 1)	*Electromagentic Emission and Suceptibility Requirements for the control of Electromagnetic Interference*
f.	MIL-STD-1773	*Aircraft Internal Time-Division Command/Response Multiplex Data Bus: Optical*
g.	GEVS-SE	*General Environmental Verification Specification and ELV Payloads, Subsystems, and Components*
h.	MIL-STD-462	*Measurement of Electromagnetic Interference Characteristics*
i.	EIA-STD-RS422A	*Telecommunications: Electrical Characteristics of Balanced Voltage Digital Interface circuits*

Section 2. Functional and Operational Requirements

2.1 Introduction

2.1.1

The TDRSS user transponder will provide the user spacecraft portion of an S-band and/or Ku-band telecommunications link between an earth-orbiting spacecraft and the earth via the TDRSS (return link) and between the earth and the spacecraft via TDRSS (forward link). Figure 2-1 illustrates these telecommunication paths for both MA, SSA, and KSA return.

2.1.2

The functional and operational requirements necessary to provide these basic telecommunication links are contained in paragraphs 2.2 through 2.6. The functional block diagram of the transponder is shown in Figure 2-2. An external Band Reject Filter and Diplexer are part of the system configuration.

2.2 TDRSS Forward Link Functional Requirements

The transponder shall provide the following functions when receiving a forward link signal as defined in Appendix A:

a. Acquire and despread the short Pseudorandom Noise (PN) code.

b. Acquire and track the suppressed carrier and demodulate the Non- return-to-zero Phase Shift Key (NRZ-PSK) command data.

c. Provide hard command data decisions and reconstructed bit timing to the spacecraft command system.

d. Provide coherent turnaround capability to the transmitter.

e. Provide a means for rejecting false acquisitions due to multipath.

f. Despread and detect the long PN code and provide PN epoch synchronization to the transmitter for ranging turnaround.

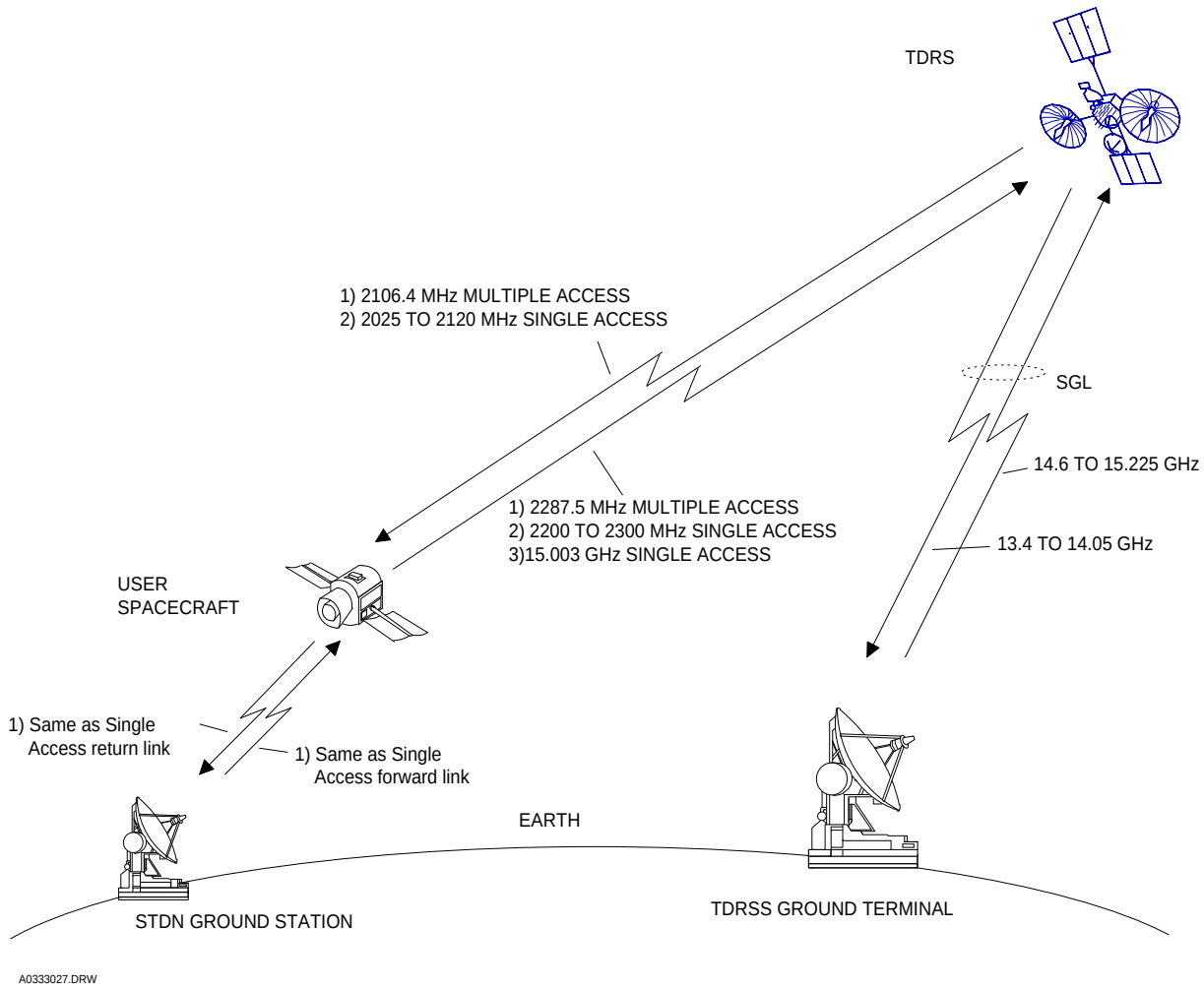


Figure 2-1. TDRSS Frequency Plan

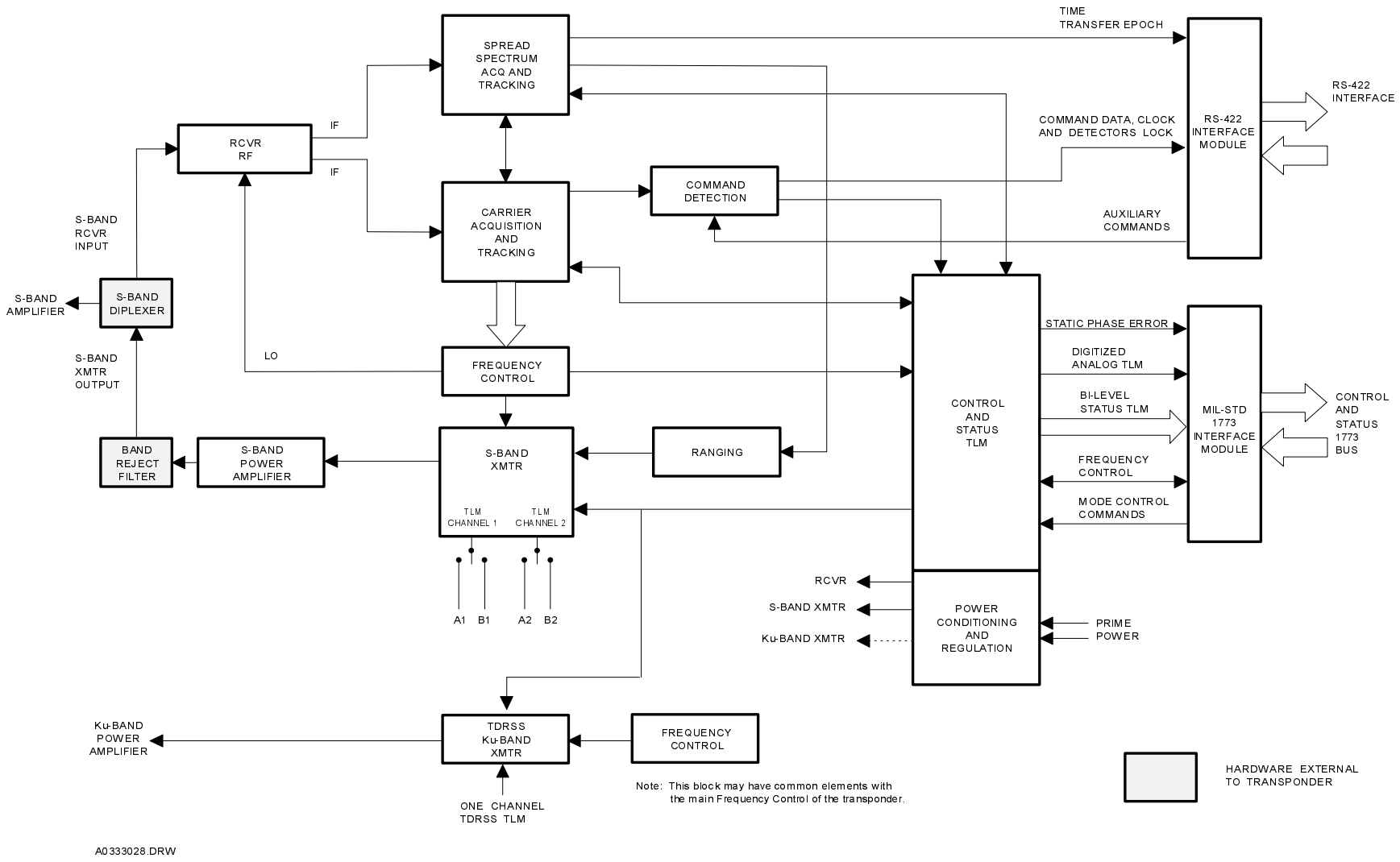


Figure 2-2. TDRSS User Transponder Functional Block Diagram

2.3 TDRSS Return Link Functional Requirements

The transponder shall provide the following transmit functions:

a. Spectrum spreading codes in accordance with STDN No. 108.

b. MA, SSA, or KSA configurations.

c. Two independent data channels (I and Q), which will be modulo-2 added to the spreading codes for MA, SSA services as defined in Appendix B, or a single data channel (which could be convolutionally encoded) for KSA service as defined in Appendix C.

d. An S-band coherent (mode 1) turnaround capability where the transmit carrier is related to the receiver frequency in the ratio 240/221 for Doppler tracking.

e. An S-band noncoherent (mode 2) capability whereby the carrier is derived within the transponder to provide a fixed frequency at approximately 240/221 times the receiver assigned center frequency. Ranging is not possible in the noncoherent mode.

f. A Ku-band noncoherent (mode 2) capability whereby the carrier is derived within the transponder to provide a fixed frequency at 15.003 GHz. Ranging is not possible in the noncoherent mode.

2.4 STDN Functional Requirements

The transponder shall provide the following STDN functions::

a. Receive and track a residual carrier unspread signal from a STDN station.

b. Track and demodulate command data from a 16-kHz subcarrier in NRZ-PSK format.

c. Provide hard command data decisions and recovered bit timing to the spacecraft command system.

d. Provide a coherent turnaround frequency reference to the transmitter for Doppler tracking.

e. Provide an internally generated 1.024 MHz subcarrier for telemetry modulation.

f. Provide a direct hardline interface for commands.

NOTE

The capability for range tone turn-around is not provided.

2.5 Spacecraft Functional Requirements and Interfaces

The design of the transponder shall provide the following capabilities and options:

a. Compatible RF interfaces to allow remote mounting of an S-band diplexer and/ or an S-band low noise preamplifier (and/or an optional Ku-band power amplifier/Band Pass Filter [BPF] assembly) without performance losses in excess of those attributed to cables and mismatch.

b. Control command interface for establishing the transponder operating modes and command data rates and for offsetting the transponder center frequency, via a dual redundant MIL-STD-1773 interface bus.

c. Status telemetry, to the spacecraft telemetry system, via a dual redundant MIL-STD-1773 interface bus.

d. Redundant command data, clock and lock indication to the spacecraft command system.

2.6 User Specified Parameters

2.6.1 Manufacturing Parameters

The transponder shall provide the following parameters which must be selected at the time the equipment is ordered:

a. Multiple access/single access: For single access configuration, center frequency assignment must be made.

b. 2.5 W or 5.0 W S-band power amplifier.

c. TDRSS mode telemetry Q:I power ratio: select 1:1, 2:1 or 4:1.

d. STDN mode uplink command modulation index: Range is from 0.5 radian peak to 1.3 radians peak with increment size of 0.1 radian.

e. STDN mode downlink telemetry modulation index: Range is from 0.2 radian/peak to 1.5 radians/peak with increment size of 0.1 radian.

f. Ku-band transmitter module telemetry data input impedance: The options are 50, 1000, and 5000 ohms nominal.

g. Temperature sensor: User may specify and/or supply the thermistors for temperature sensor telemetry, of the Temperature Compensated Crystal Oscillator (TCXO) and the power amplifier.

2.6.2 Programming Parameter

The following states are specified by the external programming connector. A change of state shall only require a simple replacement of the programming connector:

a. Powerup command rate: This option allows the user to specify a known data rate on receiver powerup. The allowed rates are 125, 250, 500, and 1000 b/sec.

b. Transponder Remote Terminal (RT) address: This option allows individual addressing to redundant transponders, via their dual redundant MIL-STD-1773 interface. The user must specify Remote Terminal (RT) for each unit.

c. PN code: The users assigned PN code address (1 of 85) must be specified.

Section 3. Performance Requirements

3.1 Overview

The TDRSS user transponder shall meet all performance requirements specified in this section, except where specific deviations are identified, under any combination of test and environmental conditions specified in Section 6. This includes transmitter-to-receiver coupling effects and interference rejection requirements, as specified in Appendix E.

3.2 Receiver Requirements

3.2.1 General

The requirements of paragraphs 3.2.2 through 3.2.11 apply when receiving a TDRSS signal or a direct Continuous Wave (CW) signal from a STDN.

3.2.2 Noise Figure

The noise figure at the receiving input connector, referenced to a 50-ohm source impedance, shall not exceed 2.5 dB.

3.2.3 Input Impedance

The nominal input impedance at the receiver input shall be 50 ohms with a Voltage Standing Wave Ratio (VSWR) of 1.5:1 or less.

3.2.4 Input Frequency

The nominal receiver center frequency shall be 2106.40625 MHz for MA service and selectable in the range 2025 to 2120 MHz for SSA service.

3.2.5 Maximum Input Level

The receiver shall not be damaged or permanently degraded by a continuous inband signal of +10 dBm or less.

3.2.6 Dual Mode Search

The receiver shall simultaneously search for TDRSS PN code correlation and a STDN CW signal greater than the detection threshold. Upon acquisition of one signal type, the other mode will be inhibited until loss of initial signal and subsequent return to search mode occurs.

3.2.7 Self Lock

The receiver shall not exhibit spurious lock indications when no signal is present. This applies both with and without the transmitter on and with full transmitter modulation.

3.2.8 False Lock

The receiver shall not false lock when the input signal level is as follows:

a. TDRSS Mode: Between 77 dB-Hz and 33 dB-Hz when the input signal has correlation sidelobes 24 dB or more down from the desired correlation peak. Acquisition of the short code and carrier will be accomplished without carrier command modulation.

b. Direct CW Mode: Between 120dB-Hz and 75 dB-Hz and swept in frequency as defined in paragraph 3.4.4. Acquisition will be accomplished without subcarrier modulation.

3.2.9 CW Spurious Signal Rejection

3.2.9.1

Response to spurious CW signals will be defined as a level sufficient to cause more than 1 dB degradation in acquisition, tracking, or command thresholds. For rejection of signals outside the band of the carrier frequency arriving at the user spacecraft $F_r \pm 50$ MHz, including the S-band and Ku-band transmit signals, the external diplexer is assumed which has performance specified in Appendix E.

3.2.9.2

Response, as defined in paragraph 3.2.9.1, to image frequencies inserted at the receiver input shall require input levels 50 dB or more above threshold level at the nominal frequency. All other responses due to signals outside of the receiver passband of $F_r \pm 10$ MHz shall require input levels 50 dB above the threshold at the center frequency.

3.2.10 Pulsed RFI Rejection

3.2.10.1

When operating in the TDRSS mode, the receiver shall perform with less than 3-dB degradation in acquisition, tracking, and command thresholds when an in-band pulsed Radio Frequency Interference (RFI) signal with the following characteristics is present:

a. Level: +10 dBm peak.

b. Frequency: $F_r \pm 10$ MHz.

c. Pulse width: 10 µsec.

d. Repetition rate: 3333 pps.

e. Duty cycle: 3 percent.

3.2.10.2

In the presence of this pulsed RFI signal, the CW signal detector must not produce false detections at an average rate exceeding 1 per 100- second period.

3.2.11 CW RFI Rejection

The receiver must be able to recover its normal operation after exposed to a CW RFI signal on the receiver input connector from -30 dBm to -135 dBm over a 12 MHz band centered at the receiver frequency.

3.2.12 Receiver Lock Detectors

The receiver is required to provide the following lock detectors:

a. Sync Detect: In the TDRSS mode, it indicates the receiver has detected energy in the receive bandwidth and it has initiated the PN code main lobe verification routine.

b. Main lobe Detect: In the TDRSS mode, it indicates the receiver has concluded successfully the PN code main lobe verification routine.

c. PN Lock: In the TDRSS mode, it indicates the receiver is locked to and tracking the short PN code. In the STDN mode, it is not used.

d. Carrier Lock: Indicates the receiver carrier loop is locked to a TDRSS or STDN signal.

e. Command Detector Lock: This indicator will provide a dual function depending on receiver mode. In the TDRSS mode, it indicates that bit synchronization has been

achieved. In the STDN mode, it indicates that Subcarrier Loop Lock and bit synchronization has been achieved.

f. Long Code Detect: In the TDRSS mode, it indicates synchronization has been established with the long PN code. In the STDN mode, it is not used.

g. CW Detector: It indicates the presence of a strong CW, therefore, the receiver is searching for a STDN signal.

3.3 Receiver Performance: TDRSS Mode

3.3.1 General

The transponder must meet the requirements of paragraphs 3.3.2 through 3.3.7 when receiving a spread spectrum signal in accordance with Appendix A.

3.3.2 TDRSS Acquisition Performance

3.3.2.1 Signal Dynamic Range

The receiver must meet the acquisition performance requirements when the Signal-to-noise density ratio (S/N_O) is between 33 dB-Hz and 77 dB-Hz in the command channel. Acquisition will be accomplished without carrier command modulation.

3.3.2.2 Acquisition Frequency Range

The receiver must meet the acquisition performance requirements when the forward link frequency has been Doppler compensated to within $\pm$1500 Hz of the actual transponder center frequency. The rate of change of frequency will not exceed 70 Hz/sec during acquisition.

3.3.2.3 Short Code Acquisition Time

The receiver must acquire short code PN lock with a probability of 90 percent or greater within 20 seconds after arrival of the forward link transmission. This applies for command channel S/N_O values of 33 dB-Hz to 77 dB-Hz. At an S/N_O of 37 dB-Hz or greater, the acquisition time must not exceed 7 seconds with a probability of 90 percent or greater.

3.3.2.4 Carrier Acquisition Time

The time required to obtain phase lock to the suppressed carrier after completion of short code (despread) acquisition must not exceed 5 seconds with a probability of 90 percent or greater over the specified dynamic range.

3.3.2.5 Long Code Acquisition Time

The receiver must establish synchronization with the long PN code with a probability of 90 percent or greater within 10 seconds after carrier lock when the S/N_o in the long code is 23 dB-Hz or greater.

3.3.3 TDRSS Tracking Performance

3.3.3.1 Tracking Threshold

The tracking threshold is defined as the lowest S/N_o where lock can be held to a static forward link signal for 1 minute with a probability of 90 percent. The requirement as a function of command data rate selected is tabulated in Table 3-1.

Table 3-1. Tracking Threshold

S/N_o (dB-Hz)	Command Data (b/sec)
32	125
35	250
38	500
41	1000
44	2000
47	4000
50	8000
51	10000
= 11 + 10 log [command data (b/sec)]	>10000

3.3.3.2 Tracking Rates

The receiver must acquire, track, and demodulate commands with Doppler rates up to those tabulated in Table 3-2. Corresponding carrier cycle slipping requirements are also tabulated.

Table 3-2. TDRSS Tracking Rates

Command Rate Selected	S/No (dB-Hz)	Maximum Tracking Rate (Hz/sec)	Cycle Slip Limit (slips/sec)
125	34	70	10^{-2}
250	37	70	10^{-3}
500	40	380	10^{-4}
1000	43	380	10^{-4}
2000	46	380	10^{-5}
4000	49	380	10^{-5}
8000	52	380	10^{-5}
10000	53	380	10^{-5}
>10000	13 + 10log [command rate (b/sec)]	380	10^{-5}

3.3.3.3 Tracking Range

Once locked, the receiver must be capable of tracking $\pm$160 kHz about the assigned center frequency.

3.3.4 Reacquisition

For signal dropouts with durations ≤ 50 msec, the carrier phase lock loop must reacquire unassisted in a time ≤ 50 msec after the signal is reestablished.

3.3.5 Multipath Rejection

The receiver acquisition logic must discriminate between direct and multipath signals and reject continuous tracking of a multipath signal by providing a timeout circuit which will declare a short code PN acquisition to be multipath if carrier lock is not achieved within 11 seconds after short code PN lock.

3.3.6 Command Detector Lock Performance: TDRSS Mode

3.3.6.1 General

The requirements of the command detector lock (TDRSS mode) apply at values of S/N_o greater than or equal to command threshold (at the selected data rate) as defined in paragraph 3.5.4.

3.3.6.2 False Drop Lock Probability

When the receiver is tracking at or above command threshold and after bit synchronization has been achieved, the probability of indicating out-of-lock must not exceed $1x10^{-9}$ in any 48-bit interval.

3.3.6.3 Drop Lock Probability

When the signal is removed or bit synchronization is lost, the command detector lock output must indicate out-of-lock within 48-bits with a probability of 0.998 or larger.

3.3.7 Receiver Center Frequency Requirements

3.3.7.1 General

When the receiver is in the search mode, the center frequency must be derived from the internal reference oscillator. It must meet the stability requirements of this paragraph.

3.3.7.2 Center Frequency Setability

The receiver center frequency, F_r shall be initially set to within $\pm$0.5 parts-per-million (ppm) of the assigned channel center frequency, F_{cf}, at time of manufacture, at a temperature of 24 $\pm$2 degrees C.

3.3.7.3 Temperature Stability

At any temperature ($\pm$0.5 degrees C) in the ranges shown in steps a and b, the frequency variation must not exceed the following limits:

a. From 10 degrees C to 40 degrees C: $\pm$0.3 ppm.

b. From -10 degrees C to +55 degrees C: $\pm$1 ppm.

3.3.7.4 Long-term Stability

At any one temperature (±0.5 degrees C) in the range from 10 to 40 degrees C, the frequency must not vary more than the following limits with a 10-minute integration time:

a. +0.1 ppm over any 5-hour period.

b. +0.3 ppm over any 48-hour period.

3.3.7.5 Aging Stability

At any one temperature (±0.5 degrees C) in the range from 10 to 40 degrees C, the frequency must not vary more than ±3 ppm from the set value in any 1 year.

3.3.7.6 Center Frequency Offset

The receiver center frequency must be capable of frequency offsets up to ±80 kHz through the use of a control word whose interface characteristics are defined in paragraph 4.5.3. The resolution for this offset capability must be 10 Hz or better.

3.4 Receiver Performance: STDN Mode

3.4.1 General

The receiver must meet the performance requirements of paragraphs 3.4.2 through 3.4.8 when receiving a swept CW signal from a STDN station. Acquisition performance assumes no carrier modulation while carrier tracking performance assumes a 16-kHz subcarrier up to 1.3 radians peak.

3.4.2 Signal Detection Range

When the Carrier-to-noise density ratio (C/N_O) is between 75 and 120 dB-Hz, the receiver must detect a STDN signal swept through the receiver center frequency with a probability greater than 0.99. If the C/N_O is less than 60 dB-Hz, the probability of detection will be less than 1 percent.

3.4.3 Best Lock Frequency

During the search for a STDN CW signal, the receiver best lock frequency shall be the center frequency derived from the reference oscillator. The stability and setability requirements of paragraph 3.3.7 apply.

3.4.4 Acquisition Sweep Rate

The receiver must detect, per paragraph 3.4.2, and phase lock to a STDN signal swept at rates between 5 and 35 kHz/sec. The probability of acquisition must be greater than 0.99 in a period corresponding to one sweep period.

3.4.5 Tracking Rate

Once acquired, the receiver must track a STDN signal with rates up to 35 kHz/sec at a C/N_o of 60 dB-Hz or greater.

3.4.6 Tracking Range

The tracking range must be $\pm$160 kHz minimum at a C/N_o of 60 dB-Hz or greater.

3.4.7 Tracking Threshold

The receiver must hold lock in the absence of frequency dynamics for 1 minute or more with a probability greater than 90 percent when the unmodulated C/N_o is 40 dB-Hz or greater.

3.4.8 Reacquisition

The receiver must be capable of reacquisition without the aid of ground sweep for signal dropout durations up to 30 msec. This applies for tracking a STDN signal with Doppler rates up to 3 kHz/sec.

3.5 Command Channel Performance: TDRSS Mode

3.5.1 General

The requirements of this paragraph apply when the receiver is a forward link signal with an S/N_o equal to or greater than command threshold.

3.5.2 Command Data Bit Rates

Command data bit rates shall be 10000, 8000, 4000, 2000, 1000, 500, 250, and 125 b/sec. Command data bit rates above 10000 b/sec are not required, but if inherent in the design, they can be provided at any rate(s) up to the maximum TDRSS rate of 300 kb/sec. One of these rates will be specified by the control command word. The power-up condition data rate will be specified at time of manufacture.

3.5.3 Command Threshold Definition

In the TDRSS mode, command threshold is defined as the command S/N_o at which the error rate in the data out of the receiver equals 1×10^{-5} per bit.

3.5.4 Command Threshold

The command threshold must occur at or below the values of S/N_O listed in Table 3-3 as a function of data rate.

Table 3-3. Command Threshold

S/N_O (dB-Hz)	Data Rate (b/sec)
34 (Note)	125
37	250
40	500
43	1000
46	2000
49	4000
52	8000
53	10000
= 13 + 10 log [Data rate (b/sec)]	>10000

NOTE

Applies for Doppler rates 35 Hz/sec. For Doppler rates between 35 and 70 Hz/sec the threshold must not exceed 35 dB-Hz.

3.5.5 Acquisition/Tracking Range

The receiver must acquire and track the data transitions within the command signal when the frequency offset and frequency offset rate are less than the limits indicated in Table 3-4. This performance must be achieved at and above the threshold defined in paragraph 3.5.4. This performance must be achieved in the presence of the worst case transition density defined in paragraph 3.5.6.

Table 3-4. Command Acquisition/Tracking Requirements

Data Rate (b/sec)	Maximum Frequency Offset (ppm)	Maximum Frequency Offset Rate (ppm/s)
>10000	50	$= \left[\frac{\text{Data rate (b/sec)}}{250}\right]$
10000	50	80
8000	50	32
4000	50	16
2000	50	8
1000	50	4.0
500	50	2.0
250	50	1.0
125	50	0.5

3.5.6 Command Data Transition Density

The receiver must meet the command threshold requirement when the command data has the following transition characteristics:

a. Maximum string of 1s or 0s: 62 bits.

b. Minimum transitions in every 64 bits: 2.

c. All data patterns may be transmitted repetitively.

3.5.7 Command Acquisition

The receiver must acquire bit synchronization on receipt of an acquisition preamble consisting of 128 bits (or more) of alternating 1/0 data at the command rate selected.

3.6 Command Channel Performance: STDN Mode

3.6.1 General

The requirements of this paragraph apply when the receiver is tracking an RF signal from the STDN with NRZ-PSK data on a 16-kHz subcarrier.

3.6.2 Carrier Modulation Index

The 16-kHz sinewave subcarrier must linearly phase modulate the STDN received signal at a single fixed modulation index between 0.5 and 1.3 radians peak. Performance requirements must be met at this selected index $\pm$10 percent.

3.6.3 Subcarrier Acquisition

The subcarrier loop must acquire and track when the subcarrier frequency is 16 kHz $\pm$1.6 Hz with a maximum rate of change of $\pm$0.05 Hz/sec.

3.6.4 Subcarrier Threshold

The receiver must acquire and maintain subcarrier lock when the Subcarrier-to- noise density ratio (SC/N_o) is 50 dB-Hz or greater.

3.6.5 Command Threshold

The bit error rate must be less than or equal to 1×10^{-5} errors per bit when the SC/N_o is 50 dB-Hz or greater.

3.6.6 Command Data Clock Rate

The command data clock rate arriving at the user transponder via the RF link will be 2 kHz $\pm$100 parts per million.

3.6.7 Command Data Transition Density

The receiver must meet the command threshold requirement when the command data has the following transition characteristics:

a. Maximum string of 1s or 0s: 62 bits.

b. Minimum transitions in every 64 bits: 2.

c. All data patterns may be transmitted repetitively.

3.6.8 Command Acquisition

The receiver must acquire bit synchronization on receipt of an acquisition preamble consisting of 128 bits (or more) of alternating 1/0 data at 2 kb/sec.

3.6.9 Command Detector Lock Performance: STDN Mode

3.6.9.1 General

The command detector lock (STDN mode) shall meet the performance requirements of paragraphs 3.6.9.2 through 3.6.9.4 when the subcarrier SC/N_o is 50 dB-Hz or greater.

3.6.9.2 False Acquisition

When the receiver is unlocked or when no 16 kHz subcarrier is present on the RF carrier, the probability that the command detector lock indicator will indicate a true or locked condition must be less than or equal to $1x10^{-4}$ in any 48-bit interval.

3.6.9.3 False Drop Lock Probability

After subcarrier acquisition and bit synchronization has been achieved, the probability of an out-of-lock indication must be $1x10^{-9}$ in any 48-bit interval.

3.6.9.4 Drop Lock Probability

The receiver must indicate the out-of-lock condition within 48 bits after the removal of RF carrier, or after the removal of the subcarrier modulation or after bit synchronization loss with a probability of 0.998 or greater.

3.7 TDRSS Ranging Performance

3.7.1 General

In the ranging mode, the transponder must synchronize the transmitted long PN code epoch with the received signal long PN code epoch. The transponder must meet the timing requirements between these epochs specified in paragraphs 3.7.2 through 3.7.5.

3.7.2 Absolute Time Delay

The nominal absolute time delay (T_o) between transmit and receive epochs must be 325 nsec $\pm$100 nsec.

3.7.3 Time Delay Variation

The time delay, when averaged over a 100-second interval, between transmit and receive epochs (T_O) must not vary from its nominal value more than $\pm$30 nsec as a function of signal strength, carrier frequency, chip rate, or primary power supply voltage, either individually or in conjunction with the environmental parameters of Section 6.

3.7.4 Time Delay Repeatability

The time delay for any specific set of signal and/or environmental parameters must be repeatable within $\pm$10 nsec.

3.7.5 Short-Term Time Delay Jitter

The time delay jitter must not exceed 10 nsec rms.

3.8 S-band Transmitter Requirements

3.8.1 General

The requirements of this paragraph apply to operation of the transmitter in either the TDRSS mode or the direct STDN mode. All performance requirements are referred to the band reject filter output as shown in Figure 2-2.

3.8.2 Transmitter RF Power Output

One of two optional power outputs will be selected at time of manufacture which shall meet the following requirements over the operating temperature range of -10 degrees C to +55 degrees C:

a. Option 1: 2.5 watt +1.0, -0.5 dB

b. Option 2: 5 watt +1.0, -0.5 dB

NOTE

Over the qualification temperature range of -20 degrees C to +65 degrees C, the variation will not exceed $\pm$1.0 dB.

3.8.3 Output Impedance

The output impedance at the RF output shall be 50 ohms nominal with 1.5 VSWR maximum.

3.8.4 Transmitter Output Load VSWR

The transponder must meet all performance requirements with a load VSWR not greater than 1.5:1 at any phase angle. It must not be damaged by the application of any load from short to open circuit at any phase angle.

3.8.5 Spurious Outputs

3.8.5.1 General

Spurious components of the transmitted signal shall be in accordance with paragraphs 3.8.5.2 through 3.8.5.4.

3.8.5.2 Inband Spurious

The root-sum square of all discrete spurious signals within $\pm$3 MHz of the nominal transmit signal frequency shall be less than 2 degrees rms when measured with a phase lock loop having a single-sided loop noise bandwidth of 24 Hz and a video bandwidth of 3 MHz.

3.8.5.3 Out-of-band Spurious

Discrete signals outside the band $F_t \pm$ PN chip rate and not attributable to the modulation process must be less than the limits shown in Figure 3-1. Total spurious power at the receiver frequency $F_r \pm$10 MHz must not exceed -130 dBm.

3.8.5.4 Broadband Noise

Additive broadband noise in the transmit band of 2200-2300 MHz, except at transmit carrier frequency $F_t \pm$6 MHz, must not exceed a power spectral density of -100 dBm/Hz. At the receive frequency $F_r \pm$10 MHz, the noise power spectral density must not exceed -180 dBm/Hz.

3.8.6 Transmit Frequency Requirements

3.8.6.1 General

In coherent modes 1 and 3 as defined in Appendix B, the transmitter frequency source will be derived from the receiver. In noncoherent mode 2, the source will be an internal TCXO. Switching between the coherent and noncoherent modes shall be automatic; however, the transfer from the TCXO to the receiver coherent reference must be capable of command override.

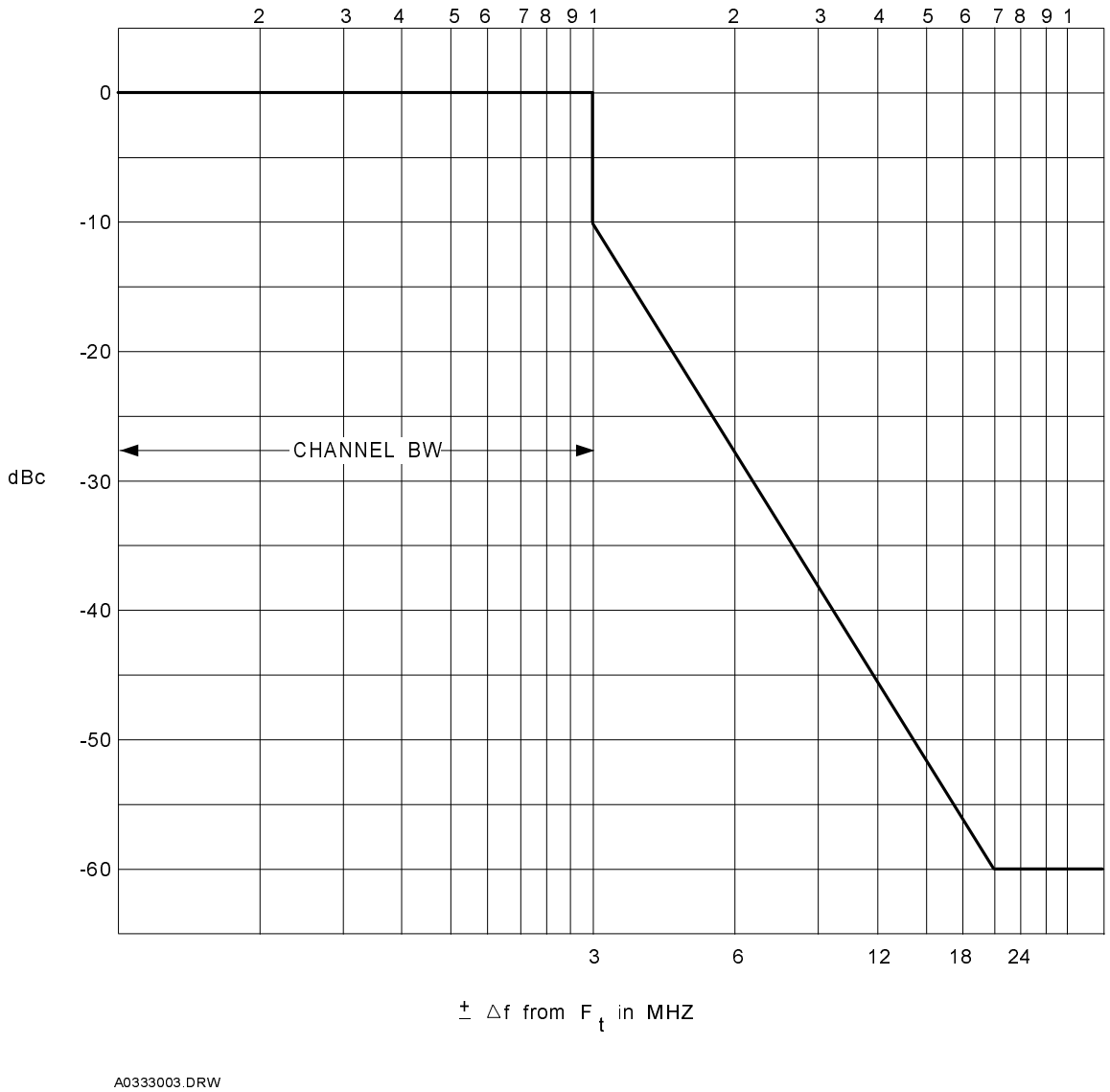


Figure 3-1. Out-of-band Spurious Rejection

3.8.6.2 Output Frequency

The transmitter center frequency in the coherent mode must be 240/221 times the received (forward link) signal frequency. In the noncoherent mode, the transmitter center frequency must be approximately 240/221 times the received signal frequency. The nominal frequency will be chosen at the time of manufacture.

3.8.6.3 Noncoherent Frequency Characteristics

The transmitter output frequency in the noncoherent mode must satisfy the requirements stated in paragraphs a through e after operating for 90 minutes.

a. Setability. The frequency will be set at time of manufacture within $\pm$0.5 ppm of the assigned channel center frequency at a baseplate temperature of 24 $\pm$2 degrees C.

b. Short-term Stability. At any one temperature (±0.5 degree C tolerance) in the range from -20 degrees C to +65 degrees C, the rms fractional frequency deviation over a 3-minute period, measured with a 1-second integration time, must not exceed 1×10^{-9}.

c. Long-term Stability. At any one temperature (±0.5 degree C tolerance) in the range from 10 to 40 degrees C, the frequency must not vary more than the following limits with a 10-minute integration time:

   1. +0.1 ppm over any 5-hour period.

   2. +0.3 ppm over any 48-hour period.

d. Temperature Stability. At any temperature (±0.5 degree C tolerance) in the ranges shown below, the frequency variation must not exceed the following limits:

   1. From 10 to 40 degrees C: $\pm$0.3 ppm.

   2. From -10 to +55 degrees C: $\pm$1 ppm.

e. Aging Stability. At any one temperature (±0.5 degree C tolerance) in the range from 10 to 40 degrees C, the frequency must not vary more than $\pm$3 ppm from the set value in a period of 1 year.

3.8.6.4 Transfer Time

a. The time required for switching to mode 1 transmitter operation must not exceed 1 second after acquisition of the forward link carrier and long code epoch synchronization provided that the conditions of paragraph 4.5.2.7 are met.

b. Upon loss of forward link carrier lock, the transmitter must return to mode 2 operation in a time interval greater than 2 seconds but less than 4 seconds.

3.8.7 Noncoherent (Mode 2) Phase Noise

When operating in the noncoherent mode, the phase noise at the transmitter output must not exceed 2 degrees rms in the 1 Hz to 3 MHz band.

3.8.8 Coherent (Mode 1) Phase Noise

When the transponder is in the coherent turnaround mode, the phase noise at the transmitter output must not exceed 2 degrees rms in the 1 Hz to 3 MHz band. The noise contributed by tracking the forward link signal and associated thermal noise will be excluded.

3.9 S-band Transmitter Performance: TDRSS Mode

3.9.1 General

When the transmitter is in the TDRSS mode, it must be capable of handling two independent, asynchronous, optionally convolutionally encoded, digital telemetry data channels; each channel must be capable of data format and symbol rates as defined in Appendix B. (The user is responsible for convolutional coding and for symbol interleaving, if required.) The transmitter must meet the requirements herein for MA and SSA data group 1, modes 1, 2, and 3. These channels must be capable of handling the same data in parallel where only one data stream is desired.

3.9.2 QPSK Modulation Performance

3.9.2.1 General

Two independent PSK-modulation functions shall be provided (I and Q) which will be combined with a selectable power ratio to form a balanced or unbalanced Quadrature Phase Shift Key (QPSK) format. The performance requirements of the QPSK modulator, referred to the transmitter output, are provided in paragraphs 3.9.2.2 through 3.9.2.5.

3.9.2.2 Telemetry Power Ratio

The telemetry power ratio shall be selectable at time of manufacture to be one of the following Q:I ratios: 1:1, 2:1, 4:1. The tolerance shall be ±0.4 dB.

3.9.2.3 QPSK Phase Imbalance

The phase imbalance between the four Quadrature PSK (QPSK) phase states relative to an ideal QPSK signal must not exceed 5 degrees for the selected Q/I ratio.

3.9.2.4 QPSK Gain Imbalance

The amplitude imbalance between the four QPSK phase states must not exceed 0.25 dB at the transmitter output.

3.9.2.5 Modulation Polarity

The RF carrier phase associated with the I channel must lead the Q channel by the nominal value of 90 degrees assuming the absence of I and Q telemetry data (logical zero condition).

3.9.3 Transmitter Distortion/Spurious Performance

3.9.3.1 General

The distortions of the transmitted signal encountered after QPSK modulation must meet the requirements of paragraphs 3.9.3.2 through 3.9.3.8. In some cases, specific distortion parameters vary depending on the choice of the MA or SSA configuration.

3.9.3.2 Gain Flatness

The deviation from an ideally flat gain response must not exceed $\pm$0.3 dB from a best horizontal fit over a frequency range of $\pm$2.1 MHz from the nominal MA transmit (F_t) frequency. For SSA operation, the frequency range will be $\pm$3.5 MHz around the selected SSA frequency (F_t).

3.9.3.3 Gain Slope

The slope of the transmitter gain characteristic must not exceed $\pm$0.1 dB/MHz over a frequency range of $\pm$2.1 MHz for MA and $\pm$3.5 MHz for SSA and over the restricted temperature range of 10 to 40 degrees C. For the full temperature range, the slope must not exceed $\pm$0.2 dB/MHz.

3.9.3.4 Phase Nonlinearity

The deviation from ideal phase linearity must not exceed ± 3 degrees over a frequency range of $F_t \pm 2.1$ MHz for MA and $F_t \pm 3.5$ MHz for SSA.

3.9.3.5 AM/PM Conversion

The AM/PM conversion introduced between the modulator and the transmitter output must not exceed 12 degrees/dB.

3.9.3.6 Incidental AM

The sum of all amplitude modulation components not resulting from the QPSK modulation process must not exceed 5 percent peak.

3.9.3.7 Out-of-band Modulation Products

At frequencies outside the nominal center frequency $\pm$PN rate, the Power Spectral Density (PSD) out of the transmitter relative to the peak PSD at the nominal center frequency must not exceed the limits shown in Figure 3-2 for mode 1 and mode 2 operation. PSD suppression in excess of 60 dB relative to the peak PSD is not required except at the $F_r \pm 10$ MHz where the PSD must not exceed -180 dBm/Hz.

3.9.3.8 RF Bandwidth

The -3 dB RF bandwidth of the transmitter must be $\geq$ 12 MHz.

3.9.4 TDRSS PN Code Performance

3.9.4.1 General

Both long and short return link codes shall be produced in the transponder in accordance with STDN No. 108 with the characteristics specified in Appendix B.

3.9.4.2 Code Modulation Coherency

The transmitter PN code and carrier shall be coherent with respect to each other for all modes of operation. For coherent forward link/return carrier operation, the transmitter shall be phase modulated by a long code PN sequence synchronized to the forward link. For noncoherent forward link/return link operation, the transmitter shall be phase modulated by a short code PN sequence synchronized to the TCXO. In either case, code modulation shall be capable of ground command disable.

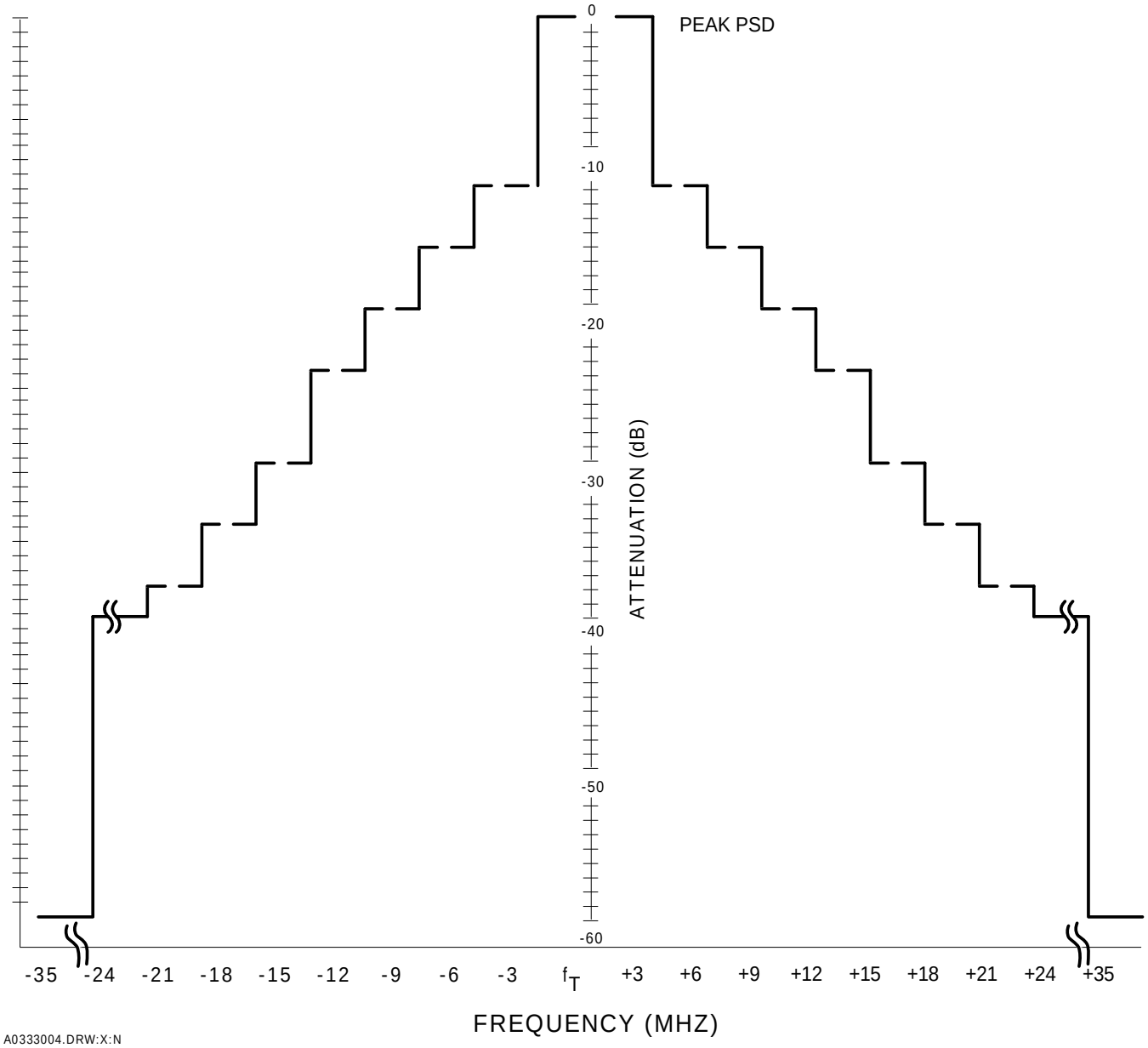


Figure 3-2. Allowable Limits of Transmitter Modulation Products

3.9.4.3 PN Chip Rate

The PN chip rate for both MA and SSA shall be as follows:

$$\frac{31}{240 \times 96} \times F_t \quad (\cong 3 \times 10^6 \text{ chips per second})$$

where: F_t = transmit carrier frequency (Hz).

3.9.4.4 PN Code Skew

The skew between the 50 percent transition points of the I and Q channel PN codes shall be 1/2 chip $\pm$0.01 chip at the modulator input.

3.9.4.5 PN Code Asymmetry

The percent asymmetry between the 50 percent points of a high-to-low PN transition versus a low-to-high transition must not exceed 1 percent.

$$\text{Percent asymmetry} = \frac{T_{LH} - T_{HL}}{T_{LH} + T_{HL}} \times 100 \text{ percent}$$

3.9.4.6 PN Chip Jitter

a. In transmitter modes 1 and 3 the PN chip jitter must not exceed 10 nsec rms.

b. For transmitter mode 2, the PN chip jitter must not exceed 4 nsec rms.

3.10 S-band Transmitter Performance: STDN Mode

3.10.1 General

3.10.1.1

When the transmitter is commanded to the STDN mode of operation, it shall meet the requirements of paragraphs 3.10.2 through 3.10.8.

3.10.1.2

The transmitter in the STDN mode shall provide a linear phase modulation capability for transmitting digital high rate data on the carrier and/or digital low rate data on a subcarrier.

3.10.1.3

The transmitter in the STDN mode shall provide a 1.024 MHz subcarrier modulation capability. In this capability a digital data signal will be BPSK modulated onto the subcarrier. The modulated subcarrier could linearly phase modulate the carrier or, be combined to digital high rate data with the composite signal linearly phase modulating the carrier. The subcarrier modulation capability must be commanded ON or OFF via the transponder's Mode Control interface.

3.10.2 Telemetry Channel Amplitude Linearity

The amplitude nonlinearity of the telemetry channel must not exceed 2 percent to 1 radian or 5 percent to 2 radians referenced to a best straight line fit.

3.10.3 Telemetry Modulation Index

One modulation index setable at manufacture shall be provided. The selected index will be within the range of 0.2 to 1.5 radians.

3.10.4 Telemetry Modulation Index Stability

The modulation index must be stable to $\pm$5 percent of the specified value.

3.10.5 Telemetry Input/Output Polarity

For the direct carrier phase modulation input, a low-to-high transition on the telemetry data input will cause the phase of the RF carrier to advance (become more positive). For the subcarrier modulation mode, the RF carrier phase will increase during the positive half cycle of the subcarrier.

3.10.6 Telemetry Channel Frequency Response

The lower -3 dB response point of the telemetry channels must be less than 100 Hz and the upper -3 dB response point must be $\geq$ 6 MHz.

3.10.7 Amplitude Modulation

Amplitude modulation of the output signal must not exceed 1 percent with no modulation or 2 percent at any modulation index up to 1.5 radians peak by any frequency in the specified frequency response.

3.10.8 Telemetry Off Isolation

When the telemetry modulation is commanded off or when the transmitter is in the TDRSS mode, the residual leakage of the modulation must be at least 40 dB below the carrier.

Section 4. Spacecraft/Transponder Interface Requirements

4.1 Overview

The transponder will interface with other spacecraft subsystems including the command subsystem, telemetry subsystem, data subsystem, and power subsystem. Detailed input and output interface requirements for these subsystems are contained in paragraphs 4.2 through 4.10.

4.2 Command Subsystem Interface

4.2.1 General

The transponder shall provide redundant detected command data, bit timing, and the command detector lock indicator signals to the command decoder. The transponder shall provide for the possibility that two command decoders may be used by providing each of the signals through two separate interface circuits as shown in Figure 4-1. The characteristics of the signals to be sent to the command decoder are described in paragraphs 4.2.2 through 4.2.5. The electrical characteristics of this interface shall conform to standard RS-422 requirements per Appendix F.

4.2.2 Detected Command Data

The command data sent to the command decoder may be the data transmitted from the ground or the 1's complement of the data transmitted from the ground. (The command decoder will resolve this ambiguity.) The command data shall be provided to the command decoder in NRZ format. The time delay of the command data through the transponder must not exceed 2 bits. A true or logical 1 state shall correspond to a binary one, and a false or logical 0 corresponds to a binary zero. The data transition must be within ± 1/8 of a bit time of the falling edge of the bit timing output (see Figure 4-2).

4.2.3 Bit Timing Output

The bit timing signal shall be a square wave at the selected data rate. Bit timing shall be output continuously and not be dependent on command detector lock states. The logic state signal shall be identical to the data output described on paragraph 4.2.2.

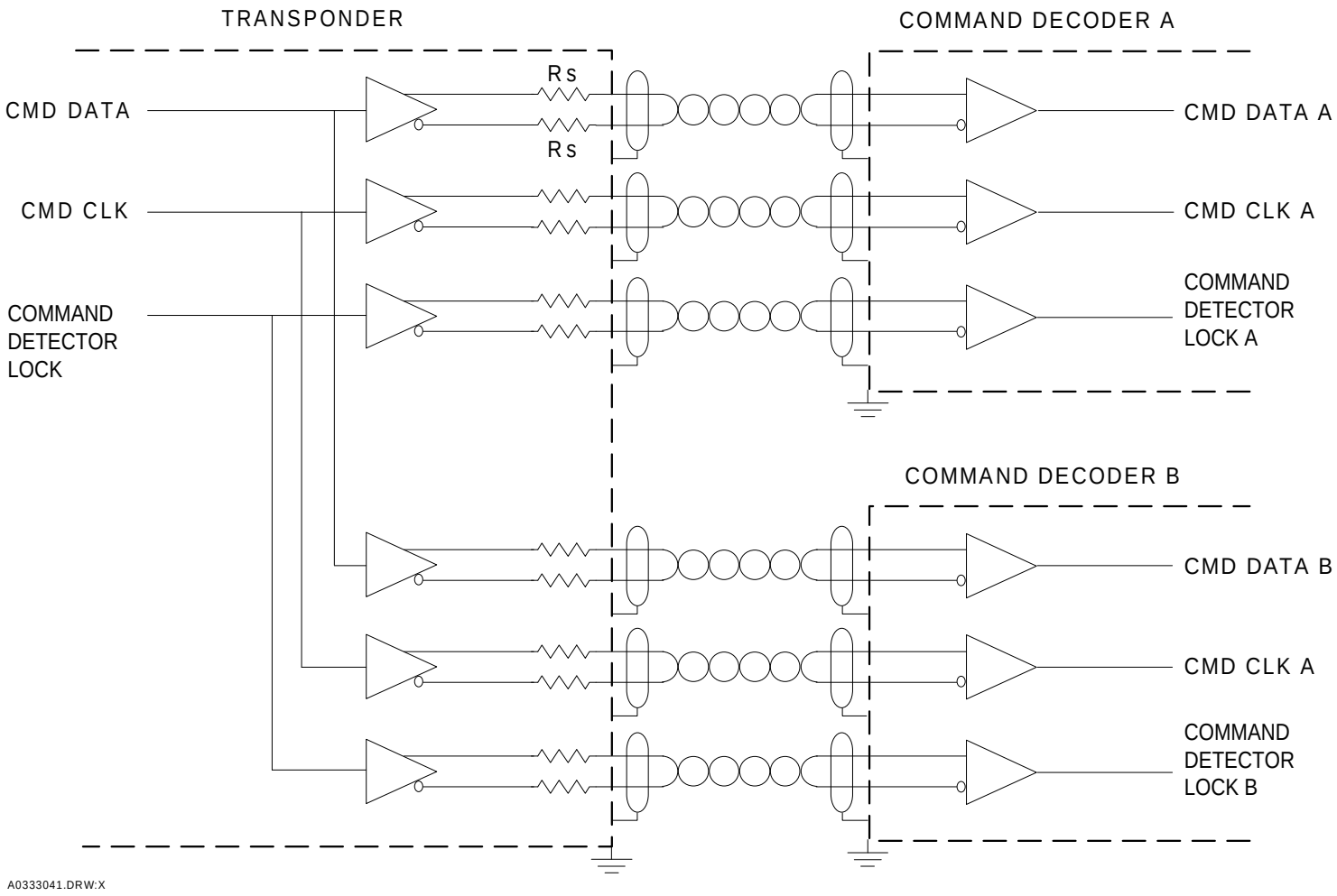


Figure 4-1. Command System Interface

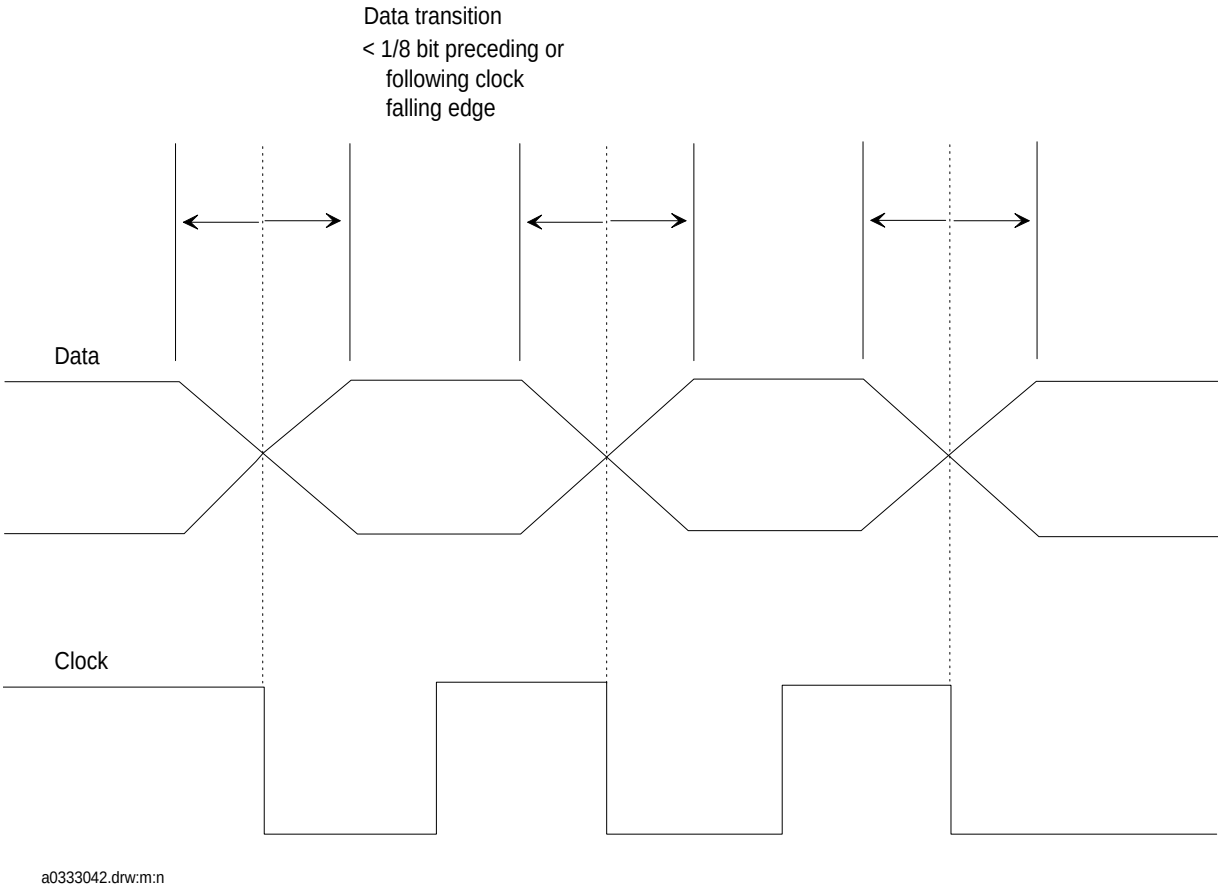


Figure 4-2. Command Data-Clock Timing Diagram

4.2.4 Command Detector Lock Output

4.2.4.1
In the STDN receiver mode or in the auxiliary command input mode, when the subcarrier demodulator is phase locked to a 16 kHz subcarrier and bit synchronization has been achieved, the command detector lock output shall indicate a logic false (zero). Otherwise, the detector lock shall be a logic true (one).

4.2.4.2
In the TDRSS mode, when the receiver is locked to the forward link carrier and bit synchronization has been achieved, the command detector lock output shall indicate a logic false (zero). Otherwise, the detector lock shall be a logic true (one).

4.2.4.3
In the auxiliary command input mode, when bit synchronization has been achieved, the command detector lock output shall indicate a logic false (zero). Otherwise, the detector shall indicate a logic true (one).

4.2.4.4
The command detector lock transitions will be independent of the bit timing. For all modes, an in-lock indication shall be made when no data modulation is present if the available signal power exceeds the lock threshold. This detector must meet the lock probabilities defined in paragraphs 3.3.6 and 3.6.9.

4.3 Auxiliary Command Input

4.3.1 General

The transponder shall provide an auxiliary command and lock override inputs. The characteristics of the signals are described in paragraphs 4.3.2 and 4.3.3. The electrical characteristics of this interface shall conform to the standard RS-422 requirements per Appendix F.

4.3.2 Auxiliary Command Signal Input

4.3.2.1
The transponder shall receive and detect a digital baseband command signal which consists of command data at a bit rate of 2 kbps.

4.3.2.2
The transponder shall accurately receive and detect the command signal at the auxiliary command input when this signal appears in the presence of common mode noise whose magnitude is between 0 and 7 volts peak measured at the auxiliary command input of the transponder.

4.3.3 Lock Override Input

4.3.3.1
The transponder shall provide a lock override function which, when exercised, shall cause the inlock condition to be indicated to the command decoder on the command detector lock interface, provided the receiver is not locked to an RF signal.

4.3.3.2
A logic false (zero) in the lock override input will indicate that the lock override function is exercised. A logic true (one) will indicate that the lock override function is not exercised.

4.3.3.3
The transponder shall select between the auxiliary command input and the command signal to be demodulated and detected. If the receiver is locked, the selected signal for demodulation and output shall unconditionally be the RF receiver. If the receiver is unlocked and the lock override is exercised, the auxiliary command input shall be selected. If both the lock override is exercised and the RF signal is present, the transponder shall select the RF signal for command detection and demodulation.

4.3.4 Auxiliary Command and Lock Override Inputs Protection

The transponder shall provide protection against permanent damage for the Auxiliary Command and Lock Override Inputs in the event of a short with a line of up to 35 volts, referenced to chassis.

4.4 Status Telemetry Interface

4.4.1 General

4.4.1.1
Transponder status shall be provided to the spacecraft telemetry subsystem through the MIL-STD-1773 interface bus as shown in Figure 4-3. The transponder interfaces with the Local Bus as a Remote Terminal (RT) via a dual redundant MIL-STD-1773B data bus. The electrical characteristics of this interface shall conform to the MIL-STD-1773 requirements (see Appendix G). The transponder telemetry shall not be formatted in 1773 packets. Specific addresses for the telemetry signals will be provided in Tables 4-1 through 4-5. In the event of MIL-STD-1773 bus communication errors, the user may elect the re-transmission of any particular data from the secondary bus. If the retry also fails, the data shall be discarded.

4.4.1.2
The vendor shall implement the transponder MIL-STD-1773 interface using generic components available from GSFC as government furnished equipment. This implementation will meet the transponder MIL-STD-1773 status Telemetry Interface as stated in this specification. A description of the GFE appears in Appendix H.

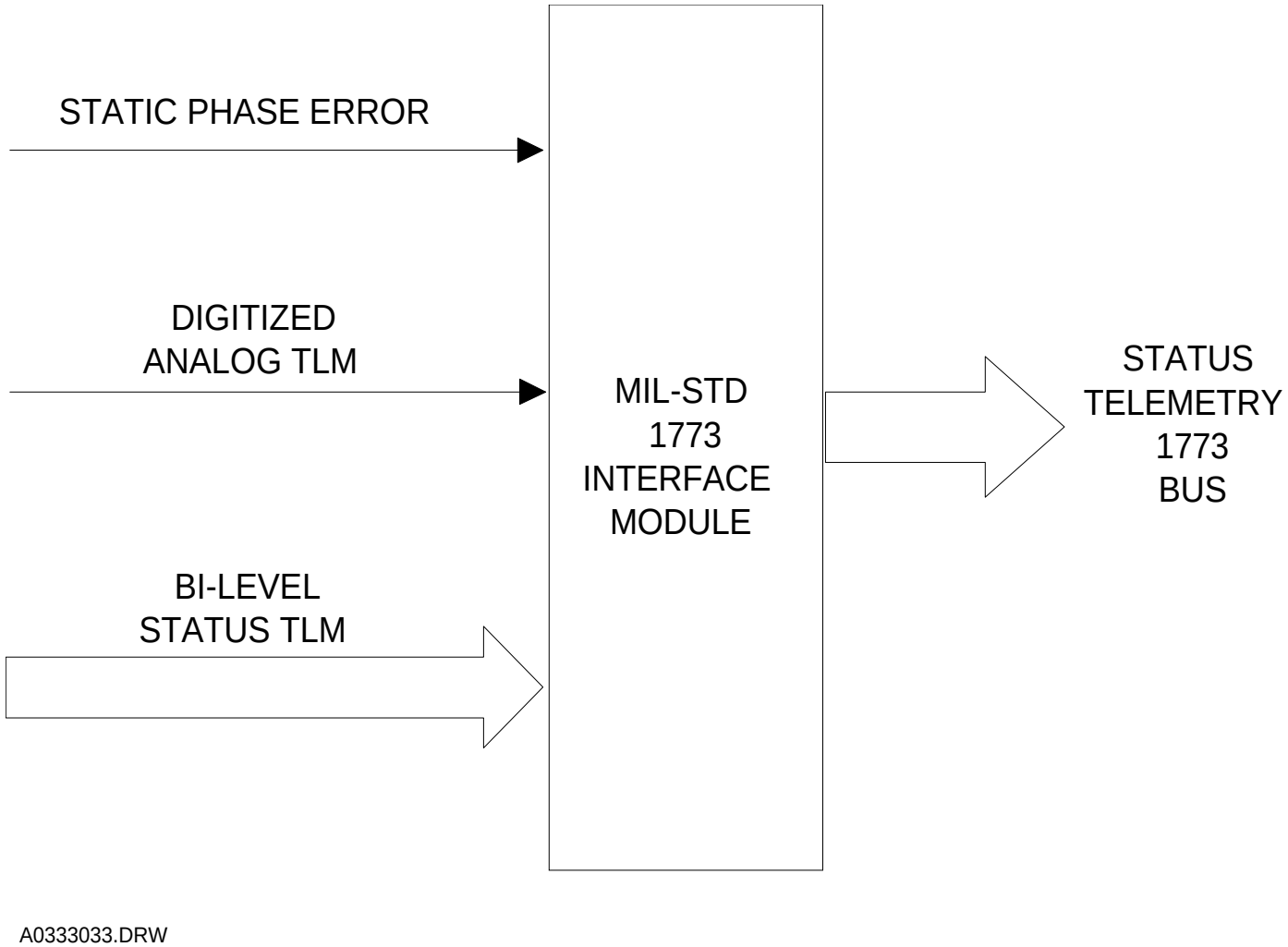


Figure 4-3. Status Telemetry Interface

4.4.2 Analog Telemetry

The transponder shall provide digitized analog telemetry to measure the telemetry outputs listed in Table 4-1. The outputs to the 1773 Bus shall be binary words representing analog signals. The analog signals range shall be as required to obtain the specified resolution. A convertion curve between the digital and analog data must be provided. In a data word, the Most Significant Bit (MSB) shall be Bit 15, while the Least Significant Bit (LSB) shall be Bit 0. All transponder analog telemetry shall be provided in RT Subaddress 1. The number of bits and minimum update frequency of these parameters are also specified in Table 4-1.

The transponder shall provide digitized temperature sensors telemetry for the S-band power amplifier and the internal reference oscillator.

Table 4-1. Digitized Analog Telemetry

RT Subaddress	Word	Parameter Name	Parameter Range	Number of Bits	Minimum Update Frequency (updates/sec)
1	1	S-Band RF power output	Nominal power +1/-5 dB typical	8	1
1	1	S-Band Reflected power	Antenna impedance of 50 Ohms to open circuit	8	1
1	2	TDRS AGC	77 dB-Hz to 33 dB-Hz	8	1
1	2	STDN AGC	75 dB-Hz to 120 dB-Hz	8	1
1	3	Receiver power converter voltage	0 to 7 Vdc	8	1
1	3	S-Band Transmitter power converter voltage	0 to 7 Vdc	8	1
1	4	S-Band Module TCXO Temperature	-20 to 65° C	8	1/ 5
1	4	S-Band Power Amplifier Temperature	-20 to 65° C	8	1/ 5

4.4.3 Bilevel Status Telemetry

The transponder shall provide the bilevel status signals in RT Subaddress 2 as specified in Tables 4-2 through 4-3.

4.4.4 Serial Digital Telemetry

The transponder shall provide the serial digital telemetry in RT Subaddress 3 as specified in Table 4-4.

4.4.4.1 Receiver Static Phase Error

The receiver Static Phase Error (SPE) is an indication of the frequency offset seen by the receiver. The SPE range must be ±200 kHz with a resolution equal or better than 100 Hz. A convertion curve must be provided.

4.4.4.2 Frequency Control Word

RT Subaddress 3, word 2 shall specify the transponder's current Frequency Control Word. In the data word, the MSB shall be Bit 15, while the LSB shall be Bit 0.

4.5 Mode Control Interface

4.5.1 General

4.5.1.1

The transponder shall be commanded to the desired configuration as specified in paragraphs 4.5.2 through 4.5.5 via a 1773 Local Bus as shown in Figure 4-4. The transponder interfaces with the Local Bus as a RT via a dual redundant MIL-STD-1773 data bus. The transponder shall receive, decode, and execute commands to control its operational state. Electrical characteristics of the control interface shall conform to the MIL-STD-1773 (see Appendix G).

4.5.1.2

In a data word, the MSB shall be Bit 15, while the LSB shall be Bit 0. The transponder shall respond to a received command within 0.5 second. The maximum rate to the transponder shall be 1 command/sec. Upon successful completion of the commanded action, the transponder shall update the corresponding status telemetry parameters.

4.5.1.3

The vendor shall implement the transponder MIL-STD-1773 interface using generic components available from GSFC as government furnished equipment. This implementation will meet the transponder MIL-STD-1773 Mode Control Interface as stated in this specification. A description of the GFE appears in Appendix H.

Table 4-2. Bilevel Telemetry (1 of 2)

RT Subaddress	Word	Bit Assignment	Function	False State (Bit = 0)	True State (Bit = 1)	Update frequency (updates/sec)
2	1	00	Carrier Lock (CAL)	Receiver is not locked	Receiver carrier loop is locked on either TDRSS or STDN signal	5
2	1	01	PN Lock (PNL)	PN code loop is not locked	PN code tracking is locked to TDRSS forward link code	5
2	1	02	CW Detect (CWD)	No strong CW signal is present	Receiver has detected a strong CW signal and is therefore in the STDN mode	5
2	1	03	Long Code detect (LCDET)	No synchronization with the long code	Indicates synchronization has been established with the range code	5
2	1	04	Main Lobe detect (MLDET)	Main lobe verification has not commenced or is in process	Indicates successful conclusion of the main lobe verification procedure	5
2	1	05	Sync detect (SYNC)	Receiver is in search mode	Indicates synchronization has been established with the short forward link PN code	5
2	1	06	Command detector lock (DTL)	TDRSS: Bit synchronization has not been achieved. STDN: Subcarrier loop not locked or bit synchronization has not been achieved Auxiliary: Auxiliary commands override has not been established.	TDRSS: Bit synchronization has been achieved STDN: 16 kHz subcarrier is locked and bit synchronization has been achieved Auxiliary: Auxiliary commands override has been established	5
2	1	07	Subcarrier mode (SUB)	Command outputs are being derived directly from TDRSS carrier	Indicates that command outputs are being derived from the 16 kHz subcarrier	5

Table 4-2. Bilevel Telemetry (2 of 2)

RT Subaddress	Word	Bit Assignment	Function	False State (Bit + 0)	True State (Bit = 1)	Update frequency (updates/sec)
2	1	08	Lock Override flag (LOF)	Auxiliary command input is disabled	Indicates that the auxiliary command input has been selected for demodulation	5
2	1	09	S-Band Transmitter On (STXON)	S-band Transmitter power control has been set to OFF state	S-band Transmitter power converter ON/OFF control line has been set to the ON state	5
2	1	10	Transmitter mode (TX MODE)	Transmitter is in the noncoherent mode and short return link PN code has been selected in the TDRSS mode	Transmitter is in the coherent turnaround mode and the range code has been deleted in the TDRSS mode	5
2	1	11	Linear Phase modulation ON/OFF (ENPM)	Phase modulation input has been disabled	Modulation input to the linear phase modulator has been enabled	5
2	1	12	Subcarrier Modulation ON/OFF (SCMOD)	Subcarrier modulation input has been disabled	Subcarrier modulation input has been enabled	5
2	1	13	I PN disable (INHI)	I PN code has been inhibited from modulating the return link carrier	I PN code is enabled	5
2	1	14	Q PN disable (INHQ)	Q PN code has been inhibited from modulating the return link carrier	Q PN code is enabled	5
2	1	15	S-band Transmitter Auto ON (AUTX)	Transmitter will not come on when receiver locks	Indicates that the transmitter will come on when CAL is 1(Word 10, Bit 01)	5
2	2	00	Reserved			
2	2	01	Telemetry Input A/B (TELIN)	Telemetry input B has been selected	Telemetry input A has been selected	5

Table 4-3. Bilevel Telemetry: Command Data Rate (DR0, DR1, DR2)

RT Subaddress	Word	Bit 02 (DR0)	Bit 03 (DR1)	Bit 04 (DR2)	Bit 05 - 07 (DR03 - DR05)	Data Rate Value (bits/sec)	Update frequency (updates/sec)
2	2	0	0	0	X	125	1
2	2	1	0	0	X	250	1
2	2	0	1	0	X	500	1
2	2	1	1	0	X	1000	1
2	2	0	0	1	X	2000	1
2	2	1	0	1	X	4000	1
2	2	0	1	1	X	8000	1
2	2	1	1	1	X	10000	1
2	2	X	X	X	X	>10000	1

Note: The "X" implies the value can be specified by the contractor.

Table 4-4. Serial Digital Telemetry

RT Subaddress	Word	Function	Parameter Range	Update frequency (updates/sec)
3	1	Receiver Static Phase Error	± 200 kHz with 100 Hz or better resolution (at least 12 bits)	1
3	2	Frequency Control Word	Same control word as specified in paragraph 4.5.3	1 / 5

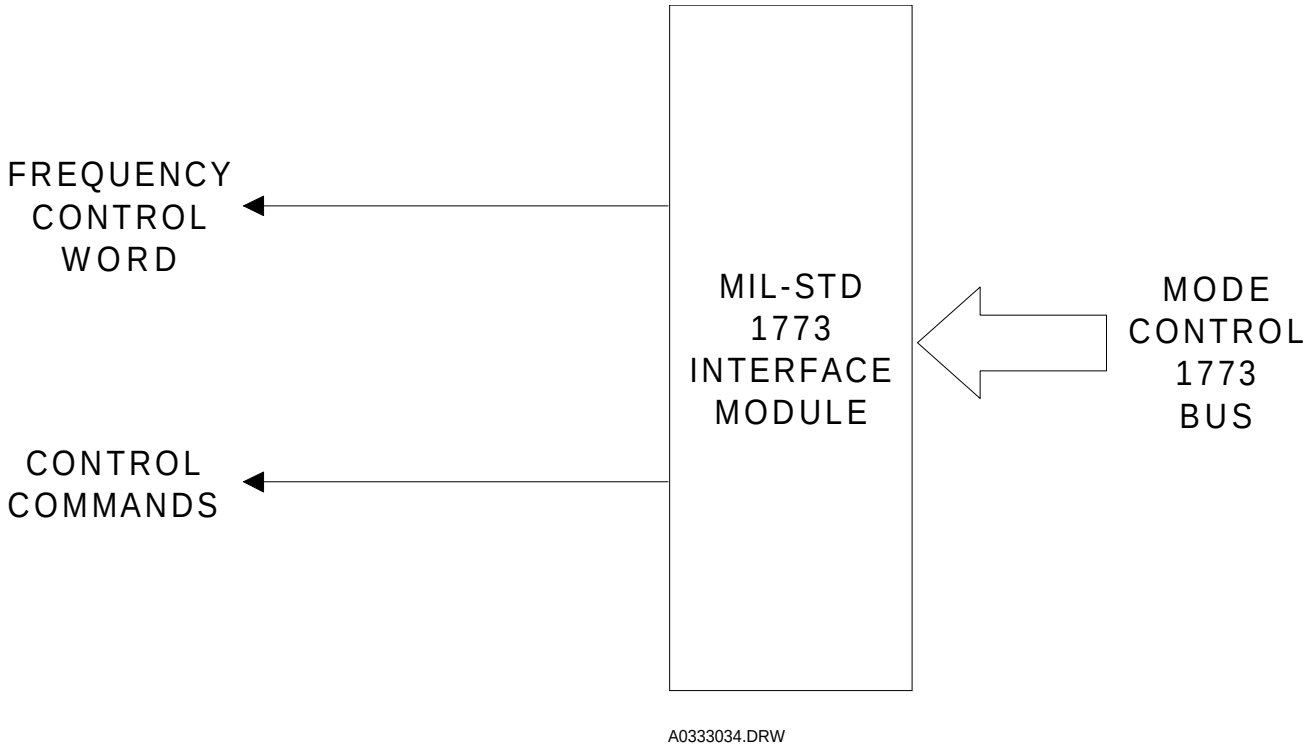


Figure 4-4. Control Mode Interface

4.5.2 Control Word Execution

4.5.2.1 General

a. In the following paragraphs, the logical operation of each command group of Tables 4-5 and 4-6 is defined. Transponder defaults and power-up states are also specified.

b. RT subaddress 4, word 1 shall provide the most frequently used transponder commands while RT subaddress 5, word 1 shall provide the remaining transponder commands. Each command shall have an enable bit preceding the command bits, e.g., a command defined by bits B2 and B1 will have enable bit B0. If the enable bit is one (1) the command shall be executed, if zero (0) the command shall not be executed. RT subaddress 6, word 1 shall provide the frequency control word.

c. For all the cases, any other word value not specified in the following paragraphs shall not be accepted as a valid command word. In that condition, the transponder shall reject the invalid received word and stay in the current state.

4.5.2.2 S-band Transmitter ON/OFF

Subaddress 4, Word 1, bits B0, B1 and B2 shall control the S-band transmitter ON/OFF information. If bit B0 is 1 (enabled) the transponder shall execute the command defined by B1 and B2. When B1 is 1 and B2 is 0, power shall be unconditionally applied to the transmitter. If B1 is 0 and B2 is 1, power shall be removed unconditionally from the transmitter. If bit B0 is 0 (disabled) the transponder shall ignore bits B1 and B2. The power up condition shall be Transmitter OFF.

4.5.2.3 Q PN Disable/ Enable

Subaddress 4, Word 1, bits B6 and B7 shall control the Q channel PN Disable/Enable information. If bit B6 is 1, the transponder shall execute the command defined by B7. When B7 is 1, the Q channel PN code shall be enabled to the modulator. If B7 is 0, the Q channel return link shall be disabled from modulating the quadrature carrier phase. If bit B6 is 0, the transponder shall ignore bit B7. The power-up condition shall be Q PN code enabled.

4.5.2.4 I PN Disable/ Enable

Subaddress 4, Word 1, bits B6 and B8 shall control the I channel PN Disable/Enable information. If bit B6 is 1, the transponder shall execute the command defined by B8. When B8 is 1, the I channel PN code shall be enabled to the modulator. If B8 is 0, the I channel return link shall be disabled from modulating the quadrature carrier phase. If bit B6 is 0, the transponder shall ignore bit B8. The power-up condition shall be I PN code enabled.

Table 4-5. Control Word Execution Logic for RT Subaddress 4, Word 1

B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0	Control Word Function
													0	1	1	S-Band Transmitter ON
													1	0	1	S-Band Transmitter OFF
										x	x	x				Reserved
										x	x	x				Reserved
								1	1							Q PN Enable
								0	1							Q PN Disable
							1		1							I PN Enable
							0		1							I PN Disable
					1	1										Linear Telemetry ON
					0	1										Linear Telemetry OFF
				1	1	1										Subcarrier Modulation ON
				0	1	1										Subcarrier Modulation OFF
		1	1													S-band Transmitter Mode 1
		0	1													S-band Transmitter Mode 2

Note:
1. Only the bits related to a control word function are shown. The remaining bits are "don’t care".
2. Bits B0, B3, B6, B9 and B12 are enable bits. A one (1) means the control function must be executed, a zero (0) means the control function is not executed.
3. Bits B3 through B5 are reserved.

Table 4-6. Control Word Execution Logic for RT Subaddress 5, Word 1

B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0	Control Word Function
									0	0	0	0	0	0	1	Command Rate 125 bits/sec
									0	0	0	0	0	1	1	Command Rate 250 bits/sec
									0	0	0	0	1	0	1	Command Rate 500 bits/sec
									0	0	0	0	1	1	1	Command Rate 1000 bits/sec
									0	0	0	1	0	0	1	Command Rate 2000 bits/sec
									0	0	0	1	0	1	1	Command Rate 4000 bits/sec
									0	0	0	1	1	0	1	Command Rate 8000 bits/sec
									0	0	0	1	1	1	1	Command Rate 10000 bits/sec
						0	1	1								S-band Transmitter Auto ON Allow
						1	0	1								S-band Transmitter Auto ON Inhibit
				1	1											Telemetry Input A
				0	1											Telemetry Input B

Note:
1. Only the bits related to a control word function are shown. The remaining bits are "don’t care".
2. Bits B0, B3, B6, B9, B11 and B13 are enable bits. A one (1) means the control function must be executed, a zero (0) means the control function is not executed.
3. Command rates >10000 bits/sec can be specified using the remaining combinations of bits B0 through B6.

4.5.2.5 Linear PM Telemetry ON/OFF

Subaddress 4, Word 1, bits B9 and B10 shall control the Linear PM Telemetry ON/OFF control commands. If bit B9 is 1, the transponder shall execute the command defined by B10. When B10 is 1, the linear telemetry modulation input (for STDN operation) shall be enabled, allowing linear phase modulation of the transmitter. For this same condition, the QPSK modulator shall be inhibited, preventing modulation to either the I or the Q PN codes and I or Q data inputs. If B10 is 0, the linear telemetry input shall be disabled, and the QPSK modulator shall be enabled. If bit B9 is 0, the transponder shall ignore bit B10. The power-up condition shall be linear PM telemetry OFF.

4.5.2.6 Subcarrier Modulation ON/OFF

Subaddress 4, Word 1, bits B9 through B11 shall control the Subcarrier Modulation ON/OFF information. If bit B9 is 1 and bit B10 is 1, the transponder shall execute the command defined by B11. When B11 is 1, the subcarrier modulation input shall be enabled, allowing BPSK modulation of the subcarrier. If B11 is 0, the subcarrier modulation input shall be disabled from modulating the subcarrier. If bit B9 is 0 or bit B10 is 0, the transponder shall ignore bit B11. The power-up condition shall be subcarrier modulation OFF.

4.5.2.7 S-band Transmitter Mode 1/Mode 2

a. Subaddress 4, Word 1, bits B12 and B13 shall control the S-band transmitter mode 1/2 control commands. If bit B12 is 1, the transponder shall execute the command defined by B13. When B13 is 1, and if the receiver is locked to a TDRSS signal, and the long code has been acquired, the following conditions shall be set:

    1. The S-band transmitter shall be configured for coherent carrier turnaround (Mode 1).

    2. The S-band transmitter shall be configured to select the long ranging PN code.

b. If bit B13 is 1, and if the receiver is locked to a STDN signal, the S-band transmitter shall be configured for coherent carrier turnaround (Mode 1).

c. When B13 is 0, the transmitter shall be in the noncoherent carrier mode and the short PN code selected (Mode 2), unless disabled by the following control commands:

    1. Q PN disabled.

    2. I PN disabled.

    3. Linear Telemetry ON.

d. If bit B12 is 0, the transponder shall ignore bit B13. The power-up condition will be as selected at time of manufacture.

4.5.2.8 Command Rate Selection

When operating in the TDRSS mode, the command data rate of the receiver shall unconditionally be set as described in this paragraph. Subaddress 5, Word 1, bits B0 through B6 shall control the command rate selection control commands. If bit B0 is 1 (enabled) the transponder shall execute the command defined by B1 through B6. If bits B1 through B6 have a decimal value of 0, a bit rate of 125 bits/sec has been selected. A decimal value of 1 indicates a command rate of 250 bits/sec. A decimal value of 2, indicates a command data rate of 500 bits/sec. A decimal value of 3, the command data rate of 1000 bits/sec has been set. A decimal value of 4, the command data rate of 2000 bits/sec has been set. A decimal value of 5, the command data rate of 4000 bits/sec has been set. A decimal value of 6, the command data rate of 8000 bits/sec has been set. A decimal value of 7, the command data rate of 10000 bits/sec has been set. Command rates >10000 bits/sec, if any, can be specified using the remaining bit combinations. If a command rate change is received while the receiver is locked, it shall be executed immediately with the allowance of a momentary loss of command detector lock. If bit B0 is 0, the transponder shall ignore bits B1 through B6.

4.5.2.9 S-band Transmitter Auto ON Allow/ Inhibit

a. Subaddress 5, Word 1, bits B7 through B9 shall contain the S-band transmitter auto ON/OFF control commands. If bit B7 is 1 (enabled) the transponder shall execute the command defined by B8 and B9. If B8 is 1, B9 is 0, and if the receiver is not locked to either a STDN or TDRSS signal, an internal memory bit shall be set which allows the S-band transmitter to power up when the receiver achieves lock (S-band Transmitter Auto ON Allow). This internal memory bit will be reset if B8 is 0 and B9 is 1: S-band Transmitter Auto ON Inhibit.

b. The S-band transmitter OFF command shall override the Auto ON function, but on a subsequent acquisition, the S-band transmitter shall again come on automatically if the S-band Transmitter Auto ON function is still allowed. If bit B7 is 0, the transponder shall ignore bits B8 and B9. The power up condition shall be S-band Transmitter Auto ON Inhibit.

4.5.2.10 Telemetry Inputs A/B Selection

Subaddress 5, Word 1, bits B10 and B11 shall contain the Telemetry Input A/B Selection control command. If bit B10 is 1, the transponder shall execute the command defined by B11. When B11 is 1, the transponder shall use telemetry data inputs A (primary). If B11 is 0, the transponder shall use telemetry data inputs B (secondary). If bit B10 is 0, the transponder shall ignore bit B11. The power-up state shall be Telemetry Inputs A.

4.5.3 Frequency Control Word Format

4.5.3.1

Subaddress 6, Word 1 shall contain the frequency offset data. The frequency offset word shall be a 2's complement representation of the desired frequency offset. The MSB used in the word is defined as the sign bit and Bit 0 the LSB. The minimum frequency control range must be ±80 kHz and the frequency resolution shall be equal or better than 10 Hz.

4.5.3.2

The transmitter frequency shall also be offset by the control word in the normal ratio of $F'_t = 240\ F'_r / 221$, where F'_r is the receiver offset center frequency.

4.5.4 Frequency Control Word Constraints

4.5.4.1

The transponder shall power up with zero frequency offset ($F'_r = F_r$), and remain there until receipt of a control word.

4.5.4.2

The frequency change must be executed within 1 second of receipt of the control word unless the receiver is locked. When the receiver is locked, the control word shall be stored and executed when the receiver loses lock.

4.5.4.3

The transmitter frequency shall be changed at the same time as the receiver.

4.5.4.4

The transponder shall be capable of receiving frequency control words at a rate of one command per second.

4.5.5 MIL-STD-1773 Mode Codes and Diagnostic Interface

4.5.5.1

The RT shall implement the following mode codes per MIL-STD-1773:

a. 00010: Transmit Status Word.

b. 00100: Transmitter Shutdown.

c. 00101: Override Transmitter Shutdown.

d. 01000: Reset Remote Terminal.

4.5.5.2

Of these, only the Reset Remote Terminal shall be sent by the Spacecraft Bus Controller, during normal flight operations. This mode will be used to clear the 1773 bus in order to prevent hang-ups due to radiation events.

4.5.5.3

In addition, the RT is required to implement a data "wrap around" function (see MIL-STD-1773 appendix notes 30.7 Data Wraparound (4.3.3.5.1.4)). The RT shall use receive subaddress #30 to which up to 32 data words of any bit pattern can be received. A valid receive message to subaddress #30 with the same word count and without any intervening valid commands to the RT shall cause the RT to respond with each data word having the same pattern corresponding to the received data.

4.5.6 External 1773 Transmitter Shutdown (Redundant Transponders)

In a redundant transponders configuration, the transponder must provide the capability to power off a failed 1773 transmitter. A failed 1773 transmitter may prevent proper operation of that transponder's 1773 interface. Therefore, the signal to power off a failed 1773 transmitter must originate from the redundant transponder unit. The command to take such action will be sent to the redundant transponder via its Mode Control Interface.

4.6 Primary Power Interface

4.6.1 Power Control

The transponder receiver and transmitter functions must be powered from separate input power lines. The transmitter must be switched on and off internally under control of the mode control input as specified in paragraph 4.5.2.2. The receiver shall be powered continuously.

4.6.2 Electric Power Input

4.6.2.1 General

The transponder shall operate from a voltage source of 28 volts ±7 volts with source impedance, transients, and ripple in accordance with the paragraphs 4.6.2.2 through 4.6.2.4.

4.6.2.2 Power Input Source Impedance

The power input source impedance shall not exceed the following:

a. 1 Hz to 1 kHz: ≤ 0.2 ohm.

b. 1 kHz to 20 kHz: ≤ 0.35 ohm.

c. 20 kHz to 100 kHz: ≤ 1.0 ohm.

4.6.2.3 Transients

The transponder shall operate normally when transients present on the power input have the following characteristics:

	Duration	Peak Voltage
1.	10 µsec	3 volts
2.	10 µsec to 1 msec	1 volt
3.	1 msec	±5 volts but within the 21 to 35 volt range

4. For transients exceeding 1 msec duration, the rise time will be less than 0.5 volt/msec and the fall time less than 5 volts/msec.

4.6.2.4 Power Input Ripple

The transponder shall operate in the presence of power input ripple in accordance with the Electromagnetic Interference (EMI) requirements of paragraph 7.4.

4.6.3 Power Input and Isolation

Separate redundant leads shall be used for both the 28-volt supply and 28-volt return. The transponder case must be electrically isolated from both leads with the minimum resistance between any power lead and case ground being greater than 1 mega ohm.

4.6.4 Maximum Input Power

The maximum dc power consumption of the transponder shall not exceed the limits shown in steps a and b over the temperature range of -20 degrees C to +65 degrees C:

		Required	Goal
a.	Receiver mode	≤ 6 watts	≤ 5 watts
b.	Transmit mode (total)		
	1. 2.5 W S-band Power Amplifier (PA)	≤ 21.5 watts	≤ 20.5 watts
	2. 5 W S-band PA	≤ 34 watts	≤ 33 watts

4.6.5 In-Rush Current

The initial in-rush surge must not exceed 10 amperes during the first 10 µsec after turn-on. The in-rush current after the initial surge must not exceed 300 percent of the normal current and must return to a steady state within 500 msec. After the initial surge, the rate of change of in-rush current must not exceed 20 mA/µsec.

4.6.6 Chopper Operating Frequency

The transponder's power supply chopper operating frequency shall be at least 40 kHz ±15 percent. The fundamental ripple current reflected back to the power source must not exceed 5 percent of the steady state load current.

4.6.7 Under/Over-Voltage Protection

The transponder shall not be damaged by a continuous power line dc voltage between 0 and 45 volts.

4.6.8 Over-Current Protection

Over-current protection shall be fuses external to and not supplied as part of the transponder.

4.6.9 Common Mode Noise

Common mode noise produced by the transponder shall not exceed 50 mV peak to peak. The measurements shall be made between primary power and chassis and between primary power return and chassis.

4.7 Telemetry Data Interface

4.7.1 General

The transponder shall provide a redundant pair of digital telemetry data inputs to be shared by both TDRSS and STDN telemetry (see Figure 4-5). The electrical characteristics of this interface shall conform to the standard RS-422 requirements (see Appendix F). The selection of telemetry data inputs A (primary) or B (secondary) must be made via command through the transponder's mode control interface, as specified in paragraph 4.5.2.10.

4.7.2 TDRSS Telemetry Mode

In the TDRSS telemetry mode, telemetry channel 1 (A1 and B1) shall be the I data input and channel 2 (A2 and B2) the Q data input. Refer to Table 4-7.

4.7.3 STDN Telemetry Mode

In the STDN telemetry mode, telemetry channel 1 (A1 and B1) shall be the subcarrier modulation data input and channel 2 (A2 and B2) the direct carrier modulation data input. Refer to Table 4-7.

4.7.4 Input Isolation

The input ports shall be isolated from each other so that a fault on one port causes no degradation of the remaing port.

4.8 Programming Interface

4.8.1

A programming interface shall be provided at a dedicated external transponder connector. Programming options for selection of the assigned user PN code set, power-up command rate, and RT address, must be provided by means of jumper wires between pins in the mating connector.

4.8.2

The programming options will be specified at time of manufacture. The mating programming connector must be supplied with the transponder.

Table 4-7. Telemetry Data Interface Modes

Telemetry Mode	Telemetry Channel 1 (A1 + B1)	Telemetry Channel 2 (A2 + B2)
TDRSS	I data	Q data
STDN	Subcarrier modulation data	Direct carrier modulation data

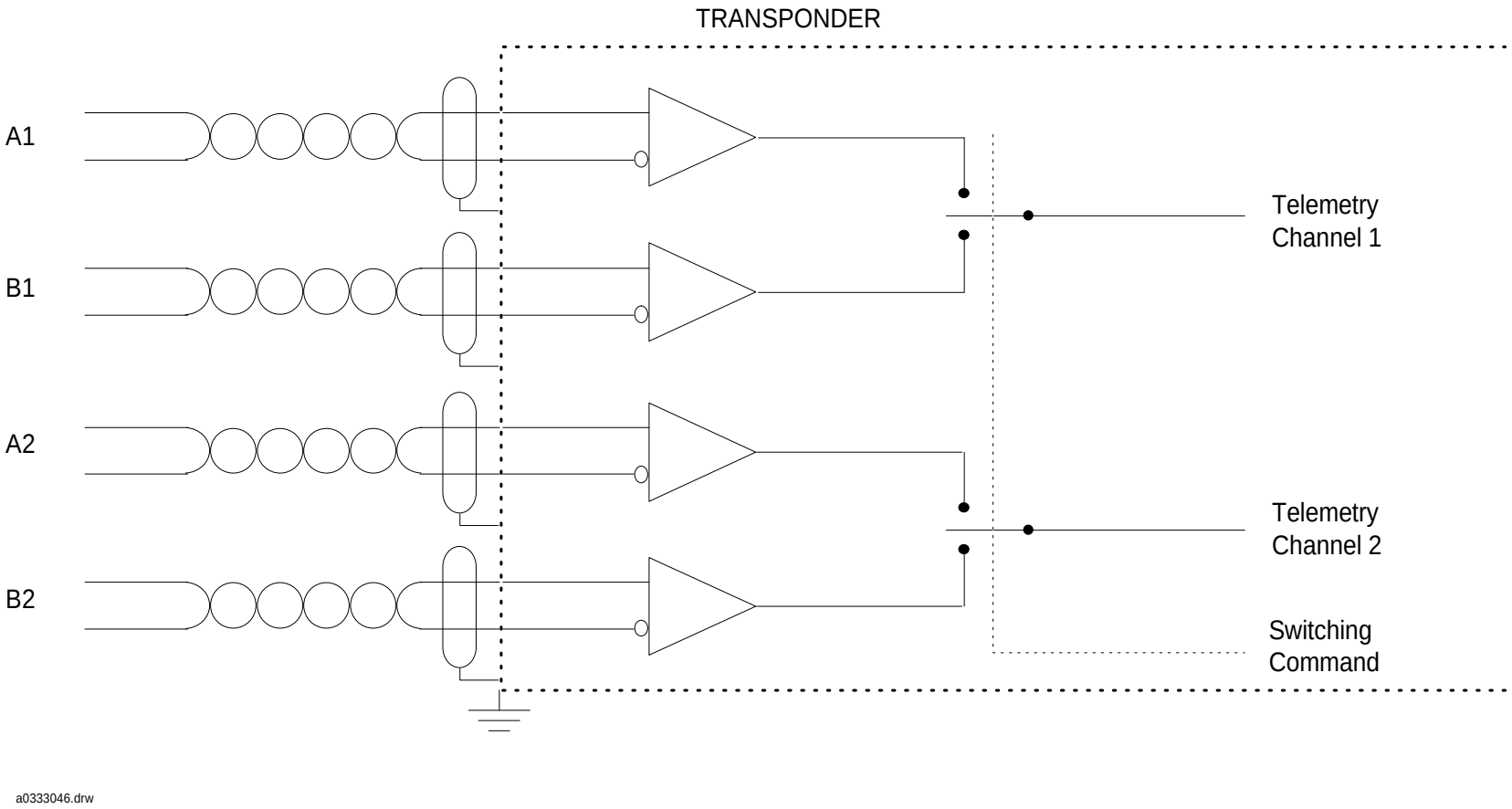


Figure 4-5. Telemetry Data Interface

4.9 Time Transfer Interface

4.9.1 General

The transponder must provide two redundant PN code epoch outputs as shown in Figure 4-6 which coincide in time with the all 1's or epoch state of the forward link long code as defined in STDN No. 108. The electrical characteristics of this interface must comply with the requirements of standard RS-422 (see Appendix F).

4.9.2 Rise and Fall Times

The epoch signal rise and fall times must not exceed 30 nsec as measured at the 10 to 90 percent points.

4.9.3 Epoch Period

The period of the epoch will nominally be determined by the equation (see Figure 4-7):

$$T_{\varepsilon} = \frac{1023 \text{ X } 256}{f_{pn}} \text{ seconds}$$

where: f_{pn} = PN chip rate in chips/sec as determined from the received signal. The duration of the epoch signal will be nominally one PN chip.

4.9.4 Epoch Timing Accuracy

The timing uncertainty between the epoch output and actual epoch transition of the receiver long code must not exceed $\pm$20 nsec when averaged over 3 minutes. The jitter component or sample-to-sample variation must not exceed 10 nsec rms.

4.10 Internal Redundancy Test Points

The transponder design shall provide test points for post storage verification of internal redundancy that can not be demonstrated in the transponder functional test.

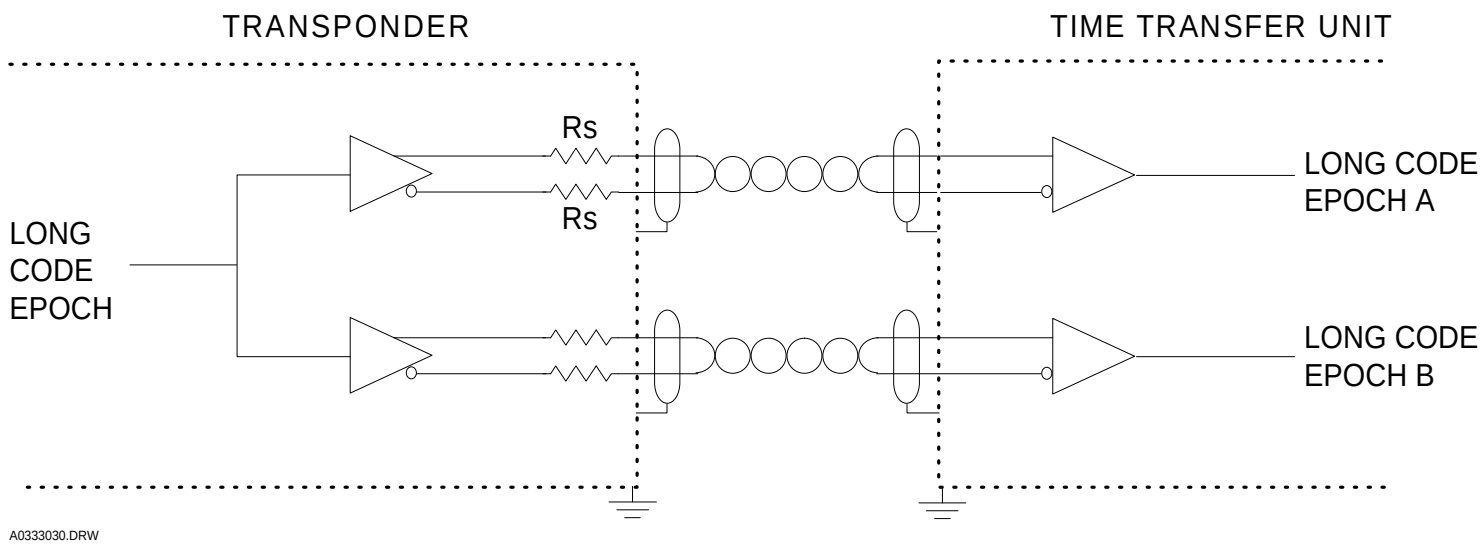
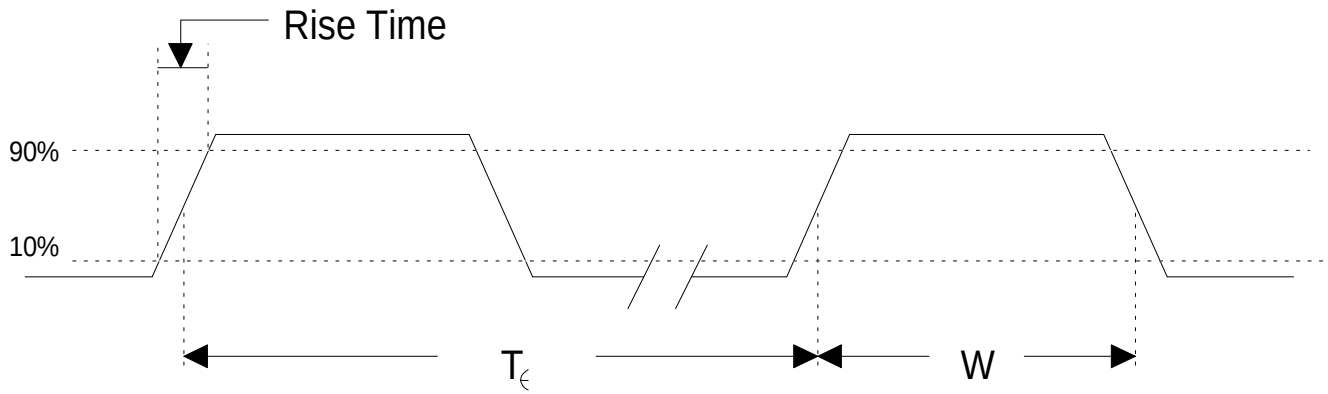


Figure 4-6. Time Transfer Interface



Rise Time must not exceed 30 nsec between the 10 and 90 percent points.

$$T_\epsilon \text{ (epoch period)} = \frac{1023 \times 256}{fpn}$$

$$fpn = \frac{31 \times Ft}{221 \times 96}$$

W (Duration of epoch) = one PN Chip

a0333045.drw

Figure 4-7. Time Transfer Interface Timing Diagram

Section 5. Mechanical and Physical Requirements

5.1 General

The deliverable transponder configuration shall consist of a single self- contained assembly plus a separate S-band reject filter and diplexer as indicated in Figure 2-2.

5.2 Footprint

5.2.1

The transponder shall have maximum footprint dimensions of 23.0 x 21.0 cm and a height above the heat sink interface of less than 13.0 cm.

5.2.2

The band reject filter shall have maximum footprint dimensions of 15.5 x 4.7 cm and a height of less than 5.3 cm.

5.2.3

The diplexer shall have maximum footprint dimensions of 7.6 x 15.2 cm and a height of less than 3.8 cm.

5.3 Mass

The maximum mass of the transponder assembly and band reject filter shall not exceed 3.6 kg. The maximum mass of the diplexer shall not exceed 600 grams.

5.4 Venting

The transponder shall be adequately vented to allow depressurization consistent with the pressure profile shown in Figure 5-1.

5.5 Thermal Interface

The transponder baseplate shall act as the heat sink interface for transfer of thermal energy to a spacecraft flat surface. The transponder mounting surface flatness must not exceed 0.51 mm over any baseplate dimension. The following temperature ranges are defined for the transponder:

a. Operating range: -10 degrees C to +55 degrees C

b. Acceptance range: -15 degrees C to +60 degrees C

c. Qualification range: -20 degrees C to +65 degrees C

d. Survival range: -25 degrees C to +65 degrees C

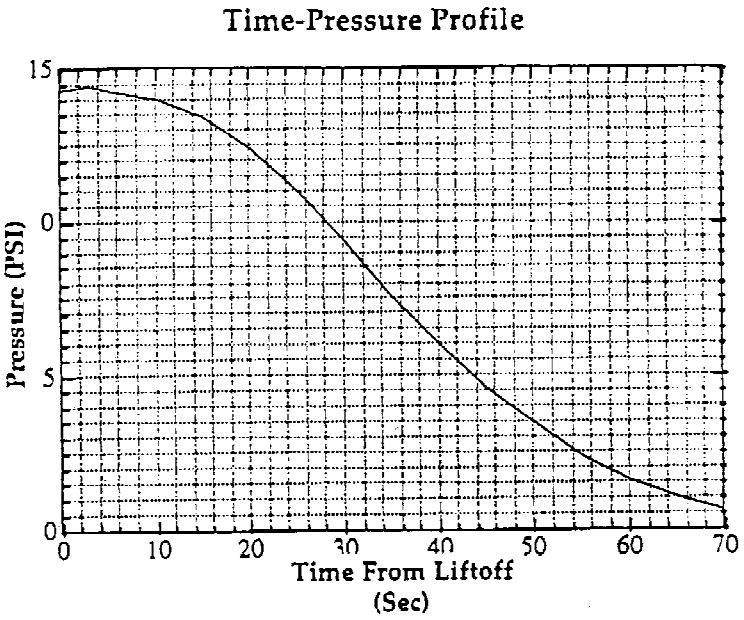


Figure 5-1. Time-Pressure Profile

5.6 RF Connectors

The receiver input, power amplifier output, diplexer input and output, and band reject filter output shall all use SMA connectors.

5.7 Optical Connectors

All transponder's MIL-STD-1773 interfaces shall use SMA 905 connectors or a spaceflight qualified equivalent.

5.8 Corona and Multipaction

The transponder shall be designed for continuous operation from atmospheric pressure to 10^{-14} Torr. The transponder shall be designed and fabricated so as to prevent the formation of corona, multipaction, or arc discharges. The transponder shall be designed to have 6 dB margin to corona, multipaction, and arc discharge.

5.9 Operational Life

The transponder shall be designed for an operational life of 5 years minimum. During the operational life, the transmitter must survive 50,000 ON/OFF cycles.

5.10 Nonoperational Life

The transponder design shall be compatible with a nonoperational life under the conditions of Table 5-1 for at least 6 years.

5.11 Finish

The transponder external surfaces shall be painted with a high emissivity finish. A primer, Chemglaze 9924 or equivalent, shall be applied prior to finishing with Chemglaze Z-306.

Table 5-1. Storage and Transportation Environments

Item	Range	Units
Temperature		
Transportation and Handling	-25 - +65	^{o}C
Storage	+15 - +35	^{o}C
Pressure		
Ground	23 to 31.3	Inches of Hg
Air Transport	3.5 to 31.3	Inches of Hg
Rate of Pressure Change		
Ground	2.9×10^{-5}	psi/sec
Air Transport	1.8×10^{-2}	psi/sec
Humidity		
Transportation and Handling	<90	% Relative Humidity
Storage	<50	% Relative Humidity

Section 6. Environmental Requirements

6.1 General

The transponder must be designed to meet the performance requirements of Section 3 during and after exposure to the environmental requirements specified in paragraphs 6.2 through 6.8.

6.2 Sinusoidal Vibration

The transponder must display no erratic operational behavior while being exposed to sinusoidal vibration levels specified in Figure 6-1 in each of three mutually perpendicular axes. After exposure, the transponder must meet all performance requirements specified in Section 3.

6.3 Random Vibration

The transponder must display no erratic operational behavior while being exposed to random vibration levels specified in Figure 6-2 in each of three mutually perpendicular axes. After exposure the transponder must meet the performance requirements specified in Section 3.

6.4 Pyrotechnic Shock

The transponder must meet all performance requirements of Section 3 after being subjected to three shocks in each of the three orthogonal axes with the acceleration spectrum shown in Figure 6-3.

6.5 Thermal Vacuum

The transponder must meet the performance requirements specified in Section 3 at a pressure of 10^{-5} Torr and at any temperature between -20 and +65 degrees C unless otherwise specified.

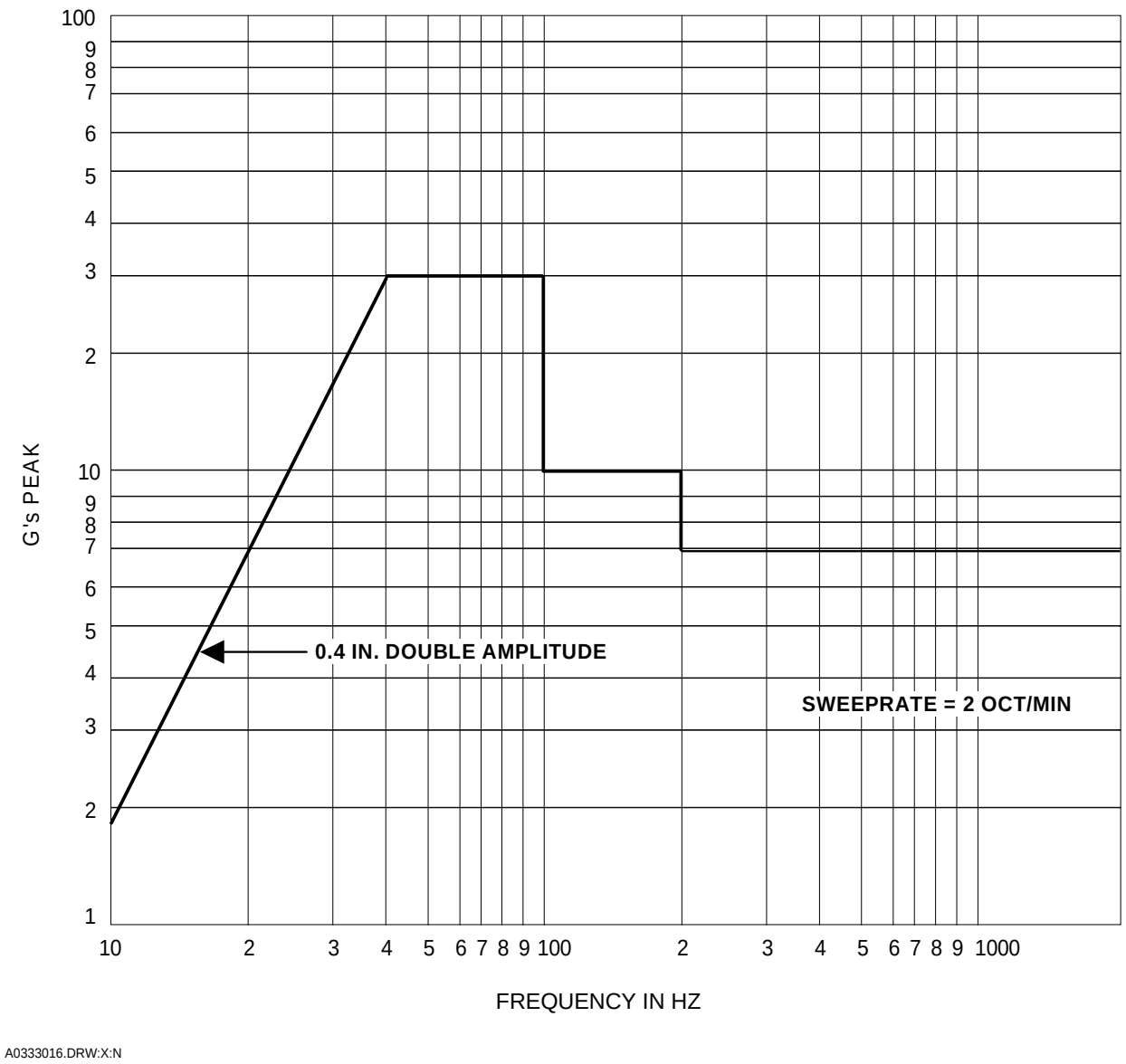


Figure 6-1. Sinusoidal Vibration Limits

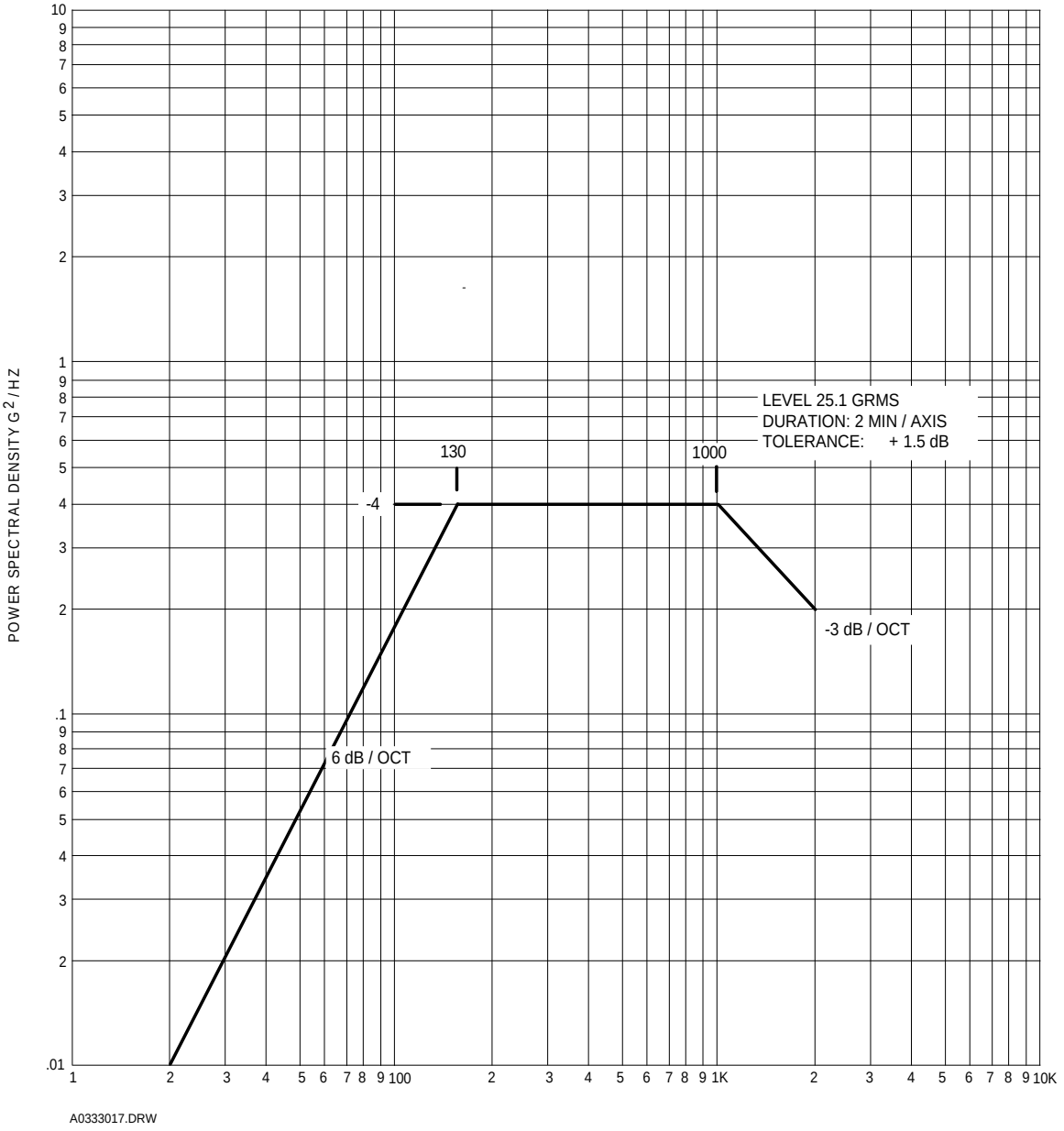


Figure 6-2. Random Vibration Profile (Qualification)

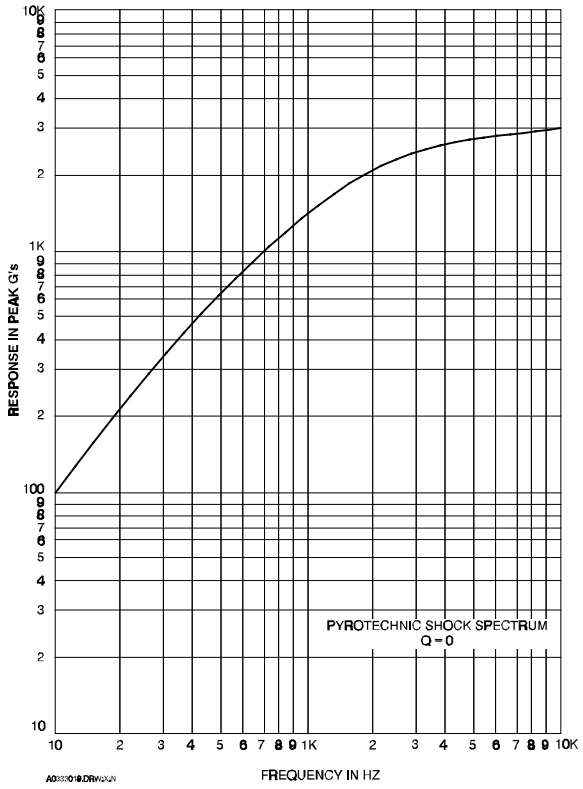


Figure 6-3. Pyrotechnic Shock Design Limits

6.6 Relative Humidity

The transponder must meet the performance requirements specified in Section 3 after exposure to a relative humidity between 0 and 90 percent at any temperature in the range of 5 to 45 degrees C provided that condensation is prevented.

6.7 Radiation

The transponder must provide the combination of shielding and part level radiation hardness which will allow performance requirements to be met when exposed to radiation environment defined herein.

6.7.1 Orbit Parameters

6.7.1.1

Worst-case radiation environments are given for spacecraft orbits with inclinations of 30, 60, or 90 degrees and an altitude of 1,000 kilometers.

6.7.1.2

Because the transponder may be used for missions over a variety of solar cycle conditions and orbital parameters, the radiation environments defined in paragraphs 6.7.2.2, 6.7.2.5, 6.7.2.6, and 6.7.2.7 are for those angles of inclination and/or solar cycle providing the most severe environment.

6.7.2 Charged Particle Effects

6.7.2.1 Solar Cycle Effects

During the 5-year durations, some of the missions will span both the minimum and maximum phases of the solar cycle. Therefore, the radiation environment will depend on the launch date of each mission. Table 6-1 gives launch dates and for each launch date, the number of years to be expected for solar minimum conditions, the number of years to be expected for solar maximum conditions, and the number of predicted extremely large Solar Flare Proton (SFP) events. The number of solar flare proton events are given for a confidence level of 95 percent. The number of events is a non-linear function of mission duration and confidence level.

Table 6-1. Solar Cycle Conditions for Launches with 5-Year Mission Durations

Launch Date	# of Years in Solar Min	# of Years in Solar Max	# of SFP Events (95%)
1998	1	4	4
1999	0	5	5
2000	0	5	5
2001	0	5	5
2002	1	4	4
2003	2	3	3

6.7.2.2 Total Ionizing Dose (TID)

a. The TID predicted for the orbit configuration in paragraph 6.7.1 is shown in Table 6-2 and Figure 6-4 for mission duration of 5 years. These values do not contain design margins. The mission scenarios includes 5 years of solar maximum conditions.

b. For the TID, the following specification shall be met:

1. Components, assemblies, and fabrication material shall operate within specifications during exposure to the total ionizing dose defined in Table 6-2 and Figure 6-4.

2. The transponder shall provide the equivalent shielding of 1.0 mm of aluminum for its components against the TID specified in this section. The spacecraft will provide an additional equivalent shielding of 0.5 mm of aluminum for a total of 1.5mm equivalent shielding.

3. Additional shielding (box walls, PC boards, device packages, spot shields) will also provide additional shielding. If it is necessary to include these structures in the shielding to meet the TID requirement, it is recommended that a 3-dimensional analysis of the transponder and its components be used for the shielding evaluation.

4. Wherever possible, all parts shall be radiation hardened to 100 KRad (Si). For parts with less than 100 KRad (Si) inherent tolerance, a Radiation Design Margin (RDM) of 2 is required. If additional spot shielding is required, the RDM shall be 3.

6.7.2.3 Single Event Upset (SEU)

a. Charged particle environments may induce SEUs. A SEU is a change of state or transient induced by a cosmic ray ion or proton in digital or certain analog devices. Vulnerable analog devices are optoelectronic devices, Analog to Digital Converters (ADC), and sense amplifiers. The change may affect information stored in the device or in a surrounding interface device.

Table 6-2. Total Dose at the Center of Solid Aluminum Spheres (RADS-SI)

Mission Duration = 5 Years (5 Years of Solar Maximum)
Orbit Inclination = 30 Deg, 5 Extremely Large Solar Flare Proton Events
Values Do Not Contain Design Margins

Shield Thickness			1000/1000 km
mm	mils	gm/sqcm	rads-si
0.25	10	0.07	3.35E + 06
0.50	20	0.14	5.78E + 05
0.75	30	0.20	2.03E + 05
1.00	39	0.27	1.05E + 05
1.50	59	0.41	5.04E + 04
2.00	79	0.54	3.35E + 04
2.50	98	0.68	2.54E + 04
3.00	118	0.81	2.05E + 04
3.50	138	0.94	1.75E + 04
4.00	157	1.08	1.52E + 04
4.50	177	1.22	1.34E + 04
5.00	197	1.35	1.21E + 04
5.50	217	1.49	1.13E + 04
6.00	236	1.62	1.08E + 04
6.50	256	1.75	1.06E + 04
7.00	276	1.89	1.02E + 04
8.00	315	2.16	9.42E + 03
9.00	354	2.43	9.16E + 03
10.00	394	2.70	8.71E + 03
12.00	472	3.24	8.07E + 03
14.00	551	3.78	7.50E + 03
16.00	630	4.32	7.02E + 03
18.00	709	4.86	6.63E + 03
20.00	787	5.40	6.24E + 03
25.00	984	6.75	5.61E + 03
30.00	1181	8.10	4.92E + 03
35.00	1378	9.45	4.43E + 03
40.00	1575	10.80	4.07E + 03
45.00	1772	12.15	3.73E + 03
50.00	1969	13.50	3.45E + 03

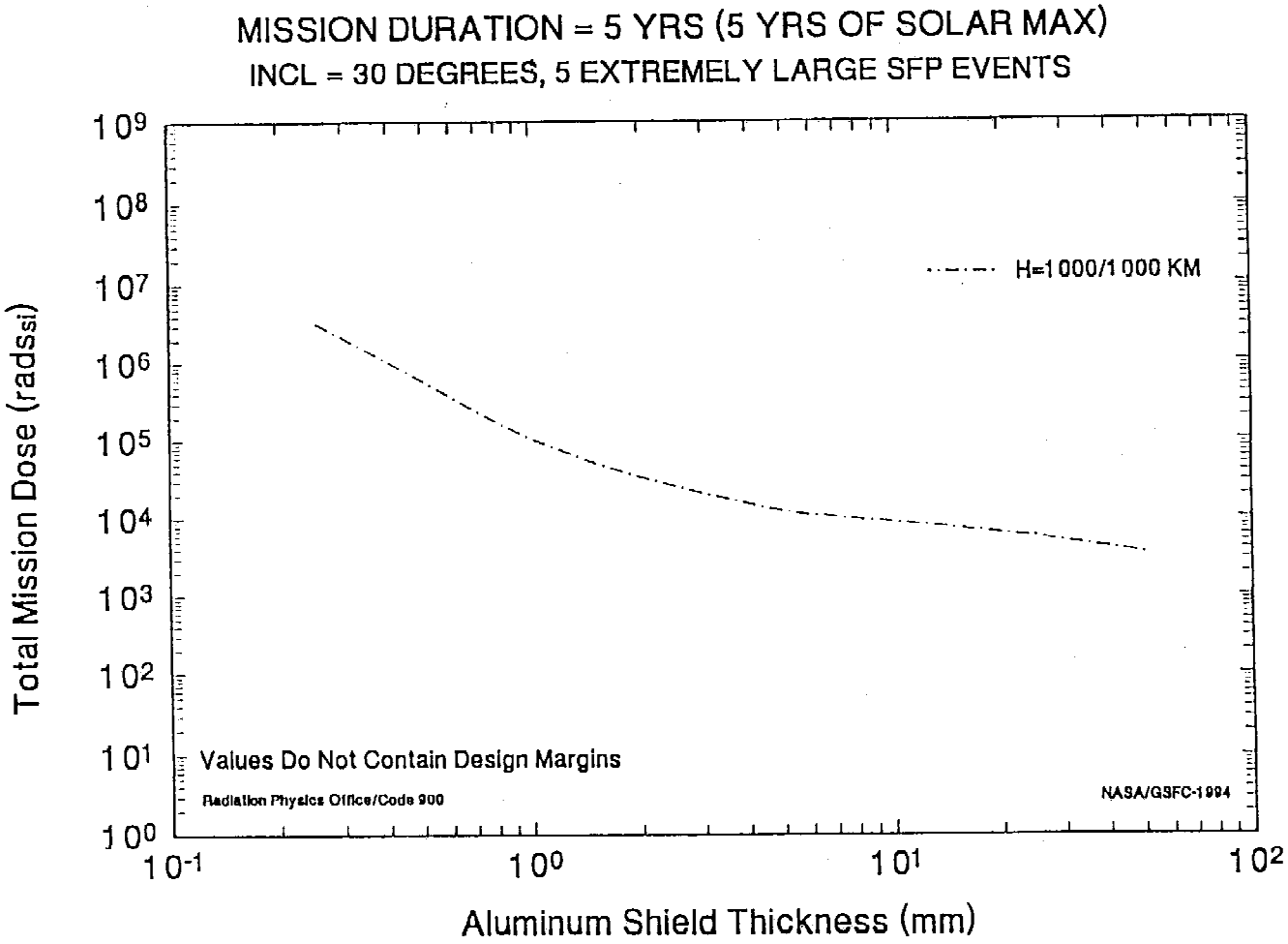


Figure 6-4. Total Dose at the Center of Solid Aluminum Spheres

b. Electronic components shall be designed, where possible, to be immune to SEU induced performance anomalies in the:

1. Solar flare proton.

2. Solar minimum and/or solar maximum trapped proton.

3. Cosmic ray charged particle environments defined below:

   Components may achieve immunity to SEU induced anomalies by using Error Detection and Correction (EDAC) or by using parts that are immune to SEU or by demonstrating that a given failure is a non-credible failure. Devices with a Linear Energy Transfer (LET) threshold of LET_{th} > 100 MeV*cm^2/mg are immune to cosmic ray effects. Devices with a cosmic ray LET_{th} < 14 MeV*cm^2/mg may be susceptible to trapped and solar flare proton SEUs. Those with cosmic ray LET_{th} < 8 MeV*cm^2/mg will experience trapped and solar flare proton SEUs. LET_{th} is defined as the minimum LET required to cause an SEU.

4. Where LET_{th} data are taken for a new device, a fluence of 1 x 10^7 ions/cm2 shall be used to establish the threshold for the device being tested.

5. Where immunity from SEU is not possible, the induced anomalies shall not require ground intervention for correction.

6. If the electronic component uses a part with a LET_{th} <30 MeV*cm^2/mg, it shall be demonstrated that the effect of the SEU will not adversely affect the normal operation of the transponder.

6.7.2.4 Single Event Latchup (SEL)

SEL is a cosmic ray, trapped proton, or solar flare proton induced anomalous state in an integrated chip, characterized by high current and degraded performance in that chip.

a. Electronic components shall be immune to SEL, secondary breakdown, and other thermal runaway effects, and snap-back induced by cosmic rays and trapped and solar flare protons.

b. This shall be accomplished through the selection of electronic parts immune to these effects.

6.7.2.5 Solar Flare Protons

Components shall operate per the requirements of sections 6.7.2.3 and 6.7.2.4 during 5 solar flares each lasting 4 days. The environment for a single flare is defined in the Table 6-3 and Figure 6-5. These data do not contain design margins.

6.7.2.6 Trapped Protons

a. Components shall operate per the requirements of paragraph 6.7.2.3 and 6.7.2.4 during exposure to the trapped proton environment (shielded) defined in Table 6-4 and Figure 6-6. In cases where the mission is during both phases of the solar cycle, the solar minimum (worst case) environment is used. These data do not contain design margins.

b. Components shall operate within specification during exposure to a peak proton flux environment (surface incident) over the South Atlantic Anomaly when the flux is defined as in Table 6-5 and Figure 6-7. In cases where the mission is during both phases of the solar cycle, the solar minimum environment is used. These data do not contain design margins.

6.7.2.7 Cosmic Ray Charged Particles

Components shall operate per the requirements of paragraphs 6.7.2.3 and 6.7.2.4 during exposure to the cosmic ray heavy ion environment defined in Table 6-6 and Figure 6-8. This plot does not contain protons. These data are for a worst case cosmic ray environment and do not contain design margins.

Table 6-3. Emerging Solar Flare Proton Spectra Behind Solid Sphere Aluminum Shields

SPECRUN16 (SOLAR MAXIMUM) BLTIME = 1999.00
90.0 DEG/1000-1000 KM

RADIATION PHYSICS OFFICE/CODE 900
NASA-GSFC 1994

INPUT SPECTRUM *		EMERGING DIFFERENTIAL FLUX (PARTICLES/CM**2*1 AL EVENT(S)*MEV)										
ENERGY (=MEV)	DIFF.FLUX #/CM**2 *1*EVENT(S)*MEV	ENERGY (=MEV)	THICKNESS (MM) 0.25	1.00	2.00	3.50	5.00	6.50	10.00	20.00	35.00	50.00
10.000	1.2967E+08	0.158	0.00E+00	7.93E+06	5.38E+06	3.10E+06	2.09E+06	1.74E+06	1.02E+06	3.33E+05	1.09E+05	3.73E+04
20.000	9.4919E+07	0.200	0.00E+00	8.58E+06	5.82E+06	3.35E+06	2.26E+06	1.88E+06	1.10E+06	3.60E+05	1.18E+05	4.03E+04
30.000	7.1274E+07	0.251	0.00E+00	9.35E+06	6.34E+06	3.65E+06	2.47E+06	2.04E+06	1.20E+06	3.93E+05	1.28E+05	4.40E+04
40.000	5.1027E+07	0.316	0.00E+00	1.03E+07	6.97E+06	4.02E+06	2.72E+06	2.25E+06	1.32E+06	4.32E+05	1.41E+05	4.84E+04
48.100	3.8166E+07	0.398	0.00E+00	1.14E+07	7.75E+06	4.46E+06	3.02E+06	2.50E+06	1.46E+06	4.80E+05	1.57E+05	5.38E+04
50.000	3.5700E+07	0.501	0.00E+00	1.28E+07	8.71E+06	5.00E+06	3.38E+06	2.80E+06	1.64E+06	5.38E+05	1.76E+05	6.03E+04
53.800	3.1370E+07	0.631	0.00E+00	1.45E+07	9.89E+06	5.66E+06	3.83E+06	3.17E+06	1.86E+06	6.09E+05	1.99E+05	6.83E+04
60.000	2.5463E+07	0.794	0.00E+00	1.66E+07	1.13E+07	6.47E+06	4.37E+06	3.62E+06	2.12E+06	6.95E+05	2.28E+05	7.79E+04
60.400	2.5111E+07	1.000	0.00E+00	1.91E+07	1.31E+07	7.45E+06	5.03E+06	4.16E+06	2.44E+06	8.00E+05	2.62E+05	8.97E+04
68.100	1.8976E+07	1.260	0.00E+00	2.21E+07	1.50E+07	8.64E+06	5.82E+06	4.82E+06	2.82E+06	9.26E+05	3.03E+05	1.04E+05
70.000	1.7742E+07	1.580	0.00E+00	2.58E+07	1.72E+07	1.01E+07	6.79E+06	5.63E+06	3.29E+06	1.08E+06	3.53E+05	1.21E+05
76.900	1.4072E+07	2.000	0.00E+00	3.03E+07	1.96E+07	1.18E+07	7.96E+06	6.62E+06	3.87E+06	1.26E+06	4.14E+05	1.42E+05
80.000	1.2659E+07	2.510	0.00E+00	3.54E+07	2.22E+07	1.38E+07	9.36E+06	7.82E+06	4.57E+06	1.49E+06	4.87E+05	1.66E+05
87.300	9.7427E+06	3.160	0.00E+00	4.11E+07	2.51E+07	1.62E+07	1.11E+07	9.25E+06	5.41E+06	1.76E+06	5.79E+05	1.96E+05
90.000	8.8212E+06	3.980	0.00E+00	4.74E+07	2.86E+07	1.90E+07	1.31E+07	1.09E+07	6.38E+06	2.09E+06	6.91E+05	2.32E+05
99.300	6.2553E+06	5.010	0.00E+00	5.37E+07	3.28E+07	2.22E+07	1.56E+07	1.27E+07	7.45E+06	2.49E+06	8.22E+05	2.77E+05
100.000	6.0969E+06	6.310	9.45E+07	5.98E+07	3.78E+07	2.58E+07	1.84E+07	1.46E+07	8.61E+06	2.97E+06	9.67E+05	3.31E+05
110.000	4.2563E+06	7.940	1.01E+08	6.51E+07	4.32E+07	2.98E+07	2.15E+07	1.67E+07	9.83E+06	3.52E+06	1.12E+06	3.99E+05
113.500	3.7579E+06	10.000	1.03E+08	6.92E+07	4.85E+07	3.37E+07	2.47E+07	1.88E+07	1.11E+07	4.13E+06	1.27E+06	4.79E+05
120.000	2.9675E+06	12.600	1.01E+08	7.14E+07	5.26E+07	3.71E+07	2.76E+07	2.08E+07	1.24E+07	4.76E+06	1.43E+06	5.68E+05
130.000	2.0447E+06	15.800	9.48E+07	7.11E+07	5.46E+07	3.95E+07	2.98E+07	2.27E+07	1.38E+07	5.36E+06	1.58E+06	6.67E+05
130.100	2.0370E+06	20.000	8.46E+07	6.68E+07	5.39E+07	4.01E+07	3.09E+07	2.41E+07	1.50E+07	5.93E+06	1.77E+06	7.64E+05
140.000	1.4105E+06	25.100	7.35E+07	6.03E+07	4.97E+07	3.83E+07	3.02E+07	2.42E+07	1.56E+07	6.29E+06	1.96E+06	8.40E+05
149.900	9.8516E+05	31.600	6.02E+07	5.11E+07	4.22E+07	3.37E+07	2.73E+07	2.26E+07	1.50E+07	6.28E+06	2.10E+06	8.79E+05
150.000	9.8160E+05	39.800	4.56E+07	3.96E+07	3.27E+07	2.69E+07	2.25E+07	1.91E+07	1.32E+07	5.79E+06	2.10E+06	8.68E+05
160.000	6.8225E+05	50.100	3.15E+07	2.77E+07	2.27E+07	1.93E+07	1.65E+07	1.44E+07	1.03E+07	4.82E+06	1.90E+06	7.92E+05
170.000	4.7407E+05	63.100	1.95E+07	1.70E+07	1.41E+07	1.23E+07	1.08E+07	9.57E+06	7.05E+06	3.54E+06	1.49E+06	6.60E+05
173.300	4.2039E+05	79.400	1.03E+07	8.73E+06	7.70E+06	6.85E+06	6.12E+06	5.50E+06	4.15E+06	2.27E+06	9.91E+05	4.92E+05
180.000	3.2865E+05	100.000	4.62E+06	3.70E+06	3.67E+06	3.30E+06	2.99E+06	2.70E+06	2.07E+06	1.23E+06	5.34E+05	3.20E+05
190.000	2.2739E+05	126.000	1.72E+06	1.25E+06	1.53E+06	1.38E+06	1.26E+06	1.14E+06	8.72E+05	5.58E+05	2.19E+05	1.27E+05
200.000	1.5798E+05	158.000	4.83E+05	2.93E+05	4.68E+05	4.10E+05	3.61E+05	3.18E+05	2.37E+05	1.40E+05	2.32E+04	0.00E+00
201.300	1.5066E+05	200.000	8.75E+04	3.56E+04	1.56E+05	1.37E+05	1.20E+05	1.06E+05	7.89E+04	4.66E+04	5.47E+04	1.75E+05

* MAGNETOSPHERICALLY ATTENUATED DIFFERENTIAL SPECTRUM GIVEN FOR 1 AL EVENT(S)

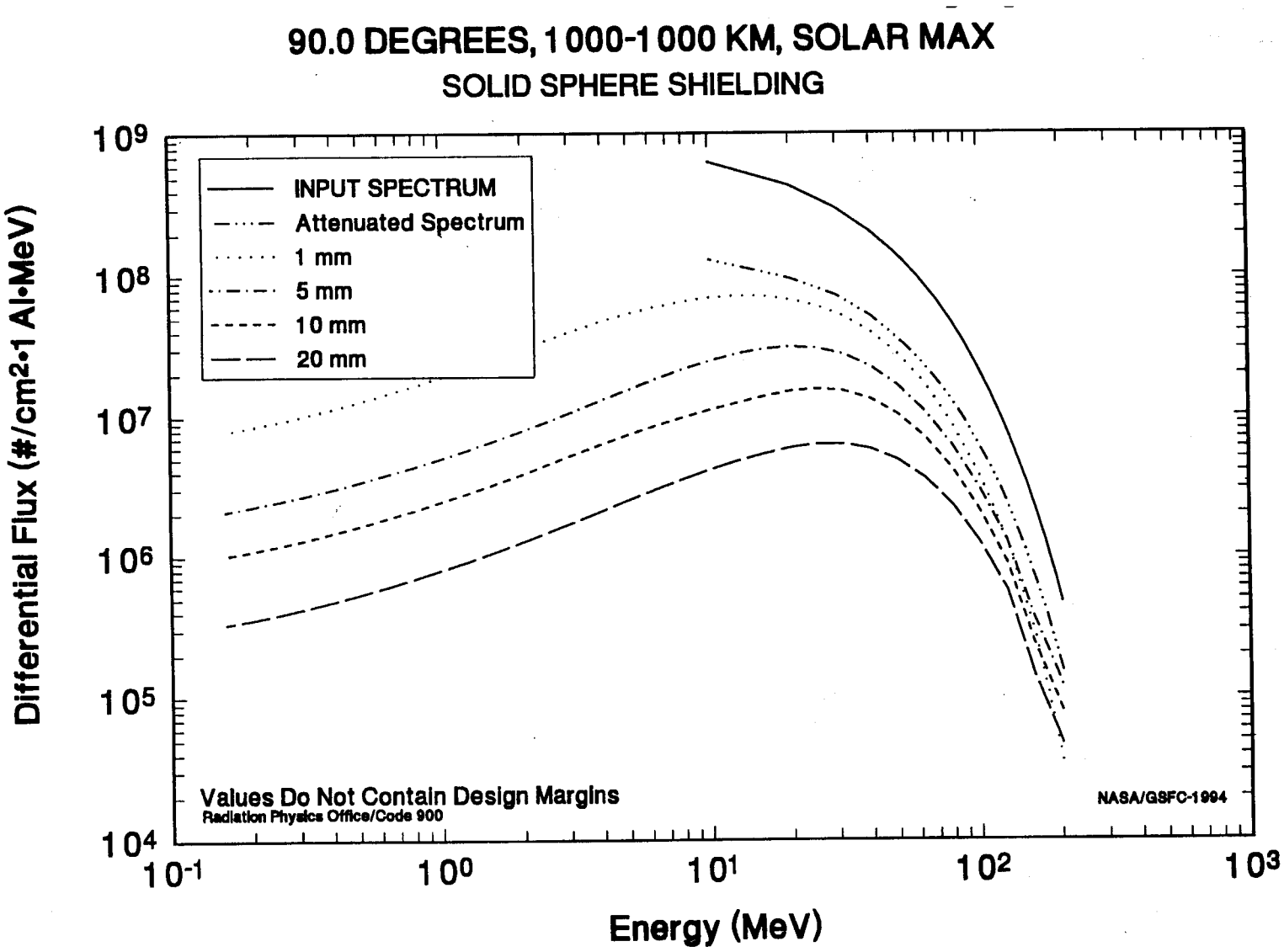


Figure 6-5. Emerging Differential Solar Flare Proton Spectra

Table 6-4. Emerging Trapped Proton Spectra Behind Solid Sphere Aluminum Shields

SPECRUN22 (SOLAR MINIMUM) BLTIME = 1999.00
30.0 DEG/1000-1000 KM

RADIATION PHYSICS OFFICE/CODE 900
NASA-GSFC 1994

****

INPUT SPECTRUM

ENERGY (=MEV)	DIFF.FLUX #/CM**2*DAY*MEV
0.040	9.0461E+06
0.070	8.8992E+06
0.100	8.4940E+06
0.500	6.1716E+06
1.000	4.9075E+06
2.000	4.0625E+06
3.000	3.8094E+06
4.000	3.6418E+06
5.000	3.4163E+06
6.000	3.2659E+06
8.000	2.8970E+06
10.000	2.3916E+06
15.000	1.6140E+06
20.000	1.1465E+06
25.000	8.4404E+05
30.000	6.6070E+05
35.000	5.6981E+05
40.000	5.2220E+05
45.000	4.9585E+05
50.000	4.7658E+05
60.000	4.3597E+05
80.000	3.5640E+05
100.000	2.9506E+05
150.000	1.7971E+05
200.000	1.0809E+05
250.000	6.5465E+04
300.000	4.0141E+04
350.000	2.4780E+04

****

EMERGING DIFFERENTIAL FLUX (PARTICLES/CM**2*DAY*MEV)

ENERGY (=MEV)	THICKNESS (MM) 0.25	1.00	2.00	3.50	5.00	6.50	10.00	20.00	35.00	50.00
0.040	3.48E+05	9.78E+04	5.29E+04	2.46E+04	1.56E+04	1.38E+04	1.04E+04	5.92E+03	3.87E+03	2.50E+03
0.050	3.49E+05	9.78E+04	5.29E+04	2.46E+04	1.56E+04	1.38E+04	1.04E+04	5.92E+03	3.87E+03	2.51E+03
0.063	3.56E+05	9.99E+04	5.40E+04	2.52E+04	1.59E+04	1.41E+04	1.06E+04	6.04E+03	3.95E+03	2.56E+03
0.079	3.68E+05	1.03E+05	5.58E+04	2.60E+04	1.65E+04	1.45E+04	1.09E+04	6.24E+03	4.08E+03	2.64E+03
0.100	3.85E+05	1.08E+05	5.85E+04	2.72E+04	1.72E+04	1.52E+04	1.14E+04	6.54E+03	4.27E+03	2.77E+03
0.126	4.07E+05	1.15E+05	6.19E+04	2.88E+04	1.83E+04	1.61E+04	1.21E+04	6.93E+03	4.53E+03	2.93E+03
0.158	4.36E+05	1.23E+05	6.63E+04	3.08E+04	1.95E+04	1.72E+04	1.30E+04	7.41E+03	4.84E+03	3.14E+03
0.200	4.72E+05	1.33E+05	7.16E+04	3.33E+04	2.11E+04	1.86E+04	1.40E+04	8.02E+03	5.24E+03	3.39E+03
0.251	5.16E+05	1.45E+05	7.81E+04	3.63E+04	2.31E+04	2.03E+04	1.53E+04	8.74E+03	5.71E+03	3.70E+03
0.316	5.71E+05	1.59E+05	8.59E+04	4.00E+04	2.54E+04	2.24E+04	1.69E+04	9.63E+03	6.29E+03	4.07E+03
0.398	6.35E+05	1.77E+05	9.55E+04	4.45E+04	2.82E+04	2.49E+04	1.88E+04	1.07E+04	6.99E+03	4.52E+03
0.501	7.11E+05	1.98E+05	1.07E+05	4.99E+04	3.17E+04	2.79E+04	2.10E+04	1.20E+04	7.83E+03	5.08E+03
0.631	7.96E+05	2.25E+05	1.22E+05	5.65E+04	3.58E+04	3.16E+04	2.38E+04	1.36E+04	8.87E+03	5.74E+03
0.794	8.91E+05	2.57E+05	1.40E+05	6.45E+04	4.09E+04	3.61E+04	2.72E+04	1.55E+04	1.01E+04	6.56E+03
1.000	9.96E+05	2.96E+05	1.62E+05	7.44E+04	4.71E+04	4.15E+04	3.13E+04	1.79E+04	1.17E+04	7.55E+03
1.260	1.11E+06	3.43E+05	1.86E+05	8.63E+04	5.45E+04	4.81E+04	3.62E+04	2.07E+04	1.35E+04	8.74E+03
1.580	1.24E+06	3.99E+05	2.12E+05	1.01E+05	6.36E+04	5.62E+04	4.22E+04	2.41E+04	1.57E+04	1.02E+04
2.000	1.40E+06	4.66E+05	2.40E+05	1.18E+05	7.45E+04	6.60E+04	4.96E+04	2.82E+04	1.84E+04	1.19E+04
2.510	1.56E+06	5.42E+05	2.69E+05	1.37E+05	8.76E+04	7.79E+04	5.85E+04	3.31E+04	2.17E+04	1.40E+04
3.160	1.72E+06	6.25E+05	3.02E+05	1.60E+05	1.04E+05	9.21E+04	6.92E+04	3.91E+04	2.57E+04	1.65E+04
3.980	1.85E+06	7.12E+05	3.40E+05	1.85E+05	1.23E+05	1.08E+05	8.16E+04	4.64E+04	3.06E+04	1.96E+04
5.010	1.92E+06	7.91E+05	3.84E+05	2.14E+05	1.45E+05	1.27E+05	9.58E+04	5.52E+04	3.63E+04	2.33E+04
6.310	1.90E+06	8.50E+05	4.30E+05	2.45E+05	1.72E+05	1.47E+05	1.12E+05	6.58E+04	4.29E+04	2.78E+04
7.940	1.77E+06	8.76E+05	4.74E+05	2.78E+05	2.01E+05	1.69E+05	1.29E+05	7.84E+04	5.02E+04	3.33E+04
10.000	1.57E+06	8.64E+05	5.08E+05	3.11E+05	2.32E+05	1.93E+05	1.48E+05	9.31E+04	5.82E+04	3.99E+04
12.600	1.33E+06	8.18E+05	5.25E+05	3.41E+05	2.65E+05	2.20E+05	1.70E+05	1.10E+05	6.68E+04	4.74E+04
15.800	1.09E+06	7.48E+05	5.25E+05	3.67E+05	2.96E+05	2.50E+05	1.95E+05	1.28E+05	7.64E+04	5.59E+04
20.000	8.90E+05	6.70E+05	5.11E+05	3.87E+05	3.23E+05	2.80E+05	2.21E+05	1.48E+05	8.77E+04	6.53E+04
25.100	7.29E+05	5.96E+05	4.88E+05	3.98E+05	3.44E+05	3.07E+05	2.47E+05	1.67E+05	1.01E+05	7.53E+04
31.600	6.08E+05	5.30E+05	4.61E+05	4.00E+05	3.57E+05	3.27E+05	2.69E+05	1.84E+05	1.15E+05	8.55E+04
39.800	5.19E+05	4.74E+05	4.31E+05	3.90E+05	3.58E+05	3.35E+05	2.82E+05	1.99E+05	1.29E+05	9.56E+04
50.100	4.53E+05	4.24E+05	3.96E+05	3.70E+05	3.47E+05	3.28E+05	2.84E+05	2.07E+05	1.41E+05	1.05E+05
63.100	3.94E+05	3.73E+05	3.55E+05	3.37E+05	3.21E+05	3.05E+05	2.71E+05	2.06E+05	1.47E+05	1.11E+05
79.400	3.34E+05	3.18E+05	3.04E+05	2.91E+05	2.80E+05	2.68E+05	2.42E+05	1.93E+05	1.44E+05	1.10E+05
100.000	2.72E+05	2.58E+05	2.47E+05	2.37E+05	2.29E+05	2.20E+05	2.02E+05	1.68E+05	1.30E+05	1.03E+05
126.000	2.10E+05	1.98E+05	1.88E+05	1.81E+05	1.75E+05	1.68E+05	1.56E+05	1.35E+05	1.08E+05	8.80E+04
158.000	1.50E+05	1.40E+05	1.33E+05	1.28E+05	1.22E+05	1.18E+05	1.10E+05	9.85E+04	8.09E+04	6.81E+04
200.000	9.88E+04	9.18E+04	8.64E+04	8.28E+04	7.88E+04	7.64E+04	7.06E+04	6.50E+04	5.51E+04	4.73E+04
251.000	5.99E+04	5.55E+04	5.20E+04	4.96E+04	4.67E+04	4.52E+04	4.13E+04	3.88E+04	3.38E+04	2.93E+04
316.000	3.28E+04	3.03E+04	2.83E+04	2.67E+04	2.49E+04	2.40E+04	2.15E+04	2.04E+04	1.82E+04	1.58E+04

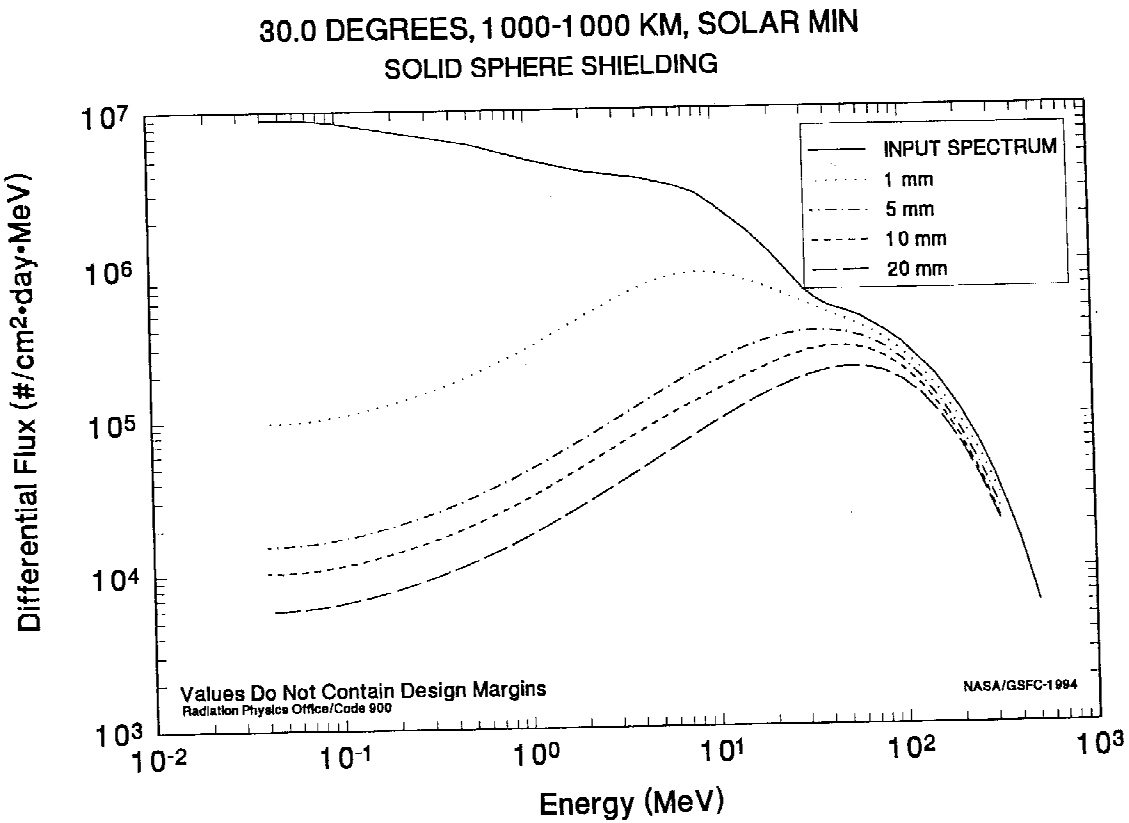


Figure 6-6. Emerging Differential Trapped Proton Spectra

Table 6-5. Integral Peak Trapped Proton Fluxes in the South Atlantic Anomaly

Inclination = 60 Degrees, Solar Minimum
Values Do Not Contain Design Margins

Energy (>MeV)	**1000/1000 km p/sqcm/sec**
10	1.40E + 04
20	1.13E + 04
30	9.72E + 03
40	8.70E + 03
50	7.78E + 03
60	6.96E + 03
80	5.56E + 03
100	4.44E + 03
150	2.59E + 03
200	1.59E + 03
250	9.85E + 02
300	6.08E + 02
350	3.91E + 02
400	2.55E + 02
500	1.08E + 02

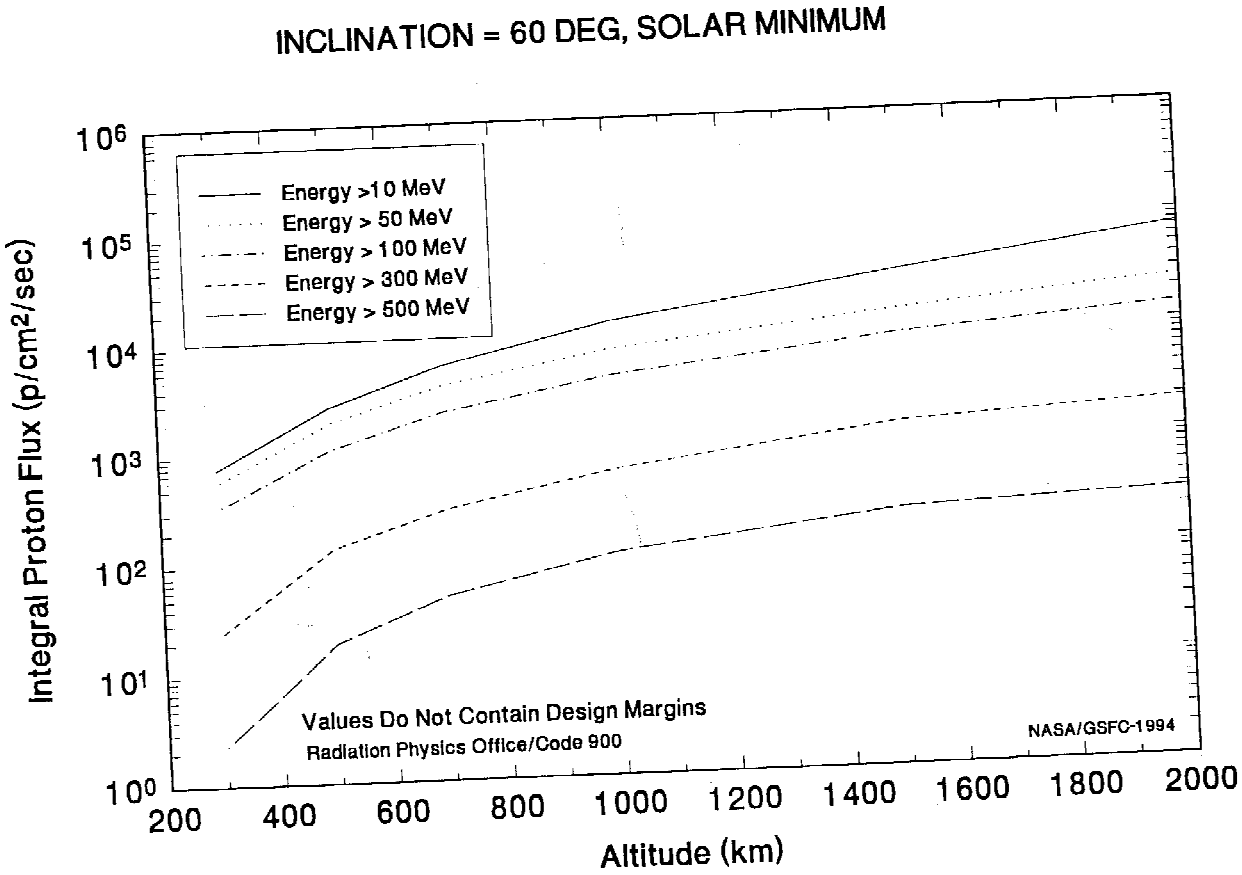


Figure 6-7. Peak Integral Proton Fluxes in the SAA

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Table 6-6. Total Integral LET Spectra in Silicon (1<Z<93)

I = 90 Deg, H=1000/1000 KM, Solid AL Sphere Shielding

LET ENERGY MeV *sqcm/mg	LET SPECTRA Thickness: 0.5 mm #/sqcm/day	LET SPECTRA Thickness: 1.0 mm #/sqcm/day	LET SPECTRA Thickness: 5.0 mm #/sqcm/day	LET SPECTRA Thickness: 50.0 mm #/sqcm/day
1.03E-01	8.19E+02	8.07E+02	7.85E+02	6.40E+02
1.30E-01	5.69E+02	5.60E+02	5.44E+02	4.24E+02
1.63E-01	4.53E+02	4.46E+02	4.35E+02	3.36E+02
2.05E-01	3.65E+02	3.59E+02	3.52E+02	2.70E+02
2.59E-01	2.76E+02	2.71E+02	2.66E_02	2.00E+02
3.25E-01	2.02E+02	1.99E+02	1.94E+02	1.42E+02
4.10E-01	1.48E+02	1.45E+02	1.43E+02	1.01E+02
5.16E-01	1.13E+02	1.12E+02	1.10E+02	7.82E+01
6.48E-01	9.07E+01	8.90E+01	8.73E+01	6.26E+01
8.20E-01	7.27E+01	7.14E+01	6.98E+01	5.03E+01
1.03E+00	5.75E+01	5.62E+01	5.50E+01	3.95E+01
1.30E+00	2.43E+01	2.32E+01	2.22E+01	1.36E+01
1.63E+00	1.31E+01	1.22E+01	1.17E+01	6.64E+00
2.05E+00	7.39E+00	6.74E+00	6.46E+00	3.65E+00
2.59E+00	4.32E+00	3.87E+00	3.71E+00	2.06E+00
3.25E+00	2.62E+00	2.29E+00	2.16E+00	1.20E+00
4.10E+00	1.61E+00	1.34E+00	1.25E+00	6.93E-01
5.16E+00	9.42E-01	7.74E-01	7.16E-01	3.91E-01
6.48E+00	5.45E-01	4.49E-01	4.14E-01	2.23E-01
8.20E+00	3.38E-01	2.63E-01	2.39E-01	1.27E-01
1.03E+01	2.03E-01	1.51E-01	1.34E-01	7.06E-02
1.30E+01	1.11E-01	7.73E-02	6.66E-02	3.50E-02
1.63E+01	5.97E-02	4.00E-02	3.38E-02	1.76E-02
2.05E+01	2.77E-02	1.83E-02	1.52E-02	7.84E-03
2.59E+01	8.10E-03	5.19E-03	4.11E-03	2.07E-03
3.25E+01	1.28E-05	1.30E-05	1.37E-05	5.18E-06
4.10E+01	4.99E-06	5.24E-06	5.58E-06	1.94E-06
5.16E+01	2.00E-06	2.14E-06	2.31E-06	7.53E-07
6.48E+01	5.92E-07	6.42E-07	7.17E-07	2.13E-07
8.20E+01	1.30E-07	1.39E-07	1.66E-07	4.52E-08
1.03E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

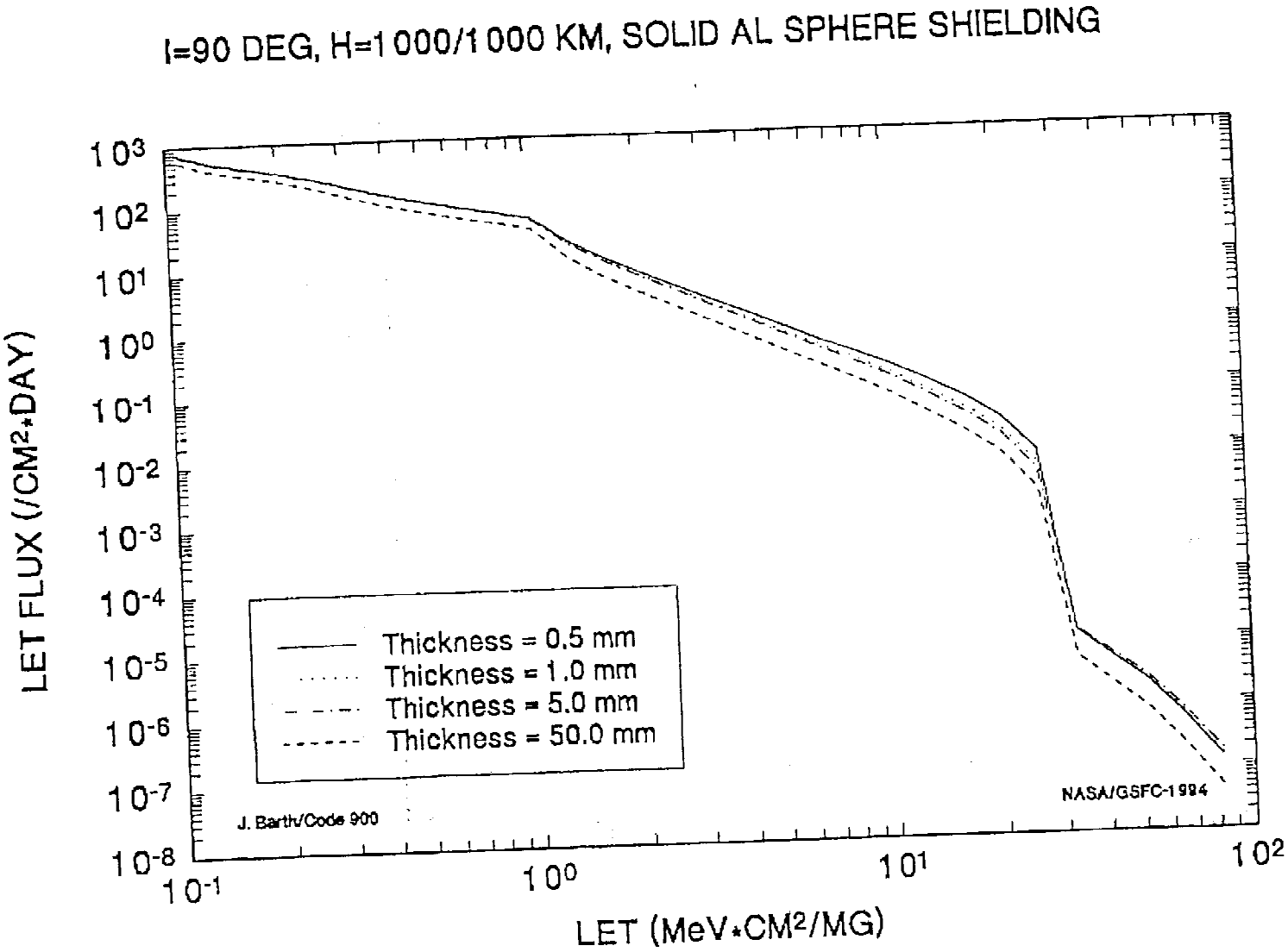

Figure 6-8. Total Integral Let Spectra in Silicon (1 < Z < 93)