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Axiomatix

ORBITER CIU/IUS COMMUNICATIONS HARDWARE EVALUATION

FINAL REPORT

Contract NAS 9-15409B

Technical Monitor: Don Pusch

Prepared for

NASA Lyndon B. Johnson Space Center
Houston, Texas 77058

Prepared by

Gaylord K. Huth

Axiomatix
9841 Airport Blvd., Suite 912
Los Angeles, California 90045

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1.0 EXECUTIVE SUMMARY

1.1 Purpose of Effort and Degree of Performance

The overall objectives of the work have been to evaluate the Inertial Upper Stage (IUS) and DOD Communication Interface Unit (CIU) communication system design, hardware specifications, and interfaces to determine their compatibility with the Orbiter payload communication and data handling equipment and the Orbiter network communication equipment. Some of the principal accomplishments made by Axiomatix under this contract have been:

(1) Algorithm developed for conversion of SGLS (Space-Ground Link System) requires 2 or 4 kbps command data to 128 kbps for Ku-band forward link.

(2) Orbiter avionics/CIU interface compatibility analysis found problems in Multiplexer/Demultiplexer (MDM) interfaces.

(3) Payload Interrogator (PI)/IUS SGLS transponder compatibility analysis found interface problems in transponder acquisition and frequency instability requirements in both IUS and PI frequency sources.

(4) Orbiter/IUS RF range analysis established the optimum choices for PI receiver sensitivity and PI transmitter power output selection as a function of range.

(5) ESTL/IUS test requirements.

(6) Recommendations for "workarounds" for failures of nonredundant equipment.

The contract Statement of Work identifies the following specific tasks that were to be performed:

Task #1, IUS/Orbiter Communication Interface Definition

Task #2, Redundancy Evaluation

Task #3, IUS RF Coverage

Task #4, ESTL Test Requirements

Task #5, Link Budgets for IUS/PI/CIU Communication Links.

During the contract period (March 1978 through June 1979), the IUS, CIU, and Orbiter communication equipment concepts and implementations developed significantly. Therefore, the majority of the effort was directed toward Task #1 and the results of this task represent the majority of this Final Report. Task #5 was added the last month of the contract. While Task #5 was not originally in the contract, the results obtained under this task will greatly expedite the development of operational scenarios for the IUS and Orbiter.

1.2 General Approach to the Activity

Development of the IUS, CIU and Orbiter payload communication equipment was a new activity beginning in CY78. The general approach has been to work with the cognizant NASA personnel, USAF SAMSO personnel, Aerospace Corporation personnel, and individuals at the IUS prime contractor (Boeing Aerospace Company), the Orbiter prime contractor (Rockwell Int'l) and the IUS, CIU and Orbiter payload communication equipment subcontractor (TRW Defense and Space Group) to ascertain directions taken. A vital part of this activity has involved Axiomatix attendance and participation in design reviews (conceptual, preliminary and critical) as well as special interface meetings. These latter gatherings usually involved detailed discussions of interface issues between the IUS and Orbiter communication systems that surfaced at the design reviews. During the performance of the FY78 effort, Axiomatix provided technical support to the CIU Conceptual Design Review, the IUS SGLS Transponder Preliminary Design Review (PDR), the CIU PDR, and the IUS SGLS Critical Design Review (CDR), as shown in Figure 1. Also shown in Figure 1 is a schedule for future design reviews that Axiomatix plans to support.

The work performed under the subject contract was strongly interrelated to parallel efforts. Contract NAS 9-15514A, "Shuttle Orbiter S-Band Communication Equipment Design Evaluation," provided support to critique the design and assess the performance of the individual NASA Orbiter S-band communication equipment (excluding the DOD CIU). Contract NAS 9-15240D, "Shuttle Payload S-Band Communications Study," forms the system framework which ties together the various payload-related equipment (excluding the IUS and CIU). Under Contract NAS 9-15604B, a handbook, "Users' Handbook for Payload-Shuttle Data Communication," was provided.

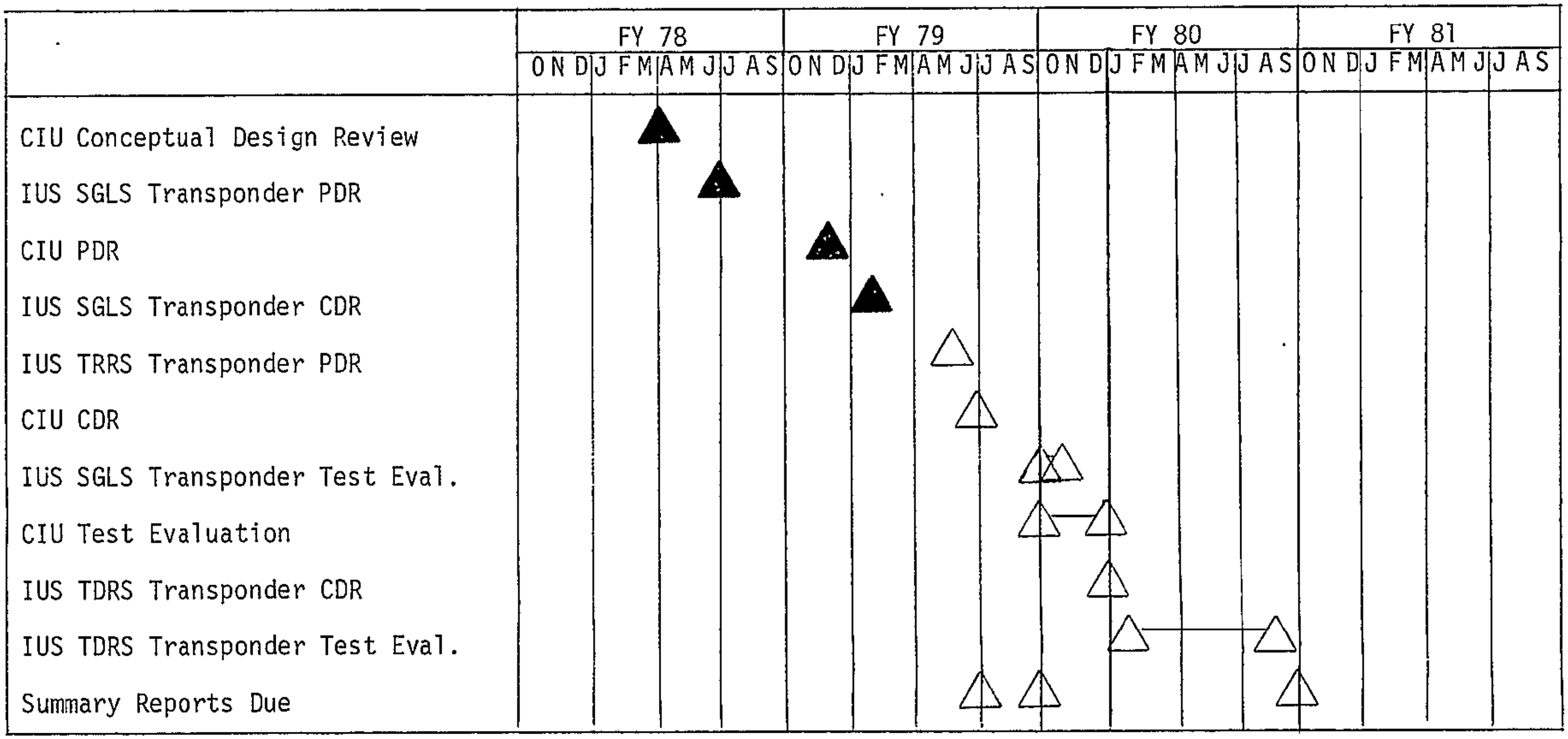


Figure 1. Orbiter/IUS Communication Interface Evaluation Schedule

Also, the report, "Guidelines for Choosing and Evaluating Payload Frequencies," produced under Contract NAS 9-15604A, was related to this effort.

1.3 Contents of the Final Report

There are five sections which address various aspects and details of the work.

Section 3.0 contains functional descriptions of the various Orbiter communication/avionic equipment and IUS communication equipment. Included in this section are the details of the IUS/Orbiter communication/avionic interface issues.

Section 4.0 addresses the IUS/Orbiter communication redundancy and illustrates the areas of single-point failures. The system performance of nonredundant failures is evaluated and possible "workarounds" are recommended.

In Section 5.0, the RF coverage of the IUS/Orbiter antennas is evaluated for a single and tandem IUS in the payload bay for IUS station-keeping and for an IUS at maximum range. Included in this section are the protection requirements for the IUS and Orbiter antennas at close proximity, the PI receiver sensitivity requirements versus range, and the PI RF power output requirements versus range.

The ESTL (Electronic System Test Laboratory) test requirements are presented in Section 6.0.

Finally, in Section 7.0, the link budgets for the IUS/PI/CIU communications are provided. From these link budgets, the PI receiver sensitivity and transmitter power output selections can be optimized versus range.

1.4 Principal Activities, Studies, Results and Assessments

The overall IUS/Orbiter communication system is still evolving. Direct payload-interfacing avionic subsystems such as the PI, PSP, and CIU are in their preliminary design stages only. Other hardware, such as the S-band network communications and the Ku-band communication equipment, is more fully developed but only the S-band network communication equipment is entering its performance verification testing phase. Thus, it will be sometime before all developmental problems are solved, and reliable, well-understood performance can be documented.

In order to present the interface compatibility issues, Figure 2 illustrates the IUS/Orbiter subsystems and interfaces. The interfaces of concern are those with the CIU by other Orbiter subsystems and those between the SGLS transponder or the STDN/TDRS transponder in the IUS with the PI when the IUS is deployed. The CIU interfaces with the following Orbiter avionic subsystems:

(1) Payload MDM
(2) GN&C MDM
(3) PI
(4) Ku-Band Signal Processor (KuSP)
(5) FM Signal Processor (FMSP)
(6) Payload Data Interleaver (PDI)
(7) Payload Recorder (PR).

Table 1 summarizes the major interface issues in which Axiomatix had been involved. The interface issues in Table 1 are addressed in terms of the nature of the issue and the effort expended by all concerned (TRW, Boeing, SAMSO, Aerospace, Rockwell, NASA and Axiomatix) toward its resolution. Specifically, Axiomatix proposed the interface between the KuSP 128 kbps data and the CIU requirement for 2 kbps command data. The design of the interface involved trading off the ease of implementation in the CIU and at the ground station versus bit error rate (BER). That is, the required BER must be met but not by so much that the implementation is unduly complicated. Axiomatix proposed the simple conversion of 64 Ku-band 128 kbps 1's equal to a 2 kbps "1" and 64 Ku-band 128 kbps 0's equal to a 2 kbps "0." The 1 ksps SGLS ternary command symbols are converted to binary 2 kbps, where an "S" is equal to '01,' a "1" is equal to '11' and a "0" is equal to '00.' In the CIU, the 64 symbols representing a "1" or "0" is sampled by a 2 kHz clock. The improvement in BER by combining the 64 symbols using majority decision or error correcting coding was unnecessary in order to meet the required BER. The binary symbols are converted by the CIU to the SGLS ternary symbols for transmission to the IUS.

Each interface between Orbiter avionic subsystems and the CIU and IUS transponders (SGLS and STDN/TDRS) are defined by a Payload Interface Control Document (ICD). Therefore, the Orbiter subsystem specification and the CIU or IUS transponder specification should agree with the Payload ICD. In order to investigate the compatibility between the interfaces,

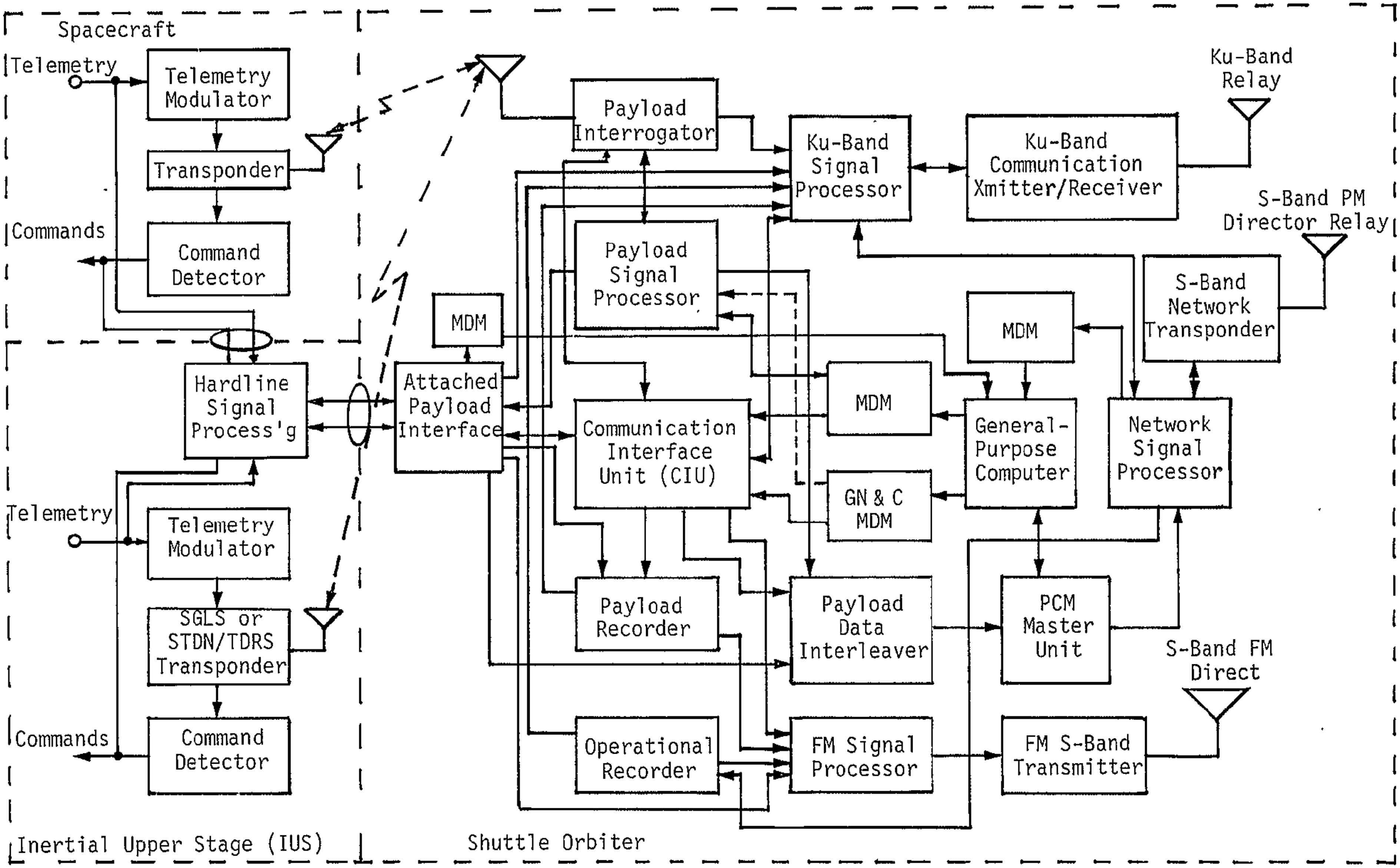


Figure 2. Inertial Upper Stage/Shuttle Orbiter Subsystems and Interfaces

Table 1. Major IUS/Orbiter Communication Interface Issues

Issue	Issue Nature	Effort Toward Resolution	Resolution
Ku-Band 128 kbps to 2 kbps command data	1. SGLS command data is 1 kbps with ternary symbols. 2. Ku-band forward link is binary data at 128 kbps.	Define format that meets the required BER and is easy to implement. (Axiomatix)	64 Ku-band 128 kbps 1's are equal to a 2 kbps "1" 64 Ku-band 128 kbps 0's are equal to a 2 kbps "0" 01 = "S" 1 ksps 11 = "1" 1 ksps 00 = "0" 1 ksps.
CIU/MDM Interface	1. CIU has only an MDM serial interface and does not have the required input/output interfaces to implement the required handshake procedure. 2. CIU buffer for the MDM command data is not large enough for a command and its complement to be held at the CIU in one MDM transfer. 2. Interface inconsistencies between CIU specification and payload ICD.	1. Axiomatix/NASA pointed out the MDM interface deficiency at a NASA/SAMSO meeting on 8/15/78. 2. RID-35 at CIU PDR. (Aerospace) 3. Tables 8 and 9 compare the PSP and CIU specifications with the Payload ICD.(Axiomatix)	1. Resolved by ground command input control or CIU control panel control by limitation on the command rate into the CIU and verification of accepted commands using the VCC word. 2. To be resolved by Boeing at CIU CDR. 3. Comparison must be made with performance data at CIU CDR.
Frequency Stability	SGLS and STDN/TDRS transponder auxiliary oscillator stability may cause a frequency uncertainty that is larger than PI receiver acquisition range.	1. Investigation of increasing the PI receiver acquisition sweep range.(TRW) 2. Analysis of aging & environmental changes to oscillator stability. (TRW)	In process. Need more data on oscillator stability for TRW

Table 1. Major IUS/Orbiter Communication Interface Issues (Cont'd)

Issue	Issue Nature	Effort Toward Resolution	Resolution
Phase Noise and Communications Turn-around Characteristics	1. Phase noise requirements of PI. 2. Phase noise requirements of SGLS & STDN/TDRS transponder. 3. Effects of turn-around phase noise.	1. PI phase noise characteristics need to be known. 2. SGLS transponder phase noise analysis as part of SGLS CDR Data Package shows that the performance is less than 3.5° rms except during vibration, where the phase noise is less than 11.5° rms. (TRW) 3. Analysis to predict performance has been developed, but needs phase noise characteristics. (Axiomatix)	Assessment awaits PI phase noise data. (TRW)
False Acquisition Susceptibility	1. PI receiver false lock avoidance with respect to SGLS and STDN modulations. 2. SGLS receiver false lock discrimination with respect to SGLS command modulation from the PI transmitter. 3. STDN/TDRS receiver false lock discrimination with respect to STDN command modulation from the PI transmitter.	1. Analysis of PI susceptibility to SGLS & STDN modulations, analysis of strong signal phase demodulation discriminator and survey of anti-false lock methods. (Axiomatix & TRW) 2. Analysis of discriminator-aided phase-lock loop and discriminator lock detector for SGLS command modulation from the PI transmitter. (TRW) 3. Analysis of discriminator lock detector for STDN command modulation from the PI transmitter. (TRW)	1. In process. Protection methods still under review. 2. In process. Discriminator may lock up to "S" tone during below threshold signal levels and remain locked at nominal signal levels. 3. In process. Discriminator may lock to data sidebands during reacquisition at strong signal levels.

Table 1. Major IUS/Orbiter Communication Interface Issues (Cont'd)

Issue	Issue Nature	Effort Toward Resolution	Resolution
PI Input Sensitivity Ranges	Exact requirement of Rockwell specification on three receiver sensitivity levels needs further definition.	1. Meet the requirement by using RF signal level limiting. (TRW) 2. Use manual signal level attenuators. (TRW/NASA)	Manual attenuator approach selected. Preamplifier overload diodes as alternate under investigation. (TRW)
PI Received Carrier Modulation Limits	1. Undetermined PI receiver performance for payload subcarrier modulation index larger than 1 radian. 2. Undetermined PI receiver performance with two or more payload subcarriers.	Complete parametric analysis of PI carrier and subcarrier levels as a function of modulation index and waveform types. (Axiomatix)	Results of analysis made known to TRW. (Axiomatix)
PI Interference Susceptibility	Rockwell specification that the PI receiver should work with an out-of-band interference signal as large as -25 dBm.	Analysis showed that, with the expected receiver first LO noise characteristics, only a -65 dBm interference signal level can be tolerated. (TRW and Axiomatix)	Specification amended to the -65 dBm signal level. (Rockwell)
CIU Interface with KuSP, PDI, FMSP	Interface inconsistencies between CIU specification and payload ICD.	1. Action Item for Boeing at CIU PDR. (Aerospace) 2. Tables 6, 7, 10, 11, 12 and 13 compare each Orbiter subsystem spec. with payload ICD and CIU specification. (Axiomatix)	To be resolved at CIU CDR.

Table 1. Major IUS/Orbiter Communication Interface Issues (Cont'd)

Issue	Issue Nature	Effort Toward Resolution	Resolution
CIU Interface with Payload Recorder	1. Interface inconsistencies between CIU specification and payload ICD. 2. TRW performance does not meet CIU specification.	1. Table 14 compares the payload ICD with the CIU specification. (Axiomatix) 2. RID-01 at CIU PDR. (Boeing)	To be resolved at CIU CDR.
PI Interface with SGLS Transponder	Interface inconsistencies between SGLS transponder specification and payload ICD.	Tables 2 and 3 compare the PI and SGLS transponder specifications with the payload ICD. (Axiomatix)	To be resolved in an interface meeting.
PI Interface with STDN/TDRS Transponder	Interface inconsistencies between STDN/TDRS transponder specification and payload ICD.	Tables 4 and 5 compare the PI and STDN/TDRS transponder specifications with the payload ICD. (Axiomatix)	To be resolved in an interface meeting.

each parameter involved in the interface, as defined by the Payload ICD, the CIU or IUS specification, or the Orbiter subsystem specification, is compared in Tables 2-14. It may be seen that the greatest interface inconsistencies between the interface parameter specifications exist where the parameter either is not defined by a specification or it is defined by a TBD or TBS. These interface inconsistencies need to be resolved and the parameters with TBD or TBS must be specified consistent with the Orbiter subsystem specification, the Payload ICD and the CIU or IUS transponder specification.

In order to resolve some of the interface parameter inconsistencies, some overall system analysis is required. For example, the phase noise specifications need to be defined for the link from the PI to the SGLS or STDN/TDRS transponder to determine the command channel BER. Both the phase noise generated by the frequency synthesizer in the PI transmitter and the oscillators used in the transponder affect the command channel BER and, therefore, system analysis must be made to allocate a phase noise specification for the PI and transponder. Similarly, the phase noise generated by the PI receiver frequency synthesizer, the oscillators used in the transponder transmitter and the turn-around characteristics of the transponder, affect the telemetry channel BER. Therefore, system analysis must be made to allocate a phase noise specification to the PI receiver, transponder oscillators and turn-around characteristics. Axiomatix has developed the analysis needed to predict the command channel BER based on phase noise characteristics; however, while some specifications have been made on the phase noise of the PI transmitter and receiver and on the phase noise of the transponder, the turn-around characteristics have not been specified and the actual phase noise performance of the PI transmitter and receiver frequency synthesizer has not been determined. Hence, final assessment of the command channel and telemetry channel BER performance awaits phase noise data from the PI frequency synthesizer.

Another area that received considerable attention in the interface compatibility analysis was the susceptibility of false lock by the PI and the IUS SGLS or STDN/TDRS transponder. It was found that certain modulation conditions could produce false states of in-lock with the TRW PI receiver conceptual design. Axiomatix determined that the problem was a

Table 2. PI Transmission to SGLS Transponder

Parameter	PI Specification	Payload ICD	SGLS Transponder Specification
Carrier Frequency Tolerance	<0.001%	±0.001%	Search ±100 kHz doppler shifted input signals
Carrier Phase Noise	4° rms (steady state) 10° rms (maximum)	10° rms, maximum	-
Output Spurs	At least [55 + 10 log (P_t)] dB below modulated carrier from 200 MHz to 16 GHz (P_t is transmitter power in watts)	<-65 dBc	-
Waveform	Sinusoidal with AM	Sinusoidal with AM	Sinusoidal with AM
Modulation	Ternary FSK	Ternary FSK	Ternary FSK
Symbol Frequencies	"S" = 65 kHz "0" = 76 kHz "1" = 95 kHz	"S" = 65 kHz "0" = 76 kHz "1" = 95 kHz	"S" = 65 kHz "0" = 76 kHz "1" = 95 kHz
Carrier Modulation Indices	0.96 ± 10% radians (determined by CIU interface)	0.3 ± 10% radians or 1.0 ± 10% radians	0.3 ± 20% radians or 1.0 ± 10% radians
Symbol Rates	1000 sps or 2000 sps	1000 sps or 2000 sps	1000 sps
AM	0.5 ± 10% AM by a triangular function equal to 500 Hz (for 1000 sps) or 1000 Hz (for 2000 sps)	0.5 ± 10% AM by a triangular function equal to one-half the command symbol rate	0.5 ± 10% AM by a triangular function of 500 Hz

Table 3. PI Reception from SGLS Transponder

Parameter	PI Specification	Payload ICD	SGLS Transponder Spec
Input Signal Range	-124 to +3 dBm	-124 to +25 dBm	N/A
False Lock	Shall not false lock	Shall not false lock below -20 dBm	Shall not false lock
Spurious Output	26 dBc	32 dBc	40 dBc
Rec. Freq. Sweep	±80 kHz	±85 kHz at minimum of 10 kHz/sec	±67 kHz due to auxiliary oscillator
Aux. Osc. Stability	0.001%	±0.001%	±29 ppm
Phase Noise	<15° rms	Additive noise < 10° rms Oscillator < 5° rms Mod. Track'g < 10° rms	< 3.5° rms <11.5° rms with vibration
Static Phase Error	±3° maximum	Frequency offset 3° Frequency Dynamics 12°	1.5° per 30 kHz frequency offset
PSK Subcarriers	Sinewave subcarrier PSK modulated (±90°) by PCM data 1.024 MHz	Sinewave subcarrier PSK modulated (±90°) by PCM data 1.024 and 1.7 MHz	Sinewave subcarrier PSK modulated (±90°) by PCM data w/at least 30 dB subcarrier suppression (1.024 and 1.7 MHz)
FM Subcarrier (1.7 MHz)	FM/FM	Max. deviation ±TBS Hz peak w/highpass rolloff of TBS db/octave & lowpass rolloff of TBS db/octave beyond 200 kHz	Max. deviation ±200 kHz peak-to-peak (minimum) Modulation bandwidths 20 Hz to 200 kHz with a rolloff of 12 dB/octave
Subcarrier Harm. Comp.	-	TBS% of fundamental frequency amplitude	-
Subcarrier Freq. Stab.	-	0.01% for PSK TBS% for FM	±50 Hz for PSK 0.1% for FM
Modulation Indices	0.3 + 0.1 radians, peak 0.3 - 0.0 radians, peak 1.0 ± 0.1 radians, peak	0.3 ± 10% radians, peak 1.0 ± 10% radians, peak	0.3 to 2.0 radians Factory set with ± 15% variation (perform ± 8%)
Data Rates	64,32,16,10,8,4,2,1, 0.5,0.25 kbps on 1.024 & 1.7 MHz subcarriers	64,32,16,10,8,4,2,1, 0.5,0.25 kbps on 1.024 & 1.7 MHz subcarriers 256 and 128 kbps on 1.7 MHz subcarrier	$\leq$128 kbps (1.024 MHz) $\leq$256 kbps (1.7 MHz) (See CIU specification)
Data Type	Biphase-L or NRZ-L	Biphase-L or NRZ-L	Biphase-L
Data Asym.	-	TBS	-
Bit Rate Stability	-	0.1% of nominal bit rate	(CIU requires 0.001%)

Table 4. PI Transmission to STDN/TDRS Transponder

Parameter	PI Specification	Payload ICD	STDN/TDRS Transponder Specification
Carrier Frequency Sweep	±75 ± 5 kHz ±55 ± 5 kHz at 10 ± 3 kHz/sec ±33 ± 3 kHz at 540 ± 60 Hz/sec	±75 ± 5 kHz ±55 ± 5 kHz at 10 ± 3 kHz/sec ±33 ± 3 kHz at TBS ± TBS Hz/sec	±100 kHz at 35 kHz/sec (unmodulated carrier)
Spurious Output	At least [55 + 10 log (P_t)]dB below unmodulated carrier from 200 MHz to 16 GHz (P_t is transmitter power in watts)	<-65 dBc	-
Carrier Phase Noise	4° rms (steady state) 10° rms (maximum)	10° rms, maximum	-
Waveform	Sinusoidal	Sinusoidal	Sinusoidal
Modulation	PSK	PSK (±90°)	PSK
Subcarrier Frequency	16 kHz	16 kHz	16 kHz
Subcarrier Harmonic Distortion	<1% of fundamental frequency amplitude (PSP Spec.)	<1% of fundamental frequency amplitude	-
Subcarrier Frequency Stability	$<10^{-5}$ of subcarrier frequency over a 60-second period (PSP Spec.)	$\pm 1 \times 10^{-5}$ of nominal subcarrier frequency averaged over 60 sec.	-
Modulation Index	1.0 ±.0.1 radian	1.0 ± 0.1 radian, peak	1.0 ± 10% radian
Data Type	Biphase-L or NRZ-L	NRZ-L, M, S	NRZ-L
Data Asymmetry	<2% of nominal bit period	<2% of nominal bit period	-
Data Bit Jitter	-	<3% of data bit period	-

Table 5. PI Reception from IUS STDN/TDRS Transponder

Parameter	PI Specification	Payload ICD	STDN/TDRS Transponder Specification
Input Signal Range	-124 to +3 dBm	-124 to +25 dBm	N/A
False Lock	Shall not false lock	Shall not false lock below -20 dBm	PI shall not false lock; STDN/TDRS transponder shall not false lock with input signal levels up to -40 dBm
Spurious Output	26 dBc	32 dBc	40 dBc
PI Transmitter Sweep	±75 ± 5 kHz ±55 ± 5 kHz at 10 ± 3 kHz/sec ±33 ± 3 kHz at 540 ± 60 Hz/sec	±75 ± 5 kHz ±55 ± 5 kHz at 10 ± 3 kHz/sec ±33 ± 3 kHz at at TBS ± TBS Hz/sec	±100 kHz at 35 kHz/second (unmodulated carrier)
PI Receiver Sweep	±80 kHz (minimum)	±85 kHz at 10 kHz/sec	±67 kHz due to auxiliary oscillator
Aux. Osc. Stability	0.001%	±0.001%	29 ppm
Phase Noise	<15° rms	Additive noise < 10° rms Oscillator < 5° rms Mod. Track'g < 10° rms	<3.5° rms <11.5° rms with vibration
Static Phase Error	±3° maximum (PI)	Frequency offset < 3° Frequency dynamics < 12° (PI)	1.5° per 30 kHz offset
PSK Subcarriers	Sinewave subcarriers PSK modulated (±90°) by PCM data 1.024 MHz	Sinewave subcarriers PSK modulated (±90°) by PCM data 1.024 and 1.7 MHz	Sinewave subcarriers PSK modulated (±90°) by PCM data with at least 30 dB subcarrier suppression 1.024 and 1.7 MHz
FM Subcarriers	FM/FM modulated by PCM data 1.7 MHz	1.7 MHz-max. deviation ±TBS Hz peak with high-pass rolloff of TBS dB/octave at 100 Hz and lowpass rolloff of TBS dB/octave beginning at 200 kHz	1.7 MHz max. deviation ±200 kHz peak-to-peak Modulation bandwidths 20 Hz to 200 kHz with a rolloff of 12 dB/octave
Subcarrier Harm. Comp.	-	TBS% of fundamental frequency amplitude	-
Subcarrier Frequency	-	0.01% for PSK TBS% for FM	50 Hz for PSK 0.1% for FM

Table 5. PI Reception from IUS STDN/TDRS Transponder (Cont'd)

Parameter	PI Specification	Payload ICD	STDN/TDRS Transponder Specification
Modulation Indices	0.3 + 0.1 radians, peak 0.3 - 0.0 radians, peak 1.0 ± 0.1 radians, peak	0.3 ± 10% radians 1.0 ± 10% radians	0.3 to 2.0 radians (PSK) 0 to TBD kHz (FM) ±15% variation (TRW performance ±8%)
Data Rates	64,32,16,10,8,4,2,1, 0.5, 0.25 kbps on 1.024 and 1.7 MHz subcarriers	64,32,16,10,8,4,2,1, 0.5, 0.25 kbps on 1.024 and 1.7 MHz sub-carriers; 256, 128 kbps on 1.7 MHz subcarrier	≤128 kbps (1.024 MHz) ≤256 kbps (1.7 MHz)
Data Type	Biphase-L or NRZ-L	Biphase-L or NRZ-L	Biphase-L
Data Asym.	-	TBS	-
Trans. Density	-	TBS	N/A
Bit Rate Stability	-	0.1% of nominal bit rate	(CIU requires 0.001%)

Table 6. CIU Output to Payload Interrogator (PI)

Parameter	PI Specification	Payload ICD	CIU Specification
Data Rate	1 K-baud or 2 K-baud	-	1 K-baud ± 0.01%
Waveform	FSK 65, 76 or 95 kHz sinewave subcarriers with amplitude envelope modulation of 500 Hz (1 K-baud) or 1000 Hz (2 K-baud)	FSK 65, 76 or 95 kHz amplitude modulated by 1 kHz or 2 kHz triangular wave	FSK 65, 76 or 95 kHz sinewave subcarriers with triangular AM at 50% modulation at 500 Hz ± 0.1%
Modulation	Ternary FSK/AM of β = 0.2-2.5 radians Logical "1" 95 kHz Logical "0" 76 kHz Logical "S" 65 kHz	Ternary FSK/AM of β = 0.2-2.5 radians Logical "1" 95 kHz Logical "0" 76 kHz Logical "S" 65 kHz	Ternary FSK/AM - Logical "1" 95 kHz ± 0.01% Logical "0" 76 kHz ± 0.01% Logical "S" 65 kHz ± 0.01%
Signal Level	1.0 to 8.0V ± 10% p-p, line-to-line for 0.2 to 2.5 radians	-	3.3V ± 10% p-p, line-to-line
Phase Linearity	-	$\leq$8% from β = 0.2 to 2.5 radians	-
Load Impedance	75 ± 5 ohms	-	75 ± 5 ohms
Signal Type	Differential, direct coupled		Differential, direct coupled

Table 7. Payload Interrogator Input to CIU

Parameter	PI Specification	Payload ICD	CIU Specification
Subcarrier Frequencies	1.024 MHz and/or 1.7 MHz	1.024 MHz or 1.7 MHz	1.024 MHz ± TBD and/or 1.7 MHz ± TBD
Data Rates	64, 32, 16, 10, 8, 4, 2, 1 kbps; 500 and 250 bps	256, 64, 32, 16, 10, 8, 4, 2, 1, 0.5 and 0.25 kbps	16 kbps (PSK) 16, 24 and 32 kbps (FM/FM)
Modulation	1.024 MHz subcarrier PSK modulated by PCM data, 1.7 MHz subcarrier frequency modulated (FM/FM) or PSK modulated by PCM data	PSK	1.024 MHz subcarrier PSK modulated by PCM data, 1.7 MHz subcarrier FM/FM by PCM data
Data Waveform	Manchester II Biphase-L or NRZ-L	Biphase-L NRZ-L	Biphase-L
Signal Level	2.0V rms ± 0.4V line-to line with 6V p-p max	-	2.0V rms ± 0.4V line-to-line
Bandwidth	4.5 MHz (3 dB points)	-	-
Equivalent Source Modulation	0.3 to 2.5 radians	0.3 to 2.5 radians	-
Signal Type	Differential-AC coupled (1000 Hz minimum)	-	Differential
Load Impedance	75 ± 5 ohms	-	75 ± 5 ohms
Subcarrier Stability	-	0.01%	<1 part in 10^5 for any 12-hour period
Data Rate Stability	-	0.1%	0.001%
Common Mode Rejection	-		>40 dB (0-2 MHz)

Table 7. Payload Interrogator Input to CTU

Parameter	PI Specification	Payload ICD	CTU Specification
Subcarrier Frequencies	1.024 MHz and/or 1.7 MHz	1.024 MHz or 1.7 MHz	1.024 MHz ± TBD and/or 1.7 MHz ± TBD
Data Rates	64, 32, 16, 8, 4, 2, 1 Kbps; 500 and 250 bps	256, 64, 32, 16, 10, 8, 4, 2, 1, 0.5 and 0.25 kbps	16 kbps (PSK) 16, 24 and 32 kbps (FM/FM)
Modulation	1.024 MHz subcarrier PSK modulated by PCM data, 1.7 MHz subcarrier frequency modulated (FM/FM) or PSK modulated by PCM data	PSK	1.024 MHz subcarrier PSK modulated by PCM data, 1.7 MHz subcarrier FM/FM by PCM data
Data Waveform	Manchester II Biphase-L or NRZ-L	Biphase-L NRZ-L	Biphase-L
Signal Level	2.0V rms ± 0.4V line-to line with 6V p-p max	-	2.0V rms ± 0.4V line-to-line
Bandwidth	4.5 MHz (3 db points)	-	-
Equivalent Source Modulation	0.5 to 2.5 radians	0.2 to 2.5 radians	-
Signal Type	Differential-AC coupled (1500 Hz minimum)	-	Differential
Load Impedance	75 ± 5 ohms	-	75 ± 5 ohms
Subcarrier Stability	-	0.01%	<1 part in 10^5 for any 12-hour period
Data Rate Stability	-	0.1%	0.001%
Common Mode Rejection	-		>40 dB (0-2 MHz)

Table 8. MDM Discretes Input to CIU

Parameter	PSP Specification	Payload ICD	CIU Specification
Receiver Type	Differential, direct coupled	Differential, direct coupled	Differential, direct coupled
Threshold	0 ± 0.5V (line-to-line)	0 ± 0.5V (line-to-line)	0 ± 0.5V (line-to-line
High State:			
Line-to-ground	2.0 to 5.9V peak	2.1 to 5.9V peak	-
Line-to-line	2.0 to 5.9V peak	2.1 to 5.9V peak	2.0 to 5.9V peak
Low State:			
Line-to-ground	-0.6 to +0.6 peak	-0.6 to +0.6V peak	
Line-to-line	-2.0 to -5.9V peak	-2.1 to -5.9V peak	-2.0 to -5.9V peak
"True" State (Logic "1")	Signal line "high with respect to return line	Signal line "high" with respect to return line	Signal line "high" with respect to return line
"False" State (Logic "0")	Signal line "low" with respect to return line	Signal line "low" with respect to return line	Signal line "low" with respect to return line
Open Circuit	Interpret as Logical "0"	Interpret as non-ambiguous state	Interpret as Logical "0"
Source Impedance (Orbiter)			
Line-to-line	100 ohms, maximum	100 ohms, maximum	100 ohms, maximum
Line-to-ground	100 ohms, maximum	100 ohms, maximum	-
Input Impedance (CIU) Line-to-line	75 ohms ± 5% in series with 3.3 pf ± 10%	90 ohms ± 5% in series with 10.0 pf ± 10%	100 ohms ± 5% in series with 10.0 pf ± 10%
Rise and Fall Times	10-200 ns 10% voltage to +2.0V (rise) or -2.0V (fall) 100-1000 ns, 10-90% voltage levels	10-200 ns, 10% voltage to +2.1V (rise) or -2.1V (fall) 100-1000 ns, 10-90% voltage levels	-
Overshoot/ Undershoot	0.25V peak, maximum	0.25V peak, maximum	0.25V peak, maximum
Common Mode Rejection	Signals from DC to 2 MHz w/amplitude up to ±10V peak applied to both signal terminals shall not activate receiver circuits	Signals from DC to 2 MHz w/amplitude up to ±10V peak applied to both signal terminals shall not activate receiver circuits	Signals from DC to 2 MHz w/amplitude up to ±10V peak applied to both signal terminals shall not activate receiver circuits
Voltage Damage	±32V either input	±32V either input via 320 ohms	±32V either input
Fault Voltage Emission	-	+8V maximum	-
Fault Current Limitation	-	40 ma	-

Table 9. MDM Serial Digital Data Input to CIU

Parameter	PSP Specification	Payload ICD	CIU Specification
Receiver Type	Transformer coupled, balanced	Transformer coupled, balanced	Transformer coupled, balanced
Waveform	Manchester II Biphase-L (MIL-STD-442)	Manchester II Bi-phase-L (MIL-STD-442)	Biphase-L in accordance with MIL-STD-1572
Data Rate	1 Mbps	1 Mbps ± 0.1%	1 Mbps ± 10%
Data Threshold			
Positive	+0.5 ± 0.1V peak line-to-line	+0.5 ± 0.1V peak line-to-line	+0.5 ± 0.1V peak, line-to-line
Negative	-0.5 ± 0.1V peak line-to-line	-0.5 ± 0.1V peak line-to-line	-0.5 ± 0.1V peak line-to-line
Logic Level "One"	+1.5V to +8V peak line-to-line	+1.5V to 8.0 peak line-to-line	+1.5V to +8V peak line-to-line
Logic Level "Zero"	-1.5V ± 8% to -8V ±8% peak line-to-line	-1.5V to -8.0 peak line-to-line	-1.5V to -8V peak line-to-line
Pulse Width Variation Plus Jitter	±125 ns maximum	40 ns (Jitter)	±125 ns maximum
Bit Error Rate	-	1.9×10^{-7}	10^{-7} for 14 dB peak SNR
Rise and Fall Time	60-150 ns measured between 10-90% of voltage levels	60-250 ns measured between 10-90% of voltage levels	40-300 ns measured between 10-90% of voltage levels
Distortion (overshoot, ringing)	250 mV maximum, peak	±250 mV maximum	300 mV maximum, peak
Input Impedance	75 ohms ± 10%	75 ohms ± 10%	75 ohms ± 10%
Isolation Resistance (line-to-ground)	100 K ohms, minimum	-	100 K ohms, minimum
Common Mode Rejection	Signals from DC to 2 MHz with amplitude to ±32V peak, line-to-ground applied on both input signal terminals, shall not activate receiver circuit	Signals from DC to 2 MHz w/amplitude to ±32V peak, line-to-ground applied on both input signal terminals, shall not activate receiver circuit	Signals from DC to 2 MHz w/amplitude to ±32V peak, line-to-ground applied on both input signal terminals, shall not activate receiver circuit
Common Mode Voltage Damage Threshold	Greater than ±50V peak	±50V peak	Greater than ±50V peak

Table 10. Ku-Band Signal Processor Input to CIU

Parameter	Ku-Band Specification	Payload ICD	CIU Spec.
Data Rate	128 kbps	128 kbps	128 kbps
Waveform:			
Data	NRZ-L	NRZ-L	NRZ-L
Clock	Square wave	Square wave	-
Signal Amplitude	High state:		TBD
	signal line to signal ground		
	3.5V maximum	3.0V maximum	
	2.0V minimum	2.0V minimum	
	signal return to sig. ground		
	0.5V maximum	0.5V maximum	
	0.0V minimum	0.0V minimum	
	Low state:		
	signal line to signal ground		
	0.5V maximum	0.5V maximum	
	0.0V minimum	0.0V minimum	
	signal return to sig. ground		
	3.5V maximum	3.0V maximum	
	2.0V minimum	2.0V minimum	
Rise and Fall Times	<2.5% of bit period measured at 10-90% points (195 ns)	<2.5% of bit period* measured at 10-90% points (195 ns)	
Source and Load Coupling	Balanced differential, direct coupled	Balanced differential, direct coupled	Differential, direct coupled
Load Impedance	75 ± 5 ohms	75 ± 5 ohms	TBD
Cable	75 ± 5 ohms, TSP	75 ± 5 ohms, TSP	TBD
Data Stability	<0.01% of bit rate	-	-
Clock Skew	<150 ns	15% clock per. max.	-
Clock Duty Cycle	50.0 ± 5% of bit period	50.0 ± 5% of bit period*	-
Frequency Jitter	±0.1% of data rate at 0.1% rms of the data rate	0.1% of bit period	-
Clock Phase Jitter	±2% rms of bit period	10% of bit period	-
Data/Clock Asymmetry	10% of bit period, maximum	TBD	-
Common Mode Voltage	-	-	TBD
Common Mode Damage Threshold	-	-	TBD

*ICD 2-19001, 10/10/77, Rise and Fall Times 40 ns and Clock Duty Cycle 50 ± 15% of bit period.

Table 11. CIU Output to Ku-Band Signal Processor

Parameter	Ku-Band Specification	Payload ICD	CIU Specification
Data Rate and Signal Coding	16 kbps to 2 Mbps NRZ-L, M, S 16-1024 kbps Biphase-L, M, S	16 kbps to 2 Mbps NRZ-L, M, S 16-1024 kbps Biphase-L, M, S	16, 64, 256 kbps Biphase-L
Signal Level	1.8 to 5.0V p-p line-to-line	1.8 to 5.0V p-p line-to-line	TBD volts p-p* line-to-line
Load Impedance	75 ± 5 ohms	75 ± 5 ohms	75 ± 10% ohms*
Cable Type	75 ± 5 ohms, TPS	75 ± 5 ohms, TPS	-
Signal Type	Balanced differential, direct coupled	Balanced differential, direct coupled	Differential, direct coupled
RMS SNR	35 dB minimum	35 dB minimum	-
Rise and Fall Times	5% or 50 ns between 10-90% points, whichever is less	5% or 50 ns between 10-90% points, whichever is less (ICD 2-19001, 10/10/77, requires 10 ns maximum)	TBD
Frequency Jitter	±0.1% rms of the data rate at 0.1% rms of the data rate	±0.1% rms of the data rate at 0.1% rms of the the data rate	-
Data Asymmetry (TDRS User Constraint)	-	±10%	±10%
Data Stability	0.01% long term	<0.01% long term	-
Bit Jitter	-	±2% of bit period	-
Common Mode Voltage	±10V DC to 10 kHz decrease 10 dB per decade to 100kHz and 10 dB per octave above 100 kHz	-	-

*Previously, signal level was 6 ± 3V p-p line-to-line, load impedance was 90 ± 10% ohms, and rise and fall times were 1 μsec.

Table 12. CIU Output to FM Signal Processor

Parameter	FM Signal Processor Specification	Payload ICD	CIU Specification
Data Rate	250 bps to 256 kbps	250 bps to 256 kbps	16, 64, 256 kbps
Signal Coding	Manchester II, Biphase-L or NRZ-L	Biphase-L or NRZ-L	Biphase-L
Signal Level	1.0 ± 0.6V p-p line-to-line	1.0 ± 0.6V p-p line-to-line	1.0 ± 0.6V p-p
Logic "1"	(Removed from spec)	+1.1V ± 0.5V p-p line-to-line	-
Logic "0"	(Removed from spec)	-0.3V to +0.4V p-p, line-to-line	
Rise and Fall Times	Less than 100 ns	Less than 100 ns	Less than 100 ns
Signal Type	Balanced differential	Balanced diffferential	Differential, direct coupled
Common Mode Rejection	Signals from DC to 2 MHz up to 1V peak line-to-ground shall not degrade output SNR to less than 45 dB	Signals from DC to 2 MHz up to 1V peak line-to-ground shall not degrade output SNR to less than 45 dB	-
Source Impedance	75 ohms ± 10%	75 ohms ± 10%	TBD
Load Impedance	75 ohms ± 10%	75 ohms ± 10%	75 ohms ± 10%

Table 13. CIU Output to Payload Data Interleaver

Parameter	PDI Specification	Payload ICD	CIU Specification
Bit Rate	10 bps to 64 kbps	10 bps to 64 kbps	16, 64 kbps
Input Signal Code	NRZ-L, M, S Biphase-L, M, S	NRZ-L, M, S Biphase-L, M, S	NRZ-L
Logic	Positive	-	-
Bit Rate Accuracy	±6%	$\leq$2%	-
Bit Rate Stability	1 part in 10^5 60-sec period	1 part in 10^6 60-sec period	-
Signal Type	Balanced differential	Balanced differential	Differential, direct coupled
Amplitude	2-12V p-p	2-12V p-p	6 ± 3V p-p line-line
Rise and Fall Time	10% between 10 and 90% points	5μ sec or 10% of bit, whichever is less, 100 ns min.	TBD
Signal Waveform Distortion	Overshoot and undershoot less than 20% of peak	Overshoot and undershoot less than 20% of signal	-
Clock Skew	±5% of clock period or 10 ms, whichever is less	±5% of clock period or 10 ms, whichever is less	±5% of clock period or 10 ms, whichever is less
Clock Duty Cycle	50.0 ± 5%	50 ± 5%	Square wave
Noise Immunity	100 mV p-p line-to-line DC-100 kHz	100 mV p-p line-to-line	-
Load Impedance	75 ± 7 ohms	75 ± 7 ohms	75 ± 7 ohms
Cable Impedance		75 ± 7 ohms	75 ± 5 ohms, TSP
Source Impedance		75 ± 7 ohms	TBD

Table 14. CIU Output to Payload Recorder

Parameter	Payload ICD	CIU Specification
Analog:		
Input Signal	1V rms ± 6 dB	1V rms ± 6 dB*
Signal Type	-	Differential
Source Impedance (CIU)	71 ± 10%	-
Load Impedance (Recorder)	71 ± 5%	71 ± 7 ohms
Cable Impedance	75 ± 5 ohms, TSP	75 ± 5 ohms, TSP
Frequency	1.9 kHz to 1.6 MHz	10 kHz to 100 kHz
Signal/Noise	39 dB over any 3 kHz slot	-
Common Mode Rejection	±15V (reference to signal ground)	±15V max (reference to signal ground)
Digital:		
Data Rates	25.5 kbps to 1.024 Mbps	256 kbps, 64 kbps
Signal Code	Biphase-L	Biphase-L
Bit Jitter	2% of bit duration (p-p)	-
Rise and Fall Times	±10% of bit duration	390 ns, maximum
Input Signal	3-9V p-p	6 ± 2V p-p line-to-line
Signal Type	Differential	Differential, direct coupled
Load Impedance	71 ± 10% ohms	71 ± 10% ohms
Cable Impedance	75 ± 5 ohms, TSP	75 ± 5 ohms, TSP
Source Impedance	71 ± 10% ohms	TBD
Common Mode Rejection	±15V (reference to signal ground)	-

*TRW performance: 1V rms + 2.9 dB
1V rms - 6.56 dB

function of lack of receiver out-of-lock IFA gain control and the setting of the lock detector threshold voltage according to a minimum operating point some 6 dB below that required by the Rockwell specification. Axiomatix therefore recommended use of a noncoherent receiver AGC during periods prior to acquisition. This recommendation was acted upon by TRW to the effect that false states of in-lock have been eliminated below a received signal of -20 dBm. The IUS SGLS transponder uses a frequency discriminator to detect false states of in-lock. For received signal levels above -117 dB, the frequency discriminator will not allow lock for a frequency larger than the phase lock loop (PLL) bandwidth, however, for received signal levels below -117 dB, the frequency discriminator does not have a large enough signal-to-noise ratio to guarantee that a noise spike could not stop the frequency sweep in the vicinity of one of the SGLS command tones (most likely, the "S" 65 kHz tone). If the frequency sweep stops in the vicinity of a command tone, the PLL will lock to the nearest command tone. If the command tone that PLL locks to is the "S" tone, the PLL could be false locked for long periods because the "S" tone is used for command preambles and postambles. While the SGLS receiver is not required to acquire below -117 dBm, signal levels below -117 dBm could occur during IUS maneuvers and antenna switching. In this case, the receiver might false lock at signal levels below -117 dBm and stay false locked as the signal level increased above -117 dBm. TRW and Boeing are still working to resolve this false lock problem.

The IUS STDN/TDRS transponder uses the same frequency discriminator as the IUS SGLS transponder but, in the case of the STDN transponder, the frequency discriminator must avoid false lock by the PLL to the 16 kHz subcarrier used to modulate the command data. The false lock performance analysis for the STDN/TDRS transponder has not been completed by TRW and, therefore, the overall system performance assessment must wait until this analysis has been completed.

A final area of concern in the interface between the PI and the IUS SGLS or STDN/TDRS transponder is the frequency stability of the auxiliary oscillator. The concern is that the frequency uncertainty due to the frequency stabilty of the auxiliary oscillator will be larger than the frequency acquisition range of the PI. To resolve this area of concern, TRW is analyzing the aging and environmental changes to the auxiliary oscillator. Also, Rockwell has requested TRW to investigate the possibility of increasing the PI receiver frequency sweep range. The initial results from TRW, however, indicate that increasing the sweep range of the PI also increases the uncertainty of the actual frequencies in the sweep and, thus, compounds the frequency uncertainty problem. Therefore, increasing the PI sweep range does not seem to resolve the problem.

Another approach to successively increasing the sweep range is by designating an adjacent channel as the nominal frequency for the next frequency sweep if acquisition is not obtained by frequency sweeping around the expected nominal frequency. While this technique might be an operational workaround; it is not a desirable approach to resolution of the frequency stability problem. Before an overall system performance assessment can be made, more data on the auxiliary oscillator stability is needed from TRW.

2.0 INTRODUCTION

2.1 Statement of Work

2.1.1 Objectives

The overall objectives of the effort have been to evaluate the Inertial Upper Stage (IUS) and DOD Communication Interface Unit (CIU) communication system design, hardware specifications, and interfaces t(determine their compatibility with the Orbiter payload communication ar data handling equipment and the Orbiter network communication equipmen1

The IUS is being developed by the DOD for joint DOD/NASA use. Two Orbiter/IUS communication configurations will be used for the DOD ε NASA IUS missions. Operational constraints, however, may require the ι of a DOD IUS for NASA payload missions such as the Tracking and Data Relay Satellite (TDRS) launch. The DOD and NASA IUS communications ha1 ware will be tested for performance verification and interface compatil ity with the Orbiter avionic subsystems in the Electronic Systems Test Laboratory (ESTL) and the Shuttle Avionics Integration Laboratory (SAIL

2.1.2 Stipulated Tasks

The contract statement of work calls out the following tasks:

"Task #1 - IUS/Orbiter Communications Interface Definition. The contractor shall review all IUS/Orbiter interface documentation such as hardware specifications and preliminary Interface Control Documents (ICD) to assess the compatibility of the IUS and Orbiter communications systems. This task shall result in a complete discussion of the interface characteristics including block diagrams. All areas of incompatibility shall be clearly defined and analyzed in terms of their effects on the IUS or Orbiter communications system performance. Proposed solutions to incompatibilities to optimize overall performance shall also be provided."

"Task #2 - Redundancy Evaluation. The degree of redundancy varies throughout the Orbiter and IUS communications systems. The contractor shall analyze the functional paths through the Orbiter and the IUS communications systems and determine the impacts of failures in nonredundant functions. Failure 'workarounds' shall be suggested whenever applicable."

"Task #3 - IUS RF Coverage. The Orbiter must establish RF communications with the IUS when the IUS is in the payload bay and maintain communications out to the maximum range of the combined systems. The contractor shall perform an analysis of the IUS and Orbiter payload communication systems (both DOD and NASA configurations) to determine if there are regions of RF blockage for single and tandem IUS's in the payload bay. A strong signal analysis shall be made for those instances where the IUS and Orbiter antennas are very close together to determine if any damage can be realized in either the Orbiter or IUS communications equipment or whether either receiver will saturate. An analysis shall also be performed to determine the required payload interrogator receiver sensitivity (high, medium, or low) versus range and the payload interrogator RF power output (high, medium, or low) versus range for DOD and NASA IUS communication configurations."

"Task #4 - ESTL Test Requirements. The contractor shall develop a complete set of test requirements for the ISU (DOD and NASA) communications equipment when it arrives at the ESTL for compatibility testing. The test requirements shall define all communication links, modes, and parameters to be tested. Any special test equipment shall be identified."

"Task #5 - Link Budgets for IUS/PI/CIU Communication Links. The contractor shall provide link budgets with a technical back-up description for the IUS/PI/CIU communication links. These link budgets shall cover all modes of operation from RF communications in the payload bay out to maximum range. Both the variable receiver sensitivity and the variable RF output power of the PI shall be reflected in the link budgets."

During the contract period (March 1978 through June 1979), the IUS, CIU, and Orbiter communication equipment concepts and implementations developed significantly. Therefore, the majority of the effort was directed toward Task #1 and the results of this task represent the majority of this Final Report. Task #5 was added the last month of the contract. While Task #5 was not originally in the contract, the results obtained under this task will greatly expedite the development of operational scenarios for the IUS and Orbiter.

2.1.3 General Approach to the Activity

Development of the IUS, CIU and Orbiter payload communication equipment was a new activity beginning in CY78. The general approach has been to work with the cognizant NASA personnel, USAF SAMSO personnel, Aerospace Corporation personnel, and individuals at the IUS prime contractor (Boeing Aerospace Company), the Orbiter prime contractor (Rockwell Int'l) and the IUS, CIU and Orbiter payload communication equipment subcontractor (TRW Defense and Space Group) to ascertain directions taken.

A vital part of this activity has involved Axiomatix attendance and participation in design reviews (conceptual, preliminary and critical) as well as special interface meetings. These latter gatherings usually involved detailed discussions of interface issues between the IUS and Orbiter communication systems that surfaced at the design reviews. During the performance of the FY78 effort, Axiomatix provided technical support to the CIU Conceptual Design Review, the IUS SGLS Transponder Preliminary Design Review (PDR), the CIU PDR, and the IUS SGLS Critical Design Review (CDR), as shown in Figure 3. Also shown in Figure 3 is a schedule for future design reviews that Axiomatix plans to support.

2.1.4 Relationship to Parallel Work

The work performed under the subject contract was strongly interrelated to parallel efforts. Contract NAS 9-15514A, "Shuttle Orbiter S-band Communication Equipment Design Evaluation," provided support to critique the design and assess the performance of the individual NASA Orbiter S-band communication equipment (excluding the DOD CIU). Contract NAS 9-15240D, "Shuttle Payload S-Band Communications Study," forms the system framework which ties together the various payload-related equipment (excluding the IUS and CIU). Under Contract NAS 9-15604B, a handbook, "Users' Handbook for Payload-Shuttle Data Communication," was provided. Also, the report, "Guidelines for Choosing and Evaluating Payload Frequencies," produced under Contract NAS 9-15604A, was related to this effort.

2.2 Contents of the Final Report

There are five sections which address various aspects and details of the work.

Section 3.0 contains functional descriptions of the various Orbiter communication/avionic equipment and IUS communication equipment. Included in this section are the details of the IUS/Orbiter communication/avionic interface issues.

Section 4.0 addresses the IUS/Orbiter communication redundancy and illustrates the areas of single-point failures. The system performance of nonredundant failures is evaluated and possible "workarounds" are recommended.

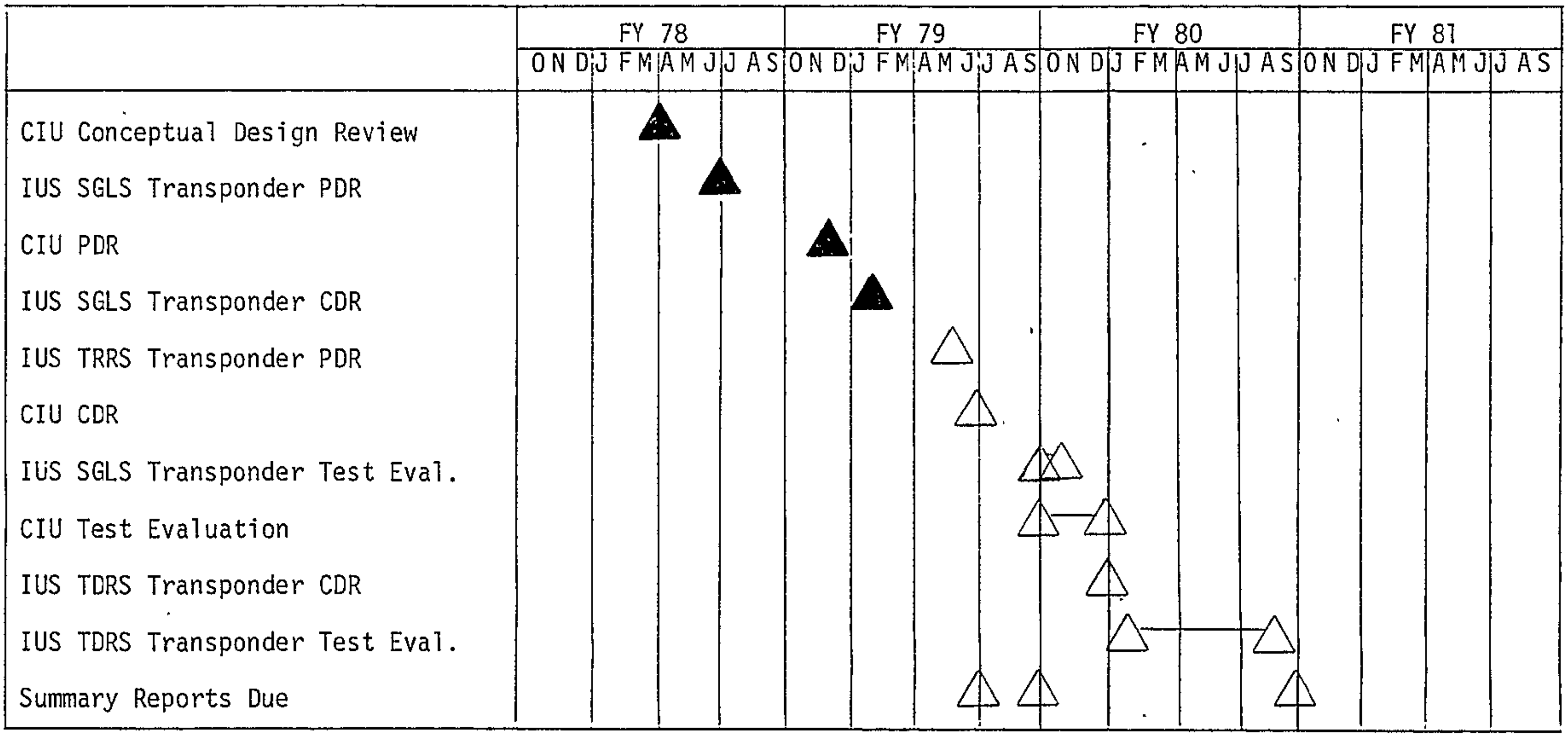


Figure 3. Orbiter/IUS Communication Interface Evaluation Schedule

In Section 5.0, the RF coverage of the IUS/Orbiter antennas is evaluated for a single and tandem IUS in the payload bay for IUS station-keeping and for an IUS at maximum range. Included in this section are the protection requirements for the IUS and Orbiter antennas at close proximity, the PI receiver sensitivity requirements versus range, and the PI RF power output requirements versus range.

The ESTL (Electronic System Test Laboratory) test requirements are presented in Section 6.0.

Finally, in Section 7.0, the link budgets for the IUS/PI/CIU communications are provided. From these link budgets, the PI receiver sensitivity and transmitter power output selections can be optimized versus range.

3.0 IUS/ORBITER COMMUNICATION INTERFACE DEFINITION

The Orbiter avionics equipment serving the IUS in the attached and detached modes perform two major functions. First, there are avionic equipment that perform payload RF and baseband signal processing functions. Second, there are avionic equipment that perform the payload data handling functions. The equipment in the first category are the Payload Interrogator (PI), Payload Signal Processor (PSP), Communication Interface Unit (CIU), and Ku-Band Signal Processor (KuSP). The equipment in the second category are the Payload Data Interleaver (PDI), PCM Master Unit (PCMMU), Network Signal Processor (NSP), and various DOD encryptor/decryptor units.

3.1 Attached IUS Communication

In the attached mode, a hard line (umbilical) provides two-way communication between the IUS and the Orbiter. Scientific data, engineering data, guidance, navigation and attitude control data (GN&C) are received by the Orbiter from the IUS.

Alternately, command data, GN&C, and uplink data are transmitted to the IUS from the Orbiter.

Figure 4 illustrates the functional scientific data interfaces for attached payloads. Only limited processing--that required to throughput data to a ground terminal--is provided for IUS medium-band and wideband scientific data inputs (inputs in the range of 16-256 kbps). For data rates below 64 kbps, the data can be routed through the PDI to the PCMMU, where it is made available to the general-purpose computers (GPC) for processing and onboard display. A payload specialist crew member may then interface directly with a specific experiment, as required. Medium-band scientific data is routed to the receiving ground terminal via either the S-band FM link or the Ku-band system, as follows:

(1) S-band FM:

	Analog:	300 Hz - 4 MHz
or		
	Digital:	200 bps - 5 Mbps NRZ-L, or 200 bps - 2 Mbps biphase-L

(2) Ku-band:

	Analog:	DC - 4.5 MHz BW
plus	Digital:	16 kbps - 1024 Mbps biphase-L
or		16 kbps - 2 Mbps NRZ-L, M or S

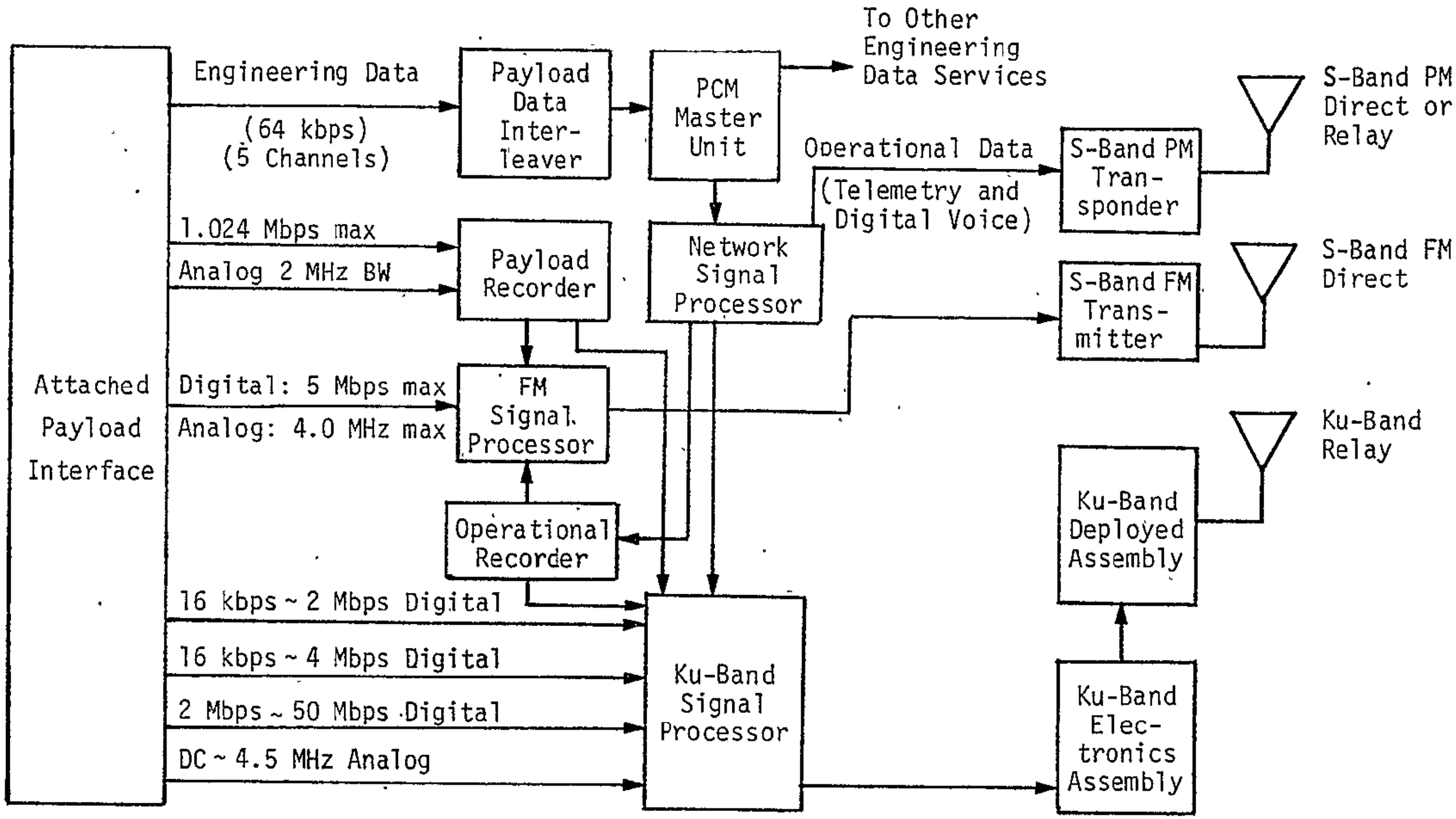


Figure 4. Attached Payload Scientific Data Interface

The Ku-band wideband analog channel input (DC - 4.5 MHz) can be used by the IUS or CIU for analog telemetry as a transparent throughput channel, which provides flexibility and minimum Orbiter processing. Capability is constrained only by the KuSP bandwidth.

Figure 5 depicts the Orbiter provisions for processing, displaying and downlinking systems status data from the IUS in support of monitoring and checkout functions. Data can be accessed by the Orbiter via one of five inputs to the PDI which makes specific parameters contained in the input PCM bit stream (0-64 kbps) available to the PCMMU for insertion into the operational instrumentation (OI) downlink and available to the GPC's for processing and display.

The PDI provides the capability to receive engineering data from up to five attached payloads simultaneously. The PDI then decommutates up to four of these inputs and provides time-tagged, time-homogeneous data from these four payloads simultaneously to the Orbiter data processing subsystem (DPS) for onboard display and/or transmission to the ground via OI downlink.

In order to provide the data processing service, the input data to the PDI must be in a standard format, as follows:

- Bits per word: 8
- Words per frame: 1024 max
- Subframe rate groups per frame: 4 max
- Words per subframe: 128 max
- Frame rate: 200 per second max
- Bits per frame synchronization: 8, or 16, or 24, or 32
- Process data rate: up to 64 kbps

The throughput data rate (composite PDI output to the PCMMU) is limited to 64 kbps maximum on-orbit and 5 kbps for ascent.

A capability to throughput data which is in nonstandard format, or other unique data such as encrypted data, is also provided by the PDI. In this mode, the frame synchronization circuitry is bypassed and artificial data blocks are established to transfer the data to the PCMMU. No onboard processing or display of the data is available when operating in the nonstandard mode.

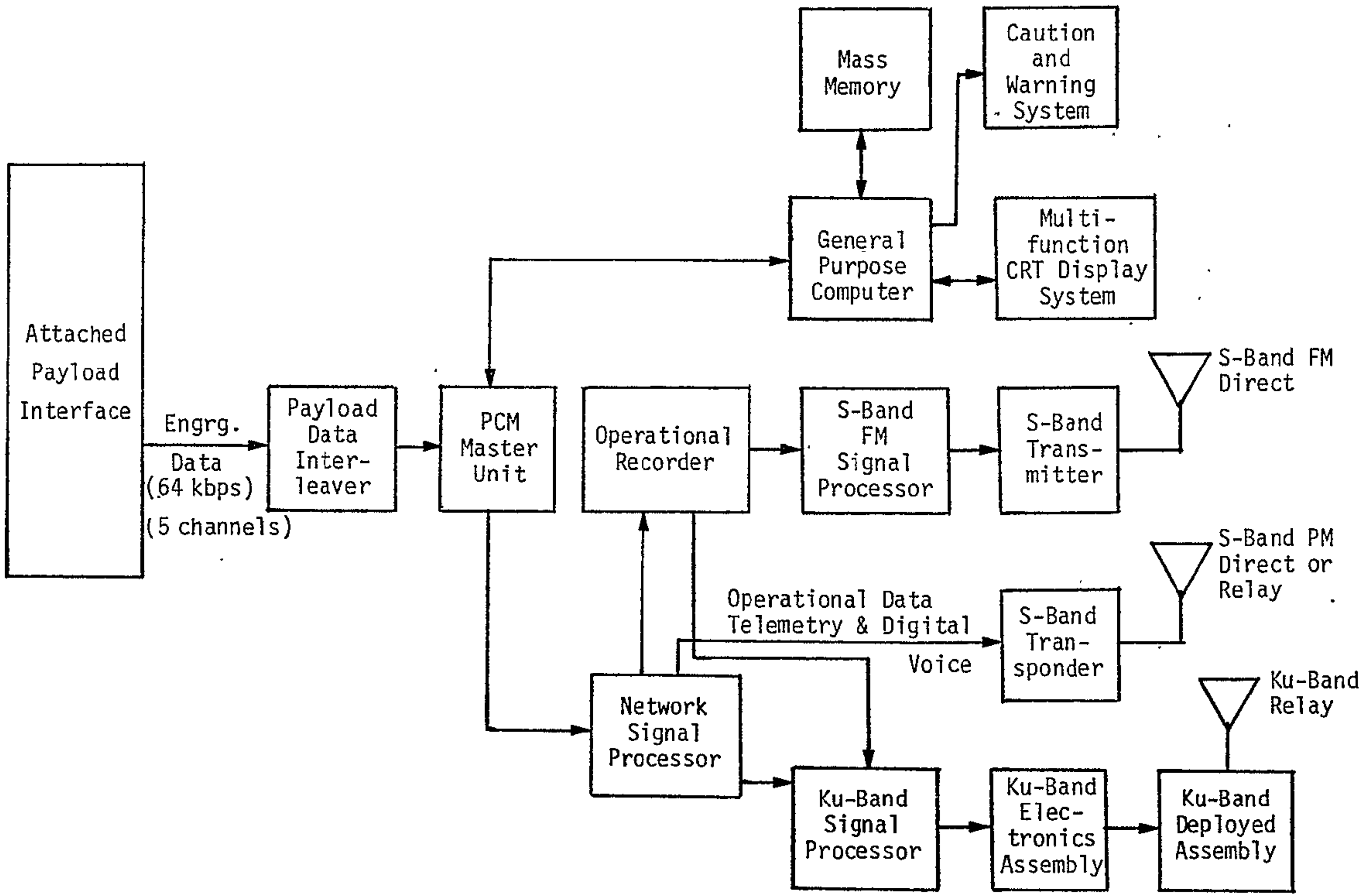


Figure 5. Attached Payload Engineering Data Interface

A capability for direct recording of certain types of payload data is provided, as shown in Figure 6. The payload recorder has 14 tracks capable of serial or parallel recording of digital and analog data. Data rates from 25.5 kbps to 1.024 Mbps and analog data of 1.9 kHz to 2 MHz may be recorded. A minimum record time of 56 minutes is provided at the maximum data rate. Simultaneous analog/digital parallel recording is limited to the first record pass. Subsequent passes are restricted to sequential single-channel digital record.

A total of 14 tape speeds (four per mission) are available and selectable by onboard or ground control.

Guidance, navigation and attitude control services are provided for the IUS by the CIU or PSP using the interface shown in Figure 7, over which the Orbiter provides state vector update data words to the IUS. The CIU transmits the Orbiter state vector data to the IUS using the SGLS command format of ternary frequency-shift-keying (FSK) with "S" tones of 65 kHz, "0" tones of 76 kHz, and "1" tones of 95 kHz. The PSP transmits the Orbiter state vector data to the NASA IUS on a 16-kHz sine wave subcarrier at a binary command data rate of 2 kbps.

3.2 Detached IUS Communication

The basic low rate data-processing/display services provided for the attached IUS are also provided for detached or deployed IUS via S-band RF communications link between the Orbiter and IUS. Figure 8 shows the interfacing hardware that supports this link. Note that, when a spacecraft is launched by the IUS, as shown in Figure 8, the spacecraft communicates only in the attached mode through the IUS. Also note that the PI cannot communicate with the IUS and the spacecraft simultaneously.

The Orbiter S-band transceiver (PI) supporting RF communications with detached payloads is compatible frequency-wise with STDN, SGLS, and DSN-compatible payloads--capable of operating at approximately 850 selectable frequencies in the 2200-2300 MHz range.

Telemetry signals in the Orbiter standard mode of operation are routed from the PI, after carrier demodulation, to the PSP or CIU, where the data is demodulated off of a 1.024 MHz subcarrier (and a 1.7 MHz subcarrier by the CIU). The data is then routed to the PDI/PCMMU/GPC for decommutation processing, display and downlinking in the same manner as the attached IUS or payload.

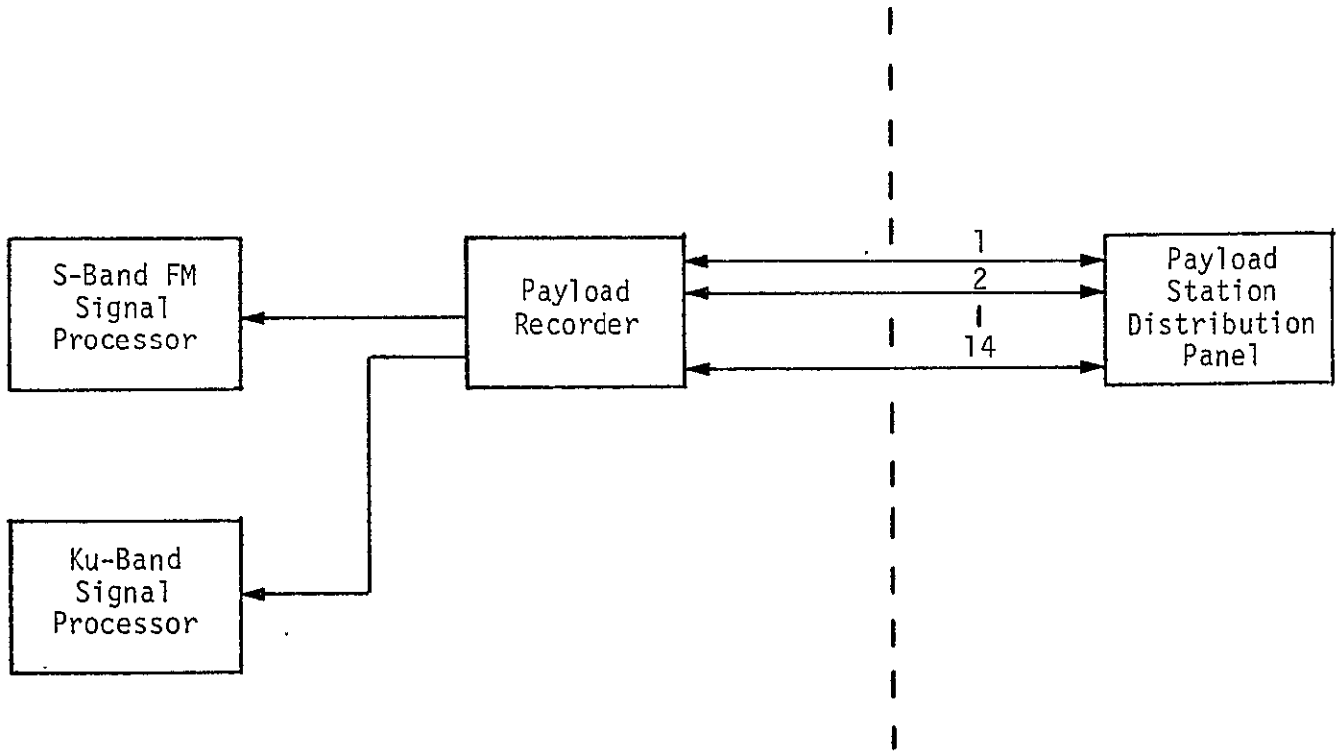


Figure 6. Attached Payload Data Recording Interface

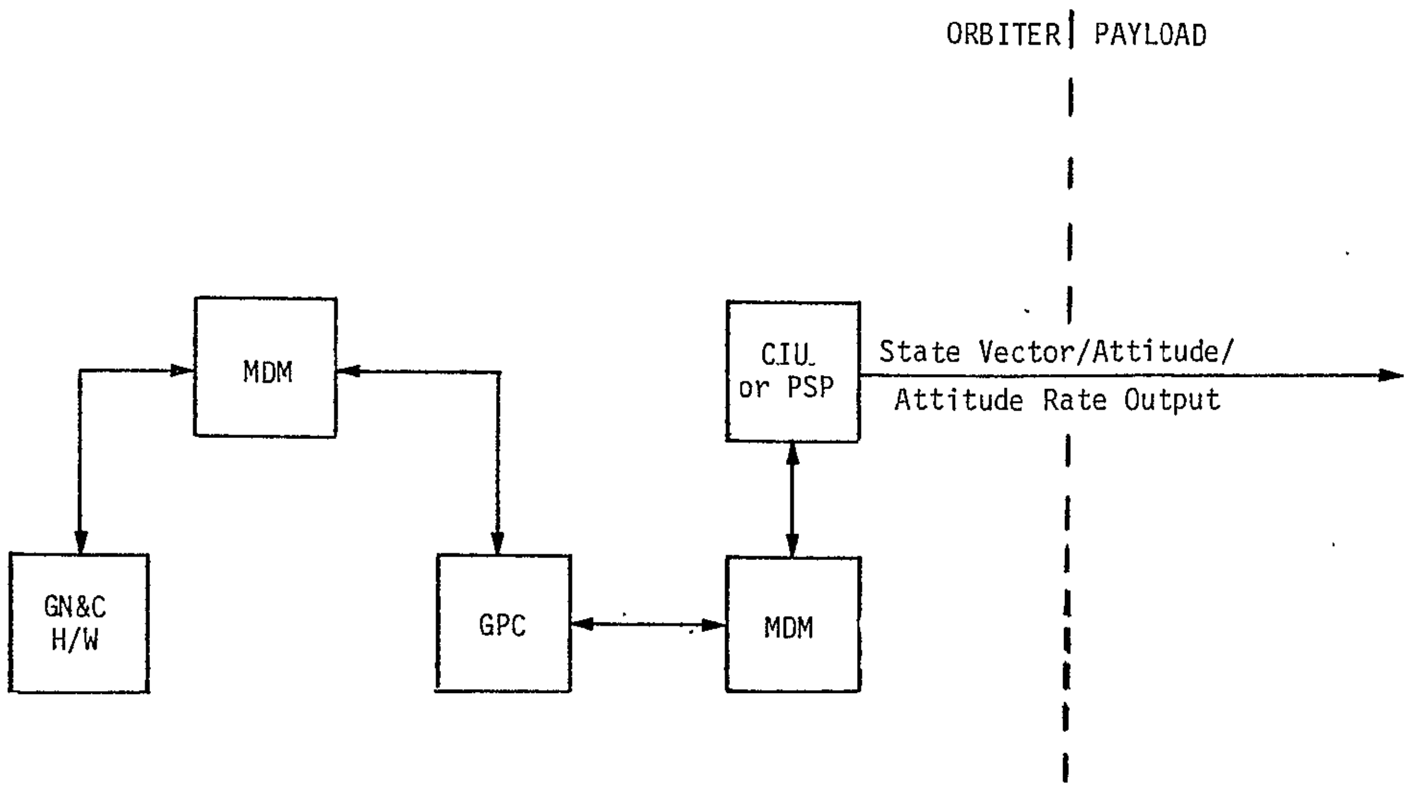


Figure 7. IUS Guidance, Navigation, and Attitude Control Interface

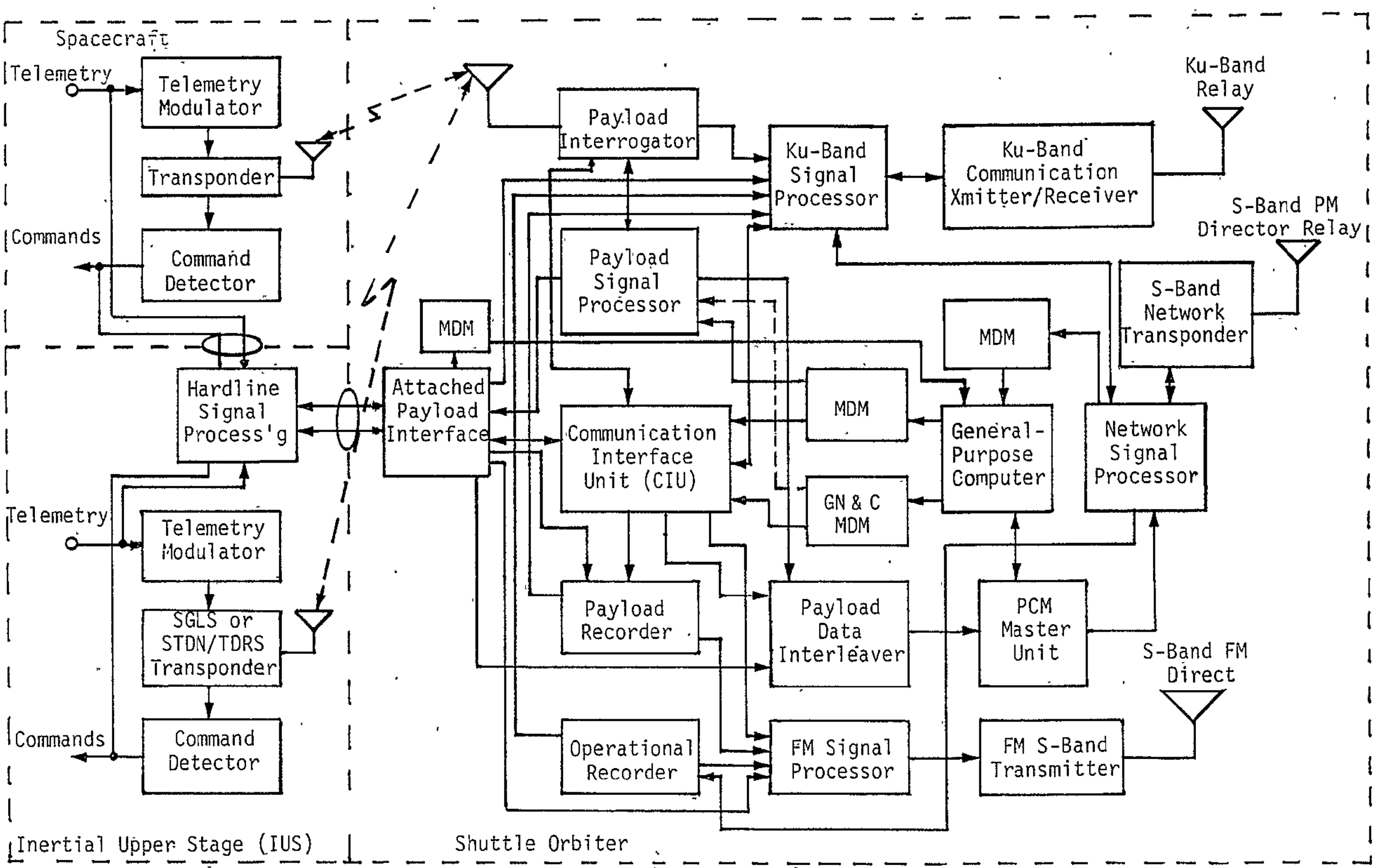


Figure 8. Inertial Upper Stage/Shuttle Orbiter Subsystems and Interfaces

Data rates that can be accommodated by the PSP in the standard mode are 16, 8, 4, 2 and 1 kbps. Processing the 32, 24 and 16 kbps may be provided by the CIU located at the payload station in the aft flight deck for DOD missions. In this mode, the PSP is bypassed. The PSP is being designed to accommodate any one of six PCM code formats in the standard mode (biphase-L, M, S and NRZ-L, M, S).

The Orbiter standard mode of operation was selected to provide a degree of flexibility of operation while minimizing basic Orbiter hardware costs. Payloads that ultimately fly on the Orbiter which are incompatible with the standard in terms of data rate or subcarrier frequency will be accommodated in a transparent throughput fashion using a "bent-pipe" mode of operation. In this mode, the interrogator output, following carrier demodulation, is routed to the KuSP 4.5 MHz analog input channel or the 2 Mbps digital channel. These inputs are essentially limited only by the respective bandwidths and are capable of a wide range of data rate/subcarrier options (the 2 Mbps channel is limited to one subcarrier). Unique demodulation hardware at either the Ku-band ground station or the payload operation center currently must be provided by the payload requiring bent-pipe service. The bent-pipe channels are available for use by one detached payload at a time with the following capabilities:

- Digital data from 2 kbps to 2 Mbps, or
- Analog data from 2 kHz to 2 MHz, or
- Digital data from 16 kbps to 4 Mbps, or
- Analog data from DC to 4.5 MHz.

No onboard processing or display of data is available when operating in the bent-pipe mode.

3.3 Orbiter Avionic Equipment Serving the IUS

In order to determine that the interfaces between Orbiter avionic equipment serving the IUS are compatible and that the NASA performance requirements are being met, the details of the avionic equipment were studied. This section summarizes the avionic equipment operation and capability.

3.3.1 Payload Interrogator

The function of the PI is to provide the RF communication link between the Orbiter and detached payloads. For communication with the NASA payloads and the NASA IUS, the PI operates in conjunction with the PSP. During DOD missions, the PI is interfaced with the CIU. Nonstandard (bent-pipe) data received by the PI from either NASA or DOD payloads is delivered to the KuSP, where it is processed for transmission to the ground via the Shuttle/TDRSS link.

Simultaneous RF transmission and reception is the primary mode of PI operation with NASA IUS, DOD IUS, and payloads. The Orbiter-to-payload link carries the commands while the payload-to-Orbiter link communicates the telemetry data. In addition to this duplex coperation, the PI provides the "transmit only" and "receive only" modes of communication with some payloads.

Figure 9 shows the functional block diagram for the PI. The antenna connects to an input/output RF port which is common to the receiver and transmitter of the PI unit. Because of a requirement to operate the PI simultaneously with the Shuttle/ground S-band network transponder which radiates and receives on the same frequency bands, a dual triplexer is employed. The S-band network transponder emits a signal at either 2217.5 MHz or 2287.5 MHz; both frequencies thus fall directly into the PI receive band of 2200-2300 MHz. Conversely, the IUS and payload transmitters, operating in either the 2025-2120 MHz (NASA) or the 1764-1840 MHz DOD bands, can interfere with uplink signal reception by the S-band network transponder receiver frequencies of 1776.733 MHz or 1831.787 MHz in the DOD mode and 2041.947 MHz or 2106.406 MHz in the NASA STDN/TDRS mode. Therefore, by use of the triplexer and by simultaneously operating the PI and network transponder in the mutually exclusive subbands, the interference problem is effectively eliminated.

The receiver frequency and phase-tracking loop begins at the second mixer. As shown in Figure 9, the output of the first IF amplifier is down-converted to the second IF as a result of mixing with a variable second LO frequency, f_{LO2}. The portion of the second IF which involves only the carrier tracking function is narrowband, passing the received signal residual carrier component and excluding the bulk of the sideband frequencies. Demodulation to baseband of the second IF signal is accomplished by

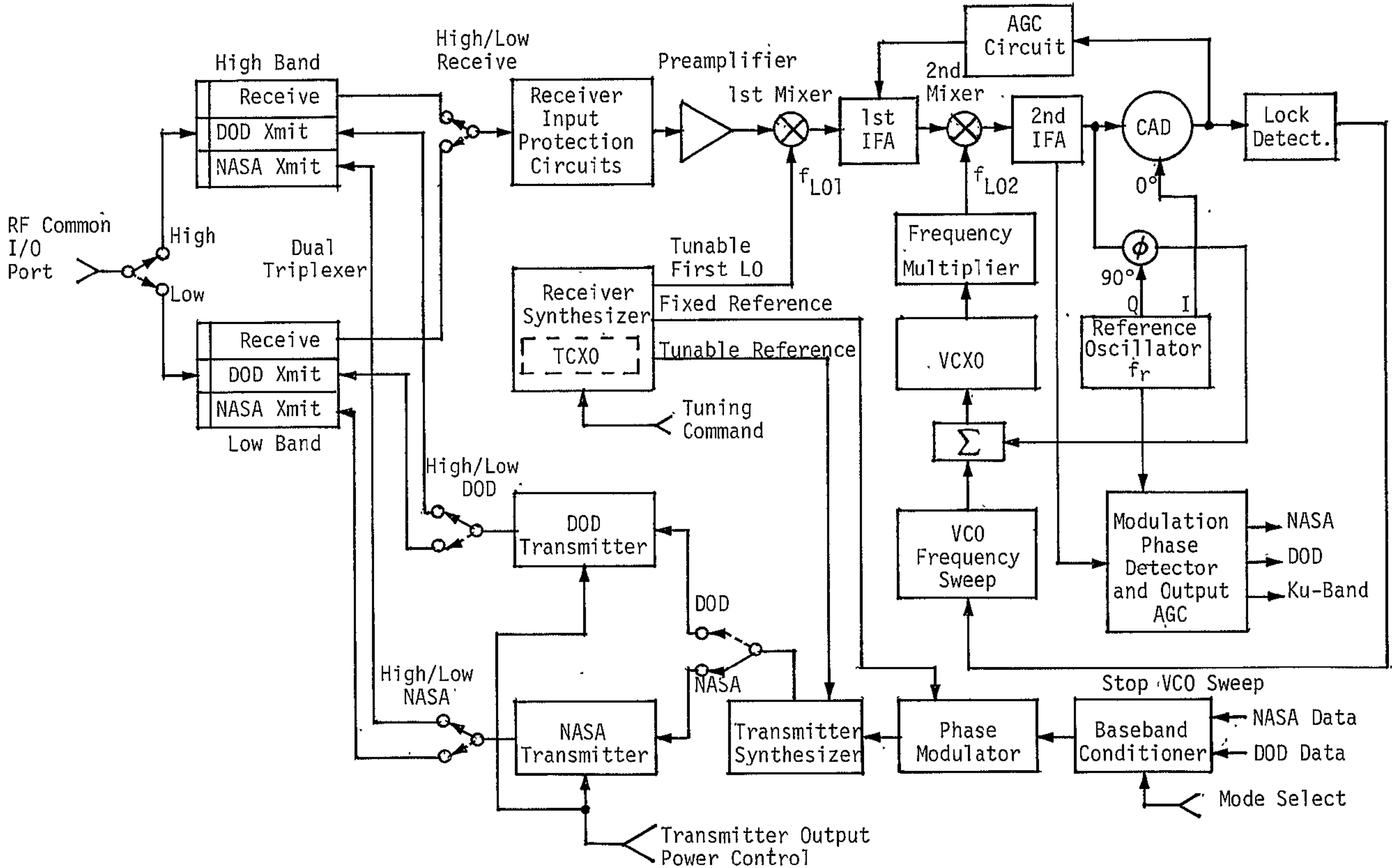


Figure 9. Payload Interrogator Functional Block Diagram

mixing with a reference frequency, f_R. The output of the tracking phase detector, after proper filtering, is applied to the control terminals of a VCO which provides the second local oscillator signal, thereby closing the tracking loop. Thus, when phase track is established, f_{LO2} follows frequency changes of the received payload signal.

For the purpose of frequency acquisition, the f_{LO2} may be swept over a ±75 kHz uncertainty region. Sweep is terminated when the output of a coherent amplitude detector (CAD) exceeds a preset threshold, indicating that the carrier tracking loop has attained lock. The output of the CAD also provides the AGC to the first IF amplifier.

A wideband phase detector is used to demodulate the telemetry signals from the carrier. The output of this detector is filtered, envelope level controlled, and buffered for delivery to the PSP, CIU, and KuSP.

The PI receiver frequency synthesizer provides the tunable first LO frequency and the corresponding exciter frequency to the transmitter synthesizer. It also delivers a reference signal to the transmitter phase modulator. Baseband NASA or DOD command signals modulate the phase of this reference signal which is, in turn, supplied to the transmitter synthesizer where it is upconverted to either the NASA or DOD transmit frequency and applied to the power amplifier.

For transmitter efficiency optimization, separate NASA and DOD RF power amplifier units are used. Depending on the operating band selected, transmitter output is applied to either the high-band or low-band triplexer.

3.3.2 Payload Signal Processor

The PSP performs the following functions: (1) it modulates NASA IUS and NASA payload commands onto a 16 kHz sinusoidal subcarrier and delivers the resultant signal to the PI and the attached payload umbilical, (2) it demodulates the NASA IUS and NASA payload telemetry data from the 1.024 MHz subcarrier signal provided by the PI, and (3) it performs bit and frame synchronization of demodulated telemetry data and delivers this data and its clock to the PDI.

The PSP also transmits status messages to the Orbiter's GPC; the status messages allow the GPC to control and configure the PSP and validate command messages prior to transmission.

The functional block diagram for the PSP is shown in Figure 10. The PSP configuration and payload command data are input to the PSP via a bidirectional serial interface. Transfer of data in either direction is initiated by discrete control signals. Data words 20 bits in length (16 information, 1 parity, 3 synchronization) are transferred across the bidirectional interface at a burst rate of 1 Mbps, and the serial words received by the PSP are applied to word validation logic which examines their structure. Failure of the incoming message to pass a validation test results in a request for a repeat of the message from the GPC.

Command data is further processed and validated as to content and the number of command words. The function of the command buffers is to perform data rate conversion from the 1 Mbps bursts to one of the selected standard command rates (see Table 15). Command rate and format are specified through the configuration message control subunit.

Table 15. NASA Command System Parameters

Subcarrier Frequency	16 kHz, sinewave
Bit Rates	$2000 \div 2^N$ bps, $N = 0,1,2,\ldots,8$
E_b/N_0 for $P_e^b = 1\times10^{-5}$	10.5 dB

From the message buffers, the command bits are fed via the idle pattern selector and generator to the subcarrier biphase modulator. The idle pattern (which, in many cases, consists of alternating "ones" and "zeros") precedes the actual command word and is usually also transmitted in lieu of command messages. Subcarrier modulation is PSK NRZ-L only.

Figure 8 also shows (dotted line) an interface between the GN&C MDM and the PSP. In the actual implementation, the PSP receives the GN&C data from the GPC in the same way it receives command data (i.e., over the payload MDM). In fact, the PSP makes no distinction between GN&C data and command data and processes the GN&C data in exactly the same way as commands.

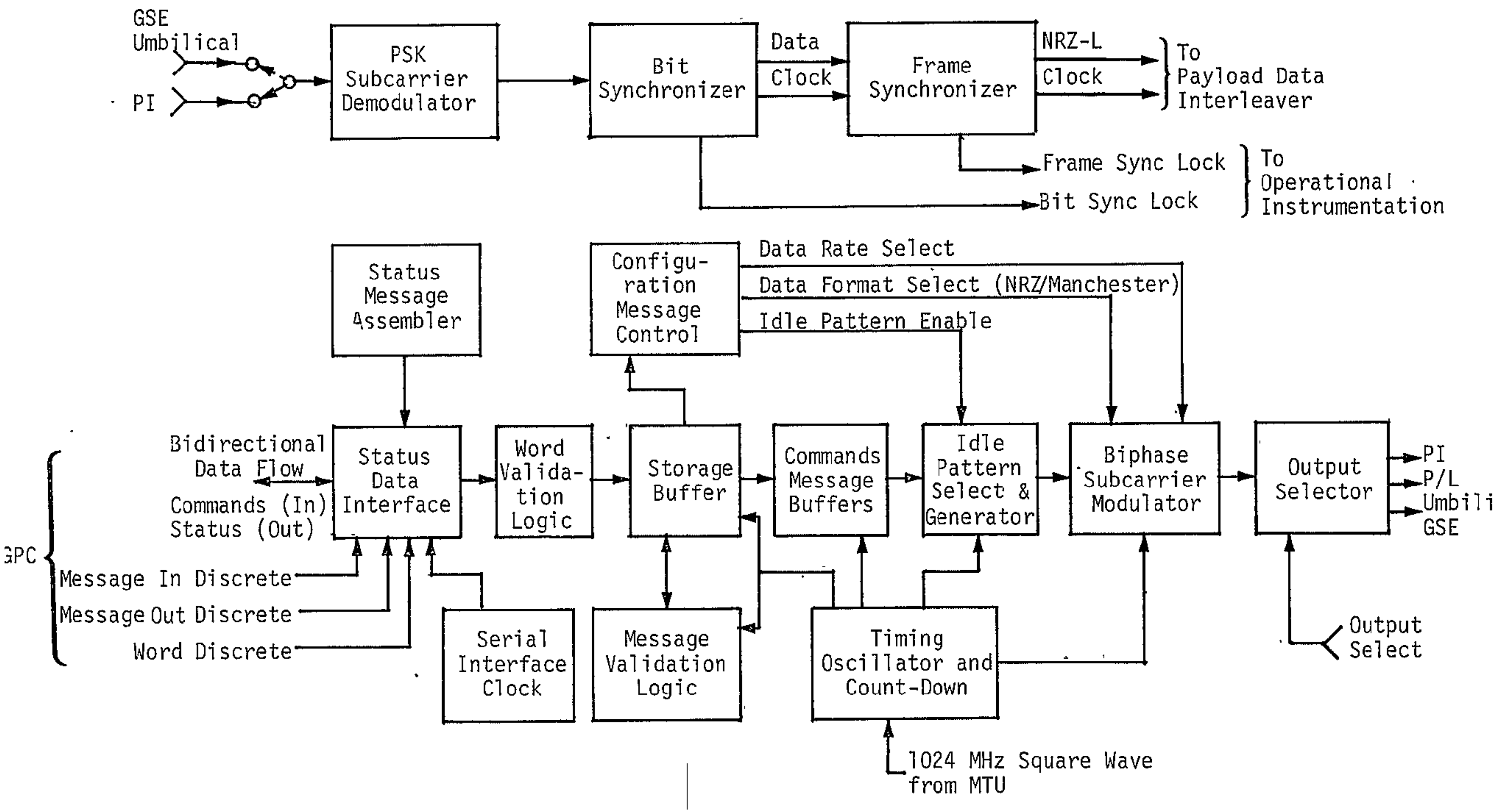


Figure 10. NASA Payload Signal Processor Functional Block Diagram

The 1.024 MHz telemetry subcarrier from the PI is applied to the PSK subcarrier demodulator. Since the subcarrier is biphase modulated, a Costas-type loop is used to lock onto and track the subcarrier. The resulting demodulated bit stream is input to the bit synchronizer subunit, where a DTTL bit synchronization loop provides timing to an integrate-and-dump matched filter which optimally detects and reclocks the telemetry data.

From the frame synchronizer, the telemetry data with corrected frame synchronization words and clock are fed to the PDI. The telemetry detection units also supply appropriate lock signals to the Orbiter operational instrumentation equipment, thus acting to indicate the presence of valid telemetry.

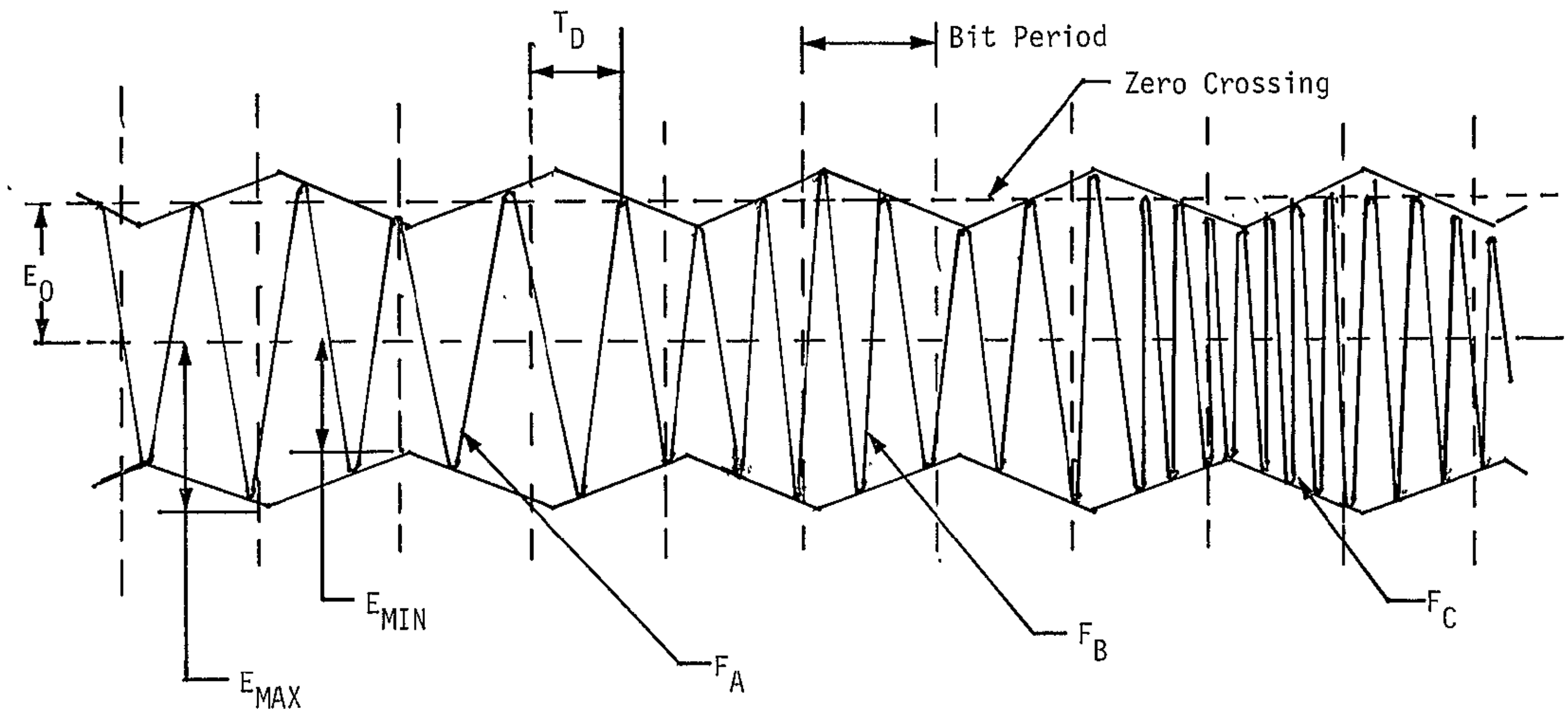
3.3.3 Communication Interface Unit

The primary function of the CIU is to provide command and telemetry data conditioning between the Orbiter and the IUS transponder. The CIU consists physically of four boxes and two control panels mounted in an Orbiter standard console. The four boxes consist of two GFE units (KGT-60 and KGR-60), a CIU BLACK unit, and a CIU RED unit. The CIU/KG control and display panels control the operating mode of the CIU. The CIU BLACK unit performs command and telemetry processing of BLACK (encrypted and clear) data. The CIU RED unit performs command and telemetry processing of RED (unencrypted) data.

The CIU accepts command data from one of five sources:

(1) S-band MDM
(2) KuSP
(3) GN&C MDM
(4) Crew-generated data from control panel
(5) T-0 umbilical.

Input command data is validated, formatted, modulated on an SGLS baseband carrier (see Figure 11) at 1 k baud, and forwarded to one of six destinations. In the attached mode, the CIU forwards the conditional command data directly over hard line to one of two redundant IUS transponders on one of two IUS's in the Orbiter payload bay. In the detached mode, the CIU forwards the conditioned command data to one of two redundant PI's for RF transmission to the IUS transponder.



T_D = Delay Time = 600 Microseconds

$$\text{Percent Modulation} = \frac{E_{MAX} - E_{MIN}}{E_{MAX} + E_{MIN}} \times 100 = 50\% \pm 10\%$$

F_A = 65 kHz Nominal = "S"

F_B = 76 kHz Nominal = "0"

F_C = 95 kHz Nominal = "1"

Figure 11. Command Tone Modulation Envelope

The CIU receives IUS telemetry over hard line (attached and from the PI (detached). In the attached or hard line mode, the CIU receives data from one of two IUS's and provides selected telemetry data (NRZ-L) to the KG-60 and the PDI. The CIU provides the same telemetry data after NRZ-L to biphase-L conversion for selection to the Payload Recorder (PR), FMSP or KuSP. The CIU also receives NRZ-L data from the Wideband Data Interleaver (WBDI) on the IUS and performs NRZ-L to biphase-L conversion. The WBDI data is selected to be supplied to the PR, FMSP or KuSP. The IUS EMU analog environmental data is received by the CIU for selection to the PR. In the detached or RF mode, the CIU receives telemetry data from one of the two PI's as a PSK subcarrier (1.024 MHz) frequency multiplexed with FM/FM environmental data on a 1.7 MHz subcarrier. The CIU performs PSK demodulation and bit synchronization to generate NRZ-L telemetry data and clock for selection to the KGR-60 or the PDI. The same telemetry data is NRZ-L to biphase-L converted for selection to the PR, FMSP or KuSP. The CIU performs FM demodulation on the 1.7 MHz subcarrier to generate three-channel FM (16, 24 and 32 kHz). The CIU provides the three-channel FM plus a 100 kHz reference for selection to the PR.

Figure 12 shows a simplified block diagram of the CIU. Microprocessor technology is fundamental to the CIU operation. The microprocessor performs the bit synchronization function on the telemetry data for processing by the KGR-60 and then receives telemetry data (NRZ-L) and clock from the KGR-60. The microprocessor performs frame synchronization, VCC extraction (required for DOD commands), command authentication, and determines command rejection. The microprocessor also accepts GN&C data and provides the command generator function to send GN&C or crew-generated command data to the FM/AM modulator via the KGT-60. The required binary-to-ternary conversion on the command data is also performed by the microprocessor. Additional functions performed by the microprocessor are CIU mode control and status display.

3.3.4 Ku-Band Signal Processor

The KuSP receives IUS and payload data from the PI, PSP, CIU, PR, operational recorder (OR), and attached payload interface (API). Similarly, the KuSP transmits data to the IUS and payload via the CIU or NSP/GPC/PSP

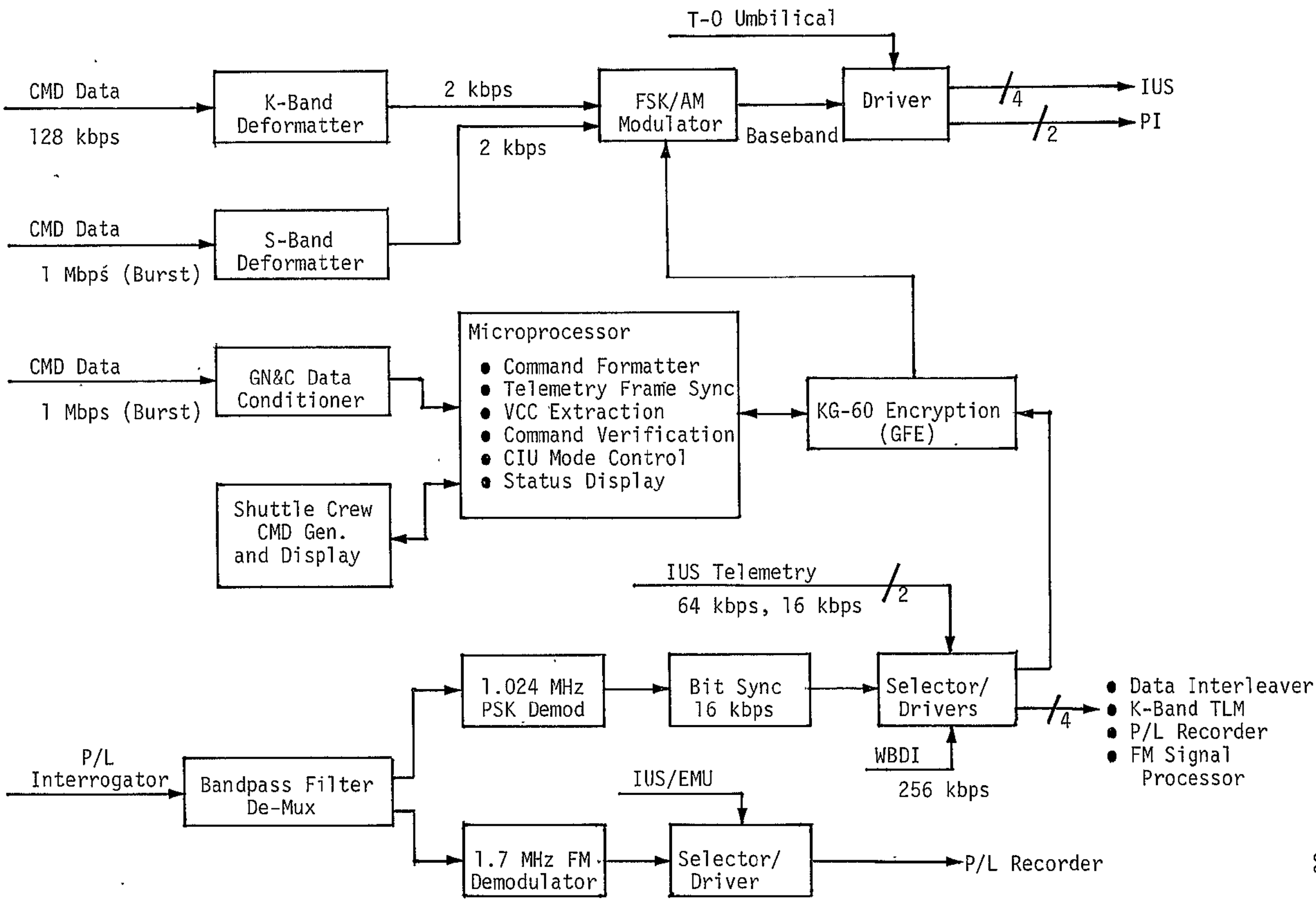


Figure 12. Communication Interface Unit

(or CIU). Table 16 presents the characteristics of the data that are handled by the KuSP. The 216 kbps data shown for the forward link originates at the TDRSS ground station and can be 72 kbps command data to the NSP, 128 kbps DOD command data to the CIU, 128 kbps text and graphics data and 216 kbps data containing 72 kbps command data plus digital voice data that is sent directly to the NSP. Figure 13 illustrates the functional processing of the KuSP for data to be transmitted to the IUS and payload (i.e., the forward link). When the forward link contains the normal S-band 216 kbps operational data of the 72 kbps command data plus digital voice data, the data mode select is set to transfer the data directly to NSP1 and NSP2 without any processing in the KuSP. Note that, in this data select position, the possible data rates are 32, 72, 96 and 216 kbps. When the 216 kbps forward link data contains either text and graphics data or DOD command data, then data mode select is set to transfer the 72 kbps command data to NSP1 and NSP2. The 128 kbps DOD command data is actually 2 kbps which has been coded to use the available 128 kbps data rate without having to modify the KuSP bit synchronizer or frame synchronizer design.

The characteristics of the data that must be processed by the KuSP on the return link are quite varied, as shown in Table 16. The return link is transmitted in one of two modes which are identified by the type of carrier modulation utilized. Mode 1 implements unbalanced quadriphase-shift-keying (UQPSK) while Mode 2 implements FM. In both modes of operation, two of the channels (1 and 2) UQPSK modulate a subcarrier. Mode 1 utilizes this modulated subcarrier along with the third channel to UQPSK the carrier, as shown in Figure 14. Mode 2 linearly sums the modulated subcarrier with the third channel and frequency modulates the carrier with the resultant summed signal, as shown in Figure 15.

Channel 1 always (Modes 1 and 2) carries the operations data of 192 kbps consisting of 128 kbps telemetry data and two 32 kbps delta-modulated voice channels. Similarly, the data on Channel 2 does not change from Mode 1 to Mode 2. Channel 2 carries the output from the PR, the OR, and the PSP as well as low rate data for the API and narrow-band bent-pipe data from the PI. The range of data rates handled by the KuSP Channel 2 is shown in Table 16 to be 16-1024 kbps Manchester coded data, 16-2000 kbps NRZ coded data or DC-2 MHz analog bent-pipe data.

Table 16. Ku-Band Signal Processor Data Characteristics

Processor Interface	Type	Rate or Bandwidth
FORWARD LINK		
Operations Data - NSP(1,2)	Digital	32,72,96,216 kbps (Manchester)
Command/Text & Graphics - NSP (1,2) and Text & Graphics	Digital	72 kbps Command 128 kbps Text & Graphics 16 kbps Frame Sync (Manchester)
Command/DOD Payload Command Data - NSP(1,2)/CIU	Digital	72 kbps Command 128 kbps DOD Payload 16 kbps Frame Sync (Manchester)
RETURN LINK		
CHANNEL 1 (MODE 1/MODE 2)		
Operations Data - NSP(1,2)	Digital	192 kbps (Manchester)
CHANNEL 2 (MODE 1/MODE 2)		
Payload Recorder (PR)	Digital	25.5-1024 kbps (Manchester)
Operations Recorder (OR)	Digital	25.5-1024 kbps (Manchester)
Payload low data rate - PSP (1,2) or Attached Payload Interface (API)	Digital	16-2000 kbps (NRZ) 16-1024 kbps (Manchester)
PI(1,2) low data rate	Digital/Analog	16-2000 kbps (NRZ) 16-1024 kbps (Manchester) 0-2 MHz
CHANNEL 3 (MODE 1)		
Attached Payload Interface (API)	Digital	2-50 Mbps (NRZ)
CHANNEL 3 (MODE 2)		
PI(1,2) high data rate	Digital/Analog	16-4000 kbps (NRZ) 0-4.5 MHz
Attached Payload Interface	Digital/Analog	16-4000 kbps (NRZ) 0-4.5 MHz
Video Interface Unit	Analog	0-4.5 MHz

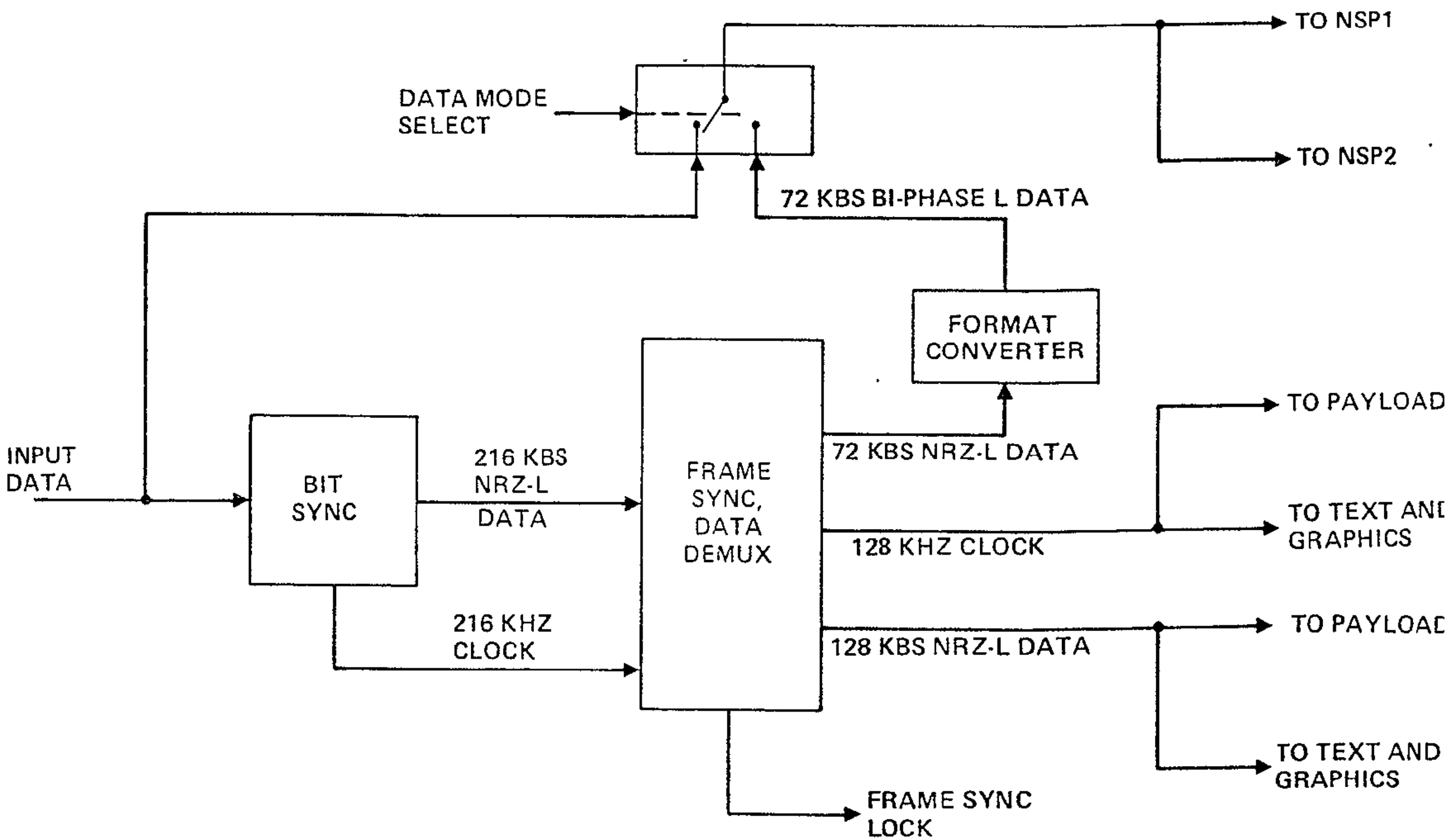


Figure 13. Ku-Band Signal Processor Forward Link Functional Block Diagram

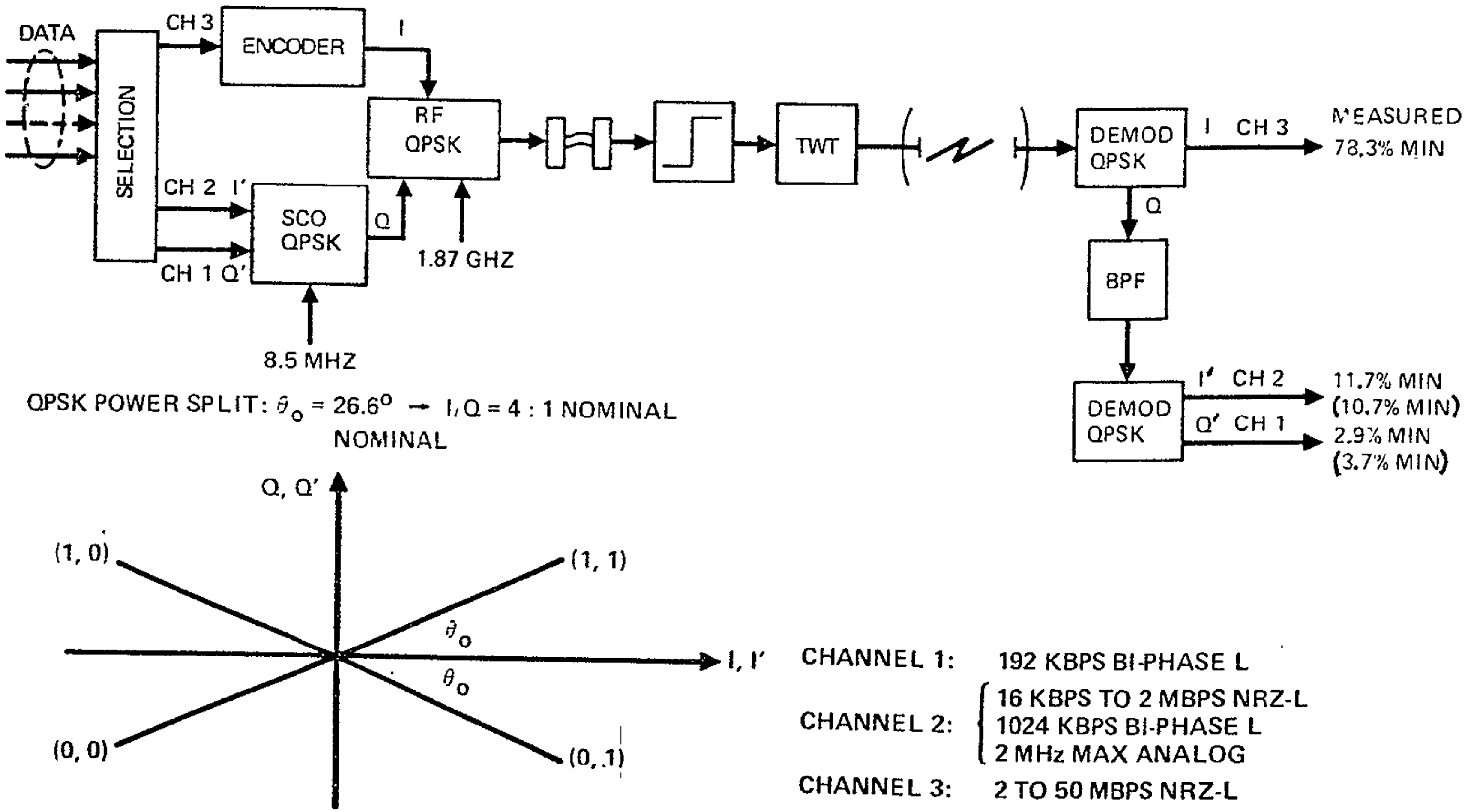


Figure 14. Ku-Band Mode 1 Three Channel Modulation

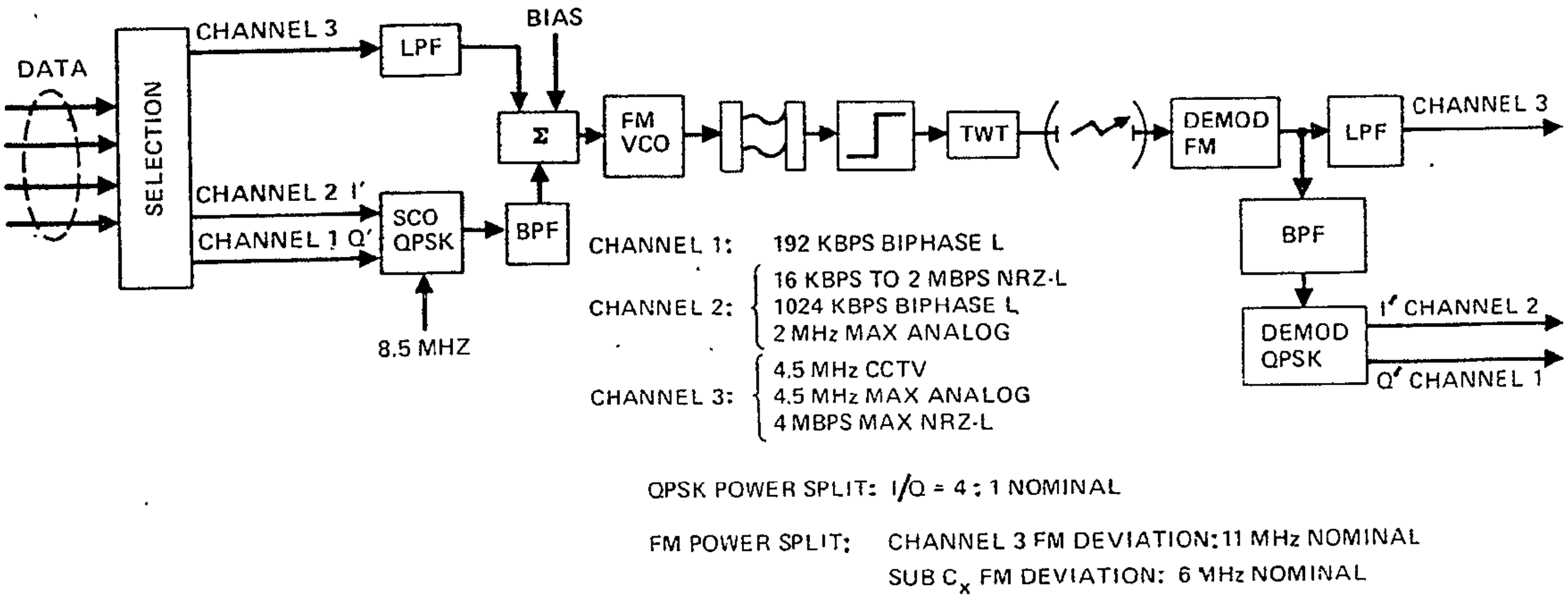


Figure 15. Ku-Band Mode 2 Three-Channel Modulation

The data carried on Channel 3 in Mode 1 is digital data of 2-50 Mbps (NRZ) which is rate 1/2-constraint length 7, convolutionally encoded by the KuSP to maintain adequate performance margin at bit error probability of 10^{-6}. Because the output data rate of the convolutional encoder is twice the input, the input data clock must be doubled by the KuSP. The input clock is regenerated and synchronized with the input data to compensate for phase offsets and to avoid sampling the data stream near transitions. A voltage-controlled oscillator (VCO) at twice the clock frequency is divided by 2 and compared in a phase/frequency detector. The detector output locks the VCO to twice the clock frequency over the entire frequency range of 2 to 5 MHz. Use of the phase/frequency detector makes it possible to cover the 25:1 frequency range without selecting bands. To correct for asymmetry in both the clock (specified at 20 percent maximum) and data (specified at 25 percent maximum) at the KuSP input, a very symmetric clock is regenerated and used to clock the convolutional encoder. The data bits are sampled using a pulse generated every other clock pulse. The KuSP clock regeneration circuit senses the proximity of a data transition to the sample pulse and inverts the clock when the transition is within 5 nsec of the sample pulse, thus shifting the sample pulse toward the middle of the data bit. The KuSP reduces the encoder output data asymmetry to less than 10 percent for all input rates and for the input clock and data asymmetry up to their maximum specified values.

In Mode 2, the UQPSK modulated 8.5 MHz subcarrier is filtered, as shown in Figure 15, by a bandpass filter with -3 dB points at 4.75 and 12.8 MHz. This BPF has extremely sharp low frequency skirts (-40 dB point $\geq$ 4.0 MHz) to minimize spectral spillover of the modulated subcarrier into the Channel 3 frequency band (DC-4.5 MHz). The Channel 3 input is passed through a lowpass filter with specified amplitude response of -3 dB at 5.5 MHz and -20 dB at 8.1 MHz. Differential delay is no more than 20 nsec due to equalization. Although the combination of these two filters will provide excellent performance of the linear Channel 3, their selection is suboptimum for Channel 2 performance since the bandpass necessarily has a high bandwidth to center frequency ratio and the lowpass filter provides only nominal skirt rejection. Note that the degradation to Channel 2 due to spectral spillover from Channel 3 depends on the type of data on Channels 2 and 3. The worst degradation occurs when Channel 2 is 2 Mbps NRZ digital data and Channel 3 has a flat spectrum greater than 8 MHz. Table 16 presents the type of data present in Channel 3 for Mode 2. The data with the greatest spectral bandwidth and hence the most potential degradation to Channel 2 is the 4.0 Mbps NRZ digital data, but it is unlikely that Mode 2 would be used to transmit this data. More likely, Mode 1 would be used to transmit digital data at this high rate. The analog data from the PI can range from DC to 4.5 MHz but, since the PI contains a lowpass filter with effective noise bandwidth equal to 5 MHz, it can be expected that this signal will cause little degradation to Channel 2. The video interface unit (VIU) outputs a television signal with spectral bandwidth of approximately 4.5 MHz. Here again, there will be little spectral spillover into Channel 2 and there should be little degradation. The data from the API can be either digital data from 16 to 4000 kbps or analog data with spectral bandwidth from DC to 4.5 MHz. Again, high rate digital data will probably be transmitted in Mode 1 rather than Mode 2. However, there is no filtering specified for the API; therefore, the greatest potential degradation to Channel 2 from Channel 3 is when Channel 2 contains 2 Mbps NRZ digital data and the output of the API has a larger spectral bandwidth than 4.5 MHz, resulting in significant spectral spillover. This worst-case degradation to Channel 2 is 3.3 dB. While the circuit margin on Channel 2 is large enough to allow this much degradation, the use of the three channels for a given mission should be examined to guarantee that the correct mode is selected and that the data to be transmitted will achieve the required performance on each of the channels.

3.3.5 FM Signal Processor

The FMSP and FM transmitter provide a capability for transmission of data not amenable for incorporation into the limited-rate PCM telemetry data stream. The data to be transmitted via FM include television, digital data from the main engines during launch, wideband payload data, or digital data from the PR or the API. The characteristics of the data and the performance specifications for the FMSP and the FM transmitter are presented in Table 17.

Table 17. S-Band FM Performance Specifications

FM Signal Processor	
TV Channel Input	EIA TV Standard RS 170
TV Channel Gain	19 dB +0.8 dB to -0.25 dB
TV Channel Dynamic Range	51 dB ±0.25 dB
Frequency Response ±0.25 dB and Phase Ripple ±1.0°	DC to 4.5 MHz
CCIR K Factor	<2%
Main Engine	
Data in 3 Channels	60 kbps BPL
Subcarrier Frequencies	576 kHz, 768 kHz, 1024 kHz
Subcarrier Modulation	±180° at ±15°
Analog Data Bandwidth	300 Hz to 4 MHz
Wideband Digital Data Rate	200 bps to 5 Mbps NRZ, or 200 bps to 2 Mbps Manchester Coded
Recorded Data - 2 Channels Data Rate	25.5 kbps to 1024 kbps
Narrowband DOD Digital Data Rate	250 bps to 256 kbps
Input Common Mode Voltage (DC to 2 MHz)	1V max
FM Transmitter	
Frequency	2250.0 MHz ±0.003%
Output Power (into 1.5:1 load)	10W min, 15W max
Deviation Sensitivity (for deviation up to ±4.5 MHz peak)	1 MHz/V peak ±10%
Frequency Response ±1 dB	DC to 5.0 MHz
Incidental AM	5% max over input range
Incidental PM	<5 kHz RMS over modulation BW
Intermodulation Distortion (2-tone equal amplitude)	≤40 dB with frequency deviation ±1 MHz

Conditioning and multiplexing for FM transmission occur in the FMSP, as shown in Figure 16. Video and wideband digital and analog signals are routed to the FM transmitter with only matching and filtering, but narrowband digital engine data are placed on subcarriers at 576, 768, and 1024 kHz.

The FM transmitter operates at 2250 MHz with an output power of 10W. Both baseband and RF filtering are provided to reduce out-of-channel interference to the PM and payload receivers. The nominal RF bandwidth is 10 MHz.

To further identify the interface between the payload system (i.e., the API and PR) and the FMSP, Table 18 presents the requirements on the input signals to the FMSP. As additional information concerning the processing of the data, Table 18 also presents the characteristics of the data signals output to the FM transmitter. Corresponding to each type of input signal, the signal source (i.e., API or PR) is identified. The signal type is either digital or analog with the digital data further specified by the type of data coding. Note that, for the NASA wideband payload data, the data coding can be either Manchester II (biphase-L) or NRZ-L, but the Manchester coded data is limited to data rates less than 2 Mbps rather than 5 Mbps for NRZ-L coded data. The signal level voltages are all peak-to-peak (p/p) and line-to-line for differential coupling and line-to-common for single-ended coupling. The impedance for all the signals is 75 ohms ±10%, except the recorded data from the PR which is 71 ohms ±10%. The rise and fall times for the digital data are also presented in Table 18. It is desirable to keep the rise and fall times less than 10% but, in some cases, absolute times are specified which determine the type of output drivers required at the PR, API and payload. Note that there is an additional specification of ±2% data asymmetry and ±0.1% bit jitter on the PR output signal to reduce the degradation associated with these types of signal distortions. The output of the FMSP for the PR signal has a specification of ±0.25% bit jitter which is expected due to the multiplication of the jitter through the FMSP buffering. Actually, each of the input signals to the FMSP should have these specifications, but typically these are not difficult specifications to meet except from tape recorders.

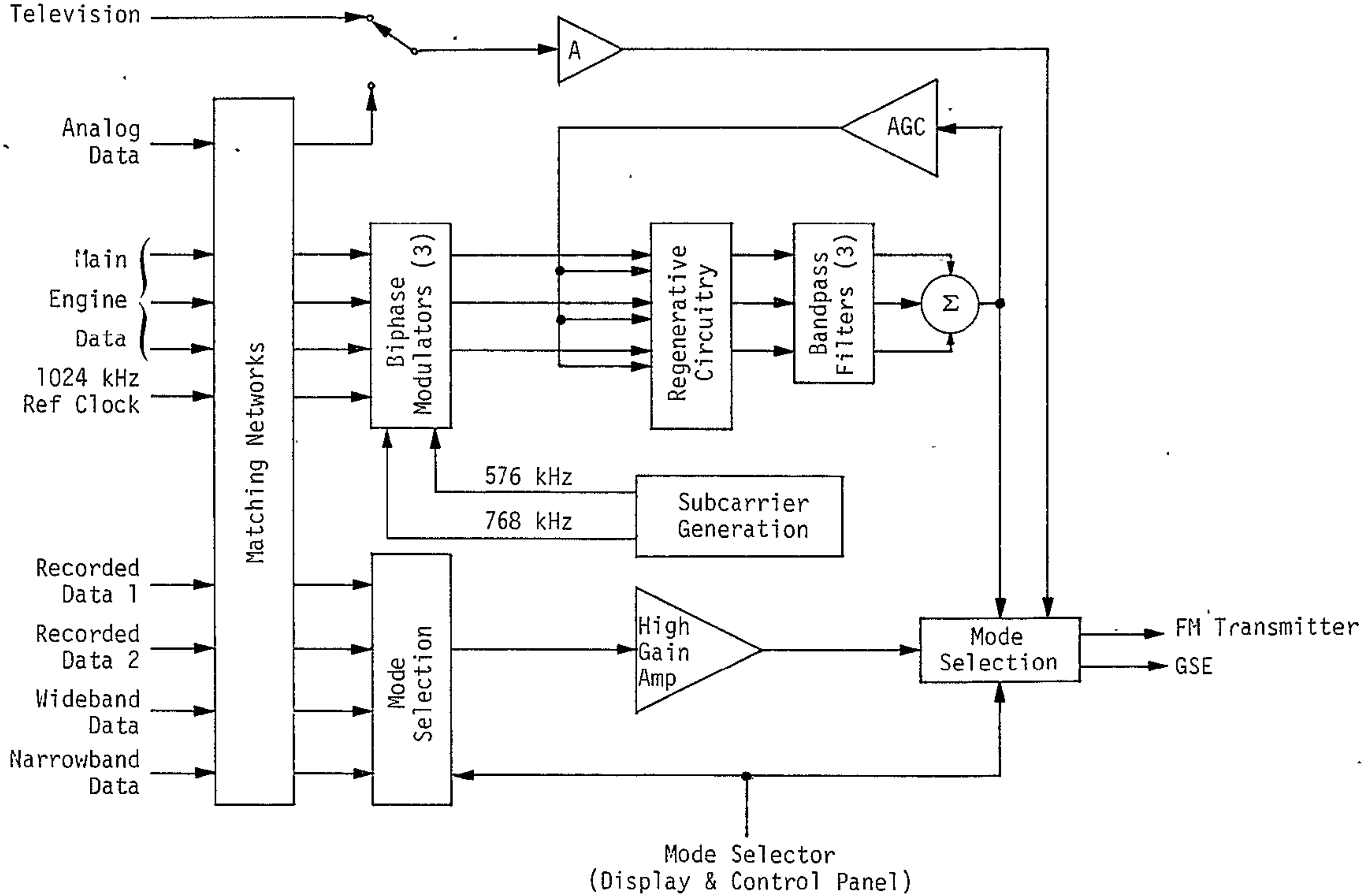


Figure 16. FM Signal Processor Functional Block Diagram

Table 18. Input and Output Signal Characteristics of FMSP for Payload Data

Signal	Signal Type	Data Coding	Data Rate	Signal Level	Rise/Fall Time	Coupling	Impedance
INPUT SIGNALS							
Recorded Data (PR)	Digital	Manchester II	22.5 kbps (min) 1024 kbps (max)	3-9V p/p line/line	<100 nsec <±2% asymmetry <0.1% bit jitter	Balanced Differential	71 ohms ±10%
Wideband Payload (API)	Digital	Manchester II NRZ-L	200 bps-2 Mbps 200 bps-5 Mbps	5V ±0.5 V p/p line/line	<50 nsec	Balanced Differential	75 ohms ±10%
Wideband Payload (API)	Analog	---	300 Hz-4 MHz	1V ±10% p/p line/line	---	Balanced Differential	75 ohms ±10%
DOD Payload (API or CIU)	Digital	Manchester II or NRZ-L	250 bps-250 kbps	1V ±0.6 V p/p line/line	<100 nsec	Balanced Differential	75 ohms ±10%
OUTPUT SIGNALS							
Recorded Data	Digital	Manchester II	22.5 kbps (min) 1024 kbps (max)	1.27V ±5% p/p	10% of bit duration;<±0.25% bit jitter	Single Ended	71 ohms ±10%
Wideband Payload	Digital	Manchester II NRZ-L	200 bps-2 Mbps 200 bps-5 Mbps	4V ±5% p/p	<10%	Single Ended	75 ohms ±10%
Wideband Payload	Analog	---	300 Hz-4 MHz	4V ±15% p/p	---	Single Ended	75 ohms ±10%
DOD Payload	Digital	Manchester II or NRZ-L	250 bps-250 kbps	1.27 V ±5%	<100 nsec	Single Ended	75 ohms ±10%

3.3.6 Multiplexer/Demultiplexer

The primary interface unit between the GPC and other subsystems is an MDM, shown in Figure 17. The MDMs act as a GPC-to-Orbiter format conversion unit. They accept serial digital information from the GPCs and convert or format this information into analog, discrete, or serial digital form for transfer to Space Shuttle subsystems. The MDMs can also receive analog, discrete, or serial digital information from the Space Shuttle subsystems and convert and format these data into serial digital words for transfer to the GPC. In addition, MDMs are used by the instrumentation subsystems, but only in a receive mode. Each MDM is controlled through either the primary port connected to the primary serial data bus or through the secondary port connected to the backup serial bus if failure is encountered with the primary system. The input and output of the MDM are via a multiplexer interface adapter (MIA).

The characteristics of the serial digital data input/output channels between the Orbiter subsystem (e.g., NSP, PSP, CIU) I/O buffer and the MDM are shown in Figure 18. The Word and Message Discretes are in the "0" states when the voltage level is between -0.6 V to +0.6 V and in the "1" states when the voltage level is between +2.1 V to +5.9 V. These discretes have differential signal termination with an impedance of 71 ±7 ohms and a rise and fall time between 10 and 90 percent of 100 to 1000 nsec, as shown in Figure 19.

When the Word Discrete is switched to a logical "1" state, the Orbiter subsystem is enabled to transmit individual words to the MDM. Figures 20 through 22 present the format for individual words to the MDM. Figure 20 illustrates the overall data format and shows the various parts of the MDM word. Figure 21 presents the specifications for the data coding. Note that the burst data rate to the MDM is 1 Mbps. The first three bits of each MDM word are used for word synchronization and are different from the normal Manchester coded bits. Figure 22 presents the specifications for the nonvalid Manchester code used for word synchronization.

When the Message Discrete is switched to a logical "1" state, the Orbiter subsystem is initiated to transfer multiple words under the control of the Word Discrete beginning with the first word. Figure 23 presents the specifications for the Message Discrete and the relationship

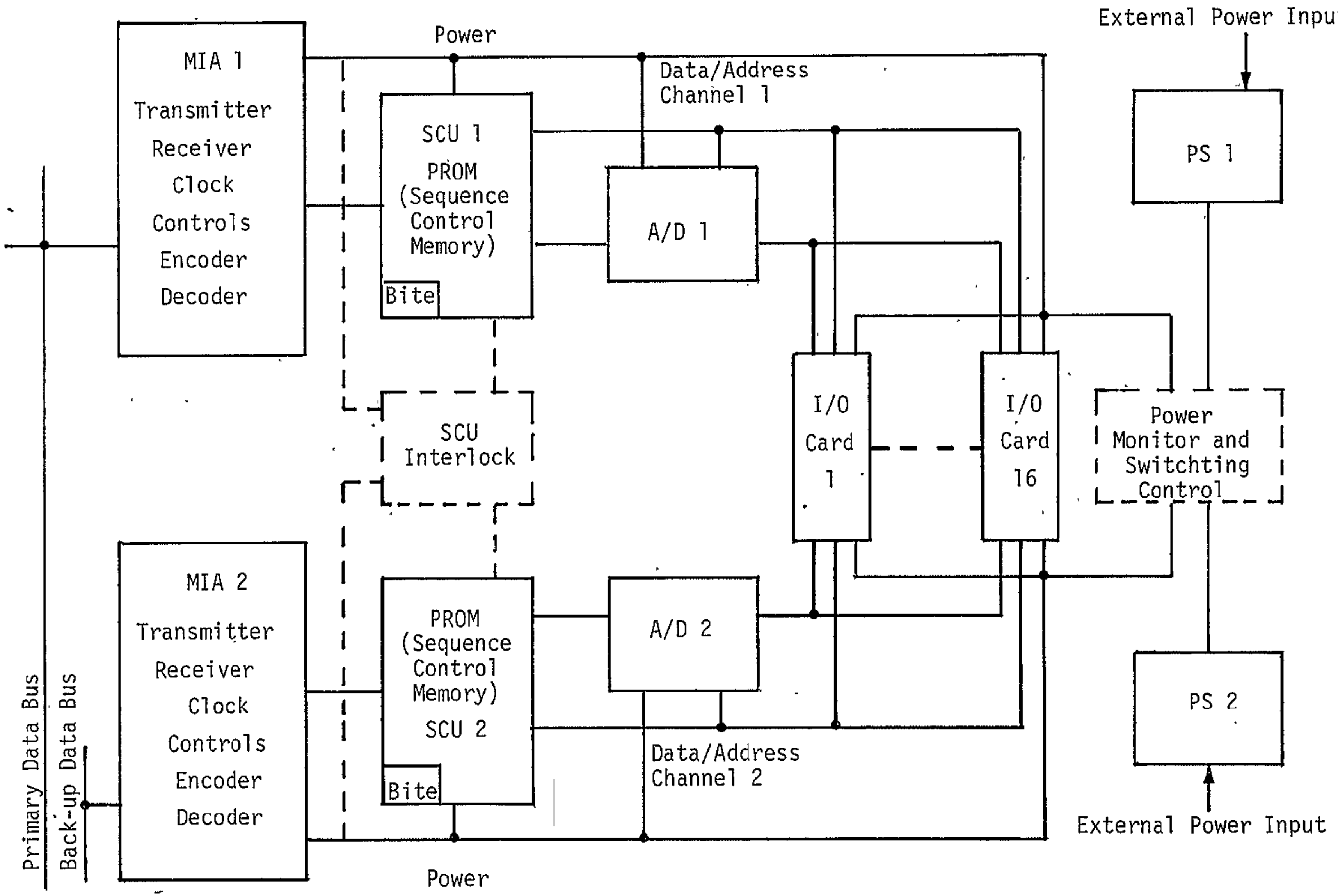


Figure 17. MDM System Block Diagram

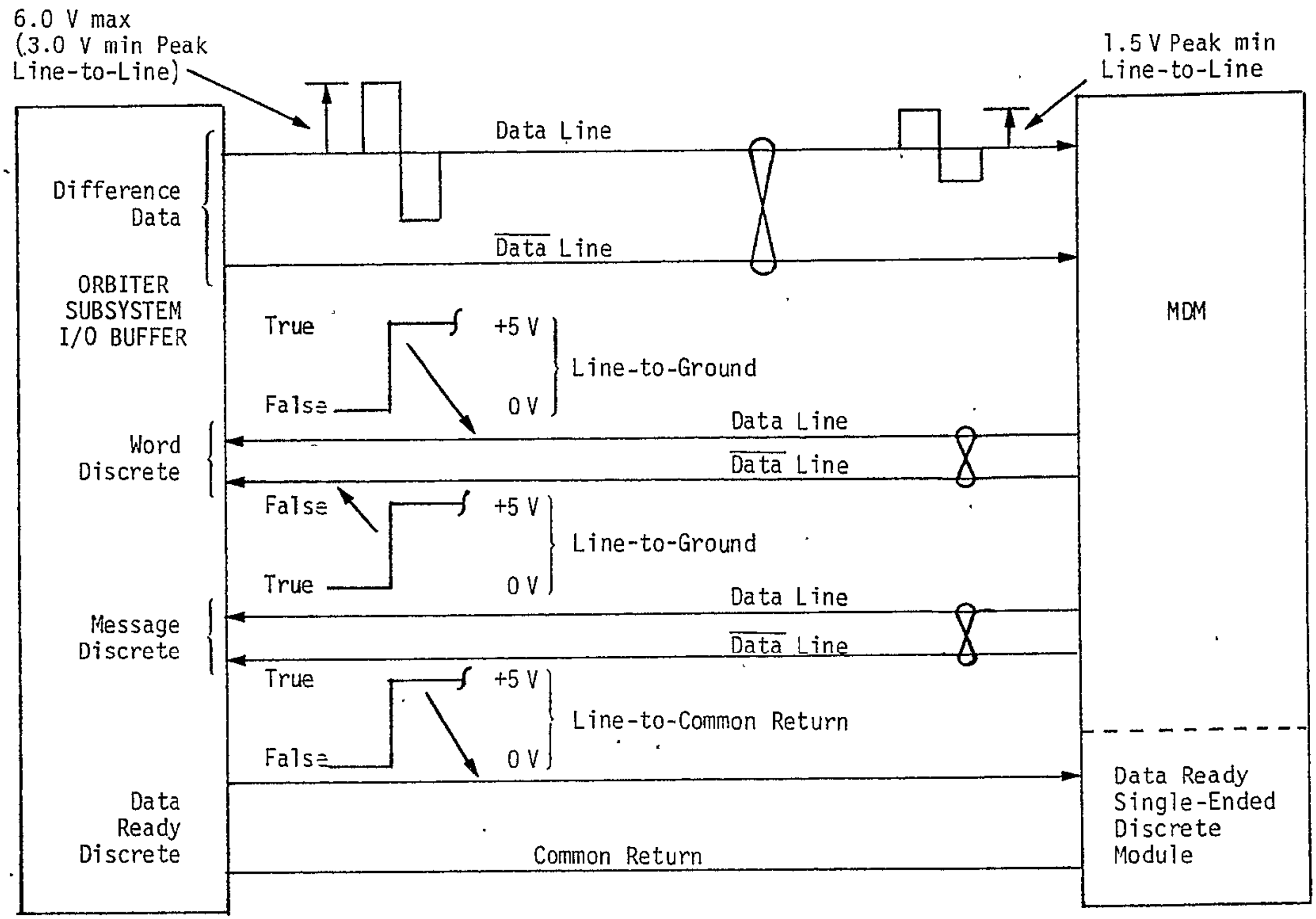
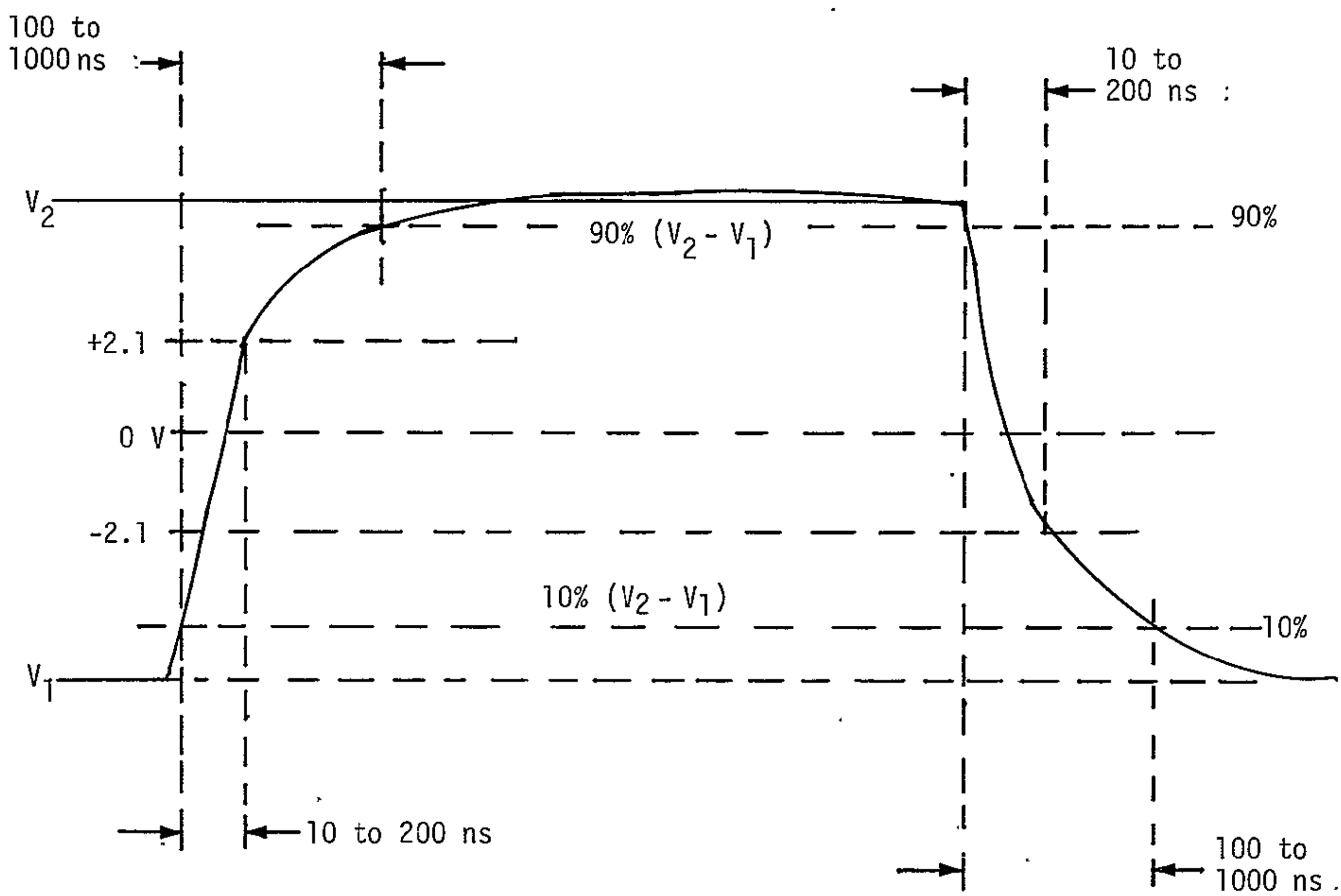


Figure 18. Serial Digital Input/Output Channel Interface



-5.9 volts $\leq V_1 \leq$ -2.1 volts

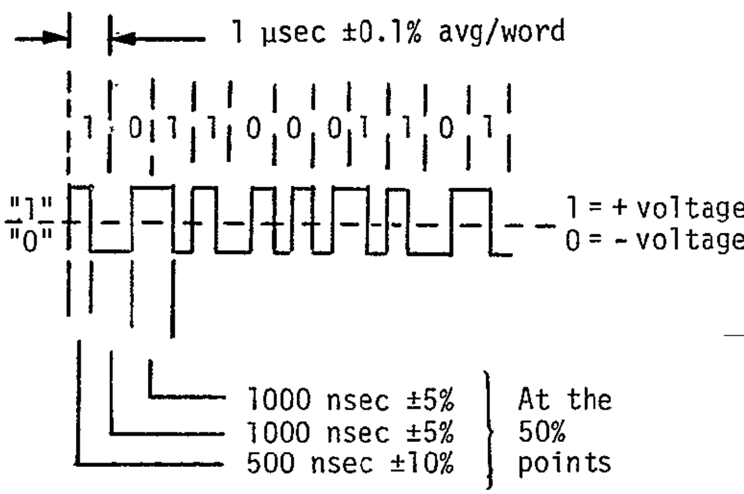
+2.1 volts $\leq V_2 \leq$ +5.9 volts

NOTE: Waveform represents line-to-line voltage excursion.

Figure 19. Rise and Fall Time

3	16		1
SYNC	SIGN OR MSB	DATA	PARITY

Figure 20. Serial Word Format



NOTE: Biphase Level (Manchester II)

"1" represented by 10
"0" represented by 01 — for Data

"1" represented by 01
"0" represented by 10 — for $\overline{\text{Data}}$

Figure 21. Data Code

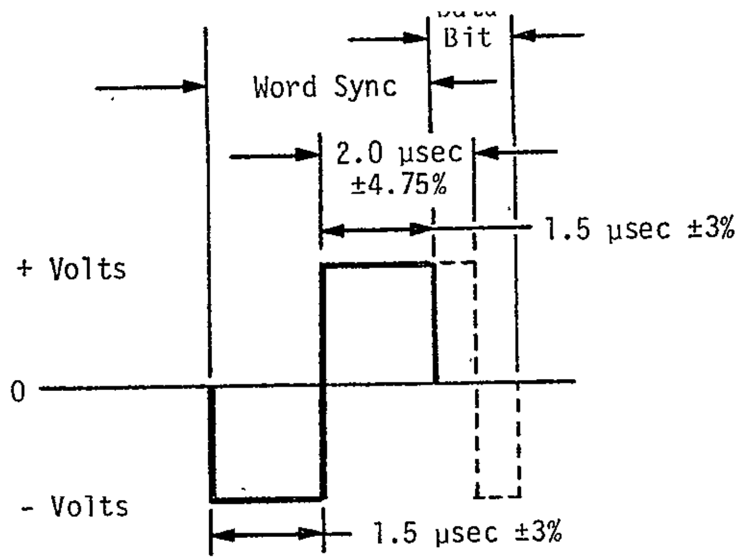


Figure 22. Data Word Synchronization, Nonvalid Manchester Code

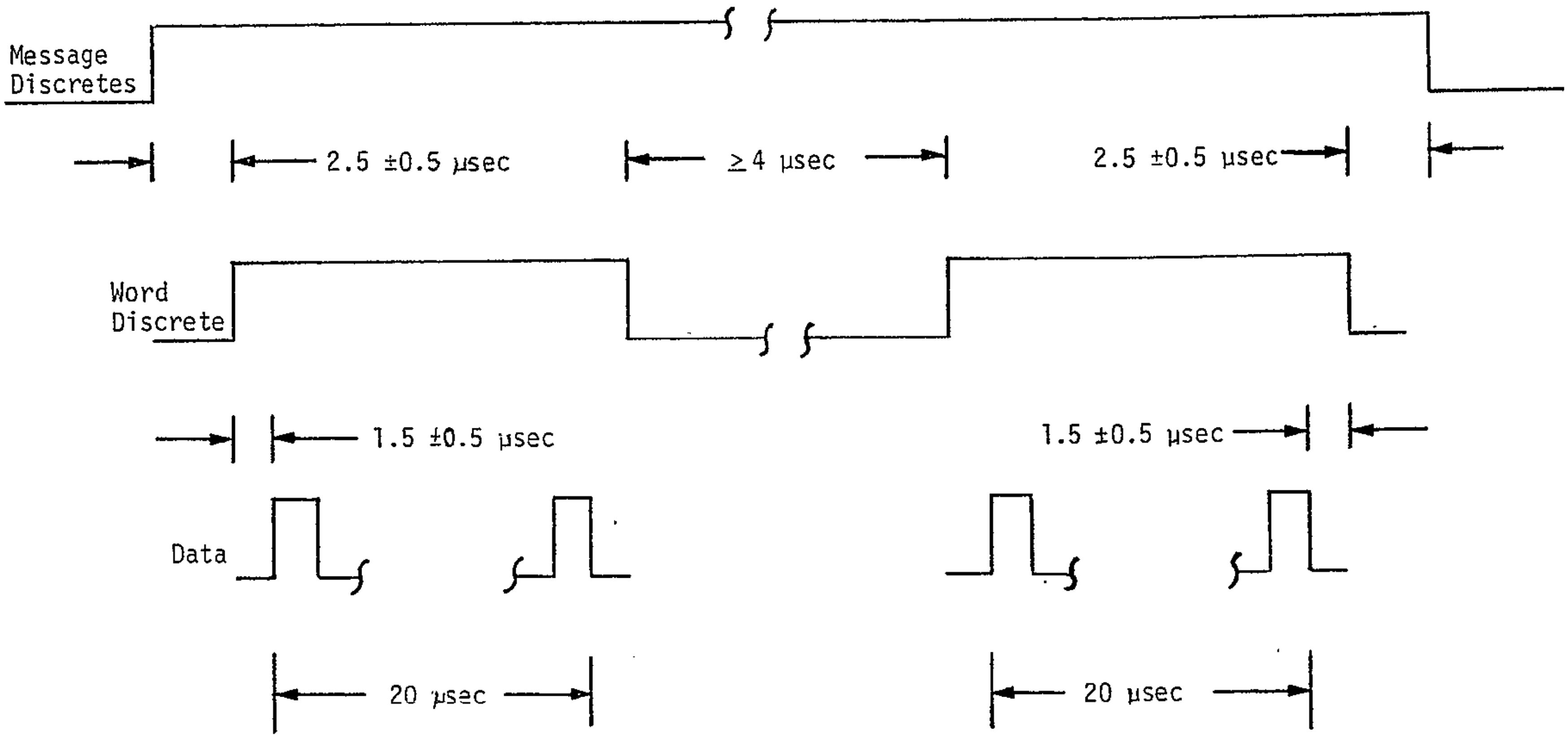


Figure 23. Serial Channel Data Transfer

between the Message Discrete and Word Discretes in the transfer of multiple MDM words.

Single-Ended Discretes are also shown in Figure 18. These discretes have the same logical state specifications as Word and Message Discretes. However, Single-Ended Discretes have rise and fall times of 20 μsec (max). The power off impedance and load impedance must be 10 kohms (max) with a line drive capacitance of 35 pf/ft (min). The corresponding input current is 2.5 mA in the "0" state and 1.25 mA in the "1" state.

The characteristics of the analog interfaces with the MDM are a voltage range of 0-5 V (peak), a source impedance of 100 ohms (max), a load impedance of 500 kohm (min), a load "OFF" impedance of 100 kohms (min) and a line drive of 35 pf/ft (min). There can be only one analog interface per return.

3.3.7 PCM Master Unit

The block diagram of the PCMMU is presented in Figure 24. Operational instrumentation (OI) sensor data (designated as downlink data) are acquired by the PCMMU in conjunction with MDMs. The MDMs, under control of the PCMMUs, accept, encode, and store the data in a random access memory (RAM) located within the PCMMU. The stored data are "refreshed" (updated) periodically under the control of a preprogrammed read-only memory. This module is known as a "fetch PROM."

GPC sensor and derived data (designated as downlist data) are acquired by GPCs and sent by a data bus to the PCMMUs. The PCMMU provides a unique double-buffer memory for each computer input, which allows data reception asynchronously while synchronously outputting previously received data. This guarantees the homogeneity of the data (i.e., output data are not overlaid by incoming data). Payload data are processed through the PCMMU in the same manner as the OI sensor data except that the PCMMU interfaces with the PDI.

The OI PCMMU, after accepting data from the MDM, computers, and PDI, formats the data into a serial digital output stream for telemetry, recording, and GSE. Format control is provided by the output formatter, which is programmable and can be modified by a set of instructions from the computers.

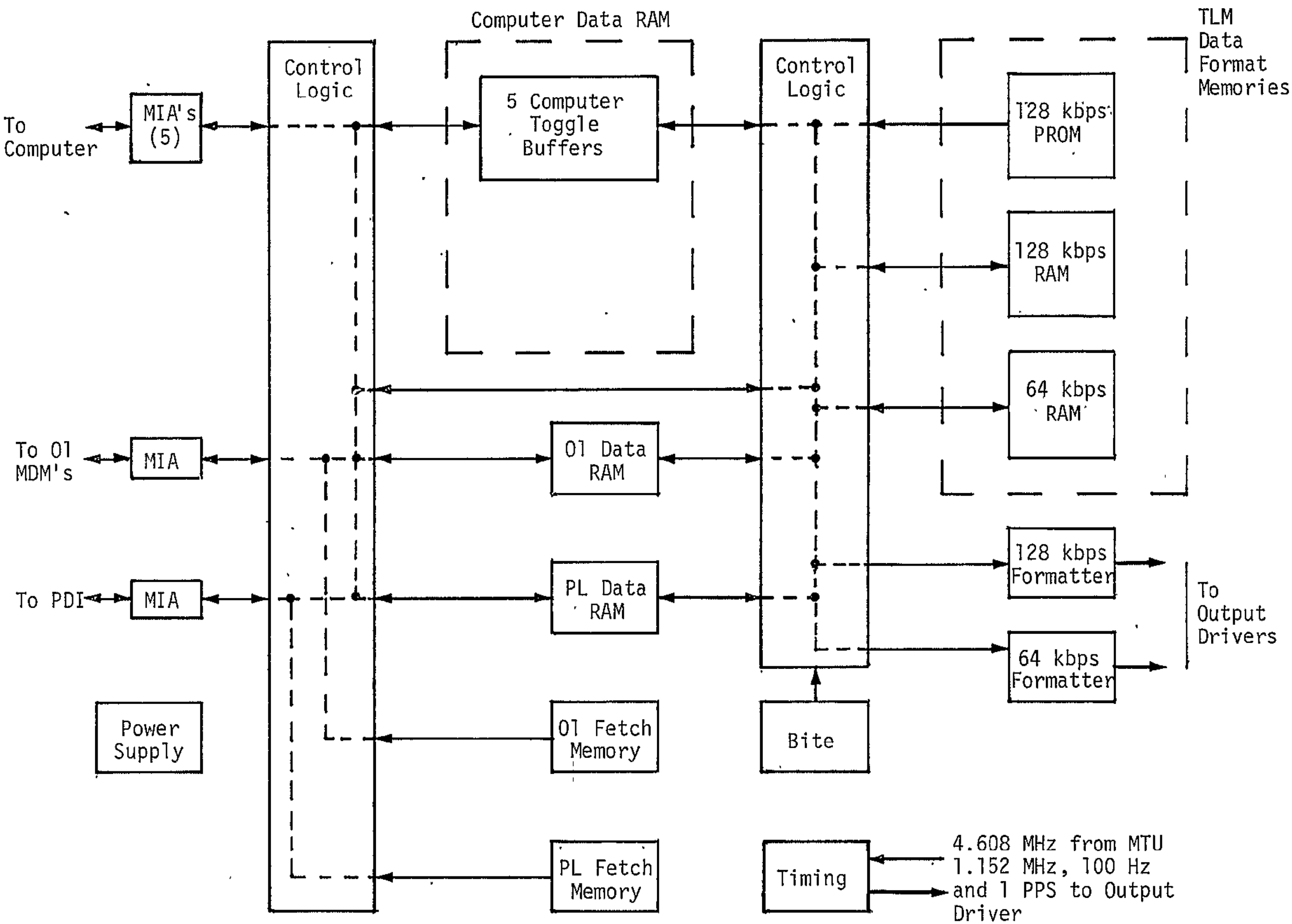


Figure 24. PCMMU Block Diagram

The PCMMU has a maximum output capability of 128 kbps for purposes of telemetry and on-board recording. The PCMMU, on command from the crew, can send 64 kbps of information. This mode is primarily used in conjunction with the low bit rate of the transmission system (S-band or Ku-band) and the TDRSS.

Formats have been developed for the ascent phase, on-orbit phase, entry phase, and ground checkout. As noted in Figure 24, one of the format memories is a 128 kbps PROM, which is a fixed format and cannot be modified by the GPC. This format is used during power-up of the Orbiter and during the ascent phase. A fixed format is necessary because loss of power to the PCMMU would result in loss of information from 64/128 kbps RAMs (volatile memory).

3.3.8 Payload Data Interleaver

The programmable PCMMU can be modified from one flight to the next. Since the Shuttle provides transportation for many types of payloads, a programmable PDI was designed to interface with the PCMMU. The PDI (Figure 25) can accept data simultaneously from five different attached payloads including the IUS/CIU and an input from the PSP, then select and individually decommutate the data for storage in a buffer memory. This memory is accessible to the PCMMU and the data are included with the Orbiter PCM stream. The PDI is programmed onboard from the mass memory through the GPC, which is used to select specific data from each payload PCM signal and transfer them to buffer memory locations. An input switch matrix selects four of the inputs for the bit synchronizers. The "chain" functions of bit synchronization, decommutation, and word selection are provided for up to four simultaneous PCM streams in two possible modes.

Mode 1: In this mode, a chain bit synchronizes, master-frame synchronizes, minor-frame synchronizes, and word synchronizes to the incoming data stream. The word selector blocks data into proper words for storage in the data RAM and/or toggle buffer. PCM code type, bit rate, PCM format, synchronization codes, and word selection are programmable under control of the decommutator format memories. Two word selection capabilities for this mode of operation are as follows:

- Type I: The first type selects all, or a subset of, the words in a payload PCM format minor frame (or master frame for formats without minor frames) for storage in the toggle buffer.

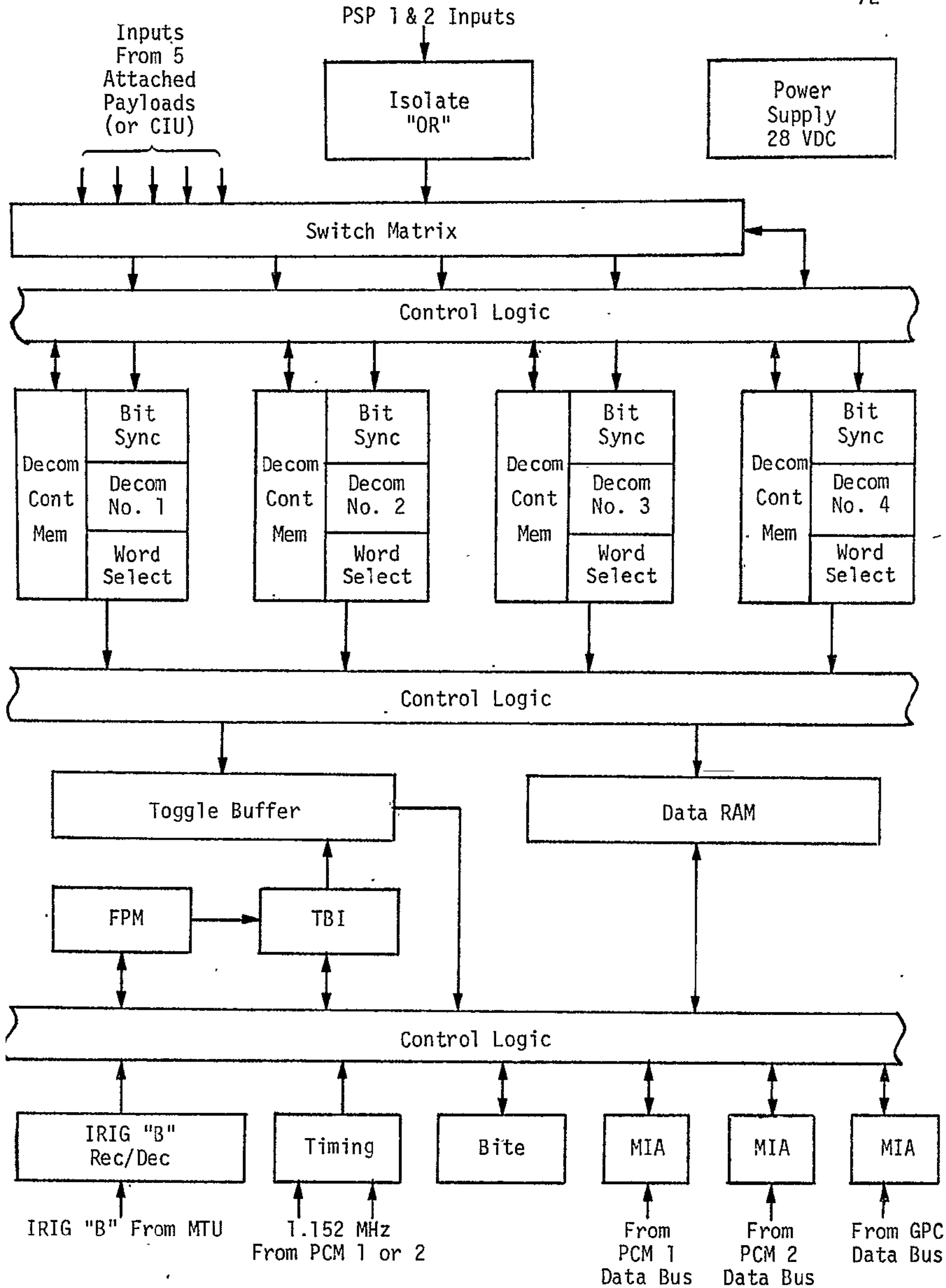


Figure 25. PDI Block Diagram

Type II: The second type of word selection is by parameter. The specification of a parameter consists of its word location within a minor frame, the first minor frame in which it appears, and its sample rate. The specification is provided as part of the decommutator control memory format load.

Mode 2: In this mode, a chain bit synchronizes to the incoming data, blocks it into 8-bit words, blocks the 8-bit words into frames, supplies synchronization pattern at the start of each frame, and includes the status register as the last three 16-bit words of each frame. A homogeneous data set for this mode of operation is defined as all information within this PDI-created frame. Code type, bit rate, frame length, and synchronization pattern are programmable under control of the decommutator format memories. The frames are supplied to the toggle buffer for storage as homogeneous data sets. No data is supplied to the data RAM in this mode of operation.

A status register containing the status and time for a given chain operation is provided by the word selector to the Toggle Buffer (TB) control logic. This logic regulates access to and from the half buffers by the word selectors and the data buses. All requests for TB data by the data ports are processed through the Fetch Pointer Memory (FPM) and the Toggle Buffer Identifier (TBI). The TB control logic also partitions data from the word selector into homogeneous data sets for access by the data bus ports.

The FPM is used to identify which TB is to be accessed by a data bus port. It also allows access to any location in the data RAM by any of the PDI data bus ports at any time. FPM control logic routes all requests for TB data to the location in the FPM identified by the data bus command word. It further provides for loading and reading of formats to and from the FPM at any time by the data bus ports.

A data RAM for storage of data from the word selector by parameter is provided. The data RAM control logic steers data provided by the word selector into addresses in the data RAM specified by the decommutator control memory.

There are three data bus ports for interface with the Orbiter GPC that have read and write access into the switch matrix, the decommutator control memory, the FPM, the PDI, and the data RAM.

An IRIG "B" receiver/decoder accepts an IRIG "B" code from an external source, decodes time, and supplies it to the four status registers.

3.3.9 Payload Experiment Recorder

The data recording system uses wideband digital and analog magnetic tape recorders to record and reproduce digital and analog signals. The magnetic tape recorder data storage system consists of two components. The first component comprises the multitrack coaxial reel-to-reel tape transport and its associated electronics. The tape transport features negator spring tension and contains a minimum of 2400 usable feet of 0.5-inch by 1-mil magnetized tape. The transport can store a minimum of 3.4×10^9 bits of digital data. The second component contains additional data conditioning circuitry and all other control logic and associated electronics.

Payload experiment data recording is provided via the payload station panel. Predetermined patch panel wiring permits digital data recording in either parallel (up to 14 tracks) or a combination of parallel-serial. Data rates from 25.5 kbps (lowest rate for a tape speed of 6 inches per second [ips]) to 1024 kbps (highest rate for a tape speed of 120 ips) can be selected from four tape speeds provided by premission wiring of recorder program plugs.

Analog data can be recorded on up to 14 tracks in parallel with frequencies from 1.9 kHz (lowest frequency for 6 ips tape speed) to 1.6 MHz (highest frequency for 120 ips tape speed) by premission program wiring. The basic recorder has the following record/playback capabilities:

Data Range (kbps)	Frequency Range (kHz)	Selectable Tape Speed (ips)	Time Per Track (min)
64-128	1.9-250	15	32
128-256	3.8-500	30	16
256-512	7.5-1000	60	8
512-1024	1.5-1600	120	4

3.4 IUS Communication Equipment

Two Orbiter/IUS communication configurations will be used for the DOD and NASA IUS missions. Operational constraints, however, may require the use of a DOD IUS for NASA payload missions such as the TDRS launch. The DOD IUS uses the SGLS transponder for communications with the Orbiter. Alternately, the NASA IUS uses the STDN/TDRS transponder in the STDN mode for communications with the Orbiter.

3.4.1 IUS SGLS Transponder

The telemetry, tracking and command (TT&C) SGLS transponder acquires and tracks, with a phase-locked loop, an incoming S-band signal and provides demodulated spacecraft commands to the decoder. The transponder also receives data and telemetry from the spacecraft and phase modulates this information and the internally demodulated ranging tones onto an S-band 3W carrier which is provided to the antenna for downlink transmission.

The transponder shown in a functional block diagram, Figure 26, is a single unit consisting of an S-band receiver and transmitter. This transponder configuration performs the following functions:

(1) Searches and acquires an SGLS-compatible S-band signal with modulation.

(2) Provides a coherent return link, when in the VCXO mode, with a fixed 256/205 transmit-to-receive frequency ratio.

(3) Provides a noncoherent stable return link signal when in the auxiliary oscillator mode.

(4) Receives, demodulates command signals, outputting commands and clock signals.

(5) Receives, demodulates to baseband, and remodulates ranging signals on the return link carrier to provide coherent turn-around ranging.

(6) Accepts, modulates, and transmits various analog and digital telemetry data on the return link.

(7) Provides telemetry outputs of key transponder parameters and operational status of the transponder.

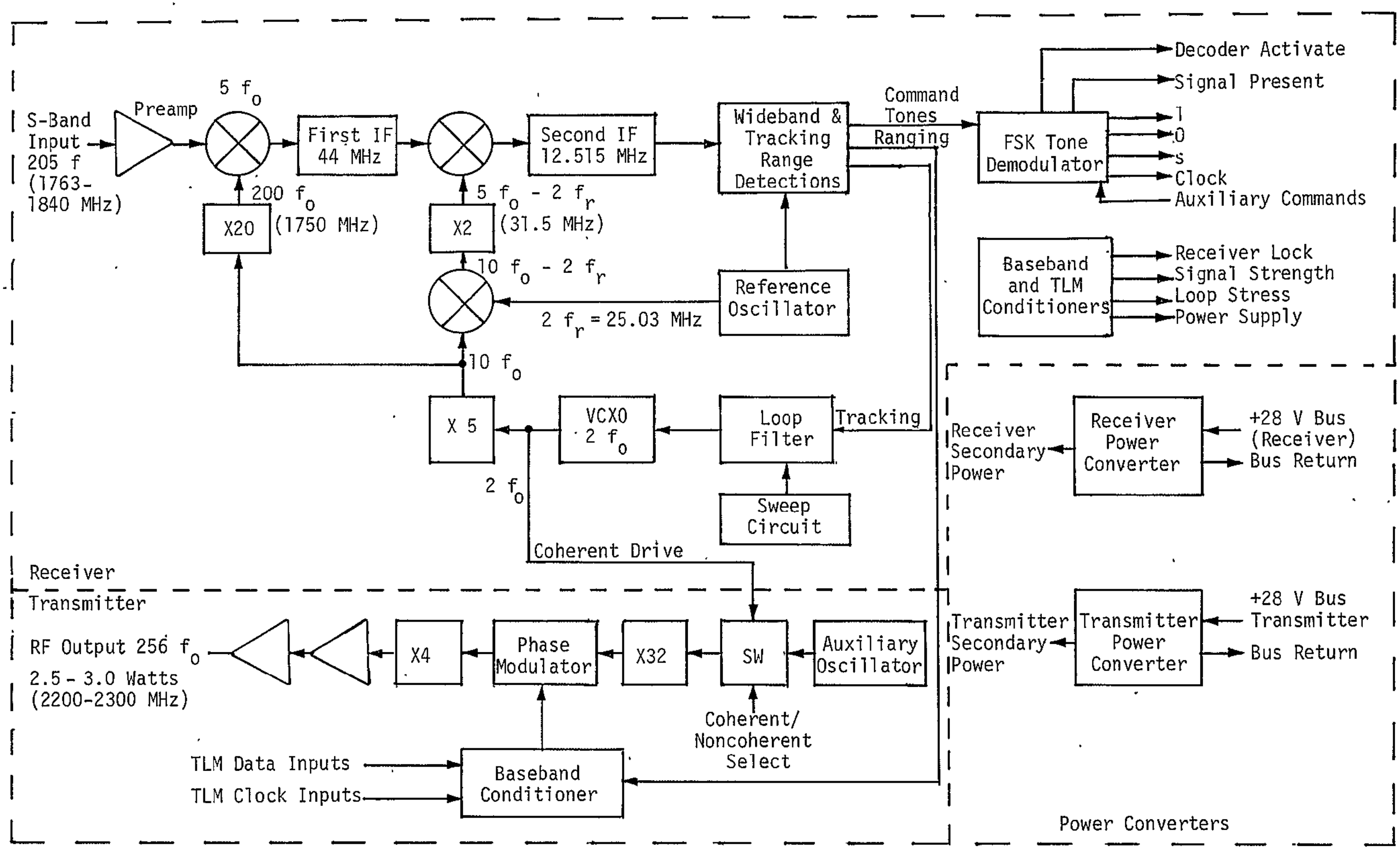


Figure 26. Transponder Functional Block Diagram

(8) Operates in the receive and transmit modes independently by way of having separate dc-to-dc converters.

The receiver utilizes a dual downconversion, fully phase-coherent design, incorporating a second-order phase-lock loop. S-band input signals in the frequency range of 1763-1840 MHz are amplified in a low noise preamplifier before downconversion to a first IF frequency of approximately 44 MHz. Amplification, gain control and bandwidth limiting are accomplished in the first IF circuits before further downconversion to 12.515 MHz. Then the signal is further amplified and sent to the demodulator module circuits. Here, four functions are performed:

(1) Acquisition. Operates in conjunction with the discriminator module to acquire an SGLS signal (including modulation).

(2) Phase detection. A predetection filter (30 kHz crystal filter) reduces the noise spectrum before phase detection takes place in the carrier tracking phase lock loop. Loop bandwidth (B_L) is 2 kHz.

(3) Coherent amplitude detection. Another detector, using a 90° phase-shifted reference, produces an output proportional to the RF carrier amplitude. This output forms the correction signal in the automatic gain control (AGC) loop and signal strength information for telemetry.

(4) Wideband detection. A wideband phase detector which, unlike the above two detectors, is not preceded by a narrowband filter, is used to demodulate the phase modulation from the uplink carrier. The output of this demodulator provides the wideband data output to the baseband circuits where filtering separates ranging and command data. The demodulator module also contains the VCXO, loop filter, and the VCXO sweep circuitry used to scan the receiver center frequency over the frequency acquisition range.

The discriminator module does not allow the receiver to acquire to a sideband and, upon carrier acquisition, commands the sweep off in the demodulator.

Acquisition threshold detectors and the AGC loop filter, along with various telemetry circuits, are contained in the baseband module with ranging and command filter channels. Command baseband signals from the baseband module are fed to a tone demodulator where command and clock signals are detected, reconstructed, and output from the receiver. Ranging baseband signals exit the receiver and are sent to the transmitter for downlink modulation and transmission.

The S-band transmitter operates from an internal auxiliary oscillator in the noncoherent mode, or from a VCXO output provided by the receiver (coherent mode). Selection of the source can be determined by command or will be automatically set by the phase lock status of the receiver. Both sources are at a frequency of $2f_0$, approximately 17.5 MHz.

Frequency multipliers utilizing SAW filters increase the output frequency to S-band at 256 f_0. Phase modulation is performed at 1/4 the output frequency, approximately 560 MHz. The modulator utilizes a quadrature hybrid terminated in voltage variable reactances to achieve linear phase modulation.

Digital telemetry and data are biphase modulated on a 1.024 MHz subcarrier while the analog data is FM modulated onto a 1.7 MHz subcarrier. These signals are summed with the turn-around ranging tones before they are provided to the linear phase modulator. An option is available to replace the 1.7 MHz FM subcarrier with a 1.7 MHz biphase modulated subcarrier. The transmitter also provides variable modulation indices of the subcarrier automatically when either of the subcarriers are commanded off.

The S-band power amplifiers are wideband circuits culminating in a circulator protecting the 2.5 to 3.5W output from shorted or open loads. A separate high efficiency dc-dc power converter provides operating power to the transmitter upon command.

3.4.2 IUS STDN/TDRS Transponder

The STDN/TDRS transponder is a multimode device capable of receiving and transmitting signals compatible with both the STDN and TDRS operational modes and signal formats. An abbreviated block diagram of the transponder is shown in Figure 27. A summary of transponder functions is given below:

- Provides two-way coherent communications with the Orbiter, STDN ground station or TDRS satellites at the appropriate S-band frequency.

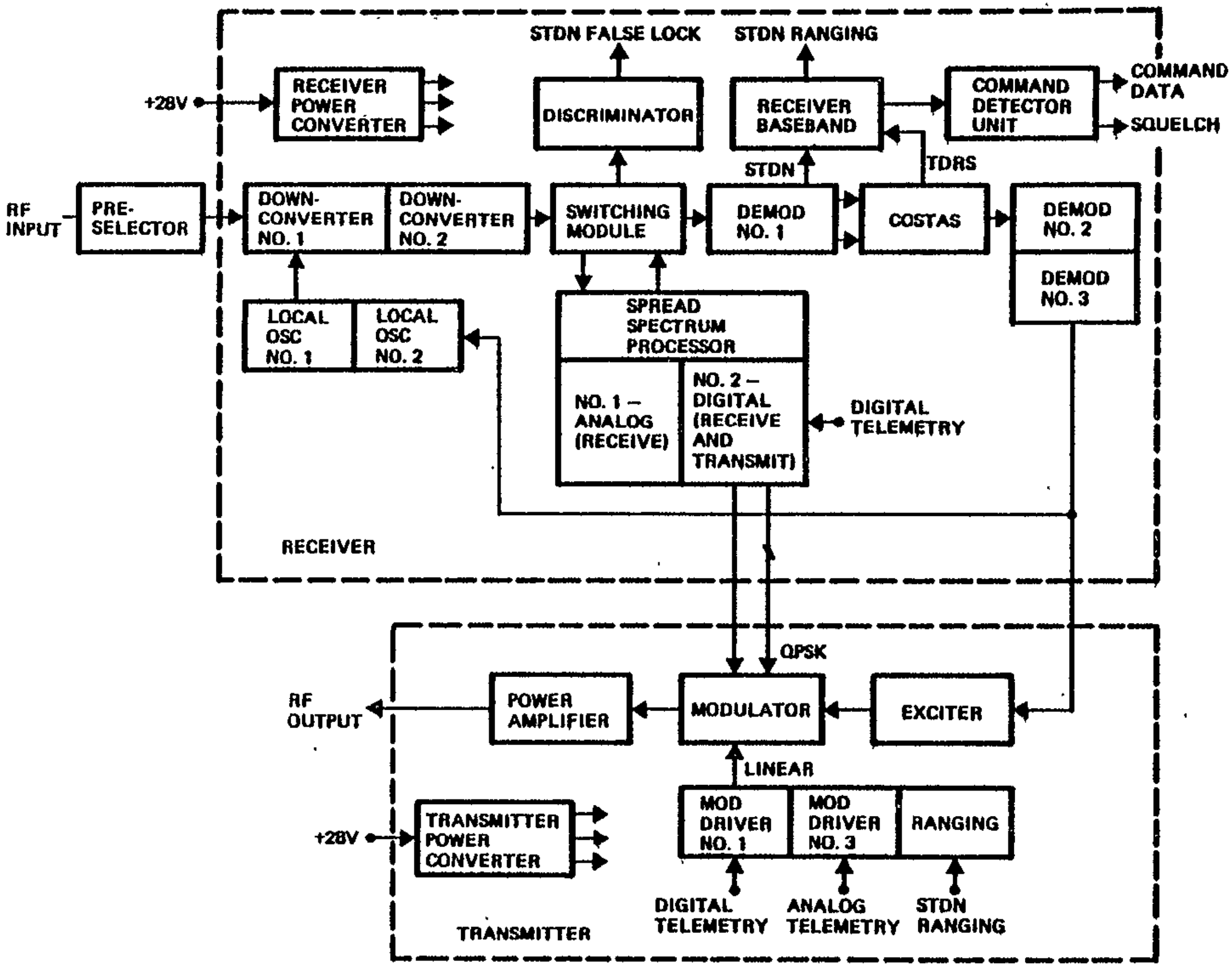


Figure 27. STDN/TDRS Transponder

- Transponds with a coherency ratio of 240/221

- Acquires and demodulates STDN signals in 1/2 second ($\geq$ -117 dBm) when commanded to the STDN ONLY fast acquisition mode

- Recognizes, acquires and demodulates either STDN or TDRS signals when commanded to the DUAL mode; transponder recognizes signals based on the signal structure rather than on the signal level

- Incorporates a command decoder unit which demodulates the STDN subcarrier and recovers the 2 kbps clock and data signals in either mode; a data squelch circuit based on the measurement of E_B/N_o is also included

- Removes the 3 Mbps spread-spectrum code from the TDRS command channel signal and recovers the range synchronization from the TDRS spread-spectrum range channel signal

- QPSK or PM modulates the coherent S-band transmit carrier with telemetry and ranging data; in TDRS, the carrier is also coherently spread at about 3 Mbps

- Provides noncoherent telemetry transmission in the absence of received signals or when commanded.

The basic transponder configuration is the same for both the STDN and TDRS modes; that is, both are configured to utilize the same frequency plan, receiver and transmitter RF and IF modules. The TDRS 3 Mbps PN code is removed by a spread-spectrum processor using a noncoherent code loop; fast acquisition is accomplished using sequential detection. The TDRS signals are demodulated using a Costas circuit; the STDN signals are demodulated using a conventional linear phase lock loop.

The received signal is amplified by a low noise preamplifier prior to a first downconversion to approximately 47 MHz. A second coherent downconversion brings the signal to the second IF (F_R = 13.8 MHz); due to the design of the frequency plan, this second IF operates at a fixed frequency regardless of the input frequency. The second IF signal is divided three ways and is simultaneously sent to the discriminator, the carrier (coherent) demodulator and the spread-spectrum processor.

The discriminator is employed as an aid to fast acquisition of modulated STDN signals; its sole purpose is to prevent the receiver from lock-

The spread-spectrum processor has two functions. The first is to acquire, despread and track the TDRS command channel signal, and to send the despread command channel IF signal to the demodulator. The second is to acquire synchronization of the TDRS range channel (spread) signal and to generate synchronized "I" and "Q" range codes for use by the transmitter in order to accomplish TDRS mode turn-around ranging.

The demodulator is employed to recover the data signals which are modulated onto the carrier. It can be configured as either a linear demodulator (STDN signals) or a Costas PSK demodulator (TDRS signals). It generates the phase error signal used to lock up the receiver VCXO; it also generates the coherent amplitude detector (CAD) signal which indicates receiver lock. In the special Spinner configuration, the demodulator is configured as a linear demodulator even though the input signal is TDRS. This is allowable since, in this mode, there is no command data modulation and, thus, the despread signal sent to the demodulator is always CW rather than PSK; the motivation is to achieve the required -135 dBm sensitivity for this mode. The receiver also contains the VCXO, switches, sweeper, etc., as well as the master control algorithm necessary to carry out the various lock-up sequences.

In the normal configuration, the demodulated data (baseband) signals are sent to the command detector unit (CDU). This unit contains a subcarrier demodulator and a bit synchronizer. The subcarrier demodulator recovers the 2 kbps data from the STDN 16 kHz PSK subcarrier; it employs a frequency-doubling subcarrier recovery loop. The bit synchronizer is an advanced design capable of recovering and reclocking data at three different selectable data rates (2 kbps, 2 kbps/N and 2 kbps/M), where N and M may be an integer from one to 16; only 2 kbps is used for the IUS program. The bit synchronizer clock recovery loop employs a crystal oscillator and an incremental phase lock loop to achieve excellent performance even at low bit transition densities. The bit synchronizer also includes a combined squelch and bit synchronization lock circuit which is insensitive to bit transition density. The outputs of the CDU are the data and clock and an ACTIVATE (desquelch) signal. Upon command, the CDU is also capable of demodulating an auxiliary 16 kHz PSK subcarrier signal.

The return link signal is provided by the transmitter, shown in the lower portion of Figure 27. The STDN mode service consists of a

1.024 MHz PSK subcarrier for digital telemetry, a 1.7 MHz subcarrier for analog telemetry and the ranging signal. These signals are assembled at baseband and used to modulate a linear phase modulator operating at 1/4 the output frequency. This signal is frequency multiplied X4; in the STDN mode, the inputs to the QPSK modulator are held to a logical one. The signal is amplified to 3.0W nominal and passed through an isolator to the output.

In the TDRS mode, the services consist of a digital telemetry signal which is convolutionally encoded within the transmitter, and range information contained within the return link spreading code (coherent mode). In the noncoherent mode, separate noncoherent PN code generators are employed. The encoded data and PN spreading codes are combined in "exclusive-OR" circuits and used to modulate the QPSK modulator. No special RF filtering is provided for PN code modulation sidebands other than that necessary to protect the receiver.

The basic frequency plan is depicted in Figure 28 which shows that the phase lock loop is closed around the first and second mixers. The first and second IF frequencies were established after careful spurious studies by TRW. The selected frequencies are not multiples of the VCXO or any internally generated signal, eliminating the potential for self-lock or regeneration problems. The first IF at 5 f_0 is at a frequency low enough to achieve a high degree of selectivity using conventional filtering and high enough to achieve broadband designs that are insensitive to time delay variation (< ±40 ns) over the dynamic range.

A unique feature of the design is the technique employed to maintain a constant second IF frequency independent of the input channel selection. A reference "offset" oscillator is combined with five times the VCXO frequency in the third mixer. The third mixer output is divided by two and used as the second mixer LO signal. The second IF signal is then at a fixed frequency. This frequency plan has the advantage that one set of hardware can service all transponder configurations. An additional advantage is that placing the higher signal power second IF and phase detector circuits at a frequency noncoherently related to the S-band input signals eliminates regeneration of self-lock problems that can arise in a system where these circuits are at submultiples of the S-band input frequency. The frequency plan allows the input channel assignment to be changed by replacing the module assemblies containing the receiver VCXO, the transmitter TCXO and the SSP VCXO.

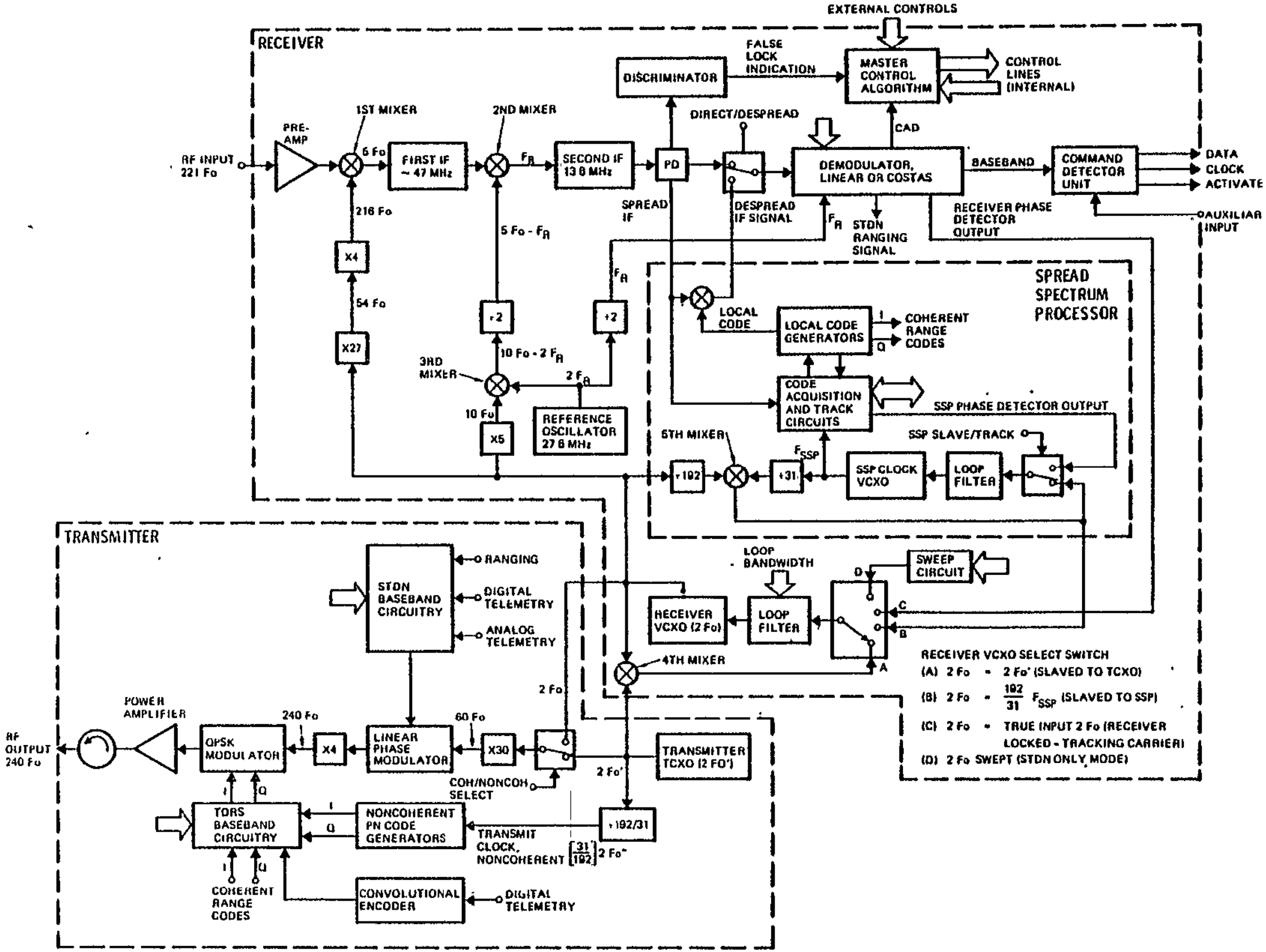


Figure 28. IUS NASA Simplified Block Diagram

Spurious outputs and harmonics of the local oscillator and the transmitter X30 frequencies are controlled by Surface Acoustic Wave (SAW) filters which also have the advantage of providing a much lower part count than discrete designs and do not require tuning. The SAW devices have been designed specifically for this transponder service and do not require change or replacement for different channel assignment selections.

Another aspect of the frequency plan relates to the PN code rates which are coherently related to the uplink and downlink carrier frequencies. The transmitter noncoherent mode PN code rate is derived from the transmitter TCXO using a ÷192/31 indirect synthesizer technique. The receiver VCXO and SSP VCXO are also tied together using the same ratio during the acquisition sequence; this sequence is detailed in the following paragraphs.

The requirement for dual-mode acquisition is to recognize either a fixed frequency TDRS spread signal or a swept unmodulated STDN signal, and to configure the receiver to allow acquisition of the recognized signal while locking out the other. This transponder differentiates between the two types of signals based on signal structure rather than power level. Figure 28 shows the transponder with all the switches in the DUAL mode acquisition configuration. The input signal is sent to both the SSP and the demodulator; the demodulator is configured as a linear demodulator and thus the coherent amplitude detector (CAD) will respond to a CW signal which sweeps through the receiver center frequency. The center frequency is fixed according to the scheme described in the next paragraph. If an STDN signal sweeps to within reach of the linear demodulator (± the loop bandwidth), the CAD will so indicate, and the algorithm will declare STDN and proceed. If, on the other hand, a TDRS signal appears, the SSP will acquire and begin to track the short (command) code signal; short code lock will be indicated and the algorithm will declare TDRS and proceed.

At the beginning of this sequence, it is required by the specification that the receiver center frequency be fixed and predictable to within ±700 Hz at S-band. This is accomplished by slaving the receiver VCXO to the transmitter TCXO using the fourth mixer; the TCXO is a very stable oscillator having a thermistor attached to the return link telemetry system; the ground station is provided with a calibration curve showing the TCXO frequency versus the thermistor voltage. In addition, the SSP code rate VCXO is slaved to the receiver VCXO using the fifth mixer and the ÷192/31 circuits; this guarantees that the SSP clock is known to within about 1 Hz, which is important to the proper operation of the sequential detection circuits within the SSP.

For a TDRS signal, the TDRS ground station adjusts the forward link frequency to correct for doppler and for what it thinks is the actual receiver center frequency. This is supposed to bring the received frequency of a TDRS signal to within ±1400 Hz of the actual receiver fixed center frequency. If a TDRS signal appears and the SSP detects the presence of a short code signal, the following sequence of events occur:

- The SSP will switch its code-tracking loop from "slave" to "track" and will begin tracking the received code; it will verify track, then send a "short code lock" indicator signal to the receiver control algorithm circuit.

- The receiver VCXO select switch will then be switched from position A to position B; this will cause the receiver VCXO to be slaved to the SSP VCXO using the fifth mixer and the ÷192/31 circuits. Since the SSP is tracking the actual received code, the receiver VCXO will be pulled toward the frequency which exactly matches the input RF frequency.

- At the same time, the demodulator is reconfigured as a Costas demodulator and the despread IF signal from the SSP is routed to the demodulator. When the received signal is pulled to within one loop bandwidth of the true center frequency by the action of the slaving circuit, the Costas CAD circuit so indicates; the receiver lockup is completed by switching the receiver VCXO select switch to position "C" to allow the carrier loop to begin tracking.

If carrier lock is not achieved within 5 seconds, the SSP algorithm assumes that the signal was multipath and the acquisition sequence is reinitiated.

If an STDN signal appears and is recognized, the receiver VCXO select switch is switched directly to position "C" and the carrier loop commences tracking. In either event, the receiver control algorithm configures the command detector unit (CDU) to match the received signal (TDRS or STDN), and also sends the lock-up information to the transmitter control algorithm circuit. The transmitter is then reconfigured and switched to coherent, assuming that the external TXR command is COHERENT. Note that, in the TDRS mode, this does not occur until long (range) code lockup is verified.

In the STDN mode only, the requirement is to correctly acquire an STDN signal modulated with a 16 kHz command subcarrier (but no range tones) and to achieve this within 1/2 second at signal levels $\geq$ -117 dBm. The STDN signal may be swept or it may be stationary. In this mode, the receiver VCXO select switch is set to position "D", which causes the receiver to sweep ±150 kHz every 300 ms. The demodulator is configured for linear. A true lock indication is declared when both of the following conditions are achieved:

- The demodulator CAD indicates the presence of a CW signal within the acquisition loop bandwidth (±4 kHz)
- The discriminator indicates that this CW signal is not a sideband of the received carrier.

The discriminator is thus used to prevent false lock on the STDN subcarrier. It is equipped with a dual (±) threshold which indicates positive if the incoming carrier is ±16 kHz from the true receiver center frequency, as it would be if the receiver was attempting to lock on to a subcarrier sideband.

If both of the above conditions are satisfied, the receiver select switch is switched to position "C" and tracking commences. When tracking is verified, the carrier loop bandwidth is narrowed to 800 Hz to prevent tracking out the 4 kHz range tone when it is turned on.

3.5 IUS/Orbiter Communication Interface Issues

The overall IUS/Orbiter communication system is still evolving. Direct payload-interfacing avionic subsystems such as the PI, PSP and CIU are in their preliminary design stages only. Other hardware, such as the S-band network communications and the Ku-band communication equipment, is more fully developed but only the S-band network communication equipment is entering its performance verification testing phase. Thus, it will be some time before all developmental problems are solved, and reliable, well-understood performance can be documented.

Table 19 summarizes the major interface issues in which Axiomatix had been involved. The interface issues in Table 19 are addressed in terms of the nature of the issue and the effort expended by all concerned (TRW, Boeing, SAMSO, Aerospace, Rockwell, NASA and Axiomatix) toward its resolution.

3.5.1 PI/SGLS Transponder Interface Issues

Each parameter involved in the interface between the PI and the SGLS transponder, as defined by the SGLS transponder specification, the Payload ICD or the PI specification, is compared in Tables 20 and 21. Note that, for the interface between the PI transmitter and the SGLS transponder receiver, there is no specification by the SGLS transponder on the carrier phase noise and the output spurs of the PI. In Table 21, there is no specification on the SGLS transponder transmitter for subcarrier harmonic components or data asymmetry. Also, the SGLS transponder specification for the allowed variation in modulation index is 15%, which is larger than the PI can tolerate (10%).

In order to resolve some of the interface parameter inconsistencies, some overall system analysis is required. For example, the phase noise specifications need to be defined for the link from the PI to the SGLS transponder to determine the command channel BER. Both the phase noise generated by the frequency synthesizer in the PI transmitter and the oscillators used in the transponder affect the command channel BER and, therefore, system analysis must be made to allocate a phase noise specification for the PI and transponder. Similarly, the phase noise generated by the PI receiver frequency synthesizer, the oscillators used in the transponder transmitter, and the turn-around characteristics of the transponder, affect the telemetry channel BER. Therefore, system analysis must be made to allocate a phase noise specification to the PI receiver, transponder oscillators and turn-around characteristics. Axiomatix has developed the analysis needed to predict the command channel BER based on phase noise characteristics; however, while some specifications have been made on the phase noise of the PI transmitter and receiver and on the phase noise of the transponder, the turn-around characteristics have not been specified and the actual phase noise performance of the PI transmitter and receiver frequency synthesizer has not been completed. Hence,

Table 19. Major IUS/Orbiter Communication Interface Issues

Issue	Issue Nature	Effort Toward Resolution	Resolution
Ku-Band 128 kbps to 2 kbps command data	1. SGLS command data is 1 kbps with ternary symbols. 2. Ku-band forward link is binary data at 128 kbps.	Define format that meets the required BER and is easy to implement. (Axiomatix)	64 Ku-band 128 kbps 1's are equal to a 2 kbps "1". 64 Ku-band 128 kbps 0's are equal to a 2 kbps "0" 01 = "S" 1 ksps 11 = "1" 1 ksps 00 = "0" 1 ksps.
CIU/MDM Interface	1. CIU has only an MDM serial interface and does not have the required input/output interfaces to implement the required handshake procedure. 2. CIU buffer for the MDM command data is not large enough for a command and its complement to be held at the CIU in one MDM transfer. 2. Interface inconsistencies between CIU specification and payload ICD.	1. Axiomatix/NASA pointed out the MDM interface deficiency at a NASA/SAMSO meeting on 8/15/78. 2. RID-35 at CIU PDR. (Aerospace) 3. Tables 26 and 27 compare the PSP and CIU specifications with the Payload ICD.(Axiomatix)	1. Resolved by ground command input control or CIU control panel control by limitation on the command rate into the CIU and verification of accepted commands using the VCC word. 2. To be resolved by Boeing at CIU CDR. 3. Comparison must be made with performance data at CIU CDR.
Frequency Stability	SGLS and STDN/TDRS transponder auxiliary oscillator stability may cause a frequency uncertainty that is larger than PI receiver acquisition range.	1. Investigation of increasing the PI receiver acquisition sweep range.(TRW) 2. Analysis of aging & environmental changes to oscillator stability. (TRW)	In process. Need more data on oscillator stability for TRW

Table 19. Major IUS/Orbiter Communication Interface Issues (Cont'd)

Issue	Issue Nature	Effort Toward Resolution	Resolution
Phase Noise and Communications Turn-around Characteristics	1. Phase noise requirements of PI. 2. Phase noise requirements of SGLS & STDN/TDRS transponder. 3. Effects of turn-around phase noise.	1. PI phase noise characteristics need to be known. 2. SGLS transponder phase noise analysis as part of SGLS CDR Data Package shows that the performance is less than 3.5° rms except during vibration, where the phase noise is less than 11.5° rms. (TRW) 3. Analysis to predict performance has been developed, but needs phase noise characteristics. (Axiomatix)	Assessment awaits PI phase noise data. (TRW)
False Acquisition Susceptibility	1. PI receiver false lock avoidance with respect to SGLS and STDN modulations. 2. SGLS receiver false lock discrimination with respect to SGLS command modulation from the PI transmitter. 3. STDN/TDRS receiver false lock discrimination with respect to STDN command modulation from the PI transmitter.	1. Analysis of PI susceptibility to SGLS & STDN modulations, analysis of strong signal phase demodulation discriminator and survey of anti-false lock methods. (Axiomatix & TRW) 2. Analysis of discriminator-aided phase-lock loop and discriminator lock detector for SGLS command modulation from the PI transmitter. (TRW) 3. Analysis of discriminator lock detector for STDN command modulation from the PI transmitter. (TRW)	1. In process. Protection methods still under review. 2. In process. Discriminator may lock up to "S" tone during below threshold signal levels and remain locked at nominal signal levels. 3. In process. Discriminator may lock to data sidebands during reacquisition at strong signal levels.

Table 19. Major IUS/Orbiter Communication Interface Issues (Cont'd)

Issue	Issue Nature	Effort Toward Resolution	Resolution
PI Input Sensitivity Ranges	Exact requirement of Rockwell specification on three receiver sensitivity levels needs further definition.	1. Meet the requirement by using RF signal level limiting. (TRW) 2. Use manual signal level attenuators. (TRW/NASA)	Manual attenuator approach selected. Preamplifier overload diodes as alternate under investigation. (TRW)
PI Received Carrier Modulation Limits	1. Undetermined PI receiver performance for payload subcarrier modulation index larger than 1 radian. 2. Undetermined PI receiver performance with two or more payload subcarriers.	Complete parametric analysis of PI carrier and subcarrier levels as a function of modulation index and waveform types. (Axiomatix)	Results of analysis made known to TRW. (Axiomatix)
PI Interference Susceptibility	Rockwell specification that the PI receiver should work with an out-of-band interference signal as large as -25 dBm.	Analysis showed that, with the expected receiver first LO noise characteristics, only a -65 dBm interference signal level can be tolerated. (TRW and Axiomatix)	Specification amended to the -65 dBm signal level. (Rockwell)
CIU Interface with KuSP, PDI, FMSP	Interface inconsistencies between CIU specification and payload ICD.	1. Action Item for Boeing at CIU PDR. (Aerospace) 2. Tables 24, 25, 28, 29, 30 and 31 compare each Orbiter subsystem spec. with payload ICD and CIU specification. (Axiomatix)	To be resolved at CIU CDR.

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Table 19. Major IUS/Orbiter Communication Interface Issues (Cont'd)

Issue	Issue Nature	Effort Toward Resolution	Resolution
CIU Interface with Payload Recorder	1. Interface inconsistencies between CIU specification and payload ICD. 2. TRW performance does not meet CIU specification.	1. Table 32 compares the payload ICD with the CIU specification. (Axiomatix) 2. RID-01 at CIU PDR. (Boeing)	To be resolved at CIU CDR.
PI Interface with SGLS Transponder	Interface inconsistencies between SGLS transponder specification and payload ICD.	Tables 20 and 21 compare the PI and SGLS transponder specifications with the payload ICD. (Axiomatix)	To be resolved in an interface meeting.
PI Interface with STDN/TDRS Transponder	Interface inconsistencies between STDN/TDRS transponder specification and payload ICD.	Tables 22 and 23 compare the PI and STDN/TDRS transponder specifications with the payload ICD. (Axiomatix)	To be resolved in an interface meeting.

Table 20. PI Transmission to SGLS Transponder

Parameter	PI Specification	Payload ICD	SGLS Transponder Specification
Carrier Frequency Tolerance	<0.001%	±0.001%	Search ±100 kHz doppler shifted input signals
Carrier Phase Noise	4° rms (steady state) 10° rms (maximum)	10° rms, maximum	-
Output Spurs	At least [55 + 10 log (P_t)] dB below modulated carrier from 200 MHz to 16 GHz (P_t is transmitter power in watts)	<-65 dBc	-
Waveform	Sinusoidal with AM	Sinusoidal with AM	Sinusoidal with AM
Modulation	Ternary FSK	Ternary FSK	Ternary FSK
Symbol Frequencies	"S" = 65 kHz "0" = 76 kHz "1" = 95 kHz	"S" = 65 kHz "0" = 76 kHz "1" = 95 kHz	"S" = 65 kHz "0" = 76 kHz "1" = 95 kHz
Carrier Modulation Indices	0.96 ± 10% radians (determined by CIU interface)	0.3 ± 10% radians or 1.0 ± 10% radians	0.3 ± 20% radians or 1.0 ± 10% radians
Symbol Rates	1000 sps or 2000 sps	1000 sps or 2000 sps	1000 sps
AM	0.5 ± 10% AM by a triangular function equal to 500 Hz (for 1000 sps) or 1000 Hz (for 2000 sps)	0.5 ± 10% AM by a triangular function equal to one-half the command symbol rate	0.5 ± 10% AM by a triangular function of 500 Hz

Table 21. PI Reception from SGLS Transponder

Parameter	PI Specification	Payload ICD	SGLS Transponder Spec
Input Signal Range	-124 to +3 dBm	-124 to +25 dBm	N/A
False Lock	Shall not false lock	Shall not false lock below -20 dBm	Shall not false lock
Spurious Output	26 dBc	32 dBc	40 dBc
Rec. Freq. Sweep	±80 kHz	±85 kHz at minimum of 10 kHz/sec	±67 kHz due to auxiliary oscillator
Aux. Osc. Stability	0.001%	±0.001%	±29 ppm
Phase Noise	<15° rms	Additive noise < 10° rms Oscillator < 5° rms Mod. Track'g < 10° rms	< 3.5° rms <11.5° rms with vibration
Static Phase Error	±3° maximum	Frequency offset 3° Frequency Dynamics 12°	1.5° per 30 kHz frequency offset
PSK Sub-carriers	Sinewave subcarrier PSK modulated (±90°) by PCM data 1.024 MHz	Sinewave subcarrier PSK modulated (±90°) by PCM data 1.024 and 1.7 MHz	Sinewave subcarrier PSK modulated (±90°) by PCM data w/at least 30 dB subcarrier suppression (1.024 and 1.7 MHz)
FM Subcarrier (1.7 MHz)	FM/FM	Max. deviation ±TBS Hz peak w/highpass rolloff of TBS db/octave & lowpass rolloff of TBS db/octave beyond 200 kHz	Max. deviation ±200 kHz peak-to-peak (minimum) Modulation bandwidths 20 Hz to 200 kHz with a rolloff of 12 dB/octave
Subcarrier Harm. Comp.	-	TBS% of fundamental frequency amplitude	-
Subcarrier Freq. Stab.	-	0.01% for PSK TBS% for FM	±50 Hz for PSK 0.1% for FM
Modulation Indices	0.3 + 0.1 radians, peak 0.3 - 0.0 radians, peak 1.0 ± 0.1 radians, peak	0.3 ± 10% radians, peak 1.0 ± 10% radians, peak	0.3 to 2.0 radians Factory set with ± 15% variation (perform ± 8%)
Data Rates	64,32,16,10,8,4,2,1, 0.5,0.25 kbps on 1.024 & 1.7 MHz subcarriers	64,32,16,10,8,4,2,1, 0.5,0.25 kbps on 1.024 & 1.7 MHz subcarriers 256 and 128 kbps on 1.7 MHz subcarrier	≤128 kbps (1.024 MHz) ≤256 kbps (1.7 MHz) (See CIU specification)
Data Type	Biphase-L or NRZ-L	Biphase-L or NRZ-L	Biphase-L
Data Asym.	-	TBS	-
Bit Rate Stability	-	0.1% of nominal bit rate	(CIU requires 0.001%)

final assessment of the command channel and telemetry channel BER performance awaits phase noise data from the PI frequency synthesizer.

Another area that received considerable attention in the interface compatibility analysis was the susceptibility of false lock by the PI and the IUS SGLS transponder. It was found that certain modulation conditions could produce false states of in-lock with the TRW PI receiver conceptual design. Axiomatix determined that the problem was a function of lack of receiver out-of-lock IFA gain control and the setting of the lock detector threshold voltage according to a minimum operating point some 6 dB below that required by the Rockwell specification. Axiomatix therefore recommended use of a noncoherent receiver AGC during periods prior to acquisition. This recommendation was acted upon by TRW to the effect that false states of in-lock have been eliminated below a received signal of -20 dBm. The IUS SGLS transponder uses a frequency discriminator to detect false states of in-lock. For received signal levels above -117 dB, the frequency discriminator will not allow lock for a frequency larger than the phase lock loop (PLL) bandwidth; however, for received signal levels below -117 dB, the frequency discriminator does not have a large enough signal-to-noise ratio to guarantee that a noise spike could not stop the frequency sweep in the vicinity of one of the SGLS command tones (most likely, the "S" 65 kHz tone). If the frequency sweep stops in the vicinity of a command tone, the PLL will lock to the nearest command tone. If the command tone that PLL locks to is the "S" tone, the PLL could be false locked for long periods because the "S" tone is used for command preambles and postambles. While the SGLS receiver is not required to acquire below -117 dBm, signal levels below -117 dBm could occur during IUS maneuvers and antenna switching. In this case, the receiver might false lock at signal levels below -117 dBm and stay false locked as the signal level increased above -117 dBm. TRW and Boeing are still working to resolve this false lock problem.

A final area of concern in the interface between the PI and the IUS SGLS transponder is the frequency stability of the auxiliary oscillator. The concern is that the frequency uncertainty due to the frequency stability of the auxiliary oscillator will be larger than the frequency acquisition range of the PI. To resolve this area of concern, TRW is analyzing the aging and environmental changes to the auxiliary oscillator.

Also, Rockwell has requested TRW to investigate the possibility of increasing the PI receiver frequency sweep range. The initial results from TRW, however, indicate that increasing the sweep range of the PI also increases the uncertainty of the actual frequencies in the sweep and, thus, compounds the frequency uncertainty problem. Therefore, increasing the PI sweep range does not seem to resolve the problem.

Another approach to successively increasing the sweep range is by designating an adjacent channel as the nominal frequency for the next frequency sweep if acquisition is not obtained by frequency sweeping around the expected nominal frequency. While this technique might be an operational workaround, it is not a desirable approach to resolution of the frequency stability problem. Before an overall system performance assessment can be made, more data on the auxiliary oscillator stability is needed from TRW.

3.5.2 PI/IUS STDN Transponder Interface Issues

Tables 22 and 23 compare each parameter involved in the interface between the PI and the IUS STDN transponder, as defined by the STDN/TDRS transponder specification, the Payload ICD or the PI specification. Note from Table 22 that the STDN/TDRSS transponder specification has no requirements on the PI for spurious output, carrier phase noise, subcarrier harmonic distortion, subcarrier frequency stability, data asymmetry, or data bit jitter. In Table 23, there is no specification on the STDN/TDRS transponder transmitter for subcarrier harmonic components or data asymmetry. Also, the STDN/TDRS transponder specification for the allowed variation in modulation index is 15%, which is larger than the PI can tolerate (10%).

In order to resolve some of the interface parameter inconsistencies, some overall system analysis is required. As was mentioned in the previous section concerning the PI/SGLS transponder interface, three interface areas in particular need overall system analysis: (1) phase noise generated by the PI transmitter, by the STDN/TDRS transponder including turn-around phase noise, and by the PI receiver, (2) frequency instability of the STDN/TDRS transponder auxiliary oscillator, and (3) false lock of the STDN/TDRS transponder on the 16 kHz subcarrier or data sidebands. Note that the IUS STDN/TDRS transponder uses the same frequency discriminator as the IUS SGLS transponder but, in the case of the STDN

Table 22. PI Transmission to STDN/TDRS Transponder

Parameter	PI Specification	Payload ICD	STDN/TDRS Transponder Specification
Carrier Frequency Sweep	±75 ± 5 kHz ±55 ± 5 kHz at 10 ± 3 kHz/sec ±33 ± 3 kHz at 540 ± 60 Hz/sec	±75 ± 5 kHz ±55 ± 5 kHz at 10 ± 3 kHz/sec ±33 ± 3 kHz at TBS ± TBS Hz/sec	±100 kHz at 35 kHz/sec (unmodulated carrier)
Spurious Output	At least [55 + 10 log (P_t)]dB below unmodulated carrier from 200 MHz to 16 GHz (P_t is transmitter power in watts)	<-65 dBc	-
Carrier Phase Noise	4° rms (steady state) 10° rms (maximum)	10° rms, maximum	-
Waveform	Sinusoidal	Sinusoidal	Sinusoidal
Modulation	PSK	PSK (±90°)	PSK
Subcarrier Frequency	16 kHz	16 kHz	16 kHz
Subcarrier Harmonic Distortion	<1% of fundamental frequency amplitude (PSP Spec.)	<1% of fundamental frequency amplitude	-
Subcarrier Frequency Stability	$<10^{-5}$ of subcarrier frequency over a 60-second period (PSP Spec.)	$\pm 1 \times 10^{-5}$ of nominal subcarrier frequency averaged over 60 sec.	-
Modulation Index	1.0 ± 0.1 radian	1.0 ± 0.1 radian, peak	1.0 ± 10% radian
Data Type	Biphase-L or NRZ-L	NRZ-L, M, S	NRZ-L
Data Asymmetry	<2% of nominal bit period	<2% of nominal bit period	-
Data Bit Jitter	-	<3% of data bit period	-

Table 23. PI Reception from IUS STDN/TDRS Transponder

Parameter	PI Specification	Payload ICD	STDN/TDRS Transponder Specification
Input Signal Range	-124 to +3 dBm	-124 to +25 dBm	N/A
False Lock	Shall not false lock	Shall not false lock below -20 dBm	PI shall not false lock; STDN/TDRS transponder shall not false lock with input signal levels up to -40 dBm
Spurious Output	26 dBc	32 dBc	40 dBc
PI Transmitter Sweep	±75 ± 5 kHz ±55 ± 5 kHz at 10 ± 3 kHz/sec ±33 ± 3 kHz at 540 ± 60 Hz/sec	±75 ± 5 kHz ±55 ± 5 kHz at 10 ± 3 kHz/sec ±33 ± 3 kHz at at TBS ± TBS Hz/sec	±100 kHz at 35 kHz/second (unmodulated carrier)
PI Receiver Sweep	±80 kHz (minimum)	±85 kHz at 10 kHz/sec	±67 kHz due to auxiliary oscillator
Aux. Osc. Stability	0.001%	±0.001%	29 ppm
Phase Noise	<15° rms	Additive noise < 10° rms Oscillator < 5° rms Mod. Track'g < 10° rms	<3.5° rms <11.5° rms with vibration
Static Phase Error	±3° maximum (PI)	Frequency offset < 3° Frequency dynamics < 12° (PI)	1.5° per 30 kHz offset
PSK Subcarriers	Sinewave subcarriers PSK modulated (±90°) by PCM data 1.024 MHz	Sinewave subcarriers PSK modulated (±90°) by PCM data 1.024 and 1.7 MHz	Sinewave subcarriers PSK modulated (±90°) by PCM data with at least 30 dB subcarrier suppression 1.024 and 1.7 MHz
FM Subcarriers	FM/FM modulated by PCM data 1.7 MHz	1.7 MHz-max. deviation ±TBS Hz peak with high-pass rolloff of TBS dB/octave at 100 Hz and lowpass rolloff of TBS dB/octave beginning at 200 kHz	1.7 MHz max. deviation ±200 kHz peak-to-peak Modulation bandwidths 20 Hz to 200 kHz with a rolloff of 12 dB/octave
Subcarrier Harm. Comp.	-	TBS% of fundamental frequency amplitude	-
Subcarrier Frequency	-	0.01% for PSK TBS% for FM	50 Hz for PSK 0.1% for FM

Table 23. PI Reception from IUS STDN/TDRS Transponder (Cont'd)

Parameter	PI Specification	Payload ICD	STDN/TDRS Transponder Specification
Modulation Indices	$0.3 + 0.1$ radians, peak $0.3 - 0.0$ radians, peak 1.0 ± 0.1 radians, peak	$0.3 \pm 10\%$ radians $1.0 \pm 10\%$ radians	0.3 to 2.0 radians (PSK) 0 to TBD kHz (FM) ±15% variation (TRW performance ±8%)
Data Rates	64,32,16,10,8,4,2,1, 0.5, 0.25 kbps on 1.024 and 1.7 MHz subcarriers	64,32,16,10,8,4,2,1, 0.5, 0.25 kbps on 1.024 and 1.7 MHz subcarriers; 256, 128 kbps on 1.7 MHz subcarrier	$\leq$128 kbps (1.024 MHz) $\leq$256 kbps (1.7 MHz)
Data Type	Biphase-L or NRZ-L	Biphase-L or NRZ-L	Biphase-L
Data Asym.	-	TBS	-
Trans. Density	-	TBS	N/A
Bit Rate Stability	-	0.1% of nominal bit rate	(CIU requires 0.001%)

transponder, the frequency discriminator must avoid false lock by the PLL to the 16 kHz subcarrier used to modulate the command data. The false lock performance analysis for the STDN/TDRS transponder has not been completed by TRW and, therefore, the overall system performance assessment must wait unit this analysis has been completed.

3.5.3 CIU Interface Issues

The CIU interfaces with the following Orbiter avionic subsystems: Payload MDM, GN&C MDM, PI, KuSP, FMSP, PDI and PR. In order to investigate the compatibility between the interfaces, each parameter involved in the interface, as defined by the Payload ICD, the CIU specification, or the Orbiter subsystem specification, is compared in Tables 24-32. It may be seen that the greatest interface inconsistencies between the interface parameter specifications exist where the parameter either is not defined by a specification or it is defined by a TBD or TBS. These interface inconsistencies need to be resolved and the parameters with TBD or TBS must be specified consistent with the Orbiter subsystem specification, the Payload ICD and the CIU specification.

The CIU output to PI interface presented in Table 24 shows no real discrepancies except the phase linearity of the PI modulator is only specified in the Payload ICD.

Two parameters in the PI input to CIU interface need to be resolved. First, the output of the PI has an RMS regulator with a peak clipper at 6V peak-to-peak. The CIU expects an RMS-regulated PI output but does not reflect the peak clipping in the CIU specification. The effect of peak clipping means that any waveform having a peak-to-RMS ratio larger than 1.5 will experience amplitude limiting which will cause SNR performance loss. The peak-to-RMS values for typical complex waveforms that may be present at the PI/CIU interface are a single sinewave subcarrier with a peak-to-RMS value of 1.4, two equal amplitude noncoherent subcarriers with a peak-to-RMS value of 2.0, and Gaussian noise with a peak-to-RMS value of 3.0 Note that only a single sinewave subcarrier will be transferred without clipping. Also, the output of PI for weak received signals (<-100 dBm) is essentially Gaussian in character and the output will be clipped. The second interface parameter that needs to be mentioned is the signal type. The CIU specification calls for a differential interface but the PI specification calls for a differential AC coupled (1000 Hz minimum) interface.

Table 24. CIU Output to Payload Interrogator (PI)

Parameter	PI Specification	Payload ICD	CIU Specification
Data Rate	1 K-baud or 2 K-baud	-	1 K-baud ± 0.01%
Waveform	FSK 65, 76 or 95 kHz sinewave subcarriers with amplitude envelope modulation of 500 Hz (1 K-baud) or 1000 Hz (2 K-baud)	FSK 65, 76 or 95 kHz amplitude modulated by 1 kHz or 2 kHz triangular wave	FSK 65, 76 or 95 kHz sinewave subcarriers with triangular AM at 50% modulation at 500 Hz ± 0.1%
Modulation	Ternary FSK/AM of β = 0.2-2.5 radians Logical "1" 95 kHz Logical "0" 76 kHz Logical "S" 65 kHz	Ternary FSK/AM of β = 0.2-2.5 radians Logical "1" 95 kHz Logical "0" 76 kHz Logical "S" 65 kHz	Ternary FSK/AM - Logical "1" 95 kHz ± 0.01% Logical "0" 76 kHz ± 0.01% Logical "S" 65 kHz ± 0.01%
Signal Level	1.0 to 8.0V ± 10% p-p, line-to-line for 0.2 to 2.5 radians	-	3.3V ± 10% p-p, line-to-line
Phase Linearity		$\leq$8% from β = 0.2 to 2.5 radians	-
Load Impedance	75 ± 5 ohms	-	75 ± 5 ohms
Signal Type	Differential, direct coupled		Differential, direct coupled

Table 25. Payload Interrogator Input to CIU

Parameter	PI Specification	Payload ICD	CIU Specification
Subcarrier Frequencies	1.024 MHz and/or 1.7 MHz	1.024 MHz or 1.7 MHz	1.024 MHz ± TBD and/or 1.7 MHz ± TBD
Data Rates	64, 32, 16, 10, 8, 4, 2, 1 kbps; 500 and 250 bps	256, 64, 32, 16, 10, 8, 4, 2, 1, 0.5 and 0.25 kbps	16 kbps (PSK) 16, 24 and 32 kbps (FM/FM)
Modulation	1.024 MHz subcarrier PSK modulated by PCM data, 1.7 MHz subcarrier frequency modulated (FM/FM) or PSK modulated by PCM data	PSK	1.024 MHz subcarrier PSK modulated by PCM data, 1.7 MHz subcarrier FM/FM by PCM data
Data Waveform	Manchester II Biphase-L or NRZ-L	Biphase-L NRZ-L	Biphase-L
Signal Level	2.0V rms ± 0.4V line-to line with 6V p-p max	-	2.0V rms ± 0.4V line-to-line
Bandwidth	4.5 MHz (3 dB points)	-	-
Equivalent Source Modulation	0.3 to 2.5 radians	0.3 to 2.5 radians	-
Signal Type	Differential-AC coupled (1000 Hz minimum)	-	Differential
Load Impedance	75 ± 5 ohms	-	75 ± 5 ohms
Subcarrier Stability	-	0.01%	<1 part in 10^5 for any 12-hour period
Data Rate Stability	-	0.1%	0.001%
Common Mode Rejection	-		>40 dB (0-2 MHz)

Table 26. MDM Discretes Input to CIU

Parameter	PSP Specification	Payload ICD	CIU Specification
Receiver Type	Differential, direct coupled	Differential, direct coupled	Differential, direct coupled
Threshold	0 ± 0.5V (line-to-line)	0 ± 0.5V (line-to-line)	0 ± 0.5V (line-to-line
High State:			
Line-to-ground	2.0 to 5.9V peak	2.1 to 5.9V peak	-
Line-to-line	2.0 to 5.9V peak	2.1 to 5.9V peak	2.0 to 5.9V peak
Low State:			
Line-to-ground	-0.6 to +0.6 peak	-0.6 to +0.6V peak	
Line-to-line	-2.0 to -5.9V peak	-2.1 to -5.9V peak	-2.0 to -5.9V peak
"True" State (Logic "1")	Signal line "high with respect to return line	Signal line "high" with respect to return line	Signal line "high" with respect to return line
"False" State (Logic "0")	Signal line "low" with respect to return line	Signal line "low" with respect to return line	Signal line "low" with respect to return line
Open Circuit	Interpret as Logical "0"	Interpret as non-ambiguous state	Interpret as Logical "0"
Source Impedance (Orbiter)			
Line-to-line	100 ohms, maximum	100 ohms, maximum	100 ohms, maximum
Line-to-ground	100 ohms, maximum	100 ohms, maximum	-
Input Impedance (CIU) Line-to-line	75 ohms ± 5% in series with 3.3 pf ± 10%	90 ohms ± 5% in series with 10.0 pf ± 10%	100 ohms ± 5% in series with 10.0 pf ± 10%
Rise and Fall Times	10-200 ns 10% voltage to +2.0V (rise) or -2.0V (fall) 100-1000 ns, 10-90% voltage levels	10-200 ns, 10% voltage to +2.1V (rise) or -2.1V (fall) 100-1000 ns, 10-90% voltage levels	-
Overshoot/ Undershoot	0.25V peak, maximum	0.25V peak, maximum	0.25V peak, maximum
Common Mode Rejection	Signals from DC to 2 MHz w/amplitude up to ±10V peak applied to both signal terminals shall not activate receiver circuits	Signals from DC to 2 MHz w/amplitude up to ±10V peak applied to both signal terminals shall not activate receiver circuits	Signals from DC to 2 MHz w/amplitude up to ±10V peak applied to both signal terminals shall not activate receiver circuits
Voltage Damage	±32V either input	±32V either input via 320 ohms	±32V either input
Fault Voltage Emission	-	+8V maximum	-
Fault Current Limitation	-	40 ma	-

Table 27. MDM Serial Digital Data Input to CIU

Parameter	PSP Specification	Payload ICD	CIU Specification
Receiver Type	Transformer coupled, balanced	Transformer coupled, balanced	Transformer coupled, balanced
Waveform	Manchester II Biphase-L (MIL-STD-442)	Manchester II Biphase-L (MIL-STD-442)	Biphase-L in accordance with MIL-STD-1572
Data Rate	1 Mbps	1 Mbps ± 0.1%	1 Mbps ± 10%
Data Threshold			
Positive	+0.5 ± 0.1V peak line-to-line	+0.5 ± 0.1V peak line-to-line	+0.5 ± 0.1V peak, line-to-line
Negative	-0.5 ± 0.1V peak line-to-line	-0.5 ± 0.1V peak line-to-line	-0.5 ± 0.1V peak line-to-line
Logic Level "One"	+1.5V to +8V peak line-to-line	+1.5V to 8.0 peak line-to-line	+1.5V to +8V peak line-to-line
Logic Level "Zero"	-1.5V ± 8% to -8V ±8% peak line-to-line	-1.5V to -8.0 peak line-to-line	-1.5V to -8V peak line-to-line
Pulse Width Variation Plus Jitter	±125 ns maximum	40 ns (Jitter)	±125 ns maximum
Bit Error Rate	-	1.9×10^{-7}	10^{-7} for 14 dB peak SNR
Rise and Fall Time	60-150 ns measured between 10-90% of voltage levels	60-250 ns measured between 10-90% of voltage levels	40-300 ns measured between 10-90% of voltage levels
Distortion (overshoot, ringing)	250 mV maximum, peak	±250 mV maximum	300 mV maximum, peak
Input Impedance	75 ohms ± 10%	75 ohms ± 10%	75 ohms ± 10%
Isolation Resistance (line-to-ground)	100 K ohms, minimum	-	100 K ohms, minimum
Common Mode Rejection	Signals from DC to 2 MHz with amplitude to ±32V peak, line-to-ground applied on both input signal terminals, shall not activate receiver circuit	Signals from DC to 2 MHz w/amplitude to ±32V peak, line-to-ground applied on both input signal terminals, shall not activate receiver circuit	Signals from DC to 2 MHz w/amplitude to ±32V peak, line-to-ground applied on both input signal terminals, shall not activate receiver circuit
Common Mode Voltage Damage Threshold	Greater than ±50V peak	±50V peak	Greater than ±50V peak

Table 28. Ku-Band Signal Processor Input to CIU

Parameter	Ku-Band Specification	Payload ICD	CIU Spec.
Data Rate	128 kbps	128 kbps	128 kbps
Waveform:			
Data	NRZ-L	NRZ-L	NRZ-L
Clock	Square wave	Square wave	-
Signal Amplitude	High state:		
	signal line to signal ground		
	3.5V maximum	3.0V maximum	
	2.0V minimum	2.0V minimum	
	signal return to sig. ground		
	0.5V maximum	0.5V maximum	
	0.0V minimum	0.0V minimum	
	Low state:		TBD
	signal line to signal ground		
	0.5V maximum	0.5V maximum	
	0.0V minimum	0.0V minimum	
	signal return to sig. ground		
	3.5V maximum	3.0V maximum	
	2.0V minimum	2.0V minimum	
Rise and Fall Times	<2.5% of bit period measured at 10-90% points (195 ns)	<2.5% of bit period* measured at 10-90% points (195 ns)	
Source and Load Coupling	Balanced differential, direct coupled	Balanced differential, direct coupled	Differential, direct coupled
Load Impedance	75 ± 5 ohms	75 ± 5 ohms	TBD
Cable	75 ± 5 ohms, TSP	75 ± 5 ohms, TSP	TBD
Data Stability	<0.01% of bit rate	-	-
Clock Skew	<150 ns	15% clock per. max.	-
Clock Duty Cycle	50.0 ± 5% of bit period	50.0 ± 5% of bit period*	-
Frequency Jitter	±0.1% of data rate at 0.1% rms of the data rate	0.1% of bit period	-
Clock Phase Jitter	±2% rms of bit period	10% of bit period	-
Data/Clock Asymmetry	10% of bit period, maximum	TBD	-
Common Mode Voltage	-	-	TBD
Common Mode Damage Threshold	-	-	TBD

*ICD 2-19001, 10/10/77, Rise and Fall Times 40 ns and Clock Duty Cycle 50 ± 15% of bit period.

	2.0V minimum	2.?V minimum	
Rise and Fall Times	<2.5% of bit period measured at 10-90% points (195 ns)	<2.5% of bit period* measured at 10-90% points (195 ns)	
Source and Load Coupling	Balanced differential, direct coupled	Balanced differential, direct coupled	Differential, direct coupled
Load Impedance	75 ± 5 ohms	75 ± 5 ohms	TBD
Cable	75 ± 5 ohms, TSP	75 ± 5 ohms, TSP	TBD
Data Stability	<0.01% of bit rate	-	-
Clock Skew	<150 ns	15% clock per. max.	-
Clock Duty Cycle	50.0 ± 5% of bit period	50.0 ± 5% of bit period.	-
Frequency Jitter	±0.1% of data rate at 0.1% rms of the data rate	0.1% of bit period	-
Clock Phase Jitter	±2% rms of bit period	10% of bit period	-
Data/Clock Asymmetry	10% of bit period, maximum	TBD	-
Common Mode Voltage	-	-	TBD
Common Mode Damage Threshold	-	-	TBD

*ICD 2-19001, 10/10/77, Rise and Fall Times 40 ns and Clock Duty Cycle 50 ± 15% of bit period.

Table 29. CIU Output to Ku-Band Signal Processor

Parameter	Ku-Band Specification	Payload ICD	CIU Specification
Data Rate and Signal Coding	16 kbps to 2 Mbps NRZ-L, M, S 16-1024 kbps Biphase-L, M, S	16 kbps to 2 Mbps NRZ-L, M, S 16-1024 kbps Biphase-L, M, S	16, 64, 256 kbps Biphase-L
Signal Level	1.8 to 5.0V p-p line-to-line	1.8 to 5.0V p-p line-to-line	TBD volts p-p* line-to-line
Load Impedance	75 ± 5 ohms	75 ± 5 ohms	75 ± 10% ohms*
Cable Type	75 ± 5 ohms, TPS	75 ± 5 ohms, TPS	-
Signal Type	Balanced differential, direct coupled	Balanced differential, direct coupled	Differential, direct coupled
RMS SNR	35 dB minimum	35 dB minimum	-
Rise and Fall Times	5% or 50 ns between 10-90% points, whichever is less	5% or 50 ns between 10-90% points, whichever is less (ICD 2-19001, 10/10/77, requires 10 ns maximum)	TBD
Frequency Jitter	±0.1% rms of the data rate at 0.1% rms of the data rate	±0.1% rms of the data rate at 0.1% rms of the the data rate	-
Data Asymmetry (TDRS User Constraint)		±10%	±10%
Data Stability	0.01% long term	<0.01% long term	-
Bit Jitter	-	±2% of bit period	-
Common Mode Voltage	±10V DC to 10 kHz decrease 10 dB per decade to 100kHz and 10 dB per octave above 100 kHz		-

*Previously, signal level was 6 ± 3V p-p line-to-line, load impedance was 90 ± 10% ohms, and rise and fall times were 1 μsec.

Table 30. CIU Output to FM Signal Processor

Parameter	FM Signal Processor Specification	Payload ICD	CIU Specification
Data Rate	250 bps to 256 kbps	250 bps to 256 kbps	16, 64, 256 kbps
Signal Coding	Manchester II, Biphase-L or NRZ-L	Biphase-L or NRZ-L	Biphase-L
Signal Level	1.0 ± 0.6V p-p line-to-line	1.0 ± 0.6V p-p line-to-line	1.0 ± 0.6V p-p
Logic "1"	(Removed from spec)	+1.1V ± 0.5V p-p line-to-line	-
Logic "0"	(Removed from spec)	-0.3V to +0.4V p-p, line-to-line	
Rise and Fall Times	Less than 100 ns	Less than 100 ns	Less than 100 ns
Signal Type	Balanced differential	Balanced diffferential	Differential, direct coupled
Common Mode Rejection	Signals from DC to 2 MHz up to 1V peak line-to-ground shall not degrade output SNR to less than 45 dB	Signals from DC to 2 MHz up to 1V peak line-to-ground shall not degrade output SNR to less than 45 dB	-
Source Impedance	75 ohms ± 10%	75 ohms ± 10%	TBD
Load Impedance	75 ohms ± 10%	75 ohms ± 10%	75 ohms ± 10%

Table 31. CIU Output to Payload Data Interleaver

Parameter	PDI Specification	Payload ICD	CIU Specification
Bit Rate	10 bps to 64 kbps	10 bps to 64 kbps	16, 64 kbps
Input Signal Code	NRZ-L, M, S Biphase-L, M, S	NRZ-L, M, S Biphase-L, M, S	NRZ-L
Logic	Positive		-
Bit Rate Accuracy	±6%	$\leq$2%	-
Bit Rate Stability	1 part in 10^5 60-sec period	1 part in 10^6 60-sec period	-
Signal Type	Balanced differential	Balanced differential	Differential, direct coupled
Amplitude	2-12V p-p	2-12V p-p	6 ± 3V p-p line-line
Rise and Fall Time	10% between 10 and 90% points	5μ sec or 10% of bit, whichever is less, 100 ns min.	TBD
Signal Waveform Distortion	Overshoot and undershoot less than 20% of peak	Overshoot and undershoot less than 20% of signal	-
Clock Skew	±5% of clock period or 10 ms, whichever is less	±5% of clock period or 10 ms, whichever is less	±5% of clock period or 10 ms, whichever is less
Clock Duty Cycle	50.0 ± 5%	50 ± 5%	Square wave
Noise Immunity	100 mV p-p line-to-line DC-100 kHz	100 mV p-p line-to-line	-
Load Impedance	75 ± 7 ohms	75 ± 7 ohms	75 ± 7 ohms
Cable Impedance		75 ± 7 ohms	75 ± 5 ohms, TSP
Source Impedance		75 ± 7 ohms	TBD

Table 32. CIU Output to Payload Recorder

Parameter	Payload ICD	CIU Specification
Analog:		
Input Signal	1V rms ± 6 dB	1V rms ± 6 dB*
Signal Type	-	Differential
Source Impedance (CIU)	71 ± 10%	-
Load Impedance (Recorder)	71 ± 5%	71 ± 7 ohms
Cable Impedance	75 ± 5 ohms, TSP	75 ± 5 ohms, TSP
Frequency	1.9 kHz to 1.6 MHz	10 kHz to 100 kHz
Signal/Noise	39 dB over any 3 kHz slot	-
Common Mode Rejection	±15V (reference to signal ground)	±15V max (reference to signal ground)
Digital:		
Data Rates	25.5 kbps to 1.024 Mbps	256 kbps, 64 kbps
Signal Code	Biphase-L	Biphase-L
Bit Jitter	2% of bit duration (p-p)	-
Rise and Fall Times	±10% of bit duration	390 ns, maximum
Input Signal	3-9V p-p	6 ± 2V p-p line-to-line
Signal Type	Differential	Differential, direct coupled
Load Impedance	71 ± 10% ohms	71 ± 10% ohms
Cable Impedance	75 ± 5 ohms, TSP	75 ± 5 ohms, TSP
Source Impedance	71 ± 10% ohms	TBD
Common Mode Rejection	±15V (reference to signal ground)	-

*TRW performance: 1V rms + 2.9 dB
1V rms - 6.56 dB

The Payload ICD and the CIU specification for the MDM/CIU interface are in basic agreement, as shown in Tables 26 and 27. The rise and fall times for the MDM discretes did not appear in the specification. This missing parameter may be due to a missing figure since the CIU specification referred to Figure 12 for the rise and fall time specification, but Figure 12 had no reference to rise and fall times. There are also slight discrepancies in the CIU specification of the MDM serial digital data input for rise and fall times, pulse width variation plus jitter, and distortion (overshoot, ringing). However, since these are MDM input specifications, there does not seem to be any major discrepancies or problems with this interface.

Tables 28 and 29 define the interface between the KuSP and the CIU. Nearly all the parameters defining this interface are either not included in the CIU specification or are TBD. This interface needs to have these parameters specified very soon if large cost impacts are to be avoided. One area of the interface was resolved by Axiomatix. This area concerns the use of the Ku-band forward link 128 kbps for the 2 kbps command data to the CIU.

The Ku-band forward link through the TRDSS is a very strong link for the data rate of 216 kbps, of which the 128 kbps command channel is a part. Table 33 presents the current NASA JSC link budget for this Ku-band forward link. First, note that the required BER is 10^{-5}, which would then be the same BER for the bits in the 128 kbps. But the circuit margin is 7.3 dB; therefore, the expected BER is actually about 10^{-23}. In addition, the circuit margin is based on current specifications and the contractor performance on various equipment that are part of the link is better (in some cases, much better) than the specifications. Therefore, the Ku-band forward link can be considered essentially error-free.

Based on the fact that the Ku-band forward link is essentially error-free (i.e., BER $<10^{-23}$), Axiomatix proposed the most simple implementation of transmitting the SGLS 1 k-baud command data. First, the 1 k-baud ternary symbols would be converted to binary digits as follows: "S" = 01, "1" = 11, and "0" = 00. Thus, the binary data rate of the SGLS commands is 2 kbps. If each binary one is transmitted as 64 ones and each zero is transmitted as 64 zeros in the 128 kbps Ku-band forward link data stream, the 128 kbps data can be easily deformatted by the CIU into the

Table 33. TDRSS-Orbiter Ku-Band Forward Link with 216 kbps TDM Digital Data (128 kbps Command Data for DOD Missions)

PARAMETER	VALUE	SOURCE
1. TDRS EIRP, dBW	46.5	ICD 2-0D004 (IRN003) specification
2. Space loss, dB	-207.7	f=13.775 GHz, R=22786 n.mi.
3. SSO Pointing loss, dB	-0.5	Rockwell spec
4. Polarization loss, dB	-0.2	JSC estimate
5. SSO receive antenna gain, dB	38.0	Rockwell spec
6. SSO receive circuit loss, dB	-3.0	Rockwell spec
7. Total received power (P_{rec}), dBW	-126.9	Sum 1 through 6
8. SSO system noise temperature, dBK	29.9	794 K (ref. to receiver input, T_a=45 K, L=-3.0 dB, T_r=627 K)
9. Boltzmann's constant, dB (W/K/Hz)	-228.6	1.38×10^{-23} W/K/Hz
10. SSO noise spectral density (N_o) db (W/K/Hz	-199.6	Sum 8 and 9
11. SSO G/T, dB/K	6.0*	5 plus 3 minus 8, Rockwell spec (ICD 2-0D004 spec value is 5.3 dB/K
12. Total received power/noise spectral density (P_{rec}/N_o), dBHz	72.7	7 minus 10
13. Spread spectrum degradation, dB	-1.5	JSC estimate
14. Bit rate bandwidth, dBHz	53.3	216 kbps
15. Signal-to-noise ratio in bit rate bandwidth (E_b/N_0), dB	17.9	12 plus 13 minus 14
16. Theoretical required E_b/N_o, dB	9.6	For 10^{-5} BEP
17. Bit sync degradation, dB	-1.0	JSC estimate
18. Encryption/decryption degradation, dB	0.0	JSC estimate for 10^{-2} prob. of command rejection.
19. Requried E_b/N_o, dB	11.4	16 minus 17 minus 18
20. Required P_{rec}/N_o, dBHz	65.4	19 plus 14 minus 13 (ICD 2-0D004 spec value is 654 dBHz)
21. Circuit Margin, dB	7.3	15 minus 19 or 12 minus 20

*These values are being submitted as changes to ICD 2-0D004 via PIRN IG 0014 into the 2 kbps binary command data. All the CIU needs to do is count down the 128 kHz clock from the KuSP to 2 kHz, then sample the 128 kbps binary data stream each 500 μs to obtain the 2 kbsp binary command data. Note that the BER of the 2 kbps binary command data is then equal to BER of the original 128 kbps data (i.e., BER $<10^{-23}$). Without considering how low the expected BER is for the 128 kbps, several people have proposed making a majority decision on the 64 bits that make up the 2 kbps binary digits. Majority decisions would improve the BER of the 2 kbps binary command data to

$$P_b < \sum_{i=33}^{64} \binom{64}{i} p^i (1-p)^{64-i} \qquad (1)$$

where P_b is the BER of the 2 kbps data and p is the BER of the 128 kbps data. Note that P_b can be further bounded by

$$\binom{64}{33} p^{33}(1-p)^{31} < P_b < \binom{64}{33} p^{33}$$

$$1.78 \times 10^{18}\ p^{33}(1-p)^{31} < P_b < 1.78 \times 10^{18}\ p^{33} \qquad (2)$$

If p is 10^{-5}, then $P_b < 1.78 \times 10^{-147}$ (an unrealistic number) and, if $p = 10^{-23}$, then $P_b < 1.78 \times 10^{-741}$ (an even more unrealistic number). Therefore, majority decisions on the 128 kbps data is not warranted. Originally, error correcting coding techniques were proposed as a method of optimally combining the 128 kbps binary digits to make the 2 kbps binary digits. Based on the performance of majority decisions, it may be seen how unwarranted even the complexity of the most simple error correcting coding technique is.

The interface between the CIU and the FMSP is presented in Table 30. The only two discrepancies between the CIU specification, the Payload ICD, and the FMSP specification are the lack of CIU specifications for common mode rejection and for source impedance.

Table 31 presents the comparison of the CIU specification, the Payload ICD, and the PDI specification for the CIU/PDI interface. This interface has a number of parameters that are not specified in the CIU specification including bit rate accuracy, bit rate stability, rise and fall times, signal waveform distortion, noise immunity, and source impedance. These parameters must be specified before this interface can be resolved and should be resolved realatively soon in order to avoid large cost impacts.

Finally, Table 32 defines the CIU/PR interface by making the comparison between Payload ICD and CIU specification. First note that the CIU specification does not include values for the analog or digital interface source impedance, the analog signal/noise, the digital interface bit jitter, or the digital interface common mode rejection. In addition, while the Payload ICD and the CIU specification agree on the analog input signal parameter, TRW is not meeting the lower specification value. Boeing wrote Review Item Disposition 1 (RID-01) against this discrepancy at the CIU PDR. The response to RID-01 is to be presented at the CIU CDR in July 1979, but the expected action by Boeing is to modify the CIU specifications to accommodate the TRW baseline design performance. Similarly, TRW isn't meeting the digital signal level CIU specification but meets a minimum of 3.5V peak-to-peak, line-to-line, which is consistent with the Payload ICD. Therefore, RID-10 requested that Boeing change the CIU specification to accommodate the TRW baseline design performance.

3.5.4 CIU Preliminary Design Review Evaluation

During the CIU PDR held November 28-29, 1979, there were 26 RID's and 20 Action Items (AI's). Tables 34 and 35 present the RID's and AI's, respectively, along with the responsibilities and due dates for resolving them. RID-01 and -10 were discussed in the previous section. A number of other RID's and AI's were written against CIU interfaces and required updates to the specifications. AI-04 noted that some of the interface requirements in the CIU specification were incompatible with the Payload ICD. Axiomatix spelled out these incompatibilities in detail with Tables 24-32 in the previous section. Other RID's and AI's concerned with the CIU interface specifications are RID-35, -43, -44 and -46, and AI-09, -12, -17, and -20.

RID-35 noted that CIU buffer for the MDM command interface was too small. In order to handle clear text commands adequately, the CIU buffer should accommodate 160 bits rather than the current design of 102 bits

Table 34. CIU-PDR RID'S

RID No.	Subject	Assigned To	Due Date
CIU-01	Payload Recorder Analog Amplitude	BAC	12-20-78
CIU-03	TEMPEST Test Plan Submittal	TRW	CDR
CIU-04	TEMPEST Control Plan Submittal	TRW	1-15-79
CIU-05	Dimmer Control Implementation	BAC	12-20-78
CIU-07	VCC Extraction	TRW	1-15-79
CIU-08	Command Data to IUS (SPF)	BAC	1-22-79
CIU-09	EMC DC Converter Requirements	BAC	1-15-79
CIU-10	Payload Recorder Digital Amplitude	BAC	Spec. Revision
CIU-11	EMC Test Plan	TRW	CDR
CIU-12	EMC Control Plan	TRW	CDR
CIU-14	KG Fill Access	BAC	Spec. Revision
CIU-15	Incorporate Overload Protection	TRW	1-15-79
CIU-16	VCC Display as Two Digits Octal	BAC	Spec. Revision
CIU-19	Evaluate BAC Connector Configuration	TRW	12-18-78
CIU-22	Command Authentication in "Clear" Mode	BAC	1-10-79
CIU-25	Test Plan	TRW	CDR
CIU-35	S-Band Commands Variable Format	BAC	CDR
CIU-37	Revise Control Panel Layout	TRW	CDR
CIU-38	Revise Control Panel Design	TRW	1-15-79
CIU-39	Revise KG Panel Design	TRW	CDR
CIU-41	Update Envelope Drawing to Reflect Design	BAC	1-20-79
CIU-42	Clarify TBD's on T-0 Umbilical Provide Switching for Redundant T-0 Umbilical	BAC TRW	CDR CDR
CIU-43	Correct CMR Discrepancy for PI Input	BAC	12-20-78
CIU-44	Correct Documentation for ±15V Damage Threshold	BAC	2-15-79
CIU-45	Correct Documentation for Touch Temperature Discrepancy	BAC	1-20-79
CIU-46	Clear Up CIU Specification TBD's	BAC	CDR

Table 35. CIU-PDR Action Items

AI Number	Action Item	Action Assigned To	Due Date
CIU-AI01	Status of Level 2 Change to Orbiter Wiring	SAMSO	12-13-78
CIU-AI02	Switch CIU and KG Panels	TRW	CDR
CIU-AI03	VCC Extraction and Command Validation Lockout	BAC	12-15-78
CIU-AI04	Interface with Orbiter Equipment	BAC	1-15-79
CIU-AI05	FSK/AM Waveform Performance Data	TRW	1-6-79
CIU-AI07	CIU Worst-Case Propagation Delay Analysis	TRW	CDR
CIU-AI08	Review Weight Estimates	TRW	1-5-79
CIU-AI09	Update Specfication for Two "S" Bits Separating CMD's	BAC	Spec. Review
CIU-AI10	GN&C Command Rejection Criteria	BAC	12-15-78
CIU-AI11	Confirm Console (GFE) Delivery Schedule	BAC	12-20-78
CIU-AI12	Provide WBDI and IUS CIU Input Symmetry	BAC	1-20-79
CIU-AI13	Submit Tantalum Cap 1A060 to PMPCB	BAC	Next PMPCB
CIU-AI14	Remove LH0002H from Design--PMPCB Action	BAC	CDR
CIU-AI15	Measure Integrated PSK Demod-Bit Sync Acquisition Time	TRW	CDR
CIU-AI16	Measure Integrated PSK Demod-Bit Sync BER	TRW	CDR
CIU-AI17	Review Specification for Adequate KG/PDI Timing Margin	BAC	1-15-79
CIU-AI18	Add NIS Extraction to CIU Baseline	BAC	12-20-78
CIU-AI19	Prepare ICD and Update Envelope Drawing for KG Compatibility	BAC	1-20-79
CIU-AI20	Ensure Power "On" Maintenance for Crypto	BAC	CDR
CIU-AI21	NIS Display Vector	BAC	With ECP

from the Orbiter MDM in the S-band PM uplink mode. This allows a command and its complement for execution to be held in the CIU in one data transfer from the MDM. Boeing is to determine the design implementation approach by the CIU CDR.

RID-43 notes that common mode rejection for the PI/CIU interface is specified at greater than 40 dB (DC to 2 MHz), as noted in Table 25, but the CIU capability is greater than 40 dB (DC to 1 MHz) and greater than 25 dB (1 MHz to 2 MHz). There is no corresponding PI specification or Payload ICD requirement for common mode rejection, as noted in Table 25. Boeing is to determine corrective action to resolve the discrepancy.

RID-44 is concerned with the voltage damage threshold for the MDM discrete envelope signals at the input of the CIU. The CIU specification and the Payload ICD require ±32V at either input as the voltage damage threshold, as shown in Table 26; however, the 9615 line receiver used by TRW to implement the CIU interface has only a ±15V worst-case voltage damage threshold. The action on this RID was for Boeing to change the CIU specification to allow only ±15V voltage damage threshold, but this is inconsistent with the Payload ICD and, therefore, either this requirement must be reviewed in terms of the Orbiter MDM design or TRW must redesign the CIU/MDM interface.

RID-46 points out that the CIU specification has a large number of TBD's, as was discussed in the previous section. Boeing is to clear up these TBD's by the CIU CDR.

AI-09 requires Boeing to update the CIU specification so that, in the clear text command mode, there is a specified separation between true and complement clear text commands by a minimum of two "S" symbols. Boeing is to complete this specification update at the next specification review.

In the previous section, the CIU interfaces with the Orbiter subsystems were investigated. The interfaces between the IUS and the CIU and between the COMSEC and the CIU were not discussed. There are also interface definition discrepancies between these subsystems. AI-12 points out that the CIU specification requires the biphase-L output from the CIU to have ±10% asymmetry, as noted in Table 29, for the interface between the CIU and the KuSP. In order for the CIU to meet this requirement, however, input requirements on the WBDI and the IUS have to be imposed. Boeing is to analyze the problem and make the necessary documentation changes to the

WBDI and IUS interfaces with the CIU. AI-17 is concerned with telemetry data and clock skew for the CIU interfaces with the COMSEC and the PDI. Table 21 shows that the PDI specification, the Payload ICD, and the CIU specification require the CIU/PDI clock skew to be ±5% of a clock period, or 10 ms, whichever is less. However, the COMSEC GFE/CIU interface requires that the data skew referenced to the clock leading edge shall be greater than 280 ns and the data skew referenced to the clock falling edge shall be greater than 330 ns. TRW analysis shows worst-case skew between leading edges of data and clock of greater than 415 ns for the COMSEC and less than 430 ns for PDI. This design margin is too small to meet. Therefore, Boeing is to review and analyze the interface definitions to determine if CIU specifications must be changed.

AI-18, -20 and -21 are concerned with CIU specifications that are not included in the TRW baseline design. The CIU specification calls for the Navigation Initialization Status (NIS) bits to be extracted from the IUS 64 kbps telemetry stream whenever attitude data, state vector data or a NAV Mode 2 command is transmitted to the IUS. The NIS bits are to be routed to the CIU control and display panel for display. AI-18 and -21 note that the NIS bit extraction is not part of the TRW baseline design of the CIU or the display panel. TRW is to add these requirements to the baseline design and Boeing is going to accompany this change with an attitude initialization Engineering Change Proposal (ECP). AI-20 notes that the NASA specification on the COMSEC calls for erasure of memory if there is a power loss of seven-seconds duration; however, there was no requirement presented to ensure that power is maintained once the COMSEC memory is filled. Boeing is to create the documentation by the CIU CDR to guarantee that the power is maintained.

RID-41 points out that some of the design concepts specified within the CIU specification have been changed due to revision of Boeing-generated authorized design changes. Boeing is to revise the CIU specification as required, but a new CIU specification has yet to be released.

The test data and analysis supplied with the CIU PDR package was not in all cases sufficient to show that the required performance was met. For example, AI-05 requested more tests from TRW to determine if the CIU-generated FSK/AM waveform was satisfying the SGLS requirement, as shown in Figure 11. AI-05 specifically requested test data to show that the bit transition versus zero crossing of the 500 Hz envelope "sync delay" = 0.6 bit period ±10%, that the frequency accuracy of the 1, 0, S tones was ±0.01%, and that the bit transitions were continuous. TRW supplied test data on January 6, 1979 that showed that the bit transition versus zero crossing of the 500 Hz AM envelope was within 0.6 bit period ±5%. The TRW test data supplied to show the continuity between bits was sufficient; however, the test data TRW supplied to show that the 1, 0 S tones met the frequency accuracy of ±0.01% was insufficient. Additional test data will have to be supplied as part of the CIU CDR Data Package.

AI-07 requested TRW to review and revise the worst-case analysis since some of the propagation delays used in the CIU PDR worst-case analysis were in question. The revised worst-case analysis is to be part of the CDR Data Package. Also to be included in the CDR Data Package is additional test data on the PSK demodulator and bit synchronizer acquisition time and BER degradation as requested by AI-15 and -16. This additional test data was requested since the PDR Data Package did not include sufficient test data to show that these acquisition time and BER degradation requirements were being met. RID-03, -04, -11, -12 and -25 were written because the test plans required by the Statement of Work (SOW) were not included in the PDR Data Package. The response to these RID's is for TRW to provide the various test plans as part of the CDR Data Package.

VCC extraction for command verification, according to the CIU specification, is to be performed by examining the subframe count such that the "A" side VCC shall be contained in odd subframe counts and the "B" side VCC shall be contained in even subframe counts, excluding zero. RID-07 noted that the present TRW design examines bit 24 of the VCC word to determine "A" side versus "B" side VCC. The TRW response to RID-07 was that the CIU design is in accordance with the CIU specification and performs the VCC extraction by examining the subframe count. AI-03 notes that there is a 1.2-second lockout time in the CIU specification to perform the VCC extraction and command validation. AI-03 requests that Boeing review the requirements for lockout of VCC for all conditions of operation and, if wrong, revise design and specify the correct lockout time. AI-10 requests that Boeing provide VCC activity rules and command rejection criteria. This is especially critical for detection of command rejection of GN&C data transfers to the IUS.

The CIU design baseline provides that the COMSEC buffers will be filled by the operator bringing his fill gun directly to the KG front panel. The CIU specification requires that the KG fill connector be located on the CIU control panel. RID-14 points out that the fill connector is to be located directly on the KGT-60 and KGR-60, but no provision has been made for access to the KG fill connector. Boeing is to revise the CIU specification to eliminate the fill connector from the panel and TRW is to provide a design approach for accessing the fill connector on the KGT-60 and KGR-60. Most likely, the CIU side panel will be designed to provide convenient access. The design details are still being worked out. It is a requirement that the access be convenient and simple because the fill operation will probably occur just prior to launch. The final design details will be presented at the CIU CDR. Also pertaining to the COMSEC, AI-01 requests that SAMSO determine the status of the Level 2 change to the Orbiter wiring that provides the Orbiter KGX-60 zeroize signal to the CIU KGT-60 and KGR-60.

RID-08 and -42 address the redundancy problem of the CIU which is discussed in more detail in Section 4.0. It is noted in RID-08 that the CIU signal control unit (SCU) is commanded to select between four outputs (IUS #1A, IUS #1B, IUS #2A and IUS #2B). For a single-string TT&C mission, a failure of the SCU A will preclude further onboard commanding on the IUS. Boeing was assigned to study this problem and present a solution. This will be discussed in greater detail at the CIU CDR. RID-42 points out that the CIU specification requires the CIU to interface with two redundant command lines from the T-0 umbilical during ground checkout. The CIU PDR Data Package shows the CIU interfacing with only one T-0 umbilical command line. By the CIU CDR, Boeing is to revise the CIU specification to reflect the proper nomenclature of the redundant T-0 umbilical "A" and "B" command lines and TRW is to alter the CIU design to accommodate interfacing with redundant T-0 umbilical command lines. This requires T-0 "A" and T-0 "B" positions on the command source select rotary switch.

RID-09 is concerned that the CIU DC power converter has surge voltage and conducted susceptibility. The CIU DC power converter is based on the NSP power converter which is a qualified Orbiter component. The CIU requirements for conducted susceptibility exceeds the NSP capability by a factor of six. To be fully compliant with the CIU requirements would require a major CIU redesign and also complicate the TEMPEST design. Since the EMC requirements for the CIU are not needed for the Orbiter, TRW recommended that the EMC requirements be revised from MIL-STD-1521 and D290-10068-1A to MIL-STD-461A, modified by NASA-SE-0002. Boeing was assigned to study and determine if the requirements can be relaxed. The result of this study will be discussed at the CIU CDR.

A number of RID's and AI's were directed toward the control panel design and layout. RID-05 was written by Boeing and assigned to Boeing to resolve the panel light dimming requirement. It was pointed out that panel light dimming was required to allow for variations in background lighting. The Orbiter has several annunciator control assemblies (ACA) for light intensity control from centralized locations, and is was requested that TRW be provided access to one of the 36 ACA channels for use by these panels. This would eliminate the need to design a CIU ACA. The CIU would require two additional lines to the Orbiter, a lamp power line and a return line. AI-02 requested that the layout of the panels be changed such that the KG control panel is switched with the CIU control panel so that the CIU control panel is closer to the operator. This change is to be included in the CIU CDR Data Package.

RID-15, -16, -22, -37, -38, -39 and -45, and AI-19 are concerned with various aspects of the control panels. RID-37 notes that the nomenclature used on the CIU panel is inconsistent with the Orbiter nomenclature and the CIU panel nomenclature should be changed to minimize ambiguity in operating the system. Also, RID-37 points out that the CIU "POWER" and "PAYLOAD LINK" switches are incorrectly illustrated as three-position switches. These changes to the CIU panel are to be included in the CIU CDR Data Package. RID-38 recommends that the panel controls be guarded to prevent inadvertent contact and selection of improper or false modes. In particular, RID-38 recommends the addition of a barrier guard on the "CLEAR" push-button switch and replacement of the "TLM RATE" and "PAYLOAD LINK" switches with a single three-position switch. The three-position switch should have the following switches: "HARDLINE-64 KBPS" (upper), "HARDLINE-16 KBPS" (middle), and "RF-16 KBPS" (lower). These panel changes were implemented by TRW on January 25, 1979. In addition, TRW added a lamp dimmer capability which includes a potentiometer and a toggle switch with normal and bright positions. The dimmer capability was added at the request of Boeing.

RID-39 itemizes several deficiencies of the KG control panel. First; the "POWER ON," "OPERATE," and "ENCRYPTED" lights do not convey any additional information and remain constantly illuminated. Therefore, these lights should be deleted. The "MEMORY" light should be located with the other failure lights. Second, the "LOAD" push button should be recessed and an additional barrier guard provided. These changes to the KG control panel are to be part of the CIU CDR Data Package. RID-16 recommends that the CIU specification be changed from the requirement to provide the "VCC" display of two-digital hexadecimal for verification of 21 bits to a two-digit octal display because of the unfamiliarity of hexadecimal. Boeing is to change the CIU specification to allow the "VCC" display to be two octal digits.

AI-19 was prepared because the CIU design for incorporating the KG-60 equipment provides toggle switches, rotary switches and push-button interfaces on the KG control panel. The electrical interface in the CIU specification is incompatible with the design description. Therefore, AI-19 requests that Boeing prepare a "one-sided" ICD for submittal to SAMSO showing the direct interface between the KGT-60 and KGR-60 and the KG control panel. RID-22 establishes the requirement for the indication in both CLEAR TEXT and KG modes for the Orbiter crew to verify that the CIU commands have been correctly accepted. With the present design, the "VCC" and "COMMAND REJECT" indications are provided in the KG mode only. The present design relies on the ground station confirmation that the commands have been correctly accepted. RID-22 notes that this design is unacceptable because it constrains the operational timelines due to reliance upon data through the ground stations and because it does not meet the basic requirement that an operator be provided with feedback on equipment response. Boeing is to provide a design approach for indicating to the crew in the CLEAR TEXT mode that the CIU commands have been correctly accepted.

The CIU specification requires that protection be provided where a failure, fault or overload could result in hazards of fire, smoke or explosion. RID-15 points out that overload protection is lacking in the current design of the CIU control panel. TRW provided overload protection by use of proper wire sizing of all cables not confined in hermetically sealed enclosures. On January 25, 1979, TRW presented the power distribution scheme utilized to provide the necessary overload protection.

The final RID concerning the CIU control panel was RID-45, which noted that the CIU specification required a maximum surface touch temperature of 113°F; however, the maximum ambient temperature is 135°F. At 135°F ambient, the CIU control panel cannot be held to 113°F. Boeing is to initiate documentation changes to correct this discrepancy.

RID-19 compares the connectors shown in the CIU PDR Data Package with the negotiated Orbiter interface wiring and connectors and finds that the connectors are incompatible. TRW reviewed the connector requirement and the space available. Although the specified connectors are larger than those TRW used on previous Shuttle equipment, TRW can accommodate them in the design. The connectors to be used by TRW are the same as those specified except that they are hermetically sealed instead of the environmental type. The TRW design concept is predicated on hermetically-sealed connectors on all the boxes.

AI-13 and -14 are concerned with components used in the CIU design. AI-13 is concerned with the use of a fixed tantalum capacitor 1A060 which, according to Aerospace, needs a series resistance of 3 ohms/V in order to functional correctly. TRW disagrees with this position. Boeing is to submit this discrepancy to the next PMPCB for resolution. AI-14 is concerned with part #LH0002H which was disapproved by the PMPCB. TRW is to delete this part from the CIU design before the CIU CDR.

AI-08 recommends a review of the CIU console contents weight, including the weight of each KG-60. AI-08 notes that a maximum CIU console contents weight of 135 lbs, including the maximum weight of each KG-60 at 35 lbs, is required. The maximum weight of the CIU excluding the KGT-60, KGR-60, and console frame is to be 75 lbs. TRW revised the CIU weights from those given in the PDR Data Package. The total weight of the CIU console contents is 124 lbs (11 lbs margin); however, this is based on an allocation of 30 lbs for the KG-60 according to the CIU specification, not the 35 lbs shown in AI-08. Also, AI-08 noted that the control panel weights appeared low in light of the power control panel weight at 50 lbs, primarily to survive kick load requirements. TRW increased the control panel weights over the PDR estimate to account for a 10.5 × 19.0 × 0.190 aluminum panel plus the estimated weight for the panel components.

Finally, it is noted that the CIU consoles are CFE to TRW. The SIL console was required in February 1979 and the Qualification and Flight consoles were required in May 1979. AI-11 was assigned to Boeing to ensure that the consoles would be delivered as scheduled.

4.0 IUS/ORBITER COMMUNICATION REDUNDANCY EVALUATION

Redundancy is used throughout the Orbiter and the IUS to protect against failures; the degree of redundancy, however, varies in both the IUS and Orbiter communication systems. In this section, the functional paths available to command the IUS in both the CLEAR TEXT and EXCRYPTED TEXT modes are investigated first; second, the functional paths available for the IUS to transmit telemetry of various data rates in the CLEAR TEXT and ENCRYPTED TEXT modes are investigated. Also, the functional paths for commands and telemetry are investigated for both the attached and detached modes.

The SGLS commanding of the IUS is presented in Figure 29. The various functional command signal paths are illustrated from the SCF ground station and CIU control panel. In the attached mode, commands from the SCF can be transmitted to the Orbiter using either the TDRS ground station to relay the commands via the TDRS over Ku-band or S-band, or the direct S-band link from the SCF ground station to the S-band network transponder. Onboard commands are entered using the CIU control panel. In terms of redundant command paths, note that the S-band network transponder and the NSP are completely redundant. Also, commands can be sent from the KuSP to the two NSP's or directly to the CIU, but note that the Ku-band system is not redundant. From each NSP, commands are sent to the GPC using MDM's but, from the GPC to the CIU, there is only a single MDM path. Thus, with only the S-band network equipment, the MDM to CIU is a single-point failure that would eliminate the capability of transmitting commands to the IUS from the ground through the Orbiter. During the first IUS flight(s) before the TDRS is operational, the Ku-band system wil not be available to provide a redundant command path through the Orbiter to the IUS. The only way commands can be transmitted from the ground to the IUS is via the SCF ground station directly to the IUS in the payload bay. When the IUS is in the payload bay, the Orbiter may have to maneuver so that the line-of-sight (LOS) from the SCF ground station to the IUS antennas is not blocked by the Orbiter. In some cases, the IUS will have to be raised on the cradle in order to assure that the LOS is not blocked by the Orbiter.

Another way to command the IUS is with crew-generated commands using the CIU control panel. A failure in the KGT-60 would eliminate the possibility of ENCRYPTED commands from the control panel. A failure in

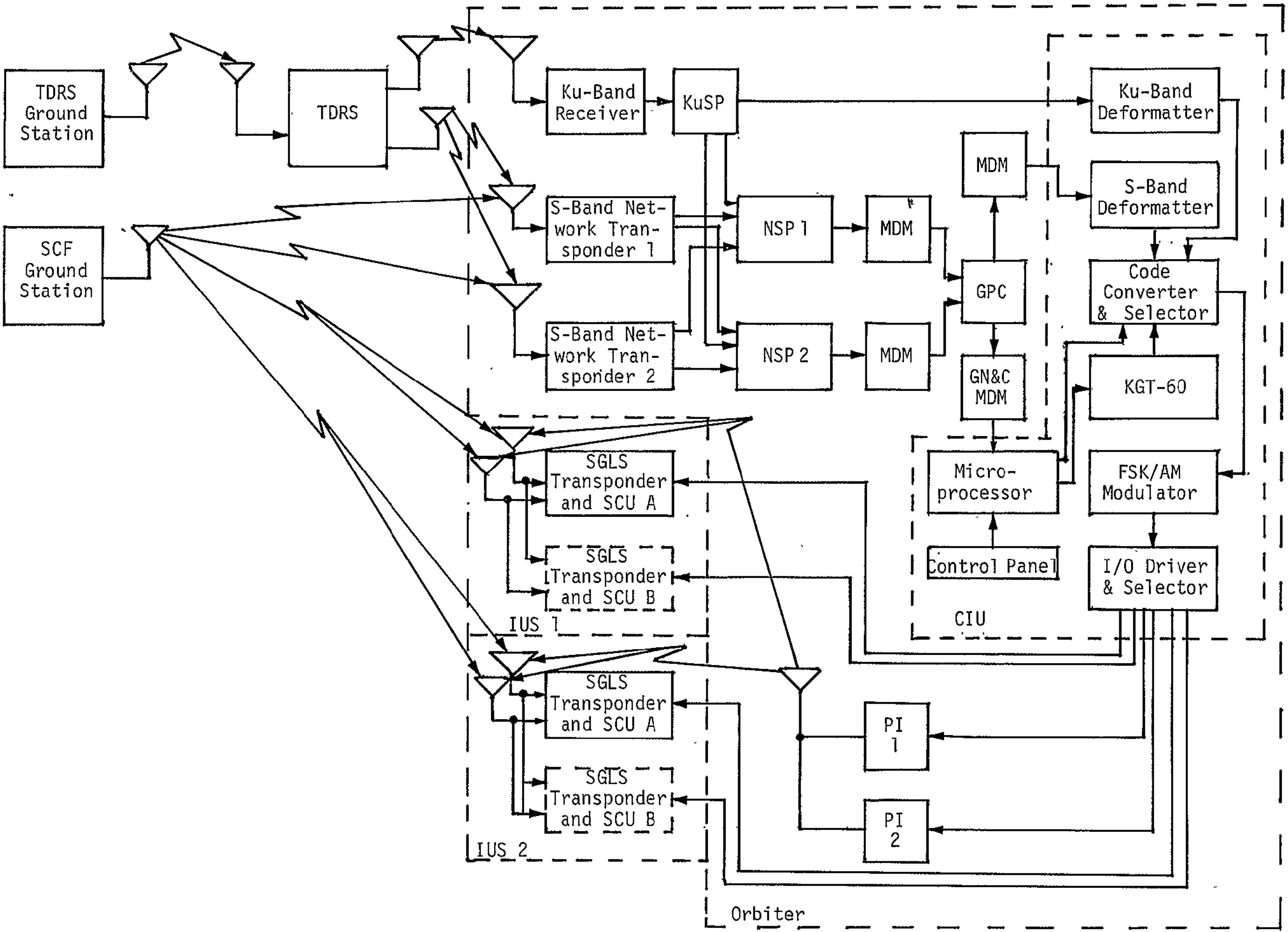


Figure 29. Functional SGLS Command Signal Flow

the CIU FSK/AM modulator or I/O driver and selector would eliminate all command signal paths through the Orbiter and the direct RF link from the SCF to the IUS described in the previous paragraph would have to be used.

In the attached mode, the CIU can command the IUS directly (hardline) or by using the PI for PF communications even though the IUS is still in the payload bay. Section 5.0 describes the RF coverage of the Orbiter payload antenna when the IUS is in the payload bay. In the detached mode, the CIU sends its commands through one of two redundant PI's.

A final area of concern in terms of redundancy is whether the IUS transponder is single-string or double-string. Currently, the IUS will be single-string (i.e., a single SGLS transponder) with a kittable option for a second string, as shown by the dotted transponder in Figure 29. Obviously, with a single string, a single failure in the transponder or IUS signal conditioning unit (SCU) containing the command decoder would eliminate all possible paths to command the IUS.

The NASA IUS employs STDN/TDRS transponders. The functional command signal flow for the NASA IUS is shown in Figure 30. Note that the Orbiter command signal flow is completely redundant, with only a single string using the Ku-band system. But, in case of a failure in the Ku-band system, there is still a fully redundant S-band system as backup. Therefore, any single failure in the Orbiter communication system would not affect the command signal flow. Also note that the IUS can be commanded from the GSTDN directly or from the TDRS ground station via the TDRS while the IUS is in the payload bay and still attached. Again, however, the Orbiter may have to maneuver so that the LOS from the GSTDN or TDRS to the IUS antennas is not blocked by the Orbiter. The maneuvers required of the Orbiter will be less demanding for the NASA IUS than the DOD IUS because of the greater coverage of the TDRS. In some cases, however, the IUS still might have to be raised on the cradle in order to make sure that the LOS is not blocked by the Orbiter.

Crew-generated commands to the IUS are via the GPC. In Figure 30, the payload station control panel is shown as a way to enter commands into the GPC and then into the PSP for transmission to the IUS. While a single MDM is shown from the payload station control panel to the GPC, there are several redundant keyboards with MDM that would allow the entering of commands into the GPC.

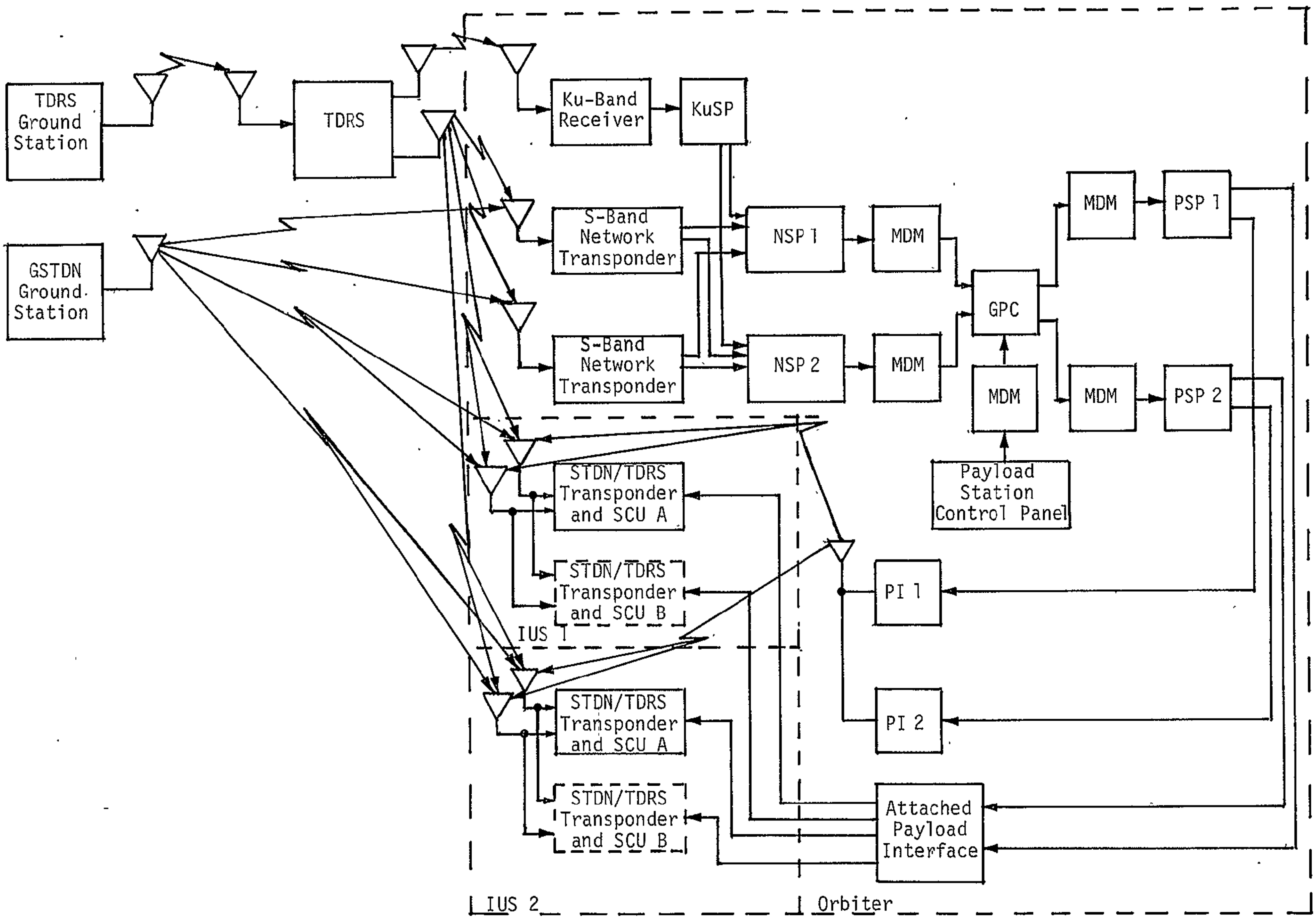


Figure 30. Functional STDN/TDRS IUS Command Signal Flow

The only area of concern in terms of redundancy for the NASA IUS is the possibility of a single-string STDN/TDRS transponder. Currently, the NASA IUS will be single-string similar to the DOD IUS with a kittable option for a second string, as shown by the dotted transponder in Figure 30. As was mentioned in discussing the DOD IUS with a single string on the IUS, a single failure in the transponder or SCU would eliminate all possible paths to command the IUS.

The SGLS telemetry functional signal flow is presented in Figure 31. In the attached mode, IUS telemetry comes from three sources: (1) the Signal Interface Unit (SIU), (2) the Environmental Measurement Unit (EMU), and (3) the Wideband Data Interleaver (WBDI). Note that each of these telemetry sources is nonredundant so, if one of these units fails, that portion of the telemetry is lost. The SIU provides switching from the two IUS computers to one SGLS transponder (A) (baseline) or two transponders when the redundant transponder (B) is installed. The SIU also provides proper interfacing with the encrypter for the ENCRYPTED TEXT mode. The FM vibration data consists of three sensors mounted on the spacecraft interface ring. Their analog output is signal conditioned to modulate three standard subcarriers in the EMU. The three subcarriers are summed together and cabled directly to the attached payload interface and the transponder 1.7 MHz input port. The WBDI interleaves up to six separate channels of asynchronous NRZ-L telemetry data. The WBDI output is serial NRZ-L data at a rate of 256 kbps.

As shown in Figure 31, the output of the attached payload interface is (1) EMU data from one of two IUS's sent to the SIU for selection to the Payload Recorder (PR), (2) WBDI data from one of two IUS's sent to the CIU for NRZ-L to biphase-L conversion and selection to the KuSP, FMSP and PR, and (3) SIU data from both IUS's (labeled IUS 1 and IUS 2 data in Figure 31) sent to the CIU for selection to the PDI or after NRZ-L to biphase-L conversion to the KuSP, FMSP and PR. If the NRZ-L to biphase-L convertor or selector for the WBDI fails, the WBDI data cannot be transmitted or recorded. If the selector between IUS 1 and IUS 2 data fails, this telemetry cannot be processed through the Orbiter. However, if the NRZ-L to biphase-L convertor used for this data failed, the data would still be sent to the PDI for downlinking. Also, the data from the SIU (IUS 1 or 2) can be transmitted directly to the SCF ground station with

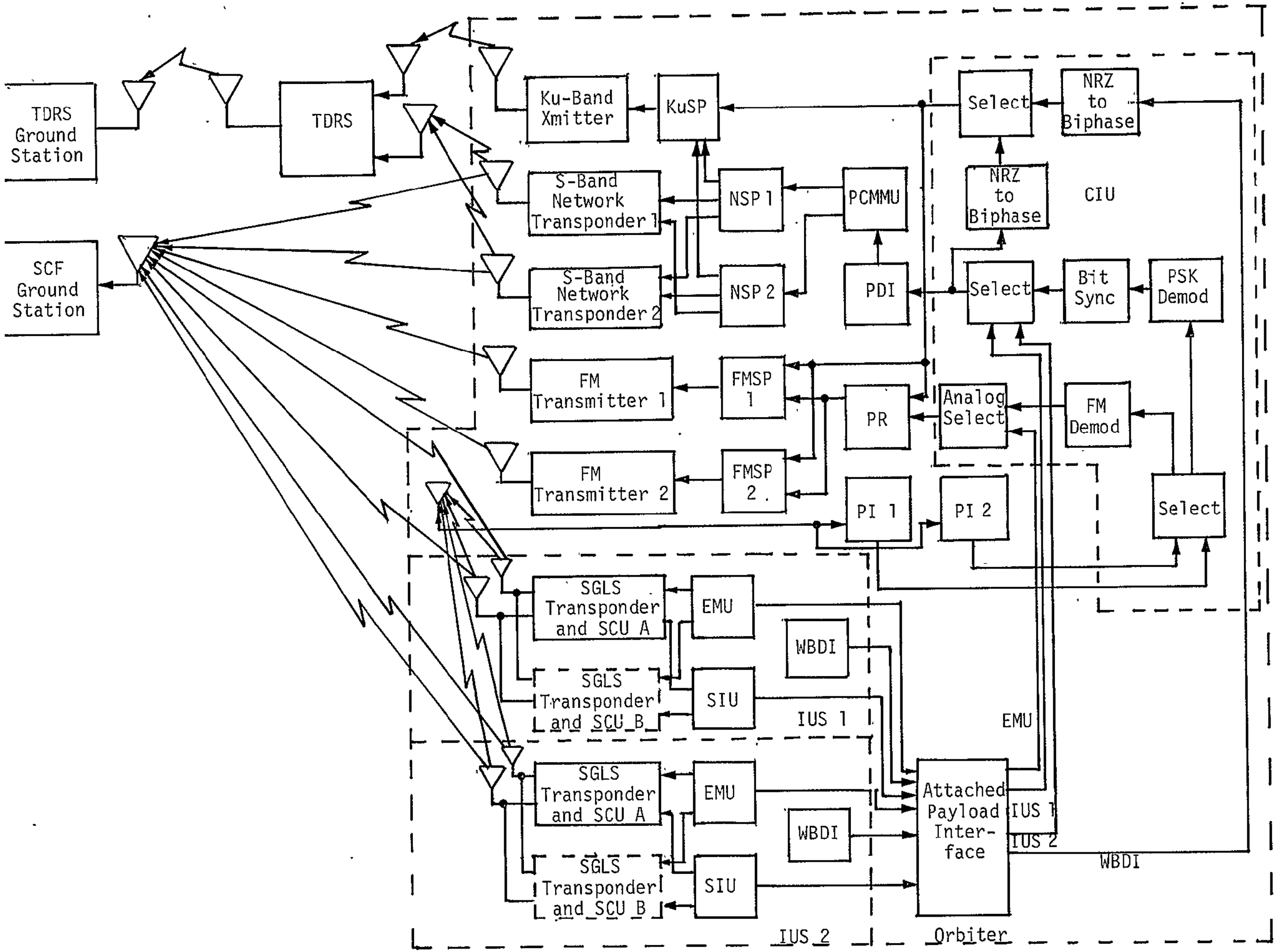


Figure 31. Functional SGLS Telemetry Signal Flow

the restriction(s) on Orbiter maneuvers described in connection with the command data signal flow. It should be noted that, even in the attached mode, the SIU and EMU data are available by using the RF link from the SGLS transponder to the Orbiter PI.

In the detached mode, the telemetry can be received by the Orbiter via the PI or by the SCF ground station via a direct RF link. On the Orbiter, the output of one of the two PI's is selected for demodulation. If the selector fails, the Orbiter cannot process telemetry data in the detached mode. Also, following selection between the two PI's, the FM demodulator and PSK demodulator are not redundant so, if either fails, then either the EMU data or the SIU data is not recovered by the Orbiter. The bit synchronizer following the PSK demodulator is implemented partially in hardware and partially in software. Here again, if the hardware portion of the bit synchronizer fails, the SIU data is not processed by the Orbiter. If the software portion of the bit synchronizer fails because of a microprocessor failure, the whole CIU will probably not function. Once the telemetry data is processed by the CIU up to the output selector, the commands on the attached mode in terms of the result of failures in the CIU apply to the detached mode.

Following telemetry processing by the CIU, the only nonredundant Orbiter subsystems are the PDI, PCMMU and PR. Failure of the PR means that no EMU data will be available for transmission to the SCF ground station via the S-band FM link. The PDI and PCMMU are internally redundant, as shown in Figures 24 and 25. The only failure that would disable the PDI is a failure of the input switch matrix; alternate paths, however, (i.e., KuSP, FMSP and PR) for the same data sent to the PDI are used to provide redundancy such that a single failure in the Orbiter subsystems other than the CIU will not cause loss of telemetry data.

The telemetry data has several RF paths available to the ground. Using the Ku-band system, the telemetry data is transmitted via the TDRS to the TDRS ground station. Using the S-band network transponder, the telemetry data can be transmitted via either TDRS to the TDRS ground station or directly to the SCF ground station. Finally, using the S-band FM transmitter, the telemetry data is transmitted directly to the SCF ground station.

The only remaining single failure that could cause loss of the telemetry data in the detached mode is by failure of the SGLS transponder with the baseline single-string system. This problem was discussed in connection with the command signal flow and represents an area of major concern.

The telemetry functional signal flow for the NASA IUS is shown in Figure 32. Note that the Orbiter telemetry signal flow is completely redundant except for the PDI, PCMMU and PR. Failures in these subsystems have exactly the same impacts as those discussed for the SGLS telemetry; however, alternate paths (i.e., KuSP and FMSP) for the same data provide redundancy for these subsystems as well. Therefore, in the attached mode, there are no single failures in the Orbiter that would cause loss of the telemetry data. The only way that portions of the telemetry data could be lost in the attached mode is failure of the telemetry sources (i.e., SIU, EMU and WBDI) on the IUS. In the detached mode, the telemetry could be lost if there were a failure in the baseline single-string transponder.

Another area of concern in the detached mode is that the EMU data is modulated on the 1.7 MHz subcarrier; the PSP, however, cannot demodulate FM data. Thus, if the EMU data is to be presented by the Orbiter in the detached mode, the CIU must be used with the PSP bypassed. Since the STDN/TDRS transponder expects command data from the PSP on a 16 kHz subcarrier, the PSP cannot be turned off (bypassed) unless command data transmission and telemetry processing are not to be performed simultaneously. Without the sequential use of the PSP and CIU, the only way the EMU data can be processed is at the ground station via the TDRS or direct RF transmission to the GSTDN.

The telemetry data has several RF paths to the ground. As was mentioned previously, the NASA IUS can transmit telemetry in the TDRS mode via the TDRS to the TDRS ground station or in the STDN mode directly to the GSTDN ground station. When the telemetry data is processed by the Orbiter, the telemetry data can be transmitted via the TDRS using either the Ku-band system or the S-band network transponder. Alternately, the Orbiter can transmit the data directly to the GSTDN ground station using either the S-band network transponder or the FM transmitter.

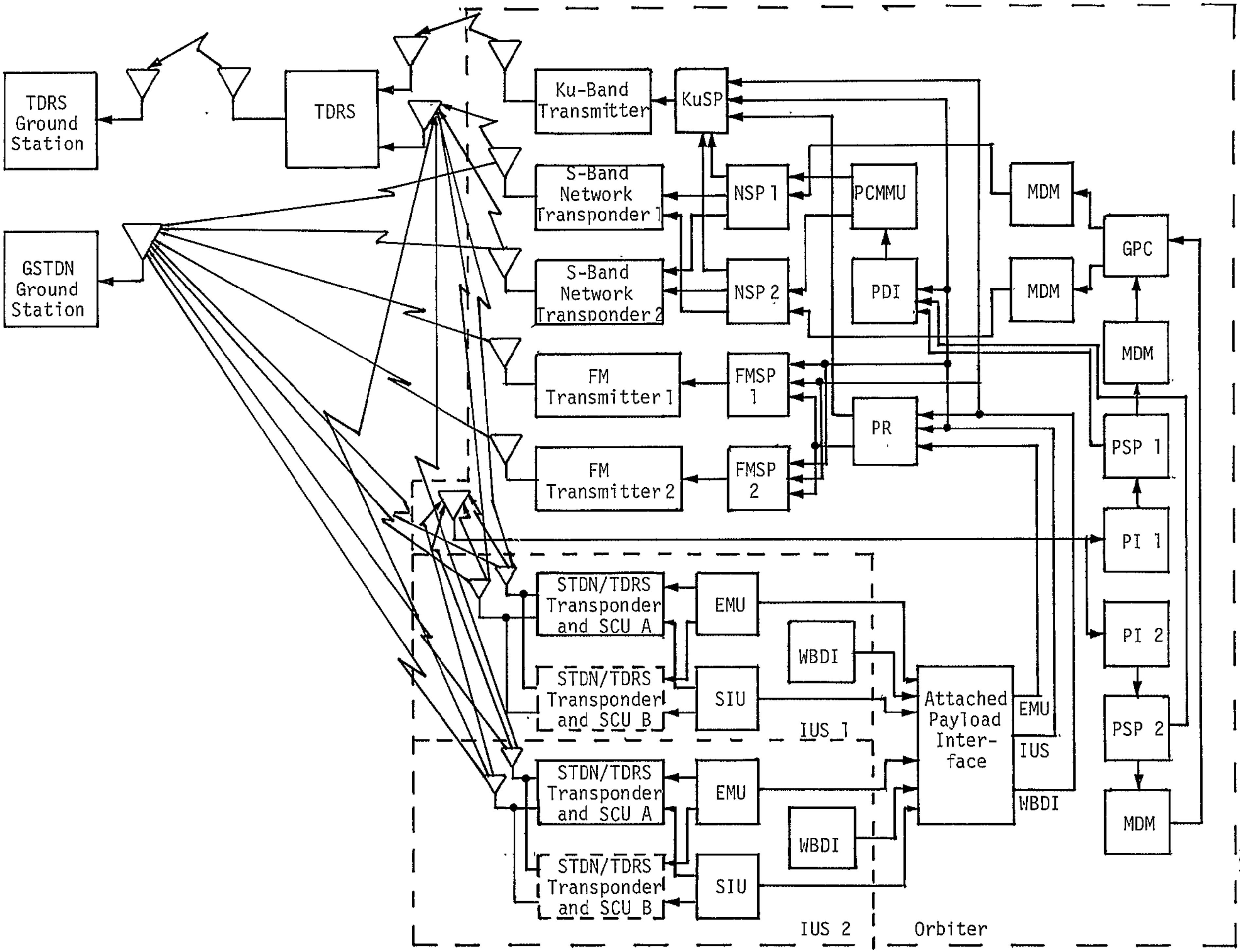


Figure 32. Functional STDN/TDRS Telemetry Signal Flow

5.0 IUS RF COVERAGE

The Orbiter-to-IUS communications link is established through a single Orbiter S-band payload antenna, which is a cross-dipole-fed cavity with both right- and left-hand circular polarization capabilities and conical log spiral antennas located on the IUS. The number, orientation and beamwidths of the IUS antennas vary depending on the particular mission, and these parameters are subject to revision as required. This section deals with the IUS RF coverage with the Orbiter for the various conditions encountered during the mission from the period prior to injection of the IUS into low-earth orbit, while the IUS is still in the Orbiter payload bay, to the IUS in geosynchronous orbit or planetary transfer orbit. Of particular concern are the ramifications of using the RF link while the IUS is in the payload bay, especially in terms of establishing carrier frequency locking and receiver protection from high RF signal levels due to close proximity.

5.1 Payload Bay RF Coverage

The task of analyzing the communications capability between the S-band payload antenna and the corresponding IUS antennas in the payload bay is extremely complex. The original concept of communications between the Orbiter and the IUS in the payload bay was by means of a detachable umbilical connecting the Orbiter and IUS until separation prior to IUS ejection from the payload bay. For this reason, the specifications for the S-band payload antenna required isolation of the radiated power from the bay itself. No provisions were therefore included to supply a direct line-of-sight link to any IUS payloads in the payload bay; rather, the present design relies on the "spillover" of the S-band payload antenna pattern to provide adequate coherent signal strength to permit the IUS receivers in the payload bay to lock up on the carrier frequency. Similarly, the transmissions from the IUS to the Orbiter must be considered to evaluate the overall effectiveness of this RF link for both the single and tandem IUS payload configurations. Various aspects of the existing problems will be discussed with the idea that, as the Space Shuttle program progresses, improvements can be implemented as a result of analyzing and understanding potential areas of difficulty.

5.1.1 Antenna Descriptions and Performance Characteristics

In order to characterize the Orbiter-IUS communications link, it is essential to describe their respective antenna systems since their designs greatly influence the overall performance. It should be noted that the present Orbiter S-band payload antenna might undergo further modifications to broaden its RF coverage. Also, the number, locations, and orientations of the IUS antennas vary (depending on the mission) and are subject to change. Therefore, for this preliminary description, only general characteristics will be considered. If specific information is required, definitive answers can be obtained only by either simulation using mock-ups or measurements using actual hardware in the flight configuration since the geometrical relationships of the antennas and the payload bay enclosure are so complex.

5.1.1.1 Orbiter S-Band Payload Antenna

The Orbiter S-band payload antenna is located on the upper section of the forward fuselage, approximately 18 inches from the payload bay, as shown in Figures 33 and 34. The locations of the other Orbiter antennas are also shown for reference purposes. The antenna is a cross-dipole-fed cavity approximately 2.75 inches on each square side and 3 inches deep. The two orthogonal dipoles are arranged so that they are electrically phased 90° apart and can be readily switched between right- and left-hand circular polarization by an astronaut in the cabin. The gain/coverage specification is 2.5 dBCI (dB gain with respect to a circularly polarized isotropic source) within a 160° cone (double angle) perpendicular to the Orbiter longitudinal axis. The first flight model S-band payload antenna does not completely satisfy these requirements and might possibly be modified for subsequent flights.

There are two structural features which affect the S-band payload antenna pattern. The thermal protection system consists of multiple layers of nylon, silicone rubber, and borosilicate which entirely cover the aperture of the antenna. Although some of these materials have a high dielectric constant, the layers used are thin so that the total effect is small. The other obstruction is a dome light approximately 2 inches in diameter which protrudes above the Orbiter skin directly between the payload antenna and the payload bay. This dome light was simulated using

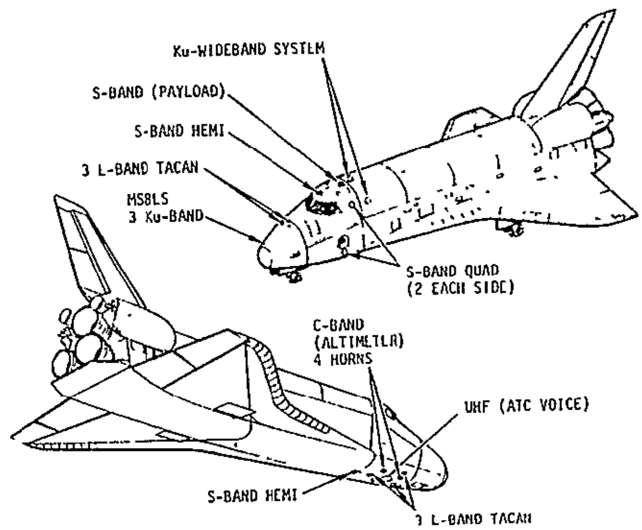


Figure 33. Antenna Locations

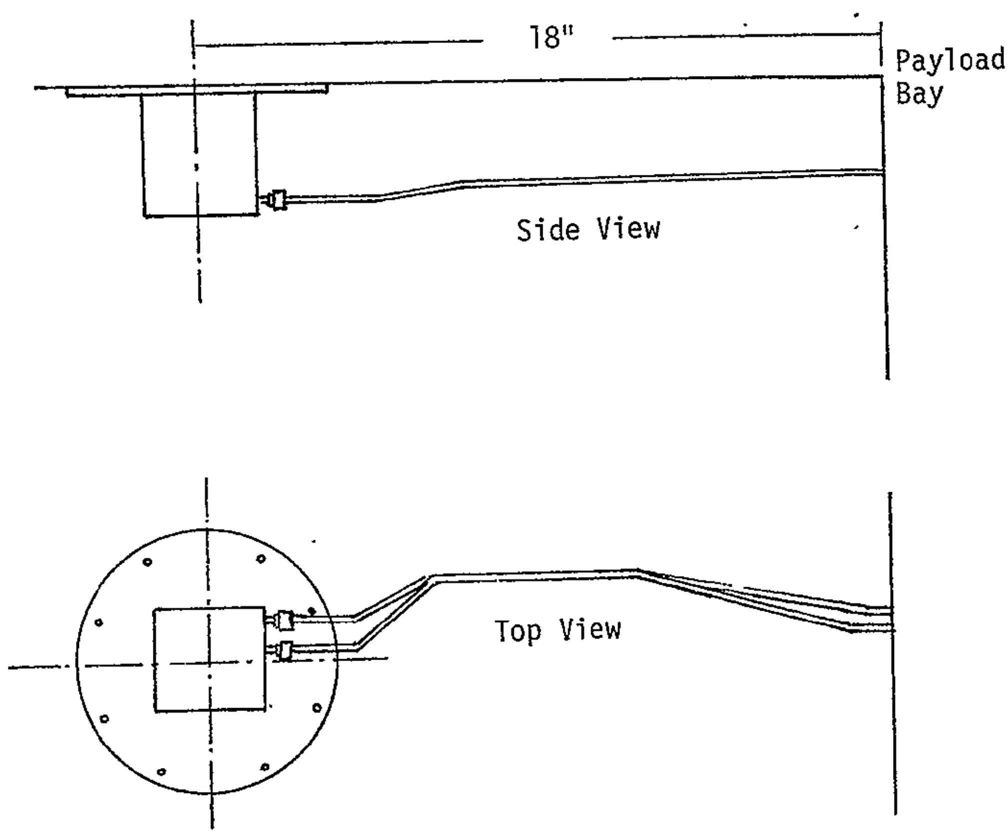


Figure 34. Sketch of Orbiter S-Band Payload Antenna

metallic foil on a scaled mock-up at JSC, and the effect on the antenna pattern was a perturbation resulting in less than the background level of -20 dB in the general vicinity of the bay.

5.1.1.2 IUS Antenna Systems

The IUS antenna systems are composed of two versions of conical log spiral antennas which are shown in Figure 35. The medium-gain antennas have half-power beamwidths (HPBW) of 85° to assure a good high data rate communication link during injection into geosynchronous orbit, as shown in Figure 36 and 37 which illustrate the antenna configurations for the DOD/STS missions. The Orbiter-launched DOD IUS has a combination of omnidirectional and medium-gain antennas, with redundant sets denoted by A and B, which can be readily switched when necessary. This combination assures a continuous RF coverage of the IUS with the Orbiter for any orientation of the IUS spacecraft.

The design and testing of these antennas appear to be straightforward except for problems encountered when either a larger diameter (180-inch) payload is used or the antenna is canted to fit within a limited envelope. In both cases, reflections due to adjacent spacecraft surfaces create destructive interference nulls which greatly distort the antenna patterns. Although these tests were made at a scaled frequency of 8.999 GHz, the results appear to be realistic and indicate that the antennas for the 180-inch diameter payloads should be extended on a 1 m boom to achieve the desired directivity characteristics.

The NASA IUS antenna requires nearly a 7 dB directivity for operation with TDRS. The system design approach incorporates two pods of antenna elements to provide spherical coverage by switching to the appropriate antenna. Each antenna is dedicated to a conical sector of the total radiation sphere. Ten antennas are required to provide 6.8 dB directivity. The antenna installation consists of two pods of five conical log spiral antennas, each pointed toward its dedicated 85° HPBW sector. A three-dimensional illustration of the antenna coverage is shown in Figure 38. In this configuration, the arrays are cocked 22.5° so that upper hemisphere coverages and vehicle shadowing would be identical to lower hemisphere coverage.

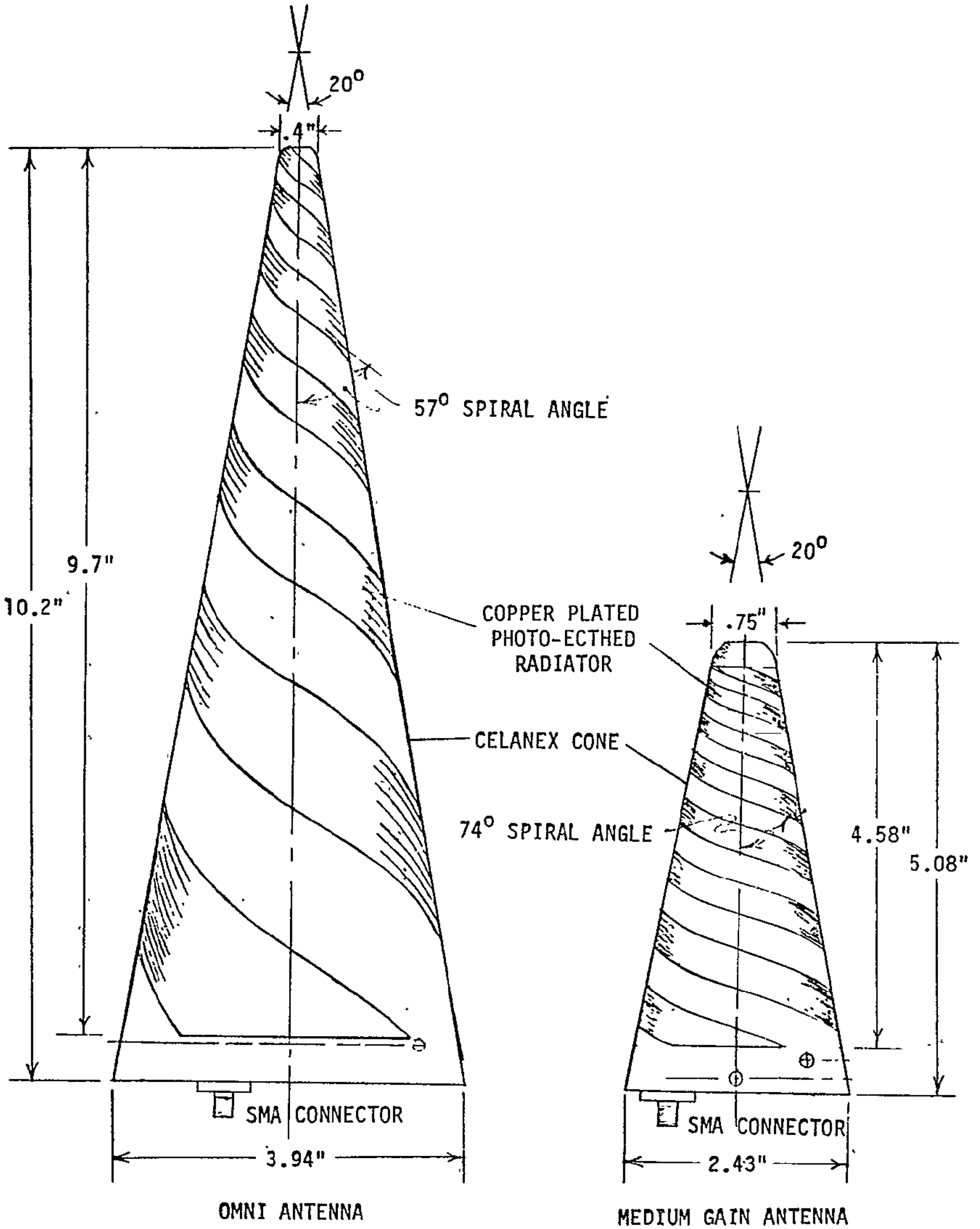


Figure 35. IUS Antenna Configurations

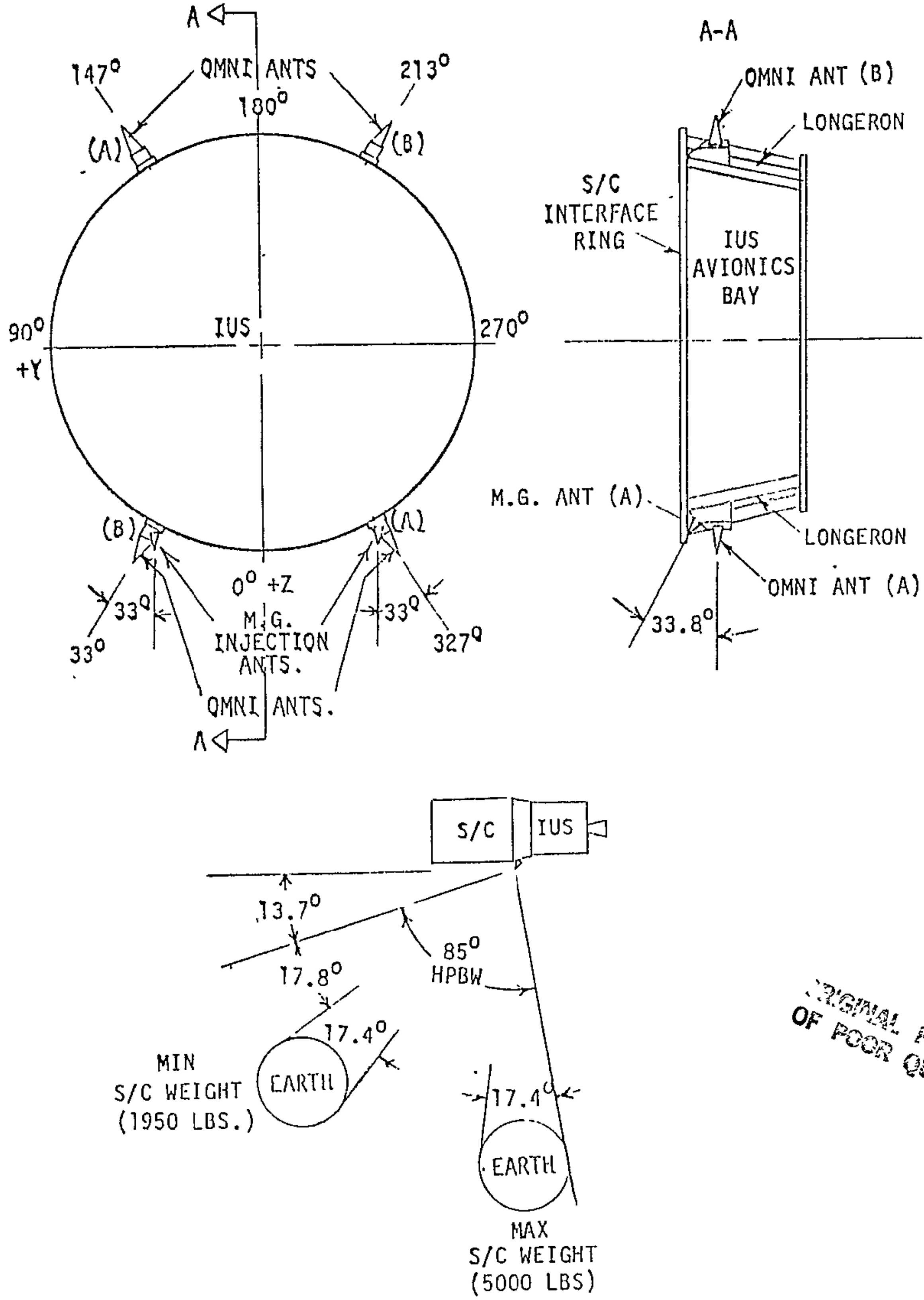


Figure 36. IUS Antenna Implementation for DOD/STS Geosynchronous Injection Coverage

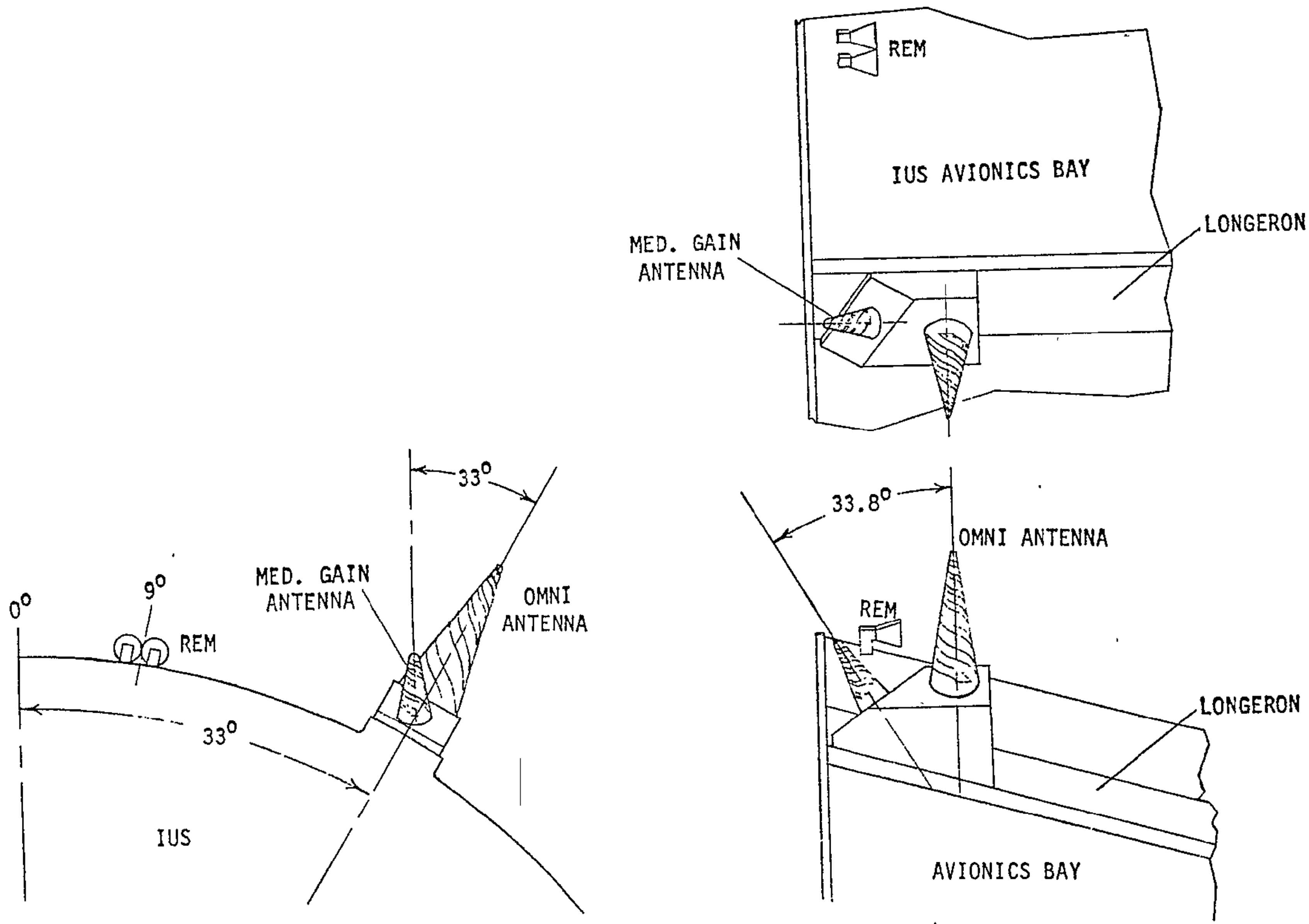
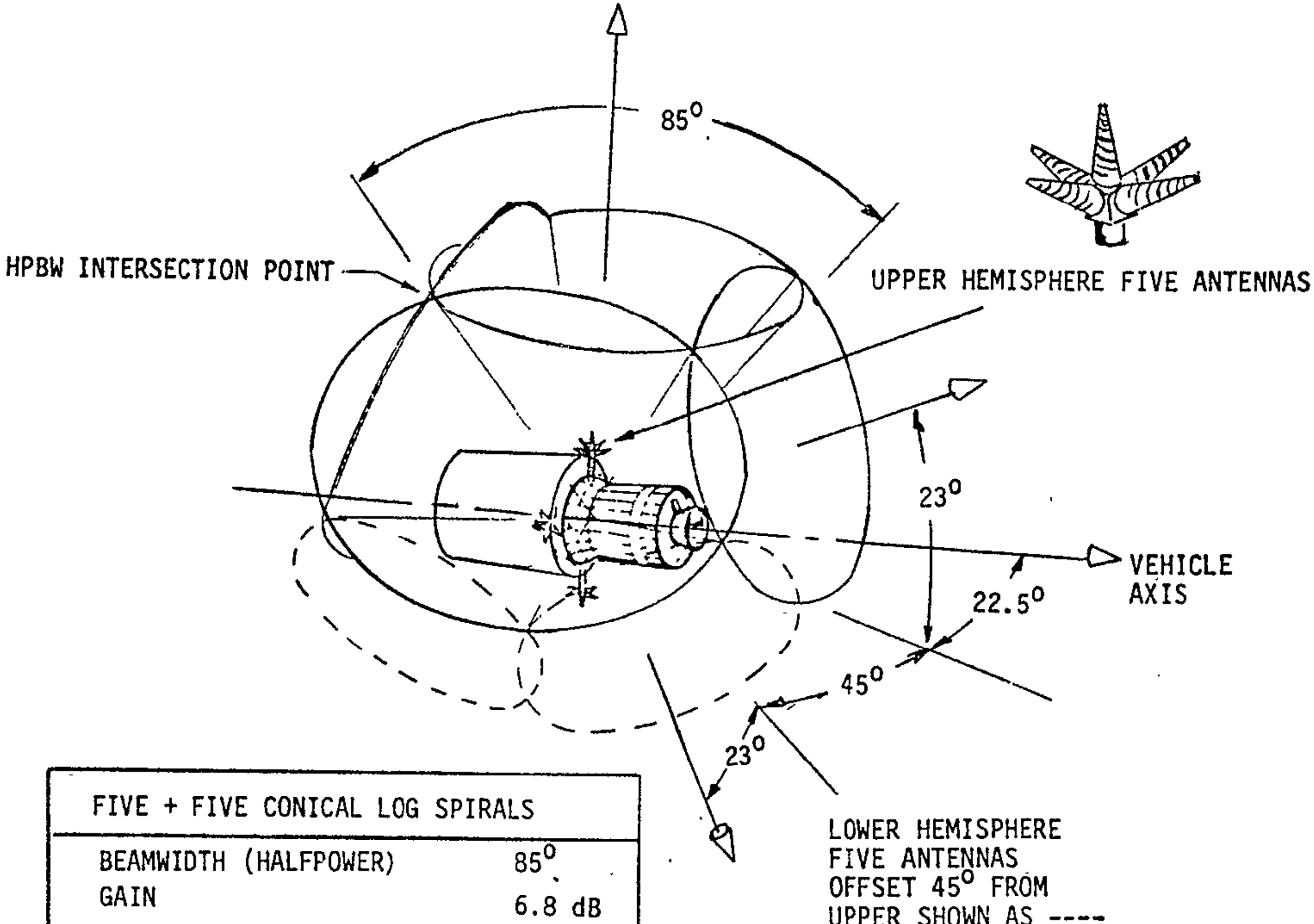


Figure 37. Antenna Installation for DOD/STS--Three Views



FIVE + FIVE CONICAL LOG SPIRALS	
BEAMWIDTH (HALFPOWER)	85°
GAIN	6.8 dB
REDUNDANT COVERAGE	31.4%

Figure 38. NASA IUS TT&C Antenna Assembly

The conical log spiral antenna for the NASA vehicle is the same medium-gain antenna used on the DOD vehicles. This antenna design (Figure 35) provides a compact size that permits a relatively close spacing of the antenna phase centers for reduced phase switching transients. The antenna provides an 85° HPBW pattern with 6.8 dB of on-axis directivity.

5.1.1.3 IUS Payload Antenna Patterns

Few antenna patterns are available for the IUS payloads. Except for the blockage effects of large diameter payloads and canted antennas, it appears that the present radiation distribution patterns are satisfactory and detailed patterns will be taken for specific IUS configurations when necessary. Some typical examples of the omnidirectional and medium-gain conical log spiral antennas for the DOD IUS are shown in Figure 39. Figure 39 shows the polar radiation patterns of the three principal planes: yaw, pitch and roll for the omnidirectional antenna.

For the special case of the communications link with the IUS still in the payload bay, it is apparent that these patterns are not necessarily representative of the actual situation due to the influence of surrounding reflective surfaces such as the open payload bay doors and Orbiter tail structures. As was found to be the case for the larger diameter payloads which partially blocked the antennas, null patterns will be created by destructive interference of out-of-phase electric field components. The exact locations and magnitudes of these nulls are impossible to predict or simulate with any degree of reproducibility so that the only practical approach is to realize that nulls can exist and therefore allow adequate link margin to compensate for possible "drop-outs" or plan corrective procedures in the event that a satisfactory link is not achievable.

5.2 Payload Interrogator (PI) Transmitter to the IUS Receiver Link

The transmitter for the PI has the capability of being switched to a power output compatible with the distance to the IUS. The power steps are 5W, 0.5W, and 0.0025W. Since the cable loss is of the order of 9.8 dB, the payload antenna EIRP is +29.7 dBm, +19.7 dBm, and -3.3 dBm. For the case of the IUS in the payload bay, the output power should be set at the lowest power level (-3.3 dBm) to avoid the possibility of saturating or damaging any of the IUS SGLS or STDN/TDRS. At this level, it is shown in

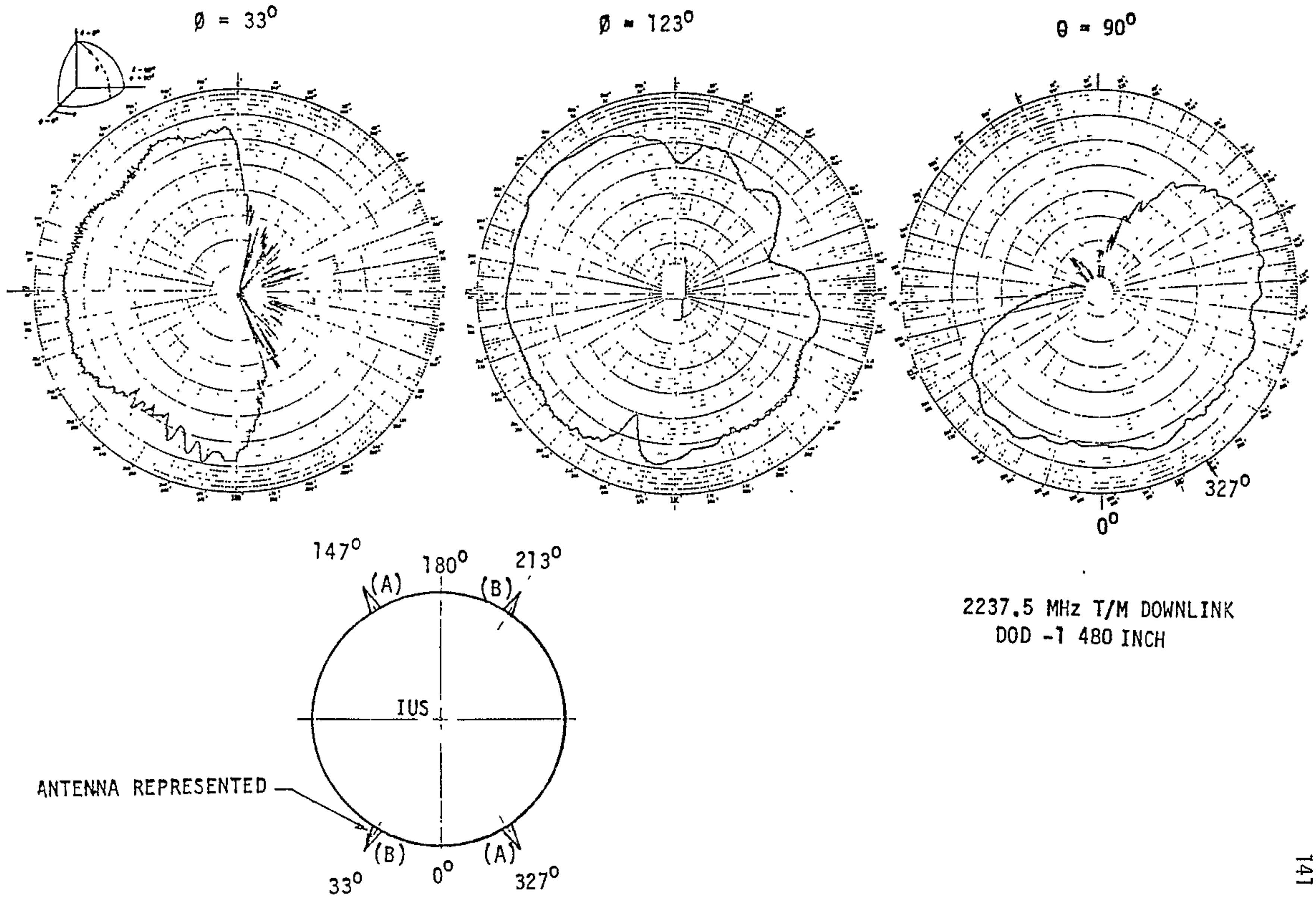


Figure 39. Preliminary Downlink DOD/STS Omni Antenna Patterns (120 Inch Dia Payload)

Table 36 that the received power at the SGLS receiver is -56.8 dBm, which is within the operating dynamic range of threshold (approximately -120 dBm) to -40 dBm maximum. However, the other two output power levels are -23.8 and -33.8 dBm, which exceed the upper limit of the SGLS transponder specified dynamic range (TRW is currently achieving an upper limit of -23 dBm). Table 37 presents the received signal power for the NASA IUS with the STDN/TDRS transponder. Again, it is shown that the lowest output power level must be used so that the IUS received power (-52.5 dBm) is less than -40 dBm, the upper limit of the specified dynamic range for the STDN/TDRS transponder.

Note that the received signal power shown in Tables 36 and 37 is somewhat vague at this time for the IUS in the payload bay since this particular situation has never been simulated. Many unknown factors such as the final IUS antenna configurations in the payload bay and the effects of the walls of the bay on the transmitted signal have not been clarified and will not be unless measurements are taken prior to the actual mission. The only conclusion at this time from Tables 36 and 37 is that the received signal power level at the lowest power setting of the PI appears to be within the dynamic range of the SGLS and STDN/TDRS receiver.

One unknown is the amount of energy actually entering the Orbiter payload bay since a line-of-sight path does not exist for the case when the IUS payload is still in the bay. Some diffraction effects around the corner of the front fuselage will exist. Preliminary measurements using a mock-up indicated a signal level 20 dB down in the vicinity of the bay. More important, probably, will be the effects of back scatter from various protrusions on the open bay doors, the rear wall of the bay, and the rocket engine nozzles and tail section of the Orbiter vehicle. The bay itself is 18 m long and, since the doors of the payload bay will be open, little standing wave phenomena would be detected which might create nulls that can cause loss of lock. A slight slope on the rear wall of the bay would alleviate any possibility of this condition by reflecting incident energy into space.

If the signal strength is found to be inadequate for communication with the IUS in the bay, it is possible to use higher output power levels from the PI transmitter until a suitable setting is found. If it is found to be essential to check out the IUS payload prior to separation from the

Table 36. Orbiter to IUS SGLS Transponder Received Signal Power

Parameter	Values			Source
1. Orbiter Payload Transmit Power, dBw	7.0	-3.0	-26.0	Rockwell Spec.
2. Orbiter Transmit Circuit Loss, dB	-9.8	-9.8	-9.8	Rockwell estimate based on latest cable lengths, etc.
3. Orbiter Payload Antenna Gain, dB	2.5	2.5	2.5	Omni, specified over 36% of upper hemisphere
4. Orbiter EIRP, dBW	-0.3	-10.3	-33.3	Sum 1 through 3
5. Space Loss, dB	-47.0	-47.0	-47.0	f = 1787.744 MHz (STS Primary), R = 3 m
6. IUS Receive Antenna Gain, dB	1.4	1.4	1.4	Boeing estimate
7. IUS Pointing Loss, dB	-4.0	-4.0	-4.0	Boeing estimate at 95° off-axis
8. IUS Receive Circuit Loss, dB	-3.9	-3.9	-3.9	Boeing estimate
9. IUS Total Received Power, dBW (dBm)	-53.8 (-23.8)	-63.8 (-33.8)	-86.8 (-56.8)	Sum 4 through 8

Table 37. Orbiter to IUS STDN/TDRS Transponder Received Signal Power

Parameter	Values			Source
1. Orbiter Payload Transmit Power, dBW	7.0	-3.0	-26.0	Rockwell Spec.
2. Orbiter Transmit Circuit Loss, dB	-9.8	-9.8	-9.8	Rockwell estimate based on latest cable lengths, etc.
3. Orbiter Payload Antenna Gain, dB	2.5	2.5	2.5	Omni, specified over 36% of upper hemisphere
4. Orbiter EIRP, dBW	-0.3	-10.3	-33.3	Sum 1 through 3
5. Space Loss, dB	-48.4	-48.4	-48.4	f = 2092.594 MHz (STS Primary, R = 3 m
6. IUS Receive Antenna Gain, dB	6.8	6.8	6.8	Boeing estimate
7. IUS Pointing Loss, dB	-3.4	-3.4	-3.4	Boeing estimate at 45° off-axis
8. IUS Receive Circuit Loss, dB	-4.2	-4.2	-4.2	Boeing estimate
9. IUS Total Receiver Power, dBW (dBm)	-49.5 (-19.5)	-59.5 (-29.5)	-82.5 (-52.5)	Sum 4 through 8

Orbiter, it might be appropriate to incorporate another payload antenna (with appropriate attenuation pads) facing directly into the payload bay. This configuration would also involve adding another RF switch, but the line-of-sight link would be more reliable for such a critical function.

5.3 IUS Transmitter to Payload Interrogator Receiver Link

No adjustments are possible for controlling the output power of the IUS transmitter so that the 20W (13 dBW) from the TWT results in 13.2W (11.2 dBW) being radiated into the bay. The payload interrogator receiver achieves a very wide dynamic operating range by use of manual attenuators selected by the crew. Table 38 compares the performance parameters for each receiver sensitivity range. Above -20 dBm, however, the receiver IF amplifier circuits begin to saturate. Although this would not adversely affect demodulation of constant envelope signals, it may cause receiver false-lock under certain conditions. Therefore, overall receiver performance is not guaranteed above -20 dBm. At input signal levels of +10 dBm and higher, a preamplifier protective diode breakdown limiter becomes operative. Purposeful receiver operation above +10 dBm is not recommended.

Table 38. PI Performance Parameter Versus Receiver Sensitivity

Receiver Sensitivity Range	Maximum No Damage Input	Acquisition		Tracking Threshold
		Minimum	Maximum	
Low	+36 dBm	-87 dBm	+3 dBm	-91 dBm
Medium	+30 dBm	-107 dBm	-7 dBm	-111 dBm
High	+20 dBm	-120 dBm	-20 dBm	-124 dBm

The PI received power from the IUS SGLS transponder at 3 m is indicated in Table 39 as -19.4 dBm. Thus, with the PI in the low sensitivity range, the receiver IF amplifier is beginning to saturate. Note that, in Table 39, the received power was calculated based on a -4.0 dB IUS pointing loss (worst case). If there is no pointing loss, the received power is -15.4 dBm and the PI IF amplifier is in saturation, but there will be no damage to the PI receiver. Similarly, the PI received power

Table 39. IUS SGLS Transponder to Orbiter Received Signal Power

Parameter	Value	Source
1. IUS SGLS Transmitter Power, dBW	13.0	Boeing specification for 20W minimum
2. IUS Transmit Circuit Loss, dB	-3.2	Boeing estimate
3. IUS Antenna Gain, dB	1.4	Boeing estimate
4. IUS Pointing Loss, dB	-4.0	Boeing estimate at 95 off-axis
5. IUS EIRP, dBW	7.2	Sum 1 through 4
6. Space Loss, dB	-49.0	f = 2232.5 MHz (STS primary), R = 3 m
7. Polarization Loss, dB	-0.3	JSC estimate
8. Orbiter Receive Antenna Gain, dB	2.5	Omni, specified over 36% of upper hemisphere
9. Orbiter Receive Circuit Loss, dB	-9.8	Rockwell estimate
10. Orbiter Total Received Power, dBW (dBm)	-49.4 (-19.4)	Sum 5 through 9

from the IUS STDN/TDRS transponder at 3 m is shown in Table 40 to be -13.6 dBm including a -3.4 dB IUS pointing loss (worst case). Either with or without pointing loss, the PI IF amplifier is in saturation and there is no guarantee on overall PI receiver performance. There will be no damage, however, to the PI receiver at these received power levels. Without any lower power output mode capability for the IUS than the 20W, it has been calculated that the electric field strengths of the order of up to 7.2 V/m can exist in the payload bay when the IUS is transmitting. This electric field strength exceeds the established susceptibility level of 2 V/m. Therefore, operation of the IUS transmitters in the payload bay pose a potential problem to other payloads.

Another aspect of the operation of the IUS payload transmitters in the payload bay is the potential problem of the inadvertent switching of power to an inboard antenna, which presents a short-circuit load to the traveling wave tube amplifier (TWTA). Although most TWTA's are protected by isolators/circulators at their outputs, the real possibility of permanent damage to the TWTA slow-wave structure due to load-imposed phase instabilities does exist. Therefore, only the outboard antennas radiating into space should be used for the final checkout phase prior to separation, and any automatic switching operation between antennas should be deactivated for this period. In the event that this procedure is not readily implemented, space-qualified absorbers in the appropriate position should shield the metallic walls of the bay. For a similar reason, the outboard antennas should be used for reception also to avoid standing waves from multiple reflections.

5.4 IUS and Orbiter Received Power Versus Range

The received power at the IUS transponders and the Orbiter PI was presented in Tables 36, 37, 39 and 40 when the IUS is in the payload bay. Figures 40 and 41 present the IUS and Orbiter received power as a function of range. Figure 40 presents the received power at the IUS SGLS and STDN/TDRS transponders versus range for the three PI output power levels. The IUS transponders are specified to achieve acquisition at a received power of -117 dBm in 0.5 sec with a probability of 0.9 for a modulated signal. In terms of the Orbiter acquisition procedure, a modulated signal would be present only during reacquisition. Therefore, the reacquisition threshold

Table 40. IUS STDN/TDRS Transponder to Orbiter Received Signal Power

Parameter	Value	Source
1. IUS STDN/TDRS Transponder Power, dBW	13.0	Boeing specification for 20W minimum
2. IUS Transmit Circuit Loss, dB	-3.3	Boeing estimate
3. IUS Antenna Gain, dB	6.8	Boeing estimate
4. IUS Pointing Loss, dB	-3.4	Boeing estimate at 45° off-axis
5. IUS EIRP, dBW	13.1	Sum 1 through 4
6. Space Loss, dB	-49.1	f = 2272.5 MHz (STS Primary), R = 3 m
7. Polarization Loss, dB	-0.3	JSC estimate
8. Orbiter Receive Antenna Gain, dB	2.5	Omni specified over 36% of upper hemisphere
9. Orbiter Receive Circuit Loss, dB	-9.8	Rockwell estimate
10. Orbiter Total Received Power, dBW (dBm)	-43.6 (-13.6)	Sum 5 through 9

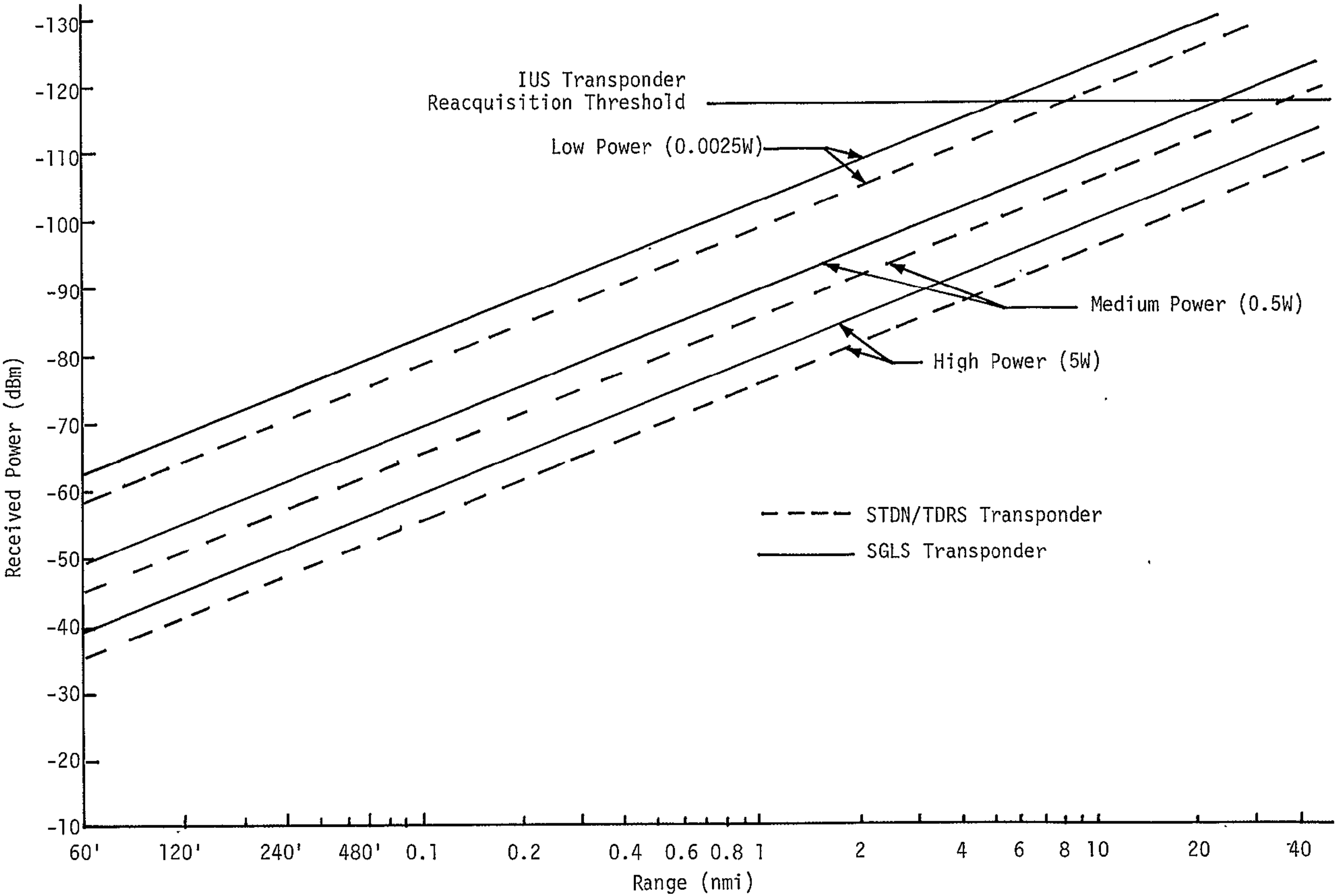


Figure 40. IUS Received Power Versus Range for Each PI Output Power Setting

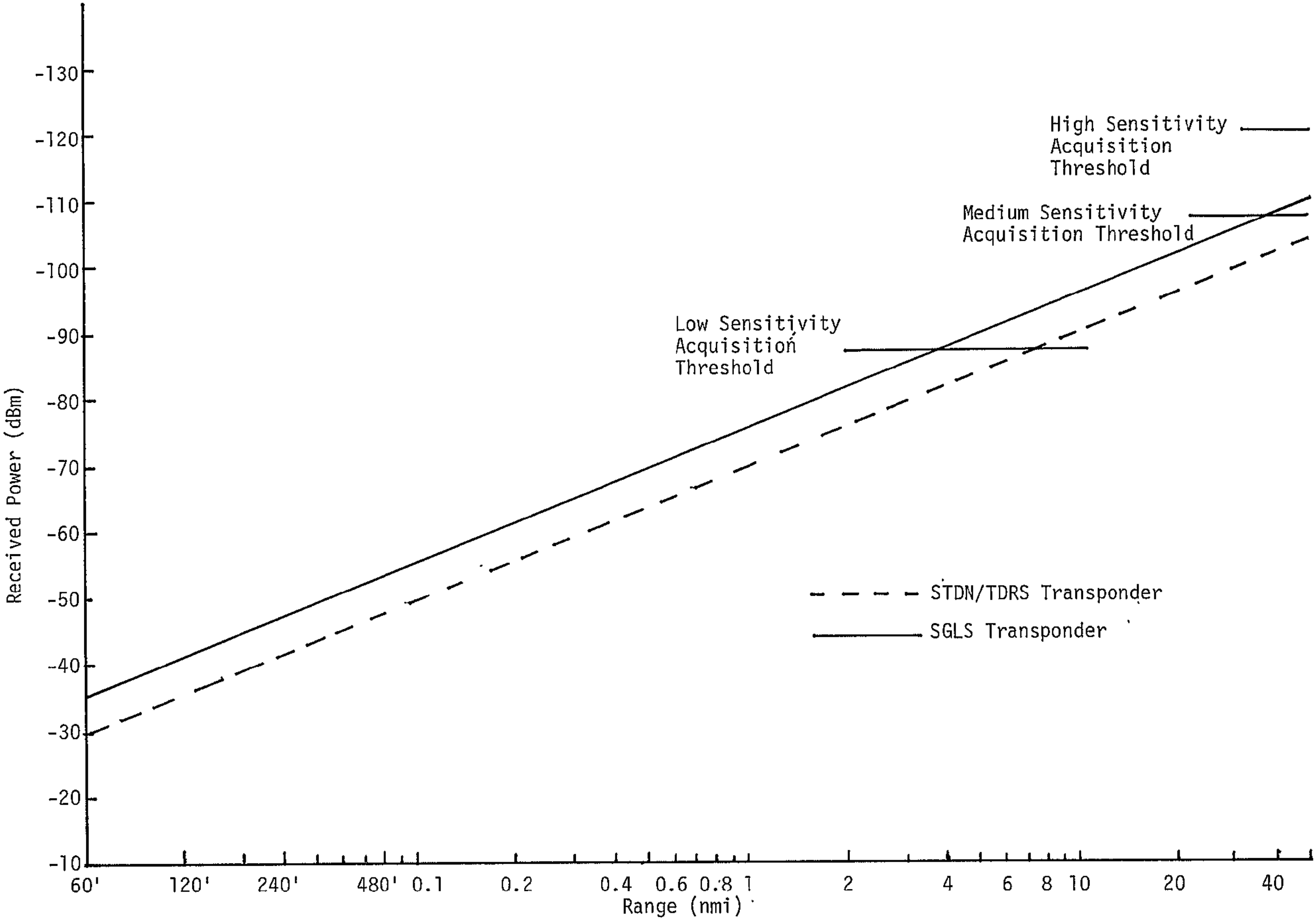


Figure 41. PI Received Power Versus Range from the IUS

for the SGLS transponder is reached at 5 nmi in the low-power mode, while the STDN/TDRS transponder reaches the reacquisition threshold at 8.5 nmi in the low-power mode. In the medium-power mode, the SGLS and STDN/TDRS transponders reach the reacquisition threshold at 14 nmi and 36 nmi, respectively.

The PI received power versus range from the IUS is presented in Figure 41. The acquisition thresholds for the PI are given in Table 38 for each receiver sensitivity. For the low receiver sensitivity, the SGLS transponder reaches the acquisition threshold at 4 nmi, while the STDN/TDRS transponder reaches the acquisition threshold at 8 nmi. For the medium receiver sensitivity, the SGLS and STDN/TDRS transponders reach the acquisition threshold at 37 nmi and 72 nmi, respectively.

6.0 ESTL TEST REQUIREMENTS

A main objective of the NASA Task 501 Program is the verification testing of the various RF space-space and space-ground links of the Shuttle and Shuttle-launched payloads. A considerable portion of this verification testing will be performed by ESTL.

The functional diagram of the ESTL is shown in Figure 42. As can be seen from this diagram, the ESTL has the capability to simulate the direct Shuttle/earth S-band links and the indirect Orbiter/ground S-band and Ku-band links. Means are additionally provided to simulate the data generated within the Orbiter itself, along with the capability for routing it via the various space-ground links for the purpose of total systems evaluation.

The Orbiter communications subsystem provides a capability for establishing communication links with both the attached IUS within the Shuttle bay and the detached IUS in the near vicinity of the Orbiter. Communication with the attached IUS is via hardwire channels, as described in Sections 3.0 and 4.0. The detached IUS RF communication is a two-way link carrying commands, telemetry, and sometimes ranging. Both the hardwire and RF links with the IUS constitute a portion of the overall space-space capability of the Orbiter communication system.

The ESTL test program objectives for the IUS and CIU with the Orbiter subsystems and ground stations are:

(1) To establish equipment/subsystem electrical compatibility

(2) To identify performance and operational limitations and constraints

(3) To verify that appropriate RF and hardwire interfaces are commensurate with mission communications requirements

(4) To verify experimentally that the Orbiter/IUS forward and return RF links are signal compatible in all modes

(5) To verify experimentally those tracking, ranging, command, and telemetry channel performance characteristics required for operational mission support.

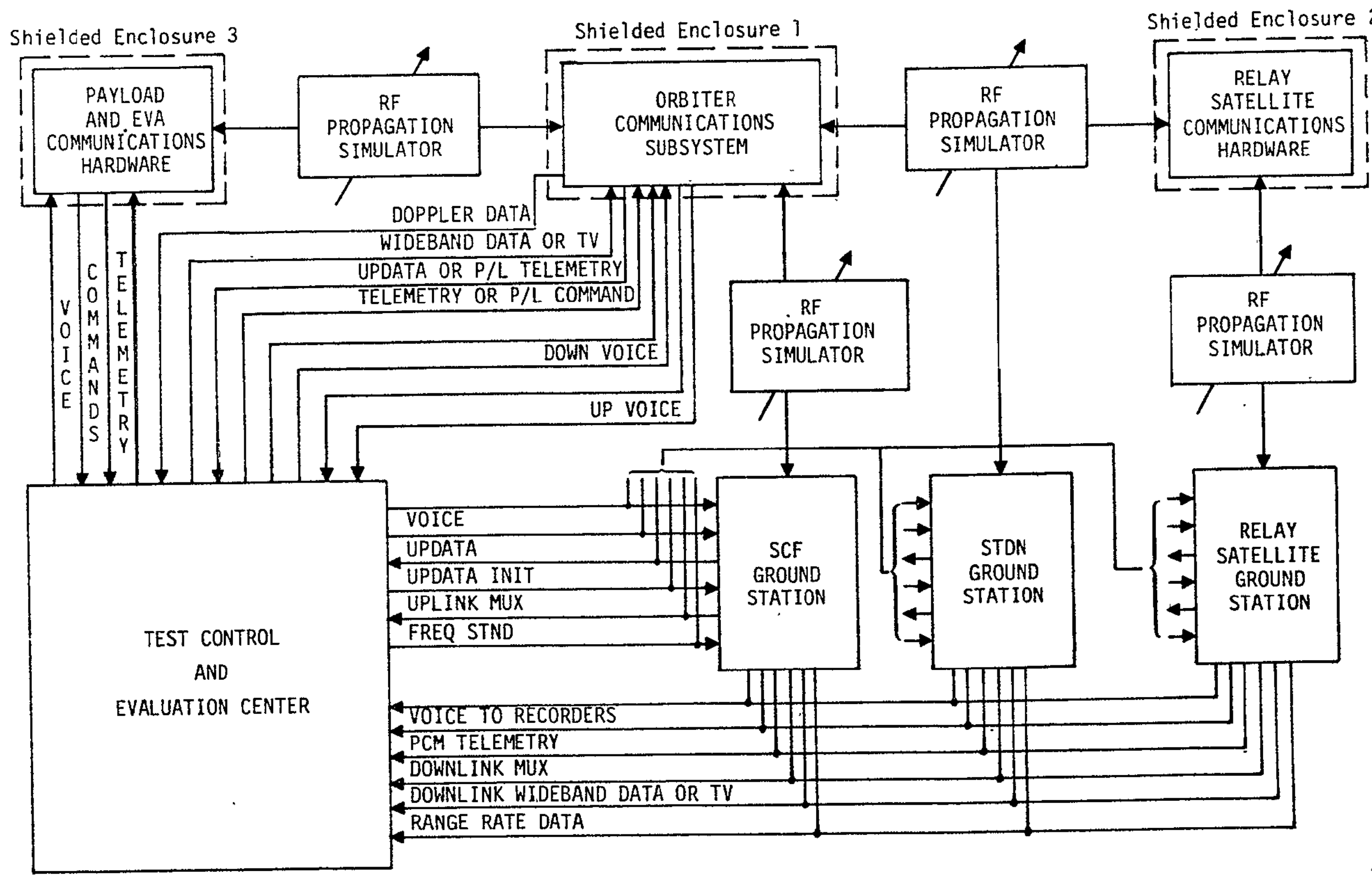


Figure 42. ESTL Functional Block Diagram

Tests may be classified under two different types, as follows:

(1) Calibration Tests. Those tests required to establish equipment and performance apart from its operational use. These tests generally establish why the piece of hardware performs in a certain manner. They parameterize the overall or end-to-end performance.

(2) Operational Tests. Those tests conducted to measure the equipment performance in terms of its intended use. Such tests establish the input/output and interactive capabilities of the hardware without specific regard to internal mechanisms.

Calibration tests will include measurements to establish:

(1) Impedances/load characteristics
(2) Voltage levels
(3) Waveform characteristics
(4) VSWR
(5) RF power levels
(6) Frequency and phase responses
(7) Spectra (normal and spurious)
(8) Linearity and dynamic range
(9) Sensitivities
(10) Gains and losses
(11) Noise figure
(12) Intermodulation products
(13) Loop parameters
(14) Suppression factors
(15) Frequency stability.

Operational tests will be conducted to measure:

(1) Acquisition characteristics/time

(2) Carrier tracking loop performance
  (a) Transient response
  (b) Noise threshold

(3) AGC performance

(4) Lock detector SNR performance

(5) Demodulation SNR

(6) Turnaround noise
  (a) Modulation
  (b) Random
  (c) Carrier phase noise

(7) Ranging performance (with SCF and GSTDN ground stations or direct link from the IUS through the TDRS)

(8) Bit error rate

(9) Data loss statistics.

Figure 43 shows the general configuration that will be used for all calibration and performance tests involving the Orbiter subsystems. The ranging and other direct link communication functions will be tested using the various ground station capabilities in the ESTL. Table 41 documents the various tests to be performed on subsystems and functional configurations. The type of test is also indicated. Some tests are so routinely conducted they may be classed as both operational and calibration. Table 42 gives a summary of the operational link test configurations required for ESTL testing of the IUS and Orbiter communications. To accomplish the operational tests listed in Table 41, the ESTL test setup must provide command data to the PSP or CIU and telemetry data to the IUS transponder. For testing of the forward (Orbiter-to-IUS) link, the Univac 642B computer generates commands which are sent to the IUS transponder via either a cable (hardwire) or the simulated RF link. Command verification is performed by the 642B computer. Return link (IUS-to-Orbiter) telemetry data is originated by either a PCM telemetry simulator or a tape recorder, and transmitted via cable or RF. PCM simulator data is usually verified directly by a bit error comparator, while tape recorder-generated data must be tested by the 642B computer for known pattern errors. The use of the 642B computer in conjunction with DOD CIU/PI testing depends on the nature of the tests to be carried out. Primarily, it is used to aid in the statistical evaluation of the link performance. The computer may also be employed to provide simulated navigation update signals for transmission to the IUS transponder. Most importantly, the 642B provides the processing and control necessary to multiplex received commands and return telemetry data, with the CIU ultimately being used to perform command verification.

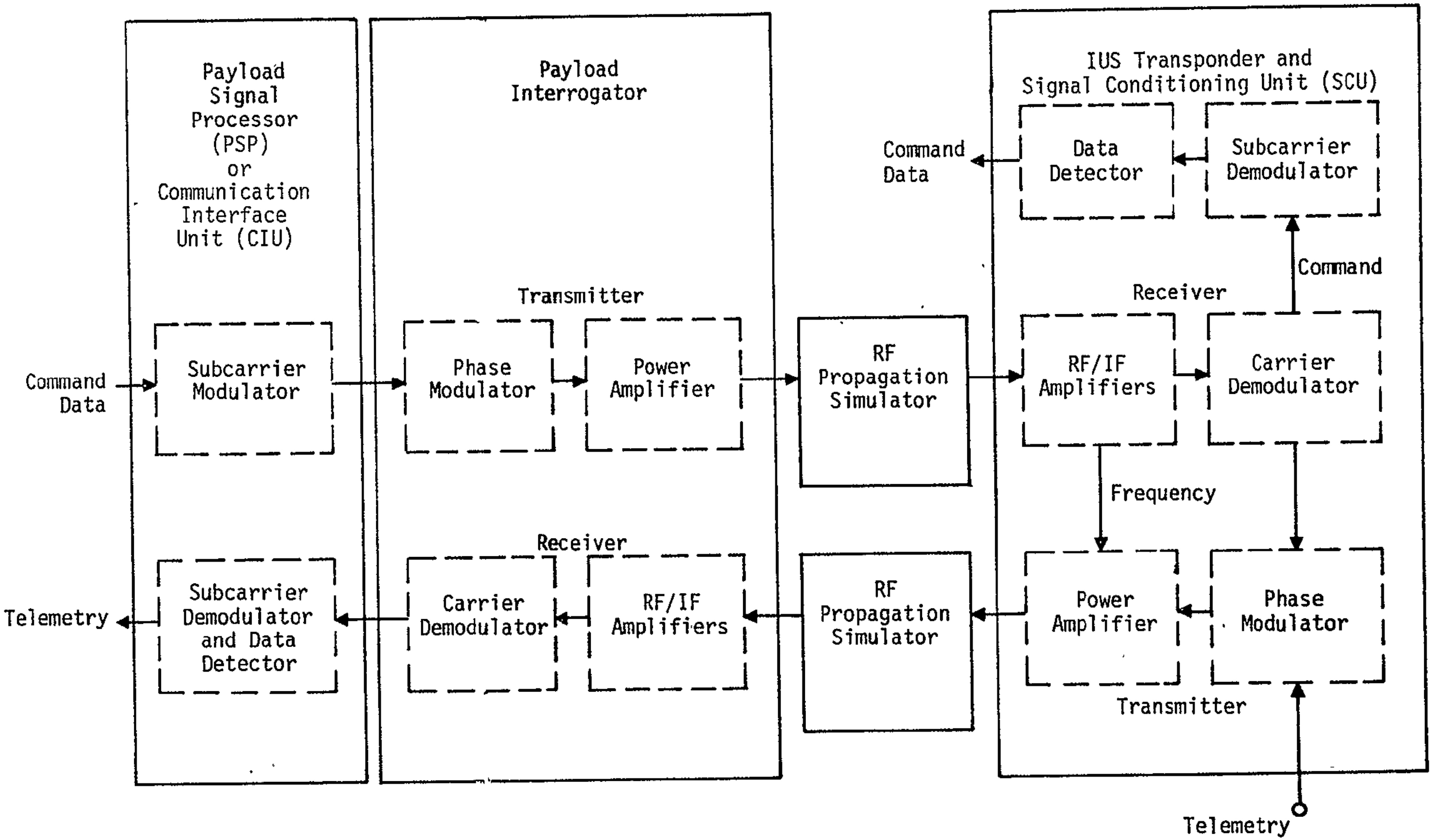


Figure 43. General Test Configuration

Table 41. Test Summary

Test	Type	
	Operational	Calibration
<u>IUS Receiver</u>		
1. Tracking and AGC Loop Parameters		X
2. Noise Figure	X	X
3. AGC versus Signal Level	X	X
4. Strong Signal Phase Noise	X	X
5. Tracking Loop Phase Error	X	X
6. Tracking Loop Noise Biasing		X
7. Frequency Swept Acquisition	X	
8. Absolute Threshold Tracking		X
9. Minimum Operating Point Tracking	X	
10. Lock Detector Statistics (False Lock)	X	X
11. Auxiliary Oscillator Stability	X	X
<u>Command Detection (IUS SCU)</u>		
1. Detector/Synchronizer Noise/BER		X
2. Subcarrier Demodulation/Detection/ Synchronizer Noise/BER		X
3. SCU Lock Statistics	X	X
4. Complete Forward Link Noise/BER	X	X
<u>IUS Transmitter</u>		
1. Command Link Modulation Feedthrough		X
2. Modulation Transfer Characteristics		X
3. Modulation Indices	X	
4. Modulated Subcarrier Spectra	X	X
5. Modulated Carrier Spectra	X	X
6. Intermodulation Products (Spurious Outputs)		X
<u>PI Receiver</u>		
1. AGC versus Signal Level	X	X
2. Strong Signal Phase Noise	X	X
3. Frequency Acquisition	X	
4. Absolute Threshold Tracking		X
5. Minimum Operating Point Tracking	X	X
6. Lock Detector Statistics (False Lock)	X	X
7. Telemetry Link Threshold Effects	X	
<u>Telemetry Detection</u>		
1. Intermodulation Effects		X
2. PCM/PSK/PM Noise/BER	X	
3. FM/PM Noise/BER	X	

Table 41. Test Summary (Cont'd)

Test	Type	
	Operational	Calibrational
CIU Interface Characteristics		
1. Rise and Fall Times		X
2. Data Asymmetry		X
3. Signal Distortion (overshoot, ringing)		X
4. Bit Jitter		X
5. Data Rate Stability		X
6. Clock Data Skew		X
7. Clock Jitter		X
8. End-to-End BER Tests (All Links)	X	
PI Transmitter		
1. Modulation Transfer Characteristics		X
2. Modulation Indices	X	X
3. Modulated Subcarrier Spectra	X	X
4. Modulated Carrier Spectra	X	X
5. Intermodulation Products (Spurious Outputs)		X

Table 42. Summary of IUS Equipment and ESTL Communication Link Test Configurations

User	Link Type	Data	Modulation Format	Signal Test Function	Signal Flow Direction Tested (Simulated)
NASA	Hardwire	CMDS	NRZ	IUS SCU Bit Detector	Orbiter to IUS
	Hardwire	CMDS	PSK	IUS SCU Performance	Orbiter to IUS
	Hardwire	TLM	NRZ	Ku-Band Processor	IUS to Orbiter
	RF	CMDS	PSK/PM	PI, PSP, IUS Transponder	Orbiter to IUS
	RF	TLM	PSK/PM	PI, PSP, IUS Transponder	IUS to Orbiter
DOD	Hardwire	CMDS	Ternary Symbols plus Clock	CIU	Orbiter to IUS
	Hardwire	CMDS	FSK/AM	CIU & IUS SCU	Orbiter to IUS
	Hardwire	NAV UPDATE	FSK/AM	CIU	Orbiter to IUS
	Hardwire	TLM	NRZ	CIU	IUS to Orbiter
	Hardwire	TLM	PSK and FM	CIU	IUS to Orbiter
	RF	CMDS	FSK/AM/PM	PI and CIU	Orbiter to IUS
	RF	TLM	PSK/PM and FM/FM	PI and CIU	IUS to Orbiter

Table 43 presents the equipment required to perform the operational tests in ESTL. Note that the 642B computer has a parallel data interface, but the CIU and PSP are serial data devices. Therefore, appropriate interface units shown in Table 43 are required to use the 642B computer in these tests. Also, the attached payload tests require an attached payload interface similar to that used on the Orbiter. Included in the special test equipment required for operational tests is equipment that is capable of delivering telemetry data with the various frame forms and data rates to the IUS transponder. Presently, ESTL has a number of types of equipment, such as the Dynatronic Inc. Model 100, which can provide the required telemetry data to the IUS transponder. Additional special test equipment to perform the calibration and operational tests are:

(1) Spectrum analyzer (HP Model 8555 with 8552B IF section and 141T mainframe display or equivalent)

(2) Noise figure meter (HP Model 949A or equivalent)

(3) Frequency counter (HP Model 5245L with 5254C heterodyne converter or equivalent)

(4) High-frequency oscilloscope

(5) Digital multimeter

(6) Low-frequency (<2 MHz) function generator.

Table 43. Equipment Required for ESTL Tests

Communication Functions		Support Functions	
RF Receiver Frequency Source/Exciter Phase Modulator } Transmitter Power Amplifier } Transmitter	Transponder	Serial to Parallel Data Converter(s) Parallel to Serial Data Converter	Univac 642B Input and Output Equipment
Subcarrier Generators Subcarrier Modulators	Telemetry Modulators	Special Test Equipment	
Command Subcarrier Demodulator Command BIt Detector	Command Detector Unit	Attached Payload Hardwire Interface Equipment	

7.0 LINK BUDGETS FOR IUS/PI/CIU COMMUNICATIONS

There are a number of possible end-to-end IUS communication links as discussed in Section 4.0. A prime link involves the IUS transponder, the PI, CIU (or PSP), and the Orbiter Ku-band relay links, or the Orbiter S-band relay and direct links. A large number of parameters are involved in the determination of the end-to-end link performance. Some link budgets (design control tables) that predict the performance of the links may be found in the report "Users' Handbook For Payload-Shuttle Data Communication," Axiomatix Report No. R7809-4, for NASA Contract NAS 9-15604B, September 27, 1978. This Users' Handbook provides a technical background for calculating the various parameters in a link budget. In this section, the link budgets for the command channel from the Orbiter to the IUS and for the telemetry channel from the IUS to the Orbiter are presented. Two of the parameters in the link budget need to be calculated as a function of the system design. The receiver noise spectral density is equal to kT_e, where k is Boltzmann's constant (1.38×10^{-23} W/°K/Hz) and T_e is the effective receiver noise temperature in degrees Kelvin. The value of T_e is calculated as follows:

$$T_e = \frac{T_A}{L} + T_L\left(1 - \frac{1}{L}\right) + T_r \tag{3}$$

where

T_A = effective antenna temperature (assumed to be 290°K)

L = losses between the antenna and the receiver

T_L = effective temperature of the losses (assumed to be 290°K)

T_r = effective temperature of the receiver, as given by

$$T_r = (F-1)(290°K) \tag{4}$$

in which F is the noise figure (NF) of the receiver.

The modulation loss, L_{MC}, for the carrier is given by

$$L_{MC} = J_0^2(\beta) \tag{5}$$

for a single subcarrier with modulation index β in radians, where J_0 is the Bessel function of zero order. For two subcarriers,

$$L_{MC} = J_0^2(\beta_1)J_0^2(\beta_2) \tag{6}$$

where β_1 and β_2 are the modulation indices for the subcarriers. The subcarrier modulation loss, L_{MS}, for a single subcarrier is given by

$$L_{MS} = 2J_1^2(\beta) \tag{7}$$

where J_1 is the Bessel function of first order. For two subcarriers,

$$L_{MS1} = 2J_1^2(\beta_1)J_0^2(\beta_2)$$

$$L_{MS2} = 2J_0^2(\beta_1)J_1^2(\beta_2) \tag{8}$$

The link budget for the Orbiter to DOD IUS is presented in Table 44 when the IUS is in the payload bay with a range of 3 m. The received power is obtained from Table 36 in Section 5.0. It may be noted that there are extremely large circuit margins for this range, even at the lowest PI output power setting of (0.0025W). Figure 44 illustrates the effect of increasing the range between the Orbiter and the DOD IUS (SGLS transponder). At the lowest PI power setting, the command circuit margin becomes zero at 1 mni, and the carrier tracking margin becomes zero at 3.2 nmi. With the medium PI power setting, the command circuit margin and the carrier tracking margin become zero at 14 nmi and 44 nmi, respectively. Finally, with the high PI power setting, the command circuit margin and the carrier tracking margin become zero at 44 nmi and at 180 nmi, respectively.

Table 45 presents the link budget for the Orbiter to NASA IUS (STDN/TDRS transponder) with the IUS in the payload bay and a range of 3 m. The received power is from Table 37. Figure 44 illustrates how the carrier tracking circuit margin and the command circuit margin decrease with increased range. At the lowest PI power setting, the command and carrier tracking circuit margins become zero at 4.2 nmi and 12 nmi, respectively. With the medium PI power setting, the command and carrier tracking circuit margins become zero at 50 nmi and 165 nmi, respectively. Finally,

Table 44. Orbiter to DOD IUS Link Budget

Parameter	Values			Source
1. IUS Total Received Power, dBW	-53.8	-63.8	-86.8	Table 36
2. IUS System Noise Temperature, dBK	29.6	29.6	29.6	$T_A = 290°K$, NF = 5.0 dB (917°K)
3. Boltzmann's Constant, dB (W/K/Hz)	-228.6	-228.6	-228.6	1.38×10^{-23}
4. IUS Noise Spectral Density, dB (W/Hz)	-199.0	-199.0	-199.0	Sum 2 and 3
5. Total Received Power Noise Spectral Density (P_{rec}/N_0), dBHz	145.2	135.2	112.2	1 minus 4
6. Carrier Modulation Loss, dB	-2.3	-2.3	-2.3	PM, β = 1.0 ±10% rad.
7. Carrier Loop Bandwidth, dB	36.0	36.0	36.0	$2B_{LO}$ = 4 kHz (TRW design)
8. Received Carrier Loop SNR, dB	106.9	96.9	73.9	5 plus 6 minus 7
9. Required Carrier Loop SNR, dB	8.0	8.0	8.0	Boeing estimate
10. Carrier Tracking Margin, dB	98.9	88.9	65.9	8 minus 9
11. Subcarrier Modulation Loss, dB	-4.1	-4.1	-4.1	PM, β = 1.0 ±10% rad.
12. Command Symbol Bandwidth, dBHz	30.0	30.0	30.0	1 k-baud
13. SNR in Symbol Rate Bandwidth (E_s/N_0), dB	111.1	101.1	78.1	5 plus 11 minus 12
14. Theoretical Required E_s/N_0, dB	19.9	19.9	19.9	For 10^{-5} symbol error probability (USAF est.)
15. Equipment Degradation, dB	-2.5	-2.5	-2.5	Aerospace Corp. est.
16. Required E_s/N_0, dBHz	22.4	22.4	22.4	14 minus 15
17. Circuit Margin	88.7	78.7	55.7	13 minus 16

Table 45. Orbiter to NASA IUS Link Budget

Parameter	Values			Source
1. IUS Total Received Power, dBW	-49.5	-59.5	-82.5	Table 37
2. IUS System Noise Temperature, dBK	29.6	29.6	29.6	$T_A = 290°K$, NF = 5.0 dB (917°K)
3. Boltzmann's Constant, dB (W/K/Hz)	-228.6	-228.6	-228.6	1.38×10^{-23}
4. IUS Noise Spectral Density, dB (W/Hz)	-199.0	-199.0	-199.0	Sum 2 and 3
5. Total Received Power/Noise Spectral Density (P_{rec}/N_0), dBHz	149.5	139.5	116.5	1 minus 4
6. Carrier Modulation Loss, dB	-2.3	-2.3	-2.3	PM, $\beta = 1.0 \pm 15\%$ rad.
7. Carrier Loop Bandwidth, dB	29.0	29.0	29.0	$2B_{LO} = 800$ Hz ±20% Boeing spec.
8. Received Carrier Loop SNR, dB	118.2	108.2	85.2	5 plus 6 minus 7
9. Required Carrier Loop SNR, dB	8.0	8.0	8.0	Boeing estimate
10. Carrier Tracking Margin, dB	110.2	100.2	77.2	8 minus 9
11. Subcarrier Modulation Loss, dB	-4.1	-4.1	-4.1	PM, $\beta = 1.0 \pm 15\%$ rad.
12. Command Bit Rate, dB	33.0	33.0	33.0	2 kbps
13. SNR in Bit Rate Bandwidth (E_b/N_0), dB	112.4	102.4	79.4	5 plus 11 minus 12
14. Theoretical Required E_b/N_0, dB	9.6	9.6	9.6	For 10^{-5} BER
15. Bit Synchronizer Degradation, dB	-1.5	-1.5	-1.5	JSC estimate
16. Required E_b/N_0, dB	11.1	11.1	11.1	14 minus 15
17. Circuit Margin, dB	101.3	91.3	68.3	13 minus 16

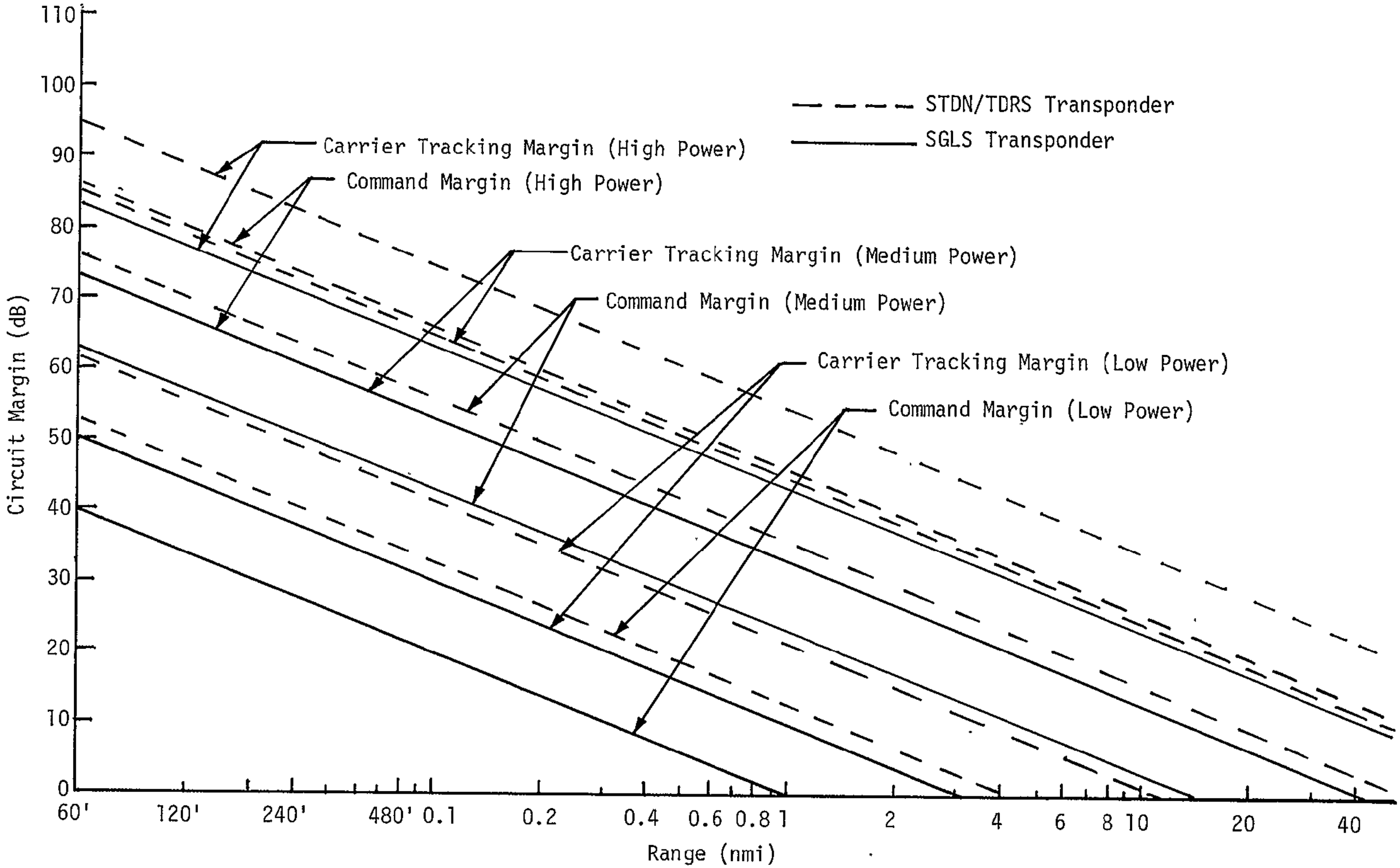


Figure 44. Circuit Margins Versus Range for Orbiter to IUS with Each PI Output Power Setting

with the high PI power setting, the command and carrier tracking circuit margins become zero at 190 nmi and 500 nmi, respectively.

The link budget for the DOD IUS (SGLS transponder) to the Orbiter with the IUS in the payload bay (i.e., a range of 3 m) is presented in Table 46. The received signal power at the Orbiter was calculated in Table 39. There are three circuit margins to be considered for this link: (1) carrier tracking, (2) PSK telemetry on the 1.024 MHz subcarrier, and (3) FM telemetry on the 1.7 MHz subcarrier. The link budget in Table 46 assumes both subcarriers are transmitted simultaneously. Figure 45 presents the relationship between circuit margin and range as a function of the PI receiver sensitivity. At the PI low sensitivity, the FM telemetry circuit margin becomes zero at 960 ft (0.16 nmi), while the PSK telemetry and the carrier tracking circuit margins become zero at 0.82 nmi and 6 nmi, respectively. At the PI medium sensitivity, the FM telemetry, the PSK telemetry and the carrier tracking circuit margins become zero at 1.6 nmi, 8.5 nmi, and 64 nmi, respectively. Finally, at the PI high sensitivity, the FM telemetry, the PSK telemetry and the carrier tracking circuit margins become zero at 7 nmi, 37 nmi, and 260 nmi, respectively.

Table 47 presents the link budget for the NASA IUS (STDN/TDRS transponder) to Orbiter for the IUS in the payload bay (i.e., the range is 3 m). The Orbiter received power is calculated in Table 40 for this range. Figure 45 shows the decrease in PSK telemetry and carrier tracking circuit margins for an increase in range. The circuit margins are given as a function of the PI receiver sensitivity. With the low PI sensitivity, the PSK telemetry and the carrier tracking circuit margins become zero at 2 nmi and 15 nmi, respectively. With the medium PI sensitivity, the PSK telemetry and the carrier tracking circuit margins become zero at 21 nmi and 160 nmi, respectively. Finally, with the high PI sensitivity, the PSK telemetry and carrier tracking circuit margins become zero at 95 nmi and 660 nmi, respectively.

The IUS/PI/CIU (PSP) link budgets and circuit margins presented in this section show the relationship between the various design parameters. Variation of design parameters can be easily taken into account. The link budgets, along with the figures relating circuit margin to range, provide a tool in developing operational scenarios for the IUS and Orbiter.

Table 46. DOD IUS to Orbiter Link Budget

Parameter	Value	Source
1. Orbiter Total Received Power, dBW	-49.4	Table 39
2. Orbiter System Noise Temperature, dBK	31.7	$T_A = 290°K$, $L = 9.8$ dB, $T_r = 1163°K$ (1474°K)
3. Boltzmann's Constant, dB (W/K/Hz)	-228.6	1.38×10^{-23}
4. Orbiter Noise Spectral Density, dB (W/Hz)	-196.9	Sum 2 and 3
5. Total Received Power/Noise Spectral Density (P_{rec}/N_0), dBHz	147.5	1 minus 4
6. Carrier Modulation Loss, dB	-4.7	PM, $\beta_1 = 1.0$, $\beta_2 = 1.0$ rad.
7. Carrier Loop Bandwidth, dB	30.0	$2B_{LO} = 1$ kHz (TRW design)
8. Received Carrier Loop SNR, dB	112.8	5 plus 6 minus 7
9. Required Carrier Loop SNR, dB	8.2	Rockwell Specification for Tracking Threshold
10. Carrier Tracking Margin, dB	104.6	8 minus 9
11. Telemetry Subcarrier Modulation Loss, dB	-6.4	PM, $\beta_1 = 1.0$, $\beta_2 = 1.0$ rad.
12. Telemetry Bit Rate, dBHz	42.0	16 kbps
13. SNR in Bit Rate Bandwidth (E_b/N_0), dB	99.1	5 plus 11 minus 12
14. Theoretical Required E_b/N_0, dB	10.5	For 10^{-6} BER
15. Bit Synchronizer Degradation, dB	-1.5	Boeing CIU Specification
16. Required E_b/N_0, dB	12.0	14 minus 15
17. Telemetry Circuit Margin, dB	87.1	13 minus 16
18. FM Subcarrier Modulation Loss, dB	-6.4	PM, $\beta_1 = 1.0$, $\beta_2 = 1.0$ rad.
19. Subcarrier Bandwidth, dBHz	53.1	B = 204 kHz (TRW design)

Table 46. DOD IUS to Orbiter Link Budget (Cont'd)

Parameter	Value	Source
20. Received SNR, dB	88.0	5 plus 18 minus 19
21. Required SNR, dB	15.0	Boeing CIU specification
22. FM Telemetry Circuit Margin, dB	73.0	20 minus 21

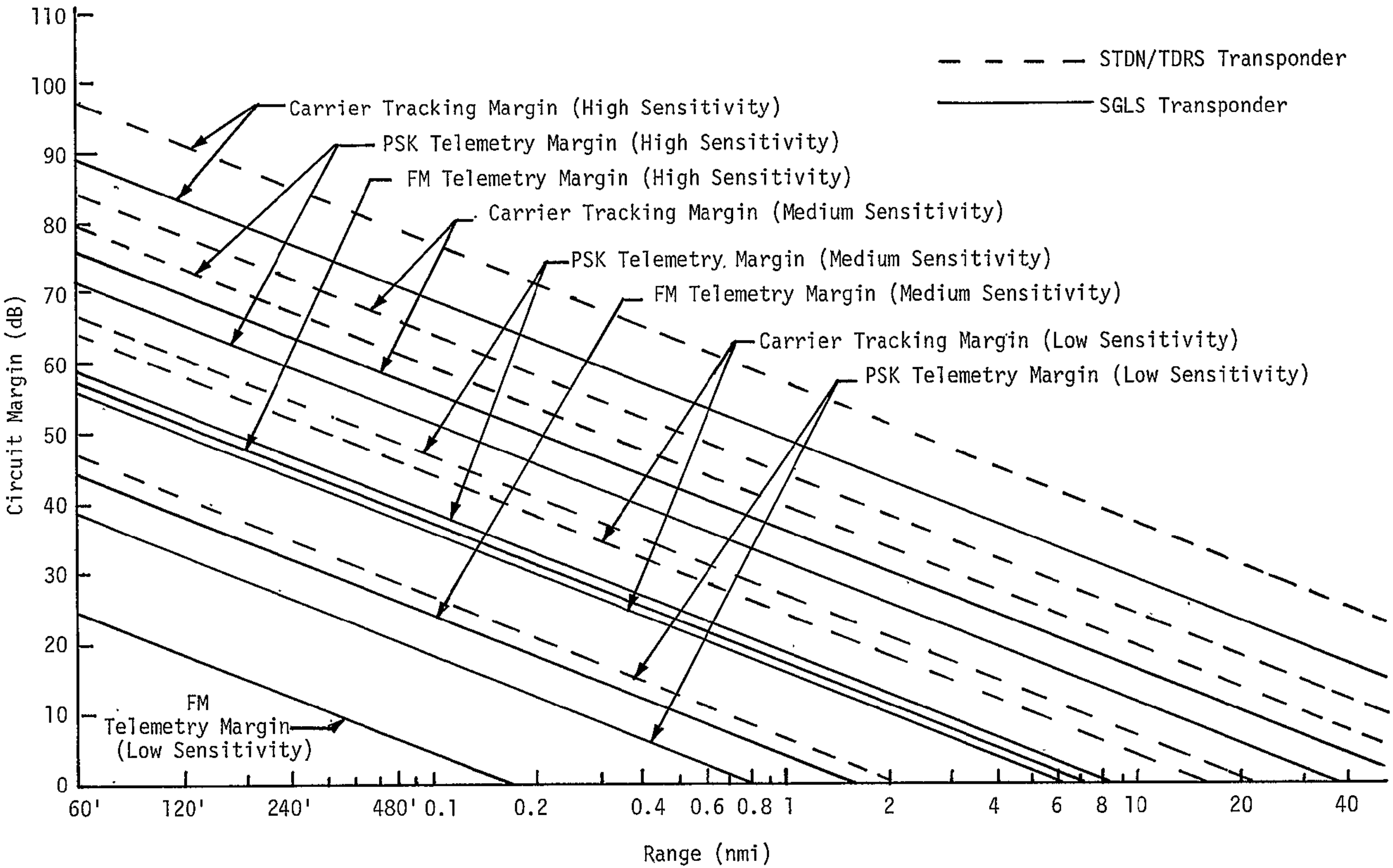


Figure 45. Circuit Margins Versus Range for IUS to Orbiter with Each PI Receiver Sensitivity

Table 47. NASA IUS to Orbiter Link Budget

Parameter	Value	Source
1. Orbiter Total Received Power, dBW	-43.6	Table 40
2. Orbiter System Noise Temperature, dBK	31.7	$T_A = 290°K$, $L = 9.8$ dB, $T_r = 1163°K$ (1474°K)
3. Boltzmann's Constant, dB (W/K/Hz)	-228.6	1.38×10^{-23}
4. Orbiter Noise Spectral Density, dB (W/Hz)	-196.9	Sum 2 and 3
5. Total Received Power/Noise Spectral Density (P_{rec}/N_0), dBHz	153.3	1 minus 4
6. Carrier Modulation Loss, dB	-2.3	PM, $\beta = 1.0$ rad.
7. Carrier Loop Bandwidth, dB	30.0	$2B_{LO} = 1$ kHz (TRW design)
8. Received Carrier Loop SNR, dB	121.0	5 plus 6 minus 7
9. Required Carrier Loop SNR, dB	8.2	Rockwell Specification for Tracking Threshold
10. Carrier Tracking Margin, dB	112.8	8 minus 9
11. Telemetry Subcarrier Modulation Loss, dB	-4.1	PM, $\beta = 1.0$ rad.
12. Telemetry Bit Rate, dBHz	42.0	16 kbps
13. SNR in Bit Rate Bandwidth (E_b/N_0), dB	107.2	5 plus 11 minus 12
14. Theoretical Required E_b/N_0, dB	10.5	For 10^{-6} BER
15. Bit Synchronization Degradation, dB	-1.5	JSC estimate
16. Required E_b/N_0, dB	12.0	14 minus 15
17. Telemetry Circuit Margin, dB	95.2	13 minus 16

8.0 CONCLUSIONS

This report summarizes the effort expended to date during FY78 and FY79. Figure 3 in Section 2.0 presented the design reviews and the tasks to be performed in the future as well as a schedule for completion of each of the tasks. Since the overall IUS/Orbiter communication system is still evolving, direct interfacing of the avionic subsystems is in only their preliminary design stages. Thus, it will be some time before all development problems are solved, and reliable, well-understood performance can be documented. The ESTL testing forms a vital part of the overall system performance verification and, therefore, Axiomatix will provide updates to the ESTL testing requirements as the Orbiter and IUS communication equipment develop.