MARCH 1972

MDC G2909

CR 115556

(NASA-CR-115556) COMMUNICATIONS SYSTEMS CHECKOUT STUDY Final Report W.G. Ginter (McDonnell-Douglas Astronautics Co.) Mar. 1972 223 p CSCL 17B

N72-23117

Unclas
G3/07 25451

FINAL REPORT COMMUNICATIONS SYSTEMS CHECKOUT STUDY

DRL NO. T-675/DRD NO. SE-2717

NAS 9-12089

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PREFACE

The engineering study of Space Station communications subsystem checkout was performed by the McDonnell Douglas Astronautics Company (MDAC), at the Space Systems Center, Huntington Beach, California, supported by the Collins Radio Company (CRC) of Cedar Rapids, Iowa.

Technical Monitor for the study was Mr. B.K. Vermillion of the NASA Manned Spacecraft Center. The guidance and support given to the study by him and by other NASA personnel are gratefully acknowledged.

Acknowledgment is also extended to individuals at MDAC and CRC who contributed significantly to the results of the study. These persons and their areas of contribution were:

R.A. Kirk, MDAC	-	Antenna systems checkout
R.A. Koos, MDAC	-	Technical supervision of CRC effort, overall checkout evaluation
R.D. Rowland, CRC	-	CRC Study Manager
R.F. Salmon, CRC	-	RF and internal communications checkout

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Section 1
INTRODUCTION

This report presents the results and conclusions of an engineering study of Space Station communications subsystem checkout performed for NASA-MSC by the McDonnell Douglas Astronautics Company (MDAC), supported by the Collins Radio Company (CRC) as its major subcontractor.

1.1 OBJECTIVES

The achievement of extended-duration Space Station missions places new emphasis on the necessity for an effective onboard checkout and maintenance capability. Whereas high-reliability equipment design and redundancy concepts have been used to assure system operation on previous short-duration missions, maintainable systems must be achieved, and practical means of checkout implementation must be provided on future extended missions.

This study is directed toward achieving these goals for the Space Station communications subsystem. The primary purpose of the study is to recommend specific guidelines and constraints for the design and utilization of the communications subsystem leading to a practical and effective means of onboard checkout implementation. Major study objectives are as follows:

A. Identify candidate communications subsystem checkout concepts.

B. Determine implementation impacts of feasible concepts.

C. Evaluate practicality and effectiveness of alternative concepts.

D. Propose baseline modifications to accommodate preferred concepts.

E. Recommend areas for additional investigation.

In addition, study results are interpreted, where appropriate, in terms of their applicability to checkout of a Shuttle-Orbiter communications subsystem.

1.2 STUDY APPROACH

Using the information developed for NASA-MSFC in the MDAC Modular Space Station studies as a baseline, the study effort involved conducting a detailed analysis of subsystem checkout requirements, investigating and evaluating alternative checkout concepts, and generating recommendations for the design and use of the communications and onboard checkout subsystems that will lead to the desired Space Station checkout and maintenance capabilities. An overall study flow diagram is provided in Figure 1-1.

1.3 KEY ISSUES

Previous studies in the area of Space Station checkout have been concerned primarily with developing maintenance and checkout requirements necessary for the general definition of ground and onboard checkout support systems. This study is more concerned with the detailed investigations and analyses of techniques to satisfy the requirements for checkout of the communications subsystem. Detailed checkout requirements for the Modular Space Station communications subsystem, however, are established as a part of this study and used in the development and evaluation of candidate checkout techniques.

Key issues of the study, addressed in subsequent sections of this report, are as follows:

A. Requirements
   1. Performance/status tests
   2. Redundancy switching
   3. Measurement/stimulus parameters

B. Checkout techniques
   1. Stimuli generation (methods, location)
   2. Signal detection
   3. Automatic monitoring/evaluation (methods, level, location)

C. Implementation impacts
   1. Technology
   2. Design and performance
   3. Interface complexity
   4. Operations
   5. DMS loading

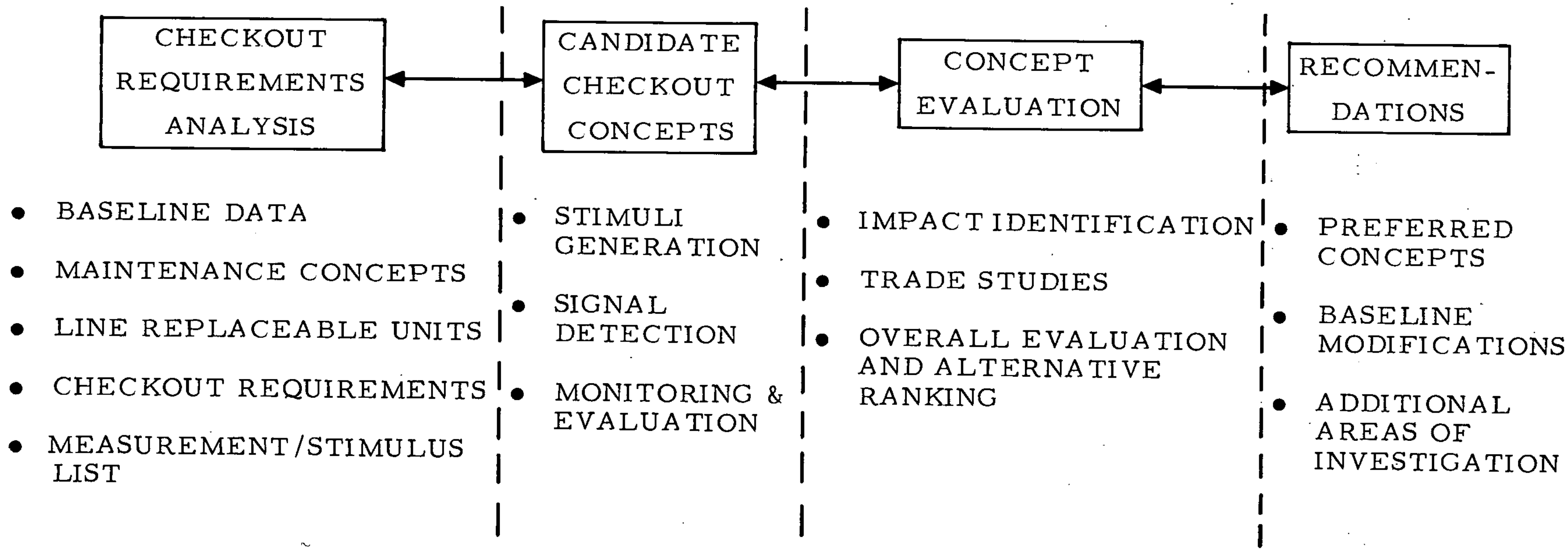

Figure 1-1. Study Flow Diagram

6. Ground support
7. Relative cost

Alternative techniques associated with stimuli generation (using both artificial and normal operational signals), signal detection, and automatic monitoring are explored in depth to determine the relative merits of their application in communications subsystem checkout. Special emphasis is also given to self-testing, redundancy switching, and the level of checkout to be employed.

Section 2
SUMMARY OF RESULTS AND CONCLUSIONS

This section provides a summary of the significant results and conclusions derived from the study. More detailed presentation and discussion of study results may be found in subsequent sections of the report. Overall conclusions related to checkout of the Space Station communications subsystem are:

A. Implement all test stimuli generation and signal detection capabilities within basic communications subsystem design.
B. Utilize data management subsystem (DMS) for communications subsystem monitoring, evaluation and control.
C. Monitor normalized sensor data instead of go-no/go status.
D. Relatively little need for continuous status monitoring, automatic redundancy switching, and telemetry.
E. No special advancement in state-of-the-art components or circuitry required for checkout.
F. Insignificant average data rates for communications subsystem checkout.
G. Significant differences expected between Space Station and Shuttle-Orbiter checkout concepts.

2.1 STUDY BASELINE

The study is based upon the communications, data management, and onboard checkout subsystems defined for the MDAC/MSFC Modular Space Station and described in Section 6. The communications subsystem provides radio-frequency (RF) communications between the station and the ground, either directly to the NASA ground network or through the NASA data relay satellite system (DRSS). Communications are also provided between the Station and the Space Shuttle during rendezvous and docking operations and for crewmen engaged in extravehicular activity (EVA). An internal communications system is also provided on the Station for voice communications between crew quarters, equipment compartments, duty stations, and docked modules. The VHF and S-band equipments utilized for communications with the DRSS, Space Shuttle, NASA ground stations, and EVA are shown in Figure 2-1.

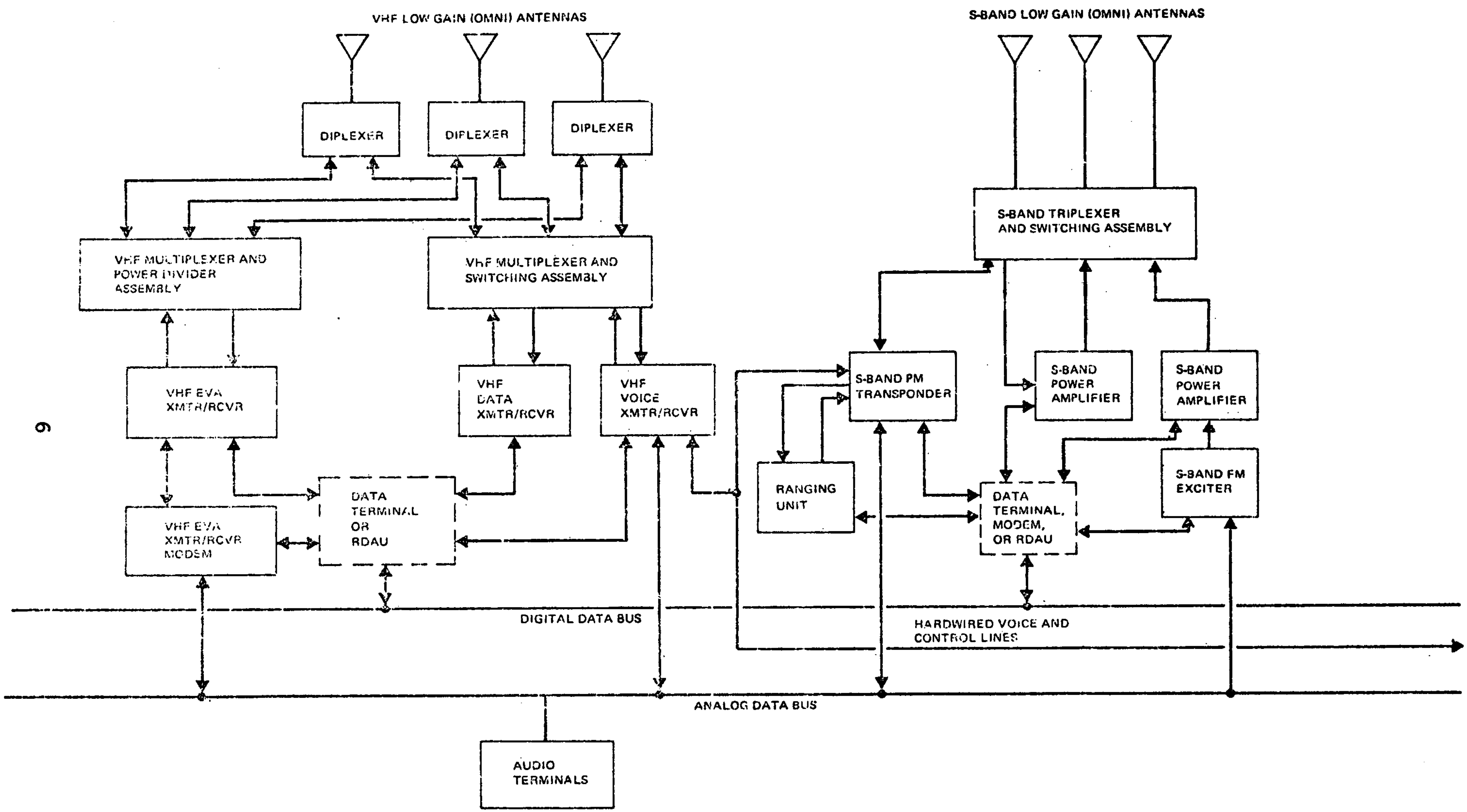

Figure 2-1. Power/Subsystem Module Communications Equipment Complement

The K_u-band and S-band equipments required to provide wideband data transmission and reception with the DRSS are shown in Figure 2-2. Also shown on these diagrams are the audio terminals and analog sync/test unit of the internal communications system. Descriptions and lower-level block diagrams of the high- and low-gain antenna systems, RF system, and internal communications system are provided in Section 6.

The major Modular Space Station checkout guidelines that are followed by the study are:

A. Continuous monitoring to provide immediate indications of out-of-tolerance conditions to the crew.
B. Periodic testing and trend analysis to assure system availability.
C. In-place fault isolation to replaceable unit level for long life assurance.
D. Onboard checkout control except during quiescent mission phases.
E. Capability for selecting and transmitting checkout data to the ground.
F. Automation techniques to the greatest practical extent.
G. Onboard checkout subsystem (OCS) self-check capability.
H. In-flight capability for restructuring checkout procedures.
I. Standard OCS interfaces.
J. Comprehensive ground test program to minimize operational risks.

Onboard capabilities must be provided to determine whether or not subsystems are operating in an acceptable manner, to supply information for repair and reconfiguration actions, and to verify subsystem operation following failure correction. The checkout functions required to implement this capability include status monitoring, periodic testing, trend analysis, and fault isolation. The level of fault isolation is keyed to the line replaceable unit (LRU) which is the smallest unit within the subsystem that is suitable for onboard replacement. Communications subsystem LRU's are listed and discussed in Section 6.

A summary of the performance/status tests required for the VHF, S-band and K_u-band portions of the communications subsystem is presented in Table 2-1. Also indicated is the applicability of these tests to the

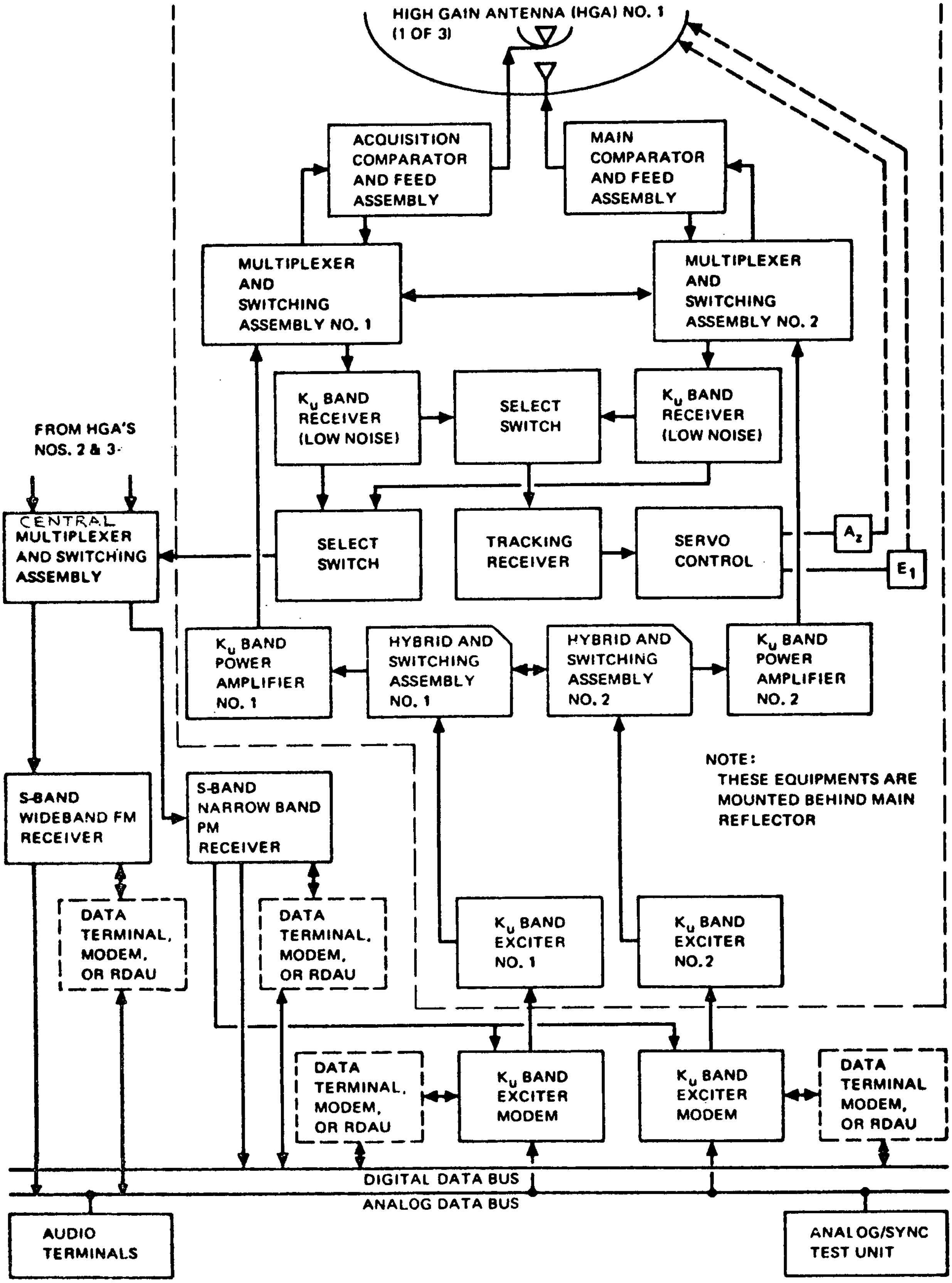

Figure 2-2. Crew/Operations Module Communications Equipment Complement

Table 2-1

COMMUNICATIONS SUBSYSTEM PERFORMANCE/STATUS TESTS

Assy Group			Test	Key Measurements	ISS		Orbiter	
VHF	S	K_u			FLT	GND	FLT	GND
X	X	X	Transmission system insertion loss	RF power level	X	X		X
X	X	X	VSWR measurement	Forward and reflected RF power	X	X		X
X	X	X	Receive system performance	AGC output level	X	X	X	X
X	X	X	Receiver sensitivity	AGC output level	X	X	X	X
X	X	X	Receiver detection sensitivity	Detected modulation output level	X	X		X
X	X	X	Transmitter RF power output level verification	RF power level	X	X	X	X
X	X	X	Transmitter modulation sensitivity	Modulation output level	X	X		X
	X		Ranging system performance	Range readout	X	X		X
X	X	X	Status monitor	PA and transmitter RF power levels. Receiver AGC output levels, PA temperature	X		X	
		X	Antenna acquisition and pointing verification	Tracking and pointing errors	X	X		X
X	X	X	Selected operational controls	Selection indications	X	X		X
X	X	X	Other operational controls	On/off, mode, and channel indications		X		X

Shuttle-Orbiter, assuming similar equipment is used. The degree of onboard testing necessary during its relatively short duration mission is expected to be much less than that expected for the extended-duration Space Station mission. Additional testing may be required for Orbiter equipment not reflected in the communications subsystem baseline used in this study.

The checkout concepts identified and evaluated in the study are based on a Space Station checkout philosophy of isolating to the faulty replaceable unit while in-flight, and are evaluated assuming the existence of an extensive DMS capability. The Orbiter philosophy, on the other hand, is expected to be one of being mainly interested in the in-flight status of communications subsystem equipment and switchover to redundant units in the event of failure or degradation in performance.

The Space Station OCS is a hybrid of (1) utilizing checkout functions built into the subsystem or experiment under test; (2) sharing other onboard capabilities, especially those of the DMS for data acquisition and distribution, computation, data storage, displays and controls, command generation, and operating system software; and (3) implementing unique OCS design required for stimuli generation, critical measurements, and checkout software. An overall block diagram depicting OCS/DMS elements is provided in Figure 2-3.

Stimuli generation, command generation, and data acquisition capabilities are distributed throughout the Station as dictated by checkout data point locations. Local caution and warning units are located in each habitable compartment with overall status provided at primary and secondary station control centers. Display, control, and data processing functions are primarily centralized with separate capabilities provided for subsystem and experiment support. Distribution of information between various elements of the system is primarily by digital data bus.

Normal on-orbit operation of the OCS is automatic until a fault is detected either by the limit checking capability of the remote data acquisition units (RDAU's) or by a periodic monitoring routine executed by the DMS processor.

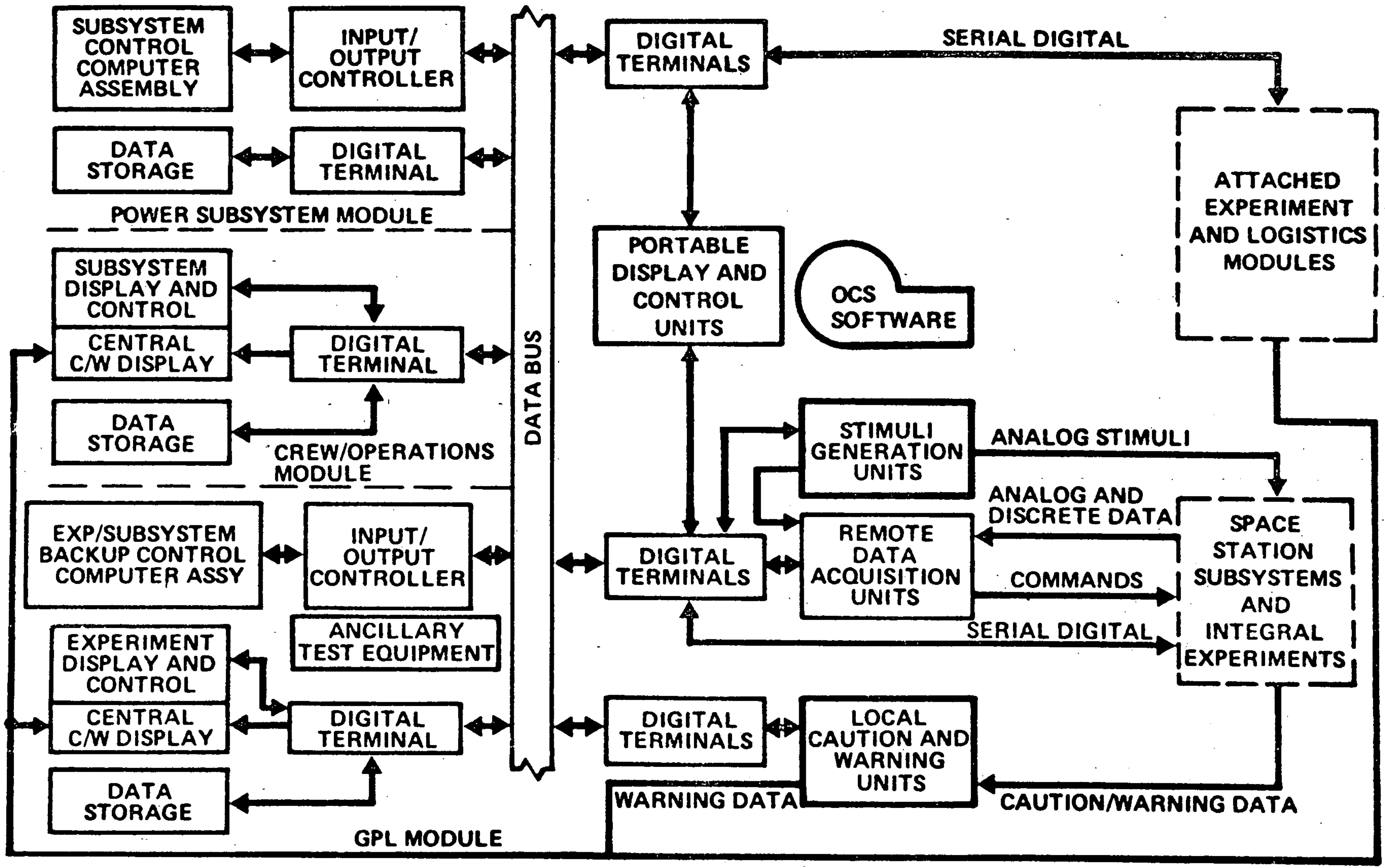

Figure 2-3. Data Management/Onboard Checkout Subsystems

Depending upon the response programmed for the particular fault, the OCS may then proceed automatically to isolate the fault to the replaceable unit or to notify the crew of the malfunction and await further instructions.

An important aspect of the data management/onboard checkout subsystems baseline is that of minimizing the types of interfaces. This is particularly important since it must interface with all other Space Station subsystems, diversified integral experiments, and docked modules. Key features of the onboard checkout capability are listed in Table 2-2.

2.2 PREFERRED CHECKOUT CONCEPT

A variety of concepts for generating test stimuli, detecting signals, and monitoring and evaluating subsystem outputs are defined and analyzed in the study. This is done for the RF, antenna, and internal communications equipment and integrated into a preferred concept for the communications subsystem. Key checkout technique issues addressed in the selection of the preferred concept are summarized in Table 2-3 and described in detail in Sections 3 and 4.

The preferred concept consists of incorporating stimuli test generators and detectors internal to operational RF system LRU's, using external signal detectors within the low- and high-gain antenna systems, and taking advantage of the already available capabilities of the DMS to determine the go-no/go status of the communications subsystem through logical evaluation of monitor signals from the LRU's and external antenna detectors. The preferred test signal format consists of utilizing simple analog test-tones and digital signals as modulation sources. The monitor signals are all normalized to standard voltage and impedance levels compatible with the DMS remote data acquisition units (RDAU's). In general, no logic processing is done within the communications subsystem.

The unmodulated RF signals provided by the subsystem transmitters in conjunction with the analog and digital modulation test generators located with the transmitters are used for checkout of transmit paths. For verification of receive paths, RF and modulation signal generators located within

Table 2-2

DATA MANAGEMENT/ONBOARD CHECKOUT SUBSYSTEM FEATURES

Function	Characteristics
• Remote data acquisition	• Computer-controlled • Random or sequential sampling • Remotely programmable limits • Digital inputs: 8 parallel bits or serial data $\leq 1 \times 10^6$ bps per channel • Bilevel inputs: momentary or continuous 5 vdc signals • Analog inputs: 0-40 mv, 0-5 vdc
• Stimuli generation	• Computer-controlled • Analog outputs: 0-115 vdc • Bilevel outputs: momentary or continuous 5 vdc signals • Serial digital data
• Checkout and fault isolation control	• General-purpose displays and controls (portable and fixed) • Automatic operation • Restructurable application programs
• Critical measurements	• Independent warning system • Local caution/warning units • Centralized displays • Audio and visual alarms

Table 2-3

SUMMARY OF KEY CHECKOUT TECHNIQUE ISSUES

Issue	Major Options	Selection Rationale
• Stimuli generation-transmit paths (Modulation only)	• **LRU internal self-test** • Centralized self-test • Operational data • DMS data bus	• Interface design • EMI considerations • Checkout effectiveness • Operational restrictions
• Stimuli generation-receive paths (RF and modulation)	• **LRU internal self-test** • Centralized self-test • Operational data • Antenna test generators • Translation	• Interface design • EMI considerations • Checkout effectiveness • Operational restrictions
• Signal detection-transmit paths (RF and modulation)	• **LRU internal self-test** • Centralized self-test • Translation • **External antenna detectors**	• Interface design • Maintainability considerations
• Internal communications checkout	• **Normal voice** • **Internal self-test tones** • Automatic test	• Design impact • Operational considerations • Checkout effectiveness
• Antenna system signal detection and conditioning	• **Envelope detector** • Mixer detector	• Ease of implementation • Reliability
• Monitoring/evaluation	• User operational • LRU internal self-test • Centralized self-test • **Data management subsystem** • Separate antenna analyzer	• DMS capabilities • Integration with operational controls • Design impact • Checkout efficiency
• High-gain antenna acquisition and pointing verification	• **Closed loop** • User operational • Near-field self-test • Solar radiometer	• Technology impact • Control of stimuli • Commonality

Selected

operational RF system LRU's are utilized. Stimuli generators are not incorporated in the S-band and K_u-band power amplifiers since the circuitry necessary to develop the normal drive signal could approach the complexity of the LRU itself. The preferred LRU test generator concept is illustrated in Figure 2-4. Figure 2-5 shows the preferred RF system monitoring/ evaluation approach of providing normalized data from detectors internal to the LRU's to the DMS for evaluation.

To facilitate checkout of the antenna system, bidirectional couplers are incorporated in the multiplexer/switching and antenna assemblies. Special envelope detectors are also located adjacent to these assemblies to detect RF signals and to normalize the data for DMS evaluation and monitoring. Detector input levels are set by a switched attenuator controlled by the DMS. In addition, phase shifters and directional couplers are incorporated in the main and acquisition feed/comparator assemblies to accommodate closed-loop checkout of the high-gain antenna system.

The preferred concept for checkout of the low-gain antenna system is illustrated in Figure 2-6 for the S-band triplexer and switching assembly. Receive paths are verified by routing test stimuli from the transponder in the reverse direction through the filters and switches to the antennas. Transmit paths are verified using the normal operational RF signals.

The preferred concept for checkout of the high-gain antenna system is shown in Figure 2-7. For receive path checkout, the concept utilizes the RF signals generated within the low-noise receiver and fed through a separate RF path to the phase shifters in the main comparator and feed assembly. The phase shifters are set to a simulated off-axis pointing angle on command from the DMS. This is repeated for left, right, and center offsets in both the azimuth and elevation channels of the comparator. The same procedure is also used to verify proper performance of the acquisition antenna. Transmit paths are verified using the normal operational RF signals.

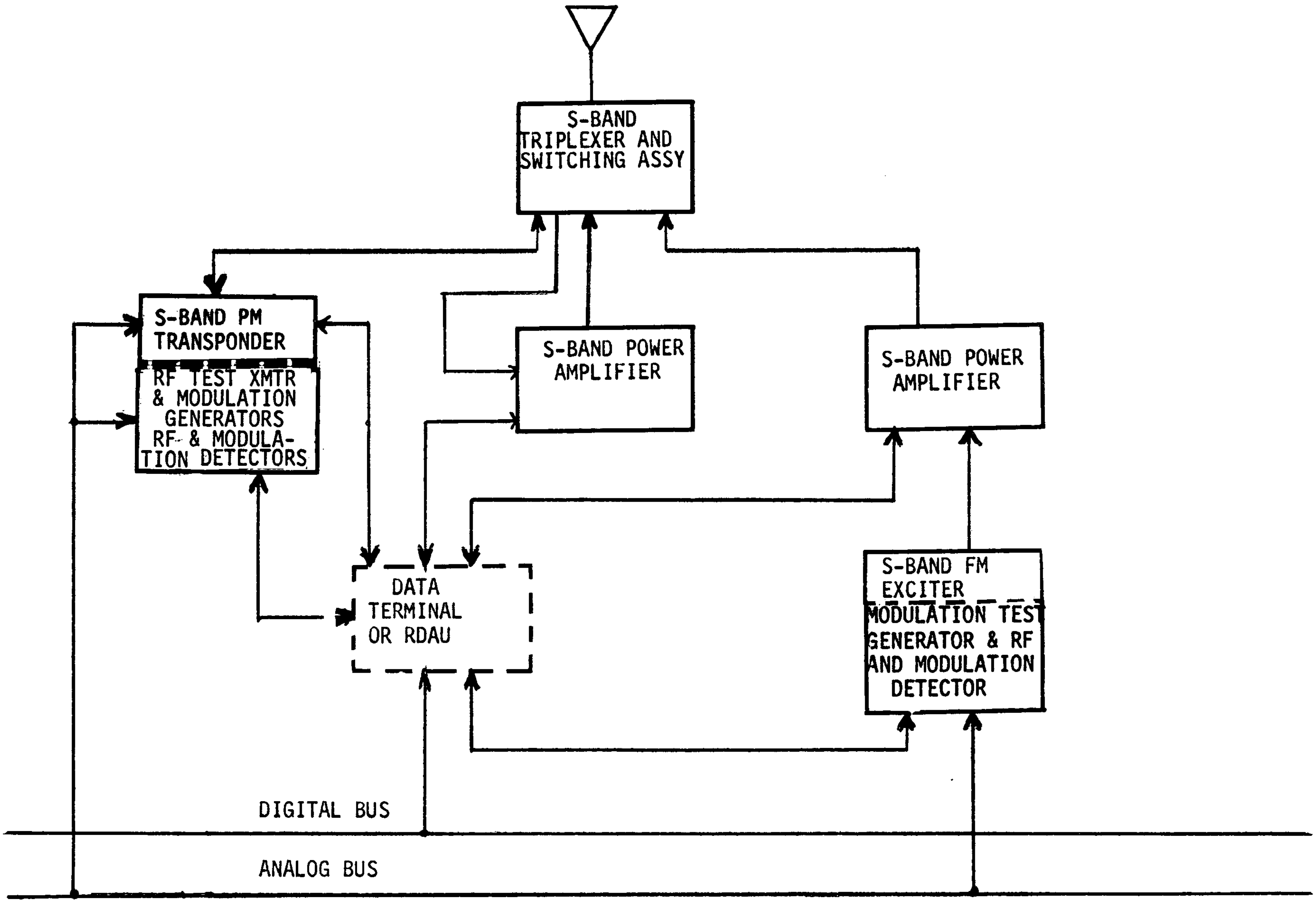

Figure 2-4. LRU Test Generator Concept

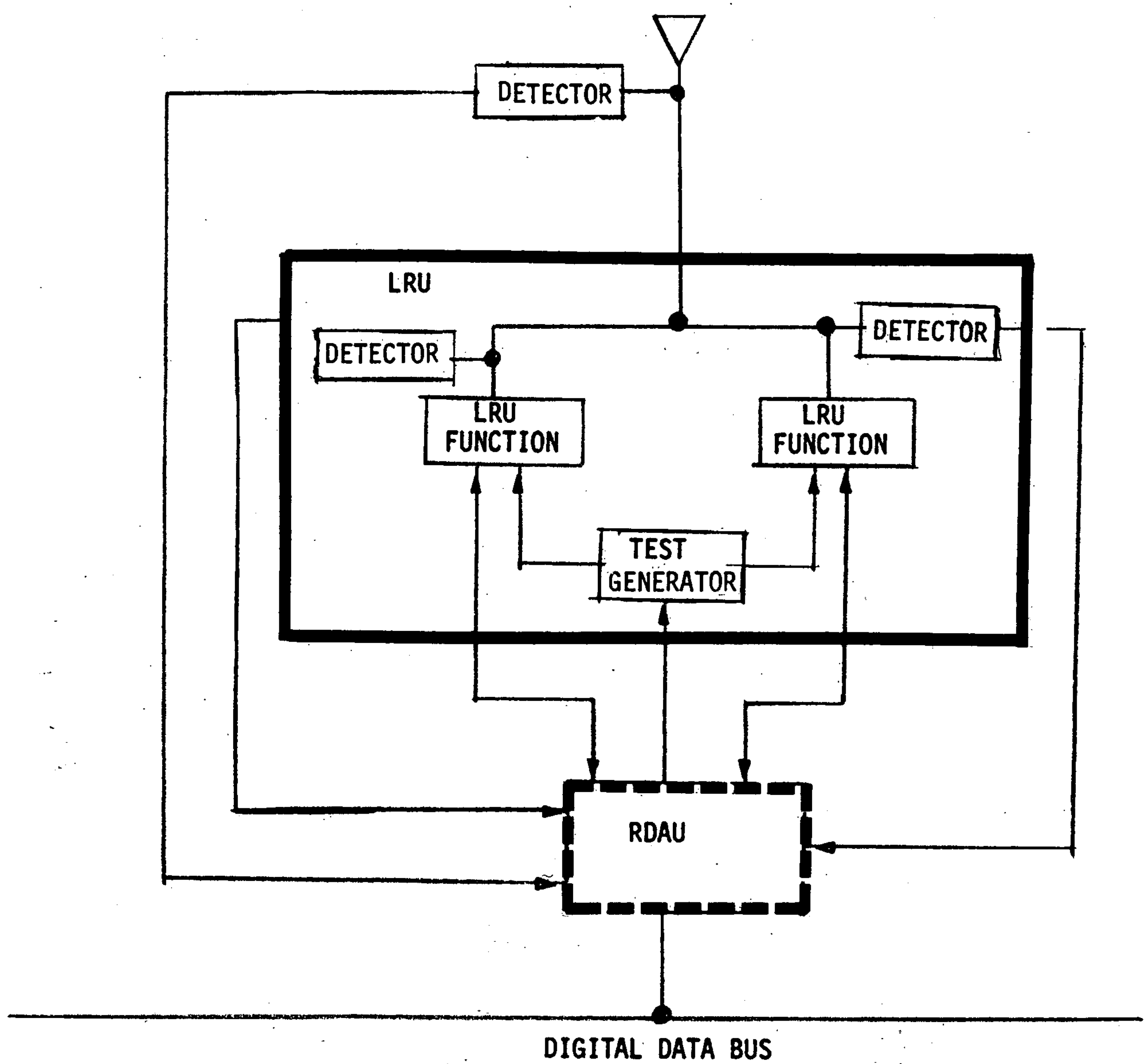

Figure 2-5. Normalized LRU Data with DMS Evaluation

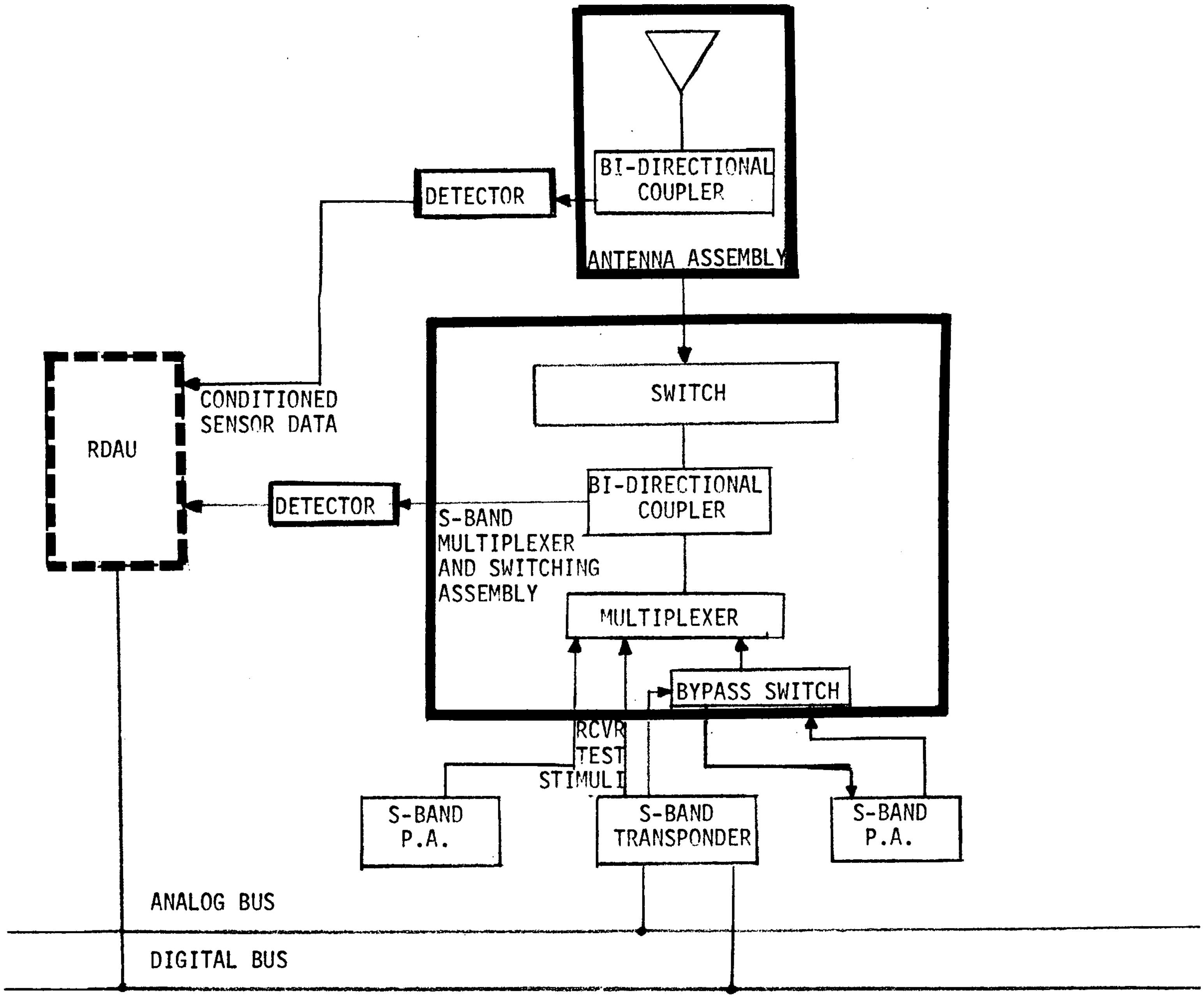

Figure 2-6. Preferred Low-Gain Antenna Checkout Concept

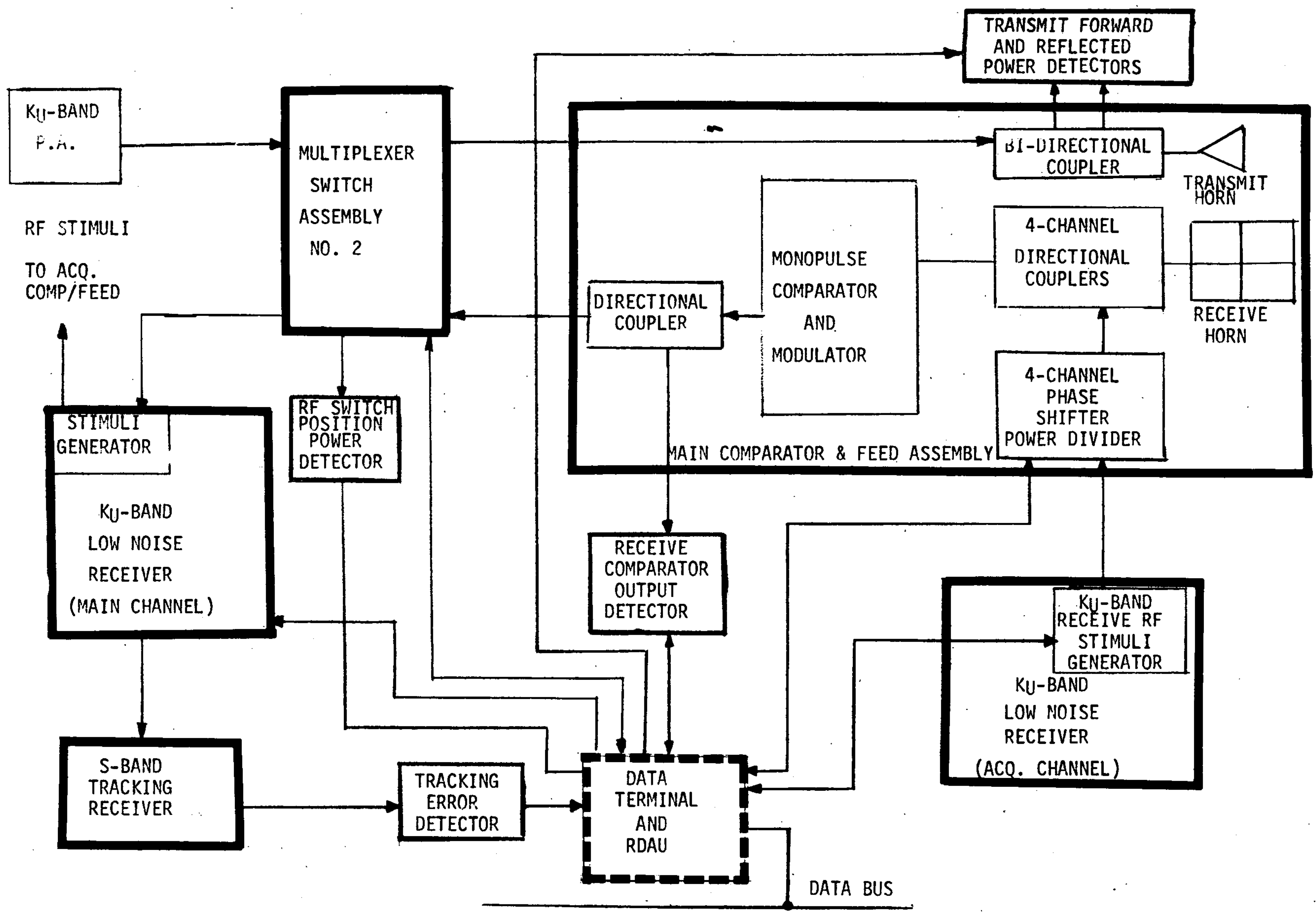

Figure 2-7. Preferred High-Gain Antenna Checkout Concept

The positioner assembly of the high-gain antenna system is checked out by injecting position commands into the servo-control assembly from the DMS. Actual position and rate readouts are monitored by the DMS from digital resolvers driven by the gimbal ac position and rate sensors.

The checkout concept selected for verifying performance and proper operation of the internal communications system audio terminal units (ATU's) is a combination of talk-back and self-test test-tone methods. Since this method utilizes voice signals and test-tones which are called up and evaluated by the user, there are no interfaces with the DMS except for power control. The performance and availability of the analog sync/test unit is determined by DMS monitoring of fault indications generated within the unit.

The preferred concept also includes automatic monitoring and redundancy switching within the communications subsystem for the analog sync/test unit and the S-band phase-modulated (PM) transponder. The analog sync/test unit generates a 4-kHz reference signal which is required for proper operation of the onboard telephone system. Loss of this reference signal would cause a loss of normal voice communications throughout the Space Station, as well as between the Space Station and the other program elements. The S-band PM transponder is utilized for communications directly with the ground stations and Shuttle-Orbiter. During Orbiter rendezvous and docking operations, loss of communications could be very serious.

Further redundancy switching is required for the EVA transmitter/receivers. The RF communications with crewmen engaged in EVA operations are normally provided by two full-duplex transmitter/receiver pairs. A third transmitter/receiver is used to provide simplex communications in the event of a failure of either of the primary units. Since an EVA controller is in the loop during these operations, redundancy switching for this essential function is best effected by manual control.

A final area of redundancy switching involves the communications subsystem equipment located on the high-gain antenna masts. To minimize EVA operations for maintenance and replacement, redundancy switching is provided for the K_u-band power amplifiers, exciters, low-noise receivers, and S-band tracking receivers. Switchover time is not critical and the redundancy is effected by the normal operational controls for these units.

The selection of the preferred checkout approach is strongly influenced by the Space Station maintenance/replacement guidelines and the availability of extensive DMS capabilities. Since the Shuttle-Orbiter is expected to rely much more on redundancy switching to eliminate faulty LRU's and not to have an extensive DMS capability, the preferred Shuttle-Orbiter checkout approach is expected to differ from that selected for the Space Station. An approach which ranked quite high in the evaluation of Space Station checkout concepts appears quite attractive for checkout of the Shuttle-Orbiter communications subsystem. This concept utilizes an antenna test generator with built-in modulation capability to verify receive paths, and either built-in LRU modulation test generators or a common modulation generator on the data bus for verification of transmit paths. Transmit path RF and modulation detectors would also be required in either the LRU's or in the antenna system.

With the added emphasis on quick fault detection for redundancy switching purposes in the Orbiter, it is logical to assume that the individual LRU's would provide go-no/go outputs which would be displayed directly. This approach requires much less dependence on the DMS than the preferred Space Station approach and, therefore, is much more applicable to systems not having an extensive DMS capability.

The Orbiter low-gain antenna system also requires RF detectors located at each antenna element to verify proper antenna switching. In-flight insertion loss and voltage standing-wave ratio (VSWR) measurements are not necessary on orbit, but could be performed during and immediately after reentry to determine plasma effects and to verify antenna availability. Very limited, if any, checkout of the Orbiter high-gain antenna system is expected to be performed on-orbit due to the relatively short flight duration. The checkout would be limited to that available during normal operation.

2.3 ONBOARD CHECKOUT SYSTEM SUPPORT REQUIREMENTS

On-orbit checkout activities required to insure the availability of the communications subsystem include monitoring of its normal operational outputs, performing periodic checks, conducting trend analysis, and selecting fault isolation routines associated with the loss of a communications function.

Access to approximately 550 subsystem measurement points and application of nearly 300 stimuli are required to perform checkout and fault isolation of the baseline Space Station communications subsystem. An identification of the type, quantity, and usage of these measurement and stimulus parameters, as well as those required to conduct normal subsystem operations, is provided in Table 2-4. A detailed listing of these parameters, their characteristics, and the required test interval, sample rate, and sample size (in bits) for each is provided in Section 6. The listing is based upon the study baseline and preferred checkout concepts previously described in this section.

As indicated in Table 2-4, less than 5 percent of the parameters are monitored almost continuously for out-of-tolerance conditions. Parameters monitored in this manner include power amplifier temperature, transmitter and power amplifier RF power output levels, and receiver automatic gain control (AGC) output levels. In addition, a very limited number of parameters are telemetered to the ground to support ground operational procedures. These include the modulation mode, AGC output level, and static phase error of the S-band PM transponder. The relative degree of status monitoring associated with the communications subsystem is much less than that anticipated for most other Space Station subsystems. An average of approximately one-third of all Space Station parameters are subjected to nearly continuous monitoring.

Over 40 percent of the parameters are used to support normal communications subsystem operations. This percentage is about the same as that required to support overall Space Station operations. Over 75 percent of these operational parameters take the form of simple bilevel stimuli and responses.

Table 2-4

PARAMETER TYPE AND USAGE SUMMARY

Parameter Type	Total	Onboard ISS Parameter Usage: Operations	Status Monitor	Test	Trend	Fault Isolation	Isolation Only	Onboard Orbiter Test
Stimuli								
• Bilevel (B)	241	141		79		235	32	
• Digital (D)	52	52		38		49		
• RF (R)	46			15	1	46	28	
Total Stimuli	339	166	0	132	1	330	60	0
Measurements								
• Analog	271	42	33	164	26	263	89	43
• Bilevel	243	146	3	62		236	46	
• Digital	42	28	4	14		37	12	
Total Measurements	556	216	40	240	26	536	147	43
Total Parameters	895	382	40	372	27	866	207	43

The quantity of parameters indicated for testing reflects those necessary for tests conducted periodically to verify the availability or proper operation of on-line systems, redundant equipment, and alternate modes. Although basic LRU operational controls have been excluded from the parameters required for testing, it should be understood that most of these are actually required to support this checkout function. Periodic checks of communications subsystem equipments are expected to be performed prior to operational usage or prior to a scheduled logistics resupply mission. The applicability of the identified parameters to Shuttle-Orbiter tests, assuming similar equipment is utilized, is also noted in Tables 2-4 and 6-11.

The function of fault isolation requires nearly all of the parameters, but only 23 percent are required solely for this purpose. Fault isolation is performed on a systematic basis on a group of LRU's associated with a particular function. Since it is reasonable that periodic checks of the subsystem would be similarly configured, it is expected that software for both periodic testing and fault isolation testing will be integrated into a common package.

To detect graceful degradation in communications subsystem receivers, power amplifiers, and transmitters, RF power outputs and receiver AGC outputs are periodically sampled and subjected to trend analysis. The AGC levels are only trended from periodic test to periodic test since known receive RF stimuli are required.

As far as the Shuttle-Orbiter is concerned, the degree of onboard testing for its relatively short duration mission is much less than that anticipated for the extended-duration Space Station mission. Only 18 percent of the measurement parameters identified for the Space Station are expected to be applicable to Shuttle-Orbiter onboard testing. Additional parameters are required for Orbiter equipments not reflected by the Space Station baseline used in this study. Special tests, for example, may be required on the Orbiter before return to the ground. The functions of fault isolation and trending are expected to be performed nearly exclusively on the ground for the Shuttle-Orbiter.

2.4 EVALUATION AND RANKING OF ALTERNATIVE CONCEPTS

The results of evaluating and ranking the viable alternative checkout concepts are summarized in this subsection for the RF, antenna, and internal communications systems. A more detailed discussion concerning the evaluation of candidate concepts is presented in Section 5.

2.4.1 RF System

The rationale utilized in the evaluation, ranking, and selection of the alternative stimuli generation, signal detection, and monitoring concepts for the RF system is discussed in the following paragraphs.

2.4.1.1 Stimuli Generation

The candidate concepts considered as possible modulation signal sources for the transmit paths include the use of operational signals and modulation generators located either on the data bus, in a centralized test unit, or within the transmitter LRU's themselves. These alternatives are ranked utilizing the evaluation criteria and weighting factors shown in Table 2-5 and discussed in Section 5. The selection of the LRU internal modulation test generator approach is based primarily on the lack of operational restrictions and interface simplicity. The data bus generator concept, however, also ranks high in the evaluation and is an acceptable alternate checkout approach. The use of operational data is limited by the characteristics and availability of the signals. The centralized test unit approach requires parallel interfaces to all LRU's and careful design to minimize electromagnetic interference (EMI).

The candidate concepts considered as possible RF and modulation signal sources for the receive paths include the use of operational signals, an RF translator, and RF and modulation generators located either in the antenna system, in a central test unit, or within the receiver LRU's themselves. Based on the evaluation in Table 2-6, the LRU internal RF and modulation test generator approach has the highest ranking, but there is not a clear-cut advantage over the antenna test generator approach. The use of operational signals fares reasonably well, but suffers from the same shortcomings noted above. The EMI and isolation problems are much more

Table 2-5

CANDIDATE TRANSMIT PATH STIMULI GENERATION AND SIGNAL DETECTION CONCEPTS

Criteria	Weight Factor	LRU Generator (Modulation Only)		LRU Detector (RF and Modulation)		Centralized Generator (Modulation Only)		Centralized Detector (RF and Modulation)		Operational Data		Bus Generator (Modulation Only)		Translator	
LRU design impact	10	Generator design required	7	Detector designs required	6	Interfaces with central generator	9	Interfaces with central detector required	9	None	10	None	10	Minor	9
Communications subsystem impact	12	None	10	Antenna power monitor	9	Central generator design required	6	Antenna power monitor and central detector design required	5	Antenna power monitor	9	Antenna power monitor and test generator design required	7	Antenna power monitor and translator designs required	6
Interface complexity (Includes switching)	8	Normal DMS	10	Normal DMS	10	Parallel interfaces to all LRU's new unit on DMS bus	5	Parallel interfaces to all LRU's, new unit on DMS bus	5	Normal DMS	10	New unit on data bus	9	New units on data bus	9
Operational restrictions	12	None	10	None	10	None, however control priority must be considered	9	None	10	Proper data may not be available	5	Possible conflict on data bus	5	Matching receiver or transmitter may not be available	3
Physical impact (weight, power, size)	8	Minor increase	8	Moderate increase, depending on LRU complexity	6	New LRU added	8	New LRU added	6	None	10	New unit added	9	New units added	7
Performance impact (Including effectivity)	14	None (High)	10	None (High)	10	Potential EMI problem (High)	7	Potential EMI problem (High)	7	Checkout capabilities may be limited by signal characteristics (Good monitor, fair fault isolation)	5	None (High)	10	Limited capability need compatible T/R signals, potential EMI problems (difficult to isolate T/R failure)	3
Cost	10	Minor increase	8	Moderate increase, depending on LRU complexity	7	New LRU design and build	5	New LRU design and build	4	None	10	New LRU design and build	8	New LRU design and build	5
Flexibility and growth constraints	8	LRU operational and test capabilities rigid, but changed together	6	LRU operational and test capabilities rigid, but changed together	6	Good flexibility and growth potential, with proper initial design	8	Moderate flexibility and growth potential, with proper initial design	8	Flexibility limited	6	Good flexibility and growth potential, with proper initial design	8	Flexibility limited	6
Reliability/ failure effects	12	Failure effects limited to one LRU	8	Failure effects limited to one LRU	8	Redundant design necessary to minimize impact of failures. Could lose all test capability	7	Redundant design necessary to minimize impact of failures. Could lose all test capability	7	Test capability dependent upon availability of operational sources	9	Redundant design necessary to minimize effect of failures in redundant unit	8	Redundant design necessary to minimize effect of failures in common translator	7
GSE considerations	6	GSE needed if more detailed prelaunch tests are required	8	GSE needed if more detailed prelaunch tests are required	7	GSE not required if central unit has expanded capability	9	GSE not required if central unit has expanded capability	9	Considerable GSE required	5	Minimal GSE required	9	Considerable GSE required	5
Totals			868		812		720		698		784		822		580

Table 2-6

CANDIDATE RECEIVE PATH STIMULI GENERATION CONCEPTS

Criteria	Weight Factor	LRU Generator and Detector (RF and Modulation)		Centralized Generator and Detector (RF and Modulation)		Translator		Operational Data		Antenna Test Generator	
LRU design impact	10	LRU generator and detector and antenna phase shifter designs required	6	Antenna phase shifter design required	9	Antenna phase shifter design required	9	Antenna phase shifter design required	9	Antenna phase shifter design required	9
Communications subsystem impact	12	None	10	Central test generator design required	5	Translator designs required	7	None	10	Antenna test generator design required	6
Interface complexity (includes switching)	8	Normal DMS	10	Parallel interfaces to all LRU's; new unit on data bus	5	New units on data bus	9	Normal DMS	10	New units on data bus	9
Operational restrictions	12	Test signal may jam operating channel	6	Test signal may jam operating channel	6	Test signals may jam operating channel; paired unit may not be available	3	Signals may not be available	2	Test signal may jam operating channel	6
Physical impact (weight, power, size)	8	Moderate increase	6	New LRU added, increased wiring runs	7	New units added	6	None	10	New LRU's added	7
Performance impact (including effectivity)	14	Minor (High)	9	Potential severe EMI problems (High)	6	Potential EMI problems limited capability (Difficult to isolate T/R failures)	3	Capabilities severely limited by availability and characteristics of signals	3	Minor (High)	8
Cost	10	Moderate increase	7	New LRU design and build	4	New LRU design and build	5	None	10	Design and build new RR LRU's	5
Flexibility and growth constraints	8	LRU operational and test capability rigid, but can be changed together	6	Fair growth and flexibility potential with proper initial design	7	Flexibility limited	6	Flexibility limited	6	Fair growth and flexibility potential with proper initial design	7
Reliability/failure effects (Maintenance of test capabilities)	12	Failure effects limited to one LRU or one receive path	8	Redundant design necessary to minimize impact of failures in common unit	7	Redundant design necessary to minimize effect of failures in common translators	7	Test capability dependent upon availability of external signal sources	7	Failure effects limited to one receive path	8
GSE considerations	6	GSE needed if more detailed prelaunch tests are required	7	Minimal GSE required if central unit has expanded capability	9	Considerable GSE required	5	Considerable GSE required	4	Minimal GSE required if unit has expanded capability	9
Totals			762		636		584		716		730

severe for the receive path than for the transmit path in the centralized test generator concept because parallel RF cabling to all LRU's is required. The RF translator approach also has potential EMI and isolation problems and may also impose difficulty in isolating transmitter/receiver failures.

The analog test-tone and digital modulation test signal format concept is selected because of its ease of implementation and because the voltage levels can be tailored to the modulation or demodulation sensitivity of each LRU. The design complexity associated with implementing the other approaches is considerably greater and is not warranted.

2.4.1.2 Signal Detection

The three RF and modulation signal detection concepts considered for RF system transmit paths are the RF translator concept, the concept of using the pair receiver as the detector, and the location of detectors either within the transmitter LRU's or in a centralized test unit. Based on the results of the detector evaluations in Table 2-5, the choice is clearly the internal LRU approach. There are no new interfaces created by utilizing this approach and there are no known performance impacts.

2.4.1.3 Monitoring and Evaluation

The evaluation and ranking of the candidate monitoring concepts is shown in Table 2-7. Two basic monitoring and evaluation concepts are considered. The first utilizes the DMS which either monitors LRU go-no/go status and then evaluates normalized data, or only evaluates LRU normalized data. The second method incorporates a communications subsystem multiplexer-computer unit (MCU) which either monitors LRU go-no/go status and then evaluates normalized LRU data, or determines LRU status by evaluating the normalized LRU data. The results of the evaluation and ranking show that the approaches which use the DMS to either monitor LRU go-no/go status and evaluate the normalized data, or evaluate the LRU normalized data are far superior to the other approaches. The selection of the preferred monitoring and evaluation approach is based primarily on the availability of an extensive DMS capability.

Table 2-7

CANDIDATE MONITORING CONCEPTS

Criteria	Weight Factor	Go-No/Go Data Only Provided by LRU's		Go-No/Go Data Provided by LRU's Detailed Data on Request		Go-No/Go Status Determined by DMS Evaluation of Normalized LRU Data		Go-No/Go Data Provided by LRU's to MCU. Detailed Data on Request. DMS Configures LRU		Go-No/Go Status Determined by MCU Based on Evaluation of of Normalized LRU Data. DMS Configures LRU		Go-No/Go Data Provided by LRU's. Detailed Data Provided upon Request. MCU Configures LRU		Go-No/Go Status Determined by MCU Based on Evaluation of Normalized LRU Data. MCU Configures LRU	
LRU Design Impact	10	LRU's must provide internal logic	8	LRU's must provide internal logic and normalized data drivers	7	LRU's must provide normalized data drivers	9	LRU's must provide internal logic and normalized data drivers	7	LRU's must provide normalized data drivers	9	LRU's must provide internal logic and normalized data drivers	7	LRU's must provide normalized data drivers	9
Communications subsystem design impact	12	None	10	None	10	None	10	MCU design required	6	MCU design required	5	MCU design required	4	MCU design required	3
Interface complexity	8	Normal DMS	10	Normal DMS	10	Normal DMS	10	Parallel interfaces required to all LRU's	9	Parallel interfaces required to all LRU's	9	Parallel interfaces required to all LRU's	8	Parallel interfaces required to all LRU's	8
Physical impacts	8	Small increase in weight, power, and size	9	Small increase in weight, power, and size	9	Baseline	10	Small increase in LRU's plus MCU	6	Small increase in LRU's plus MCU	6	Small increase in LRU's plus size	6	Small increase in LRU's plus MCU	6
Effectivity	16	Insufficient data for trend analysis	3	None	10	None	10	None	10	None	10	None	10	None	10
Cost	10	Small increase	9	Small increase	9	Baseline	10	Moderate increase due to new LRU design	6	Moderate increase due to new LRU design	5	Moderate increase due to new LRU design	5	Moderate increase due to new LRU design	4
Flexibility and growth constraints	8	Fixed by design	4	Limited flexibility	5	Limits can be changed via DMS software	8	Limited flexibility	7	Limits can be changed via MCU programs	9	Limited flexibility	7	Limits can be changed via MCU programs	9
Reliability and failure effect	12	Failure effects limited to one LRU	8	Failure effects limted to one LRU	8	Failure effects limited to one LRU	8	Redundant design necessary to minimize effect of failures in common LRU	7	Redundant design necessary to minimize effect of failures in common LRU	7	Redundant design necessary to minimize effect of failures in common LRU	6	Redundant design necessary to minimize effect of failures in common LRU	6
GSE considerations	6	Required for more detailed evaluation	5	None	9	None	9	None	10	None	10	None	10	None	10
DMS design impact	10	Simple program	8	Increased storage and program requirement for detailed data	7	Considerable increase in program requirements to evaluate all parameters	5	Simple program	7	Simple program	7	Simple program	9	Simple program	9
Totals			728		860		894		752		766		718		732

2.4.2 Antenna System

Results and rationale of the evaluation, ranking, and selection of alternative antenna system stimuli generation, signal detection, and monitoring/evaluation concepts are discussed in the following paragraphs.

2.4.2.1 Stimuli Generation

For the high-gain antenna system receive paths, candidate open-loop stimuli sources considered are far-field signals from the data relay satellite, near-field signals from an onboard antenna, and far-field RF noise from solar radiation. For closed-loop receive path checkout, both an internal LRU stimuli generator and separate antenna stimuli generator are considered. Closed-loop stimuli concepts are preferred to open-loop concepts because of control limitations and because of design and technology impacts. Of the closed-loop stimuli concepts, the use of stimuli generation capabilities internal to the low-noise receiver LRU is preferred. This preference is due to the commonality of stimuli generation requirements between the RF and antenna system, and due to the simpler interface that results between the stimuli source and the comparator feed assembly.

Candidate stimuli concepts for checkout of both the high- and low-gain transmit paths involve the use of either a separate antenna generator or the normal operational signals. Although detection problems are somewhat simplified by use of a separate generator, the utilization of operational signals is preferred to designing a new stimuli generator.

For the low-gain antenna receive paths, the use of either a separate antenna generator or an internal LRU stimuli generator is considered. The latter is preferred with the receive RF signals injected into the normal antenna input line in the reverse direction. The deciding factor is primarily the availability of RF stimuli generation capabilities within the low noise receiver.

2.4.2.2 Signal Detection

Candidate detection concepts for monitoring RF signals are the preferred diode envelope detector and a diode mixer detector. The diode envelope detector includes a predetection tone modulator and postdetection signal conditioning amplifier. The alternate diode mixer detector approach utilizes an RF mixer and intermediate frequency amplifier. A summary matrix comparing the relative merits of the two methods is provided in Table 2-8. The envelope detector is preferred primarily because of its simpler design and lower potential EMI generation.

For the high-gain antenna system receive paths, two detection candidates are considered for monitoring acquisition and tracking performance. These include either using a diode mixer detector in conjunction with an impedance analyzer, or using the operational tracking receiver. The selection of the tracking receiver as the preferred candidate eliminates designing a separate checkout assembly and provides a capability for monitoring the performance of comparator modulator outputs. The availability of a redundant tracking receiver adds to the attractiveness of using the operational tracking receiver for monitoring acquisition and tracking performance.

2.4.2.3 Monitoring and Evaluation

As for the RF system, DMS capabilities are utilized to support antenna system monitoring and evaluation functions. This approach is preferred to other concepts that require the design of an independent antenna system evaluator.

Implementation of the reflectometer or impedance analyzer candidate concepts, for example, does result in reduced dependence upon the DMS, but this advantage is very much offset by the additional complex design required.

2.4.3 Internal Communications System

Three alternative concepts are identified for checkout of the onboard telephone system. The first is a simple talk-back method which requires a crewman at both the user and dialed ATU's. Another concept is the self-test test-tone method which employs a test-tone that is manually called up and evaluated by the user. In an automatic test concept, each ATU is sequentially interrogated by a test-tone generated within a dedicated test unit. Since the duty cycle varies considerably between ATU's and the reliability is expected to be high, it is unnecessary to implement a dedicated

Table 2-8

ANTENNA DETECTOR TRADE MATRIX

Criteria	Weight Factor	Envelope Detector Low Gain Transmit	Envelope Detector Low Gain Receive	Envelope Detector High Gain Transmit	Envelope Detector High Gain Receive	Total Average Rank	Mixer Detector Low Gain Transmit	Mixer Detector Low Gain Receive	Mixer Detector High Gain Transmit	Mixer Detector High Gain Receive	Total Rank
1. Communications subsystem impact	18	Small 8	Small 8	Small 8	Small 8	144	More complex 5	5	5	5	90
2. DMS design impact	10	Small 9	Small 9	Small 9	Small 9	90	Longer execution time than alternate approach 8	8	8	8	80
3. Operational restrictions	16	No impact 10	Checkout prevents operation 5	No impact 10	Checkout prevents operation 5	120	Interference may prevent operation of receivers 7	5	7	5	96
4. Reliability failure effects	12	Better than mixer 8	Better than mixer 8	Less than low gain 7	Less than low gain 7	90	Worse than diode 6	Worse than diode 6	Worse than diode 6	Worse than diode 6	72
5. Maintainability	10	Small impact 9	9	9	9	90	Complex more calibration problems. 5	5	5	5	50
6. Flexibility	8	Can handle any change - Broad band 10	10	10	10	80	Slow response - Frequency sensitive 7	7	7	7	56
7. Effectivity	16	Better for monitoring 9	9	9	9	144	Better for isolating 9	9	9	9	144
8. Cost	10	Less than mixer 8	8	8	8	80	Greater than diode 7	7	6	6	65
Totals						838					653

test unit for checkout of the ATU's. Both the talk-back and self-test test-tone methods have some associated limitations; however, the limitations of each are complemented by the other. Therefore, a combination of the latter two has been selected as the preferred approach.

Each analog sync/test unit of the internal communications subsystem incorporates a self-monitor capability which provides reference generator operational status as an output. These outputs are monitored continuously by the DMS for fault indications. This information is then utilized to effect redundancy switching if required.

The technique selected for verifying operation of the TV monitors is one that utilizes known test patterns as the stimuli source and a crewman to visually evaluate the pattern.

2.5 RECOMMENDED BASELINE MODIFICATIONS

The study shows that the preferred checkout concept is one in which the RF and modulation stimuli generators and signal detectors are located within the operational LRU's of the system, and in which the DMS is assigned the task of both determining the system go-no/go status and locating faults by evaluating the normalized monitor data supplied by each of the LRU's.

The impact of this concept on the basic functional configuration is the added design requirement for incorporating the stimuli sources within the LRU's, and for supplying the circuitry necessary both to detect all of the critical signals at the LRU interfaces and to supply them at normalized signal levels and impedances compatible with the RDAU's. Block diagrams depicting the additional circuitry required to implement the preferred checkout approach are provided in Section 3.

While the incorporation of the stimuli generators represents a major change to the baseline communications subsystem configuration, most of the control and monitor signals used in the checkout procedures are already included in the subsystem for normal operational control and anticipated test signal outputs. Furthermore, the normalization of test signal outputs is considered to be a baseline design consideration for all concepts.

The preferred checkout concepts for verifying performance and operation of the low- and high-gain antenna systems utilize the operational RF transmitter signals and the receiver LRU internal test generator signals as stimuli sources. The impact of this concept on both antenna systems is the added design requirement of incorporating the bidirectional couplers within the multiplexer and switching assemblies located in transmit paths and the directional couplers in multiplexers located in receive paths. Phase shifters and bidirectional couplers are required additions in the high-gain main and acquisition comparator/feed assemblies to permit closed-loop checkout of the RF tracking systems.

Bidirectional couplers must be incorporated in the design of the VHF and S-band low-gain antenna feed elements. The design of separate RF power detectors is also required. These detectors are collocated with the multiplexer and switching assemblies and low-gain antenna feed elements. The design of all antenna system LRU's and power detectors must provide for conditioned monitor signal outputs which are compatible with the DMS.

No modifications are necessary for the baseline internal communications system to accommodate checkout.

2.6 RECOMMENDED ADDITIONAL AREAS OF INVESTIGATION

As a result of the study, several areas are identified as worthy of further investigation, especially those related to checkout of the Shuttle-Orbiter. Further checkout analysis of the Space Station communications subsystem should be deferred until an appropriate time prior to generating Space Station equipment specifications. The results of any studies undertaken to investigate Shuttle-Orbiter checkout concepts would be highly beneficial to the eventual detailed definition of Space Station checkout concepts.

2.6.1 Antenna Detector Design

The special envelope detector concept defined in the study for checkout of the antenna system should be further developed and designed. The design could be of significant benefit to Shuttle-Orbiter prelaunch checkout.

2.6.2 Broadband Signal Sources

Broadband signal sources such as noise or variable code length pseudo-random noise (PRN) generation in conjunction with suitable filters could be utilized as common modulation sources. A study to determine the feasibility of utilizing these techniques should be performed. This would then be followed by the development of a breadboard system to verify the concept(s).

2.6.3 Shuttle-Orbiter Communications Subsystem Checkout Study

It is recommended that a study similar to the Communications System Checkout Study performed for the Space Station be undertaken for the Shuttle-Orbiter. The proposed study would address the same key checkout requirements, techniques, and implementation impact issues of the current study, but place additional emphasis on areas more vital to the definition of Shuttle-Orbiter checkout concepts. Redundancy switching, data management subsystem loading, ground support requirements, and reentry/landing systems, for example, are of much greater concern to the development of Shuttle-Orbiter checkout concepts than they are for the Space Station. Methods and location of stimuli generation and monitoring/evaluation capabilities are also extremely important considerations for the Shuttle-Orbiter, as they are for the Space Station. These concepts must be established in a timely manner to effect their implementation in the initial specification and design of the communications subsystem equipment.

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Section 3
IMPLEMENTATION OF PREFERRED CHECKOUT CONCEPT

This section discusses the impacts of implementing the preferred checkout concept for the Space Station communications subsystem described in Subsection 2.2. Other checkout techniques investigated in the study are addressed in Section 4.

3.1 RF SYSTEM

One of the key advantages of locating the stimuli generators and detectors within the RF transmitter and receiver LRU's is the elimination of design interface problems between the checkout circuitry and the operational circuitry because the LRU design is under the control of the same designer. It also allows the monitor detectors to be loosely coupled. This prevents a failure in the checkout circuitry from degrading the normal operational channel. Potential EMI and isolation problems, such as would be present in the centralized test generator concept, are also minimized. Another advantage of this approach is that fault isolation is relatively straightforward when several LRU's are operated in series since the checkout of each LRU is not dependent upon signals from another LRU. The one exception, the power amplifier, has been noted previously. The most serious drawback to this approach is that a failure in the checkout circuitry of an LRU could require LRU replacement, even though the operational circuitry has not failed. However, since only simple modulation, low-power RF generators, and relatively simple detectors are envisioned, the reliability of the checkout circuitry can be made high enough to minimize this objection.

The additional circuitry required to implement the preferred checkout approach for several representative LRU's is shown in Figures 3-1 through 3-5. The VHF voice transmitter/receiver shown in Figure 3-1 requires the

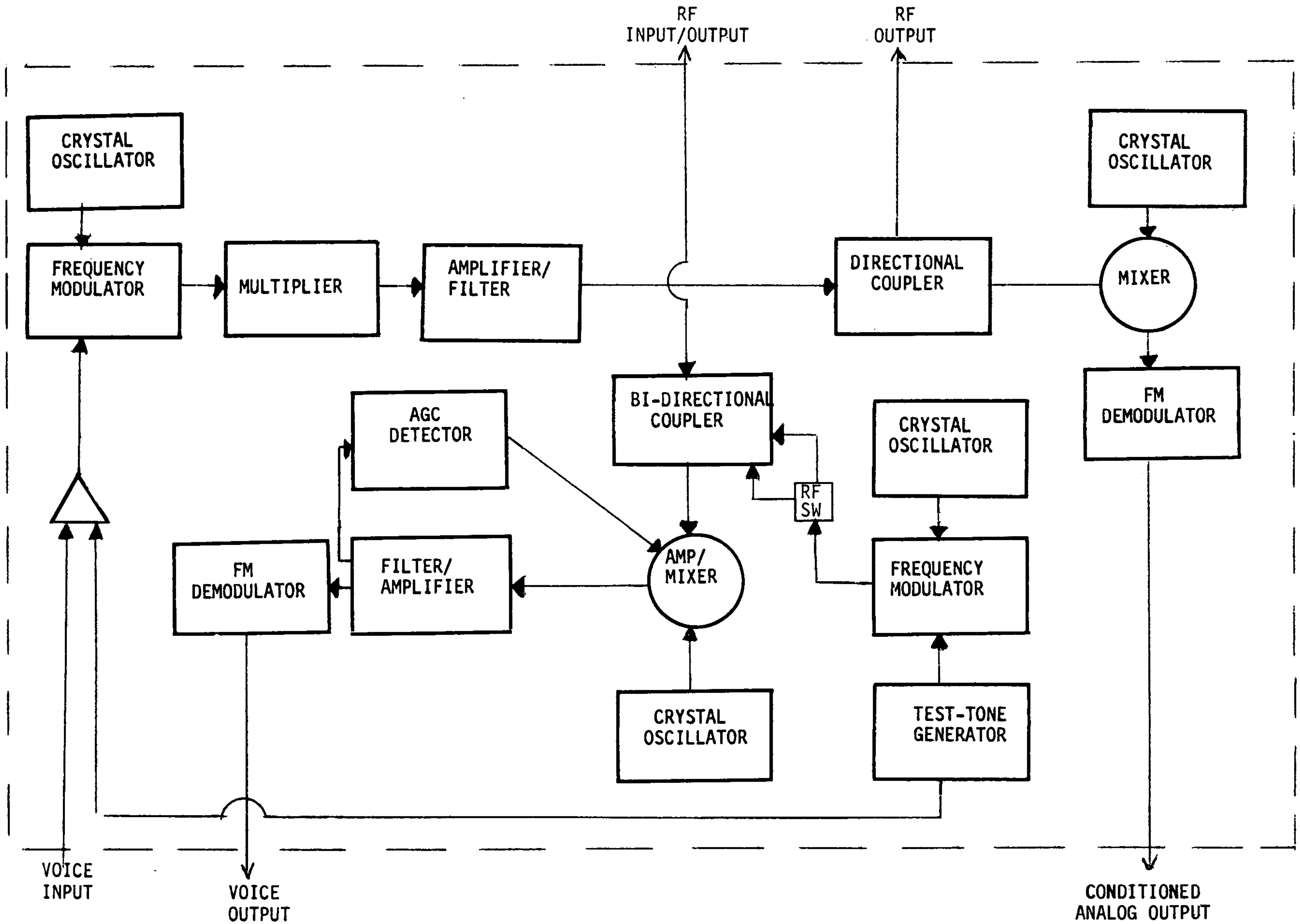


Figure 3-1. VHF Voice Transmitter/Receiver Modifications

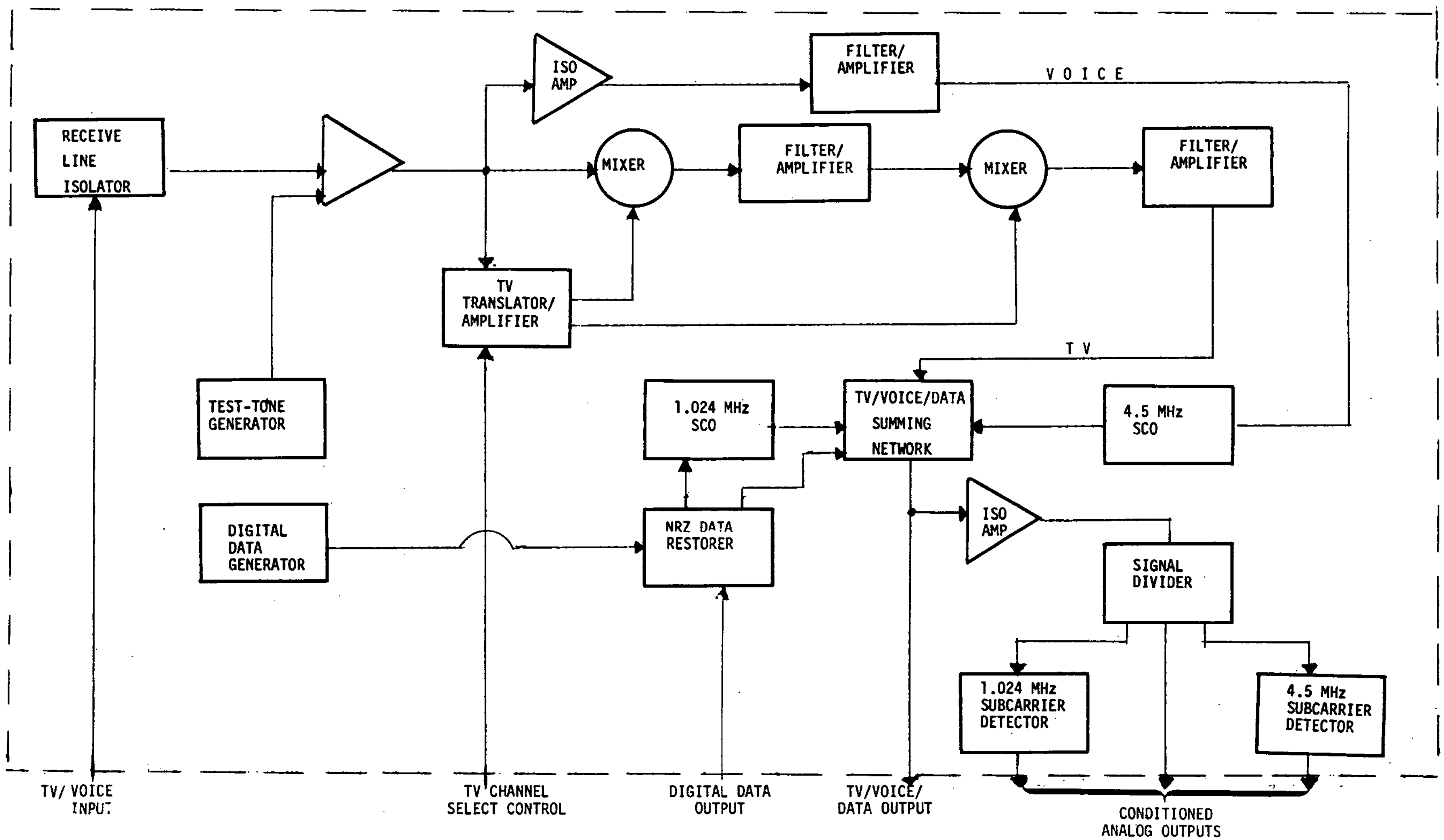


Figure 3-2. Ku-Band Exciter Modem Modifications

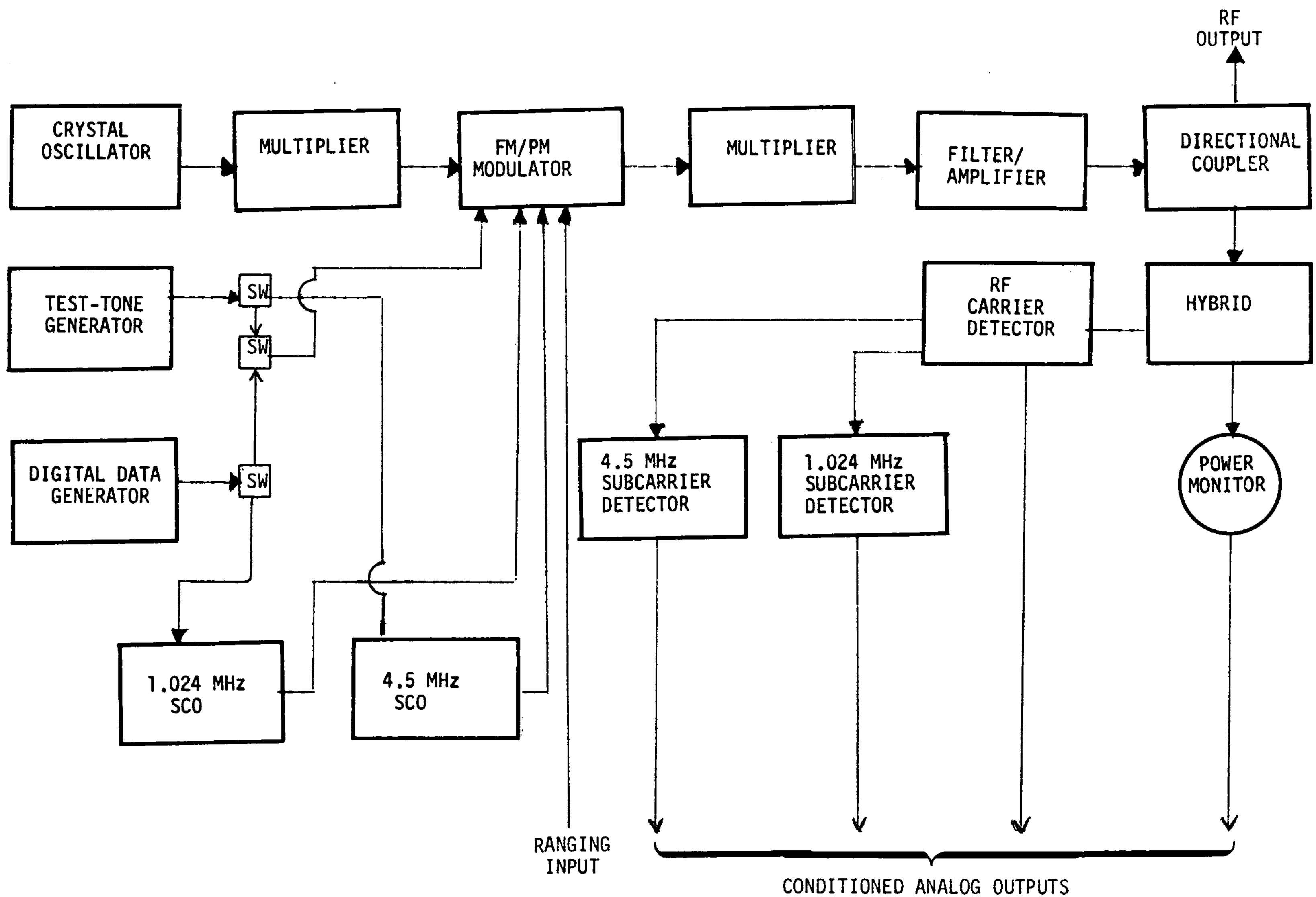


Figure 3-3. Ku-Band Exciter Modifications

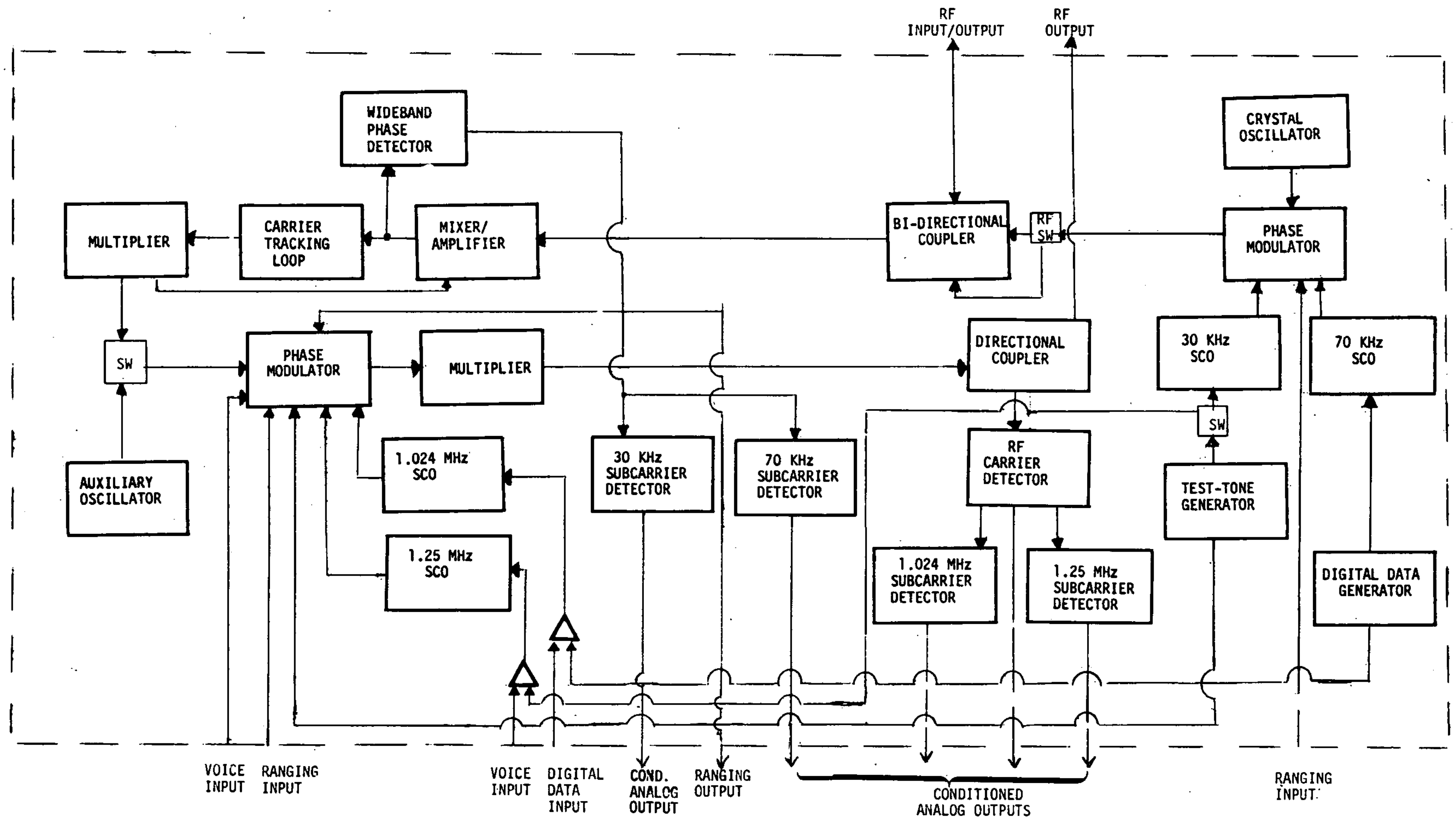


Figure 3-4. S-Band PM Transponder Modifications

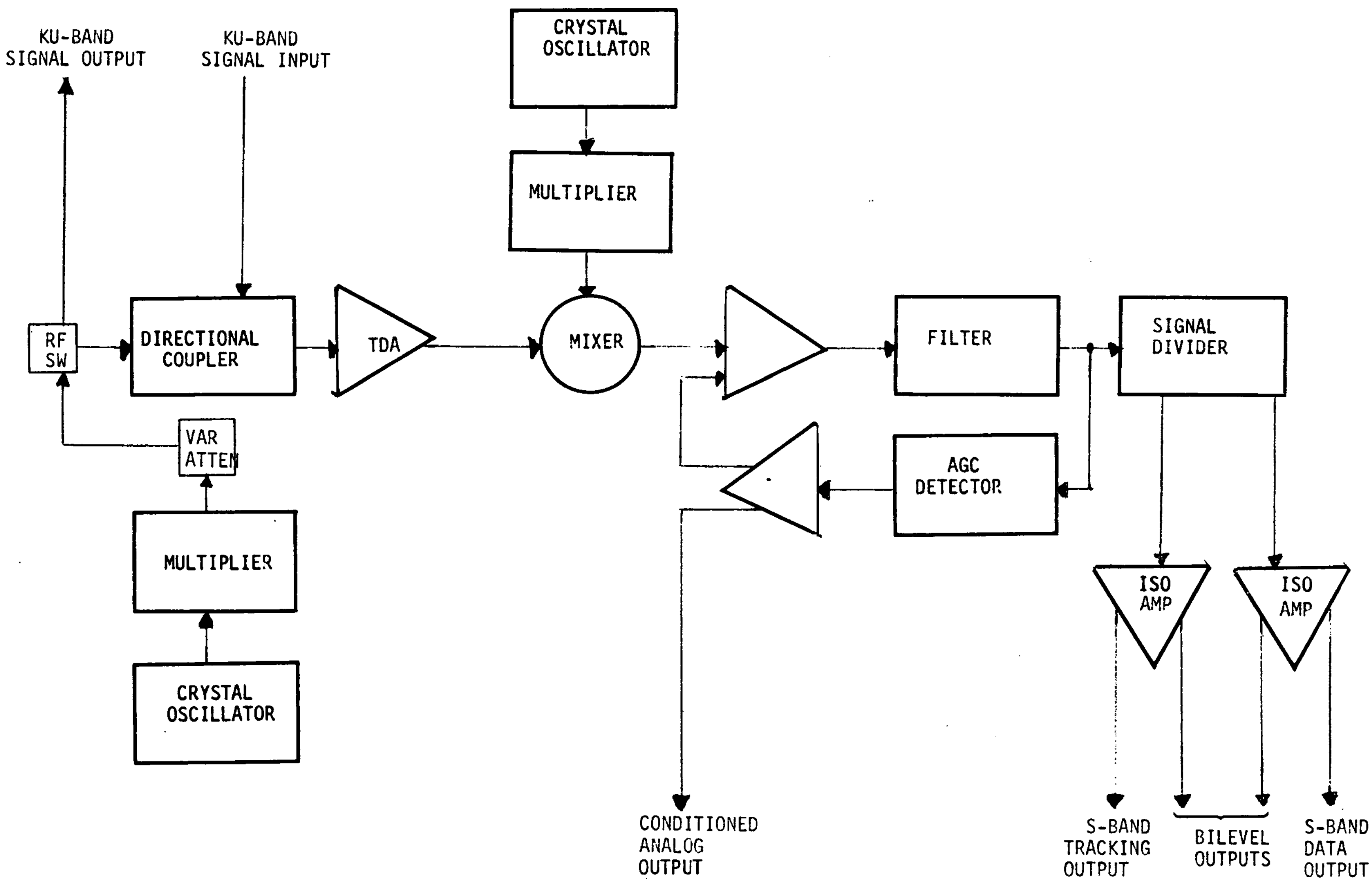


Figure 3-5. Ku-Band Low-Noise Receiver Modifications

addition of two crystal oscillators, a mixer, frequency modulator and demodulator, directional couplers, and a test-tone generator. The bidirectional coupler allows the receive channel RF test generator to be fed into the VHF low-gain antenna system for checkout of receiver paths.

The additional circuitry required in the K_u-band exciter modem is relatively minor and shown in Figure 3-2. It consists of an analog test-tone generator, digital data generator, isolation amplifier, signal divider, and 1.024- and 4.5-MHz subcarrier detectors.

The changes required in the K_u-band exciter are shown in Figure 3-3. They include variable test-tone and digital data modulation generators, RF carrier detectors, 1.024- and 4.5-MHz subcarrier oscillators and detectors, and a directional coupler and hybrid to couple the RF signals into the detection circuitry.

The RF system LRU that is most significantly affected by the incorporation of the internal test stimuli generation and detection capability is the S-band transponder shown in Figure 3-4. The additional checkout circuitry includes a phase modulator and carrier detector, 30- and 70-kHz subcarrier oscillators, 1,024- and 1.25-MHz subcarrier detectors, test-tone and digital data generators, and directional couplers. The bidirectional coupler allows a signal at the normal receive frequency to be coupled into the antenna system to allow checkout of the receiver channel filters in the S-band multiplexer and switching assembly.

The K_u-band low-noise receiver (Figure 3-5) requires only the addition of a low-power oscillator, frequency multiplexer, and directional coupler to provide the built-in test capability. It should be noted that the capability to provide a K_u-band RF signal output has also been incorporated in this LRU. This signal is utilized for closed-loop checkout of the RF tracking system.

To minimize the impact on overall system weight, size, power consumption, and interface complexity and to enhance reliability, it is mandatory that the stimuli generators and detectors be incorporated in the basic LRU design. This approach has an advantage over the other concepts that use common test generators in that redundant off-line units can be checked out while the paired unit continues to be utilized in support of normal station operations.

The utilization of the DMS RDAU's for both checkout and operational control of the communications subsystem should tend to minimize any priority control conflicts that may arise. Although this approach has the highest DMS loading of all the concepts considered, the impact on the overall DMS loading is relatively insignificant.

The only automatic monitoring and redundancy switching required for RF system LRU's is that associated with the S-band PM transponder. This LRU is utilized for communications directly with the ground stations and Shuttle-Orbiter. During Orbiter rendezvous and docking, loss of communications could jeopardize the accomplishment of critical mission operations. Implementing the capability for automatic transponder switchover is complex. This is due to the fact that a "loss-of-lock" indication from a transponder could result from either a transponder front end failure or the lack of a received signal from the Orbiter.

Other redundancy switching identified for the RF system is that required for the EVA transmitter/receivers. The RF communications with crewmen engaged in EVA operations are normally provided by two full-duplex transmitter/receiver pairs. A third transmitter/receiver is utilized to provide simplex communications in the event of a failure of either of the primary units. Since an EVA controller is in the loop during these operations, redundancy switching for this essential function is best effected by manual control.

3.2 ANTENNA SYSTEM

To facilitate checkout of the antenna system, bidirectional couplers are incorporated in the multiplexer/switching and antenna assemblies. Special envelope detectors (Figure 3-6) are also located adjacent to these assemblies

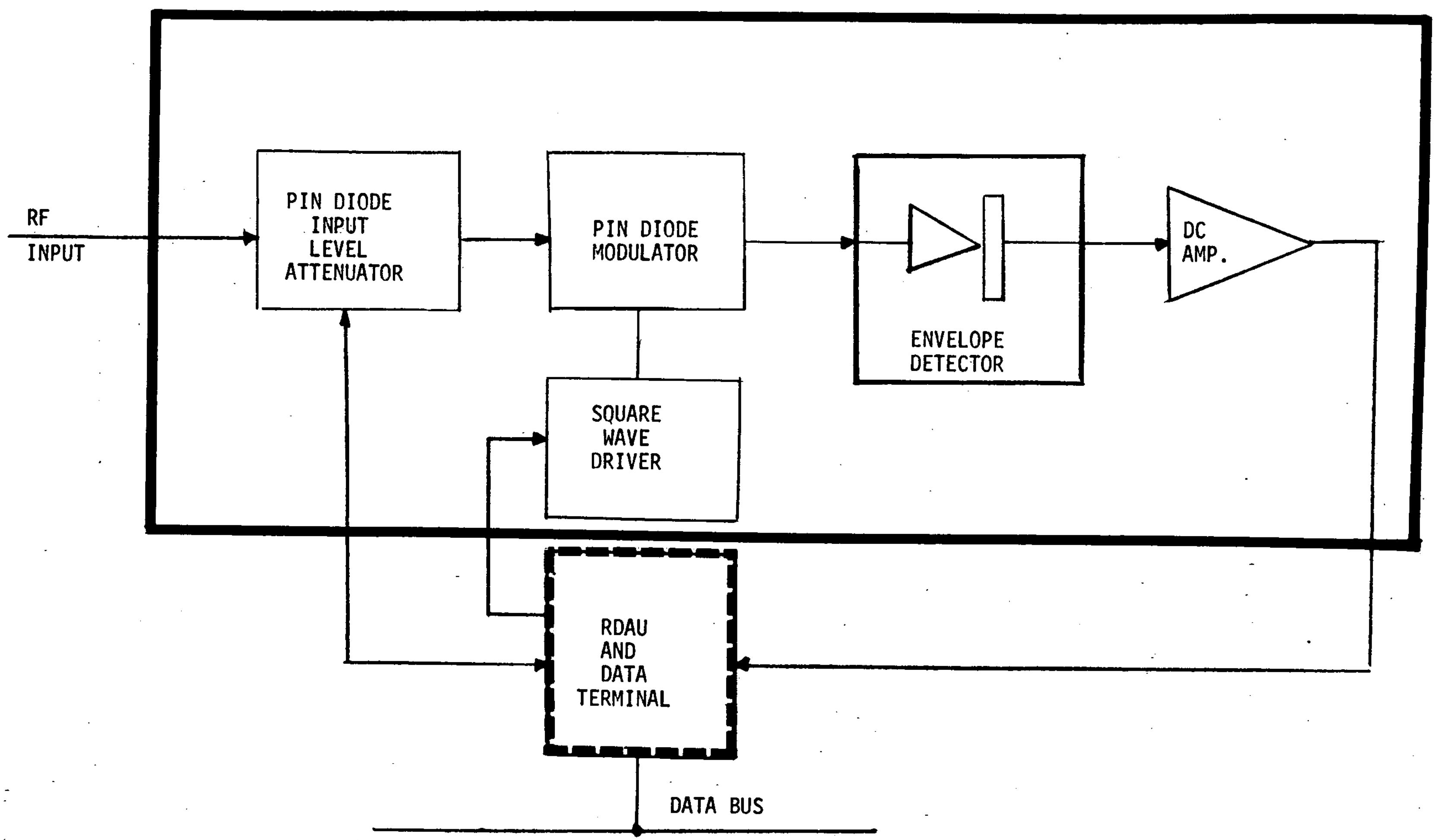


Figure 3-6. Envelope Detector Concept

to detect RF signals and to normalize the data for DMS evaluation and monitoring. Each detector includes a predetection tone modulator and post-detection signal conditioning amplifier. Detector input levels are set by a switchable attenuator controlled by the DMS. In addition, phase shifters and directional couplers are incorporated in the main and acquisition feed/comparator assemblies to accommodate closed-loop checkout of the high-gain antenna system.

3.2.1 Low-Gain Antenna System

The preferred concept for checkout of the low-gain antenna system is illustrated in Figure 2-6 for the S-band triplexer and switching assembly. Receive paths are verified by routing test stimuli from the transponder in the reverse direction through the filters and switches to the antennas. Transmit paths are verified using the normal operational RF signals with the required amplitude modulation provided by the preferred detector concept. Monitoring and evaluation functions are performed by the DMS.

Receive and transmit monitoring points are located in the multiplexer and switching assembly to take advantage of the common internal line between the filters and switches. Placement of a directional coupler and detector in this assembly provides the capability of monitoring all signals passing through the antenna system. The approach accommodates the "reverse-direction" receive path checks as well as the performance monitoring of all filters in the multiplexer and switching assembly. Detector signal level requirements are discussed in subsequent paragraphs of this subsection. Both RF and dc talk-back are utilized for switch position monitoring. The RF talk-back couplers are located at the input of the antenna terminals rather than in the multiplexer and switching assembly output terminals because of the need to monitor the output power indications at the antenna terminals.

Detector attenuation levels are set to correspond with the db difference between the strongest and weakest stimuli of the system. In the VHF system, the difference between the 20-watt transceiver and the EVA transmitter power levels is 43 db (20, 000 to 1). Thus, the attenuator levels required are zero and 40 db. For receive stimuli monitoring, the power level of the receive test stimuli is chosen to be in the same order of magnitude as the EVA operational carrier. This is approximately 1 milliwatt at the multiplexer input.

The test stimuli required for checkout of the low-gain antenna system receive paths originate from signal generators located within the receivers interfacing the respective antennas. On the other hand, transmitter operational signals provide the required transmit path test stimuli.

The stimuli have a wide range of power levels when considering both transmit and receive signals. The S-band transponder has a power output of 1 watt, whereas the outputs of the power amplifiers and VHF transmitters are each 20 watts. The EVA transmitter has a power output of only 1 milliwatt. Fortunately, it is not necessary for the internal receive stimuli to match the output power of the transmitters. It is thus feasible to specify a stimuli power level compatible with both the sensitivity range of the detectors and still not seriously impact the design requirements of the receiver LRU which must generate the stimuli. To minimize the design impact, a 1-milliwatt level is proposed as the receiver RF stimuli level to be utilized for antenna system checkout.

Coupling factors for the test couplers must be carefully chosen to provide a minimum insertion loss in the system, but still remain within the sensitivity range of the detectors and signal conditioning amplifiers. The forward power couplers are 10 db lower than the reflected channel couplers in order to provide a match between the forward and reflected power levels. The predetection levels for low-gain antenna stimuli are shown in Table 3-1. Table 3-2 provides similar information for the high-gain antenna stimuli. It is evident from these tables that the envelope detector, with a sensitivity of approximately 10^{-5} milliwatts, is adequate for both low- and high-gain antenna power monitoring. The detector has a linear range of 30 db above this level. Thus, with the switchable input attenuator, the detector operates within its linear range for all signal levels.

Table 3-1

LOW-GAIN ANTENNA SYSTEM STIMULI LEVELS

Stimuli Source	Amplitude of Stimuli at Indicated Location of Test Point					
	Transmitter		Multiplexer		Antenna	
	Forward 40-db Coupler	Reflected 30-db Coupler	Forward 40-db Coupler	Reflected 30-db Coupler	Forward 40-db Coupler	Reflected 30-db Coupler
VHF transmit EVA operational stimuli, 1 milliwatt, 2.0 to 1 VSWR	10^{-4} mw	10^{-4} mw	8×10^{-5} mw	8×10^{-5} mw	2×10^{-5} mw	2×10^{-5} mw
VHF transmit data and voice operational stimuli, 20 watts, 2.0 to 1 VSWR	2 mw	2 mw	1.6 mx	1.6 mw	0.4 mw	0.4 mw
S-band transmit transponder operational stimuli, 1 watt, 2.0 to 1 VSWR	0.09 mw	0.09 mw	0.07 mw	0.07 mw	0.06 mw	0.06 mw
S-band transmit power amplifier operational stimuli, 20 watts, 2.0 to 1 VSWR	2 mw	2 mw	1.6 mw	1.6 mw	1.3 mw	1.3 mw
VHF receiver artificial stimuli, 1 milliwatt, 2.0 to 1 VSWR	10^{-4} mw	10^{-4} mw	8×10^{-5} mw	8×10^{-5} mw	2×10^{-5} mw	2×10^{-5} mw
S-band receiver artificial stimuli, 1 milliwatt, 2.0 to 1 VSWR	10^{-4} mw	10^{-4} mw	8×10^{-5} mw	8×10^{-5} mw	6×10^{-5} mw	6×10^{-5} mw

Table 3-2

HIGH-GAIN ANTENNA SYSTEM STIMULI LEVELS

Stimuli Source	Amplitude of Stimuli at Indicated Location of Test Point						
	Transmit						Receive
	PA Output		Multiplexer Switch		Antenna Feed		Comparator Output
	Forward 50-db Coupler	Reflected 30-db Coupler	Forward 50-db Coupler	Reflected 30-db Coupler	Forward 50-db Coupler	Reflected 30-db Coupler	Sum Channel 30-db Coupler
K_u-band transmit operational, 20 watts, 1.2 to 1 VSWR	0.20 mw	0.17 mw	0.13 mw	0.13 mw	0.13 mw	0.11 mw	
K_u-band receive artificial stimuli, 1 milliwatt, 1.2 to 1 VSWR							10^{-4} mw

3.2.2 High-Gain Antenna System

The preferred concept for checkout of the high-gain antenna system is shown in Figure 2-7. As for the low-gain antenna system, transmit paths are verified using the normal operational RF signals. For receive path checkout, the concept utilizes the RF signals generated within the low-noise receivers and fed through a separate RF path to phase shifters in the main comparator and feed assembly. The phase shifters are set to a simulated off-axis pointing angle on command from the DMS. This is repeated for left, right, and center offsets in both the azimuth and elevation channels of the comparator. The S-band tracking receiver is used to detect the output of the comparator/feed assembly and provides output error signals to the DMS for evaluation. The same procedure is also used to verify proper performance of the acquisition antenna.

The power divider and phase shifters are located internal to the comparator rather than adjacent or internal to the low-noise receiver. Since only one RF signal path to the comparator is used, the concept is not sensitive to phase shift errors induced by environmental and physical changes. The phase balance occurring after power division is essential to the stability of the phase shifters. Driving signals for the phase shifters are provided by a function generator located within the assembly and interfacing the DMS. On a word command from the DMS, the desired bias combination is transmitted to the phase shifters. The phase shift offset required is a design parameter which depends upon the characteristics of the precomparator and post-comparator asymmetries. The function generator is therefore an integral part of the comparator and feed assembly to be defined by the assembly designer.

Although test stimuli originate as an unmodulated K_u-band carrier generated internal to the low-noise receiver, the approach is extended to test up to three LRU's in a chain. Each LRU receives its stimuli from the preceding link in the chain. The simuli are used for checkout of the low-noise receiver itself by means of internal switching circuits and a directional coupler. When the stimuli are switched to the antenna system for checkout,

C.2

internal leakage would jam the receiver and prevent use of that generator for stimulating its own channel. Thus, as shown in Figure 2-7, the main antenna channel is stimulated by the generator in the acquisition channel now noise receiver and, conversely, the acquisition antenna channel is stimulated by the generator in the main channel low noise receiver. To minimize failure effects, redundant generators may be required in each receiver.

The positioner assembly of the high-gain antenna system is checked out by injecting position commands into the servo control assembly from the DMS. Actual position and rate readouts are then monitored by the DMS from digital resolvers driven by the gimbal ac position and rate sensors.

The preferred concept also includes a redundancy switching capability for the communications subsystem equipment located on the high-gain antenna masts. To minimize EVA operations for maintenance and replacement, this capability is provided for the K_u-band power amplifiers, exciters, low-noise receivers, and S-band tracking receivers. Switchover time is not critical and the redundancy switching is effected by the normal LRU operational controls.

3.3 INTERNAL COMMUNICATIONS

The impact of incorporating the capability to transmit or receive and retransmit the audio test-tone required in conjunction with the normal voice signals for checkout of the ATU's has already been incorporated in the basic design of the unit. Automatic checkout of the ATU's could easily be implemented under the control of the analog/sync test unit which would interrogate each ATU in sequence. Since normal operation of the onboard telephone system is under control of the user and does not interface with the DMS except for remote power on/off control, the incorporation of automatic checkout would require the addition of a nonoperational interface with the DMS. Other factors which influence the selection of the preferred checkout concept are the low duty cycle of the ATU's, some of which are located in remote compartments, and the high-reliability of the units. The increase in weight, size, and power is negligible.

The impact of including the amplitude detectors and limit comparators within the analog/sync test unit is also minimal in terms of the additional weight, size, and power required. The circuitry required to generate the TV test patterns has been incorporated with the baseline unit.

The preferred concept also includes automatic monitoring and redundancy switching for the analog sync/test unit. The unit generates a 4-kHz reference signal which is required for proper operation of the onboard telephone system. Loss of this reference signal would cause a loss of normal voice communications throughout the Space Station as well as between the Space Station and other program elements.

Section 4
OTHER CHECKOUT CONCEPTS INVESTIGATED

The preferred concepts for generating test stimuli, detecting the signals, and monitoring and evaluating their outputs have been described in the previous section. This section describes the other RF, antenna, and internal communications checkout concepts identified and evaluated during the study.

4.1 RF SYSTEM

The checkout of the RF system is required to determine the proper operation and performance of the transmitting and receiving channels. To validate performance and availability of these channels it is necessary to measure parameters such as transmit power output, receiving system sensitivity, and the quality of the transmitted and received modulation.

Concepts for generating the modulation and RF test stimuli, detecting the signals, and monitoring and evaluating the outputs are described in the following paragraphs.

4.1.1 Stimuli Generation

The stimuli generation concepts can be separated into two general categories which include both internally and externally generated operational stimuli and artificially generated or dedicated checkout stimuli. The transmit and receive paths are treated separately because the transmit channel LRU's, with the exception of the power amplifiers, require only a modulation stimuli source; whereas receive channel LRU's require both RF and modulation test stimuli. Discussion concerning the format of the stimuli test signals is also presented below.

4.1.1.1 Transmit Paths

One concept for providing the required modulation test signals is to utilize the operationally available audio, video, and digital signals. This concept does not require any changes to the basic LRU design, but the checkout capability would be limited to qualitative go-no/go type indications of signal presence or absence due to variations in signal levels. Checkout might also be limited by the nonavailability of the operational signals. The use of operational signals is more applicable to a gross talk-through test during prelaunch checkout than for on-orbit checkout.

Another concept, shown in Figure 4-1, utilizes a variable-frequency test-tone generator which is coupled to the analog data bus and digital data terminals to provide the modulation test signals. The outstanding advantage of modulation test generators located on the data bus is that there are many LRU's having common modulation characteristics and can therefore be served by one test signal. In terms of design flexibility, redesign requiring a change of modulation test signal formats may only involve the modulation test generator. A disadvantage inherent to the bus generator concept is that it could cause certain operational restrictions. Since the bus is a transmission line for all data, there are interference problems that would have to be solved if wideband test signal formats were utilized.

In the centralized self-test concept, shown in Figure 4-2, the transmit path modulation test generators and RF and modulation detectors are incorporated within a central test unit which interfaces directly with the transmit LRU's. This could eliminate the potential operational limitations associated with the use of common bus generators.

4.1.1.2 Receive Paths

One receive path concept for providing the required modulated RF test signals is to use operationally available signals. As in the case of the transmit paths, the use of operational signals does not require LRU design changes and the checkout capability is limited by the availability of the signals. It would be difficult to make a quantitative measurement of receiving system sensitivity because of the variations in RF signal strength caused by differences in antenna gain and changes in communications range. The concept is not acceptable for checking out EVA transmitters and receivers since the EVA crewmen would be required to leave the Space Station without knowing that their communications equipments were operable.

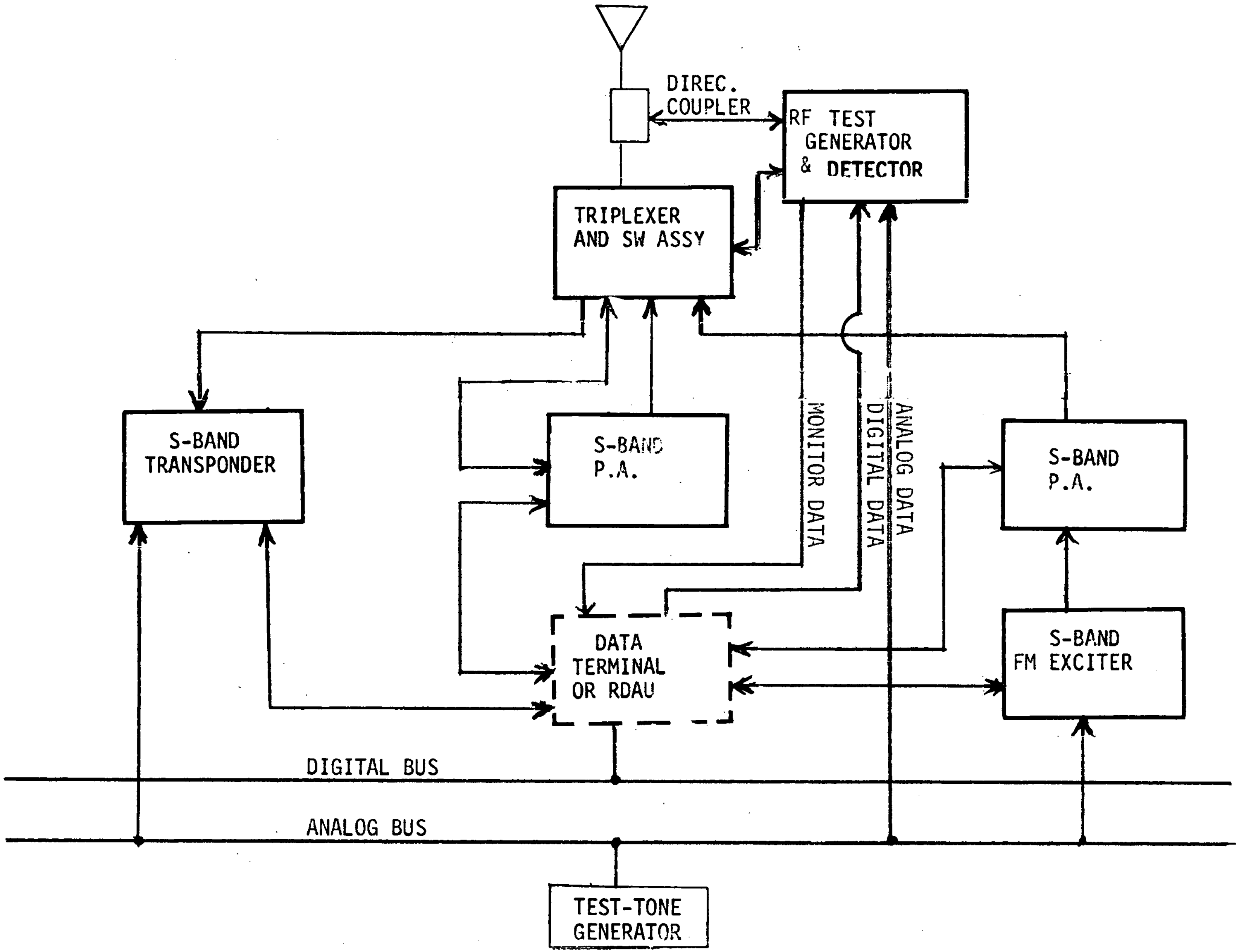


Figure 4-1. Antenna and Bus Generator Concept

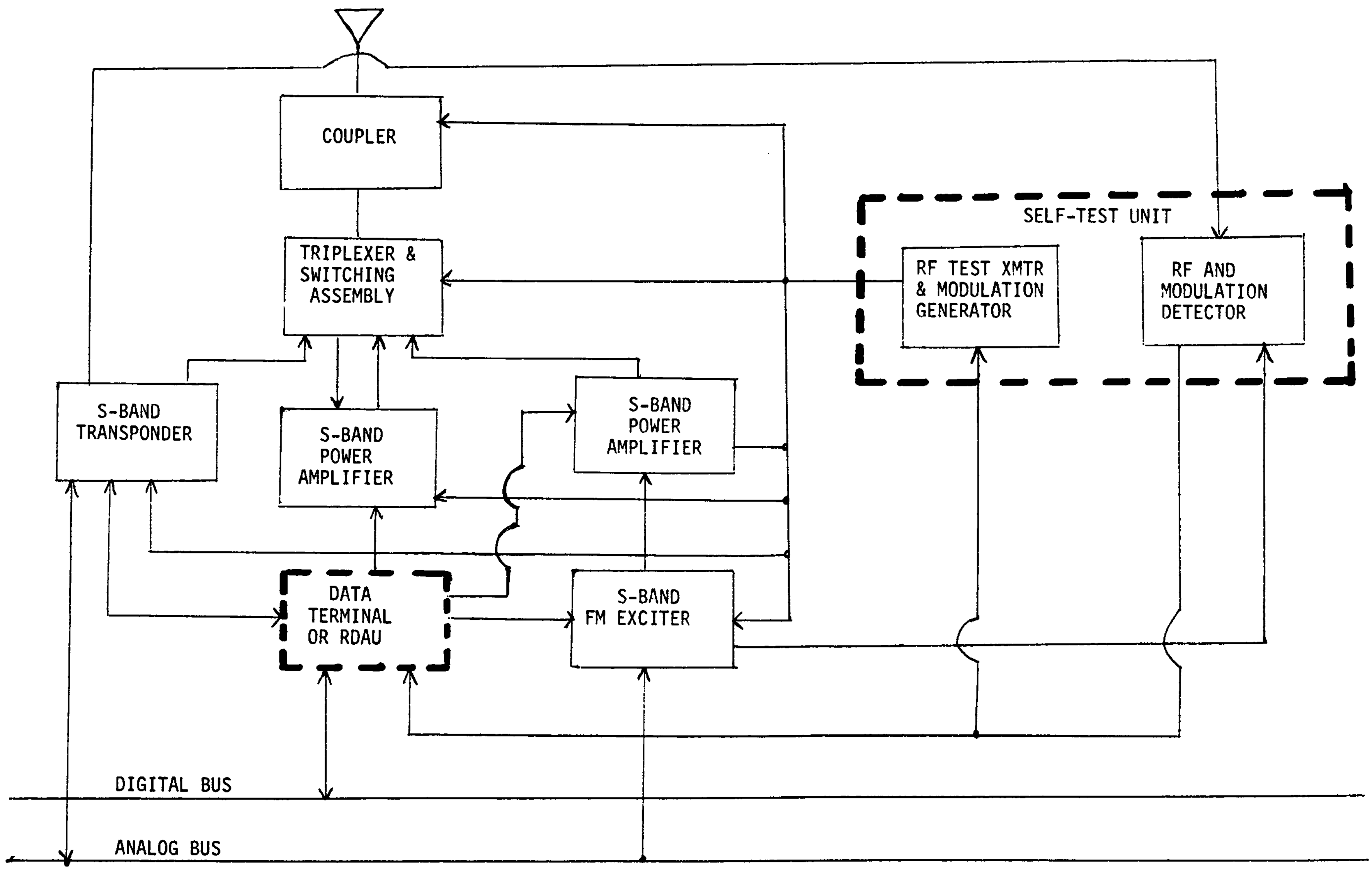


Figure 4-2. Centralized Self-Test Concept

Another concept, shown in Figure 4-3, utilizes the transmitter-generated RF carrier signals as test signal sources for the receivers. The RF translator concept is implemented by introducing couplers into the transmit and receive paths of two RF circuits such that the modulated transmitted carrier can be translated to the receiver frequency and coupled back to the receiver input for demodulation. Test modulation of the transmitter may be provided either from the analog test unit or from a digital data terminal. In another approach, the test modulation signals could be incorporated in the transmitter LRU. Another variation of this approach would be to couple the signals in and out of the antenna system to provide a more complete end-to-end test. The technique allows the use of much of the internal circuitry for test purposes, but does suffer from certain disadvantages. In addition to the translator circuitry, the need for providing a complete fault isolation capability would still require modulation stimuli and detectors at all LRU interfaces. Implementation of the RF translator concept would also result in a transmitter-receiver pair to be inoperative while isolating a fault in the other LRU. In addition, end-to-end checks require that the transmitter and receiver have a compatible modulation and demodulation capability, which is not always the case. The S-band transponder is a good example of this. Care would have to be taken so that the introduction of the translator does not change the transmit-receive channel isolation when not being utilized. Otherwise, normal channel performance could be degraded.

Another concept for checkout of the receiving system utilizes RF test generators located within the communications subsystem and controlled by the DMS. The signals used to modulate these RF test generators can be derived from the same modulation sources used to stimulate the transmitters. The RF test generators are coupled directly into the antenna system as shown in Figure 4-1. The insertion of the test signals into a common port in the antenna system, such as the S-band triplexer and switching assembly, would permit simultaneous checkout of redundant receivers connected in parallel. In addition, the signals could be coupled directly into the receivers for fault isolation or periodic checkout.

A final concept involves incorporating the required modulation and RF test signals within a central test unit having a multiple frequency generation

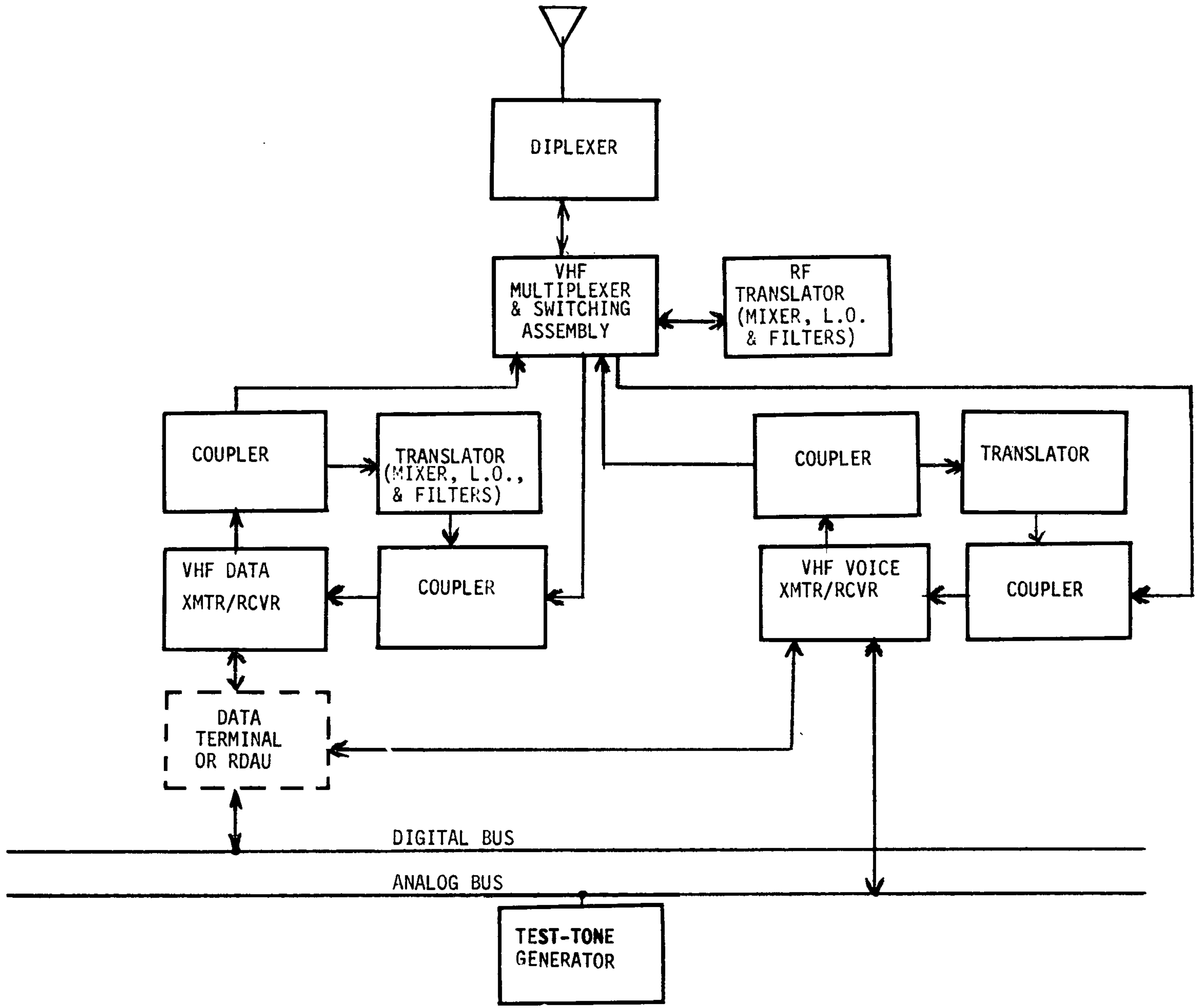


Figure 4-3. RF Translator Concept

capability. This central unit, shown in Figure 4-2, could be used as a common stimuli source for both the transmit and receive paths. The approach could create some potentially serious EMI problems, and extreme care would have to be taken to maintain isolation between the various systems.

4.1.1.3 Stimuli Format

In addition to being concerned over the location of stimuli signal sources, checkout system capabilities are dependent upon the format of the signals which are to be used for stimuli. The formats in turn are dependent upon the level of testing or monitoring required, the characteristics of the channel, and whether or not the testing is performed while operational signals are also present. The modulation test signal format concepts include the use of "edge-of-band," in-channel wideband, suppressed tracker, and broadband noise signals.

One possibility is to use an "edge-of-band" signal which is outside the spectrum range of the operational data. This signal would be used for monitoring regardless of the presence or absence of operational data. In a linear system, such a signal could provide a continuous check on channel integrity and gain. Care must be taken, however, that the test signal does not exceed the linear range of the system or degrade channel performance.

Another concept utilizes a wideband signal such as PRN which could share the channel with operational data, but at a noninterfering level. While such a technique offers the ability to obtain more information about the channel performance than could be obtained with a narrow-band signal, the precision is dependent upon the characteristics of the operational data, and it requires a wideband feedback channel to enable the output to be correlated with the input.

The use of an out-of-band tracer signal as shown in Figure 4-4 can be utilized in a nonlinear system to monitor both channel integrity and the presence of data. While not directly applicable to a linear system, the technique of automatically supplying a test signal could be achieved with an input data sensor which automatically enables a test signal generator if the input data are absent.

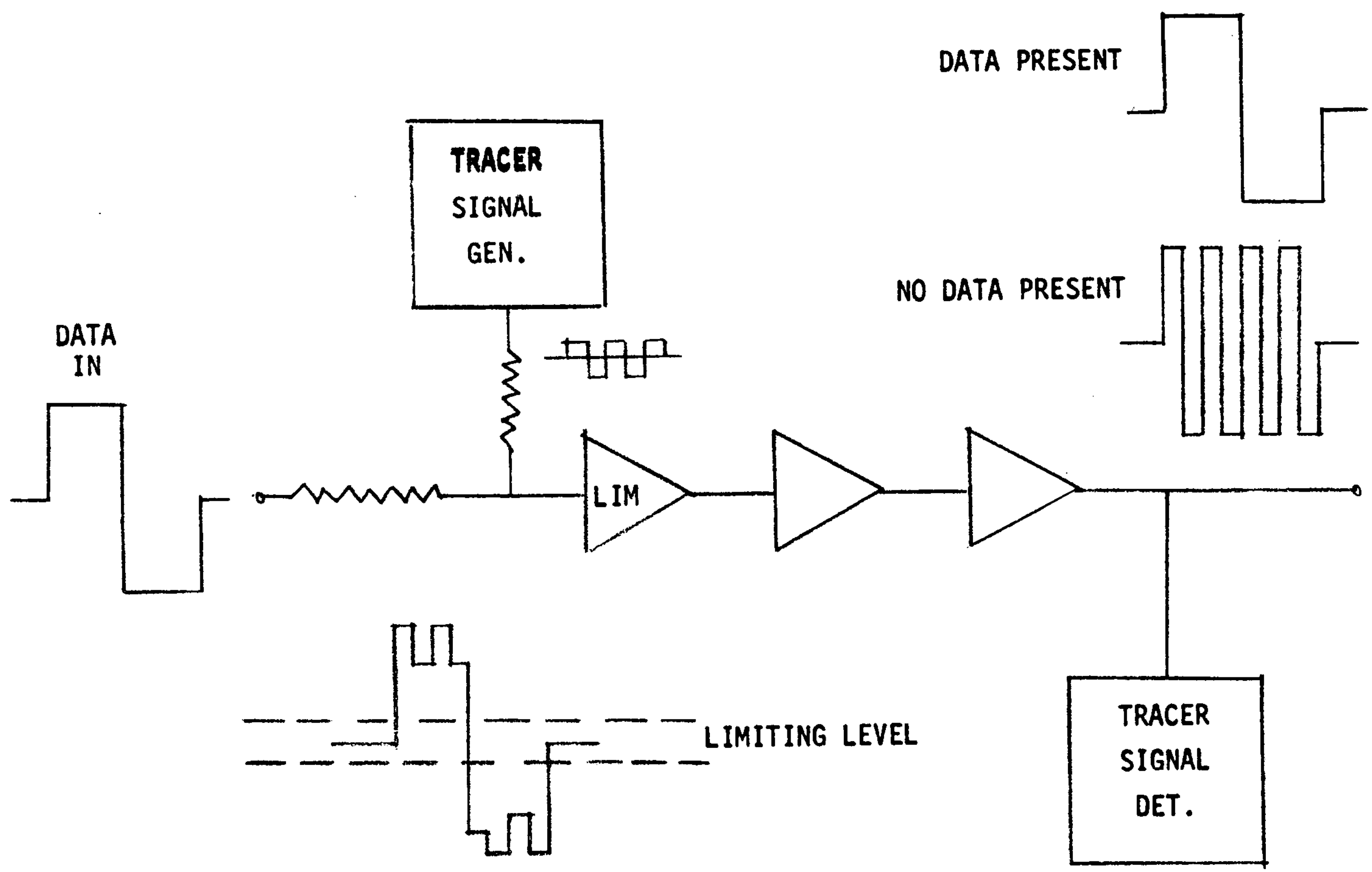


Figure 4-4. Suppressed Tracer Signal Concept

Another concept which is particularly applicable to a centralized test unit is a broadband noise source which is utilized in conjunction with shaped filters to simulate signal spectrums. If intermodulation distortion measurements were required, a test setup similar to that shown in Figure 4-5 could be utilized. It consists of placing noise loading on all channels except one and measuring the noise power ratio (NPR). This concept is probably more applicable to development testing and may be difficult to automate.

4.1.2 Signal Detection

Other concepts for detecting transmitter LRU signals include utilizing a functional receiver LRU or utilizing RF and modulation detectors located in a central test unit.

The previously described RF translator concept (Figure 4-3) can also be used to detect modulated RF signals. In this case, the transmitter and receiver roles are reversed. In the previous description, the transmitter LRU provided a test stimulus for the receiver LRU and here the receiver LRU serves as the detector for the transmitter LRU signals. The limitations and constraints discussed previously also apply here.

Transmitter-modulated RF checkout signals could also be detected by RF and modulation detectors incorporated external to the LRU's in the central test unit shown in Figure 4-2. If all stimuli generation and signal detection capability were incorporated in a common unit, considerable redundancy would have to be built into the unit to minimize the loss of all test capability. In addition, parallel interfaces with each LRU would be required. The complexities of subsystem integration, however, could be minimized if the design of the central test unit were under control of the communications subsystem designer.

4.1.3 Monitoring and Evaluation

Other monitoring and evaluation concepts identified range from those which require considerable crew involvement to those which are essentially automatic and require little or no crew involvement. The capability of the DMS, the level of checkout required, and the response time strongly influence the selection of the preferred monitoring technique.

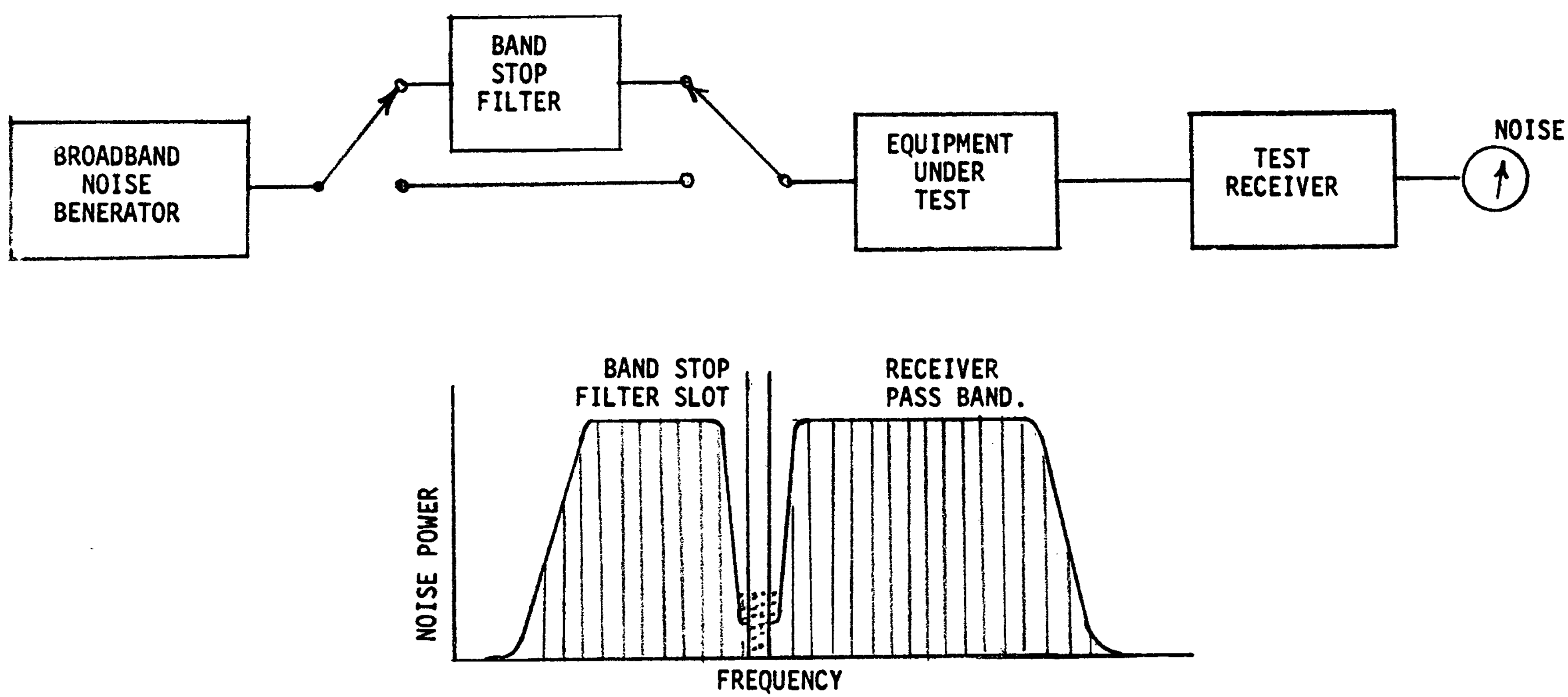


Figure 4-5. Broadband Noise Concept

4.1.3.1 User Monitoring and Evaluation

Two concepts are identified which require monitoring and evaluation by the crew. In the first concept the crew must attempt to recognize malfunctions and system performance degradation by monitoring the operational data. The accuracy and response time associated with this technique is very poor for the RF system LRU's. On the other hand, the concept is very applicable to the internal communications system which is more user-oriented. In the second concept, the LRU's provide go-no/go status outputs to the DMS and faults are isolated through manual examination of LRU test points by the crew. This concept provides quick fault detection, but slow fault isolation. Both concepts require the use of portable test equipment and extensive specialized crew training. Since it is considered extremely wasteful of a highly trained crewman's time to perform this kind of task, the concepts are not explored to any significant depth in the study. The concepts are also obviously not desirable for checkout of communications subsystem equipment located external to habitable station compartments.

4.1.3.2 Data Management Subsystem Monitoring and Evaluation

Provided that signals are conditioned to standardized analog or digital voltage levels and impedances, the centralized monitoring and evaluation concepts described below apply to both the RF and antenna systems.

The simplest concept is one in which the LRU's provide only go-no/go status data to the DMS. In this concept shown in Figure 4-6, the DMS monitors go-no/go status data only provided by the LRU's. The LRU's must provide the required mode and sensor level logic circuitry. Since the go-no/go decisions are made internal to the LRU's, sufficient data for trend analysis are not available. The flexibility and growth are fixed by the LRU design. The increase in LRU weight, size, and power is small. Since this approach requires much less dependence on the DMS, it is much more applicable to the Shuttle-Orbiter which is not expected to have an extensive DMS capability.

The concept shown in Figure 4-7 utilizes the DMS to monitor go-no/go status data provided by the LRU's. The DMS RDAU's can then request detailed data for evaluation if required. Both internal mode and sensor level logic and

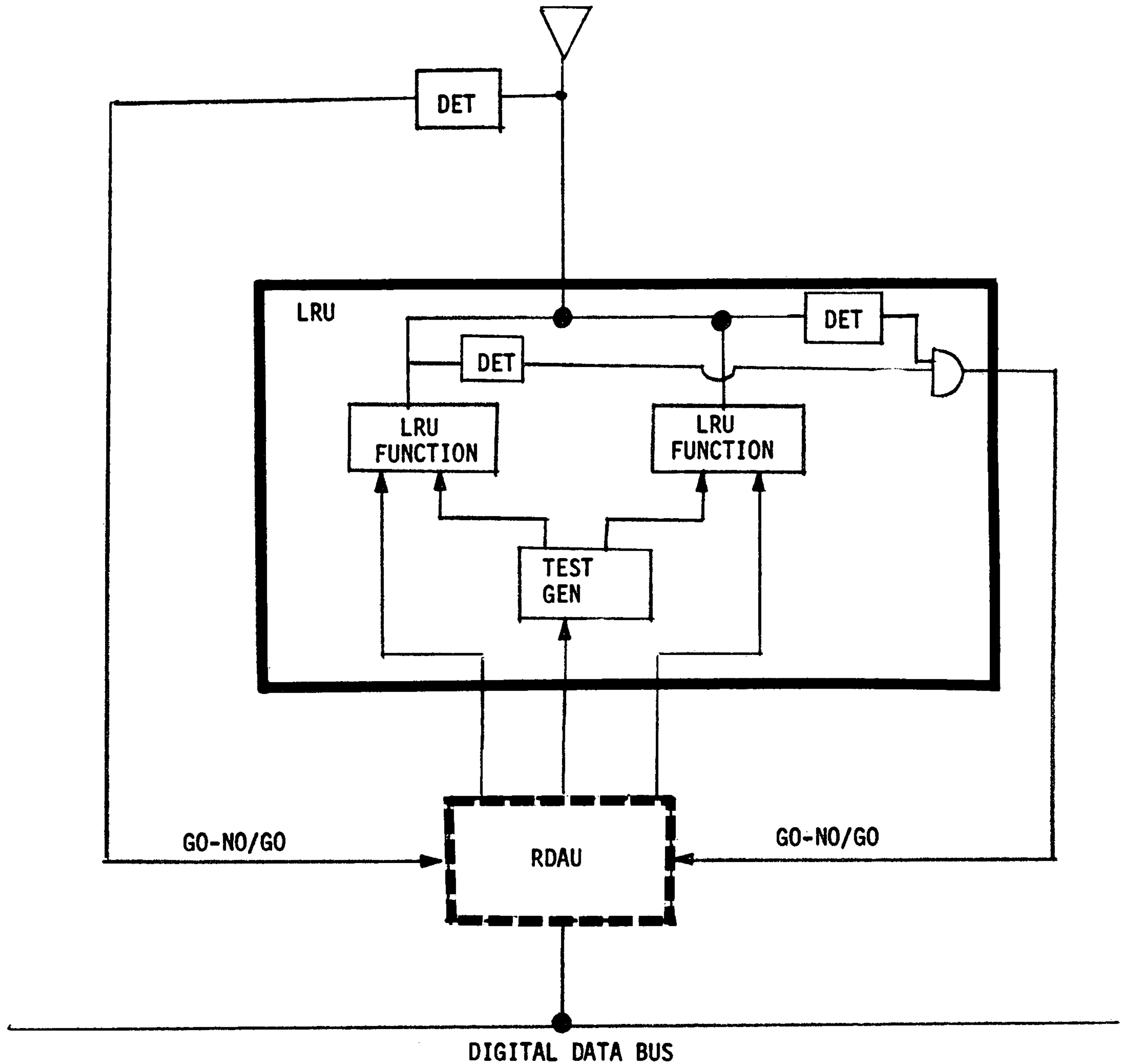


Figure 4-6. LRU Go-No/Go Only with DMS Evaluation

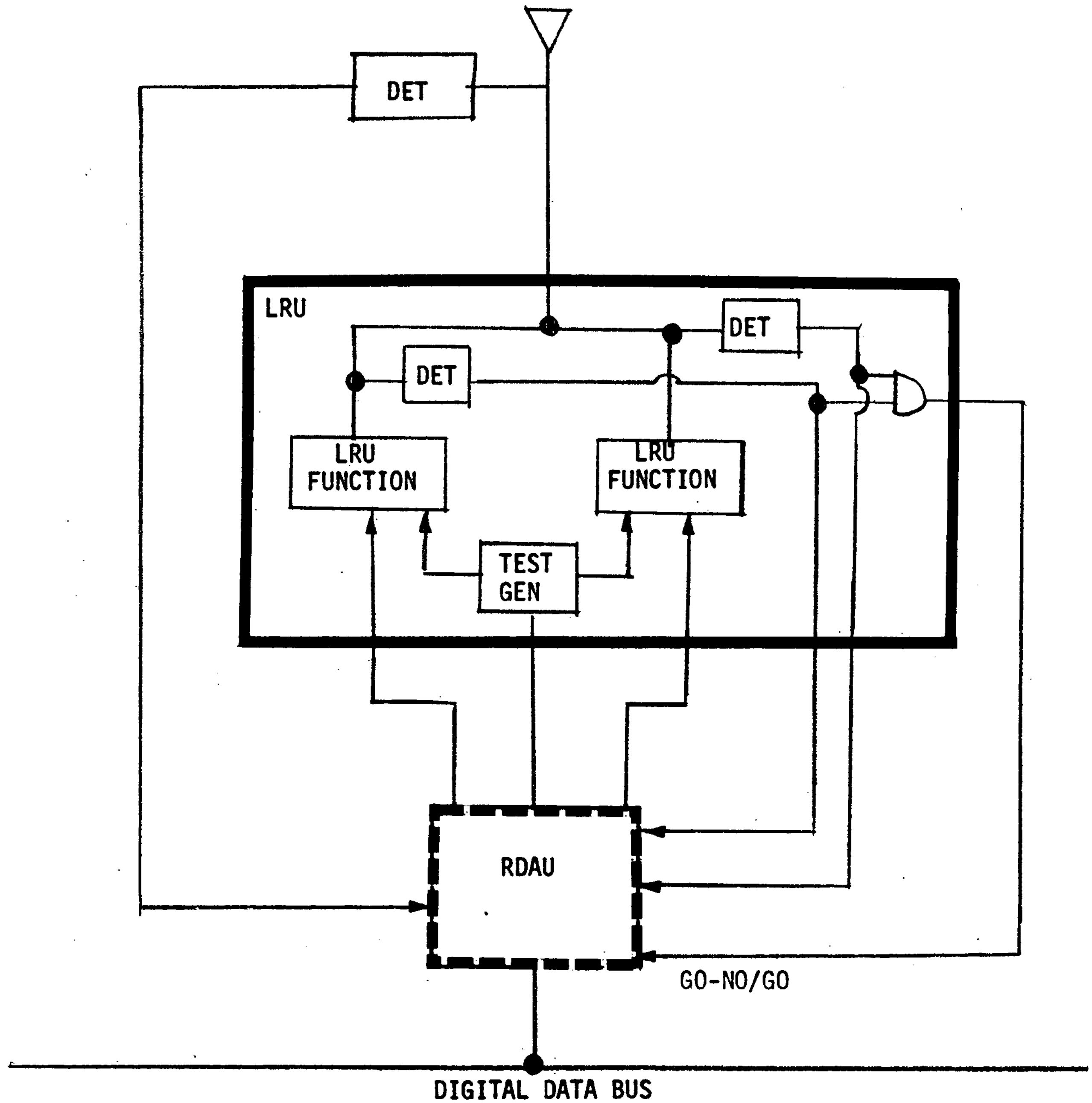


Figure 4-7. LRU Go-No/Go and Normalized LRU Data with DMS Evaluation

data driver circuitry must be incorporated in the LRU's. The flexibility to accommodate level changes is limited. This concept requires small increases in LRU weight, size, and power. The checkout procedure is controlled by the DMS. It also eliminates the basic limitations of the previous concept and lends itself to the checkout of a system requiring fast fault isolation capability.

4.1.3.3 Centralized Multiplexer-Computer Unit Monitoring and Evaluation

The following concepts incorporate a multiplexer-computer unit (MCU) dedicated to communications subsystem checkout. The MCU performs basically the same functions as the DMS RDAU. It collects and evaluates LRU go-no/go status or normalized data and then provides subsystem status information to the DMS. The MCU operation is controlled by commands from a RDAU.

A conceptual block diagram of the MCU is shown in Figure 4-8. It consists of analog and digital input gates, an analog-to-digital (A/D) converter, digital data multplexer, an arithmetic logic unit, and a programmable memory. An analog signal is also generated internally to provide for calibration of the A/D converter.

In one MCU concept, shown in Figure 4-9, each LRU provides go-no/go information as well as normalized test point data in parallel to the MCU. The normalized data are used by the MCU in performing more detailed fault isolation. In this concept, the DMS configures the LRU's for checkout. A variation of this approach is shown in Figure 4-10 which utilizes the MCU instead of the DMS to configure the LRU's for checkout.

In another concept, shown in Figure 4-11, the MCU is responsible for making the go-no/go decision for each LRU through continuous evaluation of normalized test point signals. In this concept, the DMS configures the LRU's for checkout. A variation of this approach, shown in Figure 4-12, utilizes the MCU to configure the LRU's for checkout.

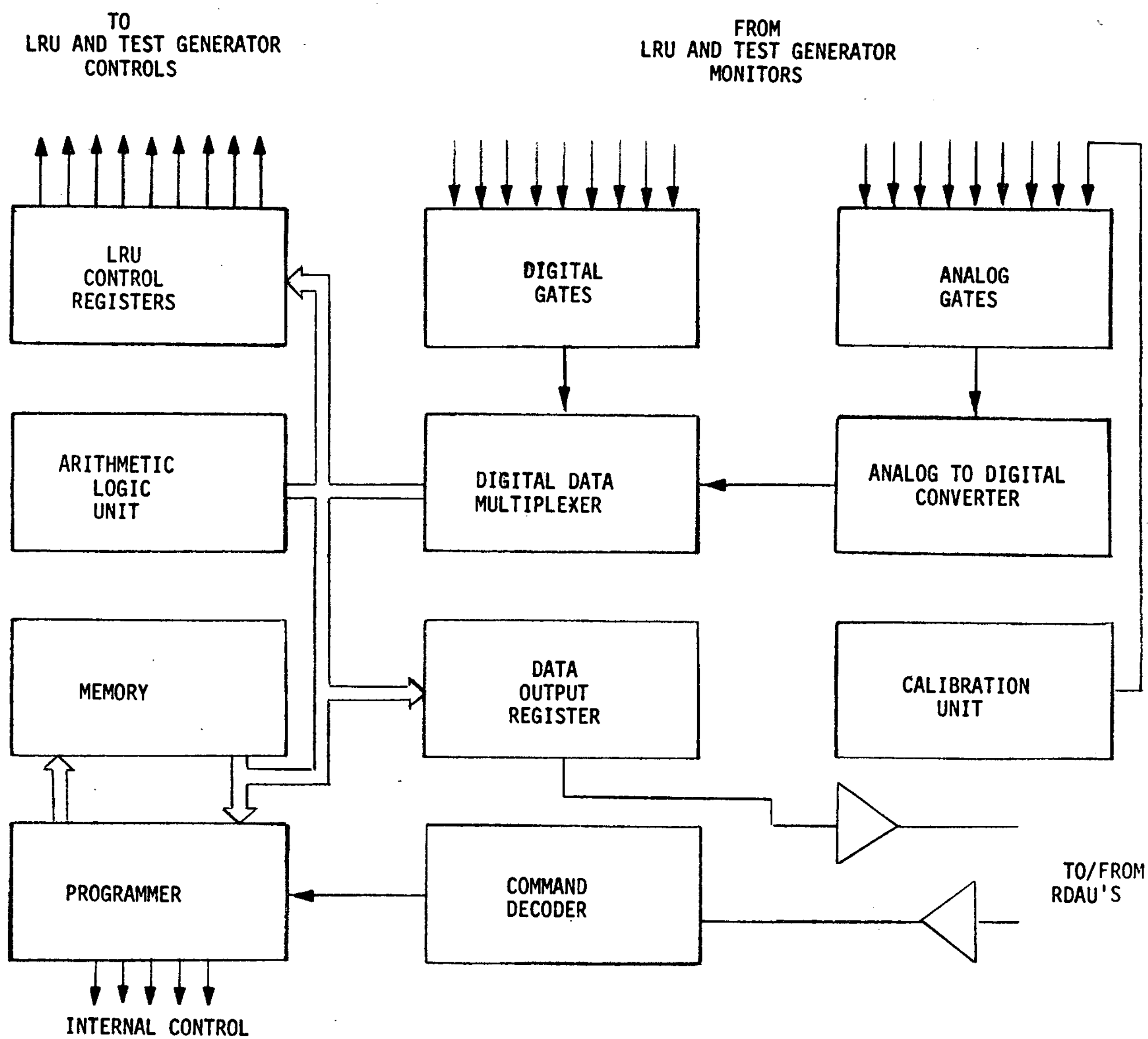


Figure 4-8. Multiplexer-Computer Unit Block Diagram

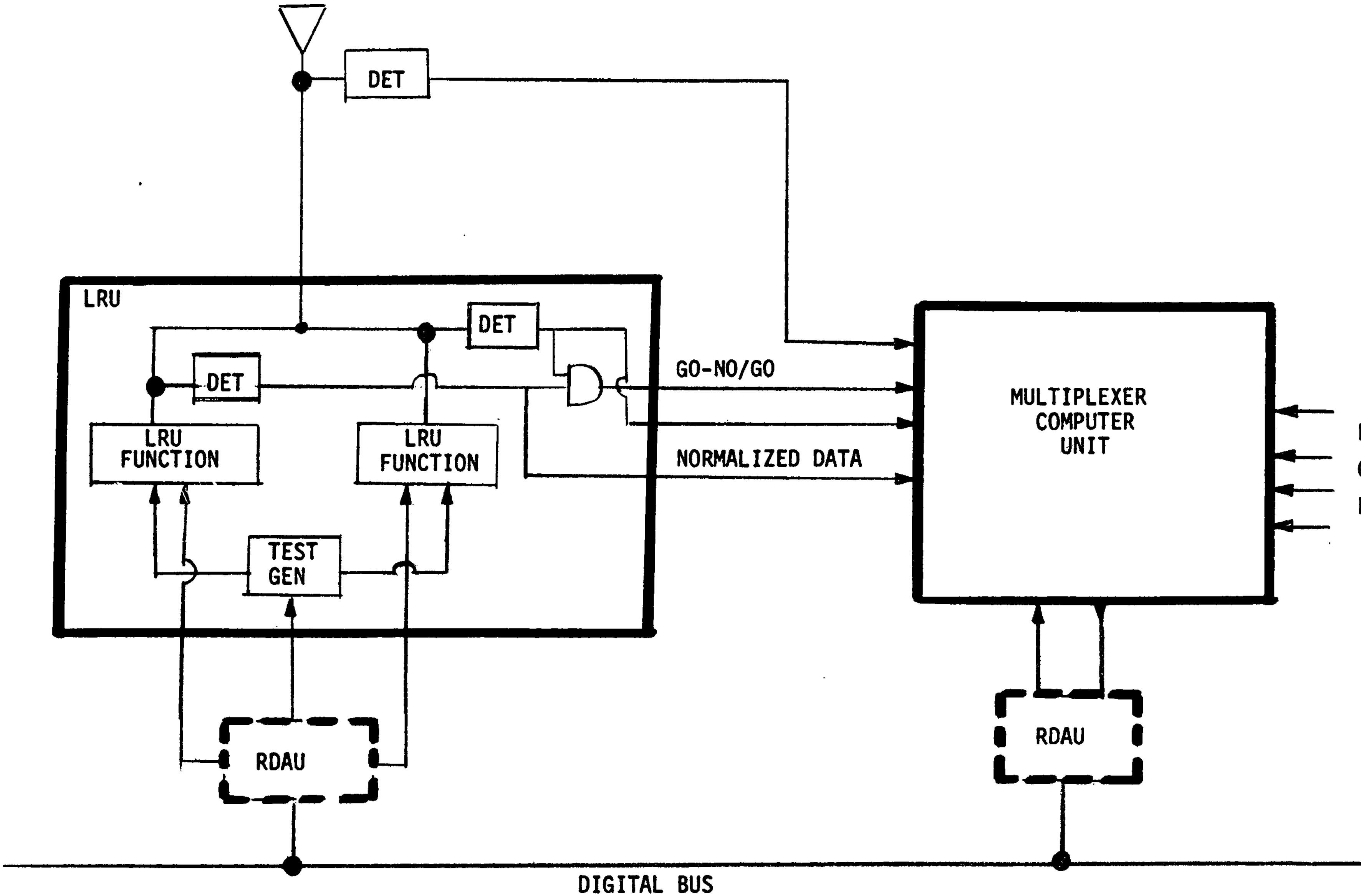


Figure 4-9. LRU Go-No/Go and Normalized LRU Data with MCU Evaluation

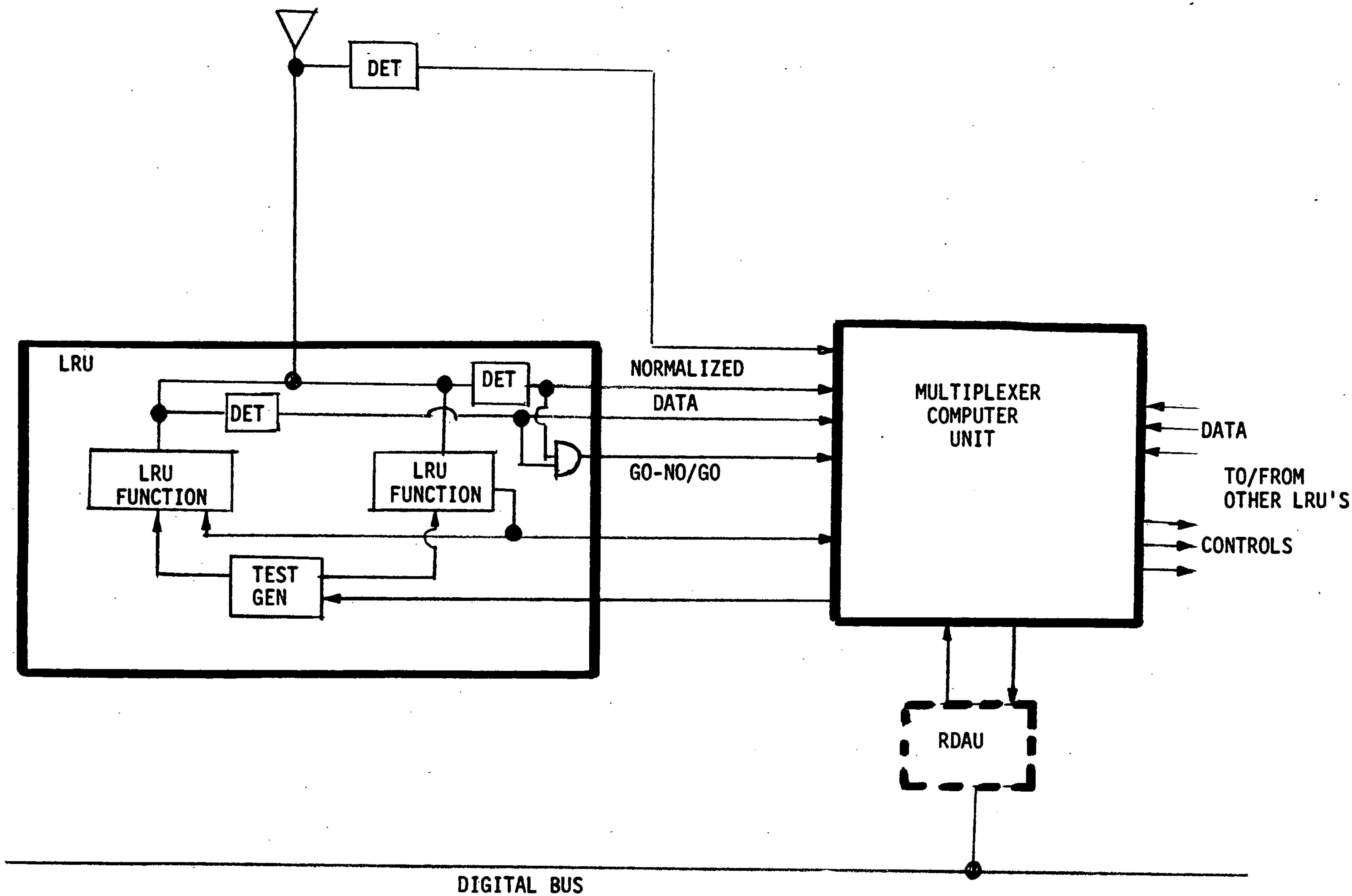


Figure 4-10. LRU Go-No/Go and Normalized LRU Data with MCU Evaluation and Control

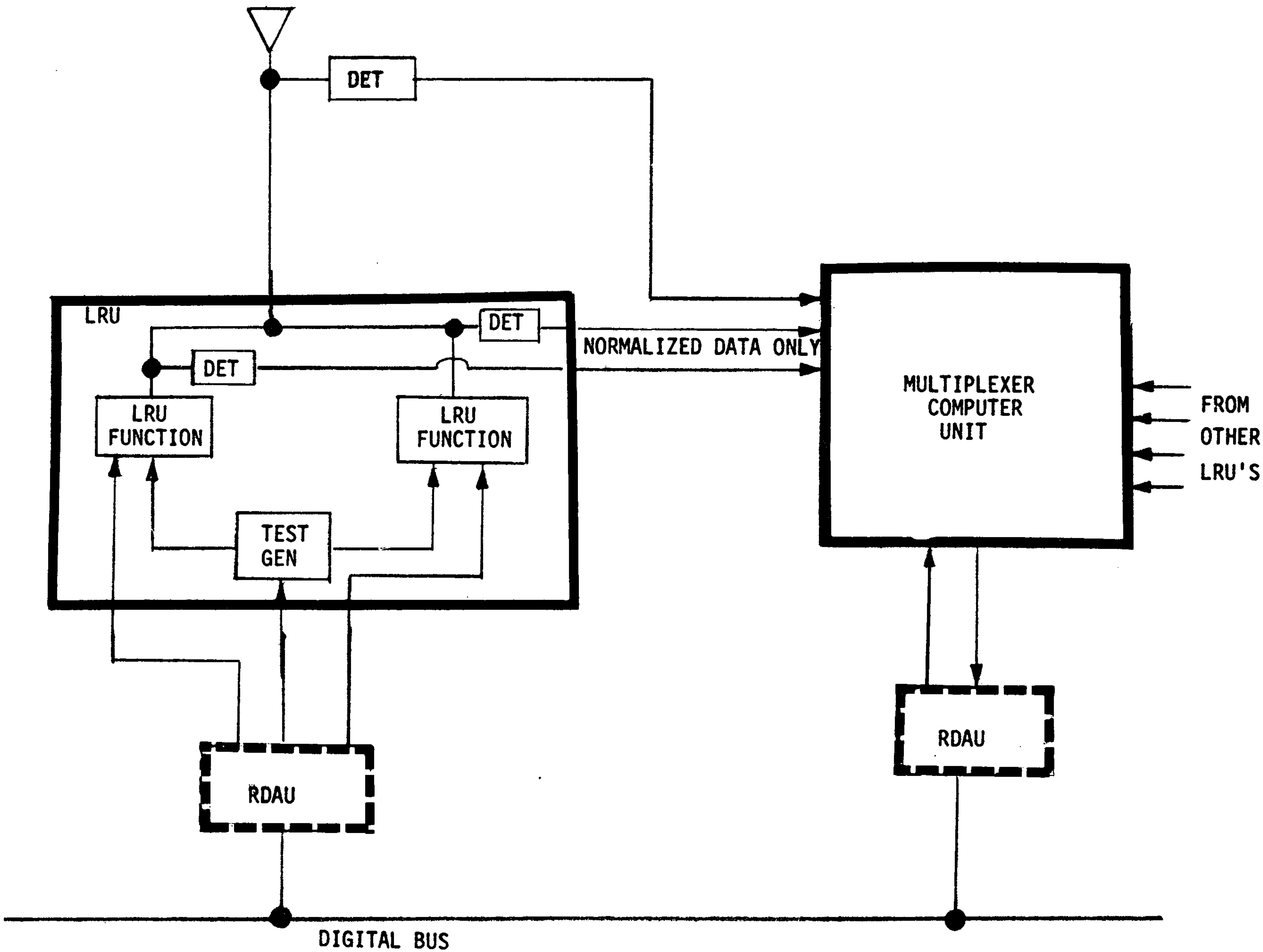


Figure 4-11. Normalized LRU Data Only with MCU Evaluation

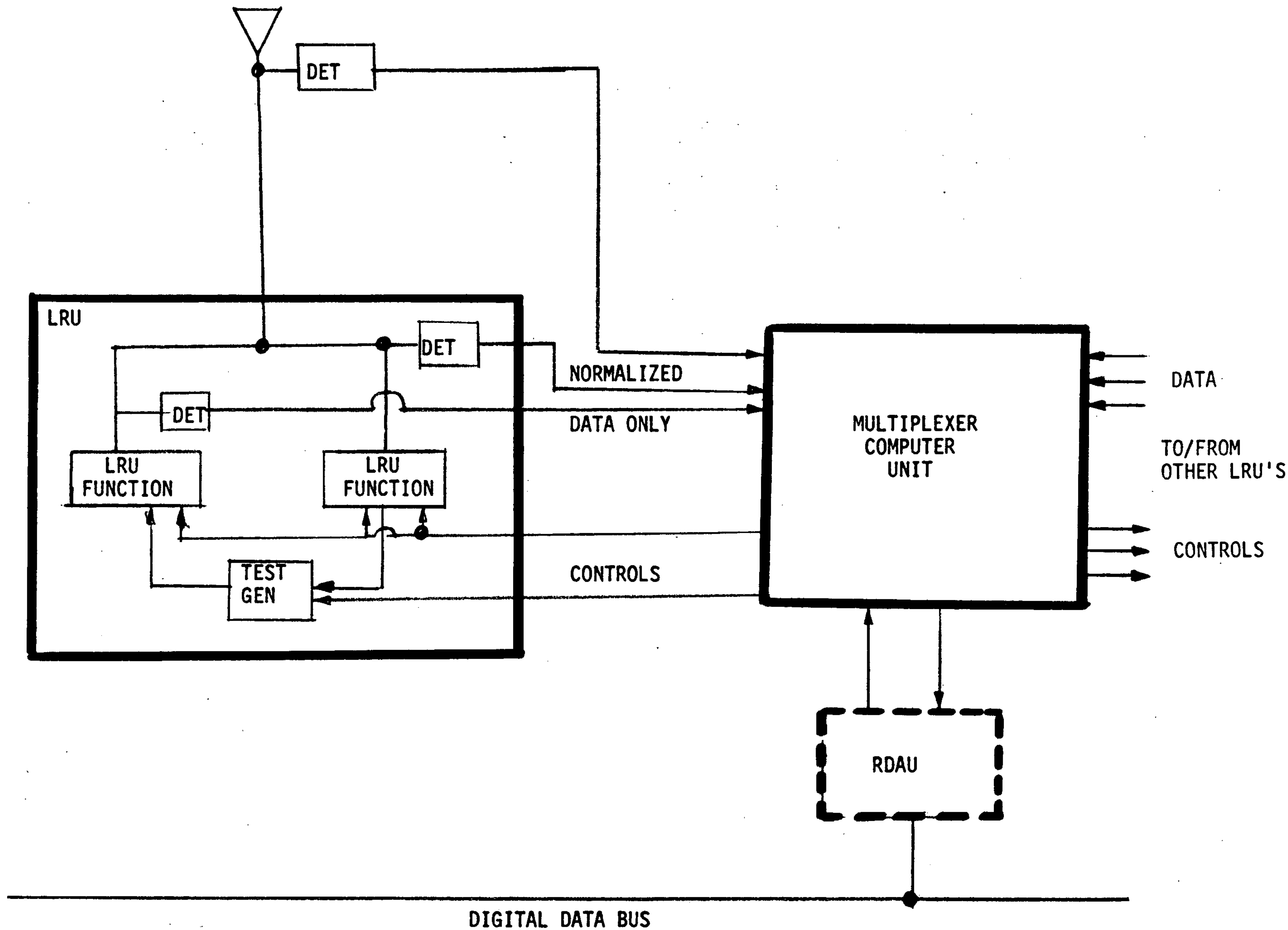


Figure 4-12. Normalized LRU Data Only with MCU Evaluation and Control

In the above MCU concepts, in which the communications subsystem is checked out on a system basis rather than on a "black-box" basis, it is assumed that the MCU communicates with the LRU's via dedicated circuits rather than via the DMS digital data bus.

4.2 ANTENNA SYSTEM

Checkout concepts investigated for the antenna system include techniques common to both the low- and high-gain systems, methods for low-level signal detection in the low-gain system, and techniques unique to the high-gain system. The concepts with common applicability are concerned with verifying the performance of antenna feeds, RF switches, transmission lines, multiplexers, and power dividers. Concepts unique to the high-gain system are concerned primarily with verification of antenna acquisition and pointing capabilities. As noted previously, the alternative concepts identified in Subsection 4.1.3 for RF system monitoring and evaluation are also applicable to antenna system checkout. The concepts preferred for checkout of the antenna system are described in Section 3. Other antenna system checkout concepts investigated during the study are presented in the following paragraphs.

4.2.1 Concepts Common to Low- and High-Gain Antenna Systems

Other checkout techniques investigated which are common to both the low- and high-gain antenna systems include the reflectometer analyzer and impedance analyzer concepts described below.

4.2.1.1 Reflectometer Analyzer Concept

The reflectometer analyzer concept contains all the elements needed for independently monitoring the status and verifying the performance of RF components in the antenna system. The approach for the low-gain antenna system is shown in Figure 4-13. It includes an external stimuli generator, analyzer, bidirectional couplers, detectors, switches for test signal control, and logic circuits for selection of measurements on command from the DMS.

In addition to the bidirectional couplers and detectors required in the multiplexer and switching assembly for the preferred approach, additional

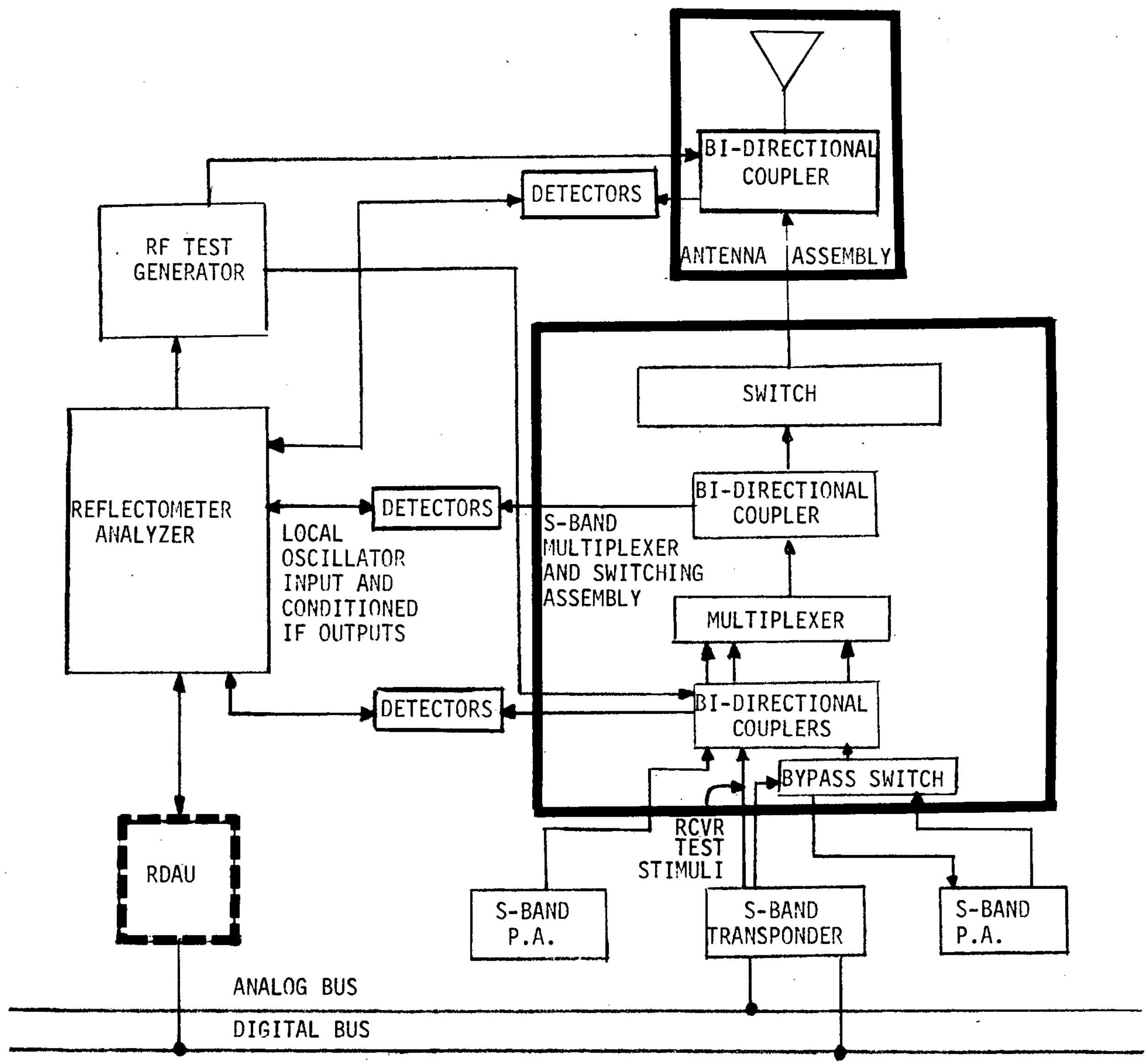


Figure 4-13. Low-Gain Reflectometer Analyzer Concept

couplers and detectors are required in each of the input lines between the multiplexer and the other communications subsystem LRU's. These are used for measuring input reflection coefficients and for injecting transponder receive stimuli. Operational carriers from the transmitters are utilized as transmit stimuli while receive stimuli are generated externally and injected into either the antenna coupler for end-to-end checks or into the input coupler for transponder checks.

The reflectometer analyzer approach for the high-gain system is shown in Figure 4-14. As in the low-gain concept, appropriate stimuli and monitoring capabilities are provided. Operational signals are again used as transmit stimuli, but special provisions are made for generating receive stimuli. These signals are injected either through open-loop probes located in quadrants around the reflector or through closed-loop directional couplers in the precomparator circuits.

The high-gain analyzer detects and monitors the sum channel carrier transmission loss and the RF boresight offset of the comparator and feed assembly as indicated at the output of the difference channels. This is done by inducing an offset in the stimuli and computing the slope of the difference channel as a sequence of commands are executed by the analyzer. The analyzer data are supplemented by the error signal data from the tracking receiver to correlate the RF boresight performance of the comparator and feed assembly with the electronic boresight of the entire system. To do this, DMS software programs are required for evaluation of error data to differentiate between comparator/feed and receiver malfunctions.

The reflectometer analyzer provides direct measurements of reflection coefficient and insertion loss to the DMS for comparison with stored criteria. A variation of this concept is where the comparisons are made within the analyzer itself and a go-no/go status indication is provided to the DMS.

4.2.1.2 Impedance Analyzer Concept

The impedance analyzer concept is similar to the reflectometer analyzer concept, but also provides a capability for measuring the phase of the reflection and transmission coefficients as well as the insertion phase shift between

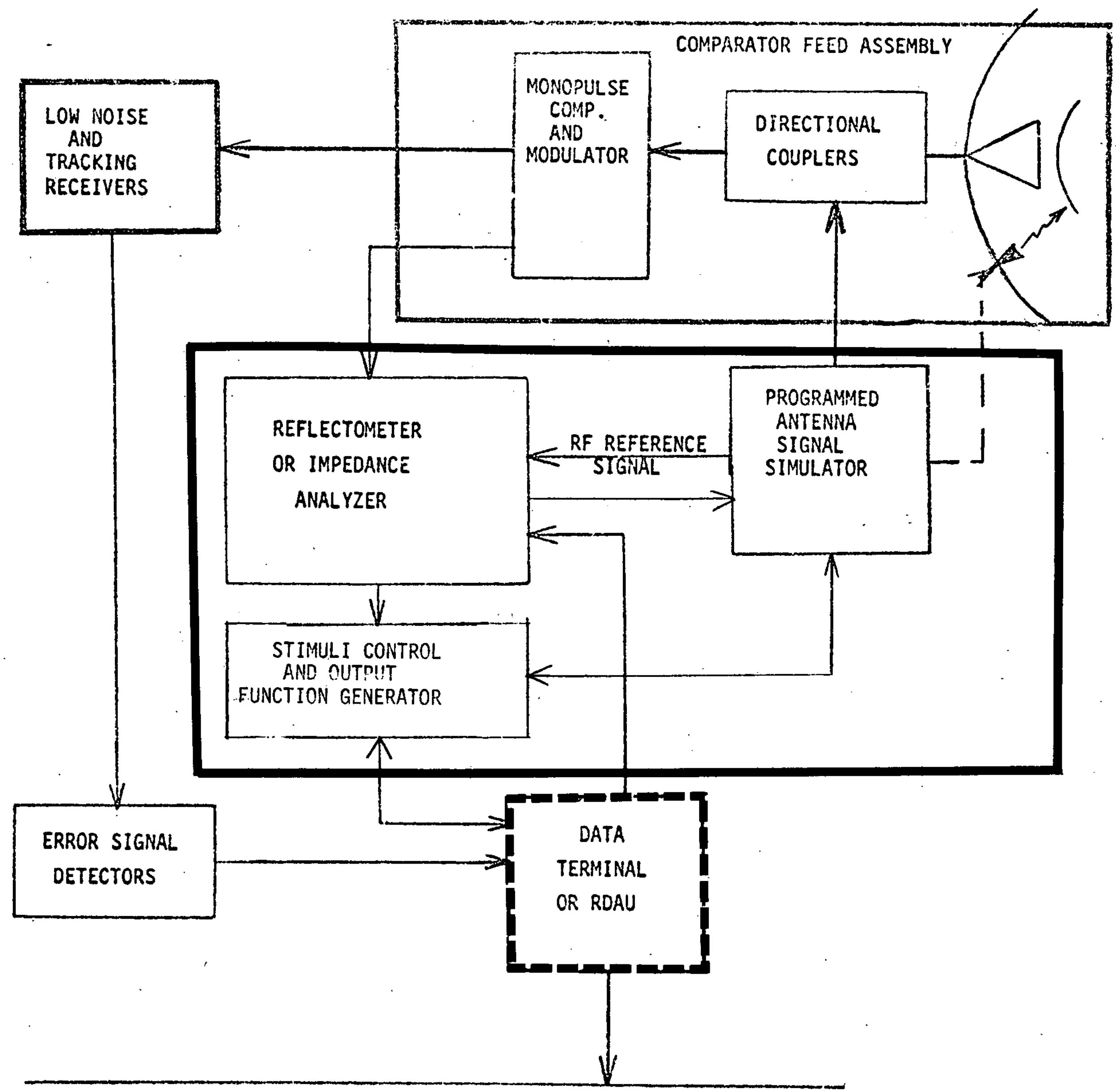


Figure 4-14. High-Gain Reflectometer Analyzer Concept

the measurement sensors as outputs. This capability is required when phase shift is an important performance parameter. This occurs primarily in the high-gain comparator and feed assemblies and the tracking receivers. This concept is basically the same as described above, except that a different type of analyzer is required.

4.2.2 Antenna System Signal Detection

In addition to the preferred concept of using an envelope detector to monitor low-level RF signals in the low-gain antenna system, an alternate approach investigated is the mixer detector concept shown in Figure 4-15. This concept is in essence a receiver with a local oscillator, mixer, and intermediate frequency amplifier.

4.2.3 High-Gain Antenna System Checkout Concepts

Other checkout techniques investigated which are unique to the high-gain antenna system include the user operational, solar radiometer open loop, near-field open loop, optical, and visual inspection concepts described below.

4.2.3.1 User Operational Concept

The operational concept uses the RF stimuli provided by the DRSS to verify the acquisition and pointing performance of the high-gain antennas. The DMS is used to monitor and correlate the acquisition lock indication from the tracking receiver and the rms tracking error from the tracking receiver angle detectors in consonance with DMS navigation computations and predicted DRSS/station position information.

The concept involves slaving the antenna under test to an on-line operational antenna for preacquisition checkout. This is accomplished in the same manner as the preacquisition procedure during handover.

4.2.3.2 Solar Radiometer Open-Loop Concept

The solar radiometer open-loop concept utilizes the solar spectral energy at K_u-band radiated directly from the sun as the test stimulus. The monitoring and detection is done by a microwave radiometer that measures the noise power output in the post comparator channels of the comparator. A block

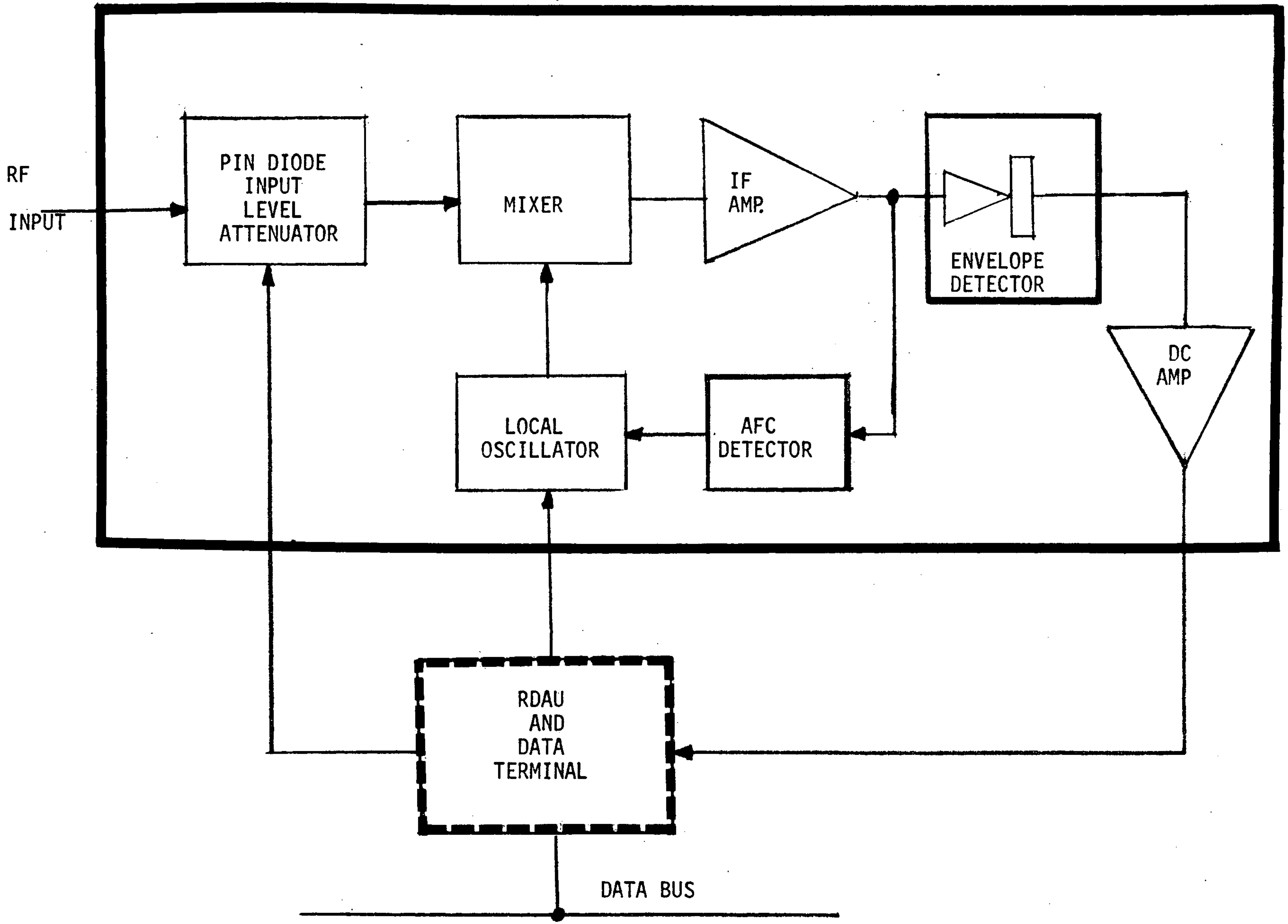


Figure 4-15. Mixer Detector Concept

diagram of the concept is shown in Figure 4-16. The technique is based on the application of microwave radiometers in radar monopulse antennas to track bright stars, the sun, and moon in radio astronomy experiments.

Directional couplers are inserted in the sum channel line and in each of the difference channel lines, thus isolating instrumentation from the operational channels and reducing degradation of performance. The noise spectra signals from each difference channel are recombined with the sum channel spectra in a 180-degree hybrid. The two output signals then appear as coherent sum and difference currents that are fed to the radiometer. The radiometer acts as a square law detector and an integrator circuit that detects the difference in power level from the two combined signals. In essence, the radiometer is a slope detector monitoring the difference channel slope.

The crossover or boresight crossover location is determined by statistical processing of the data by the computational system. The approach measures the far-field RF boresight performance of the high-gain antenna and feed, but does not provide electronic boresight performance evaluation of the complete antenna system which includes the monopulse modulator and receiver subsystems.

4.2.3.3 Near-Field Open-Loop Concept

The near-field open-loop concept, shown in Figure 4-17, involves a boresight RF test of the high-gain antenna using a target horn fixed to the Station. The test may be performed automatically or on command from the DMS. The stimuli generator is located near the horn and is energized on command from the DMS.

The antenna is pointed initially by position commands from the DMS. A short scanning routine is then implemented causing the antenna to scan in two planes about the target. Data monitored during the test includes tracking receiver error channel outputs which show the electronic boresight position and readouts of the actual gimbal position.

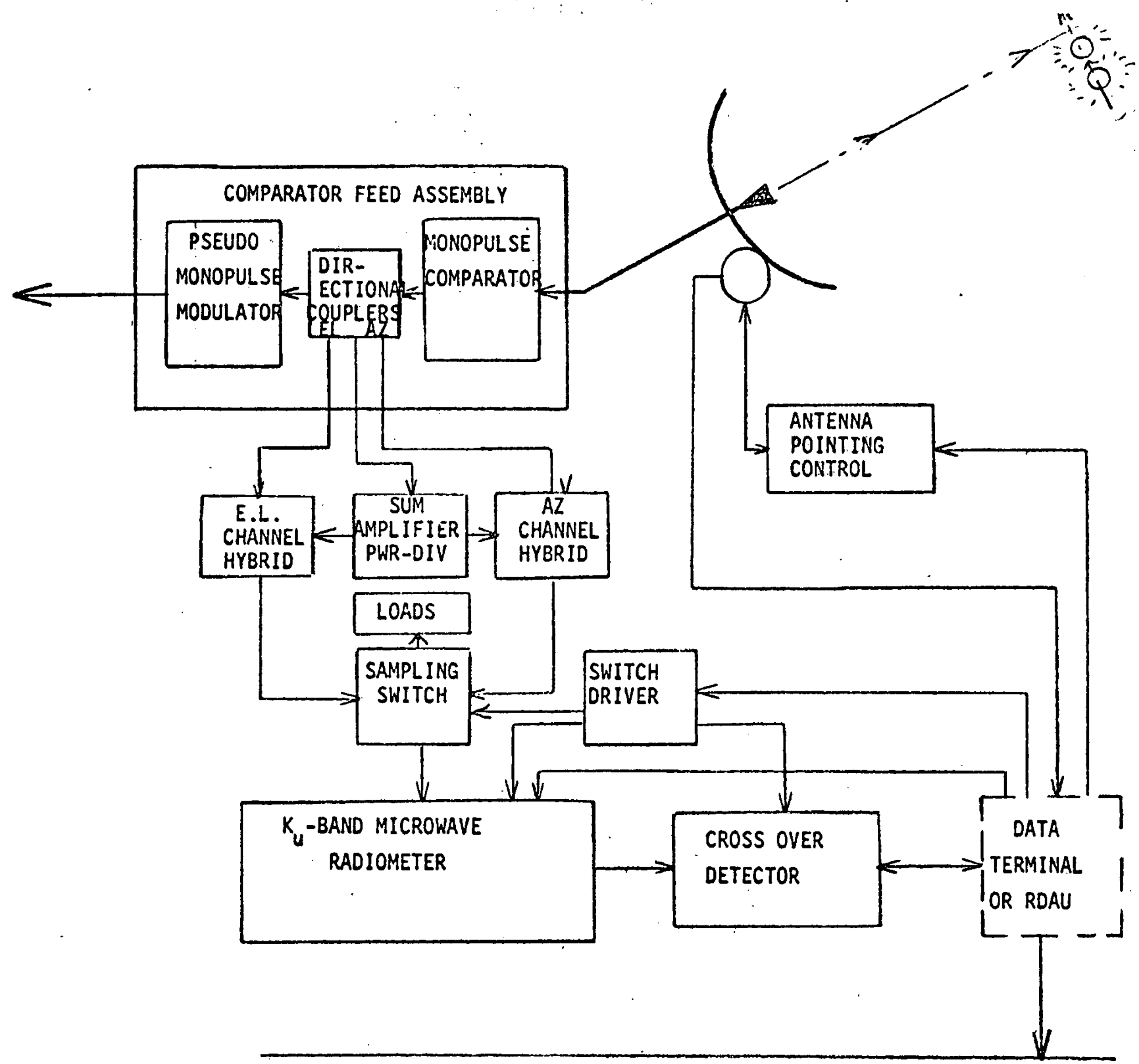


Figure 4-16. Solar Radiometer Concept

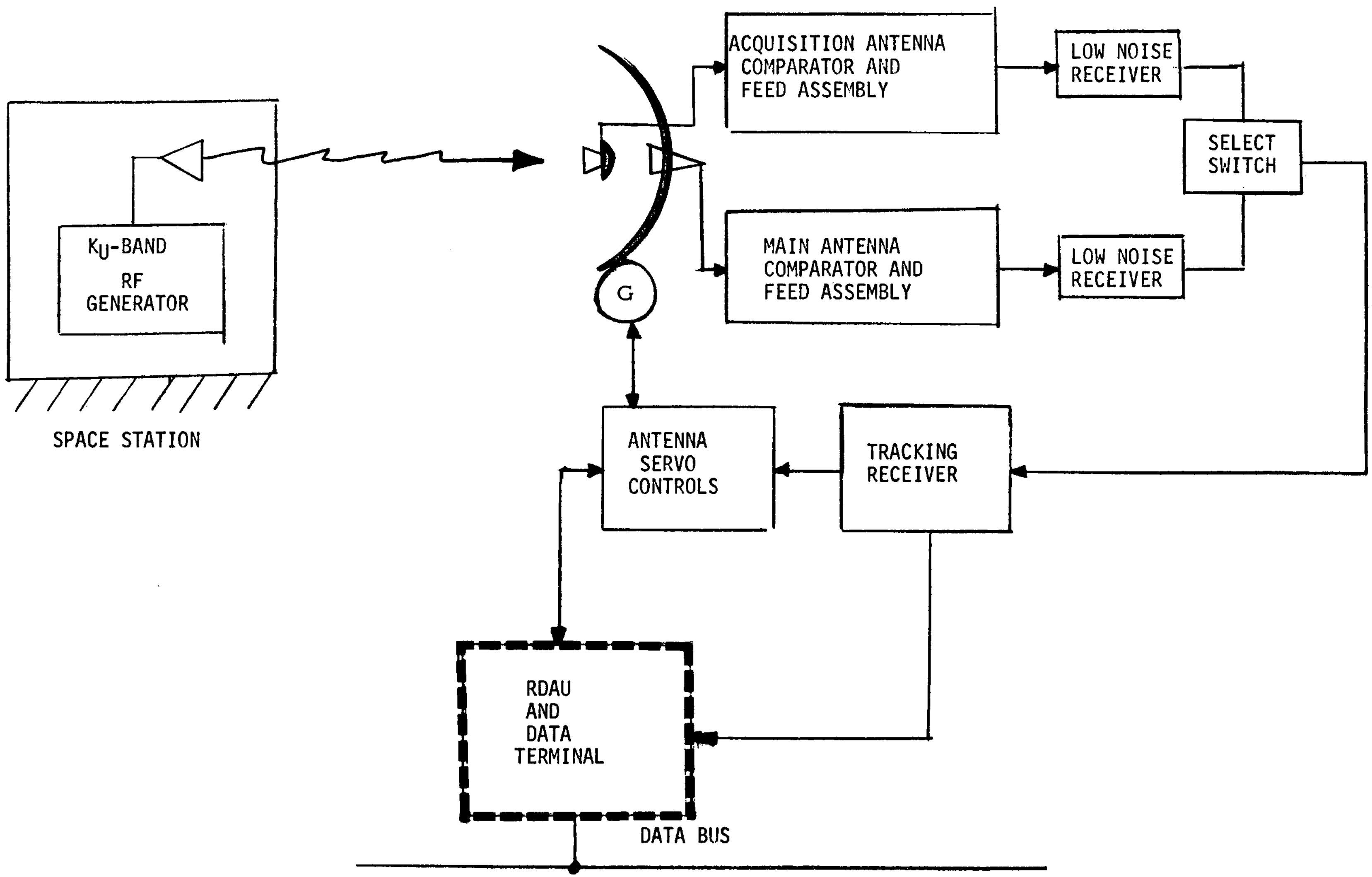


Figure 4-17. Near-Field Open-Loop Concept

This technique is especially applicable to ground testing following antenna installation. A variation to the described concept for ground testing involves locking the gimbals and switching stimuli between sources oriented in horizontal and vertical lines.

4.2.3.4 Optical Verification Concept

This concept utilizes optical stimuli and sensors for performing a distortion analysis on the reflectors, feeds and other elements of the high-gain antenna for fault isolation and verification of the physical shape of the antenna/feed structure. Extensive DMS computational support is required for this concept.

4.2.3.5 Visual Inspection Concept

The visual inspection concept is relatively unsophisticated. It provides a capability for ascertaining the general condition of the antennas and feeds, and for making a qualitative assessment of azimuth and elevation positioners. The assessment includes a visual verification of track speed, slewing, stop at slewing speed, and stop functions. This technique requires crew observation of positioner displays and controls and visually noting the respective position and rate displays.

4.3 INTERNAL COMMUNICATIONS SYSTEMS

In addition to the preferred concept which consists of a combination of the talk-back and self-test test-tone methods, an automatic test method was considered as an alternative.

In the automatic test method, each ATU is sequentially interrogated by a test-tone generated within a dedicated test modem. The retransmitted response from each ATU is then evaluated to determine proper performance. Since the duty cycle varies considerably between ATU's and the reliability is expected to be high, it appears unnecessary to implement a dedicated test unit for checkout of the ATU's.

An alternative to monitoring only the analog sync/test unit self-monitored fault indications is to monitor the output of each reference generator individually. This approach, however, increases the number of interfaces required with the DMS and increases the DMS loading.

It does not appear that there are any acceptable alternates for checkout of television cameras and monitors other than visually observing test patterns.

Section 5
CONCEPT EVALUATION

The selection of the preferred checkout concepts for the RF, antenna, and internal communications systems is based on an evaluation of the most promising candidate concepts. This section discusses the impacts of the various candidate concepts on LRU and communications subsystem design, performance, interface complexity, data management subsystem loading, and technology utilization. Also addressed are the gross effects of the concepts in terms of ground support requirements, and estimated schedule and cost impacts.

5.1 OVERALL EVALUATION AND RANKING

An overall evaluation and ranking of stimuli generation, signal detection, and monitoring concepts are presented in Subsection 2.4. The ranking matrices shown in Tables 2-5, 2-6, 2-7, and 2-8 utilize the following criteria:

A. Impacts on LRU design—This factor considers the effect of the proposed concept, in terms of design complexity, on the basic LRU design.

B. Impact on communications subsystem design—This factor considers the impact of the proposed concept on the design of the communications subsystem.

C. Impact on interface complexity—This factor considers the impact of new interfaces required to provide the checkout capability.

D. Operational restrictions—This factor considers the extent to which the proposed concept interferes with the normal operation of the communications subsystem.

E. Physical impact—This factor considers the gross impact on weight, size, and power.

F. Performance and effectivity—This factor considers the effect on performance and the effectiveness of the concept in performing the required checkout functions.

G. Cost—This factor considers the gross impact on overall communications subsystem cost.

H. Flexibility—This factor considers the ease with which the proposed concept can respond to system or LRU design changes which occur late in the design, implementation, or operational periods of the system.

I. Reliability/failure effects—This factor considers the effect of failures in the checkout circuitry on the communications subsystem.

J. GSE considerations—This factor considers the GSE requirements for prelaunch testing.

K. Impact on DMS design—This factor considers the effect of the proposed concept on the DMS in terms of hardware, software, and execution time.

To obtain at least a gross quantitative indication of the relative merits of alternate concepts, weighting factors are assigned to each of the criteria and the concepts are ranked according to the degree of compliance with the criteria as noted below.

Rank	Criteria
9-10	A characteristic which provides total or nearly total compliance with the criteria (e.g., no impact on design, no weight increase, no operational restrictions).
6-8	A characteristic which satisfies the criteria in an acceptable but not ideal manner (minor weight increase, some LRU design impact, etc.).
3-5	A characteristic which indicates a major impact if the proposed concept is used (significant LRU redesign required, important operational restrictions imposed, etc.).

1-2 A characteristic which indicates an extreme penalty if the proposed concept is adopted (e. g. , failure of checkout system propagates to checked function, failure to effectively check parameters).

5.2 DESIGN AND PERFORMANCE

This subsection discusses the impacts of the candidate checkout concepts on the design, performance, and operation of the RF, antenna, and internal communications systems.

5.2.1 RF System

Candidate RF system concepts include those required for stimuli generation, signal detection, and monitoring and evaluation.

5.2.1.1 Stimuli Generation

Because of the unique considerations involved, separate discussions of stimuli generation concepts for transmit and receive paths are provided in the following paragraphs.

Transmit Paths

The concepts identified to provide the modulation test signals required for checkout of transmit paths include the use of operational signals, a test generator located within the transmitter LRU's, a centralized test generator, and a modulation generator coupled to the data bus. In general, the impacts of providing transmit stimuli on design, performance, and operations are minor compared to those associated with receive stimuli.

The use of operational signals does not impact LRU design and performance since additional circuitry is not required for checkout purposes. Although the ability to fault-isolate is limited by the signal characteristics, gross indications of signal presence or absence could be made available. The checkout capabilities are limited by the availability of the operational signals. The concept also causes a significant impact upon crew time. Fault isolation of voice transmitters, for instance, requires direct crew involvement.

Furthermore, it is incongruous to use operational signals for test stimuli in a concept employing automated monitoring and evaluation methods.

Locating a modulation test generator within a transmit LRU does impact the design because of the additional circuitry required. This impact, however, is minimized if the design of the checkout circuitry is under control of the LRU designer. Performance impacts are also minimal if the design includes an operational override capability. No operational limitations are envisioned with this approach. In fact, off-line or redundant units could be checked out during normal operations.

Incorporating a centralized test generator impacts the design of the LRU's by requiring new external interfaces. The design of a new LRU is also required. Redundant design of the centralized test unit is necessary to minimize the effect of failures which could cause the loss of all test capability. The impact on operations is negligible; however, the question of control priority must be considered.

The use of a modulation test generator coupled to the data bus does not impact the design of the transmit LRU's, but requires the design of a new unit. There is also the possibility of interference on the bus if the test signal frequencies and formats are not carefully chosen.

Receive Paths

The concepts identified to provide the RF and modulation test signals required for checkout of receive paths include the use of operational signals generated external to the Space Station, a test generator located within the receiver LRU's, a centralized test generator, a test generator coupled into the antenna system, and transmitter signals that are translated to the receive frequencies.

The use of externally generated signals does not impact the LRU design, but the checkout capability may be severely limited by the availability and characteristics of the signals. It is not possible to check out off-line receivers during periods when data are being received.

The location of test generators within the receive LRU's increases the design complexity of these units. The test generators must be loosely coupled to the functional channel to minimize performance impacts. Since the design of this additional circuitry is under control of the LRU designer, the impacts on design and performance can be minimized. This approach also allows checkout of off-line LRU's during normal operations.

The antenna test generator approach does not impact the design of the receiver LRU's, but design of a new unit is required. As in the previous concept, the test generator must be loosely coupled to the antenna system to minimize the impact on functional channel performance. Checkout is limited to nonoperational periods, however, since the test signal would probably jam the operating channel.

The central test generator and translator approaches could impact overall subsystem and vehicle design because of the potentially serious EMI problems that could be created. Transmit/receive path isolation is another potential design impact. Both approaches require the design of new units. The design complexity of the central test generator is especially significant if a multiple frequency and modulation generation capability is incorporated. Checkout is again limited to nonoperational periods because of the possibility of jamming the operational signal. New interfaces with the LRU's are also created.

5.2.1.2 Signal Detection

The signal detection concepts considered include incorporating RF and modulation detectors within the transmit LRU's or within a central test unit. Another concept utilizes receiver LRU's to detect translated transmitter signals.

There is a moderate design impact associated with the addition of the detector circuitry within the LRU's. As before, the detectors must be loosely coupled to minimize performance degradation in the function channel and failures in the checkout circuitry. The impact on operations is negligible.

The design, performance, and operations impacts previously discussed for the centralized test unit as a stimuli source are also applicable to the concept incorporating signal detection capabilities within the unit.

The LRU design impact is minor when the receiver LRU's are utilized as the detectors; however, the design of new translator units are required. Checkout is limited to those paths where paired transmitters and receivers having compatible modulation/demodulation characteristics are available. This approach has the added disadvantage that it is difficult to isolate failures to the transmit or receive path. Checkout is also limited to nonoperational periods since the paired units must be utilized off-line.

5.2.1.3 Monitoring and Evaluation

Monitoring and evaluation concepts range from those which require considerable crew involvement to those which are essentially automatic and require little or no crew participation. Table 5-1 provides a summary of the design impacts associated with these concepts. For purposes of discussion, the concepts are separated into those that utilize primarily the crew, the DMS, or a dedicated MCU.

User Monitoring and Evaluation

Two concepts are identified which require monitoring and evaluation by the crew. The first is where the crew performs the operational data monitoring and fault isolation directly. In the second concept, the LRU's provide go-no/go status outputs to the DMS and faults are isolated through manual examination of LRU test points by the crew.

In the concept where the crew monitors the operational data, there is no impact on LRU design, performance, or operations. However, the design of portable test equipment is required. The impact on crew time is significant and could impact overall station operations. The concept also requires EVA operations for monitoring test points associated with the high-gain antenna system. This is in conflict with the baseline operational philosophy. The same crew and operational impacts also apply to the second concept. In addition, parameter comparison and mode logic circuitry are required design changes to the LRU's to provide the go-no/go status outputs.

Table 5-1

DESIGN IMPACTS (Page 1 of 2)

CANDIDATE CONCEPTS	NEW EQUIPMENT DESIGN	DELTA DESIGN EFFORT FOR EXISTING LRU'S
1. Operator evaluation of performance. Portable test equipment and LRU test points used for fault isolation.		
a. DMS bus and RF signal generators.	1. Portable test equipment 2. DMS bus test generator 3. RF test generator (3)	
b. LRU internal signal generators.	1. Portable test equipment	LRU test signal generators added.
c. Operational data only	1. Portable test equipment	
d. RF translator	1. Portable test equipment 2. RF translators	
e. Centralized Signal Generators	1. Portable test equipment 2. RF and modulation test generators.	
2. Go-No/Go data provided by LRU's. Portable test equipment and LRU test points used for fault isolation.		
a. DMS bus and RF signal generators.	1. Portable test equipment 2. DMS bus test generator 3. RF test generator (3)	1. Mode logic and sensor level logic required in LRU's to generate Go-No/Go signals.
b. LRU internal signal generators	1. Portable test equipment	1. Same as a. 2. LRU test signal generator added.
c. Operational data only	1. Portable test equipment	1. Same as a.
d. RF translator	1. Portable test equipment	1. Same as a.
e. Centralized signal generators	1. Portable test equipment 2. RF and modulation test generators	1. Same as a.
3. Go-No/Go data provided by LRU's. Fault isolation performed by DMS evaluation of LRU sensor data.		
a. DMS bus and RF signal generators.	1. DMS bus test generator 2. RF test generators (3)	1. Mode logic and sensor level logic required to generate Go-No/Go signal.
b. LRU internal signal generators.		1. Same as a. 2. LRU test signal generators added.
c. Operational data only		1. Same as a.
d. RF translator	1. RF translators	1. Same as a.
e. Centralized signal generators	1. RF and modulation test generators.	1. Same as a.
4. All Go-No/Go logic and fault isolation provided by DMS.		
a. DMS bus and RF signal generators	1. DMS bus generator 2. RF signal generators (3)	
b. LRU internal signal generators		1. LRU test signal generators added.
c. Operational data only		
d. RF translator	1. RF translators	
e. Centralized signal generators	1. RF and modulation test generators	

Table 5-1

DESIGN IMPACTS (Page 2 of 2)

CANDIDATE CONCEPTS	NEW EQUIPMENT DESIGN	DELTA DESIGN EFFORT FOR EXISTING LRU'S
5. Go-No/Go data provided by LRU's. Fault isolation performed by MCU evaluation of LRU sensor data.		
a. DMS bus and RF signal generators	1. Multiplexer-computer unit 2. DMS bus test generator 3. RF test generators (3)	1. Mode logic and sensor level logic required to generate Go-No/Go signal.
b. LRU internal signal generators	1. Multiplexer-computer unit	1. Mode logic and sensor level logic required to generate Go-No/Go signal. 2. LRU test signal generators added.
c. Operational data only	1. Multiplexer-computer unit	1. Same as a.
d. RF translator	1. Multiplexer-computer unit 2. RF translators	1. Same as a.
e. Centralized signal generators	1. Multiplexer-computer unit 2. RF and modulation test generators	1. Same as a.
6. All Go-No/Go logic and fault isolation provided by MCU		
a. DMS bus and RF signal generators.	1. Multiplexer-computer unit 2. DMS bus generator 3. RF signal generators (3)	
b. LRU internal signal generators	1. Multiplexer-computer unit	1. LRU test signal generators added.
c. Operational data only	1. Multiplexer-computer unit	
d. RF translator	1. Multiplexer-computer unit 2. RF translators	
e. Centralized signal generators	1. Multiplexer-computer unit 2. RF and modulation test generators	

Data Management Subsystem Monitoring and Evaluation

The concepts which utilize the DMS include one in which the LRU's provide go-no/go status and normalized data on request, and another in which the LRU's provide only normalized data which are evaluated by the DMS. The first concept impacts the LRU design by requiring the addition of parameter comparison and mode logic circuitry.

The increase in weight, size, and power is small. In all cases where the LRU's output normalized data, the levels and impedances are standardized. The LRU go-no/go data only concept is limited to fault-detection and fault-isolation checkout functions. Insufficient data are available for trend analysis and quantitative evaluation.

The second concept eliminates the limitations of the first, but the impact on the DMS design in terms of storage and program requirements increases as the level of evaluation increases. However, the overall impact on the DMS is small when compared to that required to support the Space Station experiment program. The impact on the crew and operations is negligible.

Centralized Multiplexer-Computer Unit Monitoring and Evaluation

Variations in concepts that incorporate an MCU dedicated to communications subsystem checkout involve a combination of two checkout system control philosophies and two implementations of the multiplexer-computer evaluation procedure.

The question of control revolves about whether it is feasible and desirable to let the MCU be responsible for configuring the LRU operational controls when a test has been requested, or whether it is preferable for control integrity or other reasons to operate in a hybrid control mode where the DMS control system is responsible for configuring the LRU operational control for the test modes.

The two variations in MCU implementation are similar to the concepts previously considered for DMS-aided evaluation. In one concept, the LRU go-no/go signals are evaluated and a detailed readout of internal test point data from an LRU is made only when that LRU indicates a no-go condition. In a second approach, the raw data from the LRU's is examined continuously by the MCU which then determines the go-no/go condition of the LRU's. The impacts of these concepts on the crew and upon the operational requirements are essentially identical to those previously considered for the concepts in which the same evaluation tasks were to be performed by the DMS. In either case, it is an automated process and it makes no difference which black box performs the task.

The transfer of the LRU evaluation function to the MCU represents a significant reduction in DMS requirements. This is particularly true in the case where evaluation of raw LRU data is to be performed on a continuous basis and where the MCU is allowed direct access to the LRU controls. Whether or not the reduction is really of any significance is dependent upon the sizing of the DMS and upon the ease with which its software can be changed. If the DMS must still be charged with the task of configuring the LRU controls to establish the test configuration, and if the LRU's themselves make the go-no/go decision, the actual reduction in DMS loading in any reasonably sized system would be very small. In such a case, it is most feasible to use the capabilities of the DMS, including the comparison circuitry available in the RDAU's themselves.

In terms of basic LRU complexity and reliability, there is no difference between the concepts employing DMS evaluation and those in which the task is performed by the dedicated MCU. The addition of the MCU to the system, however, obviously adds some complexity and another source of potential failures. In the event that the MCU itself malfunctions, the crew requirements may be somewhat increased due to the commonality of functions within that unit and the difficulty of sorting out the effects that could be caused by the cross-coupling in certain failure modes.

Because the MCU becomes the common evaluator and combines signals from all of the LRU's at one location, particular attention must be given to its design to achieve the necessary protection against EMI and failure propagation. These concepts have the disadvantage of losing all system checkout functions if a catastrophic failure occurs in the common unit.

5.2.2 Antenna System

Checkout concepts investigated common to both the high-gain and low-gain antenna systems are concerned with verifying the performance of antenna feeds, RF switches, transmission lines, multiplexers, and power dividers. Concepts unique to the high-gain system are concerned primarily with verifying the performance of the acquisition and tracking elements, the antenna comparator and feed of the main and acquisition antennas, and the positioners and servo systems. Design and performance impacts associated with candidate open-loop and closed-loop stimuli sources, compatible detection methods, and methods of monitoring and evaluation of antenna performance are described below.

5.2.2.1 Stimuli Generation

Because of the unique considerations involved, separate discussions of stimuli generation concepts for low-gain receive paths, high- and low-gain transmit paths, and high-gain receive paths are provided in the following paragraphs.

Low-Gain Receive Paths

For the low-gain receive paths, the use of either a separate antenna generator or an internal LRU stimuli generator is considered for stimulation of multiplexers, switches, transmission lines, and antennas.

Through the use of an external generator, as illustrated for the low-gain reflectometer analyzer concept in Figure 4-13, signals may be injected either in the antenna feed coupler so as to travel in the normal receive direction, or in the input to the multiplexer so as to travel in the reverse direction through the system. Either direction is satisfactory as far as checkout is concerned because all of the system elements are reciprocal in the forward and reverse sense of transmission. The approach requires the incorporation of bidirectional couplers, control switches, and logic circuitry within the antenna and multiplexer/switching assemblies, as well as new design for the external stimuli generator. Couplers and detectors are also required in each of the input lines between the multiplexer and other subsystem LRU's. These are necessary for measuring input reflection coefficients and for injecting transponder receive stimuli. The receive stimuli are injected into either the antenna coupler for end-to-end checks or into the input coupler for transponder checks.

The alternate concept, shown in Figure 2-6, utilizes the approach of routing test stimuli in the reverse direction through the filters and switches to the low-gain antennas. Receiver stimuli are conveniently injected into the incoming transmission lines using the stimuli generation capabilities located internal to receiver LRU's. Although the concept eliminates the need for the external generator and the multiplexer input couplers and detectors of the first concept, the design complexity of receiver LRU's is increased to accommodate the stimuli generation capability.

High- and Low-Gain Transmit Paths

Candidate stimuli concepts for checkout of both the high- and low-gain transmit paths involve the use of either a separate antenna generator or the normal operational carriers from subsystem transmitters.

For the low-gain transmit paths, the primary concern is whether to use unmodulated operational stimuli or modulated externally generated stimuli. An external generator can easily provide the necessary amplitude modulation, but this concept requires the design of a new generator, incorporation of directional couplers for injection, and design modifications to receiver LRU's to provide compatible modulation. Although the concept of using the normal operational carriers does not provide the amplitude modulation required for the low-gain antenna system, the concept is practical because the modulation capability can be accomplished in the detector circuits. Checkout of the high-gain transmit paths does not require modulated stimuli.

High-Gain Receive Paths

For the high-gain receive paths, candidate open-loop stimuli sources considered are far-field signals from the data relay satellite, near-field signals from an onboard antenna, and far-field RF noise from solar radiation. The major disadvantage of utilizing the data relay satellite is that it is not under control of the Space Station. Its use is limited to operational periods by either interruption or when the antenna under test is off-line. The near-field generator concept, shown in Figure 4-17, provides a much stronger signal than the data relay satellite and is under Space Station control. Use of either source, however, is heavily plagued by operational interference problems. Occultation of the signal path by vehicle structures can impede either the near-field or the far-field stimuli. Furthermore, the prevention of this interference places constraints on Space Station activities. The final concept using solar stimuli cannot be used for acquisition and tracking verification because this part of the system requires a coherent signal. Its possible use as a stimulus for antenna boresight is considered below.

Closed-loop stimuli concepts are preferred to open-loop concepts because of the control limitations associated with open-loop concepts, and the compatibility of the closed-loop stimuli signal characteristics with the candidate detection concepts considered. For closed-loop receive path checkout, both an internal LRU stimuli generator (Figure 2-7) and separate stimuli generator (Figure 4-14) are considered. In both closed-loop concepts, the stimuli are made to appear as receive signals arriving at the antenna from various small offset angles of arrival by injecting four signals of equal amplitude, but slightly different in phase, into the antenna feed via directional couplers. The stimulation of the tracking circuits is thus similar to actual circuit operation and appropriate for subsystem checkout. Both approaches provide the various stimuli required for the comparator feed assembly, the low-noise receiver, and the tracking receiver.

Using the concept of locating stimuli generation capabilities internal to the low-noise receivers has the advantage of serving both RF and antenna system receive stimuli requirements. Relative to the separate stimulator approach, the internal generator concept eliminates the need for developing a separate generator, and results in a simpler interface between the stimuli source and the comparator feed assembly. Design of the low-noise receiver must include a directional coupler and switching circuits to accommodate the application of stimuli for its own checkout as well as the checkout of other LRU's in the receive path chain. The stimuli are normally generated in the low-noise receiver not being used for subsystem operation, thus eliminating the possibility of jamming the receiver by signals leaking through the switch and directional coupler. Failure effects of the stimuli generator on the receiver reliability may be reduced by using redundant generators in the receivers. This is considered essential because it is also used for receiver checkout.

The location of the power dividers and phase shifters is also important to the checkout of the high-gain receive paths. Less design and performance impact results if these elements are located internal to the comparator rather than adjacent or internal to the low-noise receiver. Since only one RF transmission path between the receive stimuli source and the phase shifters is used, the approach is not sensitive to phase shift errors that could be caused by using multiple paths. Because the incorporation of the power dividers and phase shifters within the comparator is under the control of the comparator designers, the impacts on design and performance can be minimized.

5.2.2.2 Signal Detection

Signal detection concepts investigated include those used for monitoring forward and reflected power of the high- and low-gain antenna systems, and those used for monitoring acquisition and tracking performance of the high-gain receive paths.

Forward and Reflected Power Monitoring

The design impact of monitoring forward and reflected power in transmit and receive paths depends upon the method of detection used. Candidate detection concepts considered are the envelope detector shown in Figure 3-6 and the mixer detector shown in Figure 4-15. The relative merits of the two concepts are indicated in the comparison matrix of Table 2-8. The envelope detector generates considerably less EMI during its monitoring operation, and thus causes less impact on communications subsystem operation and performance. Its design is also less complex than the mixer detector.

Detector design is separate from other LRU's. Although this requires the development of an additional antenna system component, detector failure does not result in the replacement of an interfacing LRU. The use of active elements in the detector makes it more susceptible to failure than the passive multiplexers and antenna elements into which the detectors would otherwise be incorporated. Another factor is that use of the same detector throughout the antenna system offers the convenience of having a common set of design and performance characteristics for response monitoring.

The choice of coupling values for the directional couplers must be carefully chosen to provide a minimum insertion loss in the interfacing LRU, but still remain within the sensitivity range of the detectors and signal conditioning amplifiers. The forward power couplers are 10 db greater than the reflected in the low-gain paths and 20 db in the high-gain paths. The preferred coupling values do not result in LRU or system degradation for either detector candidate. The lowest signal levels considered for this approach are well within the sensitivity of either detector candidate. The stimuli levels in the receive and transmit paths for the low- and high-gain systems are shown in Tables 3-1 and 3-2.

Acquisition and Tracking Performance Monitoring

For the high-gain antenna system receive paths, two detection candidates are considered for checkout of acquisition and tracking performance. These include either using the mixer detector in conjunction with the impedance analyzer, or using the operational tracking receiver. The envelope detector does not have sufficient sensitivity to be used with the analyzer because at least 30-db couplers are required in the difference channel output to keep insertion losses and phase errors from degrading performance. The result is a null signal on the order of 10^{-7} milliwatts (-70 dbm) or less. The mixer detector, on the other hand, operates with a K_u-band local oscillator frequency with the analyzer.

In comparison to the relatively simple concept of using an operational tracking receiver, the mixer/analyzer approach results in significant impact because of the complexity and additional maintenance associated with the design and operation of an automatic analyzer. In addition, the capability of the mixer/analyzer approach is limited by not being able to monitor the performance of comparator modulator outputs. The tracking receiver can be used to perform this function. The availability of a redundant tracking receiver adds to the attractiveness of using the operational tracking receiver for monitoring acquisition and tracking performance.

5.2.2.3 Monitoring and Evaluation

The design and performance impacts associated with the various monitoring and evaluation concepts discussed for the RF system in Subsection 5.2.1.3 are also applicable to the antenna system. The design and performance impacts of utilizing DMS capabilities for monitoring and evaluation functions are considerably less than those associated with designing an independent antenna system evaluator. The reflectometer and impedance analyzer concept, for example, reduce dependence upon the DMS, but this advantage is very much offset by the additional complex design required.

5.3 INTERFACE COMPLEXITY

The impacts of the various candidate concepts in terms of interface complexity are examined in this subsection. Of concern are the operational, electrical, and mechanical interfaces between the communications subsystem equipment, other Space Station subsystems, and the OCS/DMS.

The basic mechanical interfaces established for the Space Station communications subsystem design and the selected electrical interface levels of 0 to 5 volts (with a 0 to 40 millivolt range available) are compatible with all of the candidate checkout concepts. Standardization of electrical interfaces is desirable whether the monitoring/checkout is manual or automatic.

5.3.1 RF System

While a variety of RF system checkout concepts are considered, they are divisible into those in which the LRU's of the communications subsystem are treated basically as black boxes and evaluated on that basis by their own internal circuitry or externally by the DMS, and those concepts in which the checkout functions are handled on a more integrated subsystem basis through a combination of external LRU test circuitry and an MCU dedicated to the checkout of the communications subsystem. There is some interfacing with the DMS in all concepts, since it represents the ultimate control and display system for all communications subsystem functions. The interface complexities associated with the various concepts are presented in Table 5-2 and further discussed below.

The use of a local MCU to assess the status of the communications subsystem LRU's and control test functions has the potential for simplifying the OCS/DMS interface by reducing the DMS data rate requirements and permitting design (and later modification) of the checkout system hardware and software to have minimum effect on the DMS hardware and software. On the other hand, disadvantages of the MCU concept include the EMI hazard of bringing signals from all units into close proximity, the increase in wiring runs between the LRU's and the MCU, and the increased potential of total checkout system failure due to the common unit.

Another major consideration is control of the communications subsystem during checkout. While the DMS workload is reduced by letting the MCU configure the subsystem controls for testing purposes, permitting this outside of the normal control circuits requires very careful design to establish fail-safe override capability for the normal controls. Allowing the MCU to control the LRU's via the DMS bus, however, greatly increases the design requirements of the MCU's, increases the DMS data bus load, and requires that the MCU be capable of controlling external data sources. While the MCU approach needs further investigation for use in other programs, it appears most desirable to retain control of the operational functions within the DMS as far as the baseline Space Station is concerned.

Table 5-2

INTERFACE COMPLEXITY FACTORS (Page 1 of 3)

	Operational	Electrical	Mechanical	Reliability	DMS Loading
I. User operational monitoring	(1) Involves crew participation for monitoring and fault isolation. (2) Portable tester required. (3) Constrained by availability of normal operational stimuli.	No effect on LRU design other than availability of normal test points.	No effect.	(1) No direct effect on LRU reliability per se. (2) Mean time between repairs is affected significantaly due to the down time required for manual fault isolation.	No effect on DMS.
II. LRU go-no/go output and local test point evaluation					
A. LRU stimuli generators	(1) Involves less crew participation than concept I since monitoring is performed by DMS. (2) Portable tester required.	(1) Impacts LRU design to include stimuli generators, and go-no/go outputs. (2) Impacts RDAU design to provide correct DMS interface.	Increased weight and volume to accomplish electrical changes for both LRU and RDAU.	(1) LRU and RDAU reliability is decreased to the extent of added circuitry. (2) Effect on operational reliability should be minimal but reliability of BITE must be added.	(1) Impact on DMS limited to interface with go-no/go signals from LRU's. (2) DMS interface is only upon request. (3) Storage of parameter data is required.
B. External stimuli generators	(1) Items (1) and (2) of concept IIA apply. (2) Additional operational impact of external generators.	(1) Impacts LRU design to include go-no/go outputs. (2) Impacts RDAU design to provide correct DMS interface. (3) Requires design of external stimuli generator unit.	(1) Increased weight and volume of LRU and RDAU. (2) Added weight and volume and power interface of new stimuli unit.	Same as concept IIA.	Same as concept IIA.
III. LRU go-no/go output and DMS evaluation					
A. LRU stimuli generators	Involves less crew participation than concept I or II. More monitoring and detailed fault isolation is performed by DMS.	(1) Impacts LRU design to include stimuli generators go-no/go and test point data for fault isolation. (2) RDAU impact is increased due to increased data bus interface.	Increased weight and volume due to LRU and RDAU additions.	(1) LRU and RDAU reliability further reduced due to increased data bus interface. (2) Operational reliability virtually unchanged but BITE reduces overall reliability.	(1) Impact on DMS includes go-no/go and test parameters from LRU's. (2) DMS loading up slightly due to usage on request. (3) Parameter storage required is increased.

Table 5-2

INTERFACE COMPLEXITY FACTORS (Page 2 of 3)

	Operational	Electrical	Mechanical	Reliability	DMS Loading
III. LRU go-no/go output and DMS evaluation (Continued)					
B. External stimuli generators	(1) Same comment as concept IIIA above. (2) Additional operational impact of external generators.	(1) Impacts LRU design to include go-no/go outputs. (2) Impacts RDAU design to provide correct DMS interface. (3) Requires design of external stimuli generator unit.	(1) Increased weight and volume of LRU and RDAU due to circuit additions. (2) Added weight and volume and power interface due to new stimuli unit.	Same as concept IIIA.	Same as concept IIIA.
IV. LRU go-no/go output and communication system evaluation A. LRU stimuli generators	(1) Involves same crew participation as concept IIIA. (2) Additional impact of separate MCU function to evaluate LRU test point data and provide processed output to DMS.	(1) Impacts LRU design to include stimuli generators, go-no/go and test point data for fault isolation. (2) Adds design of local MCU which is now responsible for data storage and fault isolation and provides processed output to DMS. (3) RDAU interfaces with multiplexer/computer unit.	(1) Increased weight and volume due to LRU circuit changes. (2) Added weight volume and power demand due to new MCU which interfaces with all LRU's.	(1) LRU reliability reduced due to increased data bus interface. (2) Operational reliability reduced due to common LRU interface with DMS via MCU.	Impact on DMS includes interface with MCU for control and monitor functions.
B. External stimuli generators	(1) Same comments as concept IVA above. (2) Additional operational impact of external generators.	(1) Impacts LRU design to include go-no/go and test point data for fault isolation. (2) Requires design of external stimuli generator unit. (3) Adds design of local MCU which is responsible for data storage and fault isolation, and provides processed output to DMS. (4) RDAU interfaces with MCU.	(1) Increased weight and volume due to LRU circuit changes. (2) Added weight, volume and power demand due to addition of external stimuli generator and multiplexer computer units.	Same as concept IVA.	Same as concept IVA.
V. Communication system evaluation					
A. LRU stimuli generators	(1) Involves same crew participation as concept IIIA. (2) Additional operations impact of MCU which now	(1) Impact on LRU design limited to stimuli generators and test point data. (2) MCU required which accepts and continuously	(1) Increased weight and volume due to LRU changes.	(1) LRU reliability reduced due to increased data bus interface.	Impact on DMS includes interface with MCU for control and monitor functions.

Table 5-2

INTERFACE COMPLEXITY FACTORS (Page 3 of 3)

	Operational	Electrical	Mechanical	Reliability	DMS Loading
V. Communication system evaluation (Continued)					
A. LRU stimuli generators (Continued)	operates on raw LRU test data and provides DMS interface via RDAU.	monitors raw data from LRU, stores, processes, fault isolation and provides DMS output interface.	(2) Added weight and volume and power demand due to new MCU which interfaces all LRU's.	(2) Operational reliability reduced due to common LRU interface with DMS via MCU.	
B. External stimuli generators	(1) Same comments as concept VA above. (2) Additional operational impact of external generators.	(1) No impact on LRU design other than availability of normal test points. (2) Requires design of external stimuli generator unit. (3) Requires design of MCU as defined in VA(2) above.	(1) No effect on LRU weight. (2) Added weight and volume and power demand for external stimuli generator and MCU's.	(1) LRU reliability unchanged. (2) Operational reliability reduced due to MCU.	Same as concept VA.
VI. DMS evaluation and monitoring					
A. LRU stimuli generators	(1) Involves same crew participation as concept IIIA. (2) Places increased demand on RDAU's and DMS by requiring them to process raw LRU test data.	(1) Impact on LRU design limited to stimuli generators and test point data. (2) RDAU design impacted to extent it must handle raw LRU test data and provide continuous DMS output.	(1) Increased weight and volume due to LRU circuit changes. (2) Added weight and volume due to requirement for more complex RDAU.	(1) LRU reliability reduced due to increased data bus interface. (2) Operational reliability effect is minimal but overall reduced due to BITE.	Impact on DMS significant since it must now continuously monitor, store, process, fault isolate and interface with RDAU.
B. External stimuli generators	(1) Same comments as concept VIA above. (2) Additional operational impact of external generators.	(1) No impact on LRU design other than availability of normal test points. (2) Requires design of external stimuli generators. (3) Requires design of more complex RDAU as described in VIA(2)	(1) No effect on LRU weight. (2) Added weight and volume due to more complex RDAU and external stimuli generators.	LRU reliability unchanged.	Same as concept VIA.

In the case of the stimuli generators, whether located within the LRU's or externally, there is less hazard in allowing the MCU to control them since the stimuli signals could be eliminated by removing power from the MCU or from the external generator. This could also be done in the case of LRU internal stimuli generators if they were configured to be powered from a source independent of the source powering the operational circuitry.

If, as has been suggested, the DMS is used to configure the operational controls for test purposes, the control of stimuli sources should also be assigned to the DMS since only a minor increase in DMS loading is involved. Several control concepts can be envisioned. One would be initiated by requesting checkout of a given function which, in turn, would result in the necessary instruction set being called into action from DMS memory. Execution of the instructions would suppress entry of operational data into LRU's which might cause interference with test signals, and would operate all controls necessary to configure the LRU's to establish the function to be tested. Stimuli generators would be energized and test point evaluation executed either by continued instructions (in the case of DMS evaluation) or by requesting that some or all of these functions be executed by an MCU from its own stored programs.

5.3.2 Antenna System

Unique interface complexity considerations for the antenna system are concerned with (1) the difference in DMS monitoring loads between the complex antenna analyzer concepts and the preferred antenna checkout concepts, and (2) the interface impacts within the antenna system resulting from the complexity of utilizing the analyzer network design.

The number of DMS interfaces is much higher for the preferred concept where each detector is controlled and monitored by the DMS, than for the analyzer concepts where the DMS controls and monitors only the outputs of the central analyzer. For the high-gain system, the DMS monitors and controls the analyzer and the tracking receiver for the analyzer approach as compared to the receiver only in the preferred approach. Although there is less capability for isolating a fault to the comparator without the analyzer interface, this fault isolation is accommodated by the DMS controlling the redundant modulators and RF paths internal to the comparator.

The internal interface complexity that the analyzer network design imposes includes an intricate network of detectors, switches, transmission lines, multiplexers and control lines for its sampling and control of test signals. In the area of multiplexers and switches which are centrally located, the analyzer network is fairly compact. Where the required data are widely dispersed, such as at remote antenna locations, a complex RF data bus is necessary to collect and combine the data from each remote location onto a common transmission line leading to and from the central area. The analyzer approach, therefore, creates EMI problems throughout the communications system. The envelope detector/DMS monitoring approach involves the transmission of dc signals which eliminates the potential EMI. In the high-gain antenna concepts, the network of the impedance analyzer is not as complex as in the low gain. In comparison to utilizing the tracking receiver, however, it is considerably more complex.

5.4 DATA MANAGEMENT SUBSYSTEM LOADING

Relative to the DMS loading imposed by other Space Station subsystems and experiments, the impact upon the DMS by any of the communications subsystem checkout concepts considered in this study is insignificant. Based on the sample sizes, rates, and intervals noted for checkout data parameters in Table 6-11, an average data rate of only 100 bits per second is anticipated at the interface between the subsystem and the DMS RDAU's for checkout. With the RDAU's limit checking capabilities, the data are normally transmitted to the centralized DMS computer only on a periodic basis which results in very low data bus loading. Peak data rates of up to 1 kbps might be reached during periodic testing. Since the baseline capacity and speed of the DMS are so large compared to any assessment task presented by the communications subsystem checkout data, it is difficult to envision any problems in the area of DMS loading.

The impact for various candidate checkout concepts in terms of addresses and transactions required on the DMS bus for RF system LRU's is shown in Table 5-3. Although quantities are listed in the table, they must be used with caution (particularly if the results are to be extrapolated to different size systems and concepts) because of the many assumptions involved as discussed below.

While it would certainly be expected that some of the LRU test parameters in Table 6-11 would change in a given system implementation, they are felt to be quite representative for the baseline subsystem and the level of checkout and maintenance planned. It is doubtful that the list would grow significantly unless there is a new requirement for extensive fault isolation within the circuitry of the LRU's. The minimum list would consist of go-no/go signals only from the LRU's, and that case is one of the candidate concepts considered. A shift to an all digital system would, of course, significantly impact the parameter lists.

The impact of "addresses" is dependent upon control and computer organization and upon how much information is located in a given core location or word. It is assumed that one address is associated with each RDAU and the LRU it services, the total of which is the summation of the LRU quantities and test generators except for the audio terminal units. These units are assumed to be controlled remotely only to the extent of some primary power control to isolate unused groups of units.

The number of bus transactions required to check out the subsystem is dependent upon the number of locations which must be controlled to set up and execute the test, required sampling rates, and the amount of information which the DMS bus can accommodate in a given transaction. The latter may be limited by the necessity of giving up the bus periodically to allow other terminals to use it, or as may be the case with limited capacity RDAU's, to permit a new set of parameter limits to be read into local memory to support a new test mode or to permit a different set of input signals to be checked. Table 5-3 lists separately the write and read sequences necessary to execute a complete system checkout for the candidate concepts.

Table 5-3

DMS LOADING

Concept	No. of Addresses	Transactions Per System Check	
		Write	Read
1. LRU go-no/go signals only.			
A. External test generators	40	162	
B. LRU test generators	36	135	
2. LRU go-no/go signals, plus detailed LRU data for fault isolation.			
A. External test generators	40	163	2
B. LRU test generators	36	136	2
3. DMS evaluation of LRU signals.			
A. External test generators	40	230	42
B. LRU test generators	36	185	38
4. MCU evaluation of go-no/go signals, plus detailed fault isolation (DMS LRU control)			
A. External test generators	41	164	42
B. LRU test generators	37	137	38
5. MCU evaluation (DMS LRU control)			
A. External test generators	41	164	42
B. LRU test generators	37	137	38
6. MCU evaluation of go-no/go signals, plus detailed fault isolation.			
A. External test generators	1	3	2
B. LRU test generators	1	3	2
7. MCU evaluation of LRU signals (MCU LRU control)			
A. External test generators	1	3	2
B. LRU test generators	1	3	2

In the case of detailed fault isolation, it is assumed that all of the detailed LRU data is input to the RDAU, along with a go-no/go discrete. In the event that a no/go is signalled, the DMS conducts a write sequence to load the RDAU limit memory with the proper values for the mode being tested. Two read sequences are then conducted first to identify the out-of-specification channel and then to read the parameter value.

In the case of DMS evaluation, where the RDAU is doing the comparisons, the number of write sequences increases because of the need to load new sets of limits into the RDAU memory as the test modes change.

In terms of DMS loading, the table makes a strong case for letting an off-line computer do as much of the task as possible. There are other system impacts to consider, however, and the use of the RDAU's does not represent a hardware impact because they are present as part of the baseline systems for LRU control. This latter item represents a major assumption, and the results could be greatly changed if the DMS characteristics are modified from those of the baseline.

In the baseline DMS system, the total time required for a device on the digital bus to conduct a read sequence with an RDAU does not exceed 710 microseconds, and the time for a write sequence is less than 680 microseconds. Even with the worst transaction load shown in Table 5-3, the system test time is less than 200 milliseconds. In practice, this time would be negligible compared to the delays required to let AGC circuits, phase-lock loops, and other circuits with long time constants to stabilize prior to measurement; and to the time required to manually evaluate such equipment as microphones, headphones, television, monitors, or hardcopy printers.

5.5 TECHNOLOGY

This subsection presents the results of reviewing candidate checkout concepts to determine if any requirements exist for special sensor or test equipment design and development, or for advanced research and development.

5.5.1 RF and Internal Communications System

None of the candidate checkout concepts considered for the RF and internal communications systems require any special advancement in state-of-the-art components or circuitry. The technology necessary to design the communications subsystem itself will suffice for the development of the checkout system. The requirements for signal sensors and generators, while encompassing a wide range of frequencies and amplitudes, also do not appear to place any unusual demands upon the technology.

The circuitry and components necessary to accommodate serial and parallel digital data at the relatively low speeds required should be available now and, in any case, would become available as a result of any development effort necessary to meet the much higher speed demands of the onboard computer system. The same is true of the requirements for analog-to-digital conversions. The demands of the proposed concepts are well within the accuracy and speed capabilities of elements already developed.

The candidate concepts are assumed to be implemented with discrete components or standard linear and digital "building blocks" such as operational amplifiers and logic elements. By this assumption, it is not intended that the problems of actually designing reliable and environmentally rugged checkout circuitry, or of developing efficient software programs to utilize the data, be minimized. The problems, however, are those of a normal development program and do not appear to present any unique technology impact.

5.5.2 Antenna System

Although technology impacts do not result from using the preferred antenna system checkout concepts, certain alternate concepts do require special sensors and/or special test equipment. These include the optical and solar radiometer concepts that could be used for boresight alignment, as well as other concepts identified for measuring insertion loss and VSWR.

5.5.2.1 Special Sensor Development

Special sensors are required only in the candidate optical verification concept which uses special photometrical techniques for geometric boresight alignment of the high-gain antenna.

The development status of these techniques is well advanced for use in the laboratory. They are currently able to provide surface distortion data for reflector antennas like those on the Space Station with a measurement accuracy of ±0.001 inch. These tests have been performed with special equipment inside high-vacuum space chambers equipped with solar simulators. The antenna is photometrically tested at required solar incident angles by rotating the assembly to the respective angle.

The techniques are not space qualified, however, and presently require trained personnel to adjust and calibrate the instrumentation as well as other personnel and computer programs to evaluate the data.

5.5.2.2 Special Test Equipment

Special test equipment is required for the candidate optical verification, solar radiometer, reflectometer analyzer, and impedance analyzer concepts. The optical verification concept requires the development of special space-qualified equipment with the long-term stability and reliability required on the Station. Requirements for the special test equipment would be determined from the precision necessary for the antenna positioner and controls and the allowable surface distortion of the high-gain antenna structure. The equipment should also have a capability for self-testing and for performing any occasional maintenance from within the Station.

The special test equipment development required for the reflectometer analyzer concept consists of a space-qualified ratio meter or resolver. This type of test equipment has a long history of successful operation in laboratories by trained personnel for measuring VSWR, reflection and transmission coefficients, and insertion loss. One system in wide laboratory use

C.3

today involves providing RF signals modulated or chopped at an audio frequency to the forward and reflected terminals of the analyzer. Another system in wide use only provides continuous-wave signals. The second approach is more suitable for this concept because of greater simplicity, sensitivity, and accuracy.

For the impedance analyzer concept, a resolver is required that measures phase as well as amplitude of the reflection or transmission coefficient. This is used only for performance verification and fault isolation of the comparator/feed assemblies on the high-gain antenna.

For the solar radiometer concept used for high-gain antenna boresight alignment, a special space-qualified radiometer is required for K_u-band operation. The current state of development of K_u-band radiometers is promising. Airborne-qualified units are available that are similar to those required to implement the concept, but are not suitable in this application because of the long-term stability, reliability, and the automatic self-test requirements imposed by Space Station missions.

5.6 GROUND SUPPORT

Although very little operational ground support is anticipated for any of the candidate communications subsystem checkout concepts, prelaunch ground support is required. Prelaunch support for the RF and antenna systems is considered in the following paragraphs.

5.6.1 RF System

The type and quantity of ground support equipment (GSE) required for checkout of the RF system is directly dependent on the level of testing employed. All checkout concepts identified in the study are based upon the assumption that parameters normally measured during LRU acceptance testing, such as harmonic distortion, frequency and spurious response, and bandwidth are not remeasured during prelaunch checkout. Measurements of this type require the use of sweep generators, spectrum analyzers, and distortion analyzers. Incorporation of sweep generators and analyzers within the operational LRU's could pose a serious design impact and is not recommended. If, however, it is deemed necessary to perform LRU-level acceptance testing, the design impact could be minimized by incorporating the sweep generators and analyzers in common modulation signal generators, or by providing a coupler on the data bus to which portable carry-on test equipment could be connected.

The use of operational signals for ground checkout requires the addition of RF transmitters and receivers to the GSE which are compatible with the onboard equipment. The amount of open-loop testing on the ground should be minimized because of RFI considerations. In addition, closed-loop checkout via an umbilical cable would be difficult at K_u-band frequencies because of the high cable attenuation.

The requirements of RF system prelaunch GSE are minimal. Except for the operational data and translator approaches, all of the candidate RF system checkout concepts include the capability to fault-isolate to the LRU level and to provide the necessary status data required for the level of checkout defined in this study.

5.6.2 Antenna System

The testing of antenna systems, as considered in this study, is primarily concerned with on-orbit requirements that can be satisfied with closed-loop stimuli and monitoring capabilities contained within the Space Station. Open-loop testing is confined to prelaunch ground testing where external stimuli for receive tests and external monitoring of transmit tests are more easily controlled.

It is anticipated that a series of high-gain antenna subassembly tests will be conducted during ground checkout. This will include tests that cannot be performed on a completely assembled antenna in an Earth gravity environment because the antenna gear drive is designed for a zero-g environment. The first test consists of demonstrating performance of the drive system before mating the reflector, feed, and RF electronics assemblies. The boresight performance is then checked by utilizing a large anechoic chamber with a phased-array antenna to provide simulated offset stimuli signals. The high-gain antennas are checked with their gimbals locked and are physically supported to remove the load from the bearings. Thus, the ground support impact from high-gain antenna testing is significant in terms of the equipment, trained personnel, and time required. This is true regardless of the onboard checkout concepts adopted.

The testing of low-gain antenna elements can be accomplished by coupling hats that provide essentially an isolated transmission path for stimuli. These do alter the radiation characteristics of the antenna, but for close-quarters checkout it provides usable data for go-no/go decisions.

5.7 GROSS SCHEDULE AND COST

Gross estimates of the schedule and cost impacts associated with implementing the candidate checkout concepts are described below.

5.7.1 Schedule

It is difficult to estimate the schedule impact on any of the concepts except in general terms. It is assumed that the preferred onboard checkout concept is defined at the time the LRU design is initiated. A concept which requires the design of additional LRU's or increases the complexity of an existing LRU presents an additional schedule risk. For the Space Station, however, this involves a parallel design effort, not a serial one. Furthermore, if it is not to present more problems than advantages, the checkout portion of the design should be less complex than the basic LRU. There is no clear-cut reason to expect a schedule slip due to the incorporation of the checkout circuitry if it is part of the initial design effort and is not added at a later time. For this reason, the schedule impact data consist of only identifying those areas where an increased schedule risk might be incurred if the proposed concept is adopted.

A concept in which the checkout circuitry is not contained within the basic LRU's would have a potential schedule risk advantage in that delivery of initial operational equipment could not be delayed by checkout circuitry problems, and preliminary communications subsystem tests could be made without checkout capability. Assuming that checkout concepts are completely defined at the time of LRU design, minimal, if any, schedule risk is expected as a result of incorporating the concepts.

5.7.2 Cost Estimates

Relative nonrecurring (NR) and recurring (R) costs for the hardware portions of the concepts are estimated in Table 5-4. Each combination of stimuli generation/detection and monitoring concept is rated in terms of its relative cost increase over the baseline case which utilizes operational data as the test stimuli and the DMS for evaluation. The design and hardware estimates are based on the communications subsystem cost estimates prepared for the 33-ft Space Station. Costs have not been prepared for the DMS hardware or software. While care has been taken in the preparation of the cost data, it should be recognized that they are only estimates.

The cost estimates are based on the following assumptions:

A. Costs are stated in 1971 dollars.
B. The checkout concept is completely defined at the start of LRU design.
C. Recurring costs are on a per system basis.

The LRU modification costs due to the incorporation of internal generators are based upon the inclusion of such generators in each LRU which interfaces either the DMS bus (or RDAU) or the antenna subsystem. In the case of antenna interfaces, the generator is assumed to provide a single carrier frequency and either selectable thresholds or strong signal levels. Baseband and subcarrier modulation is provided to exercise each path back to the DMS bus. Only single frequency (or data rate) and single level signals are assumed. In the case of antenna interfaces, single-frequency and single-level modification inputs are provided to exercise each path to the antenna subsystem interface.

Table 5-4

RELATIVE COST ESTIMATES

Monitoring Concepts \ Stimuli and Detection Concepts	DMS and Bus Test Generator	LRU Internal Test Generator	Operational Data	Translator	Centralized Test Unit
Operator evaluation of performance (PTE required)	(NR) 1.11 (R) 1.03	(NR) 1.05 (R) 1.02	(NR) 1.03 (R) 1.01	(NR) 1.08 (R) 1.03	(NR) 1.10 (R) 1.04
Go-no/go provided by LRU Operator evaluation of test point (PTE required)	(NR) 1.13 (R) 1.04	(NR) 1.07 (R) 1.03	(NR) 1.05 (R) 1.02	(NR) 1.10 (R) 1.04	(NR) 1.12 (R) 1.04
LRU go-no/go plus DMS evaluation	(NR) 1.11 (R) 1.04	(NR) 1.05 (R) 1.03	(NR) 1.03 (R) 1.02	(NR) 1.07 (R) 1.03	(NR) 1.09 (R) 1.04
DMS evaluation	(NR) 1.09 (R) 1.02	(NR) 1.03 (R) 1.01	(NR) 1.00 (R) 1.00	(NR) 1.05 (R) 1.02	(NR) 1.07 (R) 1.02
LRU go-no/go plus MCU evaluation	(NR) 1.14 (R) 1.05	(NR) 1.08 (R) 1.04	(NR) 1.06 (R) 1.03	(NR) 1.10 (R) 1.04	(NR) 1.12 (R) 1.05
MCU evaluation	(NR) 1.12 (R) 1.04	(NR) 1.06 (R) 1.03	(NR) 1.04 (R) 1.02	(NR) 1.08 (R) 1.03	(NR) 1.10 (R) 1.04

The LRU modification costs necessary to provide raw data signals to the DMS for evaluation of inputs and internal process monitoring are included but are minimal since many of these sensors are included in the previous LRU costs for the 33-ft Space Station.

The LRU modification costs necessary to provide go-no/go signals include: (1) control mode logic sensors; (2) input signal level sensors; (3) internal monitor sensors keyed to (1) and (2); and (4) logic to combine the results of (1), (2), and (3) to provide the go-no/go output.

Referring to Table 5-4, it can be seen that the increase in NR costs range from a minimum of 2 percent to a maximum of 14 percent. The increase in recurring costs range from 2 to 5 percent. It is felt that the relative increase in costs are accurate within plus or minus 2 percent.

A cost comparison for the implementation of antenna system detectors (Table 5-5) indicates the relative savings in both the high- and low-gain antenna systems of using LRU internally generated stimuli in lieu of a separate antenna stimuli generator. Also shown is the relative cost savings in using a self-modulating envelope detector instead of a mixer detector for RF power monitoring. To provide a more realistic comparison, the reference cost used as the normalizing factor includes the cost of the LRU generators.

Table 5-5

RELATIVE COST ESTIMATES—DETECTOR IMPLEMENTATION

Detector Method	Stimuli Source	Modulated Antenna Generator		Unmodulated LRU Stimuli (Receive Stimuli in Receiver LRU) (Transmit Stimuli-Operational Carrier)	
Low-Gain System	Envelope	NR	1.36	NR	1.00
		R	1.87	R	1.00
	Mixer	NR	1.46	NR	1.12
		R	2.00	R	1.18
High-Gain System	Envelope	NR	1.10	NR	1.00
		R	1.13	R	1.00
	Mixer	NR	1.12	NR	1.02
		R	1.14	R	1.02

Section 6
BASELINE DATA AND REQUIREMENTS ANALYSIS

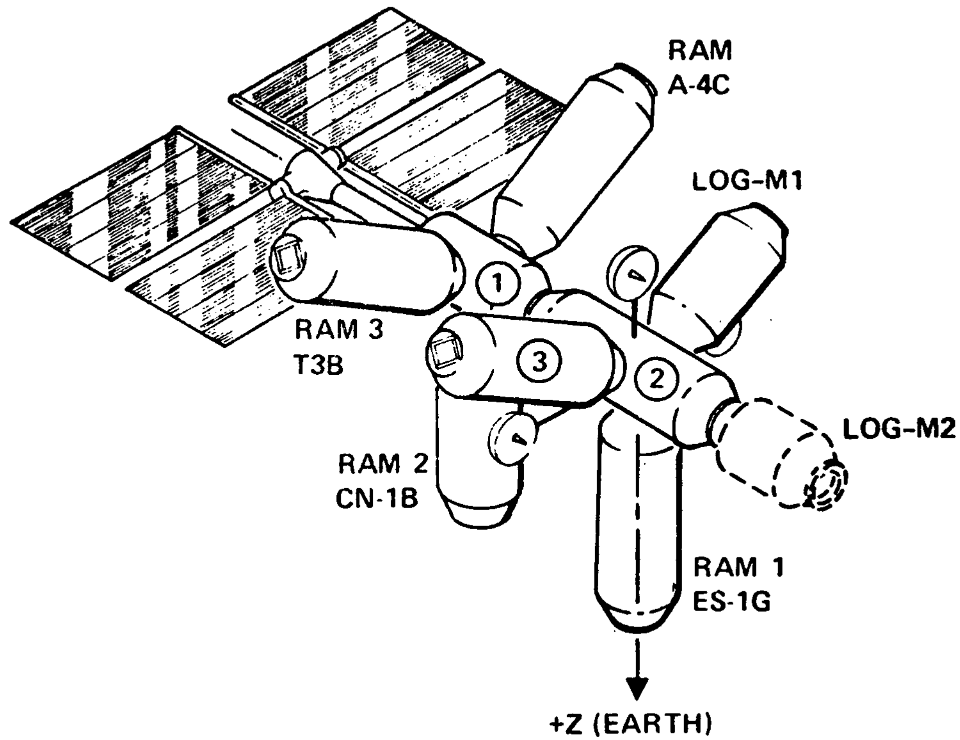
This section presents the baseline data and maintenance guidelines used in the study. The section also presents the results of analyses conducted to establish communications subsystem line replaceable units (LRU's) and the detailed requirements for subsystem checkout and fault isolation. This basic information is derived primarily from the MSFC/MDAC Modular Space Station studies performed under Contract NAS8-25140.

6.1 BASELINE DATA

Baselines for the communications, data management, and onboard checkout subsystems are described in Reference 1 and summarized in the following paragraphs. Prelaunch and flight operations defined for the Modular Space Station are presented in References 2 and 3 and also briefly discussed below.

These baselines are those defined for the Initial Space Station (ISS) depicted in Figure 6-1. The ISS is delivered to orbit by three Space Shuttle launches and assembled in space. The Power/Subsystems Module is launched first, followed at 30-day intervals by the Crew/Operations Module and General Purpose Laboratory (GPL) Module. The ISS provides for a crew of six. Resupply and crew rotation are carried out via round-trip Space Shuttle flights using Logistics Modules for transport and on-orbit storage of cargo.

A second group consisting of a Power/Subsystems Module and Crew/Operations Module that may be launched 5 years later would provide for growth to a full 12-man capability or Growth Space Station (GSS). The ISS configuration is the only one considered in this study since a Phase B level definition of the GSS is not available.



LAUNCH SEQUENCE/MODULE	1*	2*	3*	
PRIMARY FUNCTION	POWER/ SUBSYS	CREW/ OPNS	GPL	LOG M
CREW LAUNCHED	0	0	0	2

* 2 MEN ACTIVATION CREW POTENTIAL FOR SHUTTLE ORBITAL DURATION

Figure 6-1. Initial Space Station (ISS)

6.1.1 Communications Subsystem

The communications subsystem provides RF communications between the ISS and the ground, either directly to the NASA ground network or through the NASA data relay satellite system (DRSS). Communications are also provided between the ISS and Space Shuttle during rendezvous and docking operations and for crewmen engaged in extravehicular activity (EVA). The ISS RF communications channel requirements and frequency allocations are summarized in Figure 6-2.

The internal communications system provides nominal voice communications between crew quarters, equipment compartments, duty stations, and docked modules. Emergency voice communications, public address, and entertainment audio reception capabilities are also provided.

6.1.1.1 Summary

Direct communications with the ground stations are provided by an S-band transponder which receives voice, commands, and ranging information at approximately 2.1 GHz and transmits voice, telemetry, and ranging data at a frequency between 2.2 and 2.3 GHz. An S-band FM exciter and power amplifier having a power output of 20 watts operating between 2.2 and 2.3 GHz is also provided for the transmission of video and digital experiment data. Two-way voice, low-rate-data, and ranging communications with the Shuttle are also provided by the same S-band transponder used for direct ground communications. However, a power amplifier operating in conjunction with the transponder is required to provide simultaneous voice, data, and ranging at ranges up to 200 km. A common, low-gain S-band antenna system is utilized for communications with both the ground and the Shuttle.

Communications with the DRSS are provided by K_u-band transmitting and receiving systems operating in the 14.4 to 15.35 GHz and 13.4 to 14.2 GHz frequency bands, respectively. A power output of 20 watts operating in conjunction with an 8-ft-diameter high-gain antenna is required to provide for commercial-quality television or up to 10-Mbps digital data transmissions

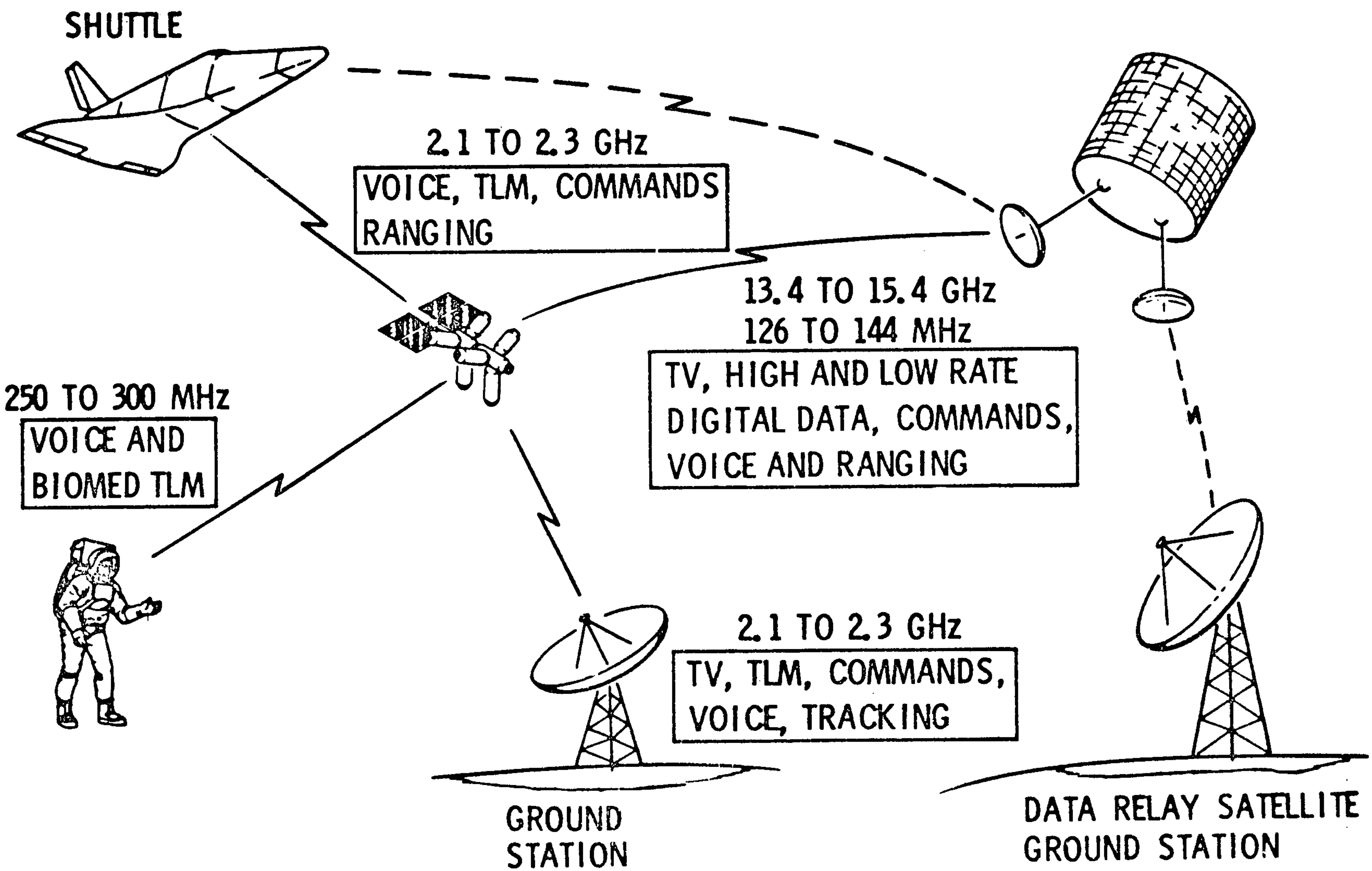


Figure 6-2. Radio-Frequency Allocations

through the DRSS. Multiple voice channels, medium data rates up to 100 Kbps, and turned-around ranging transmissions are provided simultaneously with the wideband transmission on a separate carrier. A receiving system noise temperature of approximately 1, 000°K is required for the reception of television from the relay satellite. Simultaneous reception of multiple-voice, medium-rate-data, and ranging information is also provided.

Two-way voice and up to 10-kbps low-data range communications between the ISS and DRSS are also provided in the VHF band at frequencies between 126 and 130 MHz and 136 to 144 MHz. These links utilize a low-gain antenna system which provides nearly omnidirectional coverage.

Full-duplex voice communications with crewmen engaged in EVA and the reception of crew biomedical telemetry are provided. These channels utilize frequencies in the 250 to 300 MHz band. The VHF links are multiplexed into a common VHF low-gain antenna system.

6.1.1.2 Description

The VHF and S-band equipments utilized for communications with the DRSS, Space Shuttle, NASA ground stations, and EVA are located in the Power/Subsystems Module. A block diagram showing the VHF and S-band equipment, including low-gain (omni) antennas, transmitters, receivers, modems, and audio terminals is shown in Figure 6-3.

The K_u-band and S-band equipments required to provide wideband data transmission and reception with the DRSS are located in the Crew/Operations Module. A block diagram depicting the high-gain antenna system, power amplifiers, exciters, receivers, and modems is shown in Figure 6-4. The analog sync/test unit which generates the reference signals required for operation of the onboard telephone system and audio terminals located in this module is also shown. The total complement of RF equipmentsis contained within the Power/Subsystem and Crew/Operations Modules. However, additional audio terminals are required in the GPL and docked modules.

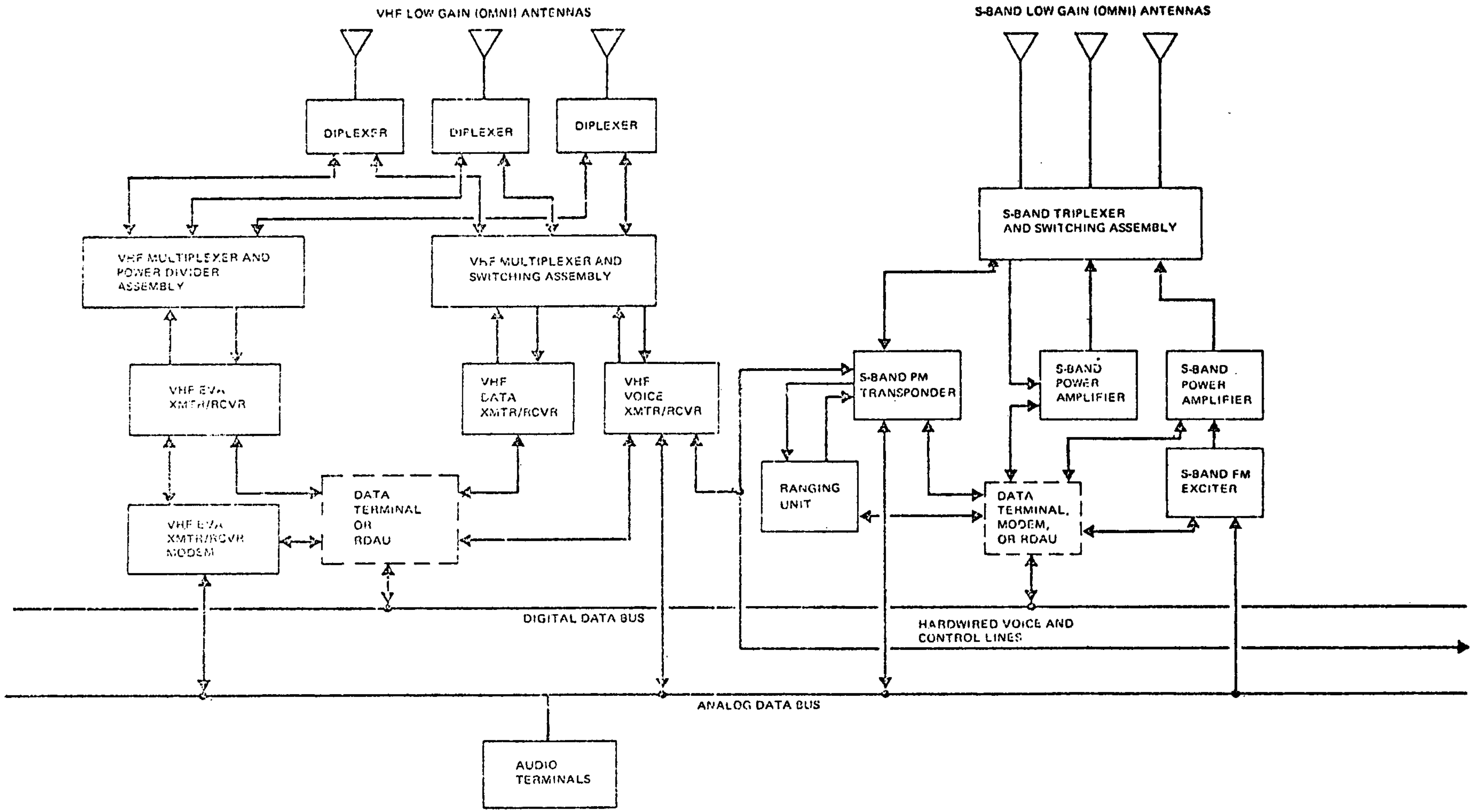


Figure 6-3. Power/Subsystem Module Communications Equipment Complement

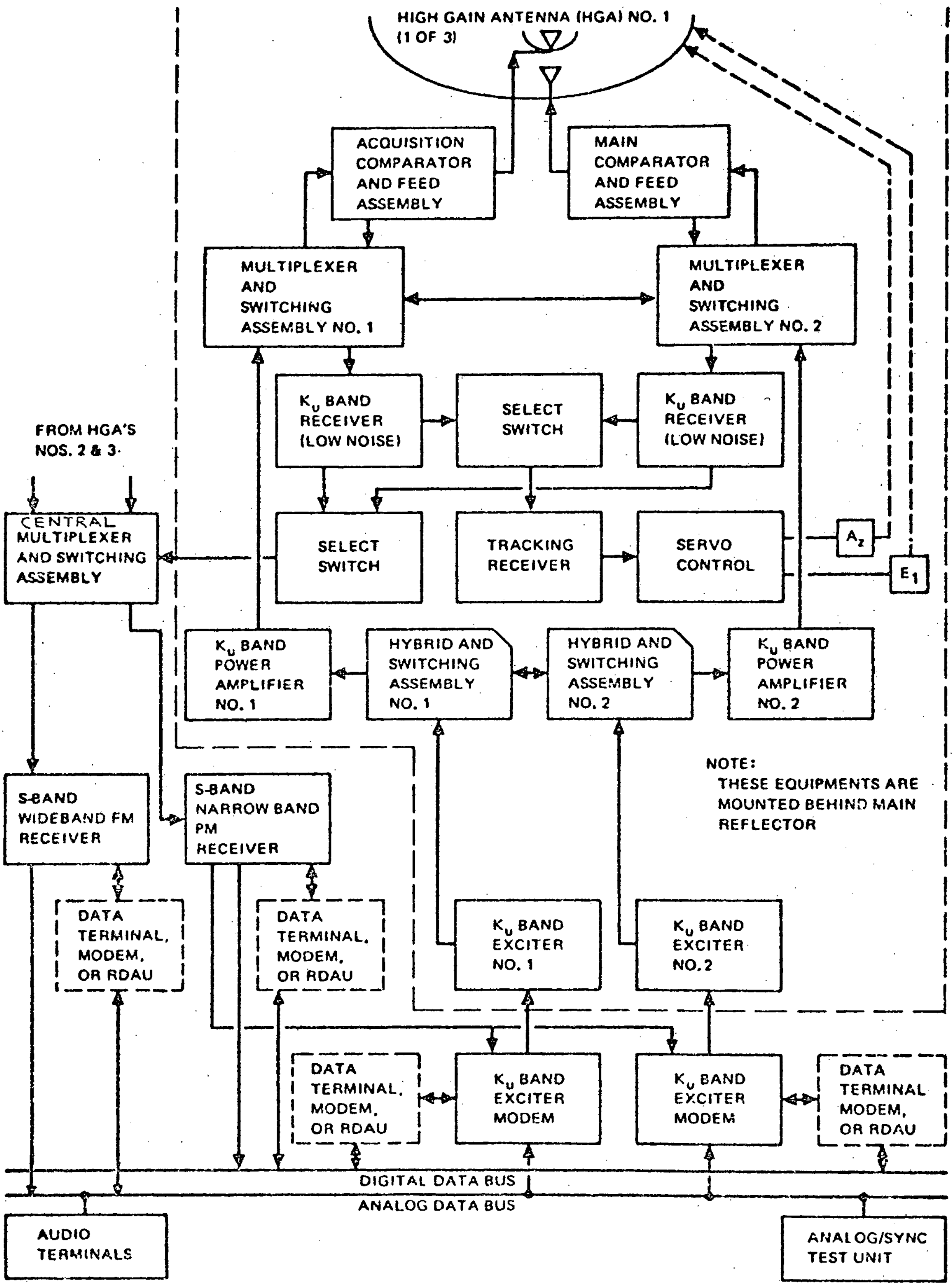


Figure 6-4. Crew/Operations Module Communications Equipment Complement

Descriptions and lower-level block diagrams of the high- and low-gain antenna systems, RF system, and internal communications system are provided below.

Antenna System Description

Descriptions of the K_u-band high-gain and VHF and S-band low-gain antenna assembly groups are presented in the following paragraphs.

High-Gain Antenna Assembly Group—The high-gain antenna assembly group consists of three independently controlled 8-ft parabolic reflectors which are located on the Crew/Operations Module and are separated by 120 degrees. They are located at 60, 180, and 300 degrees referenced to the +Z axis as shown in Figure 6-5. This assembly group includes main and acquisition aid antennas, multiplexer and switching assemblies, main and acquisition comparator/feed assemblies as shown in Figures 6-6 and 6-7, S-band tracking receivers as shown in Figure 6-8, antenna positioner and positioner servo controls as shown in Figures 6-9 and 6-10, and low-noise K_u-band receivers as shown in Figure 6-11. The high-gain antenna assembly group design is based on the performance requirements shown in Table 6-1.

As shown in Figure 6-6, the RF signals received by the four horns are combined in the RF comparator network of the main comparator and feed assembly. The resulting azimuth and elevation difference channel outputs are chopped by the timing switch and then combined with the sum channel output in the coupler. The amplitude-modulated RF carrier is subsequently detected in the S-band tracking receiver to provide steering error signals. A separate horn is utilized to illuminate the subreflector on transmit. The acquisition comparator and feed assembly is very similar except that only four horns are used.

The high-gain antenna system acquisition and tracking procedure requires initial pointing information generated by the onboard DMS computer. Upon acquisition and lock of an RF signal transmitted by the DRSS by the high-gain

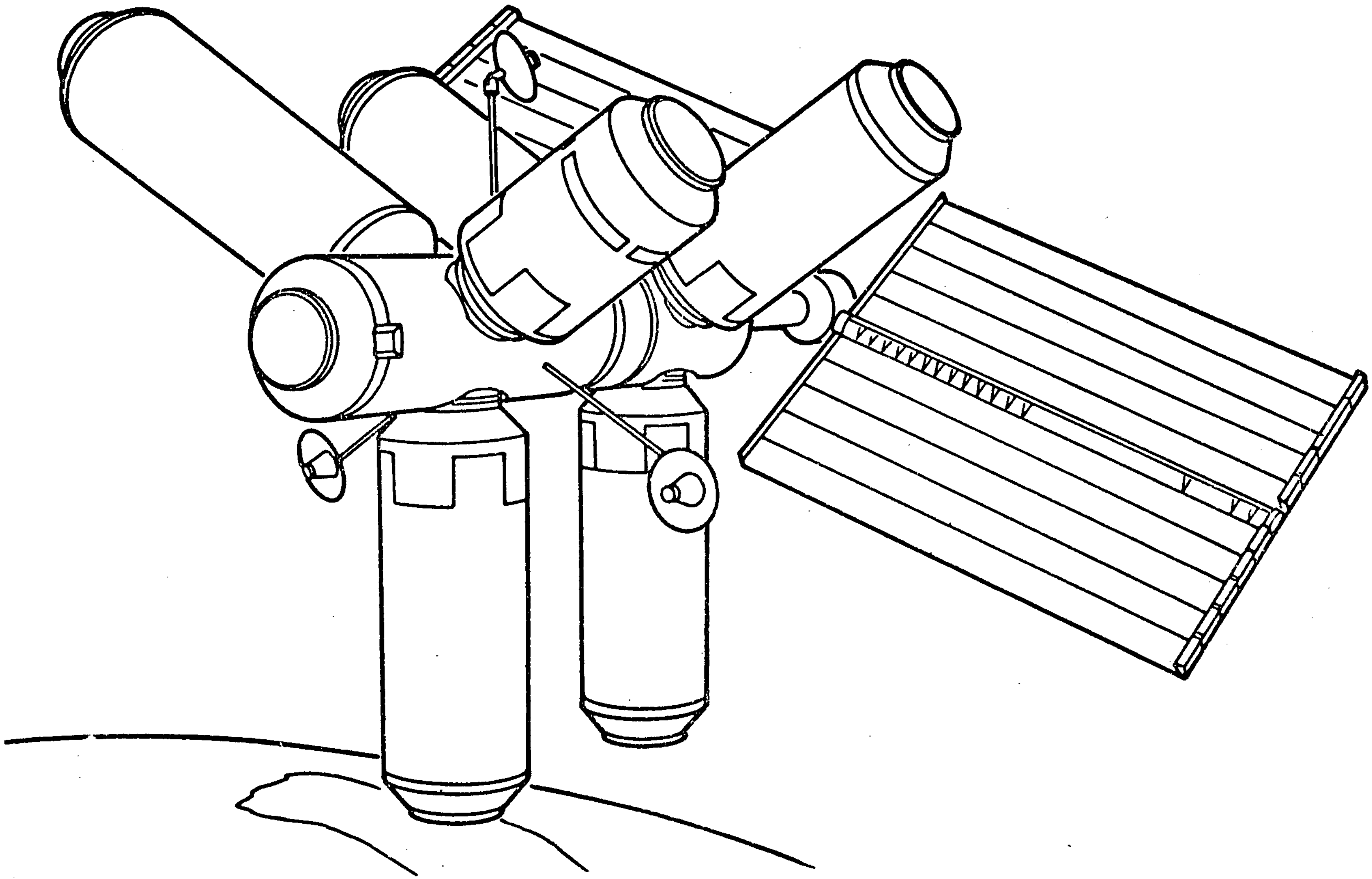


Figure 6-5. ISS Antenna Locations

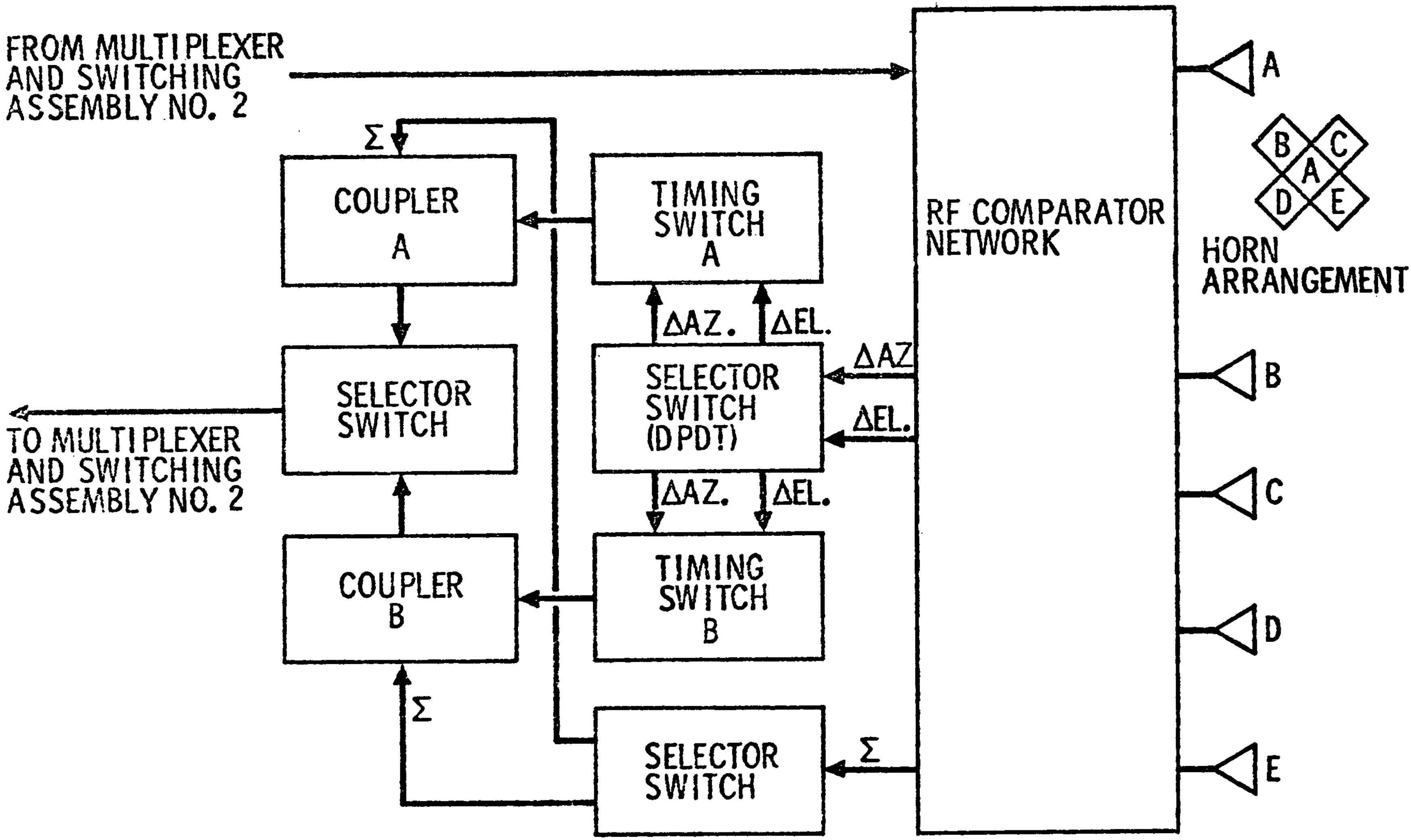


Figure 6-6. Main Comparator and Feed Assembly

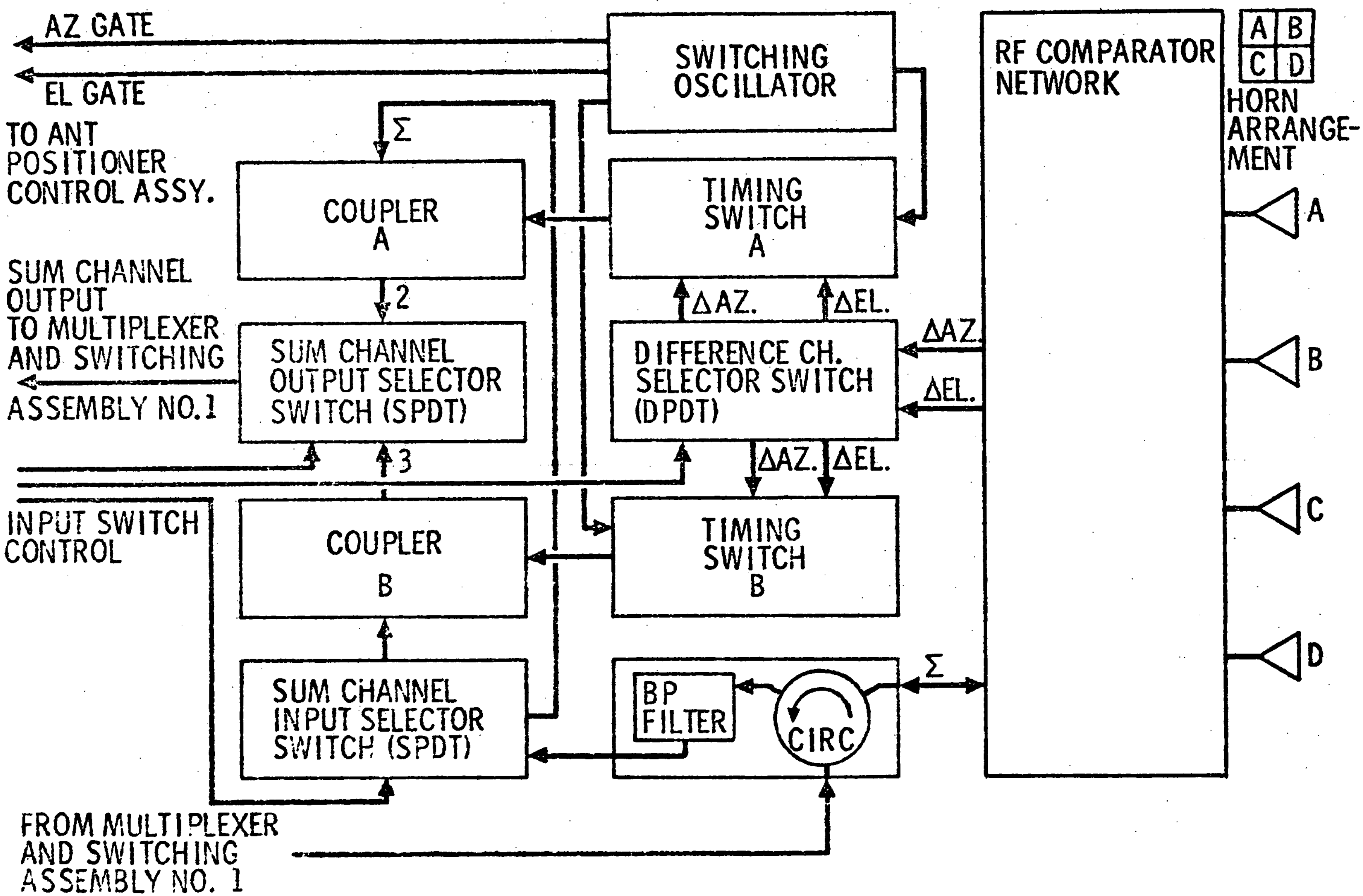


Figure 6-7. Acquisition Comparator and Feed Assembly

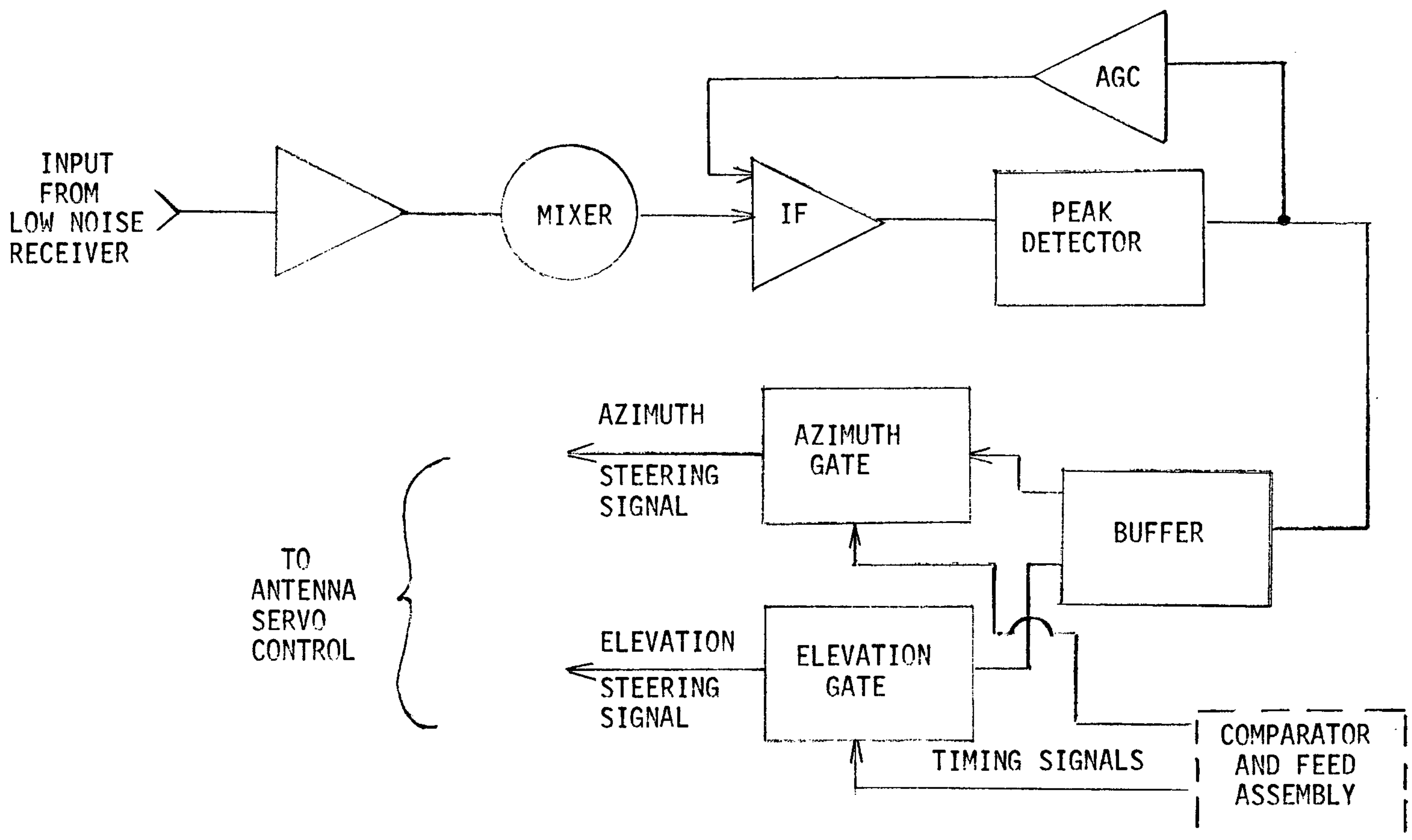


Figure 6-8. S-Band Tracking Receiver

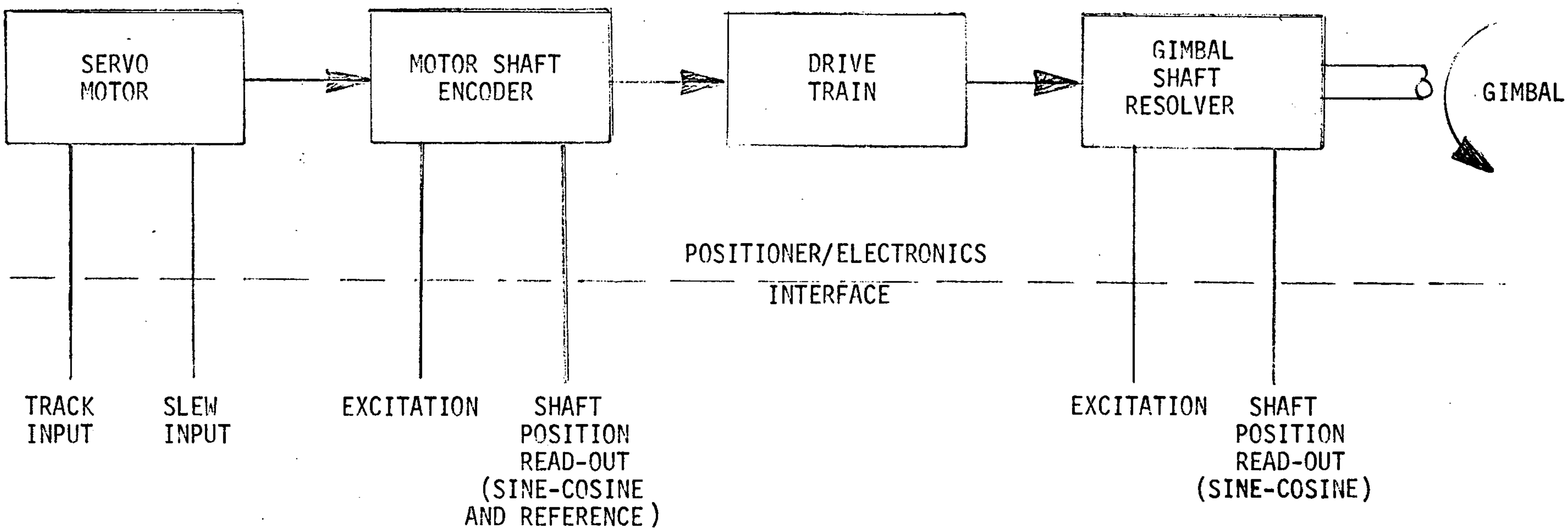


Figure 6-9. High-Gain Antenna Positioner

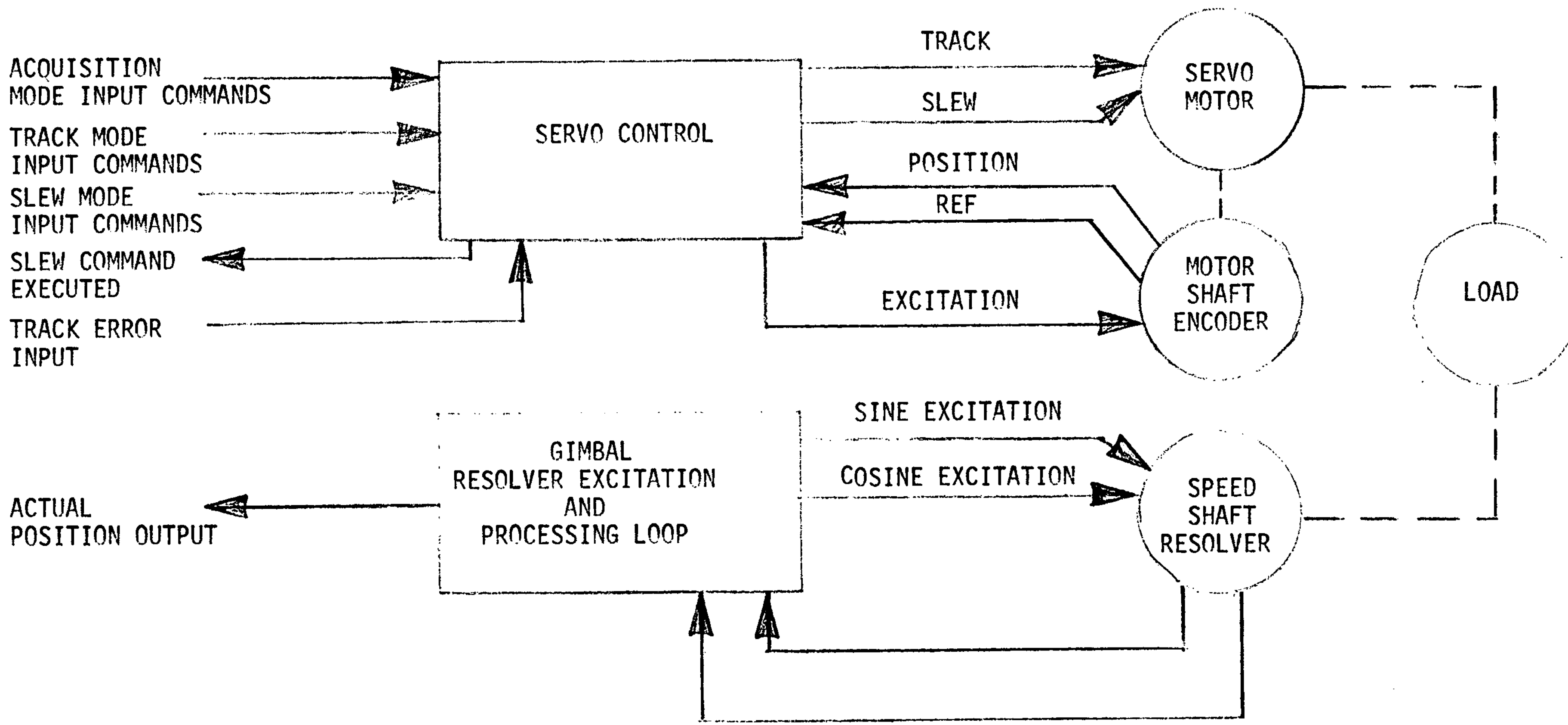


Figure 6-10. High-Gain Antenna Position Servo Control

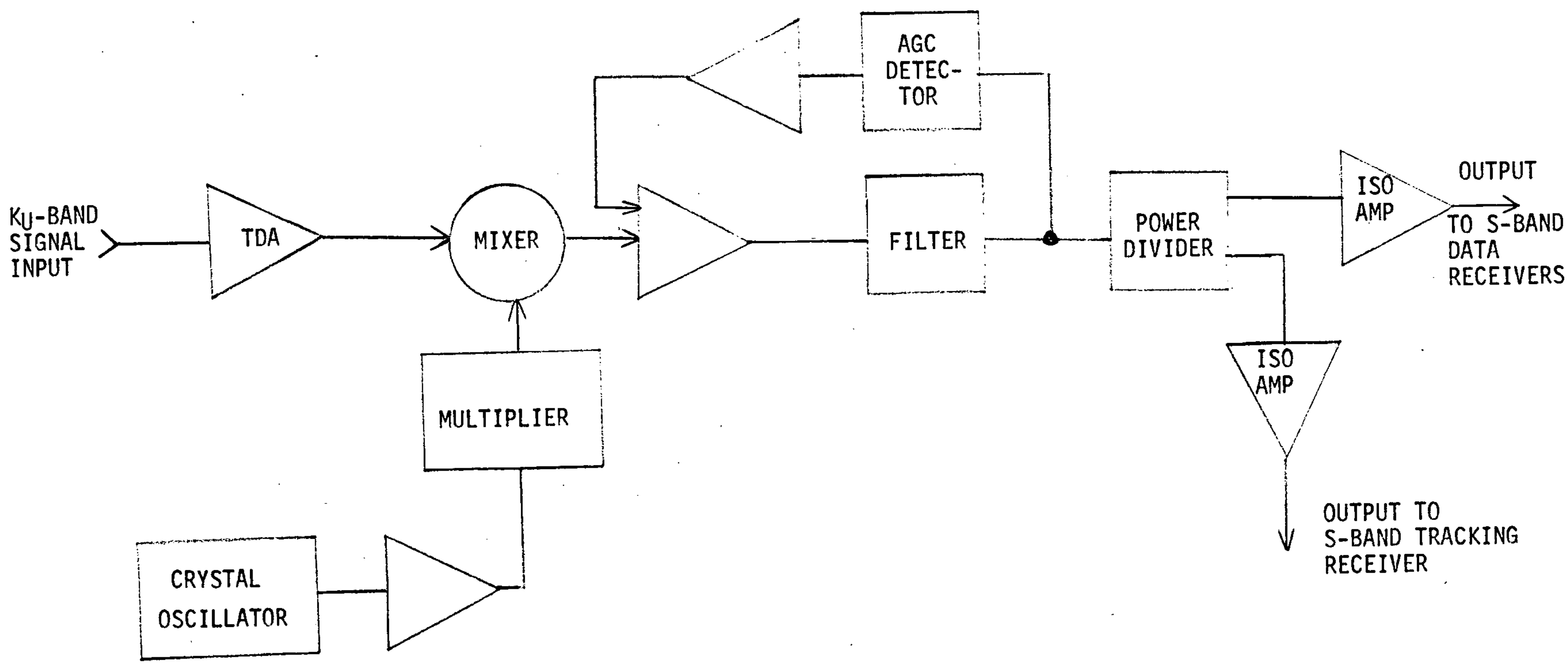


Figure 6-11. K_u-Band Low-Noise Receiver

Table 6-1

HIGH-GAIN ANTENNA PERFORMANCE CHARACTERISTICS

Nominal transmit frequency	14.5 GHz
Nominal receive frequency	13.5 GHz
Minimum G/T (including all losses)	15.0 db/°K
Minimum EIRP (including all losses)	60.0 dbw
Minimum antenna RF bandwidth	20.0 MHz
Mast-mounted equipment:	
Transmit	
Power amplifier output (20 watts)	13 dbw
System loss (maximum)	1.5 db
Antenna gain (minimum)	50.0 db
EIRP (minimum)	61.5 dbw
Receive	
Antenna gain (minimum)	49.4 db
System loss (maximum)	2.0 db
System temperature (maximum) (6.5 db noise figure)	30.0 db/°K
G/T_S (minimum)	17.4 db/°K
Acquisition	
Antenna gain (minimum)	29 db
Insertion loss (maximum)	1.7 db

antenna pseudo-monopulse tracking system, the drive information from the computer is terminated. In the event that the RF tracking signal "drops out" during a communications pass, the computer is called upon to drive the antenna until the RF signal is reacquired.

Prior to an anticipated communications contact with a relay satellite, the computer runs a prepass simulation to determine the look angles to the DRSS. It is estimated that the look-angle predictions should be performed in 30-sec to 1-min increments. Each look angle is then tested to determine which antennas are blocked by the docked modules and solar arrays as a function of time. The optimum antenna for providing communications during the next pass is then selected. In the event that the prepass simulation shows that switchover from one antenna to another is required during a communications pass to eliminate blockage due to the docked modules, the second antenna is slewed into position and acquires the DRSS RF signal before the blockage occurs. Since overlapping coverage is provided for the docked modules, it is anticipated that the switchover procedure will cause little or no loss of communications.

Low-Gain Antenna Assembly Group—The low-gain antenna assembly group consists of separate VHF and S-band antenna systems. Both of these systems consist of flush-mounted, slot-type antenna elements located on the Power/ Subsystems Module and separated by 120 degrees. They are located approximately at 60, 180, and 300 degrees referenced to the +Z axis. The performance characteristics of the low-gain antenna system are summarized in Table 6-2.

The VHF system consists of three "dumbbell" circumferential slot antennas, diplexers, a multiplexer and power divider assembly, and a multiplexer and switching assembly. The multiplexer and power divider assembly allows the three antennas to be fed simultaneously, thus eliminating any requirement for antenna switching during EVA operations. However, during normal voice and low-data-rate communications with the DRSS, the multiplexer and switching assembly allows the optimum antenna to be selected. All three antennas are capable of being fed simultaneoulsy during contingency operations. A block diagram of the VHF multiplexer and switching assembly is shown in Figure 6-12.

The S-band system consists of three circumferential slot antennas which can be selected individually or fed simultaneously. The S-band triplexer and switching assembly, shown in Figure 6-13, allows for the simultaneous

Table 6-2

LOW-GAIN ANTENNA PERFORMANCE CHARACTERISTICS

VHF System	
Gain	
Individually	0 db minimum over a 120 deg beam-width referenced to a right-hand circularly polarized (RCP) source.
Simultaneously	-10 db minimum over 90 percent of sphere referenced to an RCP source.
Insertion loss	
Individually	2 db (maximum)
Simultaneously	7 db (maximum)
Impedance	50 ohm (nominal)
S-band System	
Gain	
Individually	-3 db minimum over a 120 deg beam-width referenced to a RCP source.
Simultaneously	-13 db minimum over 90 percent of a sphere referenced to an RCP source.
Insertion loss	
Individually	2 db (maximum)
Simultaneously	7 db (maximum)
Impedance	50 ohms (nominal)

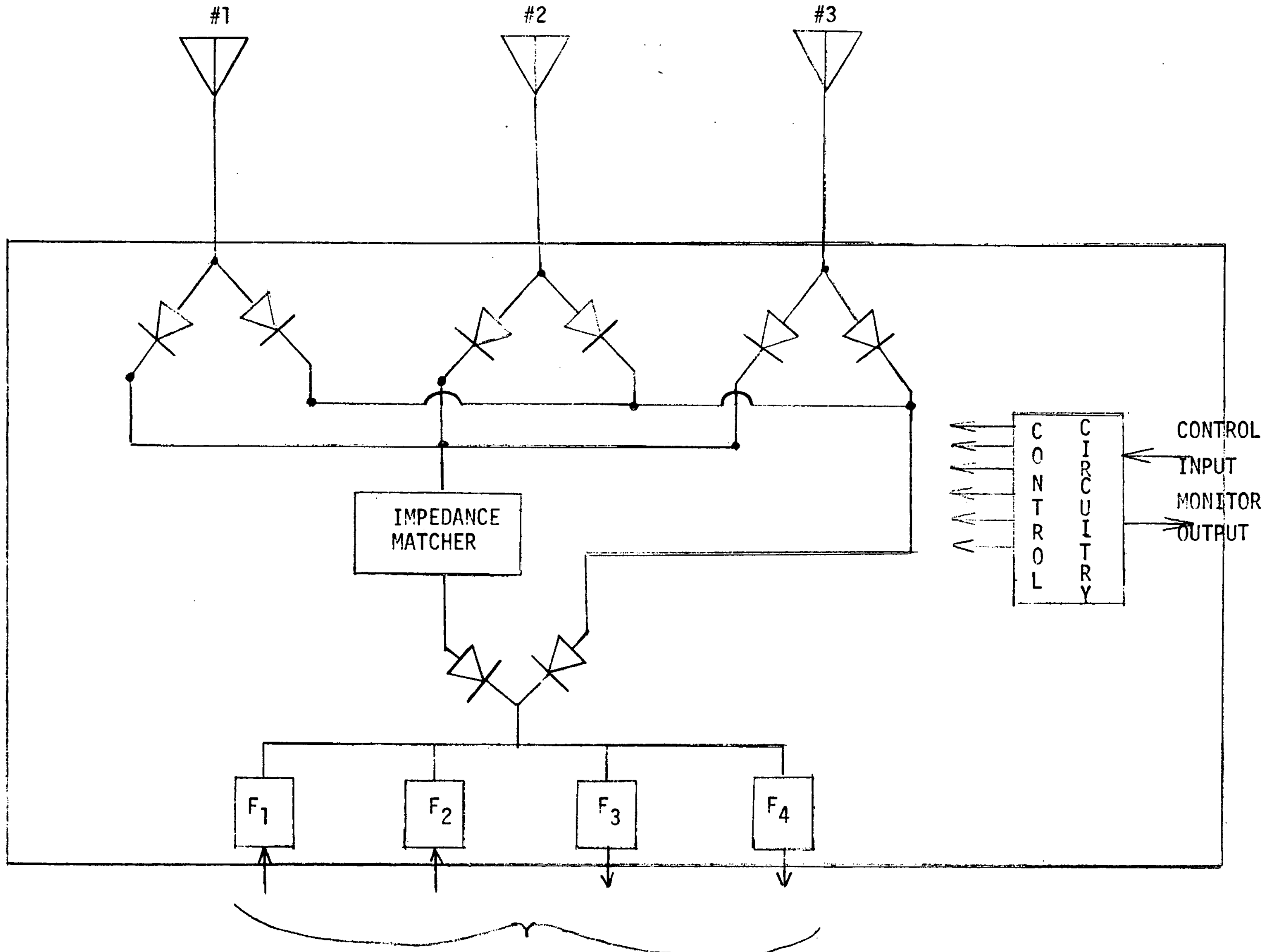


Figure 6-12. VHF Multiplexer and Switching Assembly

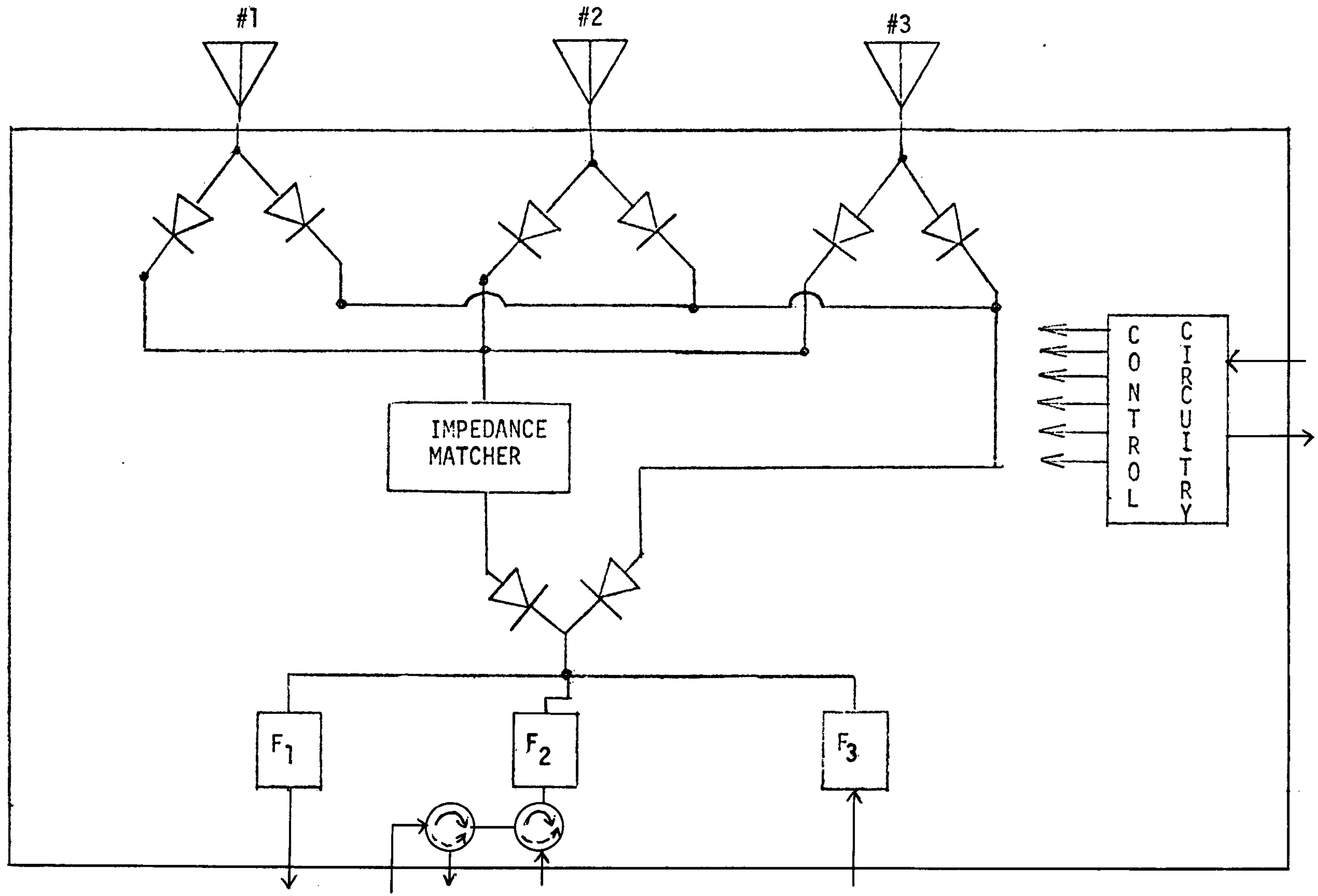


Figure 6-13. S-Band Triplexer and Switching Assembly

reception of one carrier and the transmission of two carriers. It interfaces between the S-band transponder and power amplifiers and the S-band low-gain antenna elements. It consists of solid-state RF switches which select the appropriate antenna, filters which provide isolation between the transmit and receive paths, and a bypass switch which allows the transponder to be connected directly to the antennas or routed to a power amplifier.

RF Assembly Descriptions

The RF assemblies for the VHF, S-band, and K_u-band systems are described in the following paragraphs.

EVA VHF Transmitter/Receiver—The EVA VHF voice transmitter/receivers provide for the transmission and reception of voice communications between personnel engaged in EVA and the ISS. It also provides for simultaneous reception of biomedical data from the EVA units. The transmitter provides an output of 1 milliwatt, frequency modulated with 6-kHz peak-to-peak baseband voice signals from the EVA voice transmitter/receiver modem. The receiver has a noise figure of 4 db and a predetection bandwidth of 50 kHz. A block diagram of the LRU is shown in Figure 6-14.

The receiver demodulates the incoming frequency-modulated signals consisting of baseband voice and biomedical data subcarriers, and provides the composite signal as an output to the EVA voice transmitter/receiver modem.

EVA Voice Transmitter/Receiver Modem—The EVA voice transmitter/receiver modem provides an interface between a group of three transmitters and receivers used to handle EVA voice and biomedical signals, and the analog/digital data bus. A block diagram of the unit is shown in Figure 6-15.

The unit contains circuitry similar to that of the audio terminal units discussed later, to enable the unit to be dialed up from any other audio terminal unit in the station, and to provide the composite voice signals from the three receivers as an output on that same circuit.

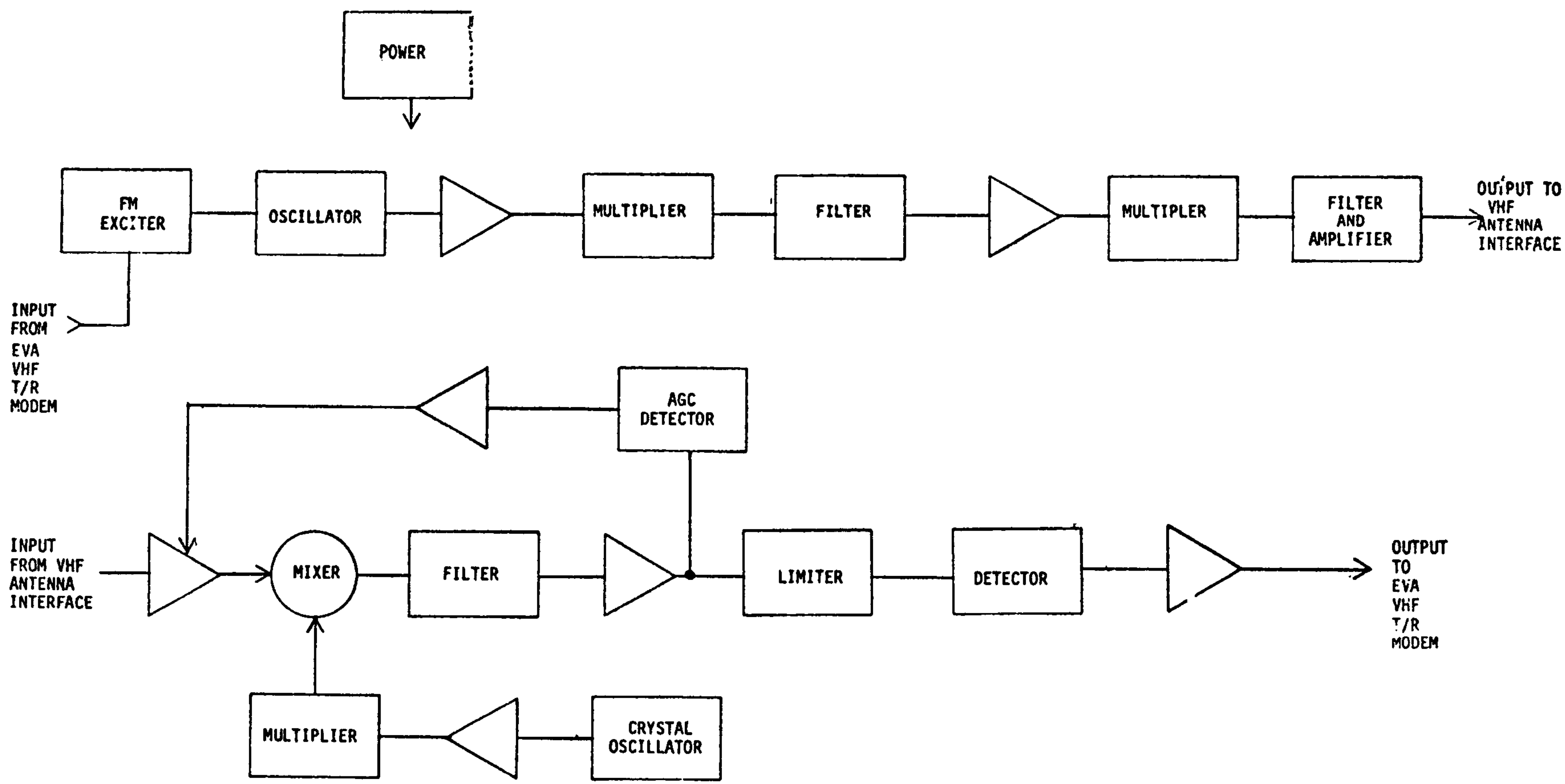


Figure 6-14. EVA VHF Voice Transmitter/Receiver

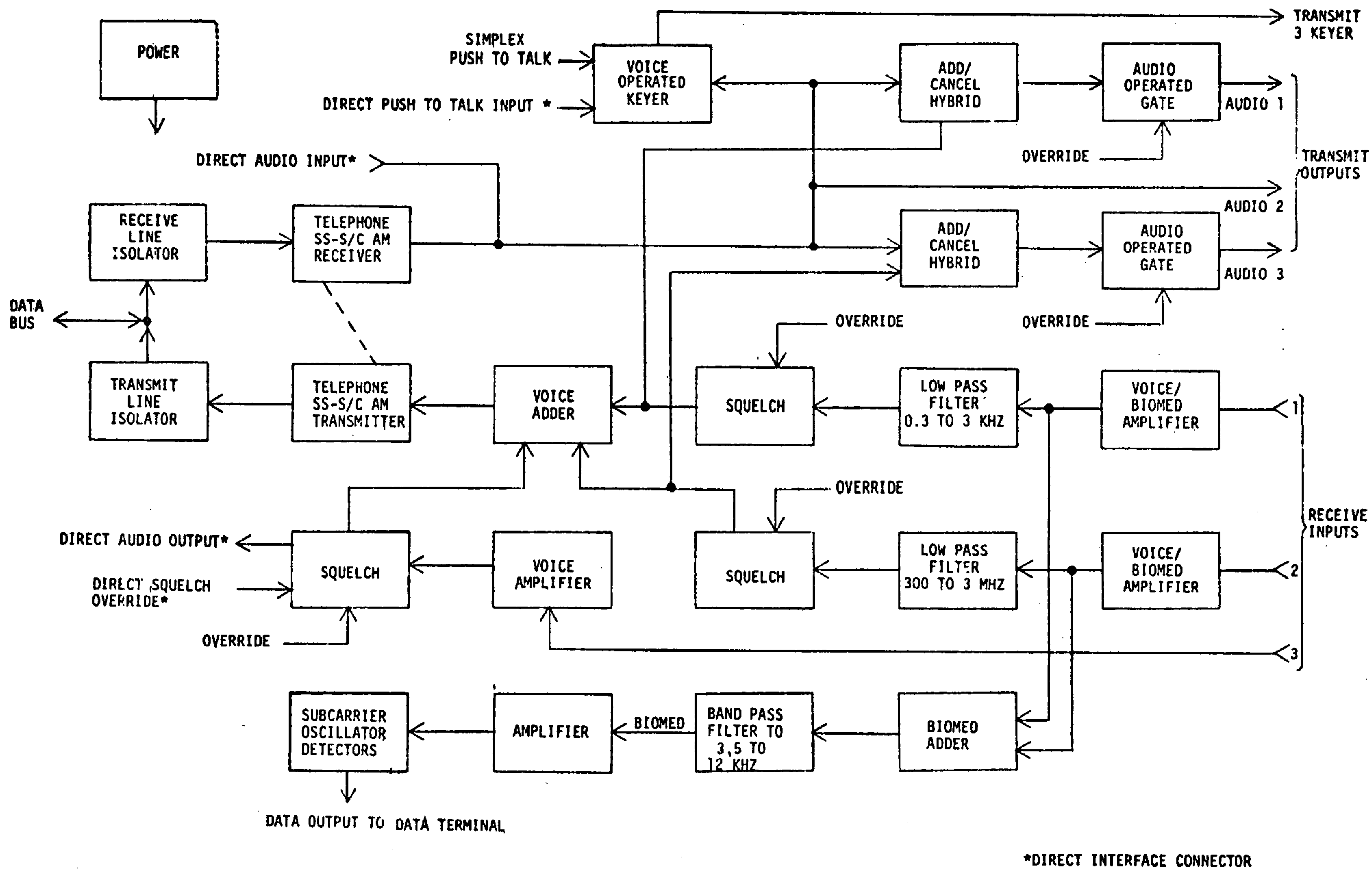


Figure 6-15. EVA VHF Voice Transmitter/Receiver Modem

Two of the receiver inputs contain biomedical data signals in the form of modulated subcarriers, and circuitry is provided to separate them from the voice signals, demodulate them, and provide the data as outputs to a digital data terminal.

Conferencing is accomplished by routing the voice signal received from one crew member to the audio output associated with the transmitter tuned to the second crew member's receiver (through commands received via a digital data terminal of the DMS). Squelch circuitry is provided to suppress noise in the circuits when they are not in actual use; however, a capability to override this feature is also provided.

Voice signals originating from the onboard controller can be used to modulate any or all of the audio outputs.

VHF Data Transmitter/Receiver—The VHF data transmitter/receiver provides digital data communications between the ISS and a relay satellite in the frequency band from 126 to 144 MHz. Frequency modulation is used on both transmission and reception. A block diagram is shown in Figure 6-16. The transmitter provides a 20-watt RF output, with data rates up to 10 kbps and deviations of up to 10-kHz peak to peak. The receiver accepts inputs having the same modulation characteristics and provides the detected signals as an output to a DMS digital data terminal. The receiver has a noise figure of 4 db and a 50-kHz predetection bandwidth.

VHF Voice Transmitter/Receiver—The VHF voice transmitter/receiver provides voice communications between the ISS and a relay satellite in the 126 to 144 MHz frequency band. Frequency modulation is used on both transmission and reception. A block diagram is shown in Figure 6-17. The transmitter provides a 20-watt RF output, with baseband voice modulation and a peak-to-peak deviation of 6 kHz. The receiver accepts an input having the same modulation characteristics and provides the detected voice signal as an output. The receiver has a noise figure of 4 db and a 50-kHz predetection bandwidth. Control of the unit is by means of an associated digital data

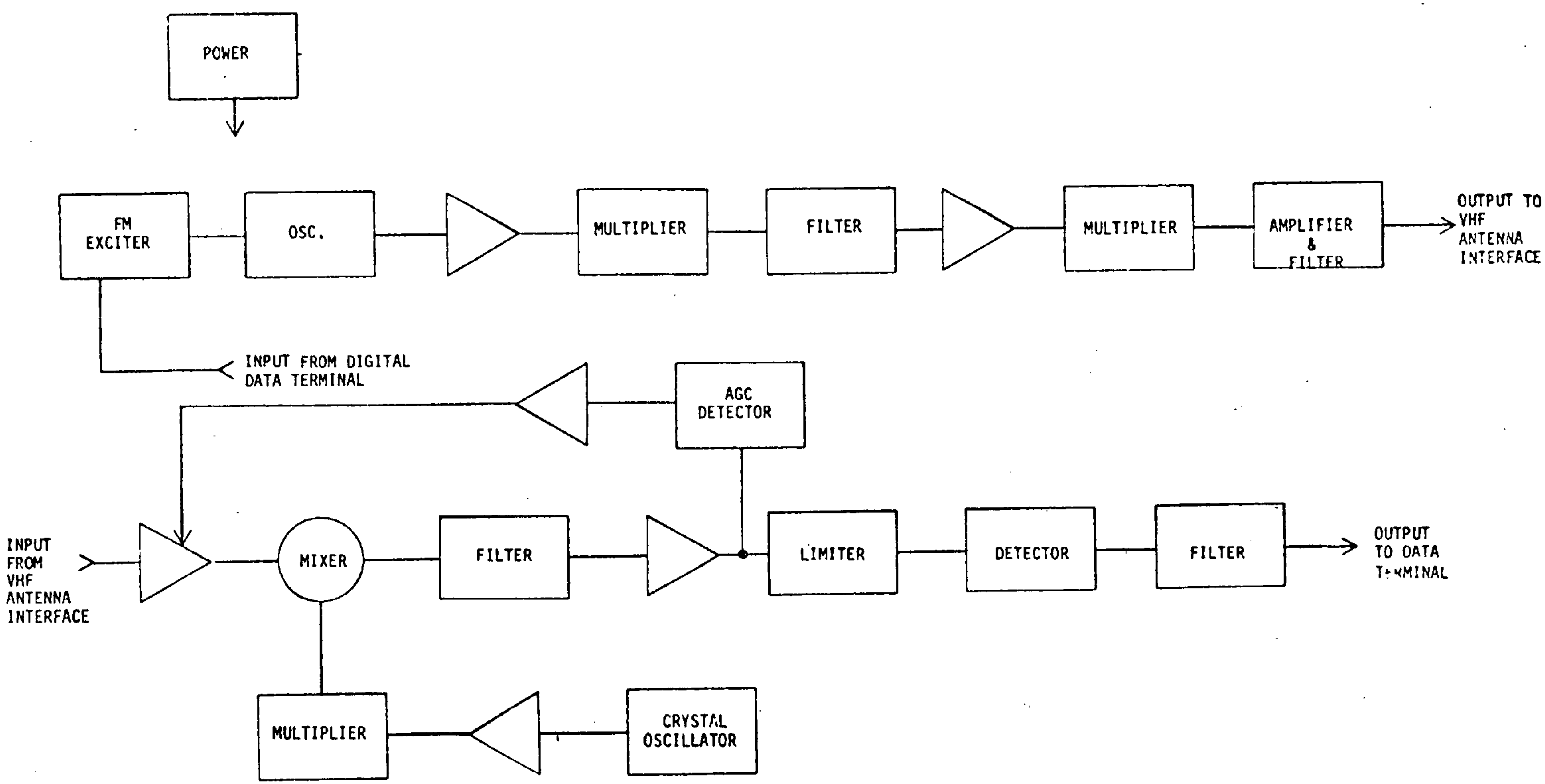


Figure 6-16. VHF Data Transmitter/Receiver

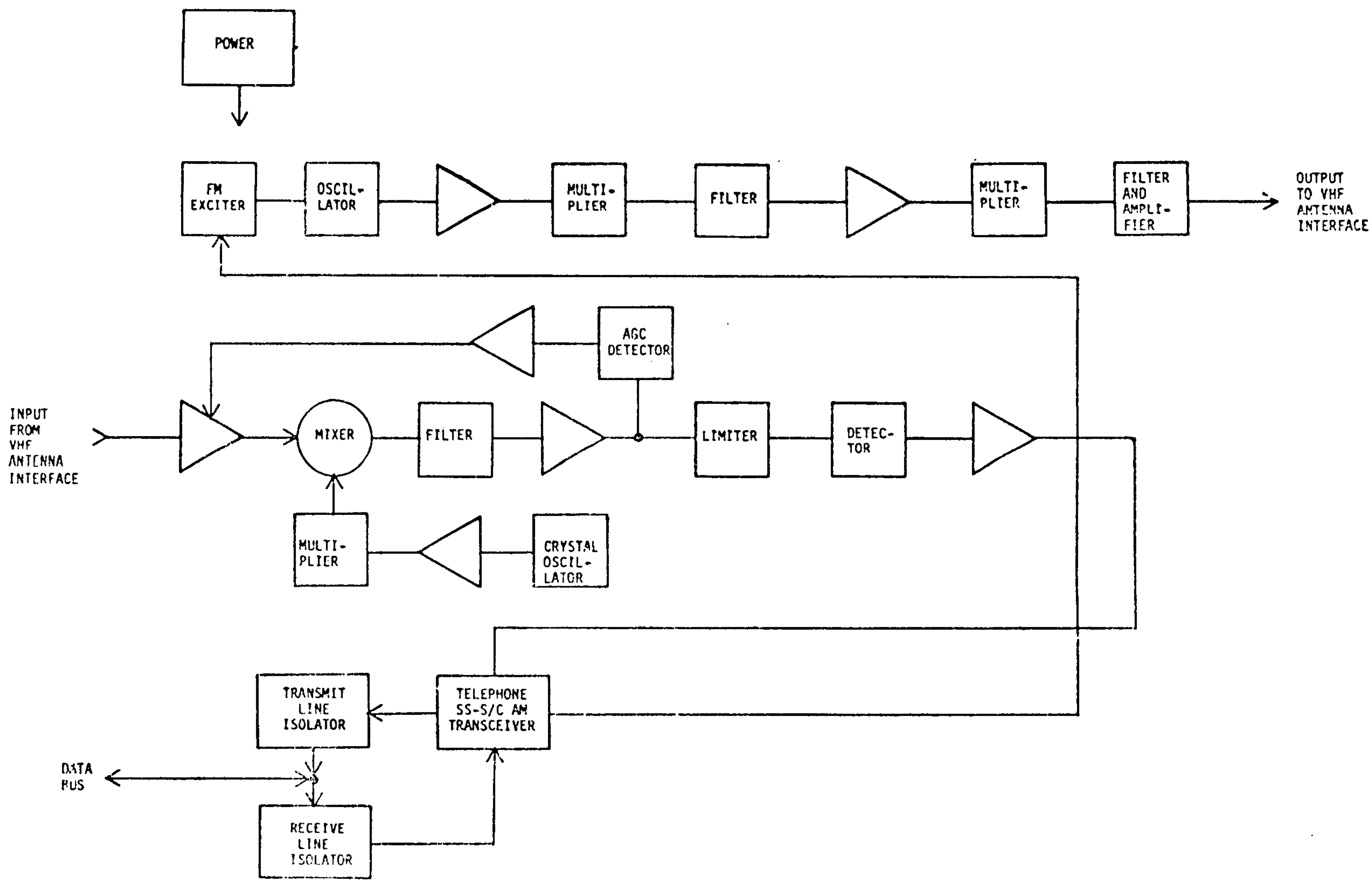


Figure 6-17. VHF Voice Transmitter/Receiver

terminal; however, the transmitter/receiver contains circuitry similar to that in the ATU which interfaces directly with the analog data bus and enables any ATU on the bus to access the RF channel by simply dialing its assigned number.

S-Band PM Transponder—The S-band PM transponder provides for the transmission and reception of voice, data, and ranging signals between the ISS and Space Shuttle, and between the ISS and ground stations. The voice and data subcarrier frequencies are identical to those used on the Apollo Command Module.

A block diagram of the S-band PM transponder is shown in Figure 6-18. The unit contains circuitry similar to the ATU's to select one of the voice channels on the analog data bus for transmission and reception over the RF circuits. The selection of the channel, as well as all other control functions and the readout of monitor data, is done over the digital data bus via a DMS RDAU. The digital data terminal interfaces between the bus and both the incoming digital data on a 70-kHz subcarrier and the outgoing digital data which are transmitted as biphase modulation on a 1.024-MHz subcarrier. The transponder also interfaces with the ranging unit to receive and transmit baseband PRN ranging signals.

A summary of the unit's signal-handling capability is provided in Table 6-3. All of the noted subcarriers are transmitted and received as PM of the S-band carrier. The RF circuitry consists of a solid-state, phase-lock transponder, with an output power of 1 watt and a receiver noise figure of 7 db.

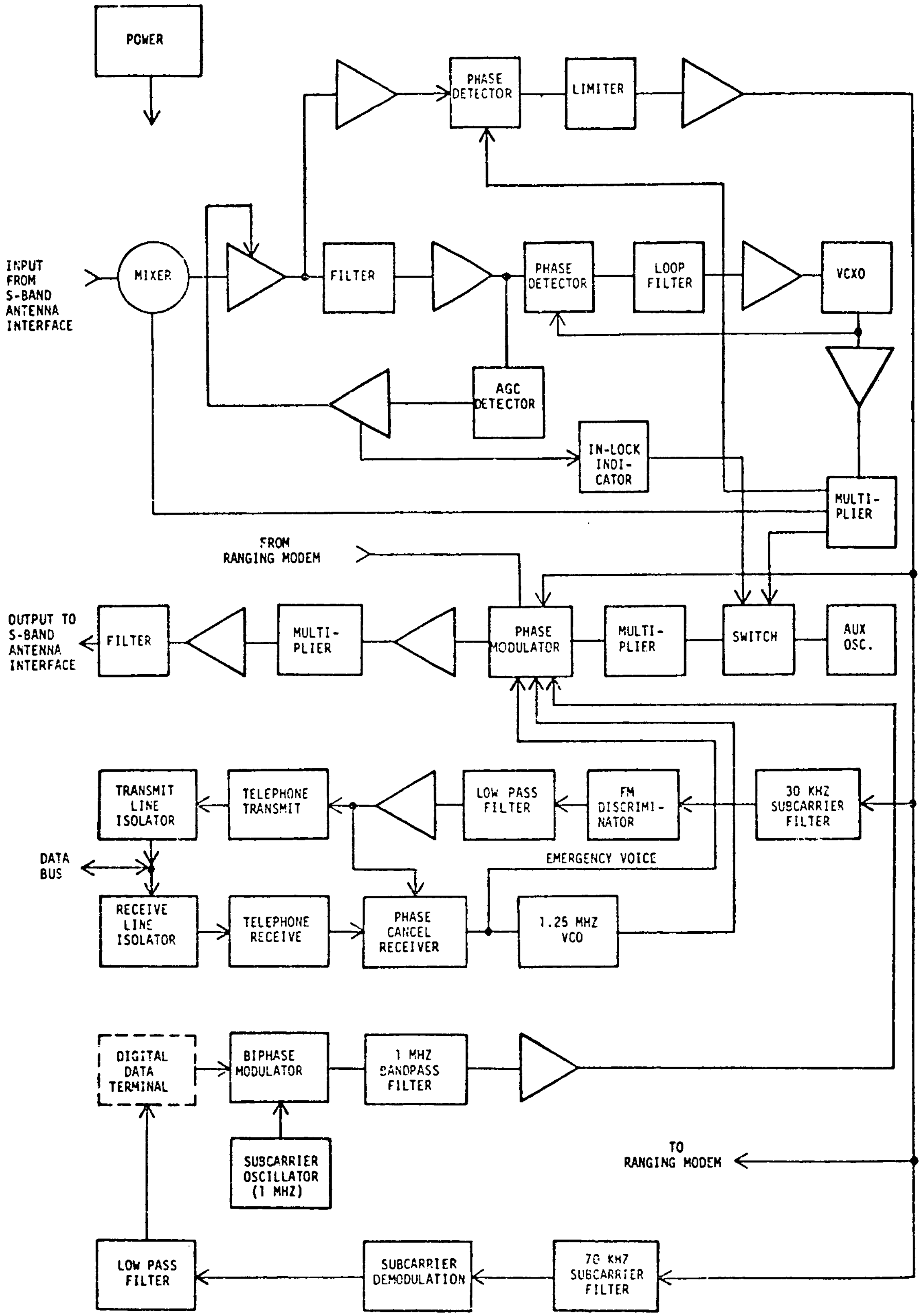


Figure 6-18. S-Band PM Transponder

Table 6-3

SIGNAL-HANDLING CAPABILITY

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1. One voice channel input and output. Transmitted as FM modulation on a 1.25 MHz subcarrier, received as FM modulation on a 30 kHz subcarrier.

2. One data channel output of 51.2 kbps, transmitted as biphase modulation on a 1.024 MHz subcarrier.

3. One data channel input of kbps, received as FM modulation on a 70 kHz subcarrier. The signal on the subcarrier consists of a biphase modulated 2 kHz tone plus a 1 kHz reference tone.

4. PRN ranging signals transmitted and received as baseband PM modulation of the S-band carrier.

S-Band FM Exciter—The S-band FM exciter generates a 40 to 100 milliwatt RF signal to drive the S-band power amplifier, and frequency-modulates it with either a wideband digital data signal or a television signal. A block diagram of the unit is shown in Figure 6-19. The unit interfaces with a digital data terminal for control and monitor functions, and for receiving its digital data input. It also interfaces directly with the analog data bus to obtain the television signal input. The exciter contains the channel selection circuitry necessary to side-step the desired channel down to baseband for transmission.

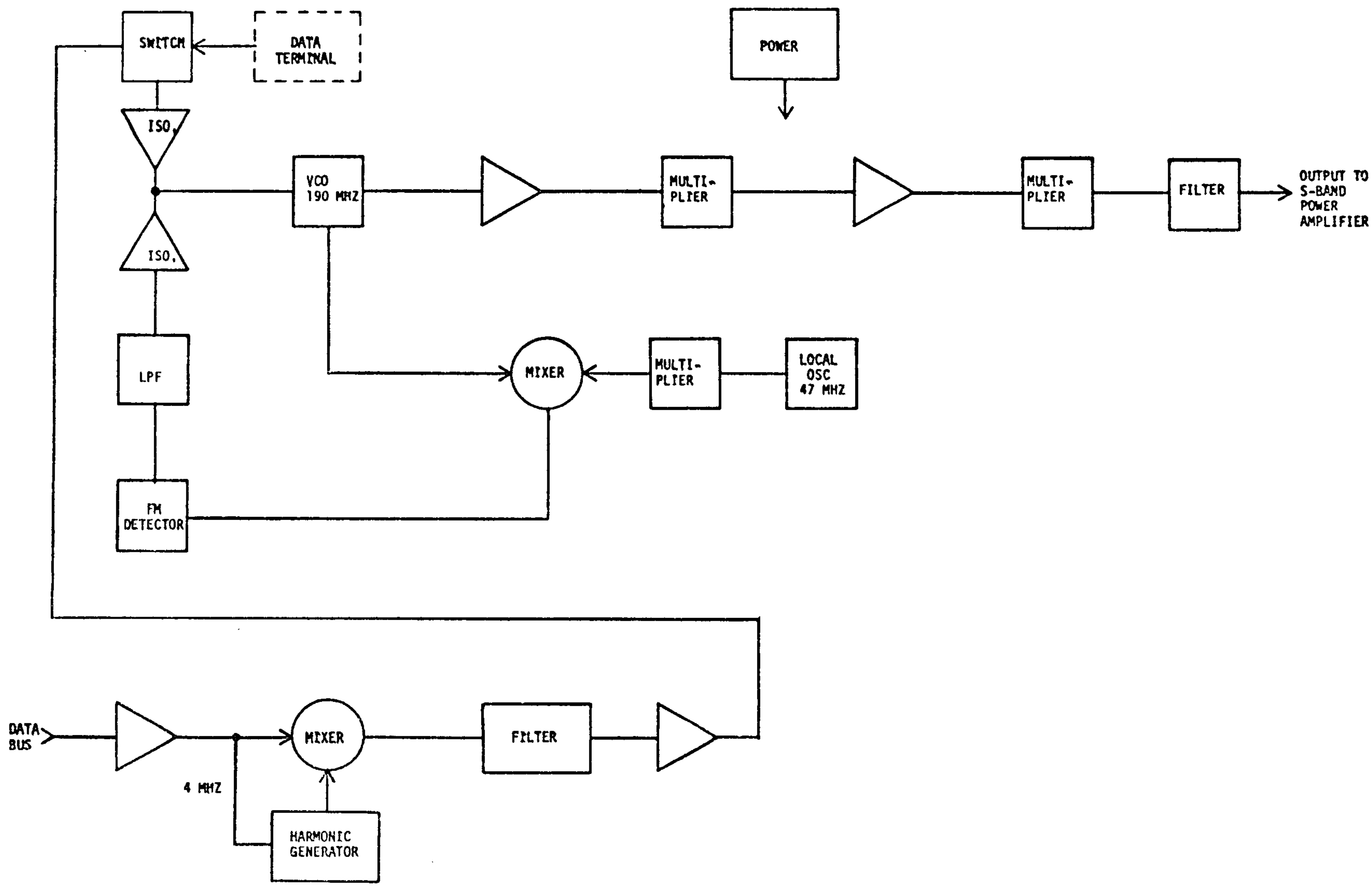


Figure 6-19. S-Band Exciter

S-Band Power Amplifier—The S-band power amplifier provides amplification of the 40 to 100 milliwatt input from the S-band exciter to the 20-watt output level necessary to support wideband data transmissions. The required power level is generated through a hybrid arrangement of power transistors as shown in the block diagram of Figure 6-20.

S-Band Wideband Receiver—The S-band wideband receivers provide for the reception of relay satellite signals which have been down-converted from K_u-band. The incoming signal is frequcncy modulated with a baseband video signal plus a 4.5-MHz subcarrier frequency-modulated with a voice signal, or an FDM signal consisting of 36 SSB voice signals in the band from 60 to 204 kHz, plus entertainment channel subcarriers at 1.0, 1.35, and 1.7 MHz. A block diagram of the receiver is shown in Figure 6-21.

In the video mode, the incoming video signal is side-stepped to the desired analog data bus channel and placed on the bus with the 4.5-MHz subcarrier. In the voice mode, the demodulated voice and entertainment channel spectrum is placed on the analog data bus.

S-Band Narrow-Band Receiver—The S-band narrow-band receiver provides for the reception of relay satellite signals which have been down-converted from K_u-band. The incoming information is in the form of PCM/PSK modulation of a subcarrier, multiple-voice channels, frequency modulated on a 4.5-MHz subcarrier, and a baseband pseudorandom ranging code. A block diagram of the receiver is shown in Figure 6-22.

The receiver phase locks to the incoming S-band signal and coherently detects the ranging signal (which is provided to the K_u-band exciter for retransmission) and the modulated subcarriers. The PSK detector extracts the digital data on a subcarrier and provides the information as an output to a digital data terminal. An FM discriminator detects the multiple voice channels on the 4.5-MHz subcarrier and provides the voice as an output to the analog data bus.

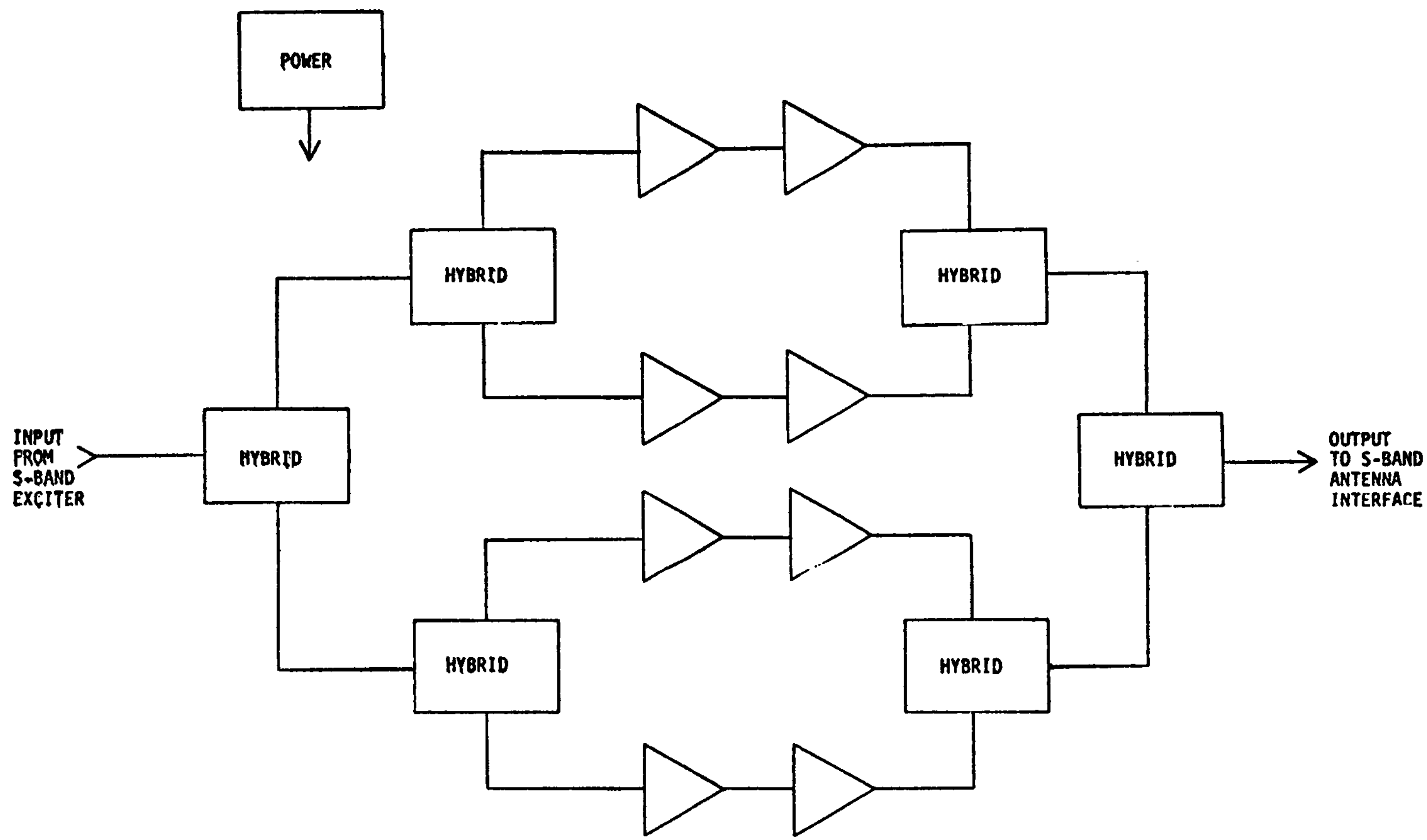


Figure 6-20. S-Band Power Amplifier

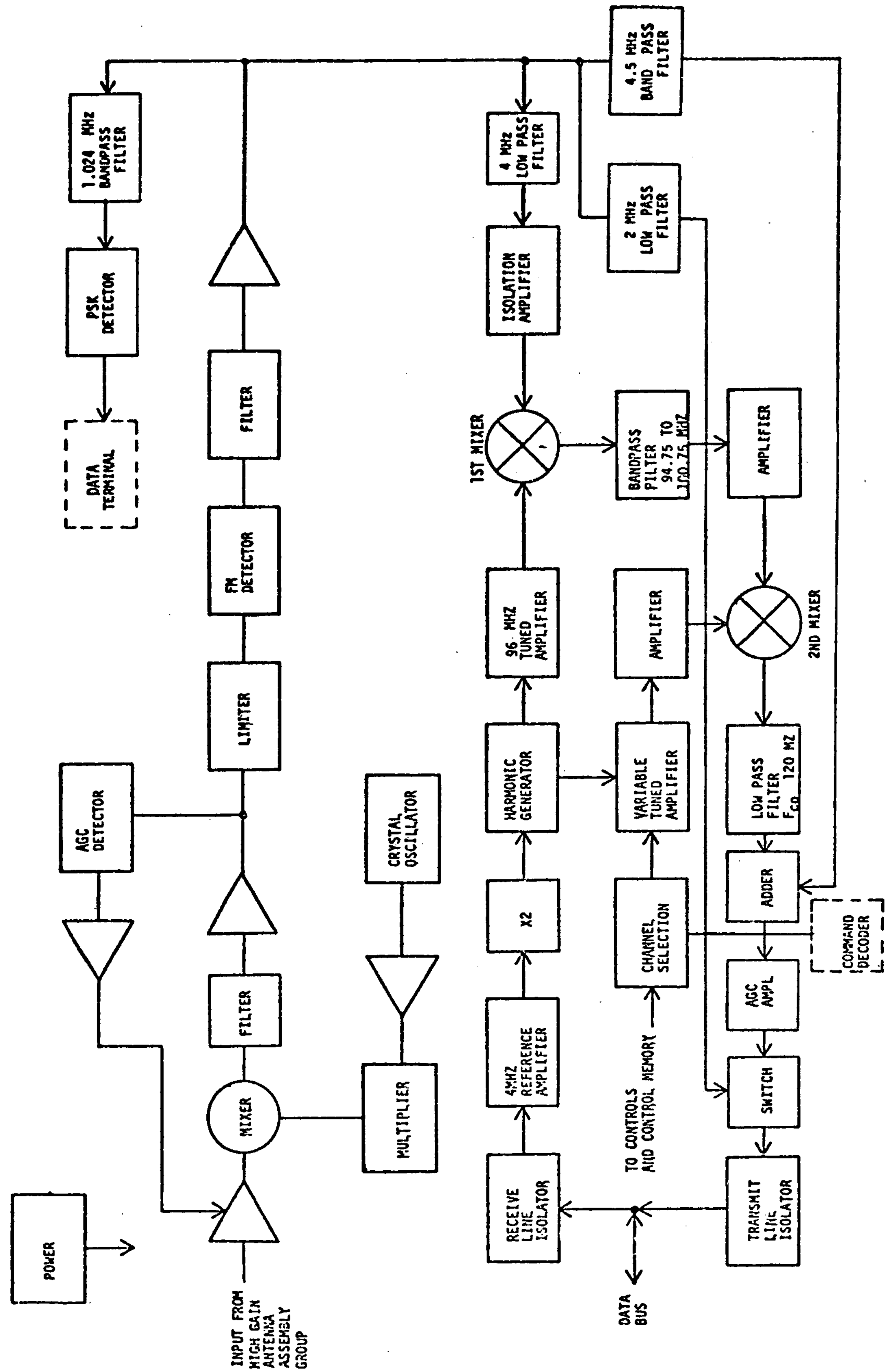


Figure 6-21. S-Band Wideband Receiver

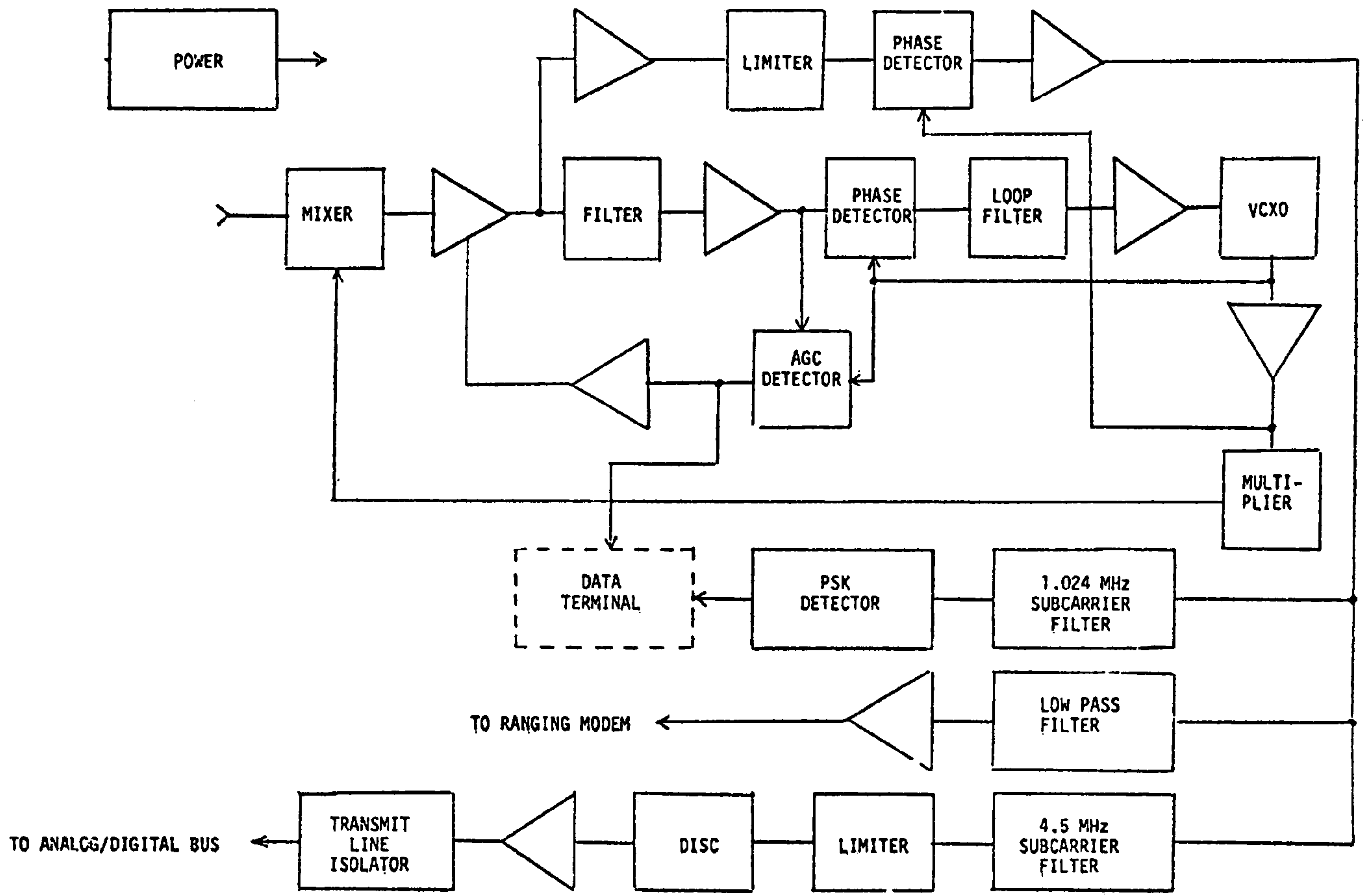


Figure 6-22. S-Band Narrow-Band PM Receiver

K_u-Band Power Amplifier—The K_u-band power amplifier provides amplification of a 20 to 50 milliwatt input from the K_u-band exciter to the 20-watt output level necessary to support wideband signal transmission to Earth via a relay satellite. The unit contains a TWT amplifier and its associated power supplies. The amplifier has a 0.5-db bandwidth of 40 MHz. A block diagram of the power amplifier is shown in Figure 6-23.

K_u-Band Exciter—The K_u-band exciter generates a 50-milliwatt K_u-band RF signal to drive the K_u-band power amplifier, and incorporates provisions for either phase or frequency modulating that carrier with digital or analog data. Inputs are provided for digital signals from the ranging unit and a digital data terminal, and for a wideband analog signal from a signal modem. It will output digital data rates up to 10 Mbps and analog signals over the range from 10 Hz to 7.75 MHz. The modulation level extends to 10 MHz peak-to-peak on FM and 2 radians peak-to-peak on PM. A block diagram of the unit is shown in Figure 6-24.

K_u-Band Exciter Modem—The K_u-band exciter modem provides an interface between the analog/digital data bus and the K_u-band exciter for the control and processing of analog signals. A block diagram of the unit is shown in Figure 6-25. Under direction of commands received from a digital data terminal, the unit side-steps and inverts the selected television channel so that it appears as a vestigial lower sideband signal with the carrier centered at 6.5 MHz. The FDM voice spectrum, which was separated from the rest of the signals on the bus by the 500-kHz low-pass filter, is then added back in to form a composite signal consisting of all the voice channels but just the one selected video channel. The composite signal is then provided as an output to the K_u-band exciter.

Ranging Unit—The ranging unit operates in conjunction with the S-band PM transponder (and a cooperative ranging system in the Space Shuttle) to determine the range to that vehicle. A block diagram of the unit is shown in Figure 6-26. The ranging unit generates a pseudorandom coded NRZ signal and provides it as an output to either one or two transmitters. It accepts the returned PRN code from one of five receivers and from the delay as a function of time determines range and range rate to the cooperating vehicle. The range and range rate information is provided as an output to a digital data terminal.

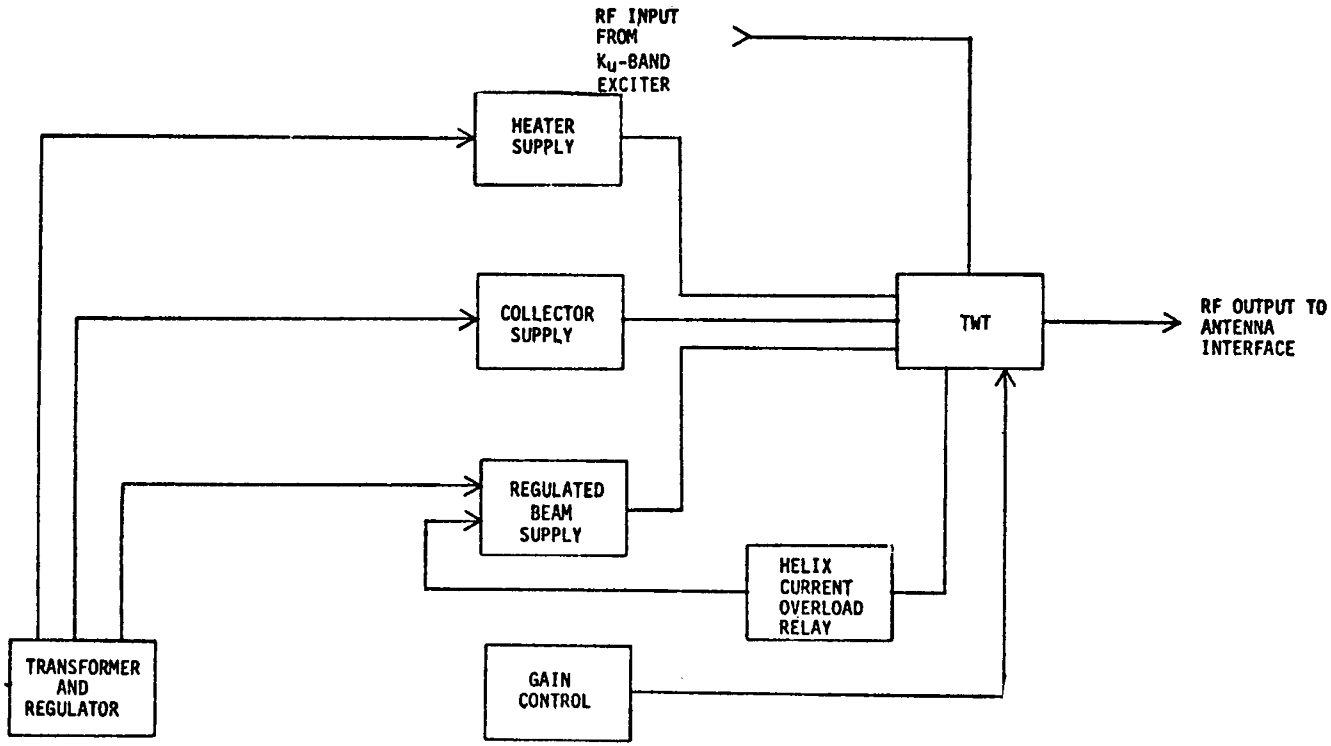


Figure 6-23. K_u-Band Power Amplifier

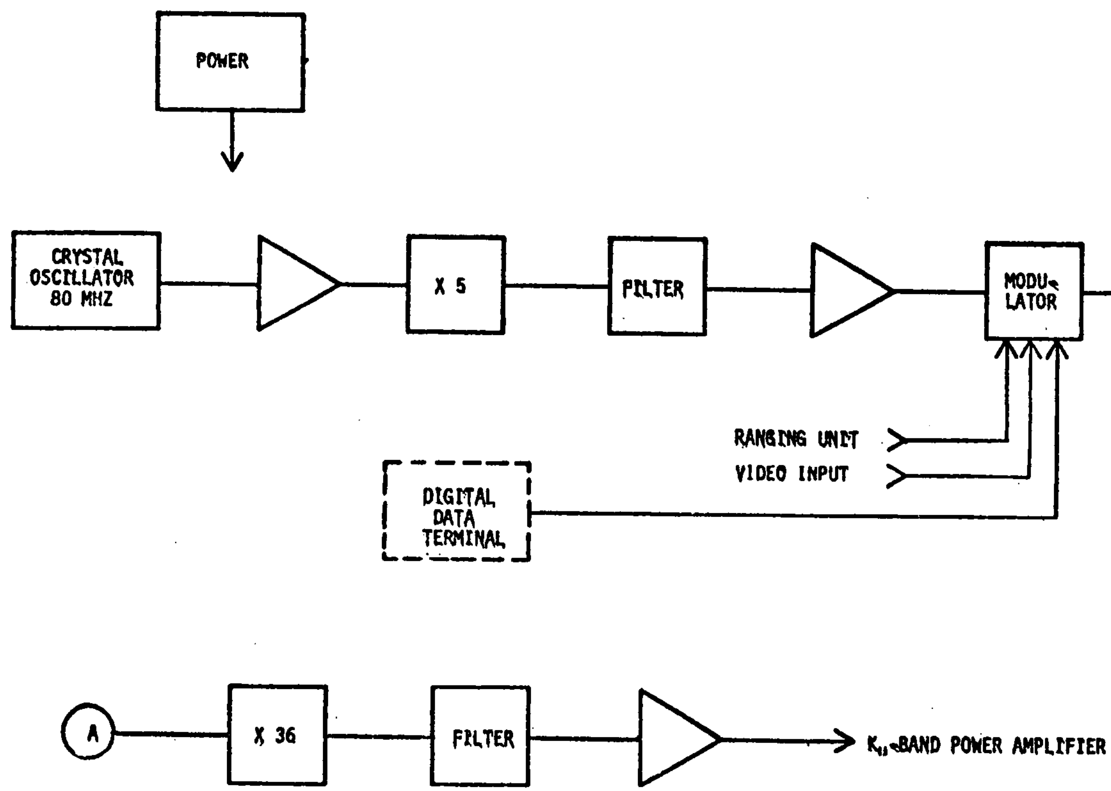


Figure 6-24. K_u-Band Exciter

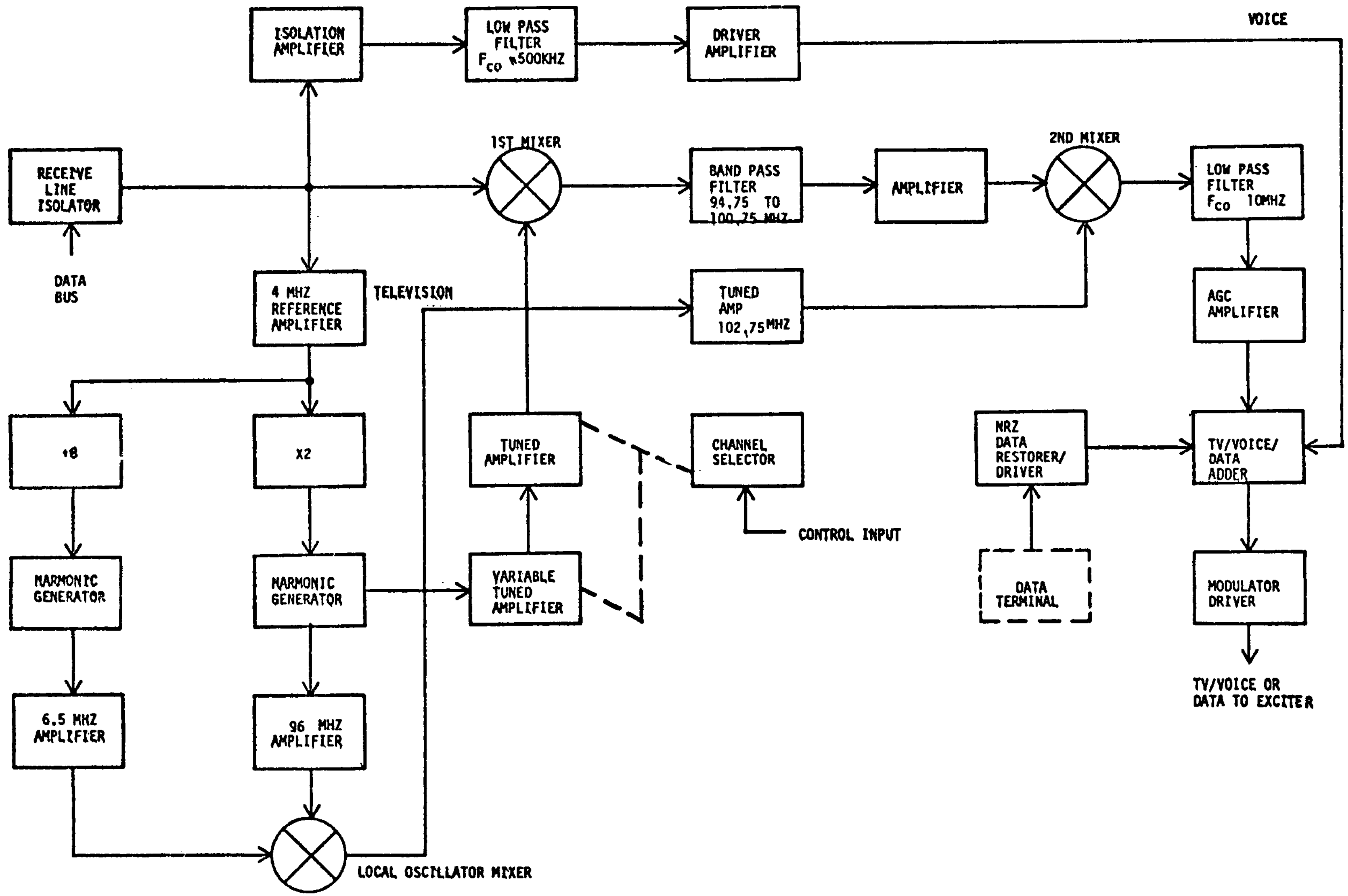


Figure 6-25. Ku-Band Exciter Modem

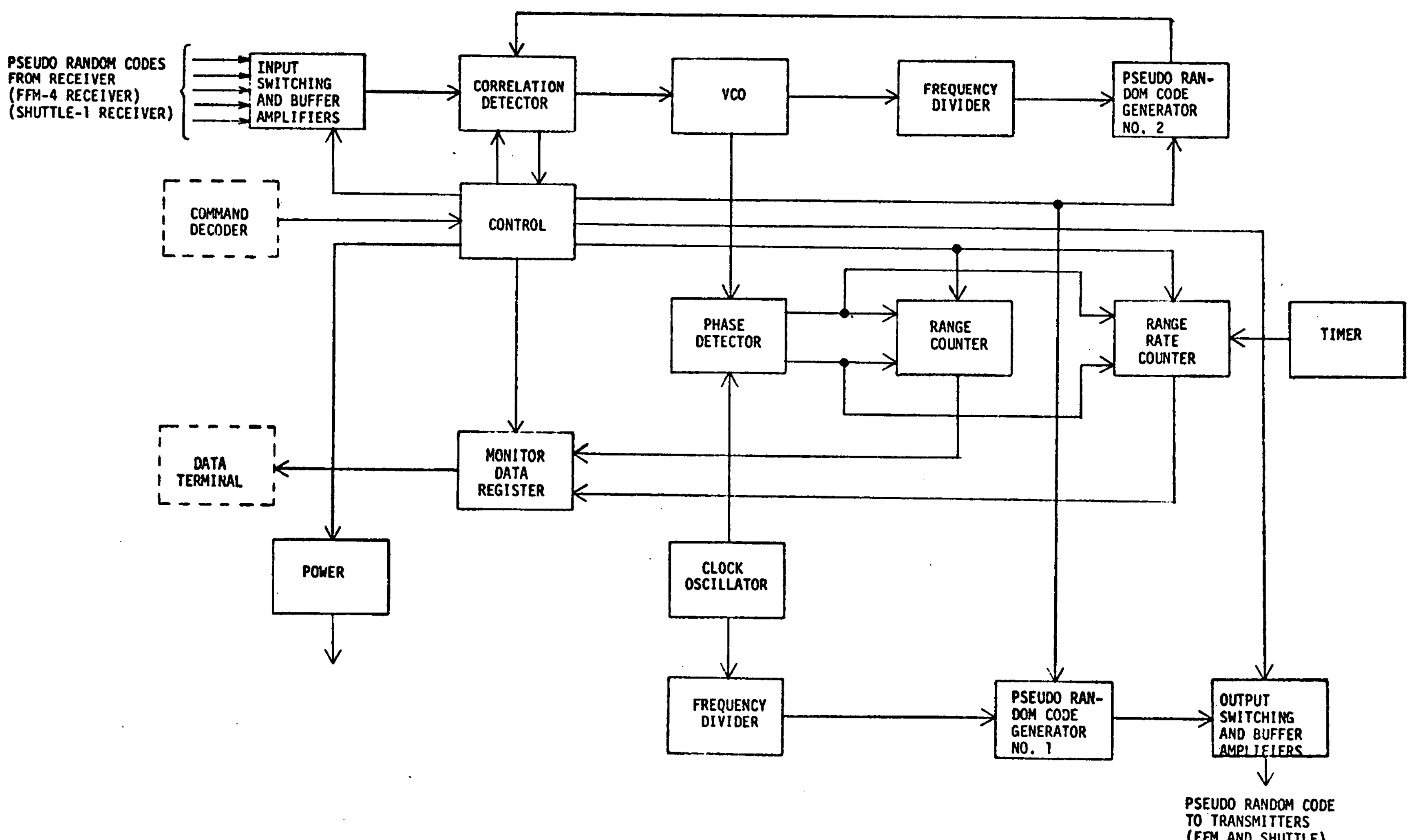


Figure 6-26. Ranging Unit

Internal Communications System Description

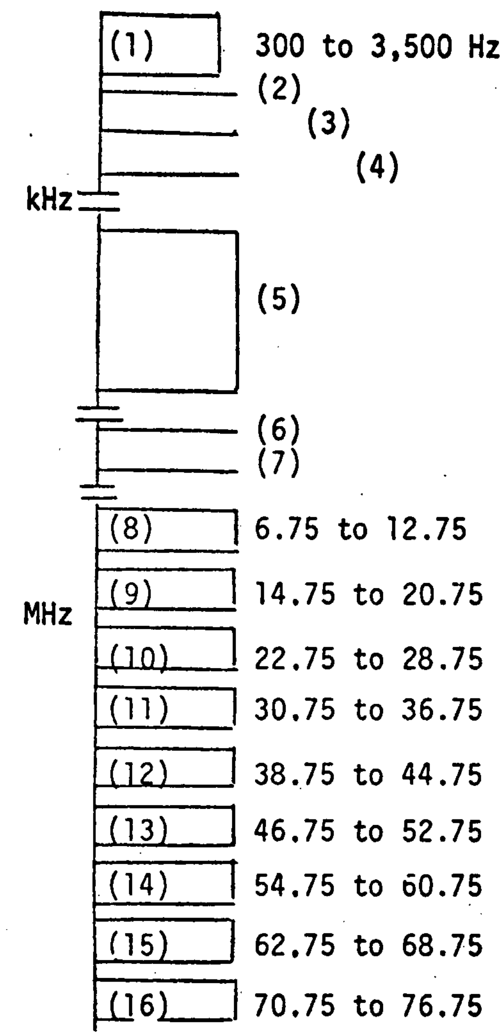
Functionally, the internal communications system for the Modular Space Station closely resembles a standard Bell Telephone system. Except for special circuits which may be deliberately locked out of some terminals to restrict operational access, each terminal unit can obtain private access to any other terminal unit by simple "dialing" it. Conference capability is provided under control of the called terminal.

Communications between the various terminal units are carried on a common analog/digital data bus in a frequency division multiplex (FDM) format. Thirty-six 300 to 3,000 Hz channels are provided. Each of the decks in the ISS will have one of these channels assigned to it for two public address functions unique to that deck. In addition, the baseband 300 to 3,000 Hz channel on the bus is common to all terminals on all decks for use as a public address or emergency "all-stations" circuit.

As described previously, all the features of the intercom system are extended to the ground when K_u-band DRSS communications are available, so that a ground terminal can "dial" any terminal in the ISS and vice versa. The voice bandwidth channels can also be used for data phone, facsimile, or teletype service if so desired.

In addition to the voice channels, the ATU's are configured to receive any one of three wideband (50 to 15,000 Hz) channels assigned to entertainment use.

The intercommunications signals are distributed throughout the ISS on an analog bus which also carries television information. The frequency allocation of signals on the bus is shown in Figure 6-27. The voice signals are transmitted in the form of single-sideband-suppressed carrier amplitude modulation on channels spaced 4 kHz apart in the band from 60 to 204 kHz. The entertainment signals are transmitted in the form of frequency modulation on subcarriers of 1.0, 1.35, and 1.7 MHz.



(1) Public Address, Emergency Call, 300 to 3,000 Hz
(2) Telephone Carrier Reference, 4,000 Hz sine wave
(3) Emergency Call Tone, 5,000 Hz Sine Wave
(4) Emergency Alert Tone, 6,000 Hz Sine Wave
(5) 36 Telephone Channels, 60 kHz to 204 kHz, SSB-Sc-AM 300 to 3,000 Hz Audio
(6) 3 Entertainment channels, 1.0 MHz ± 75 kHz, 1.35 MHz ± 75 kHz, 1.7 MHz ± 75 kHz
(7) Television Carrier Reference, 4 MHz Sine Wave
(8) to (15) Television and Video Channels, 4.75 MHz Baseband 6 MHz Vestigial Sideband AM, Carrier Frequencies Space at 8 MHz Intervals starting with 8 MHz, 2 MHz Guard Band.
(16) Onboard Generated Test Channel, 4.75 MHz Baseband, 6 MHz Vestigial Sideband AM, Located in the Interval of 70.75 to 76.75 MHz.

Figure 6-27. Data Bus Channel Frequency Allocations

Audio Terminal Unit — A block diagram of the ATU is shown in Figure 6-28. The heart of the voice channel system is the telephone LSB-SC-AM transceiver, which is tunable (by means of 10 pushbutton touch-tone matrix) in 4-kHz increments to any of the 36 channels located in the band from 60 to 204 kHz. The transmit and receive functions are tuned to the same frequency source of their own. They are all normally referenced to a 4-kHz reference tone on the analog data bus. The reference tone is provided by a separate sync tone generator unit. Dialing another station number results in tuning your station to the unique "home" frequency of the called station. If the called station is off-hook, a busy signal would be received, and no connection would be made unless the called station selects conference mode. All of the supervisory signals are compatible with Bell-system practice.

Microphone input signals are normally blocked until a VOX threshold level is reached. This prevents noise buildup in the channel when several terminals are conferenced. The VOX switch may be overridden in the selectable PTT mode of operation; however, a transmit side tone is also provided.

Automatic gain control (AGC) of received signals is provided to maintain nearly constant audio output levels over a wide range of input signal levels.

Operation of the entertainment receiver is straightforward, consisting simply of tuning of the receiver to the selected subcarrier frequency and demodulating the FM signal present on that subcarrier.

The public address/emergency call/emergency alert transceiver provides for transmission and reception of audio signals in the 300 to 3, 000 Hz baseband channel on the analog/digital data bus. The microphone VOX/PTT operation and receiver AGC functions described above also apply to this channel.

Actuation of the emergency call control at any station enables that station to transmit to all other stations on the bus. At the same time, a 5-kHz tone is placed on the analog data bus which, when received by any station, causes a visual indicator to be energized.

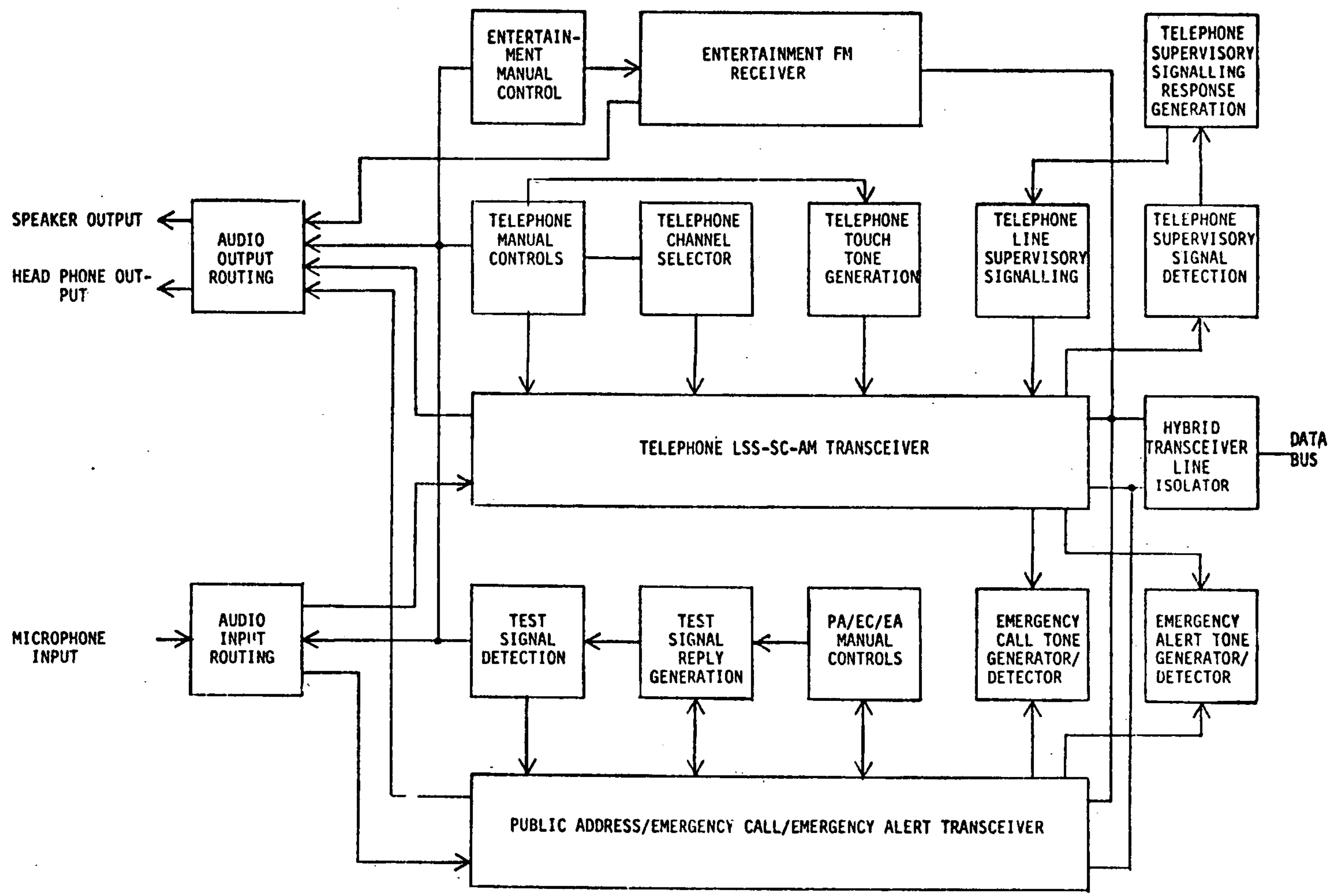


Figure 6-28. Audio Terminal Unit

Actuation of the emergency alert control at any station causes a 6-kHz tone to be transmitted on the analog data bus which, when detected by any station on the bus, causes them to emit an aural alert signal over the headphone/speaker system.

Analog Sync/Test Unit — Provisions for automatic testing and generation of synchronizing signals for the internal communications system are incorporated in the analog sync/test unit whose block diagram is shown in Figure 6-29. The unit provides two synchronizing tones as outputs on the analog/digital data bus, a 4-kHz reference for the ATU's, and a 4-MHz reference for the television signals on the bus. Both of these reference signals on the bus are continually monitored for amplitude and frequency stability, and an out-of-tolerance condition will automatically result in replacing the faulty signal on the bus with a signal from backup generators contained within the unit. The status of the reference signals is provided as a monitor output.

In addition to the generation of synchronizing signals, the unit provides two basic test functions. For the television receivers on the bus, it provides (on a dedicated test channel as shown in Figure 6-28) a selection of test patterns for alignment and checkout.

For checkout of the ATU's, a double-loop test is established, in which the test unit transmits a test tone on the home channel frequency of a selected ATU and in reply receives a test-tone bank on the baseband channel. A loop is also established over the same channels in the other direction to verify the operation of the other transmit and receive functions. Either manual selections of the channel to be tested or automatic sequencing through all channels can be accomplished. The test unit automatically evaluates the status of the channel and provides the data as an output.

6.1.2 Data Management/Onboard Checkout Subsystems

The ISS onboard checkout subsystem (OCS) is a hybrid of (1) utilizing checkout functions built into the subsystem or experiment under test; (2) sharing other onboard capabilities, especially those of the DMS for data acquisition

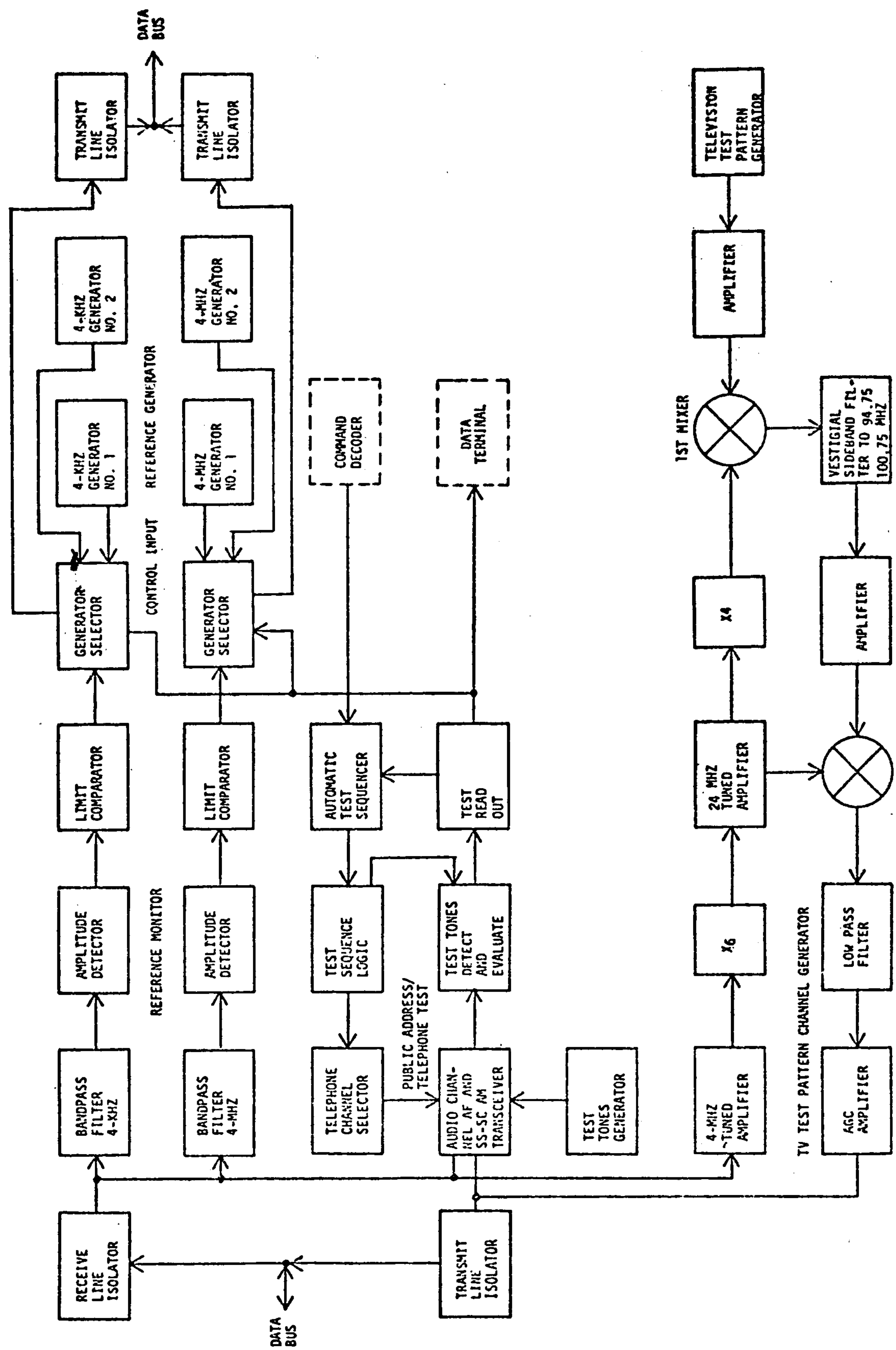


Figure 6-29. Analog Sync/Test Modem

and distribution, computation, data storage, displays and controls, command generation, and operating system software; and (3) implementing unique OCS design required for stimuli generation, critical measurements, and checkout software.

An overall block diagram depicting OCS/DMS elements is provided in Figure 6-30. An OCS/DMS assembly group breakdown for checkout and fault isolation is shown in Figure 6-31. Stimuli generation, command generation, and data acquisition capabilities are distributed throughout the ISS as dictated by checkout data point locations. Local caution and warning units are located in each habitable compartment with overall status provided at both the primary and secondary ISS control centers. Display, control, and data processing functions are primarily centralized with separate capabilities provided for subsystem and experiment support. Distribution of information between various elements of the system is primarily by digital data bus.

An important aspect of the OCS/DMS baseline is that of minimizing the types of interfaces. This is particularly important since the OCS/DMS must interface with all other ISS subsystems, diversified integral experiments, and docked modules. Key features of ISS onboard checkout capability are listed in Table 6-4. Detailed descriptions of OCS/DMS assemblies are provided in Reference 1.

6.1.3 Prelaunch Operations

The prelaunch operations baseline for the study involves the launch site activities necessary to process (receive, service, install in Orbiter, and launch) ISS modules required to complete orbital buildup. These modules are the Power/Subsystems, Crew/Operations, and General Purpose Laboratory Modules shown in Figures 6-32, 6-33, and 6-34. These three modules launched comprise the ISS shown in Figure 6-1. A second group consisting of a Power/Subsystems Module and Crew/Operations Module that may be launched 5 years later would provide for growth to a full 12-man capability or Growth Space Station (GSS) shown in Figure 6-35. An overall Space Station launch schedule is shown in Figure 6-36. The ISS configuration is the only one being considered in this study since a Phase B level definition of the GSS is not available.

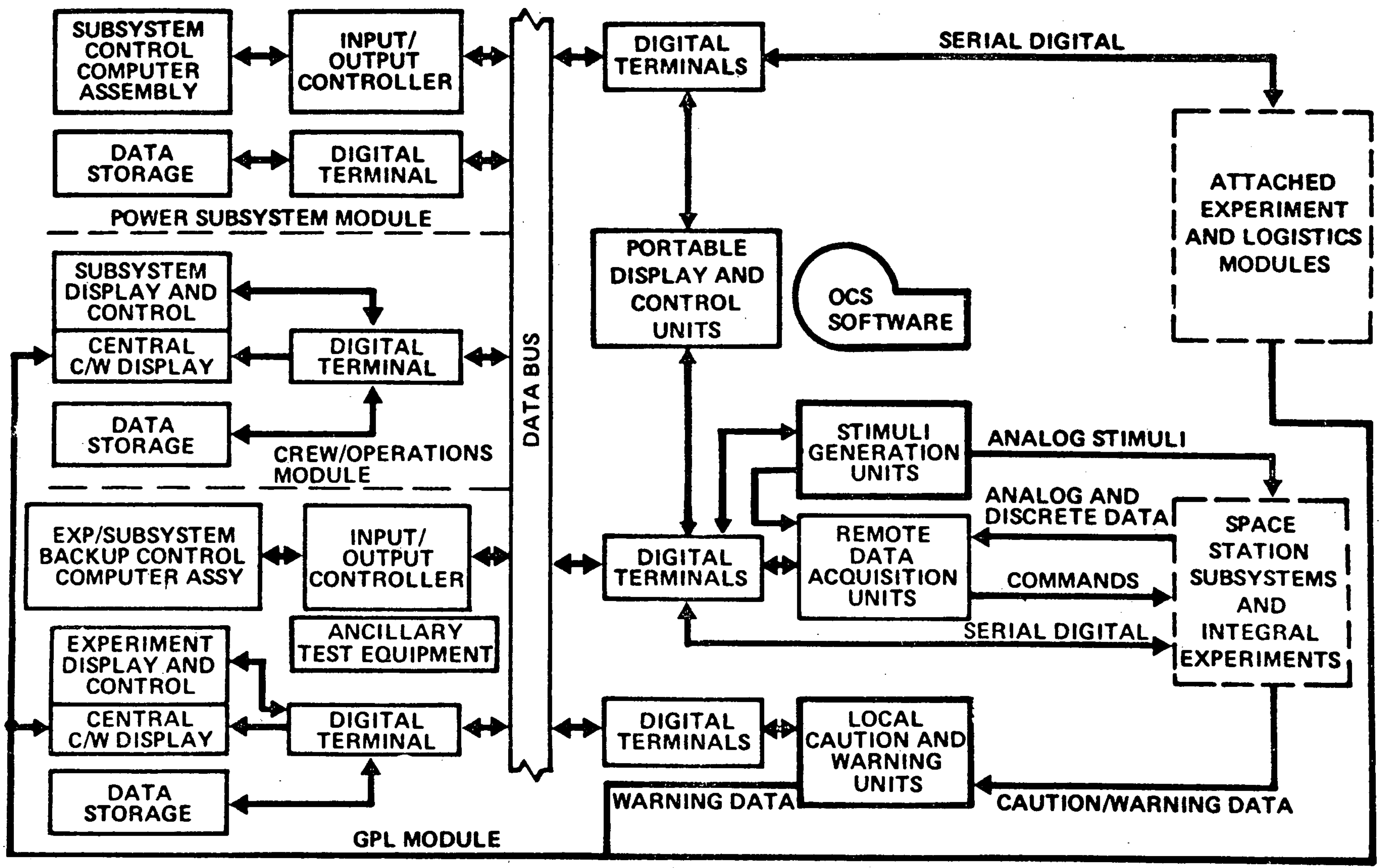


Figure 6-30. OCS/DMS Block Diagram

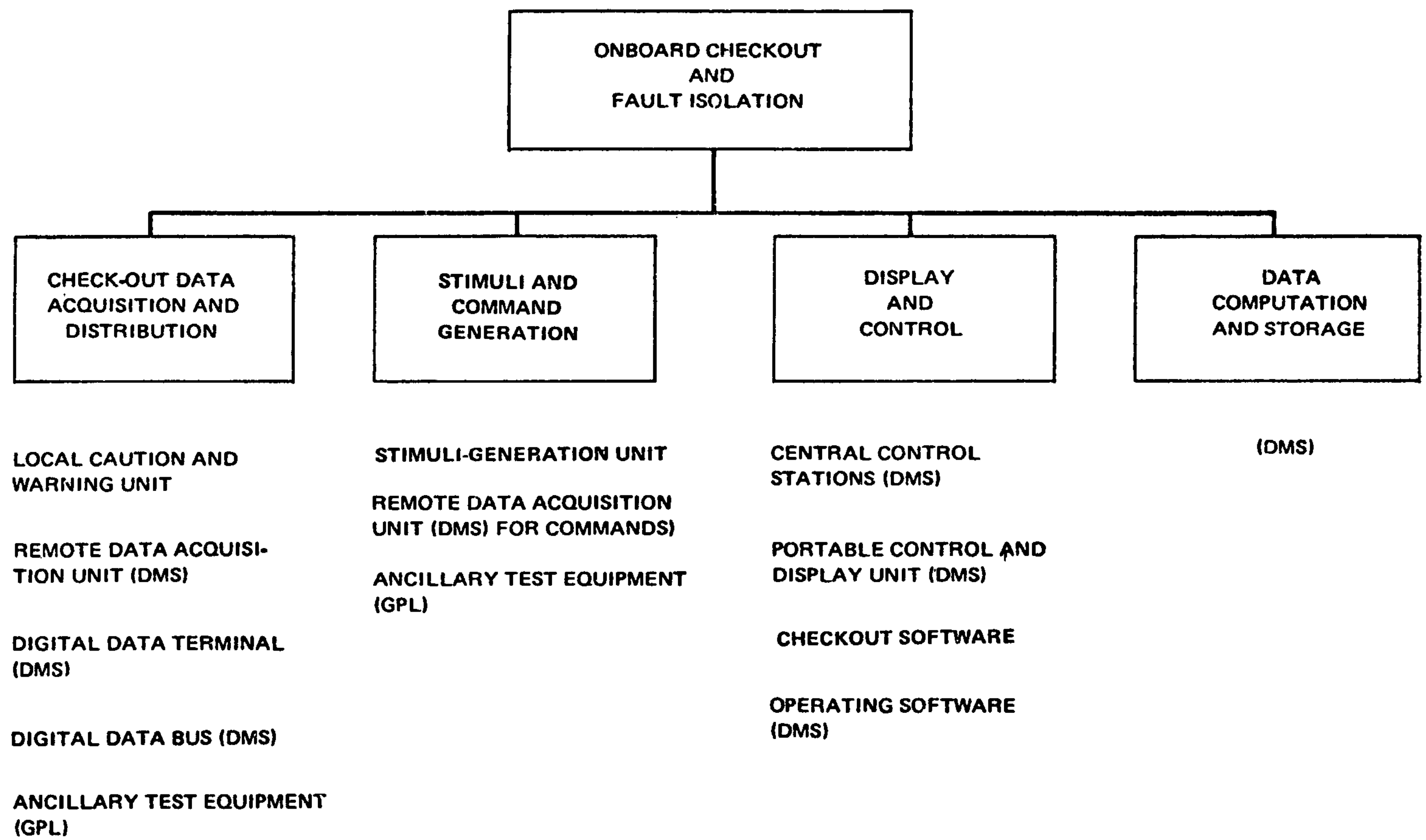


Figure 6-31. OCS/DMS Assembly Group Breakdown

Table 6-4

DATA MANAGEMENT/ONBOARD CHECKOUT SUBSYSTEM FEATURES

Function	Characteristics
• Remote data acquisition	• Computer-controlled • Random or sequential sampling • Remotely programmable limits • Digital inputs: 8 parallel bits or serial data $\leq 1 \times 10^6$ bps per channel • Bilevel inputs: momentary or continuous 5 vdc signals • Analog inputs: 0-40 mv, 0-5 vdc
• Stimuli generation	• Computer-controlled • Analog outputs: 0-115 vdc • Bilevel outputs: momentary or continuous 5 vdc signals • Serial digital data
• Checkout and fault isolation control	• General-purpose displays and controls (portable and fixed) • Automatic operation • Restructurable application programs
• Critical measurements	• Independent warning system • Local caution/warning units • Centralized displays • Audio and visual alarms

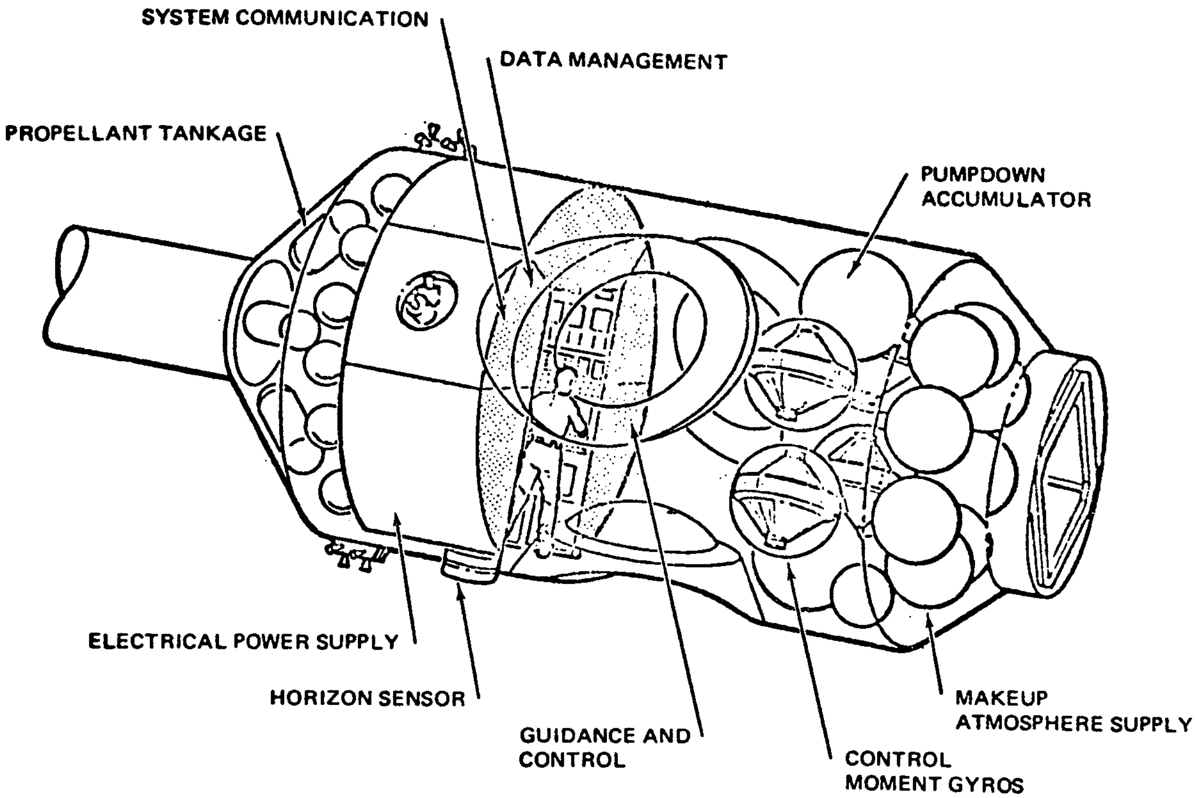


Figure 6-32. Power/Subsystems Module

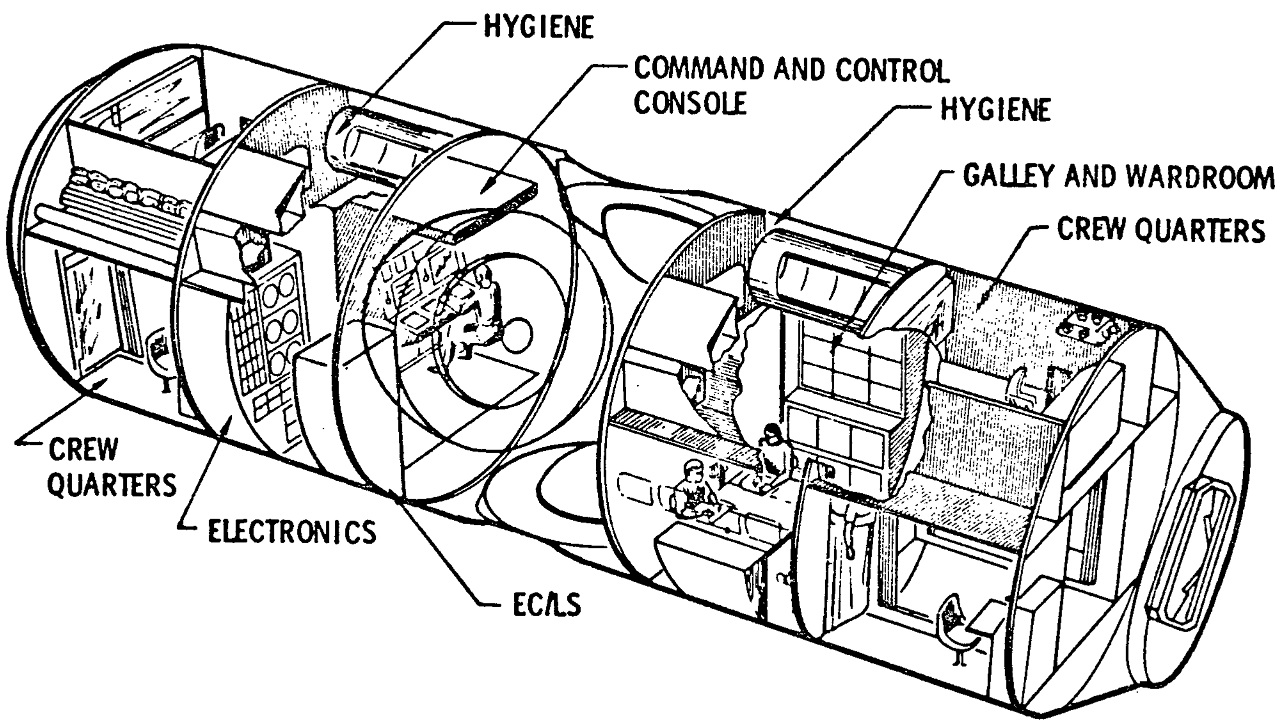


Figure 6-33. Crew/Operations Module

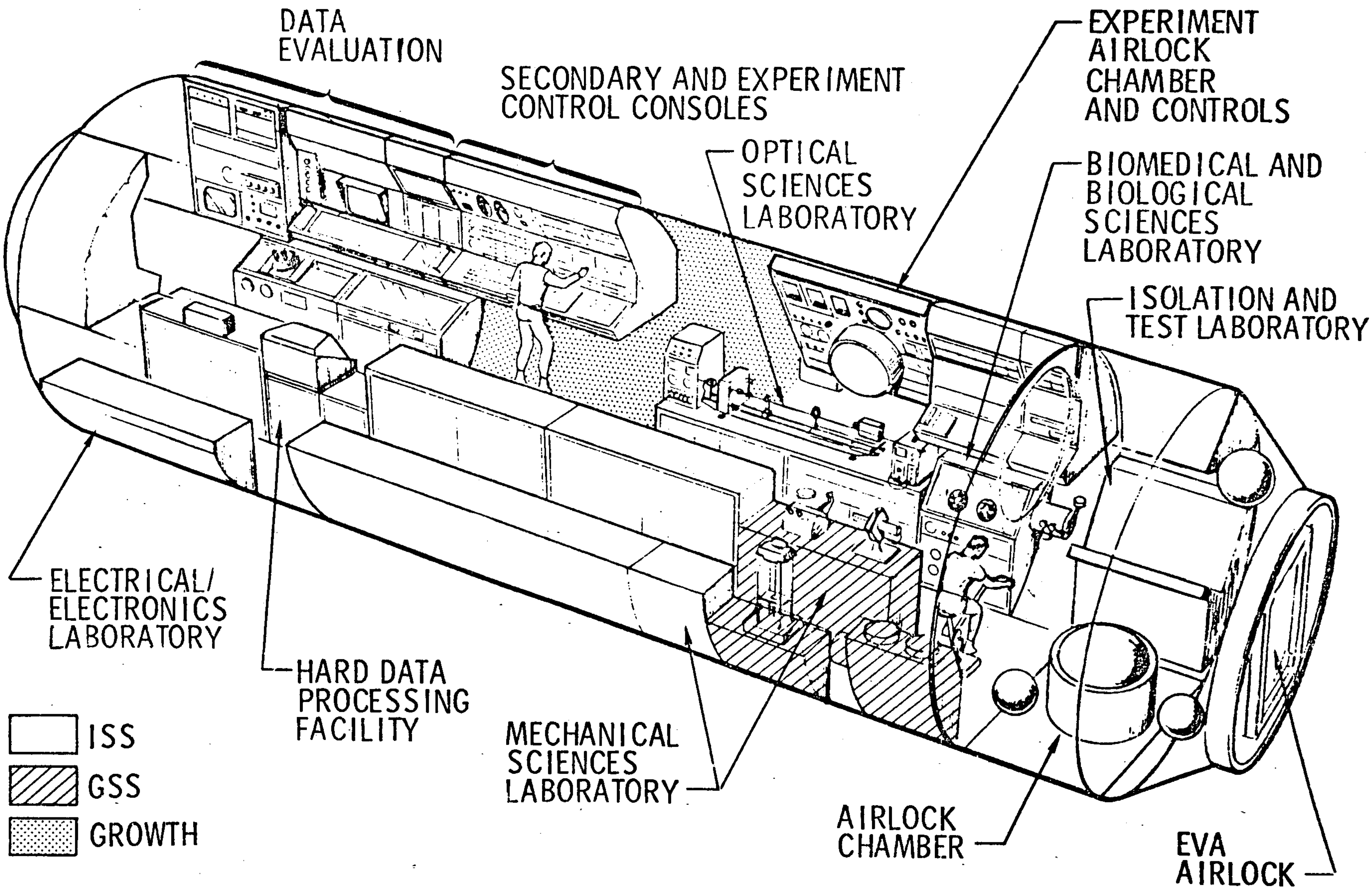
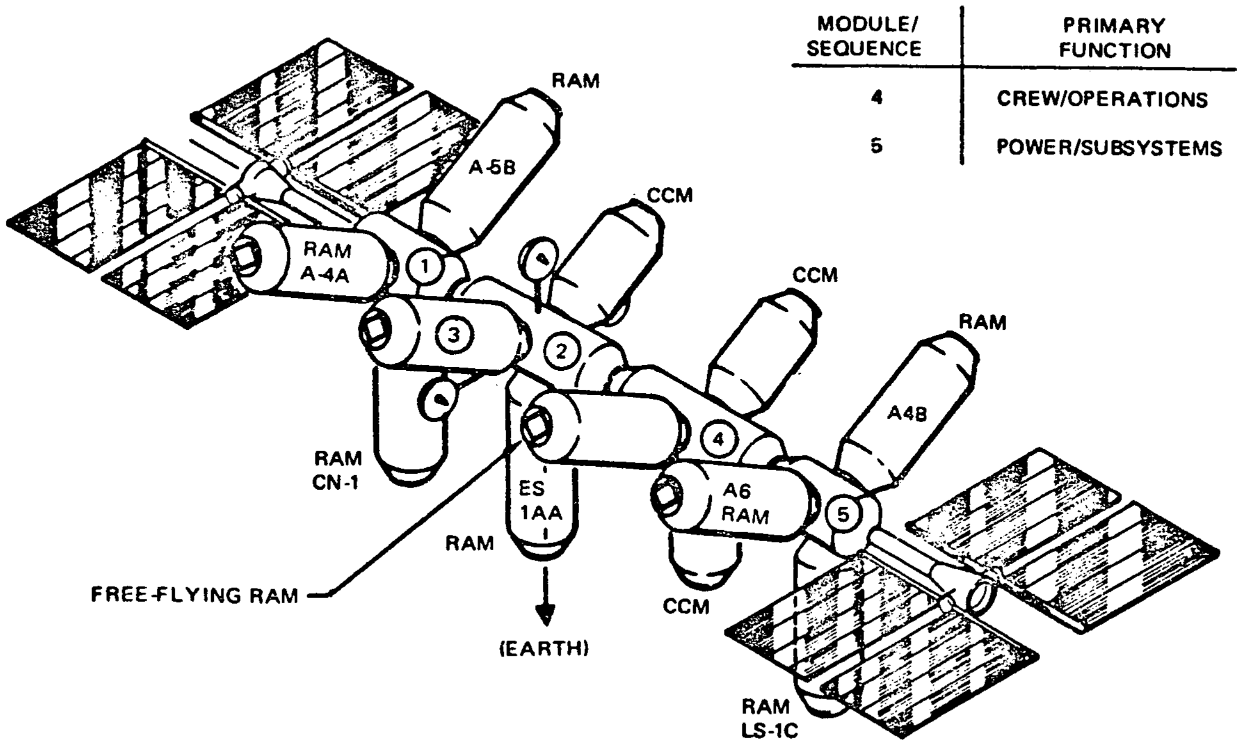


Figure 6-34. Baseline General Purpose Laboratory



MODULE/ SEQUENCE	PRIMARY FUNCTION
4	CREW/OPERATIONS
5	POWER/SUBSYSTEMS

Figure 6-35. Growth Space Station

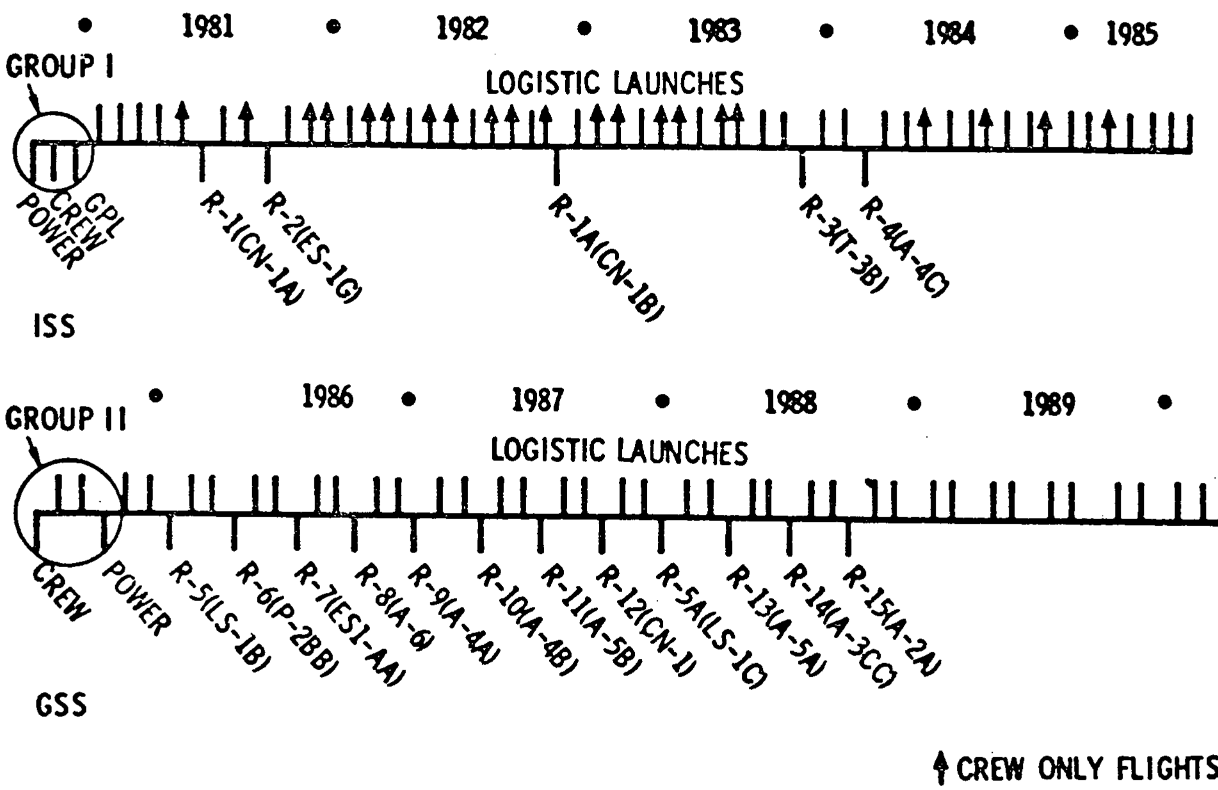


Figure 6-36. Space Station Buildup Module Delivery Schedule

C. 4

6.1.3.1 Test Philosophy

Although prelaunch and launch operations begin with the first module activity at the launch site and end when the last ISS module has been launched, any discussion of ISS test philosophy must also consider integration of the modules performed before delivery to the launch site. The test philosophy developed for the ISS embraces all aspects of testing in the categories of development tests, qualification tests, acceptance tests, prelaunch and launch tests, and on-going mission tests. Some of the most important guidelines of the test philosopy are as follows:

A. Imposed environment testing, both development and qualification, is at the assembly and subsystem hardware level.

B. Testing of assembled modules and/or assembled clusters is limited to the following:

   1. Design — Development tests utilizing a functional model (FM) that is an electrical/electronic/data subsystem breadboard of the ISS modules.

   2. Design — Qualification demonstrations utilizing an integration fixture that is a physical/functional replica of the ISS modules (also used for sustaining support of mission operations).

   3. Hardware — Acceptance tests of flight modules.

   Implicit in this test philosophy is the intent to eliminate environmental mission profile qualification testing at the module level or above, and to minimize undue repetition of integrated systems tests, whether performed at the factory or launch site.

C. A policy of shipping an orbit-ready module from the factory is followed with regard to launch site testing; however, should any launch site testing be unavoidable, it will be no more rigorous than acceptance testing performed at delivery of the module at the factory. Tests performed are end-to-end. Major disassembly and tests at lower levels of assembly are not permitted in the field except when necessary to isolate malfunctions. Launch checkout is accomplished using onboard checkout capabilities. (Although a complete onboard checkout capability does not exist in single modules, these capabilities are supplemented, as required, with external GSE.)

D. Tests are assembled into an overall test plan covering all aspects of testing such that (1) tests conducted at lower hardware levels are not repeated at higher levels unless inherent in hardware operation and unavoidable, and (2) development testing is constructed so that sensors and parameters which are ultimately used for acceptance testing have a credible data base. Similarly, acceptance and prelaunch testing is constrained to those sensors and parameters properly explored, and previously developed in the development qualification testing programs.

6.1.3.2 ISS Integration

The three ISS modules equipped with the integral experiment hardware installed in the GPL are fully assembled and a complete integrated test performed at the manufacturing site. The entire ISS is acceptance tested, the three modules demated, and pre-established items off-loaded to bring the module gross weight within the Orbiter cargo weight limit. The off-loaded items are limited to those which do not impair ISS buildup or initial operation. The concept baselined for ISS integration is illustrated in Figure 6-37. It is a hybrid of flight module mating and the use of a physical/functional replica or flight integration tool (FIT). A detailed description of the concept can be found in Reference 2.

6.1.3.3 Prelaunch and Launch Operations

The launch of the ISS is essentially a one-time launch and as such does not warrant the buildup of a field station crew to repeat testing that should be performed at the manufacturing site where facilities, equipment, procedures, and manpower already exist to perform this function.

Three basic types of modules are launched. The capabilities of each module at the time of launch differ considerably as shown in Table 6-5. The overall ground operational flow (Figure 6-38) for each type of module is identical, nevertheless, differing only in details. This results from delivering to the launch site fully checked and integrated modules that are orbit-ready except for preflight servicing. Prelaunch operations for ISS modules are detailed in Reference 2.

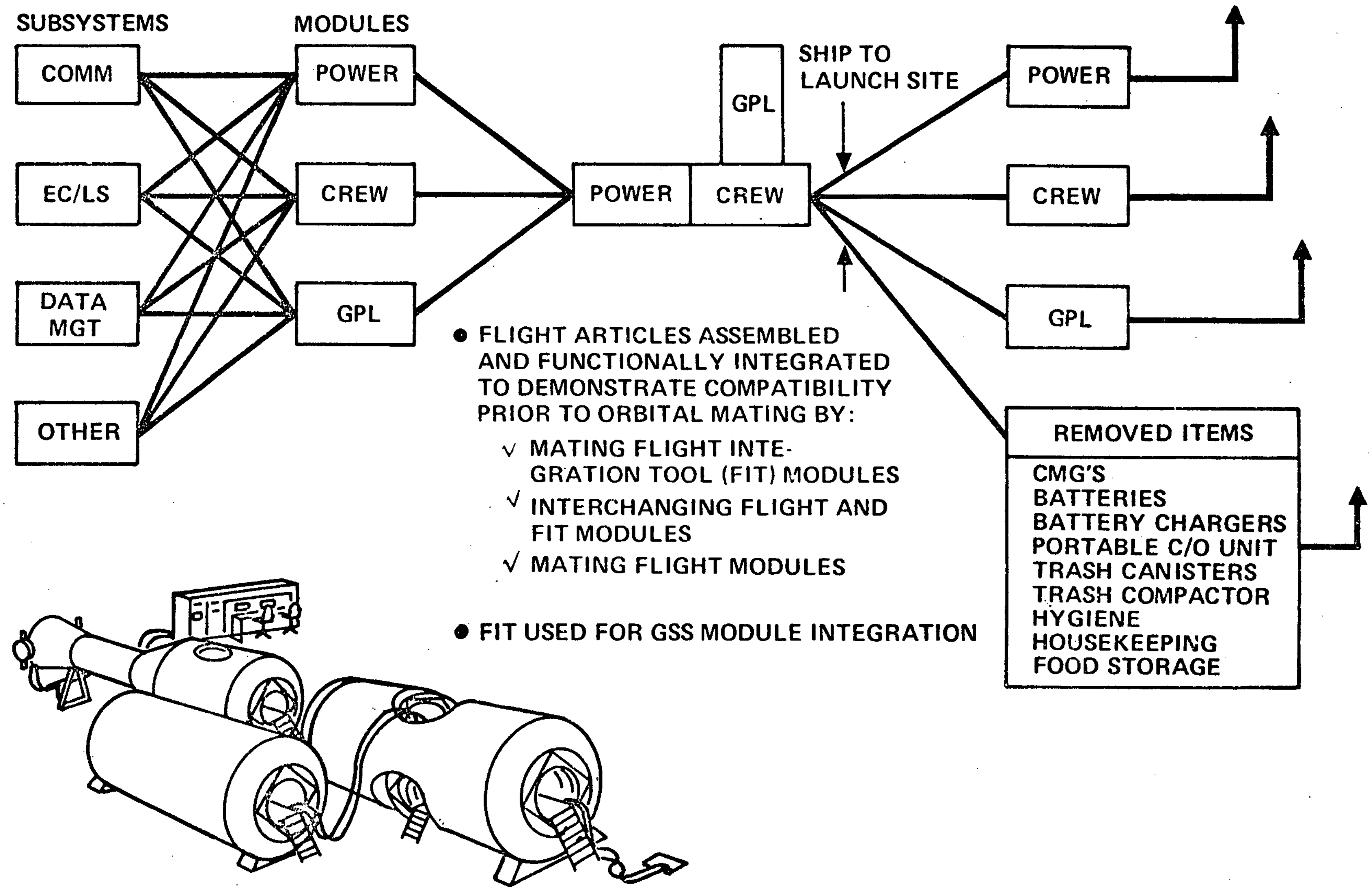


Figure 6-37. Modular Space Station ISS Hardware Flow (Ground)

Table 6-5

SPACE STATION CAPABILITY DURING BUILDUP

Subsystem	Launch/Module First/Power	Second/Crew	Third/GPL	Fourth/Logistics	Fifth/Logistics
Habitability	Shirtsleeve Shuttle air	6-man EC/LS	6-man EC/LS	Repressurization gas	
Power	Solar array, No. 1 battery set			No. 2 and No. 3 battery sets	No. 4, 5, and 6 battery sets
Attitude Control	RCS No. 1	RCS No. 2		4 CMG's	
Communications	VHF S-Band	Wide band Ku antenna			
Data Management	Central Computer	Control and display	Redundant data management		
Onboard Checkout	Central computer, Portable control and display unit			3 portable control and display units	
Thermal Control	Operable for each module	→	→		

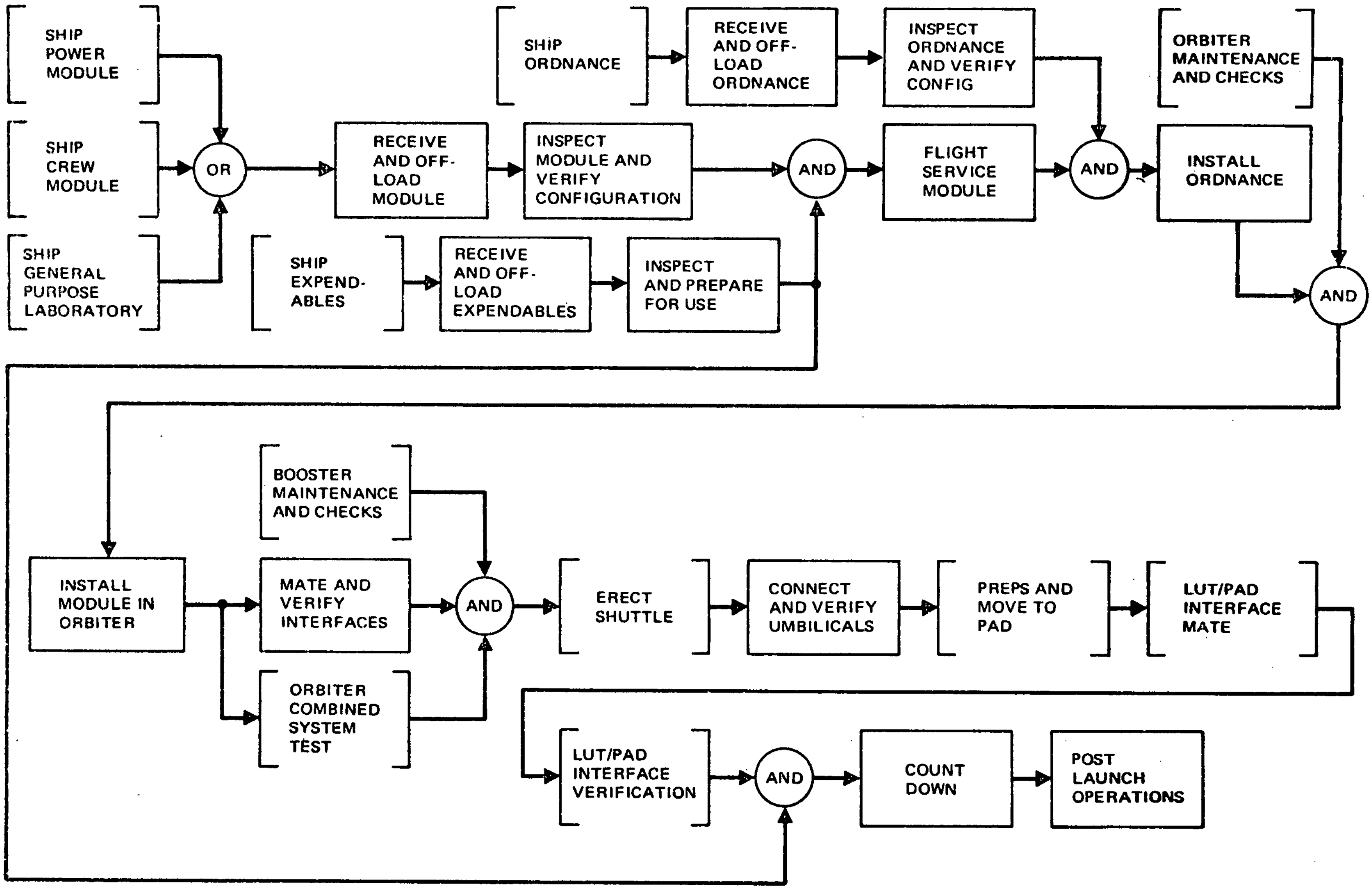


Figure 6-38. Typical Module Operational Flow

6.1.4 Flight Operations

Flight operations for the ISS are concerned with buildup and activation, unmanned operation, normal on-orbit operations, and associated Space Shuttle flight support (Figure 6-36). Baseline ISS flight operations are detailed in Reference 3.

6.1.4.1 Buildup Operations

Communications subsystem VHF and S-band equipment are checked during the on-orbit activation of the Power/Subsystems Module. This equipment then provides for the transmission and reception of information during all stages of ISS buildup. An OCS/DMS portable display and control unit is used to initiate, monitor, and control checkout software routines used to verify proper operation of subsystems activated within the module.

Before mating the Crew/Operations Module with the Power/Subsystems Module, the high-gain antennas on the Crew/Operations Module are rotated to a docking configuration to eliminate any interference with the docking operation. This is shown in Figure 6-39. The antennas are then deployed to their normal positions following mating of the two modules. The K_u-band equipment is not required until after normal on-orbit ISS operations are initiated. The operational readiness of the equipment is verified during subsystems tests of the first two modules conducted as a part of ISS buildup operations. These tests are conducted from the primary control station in the Crew/Operations Module. The portable display and control units, if required, can be used as additional operating stations.

Voice communications are provided between crewmen in the ISS mdoule and the Shuttle-Orbiter crew during buildup operations. The baseband voice channel normally used for public address or emergency voice communications provides this capability, and is available in all of the modules.

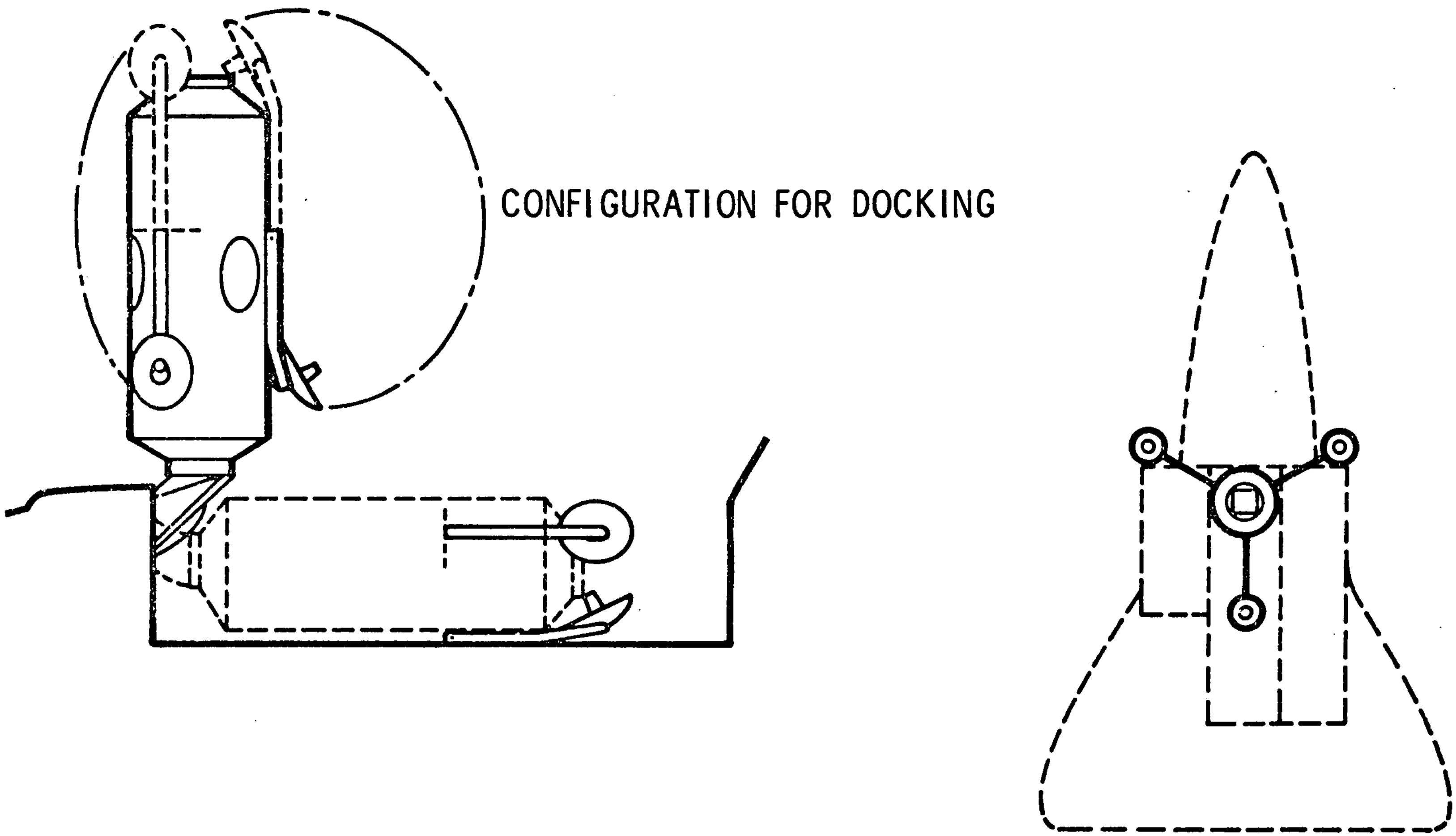


Figure 6-39. High-Gain Antenna Installation

6.1.4.2 Normal Communications Subsystem On-Orbit Operations

During normal on-orbit operations the communications subsystem provides for the transmission and reception of the following types of information:

A. Direct ground link
   1. Command, voice, and ranging reception.
   2. Telemetry, voice, and ranging transmission.
B. DRSS link
   1. Television, multiple voice, entertainment audio, digital data, and ranging reception.
   2. Television, experiment data, multiple voice, digital data, and ranging transmission.
C. Shuttle-Orbiter link
   1. Voice, command, and ranging reception.
   2. Voice, telemetry, and ranging transmission.
D. EVA link
   1. Voice and biomedical data reception
   2. Voice transmission.

The direct ground link is used primarily for ISS tracking and position update information. The capabilities for command, voice, telemetry, and experiment data dump can be utilized during relay satellite system down periods or outages.

The relay satellite link, using the high-gain antenna system shown in Figure 6-40, is primarily for experiment operations support and provides a wideband uplink and downlink capability. The transmission of experiment data is normally controlled on a scheduled basis, but can be called up on short notice by the VHF voice link through the relay satellite. The establishment of a solid wideband RF link with the DRSS requires that a cooperative high-gain acquisition procedure be performed.

During manned operations the VHF link through the DRSS is primarily used for administrative and procedural voice and low-data-rate traffic between the ISS and ground mission operations support. A capability for simultaneous

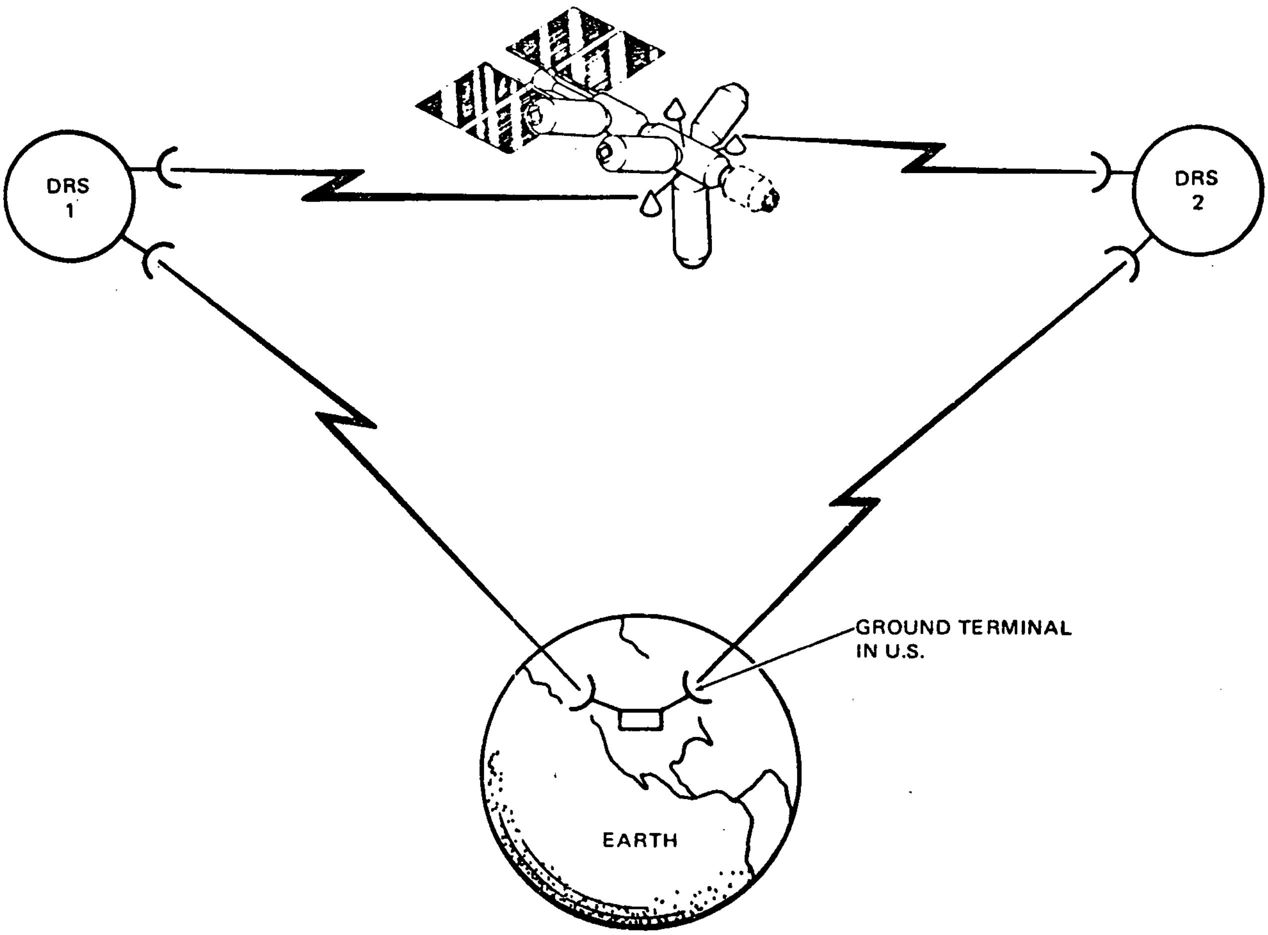


Figure 6-40. Data Relay Satellite Network

voice, data, and ranging between the ISS and Shuttle-Orbiter can be provided at ranges up to 200 kilometers.

During EVA operations, duplex voice communications as well as biomedical and pressure unit data are provided to the ISS. The data can be displayed on the operations consoles in either the Crew/Operations Module or the GPL Module.

The internal communications system provides voice communications within the ISS and the docked modules. Normal voice communications are provided by an onboard telephone which is compatible with and similar in operation to the Bell Telephone system. A capability for public address and individual module paging is also provided. A "direct dial" capability is also available between personnel on the station and the ground when the high-gain antennas are operating.

During contingency operations, the crew has the capability to communicate with ground personnel on an intermittent basis with the S-band system, or on a nearly continuous basis using VHF through the DRSS. The operation of these systems can be controlled either by the portable display and control units or by hardwired controls located at each docking port. Voice communications are available from any of the modules by the use of audio terminals which access the transmitters and receivers through the analog data bus. Additional hardwired voice capability to the VHF and S-band systems is available at each docking interface.

6.1.4.3 Normal OCS/DMS On-Orbit Operations

Normal on-orbit operation of the OCS is automatic until a fault is detected either by the limit checking capability of the remote data acquisition units (RDAU's) or by a periodic monitoring routine executed by the DMS processor. Depending upon the response programmed for the particular fault, the OCS may then proceed automatically to isolate the fault to the replaceable unit, or to notify the crew of the malfunction and await further instructions. The programmed response may also include the selection of alternate modes of operation or activation of redundant systems if desired. If crew action is required to complete the isolation to the replaceable unit, the operator can call up additional programmed diagnostic routines, call up and examine selected test point measurements, or create special test routines "on line" using the operating system language. He may also call up supplementary documentation in the form of schematics, diagrams, or printed material stored in the data processor memory or on microfilm. Still another source of potential diagnostic data which may be called up from the processor memory is a continuously maintained record of the past hour's operation and test results, analysis of which may reveal events leading up to the failure. When the faulty unit has been isolated and replaced, the system is reverified and the inventory status updated to reflect the parts used.

The OCS interface with ground facilities during normal operations is generally limited to the downlink transfer of summary status information and selected data for long-term trend analysis. The capability exists for transmitting selected or complete test point data to the ground if this becomes necessary for any reason.

6.2 MAINTENANCE AND CHECKOUT PHILOSOPHY

6.2.1 Maintenance Concepts

Providing an effective onboard repair capability is essential in supporting a long-duration Space Station since complete reliance on redundancy to achieve long life is not feasible. The need for repair, in turn, requires that a malfunction be isolated to at least its in-place remove and replace level. The level of fault isolation on the ISS is keyed to the line replaceable unit (LRU) which is the smallest unit within a subsystem that is suitable for onboard replacement. Redundant capabilities are provided where necessary to assure adequate maintenance reaction time and are used as a means to reduce requirements for EVA maintenance excursions. Entire modules are returned only when major refurbishment is required.

A detailed discussion of ISS maintenance concepts can be found in Section 7 of Reference 3. The distribution of maintenance man-hours between modules and the relative contribution of each ISS subsystem to the total workload are illustrated in Figure 6-41. As seen in the figure, the contribution of the communications subsystem to total ISS maintenance workload is nearly negligible. The total preventive and corrective maintenance workload is estimated at 65 man-hours per month for the ISS. This represents the replacement of 13 random failure items and 15 scheduled replacement items on the average per month. For the communications subsystem, an average of only 0.6 repair actions per month involving 0.7 maintenance man-hours is anticipated.

6.2.2 Checkout Guidelines

An onboard checkout capability is provided to determine whether or not ISS subsystems and experiments are operating in an acceptable manner, to supply information for repair and reconfiguration actions, and to verify subsystem and experiment operation following failure correction. The checkout functions required to implement this capability include status monitoring, periodic testing, trend analysis, and fault isolation. Major ISS checkout guidelines are shown in Figure 6-42 and further described in Section 4.11 of Reference 1. Communications subsystem checkout requirements are presented below in Subsection 6.3.

6.2.3 Communications Subsystem Criticality Analysis

To facilitate the identification of subsystem LRU's and redundancy switching requirements, a reliability/criticality analysis was performed. Table 6-6 presents an ordered ranking of the five communications subsystem elements having the highest criticality (or failure expectation) numbers. The criticality number is the product of (1) the element's failure rate (or the reciprocal of mean-time-between-failure), (2) its anticipated usage or duty cycle, and (3) an orbital time period of 2 months (1,460 hours). Two months was chosen as the time period of interest to allow one missed resupply on the basis of normal resupply occurring at 1-month intervals. In other words, the criticality number is the failure expectation for a particular subsystem element over any 2-month time period.

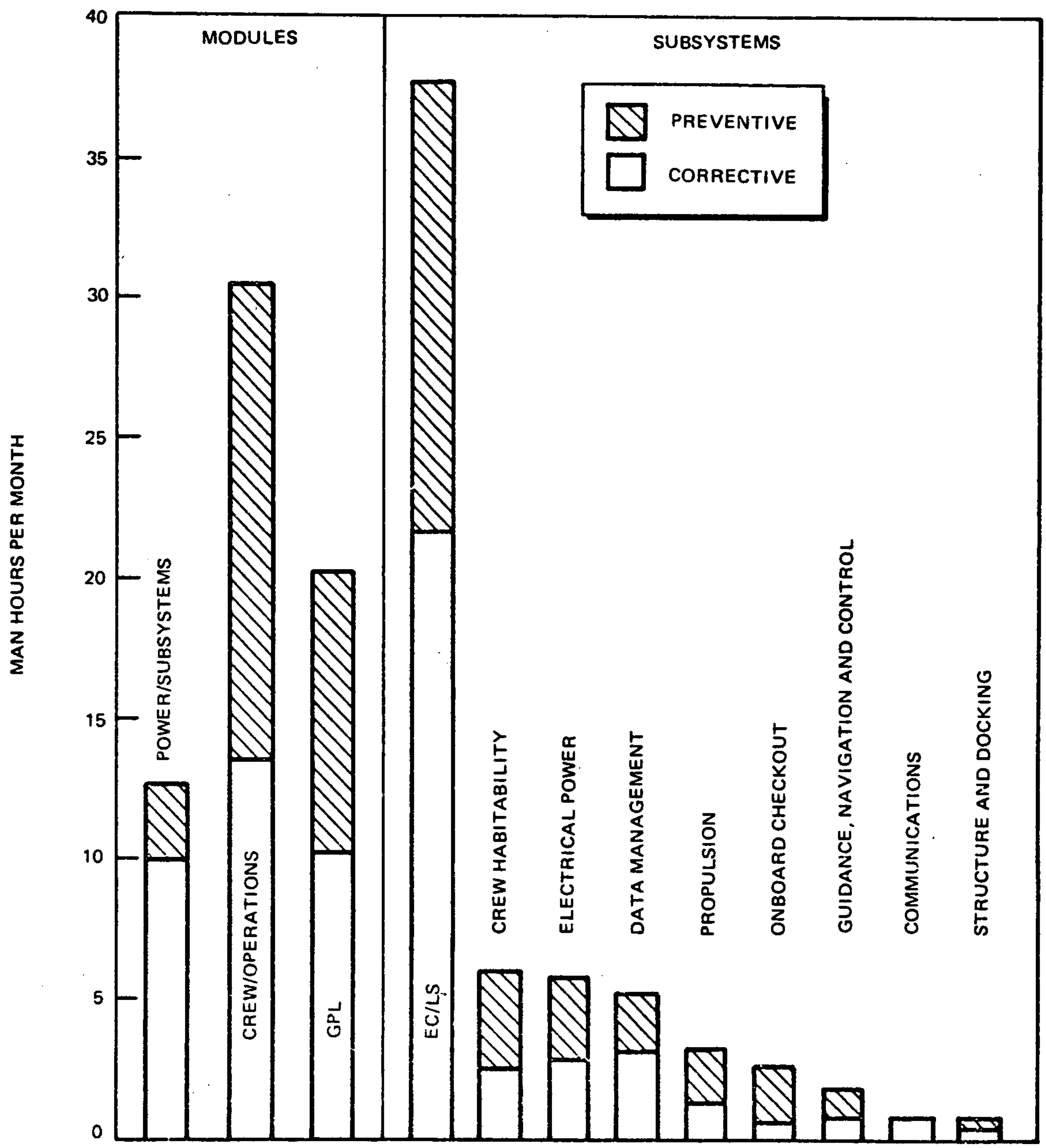


Figure 6-41. Maintenance Workload (ISS)

- CONTINUOUS MONITORING TO PROVIDE IMMEDIATE INDICATIONS OF OUT-OF-TOLERANCE CONDITIONS TO THE CREW
- PERIODIC TESTING AND TREND ANALYSIS TO ASSURE SYSTEM AVAILABILITY
- IN-PLACE FAULT ISOLATION TO REPLACEABLE UNIT LEVEL FOR LONG LIFE ASSURANCE
- ONBOARD CHECKOUT CONTROL EXCEPT DURING QUIESCENT MISSION PHASES
- CAPABILITY FOR SELECTING AND TRANSMITTING CHECKOUT DATA TO THE GROUND
- AUTOMATION TECHNIQUES TO THE GREATEST PRACTICAL EXTENT
- OCS SELF-CHECK CAPABILITY
- IN-FLIGHT CAPABILITY FOR RESTRUCTURING CHECKOUT PROCEDURES
- STANDARD OCS INTERFACES
- COMPREHENSIVE GROUND TEST PROGRAM TO MINIMIZE OPERATIONAL RISKS

Figure 6-42. Modular Space Station Checkout Guidelines

Table 6-6

COMMUNICATIONS SUBSYSTEM ORDERED COMPONENT CRITICALITY

Element	MTBF (Hours)	Single Unit Criticality*
Analog sync/test unit	174,000	0.00840
S-band narrow-band FM receiver	89,000	0.00820
K_u-band power amplifier	70,000	0.00689
S-band PM transponder	42,600	0.00343
S-band wideband FM receiver	120,000	0.00304

* Failure expectation over two months.

The most probable failure modes as well as their mission effect are indicated in Table 6-7 for each major communications subsystem element. The failure effects noted, however, are for the worst case and do not consider the offsetting effects of redundant components, subsystem maintainability, and alternate operational procedures available. There would be practically "no effect" if these factors were considered.

In most cases, a double failure is required to lose totally the information on a given RF link. Antenna RF switch failures, for example, may prevent selection of the optimum antenna, but do not prevent transmission via alternate antennas. If data transmissions to the ground via relay satellite are lost, the ISS is capable of communicating directly with the ground or storing the data for transmission at a later time. All failures identified for the communications subsystem have the potential for causing the loss of some mission objectives, but none have been identified that are life critical.

6.2.4 Line Replaceable Units

In general, the definition of subsystem LRU's is dependent upon ISS maintenance concepts, subsystem design (weight, volume, location, and interchangeability characteristics), component-level failure rates, crew time and skills required for fault isolation and repair, and resultant checkout hardware and software complexity. A listing of LRU's for the communications subsystem is provided in Table 6-8.

The RF transmitter/receivers, receivers, exciters, power amplifiers, and modems are selected as assembly-level LRU's largely because of packaging, reliability, and electromagnetic interference (EMI) considerations. Initial reliability estimates indicate that the power amplifiers are the most critical of this group of assemblies. Lower-level modularization of the power amplifiers is not practical because of restrictions caused by the physical dimensions of the traveling wave tube (TWT), thermal cooling requirements, and sensitivity to changes in power supply voltages. It is planned, therefore, that the TWT and power supplies be mated and adjusted as a unit on the ground. Furthermore, lower-level modularity would increase the number of

Table 6-7
CRITICALITY ANALYSIS (Page 1 of 2)

Major Subsystem Element	Failure Mode(s)	Mission Effect	Number of Units	(A) MTBF (Thousands of Hours)	(B) Duty Cycle (%)	Criticality Per Unit (1460 Hours x B/A x 10^6)
VHF Assembly Group						
(1) EVA transmitter/receiver	Open/short in oscillator, amplifier, detector circuitry, or power supply.	Loss of voice communication with EVA crewmen. Loss of bimedical data. Crew hazard only if EVA crewmen in jeopardy (secondary failure). Biomedical data considered secondary objectives.	3	640	1	20
(2) EVA transmitter/receiver Modem	Open/short in amplifier, filters, or logic circuitry.	Failure to extract voice data from biomedical data signals. Biomedical data considered secondary objectives. Crew hazard only if EVA crewmen in jeopardy (secondary failure).	1	385	1	40
(3) VHF data transmitter/receiver	Open/short in power supply, oscillators, or detectors.	Loss of digital data transfer capability between ISS and relay satellite.	2	640	10	230
(4) VHF voice transmitter/receiver	Open/short in power supply, mixer, frequency oscillators, or detectors. Unstable crystal oscillator.	Loss of voice communication between ISS and relay satellite.	2	170	10	860
(5) VHF low-gain antenna system	RF switch failure.	Loss of communications with EVA or relay satellite.	3	2, 780	33	170
S-Band Assembly Group						
(6) S-band PM transponder	Open/short in detectors, oscillator, mixer, power supply, or modulators.	Loss of voice, ranging, and digital data between ISS and Shuttle Orbiter, and between ISS and ground. Could be critical if failed during docking.	2	42.6	10	3, 430
(7) S-band FM exciter	Open/short in power supply, oscillator, or multiplying logic circuitry.	Loss of television or wideband digital data between ISS and ground.	1	310	10	470
(8) S-band power amplifier	Open/short in power supply, amplifiers or power transistor hybrids.	Loss of wideband data transmissions.	2	200	10	730
(9) Ranging unit	Open/short in power supply, amplifiers, oscillator, generators, or counters.	Loss or range and range rate data with shuttle orbiter. Could be critical if failed during docking.	1	225	2	130
(10) S-band low-gain antenna system	RF switch failure	Loss of voice, ranging, and digital data between ISS and Shuttle Orbiter, and between ISS and ground. Could be critical if failed during docking.	3	2, 780	50	260

Table 6-7

CRITICALITY ANALYSIS (Page 2 of 2)

Major Subsystem Element	Failure Mode(s)	Mission Effect	Number of Units	(A) MTBF (Thousands of Hours	(B) Duty Cycle (%)	Criticality Per Unit (1460 Hours x B/A x 10^6)
Ku-band Assembly Group						
(11) S-band narrow-band FM receiver	Open/short in power supply, amplifiers, mixer or detectors.	Loss of voice or digital data between ISS and relay satellite.	1	89	50	8, 200
(12) S-band wideband FM receiver	Open/short in power supply, mixers, amplifiers or detectors. Oscillator drift.	Loss of voice or video data between ISS and relay satellite.	1	120	25	3. 040
(13) Ku-band power amplifier	TWT short to case, heater open, power supply open/short.	Loss of wideband data between ISS and realy satellite.	6	70	33	6, 890
(14) Ku-band exciter	Open/short in amplifer, filter modulator, or power supply. Unstable crystal oscillator.	Loss of digital or wideband analog data between ISS and relay satellite.	6	920	33	520
(15) Ku-band exciter modem	Open/short in power supply, amplifiers, generators, mixers, or filters.	Loss of voice and video data between ISS and realy satellite.	6	300	33	1, 610
(16) High-gain antenna system	Failure of drive system, low-noise receiver, or RF switch.	Loss of wideband communications between ISS and relay satellite.	3	175	33	2, 750
(17) Audio terminal unit	Open/short in transceiver or FM receiver.	Loss or degradation of individual voice/entertainment stations.	18	188	25	1, 940
(18) Analog sync/test unit	Open/short in reference generators, amplifiers, detectors, or mixers.	Loss of internal voice communications (secondary failure).	2	174	100	8, 400

Table 6-8

COMMUNICATIONS SUBSYSTEM LRU'S

Assembly Group	Subgroup	Line Replaceable Unit (LRU)	LRU Module Location and Quantity: Power/Subsystems	Crew Operations	GPL	Total
VHF	Low-gain antenna	VHF antenna element	3			3
		VHF diplexer	3			3
		Multiplexer and power divider assembly	1			1
		Multiplexer and switching assembly	1			1
	RF	EVA transmitter/receiver	3			3
		EVA transmitter/receiver modem	1			1
		VHF data transmitter/receiver	2			2
		VHF voice transmitter/receiver	2			2
S-band	Low-gain antenna	S-band antenna element	3			3
		S-band triplexer and switching assembly	1			1
	RF	S-band PM transponder	2			2
		S-band FM exciter	1			1
		S-band power amplifier	2			2
		Ranging unit	1			1
K_u-band	High-gain antenna	Reflector and subreflector		3		3
		Positioner		3		3
		Position servo control		6		6
		Acquisition comparator and feed assembly		3		3
		Main comparator and feed assembly		3		3
		Multiplexer and switching assembly		7		7
		K_u-band low-noise receiver		6		6
		S-band tracking receiver		6		6
		Selector switch		6		6
	RF	S-band narrow-band PM receiver		1		1
		S-band wideband FM receiver		1		1
		K_u-band power amplifier		6		6
		K_u-band exciter		6		6
		K_u-band exciter modem		6		6
		Hybrid and switching/assembly		6		6
Internal communications		Audio terminal units	3	9	6	18
		Analog sync/test unit		2		2

connectors required, thereby decreasing overall reliability and creating potential sources of EMI. Another problem encountered with a lower replacement level is module-to-module tolerance buildup. This concept was attempted, for example, on an S-band transponder for another program and resulted in modules not being interchangeable that were supposed to be interchangeable.

The primary considerations used in the selection of LRU's for the high- and low-gain antenna systems are somewhat different from those used for RF subgroup equipment. Antenna system LRU's typically do not require thermal cooling and are consequently located largely on the basis of minimizing RF transmission line losses. The reliability of multiplexers, power dividers, switching assemblies, and low-gain antenna elements is relatively high. The majority of the problems associated with low-gain antenna (omnidirectional) systems, if encountered, usually occur during initial installation and checkout. The most difficult maintenance and replacement problems are posed by the portion of the high-gain antenna system located at the end of the mast. Redundant electronics are utilized wherever possible to minimize maintenane downtime for the high-gain antenna system.

6.3 COMMUNICATIONS SUBSYSTEM CHECKOUT

On-orbit checkout activities required to insure the availability of the communications subsystem include monitoring of its normal operational outputs, performing periodic checks, conducting trend analysis, and selecting fault isolation routines associated with the loss of a communications function. A summary of the performance/status checks required for the VHF, S-band, and K_u-band assembly groups are presented in Table 6-9. An identification of the type, quantity, and usage of measurement and stimulus parameters required to implement communications subsystem checkout and fault isolation functions, as well as those required to conduct normal subsystem operations, is provided in Table 6-10. A detailed listing of these parameters and their characteristics is provided in Table 6-11.

Table 6-9

COMMUNICATIONS SUBSYSTEM PERFORMANCE/STATUS TESTS

Assy Group			Test	Key Measurements	ISS		Orbiter	
VHF	S	K_u			FLT	GND	FLT	GND
X	X	X	Transmission system insertion loss	RF power level	X	X		X
X	X	X	VSWR measurement	Forward and reflected RF power	X	X		X
X	X	X	Receive system performance	AGC output level	X	X	X	X
X	X	X	Receiver sensitivity	AGC output level	X	X	X	X
X	X	X	Receiver detection sensitivity	Detected modulation output level	X	X		X
X	X	X	Transmitter RF power output level verification	RF power level	X	X	X	X
X	X	X	Transmitter modulation sensitivity	Modulation output level	X	X		X
	X		Ranging system performance	Range readout	X	X		X
X	X	X	Status monitor	PA and transmitter RF power levels. Receiver AGC output levels, PA temperature	X		X	
		X	Antenna acquisition and pointing verification	Tracking and pointing errors	X	X		X
X	X	X	Selected operational controls	Selection indications	X	X		X
X	X	X	Other operational controls	On/off, mode, and channel indications		X		X

Table 6-10

PARAMETER TYPE AND USAGE SUMMARY

Parameter Type	Assembly Group				Total	% of Total	Onboard ISS Parameter Usage							Onboard Orbiter Test
	Int Comm	VHF	S	K_u			Oper-ations	Status Mon-itor	Test	Trend	Fault Iso-lation	Iso-lation Only	T/M	
Stimuli														
Bilevel (B)	8	52	24	157	241	26.9	141		79		235	32		
Digital (D)	2	1	3	46	52	5.8	25		38		49			
RF (R)		15	7	24	46	5.1			15	1	46	28		
Total Stimuli	10	68	34	227	339	37.8	166	0	132	1	330	60	0	0
Measurements														
Analog		76	37	158	271	30.3	42	33	164	26	263	89	4	43
Bilevel	6	52	25	160	243	27.2	146	3	62		236	46		
Digital	2	1	5	34	42	4.7	28	4	14		37	12	2	
Total Measurements	8	129	67	352	556	62.2	216	40	240	26	536	147	6	43
Total Parameters	18	197	101	579	895	100.0	382	40	372	27	866	207	6	43
Percent of Total	2.0	22.0	11.3	64.7	100.0		42.7	4.5	41.6	3.0	96.8	23.1	0.7	4.8

Table 6-11

MEASUREMENT/STIMULUS LIST (Page 1 of 14)

WORKSHEET

ASSEMBLY GROUP: VHF (1 of 4)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D,R)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	PERIODIC TEST: ISS	PERIODIC TEST: ORBITER	FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
EVA Transmitter/ Receiver (3)	Primary Power Control	3	S	B	X						X	X	X		1					On/Off	(1) All bilevel signals are
	Primary Power On Indication	3	M	B	X						X	X	X		1					On/Off	are 0 or 5 vdc TTL levels.
	Push-to-talk (PTT) Control (simplex)	3	S	B	X						X	X			1					On/Off	(2) Status monitoring indicated is only done during subsystem operation.
	PTT (simplex) On Indication	3	M	B	X						X	X			1					On/Off	(3) Add'l VHF status monitoring
	Tranmitter Control	3	S	B	X						X	X	X		1					On/Off	is performed operationally by the DMS for biomedical
	Transmitter On Indication	3	M	B	X						X	X	X		1					On/Off	data and by the crew for voice.
	Receiver Control	3	S	B	X						X	X	X		1					On/Off	
	Receiver On Indication	3	M	B	X						X	X	X		1					On/Off	
	Modulated RF Stimulus Control	3	S	B							X		X		1					On/Off	(4) Periodic tests per-
	Modulated RF Stimulus Indication	3	M	B							X		X	B	1					Present/Absent	formed prior to usage or prior to scheduled resupply for
	Receiver AGC Output Level	3	M	A					X	X	X	X	X	B/S	7		(4) Mo			0 to 5±10% vdc	ISS; and prior to usage or during gnd. checks for orbiter.
	Receiver Detected Output Level	3	M	A						X	X		X		7					0 to 5±10% vdc	(5) Stimulus applied at modem ~~input~~.
	Transmitter Modulation Stimulus Cont'l	3	S	B							X		X		1					On/Off	(6) All parameters for on-
	Transmitter Modulation Input Indication	3	M	B							X				1					Present/Absent	board fault isolation for the ISS are also considered
	Transmitter Modulation Output Level	3	M	A		X			(5) X		X	X	X	B	7	1/S				0 to 5±10% vdc	applicable to orbiter or ISS fault isolation on the ground.
	Transmitter RF Power Output	3	M	A					X	X	X	X	X	B	7		Mo			0 to 5+5% vdc	(7) Orbiter assumed not to have an EVA transmitter/
																					receiver modem.
EVA Transmitter/ Receiver Modem	Primary Power Control	1	S	B	X						X	X			1					On/Off	
	Primary Power On Indication	1	M	B	X						X	X			1					On/Off	
	Voice Mode Control	1	S	B	X						X	X			1					On/Off	
	Voice On/Off Indication	1	M	B	X						X	X			1					On/Off	
	Squelch Control	3	S	B	X						X	X			1					Enable/Override	
	Squelch Enable/Override Indication	3	M	B	X						X	X			1					Enable/Override	

M - Measurement
S - Stimulus

A - Analog
B - Bilevel
D - Digital
R - RF

B - Box Level
S - Subsystem Level

S - Second
M - Minute
H - Hour

W - Weekly
Mo - Monthly

Table 6-11

MEASUREMENT/STIMULUS LIST (Page 2 of 14)

WORKSHEET

ASSEMBLY GROUP: VHF (2 of 4)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	PERIODIC TEST: ISS	PERIODIC TEST: ORBITER	FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
EVA T/R Modem (Continued)	VOX Mode Control	2	S	B	X						X	X			1					Enable/Override	
	VOX Enable/Override Indication	2	M	B	X						X	X			1					Enable/Override	
	Simplex Mode Control	1	S	B	X						X	X			1					VOX/PTT	
	Simplex Mode Indication	1	M	B	X						X	X			1					VOX/PTT	
	Transmitted Audio Output	3	M	A							X				7					0 to 5 vdc ±5%	
	Received Audio Output	3	M	A					X		X	X		S	7		Mo			0 to 5 vdc ±5%	
	Modulation Stimulus Control	1	S	B					X		X	X		S	1		Mo			On/Off	
	Received Biomed Output	2	M	A					X		X	X		S	7		Mo			0 to 5 vdc	
	Modulation Stimulus Indication	1	M	B							X				1					On/Off	
	Receive Stimuli Control	3	S	B							X				1					On/Off	
	Receive Stimuli Indication	3	M	B							X				1					Present/Absent	
VHF Data Transmitter/Receiver(2)	Primary Power Control	2	S	B	X						X	X			1					On/Off	
	Primary Power On Indication	2	M	B	X						X	X			1					On/Off	
	Transmitter Control	2	S	B	X						X	X			1					On/Off	
	Transmitter On Indication	2	M	B	X						X	X			1					On/Off	
	Receiver Control	2	S	B	X						X	X			1					On/Off	
	Receiver On Indication	2	M	B	X						X	X			1					On/Off	
	Modulated RF Stimulus Control	2	S	B					X		X	X		B	1		W			On/Off	
	Receiver AGC Output Level	2	M	A		X		(9) X	X	(8)	X	X	(8)	B	7	6/M				0 to 5 vdc	
	Modulated RF Stimulus Indication	2	M	B					X		X	X		B	1		W			Present/Absent	(8) No direct correlation
	Receiver Detected Output Level	2	M	A					X	(8)	X	X	(8)	B	7		W			0 to 5±10% vdc	with orbiter for VHF data and voice transmitter/receiver
	Transmitter Modulation Stimulus Control	2	S	B					X		X	X	(8)	B	1		W			On/Off	(9) Trended from periodic test
	Transmitter Modulation Stimulus Indication	2	M	B					X		X	X		B	1		W			Present/Absent	to periodic test (10) Trend sample rate of
	Transmitter Modulation Output Level	2	M	A					X		X	X	(8)	B	7		W			0 to 5+10% vdc	once per hour during operation; check against previous 48
	Transmitter RF Power Output	2	M	A		X		(10) X	X	(8)	X	X	(8)	B	7	6/M	W			0 to 5±5% vdc	samples; retain daily average for 3 months.

Table 6-11

MEASUREMENT/STIMULUS LIST (Page 3 of 14)

WORKSHEET

ASSEMBLY GROUP: VHF (3 of 4)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	PERIODIC TEST: ISS	PERIODIC TEST: ORBITER	FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
VHF Voice Transmitter/Receiver	Primary Power Control	2	S	B	X						X	X			1					On/Off	
	Primary Power On Indication	2	M	B	X						X	X			1					On/Off	
	Transmitter Control	2	S	B	X						X	X			1					On/Off	
	Transmitter On Indication	2	M	B	X						X	X			1					On/Off	
	Receiver Control	2	S	B	X						X	X			1					On/Off	
	Reciver On Indication	2	M	B	X						X	X			1					On/Off	
	Squelch Control	2	S	B	X						X	X			1					On/Off	
	Squelch Enable/Override Indication	2	M	B	X						X	X			1					On/Off	
	Modulated RF Stimulus Control	2	S	B					X		X	X		B	1					On/Off	
	Receiver AGC Output Level	2	M	A		X		(9) X	X	(8)	X	X	(8)	B	7	6/M				0 to 5 vdc	
	Modulated RF Stimulus Indication	2	M	B					X		X	X		B	1		W			TBD ±5% vac (design parameter)	
	Receiver Detected Output Level	2	M	A					X	(8)	X	X	(8)	B	7		W			0 to 5 ±10% vdc	
	Transmitter Modulation Stimulus Control	2	S	B					X		X	X	(8)	B	1		W			On/Off	
	Transmitter Modulation Stimulus Indication	2	M	B					X		X	X		B	1		W			Present/Absent	
	Transmitter Modulation Output Level	2	M	A					X		X	X	(8)	B	7		W			0 to 5 +10% vdc	
	Transmitter RF Power Output	2	M	A		X		(10) X	X	(8)	X	X	(8)	B	7	6/M				0 to 5±5% vdc	
VHF Antenna Element (3)	Transmit RF Power Input (Forward Pwr)	15	M	A	X				X		X	X	X	S	7		W			0 to 5±5% vdc	
	Reflected RF Power	15	M	A					X		X	X	X	B	7		W			0 to 5±5% vdc	
	Transmit RF Stimulus	5	S	R							X				-					Not less than 10 watts or not less than 0.5 milliwatt	From Multiplexer Assemblies

Table 6-11

MEASUREMENT/STIMULUS LIST (Page 4 of 14)

WORKSHEET

ASSEMBLY GROUP: VHF (4 of 4)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	USAGE: ONBOARD CHECKOUT: STATUS MONITOR	USAGE: ONBOARD CHECKOUT: REDUNDANCY SWITCHING	USAGE: ONBOARD CHECKOUT: TREND ANALYSIS	USAGE: ONBOARD CHECKOUT: PERIODIC TEST: ISS	USAGE: ONBOARD CHECKOUT: PERIODIC TEST: ORBITER	USAGE: ONBOARD CHECKOUT: FAULT ISOLATION	USAGE: GND C/O: ISS PRELAUNCH	USAGE: GND C/O: ORBITER	TEST LEVEL (B, S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
Multiplexer and Switching Assy	Antenna Select Command	1	S	D	X				X		X	X	X	S	2		W			1 of 3	
	Antenna Selected	1	M	D	X				X		X	X	X	S	2		W			1 of 3	
	Transmit RF Power Input (Forward Pwr)	2	M	A							X				7					0 to 5±5% vdc	
	Reflected RF Power	2	M	A							X				7					0 to 5±5% vdc	
	Transmit RF Simulus	2	S	R							X				-					Not less than 15 watts	From voice or data
	Receive RF Stimulus	2	S	R					X		X	X	X	S	-		W			Not less than -20 dbm	transmitter/receivers
Multiplexer and Pwr Divider Assy	Transmit RF Power Input (Forward Pwr)	3	M	A							X				7					0 to 5±5% vdc	
	Reflected RF Power	3	M	A							X				7					0 to 5±5% vdc	
	Transmit RF Stimulus	3	S	R							X				-					Not less than 0.75 milliwatt	From EVA transmitter/
	Receive RF Stimulus	3	S	R					X		X	X	X	S	-		W			Not less than -20 dbm	receivers.

Table 6-11

MEASUREMENT/STIMULUS LIST (Page 5 of 14)

WORKSHEET

ASSEMBLY GROUP: S-Band (1 of 3)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D,R)	USAGE: OPERATION	USAGE: ONBOARD CHECKOUT: STATUS MONITOR	USAGE: ONBOARD CHECKOUT: REDUNDANCY SWITCHING	USAGE: ONBOARD CHECKOUT: TREND ANALYSIS	USAGE: ONBOARD CHECKOUT: PERIODIC TEST: ISS	USAGE: ONBOARD CHECKOUT: PERIODIC TEST: ORBITER	USAGE: ONBOARD CHECKOUT: FAULT ISOLATION	USAGE: GND C/O: ISS PRELAUNCH	USAGE: GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
S-Band PM Transponder (2)	Primary Power Control	2	S	B	X						X	X	X		1					On/Off	
	Primary Power On Indication	2	M	B	X						X	X	X		1					On/Off	
	Ranging Channel Control	2	S	B	X						X	X	X		1					On/Off	
	Ranging Channel Indication	2	M	B	X						X	X	X		1					On/Off	
	Local Reference Control	2	S	B	X						X	X	X		1					On/Off	
	Local Reference Enabled	2	M	B	X						X	X	X		1					On/Off	
	1.25 MHz Subcarrier Control	2	S	B	X						X	X	X		1					On/Off	
	Emergency Voice Control	2	S	B	X						X	X	X		1					On/Off	
	Emergency Voice On Indication	2	M	B	X						X	X	X		1					On/Off	
	1.024 MHz Subcarrier Control	2	S	B	X						X	X	X							On/Off	
	Modulated RF Stimulus Control	2	S	B	X				X		X	X	X	B	1		(10) Mo			On/Off	
	Modulated RF Stimulus Indication	2	M	B					X		X	X	X	B	1		Mo			Present/Absent	
	Receiver AGC Output Level	2	M	A		X		(9) X	X	X	X	X	X	B/S	7	1/S		X	X	0 to 5±10% VDC	
	Receiver Loop/Lock Indication	2	M	B	X	X	X				X	X	X		1	1/S				In/Out	
	Receiver Detected Output Levels	4	M	A					X		X	X	X	B	7		Mo			0 to 5±10% VDC	
	Transmitter Modulation Stimulus Cont'l	2	S	B					X		X	X	X	B	1		Mo			On/Off	
	Transmitter Modulation Stimulus Indication	2	M	B							X				1					Present/Absent	
	Transmitter Modulation Output Levels	4	M	A					X		X	X	X	B	7		Mo			0 to 5±10% VDC	
	Transmitter RF Power Output	2	M	A		X			X		X	X	X	B	7	1/S				0 to 5±10% VDC	
	Static Phase Error	2	M	A	X	X			X			X	X	B	7	1/S		X	X	0 to 5±10% VDC	
	Transmit and Receive Modulation Mode	2	M	D	X	X						X	X		4	1/S		X	X	1 of 16	

Table 6-11

MEASUREMENT/STIMULUS LIST (Page 6 of 14)

WORKSHEET

ASSEMBLY GROUP: S-Band (2 of 3)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	PERIODIC TEST: ISS	PERIODIC TEST: ORBITER	FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISSA	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
S-Band FM Exciter	Primary Power Control	1	S	B	X						X	X	X		1					On/Off	
	Primary Power On Indication	1	M	B	X						X	X	X		1					On/Off	
	Exciter Control	1	S	B	X						X	X	X		1					On/Off	
	Exciter On Indication	1	M	B	X						X	X	X		1					On/Off	
	Television Mode Control	1	S	B	X						X	X	X		1					On/Off	
	Television On Indication	1	M	B	X						X	X	X		1					On/Off	
	Data Mode Control	1	S	B	X						X	X	X		1					On/Off	
	Data On Indication	1	M	B	X						X	X	X		1					On/Off	
	Television Channel Select Control	1	S	D	X						X	X	X		3					1 of 8	
	Television Channel Selected	1	M	D	X						X	X	X		3					1 of 8	
	Television Modulation Stimulus Indic.	1	M	B							X				1					Present/Absent	
	Transmitter Modulation Output Level	1	M	A					X		X	X	X	B	7					0 to 5±10% VDC	
	RF Power Output	1	M	A					X	X	X	X	X	B	7		Mo			0 to 5±5% VDC	
	Modulation Stimulus Control	1	S	D					X		X	X	X	B	2		Mo			1 of 2	
	Modulation Stimulus Indication	1	M	B							X				1					Present/Absent	
S-Band Power Amplifier (2)	Primary Power Control	2	S	B	X						X	X	X		1					On/Off	
	Primary Power On Indication	2	M	B	X						X	X	X		1					On/Off	
	RF Power Output	2	M	A		X		(11) X	X	X	X	X	X	B/S	7	1/S				0 to 5±10% vdc	Subsystem level status monitoring
	RF Input Stimulus	2	S	R							X				-					Not less than 1 watt	From Exciter
	RF Power Input	2	M	A							X				7					0 to 5±10% vdc	(11) Trend sample rate of once per day during operation; check against previous 30 sample points; retain 30 sample point averages.

Table 6-11

MEASUREMENT/STIMULUS LIST (Page 7 of 14)

WORKSHEET

ASSEMBLY GROUP: S-Band (3 of 3)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	ONBOARD CHECKOUT: PERIODIC TEST ISS	ONBOARD CHECKOUT: PERIODIC TEST ORBITER	ONBOARD CHECKOUT: FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
Ranging Unit	Primary Power Control	1	S	B	X						X	X	X		1		Mo			On/Off	
	Primary Power On Indication	1	M	B	X						X	X	X		1		Mo			On/Off	
	Code Correlation Lock Indication	1	M	B	X	X						X	X		1	1/S				In/Out	
	Range Readout	1	M	D	X				X		X	X	X	B	16		Mo			16 bit binary	Calibrated time delay required for periodic testing
	Pseudo-Random Code (PRC) Output	1	M	A							X				7		Mo			0 to 5±5% vdc	
Antenna Element (3)	RF Power Input (Forward Power)	6	M	A	X				X		X	X	X	S	7		Mo			0 to 5±5% vdc	
	Reflected RF Power	6	M	A					X		X	X	X	B	7		Mo			0 to 5±5% vdc	
	Transmit RF Stimulus	2	S	R							X				-					Not less than 10 watts or not less than 0.5 watts	From Triplexer and Switching Assembly
Triplexer and Switching Assy	Antenna Select Command	1	S	D	X				X			X	X	S	3		Mo			3 bits	
	Antenna Selected	1	M	D	X				X			X	X	S	2		Mo			1 of 3	
	RF Power Output (Forward Power)	2	M	A							X				7					0 to 5±5% vdc	
	Reflected RF Power	2	M	A							X				7					0 to 5±5% vdc	
	Transmit RF Stimulus	2	S	R							X				-					Not less than 15 watts or not less than 0.75 watts	From Transponder and/or Power Amplifier
	Receive RF Stimulus	1	S	R				(9) X	X		X	X	X	S	-		Mo			Not less than -20 dbm	From Transponder
	Bypass Mode Control	1	S	B	X				X		X	X	X	S	1					Enable/Disable	
	Bypass Mode Enabled	1	M	B	X				X		X	X	X	S	1					Enable/Disable	

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MEASUREMENT/STIMULUS LIST (Page 8 of 14)

WORKSHEET

ASSEMBLY GROUP: Ku-Band (1 of 6)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	PERIODIC TEST: ISS	PERIODIC TEST: ORBITER	FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B, S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
Ku-Band Power Amplifier (6)	Primary Power Control	6	S	B	X						X	X	X		1					On/Off	
	Primary Power On Indication	6	M	B	X						X	X	X		1					On/Off	
	Temperature	6	M	A	X	X									7	4/H				0 to 5±10% vdc	
	Warm-up Complete	6	M	B	X						X	X	X		1					Warm-up/Ready	
	Helix Current	6	M	A				(10) X			X				7					0 to 5±10% vdc	
	RF Power Output	6	M	A		X		(11) X	X	X	X	X	X	B	7	6/M				0 to 5±10% vdc	
	RF Power Input	6	M	A							X				7					0 to 5 vdc	
	RF Input Stimulus	6	S	R							X				-					Not less than 0.5 watts	From Exciter
Ku-Band Exciter (6)	Primary Power Control	6	S	B	X						X	X	X		1					On/Off	
	Primary Power On Indication	6	M	B	X						X	X	X		1					On/Off	
	PM Mode Control	6	S	B	X						X	X	X		1					On/Off	
	PM Mode Indication	6	M	B	X						X	X	X		1					On/Off	
	FM Mode Control	6	S	B	X						X	X	X		1					On/Off	
	FM Mode Indication	6	M	B	X						X	X	X		1					On/Off	
	RF Power Output	6	M	A					X	X	X	X	X	B	7		W			0 to 5±10% vdc	
	Modulation Output Level	18	M	A					X		X	X	X	S	7		W			0 to 5±10% vdc	
	Modulation Stimulus Control	6	S	B							X				1					On/Off	
	Modulation Stimulus Indication	6	M	B							X				1					Present/Absent	

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MEASUREMENT/STIMULUS LIST (Page 9 of 14)

WORKSHEET

ASSEMBLY GROUP: Ku-Band (2 of 6)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	PERIODIC TEST: ISS	PERIODIC TEST: ORBITER	FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
Ku-Band Exciter Modem (6)	Primary Power Control	6	S	B	X						X	X			1					On/Off	
	Primary Power On Indication	6	M	B	X						X	X			1					On/Off	
	Voice Control	6	S	B	X						X	X			1					On/Off	
	Voice On/Off Indication	6	M	B	X						X	X			1					On/Off	
	Television Control	6	S	B	X						X	X			1					On/Off	
	Television On/Off Indication	6	M	B	X						X	X			1					On/Off	
	Data Control	6	S	B	X						X	X			1					On/Off	
	Data On/Off Indication	6	M	B	X						X	X			1					On/Off	
	TV Channel Control	6	S	D	X						X	X			3					1 of 8	
	TV Channel Selected	6	M	D	X						X	X			3					1 of 8	
	Modulation Mode Control	6	S	D	X						X	X			2					1 of 4 (2 bits)	
	Modulation Mode Indication	6	M	D	X						X	X			2					1 of 4 (2 bits)	
	Modulation Input Indication	6	M	B							X				1					Present/Absent	
	Modulation Stimulus Control	6	S	B					X		X	X		S	1		W			On/Off	
	Modulation Stimulus Indication	6	M	B					X		X			S	1		W			Present/Absent	
	Output Level	6	M	B							X				7					0 to 5±10% VDC	
S-Band Narrow-Band Receiver	Primary Power Control	1	S	B	X						X	X	X		1					On/Off	
	Primary Power On Indication	1	M	B	X						X	X	X		1					On/Off	
	Modulated RF Stimulus Control	1	S	B							X				1					On/Off	
	Receiver AGC Level	1	M	A	X	X		(9) X	X	X	X	X	X	S	7	6/M				0 to 5±10% VDC	
	Modulated RF Stimulus Indication	1	M	B							X				1					Present/Absent	

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MEASUREMENT/STIMULUS LIST (Page 10 of 14)

WORKSHEET

ASSEMBLY GROUP: Ku-Band (3 of 6)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	PERIODIC TEST: ISS	PERIODIC TEST: ORBITER	FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B, S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
S-Band Narrow-Band Rec. (cont)																					
	Detected Output Levels	2	M	A					X	X	X	X	X	B	7		W			On/Off	
	Subcarrier Indications	2	M	B							X				1					Present/Absent	
S-Band Wide-Band Receiver	Primary Power Control	1	S	B	X						X	X			1					On/Off	
	Primary Power On Indication	1	M	B	X						X	X			1					On/Off	
	Television Control	1	S	B	X						X	X			1					On/Off	
	Television On Indication	1	M	B	X						X	X			1					On/Off	
	Entertainment Control	1	S	B	X						X	X			1					On/Off	
	Entertainment On Indication	1	M	B	X						X	X			1					On/Off	
	TV Channel Select Control	1	S	D	X						X	X			3					1 of 8	
	TV Channel Selected	1	M	D	X						X	X			3					1 of 8	
	Voice Control	1	S	B	X						X	X			1					On/Off	
	Voice On Indication	1	M	B	X						X	X			1					On/Off	
	Receiver AGC Level	1	M	A		X		(9) X	X		X	X		S	7	6/M				0 to 5±10% VDC	
	Modulated RF Stimulus Control	1	S	B							X				1					On/Off	
	Receiver Detected Output Level	1	M	A					X		X	X		B	7		W			0 to 5 ±10% vdc	
	Modulated RF Stimulus Indication	1	M	B							X				1					Present/Absent	
	4.5 MHz Subcarrier Indication	1	M	B							X				1					Present/Absent	

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MEASUREMENT/STIMULUS LIST (Page 11 of 14)

WORKSHEET

ASSEMBLY GROUP: Ku-Band (4 of 6)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	ONBOARD CHECKOUT: PERIODIC TEST ISS	ONBOARD CHECKOUT: PERIODIC TEST ORBITER	ONBOARD CHECKOUT: FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B, S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
Main Comparator and Feed Assy(3)	Transmit RF Power Input (Forward Pwr)	6	M	A	X				X		X	X	X	B/S	7		W			0 to 5±5% vdc	
	Reflected RF Power	6	M	A					X		X	X	X	B	7		W			0 to 5±5% vdc	
	Transmit RF Stimulus	2	S	R							X				-					Not less than 15 watts	Normal operational signal from power amplifier
	Sum Channel Input Select	3	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Sum Channel Input Selected	3	M	B					X		X	X	X	B	1		W			Primary/Secondary	
	Sum Channel Output Select	3	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Sum Channel Output Selected	3	M	B					X		X	X	X	B	1		W			Primary/Secondary	
	Difference Channel Select	3	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Difference Channel Selected	3	M	B					X		X	X	X	B	1		W			Primary/Secondary	
	Timing Channel Select	6	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Timing Channel Selected	6	M	B					X		X	X	X	B	1		W			Primary/Secondary	
	Receive RF Stimulus	3	S	R					X		X	X	X	S	-		W			Not less than -50 dbm	From Low-Noise Receiver
	Sum Channel RF Output	3	M	A					X		X	X	X	B	7		W			0 to 5±5% vdc	
	Comparator Power On Control	3	S	B	X						X	X	X		1					On/Off	
	Comparator Power On Indicaton	3	M	B	X						X	X	X		1					On/Off	
Acquisition Comparator & Feed Assy (3)	Transmit RF Power Input (Forward Pwr	3	M	A	X				X		X	X	X	B/S	7		W			0 to 5±5% vdc	
	Reflected RF Power	3	M	A					X		X	X	X	B	7		W			0 to 5±5% vdc	
	Transmit RF Stimulus	1	S	R							X				-					Not less than 15 watts	Normal operational signal from power amplifier
	Sum Channel Input Select	3	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Sum Channel Input Selected	3	M	B					X		X	X	X	B	1		W			Primary/Secondary	
	Sum Channel Output Select	3	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Sum Channel Output Selected	3	M	B					X		X	X	X	B	1		W			Primary/Secondary	

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MEASUREMENT/STIMULUS LIST (Page 12 of 14)

WORKSHEET

ASSEMBLY GROUP: Ku-Band (5 of 6)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	ONBOARD CHECKOUT: PERIODIC TEST ISS	ONBOARD CHECKOUT: PERIODIC TEST ORBITER	ONBOARD CHECKOUT: FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: TSS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
Acquisition Comparator & Feed Assy (continued)	Difference Channel Select	3	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Difference Channel Selected	3	M	B					X		X	X	X	B	1		W			Primary/Secondary	
	Timing Channel Select	6	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Timing Channel Selected	6	M	B					X		X	X	X	B	1		W			Primary/Secondary	
	Receive RF Stimulus	3	S	R					X		X	X	X	S	—		W			Not less than -50 dbm	
	Sum Channel RF Output	3	M	A					X		X	X	X	B	7		W			0 to 5±5% vdc	
	Comparator Power On Control	3	S	B	X						X	X	X		1					On/Off	
	Comparator Power On Indication	3	M	B	X						X	X	X		1					On/Off	
Multiplexer and Switching Assy. (6)	Transmit RF Power Input (Forward Pwr)	6	M	A							X				7					0 to 5±5% vdc	
	Reflected RF Power	6	M	A							X				7					0 to 5±5% vdc	
	PA and Receiver Select	6	S	D	X				X		X	X	X	B	2		W			1 of 4	
	PA and Receiver Selected	6	M	D	X				X		X	X	X	B	2		W			1 of 4	
	Transmit RF Stimulus	6	S	R							X				-					Not less than 15 watts	Normal operational signal from power amplifier
Low Noise Receiver (6)	RF Stimulus Control	6	S	B							X				1					On/Off	
	RF Stimulus Indication	6	M	B							X				1					Present/Absent	
	AGC Output Level	6	M	A					X	X	X	X	X	B	7		W			0 to 5±5% VDC	
	Primary Power On Control	6	S	B	X						X	X	X		1					On/Off	
	Primary Power On Indication	6	M	B	X						X	X	X		1					On/Off	
Central Multiplexer & Switching Assy.	Receive RF Power Input (Forward Pwr.)	3	M	A	X				X		X	X		S	7		W			0 to 5±5% VDC	
	Antenna Select Command	3	S	D	X				X		X	X	X	S	2		W			1 of 3	
	Antenna Selected	3	M	D	X				X		X	X	X	S	2		W			1 of 3	
	Receive RF Stimulus	3	S	R					X		X			S	-		W			Not less than -50 dbm	From low noise receiver

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MEASUREMENT/STIMULUS LIST (Page 13 of 14)

WORKSHEET

ASSEMBLY GROUP: Ku-Band (6 of 6)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D,R)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	ONBOARD CHECKOUT: PERIODIC TEST ISS	ONBOARD CHECKOUT: PERIODIC TEST ORBITER	ONBOARD CHECKOUT: FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B,S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
Selector Switch (6)	Receiver Select Command	6	S	B	X				X		X	X	X	B	1		W			Primary/Secondary	
	Receiver Selected	6	M	B	X				X		X	X	X	B	1		W			Primary/Secondary	
S-Band Tracking Receiver (6)	Primary Power On Indication	6	M	B	X						X	X	X		1					On/Off	
	RF Stimulus Control	6	S	B							X				1					On/Off	
	Timing Signal Input	12	M	A							X				7					0 to 5±5% VDC	
	Steering Signals	12	M	A							X				7					0 to 5±5% VDC	
	AGC Output Level	6	M	A					X	X	X	X	X	B	7		W			0 to 5±5% VDC	
	Primary Power On Control	6	S	B	X						X	X	X		1					On/Off	
	RF Stimulus Indication	6	M	B							X				1					Present/Absent	
Positioner (3)	Servo Motor Excitation	12	M	A							X				7					0 to 5±5% VDC	
Position Servo Control (6)	Acquisition Mode Input Command	12	S	B					X		X	X	X	S	1		W			Slow/Fast	
	Tracking Input Command	12	S	D					X		X	X	X	S	16		W			TBD (design parameter)	
	Slewing Input Command	12	S	D					X		X	X	X	S	16		W			TBD (design parameter)	
	AutoTrack Error Input	12	M	A							X				7					0 to 5±5% VDC	
	Actual Position Output	12	M	D							X				16					TBD (design parameter)	
	Primary Power On Control	6	S	B	X						X	X	X		1					On/Off	
	Primary Power On Indication	6	M	B	X						X	X	X		1					On/Off	
	Resolver Loop Control	3	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Resolver Loop Indication	3	M	B					X		X	X	X	B	1		W			Primary/Secondary	
	Servo Motor Loop Control	3	S	B					X		X	X	X	B	1		W			Primary/Secondary	
	Servo Motor Loop Indication	3	M	B					X		X	X	X	B	1		W			Primary/Secondary	

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WORKSHEET

ASSEMBLY GROUP: Internal Communications (1 of 1)

LRU	PARAMETER	QUANTITY (TOTAL)	TYPE (M,S)	FORM (A,B,D)	USAGE: OPERATION	ONBOARD CHECKOUT: STATUS MONITOR	ONBOARD CHECKOUT: REDUNDANCY SWITCHING	ONBOARD CHECKOUT: TREND ANALYSIS	PERIODIC TEST: ISS	PERIODIC TEST: ORBITER	FAULT ISOLATION	GND C/O: ISS PRELAUNCH	GND C/O: ORBITER	TEST LEVEL (B, S)	SAMPLE: BITS	SAMPLE: RATE	SAMPLE: TEST INTERVAL	TELEM: ISS	TELEM: ORBITER	PARAMETER CHARACTERISTICS	NOTES
Analog/Sync Test Unit (2)	Primary Power Control	2	S	B	X							X			1					On/Off	
	Primary Power on Indication	2	M	B	X							X			1					On/Off	
	Reference Generator Control	2	S	B	X				X			X		B	1					Primary/Alternate	
	Reference Generator on Indication	2	M	B	X				X			X		B	1					Primary/Alternate	
	Reference Fault Indication	2	M	B		X			X					B	2	1/M				1 of 4	Internal redundancy switching
	TV Test Pattern Transmitter Control	2	S	B					X		X	X		S	1					On/Off	
	TV Transmitter On Indication	2	M	B					X			X		S	1					On/Off	
	Pattern Selector Control	2	S	D					X			X		S	2					Bar/Convergence/Staircase	
	TV Signal Type Control	2	S	B					X			X		S	1					FCC/Special	
												X									
Audio Terminal Unit (18)	Primary Power Control	18	S	B	X							X			-					On/Off	
	Primary Power On Indication	18	M	B	X							X			-					On/Off	
	Volume Control (manual)	18	S	A	X							X			-					Design parameter	
	Emergency Call Control (manual)	18	S	B	X				X			X		B	-					On/Off	
	Emergency Alert Control (manual)	18	S	B	X				X			X		B	-					On/Off	
	Public Address Control (manual)	18	S	B	X							X			-					On/Off	
	Emergency Indication (local)	18	M	B	X				X			X		B	-					On/Off	

Access to approximately 550 subsystem measurement points and application of nearly 300 stimuli (excluding RF signals which are internal to the communications subsystem) are required to perform checkout and fault isolation of the baseline ISS communications subsystem. The parameter listing is based upon the preferred ISS concept of locating test stimuli within the communications subsystem and of being dependent upon the DMS/OCS for monitoring and control of all testing.

As indicated in Table 6-10, less than 5 percent of the parameters are monitored nearly continuously for out-of-tolerance conditions. Parameters monitored in this manner include power amplifier temperature, transmitter and power amplifier RF power output levels, and receiver AGC output levels. In addition, a very limited number of parameters are telemetered to the ground to support ground operational procedures. These include the modulation mode, AGC output level, and static phase error of the S-band PM transponder. The relative degree of status monitoring associated with the commincations subsystem is much less than that anticipated for most other ISS subsystems. According to Reference 1, one-third of ISS parameters are subjected to nearly continuous monitoring.

Over 40 percent of the parameters are used to support normal communications subsystem operations. This percentage is about the same as that noted in Reference 1 as being required to support overall ISS operations. Over 75 percent of the operational parameters take the form of simple bilevel stimuli and responses.

The quantity of parameters indicated for testing reflects those necessary for tests conducted periodically to verify the availability or proper operation of on-line systems, redundant equipment, and alternate modes. Although basic LRU operational controls have been excluded from the parameters required for testing, it should be understood that most of these are actually required to support this checkout function. Periodic checks of communications subsystem equipments are expected to be performed prior to operational usage or prior to a scheduled logistics resupply mission. The applicability of the identified tests and test parameters to the Shuttle-Orbiter, assuming similar equipment is utilized, is also noted in Tables 6-9, 6-10, and 6-11.

The function of fault isolation requires nearly all of the parameters, but only 23 percent are required solely for this purpose. Fault isolation is performed on a systematic basis on a group of LRU's associated with a particular function. Since it is reasonable that periodic checks of the subsystem would be similarly configured, it is expected that software for both periodic testing and fault isolation testing will be integrated into a common package. This conclusion is based on the comprehensive software requirements analysis made in the checkout study of Reference 4.

To detect graceful degradation in communications subsystem receivers, power amplifiers and transmitters, RF power outputs and receiver AGC outputs are periodically sampled and subjected to trend analysis. The AGC levels are only trended from periodic test to periodic test since known receive RF stimuli are required.

As far as the Shuttle-Orbiter is concerned, the degree of onboard testing for its relatively short duration mission is much less than that anticipated for the longer-duration ISS mission. Only 18 percent of the measurement parameters identified for the ISS are expected to be applicable to Shuttle-Oribter onboard testing. Additional parameters, of course, would be required for Orbiter equipments not reflected by the ISS baseline used in this study. Special tests, for example, may be required on the Orbiter prior to return to the ground. The function of fault isolation and trending are expected to be performed nearly exclusively on the ground for the Shuttle-Orbiter.

Section 7
SUMMARY OF RELIABILITY AND SAFETY CONSIDERATIONS

This section presents a summary of reliability and safety considerations addressed during the study.

7.1 RELIABILITY

Reliability considerations are evident both in the basic checkout requirement analyses and in the identification and evaluations of candidate checkout concepts performed during the study. Failure modes and effects on Space Station performance, for example, are essential to the selection of subsystem LRU's. Reliability is also considered as a basic factor in the stimuli and monitoring trade studies.

The design requirements for the Space Station communications subsystem included a very high degree of equipment reliability. It follows then that the checkout operation will normally indicate a good system and a case could be made for conducting routine checkout operations only at very rare intervals. This is not the case for operationally redundant systems where backup speed is important. These redundant systems should certainly be checked prior to any critical operation. In other cases, it could be argued that frequent testing of a highly reliable system merely increases the probability of failures in both the operational and checkout systems through thermal or electrical transients, mechanical wear, and similar factors.

It is very easy to monitor and test a system to the point that the checkout system itself is the major subject of repair actions. However, there are cases (e.g., an instrument landing system) where false fault indications may be much more preferable than undetected faults, and a very high degree of monitoring is needed. Such does not appear to be the case for the present baseline Space Station communications subsystem.

The reliability of the checkout system should be an order of magnitude greater than that of the basic communications subsystem. This is even more important in the concepts in which the bulk of the checkout system is incorporated within the LRU's, as a fault within the checkout circuitry requires removal of the operational LRU as a repair action. The concepts employing a dedicated MCU or external test signal generators have an advantage in this respect, in that a failure within the external test unit does not require removal of the operational LRU's. Being units in which the test functions for many LRU's are concentrated, on the other hand, they have the disadvantage that certain failure modes impair the testing of more than one LRU.

7.2 SAFETY

The onboard checkout system can affect crew safety in several ways, and whether or not the impact is good or bad is a function of the baseline communications subsystem hardware configuration and functional requirements. There do not appear to be any failure modes in the baseline system which would directly endanger the crew, nor do any of the candidate checkout concepts create such a situation. There are operational situations, such as during EVA or docking maneuvers, in which a communications loss could add to the inherent hazards of such maneuvers, but these have been met by operational redundancy and would thus normally make no speed demands upon the checkout system.

Despite the lack of a direct safety impact, secondary failure modes can be hypothesized in both the communications subsystem and the checkout system. One would be a case in which a failure has occurred in a nonredundant communications circuit and the crew safety is indirectly affected by the speed of the checkout system because it delays expeditious solution of a nonrelated failure in a critical area via the communications channel. A case of more direct impact of the checkout system on safety would be a false fault indication which led to an unnecessary EVA to replace a supposedly faulty assembly located on an antenna. The self-test features of the onboard checkout system, however, are designed to preclude this possibility. In addition, none of the status monitoring planned for the communications subsystem is classified in a caution or warning category. Even if safety were not impaired, a slow or unreliable checkout system would be undesirable from the standpoints of possible experimental data loss and crew inconvenience.

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Section 8
REFERENCES

References called out in previous sections as well as other documents used as a source of study information are listed below:

1. Modular Space Station Detailed Preliminary Design, Volume III, Sections 4.9 through 6, dated November 1971 (Contract NAS8-25140, MSFC-DPD-235/DR No. SE-04, MDAC).

2. Space Station Program (Modular) Mission Analysis, Volume I, dated November 1971 (Contract NAS8-25140, MSFC-DPD-235/DR No. MP-01, MDAC).

3. Integrated Mission Management Operations, dated November 1971 (Contract NAS8-25140, MSFC-DPD-235/DR No. MP-03, MDAC).

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