1-8

An Engineering Study of Onboard Checkout Techniques

CR 115256

A GUIDE TO ONBOARD CHECKOUT
VOLUME VII: RF COMMUNICATIONS

Huntsville

IBM

An Engineering Study of Onboard Checkout Techniques

A GUIDE TO ONBOARD CHECKOUT
VOLUME VII: RF COMMUNICATIONS

IBM NUMBER: 71W-00314

SEPTEMBER 1971

Prepared for the
National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas 77058

CONTRACT NUMBER NAS9-11189

IBM Federal Systems Division, Electronics Systems Center/Huntsville, Alabama

TABLE OF CONTENTS

PRECEDING PAGE BLANK NOT FILMED

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

FOREWORD

This is one of a set of seven reports, each one describing the results, for a particular subsystem, of a study titled "An Engineering Study of Onboard Checkout Techniques." Under the general title of "A Guide to Onboard Checkout," the reports are as follows.

Volume	IBM Number	Subsystem
I	71W-00308	Guidance, Navigation and Control
II	71W-00309	Environmental Control and Life Support
III	71W-00310	Electrical Power
IV	71W-00311	Propulsion
V	71W-00312	Data Management
VI	71W-00313	Structures/Mechanical
VII	71W-00314	R.F. Communications

This set of guides was prepared from the results of a nine month "Engineering Study of Onboard Checkout Techniques" (NAS9-11189) performed under NASA contract by the IBM Federal Systems Division at its Space Systems facility in Huntsville, Alabama, with the support of the McDonnell Douglas Astronautics Company Western Division, Huntington Beach, California.

Technical monitor for the study was Mr. L. Marion Pringle, Jr. of the NASA Manned Spacecraft Center. The guidance and support given to the study by him and by other NASA personnel are gratefully acknowledged.

Section 1

INTRODUCTION

1.1 OBJECTIVE

With the advent of large scale aerospace systems, designers have recognized the importance of specifying and meeting design requirements additional to the classical functional and environmental requirements. These "additional" requirements include producibility, safety, reliability, quality, and maintainability. These criteria have been identified, grown into prominence, and become disciplines in their own right. Presently, it is inconceivable that any aerospace system/ equipment design requirements would be formulated without consideration of these criteria.

The complexity, sophistication and duration of future manned space missions demand that still another criterion needs to be considered in the formulation of system/equipment requirements. The concept of "checkoutability" denotes the adaptability of a system, subsystem, or equipment to a controlled checkout process. As with other requirements, it should also apply from the time of early design concept formulation.

The results of "An Engineering Study of Onboard Checkout Techniques" and other studies indicate that for an extended space mission onboard checkout is mandatory and applicable to all subsystems of the space system. In order to use it effectively, "checkoutability" should be incorporated into the design of each subsystem, beginning with initial performance requirements.

Conferences with researchers, system engineers and subsystem specialists in the course of the basic Onboard Checkout Techniques Study revealed an extensive interest in the idea of autonomous onboard checkout. Designers are motivated to incorporate "checkoutability" into their subsystem designs but express a need for information and guidance that will enable them to do so efficiently.

It is the objective of this report to present the results of the basic study as they relate to one space subsystem to serve as a guide, by example, to those who in the future need to implement onboard checkout in a similar subsystem. It is not practicable to formulate a firm set of instructions or recipes, because operational requirements, which vary widely among systems, normally determine the checkout philosophy. It is suggested that the reader study this report as a basis from which to build his own approach to "checkoutability."

1.2 BASIC STUDY SUMMARY

1.2.1 STUDY OBJECTIVE

The basic study was aimed at identification and evaluation of techniques for achieving the following capabilities in the operational Space Station/Base, under control of the Data Management System (DMS), with minimal crew intervention.

- Automated failure prediction and detection
- Automated fault isolation
- Failure correction
- Onboard electronic maintenance

1.2.2 STUDY BASELINE

The study started in July 1970. The system design baseline was established by the Space Station Phase B study results as achieved by the McDonnell-Douglas/IBM team, modified in accordance with technical direction from NASA-MSC. The overall system configuration was the 33-foot diameter, four-deck, 12-man station. Individual subsystem baseline descriptions are given in their respective "Guide to Onboard Checkout" reports.

1.2.3 STUDY TASKS

The basic study comprised five tasks. Primary emphasis was given to Task 1, Requirements Analysis and Concepts. This task established subsystem baseline descriptions and then analyzed them to determine their reliability/maintainability characteristics (criticality, failure modes and effects, maintenance concepts and line replaceable unit (LRU) definitions), checkout strategies, test definitions, and definitions of stimuli and measurements. After software preliminary designs were available, an analysis of checkout requirements on the DMS was performed.

A software task was performed to determine the software requirements dictated by the results of Task 1.

Task 3 was a study of onboard electronic maintenance requirements and recommendations of concepts to satisfy them. Supporting research and technology tasks leading to an onboard maintenance capability were identified. The study implementation plan and recommendations for implementing results of the study were developed in Task 4. The task final report also summarizes results of the study in all technical tasks.

Reliability, Task 5, was very limited in scope, resulting in an analysis of failure modes and effects in three Space Station subsystems, GN&C, DMS (computer group) and RF communications.

1.2.4 PREVIOUS REPORTS

Results of the basic study were reported by task in the following reports, under the general title of "An Engineering Study of Onboard Checkout Techniques, Final Report."

IBM Number	Title
71W-00111	Task 1: Requirements Analysis and Concepts
71W-00112	Task 2: Software
71W-00113	Task 3: Onboard Maintenance
71W-00114	Task 4: Summary and Recommendations
71W-00115	Task 5: Subsystem Level Failure Modes and Effects

Section 2

BASELINE SUBSYSTEM DESCRIPTIONS

2.1 GENERAL

This section describes the baseline RF Communications Subsystem which was analyzed to define onboard checkout requirements. In order to assess requirements for onboard checkout, descriptions at the subsystem level and the assembly level are required, as well as the major interfaces between subsystems.

The assembly level description for each of the subsystems (MSFC-DRL-160, Line Item 13) provided the primary working document for subsystem analysis. To reduce documentation, these documents have been incorporated by reference into this report, where applicable. Therefore, where no significant differences exist from the Phase B definition, this report contains a brief subsystem description and an identification of the referenced document containing the assembly level descriptions for that subsystem. Where significant differences do exist, the subsystem level description includes these changes in as much detail as is available. MSFC-DRL-160, Line Item 19, provided the major subsystem interface descriptions for analysis of integrated test requirements.

2.2 SUBSYSTEM LEVEL DESCRIPTION

The Communications Subsystem comprises all equipment necessary for transmitting and receiving, tracking and ranging, command, multiple voice and television information, and broadband experiment data. The major RF subsystem equipment consists of K_u-band high gain and VHF/S-band/K_u-band low gain (omnidirectional) antennas, preamplifiers, receivers, transmitters with appropriate switching and multiplexing units, signal interface modems, and ranging unit.

The Communications Subsystem provides a radio frequency (RF) interface between the Space Station and the ground stations, either directly or indirectly, through a Data Relay Satellite System (DRSS), independent free-flying experiment modules (FFM), and logistics vehicles (LV).

The transmission and reception of television, multiple voice, and digital information between the Space Station and ground stations through the DRSS will be provided by a K_u-Band System. This link employs three uplink and downlink K_u-band RF carriers operating at frequencies between 13 and 15 GHz. The K_u-Band System consists of (1) four high-gain parabolic reflectors for normal operation, (2) transmitters and receivers, and (3) signal interface modems that sum, separate, and condition the incoming and outgoing signals.

In addition to the DRSS link, direct communications to the ground at S-band are required during the early mission phases. Uplink and downlink voice, digital data, and ranging capability will be provided by an S-band transponder compatible with the MSFN. An S-band FM transmitter is provided on the Space Station to permit an Apollo-type television signal, or wide-band real-time or stored data to be transmitted to the existing MSFN facilities. The S-band circuits transmit and receive through a low gain antenna system.

The Communications Subsystem provides the capability for simultaneously receiving up to 10 channels of video and digital data and transmitting command and ranging information from and to the FFMs at K_u-band. One of the four high gain antennas is utilized to support the FFMs while in the normal stationkeeping loop. During docking and undocking operations, the K_u-band Low Gain Antenna System provides the required coverage.

Two-way voice, data, and ranging communications between the Space Station and the Logistics Vehicles are provided by transmitters and receivers in the VHF frequency range. A Low Gain Antenna System at VHF is utilized to provide essentially spherical coverage. This system also provides voice and low data rate communications between the SS and DRSS during artificial gravity and contingency operations. Duplex voice and biomedical data reception capability from two crewmen engaged in extravehicular activity (EVA) has been provided at VHF.

The Communications Subsystem equipment has been broken down into eight assembly groups and has been grouped primarily according to function as listed below:

1. K_u-Band High Gain Antenna
2. VHF/S-Band/K_u-Band Low Gain Antenna
3. Free-Flying Module
4. Data Relay Satellite System
5. DRSS/FFM Common
6. Ground (Direct)
7. Shuttle
8. Extravehicular Activity

In addition to the DRSS link, direct communications to the ground at S-band are required during the early mission phases. Uplink and downlink voice, digital data, and ranging capability will be provided by an S-band transponder compatible with the MSFN. An S-band FM transmitter is provided on the Space Station to permit an Apollo-type television signal, or wide-band real-time or stored data to be transmitted to the existing MSFN facilities. The S-band circuits transmit and receive through a low gain antenna system.

The Communications Subsystem provides the capability for simultaneously receiving up to 10 channels of video and digital data and transmitting command and ranging information from and to the FFMs at K_u-band. One of the four high gain antennas is utilized to support the FFMs while in the normal stationkeeping loop. During docking and undocking operations, the K_u-band Low Gain Antenna System provides the required coverage.

Two-way voice, data, and ranging communications between the Space Station and the Logistics Vehicles are provided by transmitters and receivers in the VHF frequency range. A Low Gain Antenna System at VHF is utilized to provide essentially spherical coverage. This system also provides voice and low data rate communications between the SS and DRSS during artificial gravity and contingency operations. Duplex voice and biomedical data reception capability from two crewmen engaged in extravehicular activity (EVA) has been provided at VHF.

The Communications Subsystem equipment has been broken down into eight assembly groups and has been grouped primarily according to function as listed below:

1. K_u-Band High Gain Antenna
2. VHF/S-Band/K_u-Band Low Gain Antenna
3. Free-Flying Module
4. Data Relay Satellite System
5. DRSS/FFM Common
6. Ground (Direct)
7. Shuttle
8. Extravehicular Activity

The RF communications assembly groups interface directly with the analog distribution bus. The operation of the subsystem is controlled by discrete commands from command decoders. Monitor and checkout information is provided to remote data acquisition units (RDAUs). Serial digital data streams are accepted from and provided to data terminals and modems which interface with the digital distribution bus. The command decoders, RDAUs and data terminals, and modems are described under the Data Management Subsystem Description.

2.3 ASSEMBLY LEVEL DESCRIPTIONS

Descriptions of the Communications Subsystem assemblies are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 2, Space Station Electronics. These descriptions include block diagrams, discussions of major subassemblies, physical characteristics summary, control inputs, monitor outputs, and a table of interface characteristics. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the RF

Section 3

RELIABILITY AND MAINTAINABILITY ANALYSES

3.1 CRITICALITY ANALYSIS

As a guide to emphasis in subsequent checkout technique studies, an analysis has been made of the overall subsystem and major component criticality (failure probability) of the Space Station subsystems and equipment. As an input to the Checkout Requirements Analysis Task, this data along with the failure mode and effects data will be useful in determining test priorities and test scheduling. Additionally, this data will aid in optimizing checkout system design to ensure that confidence of failure detection is increased in proportion to added system complexity and cost.

3.1.1 CRITICALITY ANALYSIS PROCEDURE

A criticality number (related to failure probability) was generated for each major subsystem component. This number is the product of: (1) the component failure rate (or the reciprocal of mean-time-between-failure), (2) the component's anticipated usage or duty cycle, and (3) an orbital time period of six months, or 4,380 hours. Six months was chosen as the time period of interest to allow one missed resupply on the basis of normal resupply occurring at three-month intervals. The criticality number, then, is the failure expectation for a particular component over any six-month time period.

For visibility, the major components of each subsystem analyzed have been ordered according to the magnitude of their criticality numbers. This number, however, should not be considered as an indication of the real risk involved, since it does not take into account such factors as redundant components, subsystem maintainability, and the alternate operational procedures available.

Overall subsystem criticality has been determined by a computerized optimization process whereby spares and redundancy are considered in terms of a trade-off between increased reliability and weight. This determination, therefore, reflects not only the failure probability of subsystem components, but also the probability that a spare or redundant component may not be available to restore the subsystem to operational status. The methodology used is described in Section 9, Long-Life Assurance Study Results, DRL 13 (Preliminary Subsystem Design Data), Volume III (Supporting Analyses), Book 4 (Safety/Long Life/Test Philosophy) from the MDAC Phase B Space Station Study. Component-level failure mode and criticality data are presented in subsequent paragraphs.

Table 3-1. Communications Subsystem Criticality Ranking - Highest 10

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
S-Band PM Transponder	41,800	450	Reflects that ground transmission via DRSS is inoperative
K_u-Band Power Amplifier	31,400	<100	Reflects ground direct transmission inoperative
FM Xmtr Modem	18,400	970	Reflects that direct ground communication is inoperative
High-Gain Antenna System Assembly	12,500	1290	Reflects less than optimum antenna positioning
S-Band Video Receiver Modem	11,400	<100	Considers 3 spares not operating
S-Band Power Amplifier	9,000	<100	Considers ground communication via DRSS outage
S-Band FM Exciter	7,100	128	Considers backup with ground communications via DRSS
S-Band Data Receiver	5,030	<100	Considers 3 spares available
S-Band Video Receiver	4,600	<10	Spares available
S-Band PM Receiver	3,420	<10	Spares available

3.1.2 SUBSYSTEM CRITICALITY DATA

The optimized six-month reliability prediction for the Communications Subsystem is 0.9972 with 562 pounds of spares. This value assumes optimum performance of all components with no alternate paths of reception and transmission allowed. This value cannot be obtained directly from the criticality numerics given in Table 3-1.

Loss of digital data transmission to ground via relay satellite would require either communicating directly with the ground until the failed component was replaced, or storing digital data for transmission at a later time. This concept is reflected in the "conditional loss criticality" column of Table 3-1.

3.2 FAILURE EFFECTS ANALYSIS (FEA)

The procedure employed in this section is similar to that of the earlier FEA analysis, except that a distinction was made between "single" and "multiple" failures. The term "multiple failures" implies complete loss of the function under consideration. A description of the baseline subsystems is contained in Section 2.

Generally, this FEA, coupled with other results, indicates that no failure modes exist which invalidate the onboard checkout concepts. It is noted that this analysis was conducted at the component level, commensurate with available Space Station subsystem design definition.

Examples of the results of the RF Communications Subsystem (RFCS) FEA are given in Table 3-2 (a partial listing).

3.3 MAINTENANCE CONCEPT ANALYSIS

General maintenance concepts and analyses are summarized in Section 7.

The RF Communications System is comprised of the High-Gain and Low-Gain Antenna Systems, transmitters and receivers, and modems which interface the transmitters and receivers with the analog distribution bus. Except for the High-Gain Antenna System which has the parabolic reflector, feeds, positioner, and low noise preamplifiers located at the end of a boom, and the low-gain antenna radiating elements which are located on the surface of the pressure shell, the RF communications assemblies are located in either pressurized or pressurizable compartments.

Table 3-2. RF Communications Subsystem Failure Effect Analysis

Item	Function	Failure Effect On		Space Station
		Failure Type	Subsystem	
K_u-Band Power Amplifier	Provides power amplification required for transmission of K_u-band signals.	TWT failure; power supply failure; heater failure.	a. Single failures: No effect due to redundancy. b. Multiple failures: Loss of K_u-band transmission capability.	a. None b. Loss of TV, voice and digital communication with ground via DRSS; loss of ranging and command data to FFM.
K_u-Band PM Exciter	Phase-modulates K_u-band carrier with inputs from data and ranging modems.	Open/short electronics.	a. Single failures; No effect due to redundancy. b. Multiple failures; Loss of K_u-band PM data transmission.	a. None b. Loss of digital/ranging interface with FFMs; degraded digital transmission to ground via DRSS.
K_u-Band FM Exciter	Frequency modulates K_u-band carrier with television, digital, voice, or analog data.	Open/short electronics.	a. Single failures; No effect due to redundancy. b. Multiple failures; Loss of K_u-band FM data.	a. None b. Loss of TV, voice, digital, and analog communication with ground via DRSS.

The high-gain parabolic antennas are designed to be rotated into the end docking port for maintenance. This requires the maintenance to be performed in a space suit, but in a more compatible work position. The maintenance must be planned in less than three-hour task elements because of portable life support suit (PLSS) use limits.

Although undesirable, the Low-Gain Antenna System elements require replacement by EVA. These elements are currently inaccessible from the interior of the station.

The transmitters, receivers, and interface modems are packaged in multiples of the 1.25-inch width of the standard 8- x 9-inch electronic module described in DRL 13, Volume I, Book 2, Space Station Electronics. Where possible, the assemblies have been sized so as not to exceed more than four standard widths. A notable exception is the S-Band power amplifier. Adherence to this packaging concept should facilitate maintenance and handling.

3.4 LINE REPLACEABLE UNIT ANALYSIS

General guidelines and criteria for the definition of LRUs were established and these along with the maintenance philosophies reported in Section 3-3 were used to determine at what level line maintenance would be performed. For the Space Station subsystems specific justification applicable to LRU selection for the particular subsystem under examination was derived from the guidelines and these justifications are presented along with the LRU listing. The "functional LRUs" were then considered in the light of the standard electronic packaging scheme and actual LRUs were defined and listed. The method employed and the results achieved are discussed in the following sections.

3.4.1 SPACE STATION RF SUBSYSTEM LINE REPLACEABLE UNITS

The definition of Line Replaceable Units (LRUs) is keyed to repairing subsystems in an in-place configuration with the LRU being the smallest modular unit suitable for replacement. General factors considered in identifying subsystem LRUs include: (1) maintenance concepts developed and defined in Section 3.3; (2) the component-level failure rates delineated in the criticality analyses of Section 3.1; (3) the amount of crew time and skill required for fault isolation and repair; (4) resultant DMS hardware and software complexity; and (5) subsystem weight, volume, location, and interchangeability characteristics. Listings of LRUs and more specific justification for their selection follows.

The transmitters (exciters and power amplifiers), receivers, and interface modems are selected as assembly-level LRUs largely because of packaging, reliability, and electromagnetic interference (EMI) considerations. These assemblies are packaged in multiples of the standard module size for mounting in the integrally-cooled mounting racks. Initial reliability estimates indicate that the power amplifiers are the most critical of this group of assemblies. Lower level modularization of the power amplifiers, however, 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 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 LRUs for the High- and Low-Gain Antenna Systems are somewhat different from those used for transmitters, receivers, and modems. Antenna system LRUs 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, coaxial cables, and the 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. This is also true for similar components of the High-Gain Antenna System located within the pressure shell.

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. If a failure occurs in the drive system, the drive system is replaced in its entirety to eliminate alignment problems. The drive motors, on the other hand, can be replaced separately in the event of failure. Redundant electronics are utilized wherever possible to minimize the high-gain antenna downtime.

A listing of LRUs for the RF Communications Subsystem is provided in Table 3-3.

Table 3-3. RF Communications

LRU	Quantity Required	Quantity Standby Redundant
Transmitter/Receiver/Modem/Group		
S-Band Video Receiver	10	
Video Receiver Modem	10	
S-Band Data Receiver	10	
S-Band PM Receiver	2	
K_u-Band FM Exciter	2	
FM Xmtr Modem	2	
S-Band FM Receiver	2	
Receiver Modem	2	
K_u-Band PA	5	
K_u-Band PM Exciter	5	
S-Band PM Transponder	2	
Transponder Modem	2	
S-Band Power Amp	2	
S-Band FM Exciter	2	
Transmitter Modem	2	
VHF Voice Ranging T/R	2	
Ranging Modem	2	
Voice Modem	2	
VHF Data T/R	2	
VHF-FM T/R	6	
Modem	2	
Low-Gain Antenna Group		
VHF Antennas	4	
VHF Diplexers	4	
VHF Multiplexer, Power Dividers and Switches	2	
S-Band Antennas	4	
S-Band Triplexer and Switches	2	
K_u-Band Antennas	8	
K_u-Band Preamp/Mixer/Diplexer/Switches	2	
S-Band Multiplexer and Circulator	2	
K_u-Band Waveguides	8	
VHF/S-Band Coaxial Cables	8	

Table 3-3. RF Communications (Continued)

LRU	Quantity	
	Required	Standby Redundant
High-Gain Antenna Group		
Main Reflector/Feed	4	
Acquisition Reflector/Feed	4	
Pseudo Monopulse Comp/Mod.	8	8
Positioner		
Drive Motors	8	
Drive System	8	
Electronics	8	8
K_u-Band TDA/Mixer/L.O.	8	8
RF Switches (External)	2	
RF Switches (Internal)	8	
K_u-Band Quadriplexers and Circulators	4	
K_u-Band Diplexer	1	
S-Band Quadriplexer and Power Divider	4	
S-Band Diplexer	1	
K_u-Band Waveguides	4	

Section 4

OCS CHECKOUT STRATEGIES

4.1 SUBSYSTEM CHECKOUT STRATEGY

Prior to any further requirements analysis, it is necessary to develop a checkout strategy for all Space Station subsystems to meet the checkout objectives of the Space Station OCS. The objectives of the Space Station OCS can be summarized as follows:

- To increase crew and equipment safety by providing an immediate indication of out-of-tolerance conditions
- To improve system availability and long-life subsystems assurancy by expediting maintenance tasks and increasing the probability that systems will function when needed
- To provide flexibility to accommodate changes and growth in both hardware and software
- To minimize development and operational risks

Specific mission or vehicle-related objectives which can be imposed upon subsystem level equipment and subsystem responsibilities include the following:

- OCS should be largely autonomous of ground control.
- Crew participation in routine checkout functions should be minimized.
- The design should be modular in both hardware and software to accommodate growth and changes.
- OCS should be integrated with, or have design commonality with, other onboard hardware or software.
- The OCS should use a standard hardware interface with equipment under test to facilitate the transfer of data and to make the system responsive to changes.
- Failures should be isolated to an LRU such that the faulty unit can be quickly removed and replaced with an operational unit.

- A Caution and Warning System should be provided to facilitate crew warning and automatic "safing" where required.
- Provisions must be included to select and transmit any part or all of the OCS test data points to the ground.

To attain these objectives via the use of an Onboard Checkout System which is integrated with the Data Management System, checkout strategies have been developed which are tailored to each Space Station subsystem.

Special emphasis has been applied to a strategy for checkout of redundant elements peculiar to each subsystem. The degree to which each of these functions is integrated into the DMS is also addressed.

4.1.1 SPACE STATION SUBSYSTEMS

Each major Space Station subsystem was examined with respect to the required checkout functions. The checkout functions associated with each subsystem are identified and analyzed as to their impact on the onboard checkout task. The functions considered are those necessary to verify operational status, detect and isolate faults, and to verify proper operation following fault correction. Specific functional requirements considered include stimulus generation, sensing, signal conditioning, limit checking, trend analysis, and fault isolation.

4.1.1.1 RF Communications Subsystem

The RF Communications Subsystem (RFCS) contains the receivers, transmitters, power amplifiers, transponders, modems, and antenna systems to provide radio frequency communications between the Space Station and the ground, DRSS, Shuttle, free-flying experiment modules, and EVA crewmen. The subsystem operates in the S, K_u, and VHF bands.

4.1.1.1.1 Checkout Functions

Fault detection in the RF Communications Subsystem utilizes both operational monitoring and specific functional test routines. The operational monitoring takes place continuously while the system is in use and involves both the onboard and ground crews to a great extent. Assessment of system performance is made in much the same way one "checks out" his home communications equipment such as telephone and television, i.e., by listening to or looking at the output. Such tests are somewhat gross and subjective of course, and must be augmented by functional tests which include more precise qualitative analysis of performance. These functional tests may be performed on a scheduled periodic basis or as an aid to fault isolation in the event of a malfunction. Checkout of portions of the system will also be required prior to initiation of certain operations, such as a rendezvous and docking. Functional tests generally involve the injection of calibrated test stimuli and evaluation of equipment response.

- Stimulus Generation - Checkout of the various S-band, K_u-band, and VHF receivers requires the capability to inject RF test stimuli of the appropriate frequency and modulation characteristics into the receiver front ends and measure the corresponding receiver outputs and Automatic Gain Control (AGC) levels. Testing of transmitters and of the receiver and transmitter modems requires the injection of modulating test signals of the appropriate type and format. Stimulus requirements are included in Appendix I.

- Sensing - Sensing requirements associated with the RFCS are tabulated in Appendix I.

  The 0-5 Vdc range given for the AGC, RF power, and Voltage Standing Wave Ratio (VSWR) levels are conditioned sensor output levels rather than "raw" signal ranges and reflect the selected RFCS design approach of providing integral signal conditioning at the LRU level. Similarly, the bilevel status indicator parameters represent a variety of "raw" parameters including mode selections, switch positions, presence of primary power, and presence of input and/or output modulation. The selector switch position parameters indicate the position of multiposition switch elements such as channel selectors and antenna switches. These parameters are internally encoded such that a twelve-position switch, for example, is represented in the form of a four-bit binary word.

- Signal Conditioning - The measurement signal conditioning for the RFCS is included as an integral portion of the subsystem at the "black box" or LRU level. The measurements are therefore directly compatible with the data management subsystem.

- Limit Checking - Limit checks of the continuous or random type have limited applicability in the RFCS. This is due to the fact that the majority of the significant subsystem performance parameters, such as RF output power, are meaningful only when the equipment is actually transmitting or, as in the case of receiver sensitivity (AGC) measurements, when a calibrated input signal is present. Limit testing opportunities are therefore largely confined to periodic test situations where the necessary conditions can be established.

- Trend Analysis - Application of trend analysis techniques to selected RFCS measurements is potentially useful in detecting degradation and impending failures in such equipment as transmitters and receivers. In particular, the RF power output and VSWR of the transmitters and the AGC level of the receivers are good performance indicators and are amenable to such analysis. Care must be exercised, however, to assure proper correlation between these measurements and the various factors which influence them. Meaningful receiver sensitivity data, for example, is highly dependent upon accurate calibration of the input test signal. The maintenance of sufficiently accurate calibration of test stimuli and measurement equipment over a long term orbital mission is a problem not previously encountered in the space program and will require careful consideration.

4.1.1.1.2 Redundant Element Checkout

Redundancy in the RFCS is in the form of functional redundancy, as typified by the capability to communicate with the ground either directly or via DRSS, and in duality of systems as in the case of the dual antenna systems. These dual or functionally overlapping areas of equipment are independent of each other, however, and therefore do not constitute redundancy in the normal switchable or parallel equipment sense. As such, no unique checkout problems exist.

4.1.1.1.3 Integration with Data Management Subsystem

Stimulus requirements for the RFCS include modulated S-band, K_u-band, and VHF RF signals, analog signals, and digital inputs. The RF signals in particular are relatively complex and are unique to the subsystem. These are therefore generated by equipment internal to the subsystem. The control of these signals is a function of the DMS. The various analog signals (i.e. audio, video, etc.) required for modulation testing are likewise generated internally under DMS control. Digital test inputs required for checkout of the PM modems and exciters are supplied directly by the DMS via the data bus.

Measurement sensors and signal conditioning for the Communications Subsystem are provided as an integral part of that subsystem. The signal interface between the RFCS and the DMS is in the form of standard 0-5 Vdc signals for each measurement.

4.2 INTEGRATED CHECKOUT STRATEGY

This analysis identifies the integrated checkout functions associated with Space Station subsystems during the manned orbital phase of the mission. These functions are depicted in Figure 4-1 and are those required to ensure overall availability of the Space Station. Characteristic of integrated testing is the fact that the test involves subsystem interfaces, and, therefore, test objectives are associated with more than one subsystem.

4.2.1 INTEGRATED STRATEGY

Six checkout functions have been identified:

- Caution and warning
- Fault detection
- Trend analysis
- Operational status
- Periodic checkout
- Fault isolation

These functions represent a checkout strategy of continuous monitoring and periodic testing with eventual fault isolation to a line replaceable unit (LRU). Under this aspect the functions are grouped as -

CONTINUOUS MONITORING	PERIODIC TESTING	FAULT ISOLATION
• Caution and warning	• Automatic tests	• Localize to SS
• Fault detection	• Operational Verification	• Isolate to RLU
• Trend analysis		
• Operational status		

General characteristics of these groups are defined below:

4.2.1.1 Continuous Monitoring

Continuous monitoring is not a test per se. It is a concept of continuously sampling and evaluating key subsystem parameters for in/out-of-tolerance conditions. This evaluation does not necessarily confirm that the subsystems have failed or are operating properly. The evaluation is only indicative of the general status of the subsystems. For example, a condition exists where the integrated subsystems are indicating in-limit conditions, but during the next series of attitude control commands, an error in Space Station position is sensed and displayed. Since three subsystems, DMS, GN&C, and P/RCS, are involved in generating and controlling the Space Station attitude, a "positional error" malfunction is not directly related to a subsystem malfunction. The malfunction indication is only indicative of an out-of-tolerance condition of an integrated function. Final resolution of the problem to a subsystem and eventually to LRU will require diagnostic test-procedures that are separate from the continuous monitoring function.

There are situations in which the parameters being monitored are intended to be directly indicative of the condition of a subsystem or an LRU. Examples of these include tank pressures, bearing temperatures, and power source voltages. However, even in these simpler cases when a malfunction is detected, an integrated evaluation will be performed to ascertain that external control functions, transducers, signal conditioning, and the DMS functions of data acquisition, transmission, and computation are performing properly. This evaluation will result in either a substantiation of the malfunction or identification of a problem external to the parameter being monitored.

Figure 4-1 shows the logic associated with each function in the continuous monitoring group, as well as the integrated relationships between these and the total checkout functions. The caution/warning and fault detection functions are alike in their automatic test and malfunction detection approaches, but are different in terms of parameter criticality and malfunction reaction. The caution/warning function monitors parameters that are indicative of conditions critical to crew or equipment safety. Parameters not meeting this criticality criteria are handled as fault detection functions. Figure 4-1 shows that in the event of a critical malfunction, automatic action is initiated to warn the crew and sequence the subsystems to a safe condition. Before this automatic action is taken, the subsystems must be evaluated to ascertain that the failure indication is not a false alarm and that the corrective action can be implemented. After the action is taken, the subsystems must be evaluated to determine that proper crew safety conditions exist. Since automatic failure detection and switching can be integral to subsystem design (self-contained correction) and subsystems can be controlled by the operational software or manual controls, it is imperative that the status of these events be maintained and that the fault detection and correction software be interfaced with the prime controlling software. For malfunctions that are not critical, the crew is notified of their occurrence, but any subsequent action is initiated manually.

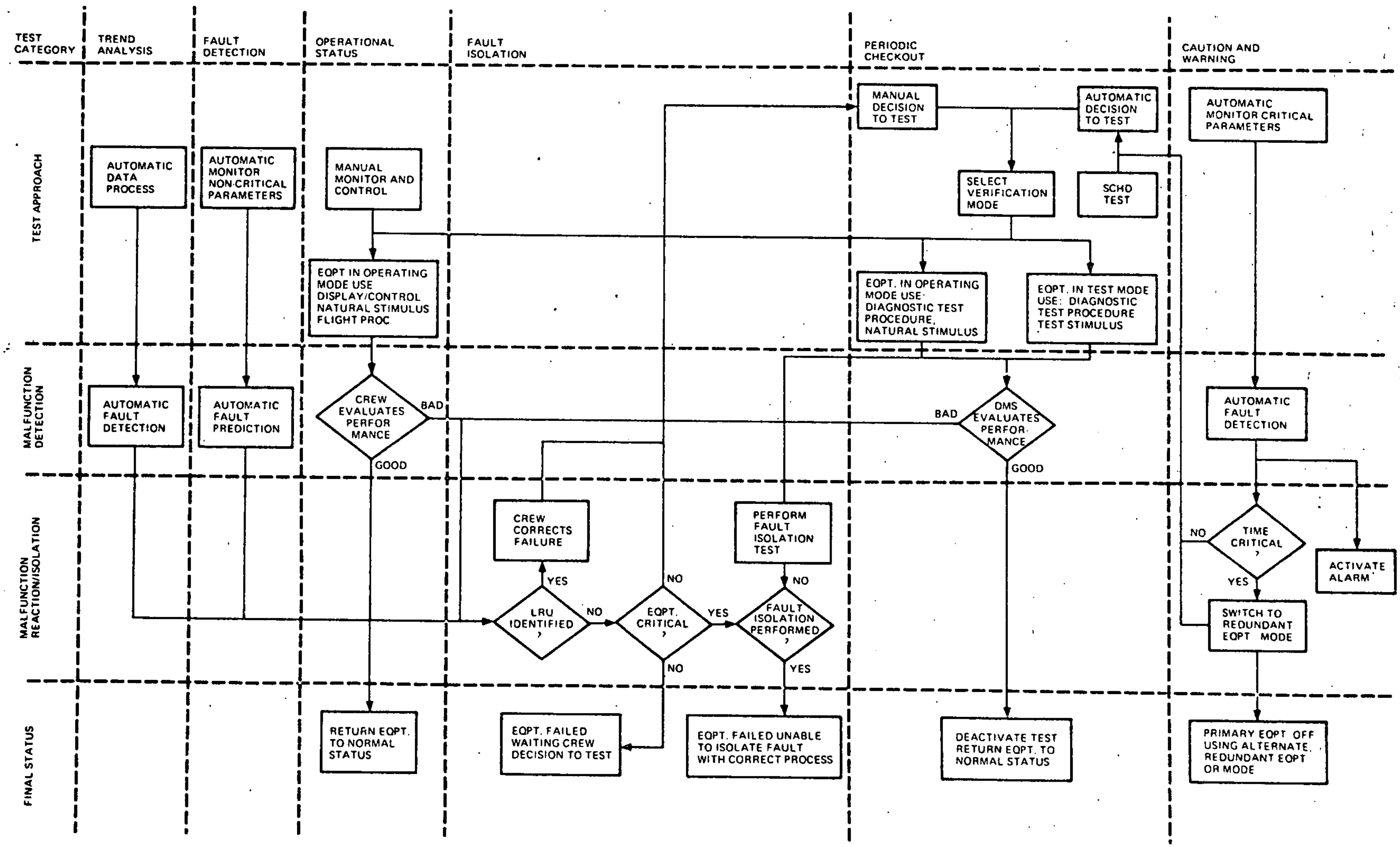

Figure 4-1. Integrated Checkout Functional Flow

The next continuous monitoring function, trend analysis, automatically acquires data and analyzes the historical pattern to determine signal drift and the need for unscheduled calibration. It also predicts faults and indicates the need for diagnostic and fault isolation activities. An example of a parameter in this category is the partial pressure of nitrogen. Nitrogen is used to establish the proper total pressure of the Space Station. Since it is an inert gas, the only make-up requirements are those demanded by leakage or airlock operation. The actual nitrogen flow rate is measured, and calculations are performed which make allowances for normal leakage and operational use. When these calculations indicate a trend toward more than anticipated use, the crew is automatically notified and testing is initiated to isolate the problem to the gas storage and control equipment or to an excessive leak path. The historical data is not only useful in predicting conditions but is also useful in providing trouble-shooting clues. The data might reveal, for example, that the makeup rate increased significantly after the use of an airlock. This could lead directly to verifying excessive seal leakage.

The final continuous monitor function is in operational status. This function is performed by the crew and is nonautomatic with the exception of the DMS computer programs associated with normal Space Station operational control and display functions. The concept of continuous monitoring recognized and takes advantage of the crew's presence and judgment in evaluating Space Station performance. In many instances the crew can discern between acceptable and unacceptable performance, and they can clearly recognize physically-damaged equipment or abnormal conditions.

4.2.1.2 Periodic Testing

As opposed to continuous monitoring, periodic testing is a detailed evaluation of how well the Space Station subsystems are performing. Figure 4-1 shows that periodic testing is not accomplished by any one technique. Rather, a combination of operational and automatic test approaches is employed. The actual operational use of equipment is often the best check of the performance of that equipment. Operation of Space Station equipment and use of the normal operating controls and displays will be used in detecting faults and degradation in the subsystems. This mode of testing is primarily limited to that equipment whose performance characteristics are easily discernible, such as for motors, lighting circuits, and alarm functions.

Automatic testing is performed in two basic modes:

- With the subsystems in an operating mode, the DMS executes a diagnostic test procedure which verifies that integrated Space Station functions are being properly performed under normal interface conditions in response to natural or designed stimulation. This mode of testing allows the evaluation of Space Station performance without interrupting mission operations.

- For those situations where the integrated performance or interface compatibility between subsystems cannot be determined without known references or control conditions, the DMS will execute a diagnostic procedure in a test mode. In this mode, control, reference, or bias signals will be switched in or superimposed on the subsystems to allow an exact determination of their performance or localization of problem between the interfaces. Since the test mode may temporarily inhibit normal operations, the DMS must interleave the test and operational software to maintain the Space Station in a known and safe configuration.

The scheduled automatic tests are performed to verify availability or proper configuration of "on-line" subsystems, redundant equipment, and alternate modes.

- Periodic Verification of "On-Line" Subsystems - The first checkout requirement is a periodic verification that on-line subsystems are operating within acceptable performance margins. The acceptable criteria for this evaluation is based on subsystem parameter limits and characteristics exhibited during Space Station factory acceptance or pre-flight testing. The rejection criteria and subsequent decision to repair or reconfigure subsystems is based on the criticality of the failure mode. If the subsystems appear to be operating properly, but the test clearly indicates an out-of-tolerance condition, then one of the following alternatives must be implemented:
  - If the failure mode is critical, the crew normally takes immediate action to isolate and clear the problem.
  - If the failure mode is not critical, the crew can take immediate action, schedule the work at a later time, or wait until the condition degrades to an unacceptable level.

- Redundant Equipment Verification - A second checkout requirement is verifying that standby, off-line, or redundant equipment and associated control and switching mechanisms are operable. The acceptable/rejection criteria for these evaluations is identical to those for normally operating equipment. A primary distinction of this function is that equipment may have known failures from previous usage or tests. This situation occurs when the crew has knowledge of a failure but has not elected to perform the necessary corrective action. The checkout function then becomes one of equipment status accounting and maintenance/repair scheduling. The status information is interlocked with mission procedures and software to preclude activation of failed units while they are being repaired or until proper operation following repair is verified.

- Alternate Mode Verification - The third checkout function is verifying the availability of alternate modes of operation. This function is essentially a confidence check of the compatibility of subsystems' interaction and performance during and after a change in the operating mode. To some extent this function overlaps with redundant equipment verification, but is broader in scope in that it verifies other system-operating characteristics. For example, some modes will involve manual override or control of automatic functions or automatic power-down sequences.

4.2.1.3 Fault Isolation

Fault isolation to an LRU is a Space Station goal. As shown in Figure 4-1, fault isolation testing is initiated when malfunction indications cannot be directly related to a failed LRU. The integrated test functions associated with fault isolation are localizing a malfunction to a subsystem or to an explicit interface between two subsystems and identifying the subroutine test necessary for LRU isolation. In structuring this relationship between integrated subsystem tests for fault localization and subroutine tests for fault isolation, the DMS, in conjunction with the test procedure documentation, must establish an effective man-machine interface so that in the event of an unsolved malfunction the crew will be able to help evaluate the condition and determine other test sequences necessary to isolate the problem. To accomplish this requirement, the DMS must be capable of displaying test parameters and instructions in engineering units and language and be capable of referencing these outputs to applicable documentation or programs that correlate test results to corrective action required by the crew.

Section 5

ONBOARD CHECKOUT TEST DEFINITIONS

5.1 SUBSYSTEM TEST DEFINITIONS

The on-orbit tests required to insure the availability of the Space Station subsystems are defined herein. Also delineated are the measurement and stimulus parameters required to perform these tests. Two discrete levels of testing are defined, i.e., continuous status monitoring tests for fault detection of critical and noncritical parameters, and subsystem fault isolation tests for localization of faults to a specific Line Replaceable Unit. In addition to these two levels, tests are defined for periodic checkout and calibration of certain units, and parameters requiring analysis of trends are defined.

Due to the software module approach to DMS checkout, it was deemed necessary to estimate the CPU time and memory required to implement these modules along with an assessment of the services required from an Executive Software System to control the checkout.

These test descriptions, measurement, and stimulus information provided for each subsystem, and the software sizing information provided for the Data Management System provide the data required to estimate the checkout impact on the DMS software and hardware. Table 5-1 is a summary of the measurement and stimulus requirements for the Space Station.

The RF Communications Subsystem contains the receiver, transmitters, power amplifiers, transponders, modems, and antenna systems to provide radio frequency communications between the Space Station and the ground, DRSS, Shuttle, free-flying experiment modules, and EVA crewmen. The subsystem operates in the S, K_u, and VHF bands.

On-orbit checkout activities required to insure the availability of the subsystem include monitoring of its normal operational outputs, performing periodic checks, and selecting fault isolation routines associated with the loss of a communications function. In addition, some trending and calibration are required.

The RF communications assembly groups interface directly with the analog distribution bus. The operation of the subsystem is controlled by discrete commands from command decoders. Monitor and checkout information is provided to remote data acquisition units (RDAUs). Serial digital data streams are accepted from and provided to data terminals and modems which interface with the digital distribution bus. The command decoders, RDAUs and data terminals, and modems are described under the Data Management Subsystem Description.

2.3 ASSEMBLY LEVEL DESCRIPTIONS

Descriptions of the Communications Subsystem assemblies are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 2, Space Station Electronics. These descriptions include block diagrams, discussions of major subassemblies, physical characteristics summary, control inputs, monitor outputs, and a table of interface characteristics. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the RF

Section 3

RELIABILITY AND MAINTAINABILITY ANALYSES

3.1 CRITICALITY ANALYSIS

As a guide to emphasis in subsequent checkout technique studies, an analysis has been made of the overall subsystem and major component criticality (failure probability) of the Space Station subsystems and equipment. As an input to the Checkout Requirements Analysis Task, this data along with the failure mode and effects data will be useful in determining test priorities and test scheduling. Additionally, this data will aid in optimizing checkout system design to ensure that confidence of failure detection is increased in proportion to added system complexity and cost.

3.1.1 CRITICALITY ANALYSIS PROCEDURE

A criticality number (related to failure probability) was generated for each major subsystem component. This number is the product of: (1) the component failure rate (or the reciprocal of mean-time-between-failure), (2) the component's anticipated usage or duty cycle, and (3) an orbital time period of six months, or 4,380 hours. Six months was chosen as the time period of interest to allow one missed resupply on the basis of normal resupply occurring at three-month intervals. The criticality number, then, is the failure expectation for a particular component over any six-month time period.

For visibility, the major components of each subsystem analyzed have been ordered according to the magnitude of their criticality numbers. This number, however, should not be considered as an indication of the real risk involved, since it does not take into account such factors as redundant components, subsystem maintainability, and the alternate operational procedures available.

Overall subsystem criticality has been determined by a computerized optimization process whereby spares and redundancy are considered in terms of a trade-off between increased reliability and weight. This determination, therefore, reflects not only the failure probability of subsystem components, but also the probability that a spare or redundant component may not be available to restore the subsystem to operational status. The methodology used is described in Section 9, Long-Life Assurance Study Results, DRL 13 (Preliminary Subsystem Design Data), Volume III (Supporting Analyses), Book 4 (Safety/Long Life/Test Philosophy) from the MDAC Phase B Space Station Study. Component-level failure mode and criticality data are presented in subsequent paragraphs.

Table 3-1. Communications Subsystem Criticality Ranking - Highest 10

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
S-Band PM Transponder	41,800	450	Reflects that ground transmission via DRSS is inoperative
K_u-Band Power Amplifier	31,400	<100	Reflects ground direct transmission inoperative
FM Xmtr Modem	18,400	970	Reflects that direct ground communication is inoperative
High-Gain Antenna System Assembly	12,500	1290	Reflects less than optimum antenna positioning
S-Band Video Receiver Modem	11,400	<100	Considers 3 spares not operating
S-Band Power Amplifier	9,000	<100	Considers ground communication via DRSS outage
S-Band FM Exciter	7,100	128	Considers backup with ground communications via DRSS
S-Band Data Receiver	5,030	<100	Considers 3 spares available
S-Band Video Receiver	4,600	<10	Spares available
S-Band PM Receiver	3,420	<10	Spares available

3.1.2 SUBSYSTEM CRITICALITY DATA

The optimized six-month reliability prediction for the Communications Subsystem is 0.9972 with 562 pounds of spares. This value assumes optimum performance of all components with no alternate paths of reception and transmission allowed. This value cannot be obtained directly from the criticality numerics given in Table 3-1.

Loss of digital data transmission to ground via relay satellite would require either communicating directly with the ground until the failed component was replaced, or storing digital data for transmission at a later time. This concept is reflected in the "conditional loss criticality" column of Table 3-1.

3.2 FAILURE EFFECTS ANALYSIS (FEA)

The procedure employed in this section is similar to that of the earlier FEA analysis, except that a distinction was made between "single" and "multiple" failures. The term "multiple failures" implies complete loss of the function under consideration. A description of the baseline subsystems is contained in Section 2.

Generally, this FEA, coupled with other results, indicates that no failure modes exist which invalidate the onboard checkout concepts. It is noted that this analysis was conducted at the component level, commensurate with available Space Station subsystem design definition.

Examples of the results of the RF Communications Subsystem (RFCS) FEA are given in Table 3-2 (a partial listing).

3.3 MAINTENANCE CONCEPT ANALYSIS

General maintenance concepts and analyses are summarized in Section 7.

The RF Communications System is comprised of the High-Gain and Low-Gain Antenna Systems, transmitters and receivers, and modems which interface the transmitters and receivers with the analog distribution bus. Except for the High-Gain Antenna System which has the parabolic reflector, feeds, positioner, and low noise preamplifiers located at the end of a boom, and the low-gain antenna radiating elements which are located on the surface of the pressure shell, the RF communications assemblies are located in either pressurized or pressurizable compartments.

Table 3-2. RF Communications Subsystem Failure Effect Analysis

Item	Function	Failure Effect On		Space Station
		Failure Type	Subsystem	
K_u-Band Power Amplifier	Provides power amplification required for transmission of K_u-band signals.	TWT failure; power supply failure; heater failure.	a. Single failures: No effect due to redundancy. b. Multiple failures: Loss of K_u-band transmission capability.	a. None b. Loss of TV, voice and digital communication with ground via DRSS; loss of ranging and command data to FFM.
K_u-Band PM Exciter	Phase-modulates K_u-band carrier with inputs from data and ranging modems.	Open/short electronics.	a. Single failures; No effect due to redundancy. b. Multiple failures; Loss of K_u-band PM data transmission.	a. None b. Loss of digital/ranging interface with FFMs; degraded digital transmission to ground via DRSS.
K_u-Band FM Exciter	Frequency modulates K_u-band carrier with television, digital, voice, or analog data.	Open/short electronics.	a. Single failures; No effect due to redundancy. b. Multiple failures; Loss of K_u-band FM data.	a. None b. Loss of TV, voice, digital, and analog communication with ground via DRSS.

The high-gain parabolic antennas are designed to be rotated into the end docking port for maintenance. This requires the maintenance to be performed in a space suit, but in a more compatible work position. The maintenance must be planned in less than three-hour task elements because of portable life support suit (PLSS) use limits.

Although undesirable, the Low-Gain Antenna System elements require replacement by EVA. These elements are currently inaccessible from the interior of the station.

The transmitters, receivers, and interface modems are packaged in multiples of the 1.25-inch width of the standard 8- x 9-inch electronic module described in DRL 13, Volume I, Book 2, Space Station Electronics. Where possible, the assemblies have been sized so as not to exceed more than four standard widths. A notable exception is the S-Band power amplifier. Adherence to this packaging concept should facilitate maintenance and handling.

3.4 LINE REPLACEABLE UNIT ANALYSIS

General guidelines and criteria for the definition of LRUs were established and these along with the maintenance philosophies reported in Section 3-3 were used to determine at what level line maintenance would be performed. For the Space Station subsystems specific justification applicable to LRU selection for the particular subsystem under examination was derived from the guidelines and these justifications are presented along with the LRU listing. The "functional LRUs" were then considered in the light of the standard electronic packaging scheme and actual LRUs were defined and listed. The method employed and the results achieved are discussed in the following sections.

3.4.1 SPACE STATION RF SUBSYSTEM LINE REPLACEABLE UNITS

The definition of Line Replaceable Units (LRUs) is keyed to repairing subsystems in an in-place configuration with the LRU being the smallest modular unit suitable for replacement. General factors considered in identifying subsystem LRUs include: (1) maintenance concepts developed and defined in Section 3.3; (2) the component-level failure rates delineated in the criticality analyses of Section 3.1; (3) the amount of crew time and skill required for fault isolation and repair; (4) resultant DMS hardware and software complexity; and (5) subsystem weight, volume, location, and interchangeability characteristics. Listings of LRUs and more specific justification for their selection follows.

The transmitters (exciters and power amplifiers), receivers, and interface modems are selected as assembly-level LRUs largely because of packaging, reliability, and electromagnetic interference (EMI) considerations. These assemblies are packaged in multiples of the standard module size for mounting in the integrally-cooled mounting racks. Initial reliability estimates indicate that the power amplifiers are the most critical of this group of assemblies. Lower level modularization of the power amplifiers, however, 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 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 LRUs for the High- and Low-Gain Antenna Systems are somewhat different from those used for transmitters, receivers, and modems. Antenna system LRUs 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, coaxial cables, and the 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. This is also true for similar components of the High-Gain Antenna System located within the pressure shell.

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. If a failure occurs in the drive system, the drive system is replaced in its entirety to eliminate alignment problems. The drive motors, on the other hand, can be replaced separately in the event of failure. Redundant electronics are utilized wherever possible to minimize the high-gain antenna downtime.

A listing of LRUs for the RF Communications Subsystem is provided in Table 3-3.

Table 3-3. RF Communications

LRU	Quantity Required	Quantity Standby Redundant
Transmitter/Receiver/Modem/Group		
S-Band Video Receiver	10	
Video Receiver Modem	10	
S-Band Data Receiver	10	
S-Band PM Receiver	2	
K_u-Band FM Exciter	2	
FM Xmtr Modem	2	
S-Band FM Receiver	2	
Receiver Modem	2	
K_u-Band PA	5	
K_u-Band PM Exciter	5	
S-Band PM Transponder	2	
Transponder Modem	2	
S-Band Power Amp	2	
S-Band FM Exciter	2	
Transmitter Modem	2	
VHF Voice Ranging T/R	2	
Ranging Modem	2	
Voice Modem	2	
VHF Data T/R	2	
VHF-FM T/R	6	
Modem	2	
Low-Gain Antenna Group		
VHF Antennas	4	
VHF Diplexers	4	
VHF Multiplexer, Power Dividers and Switches	2	
S-Band Antennas	4	
S-Band Triplexer and Switches	2	
K_u-Band Antennas	8	
K_u-Band Preamp/Mixer/Diplexer/Switches	2	
S-Band Multiplexer and Circulator	2	
K_u-Band Waveguides	8	
VHF/S-Band Coaxial Cables	8	

Table 3-3. RF Communications (Continued)

LRU	Quantity Required	Quantity Standby Redundant
High-Gain Antenna Group		
Main Reflector/Feed	4	
Acquisition Reflector/Feed	4	
Pseudo Monopulse Comp/Mod.	8	8
Positioner		
Drive Motors	8	
Drive System	8	
Electronics	8	8
K_u-Band TDA/Mixer/L.O.	8	8
RF Switches (External)	2	
RF Switches (Internal)	8	
K_u-Band Quadriplexers and Circulators	4	
K_u-Band Diplexer	1	
S-Band Quadriplexer and Power Divider	4	
S-Band Diplexer	1	
K_u-Band Waveguides	4	

Section 4

OCS CHECKOUT STRATEGIES

4.1 SUBSYSTEM CHECKOUT STRATEGY

Prior to any further requirements analysis, it is necessary to develop a checkout strategy for all Space Station subsystems to meet the checkout objectives of the Space Station OCS. The objectives of the Space Station OCS can be summarized as follows:

- To increase crew and equipment safety by providing an immediate indication of out-of-tolerance conditions
- To improve system availability and long-life subsystems assurancy by expediting maintenance tasks and increasing the probability that systems will function when needed
- To provide flexibility to accommodate changes and growth in both hardware and software
- To minimize development and operational risks

Specific mission or vehicle-related objectives which can be imposed upon subsystem level equipment and subsystem responsibilities include the following:

- OCS should be largely autonomous of ground control.
- Crew participation in routine checkout functions should be minimized.
- The design should be modular in both hardware and software to accommodate growth and changes .
- OCS should be integrated with, or have design commonality with, other onboard hardware or software .
- The OCS should use a standard hardware interface with equipment under test to facilitate the transfer of data and to make the system responsive to changes.
- Failures should be isolated to an LRU such that the faulty unit can be quickly removed and replaced with an operational unit.

- A Caution and Warning System should be provided to facilitate crew warning and automatic "safing" where required.
- Provisions must be included to select and transmit any part or all of the OCS test data points to the ground.

To attain these objectives via the use of an Onboard Checkout System which is integrated with the Data Management System, checkout strategies have been developed which are tailored to each Space Station subsystem.

Special emphasis has been applied to a strategy for checkout of redundant elements peculiar to each subsystem. The degree to which each of these functions is integrated into the DMS is also addressed.

4.1.1 SPACE STATION SUBSYSTEMS

Each major Space Station subsystem was examined with respect to the required checkout functions. The checkout functions associated with each subsystem are identified and analyzed as to their impact on the onboard checkout task. The functions considered are those necessary to verify operational status, detect and isolate faults, and to verify proper operation following fault correction. Specific functional requirements considered include stimulus generation, sensing, signal conditioning, limit checking, trend analysis, and fault isolation.

4.1.1.1 RF Communications Subsystem

The RF Communications Subsystem (RFCS) contains the receivers, transmitters, power amplifiers, transponders, modems, and antenna systems to provide radio frequency communications between the Space Station and the ground, DRSS, Shuttle, free-flying experiment modules, and EVA crewmen. The subsystem operates in the S, Ku, and VHF bands.

4.1.1.1.1 Checkout Functions

Fault detection in the RF Communications Subsystem utilizes both operational monitoring and specific functional test routines. The operational monitoring takes place continuously while the system is in use and involves both the onboard and ground crews to a great extent. Assessment of system performance is made in much the same way one "checks out" his home communications equipment such as telephone and television, i.e., by listening to or looking at the output. Such tests are somewhat gross and subjective of course, and must be augmented by functional tests which include more precise qualitative analysis of performance. These functional tests may be performed on a scheduled periodic basis or as an aid to fault isolation in the event of a malfunction. Checkout of portions of the system will also be required prior to initiation of certain operations, such as a rendezvous and docking. Functional tests generally involve the injection of calibrated test stimuli and evaluation of equipment response.

- Stimulus Generation - Checkout of the various S-band, K_u-band, and VHF receivers requires the capability to inject RF test stimuli of the appropriate frequency and modulation characteristics into the receiver front ends and measure the corresponding receiver outputs and Automatic Gain Control (AGC) levels. Testing of transmitters and of the receiver and transmitter modems requires the injection of modulating test signals of the appropriate type and format. Stimulus requirements are included in Appendix I.

- Sensing - Sensing requirements associated with the RFCS are tabulated in Appendix I.

  The 0-5 Vdc range given for the AGC, RF power, and Voltage Standing Wave Ratio (VSWR) levels are conditioned sensor output levels rather than "raw" signal ranges and reflect the selected RFCS design approach of providing integral signal conditioning at the LRU level. Similarly, the bilevel status indicator parameters represent a variety of "raw" parameters including mode selections, switch positions, presence of primary power, and presence of input and/or output modulation. The selector switch position parameters indicate the position of multiposition switch elements such as channel selectors and antenna switches. These parameters are internally encoded such that a twelve-position switch, for example, is represented in the form of a four-bit binary word.

- Signal Conditioning - The measurement signal conditioning for the RFCS is included as an integral portion of the subsystem at the "black box" or LRU level. The measurements are therefore directly compatible with the data management subsystem.

- Limit Checking - Limit checks of the continuous or random type have limited applicability in the RFCS. This is due to the fact that the majority of the significant subsystem performance parameters, such as RF output power, are meaningful only when the equipment is actually transmitting or, as in the case of receiver sensitivity (AGC) measurements, when a calibrated input signal is present. Limit testing opportunities are therefore largely confined to periodic test situations where the necessary conditions can be established.

- Trend Analysis - Application of trend analysis techniques to selected RFCS measurements is potentially useful in detecting degradation and impending failures in such equipment as transmitters and receivers. In particular, the RF power output and VSWR of the transmitters and the AGC level of the receivers are good performance indicators and are amenable to such analysis. Care must be exercised, however, to assure proper correlation between these measurements and the various factors which influence them. Meaningful receiver sensitivity data, for example, is highly dependent upon accurate calibration of the input test signal. The maintenance of sufficiently accurate calibration of test stimuli and measurement equipment over a long term orbital mission is a problem not previously encountered in the space program and will require careful consideration.

4.1.1.1.2 Redundant Element Checkout

Redundancy in the RFCS is in the form of functional redundancy, as typified by the capability to communicate with the ground either directly or via DRSS, and in duality of systems as in the case of the dual antenna systems. These dual or functionally overlapping areas of equipment are independent of each other, however, and therefore do not constitute redundancy in the normal switchable or parallel equipment sense. As such, no unique checkout problems exist.

4.1.1.1.3 Integration with Data Management Subsystem

Stimulus requirements for the RFCS include modulated S-band, K_u-band, and VHF RF signals, analog signals, and digital inputs. The RF signals in particular are relatively complex and are unique to the subsystem. These are therefore generated by equipment internal to the subsystem. The control of these signals is a function of the DMS. The various analog signals (i.e. audio, video, etc.) required for modulation testing are likewise generated internally under DMS control. Digital test inputs required for checkout of the PM modems and exciters are supplied directly by the DMS via the data bus.

Measurement sensors and signal conditioning for the Communications Subsystem are provided as an integral part of that subsystem. The signal interface between the RFCS and the DMS is in the form of standard 0-5 Vdc signals for each measurement.

4.2 INTEGRATED CHECKOUT STRATEGY

This analysis identifies the integrated checkout functions associated with Space Station subsystems during the manned orbital phase of the mission. These functions are depicted in Figure 4-1 and are those required to ensure overall availability of the Space Station. Characteristic of integrated testing is the fact that the test involves subsystem interfaces, and, therefore, test objectives are associated with more than one subsystem.

4.2.1 INTEGRATED STRATEGY

Six checkout functions have been identified:

- Caution and warning
- Fault detection
- Trend analysis
- Operational status
- Periodic checkout
- Fault isolation

These functions represent a checkout strategy of continuous monitoring and periodic testing with eventual fault isolation to a line replaceable unit (LRU). Under this aspect the functions are grouped as -

CONTINUOUS MONITORING	PERIODIC TESTING	FAULT ISOLATION
• Caution and warning	• Automatic tests	• Localize to SS
• Fault detection	• Operational Verification	• Isolate to RLU
• Trend analysis		
• Operational status		

General characteristics of these groups are defined below:

4.2.1.1 Continuous Monitoring

Continuous monitoring is not a test per se. It is a concept of continuously sampling and evaluating key subsystem parameters for in/out-of-tolerance conditions. This evaluation does not necessarily confirm that the subsystems have failed or are operating properly. The evaluation is only indicative of the general status of the subsystems. For example, a condition exists where the integrated subsystems are indicating in-limit conditions, but during the next series of attitude control commands, an error in Space Station position is sensed and displayed. Since three subsystems, DMS, GN&C, and P/RCS, are involved in generating and controlling the Space Station attitude, a "positional error" malfunction is not directly related to a subsystem malfunction. The malfunction indication is only indicative of an out-of-tolerance condition of an integrated function. Final resolution of the problem to a subsystem and eventually to LRU will require diagnostic test-procedures that are separate from the continuous monitoring function.

There are situations in which the parameters being monitored are intended to be directly indicative of the condition of a subsystem or an LRU. Examples of these include tank pressures, bearing temperatures, and power source voltages. However, even in these simpler cases when a malfunction is detected, an integrated evaluation will be performed to ascertain that external control functions, transducers, signal conditioning, and the DMS functions of data acquisition, transmission, and computation are performing properly. This evaluation will result in either a substantiation of the malfunction or identification of a problem external to the parameter being monitored.

Figure 4-1 shows the logic associated with each function in the continuous monitoring group, as well as the integrated relationships between these and the total checkout functions. The caution/warning and fault detection functions are alike in their automatic test and malfunction detection approaches, but are different in terms of parameter criticality and malfunction reaction. The caution/warning function monitors parameters that are indicative of conditions critical to crew or equipment safety. Parameters not meeting this criticality criteria are handled as fault detection functions. Figure 4-1 shows that in the event of a critical malfunction, automatic action is initiated to warn the crew and sequence the subsystems to a safe condition. Before this automatic action is taken, the subsystems must be evaluated to ascertain that the failure indication is not a false alarm and that the corrective action can be implemented. After the action is taken, the subsystems must be evaluated to determine that proper crew safety conditions exist. Since automatic failure detection and switching can be integral to subsystem design (self-contained correction) and subsystems can be controlled by the operational software or manual controls, it is imperative that the status of these events be maintained and that the fault detection and correction software be interfaced with the prime controlling software. For malfunctions that are not critical, the crew is notified of their occurrence, but any subsequent action is initiated manually.

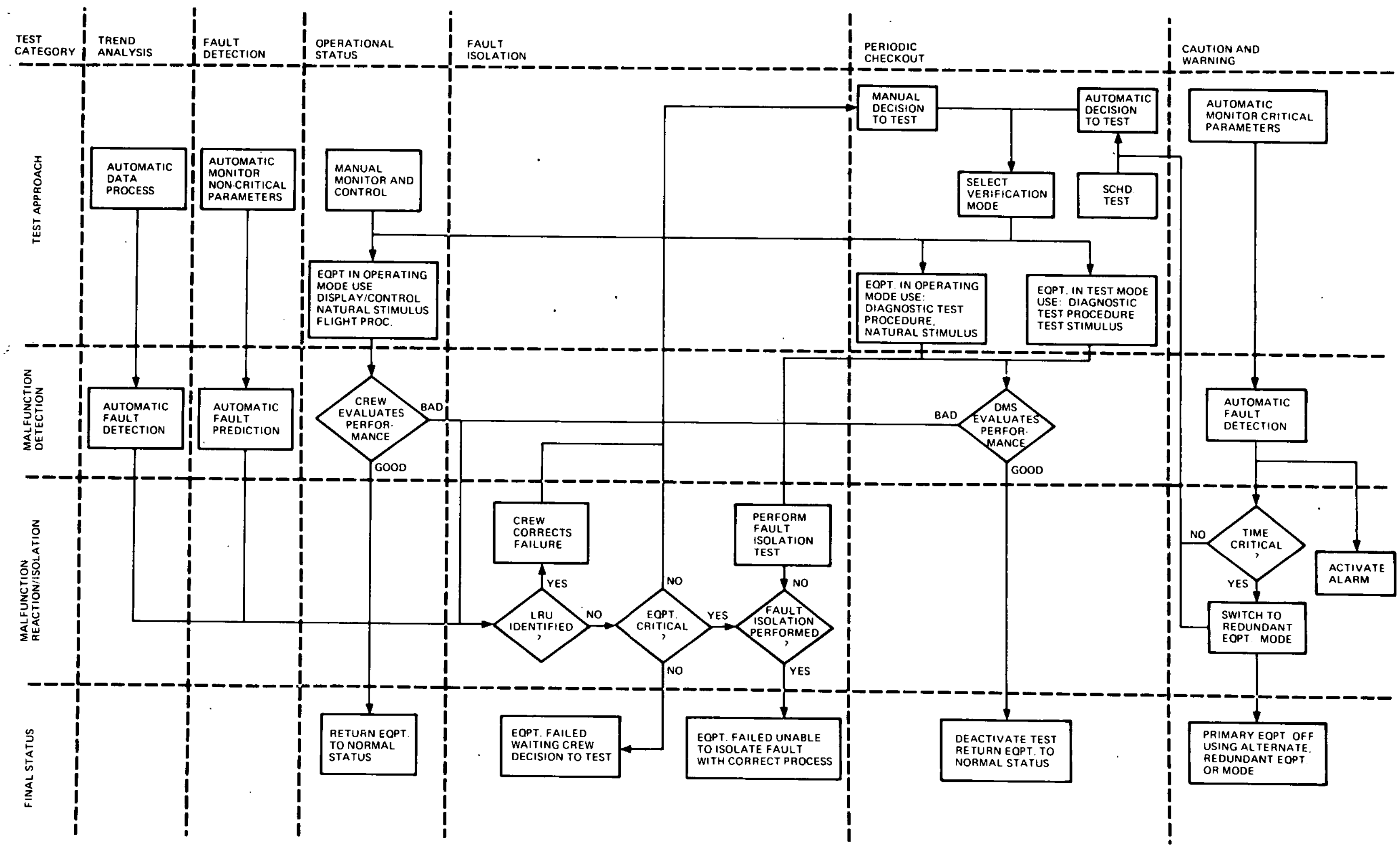

Figure 4-1. Integrated Checkout Functional Flow

The next continuous monitoring function, trend analysis, automatically acquires data and analyzes the historical pattern to determine signal drift and the need for unscheduled calibration. It also predicts faults and indicates the need for diagnostic and fault isolation activities. An example of a parameter in this category is the partial pressure of nitrogen. Nitrogen is used to establish the proper total pressure of the Space Station. Since it is an inert gas, the only make-up requirements are those demanded by leakage or airlock operation. The actual nitrogen flow rate is measured, and calculations are performed which make allowances for normal leakage and operational use. When these calculations indicate a trend toward more than anticipated use, the crew is automatically notified and testing is initiated to isolate the problem to the gas storage and control equipment or to an excessive leak path. The historical data is not only useful in predicting conditions but is also useful in providing trouble-shooting clues. The data might reveal, for example, that the makeup rate increased significantly after the use of an airlock. This could lead directly to verifying excessive seal leakage.

The final continuous monitor function is in operational status. This function is performed by the crew and is nonautomatic with the exception of the DMS computer programs associated with normal Space Station operational control and display functions. The concept of continuous monitoring recognized and takes advantage of the crew's presence and judgment in evaluating Space Station performance. In many instances the crew can discern between acceptable and unacceptable performance, and they can clearly recognize physically-damaged equipment or abnormal conditions.

4.2.1.2 Periodic Testing

As opposed to continuous monitoring, periodic testing is a detailed evaluation of how well the Space Station subsystems are performing. Figure 4-1 shows that periodic testing is not accomplished by any one technique. Rather, a combination of operational and automatic test approaches is employed. The actual operational use of equipment is often the best check of the performance of that equipment. Operation of Space Station equipment and use of the normal operating controls and displays will be used in detecting faults and degradation in the subsystems. This mode of testing is primarily limited to that equipment whose performance characteristics are easily discernible, such as for motors, lighting circuits, and alarm functions.

Automatic testing is performed in two basic modes:

- With the subsystems in an operating mode, the DMS executes a diagnostic test procedure which verifies that integrated Space Station functions are being properly performed under normal interface conditions in response to natural or designed stimulation. This mode of testing allows the evaluation of Space Station performance without interrupting mission operations.

- For those situations where the integrated performance or interface compatibility between subsystems cannot be determined without known references or control conditions, the DMS will execute a diagnostic procedure in a test mode. In this mode, control, reference, or bias signals will be switched in or superimposed on the subsystems to allow an exact determination of their performance or localization of problem between the interfaces. Since the test mode may temporarily inhibit normal operations, the DMS must interleave the test and operational software to maintain the Space Station in a known and safe configuration.

The scheduled automatic tests are performed to verify availability or proper configuration of "on-line" subsystems, redundant equipment, and alternate modes.

- Periodic Verification of "On-Line" Subsystems - The first checkout requirement is a periodic verification that on-line subsystems are operating within acceptable performance margins. The acceptable criteria for this evaluation is based on subsystem parameter limits and characteristics exhibited during Space Station factory acceptance or pre-flight testing. The rejection criteria and subsequent decision to repair or reconfigure subsystems is based on the criticality of the failure mode. If the subsystems appear to be operating properly, but the test clearly indicates an out-of-tolerance condition, then one of the following alternatives must be implemented:

    - If the failure mode is critical, the crew normally takes immediate action to isolate and clear the problem.

    - If the failure mode is not critical, the crew can take immediate action, schedule the work at a later time, or wait until the condition degrades to an unacceptable level.

- Redundant Equipment Verification - A second checkout requirement is verifying that standby, off-line, or redundant equipment and associated control and switching mechanisms are operable. The acceptable/rejection criteria for these evaluations is identical to those for normally operating equipment. A primary distinction of this function is that equipment may have known failures from previous usage or tests. This situation occurs when the crew has knowledge of a failure but has not elected to perform the necessary corrective action. The checkout function then becomes one of equipment status accounting and maintenance/repair scheduling. The status information is interlocked with mission procedures and software to preclude activation of failed units while they are being repaired or until proper operation following repair is verified.

- Alternate Mode Verification - The third checkout function is verifying the availability of alternate modes of operation. This function is essentially a confidence check of the compatibility of subsystems'interaction and performance during and after a change in the operating mode. To some extent this function overlaps with redundant equipment verification, but is broader in scope in that it verifies other system-operating characteristics. For example, some modes will involve manual override or control of automatic functions or automatic power-down sequences.

4.2.1.3 Fault Isolation

Fault isolation to an LRU is a Space Station goal. As shown in Figure 4-1, fault isolation testing is initiated when malfunction indications cannot be directly related to a failed LRU. The integrated test functions associated with fault isolation are localizing a malfunction to a subsystem or to an explicit interface between two subsystems and identifying the subroutine test necessary for LRU isolation. In structuring this relationship between integrated subsystem tests for fault localization and subroutine tests for fault isolation, the DMS, in conjunction with the test procedure documentation, must establish an effective man-machine interface so that in the event of an unsolved malfunction the crew will be able to help evaluate the condition and determine other test sequences necessary to isolate the problem. To accomplish this requirement, the DMS must be capable of displaying test parameters and instructions in engineering units and language and be capable of referencing these outputs to applicable documentation or programs that correlate test results to corrective action required by the crew.

Section 5

ONBOARD CHECKOUT TEST DEFINITIONS

5.1 SUBSYSTEM TEST DEFINITIONS

The on-orbit tests required to insure the availability of the Space Station subsystems are defined herein. Also delineated are the measurement and stimulus parameters required to perform these tests. Two discrete levels of testing are defined, i.e., continuous status monitoring tests for fault detection of critical and noncritical parameters, and subsystem fault isolation tests for localization of faults to a specific Line Replaceable Unit. In addition to these two levels, tests are defined for periodic checkout and calibration of certain units, and parameters requiring analysis of trends are defined.

Due to the software module approach to DMS checkout, it was deemed necessary to estimate the CPU time and memory required to implement these modules along with an assessment of the services required from an Executive Software System to control the checkout.

These test descriptions, measurement, and stimulus information provided for each subsystem, and the software sizing information provided for the Data Management System provide the data required to estimate the checkout impact on the DMS software and hardware. Table 5-1 is a summary of the measurement and stimulus requirements for the Space Station.

The RF Communications Subsystem contains the receiver, transmitters, power amplifiers, transponders, modems, and antenna systems to provide radio frequency communications between the Space Station and the ground, DRSS, Shuttle, free-flying experiment modules, and EVA crewmen. The subsystem operates in the S, K_u, and VHF bands.

On-orbit checkout activities required to insure the availability of the subsystem include monitoring of its normal operational outputs, performing periodic checks, and selecting fault isolation routines associated with the loss of a communications function. In addition, some trending and calibration are required.

Table 5-1. Measurement/Stimulus Summary

SUBSYSTEM	STIMULUS					RESPONSE			STATUS MONITORING									
	Analog	Bilevel	Digital	Pulse	RF	Analog	Bilevel	Digital	Total	Non-Critical	Caution	Warning	Periodic Checkout	Calibration	Trend	Fault Isolation	Remarks
Guidance, Navigation and Control	20	146	62	6		127	161	70	592	130	16		516	74	74	592	
Propulsion - Low Thrust		134				120	124		378	152	14		378	48	8	378	
Propulsion - High Thrust		126/62				287/117	123/63		536/242	80/28	33/15	14/10	536/242	259/111	117/43	482/222	Art-g/Zero-g periods
Environmental Control/ Life Support	34	111				691	280		1116	139	205	32	1116		135	1116	172 Caution/Warning Signals are for IVA, EVA
RF Communications	37	206	36		77	131	286	28	801	58			576	24	93	801	
Structures	15/16	21/19				60/53	75/66		174/154	7			123/104			174/154	
Electrical Power - TCD	52	1952				292	1292	20(1)	7608	1404	20		724		134	3608	(1) Twelve of these take pulse form
Electrical Power - Solar Array/Battery		1916				4044	928		6780	3704	12		2184		332	6788	
Data Management			53			33	188	83	357	357			62	62	62	357	
Total	151/169	4512/ 4446	151	6	77	5785/ 5628	3457/ 3388	201	14,350/ 14,035	6031/ 5979	300/282	46/42	5110/ 5902	467/ 319	935/ 861	14,266/ 14,016	

The measurements and stimuli associated with these checkout activities are identified in Appendix I-5 of the Task 1 Final Report. All analog and RF stimuli are generated by the subsystem but controlled by the DMS. Conditioning of sensor outputs is also integral to subsystem LRUs and results in all measurements being compatible with DMS data acquisition elements.

Go/No-Go decision outputs are provided where possible for checkout of the RF communications subsystem. The acceptance/rejection criteria associated with the occurrence of an event such as primary power ON/OFF, modulation output present, switch position selected, and channel or mode selected are straightforward. A bilevel output is either present or absent and would be indicated by two distinct voltage levels. An absolute acceptance/rejection criterion associated with analog responses such as RF power output level, VSWR level, and AGC output level, on the other hand, is more difficult to establish. This is due to design variances between equipment and the accuracy of the individual measurement. For instance, the K_u-band PA may be specified to deliver not less than 10 watts of RF power, and this would be indicated by a 4.0-volt analog output. A tolerance of $\pm$ 10 percent due to design and measurement variances results in a range of outputs from 3.6 to 4.4 volts. Reliance on an absolute level could result in the rejection of a unit that is operating normally. Therefore, the analog outputs should be utilized primarily for trend analysis purposes.

The checkout of the RF Communications Subsystem can be automatically controlled by the DMS and should require minimal crew participation. The crew participation would be limited to calling up preprogrammed fault isolation and periodic checkout routines and interpretation of anomalies.

5.1.1 STATUS MONITORING

During normal operation of the subsystem, only two different types of parameters are monitored on a nearly continuous basis. These are the transmitter or exciter and power amplifier RF power output levels, and the receiver AGC output levels. These noncritical parameters are sampled once per minute. This sampling can be performed during normal operation of the subsystem without the need for stimuli. In the case of AGC output level, for example, the signal stimulus is the modulated RF signal transmitted by the Shuttle, free-flying experiment module, etc. Since the AGC level varies as a function of received signal strength, this parameter should be compared on a sample-to-sample basis to detect large changes in output level. Unless a failure occurs, the RF power output should stay fairly constant during a normal operating period. For power output levels, the RF output of the exciter associated with the power amplifier provides the required input stimulus. Measurement of power output during normal operation actually provides a better indication of overall performance than would a check of the power amplifier by itself.

Although several parameters are monitored continuously during subsystem operation, none of these can be classified in a caution or warning category.

5.1.2 TREND ANALYSIS

To detect graceful degradation in Communication Subsystem receivers, exciters, power amplifiers, and transmitters, internally generated AGC, RF stimuli, AGC outputs, and power outputs are periodically sampled. The internally generaged RF stimuli are necessary to obtain an accurate indication of the AGC output levels. Sampling should occur approximately once per day for equipment utilized to support the Shuttle, free-flying experiment modules, and direct-to-ground links. Equipment that supports the primary link between the Space Station and the relay satellite, on the other hand, should be sampled about once per hour.

5.1.3 PERIODIC CHECKOUT AND CALIBRATION

The only calibration functions that have been identified are the RF power levels at the high-gain antenna feeds and low-gain antenna elements. The measurement of RF System insertion loss is required after the replacement of an LRU in the RF Transmission System to verify that the unit has been properly replaced.

Periodic checks of subsystem status and availability are performed at once-per-month and one-per-week intervals. The monthly checks should be performed several days ahead of anticipated operational usage. This primarily pertains to that equipment utilized to support the Shuttle and experiment modules. During the artificial-gravity portion of the mission, the S-band equipment utilized for the direct-to-ground link should be checked once per week. After completion of artificial gravity, these checks can be performed at monthly intervals. Week-by-week checks should also be performed on the transmitters (exciters and power amplifiers), receivers, signal interface modems, and High Gain Antenna System utilized for the Space Station relay satellite K_u-band link.

The procedure for periodic checkout requires systematic checks performed on a group of LRUs associated with a particular mission support function. Except for the High Gain Antenna System, the following represents a periodic checkout procedure for a typical set of RF link equipment.

1. Apply primary power to all units.
2. Monitor primary power indication.
3. Check for completion of power amplifier warm-up cycle.
4. Monitor exciter, power amplifier, and antenna feed RF power output levels.
5. Monitor VSWR levels at power amplifier output and antenna feed.
6. Apply modulation input stimulus.
7. Monitor modem and exciter outputs for presence of modulation.
8. Apply modulated RF signal at input to low noise preamplifier.
9. Monitor preamplifier output level and receive AGC output level.
10. Monitor modem and receiver outputs for presence of modulation.
11. Switch to redundant preamplifier and repeat steps 8, 9, and 10.
12. Apply known antenna position control input.
13. Monitor antenna position output indication and compare with input.

5.1.4 FAULT ISOLATION

Fault isolation of the RF Communications Subsystem is performed on a systematic basis on a group of LRUs that are associated with the loss of a particular function. A typical fault isolation flow diagram is depicted in Figure 5-1 for the case where no video signal is received from the ground. This particular routine culminates in the identification of an LRU to be replaced or calls for further testing of the High Gain Antenna System or interfacing portions of the Data Management Subsystem.

5.2 INTEGRATED TEST DEFINITION

The task of ensuring overall Space Station availability is primarily dependent upon the proper structuring of individual subsystem tests. The ability to test the subsystems independent of other subsystems is directly related to the number and types of interfaces. As shown in Figure 5-2, the DMS and Electrical Power Subsystems (EPS) interface with every other Space Station subsystem. In addition, the EC/LS Subsystem provides cooling to most of the electronic packages.

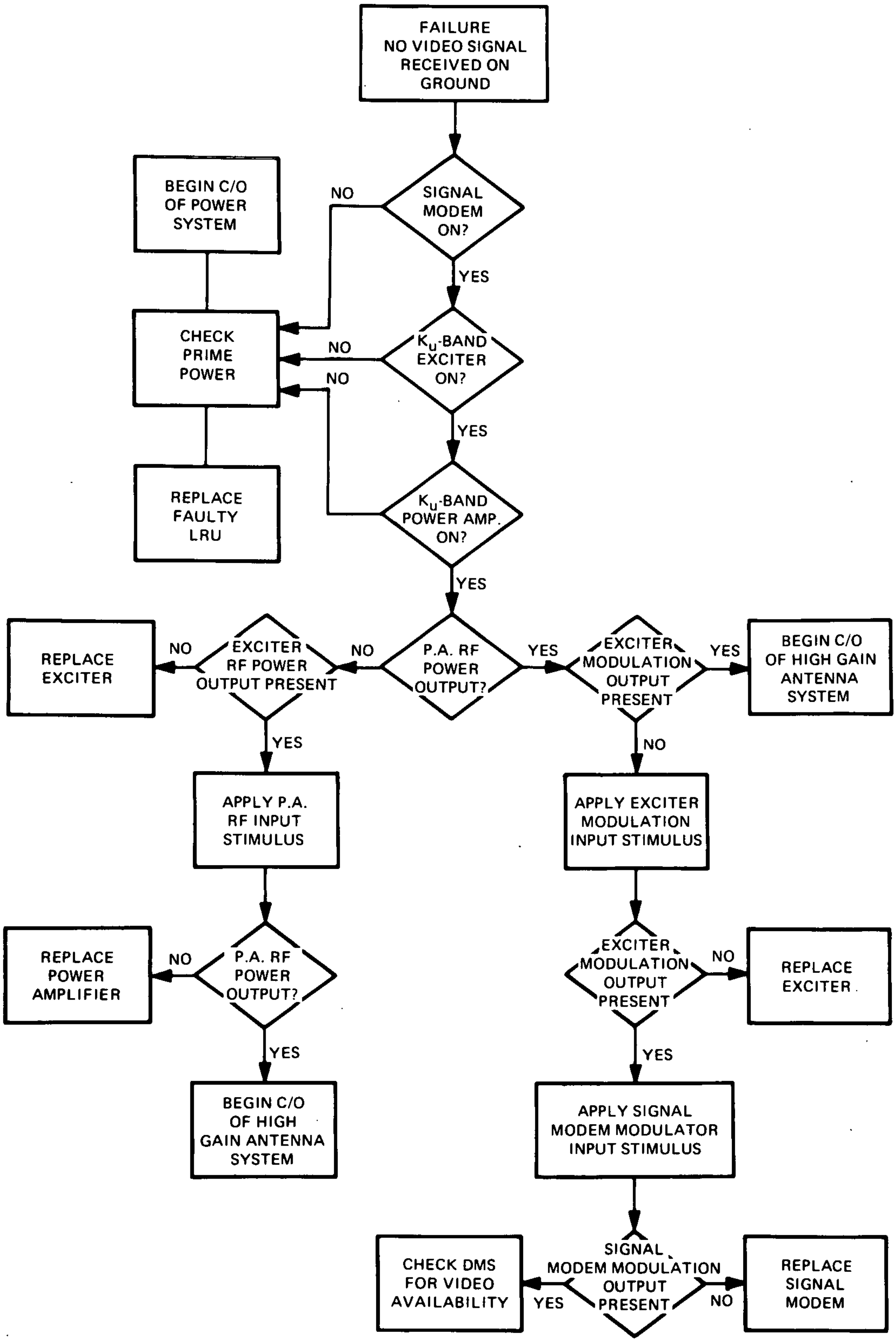

Figure 5-1. Typical Fault Isolation Routine Flow Diagram

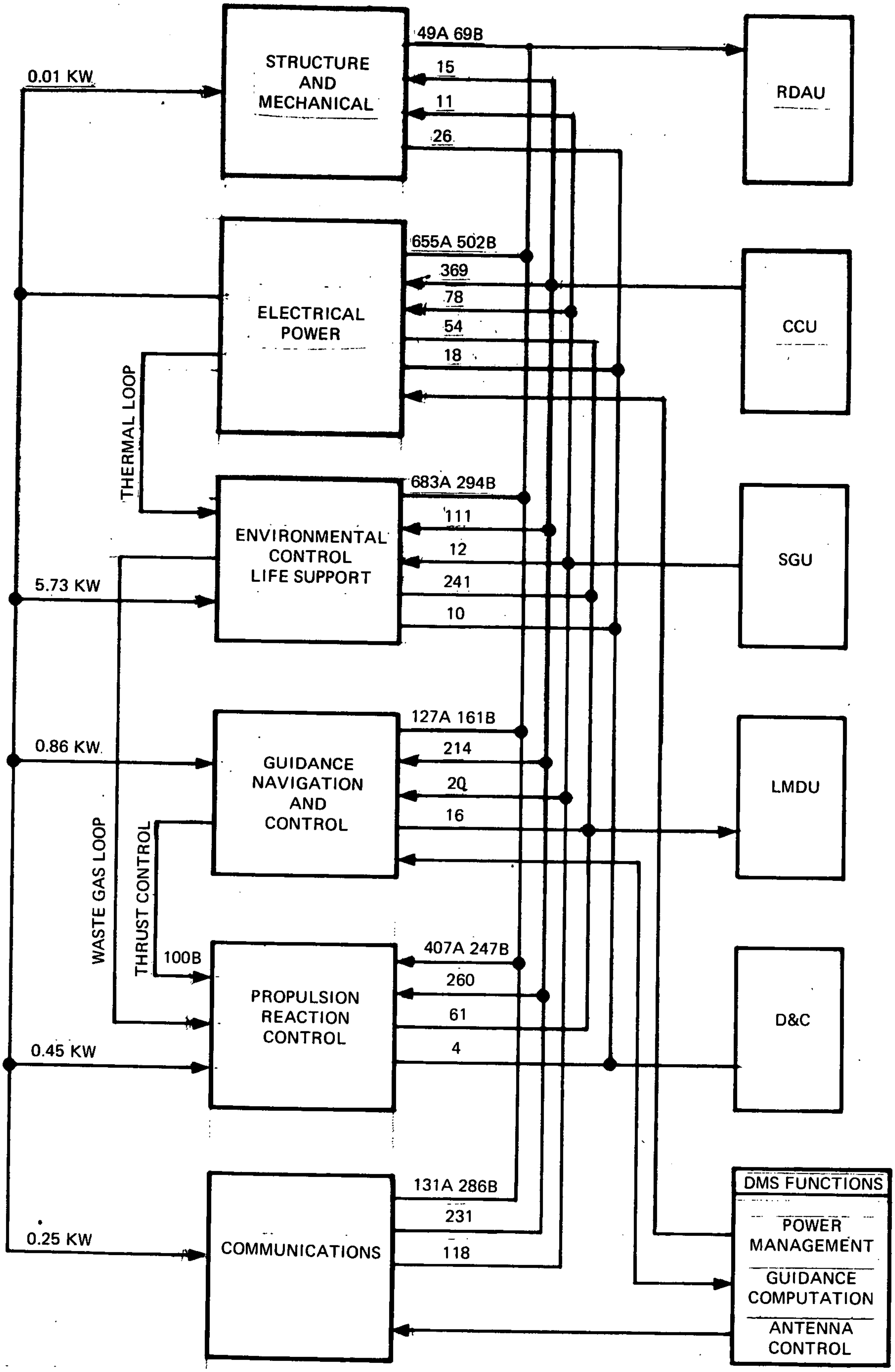

Figure 5-2. Subsystem Interfaces

This situation demands that in constructing the test for a subsystem these interfaces be taken into account so that erroneous or ambiguous test results will not be obtained. In other words, before detailed subsystem fault isolation tests are initiated, a higher level of testing should be performed to verify that all interfaces and Space Station conditions that influence the subsystem are proper. Properly designed, these higher-level tests will (1) indicate what Space Station conditions must be verified, maintained, or changed; (2) localize the malfunction to a single subsystem; and (3) identify the subroutine test necessary for fault isolation.

Since the DMS interfaces with all of the Space Station subsystems and is used as the OCS, it would appear that all of the tests would be integrated. However, this is not a proper interpretation. When the DMS is used to verify the performance of another subsystem, it must first establish itself as a test standard against which the subsystem parameters are compared. Subsequent to this verification, the test is dedicated to the evaluation of the subsystem. This test would be considered as an independent test since the objective of the test was to verify the subsystem and not the DMS. For a test to be considered as an integrated test it must meet one or more of the following conditions:

- Test objectives associated with more than one subsystem
- Test involves subsystem interfaces
- Test requires proper operation of other subsystems

In several cases, the DMS must simultaneously perform the dual role of OCS and functional elements. As an example, the DMS has a functional interface with the GN&C and Prop Subsystems for the computation of guidance equations and the execution of commands to the control actuators. When this functional closed loop is being tested, the DMS must, in addition to performing its normal functions, execute the test routine. For this type of integrated test there must be an intrinsic relationship between the operational and test software. This relationship must be carefully considered in structuring the integrated tests since unstable or intermittent performance may be detected only in the exact operating mode under closed-loop conditions. The number of integrated tests is not extensive due to the approach of minimizing the different types of interfaces between Space Station subsystems. For example, interfaces between the DMS and other subsystems are largely standardized. As a result, relatively common tests can be designed for verification of the multitude of DMS subsystem interfaces or for localization of a fault to one side of a DMS subsystem interface. A special integrated test that has been identified is discussed in the following paragraph.

5.2.1 GN&C/DMS/COMM

The DMS has a functional interface with the GN&C and COMM Subsystems for the pointing and control of antennas. The GN&C sends navigation and attitude information to the DMS which in turn uses it to compute antenna pointing positions and slewing rates. Once computed, the DMS transfers these commands to the antenna actuators in the Communication Subsystem.

Localizing a malfunction to one of the three subsystems will be performed in a manner similar to that described in subsection 6.2.1 of the Task 1 Final Report. The DMS will verify receipt of proper attitude and navigation data from the GN&C Subsystem, check its capability to operate on and transform the data into appropriate antenna commands, and verify the transmission of the control data to the Communication Subsystem. Verification of proper response and operation of Communication Subsystem equipment will be aided by the switching and use of redundant transmitters and receivers.

Section 6

SOFTWARE

6.1 GENERAL CONSIDERATIONS

The recommended software checkout startegy involves a sequence of detecting faults, isolating faults to a failing LRU or LRUs, and reconfiguring the system to continue operation while the failures are being repaired.

This recommendation was developed by evaluating each subsystem with respect to the three general requirements of fault detection, fault isolation, and reconfiguration.

Fault detection incorporates both the recognition of failure occurrence, and the prediction of when a failure can be expected to occur. The Remote Data Acquisition Units (RDAUs) continually check selected test point measurements against upper and lower limits, and notify the executive on an exception basis when a limit is exceeded. This approach avoids occupying the central multi-processor with the low-information task of verifying that measurements are within limits.

Trend analysis is a fault detection technique recommended for predicting the time frame during which a failure can be anticipated. Data is acquired on a basis of time or utilization, and compared with previous history to determine if a "trend" toward degraded performance or impending failure can be detected.

Another checkout requirement evaluated for each subsystem is periodic testing. This type of test is provided to exercise specific components at extended time intervals or prior to specific events, to assure operational integrity. In the event that a failure is detected, the periodic test will isolate to the failing Line Replaceable Unit (LRU) and accomplish recertification after a repair operation.

Calibration of specific subsystem components will be required periodically, or subsequent to a repair and/or replace operation. The techniques involved are unique to the individual component; and, in some cases, require the acquisition of operational data.

Fault isolation is required when a fault is detected. When a particular fault provides an indication that a life critical failure has occurred, the fault isolation routines are automatically initiated. If the failure does not represent an immediate danger to the vehicle occupants, the crew is notified and they will initiate the fault isolation modules at their convenience.

The basic requirements of the fault isolation function is to analyze the available information relevant to a problem, and identify the LRU which is responsible for the anomaly.

Three basic approaches to meeting this requirement were considered. These are:

- Analyze each fault as an independent problem
- Analyze each fault with a state matrix which defines the possible error states of the subsystem
- Associate each fault with a specific subsystem, and evaluate that subsystem in detail

The third approach was selected on a basis of software commonality and cost effectiveness. The complexity associated with the testing can be reduced by localization of the logic associated with the analysis of the subsystem in a unique package. The software commonality will result in reduced software development and maintenance costs, while increasing the reliability of the software.

The fault isolation software is structured modularly for compatibility with the hardware structure of the subsystem. Checkout modules evaluate the performance of a specific portion of the subsystem. A convenient division for this modular structure is at the assembly level or functional area. A program module which can determine and control the sequence in which these checkout modules are executed is also required for each subsystem.

Subsequent to fault detection, the software associated with the subsystem which is most likely to contain the error will be activated.

The subsystem software will analyze the error indication, and initiate a sequence of checkout modules to isolate the problem. If successful, the crew is notified regarding the Line Replaceable Unit (LRU) to be replaced. If an error cannot be identified, the crew is informed of the situation and has an option to execute the periodic test of the subsystem.

After a fault has been isolated, reconfiguration software restores the functional capability of the subsystem. This is most commonly accomplished by exchanging a redundant element for the failing unit, or by defining an alternate path to accomplish the required function.

The Task 2 Final Report of the basic onboard checkout techniques study provides descriptions of the software requirements, definitions and design in addition to detailed flow charts of specific checkout routines.

6.2 SPACE STATION SUBSYSTEM

This section provides performance and design requirements for the Communications Subsystem checkout programs to be used for the Space Station during preflight testing and while in orbit. The detail to which these requirements are developed is a function of the engineering design details available in the Phase B Space Station studies.

The checkout functions identified are those for trend analysis, operation interface, fault isolation, periodic check, and calibration. Fault detection is feasible with human interface and the RDAU preprocessor; therefore, it is not identified as a checkout program function. However, management of the RDAU fault detection facilities is under control of the checkout executive program.

The technical aspects of the Communication Subsystem checkout programs are described. Modularization concepts are utilized extensively in identifying the computer program components. Under the assumption that just as the Communications Subsystem itself is modularized, in the final implementation, the computer programs will be also. The functions, structures, processing, input, output, and data base requirements of the computer program components are discussed.

The Communications Subsystem requires trend analysis to assess assembly performance based on past history. Operation interface is used to enable and disable the RDAU fault detection capability, as well as to initiate certain forms of trend analysis. Fault isolation is required to identify the failed LRU or LRU group, and to assess assembly capability prior to use. Periodic check functions augment and cross-check the assessments made by fault isolation. Calibration verifies the operational characteristics of certain assemblies after LRU replacement.

6.2.1 SYSTEM REQUIREMENTS

Continuous monitoring is performed only for the non-critical measurements associated with RF power output levels and AGC output levels. These measurements provide the only means of automatic fault detection by the RDAU preprocessor technique. Fault detection relies extensively on human evaluation of operating results, in addition to RDAU limit checking.

Stimuli are required prior to making certain trend analysis measurements, and must be applied when the associated assembly is not providing an operational function.

Fault isolation is performed on a group of LRUs which are associated with the loss of a particular function.

After LRU replacement has been performed in the RF transmission system, which consists of the signal path from the power amplifier outputs through the antennas, the RF power level at the antennas is used for calibration purposes.

6.2.2 OPERATIONAL REQUIREMENTS

The communications checkout programs required for trend analysis, operation interface, fault isolation, periodic check, and calibration are discussed in the following sections.

6.2.2.1 Trend Analysis Function

The trend analysis checkout programs are used to periodically sample selected RF and AGC measurements for the purpose of detecting degraded performance prior to the time that the fault might otherwise be detected.

Input consists of single test point measurements and the intermediate results obtained after the last sample. In the case of certain AGC test points, output consists of stimuli to supply a reference for the measurement. Other output consists of a checkpoint just prior to termination, and parameters passed to other checkout functions such as fault isolation.

Information processing consists of averaging a series of measurements, comparing the most recent measurement to the average, and storing averages for later retrieval upon request and for use in the next cycle. A trend analysis function for RF power test points is initiated by the executive at a specified rate. For AGC test points, the trend analysis function is initiated by the shutdown program, since trending must be done during periods of inactivity because of the stimulus required. Executive checkpoint services are used to store results after each cycle. Restart services of the executive are employed to begin each successive cycle.

The trend analysis methods required for the Communications Subsystem are as follows:

1. Provide stimulus and make measurement, comparing with the average of 30 previous measurements. Retain, for retrieval on an as-required basis, 30 averages.

2. Compare measurement with the average of 48 previous measurements. Retain, for retrieval on an as-requested basis, the daily average for three months. A stimulus may or may not be required prior to the measurement.

In Table 6-1, the trend analysis requirements of the Communications Subsystem are summarized. Auxiliary storage requirements for data storage, assuming three checkpoints are available at any time, is approximately 5.7K words.

6.2.2.2 Operation Interface Function

While fault detection is done by means other than software, there is a checkout program involvement in activating and deactivating the fault detection mechanism provided by the RDAU preprocessor. This is the operation interface function of communication checkout.

Input consists of the symbolic identity of the assembly being activated or deactivated, such as the K_u-band FM transmitter. Output consists of a memory update for the RDAUs which are connected to the status monitoring test points of the assembly.

Information processing consists of identifying the RDAUs involved, and either masking or unmasking the RDAU channels which measure the status test points. While the assembly is on standby, the channel is masked to prevent a limit check interrupt which might give a false error indication. After the assembly has been activated, the channel is unmasked to allow limit checking to proceed.

For assemblies requiring procedures beyond simply applying or disconnecting electrical power, special modules are utilized. For example, these modules supply logic necessary to complete the warmup cycle of a power amplifier or to assure signal acquisition. Other assemblies require an AGC stimulus in order that the trend measurement can be made. Since this stimulus must be made while the assembly is not in normal operational use, the shutdown routine will invoke the trend analysis program, provided sufficient time has elapsed since the last measurement.

6.2.2.3 Fault Isolation Function

Upon detection of a fault by the crew, ground, or RDAU's, the fault isolation functions are invoked to identify the failed assembly or LRU. Although automatic isolation to the failed LRU is attempted, in cases such as the high gain antenna group, it is only feasible to isolate to a larger assembly because of the instrumentation problems involved. In some cases, additional test points would increase the system insertion losses; therefore increasing the power required to compensate for these losses, compared with that required for operational purposes.

No unusual input or output requirements for fault isolation beyond those required for GN&C, Structures, EP and EC/LS Subsystems have been identified.

Table 6-1. Communications Trend Analysis

	Number of Applications	Trend Method	Stimulus Required	Measurement Rate	Averages and Measurements Retained Per Test Point
S-Band Video Receiver AGC	10	1	Yes	1/day	61
S-Band Data Receiver AGC	10	1	Yes	1/day	61
S-Band PM Receiver AGC	2	2	Yes	1/hour	139
Ku-Band FM Exciter RF Power	2	2	No	1/hour	139
S-Band FM Receiver AGC	2	2	Yes	1/hour	139
Ku-Band PA RF Power	5	2	No	1/hour	139
Ku-Band PM Exciter RF Power	5	2	No	1/hour	139
S-Band PM Transponder AGC	2	1	Yes	1/day	61
S-Band PM Transponder RF Power	2	2	No	1/hour	139
S-Band PA RF Power	2	2	No	1/hour	139
S-Band FM Exciter RF Power	2	2	No	1/hour	139
VHF Voice/Ranging RF Power	2	2	No	1/hour	139
VHF Voice/Ranging AGC	2	1	Yes	1/day	61
VHF Data Receiver AGC	2	1	Yes	1/day	61
VHF FM Transmitter RF Power	3	2	No	1/hour	139
VHF FM Receiver AGC	3	1	Yes	1/day	61
VHF Data Transmitter RF Power	2	1	Yes	1/day	61

Information processing for each fault isolation function follows the same form identified in the referenced Space Station OCS Interim Reports. In most cases, communications fault isolation requires exclusive use of the LRUs associated with the function which is suspected of containing a fault.

The fault isolation modules for the Communications Subsystem relate to functions such as video reception, voice transmission, etc. These routines are then applied to the hardware assembly groups of S-band low gain, K_u-band low gain, high gain, and VHF low gain shown in Figure 6-1. Further breakdown of each group, detailing LRU interfaces is shown in Figure 6-2 through Figure 6-5. In each block of the LRU interface diagrams, the LRU quantity is indicated in parentheses.

The LRUs associated with the VHF low gain group are shown in Figure 6-2. The fault isolation functions are identified below, with the LRU coverage for each function indicated in parentheses:

- VHF RF Transmission (VHF low-gain antennas, VHF diplexers, VHF multiplexer/power divider/switches)
- VHF Voice (VHF voice XMTR/RCVRs, signal modems)
- VHF PM Data (VHF PM Data XMTR/RCVRs)
- VHF Voice/Ranging (VHF FM voice/ranging XMTR/RCVRs, voice transceiver modems, ranging modems)

The LRUs associated with the K_u-band low-gain group are shown in Figure 6-3. The fault isolation functions are identified below, with the LRU coverage for each function indicated in parentheses:

- K_u-Band RF Transmission (K_u-band low-gain antennas, K_u-band pre-amp/mixer/diplexer/switches, S-band multiplexers and circulators)
- S-Band Data (S-band data receivers)
- S-Band Video (S-band video receivers, video receiver modems)

The LRUs associated with the S-band low-gain group are shown in Figure 6-4. The fault isolation functions are identified below, with the LRU coverage for each function indicated in parentheses:

- S-Band RF Transmission (S-band low-gain antennas, S-band triplexer/switches)
- S-Band Transponder (S-band PM Transponders, transponder modems)
- S-Band FM Transmitter (S-band power amplifiers, S-band FM exciters, transmitter modems)

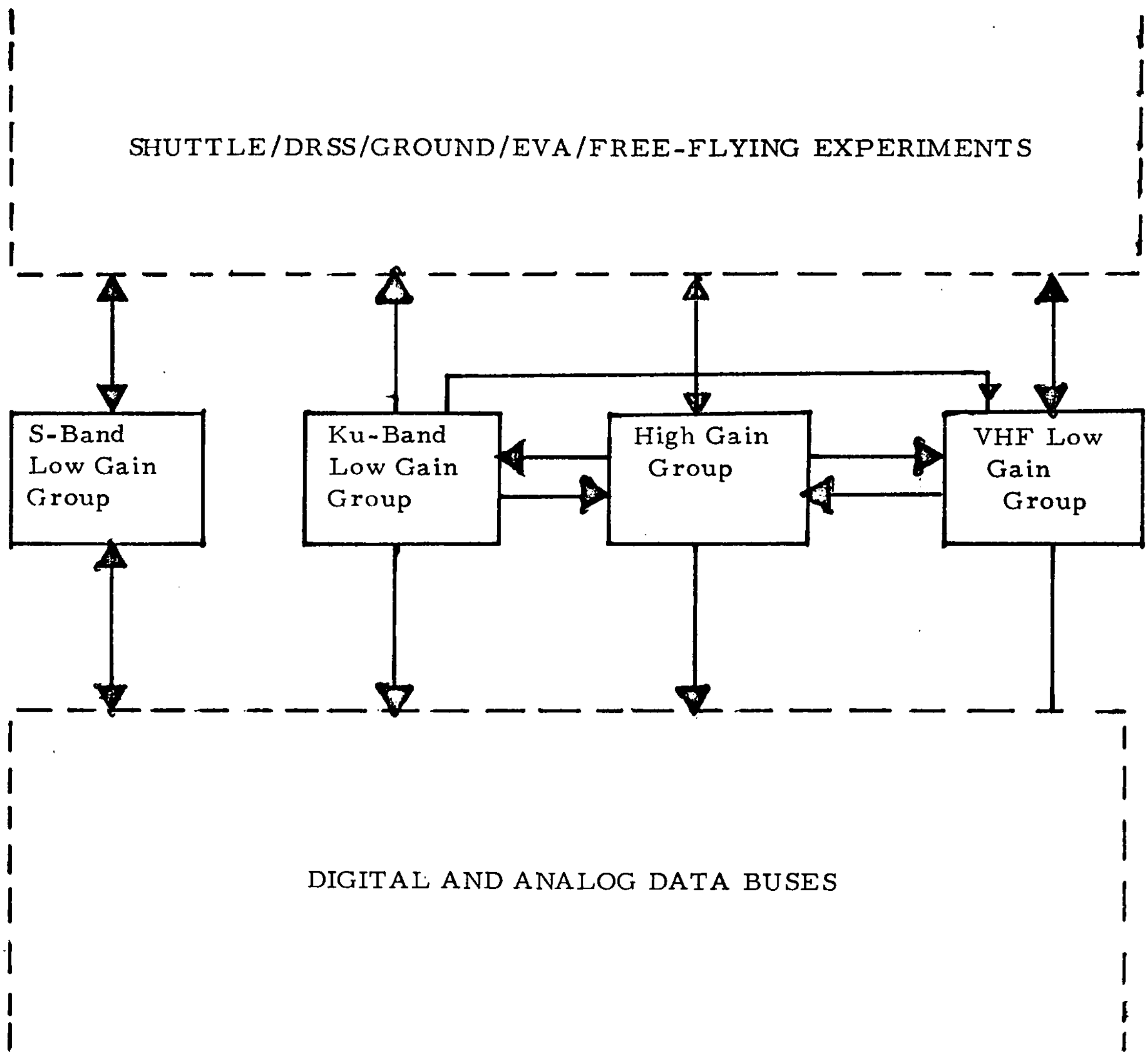

Figure 6-1. Communications Assembly Group Interfaces

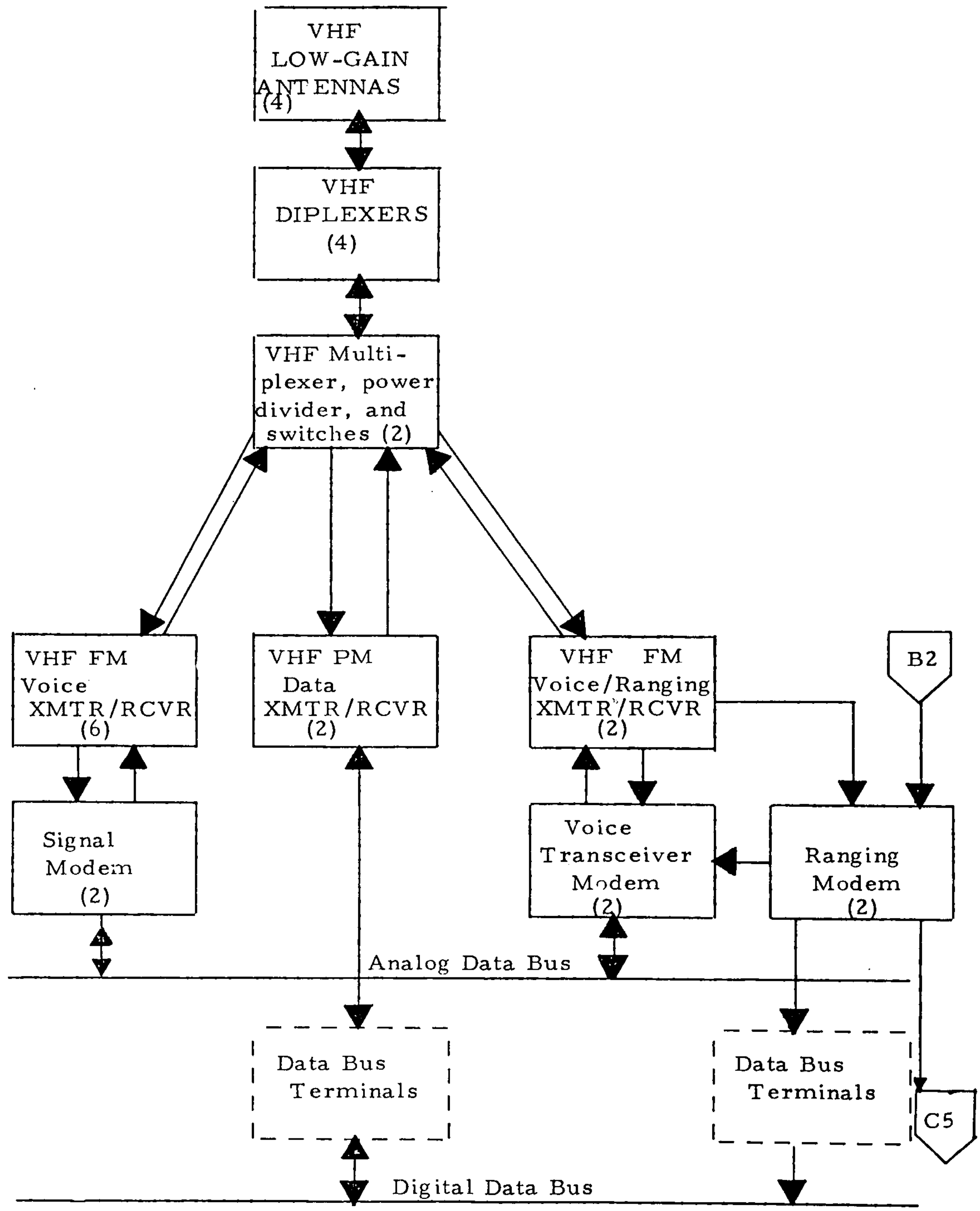

Figure 6-2. LRU Interface Diagram VHF Low-Gain Group

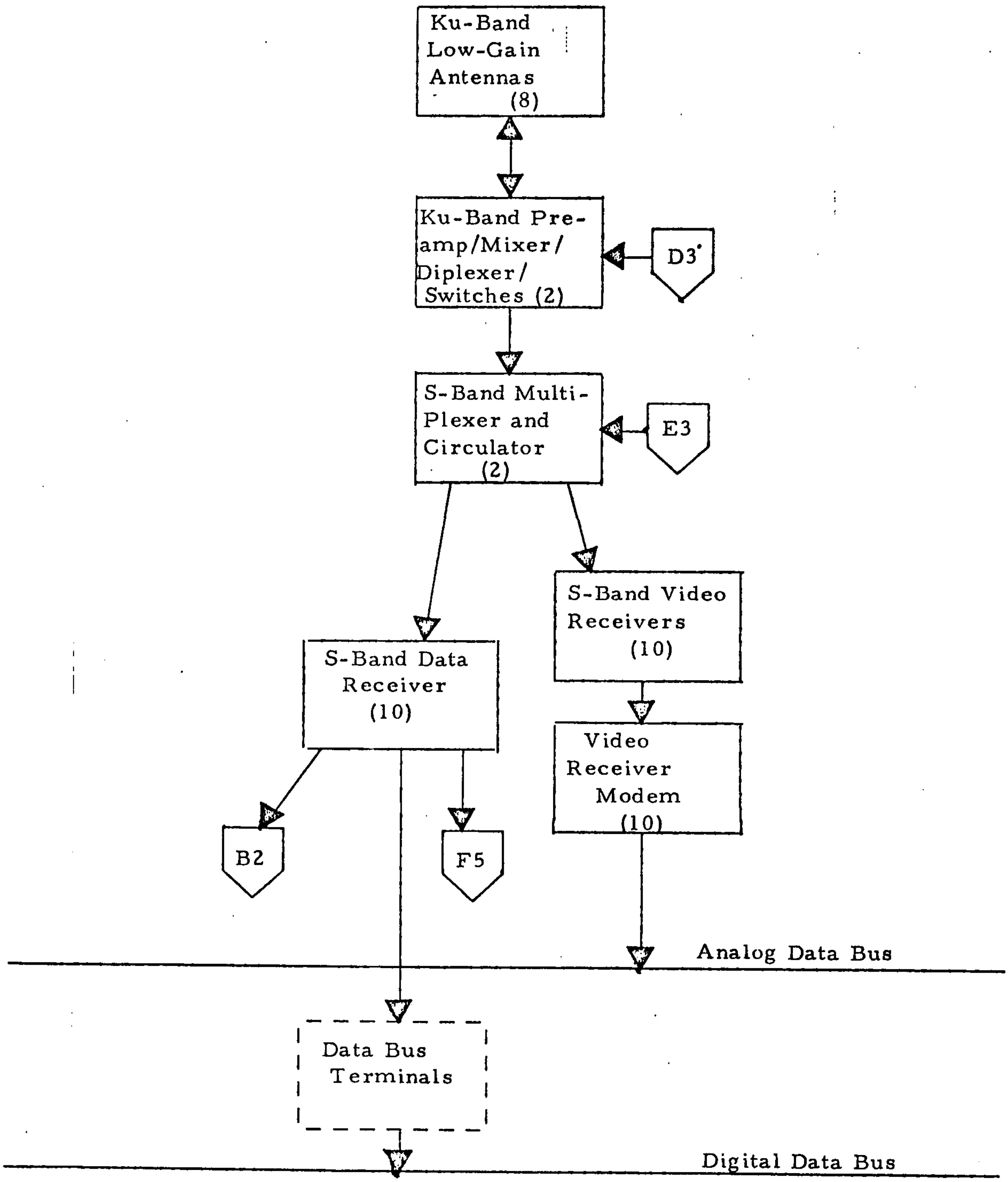

Figure 6-3. LRU Interface Diagram K_u-Band Low-Gain Group

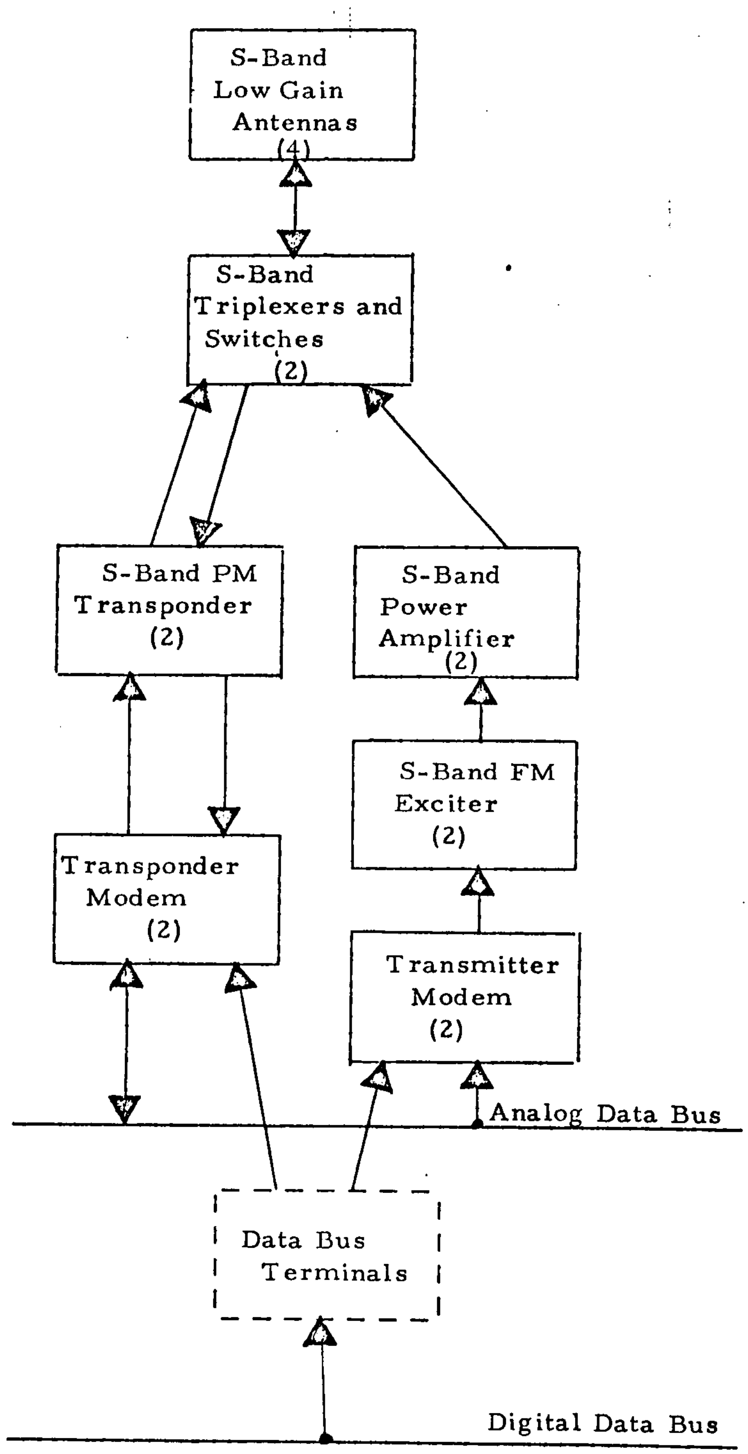

Figure 6-4. LRU Interface Diagram S-Band Low-Gain Group

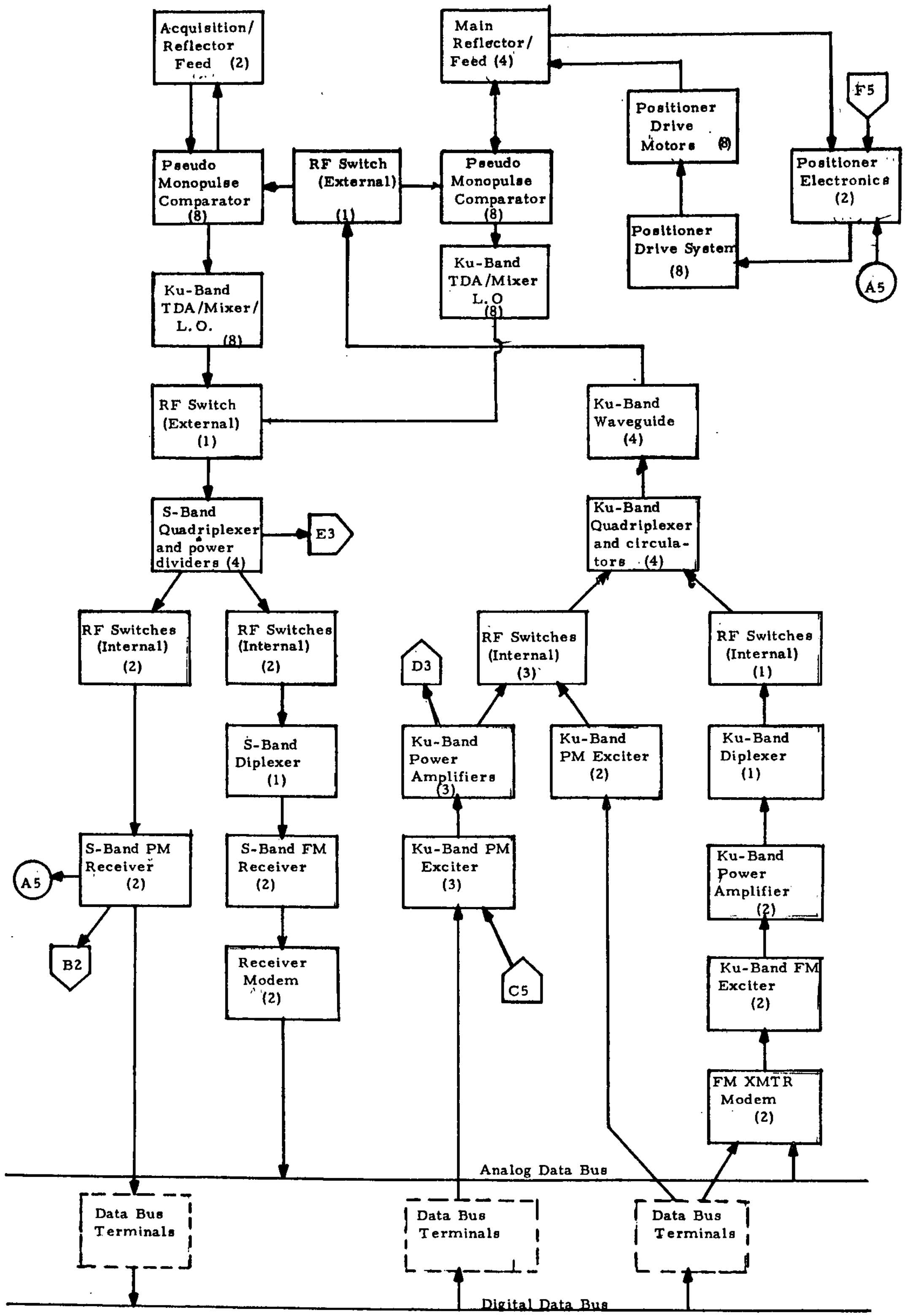

Figure 6-5. LRU Interface Diagram High-Gain Group

The LRUs associated with the high-gain group are shown in Figure 6-5. The fault isolation functions are identified below, with the LRU coverage for each function indicated in parentheses:

- Reception (main reflector/feeds, acquisition reflector/feeds, pseudo monopulse comparators, external RF switches, K_u-band TDA/mixers/ L.O.'s, S-band quadriplexers and power dividers, internal RF switches)

- Transmission (main reflector/feeds, acquisition reflector/feeds, pseudo monopulse comparators, external RF switch, K_u-band waveguide, K_u-band quadriplexers/circulators, internal RF switches)

- S-Band PM Receiver (S-band PM receivers)

- S-Band FM Receiver (S-band diplexer, S-band FM receivers, receiver modems)

- K_u-Band High Power (K_u-band power amplifiers, K_u-band PM exciters)

- K_u-Band Low Power (K_u-band PM exciters)

- FM Transmitter (K_u-band diplexer, K_u-band power amplifiers, K_u-band FM exciters, FM XMTR modems)

6.2.2.4 Periodic Check Function

The periodic check functions identified in this section augment the periodic tests which can be performed by executing the fault isolation function for an assembly group.

Input consists of test point measurements, as well as configuration, status, and limit information from the data base. Output consists of exceptional conditions displayed to crew or ground, and data base updates where exclusive use of the assembly being checked is required.

Information processing consists of obtaining the limit values from the data base, ascertaining that the test point is within these limits, and that the RDAU memory contains the proper values.

6.2.2.5 Calibration Function

The calibration functions required for the Communications Subsystem measure insertion loss in the RF transmission system, and compare with values which have been established in pre-flight and operational evaluations. The RF transmission system is defined as those assemblies which form the signal paths between power amplifiers and exciters, and the antennas of the Space Station.

Input consists of test point measurements associated with RF power and the Calibration Table. Output consists of messages to the crew.

Information processing consists of using RF power output at the power amplifier or exciter side of the RF transmission system, and RF power level at the antenna to compute insertion loss in decibels, the most convenient form for human interface. Logarithmic calculations required for this function will be performed by a library routine written in machine language, and invoked by high-level language programs, using the CALL language element.

6.2.3 INTERFACE REQUIREMENTS

In this section, program to program, program to data base, and program to DMS I/O, assembly interfaces are indicated.

The checkout program to executive interfaces required for the Communication Subsystem are as follows:

- Data base access is gained through the services of the executive in order to control data base changes and to assure the ability to reconfigure memory without impacting program performance.
- Reference to all I/O devices, including those associated with test points, is done through executive services in order to keep clerical details in the programming language to a minimum.
- Programs refer symbolically to test points and rely on the executive to translate the symbols into actual addresses at execution time by using the configuration information maintained in the data base. This assures use of the latest hardware configuration without program modification.

The relationships among the Communications Subsystem checkout functions are shown in Figure 6-6.

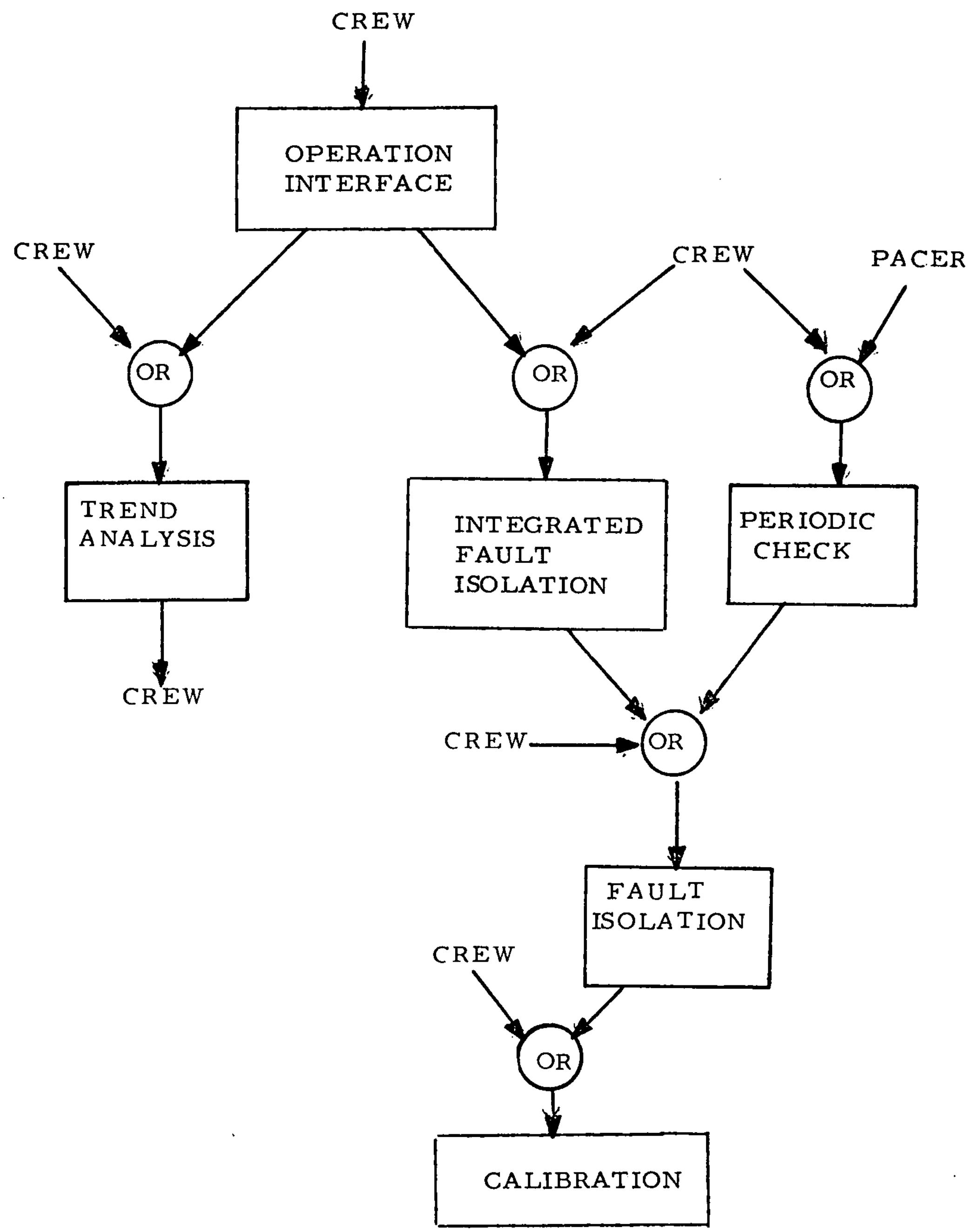

Figure 6-6. Communication Checkout Interface

Section 7

MAINTENANCE

There are two aspects of maintenance which entered into the basic study. Basic maintenance concepts were provided as part of the baseline resulting from the Phase B Space Station study; they are discussed in subsection 7.1 below. Additionally, one of the study tasks was aimed at implementation of an onboard electronics maintenance capability. The results of that task are summarized in subsection 7.2.

7.1 BASELINE MAINTENANCE CONCEPTS

Maintenance concepts defined for Space Station subsystems are intended to facilitate their preservation or restoration to an operational state with a minimum of time, skill, and resources within the planned environment.

7.1.1 GENERAL SPACE STATION MAINTENANCE POLICY

It is a Space Station objective that all elements be designed for a complete replacement maintenance capability unless maintainability design significantly decreases program or system reliability. This objective applies to all subsystems wherever it is reasonable to anticipate that an accident, wearout, or other failure phenomenon will significantly degrade a required function. Estimates of mean-time-between-failure, or accident/failure probability, are not accepted as prima facie evidence to eliminate a particular requirement for maintenance. Should the accident/failure probability be finite, the hardware is to be designed for replacement if it is reasonable and practical to do so.

As a design objective, no routine or planned maintenance shall require use of a pressure suit [either EVA or internal vehicular activity (IVA)] . Where manual operations in a shirtsleeve environment are impractical, remote control means of affecting such maintenance or repairs should be examined. However, EVA (or pressure suit IVA) is allowable where no other solution is reasonable, such as maintenance of external equipment.

Time dependency shall be eliminated as a factor of emergency action insofar as it is reasonable and practical to do so. This includes all program aspects of equipment, operations, and procedures which influence crew actions. When time cannot be eliminated as a factor of emergency action, a crew convenience period of 5 minutes is established as the minimum objective. The purpose of the convenience period is to provide sufficient time for deliberate, prudent, and unhurried action.

7.1.2 ONBOARD MAINTENANCE FACILITY CONCEPTS

In addition to OCS/DMS capabilities, other onboard maintenance support facilities provided on the Space Station include:

- Special tools for mission-survival contingency repairs such as soldering, metal cutting, and drilling, as determined from contingency maintenance analyses, although repairs of this type are not considered routine maintenance methods.

- Protective clothing or protective work areas for planned hazardous maintenance tasks (such as those involving fuels, etc.).

- Automated maintenance procedures and stock location data for both scheduled and unscheduled maintenance and repair activities.

- Real-time ground communication of the detailed procedures, update data, and procedures not carried onboard.

- Onboard cleanroom-type conditions by "glove box" facilities compatible with the level at which this capability is found to be required.

- Maintenance support stockrooms or stowage facilities for spares located in an area that provides for ease of inventory control and ready accessibility to docking locations or transfer passages.

7.1.3 SUBSYSTEM MAINTENANCE CONCEPTS

Space Station subsystems utilize modular concepts in design and emplacement of subsystem elements. Subsystem modularity enhances man's ability to maintain, repair, and replace elements of subsystems in orbit. Providing an effective onboard repair capability is essential in supporting the Space Station's ten-year life span since complete reliance on redundancy to achieve the long life is not feasible. The need for a repair capability, in turn, requires that a malfunction be isolated to at least its in-place remove-and-replace level. The level of fault isolation is keyed to the LRU, which is the smallest modular unit suitable for replacement. The identification of subsystem LRUs is addressed as a separate, but interdependent, part of the Onboard Checkout Study.

Specific subsystem maintenance concepts, of course, depend upon examination of the subsystems. These concepts are discussed in subsequent subparagraphs. General subsystem-related maintenance guidelines that have been established for the Space Station are:

- It is an objective to design so that EVA is not required. However, EVA may be used to accomplish maintenance/repair when no other solution is reasonable.

- Subsystems will be repaired in an in-place configuration at a level that is acceptable for safety and handling, and that can be fault-isolated and reverified by the integrated OCS/DMS. This level of maintenance is referred to as line maintenance and the module replaced to effect the repair is the LRU.

- A limited bench-level fault isolation capability will be provided on the Space Station, but is only intended for contingency (recovery of lost essential functions beyond the planned spares level) or for development purposes. Limited bench-level support is also provided in the form of standard measurement capabilities which are used primarily to reduce the amount of special test equipment required.

- Subsystem elements, wherever practical, will be replaced only at failure or wearout. Limited-life items that fail with time in a manner that can be defined by analysis and test will be allowed to operate until they have reached a predetermined level of deteriorated performance prior to replacement. Where subsystem downtimes for replacement or repair exceed desirable downtimes, the subsystem will include backup (redundant) operational capability to permit maintenance. Expendable items (filters, etc.) will be replaced on a preplanned, scheduled basis.

7.2 ONBOARD ELECTRONIC MAINTENANCE (STUDY TASK 3)

The objective of this task was to generate recommendations of supporting research and technology activities leading to implementation of a manned electronics maintenance facility for the Space Station. Early in the task it became apparent that attention could not be confined to a central maintenance facility; it was necessary to refocus the task to address implementation of an on-board maintenance capability encompassing in-place as well as centralized maintenance activities. The critical questions are the following:

- What is the optimum allocation of onboard maintenance functions between in-place and centralized maintenance facility locations?

- What is the optimum level of onboard repair (i.e., to line-replaceable unit, subassembly or module, piece part, or circuit element)?

7.2.1 MAINTENANCE CYCLE

In order to place the task in the proper context, a generalized Space Station electronic maintenance cycle is depicted in Figure 7-1.

A convenient place to enter the cycle is with detection of a fault ("In-Place Maintenance" block). The fault is isolated to a Line Replaceable Unit (LRU). The affected subsystem is restored to full capability by replacing the failed LRU with an operable one from spares storage.

The failed LRU is taken to a maintenance facility (assumed for the moment to have a fixed location in the Space Station) where it is first classified as repairable or non-repairable. Classifications will likely be predetermined, and a listing should be retained in the Data Management Subsystem. If the LRU is non-repairable, it is placed in segregated storage. If the LRU is repairable on board, the fault is further isolated to the failed Shop Replaceable Assembly (SRA). The LRU is then repaired by replacing the failed SRA with one from spares storage. The repaired LRU is then calibrated (if necessary), and its operation verified before it is placed in spares storage.

Logistics requirements (replacement LRUs and SRAs needed) are transmitted to ground-based logistics support functions by RF communications and/or Space Shuttle. Failed units are taken away from and replacement units are delivered to the Space Station by the Space Shuttle.

7.2.2 SUMMARY OF RESULTS

The study confirmed and emphasized the necessity of onboard maintenance for any manned mission of any complexity and duration measured in months (up to 10 years for Space Station). Formulation of recommendations for implementing such a capability required consideration of other topics first, and achievement of certain interim results. The principal conclusions of this study task are summarized below. The analyses leading to them are explained in the Task 3 Final Report.

- Prior studies and developments of in-space maintenance have emphasized justification of first-level (in-place) maintenance, fasteners, and tools for space application and human factors criteria. Much less attention has been devoted to test equipment, maintenance training, or definition of shop level maintenance requirements.

2

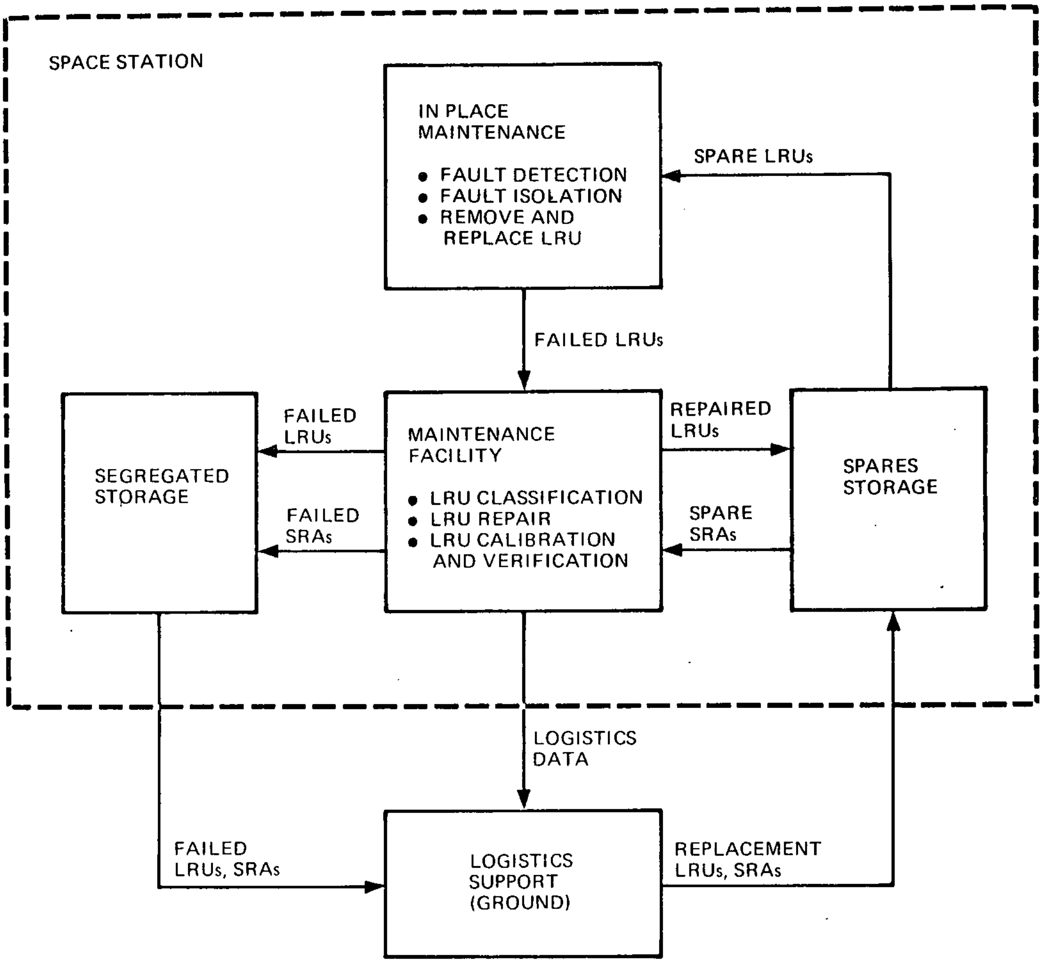

Figure 7-1. Space Station Maintenance Cycle

- The baseline subsystem descriptions, checkout requirements analysis, and software requirements analysis indicate that approximately 60 percent of all faults (over a long period) can be isolated to the failed LRU automatically under software control, without crew intervention. In an additional 27 percent of failure cases, fault isolation to one LRU can be achieved by the crew using the onboard Data Management System as a tool. In the remaining failure cases, additional fault isolation capabilities are needed. This is a good result for a "first iteration" and can probably be improved considerably with a modest effort to modify stimulus and measurement provisions.

- Crew involvement in scheduled and unscheduled maintenance (including participation in fault isolation) is estimated to average 7.2 manhours per week over the total mission time. This estimate is most sensitive to equipment reliability and levels at which onboard repair is performed. It is affected little by the efficiency of automated fault isolation under control of the Data Management Subsystem (DMS).

- The recommended approach to maintenance in the baseline Space Station is in-place removal and replacement of LRUs, without attempts to repair LRUs onboard, if the resupply interval is less than nine months. Onboard spares should be LRUs.

- For long resupply intervals or non-resupplied missions (as in a manned interplanetary mission), in-place maintenance should be by removal and replacement of LRUs. Repair of LRUs should be by removal and replacement of Shop Replaceable Assemblies (SRAs). Onboard spares should be SRAs.

- The Earth-orbital Space Station should include provision for development of onboard maintenance capability and techniques applicable to long duration non-resupplied missions and/or the larger, more complex Space Base.

- The baseline subsystem descriptions are at such a level of detail that precise specification of onboard tools and test equipment is neither feasible nor desirable. Anticipated needs identified qualitatively in the study are: (1) a portable test module to supplement software fault isolation as well as to assist mechanical adjustments and calibrator, (2) hand tools for removal and replacement of electronic assemblies, (3) devices for transporting and positioning spare assemblies, and (4) a central maintenance/repair bench.

- Several tasks have been identified and recommended for future performance, as part of a system study/design program or as separate supporting research and technology tasks. The principal ones deal with (1) development of a portable test assembly, (2) development of a repair/test bench with special provisions for small parts retention and for debris collection, (3) design for accessibility of test points and subassemblies, and (4) devices for transporting equipment within the Space Station.

The foregoing conclusions apply to the Modular Space Station as well as the 33-foot diameter, four-deck configuration.

The results of the study rest upon several assumptions and estimates, derived wherever possible from related experience. The results are not sensitive to small variations of the assumed or estimated values, except for equipment failure rates, which are most influential. Furthermore, it has not been practicable to pursue all trade analyses to include all relevant factors. Nevertheless, the study has generated valid insights into Space Station onboard maintenance and useful visibility of the path to implementation of that capability.