SD-TR-81-87

AD A106063

LEVEL III

Autonomous Spacecraft Project

Assessment of Autonomous Options for the DSCS III Satellite System

Volume II: Description and Autonomy Assessment of Current DSCS III Design

Approved for Public Release; Distribution Unlimited

6 August 1981

Interim Report for Period
1 November 1980 through 6 August 1981

Prepared for
**U.S. Air Force Systems Command
Headquarters, Space Division**

Through an agreement with

National Aeronautics and Space Administration

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

81 10 22

This technical report has been reviewed and is approved for publication.

RALPH R. GAJEWSKI, Major, USAF
Chief, Advanced Materials
  and Structures

JOSEPH J. COX, JR., Lt Col, USAF
Chief, Advanced Technology Division

BURTON H. HOLADAY, Colonel, USAF
Director of Space Systems Planning
Deputy for Technology

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (19) TR-81-84-VOL-2	2. GOVT ACCESSION NO. AD-A106 333	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) ASSESSMENT OF AUTONOMOUS OPTIONS FOR THE DSCS III SATELLITE SYSTEM. VOLUME II. DESCRIPTION AND AUTONOMY ASSESSMENT OF CURRENT DSCS III DESIGN		5. TYPE OF REPORT & PERIOD COVERED Interim (1 Nov 80-6 Aug 81)
		6. PERFORMING ORG. REPORT NUMBER (14) JPL-7030-2-VOL-2
7. AUTHOR(s) (10) Donna L. S. Pivirotto Michael Marcucci		8. CONTRACT OR GRANT NUMBER(s) (15) NAS7-100 JPL Task Plan No. 80-1487
9. PERFORMING ORGANIZATION NAME AND ADDRESS Jet Propulsion Laboratory California Institute of Technology 4800 Oak Grove Dr., Pasadena, CA 91109		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (12) 150
11. CONTROLLING OFFICE NAME AND ADDRESS HQ Space Division/YLXT Box 92960 Worldway Postal Center Los Angeles CA 90009		12. REPORT DATE (11) 6 August 1981
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office) (9) Interim rept. 1 Nov 80 - 6 Aug 81,		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Autonomy, DSCS III, autonomous spacecraft, autonomous satellite, fault protection, fault tolerance, on-board computing, autonomous satellite control, autonomous stationkeeping, autonomous health and welfare, redundancy management, autonomous navigation.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This volume presents the results of an assessment of the current capabilities of the next generation Defense Systems Communication Satellite (DSCS III) to operate without ground intervention. The DSCS III Block A design is described functionally and the level of autonomy of each function is evaluated. DSCS III is a complex spacecraft which requires frequent ground interaction to meet mission requirements. It incorporates an on-board computer primarily used for real-time attitude control. By the use of hard wired automatic functions and—

DD FORM 1473   EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73

BLOCK 20, ABSTRACT (continued):

the on-board computer, the satellites routine, on-station service functions (power, attitude control, thermal control, etc.) are already quite autonomous. Health and welfare maintenance and fault protection activities are nearly all ground controlled. Stationkeeping is a totally ground-performed function. A considerable increase in the overall autonomy level of the spacecraft is required for it to operate without ground intervention for a six-day to six-month period (an autonomy goal).

ASSESSMENT OF AUTONOMOUS OPTIONS

FOR THE DSCS III SATELLITE SYSTEM

VOLUME II: Description and Autonomy Assessment of Current DSCS III Design

Prepared by
Donna L. S. Pivirotto, Assessment Team Leader
and
Michael Marcucci, Spacecraft Systems Engineer
Autonomous Spacecraft Project

6 August 1981

Approved: Approved:

Glenn E. Cunningham   David D. Evans
Project Engineer   Manager
Autonomous Spacecraft Project   Autonomous Spacecraft Project

PREFACE

   This document is the second of three volumes which make up the
assessment of autonomy for the DSCS III satellite system. Volume I is an
overview and summary of the assessment; review of it is recommended prior to
reading subsequent Volumes. Volume II (this volume) is a functional
description of the existing DSCS III satellite system and an assessment of its
current autonomy. Volume III presents options, at the functional level, for
increasing the autonomy of DSCS III.

   The DSCS III assessment was performed by the Autonomous Spacecraft
Project Team. Authorship of specific sections of the report by individual
contributors is acknowledged in this volume and in Volume III. Unless
otherwise noted, all contributors are JPL personnel.

CONTENTS

3

Figures

Tables

SECTION 1

INTRODUCTION

1.1 PURPOSE, FORMAT AND USE OF THIS VOLUME

1.1.1 Purpose

The purpose of this volume is to describe the existing DSCS III satellite system in a functional manner, and to assess its current level of autonomy. This volume addresses only the current (Block A) design for the first DSCS III, and does not address any programmed changes in future Blocks of DSCS III.

1.1.2 Format and Use

The format of this volume is designed to describe each function in terms of the "sensing", "direction" and "action" functions as explained in Section 6.1.2 of Volume I. While this format creates a lack of "flow" in the text, it has been selected for easy cross-reference with Volume III, which describes options for making the DSCS III more autonomous. Volume I should be read as background for Volumes II and III.

The formats of Volumes II and III are identical, in that paragraphs devoted to each function have the same numbers in Volumes II and III. Therefore, the user can cross-reference between the current way the function is performed (Volume II), and the options for performing the function more autonomously (Volume III) by referring to the same paragraph numbers.

1.2 ASSESSMENT FUNCTIONAL CLASSIFICATION

The DSCS III functions were classified in three ways: by level of autonomy, by importance, and by difficulty of implementation. Two of these classifications (level and importance) are used in this volume, and are described in the following paragraphs.

1.2.1 Levels of Autonomy

The levels specified in the Goals Document (Reference 1) were applied to both the existing DSCS III and the autonomy options. These levels (from 0 to 10) are reproduced in Appendix A.

1.2.2 Importance

The primary requirement which drives the DSCS III autonomy is for the spacecraft to operate with reduced ground intervention. As stated in the Goals Document:

9

The autonomous spacecraft shall be capable of successfully performing the mission function for an extended period of time without ground support at a specified level of conflict. Specifically:

(1) Autonomous spacecraft shall operate without performance degradation for up to 60 days from the last initialization update.

(2) Autonomous spacecraft shall operate for up to 6 months from the last initialization update. They shall do so within acceptable performance degradation limits for mission-prioritized functions as defined by each mission.

These requirements were used as the basis for prioritization of autonomous operation as follows:

(1) Category I: Functions which must be performed autonomously for the spacecraft to meet the 60-day/6-month requirement.

(2) Category II: Functions which must be performed autonomously for lifetime protection (battery conditioning, etc.) or which, if performed autonomously, would increase the operability or operational flexibility of the spacecraft.

(3) Category III: Functions not requiring autonomy.

1.3 OVERVIEW DESCRIPTION OF EXISTING DSCS-III DESIGN[*]

An overview is given in this section to describe the DSCS III configuration which was assessed in this study. Mission and system requirements on the existing DSCS III are called out in Sections 1.4 and 1.5. These requirements will also apply to the Autonomous DSCS III satellite. Requirements on each function which are applicable to the existing DSCS III are noted in each Section at the beginning of the function's description.

1.3.1 Mission

The mission of the DSCS III satellite is to provide enhanced military communication capability during the 1980's and 1990's period. Several DSCS III satellites, each with a 10 year mission life, operating in geostationary orbit, provide long term, worldwide, protected services to ground, ship and airborne forces. Users of the system range from airborne terminals with 33 in. diameter antennas to fixed installations with 60 foot diameter antennas. Mobile terminals supporting ground and naval operations communicate with each other and the command chain through the satellite. Communication resources are provided through six independent satellite channels for user grouping according to their operational needs or geographic situation; and also receiver sensitivity or transmitter power is allocated among them for maximum efficiency. The DSCS III satellite also provides an on-board Single Channel Transponder to supplement currently dedicated AFSATCOM spacecraft for Command and Control Communication from the National Command Authorities and Commanders to the nuclear and support forces.

1.3.2 Communications Subsystem

The primary purpose of the Communications Payload of the DSCS III satellite is to provide a flexible, wide-band transmission medium so that satellite unique services are provided to approved users under varying degrees of system stress. The user terminals are distributed throughout the world and are of varying sizes. The operational concept is to maximize communication throughout by distributing the satellite Effective Isotropic Radiated Power (EIRP) optimally according to terminal location, size and capacity requirements. The EIRP distribution is implemented by reconfiguring the transmit Multi-Beam Antennas (MBA's) to provide earth coverage or selective coverage and/or utilizing the Earth Coverage Horn (ECH) antenna, Gimbaled Dish Antenna (GDA) or MBA for transponder channels 1, 2, 3, and 4. Uplink antenna gain and jammer discrimination is implemented by using ECH or MBA and configuring the MBA for earth coverage, selected coverage or jammer nulling. Each transponder channel gain may also be set by ground command.

---

[*]By S. J. Kerridge

1.3.3   Single Channel Transponder

The AFSATCOM Single Channel Transponder (SCT) is a dual frequency band, frequency conversion, digital demodulation/remodulation, communications transponder with integral command reception/execution capability. The primary function of the SCT is secure and reliable dissemination of the Emergency Action Message (EAM) and Single Integrated Operational Plan (SIOP) Communications from Worldwide Command Post ground stations and aircraft to the force elements.

1.3.4   Operations

The primary operational monitoring and control of the Communications Payload is via Superhigh Frequency (SHF)-band from an Engineering Development Model of the Satellite Configuration Control Element (EDM-SCCE) and the collocated SHF Ground Terminal; the primary operational monitoring and control of satellite support subsystems is via S-Band from the Air Force Satellite Control Facility (AFSCF).

Various secondary operational modes of control are possible in the event of temporary unavailability of the Satellite Control Facility -Remote Tracking Station (SCF-RTS) Network, temporary outages at the EDM-SCCE's and/or the SHF Ground Terminals, or permanent Telemetry, Tracking and Command Subsystem (TT&C) failures.

Backup command and control capability for the Communication Payload will be provided by the SCF based on command sequences generated by the Communications Configuration Program (CCP) and transferred to the SCF via secure teletype links from the EDM-SCCE in the event of SHF Ground Terminal temporary outages for transmission to the satellite by S-band. The backup S-band capability will also be used in the event of permanent failure to the SHF TT&C. Operational discipline will be maintained to avoid conflicting commands.

Backup command and control capability of the satellite support subsystems will be provided by the EDM-SCCE and the associated, collocated SHF Ground Terminals based on command or command sequences generated by the SCT and transferred by secure telephone links to the EDM-SCCE. This backup capability will be used primarily to react to support subsystem anomalies detected at the EDM-SCCE for fast reaction correction capability or in the event of permanent failures to the satellite S-band TT&C system.

Figures 1-1 and 1-2 show the major elements involved in DSCS III Communications Subsystems operation. Their functions are as follows:

(1)   The Defense Communication Agency Operations Center (DCAOC) provides the traffic coordination between the users and the Defense Communications Engineering Center (DCEC).

(2)   The DCEC provides the resource allocation function between the DCAOC and the EDM-SCCE to convert the user traffic requirements into a valid set of DSCS III satellite Communication Payload configuration requirements.

Figure 1-1. Operational Overview
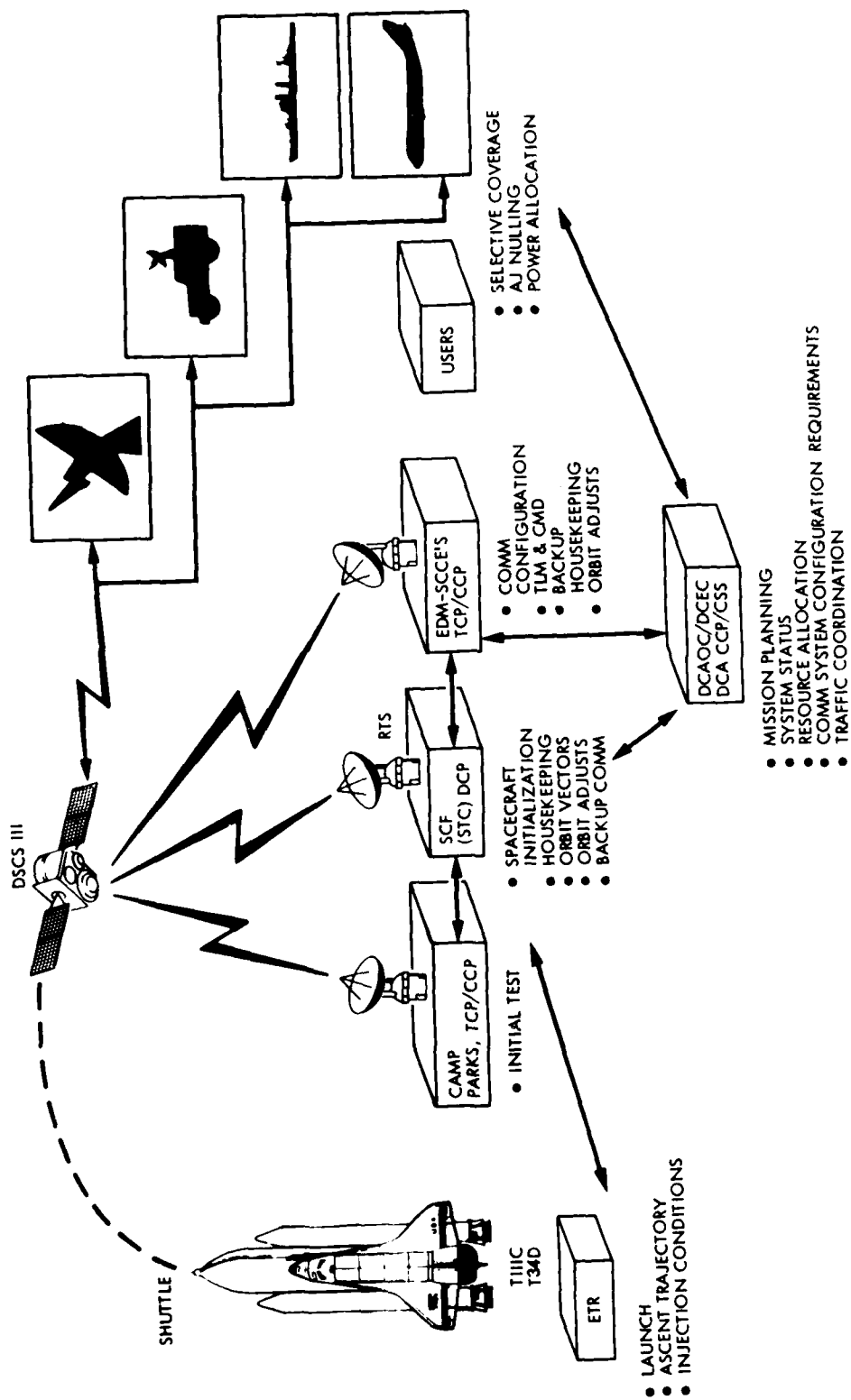
Figure 1-2. System Integration Operations

14

(3) The EDM-SCCE provides the processing function between the DCEC and the DCSC III Ground terminals to convert satellite communication payload configuration requirements into command sequences.

(4) The DSCS Earth Terminal provides continuous SHF telemetry and command links between the EDM-SCCE and the DSCS III Satellite.

(5) The satellite, when deployed in synchronous equatorial orbit provides relaying of communications between users through the Communication Payload which consists of a combination of Multibeam Antennas and Earth Coverage Antennas interconnected to six SHF variable gain transponders.

(6) The Satellite Control Facility (SCF) consisting of the Satellite Test Center (STC) and various Remote Tracking Stations (RTS's) provides the command and control of the DSCS subsystems and performs orbit determination.

Three major software elements are defined for command and control of the satellite, the CCP, the Telemetry and Command Program (TCP), and the DSCS III Control Programs (DCP) which are resident at locations shown in Figure 1-2. In addition, Communications Simulator Software is available for planning and evaluation of Communication configuration and performance in meeting user requirements.

1.4   DSCS III MISSION REQUIREMENTS

A fully autonomous DSCS III satellite must meet the same requirements as the current DSCS III satellite, but must do so, allowing for acceptable degradation, without ground intervention for up to 6 months. Current DSCS III requirements are included here for the purpose of defining requirements on the autonomous DSCS III. The DSCS III satellite will continuously provide secure communications capability between any two points in a designated service area.

The service area contains all points within line of sight of the satellite and where the elevation angle to the satellite is 7.5 degrees or greater. The center of a service area is nominally a specified fixed point on the earth's equator.

The communication capability will be maintained in a defined nuclear environment and in an electronic jamming environment.

The expected satellite operational life will be ten years.

15

The satellite will relay signals in the SHF region. The signals will contain telephone, data, wide-band imagery, and secure digital voice signals. The signals to be relayed will use Frequency Modulation (FM); Bi-Phase Shift Keying (BPSK); Quadra-Phase Shift Keying (OPSK); Staggered Quadra-Phase Shift Keying (SOPSK); and frequency-hopping, Pseudo-Random Noise (PRN), spread-spectrum modulation. Access techniques will include Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA) and Spread Spectrum Multiple Access (SSMA).

1.5   DSCS III SYSTEM REQUIREMENTS

        This section provides an overview of requirements on the
existing DSCS III System. More detailed requirements which are placed by the
payload on the spacecraft are outlined in Appendix B.

1.5.1   Communications Payload

        To meet the sensivity requirements of all users, the spacecraft
communications payload will provide steerable, adjustable-width antenna beams
that produce the minimum EIRP's over the defined beam widths, as shown in
Table 1-1.

Table 1-1. Downlink EIRP Requirements

Channel	TWTA Output Power (dBw)	Effective Isotropic Radiated Power (dBw)			
		MBA Narrow[1] Coverage	MBA Earth[3] Coverage	Earth Coverage Horn (4)	Gimballed Dish Antenna (2)
1	16	40	29	Not used	44.0
2	16	40	29	Not used	44.0
3	10	34	23	25	Not used
4	10	34	23	25	37.5
5	10	Not used	Not used	25	Not used
6	10	Not used	Not used	25	Not used

(1)   Narrow coverage refers to providing the EIRP over a narrow coverage
      beam width of +0.71°.
(2)   The GDA will provide the EIRP over a beam width of +1.8°.
(3)   Earth coverage for the MBA refers to providing the EIRP over a beam width
      of +8.75°.
(4)   Earth coverage for the Earth Coverage Horn refers to providing the EIRP
      over a beam width of +8.8°.

17

To meet the satellite receiver sensitivity requirements
necessary to interface with any ground transmitter, the
ratios of receive antenna gain to system noise temperature (G/T) will be as
shown in Table 1-2.

Table 1-2. G/T Requirements

CHANNEL	1, 2, 3, 4			5, 6
	MBA		HORN	HORN
	NC	EC	EC	EC
ANTENNA				
G/T (dB/K)	-1 to 10.1	-15.1	-13.0	-12.8

NOTE: EC = Earth Coverage

       NC = Narrow Coverage

Performance defined for the
same beam widths as for EIRP.

The given values of EIRP and G/T include any and all
contributors; specifically pointing, attitude control, and stationkeeping.

1.5.2   Orbit

The DSCS III satellite will operate from designated locations in
geostationary orbit while maintaining station and attitude.

1.5.3   Launch

The first satellite will be launched from the Eastern Test Range
(ETR) on a Titan IIIC as a dual launch with a DSCS II satellite. The launch
time will be chosen such that the initial inclination decays toward zero
degrees.

Dry weight at launch ≤860 kg

Wet weight at launch ≤1137 kg.

1.5.4   Propulsion

Sufficient propulsion capability should be provided for:

(1)   correction of launch vehicle injection errors.

(2)   attitude control for the planned mission duration of 10 years.

(3)   adjusting inclination from 2.5 degrees to 0.5 degrees before reaching initial orbital station longitude.

(4)   achieving the initial orbital test station of 105°W or 115°W within 40 days of injection.

(5)   repositioning from the initial orbital test station to initial operational station at any longitude.

(6)   maintaining the satellite at achieved station to ± 0.1 degree in longitude.

(7)   maintaining the inclination within 0.1 degree.

The budget will be at least 600 ft/sec maneuvering capability either for N-S stationkeeping or relocation to be used at the discretion of the operators.

1.5.5   *S/C Control and Monitoring*

The satellite shall be capable of being commanded both at SHF and S-Band to allow housekeeping, orbit maintenance and Communication Payload subsystem reconfiguration by the SCF and DSCS ground stations.

The satellite shall be capable of sending telemetry at both SHF and S-Band to allow routine housekeeping monitoring, to verify command reception and execution, and to monitor operations.

The telemetry, tracking, and command operations shall be capable of being conducted simultaneously with the payload communication operations, without degradation or interference with either operation.

1.5.6   Navigation

Ephemeris information will be furnished to sufficient accuracy to meet user needs for pointing, range, and range rate information. Information will also be furnished to sufficient accuracy for appropriate stationkeeping maneuvers. Stationkeeping must be sufficiently accurate to not cause the EIRP and G/T limitations to be violated.

1.5.7   Power

          The satellite shall provide power throughout the mission, including eclipse periods. With total battery charge depletion the satellite shall continue to provide full communications during sunlight, following the post-eclipse recovery period.

1.5.8   Attitude Control

          Attitude control shall be autonomous with a ground override command capability.

          Attitude control accuracy will be sufficient not to cause the payload EIRP and G/T limitations to be violated.

1.5.9   Reliability

          The satellite shall have a design life in orbit of at least 10 years, by maintaining performance despite all identifiable wearout factors and depletion of expandables.

          A requirement for survival shall be: (a) at least 50% of the communications channels shall be operative, with at least one being a 40W channel which must be able to transmit through an MBA as well as receive through an MBA. Sufficient Earth-coverage transmit/receive horns shall be operative to provide the specified minimum channels; (b) either the S-Band or SHF command capability shall be operative; (c) minimum essential telemetry with continuous power to maintain communications service shall be operative; (d) attitude and pointing control shall be sufficient to support (a), (b), and (c).

          Single point failures are to be avoided in the design. Recovery from a failure shall not be contingent upon continuous monitoring of the satellite telemetry system.

1.5.10   Timing

          The space segment will furnish a network timing signal to the appropriate users. Timing standard accuracy will be maintained to a degree sufficient to satisfy the needs of all users at all times.

1.5.11   Ground Antenna Pointing

          The satellite will furnish a radio frequency (RF) beacon signal that certain users can utilize to automatically keep their antennas pointing at the satellite.

1.5.12   Thermal Control

        The satellite shall be thermally controlled so that all
components are maintained at or above their minimum operating temperature
under normal conditions. Under abnormal conditions, when possible, the
satellite components shall be maintained at or above their survival
temperatures.

1.6   AUTONOMY ASSESSMENT SUMMARY OF THE EXISTING DSCS III SATELLITE

        The existing DSCS III has the following characteristics relevant
to autonomy (Refer to Appendix A for level definitions):

    (1)   It is a complex spacecraft which requires frequent ground
          interaction to meet the mission requirements,

    (2)   The routine, on-station service functions (power, attitude
          control, thermal control, etc) are already quite autonomous
          (up to level 5) except for stationkeeping, which is a level
          zero.

    (3)   The resource management and integrity maintenance functions
          almost all require ground intervention. They range from
          level 0 to level 5, but are predominantly at level 2.

    (4)   It appears that an overall spacecraft autonomy level of 5
          is required to meet the 60 day/6 month undirected
          performance requirement.

        Figure 1-3 summarizes the autonomy levels of the existing DSCS
III functions. As before, the functions are classified as Services,
Resources, and Integrity, and by Category (I, II, III). The length of each
bar in the figure represents the number of functions at that level of
autonomy. (Refer to Appendix A for autonomy level definitions.) Category I,
II, and III functions are designated separately.

        Figure 1-3 illustrates that the Services functions tend to
cluster around Level 3, the Resources functions around Level 1 or 2, and the
integrity functions around Level 2. Services functions, except for
stationkeeping, are at higher levels because:

    (1)   The power and thermal control functions have a good deal of
          hard-wired, autonomous functions, and

    (2)   The attitude control function has considerable autonomy
          implemented in both software and hardware, whereas

    (3)   Resources and Integrity functions are almost entirely
          ground directed, and

    (4)   Stationkeeping is entirely ground directed.

        Figure 1-3 also illustrates that the majority of functions are
Category I, that is, they must be autonomous for the spacecraft to operate for
6 months without ground intervention. In order to meet the requirements, the
majority of Category I functions will need to be raised to about Level 5.
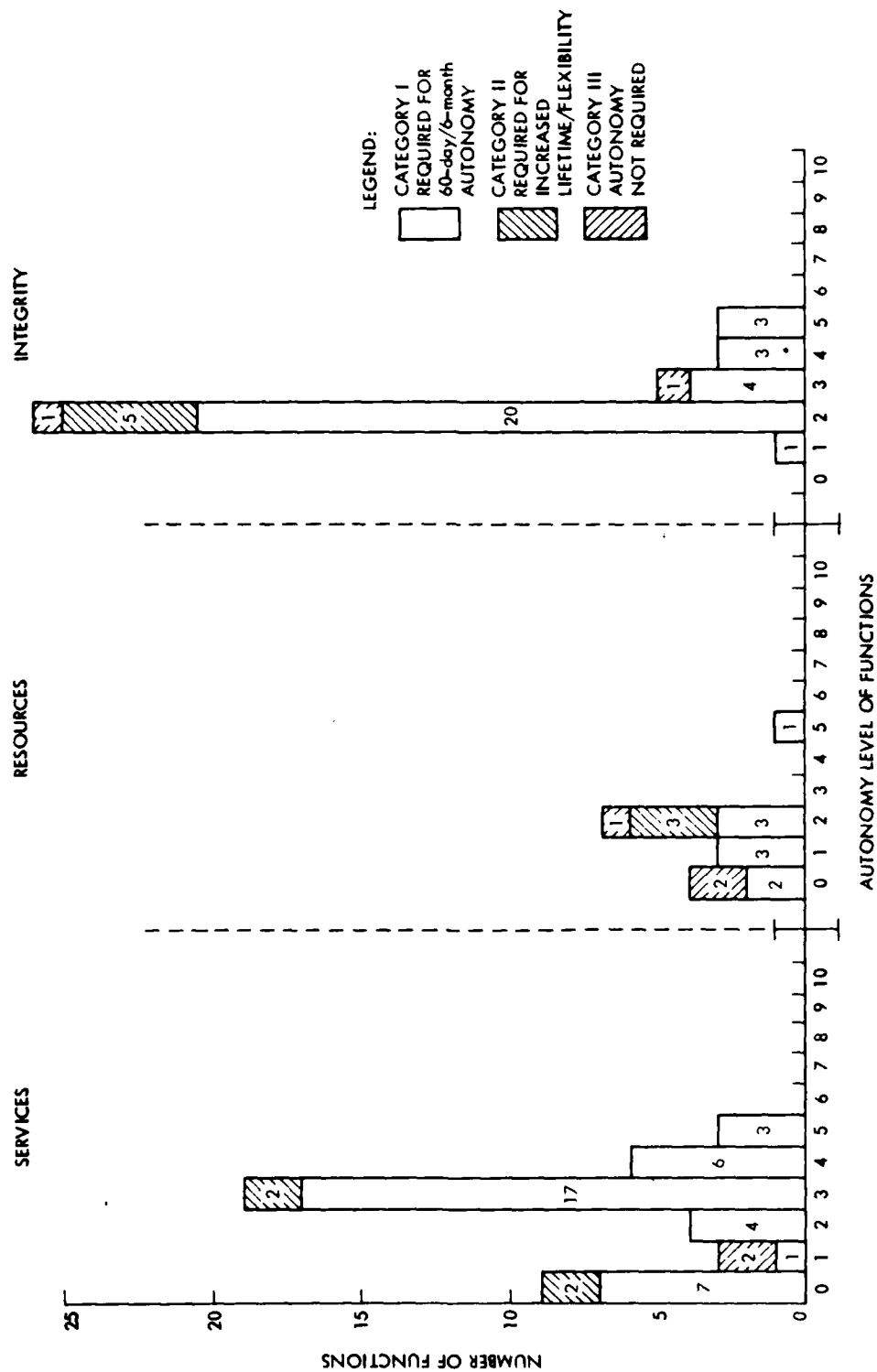
Figure 1-3. Summary of DSCS III Functions' Autonomy Levels and Need for Autonomy

Table 1-3 lists the functions which were used to make up Figure 1-3, by autonomy level and category. The paragraph numbers in Table 1-3 refer to both Volumes II and III. Later sections in Volume II contain a detailed description of these functions. Volume III gives details on options for increasing the autonomy of each function.

Table 1-3. List of Current DSCS III Functions by Autonomy Level and Category:
(a) Services, (b) Resources, (c) Integrity

(a) SERVICES

LEVEL	CATEGORY I		CATEGORY II		CATEGORY III	
0	2.7.2.1	PROCESS LOCATION MEASUREMENTS (NAV)	2.7.1.2	SPACE SEGMENT TRACKING (NAV)		
	2.7.2.2	DETERMINE S/C LOCATION (NAV)	2.7.2.6	VERIFY NAVIGATION PERFORMANCE (NAV)		
	2.7.2.3	PROPAGATE EPHEMERIS (NAV)				
	2.7.2.4	PLAN MANEUVERS (NAV)				
	2.7.2.5	GENERATE MANEUVER COMMANDS (NAV)				
	2.7.4.1.1	SELECT TANKS (NAV)				
	2.7.4.1.2	SELECT THRUSTERS (NAV)				
1	2.3.4.2	CONTROL CATALYST BED HEATERS (TCS)				
2	2.1.3.1	SENSE DISTRIBUTION RELAY STATUS (EPDS)				
	2.1.3.2	DIRECT/CONTROL POWER DISTRIBUTION (EPDS)				
	2.1.3.3	OPEN/CLOSE RELAYS (EPDS)				
	2.7.4.1.4	DIRECT/CONTROL MANEUVERS (ACS)				
3	2.2.1.2	ACQUIRE EARTH (ACS)	2.4.1.3	SEND TELEMETRY (TT & C)	2.6.1.1	REORIENT GDA (ACS)
	2.2.1.3	CONFIGURE S/C (ACS)	2.4.2.4	RECEIVE COMMANDS (TT & C)	2.6.1.2	RECONFIGURE MBA (ACS)
	2.2.1.4	REACQUIRE REFERENCES (ACS)				
	2.2.2.1	DETERMINE ATTITUDE (ACS)				
	2.3.2.1	ENABLE SURVIVAL HEATERS (TCS)				
	2.3.2.2	ENABLE CONTROL HEATERS (TCS)				
	2.3.3.1	ENABLE SURVIVAL THERMOSTATS (TCS)				
	2.3.3.2	ENABLE OTHER HEATERS (TCS)				
	2.3.4.1	CONTROL ELECTRIC COMP. HEATERS (TCS)				
	2.3.4.3	CONTROL SURVIVAL HEATERS (TCS)				
	2.4.1.1	ACQUIRE INFORMATION (TT & C)				
	2.4.1.2	GENERATE TELEMETRY (TT & C)				
	2.4.2.5	PROCESS COMMANDS (TT & C)				
	2.4.2.6	DISTRIBUTE INSTRUCTIONS (TT & C)				
	2.7.4.1.3	WARM UP CATALYST BED (ACS)				
	2.7.4.1.5	FIRE THRUSTERS (ACS)				
	2.7.4.2	MAINTAIN ATTITUDE IN MANEUVERS (ACS)				

(continued)

25

Table 1-3 (continued)

LEVEL	CATEGORY		
	I	II	III
4	2.1.1.1 ORIENT SOLAR ARRAY (ACS)		
	2.1.1.2 MAINTAIN SA ORIENTATION (ACS)		
	2.2.1.1 ACQUIRE SUN (ACS)		
	2.2.2.2 DIRECT/CONTROL ATTITUDE (ACS)		
	2.2.2.3 CONTROL ATTITUDE (ACS)		
	2.5.1 PROVIDE TIMING (ACS)		
5	2.1.2.1 REGULATE MAIN BUS VOLTAGE (EPDS)		
	2.1.2.2 PROVIDE AUXILIARY VOLTAGES (EPDS)		
	2.1.2.3 FIRE ELECTRO-EXPLOSIVE DEVICES (EPDS)		

(b) RESOURCES

LEVEL	CATEGORY		
	I	II	III
0	3.1.2.2 ASSESS POWER STATE (EPDS)		3.1.1.2 SOLAR ARRAY OPERATING POINT (EPDS)
	3.1.3.2 ASSESS BATTERY DEPLETION (EPDS)		3.2.1.3 REDUCE N/S STATIONKEEPING (NAV)
1	3.1.2.1 SENSE ON-BOARD PARAMETERS (EPDS)		
	3.1.3.1 SENSE BATTERY PARAMETERS (EPDS)		
	3.2.2.1 DETERMINE C OF M LOCATION (PROP)		
2	3.1.2.3 EXECUTE RELAY COMMANDS (EPDS)	3.2.1.1 COMPUTE HYDRAZINE MASS (PROP)	3.2.3.2 MANAGE THRUSTER STEADY-STATE LIFE (PROP)
	3.1.3.3 EXECUTE RELAY COMMANDS (EPDS)	3.2.1.2 DIRECT HYDRAZINE MNGMT. (PROP)	
	3.2.2.2 SELECT TANKS (ACS/PROP)	3.2.3.1 MANAGE THRUSTER PULSE LIFE (PROP)	
3			
4			
5	3.1.1.1.1 MANAGE SOLAR ARRAY ATTITUDE (ACS)		

(continued)

Table 1-3 (continued)

(c) INTEGRITY

LEVEL	CATEGORY		
	I	II	III
0			
1	4.2.1.2 PROTECT POWER BUS (EPDS)		
2	4.2.2.1 BATTERY CHAIN FAILURE (EPDS)	4.2.3.1 BASELINE ENERGY STORAGE (EPDS)	4.3.4.1 RAM PATCH (ACS)
	4.2.2.3 SECONDARY CONVERTER FAILURE (EPDS)	4.3.4.4 ALL AXES SUN CONTROL (ACS)	
	4.2.2.5 SINGLE LOAD SWITCH FAILURES (EPDS)	4.5.1.3 MAINTAIN TELEMETRY TRANSMISSION (TT & C)	
	4.2.4.1 FAILED BATTERY CHAIN (EPDS/ACS)	4.5.2.3 MAINTAIN S/C COMMAND RECEPTION (TT & C)	
	4.2.4.2 SAD POT FAILURE (ACS)	4.7.1 MAINTAIN TRACKING FUNCTION (TT & C)	
	4.3.1.2 SENSE DEVICE STATE (ACS)		
	4.3.2.1 ATTITUDE DURING ECLIPSE (ACS)		
	4.3.2.5 YAW RATE REDUCTION (ACS)		
	4.3.3.1 REACTION WHEEL FAILURE (ACS)		
	4.3.3.2 ACE FAILURE (ACS)		
	4.3.3.3 EARTH SENSOR FAILURE (ACS)		
	4.3.3.4 SUN SENSOR FAILURE		
	4.3.4.3 TELEMETRY CONTINGENCY MODES (ACS)		
	4.4 MAINTAIN THERMAL CONTROL (TCS)		
	4.5.1.1 MAINTAIN INFO ACQUISTION (TT & C)		
	4.5.1.2 MAINTAIN TELEMETRY GENERATION (TT & C)		
	4.5.2.4 MAINTAIN COMMAND PROCESSING (TT & C)		
	4.5.2.5 MAINTAIN COMMAND DISTRIBUTION (TT & C)		
	4.6.1 MAINTAIN THRUSTER HEALTH (PROP)		
	4.6.2 MAINTAIN PROPELLANT SYSTEM (PROP)		
3	4.2.1.1 ISOLATE LOAD FAULTS (EPDS)		4.3.4.2 GROUND OVERRIDE (ACS)
	4.2.2.2 SA OR SHUNT DISSIPATOR FAILURE (EPDS)		
	4.2.3.2 BATTERY OPERATIONS INTEGRITY (EPDS)		
	4.3.2.2 LOSS OF EARTH PRESENCE (ACS)		
4	4.3.1.1 DATA TRANSFER HANDSHAKES (ACS)		
	4.3.1.3 PROTECT FROM FALSE COMMANDS (ACS)		
	4.3.1.4 CHECK PARAMETER STATES (ACS)		

(continued)

Table 1-3 (continued)

LEVEL	CATEGORY		
	I	II	III
5	4.2.2.4 REG ELECTRONICS/QUAD RELAY FAILURE (EPDS)		
	4.3.2.3 NUCLEAR EVENT (ACS)		
	4.3.2.4 PROTECT EARTH SENSOR (ACS)		

LEGEND:

ACS	=	ATTITUDE CONTROL SUBSYSTEM
EED	=	ELECTRO-EXPLOSIVE DEVICE
EPDS	=	ELECTRIC POWER DISTRIBUTION SUBSYSTEM
GDA	=	GIMBAL DISH ANTENNA
MBA	=	MULTIBEAM ANTENNA
NAV	=	NAVIGATION
POT	=	POTENTIOMETER
PROP	=	PROPULSION SUBSYSTEM
RAM	=	RANDOM ACCESS MEMORY
SAD	=	SOLAR ARRAY DEVICE
TCS	=	THERMAL CONTROL SUBSYSTEM
TLM	=	TELEMETRY
TT & C	=	TRACKING, TELEMETRY, AND COMMAND SUBSYSTEM

SECTION 2

PAYLOAD SERVICES

This Section describes the current functions of the spacecraft which make it possible for the payload to carry out the mission of DSCS III. These functions are:

(1) Provide power

(2) Provide attitude control

(3) Provide thermal control

(4) Provide spacecraft control and monitoring

(5) Provide timing

(6) Provide direct payload services

(7) Provide stationkeeping

Figure 2-1 displays these functions in a hierarchical form. Each of these functions has its own, lower-level hierarchy displayed in the section which address that function. The numbers in boxes correspond to paragraph numbers.
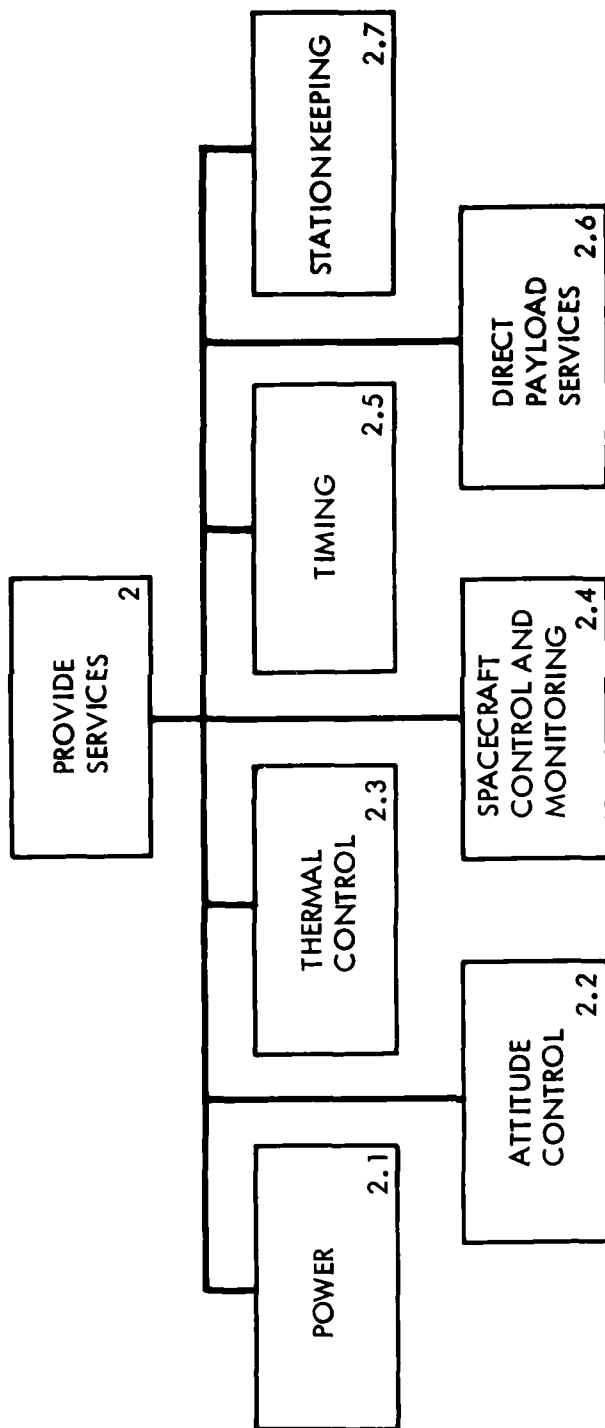
Figure 2-1. DSCS III Services Functional Hierarchy

30

2.1   PROVIDE POWER*

The power provision function comprises solar power collection, power conditioning, energy storage and power distribution. Power is collected by solar panels. Three batteries provide storage for eclipses and other cases where consumption exceeds the direct capacity of the solar panels. Although the solar array articulation is controlled by the attitude control subsystem, its functional description is included in this section. The power provision function contains a number of autonomous features implemented in hardware. Figure 2-2 shows the power provision functions in a hierarchy.

2.1.1   Collect Solar Power - Level 4/Category I

2.1.1.1   (Post Separation) Orient Solar Array.

2.1.1.1.1   Control Solar Array (SA) Articulation. The post-launch initiation timer triggers SA articulation. Normal drive signals are triggered by the ACE clock. Special slew commands are sent from the ground. The solar array drive (SAD) is controlled by the ACS, which provides articulation pulses for the SAD stepper motor driver signals.

2.1.1.1.2   Select SA Drive Mode. Post launch, the SA drive mode is preselected by the ground and autonomously implemented by the ACS. The ACS controls SAD polarity by providing normal SAD drive signals or variable forward slew rates by ground command.

2.1.1.1.3   Select SA Drive Pot. The solar array drive pot is preselected by the ground.

2.1.1.2   Maintain Solar Array (SA) Orientation Accuracy of $\pm 1^o$ to Sun Line.

2.1.1.2.1   SA Position Control. The ACS sun sensors (Pitch sensors) provide the sun line angle relative to the SA. The ACS computes the error and directs the SAD. The SAD nulls the sun line error.

---

*By R. C. Detwiler, E. P. Kan, T. W. Koerner, E. Mettler and G. W. Wester.

31
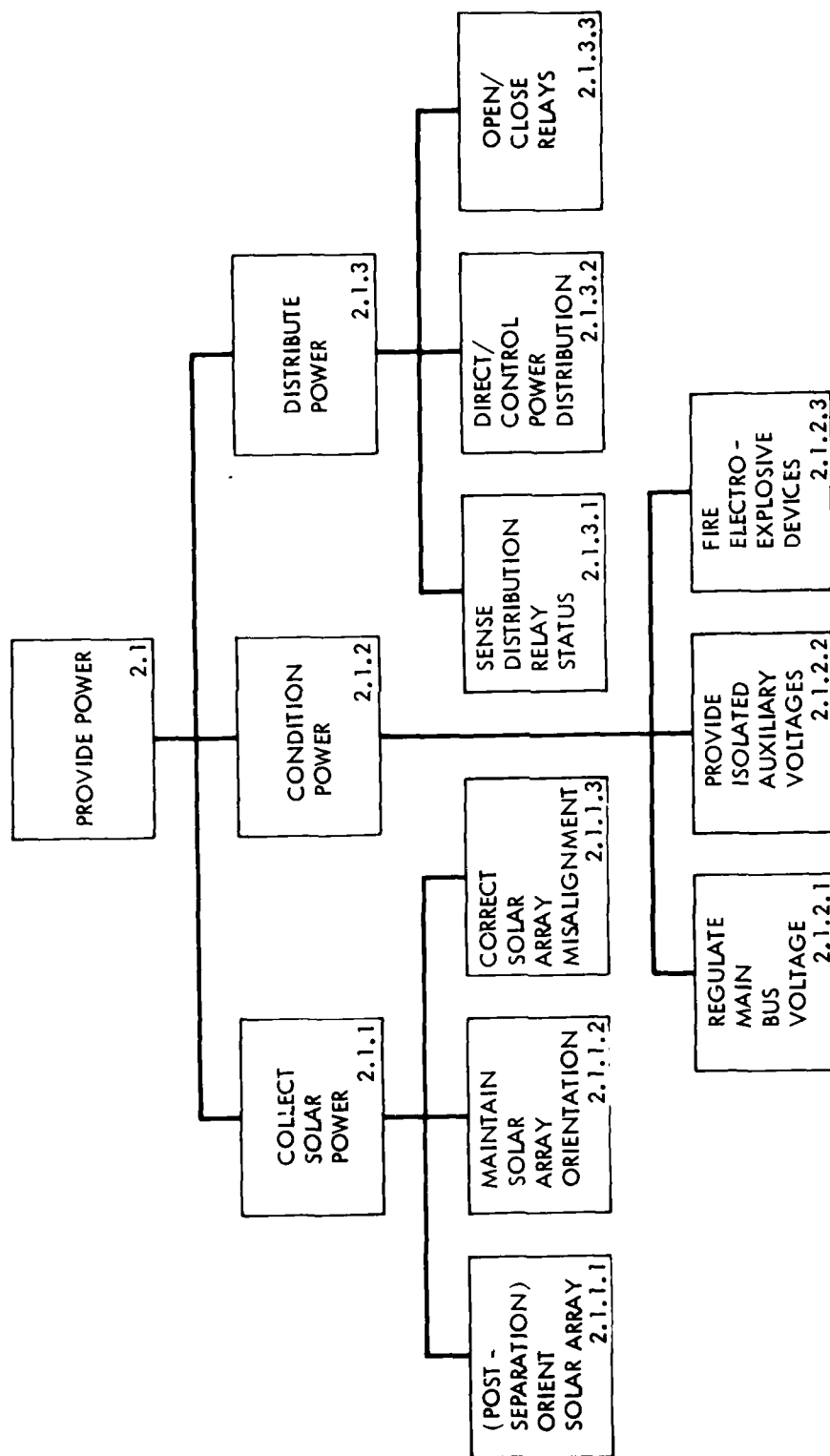
Figure 2-2. Power Service Functional Hierarchy

2.1.1.2.2   SA Misalignment Bias Correction; Initial Prelaunch Ground
             Calibration. ACS sun sensor data is issued by the ground to
perform the calibration. The ACS uses the calibration bias values for
corrected sun sensor angle and SAD command generation. The SAD drives the
Solar Array to the corrected orientation.

2.1.1.3   Correct Solar Array Misalignment. The ground periodically
calibrates the solar arrays for misalignment. A misalignment bias correction
signal is provided to the ACS which adds it to the roll differential signal
for driving the solar array to the correct orientation.

2.1.2   Condition Power

2.1.2.1   Regulate Main Bus Voltage (28 VDC ±1%) - Level 5/Category I.

2.1.2.1.1   Sense Bus Voltage. The bus voltage is sensed and the error
signal is generated in the Power Regulation Unit (PRU).

2.1.2.1.2   Direct Voltage Regulation. Using the error signal, the PRU
directs and controls the boost converter, battery charge regulator (BCR), and
shunt dissipator (SD) in an automatic analog feedback loop.

2.1.2.1.3   Drive Boost Converter. The PRU drives the boost converter,
battery charge regulator and shunt dissipator.

2.1.2.2   Provide Isolated Auxiliary Voltages - Level 5/Category I. DC to
DC converters autonomously convert the 28 VDC Main Bus Voltage to auxiliary
voltages for various loads (+28 Vdc, +24 Vdc, +15 Vdc, +12 Vdc, +19 Vdc,
+8 Vdc, +5 Vdc)

2.1.2.3   Fire Electro-Explosive Devices - Level 5/Category I. The firing
of electro-explosive devices (EED) is a parallel, block redundant, automatic
function. EED functions are presently a part of the launch sequence.

2.1.3   Distribute Power - Level 2/Category I

2.1.3.1   Sense Distribution Relay Status. Status signals (open/closed)
of selected relays are sensed and provided to telemetry.

2.1.3.2   Direct/Control Power Distribution. The ground segment directs power distribution by controlling relays.

2.1.3.3   Open/Close Relays. Commands to open/close power distribution relays are executed.

2.2 PROVIDE ATTITUDE CONTROL*

The attitude control service function initially stabilizes the spacecraft after separation from the launch vehicle, and then maintains stability, both during normal on-orbit operations and during maneuvers. The attitude control function also reacquires references, if lost, when commanded to do so by the ground. The attitude control service function includes computational capability and a number of autonomous features implemented in both hardware and software.

The attitude control function utilizes sun sensors, earth sensors, rate gyros, reaction wheels, thrusters, and a computer to stabilize and maintain the spacecraft attitude. The attitude control subsystem (ACS) implements the attitude control functions. The ACS also performs a number of other functions, such as solar array articulation, post separation timing and direct commanding of some payload antenna functions. These auxiliary ACS functions are described in their appropriate functional areas.

Because of its computer the attitude control function contains a number of autonomous capabilities. These include:

Post Launch 3-Axis Stabilization

Automatic Sun Acquisition - Sensed sun line and satellite orientation control for (-Z) to sun

Automatic Earth Acquisition - Earth limb detection and control (+Z) NADIR, upon ground enable command.

Nominal On-Orbit Autonomy

Attitude States - Estimated and sensed attitude within limits for pitch, roll, yaw.

Momentum states - Reaction wheel speed is tachometer sensed.

Momentum Distribution - Comparison of actuals to predicted values for disturbance torque is reconciliation method.

Yaw Noon/Midnight Control - Actual yaw drift within predicted limits.

Sun Bias Update - Noon/midnight yaw drift used to compute roll torques/ updates.

Wheel Unloading - Momentum thresholds and actual wheel speeds compared/thruster fired to satisfy required distribution.

---

*By S. H. Graff, E. P. Kan, J. R. Matijevic, E. Mettler

The attitude control function utilizes a computer and peripheral devices:

Computer:

Central Processor Units (CPU)
Random Access Memories (RAM)
Read Only Memories (ROM)
Hardened Random Access Memories (HRAM)
Input/Output Ports

Peripheral Devices:

Reaction Wheels
Thrusters
Solar Array Drive
Payload Beam Forming Network (BFN)
Gimbaled Dish Antenna (GDA)
Earth Sensor and Sun Sensors
Rate Gyro
Command and Telemetry
Radiation Detector

A more complete description of the computer and the peripherals is contained in Appendix C.

Figure 2-3 shows the hierarchy of the Provide Attitude Control Function.

2.2.1   Stabilize Attitude (From any attitude, for Rates <1º/sec/axis)

2.2.1.1   (Post Launch) Acquire Sun and Reduce Tip-off Rates - Level 4/Category I.

2.2.1.1.1   Sense Attitude and Rates. Post separation tip-off is required to be less than 1.1º/sec/axis. When the sun is in the sun sensor field of view (which is almost 180º), the sensor provides pitch/roll information to the ACS control loop. The rate gyro provides yaw rate information to the ACS control loop. The rate gyro is used during post launch initialization, reference reacquisition, and may be used for yaw control at other times if ground commanded. The ACS control loop determines pitch/roll positions from the sun sensor signal and yaw rate from rate gyro signal.

2.2.1.1.2   Direct/Control Sun Acquisition/Tip-Off Rate Reduction. The ACS selects control loop parameters by putting the outer control loops (pitch, roll, and yaw) in the fast (2-second) update mode and the wide dead band mode (wide dead band = +7.68º pitch position, +3.84º roll position, 0.32º/sec yaw rate). The ACS directs the thrusters to low torque mode (16 ms pulse width) and directs catalyst bed heater warmup. The ground preselects thruster pairs and latch-valve/tank configuration for resource management and integrity maintenance. The outer loop control directs thruster firings to reduce errors within these wide dead band limits.
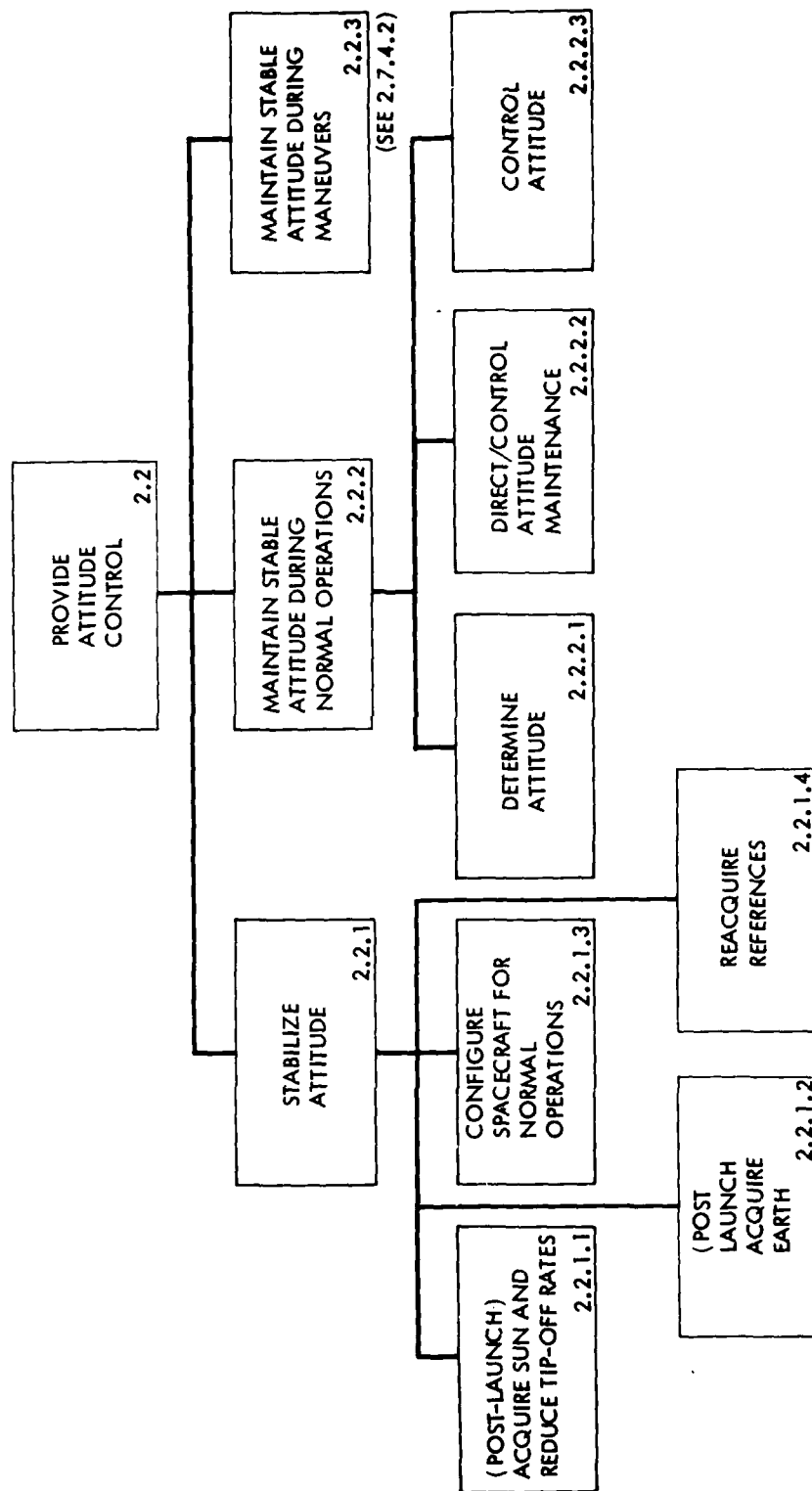
Figure 2-3. Attitude Control Service Functional Hierarchy

37

2.2.1.1.3   Acquire Sun/Reduce Rates. Pitch roll, yaw thrusters of the
selected bank are fired to provide turn impulse until the sun is acquired and
pitch, roll, yaw position and rate errors are within the wide dead band
limits. In order to maintain attitude the thrusters provide limit cycle
pulsing. The S/C attitude/rate is maintained within wide dead band limits
until earth acquisition is initiated. (This is called the sun-hold mode.)

2.2.1.2   (Post Launch) Acquire Earth - Level 3/Category I.

2.2.1.2.1   Sense Attitude and Rates. The sun sensor senses pitch and roll
angles and the sun line direction. The solar array drive pot senses the solar
array angle relative to S/C. The rate gyro provides yaw rate information to
ACS control loop.

When the earth is in the field of view of the earth sensor, an
earth presence signal is transmitted to the ground. If the S/C is coning at
an angle greater than 8.5° declination the earth may not enter the field of
view of the sensor until thrusters are fired (by ground command) to reduce the
coning angle. When the earth sensor views the earth it provides pitch and
roll data.

2.2.1.2.2   Direct/Control Earth Acquisition. When sun acquisition is
complete, as indicated by pitch, roll, yaw position and rate telemetry the
ground monitors the earth presence signal at local noon, or midnight. When
the earth presence signal occurs at the proper intervals (due to S/C coning),
the ground sends earth acquisition mode enable signal and also sends the sun
declination bias angle which is used in the on-board sun orientation
algorithms. If no sun bias were included the S/C would point directly at the
sun rather than maintaining earth reference.

The ACS puts outer control loops in the fast (2 sec) update mode
and selects the medium deadband $+1.92^{\circ}$ pitch, $+1.92^{\circ}$ roll, 0.24°/sec rate in
yaw. The ACS directs the thrusters to the high torque mode (1 sec pulse
width) and directs catalyst bed heater warm-up. The ground preselects latch
valve/tank configuration and thruster pairs.

2.2.1.2.3   Acquire Earth. Pitch, roll, yaw thrusters of the selected bank
are fixed to provide turn impulse until the earth is acquired and pitch, roll,
yaw position and rate errors are within medium dead band limits. The
thrusters provide limit cycle pulsing to maintain attitude until reaction
wheels are activated. The S/C attitude/rate is maintained within medium dead
band limits.

2.2.1.3   Configure S/C for Normal Operations - Level 3/Category I.

2.2.1.3.1   Sense S/C Orientation. The pitch sun sensor gives sun line
information; the solar array drive pot gives solar array spacecraft angle
information.

2.2.1.3.2   Direct/Control S/C Configuration. The ACS directs solar array slewing to sun line normal. The ACS selects narrow dead band outer control loop parameters and low torque thruster pulse width (16 ms). The ground directs reaction wheel turn-on. The ground enables ACS autonomous modes for routine on-orbit attitude stabilization.

2.2.1.3.3   Configure S/C. The solar array slews, the thrusters fire to reduce the dead band, and the reaction wheel drive motors are turned on.

2.2.1.4   Reacquire References - Level 3/Category I. Reference reacquisition repeats the initial acquisition from the point where the specified reference is lost. If the sun is lost, see 2.2.1.1. If the earth is lost see 2.2.1.2. Before reacquiring the sun, the ground must drive the solar arrays to the noon/midnight position. Sun reacquisition is autonomous unless disabled. Earth reacquisition must be ground enabled. The gyro for yaw rate control is turned on by the ground. This gyro is most often used for reacquisition, but can also be used as a backup to the sun/earth sensors for yaw sensing.

2.2.2   Maintain Stable Attitude During Normal Operations

2.2.2.1   Determine Attitude - Level 3/Category I.

2.2.2.1.1   Sense Attitude Relative to Sun. The pitch sun sensor measures the sun location relative to the S/C. The roll sun sensor provides yaw information except near noon or midnight, when the sun sensor provides only roll information. Solar array position information is from the solar array drive pot.

2.2.2.1.2   Sense Attitude Relative to Earth. The earth sensor provides pitch and roll information. During solar eclipse only earth sensor data is used for attitude control.

2.2.2.1.3   Analyze Pitch, Roll, Yaw Position. The ACS logic computes attitude from sun sensor and earth sensor inputs.

2.2.2.1.4   Sense Reaction Wheel Speed. The speed of each reaction wheel is sensed by a tachometer. The ACS logic converts the tachometer rate to a momentum equivalent rate (MER) for directing wheel unloading. Unload timing is derived from the solar array drive pot angle.

2.2.2.2 _Direct/Control Attitude Maintenance._

2.2.2.2.1 _Select Control Loop Parameters - Level 4/Category I._ The ACS selects both outer and inner loops with the outer loop in the 16 second update mode and the inner loop in its normal 1 second update mode.

2.2.2.2.2 _Control Reaction Wheel Momentum - Level 4/Category I._ The ACS control logic directs reaction wheel change. It processes tachometer signals in the pitch, roll, yaw estimator and sends a corrective control signal. (Tachometer selection is done by the ground). The logic computes the nominal roll acceleration (RACC) disturbance and feeds it to the ACS roll estimation to minimize roll/yaw error near noon and midnight. The ACS controls the reaction wheels by providing motor drive signals. Reaction wheel speeds are redistributed for momentum balancing and gain compensation.

2.2.2.2.3 _Manage Reaction Wheel Momentum - Level 4/Category I._ When one reaction wheel tachometer senses that its speed is less than 250 rpm, momentum can be distributed to slow down other wheels and speed that one up. Similarly, a wheel running too fast is slowed down by transferring momentum to other wheels. Momentum management is conducted automatically.

2.2.2.2.4 _Manage Control Parameters - Level 0/Category I._ Control parameters are stored in the ACS and are occasionally modified by the ground. If necessary, the ACS automatically reloads these parameters. The active random access memory (RAM) is reloaded from the radiation hardened RAM. The reloadable parameters are: commanded dead bands, pulse widths, wheel unload windows, bias for pitch momentum, solar array misalignment, sun declination bias values, position gains and momentum equivalent rate, wheel integral terms, RACC values, and certain flags for processing.

2.2.2.2.5 _Direct Reaction Wheel Unloading - Level 4/Category I._ The ground selects 0600 or 1800 as the unloading time (unloading may be done once or twice daily, as required). The ACS checks the MER against the dead band limit and issues commands for thruster firings.

2.2.2.2.6 _Select Thrusters - Level 2/Category II._ The ground selects thrusters so that ΔV induced by reaction wheel unloading is directed to offset East/West drift, thereby aiding East/West stationkeeping.

2.2.2.3 _Control Attitude - Level 4/Category I._

2.2.2.3.1 _Change Reaction Wheel Speed._ Selected reaction wheels are driven by motors to maintain spacecraft attitude. Reaction wheels speed up or slow down, as required, and momentum can be traded between wheels. Reaction wheels control attitude in all axes.

2.2.2.3.2　　Unload Reaction Wheels.　Selected thrusters pulse to transfer
momentum from the reaction wheels, which are allowed to slow down.　Thrusters
fire every 64 cycles until the MER is less than the dead band.

2.2.3　　　　　Maintain Stable Attitude During Maneuvers - See 2.7.4.2

2.3   PROVIDE THERMAL CONTROL*

         The basic thermal control subsystem design uses passive thermal
control techniques to control the energy balance between the spacecraft and
space, thus controlling the temperature level of the spacecraft and its
components. The active thermal control components are used to maintain the
internally generated energy at a level such that the temperature of the
spacecraft and its components are kept within operational limits even when
internally generated heat varies or when there are variations in the energy
level of external sources.

         The passive thermal control design does not use any semi-active
equipment (louvres, heat pipes, etc.). Thus, once the design is finalized,
assembled, and tested, the temperature level of the spacecraft and its
components is defined and controlled by the spacecraft power state and orbit
condition relative to sun angle, inclination, and spacecraft orientation and
there is no capability for any change in designed control temperature level.
Figure 2-4 shows the Thermal Control function hierarchy.

2.3.1   Provide Prelaunch Phase Thermal Control

         Provide and manage air conditioning systems.

2.3.2   Provide Launch Phase Thermal Control

         During the launch phase the system relies on its own heat
capacitance to protect against cold.

2.3.2.1   Enable Survival Heaters - Level 3/Category I.

2.3.2.2   Enable Control Heaters - Level 3/Category 1.

2.3.3   Provide Orbit Transfer Phase Thermal Control

2.3.3.1   Enable Survival Thermostats - Level 3/Category I.

2.3.3.2   Enable Battery, Propulsion and Solar Array Actuator (SAA)
Heaters - Level 3/Category I.

2.3.4   Provide On-Orbit Thermal Control

---

*By R. N. Miyake and J. A. Plamondon
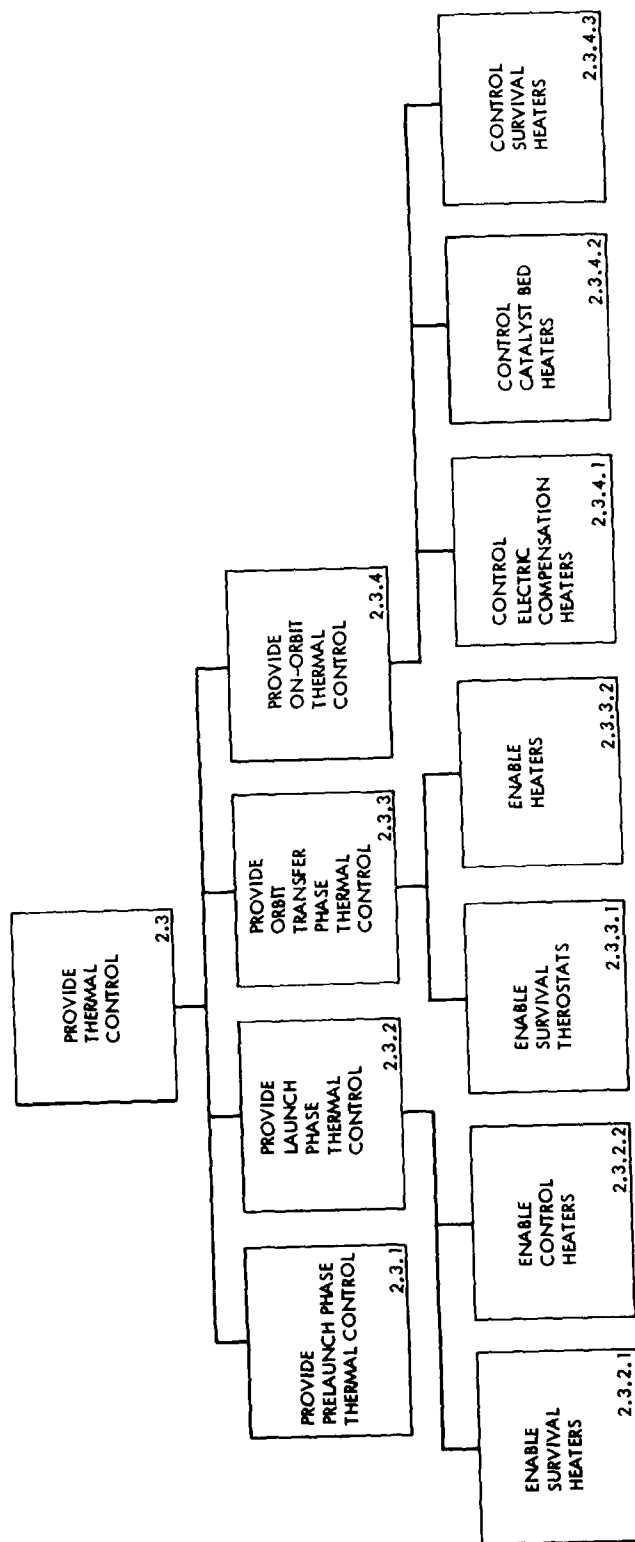
Figure 2-4. Thermal Control Service Functional Hierarchy

43

The active thermal control components are divided into two functions; a control function that is designed to be commanded on, and a survival function that is always on.

2.3.4.1   Control Electric Compensation Heaters - Level 3/Category I.

2.3.4.1.1   Sense Temperature. Temperature sensor set points are hard wired and are tailored to the specific component served.

2.3.4.1.2   Direct/Control Temperature Maintenance. The Low Noise Amplifier (LNA) oven has an electronic thermostat for control while its survival heaters use mechanical thermostats. The north and south sun sensor assemblies use three electronic thermostats in parallel. The three thermostats sample the temperature of the sun sensor assembly, and the sun sensor assembly temperature is controlled by the thermostat whose temperature falls in the middle of the three readings. The ground monitors temperature and can enable/disable heaters to control temperature and power consumption.

2.3.4.1.3   Heaters Switch. The heaters autonomously switch on or off to maintain temperature in the required range.

2.3.4.2   Control Catalyst Bed Heaters - Level 1/Category I. Catalyst bed heaters must be turned on for 100 minutes prior to thruster firing (see 2.1.1.3, 7.4.1.3). Catalyst bed minimum temperatures are: $140^{\circ}C$ normal operation; $82^{\circ}C$ North-South stationkeeping maneuvers; 40° post-launch initialization and/or emergency.

2.3.4.3   Control Survival Heaters - Level 3/Category I.

2.3.4.3.1   Sense Temperatures. The survival thermostats are activated whenever temperatures fall below specified limits.

2.3.4.3.2   Direct/Control Survival Heaters. The survival heaters are completely autonomous and cannot be controlled by the ground. Hard wired circuits activate the battery, sun sensor assembly (SSA) and propulsion heaters autonomously.

2.3.4.3.3   Heaters Switch. The survival heaters switch on/off autonomously to maintain the temperature above the required limits. Activation of the load shed relay (a power function described in Sections 3.1.1 and 4.2.1) does not disable these heaters.

2.4   PROVIDE SPACECRAFT CONTROL AND MONITORING FUNCTION*

          The purpose of the spacecraft control and monitoring function is
to:

>   (1)   acquire, condition, format and transmit satellite telemetry
>   data from the spacecraft to the ground, and

>   (2)   receive, decode and distribute commands from the ground to
>   the spacecraft.

          Concurrently, the SHF telemetry downlinks are also used to
provide a payload-derived network timing signal and a ground antenna pointing
beacon to certain comm system users.

          The spacecraft control and monitoring system is currently
implemented in the Telemetry, Tracking and Command Subsystem (TT&C) on the
spacecraft, and in the Satellite Control Facility (SCF) on the ground.

          The personnel and facilities of the ground system monitor the
S/C via the RF links. Providing the means of controlling the S/C via the
command link, monitoring the S/C over the telemetry link, and determining the
orbit by the two way tracking link are the functions of the TT&C subsystem.
Determination of the commands to be sent, the S/C performance and the orbit
are ground decisions and functions of other subsystems, except where the
information relates to the TT&C subsystem. Figure 2-5 shows the hierarchy of
spacecraft control and monitoring functions.

          Most of the command, telemetry and tracking services are
performed autonomously. For example, the S/C autonomously acquires and issues
commands. However, the ground based function is required to send the command
information. Tracking is a function related to stationkeeping and is
described as part of the Stationkeeping/Navigation Function in Section 2.7.1.

2.4.1   Provide Telemetry Function

          This function provides the service of acquiring, generating and
transmitting the S/C telemetry parameters to the ground. This function also
provides for the reception, processing and distribution of the S/C telemetry
information on the ground. The DSCS III S/C telemetry service function, as
currently planned, is basically autonomous. The S/C acquires and sends
telemetry without help. However, ground support is required to request
transmission of the data, and to process and analyze the data.

2.4.1.1   Acquire Information - Level 3/Category I. The Master Telemetry
Unit (MTU) acquires information from four other spacecraft subsystems: the
Communication Payload (COMM), the Attitude Control Subsystem (ACS), the Single
Channel Transponder (SCT), and the Electric Power Distribution System (EPDS).
It acquires information indirectly from three additional subsystems through
one or more of the above subsystems. These additional sources are the Thermal

---

*By W. E. Arens and S. O. Burks

45
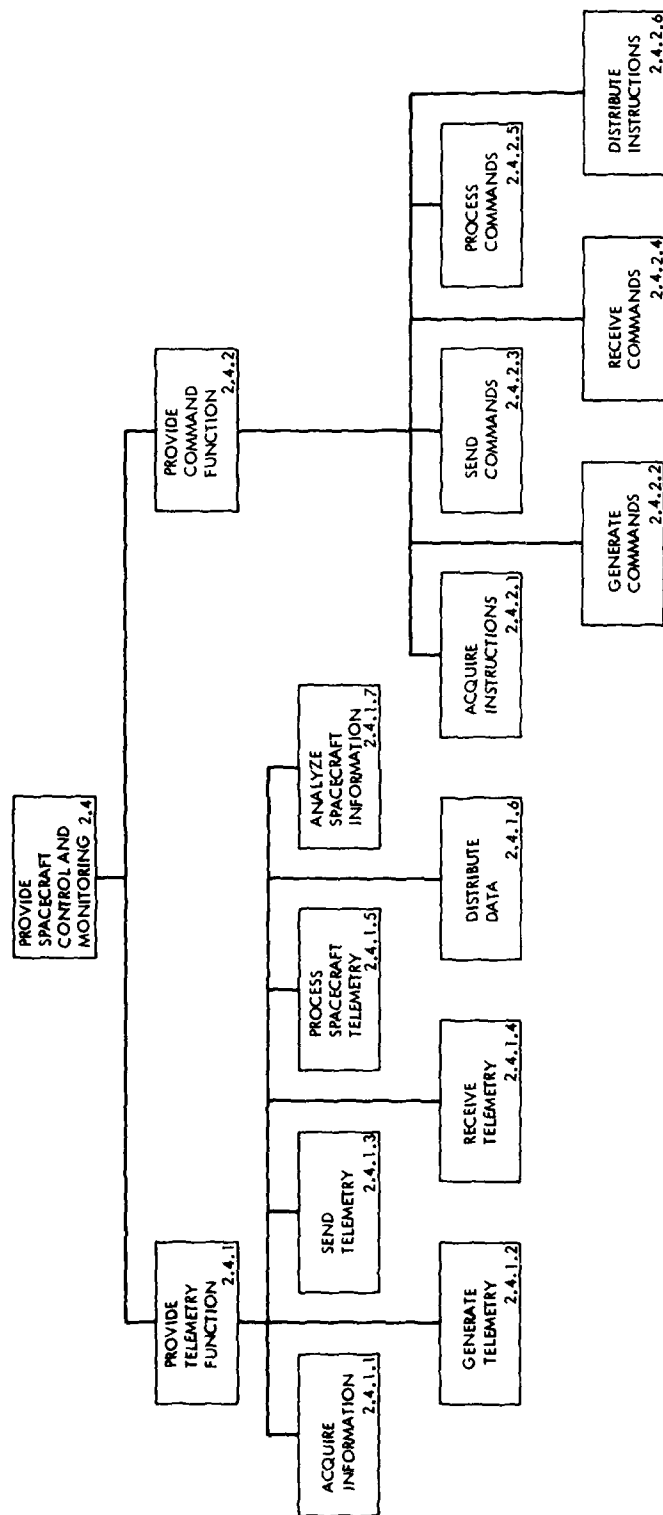
Figure 2-5. Spacecraft Control and Monitoring Service Functional Hierarchy

Control Subsystem (TCS), the Propulsion Subsystem (PROP), and the Structural/Mechanical Subsystem. The Remote Telemetry Unit (RTU) acquires information from North Panel sensor sources.

2.4.1.1.1   Acquire Analog Data. The MTU receives 192 analog inputs. The RTU receives 128 analog inputs. Analog measurement inputs from subsystem sensor sources are accessed by the MTU and RTU via dedicated lines from these sources. Signals are provided continuously on each dedicated line from each subsystem sensor source for interrogation by the MTU and/or RTU. No direction or action is necessary since the required analog data is continuously available on dedicated lines at the MTU and RTU inputs.

2.4.1.1.2   Acquire Bi-Level Data. The MTU receives 350 bi-level digital inputs. The RTU receives 140 bi-level digital inputs. Bi-level measurement inputs from subsystem sensor sources are accessed by the MTU and RTU via dedicated lines from these sources. Signals are provided continuously on each dedicated line, from each subsystem sensor source, for interrogation by the MTU and/or RTU. No direction or action is necessary since the required bi-level data is continuously available on dedicated lines at the MTU and RTU inputs.

2.4.1.1.3   Acquire Serial Digital Data. The MTU receives two 23-bit serial digital and sixteen 8-bit serial digital inputs. The RTU receives no serial digital measurement inputs. Serial digital measurement inputs from subsystem sources are accessed by the MTU via dedicated lines from subsystem sensor sources. Signals are provided on a given line only upon request by the MTU. Acquisition of serial digital measurement signals from subsystem sources by the MTU is initiated and controlled by appropriate logic control and timing circuits in accordance with a predetermined sequence stored in Programmable Read-Only Memory (PROM). The MTU provides enable and clock signals over dedicated lines to a subsystem source when readout of a serial-digital measurement is desired.

2.4.1.2   Generate Telemetry - Level 3/Category I. Following acquisition of information, the major functions performed in the generation of a telemetry data output stream are (1) multiplexing of analog data, (2) digitization of analog data, (3) multiplexing of digital data, and (4) formatting of data.

2.4.1.2.1   Multiplex Analog Data. The MTU provides time division multiplexing of analog input data from spacecraft subsystem sensor sources and the RTU. The RTU provides time division multiplexing of analog data from North Panel sensor sources. The output of the RTU analog multiplexer is routed to the MTU analog multiplexer for multiplexing with other analog measurements accessed by the MTU.

Analog measurement inputs are provided directly to dedicated analog switches in an analog multiplexer via dedicated lines from subsystem sensor sources. Interrogation of analog measurement signal lines by the MTU and/or RTU is initiated and controlled by appropriate logic control and timing circuits in accordance with a predetermined sequence stored in PROM. Analog switches are selectively closed and the associated input measurement lines

47

connected to the MTU analog multiplexer output so that a single output line containing time-division multiplexed, analog data results.

2.4.1.2.2   Digitize Analog Data. Analog samples to be digitized are sequentially provided at the output of the MTU analog multiplexer. Timing and logic control circuits in the MTU provide signals to determine the sample availability for the digitization and to initiate and control the digitization process for each sample. Each analog sample is digitized into an 8-bit word by an analog-to-digital converter (ADC) in the MTU.

2.4.1.2.3   Multiplex Digital Data. Digital data is accessed from (1) the MTU ADC, (2) the dedicated bi-level digital source lines accessed by the MTU, (3) the output of the RTU bi-level digital data multiplexer, and (4) the dedicated serial-digital data lines.

Digital measurements from the aforementioned sources are provided via dedicated lines to the inputs of dedicated digital switches in the MTU digital multiplexer. Interrogation of digital measurement signal lines by the MTU is initiated and controlled by appropriate logic control and timing circuits in accordance with a predetermined sequence stored in PROM. Digital switches are selectively closed, and the associated input measurement lines are connected to the MTU digital multiplexer output so that a single output line containing time-division multiplexed digital data results.

2.4.1.2.4   Format Data. A single multiplexed digital data stream is provided at the output of the MTU digital multiplexer for formatting into main and master telemetry output frames. Timing and logic control circuits in the MTU provide signals to generate header information and execute the formatting process in accordance with a sequence stored in PROM. The digital data output stream from the MTU digital multiplexer is formatted into main frames each consisting of 256 8-bit telemetry words and master frames each consisting of 30 main frames. The output bit rate is 1000 bps resulting in a main frame period of 2.048 seconds and a master frame period of 61.44 seconds. The formatted digital data output stream from the MTU is routed to the TT&C RF equipment for transmission to the ground.

2.4.1.3   Send Telemetry (S/C) - Level 3/Category II. This function is provided by the DSCS III S/C for transmission of S/C data to the ground stations. The S/C data is acquired from the various subsystems by the TT&C subsystem and generated into a format suitable for sending on the RF downlink.

The S-Band and SHF RF signals have virtually identical telemetry data modulated on them. These links can be used interchangeably but generally are used in specific ways. The S-Band telemetry RF link from the S/C to the Satellite Control Facility (SCF) Remote Tracking Stations (RTS) is primarily used for normal status and health telemetry information. The X-Band link to the EDM-SCCE DSCS ground station is primarily used for payload status and configuration and health monitoring.

Both the S and X-Band RF links "send telemetry" autonomously. That is, after the appropriate hardware is turned on by ground command, the

telemetry is modulated on the RF carrier and transmitted via one of the S/C antennas to the ground stations.

2.4.1.3.1   Send S-Band Telemetry.   For sending S-Band telemetry, a digital telemetry signal is received from the Master Telemetry Unit (MTU). This signal is encrypted and then modulated on a subcarrier. This composite signal is modulated on the carrier. The modulated carrier is then multiplied up in frequency, amplified and transmitted to the ground.

In the normal operating mode the downlink telemetry is activated by the uplink command function as follows: uplink receiver and command lock are obtained; command "S-Pulses" are modulated in the uplink; the detector locks to the S-Pulses and outputs an "AM-Sync" to the command decoder (CD); the CD outputs a signal to the South Power Controller (SPC); the SPC turns on a number of items, including the S-Band transmit function. The transmitter also can be turned on by ground command. The S-Band transmitter is normally "off" until activated by the ground. The S-Band transmitter may also be turned on continuously by ground command.

Also, the transmitter can be automatically turned on by loss of "earth presence" via the attitude control function. The power system "80 minute timer" can activate the downlink. The separation timer can activate the S-Band downlink during the launch phase.

The function of sending telemetry over the RF link to the ground is basically autonomous and free of ground intervention as currently designed in DSCS III. The link does need to be activated by uplink command actions from the ground.

2.4.1.3.2   Send X-Band (SHF) Telemetry.   To send X-Band telemetry, data is first received from the MTU. The data is then encrypted and mixed with a Pseudo-Noise (PN) code and clock. This composite signal is modulated on a stable carrier derived from the comm subsystem frequency reference, multiplied to X-Band and transmitted out of one of the payload antennas. The composite signal contains network timing information and the stable carrier provides a pointing reference for comm system user ground antennas.

The SHF telemetry is sent (transmitted) by two active and redundant X-Band beacons operating at different frequencies over different comm subsystem antennas. The beacons are normally on but can be turned on and off as required by ground command. The beacons are automatically turned off by the "80 minute timer" or the loss of "earth presence" sensor.

The function of sending telemetry over the X-Band RF link basically is accomplished without ground intervention. Once the link is turned on and set to the desired operating mode, the telemetry is returned without further action by ground based operations.

2.4.1.4   Receive Telemetry (Ground Segment).   The S/C transmitted telemetry signal is received on the ground by S and X-Band ground stations. The SCF receives data from the S-Band stations and uses this data for general health and status information on the S/C. The X-Band signal is received by the DSCS III stations and processed through the EDM-SCCE. The payload users

49

also receive the X-Band telemetry signals. EDM-SCCE and the payload users use the telemetry data for payload status information.

2.4.1.4.1.   Receive S-Band Telemetry. The reception of telemetry is accomplished by deciding which S/C and which frequency will be used (typically the S/C "A" string); pointing the antenna and transmitting an uplink signal to the S/C with S-Pulse command modulation; confirming that the "AM Sync" activated by the S-Pulse data has turned on the S-Band downlink; acquiring the downlink S-Band signal; demodulating the 1.024 MHz subcarrier from the carrier; demodulating the data from the subcarrier; decrypting the data; and, conditioning the data for processing.

2.4.1.4.2   Receive X-Band (SHF) Telemetry. The SHF telemetry signals transmitted by both of the S/C X-band beacons are received by the primary EDM-SCCE stations and the payload users. The data is used primarily for payload related functions (any payload problems are referred to SCF for resolution over the S-Band link). Both of the redundant X-Band beacons are normally on, transmitting at different frequencies over different communications subsystem antennas. To use these signals, the ground stations determine which frequency to receive, and where to point their antennas to acquire the beacon downlink signal (which is a spread spectrum, suppressed carrier signal modulated with PN, clock and data). The clock and PN code are acquired and the data stripped off. The data is decrypted and conditioned for processing.

2.4.1.5   Process S/C Telemetry (Ground). The following discussion is applicable to S/C health and welfare information only. Payload data processing is not discussed herein.

The modulated RF telemetry signal transmitted from the spacecraft is received by the RTS over the S-Band or SHF telecommunications channel. The RTS uses an analog tape recorder to store the received telemetry signal. The stored data is subsequently 1) read from tape, 2) demodulated, 3) decrypted, and 4) routed to the RTS Univac 1230 computer.

At this point, the data is then decommutated wherein individually selected measurement data is separated from the composite telemetry stream for processing. Selected measurements are limit checked to provide definitive information on spacecraft health status. The Satellite Test Center (STC) provides telemetry processing requirements in the form of ground telemetry modes prior to each RTS station pass. These modes are specified in the form of pre-canned telemetry mode software and are used to process subsets of telemetry data where each is associated with a particular spacecraft function assessment. (See 5.0)

2.4.1.6   Distribute Data (Ground). The RTS sends processed telemetry and alarm violation data to the Mission Control Complex (MCC) of the STC where it is stored and selectively displayed for analysis. (See 5.0)

2.4.1.7   Analyze Spacecraft Information (Ground). The data received from the RTS is analyzed by MCC operations personnel for routine or contingency action decisions under the overall direction of the Mission Controller. (See 5.0)

2.4.2   Provide Command Function

The command function provides the service of acquiring and sending commands to the S/C by the ground segment and the reception and execution of these commands by the S/C. The ground based operations determine the commands which need to be sent, acquire the command instructions, generate the command data, and transmit the command data. The spacecraft receives and detects this transmitted data, processes the command data (decodes), and issues command instructions to the subsystems.

The command transmission (ground segment) and command reception (space segment) is accomplished over two functionally identical, but independent systems. One is an S-Band system used for general health, maintenance, and status changes on the S/C from the Satellite Control Facility (SCF). This includes health and maintenance functions of the payload. The second is the X-Band System which is used for operations with the payload. These X-Band (SHF) payload commands are normally transmitted by the DSCS III ground system (EDM-SCCE). Both links will perform identical command functions and each serves as a backup to the other.

The DSCS III command function on the S/C is basically autonomous. Once the ground system has established the command path the S/C will receive and execute the ground transmitted instructions.

2.4.2.1   Acquire Instructions (Ground). The first step in the command processes is the decision by operations personnel on what commands or instructions need to be transmitted to the S/C. By established operational procedures these instructions are gathered and put into a form such that the ground system can 'generate' the command data. The acquisition and subsequent decisions on what commands need to be sent have to be carefully coordinated by the two somewhat independent ground operations, the S-Band SCF and the SHF system EDM-SCCE. Both of these systems can issue commands. However, the NCA does maintain executive control over the operations system.

2.4.2.2   Generate Commands (Ground). Once the command instructions are acquired and the operations personnel have determined the commands to be sent and the command sequences, the actual commands have to be generated in preparation for transmission. The basic command instructions and the sequence of the instructions is processed and a command data set is generated. This generated command data set is then forwarded by the SCF or EDM-SCCE to the appropriate stations for transmission to the satellite.

2.4.2.3   Send Commands (Ground). There are two ground segment systems
used for sending commands to the S/C. One is the S-Band (SGLS) System
controlled from SCF and the other is the X-Band (SHF) system controlled from
EDM-SCCE. Payload related commands normally are sent via the SHF system.
Health, maintenance and general S/C commands are sent via the S-Band system.

2.4.2.3.1   Send S-Band Commands. Before commands can be sent to the S/C the
command instructions are acquired and the command signals formatted and
generated. For sending commands, this data is then encrypted and modulated on
an S-Band carrier at the SCF ground stations. The modulated carrier is then
transmitted to the S/C. The carrier is phase modulated by a three tone (S, 0,
1) AM-PCM/FSK command signal. The uplink is first modulated with S-bit tones
which cause the S/C to activate some of the command channel hardware. The
transmitter frequency is chosen to select the S/C "A" or "B" command channel
(redundant channels).

2.4.2.3.2   Send X-Band (SHF) Commands. Before commands can be sent to the
S/C, the command instructions have to be acquired. These instructions are
then formatted and command data generated. For sending commands, this command
data is then encrypted and modulated on an X-Band (SHF) carrier. The EDM-SCCE
controlled DSCS III X-Band stations then transmit the modulated carrier to the
S/C. The redundant S/C command channels (A and B) are selected by selection
of the transmitter frequency.

2.4.2.4   Receive Commands (Space Segment) - Level 3/Category II.
Commands can be received over the S-Band or the X-Band (SHF) paths. Both
paths are fully block redundant and selection of the redundant path is by
selection of the ground transmitting frequency.

          In the S-Band link the redundant decrypters are continuous in
operation so that the failure of a single decrypter still leaves an operating
S-Band command channel. At X-Band, only one decrypter can be on at one time
and there is no autonomous mechanism for turning on the other. If an X-Band
decrypter fails the redundant one must be activated by an S-Band command
before an X-Band command channel is again available.

          Once the command links are established by the ground, the S/C
command receiving function autonomously performs the reception and detection
of command data.

2.4.2.4.1   Receive S-Band Commands. The command data modulated, S-Band carrier transmitted from the ground is received over one of the two, hybrid, connected antennas. The received signal is provided to both receivers, one of which automatically acquires the carrier and demodulates the composite command signal. The receiver is selected by selection of the ground transmitter frequency. The receiver command detector then converts the composite signal to data. The first data sent is S-bits. The S-bits activate the AM-Sync in the receiver detector. The AM-Sync activates the decrypters, the MTU and the S-Band transmitters (the command decoder is chosen by the command preamble word). After activation, the received command information is detected and decrypted and sent to the command decoder for processing.

The S/C performs the receive command function autonomously. It receives, demodulates, detects, decrypts and sends the command data to the command decoder without ground intervention.

2.4.2.4.2   Receive X-Band Commands. The ground transmitted X-Band carrier modulated with command data is received by the S/C over one of three antennas and one of two redundant receivers. If the SHF channel 1 frequency is transmitted, either the multibeam antenna (MBA) or the earth coverage horn antenna #2 (E2R) can be selected to provide the signal to the channel 1 receiver ("B" receive path). If channel 5 is transmitted, the signal is received over the earth coverage horn antenna #1 (E1R) and receiver "A". The antennas and components prior to the input to the TT&C receivers are part of the payload communications subsystem. The TT&C subsystem receivers also get frequency references from the comm subsystem. The X-Band signal received from the antennas is down converted to a lower frequency and provided to the decrypters for command demodulation, detection and decryption. The decrypted (plain text) command data then is conditioned and sent to the command decoder for processing and issuance of command instructions to the S/C subsystems.

The X-Band channel is functionally identical to the S-Band command channel and the two can be used interchangeably. However, the X-Band channel normally is used only for payload related commands.

The S/C performs the command function autonomously. After the signal arrives at the antenna it is processed without further intervention from the ground.

2.4.2.5   Process Commands - Level 3/Category I.   The Command Decoder (CD) receives commands from both the TT&C S-Band and SHF equipment and provides the necessary processing that must be accomplished prior to their distribution and execution.

53

2.4.2.5.1   Route Encrypted S-Band Commands. AM Sync is provided to the CD by the S-Band transponder via a dedicated line when command modulation is present. Demodulated, but encrypted command data is provided to the CD by the S-Band receiver over four separate lines (S, 1, 0 and clock). Using the AM sync signal, the CD turns on the S-Band decrypters. Encrypted S-Band command data (S, 1, 0, and clock) from the S-Band receiver is then routed through the CD to the S-Band decrypters. When AM sync is lost, a power off signal is output from the CD to disable the decrypters.

2.4.2.5.2   Acquire/Check Plain-Text Data. Plain-text command data is provided to the CD from either of the S-Band decrypters or from the single operating SHF decrypter in the TT&C RF equipment. Only one of two SHF decrypters is on.

Plain-text command data is provided to the CD in a 4 signal format of S, 1, 0, and clock over dedicated lines at rates of 500 bps from the S-Band channel and 100 bps from the SHF channel. Validity checks and priority determination are performed on the incoming command data prior to command decoding.

2.4.2.5.3   Determine Command Type. Following validation and prioritization, the CD determines the command type from information contained within the received plain-text command. The first five bits of a plain-text command provided to the CD indicate the command type. There are the following six command types:

    (1) CD configuration command

    (2) Discrete command

    (3) Message precursor command

    (4) Message command

    (5) Abort command

    (6) BFN readout command

2.4.2.6   Distribute Instructions (Commands) - Level 3/Category I. After determination of command type, the CD routes commands to the appropriate internal or external destination for execution purposes.

2.4.2.6.1   Execute Internal Commands. Command types that are executed internally include the CD configuration command and the abort command. CD configuration commands direct which of the redundant command decoders is to decode subsequent commands. The abort command is provided to terminate the message mode if abnormal operation occurs. This command is provided to prevent a message-mode lockup.

2.4.2.6.2   Output Discrete Commands. Discrete commands are routed on
dedicated lines to other subsystems in the form of discrete pulses which are
used to activate relays. 430 of a maximum of 600 lines are used. The CD
generates a discrete pulse from the decoded command message and sends it over
a dedicated line to the appropriate address contained within the message
through interface circuitry capable of activating a relay at the destination.

2.4.2.6.3   Output Message Commands. Message precursor commands signal the
start of the message mode and contain the number of 20-bit messages to follow
and the message destination (one of six subsystems). After reception of the
precursor command, 18 of the 20 bits of each successive message command is
output to the specific subsystem until the message count is satisfied.

2.4.2.6.4   Output BFN R/O Commands. The BFN readout command (R/O) is
issued to read out the BFN command register after its receipt of a message
command.

2.5   PROVIDE TIMING

2.5.1   Provide Timing for Post Launch Events - Level 4/Category I

         The initiation timer triggers programmed post-launch events,
which are verified by telemetry. These events are solar array deployment,
gimbaled dish antenna deployment, catalyst bed heater warm-up and S-Band
telemetry turn-on. The events are directed by the ACE which is enabled by the
timer.

2.6   PROVIDE DIRECT PAYLOAD SERVICES

          In addition to providing the proper environment for the payload,
the spacecraft also provides a few direct services. However, most payload
functions are carried out independently of the service functions.

2.6.1   Provide Payload Antenna Control

          The payload controller send command requests to the S/C Control
and Monitoring Function(see 2.4.2) for pointing the Gimbaled Dish Antenna
(GDA) and reconfiguring the Multiple Beam Antenna (MBA). These commands are
executed by the Attitude Control Electronics.

2.6.1.1   Reorient GDA - Level 1/Category III. The position of the GDA in
azimuth and elevation is sensed by pots on the GDA and verified via telemetry.
The ground commands azimuth and elevation angles and the ACE generates azimuth
and elevation drive signals. The GDA stepper motor executes the ACE commands
with open loop control on the S/C. The loop is closed via telemetry to the
ground.

2.6.1.2   Reconfigure MBA - Level 1/Category III. The MBA configuration
is determined by the ground via telemetry. The ground then uses this
information to determine any needed reconfiguration commands. The ACS directs
commands to the Payload Beam Forming Network (BFN).

2.7   PROVIDE STATIONKEEPING*

       The stationkeeping/navigation function is entirely ground based.
The direct purposes of the function are to provide a set of useful services
for the S/C and to supply users with ephemeris information. Although the
function processes hydrazine data (Resource management), it does not directly
or automatically have control over the actual resource management function.
It has no part in maintaining S/C integrity short of providing the "useful
service". The function does not directly participate in sensing activities.
All inputs are from the Ground Systems and its tracking and telemetry
functions. The function does not directly act to fire thrusters or command
the S/C. It outputs sequences of commands and/or command parameters that are
supplied to the Ground System in a manner that can be uplinked to the S/C.
The current stationkeeping function is provided by the ground system which
provides stationkeeping for a large number of other spacecraft. Figure 2-6
shows the functional hierarchy of the stationkeeping function.

2.7.1   Provide Tracking Function

       The S-Band uplink and downlink signals between the S/C and the
SCF ground stations are used for tracking the S/C.

       This tracking service is made up of functional elements which
include 1) the ground generated carrier and ranging signal transmitted to the
spacecraft; 2) the spacecraft TT&C equipment to receive and detect the carrier
and ranging; 3) the spacecraft equipment to re-transmit the detected carrier
and ranging; and 4) the ground system to receive the signals, process the data
and distribute the data to the users. The data is used to find out, somewhat
precisely, where the spacecraft is located and its motion (i.e., its orbit).

       The tracking function is made up of ground and spaceborne
functional elements. Tracking the spacecraft requires ground interaction with
the spacecraft. Signals have to be transmitted to the spacecraft and received
from the spacecraft to be able to do precision tracking. Far less precise
tracking can be done with the S-Band downlink only.

       The current autonomy features of the tracking function, which
are minimal, are the same as those discussed under the telemetry and command
service function sections(2.4.1 and 2.4.2). It is obvious that tracking with
the current design requires active ground participation. In particular, the
ground is required to transmit and receive the tracking signals. Also, active
ground participation is required to command the ranging channel on and off,
and to command tracking in the coherent or noncoherent mode.

_____

*By S. O. Burks, J. B. Jones, E. P. Kan, E. Mettler and P. R. Turner
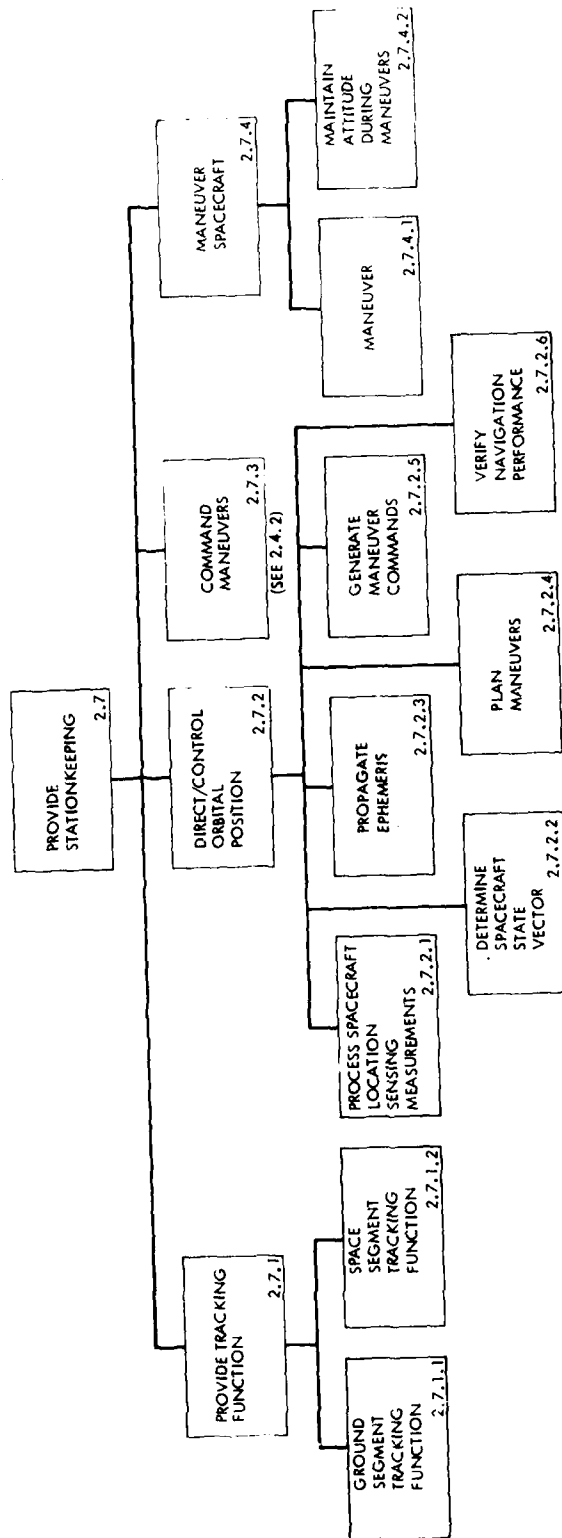
Figure 2-6. Stationkeeping Service Functional Hierarchy

59

2.7.1.1   Ground Segment Tracking Function. The SCF ground stations
provide the tracking functions of transmitting to the S/C a stable uplink
S-Band carrier modulated with a ranging signal, receiving the S/C downlink
S-Band turned around carrier with ranging modulation, processing the
information derived from a comparison of the uplink and downlink signals, and
distributing tracking data to the users for S/C orbit determination.

        The tracking function typically is performed simultaneously with
the command and telemetry functions. Thus, for normal tracking those
descriptions associated with sending commands and receiving telemetry at
S-Band apply here (paragraphs 2.4.1.4.1 and 2.4.2.3.1).

2.7.1.2   Space Segment Tracking Function-Level 2/Category II. The S/C
S-Band portion of the TT&C subsystem receives the carrier and ranging signal,
phase locks to the carrier, demodulates the ranging data, modulates the
detected ranging data on the coherent downlink carrier, and transmits the
signal at S-Band to the SCF tracking stations.

        Per the mentioned similarity to the command function, the uplink
signal is acquired in the same fashion as described for the receive command
function (paragraph 2.4.2.4.1). Commands are sent to activate the ranging
channel and to command the receiver and transmitter into the two way coherent
mode. The downlink signal is established in the same manner as the send
telemetry function (paragraph 2.4.1.3.1).

        The tracking function on board the S/C is carried out
autonomously once the transmit, receive and range functions are established
from the ground. Obviously, the S/C needs the ground based signals to receive
then transmit to the ground. Thus, two way tracking by definition cannot be
divorced from the ground.

2.7.2   Direct/Control Orbital Position of the Spacecraft

2.7.2.1   Process S/C Location Sensing Measurements - Level 0/Category I.

2.7.2.1.1   Schedule Tracking. The stationkeeping function schedules
tracking and data acquisition based on the stationkeeping strategy selected
and on station availability.

2.7.2.1.2   Request Tracking Data. Tracking data is requested for desired
times, the desired spacecraft and from the desired station.

2.7.2.1.3   Process Tracking Telemetry Data. Both tracking and telemetry
data are received from the tracking stations. Telemetry measurements for fuel
tank temperature and pressure are separated out and converted to engineering

units. Tracking data for the selected station and spacecraft are also
separated from the mass of tracking data.

2.7.2.1.4   Update Navigation Data Base. The data base for navigation
software is updated with the selected telemetry and tracking data.

2.7.2.2   Determine Spacecraft Location - Level 0/Category I.

2.7.2.2.1   Maintain Navigation Data Base. Data editing controls and model
information and descriptions are maintained in the Navigation Software Data
Base.

2.7.2.2.2   Provide Environmental Models. The following environmental
models are developed and maintained for the stationkeeping calculations:
gravitational, luni-solar perturbations, outgassing, solar pressure, and
maneuver ΔV's and epochs.

2.7.2.2.3   Determine S/C Location at an Epoch. The state of the S/C at an
epoch is determined by a batch weighted, least squares fit to the tracking
data measurements. The covariance matrix from the fit is a measure of
accuracy. The State of Epoch is the latest estimate of the orbit. Other
model parameters (ΔV's, drag, outgassing) are solved for as desired.

2.7.2.2.4   Update Navigation Data Base. The state and model data derived
in 2.7.2.2.3 are used to update the Navigation Software Data Base.

2.7.2.3   Propogate Ephemeris - Level 0/Category I.

2.7.2.3.1   Determine Position/Velocity vs. Time. The S/C and physical
environment are modelled to integrate the equations of motion, giving position
and velocity as a function of time.

2.7.2.3.2   Calculate Station Limits Violations. These are calculated over
a span of time for a given ephemeris. North-South violations of inclination
and East-West longitude violations may occur when the S/C position exceeds
predefined hard and/or soft bounds.

2.7.2.3.3   Predict Orbit Related Events. The following orbit related
events are predicted:

          (1) Tracking station antenna pointing parameters.

61

(2) Sun and/or moon interference with attitude control earth sensor.

(3) Eclipse and occultation events for attitude controls.

(4) Orbital State vector to Payload Users

The DSCS payload operations personnel require the satellite position and velocity (i.e., its state vector) for communication operations. The orbital state vector must be accurately known. For DSCS III, the range from any earth station to the satellite must be known within 9400 meters. The range-rate of the satellite relative to any earth station must be known within 0.19 meters/second when propagated ahead for 5 days.

2.7.2.3.4   Supply Event Data to Other Functions. These event data are provided to the user, the ground service and integrity maintenance functions.

2.7.2.4   Plan Maneuvers - Level 0/Category I.

2.7.2.4.1   Plan to Acquire Station or Reposition. The following steps are iterated until the S/C is in the required orbital position:

(1) Update the navigation data base with station, ephemeris, and constraint data.

(2) Compare the state/ephemeris with the desired conditions for this phase of the mission.

(3) Compute the next maneuver in this sequence.

(4) Update the data base to reflect the new maneuver for command generation.

2.7.2.4.2   Plan North/South Maneuvers. North/South (Inclination) stationkeeping maneuvers are planned by updating the data base with the ephemeris and constraints and then computing the N/S stationkeeping ΔV and time. This is used to update the data base for command generation.

2.7.2.4.3   Plan East/West Maneuvers. East/West (Longitude) stationkeeping maneuvers are planned by updating the data base with the ephemeris and constraints and then computing the E/W stationkeeping ΔV and time. This is used to update the data base for command generation.

2.7.2.5   Generate Maneuver Commands - Level 0/Category I.

2.7.2.5.1   Maintain Propulsion Model Status. The propulsion model is updated with the propellant status from tank temperature/pressure telemetry. The post-maneuver center of gravity location is calculated and checked for constraint violation. Tank valve configuration and operability status is determined and maintained in the model.

2.7.2.5.2   Model Propulsion Performance. The propellant required for the desired ΔV and burn time is calculated and the tank configuration is selected to maintain the center of gravity within limits.

2.7.2.5.3   Assemble Total Command Sequence. Propulsion and attitude control configuration commands are integrated with thruster selection and duration commands and the total command sequence is checked.

2.7.2.5.4   Supply Command Sequence to Ground System. The maneuver is provided to the Spacecraft Control and Monitoring Service described in Section 2.4.2.

2.7.2.6   Verify Navigation Performance - Level 0/Category II. After a maneuver is accomplished (see 2.7.4, following) the performance is evaluated to improve the performance of following maneuvers.

2.7.2.6.1   Verify Maneuver Accuracy. The accuracy of both North/South and East/West Maneuvers is verified by the same procedure. The commanded ΔV is compared with the results of the post maneuver orbit determination solution. This is used to check thruster performance. Propellant usage and center of gravity predicts are compared with the propellant state derived from telemetry. The navigation software data base is updated as necessary to improve maneuver performance.

2.7.2.6.2   Assess Ephemeris Computation Accuracy. The predicted ephemeris from the pre-maneuver orbit determination is compared with that from the post-maneuver orbit determination. Station limits behavior is compared with that predicted. As a result of these comparisons, the navigation strategy may be modified or the environmental models may be changed to improve the ephemeris accuracy.

2.7.2.6.3   Assess Current Propellant Status Effect on Navigation Strategy. This provides an adaptive capability to adjust the maneuver strategy based on fuel status. Propulsion efficiency will change from the beginning to the end of S/C life, and fuel tank failures are possible. Such changes require modifications to maneuver strategy such as deleting North-South maneuvers or changing the timing or dead bands of East-West maneuvers.

2.7.3   Command Maneuvers (See Section 2.4.2)

2.7.4   Maneuver Spacecraft

Less than 24 maneuvers per year are to be required (this is a ground resources constraint). Four types of maneuvers are performed: 1) adjustments to the initial orbit inclination and orbit eccentricities immediately after launch/injection, 2) East-West stationkeeping maneuvers, 3) North-South stationkeeping maneuvers, and 4) Station Repositioning maneuvers. The strategy is similar for all four. Attitude control is maintained during all maneuvers with the following tolerances:

```
Initial Orbit Trim:    Pitch  +1.0°
                       Roll   +1.0°
                       Yaw    +2.0°

Stationkeeping
Maneuver:              Pitch  +0.1°
                       Roll   +0.1°
                       Yaw    +1.0°
```

The frequency of in-plane (East-West) Stationkeeping maneuvers is a function of both the nominal station longitude and the allowable dead band. Using the most optimistic assumptions, about 75% of the longitudes will require an East-West Stationkeeping maneuver every 30 to 60 days, for a +0.1° dead band. This is illustrated in Figure 2-7, which plots a typical station longitude segment vs. the frequency of maneuvers for several dead band values. When errors in the orbit determination, maneuver execution, and a complete force model are considered, the time between East-West maneuvers could decrease to 10-15 days. North-South maneuvers will be required less often, but use more propellant.

2.7.4.1   Maneuver.

2.7.4.1.1   Select Thrusters - Level 0/Category I. The ground selects North-South or East-West thrusters depending on the type of maneuver. East-West maneuvers are performed by the attitude control pitch or yaw thrusters. North-South maneuvers are performed by dedicated North or South thrusters. Selection of redundant thruster pairs is also made for resource management/integrity maintenance.

2.7.4.1.2   Select Tanks - Level 0/Category I & II. The ground selects hydrazine tanks for center of mass (CM) control and hydrazine resource management.

2.7.4.1.3   Warm-up Catalyst Bed - Level 3/Category I & II. Catalyst Bed Heater switch-on is directed by the ACS or by ground command. Telemetry verifies switch closures and catalyst bed temperature.
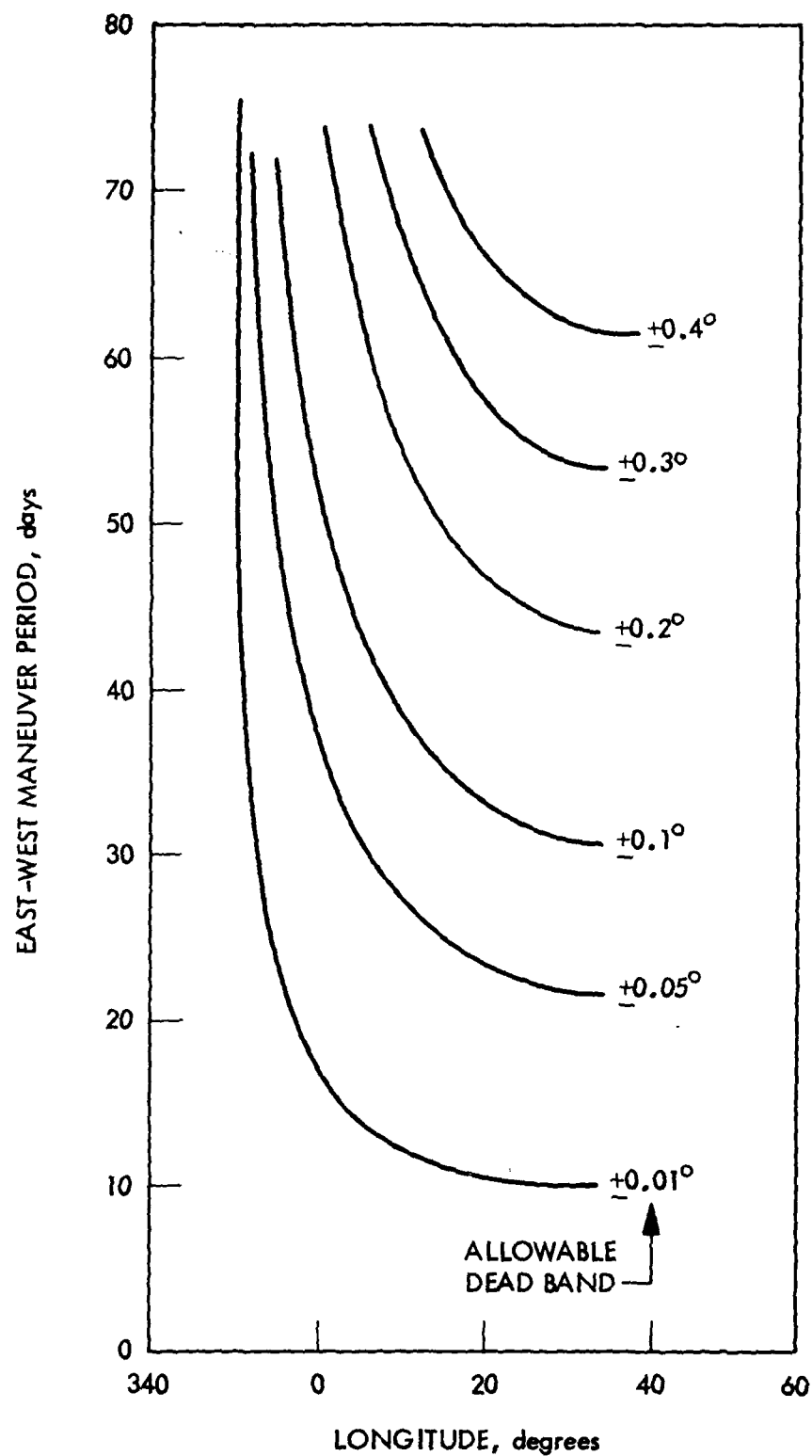
Figure 2-7. Approximate Maneuver Period for East-West
Stationkeeping Typical Longitude Band
(Based Upon Gravitational Perturbations Only)

65

2.7.4.1.4   Direct/Control Maneuver - Level 2/Category I. The ground
transmits attitude control parameters and the computed ΔV duration to the ACS.
The ground initiates the maneuver. The ACS controls attitude with the
thrusters and terminates ΔV thrusting after the preset duration.

2.7.4.1.5   Fire Thrusters - Level 3/Category I. Thrusters fire for preset
duration.

2.7.4.2   Maintain Attitude During Maneuvers - Level 3/Category I.
Preferred mode of attitude during maneuvers is ΔV pulse-off. Reaction wheels
may also be used for East-West maneuvers in which the thrust from the selected
pair is well balanced. In addition, both reaction wheels and pulse-off may be
used together.

2.7.4.2.1   Sense Attitude. The Earth sensor senses pitch and roll
attitude. The sun sensor senses yaw attitude.

2.7.4.2.2   Direct/Control Attitude Maintenance. Pulse Off vs Reaction
Wheel Mode is selected. The ground commands the ΔV mode and reaction wheel
bias for pulse off mode. The ACS logic disables the reaction wheels and
removes the pitch momentum bias. The ACS provides a reaction wheel motor
drive signal to disable the wheels. If reaction wheels are not disabled they
continue to be directed to spin up/down to maintain attitude. The ACS selects
outer and/or inner control loops. For the pulse-off mode, the outer loop
2-second update mode is selected for the axis which will be controlled. Inner
or outer loops are selected for the other two axes by the ground. In the
pulse-off mode, the ACS control loop directs the selected thruster of a pair
to stop firing for short times so that attitude control is maintained.

2.7.4.2.3   Maintain Attitude. In the pulse-off mode, the selected thruster
pulses to control attitude. In the reaction wheel mode, the reaction wheel
drive motor spins wheels up or down.

SECTION 3

MANAGE RESOURCES

Management of depletable spacecraft resources is conducted both to carry out the service functions and to maintain the integrity of the spacecraft. At present, two types of resources can be managed by the spacecraft: power resources and propulsion resources. Resource management is currently a ground intensive function.

Another type of resource to be managed on the spacecraft is spares. However, since the substitution of functional spare elements for disfunctional elements is the basis of spacecraft failure recovery (fault correction), spares management functions are described under "Maintain Integrity", Section 4.0. When the spacecraft becomes more autonomous computing capacity, data movement capacity, data storage capacity, etc, will all become manageable resources.

Figure 3-1 shows a hierarchy of the Resource Management functions.
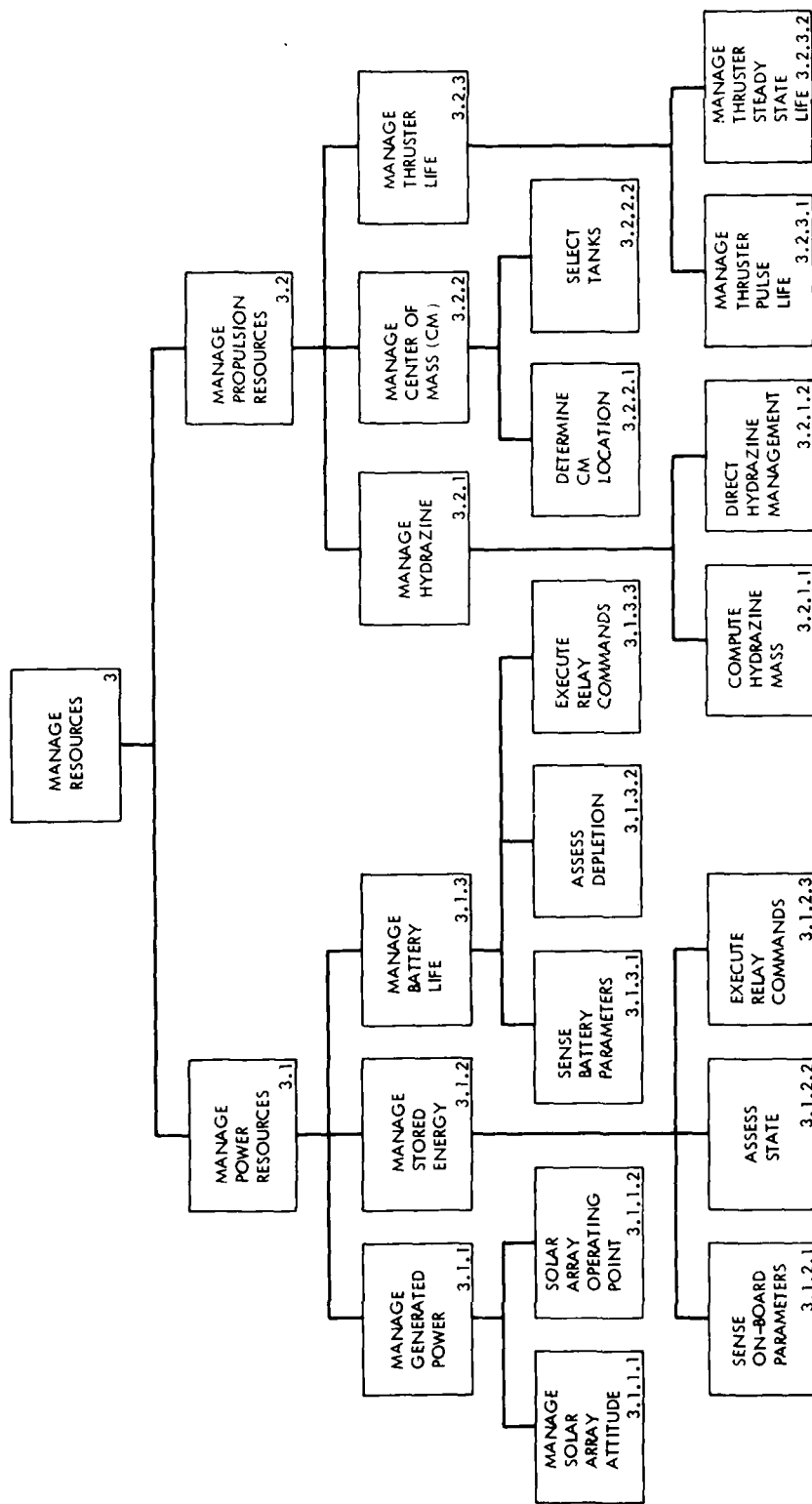
Figure 3-1. Resource Management Functional Hierarchy

3.1   MANAGE POWER*

         Three types of power resources are managed: generated power,
stored energy, and battery life.

3.1.1   Manage Generated Power

3.1.1.1   Manage Solar Array (SA) Attitude - Level 5/Category I. The SA
attitude with respect to the sun is sensed by the sun sensor and Solar Array
Drive potentiometer (SAD pot). The ACS directs and controls SA attitude,
which affects SA output. This is an autonomous capability. The SA drive
adjusts SA angle.

3.1.1.2   Solar Array Operating Point - Level 0/Category III. There is a
certain operating point (V, I) that maximizes SA output power. SA output
power is neither sensed nor controlled in DSCS III.

3.1.2   Manage Stored Energy

3.1.2.1   Sense On-Board Parameters - Level 2/Category I. Numerous SA,
load, and battery parameters are sensed on the S/C and telemetered to the
ground.

3.1.2.2   Assess State - Level 0/Category I. The ground segment assesses
net energy storage for a complete orbit using measured and/or projected
profiles of SA and load power. If it becomes necessary for energy balance,
the ground segment directs load management.

3.1.2.3   Execute Relay Commands - Level 2/Category I. Load management is
implemented by the execution of commands to open/close power distribution
relays.

3.1.3   Manage Battery Life - Category I

3.1.3.1   Sense Battery Parameters - Level 1. The voltage, current, and
temperature of each battery (three in space segment) are sensed and
telemetered to the ground.

---

*By R. C. Detwiler, T. W. Koerner and G. W. Wester

3.1.3.2   <u>Assess Depletion - Level 0</u>. Using the recent history of battery parameters, the ground segment determines the existing battery state of charge. With this information, together with projected profiles of SA and load power, the ground segment assesses the battery depth of discharge (DOD) for the next orbit, which affects battery life. If it is necessary to keep DOD $\leq 80\%$, the ground segment directs load management.

3.1.3.3   <u>Execute Relay Commands - Level 2</u>. Load management is implemented by the execution of commands to open/close power distribution relays.

3.2   MANAGE PROPULSION RESOURCES*

            Three types of propulsion resources are managed: Hydrazine
propellant, the S/C center of mass (controlled by selecting hydrazine
depletion strategy) and thruster life.

3.2.1   Manage Hydrazine

               Requirement: 10 year Lifetime

               Allocation: (first DSCS III launch carries 225 kg)

               Relocation   2.7 kg
               E-W Adjust   10.2
               N-S Adjust   139.4
               Initial Acquisition
                 and Location   62.2
               Reacquisition and
               Wheel Unload   Not Defined

                                    214.5 kg

3.2.1.1   Compute Hydrazine Mass - Level 2/Category II.

3.2.1.1.1   Sense Tank Temperature and Pressure. Transducers provide
temperature and pressure measurements for the 4 hydrazine tanks to the
telemetry.

3.2.1.1.2   Determine Hydrazine Mass. The ground computes the mass of
the remaining hydrazine from the temperature/pressure telemetry.

3.2.1.2   Direct Hydrazine Management - Level 2/Category II.

3.2.1.2.1   Select Thrusters. The ground selects thruster banks by using
the reaction wheel unloading impulse. The ACS stores this thruster selection
until it is changed by ground command.

3.2.1.2.2   Select Stationkeeping Strategy. When the depletion of the
hydrazine mass is determined to be endangering mission lifetime, N-S
stationkeeping is reduced to conserve hydrazine.

_____

*By R. W. Rowley

3.2.1.3   Reduce N-S Stationkeeping - Level 0/Category III. For the first DSCS III launch, discontinuation of N-S stationkeeping is anticipated after 7 years, to preserve attitude control and E-W stationkeeping capabilities for the 10 year lifetime.

3.2.2   Manage Center of Mass (Requirement = $\pm$2.5mm along yaw axis)

3.2.2.1   Determine Center of Mass Location - Level 1/Category I. The ground computes center of mass location from hydrazine-mass-remaining calculations. Center of mass location knowledge is used in maneuver planning.

3.2.2.2   Select Tanks - Level 2/Category I. The ground selects tank and latch valve configuration for attitude control and maneuvers so that the center of mass will be maintained within the requirement. This control is required for maneuver accuracy.

3.2.3   Manage Thruster Life

Thruster Life Requirements:

(1) Pulse mode

42,000 pulses per thruster

(2) Steady state

200,000 N-sec per thruster (equivalent to to $\approx$ 90 kg hydrazine)

3.2.3.1   Manage Thruster Pulse Life - Level 2/Category II.

3.2.3.1.1   Sense Accumulated Pulses. The number of pulses must be inferred from available telemetry and estimates of system performance during pulse modes.

3.2.3.1.2   Manage Thruster Utilization. The ground determines if thrusters can meet remaining mission life without exceeding the pulse limits. If not, mission sequences and/or thruster selection may have to be modified to reduce the accumulated pulses.

3.2.3.2   Manage Thruster Steady State Life (Only Affects North-South Thrusters on DSCS III) - Level 2/Category III.

3.2.3.2.1   <u>Determine Accumulated Steady-State Impulse.</u> The ground determines the total accumulated thruster on-time and/or propellant throughput.

3.2.3.2.2   <u>Manage Thruster Utilization.</u> The ground determines if thrusters can meet remaining mission lifetime requirements. If not, alternate thrusters are selected or the sequence is modified to reduce North-South stationkeeping.

SECTION 4

MAINTAIN INTEGRITY OF DSCS III SYSTEM

Integrity maintenance encompasses both routine activities which keep the spacecraft operating normally, and activities which correct faults or failures. Integrity maintenance is also called health and welfare maintenance. Functions which protect the spacecraft against predictable events which would impair normal operations are discussed in this section.

Integrity maintenance is primarily ground directed. In particular, almost all unexpected fault correction is done with ground analysis and direction using information contained in the telemetry stream.

Functions for which integrity maintenance is discussed are:

(1) The spacecraft as a whole.

(2) Power

(3) Attitude Control

(4) Thermal Control

(5) Spacecraft Control and Monitoring

(6) Propulsion

(7) Stationkeeping

Figure 4-1 displays a hierarchy of the integrity maintainance functions. Each function's description includes its own, lower-level hierarchy.
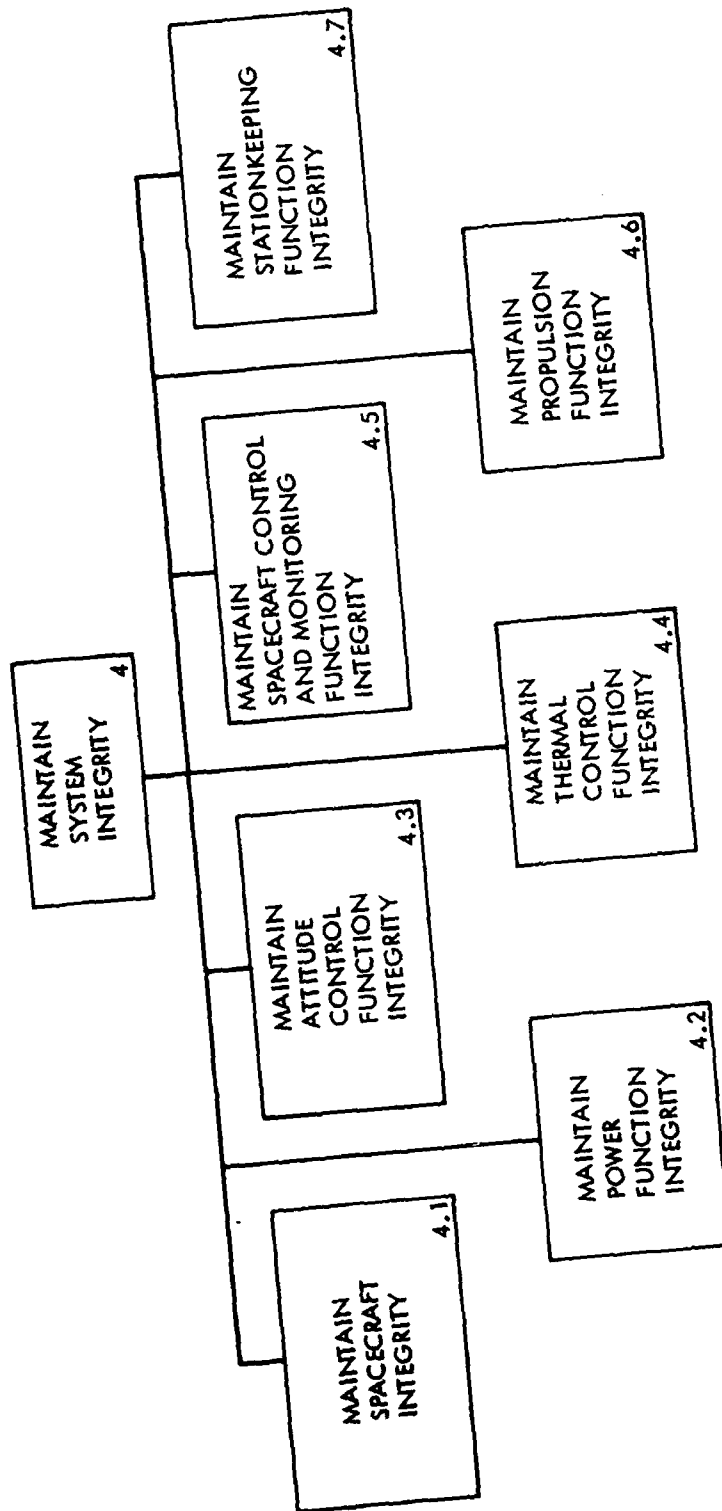
Figure 4-1. Integrity Maintenance Functional Hierarchy

75

4.1   MAINTAIN S/C INTEGRITY*

4.1.1   Acquire S/C Health Information

Each function in the S/C provides state telemetry from which health of the function can be inferred. A telemetry data stream containing system and subsystem health status information is generated on the spacecraft by the TT&C Master Telemetry Unit (MTU) and transmitted to the earth via a modulated RF carrier as part of the Spacecraft Control and Monitoring Service described in 2.4.1. This signal is received by a Remote Tracking Station (RTS) over the S-Band telecommunications channel. The telemetry link is also received over the SHF (X-Band) telemetry link by the EDM-SCCE stations and by the payload user terminal. The S-Band link, however, is the primary link for health and maintenance functions. The RTS uses an analog tape recorder to store the received telemetry signal on tape for subsequent demodulation and decryption. The stored telemetry signal is 1) read from tape, 2) demodulated, 3) decrypted, and 4) routed to the RTS Univac 1230 computer.

4.1.2   Analyze Spacecraft Health Information

The telemetry data received by the RTS Univac 1230 computer is decommutated and individually selected measurement data is separated from the composite telemetry stream for processing. Selected measurements are limit checked and displayed to provide definitive information on spacecraft health status. The STC provides telemetry processing requirements in the form of ground telemetry modes prior to each RTS station pass. These modes are specified in the form of pre-canned telemetry mode software and are used to process subsets of telemetry data where each is associated with a particular spacecraft function assessment. The RTS sends the processed telemetry and alarm violation data to the MCC of the STC where it is stored, displayed, and analyzed by operations personnel under the direction of the Mission Controller.

4.1.3   Generate Redundancy Management Commands

The Mission Controller within the MCC of the STC coordinates ground operations which require the definition and approval of command requests required for spacecraft redundancy management. MCC operations personnel request necessary command operations for spacecraft redundancy management. The command requests are approved by the Mission Controller for processing by MCC operations personnel. Command software in the CDC 3800 computer is used for processing command requests. The command file generated by this software is combined with antenna pointing data and input to a Varian V-73 computer for formatting with telemetry processing directives.

---

*By W. E. Arens

76

4.1.4   Process Redundancy Management Commands

        Processing commands for spacecraft redundancy management
involves 1) encryption, 2) modulation of an RF carrier, 3) transfer to the
TT&C subsystem in the spacecraft via an RF link, 4) demodulation, 5)
decryption, 6) decoding, and 7) distribution. The latter four functions are
accomplished by the TT&C subsystem as part of the Spacecraft Control and
Monitoring Service described in 2.4.2. The actual execution of a command
following issuance is accomplished by appropriate switching and control
circuits at the command address destination. The command data from the STC is
received at the RTS by a Univac 1230 computer. Spacecraft-unique software
within the Univac 1230 computer at the RTS is used to generate a command table
from the received command data. The command data to be transmitted is
encrypted and used to modulate an RF carrier which is then transmitted to the
spacecraft by the Operations Controller over the S-Band or SHF
ground-to-spacecraft telecommunications link. The modulated RF carrier is
received by the TT&C RF equipment and demodulated. The resultant command data
is decrypted by appropriate decrypters in the TT&C RF equipment and
subsequently routed to the TT&C Command Decoder (CD). The TT&C CD determines
the command type and address to which a command is to be issued. It then
distributes the decoded command to the proper internal or external address
resulting in the switching of redundant elements in the designated subsystem.

4.2   MAINTAIN S/C POWER FUNCTION*

          The spacecraft power function is maintained by providing
isolation and protection from user load anomalies, reconfiguring the power
subsystem by switching elements and conditioning the batteries when required.
In the event of a complete battery chain failure the power function configures
the spacecraft to operate on solar panels only.

          Figure 4-2 shows the hierarchy of the Maintain Power Function.

4.2.1   Provide Isolation/Protection from User Load Anomalies -
               Category I

4.2.1.1   Isolate Load Faults - Level 3. Spacecraft load fault currents
are sensed and controlled automatically via a fuse function whose inherent
design removes the faulted load from the primary or secondary bus. Fuse sizes
depend on individual user load requirements.

4.2.1.2   Protect Power Bus from User Overloads - Level 1.

4.2.1.2.1   Sense Overcurrents. Load overcurrents are sensed from load
current monitors in the North and South Panel distribution bus lines. An
overcurrent condition is determined by ground segment analysis of the
particular power profile.

4.2.1.2.2   Direct Overcurrent Protection. The spacecraft is directed to
remove the over-current condition after ground analysis of the actual in-orbit
power profile vs predicted power profile has determined a faulted load.
Alternatively, the degraded load condition is accepted and the space segment
power profile is adjusted to accommodate the overload.

4.2.1.2.3   Switch Loads. The spacecraft acts by switching off the faulted
load in the particular power controller, or by switching other loads to
provide the required load management function.

4.2.2   Provide Power Function Protection from Internal Faults -
               Category I

4.2.2.1   Protect Against Battery Chain Failure - Level 2. Battery chain
failures are presently detected through a review of telemetered battery
temperature, voltage, and current data. Based on analysis of the data a
failed battery is removed from the bus by turning off its Battery Charge

---

*By R. C. Detwiler, T. W. Koerner, G. W. Wester
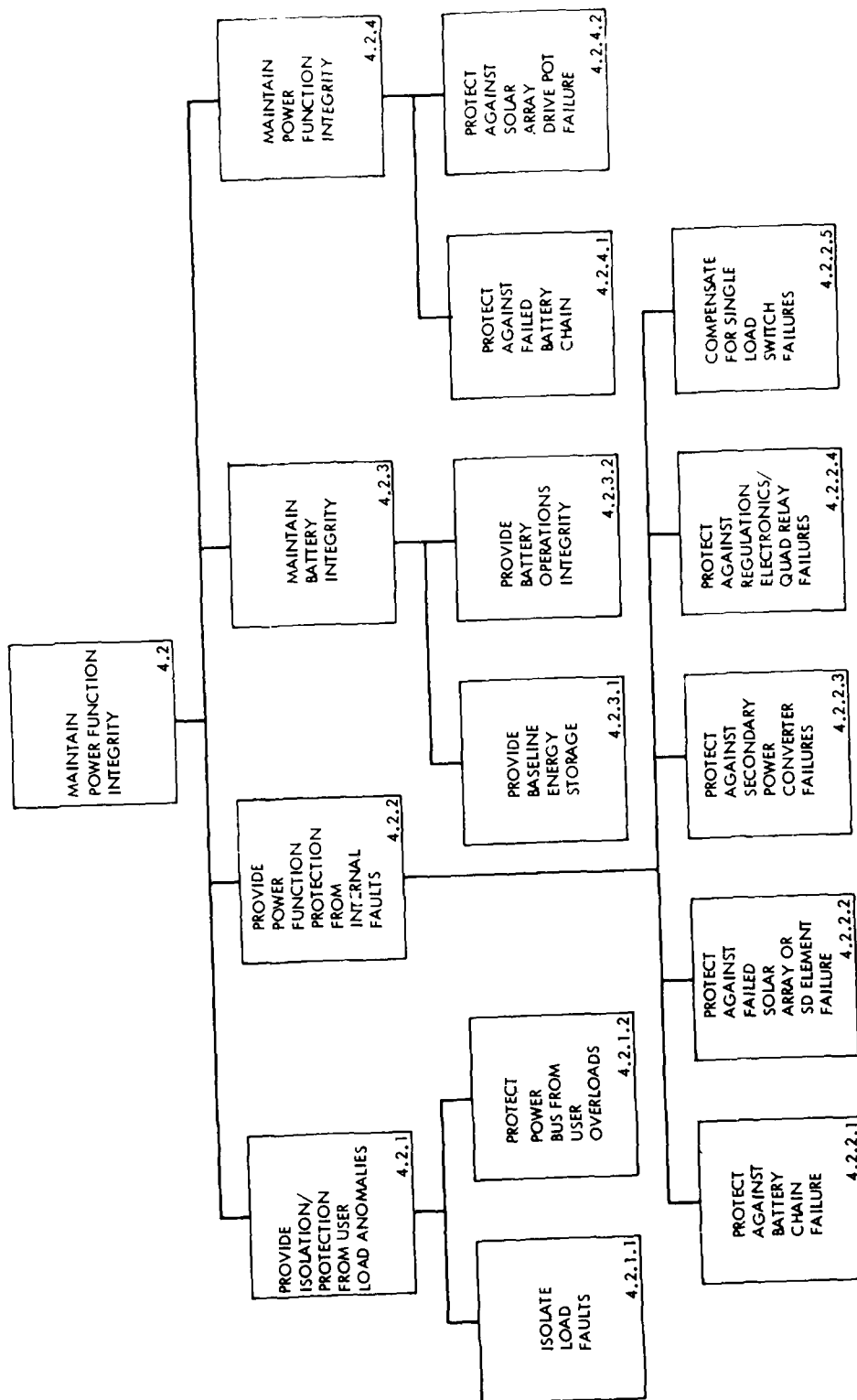
Figure 4-2. Spacecraft Power Integrity Maintenance Functional Hierarchy

Regulator (BCR). Spacecraft operations with one or two failed batteries requires load management to meet the 80% battery Depth of Discharge (DOD) requirement. The power required for heaters has a direct bearing on load management requirements as the thermal loads can cycle on at any time. Peak load demands during the day at equinox must also be scheduled such that the batteries can be recharged. Spacecraft operations on one battery in eclipse requires almost survival mode conditions, due to the uncertainties in thermal load requirements with a majority of the subsystems and payload turned off. Operation with all batteries failed requires load management to keep peak load demands below the capability of the solar array and special attitude control functions prior to spacecraft power down during eclipse.

4.2.2.1.1   Sense Battery Parameters. Individual battery current, voltage and temperature are sensed on the spacecraft:

Normal Battery Characteristics

Current:	Charge	-	0 to 5 amperes, 10 amperes, maximum peak at start of charge
	Discharge	-	0 to 29 amperes
	Voltage	-	18.4 to 23.1 VDC
	Temperature	-	$0^{o}C$ to $20^{o}C$

4.2.2.1.2   Direct Battery Chain Charge Controls. Spacecraft battery charge controls are directed from the ground segment, to determine the type of battery anomaly. The ground may modify charging conditions, remove the battery from bus or accept degraded battery/ battery charge regulator operation by revising the spacecraft power profile, or switch off the battery charge regulator if the battery has failed.

4.2.2.1.3   Switch Battery. The spacecraft acts by switching to an alternate voltage/temperature curve or switching off the battery charge control to remove the battery from the bus.

4.2.2.2   Protect Against Solar Array or Shunt Dissipator Element Failure - Level 3. Failure of a single element reduces source power by less than 3.3% and is isolated from failure propagation automatically by the nature of the circuit design.

4.2.2.2.1   Detect Failure. Abnormal solar array degradation is sensed through ground segment analysis of energy balance and battery Depth of Discharge (DOD) over an orbit. Solar array power capability can only be measured indirectly when no power is being shunted and the thermal load power is known, so a 3.3% down delta in output power may not be instantly determined.

80

4.2.2.2.2   Direct Power Management. The spacecraft is directed from the ground segment into power management of the load profile that preserves both energy balance and the DOD criteria.

4.2.2.2.3   Switch Loads. The North and South Power Controllers act to recover by switching spacecraft loads as required.

4.2.2.3   Protect Against Secondary Power Converter Failures - Level 2.

4.2.2.3.1   Sense Failure. Abnormal North/South Power Controller currents/and or user load malfunction are sensed via routine checks of spacecraft telemetry by the ground segment. Converter over-current or failure condition detection is dependent on the particular power profile in operation on the space segment.

4.2.2.3.2   Isolate Failure. The spacecraft North and South Power Controllers are directed from the ground segment through a converter check routine to determine that a converter has failed.

4.2.2.3.3   Replace Converter. The failed converter is replaced with the redundant converter via relay switches in either Power Controller.

4.2.2.4   Protect Against Regulation Electronics/Quad Relay Failures - Level 5. These functions recover from single point failures automatically via inherent design features within each of the circuits. Any single point failure will be corrected without space or ground segment knowledge of the event.

4.2.2.5   Compensate for Single Load Switch Failures - Level 1.

4.2.2.5.1   Sense Failure. Abnormal load switch operation and or user load malfunction are sensed via routine checks of spacecraft telemetry/operation by the ground segment.

4.2.2.5.2   Isolate Failure. The spacecraft load switches in the North/South Power Controllers are directed to determine relay switch failure by ground commands.

4.2.2.5.3   Work Around Failure. Ground segment operations act to work around relay failures.

4.2.3   Maintain Battery Integrity

4.2.3.1   Provide Baseline Energy Storage - Level 1/Category II.

4.2.3.1.1   Maintain Baseline Energy Storage Capacity. Either of the
following is sensed: a) battery energy storage capacity degradation by
ground segment analysis of battery telemetry voltage/current data and length
of eclipse or b) battery power draw time.

     Battery reconditioning conditions:

     Eclipse Period   -   72 minutes maximum

     DOD   -   70% (with SCT on)

     Voltage   -   below 19.0 VDC
     (all other conditions normal)

     The need for battery reconditioning is determined by ground
analysis of recent battery operation (i.e., battery parameter degradation)
prior to the start of the eclipse season.

4.2.3.1.2   Direct Conditioning. The battery reconditioning function is
directed by ground segment commands.

4.2.3.1.3   Recondition Battery. A battery is reconditioned by switches in
the PRU that turn off the BCR and switch on the battery recondition mode.

4.2.3.2   Provide Battery Operations Integrity - Level 3/Category I.

4.2.3.2.1   Control Battery Temperature. Battery temperature is sensed to
be greater than $32^{\circ}C$ by spacecraft sensor/ground analysis. The battery
charger is directed to stop charging automatically and battery charging is
stopped by switching functions in the Power Regulation Unit.

4.2.3.2.2   Control Battery Discharge Time. The battery discharge time-out
is sensed to be greater than 80 minutes by the spacecraft timer. The
spacecraft is directed to remove nonessential loads automatically and loads
are removed by switches in the North/South Power Controllers.

4.2.3.2.3   Control Battery Survival Mode. Loss of earth lock is sensed in
the Attitude Control Subsystem of the S/C. The Power Subsystem is directed to
automatically remove nonessential loads and the ACS. These loads are removed
by switches in the North/South Power Controllers.

4.2.4   Maintain Power Function Integrity

82

4.2.4.1   Protect Against Failed Battery Chain - Level 2/Category I.

         If all batteries have failed the S/C must depend only on solar array power and must therefore be configured to go through solar and lunar eclipses with a minimum of disruption of the power and ACS sources.

4.2.4.1.1   Sense Battery Chain Failure. The power function senses and the ground determines that all batteries have failed.

4.2.4.1.2   Direct Eclipse Compensation. The ground prepares the spacecraft for solar and lunar eclipse by loading command sequences shortly before occurrence of the eclipse.

4.2.4.1.3   Compensate for Eclipses. The solar array is pointed correctly to maximize power upon exit from the eclipse. In addition, power loads are shut down, the reaction wheels are manually unloaded and the thruster logic is disabled. After eclipse exit these events are reversed, i.e., loads are switched on and thruster logic is enabled. The solar array position is set to the true orbit position by enabling the circularization mode. These functions are controlled from the ACS.

4.2.4.2   Protect Against Solar Array Drive Potentiometer Failure - Level 2/Category I.

4.2.4.2.1   Determine SAD Position. The ground determines from the telemetered SAD pot data that the reading is different from the expected solar array position.

4.2.4.2.2   Switch SAD Pot. The ground commands a switch to the redundant SAD pot.

4.3   MAINTAIN S/C ATTITUDE CONTROL*

            The attitude control function is maintained through routine
health checks and maintenance, reconfiguration for both expected and
unexpected external events, and device failure detection and correction.
Attitude control maintenance is accomplished by mode selection in and
reprogramming of the ACS electronics. The hierarchy of attitude control
maintenance functions is shown in Figure 4-3.

4.3.1   Perform Routine Health Checks and Maintenance

4.3.1.1   Perform Data Transfer Handshakes - I/O Ports - Level 4/
               Category I. The ACE computer is described in Appendix C. The
computer performs checks of data transferred between the CPU and various I/O
ports to ensure correct transmission/reception.   These handshakes occur
between:

               (1) CPU - Reaction Wheel Port
               (2) CPU - Thruster Control Port
               (3) CPU - Solar Array Drive Port
               (4) CPU - BFN port
               (5) CPU - Gimbal Dish Antenna Drive Port
               (6) CPU - Sensor Signal Port
               (7) CPU - Telemetry Port
               (8) CPU - Command Port
               (9) CPU - Nuclear Event Detector

4.3.1.2   Sense Device State - Level 2/Category I. Various devices
provide telemetry information on the status of their power, temperature,
switch positions, rates, positive/negative orientations, redundant component
selection, etc.

               Devices providing this information are:

               (1)   Earth Sensor
               (2)   Sun Sensors
               (3)   Rate Gyro
               (4)   Reaction Wheels
               (5)   Thrusters
               (6)   Solar Array Drives and Pots
               (7)   BFN Port
               (8)   Gimbal Dish Antenna Drives
               (9)   Sensor Signal Conditioning Ports: A/D Converter and MUX
               (10) Telemetry Port
               (11) Serial Message Port

---

*By S. H. Graff, E. P. Kan, J. R. Matijevic, and E. Mettler
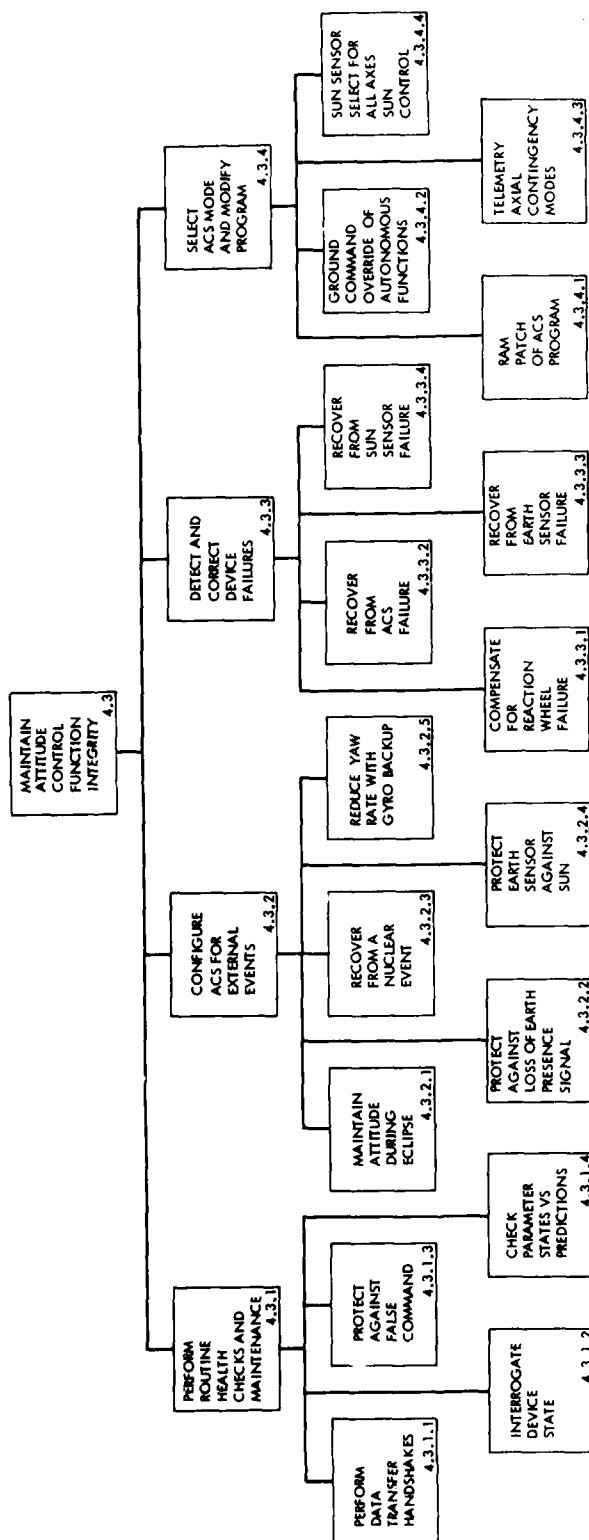
Figure 4-3. Attitude Control Integrity Maintenance Functional Hierarchy

(12) Nuclear Event Detector
(13) Clock and Timing Port
(14) ACE Power Supply
(15) Initiation Timer
(16) Memory

The information is used by the ground to infer the health status of the Attitude control function.

4.3.1.3 Protect Against False Command - Level 4/Category I. Discrete commands, which involve no change in critical spacecraft subsystems, are automatically enabled and executed. No extra protection is implemented. Certain discrete commands, involving a change from normal modes of operation, require an "enable, execute" command sequence. A special "Enable" command allows for "enabling" a collection of discrete commands before a "clear" ends the enabled stream of commands: (enable, -----, clear). These are filtered through the command decoder for the sequence check. Special message commands are processed through the decoder with (1) an "enable" of nominal stored commands disable (2) an "enable" of ground command dead bands, and biases and (3) data words containing the ground commanded values.

Other message commands are used for controlling GDA and BFN components as well as setting certain modes of operation in the ACE. These commands contain "enables" and "executes."

Four "enable" commands

Enable 1: Provides enabling of the commands:

- Reaction wheel P-Y(+) OFF and EXECUTE
- All N-S thrusters, heaters and ports off and execute
- Auto sun bias update disable
- HRAM #5 off and execute
- HRAM #6 off and execute
- Failed battery mode disable

Enable 2: Provides enabling of the commands:

- Reaction wheel P-Y(-) off and execute
- Thruster logic disable
- Nominal stored commands disable
- 2 second update
- Roll positive sun sensor B to roll differentials B select
- Lunar Eclipse mode select
- HRAM #7 off and execute
- HRAM #8 off and execute
- Thruster & Cat. Bed Htr. for pitch A/B off

- Thruster & Cat. Bed Htr. for roll A/B off
- Thruster & Cat. Bed Htr. for yaw A/B off
- Auto Sun Stabilization Enable

Enable 3: Provides enabling of the commands:

- Reaction wheel P-R(+) off and execute
- SAD A power on for backup
- SAD A power off and execute
- Pitch sun sensor control selected
- HRAM #1 off and execute
- HRAM #2 off and execute
- Yaw sensor LSB reset
- Thruster/CBH Power control override disable

Enable 4: Provides enabling of the commands:

- Reaction wheel P-R(-) off/execute
- SAD B power on for backup
- SAD B power off and execute
- HRAM #3 off and execute
- HRAM #4 off and execute
- Roll sun sensor control select
- Yaw sensor select MSB reset

Message Commands:

The following data may be sent after the commands which enable
'nominal stored command disable' (See Enable 2) and allow for
the enabling of 'commanded dead bands and biases.'

- Pitch bias
- Roll bias
- Yaw bias
- Pitch thruster dead band
- Roll thruster dead band
- Yaw thruster dead band
- Pitch thruster rate increment
- Roll thruster rate increment
- Yaw thruster rate increment
- Pitch wheel unload start time
- Pitch wheel unload stop
- SAD rate adjust
- Pitch thruster pulse width
- R/Y axis wheel unload start time
- R/Y axis wheel unload stop time
- Roll thruster pulse width
- Yaw thruster pulse width
- Pitch connection bias
- Yaw gain circularization
- Roll solar array misalignment bias
- Roll dead band offset
- Pitch dead band offset

- Yaw dead band offset
- Sun sensor processing count gain
- Sun sensor processing level gain
- Roll update of yaw gain

4.3.1.4 Check Parameter States vs Predictions - Level 4/Category I.

4.3.1.4.1 Attitude Health Check. Pitch, Roll and Yaw (P, R, Y) are sensed to be outside maximum limits of 0.25 deg (P, R) and 2.5 deg (Y) during nominal orbit modes. Attitude control is recovered by: acquiring the sun, acquiring the earth, selecting for yaw control, selecting for normal mode, etc.

4.3.1.4.2 Solar Array Position Check. The array is sensed to be outside of +2 deg of true orbit position. The ACS can switch to the backup POT's and pitch sun sensor, and perhaps the backup sensor port. The solar arrays can be slewed if necessary.

4.3.1.4.3 Yaw Drift Performance Check. The yaw drift is sensed to be greater than 1.5° over last deweighting period. The values for sun bias and for the RACC can be manually set. A switch to the pitch sensor is possible for yaw control, and the RACC is autonomously disabled if the anomaly continues.

4.3.1.4.4 Sun Bias Check. If the sun bias value is sensed to be not within 0.25° of the predicted value the sun bias declination angle can be updated manually.

4.3.2 Configure ACS for External Events

4.3.2.1 Maintain Attitude During Eclipse - Level 2/Category I.

4.3.2.1.1 Compensate for Solar Eclipse. The ground navigation function determines the parts of the orbit and parts of the day (around midnight, no more than 72 minutes) when the solar eclipse will occur. No special action takes place because the eclipse only affects the sun sensor which drives the yaw control normally. The yaw noon/midnight controller takes control around midnight anyway.

4.3.2.1.2 Compensate for Lunar Eclipse. The ground function determines when a lunar eclipse will take place. If the sun intensity is predicted to fall below 40% of normal intensity, the lunar eclipse mode is enabled. If the eclipse is to fall within noon or midnight +40 minutes, this mode is not enabled. The lunar eclipse mode is enabled, by the ground, shortly before the eclipse occurs. If the lunar eclipse mode is enabled the yaw axis controller deweights the yaw control signal by one-half. RACC is applied to yaw control signal. The auto RACC update mode is bypassed.

4.3.2.2   Protect Against Loss of Earth Presence Signal - Level 3/
             Category I.

4.3.2.2.1   Sense Loss of Earth Presence. The earth presence sensor shows
no response.

4.3.2.2.2   Direct S/C Reconfiguration. The ACS autonomously directs the
S/C to a survival mode.

4.3.2.2.3   Enter Survival Mode. The ACS signals the power subsystem to
turn off nonessential loads including the X-Band (SHF) equipment and the SCT.
The power subsystem disables control heaters (but survival heaters cannot be
disabled), and turns on the S-Band downlink. The ACS turns off the ACE to
safe against thruster firings. Loss of earth presence is signalled to the
ground, which determines appropriate action.

4.3.2.3   Recover from a Nuclear Event - Level 5/Category I.

4.3.2.3.1   Sense Occurrence of Event. Three nuclear event detectors detect
radiation presence above a preset threshold.

4.3.2.3.2   Direct Recovery. The ACS computer has a recovery sequence in
ROM which reconfigures the ACS control logic to a normal operational state.

4.3.2.3.3   Recover from Event. The CPU and CPU-event flags are reset. The
thruster enable is reset. The HRAM write is disabled and the telemetry is
reset. After a telemetry sync pulse is received the CPU is turned back on.
The CPU then executes the nuclear safeing software which clears the RAM and
CPU, reloads the HRAM parameters into the RAM and resets BFN software flags.
The use of earth sensor signals is inhibited for 5 seconds and sun sensor
signals for 300 seconds, in order to allow transients to die down.

4.3.2.4   Protect Earth Sensor Against Sun - Level 5/Category I.

4.3.2.4.1   Sense Sun Intrusion. Eight sun detectors are collocated with the
eight earth presence detectors. These automatically detect the presence of the
sun.

4.3.2.4.2   Protect Earth Sensor. The earth sensor electronics shut off the
threatened earth sensor as well as the sensor on the opposite side of the
circular array.

4.3.2.4.3   Resume Sensor Operation. After the sun has left the sensor fields of view, normal earth sensor operation resumes.

4.3.2.5   Yaw Rate Reduction with Gyro Backup - Level 2/Category I. The ground initiates this mode for post-launch operations and as required for reacquisition of sun and earth, or as a backup for yaw control to the sun/earth sensors. The gyro is turned on by the ground, to be used for yaw rate control.

4.3.3   Detect and Correct Device Failures

4.3.3.1   Compensate for Reaction Wheel Failure- Level 2/Category I.

4.3.3.1.1   Determine Failure Mode. Each reaction wheel's (R/W) tachometer reading is telemetered to the ground. If the absolute value of the rotation is less than 150 counts the reaction wheel and/or the tachometer is assumed to be faulty. If the absolute value of the rotation is between 64 and 150 counts possible wheel degradation has occurred. If the tachometer reading is zero the tachometer is assumed to be faulty. If the wheel is considered to be degraded but not failed, surveillance of the wheel is continued.

4.3.3.1.2   Direct Failure Recovery. Failure recovery is by ground command. The first step is to switch the redundant tachometer. If this does not solve the problem the autonomous momentum management is disabled and the faulty wheel is switched off. To maintain attitude control the opposite wheel is set to double gain.

4.3.3.1.3   Recover from R/W Failure. The faulty wheel is switched off and the opposite wheel performs its function.

4.3.3.2   Recover from Attitude Control Electronics (ACE) Failure - Level 2/Category I.

4.3.3.2.1   Detect Failure. A loss of attitude and/or ACE telemetry indicates an ACE failure. The ground determines the type of failure from trace words in the ACE telemetry.

4.3.3.2.2   Direct Failure Recovery. The ground examines the trace words and commands necessary swapping of RAM's, ROM's, CPU's, power supplies, A/D and MUX units.

4.3.3.2.3   Recover from Failure. Ground command swapping continues until failure is corrected.

4.3.3.3   Recover from Earth Sensor Failure - Level 2/Category I.

4.3.3.3.1   Detect Failure. The ground investigates attitude telemetry. An erroneous pitch and roll attitude suggests a possible earth sensor or earth sensor electronics error.

4.3.3.3.2   Recover From Failure. The ground selects switching between redundant earth sensor electronics. When one specific earth sensor (out of eight) is determined to have failed, the pair of detectors containing the failed one is switched off.

4.3.3.4   Recover from Sun Sensor Failure - Level 2/Category I

4.3.3.4.1   Detect Failure. Erroneous sun sensor (SS) signals and yaw attitude control suggest possible pitch SS and/or roll SS failures. Redundant SS readings are compared to determine the health of SS. The SS with the smaller and near-zero reading is assumed faulty.

4.3.3.4.2   Recover from Failure. The ground selects switching on and off redundant sensors and amplifiers.

4.3.4   Select ACE Modes and Modify Programs

4.3.4.1   RAM Patch of ACE Program - Level 2/Category III. A tested program patch is placed in the redundant RAM, if available. The RAM patch enable and execute flags are set. When a breakpoint is encountered in the program, a 'patch' table is checked for a patch for this part of the program. When found, the patch is executed. A return is made to some spot in the program which may be the instruction after the breakpoint.

4.3.4.1.1   Sense. When a 'fix' has been found and tested for anomaly, the patch enable and execute flags are sensed at breakpoints.

4.3.4.1.2   Direct/Control/Act. The program executes new code.

4.3.4.2   Ground Command Override Autonomous Function - Level 3/ Category III. Autonomous modes and override procedures are defined below.

4.3.4.2.1   Autonomous Sun Acquisition Disabled. This command is initiated in two cases:

(1)   Normal: Once sun acquisition has been completed, the auto sun acquisition disable command and auto earth acquisition enable commands allow autonomous auto earth acquisition to proceed.

(2)   Abnormal: Either the auto sun acquisition sequence has failed to drive the solar arrays within 2 hours of the predicted SA position or the SA position is midnight and an eclipse is predicted. In either case a sun hold mode is disabled unless the command of auto sun acquisition disable is given.

Telemetry for SA position is sent to the ground. Auto sun acquisition is disabled via ground command. In the normal mode, auto earth acquisition can proceed or, in the abnormal mode, the sun hold mode is entered.

4.3.4.2.2   Disable Autonomous Sun Declination Bias Update. The absolute value of the sun bias value minus the predicted sun bias is sensed to be greater than .25 degree. The auto sun bias mode is disabled and the ground uplinks new/old sun bias values and reenables the autonomous mode.

4.3.4.2.3   Disable Auto RACC Updates. Yaw drift is sensed to be more than 1.5 degrees and the following conditions are present:

(1) Sun bias value is correct

(2) SA position is correct

(3) Pitch momentum bias is correct.

If this anomaly occurs twice in three days the ground disables the auto RACC and commands RACC values, or uses Pitch SS to determine Yaw.

4.3.4.2.4   Disable Autonomous Solar Array Position Updates. The solar array position is sensed to be erroneous when compared with predicted position. The ground disables the auto solar array position updates, and checks the pitch sun sensor for anomalies. If an anomaly is found, the ground commands a switch to the backup SADPOT or to the backup Pitch sun sensor. If needed, the ground can switch to the backup SAD and perform a slew to the correct position.

4.3.4.2.5   Unload Reaction Wheel Manually. If one of the three tachometers has a count above 1091, the ground disables the thruster logic, selects torque modes for the thrusters and sets for thruster fire. The ground commands a manual wheel unload procedure.

4.3.4.2.6   Disable Auto Dead Band Bias Processing. Anomalies are sensed in autonomous corrections to sensor control signals during stationkeeping maneuvers. An Auto dead band bias disable command is sent by the ground, which causes processing for an autonomous correction of sensor control signals to be bypassed during the stationkeeping mode.

4.3.4.3   Telemetry "Axial" Contingency Modes - Level 2/Category I. Ground Commands set the telemetry processing to the 'Interrupt Mode'. This allows for additional ACS and BFN Data to be transmitted per each main frame (2 CPU cycles). Processing is flagged to allow 'waits' for telemetry transmission. When the special telemetry interrupt mode is set, 252 bytes is output per main frame, as opposed to the normal output of 107 formatted into 68 bytes of telemetry data.

4.3.4.4   Sun Sensor Select for all Axes Sun Control - Level 2/ Category II. One of a redundant pair of positive pitch sun sensors (North array) and one of a redundant pair of negative pitch sun sensors (South array) are selected by the ground. The ground selects one of redundant pair of positive roll sun sensors (South array). With the positive roll sensor selected, the differential amplifier is selected. In addition, the ground selects one of redundant pair of negative roll sun sensors (North array). The Pitch sun sensor is also used for yaw control in a mode where the sun declination angle >18.5 deg and where time is outside the $\pm$2 hours window about noon or midnight. The differential roll sun sensors are used to control yaw (normal mode). Individual roll sun sensors are used to control roll or yaw.

The heater circuits, with the exception of the north and south shunt panels and the north and south sun sensor assemblies, are redundant. (Although Reference states that all heater circuits are redundant.). The redundancy is complete and includes thermostats, heaters, and power lines back to the electrical power bus. The normal mode of operations is for both heaters of a redundant pair to be on.

The active components of the thermal control subsystem can operate autonomously if the control heaters are commanded on. With the control heaters commanded on, the spacecraft and its components can be kept within allowable operational temperature limits. Further, since the survival heaters are always active, the temperature of the components of the DSCS III will remain at survival temperature levels even if there is a failure of both control heater circuits. Thus, with the control heater system commanded on, the thermal control subsystem will operate autonomously. Further analysis will be required to determine lifetime capability. This system has no direct means of determining failure of any components, and this knowledge is not necessary for operation of the system as designed.

Figure 4-4 is a hierarchy of the Thermal Control Maintenance Function.

4.4.1   Detect Thermal Control Failures

The thermal telemetry data used to monitor the temperature of the components of the spacecraft consists of 149 thermistors. The location of the thermistors is shown in Table 7.2-3 of Reference 2. If the telemetry data indicates that the temperature of a specific component is out of limits, the only means of isolating failures is by trial and error.

4.4.2   Direct Recovery

4.4.2.1   Direct Recovery From Low-Side Failures. If only one of a redundant pair of heaters is on and the temperature is too low, the other heaters can be commanded on. If the temperature rises the first heater is assumed to have failed. If not, or if both heaters were already on (normal mode), both heaters are assumed to have failed. The survival heaters, which are hard wired, will automatically maintain the component at the survival temperature, unless they also fail.

---

*By R. N. Miyake and J. A. Plamondon
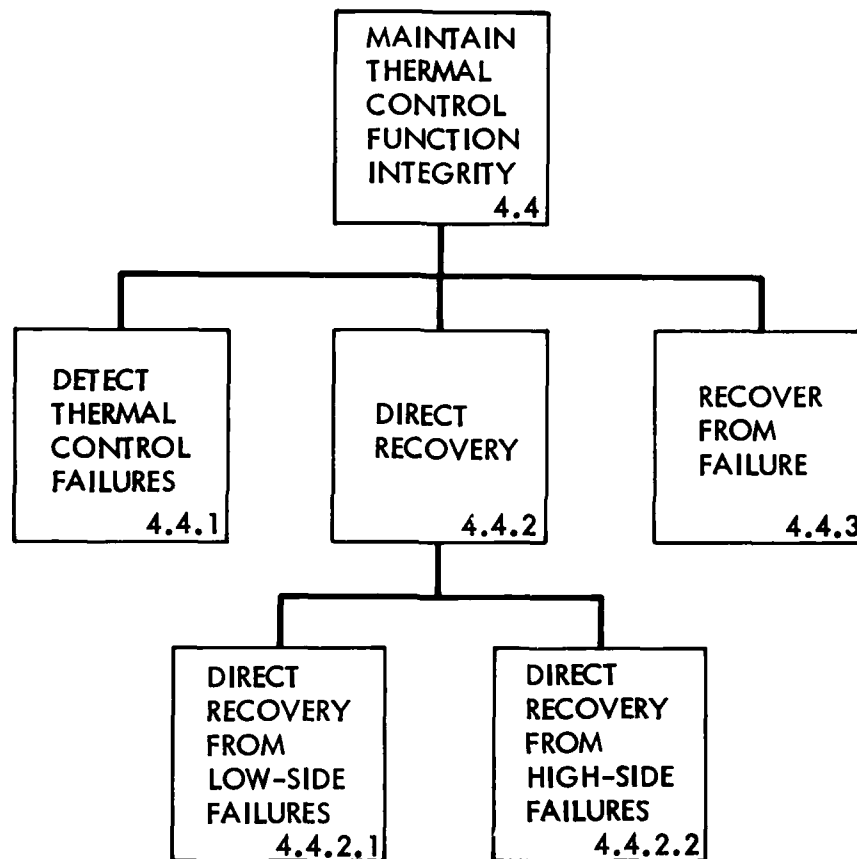
Figure 4-4. Thermal Control Integrity Maintenance
Functional Hierarchy

4.4.2.2 <u>Direct Recovery From High-Side Failure</u>. The heater circuits, which are controlled by mechanical thermostats, have both a control thermostat and an over-temperature thermostat. the electronic thermostats are all $\pm 1^{o}C$ range, thus also have over-temperature protection. If the temperature telemetry indicates that the temperature of a component is too high, one or both heaters can be commanded off, or one heater can be turned off and the other on.

4.4.3 Recover from Failure

Heater power is commanded on and off by the ground.

4.5 MAINTAIN S/C CONTROL AND MONITORING FUNCTION[*]

The service of S/C control and monitoring is "maintained" by redundancy management. The maintenance of these functions is required only in the event of a failure. A failure of the current DSCS III S/C design control and monitoring function to perform as required can only be detected by ground based operations. (The failure of the ground segment to perform will not be addressed.) If there is a failure in the control or monitor functions, other than ground cockpit error, the failure can be corrected by selection of the various "block" redundant elements in the TT&C S/C subsystem. To correct a failure the ground segment has to take action. This action typically would be to send a direct command to switch to a redundant element, change the frequency of the uplink or downlink, or change the command word preamble.

The following functions have to be maintained to complete the basic control and monitoring service functions of command and telemetry.

(1) Telemetry (information) acquisition

(2) Telemetry generation

(3) Telemetry transmission

(4) Command reception

(5) Command processing

(6) Command (instruction) distribution

S/C functions will be addressed, however, the methods used by the ground segment to maintain these functions will not be addressed (e.g., how the ground station reliably maintains the reception of telemetry over the X or S-Band links). The ground segment is addressed only in terms of how it influences the space segment.

There is currently a minimal amount of autonomy in the TT&C subsystem for maintenance of the command and telemetry functions. Ground decisions, intervention and commands are required to maintain essentially all of the TT&C functions. There are many actions taken by the spacecraft automatically, like the "AM Sync" function of activating various TT&C elements. However, these automatic features are for providing the service, not for making sure that service is available in the event of a failure or anomaly.

Figure 4-5 shows the Maintain S/C Control and Monitoring functional hierarchy.

---

[*]By W. E. Arens and S. O. Burks

Figure 4-5. Spacecraft Control and Monitoring Integrity Maintenance Functional Hierarchy

4.5.1 Maintain Telemetry Function
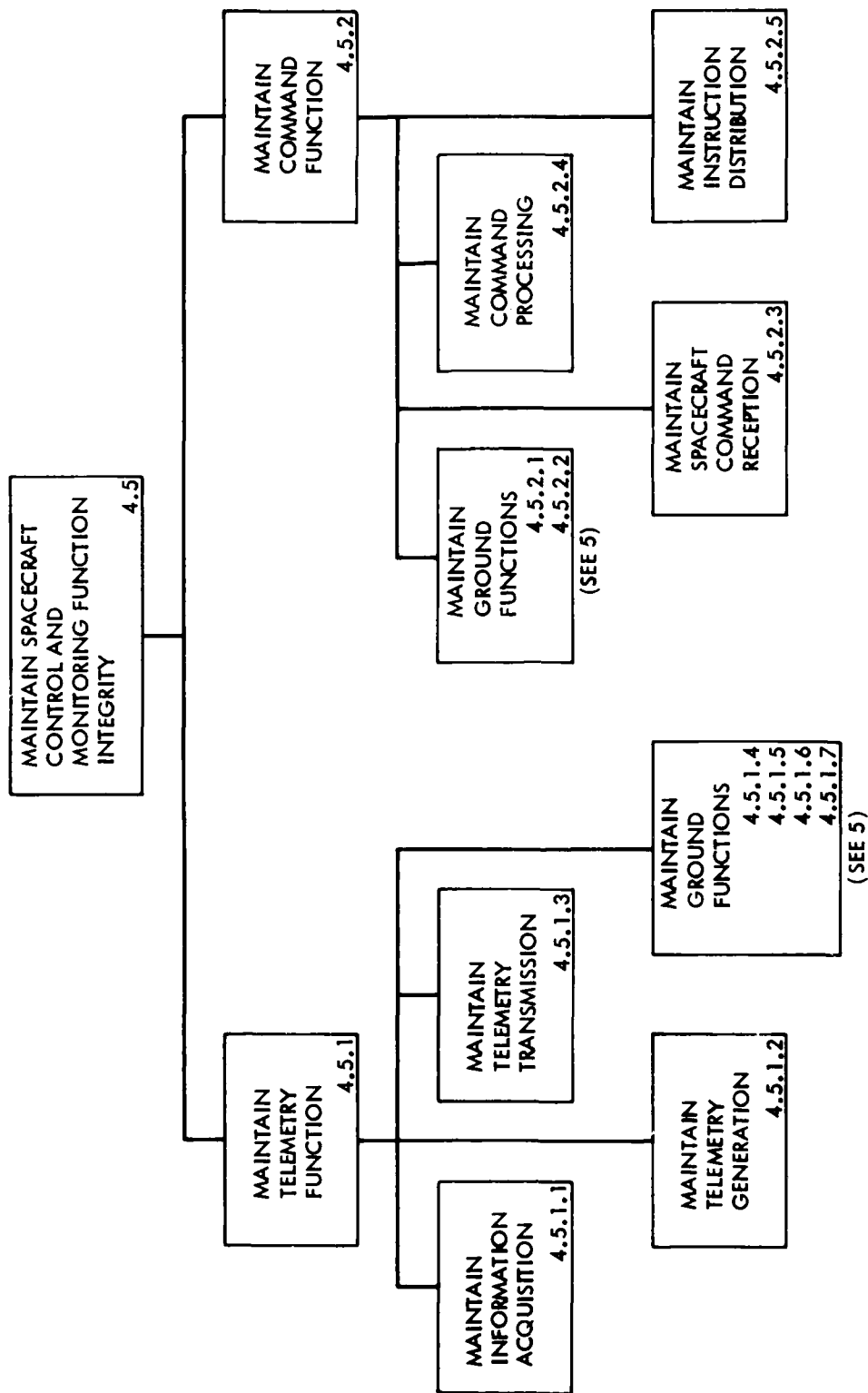
The S/C telemetry function service is provided by X-Band and S-Band communications links between the S/C and the ground. The space segment service is maintained by redundancy management. If the S/C downlink telemetry function were to fail, the failure would be detected on the ground. Ground decisions would be made to correct the failure by commanding the switch of block redundant elements, or receiving a different downlink telemetry signal (in normal operation the same information is being transmitted at two X-Band and one S-Band frequencies). The S/C cannot autonomously correct a telemetry function problem. Ground segment action is required.

4.5.1.1 Maintain Information Acquisition - Level 2/Category I. The telemetry information acquisition function is accomplished by the TT&C subsystem MTU and RTU by means of dedicated input lines from sensor sources. In the current DSCS III design, information acquisition functional integrity, in the presence of faults, can only be maintained by switching redundant blocks of the TT&C MTU and RTU via ground issued commands.

All measurement input signals are applied to multiplexer inputs. Analog signals are applied to a redundant analog multiplexer/ADC block in the MTU. These analog signals include analog data acquired by an analog multiplexer in a redundant RTU block. Bi-level and serial-digital measurements are applied to a redundant bi-level/serial-digital multiplexer block in the MTU. These measurements include bi-level data acquired by a bi-level multiplexer in a redundant RTU block. The serial-digital measurements require enable and clock signals to be sent by the MTU to subsystem sensor sources when readout of a serial-digital measurement is desired.

A fault of the information acquisition function likely will result in the loss of one or more measurements in the telemetry data stream. This type of fault can only be detected on the ground by personnel analyzing processed data. If the fault were isolated to the TT&C information acquisition hardware (the MTU and RTU) a command would have to be transmitted to switch to the appropriate redundant unit.

4.5.1.2 Maintain Telemetry Generation - Level 2/Category I. The telemetry generation function is accomplished by the TT&C MTU and RTU using the acquired telemetry information from 2.4.1.1 under control of the MTU timing and control block. In the current DSCS III design, telemetry generation functional integrity, in the presence of faults can only be maintained by switching redundant blocks of the TT&C MTU and RTU via ground issued commands.

An analog multiplexer in a redundant RTU block and a redundant analog multiplexer/ADC block in the MTU are provided for time sampling and digitizing the acquired analog measurements. A bi-level multiplexer in a redundant RTU block and a redundant bi-level/serial-digital multiplexer block in the MTU are provided for time sampling the acquired digital measurements.

A redundant timing and control block in the MTU is used to control the sampling, digitization, and formatting functions in accordance with information stored in PROM.

Typical failure modes associated with the telemetry generation function would appear as improper measurement values, timing, sync or format in the output telemetry stream. A failure would be detected on the ground and fault isolation to the redundant block level accomplished by analysis of the status of other telemetry stream data. Following fault isolation, a command would be generated and issued to the spacecraft to switch to the selected redundant block.

4.5.1.3   Maintain Telemetry Transmission - Level 2/Category II.

4.5.1.3.1   Description. The S/C has two basic methods of maintaining telemetry. One method is multiple, simultaneous data streams. The other is switchable, redundant elements. The data can be transmitted over the S-Band system, which is fully redundant. It also is normally transmitted simultaneously over the S/C's two active X-band beacon transmitting paths. These S/C service functions are "maintained" by ground command selection of block redundant elements. If there is a failure, ground detection of the failure and ground action is required to correct the failure.

a. The S-Band function has the following redundant elements:

(1) S-Band transmitter A and B. A is prime, B is redundant.

(2) S-Band Encrypter A and B. A is prime, both can be cross-strapped to the transmitters. The MTU's drive the encrypters and are cross-strapped in the MTU.

NOTE: The redundant S-Band telemetry hardware is in passive standby.

b. The X-Band function has the following redundant elements:

(1) Beacon A and B Transmitters. (Both normally active)

(2) Frequency Reference Standard redundant pair - part of the communication subsystems (the redundant unit is in passive standby).

(3) PN Generator: A or B (A is prime, B is in passive standby. Outputs are cross-strapped to beacons).

(4) Encrypters A or B (A is prime, B is in passive standby. Outputs are cross-strapped to data mixer and Beacon modulator inputs.) The MTU outputs are cross-strapped to the encrypters. Cross-strapping is in the MTU.

The following is the failure detection and correction process for selecting the redundant units.

(1) <u>Detect Telemetry Failures</u>

Telemetry failures are detected on the ground. The indications would be no telemetry, no RF signal, or bad telemetry data. The failure could also be indicated in the TT&C telemetry data.

(2) <u>Corrective Action to Restore Telemetry</u>

The analysis of the information will likely result in a ground receiver frequency change to receive one of the alternate, simultaneous data streams.

To correct the failure, ground commands can be issued to select redundant hardware.

(3) <u>Recovery</u>

The recovery from a failure typically will be by the selection of a redundant unit. Also, either one of the X-Band or the one S-Band paths could be used temporarily for telemetry. These paths are almost functionally identical and can be used interchangeably. The X and S-Band telemetry functions provide alternate paths but normally are not used interchangeably.

The S/C telemetry transmission service ("Send Telemetry" in the functional hierarchy) is composed of two, basic, functional areas. These are X-Band (SHF) and an S-Band telemetry system. Both of these systems are made up of block redundant hardware with cross-strapping of some functional elements. The X and S-Band telemetry functions on the spacecraft are almost functionally identical. Both are made up of the following type of functional elements. A data encrypter, a modulator, a transmitter, the microwave components and an antenna(s). Other than some of the microwave hardware, these functional elements are block redundant within the S-Band and the X-Band (SHF) telemetry system.

For the current DSCS III design, the S-Band is used for general health and status telemetry. The X-Band telemetry function is used primarily for operations with the payload and as a backup TT&C link for the S-Band telemetry. Typically the S-Band telemetry is planned only when an uplink command signal is present. However, the S-Band telemetry function can be commanded to be independent of the uplink. The X-Band telemetry function is normally on and can be used as a backup for the general health and maintenance TT&C functions if S-Band telemetry is down for some reason.

101

The X-Band telemetry link normally is used for direct payload (communications subsystems) operations to monitor status and health. The X-Band has the same data available as the S-Band link. Unlike the S-Band link, the X-Band is normally always on. The X-Band downlink beacon PN sequences and carrier provide timing information to the users.

4.5.1.3.2   Current Design Autonomy. The current DSCS III X or S-Band telemetry function can only be activated by a ground command signal or a couple of on-board spacecraft commands. The switching of redundant elements can only be done by ground command. The X-Band (SHF) Beacon Telemetry Transmitter is turned on and off by ground command and it can be turned off indirectly by the loss of earth presence signal or by the 80 minute battery timer signal. The S-Band normal "on" mode is accomplished by acquiring the uplink, applying command modulation and sending command S-Band data. This uplink command signal, when received by the S-Band receive function, sends an "AM Sync" signal to the Command Decoder (CD). Indirectly (via the South power controller) the CD turns on the MTU (if off, normally on), the encrypters and the transmitter. If the transmitter and encrypters are not in the "AM Sync" on mode they can be turned on by direct command. The S-Band transmitter can be turned on by the loss of earth presence or by the battery 80 minute timer. Also, during the launch phase, the S-Band transmit function is activated by the "initiation timer".

All of the above automatic on/off activities are for providing the telemetry service. There are no "automatic" features on-board to correct a telemetry failure.

4.5.1.4   Maintain Telemetry Reception. ⎫

4.5.1.5   Maintain Telemetry Processing. ⎪
                                                 ⎬ Ground Functions
4.5.1.6   Maintain Telemetry Distribution. ⎪

4.5.1.7   Maintain Telemetry Analyses. ⎭

4.5.2   Maintain Command Function

The maintenance of the command function service for DSCS III includes ground and spaceborne functional elements. The ground based operations determine the commmands which need to be sent, acquire the command instructions, generate the command data, and transmit the command data. The spacecraft receives and detects this transmitted data, processes the command data (decodes), and issues command instructions to the users.

102

The command transmission (ground segment) and command reception
(space segment) is accomplished over two functionally identical but
independent systems. One is an S-Band system used for general health,
maintenance, and status changes on the S/C from the Satellite Control Facility
(SCF). This includes health and maintenance functions of the payload. For
operations with the payload communications subsystem, the X-band link is used.
These X-Band payload commands are normally transmitted by the DSCS III ground
system (EDM-SCCE). Both links will perform identical command functions and
each serves as a backup to the other. Once the links are established, they
pretty much perform their intended function without ground intervention.
These links would require maintenance only in the event of a failure. A
failure on the uplink which is due to the S/C hardware can be corrected only
by ground action. Essentially there are four possible command paths. Any one
of these paths can be used to command the S/C. Once a command path is
established, redundant units can be selected by command to reestablish the
failed function.

4.5.2.1   Maintain Command Generation - Ground Function. (See 5.0)

4.5.2.2   Maintain Command Transmission - Ground Function. (See 5.0)

4.5.2.3   Maintain Spacecraft Command Reception - Level 2/Category II.

4.5.2.3.1   Description. The DSCS III S/C has two basic methods of providing
the S/C command reception service. Commands can be received over the S-Band
link or over the X-Band link. Both of these links are fully redundant. These
command reception service functions basically perform as required without
ground intervention. However, the maintenance of this command reception
function in the event of a failure can only be accomplished by ground based
actions. These ground actions take the form of selecting an alternate X or
S-Band command frequency and/or commanding a change in the redundant elements.
Both paths have a receiving antenna, microwave components, a receiver, a
command detector, a decrypter, and an output to the redundant command decoders
(CD).

For DSCS III, the S-Band command function is used to receive
general spacecraft control and maintenance commands from the SCF. The X-Band
command function is used primarily for payload (communications subsystem)
control and commands typically are received from the DSCS III EDM SCCE X-Band
ground stations. These command systems appear to be used at relatively random
times and for varying time durations. However, most of the S and the X-Band
redundant hardware is left on continuously for immediate command reception
capability. The S-Band redundant hardware is in active standby (i.e., is
powered on). However, the decrypters are off (turned on automatically by
"AM-Sync"). The X-Band hardware has some redundant elements in active and
others in passive standby (e.g., the redundant decrypter is off and can only
be turned on by ground command).

For the S-Band and the X-Band system there are basically redundant A and B command reception channels. Channels A and B work on different frequencies. Access to the X or S-Band command channel is by selection of the correct A or B channel frequency (the A channel is considered the normal channel and B the backup).

The S/C S-Band Command path has the following redundant elements:

(1) Receiver (and command detector) A and B. A is prime and, B is in active standby;

(2) Decrypter A and B. A is prime and B is in active standby (when activated by AM Sync). The receiver outputs and decrypter inputs are cross-strapped with control in the command decoder (CD). The decrypter outputs are cross-strapped in the CD.

The X-Band Command path has the following redundant elements:

(1) Antennas E1R, E2R and MBA; microwave components, and low noise amplifiers which are in the communications subsystem.

(2) SHF to S down-converter A and B. A is prime, B is in active standby.

(3) S to IF down-converter A and B. A is prime, B is in active standby. Inputs cross-strapped passively and actively to SHF-to-S down converter output.

(4) Communications Subsystem Frequency Reference Standard. Redundant unit in passive standby.

(5) Decrypters A and B. A is prime and B is in passive standby. Decrypter inputs cross-strapped by active switching to S-IF output. Decrypter outputs cross-strapped to Command Decoder (CD).

The following is the failure detection and correction process for selecting the redundant units.

(1) Detect Command Failure

A failure of the command function can only be detected by ground personnel. A failure in the hardware could result in the failure of the S/C to execute a command instruction. A failure could be indicated in the downlink TT&C telemetry. The S/C design cannot recognize a failure of this function.

104

(2) Take Corrective Action to Restore Command

The ground operations will have to evaluate the failure information available and execute the process of selecting an alternate command path. In normal operations both S-Band command channels are active. If one path fails the other can be selected by changing the ground transmitter frequency. Some cross-strapping functions and the operating command decoder can be selected by the command word preamble.

The X-Band command channels are selected in a manner similar to the S-Band. The key difference being that some of the X-Band command hardware elements are in passive standby and have to be <u>ground commanded</u> "on". This would have to be done through the S-Band command channels.

There essentially are four actively available command channels, two at X-Band (at different frequencies) and two at S-Band (at different frequencies). However, because of its implementation, the X-Band path can be wiped out by one failure (e.g., the frequency reference or the decrypter). The cross-strapped paths can be selected by ground commands once one of the four available paths is made operational by ground operations selection of the path.

(3) Recover

The recovery from failure could be accomplished on either the X or the S-Band command channel once the alternate channel frequency is selected and transmitted from the ground.

4.5.2.3.2   <u>Current Design Autonomy</u>. The maintenance of the command reception on S or X-Band currently requires a ground decision. If either channel A, (X or S) is selected and will not process commands, ground operations first approach might be to change the ground transmitter frequency to the B channel and attempt commands over that channel. This is pseudo-autonomous in that a ground decision is required to determine that the first command channel did not work and then to change the uplink transmitter frequency to select an alternate command channel.

Both S and X Band command paths use frequency diversity to select the receiver path. Decoders are selected by a command preamble word. Decrypters are selected by having a <u>ground command</u> link.

The redundant X-Band link requires direct commanding of some redundant elements because some of these redundant units are normally off in passive standby and are activated only by ground command (e.g., the decrypter and Comm subsystem frequency standard). Thus, the X-Band redundant paths have single point failure modes which are backed up by the fully redundant S-Band paths.

4.5.2.4   Maintain Command Processing - Level 2/Category I. The command
processing functions of prioritization, validation, and determination of type
are accomplished by the TT&C CD following receipt of commands from either the
TT&C S-Band or SHF RF equipment. In the current DSCS III design, command
processing functional integrity, in the presence of faults, can only be
maintained by switching the roles of redundant command decoders via ground
issued commands. Each of the redundant command decoders has its own internal
power converter. Appropriate logic for the backup command decoder is
adequately powered from its own power converter so that it can respond to
commands from the ground to switch the prime and secondary roles of the two
command decoders.

There are basically two faults associated with on-board command
processing that can occur. These are: 1) failure to issue the requested
command or 2) issuance of an incorrect command to a designated spacecraft
subsystem recipient. Failure to respond or incorrect response to an issued
command is detected on the ground by monitoring the telemetry output stream
from the TT&C subsystem. By analyzing the fault occurrence in terms of the
integrity of all elements in the command loop, if a failure in the CD command
processing function were isolated to the TT&C CD, the ground would generate a
command and issue it, through the backup uplink, to the backup command decoder
to make it prime.

4.5.2.5   Maintain Instruction (Command) Distribution - Level 2/Category
I. The command distribution function of routing commands to the appropriate
internal or external destinations for execution is accomplished by the TT&C CD
in the same manner as the command processing function in 4.5.2.4.

The primary failure mode associated with the on-board command
distribution function is failure to issue a requested command to the
designated spacecraft subsystem recipient. Detection of such a fault on the
ground, if isolated to the CD, would result in the same actions as outlined in
4.5.2.4.

106

4.6 MAINTAIN S/C PROPULSION FUNCTION*

The spacecraft propulsion function is maintained by maintaining the thrusters and the propellant system tanks and valves. Figure 4-6 shows the hierarchy of the propulsion maintenance function.

4.6.1 Maintain Thruster Health - Level 2/Category I

4.6.1.1 Detect Failure. The ground analyzes propulsion telemetry to detect failures. Catalyst bed temperature is used to detect heater failures. The number of pulses required to produce a given ΔV or momentum change is monitored to determine thruster pulse performance. The delivered ΔV is monitored to determine steady-state performance of the thruster. The spacecraft rates and catalyst bed temperature are monitored to detect a thruster valve failed open/closed or leaking. Determination of thruster faults in general requires the analysis of performance over time (trend analysis).

4.6.1.2 Direct Recovery. The ground determines latch valve configurations to isolate the branch with the offending thruster.

4.6.1.3 Recover from Failure. If required, the latch valves are reconfigured to switch out the faulty thruster branch.

4.6.2 Maintain Propellant System Health - Level 2/Category I

Pressurant loss from leakage is required to be less than 10% in 10 years.

4.6.2.1 Detect Failure. The ground monitors tank pressure and temperature telemetry and thruster activity to detect unexplained propellant or pressurant loss. Schematic and plumbing diagrams are analyzed to determine the location of the leak.

4.6.2.1.1 Monitor Propellant Valve Position. Anomalous use of propellant is sensed from telemetry. Also valve positions are checked during orbit injection and launch and are checked as a part of center of mass (cm) control. Opening/closing of valves is commanded by the ground to reconfigure propellant usage or to correct cm control.

---

*By R. W. Rowley
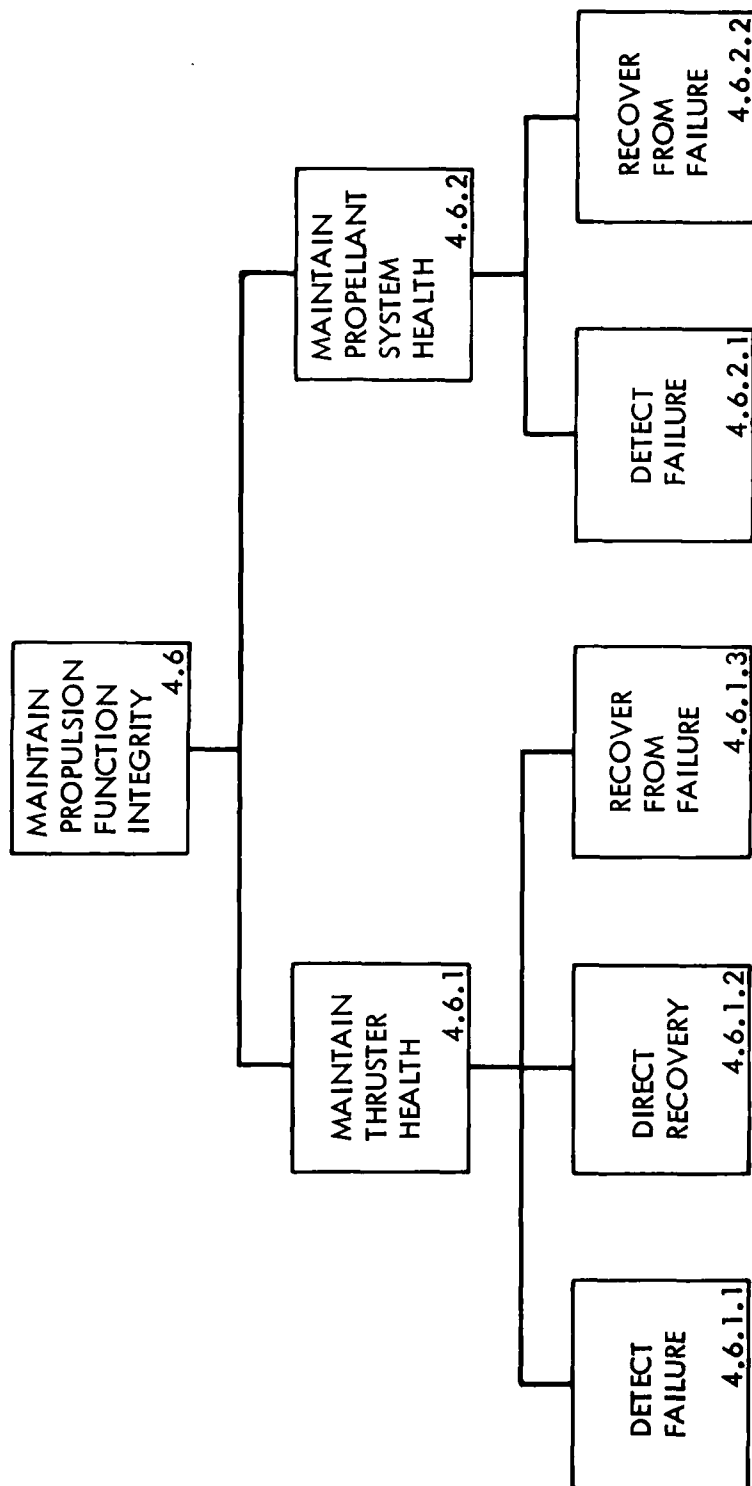
Figure 4-6. Propulsion Integrity Maintenance Functional Hierarchy

4.6.2.1.2   Monitor Propellant Tank Pressure. As a health check before
control maneuvers or as a result of anomalies in predicted vs. present state
of propulsion subsystem, the tank pressure readings from telemetry are
analyzed. If the pressure in a tank drops below 95 psi or rises above 350
psi, contingency operations are planned.

        The ground assesses the anomaly as caused by: propellant leak,
faulty pressure transducer, or thruster leak. The ground also checks for
possible propellant decomposition. The ground reconfigures for fault
isolation and center of mass maintenance by directing shutting of latch valves
and disabling of thrusters.

4.6.2.2   Recover from Failure. The latch valves are directed by the
ground to be configured to isolate the failed propellant tank. Mission
replanning may be required to accommodate the lost propellant.

4.7   MAINTAIN STATIONKEEPING FUNCTION*

The stationkeeping is currently a ground function, except for
the spacecraft portion of the tracking function. Therefore only maintenance
of the tracking function is discussed in this section. Figure 4-7 shows a
functional hierarchy of stationkeeping maintenance. A space (4.7.2) is left
for maintenance of the remainder of the stationkeeping functions, because this
will become necessary when on-board stationkeeping is included (See Volume
III, Section 4.7). Section 5 discusses maintenance of the ground
stationkeeping functions.

4.7.1   Maintain Tracking Function - Level 2/Category II

4.7.1.1   Description. The tracking function is accomplished over the
uplink and downlink S-Band communication paths. This two-way coherent
tracking service requires the S/C receiver and transmitter functions.
Tracking function maintenance is only required in the event of a failure. The
correction of the failure usually will be by the selection of receive or
transmit path redundant components.

The tracking service in the functional hierarchy basically
provides the means for spacecraft orbit determination through the use of the
S-Band RF uplink and downlink signals. The hierarchy provides for the
maintenance of this service. Maintenance is a redundancy management function
directly associated with the maintenance of the uplink and downlink signals
(i.e., "Maintain Telemetry Function" and "Maintain Command Function" described
in Section 4.5).

The "maintenance" of ground functions toward automating ground
functions will not be addressed herein, only the spacecraft elements. The
spacecraft functional areas applicable to the tracking function are "Receive
Ground Signals," "Detect Ground Signals" and "Transmit Tracking Signals." The
maintenance of these three functions is basically the selection of block
redundant elements in the event of a failure.

4.7.1.2   Current Design Autonomy. The current autonomy features of the
tracking function, which are minimal, are the same as those discussed under
the command and telemetry sections. Also, active ground participation is
required to command the ranging channel on and off and to command tracking in
the coherent or noncoherent mode. The latter two commands are associated
with the tracking function.

---

*By S. O. Burks

```
                  ┌─────────────────┐
                  │ MAINTAIN        │
                  │ STATIONKEEPING  │
                  │ FUNCTION        │
                  │ INTEGRITY       │
                  │            4.7  │
                  └────────┬────────┘
          ┌────────────────┴────────────────┐
  ┌───────┴────────┐              ┌──────────┴──────────┐
  │ MAINTAIN       │              │ MAINTAIN            │
  │ TRACKING       │              │ OTHER               │
  │ FUNCTION       │              │ STATIONKEEPING      │
  │                │              │ FUNCTIONS           │
  │         4.7.1  │              │              4.7.2  │
  └────────────────┘              └─────────────────────┘
                                         (SEE 5)
```
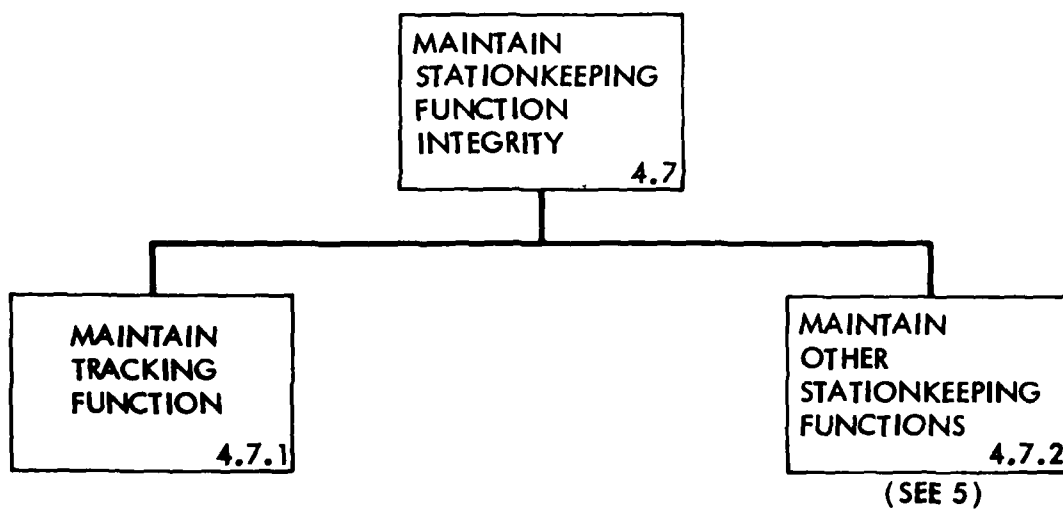
Figure 4-7.   Stationkeeping Integrity Maintenance
              Functional Hierarchy

111

The S-Band redundant elements involved are:

(1) Receiver A and B

(2) Transmitter A and B.

The following is the failure detection and correction process for selecting the redundant units.

(1) Detect Tracking Failure

Failures can only be detected on the ground. The failures could be in the receiver, the transmitter, or the connecting elements between the receiver and transmitter. Failures would be indicated by the inability of the ground to process two-way coherent tracking data.

(2) Corrective Action to Restore Tracking

Ground commands can be issued to select the alternate transmitter. Also, the ground transmitter frequency can be changed to select the alternate receiver. For two-way coherent ranging, the A receive/transmitter pair or the B receiver/transmitter pair must be chosen.

(3) Recovery

Recovery is achieved after the above ground actions have established a functioning receiver/transmitter pair and two-way coherent tracking data is observed at the ground station.

SECTION 5

CURRENT DSCS III GROUND SYSTEM*

This section describes and summarizes the functions now performed by the DSCS III ground system. Volume III, Section 5 describes the ground impacts of, and issues in adding autonomy to the spacecraft.

The DSCS satellite payload is controlled primarily by the Defense Communications Agency through its control center and associated tracking stations. (See Section 1) The spacecraft primary operational monitoring and control is from the Air Force Satellite Control Facility (AFSCF) and its associated tracking stations as described in Section 2.4. Their interfaces are depicted in Figure 5-1.

5.1   DSCS III SPACECRAFT CONTROL SYSTEM

The DSCS III spacecraft is controlled and monitored as described in Section 2.4 by operations personnel at the AFSCF. The ground portion of this control and monitoring function is described herein as DSCS III Mission Control (MC). Figure 5-2 is a functional flow diagram of the DSCS III MC and Figure 5-3 is a hierarchical, functional description of the DSCS III MC. The current functions of the DSCS III MC are described in the following paragraphs.

5.1.1   Service Functions

As shown in Figure 5-4 the ground performs all the information collection and analysis not performed autonomously on the spacecraft. Activity planning is done using this information. These activities are described as a part of the spacecraft functional description in Sections 2, 3 and 4. During real time operations the ground performs these services as well as managing the ground resources necessary to perform them, as described in Figure 5-4.

5.1.2   Resource Management Functions

Management of ground resources is done by scheduling activity of ground supporting systems and personnel. This aspect of DSCS III Mission Control is not addressed in detail in this report. Much of the information that would fill in this portion of the hierarchy outline, as structured here, is not readily available, and much of it may not be directly pertinent to the Autonomy study. Many considerations in resource management, e.g., time-sharing of computers, number of spacecraft being supported, number of personnel (teams, shifts, redundancy, etc.), and time-criticality of functions are out-of-scope for this assessment.
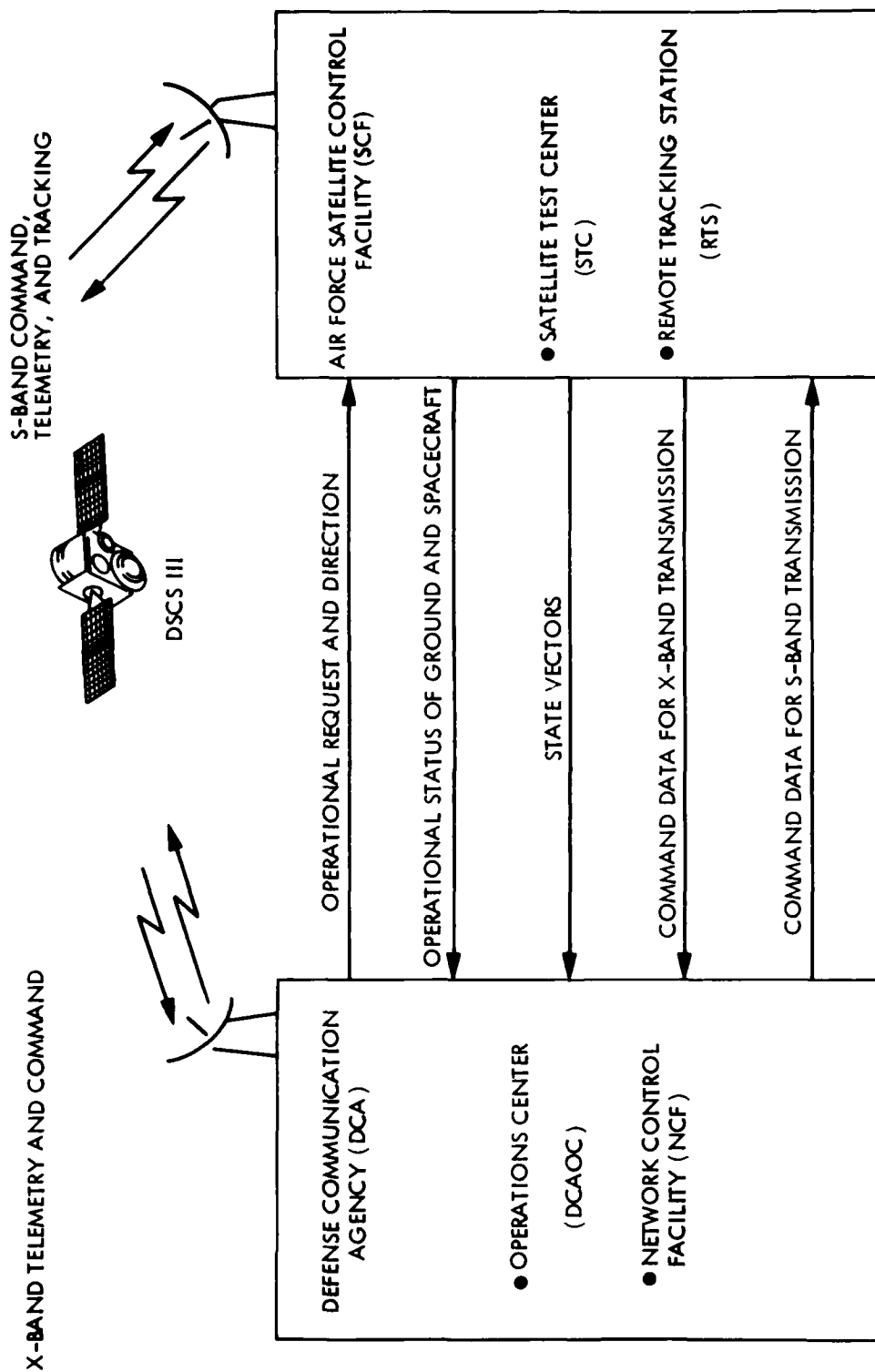
---

*By B. L. Sharpe

113

Figure 5-1. DSCS III Mission Control External Functions and Interfaces
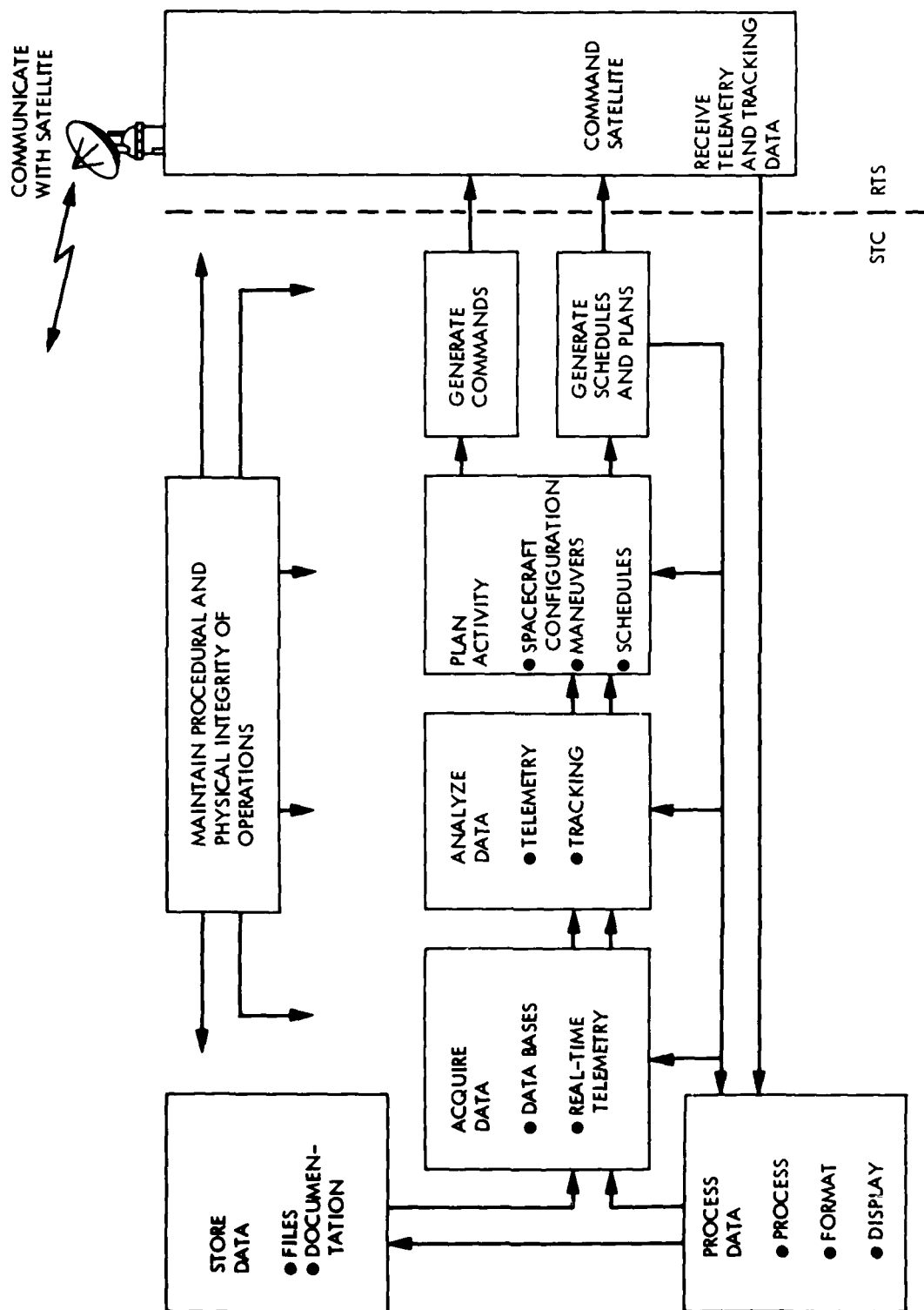
Figure 5-2. DSCS III Mission Control Functional Flow Internal Functions and Interfaces
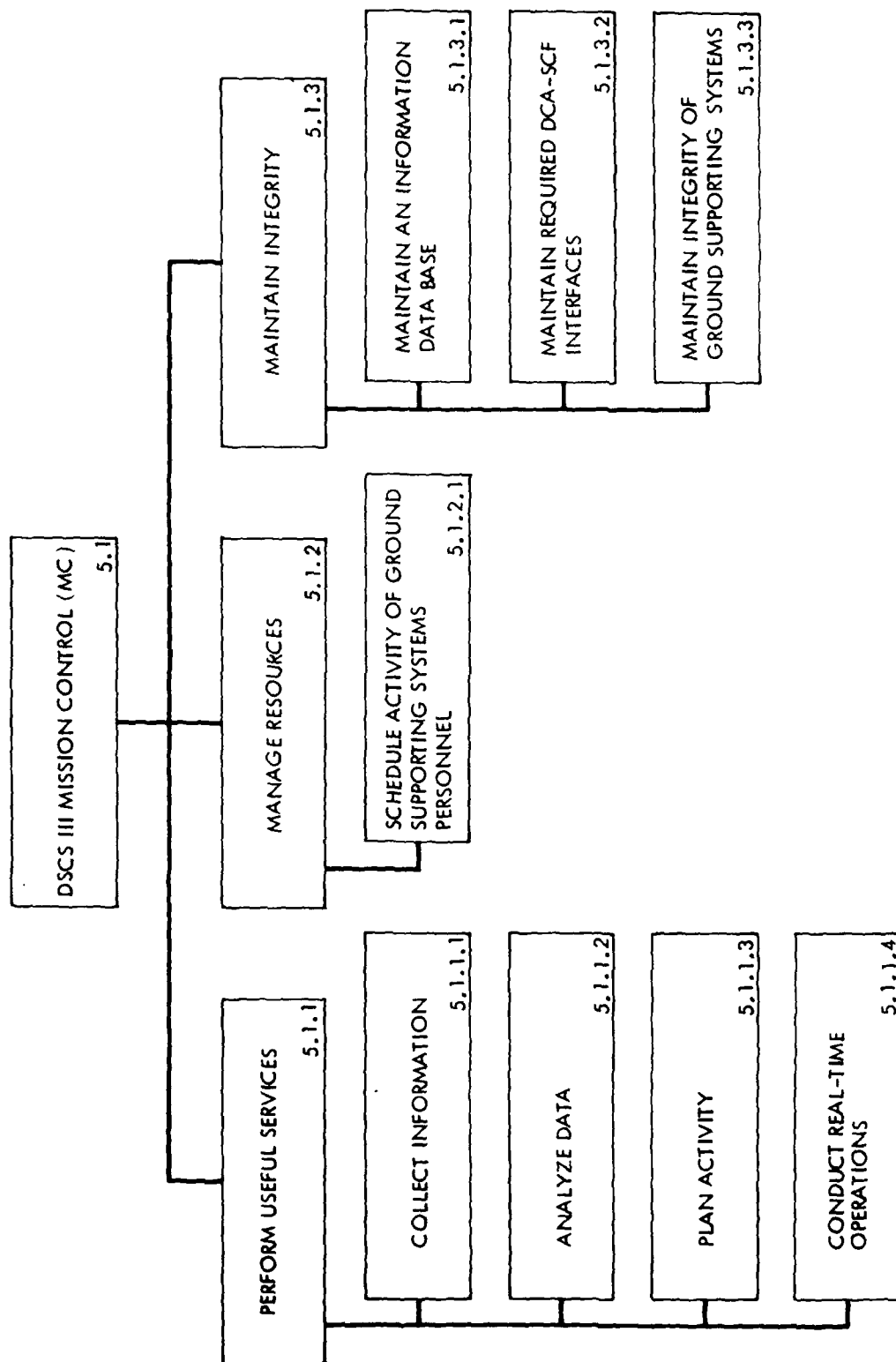
Figure 5-3. Mission Control Functional Hierarchy - Overview
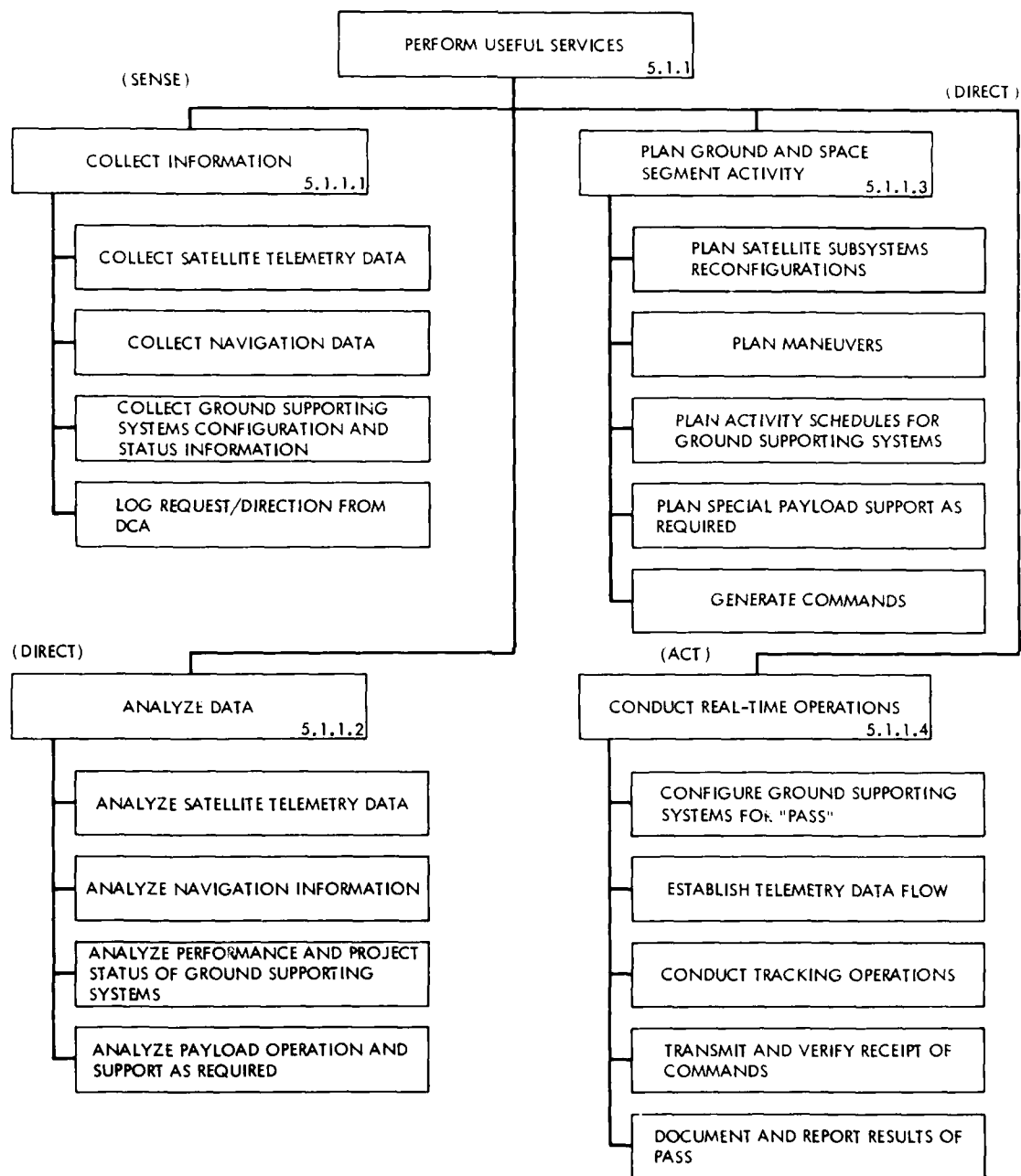
Figure 5-4. Mission Control Functional Hierarchy -
Useful Services

5.1.3   Maintenance of Integrity

          The functional description is in Figure 5-5. Maintaining the
integrity of the ground system includes maintaining data bases, interfaces,
and facilities.

5.1.3.1   Maintain an Information Data Base, with Safeguards for
               Configuration Control and Security.

5.1.3.1.1   Maintain a Satellite Systems Data Base. This includes:

               (1) Maintain a file of reference material describing the space
                    segment, its performance capabilities and constraints.

               (2) Maintain a log of present and predicted satellite states
                    and parameter values, beginning at launch.

               (3) Maintain files of trend and history data.

               (4) Maintain a log of anomalies, failures and failure
                    analysis.

               (5) Maintain a current representation of satellite on-board
                    software.

               (6) Maintain the capability to accurately model performance of
                    selected systems.

               (7) Maintain a file of telemetry parameter limit sense values
                    for each satellite.

5.1.3.1.2   Maintain a Navigation Data Base - See Section 2.7.

5.1.3.2   Maintain Required DCA-SCF Interfaces. This includes:

               (1) Maintain the capability to transmit DCS-originated command
                    sequences from AFSCF (via SGLS) using the teletype
                    interface between the two agencies.

               (2) Maintain the backup capability at the DCS to transmit
                    X-Band satellite housekeeping commands as requested by
                    AFSCF.

               (3) Maintain the backup capability at the DCA to transmit
                    X-Band satellite houskeeping commands as requested by
                    AFSCF.
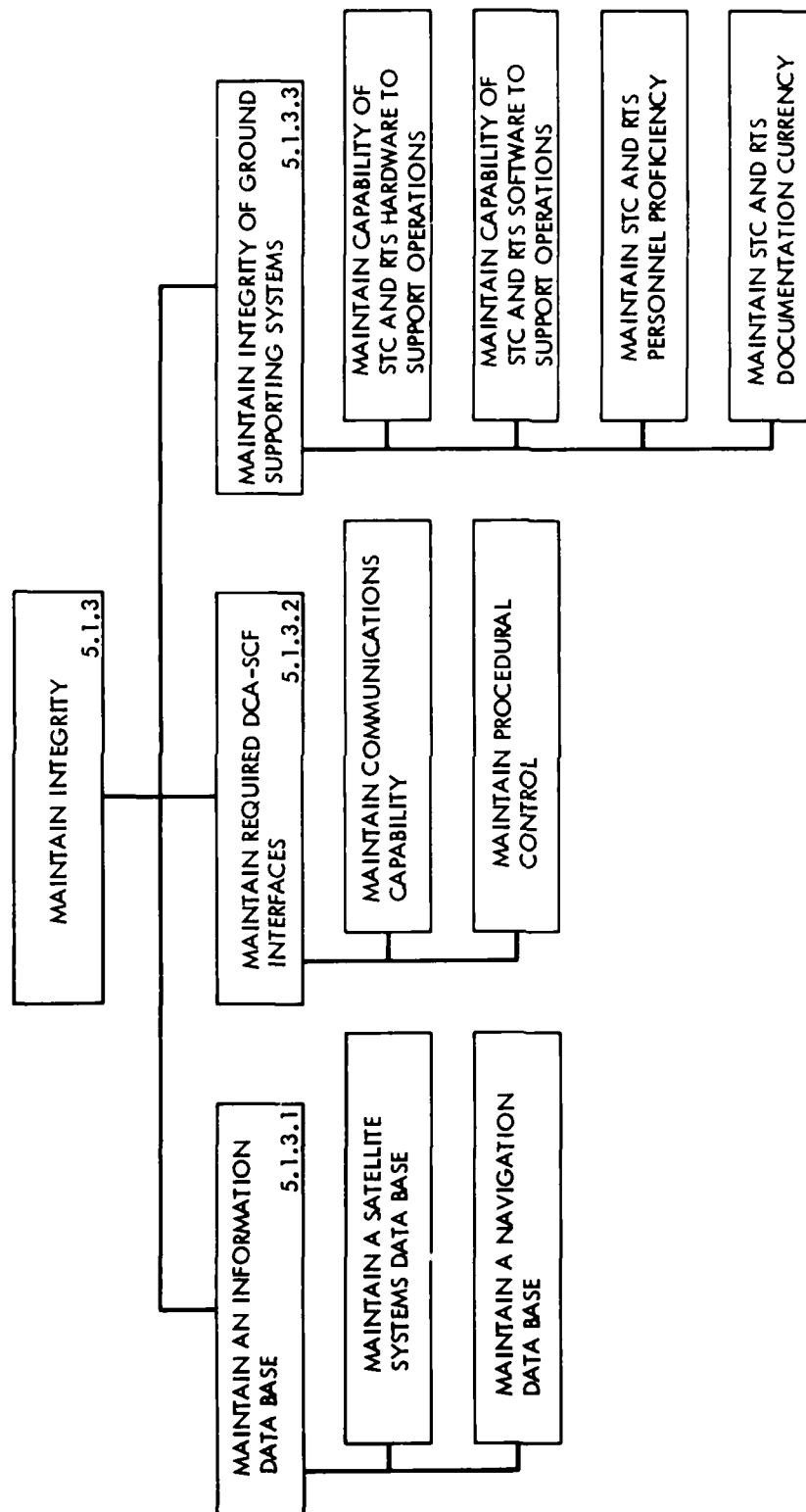
Figure 5-5. Mission Control Functional Hierarchy - Integrity

119

(4) Maintain the capability to transmit orbit state vector data from AFSCF to DCA NCF (via DCAOC) for the use of generating ephemeris data.

5.1.3.3   Maintain Integrity of Ground Supporting Systems.

5.1.3.3.1   Maintain Capability of STC and RTS Hardware to Support Operations. This includes:

(1) Conduct routine inspections and tests of equipment.

(2) Repair equipment/restore outages.

(3) Conduct preventive maintenance.

(4) Resolve scheduling or time-share loading conflicts with other users.

5.1.3.3.2   Maintain Capability of STC and RTS Software to Support Operations by Exercising Configuration and Change Control.

5.1.3.3.3   Maintain STC and RTS Personnel Proficiency. This includes:

(1) Maintain an appropriate training capability.

(2) Test and maintain individual proficiency.

(3) Test and maintain group and team proficiency.

5.1.3.3.4   Maintain STC and RTS Documentation Currency. This includes:

(1) Maintain a file of reference material describing the ground segment.

(2) Maintain a current log of performance and failure reports for ground hardware.

(3) Maintain current operational procedures.

5.2   DSCS III PAYLOAD CONTROL INTERFACES WITH MISSION/SPACECRAFT
               CONTROL

          The payload and its control system are described in Section 1.3.
Interfaces between payload control and mission control are described in Figure
5-3, above. There are some characteristics of payload control operations
which have a bearing on the operations of the autonomous spacecraft. These
characteristics are described here, and their relations to the autonomy
options are discussed in Volume III, Section 5.2.3.

5.2.1   Payload Reconfiguration

          At the present time, reconfiguration of the payload for
communication network changes is accomplished through the SHF telemetry and
command link. However, switching of redundant elements to mitigate payload
failures is done by AFSCF through the S-Band link.

5.2.2   Timing

          The payload provides a timing function from a 5 MHz frequency
standard. The signal is provided to users via the SHF beacons which are part
of the TT&C subsystem. The frequency of the frquency standard is checked
periodically by means of comparisons between the SHF beacon signal and
information obtained from the S-Band range and range rate tracking function.
If the frequency standard has drifted beyond acceptable limits, frequency
update commands are sent via the S-Band link.

5.2.3   Payload Integrity Maintenance

          Bus and payload health are checked periodically by the AFSCF
from telemetry data contained on the S-Band link. However, the SHF telemetry
through the beacons contains identical information to the S-Band telemetry
system so that failures will often be detected first by DCA since they will be
receiving the beacon signal continuously. Whenever a failure in either the
bus or the payload is detected it is normally referred to AFSCF for diagnosis
and corrective action through the S-Band command link, although identical SHF
command capability is available.

5.2.4   Ephemeris Information

          Epoch orbital state vectors are presently calculated on the
ground from information obtained from the range and range rate tracking data
obtained by AFSCF on S-Band. These state vectors are then furnished to DCA
for ephemeris propagation between epochs, and DCA furnishes ephemeris
information to users who require it.

5.2.5   SHF Command Failure

There are at least two single point failures which can fail the
SHF command function. The first is the decrypter. The second is the
frequency reference standard generator output from the comm subsystem. Only
one of the redundant KI-24 decrypters and only one of the redundant frequency
reference generators are on at any one time. They can only be activated by
ground command. Thus, if the decrypter or frequency generator fails the
S-Band command link must be used to activate the redundant units. (Note that
the switching for the decrypter inputs and outputs and the input from the
frequency standard may also represent potential single point failures.
Sufficient detail was not available to assess this farther.)

5.2.6   Command/Telemetry Redundancy

The technical capability for performing all telemetry and
command functions exists at either SHF or S-Band. Operationally, the ground
procedures are strucured as indicated above. The range and range rate
tracking function exists only at S-Band.

122

REFERENCES

1. Marshall, M. H., "Goals for Air Force Autonomous Spacecraft," JPL Internal Document 7030-1, Preliminary Issue, 2 February 1981.

2. DSCS III Satellite Engineers Handbook, CDRL-A041, December, 1978.

APPENDIX A

LEVELS OF AUTONOMY

LEVELS OF AUTONOMY

(Reproduced directly from Reference 1)

In performance of a space mission, four major policy goal categories have been indentified. These are:

(1) Ground interaction reduction.

(2) Spacecraft integrity maintenance.

(3) Autonomous features transparency.

(4) On-board resource management.

The extent to which these goals have been accomplished to date has been through a mix of functions resident in either the space segment or the ground segment. Furthermore, the ground segment, as an integral part of the total system, has been responsible for accomplishing maintenance, navigation mission control, and payload data processing. Thus, only minimal spacecraft autonomy has been needed.

The levels of autonomy described in this appendix are used to define a step-wise increase in spacecraft autonomous capability. By proceeding through the levels, autonomous capability is increased in the space segment and dependency on the ground segment is reduced.

The levels of autonomy are described as follows:

Level 0. A design without redundant elements which meets all mission needs by operating without the on-board control of state parameters (such as rates and position). May respond to a prespecified vocabulary of external commands, but cannot store command sequences for future time-or event-dependent execution or validate external commands. (An open-loop, on-board system controlled from the ground.)

Level 1. Includes Level 0 but uses on-board devices to sense and control state parameters (such as rates and positions) in order to meet performance needs. Is capable of storing and executing a prespecified command sequence based on mission-critical time tags. Will respond to prespecified external commands, but cannot validate external commands. Functionally redundant modes may be available for a degraded-performance mission.

Level 2. Include Level 1 plus the use of block redundancy. Ground-controlled switching of spare resources is required. Uses cross-strapping techniques to minimize effect of critical command link (uplink) failure modes. Significant ground-operator interaction is required to restore operations after most faults if spare spacecraft resources are available. Requires operator interaction for fault recovery. Is capable of storing and executing mission-critical events which are sensed on-board and may be independent of time.

Level 3. Includes Level 2 and is capable of sensing prespecified mission-critical fault conditions and performing predefined self-preserving (entering a safe-hold state) switching actions. Is capable of storing contingency or redundant software programs and being restored to normal performance (maintaining the command link with a single link fault) in the event of a failure. Timers may be used to protect resources. Requires ground operator interaction for fault recovery. In general, the failure to sense and/or execute the mission-critical event(s) will cause mission failure or loss of a major mission objective.

Level 4. Includes Level 3 but is also capable of executing prespecified and stored command sequences based on timing and/or sensing of mission events. Ground-initiated changes to command sequences may be checked on-board for syntactical errors (parity, sign, logic, time). Uses coding or other self-checking techniques to minimize the effects of internally generated data contamination for prespecified data transfers. Requires ground-operator interaction for fault recovery. In general, failure to sense and/or execute the mission event(s) or state-changes (excluding failure-induced state-changes) will cause mission failure or loss of a major mission objective.

Level 5. Includes Level 4 and is also autonomously fault-tolerant. Is capable of operating in the presence of faults specified a-priori by employing spare system resources, if available, or will maximize mission performance based upon available capability and/or available expendables (i.e., self-loading of contingency programs) without ground intervention.

Level 6. Includes Level 5 and is capable of functional commanding with on-board command-sequence generation and validation prior to execution. Functional commanding may include a high-level, pseudo-English language, spacecraft-system/operator communication and control capability.

Level 7. Includes Level 6 and is capable of autonomously responding to a changing external environment, defined a-priori, so as to preserve mission capability. The capability to change orbit in order to compensate for degradation or to protect the satellite from an external threat is included.

Level 8. Includes Level 7 and is capable of operating successfully within the presence of latent design errors which could cause loss of major mission objectives.

Level 9. Includes Level 8 and is capable of task deduction and internal reorganization based upon anticipated changes in the external environment. This situation is exemplified by multiple satellites operating in a cooperative mode. In the event of a satellite failure, remaining satellites would detect autonomously the condition (task deduction) and may generate and execute orbit-and spacecraft-reconfiguration commands.

Level 10. Includes Level 9 and is capable of internal
reorganization and dynamic task deduction based on unspecified and
unknown/unanticipated changes in external environment. The system will strive
to maximize system utility. Thus, mission objectives should be adaptive and
automatically reprogrammable. System resources should be maximized to
preserve task adaptiveness.

APPENDIX B

REQUIREMENTS PLACED ON SPACECRAFT BY PAYLOAD

B.   REQUIREMENTS PLACED ON SPACECRAFT BY PAYLOAD[*]

The performance of the payload is dependent on the requirements it levies on the S/C bus. This Appendix supplies traceability of those requirements from the payload. During design of the autonomous DSCS III these requirements may be used in system trades. The requirements were derived from References B-1 through B-6.

1.   Electric Power and Distribution System (EPDS)

The payload will derive electric power from the EPDS which collects, conditions, stores, and distributes power. The regulated satellite bus will provide a nominal +28 volts +0.28 volts over all satellite load conditions and lifetime as measured at the Power Regulator Unit (PRU) output.

With regard to Travelling Wave Tube Amplifiers, primary and redundant TWTA's shall not be operated simultaneously or on any one communications channel. The TWTA turn-on sequence shall be staggered to minimize the effects of transients in the EPDS.

The communications subsystem power requirements are presented in Table B-1. In the normal orbit mode of operation in sunlight or eclipse, the average subsystem demand is 480.6 watts.

There are other communications subsystem average heater power dissipations as follows:

TDAL	5.8 watts (average)
LNA Oven	1.5 W (solstice) 17.0 W (equinox)
BFN-61	16.0 W
GDA	3.2 W

During certain transient operations, there are additional power dissipations:

GDA driving	9.8 W for 352 sec per day
BFN-61 Reconfiguring	43.0 W for 3 sec
BFN-19 Reconfiguring	21.5 W for 1 sec

The Single Channel Transponder (SCT) subsystem power requirements are presented in Table B-2; average and peak loads are shown for five elements plus power controller losses. Table B-3 shows that the SCT power demand varies from 0.0 watts to 231.8 watts depending upon the selected operating mode.

---

[*]By A. M. Goldman, Jr.

TABLE B-1   Communications Subsystem Power Requirements

COMPONENTS	UNITS OPERATING	AVERAGE POWER DISSIPATION (W)
Frequency Generator	1	8.24
Frequency Standard	1	2.50
MBA Low Noise Amp	1	1.80
ECH Low Noise Amp	2	3.60
MBA Ferrite Drivers	3	0
North Panel Ferrite Drivers	16	0
TDAL	6	5.04
FET Driver	6	8.00
40 watt TWTA (Hughes)	2	242.00
10 watt TWTA (Hughes)	4	154.30
RLM Switch	1	0.88
TLM Power Monitor	6	2.70
TWT Input RF Relay	2	0
TWT Output Waveguide Switch	2	0
CMD/TLM Interface Unit	1	6.60
NP Power Controller Losses (85%)	1	6.70
Beam Forming Network - 61	1	0.30
Beam Forming Network - 19	2	0.30
JL RF Switch	1	1.35
JL RF Detector	1	21.80
JL Digital Controller	1	8.35
SP Power Controller Losses (85%)	1	5.70
SUBSYSTEM TOTALS		480.60 Watts

TABLE B-2   SCT Power Requirements

COMPONENT	AVERAGE LOAD (WATTS)		PEAK LOAD (WATTS)
Frequency Synthesizer	27.5 Standby 35.3 Xmit		Continuous
Digital Processor	LSG ON 20.1 17.5	LSG OFF 17.6 EAM Store & Forward 15.0 EAM Bypass or Standby	Continuous
KI-35	0.6 OFF 6.5 ON		Continuous
UHF/SHF Receiver	2.5		Continuous
UHF Transmitter	137.2		Continuous
SCT Power Controller Losses	15% of load		Continuous

TABLE B-3   SCT Power Demand by Mode

Mode 1.   Standby
(Frequency Synthesizer, Digital Processor,   55.3W LSG ON
Receiver, SCT Power Controller)   59.2W KI-35 ON
                                                  60.1W LSG & KI-35

Mode 2.   EAM Store and Forward   225.0W LSG ON
(Mode 1 plus transmitter)   229.0W KI-35 ON
                                                  231.8W LSG & KI-35

Mode 3.   EAM Bypass   222.1W LSG ON
(Mode 1 plus Transmitter)   226.0W KI-35 ON
                                                  228.9W LSG & KI-35

Mode 4.   Survival Mode (SCT OFF)   0.0W

131

2. Attitude Control Subsystem (ASC)

The payload, which includes a variety of communications antennas, will require that the ACS stabilize the spacecraft and maintain it in a stable attitude.

When the spacecraft is on station in geosynchronous orbit, the ACS will maintain the ACS reference axis in alignment with the orbital reference frame within the 3-sigma accuracy limits stated in Table B-4, which were taken from Reference B-1.

TABLE B-4 ACS ON-STATION POINTING ACCURACY			
Operating Condition	Roll (Deg.)	Pitch (Deg.)	Yaw (Deg.)
On-station, steady-state	+0.09	+0.09	+1.0
Stationkeeping	+0.2	+0.2	+1.0

Payload antenna control consists of electronically reconfiguring the fixed Multiple Beam Antennas (MBA's) or reorienting the steerable Gimbaled Dish Antenna (GDA).

Configuration control of the MBA BFN's and pointing control of the GDA are accomplished by the Attitude Control Electronics (ACE). Uplink commands for the BFN's are processed by the TT&C Command Decoder and stored in the ACE. The ACE microprocessor formats the data and sends the commands to the BFN Central Electronics (CE) when commanded. Serial digital telemetry from the BFN is stored in the Attitude Control Electronics and relayed to the downlink telemetry.

The GDA receives electrical power from the ACS for operating gimbal actuator stepper motors. The GDA contains potentiometers that provide a position indication for both the X and Y axes by means of a calibrated dc voltage of 5 volts. Analog position information is converted to digital in the ACS Analog to Digital (A/D) converter. These positional data are placed in the ACE memory and relayed to the TT&C Subsystem for the downlink telemetry.

3. Thermal Control Subsystem (TCS)

The payload will require both active and passive thermal control by the TCS. Passive techniques will be applied to the communications antennas (MBA-61, twin MBA-19, GDA, and twin ECH) and to the SCT UHF antennas. Active techniques will be applied to payload elements, such as TWTA's and LNA's for the Comm and SCT subsystems mounted on the spacecraft bus North and South panels, respectively.

No temperature control limits for subsystem elements are stated

here.   However, estimates of maximum and minimum expected on-orbit
operational temperatures may be found in Section 7 of Reference B-2.

From section 2.3.4, we observe that temperature control is primarily
autonomous through the use of thermostats, but that the ground does have
discretionary control if required from an analysis of telemetry data. The
normal control mode is through the thermostatically controlled heaters.

These heaters provide active thermal protection for structure and/or
components from the specified minimum temperatures. Two levels of control are
provided. The first level of thermal control is provided by heater circuits
called control heaters. The control heaters maintain temperatures above the
minimum operating temperatures for their associated components. The control
heater circuits power is controlled by discrete commands from the TT&C while
their actual heating cycle is controlled by thermostats. All control heater
power is removed automatically by the Load Shed Relay except for PS, ACS and
battery heaters.

The second level of thermal control is provided by heater circuits
called survival heaters. The survival heaters maintain temperatures above the
minimum survival (nonoperating) temperature limits. Survival heater power is
provided continuously and is not commandable.

Each heater circuit has a thermostat to control the heater duty
cycle to maintain its temperature (either control level or survival level).
Each circuit also has an over-temperature thermostat to protect against a
failed closed heater circuit. All thermostatically controlled heater circuits
are redundant.

The payload, of course, will also require specific levels of thermal
control during other mission phases such as prelaunch, launch, and orbit
transfer.

4.   Structure Subsystem

The payload places requirements on the Structure Subsystem with
regard to mechanical alignment of the antennas as shown in Table B-5.
Three-sigma root-sum-square values are given.

TABLE B-5 MECHANICAL ALIGNMENT REQUIREMENTS (DEGREES)

Narrow Coverage Antennas						Earth Coverage Antennas					
GDA			MBA's			MBA's		ECH's		SCT's	
Roll	Pitch	Yaw	Roll	Pitch	Yaw	Roll	Pitch	Roll	Pitch	Roll	Pitch
0.01	0.06	0.01	0.02	0.02	0.02	0.02	0.02	0.07	0.07	0.25	0.25

5. Telemetry, Tracking and Command (TT&C) Subsystem

The payload requires commands from the ground. The payload also telemeters to the ground data on its performance, status, and health. These functions are supplied by the TT&C. A discussion of payload tracking requirements will be deferred to the navigation subsection.

The Comm payload provides the antenna capability for the SHF telemetry and command links. It will receive, filter, preamplify and provide SHF ground command transmissions on channels 1 and 5. The RF Interface between the Comm and TT&C subsystems is defined at the input port to the SHF-to-S-Band downconverter. The Comm subsystem will also provide a Command and Telemetry Interface Unit (IFU) which is digital and separate from the RF interface with the TT&C. This unit processes commands coming into the payload from the TT&C and telemetry coming into the TT&C from the payload. The Comm subsystem also provides a stable frequency reference to the TT&C down converters.

The Comm Subsystem is operated and controlled by commands and telemetry through TT&C Subsystem SHF and S-Band RF links. Both discrete commands and message commands are used to provide subsystem configuration and mode control, antenna pattern control and communications parameter adjustment capability. Bi-level, analog and serial data telemetry are used to verify command execution and subsystem performance.

Commands affecting the Comm Subsystem are routed from the Command Decoder to any one of several satellite locations for processing and implementation. These include the North Panel Power Controller (NPC), the Command and Telemetry Interface Unit (IFU), the South Panel Power Controller (SPC) and the Jammer Location Electronics (JLE). In addition, MBA reconfiguration commands are processed by the Attitude Control Electronics (ACE), which subsequently controls the reconfiguration execution.

Commands to reconfigure the communication network (e.g., changing antenna pointing) are normally sent via the SHF link; commands to mitigate failures (e.g., switching in redundant TWTA's) are normally sent via the S-band link. However, the technical capability must exist to send any command by either link.

Processing of Comm subsystem discrete commands and generation of bi-level and analog telemetry is relatively simple and straightforward. However, message command processing and serial data telemetry generation is generally more complex. Many commands involve operation of the IFU, the NPC and its ferrite Switch Relay Tree, and/or the JLE. MBA reconfiguration and Gimbaled Dish Antenna message command processing involve data processing and storage by the ACE, and reconfiguration execution under control of the ACE software. In addition, the communications subsystem relies on dedicated ground software - the Communications Configuration Program (CCP) and the Telemetry Command Program (TCP).

134

The Comm subsystem uses both discrete and message commands. Discrete commands generally perform a single function such as turn off of a particular component or switching redundant components by setting or resetting latching relays. Message commands are used to transmit data to the Communications subsystem and to set up or execute more complicated operations. Eighty-one discrete and 17 message commands received from the satellite TT&C subsystem are used to control the communications subsystem. Figure B-1 shows the satellite components where the command processing takes place. The following should be noted:

(1) All MBA and BFN configuration commands are processed by the ACE. The only exception is the selection of the prime or redundant Central Electronics by discrete command which is processed by each Central Electronics. Reconfiguration data contained in message commands is processed and stored in the ACE until the execution is initiated by discrete command to the ACE.

(2) All other Comm subsystem commands except JLE commands are processed by the IFU. Control signals are then applied to the specific Comm subsystem component either directly or after further processing on the North Panel Power Controller (NPC).

(3) Most discrete commands which are used to turn on power, or make selections in other Communications subsystem components are processed by the NPC which sets/resets a latching relay to apply/remove power, select components, etc.

These discrete commands are executed by connecting latching relay coils to specific top and bottom switches of the Command Decoder matrix. Routing of message commands is accomplished by means of a Precursor word which is the first word of any message command to the satellite. This word is decoded by the Command Decoder to determine the message destination and number of message words to follow.

Commands may be sent individually or in sequences composed of many discrete commands and/or message commands. Each message command in a sequence may contain up to 64 message words. The command sequences may be generated and sent manually by the command operator or generated automatically by the CCP software and transmitted under control of the TCP software after initiation of the sequence by the operator.

Eighty-nine bi-level, 116 analog and 8 serial data telemetry functions transmitted by the satellite TT&C Subsystem are used to monitor command execution, and Comm subsystem performance, health and status. Most telemetry sensors, pick-offs and associated conditioning circuits are located in the specific component they are monitoring and are sampled periodically by the TT&C Subsystem. Serial telemetry is provided by the IFU and JLE. The MBA BFN ferrite state data is read out of the ACE where it is stored after the reconfiguration.
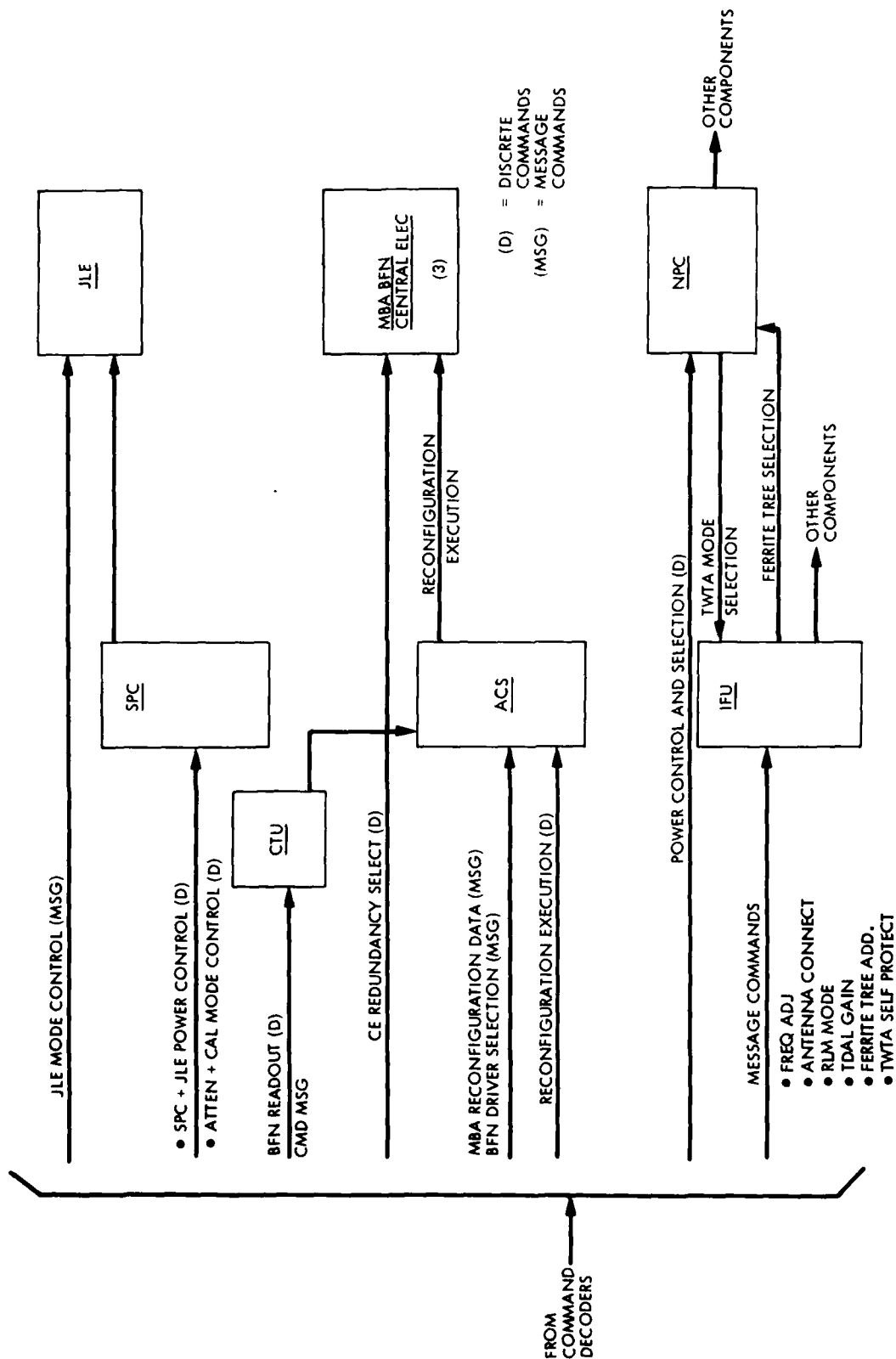
135

Figure B-1. Command Paths and Processing

136

All serial digital telemetry is connected to the Master Telemetry Unit on the South panel, while all bi-level and analog telemetry is connected to the Remote Telemetry Unit located on the North panel. Virtually identical telemetry streams are sent simultaneously over the SHF and S-Band links.

A vital spacecraft and Communications network function is timing. A redundant 5.0 MHz Frequency Standard in the payload is used to supply a reference frequency to the SHF-to-S-band downconverter, S-band-to-IF downconverter, and to the two SHF beacons. The 5.0 MHz distribution network is contained in the frequency generator and provides the output signal levels into nominal 50 ohm loads. The TT&C subsystem must furnish frequency update commands from the ground to the reference Frequency Standard.

The initial error in the downconverter and mixer injection signals, code generator, and beacon frequencies shall not exceed 1 ppm (3 sigma). The stability shall be better than the requirements specified in Table B-6.

All short-term frequencies shall satisfy the requirements of Table B-6 within four hours after turn-on. The frequency stability shall be better than 1 ppm (3 sigma) within one hour after turn-on under all conditions.

TABLE B-6   MINIMUM FREQUENCY STABILITY REQUIREMENTS*

Parameter	Communications	Beacon Code	AFSATCOM SCT
Short Term Stability			--
0.1 sec	5×10^{-10} (1 sigma)	1×10^{-6} (1 sigma)	--
0.001 sec	--	--	
Long Term Stability			
1 hour after turn-on	1×10^{-6} (3 sigma)	1×10^{-6} (3 sigma)	1×10^{-6} (3 sigma)
24 hours			3×10^{-11}
Per month	1×10^{-8} (3 sigma)	--	--
Long Term Stability (over spacecraft life)	3×10^{-6} (3 sigma)	--	3×10^{-9}

*All short term requirements shall be satisfied within 4 hours after turn-on.

6.   Navigation

The navigation function relies on tracking data from the TT&C subsystem, ground computation, and on the spacecraft Propulsion Subsystem (PS). The navigation function involves:

(1) Obtaining spacecraft ranging and Doppler tracking data;

(2) Ground computation of spacecraft position and velocity as a function of time (the ephemeris), and the

(3) Computation, commanding, and execution of spacecraft stationkeeping maneuvers using the PS.

The payload places requirements on stationkeeping accuracy. North-South excursions from the equatorial plane must be limited to $+0.1$ degrees in orbit inclination. East-West excursions from the assigned longitudinal station must be limited to ±0.1 degrees.

Spacecraft users require that, at any time, the location of the satellite relative to any ground station from which it is visible with an elevation angle of 7.5 degrees or more must be known to a range accuracy of 9400 meters or less. The relative velocity must also be known to 0.19 meters/second or less.

The navigation function is required to provide users with orbital state vectors (spacecraft position and velocity) of sufficient accuracy that the existing user ephemeris propagation can meet the previously stated 9400 meter/0.19 meter/second requirement at all times between the receipt of state vector updates. It is required that the user ephemeris propagation maintain this required accuracy for five days between updates, with a goal of 21 days between state vector updates from the navigation function.

REFERENCES

B-1.   Prime Item Development Specification for DSCS III Satellite,
       SVS-8950-I-C, 30 June 1980.

B-2.   DSCS III Satellite Engineers Handbook, CDRL-A041, December, 1978.

B-3.   DSCS III Orbit Operations Handbook, CDRL-A042, January, 1980.

B-4.   DSCS III STC Training Course Material, CDRL-A049, November, 1980.

B-5.   Specification for the DSCS III Satellite Communications Subsystem,
       SVS-9630-I-C, Part I of II Parts, 18 May 1979.

B-6.   DSCS III Space Segment Specification, 07868-DSCS III-IA, 15 December
       1980.

APPENDIX C

ACS MICROCOMPUTER ARCHITECTURAL CHARACTERIZATION

C. ACS MICROCOMPUTER ARCHITECTURAL CHARACTERIZATION*

Figure C-1 is a block diagram of the computer. The description of the computer in this Appendix is based on available literature and is subject to the constraints discussed in the preface to Volume I.

1.0   Central Processor Unit (CPU)

The CPU is a microprogrammed, 16-bit, parallel, digital processor. LSI11 processors of similar vintage have direct addressing capability to 32k words of memory. The CPU can address memory in two modes; word (16 bits) and byte (8 bits). Word addresses are alway even-numbered. Byte addresses are even and odd-numbered. CPU instructions occupy whole address words. The CPU with dedicated power supply is block redundant and is powered on a strobed basis. The strobe is activated by a 1.024 second cycle clock which is synchronized to the Telemetry, Tracking and Command (TT&C) subsystem main frame sync pulse (2.048 seconds). The power strobe is terminated by a control signal generated when a 'halt' instruction is executed in software. The CPU is under the control of the 'embedded flight software program' stored in nonvolatile Read-only Memory (ROM). The CPU uses volatile Random Access Memory (RAM) as a 'scratch pad' for control algorithms. The CPU uses hardened RAM (HRAM) to store critical RAM data which can be loaded back into RAM following detection of a nuclear event or a power off/on event. The CPU interfaces with the rest of the system via the digital bus. LSI11 design allows for vectored interruption of the CPU by devices on the digital bus (see B.2 below). The interrupt vector is a reserved address pointer to memory where the interrupt service routine for the particular device is located. The priority of the interrupt is determined by the physical proximity of the device to the CPU on the bus. The CPU can enable or disable all interrupts. Although this is a capability of LSI11-type systems, it does not appear to be the manner in which the ACS microcomputer devices are configured. One bus signal line functions as an external event interrupt line to the CPU. When configured, this line has the highest priority. A special interrupt vector address is reserved for this function. It has not been determined if this interrupt is being used in the ACS microcomputer design.

2.0   Digital Bus (BUS)

The digital bus structure links the CPU with memory and all other peripheral devices. It is comprised of 50 nonredundant lines. Parallel, 16-bit address lines interface CPU to memory and input/output (I/0) peripherals (ports). Parallel, bi-directional, 16-bit data lines transmit read/write data between CPU and memory ports. Three lines control read/write synchronization. Eight interrupt lines are provided for the telemetry port. Their function is not understood to date. Seven lines provide clock and
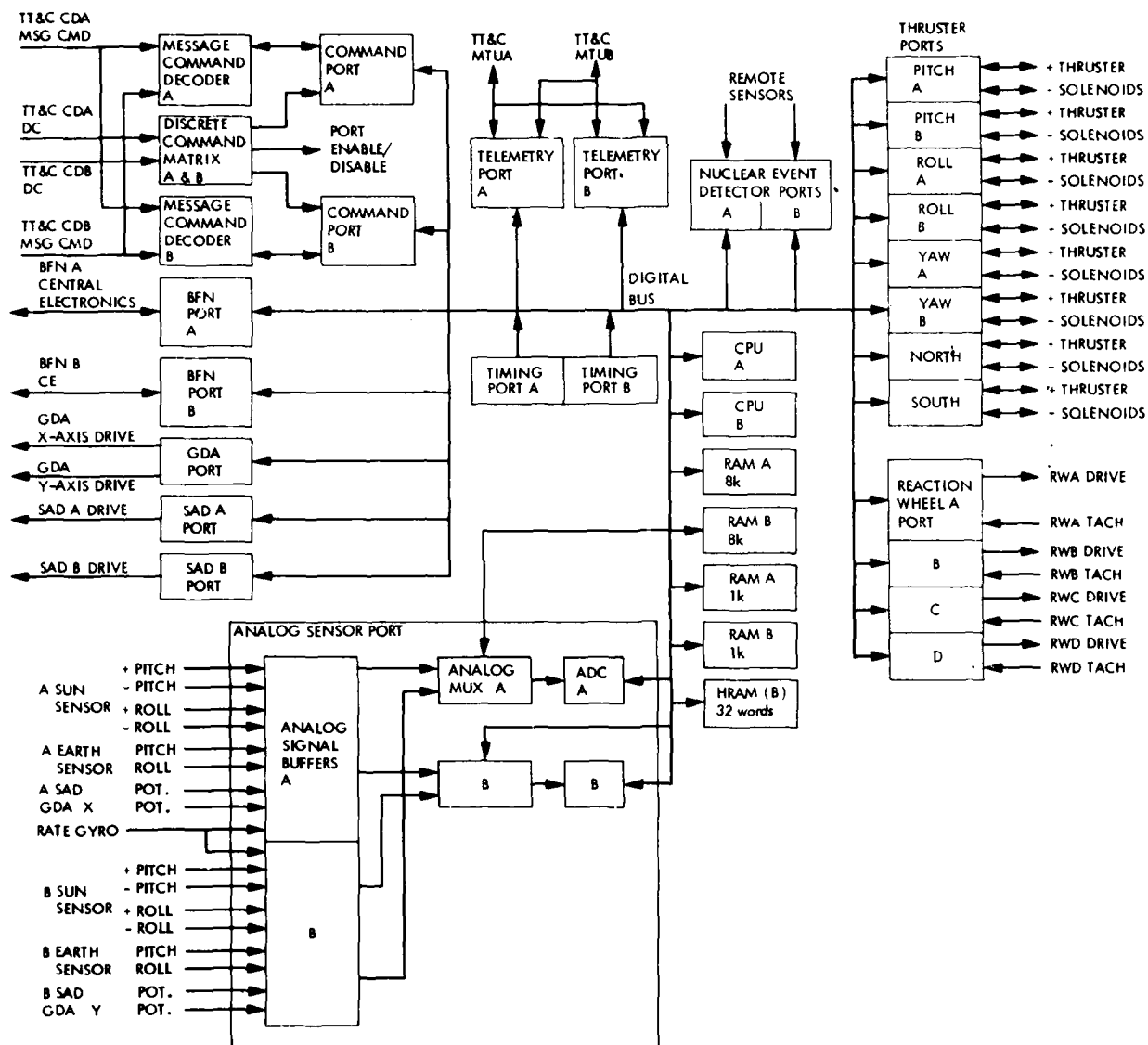
---

*By D. J. Eisenman (General Electric Co.)

Figure C-1. ACS Microcomputer Block Diagram

timing signals. The bus is under the direct control of the CPU, which is responsible for meeting port timing restrictions. Bus communications are asynchronous to provide automatic compensation for clock skews and varying memory I/O port response times. Data transfer is accomplished using program initiated, memory mapped I/O, i.e., each device on the bus is assigned a special memory address and the CPU passes data to and from the device as though memory was being addressed. Bussed units are power switchable such that any failed unit (CPU, memory, I/O port) can be totally isolated from the bus. Redundancy, via cross strapping, is achieved by selectively powering desired units.

3.0 Read Only Memory (ROM)

The ROM is a nonvolatile, block redundant, 8k by 16-bit memory. Only one ROM is powered at a time and is power strobed in a similar fashion to the CPU. ROM is interfaced with the rest of the system via the bus. The operating speed is less than 10 microseconds. ROM houses permanent, nearly unalterable computer program instructions/constants (embedded flight software) to control operation of the ACS and BFN. This program is executed by the CPU on a 1.024 second cycle. The ACS portion of the program executes each cycle and the BFN portion executes on command from the ground. ACS program execution will not exceed 400 milliseconds running time and the BFN portion will not exceed 500 milliseconds. This program can be modified in a limited way by using the redundant RAM (1k) to store selected ROM patches. Certain ROM memory locations are reserved for interrupt and trap handling. Interrupt memory locations are discussed under CPU, above. Traps are special interrupt vector locations used for conditions such as: bus device time-out (addressed device does not respond within a certain time interval), illegal CPU instruction code, and software instruction forced traps.

4.0 Random Access Memory (RAM)

The RAM is a volatile, block redundant, 1k by 16-bit memory. Normally one RAM is powered at a time. However, the redundant RAM can be powered to operate in a 'RAM patch' mode to provide limited ROM reprogramming. The RAM is interfaced with the rest of the system via the bus. RAM read/write speed is less than 10 microseconds. The RAM houses variable data computed and used by control algorithms and allows programming flexibility to perform double precision multiply and divide processing.

5.0 Hardened Random Access Memory (HRAM)

The HRAM is a 4 word by 16 bit memory. There are eight HRAM's, only six of which are normally powered and required for normal operations. The two remaining HRAM's provide functional redundancy. Any or all of them can be powered. The HRAM is interfaced with the rest of the system via the bus. HRAM read speed is 15+ or -10 microseconds. The write speed is 156+ or -10 microseconds. HRAM's are made up of individual 'slow' flip-flop cells for each bit of hardened information. HRAM is used to store RAM variables which must not be lost if a nuclear event is detected or if the RAM experiences a power off/on event.

143

6.0   Input/Output

Sixteen peripheral devices (ports) of different types are on the
bus. All are redundant (block or functional) but one, the Gimbaled Dish
Antenna (GDA) port. Ports are interfaced to attitude control actuators,
analog sensors, command and telemetry hardware (TT&C), beam forming network
(BFN) electronics, clock and timing hardware and special event (nuclear)
detectors. Ports are operated using program-initiated I/O transfers (memory
mapped I/O) vs interrupt-initiated I/O transfer (interrupt vector I/O).

6.1   Reaction Wheel (RW) Ports

There are four RW ports, one per RW. All four are normally powered.
Any three can provide proper control. The port outputs the RW drive count and
the tachometer select command from the CPU. The port inputs the RW tachometer
count data to the CPU when polled.

6.2   Thruster Ports

There are eight ports configured as four complementary pairs, e.g.,
pitch a/b, roll a/b, etc. Only one of each pair is powered. The ports
provide thruster solenoid activation in the mode, direction and duration
commanded by the CPU. The ports input thruster valve firing status to the
CPU when polled.

6.3   Solar Array Drive (SAD) Ports

There are two ports, one per SAD stepper motor. One is normally
powered. Both can be operated for higher torque levels. The port provides
motor drive stepping in the direction and rate commanded by the CPU. SAD
drive modes, the normal RATE mode and the SLEW mode are selected by, and
stored in, a flag in the CPU.

6.4   Gimbaled Dish Antenna (GDA) Port

There is one nonredundant port dedicated to the GDA gimbal motors.
The port provides motor drive stepping on the X and Y axis in the direction
and slew angle commanded by the CPU.

6.5   Analog Sensor Ports

There are two ports, each comprised of an analog signal buffer,
multiplexer, decoder and a/d converter. Both signal buffers are always
powered. Only one mux, decoder and a/d converter is powered. Each port uses
both signal buffers and one set of mux, decoder and a/d converter to input
digitized signals for positive and negative pitch and roll sun sensor
attitude, pitch and roll earth sensor error, rate gyro, SAD potentiometer, GDA
X and Y axis potentiometers to the CPU, when polled.

6.6 Clock and Timing Ports

There are two ports which can drive seven lines on the bus. Only one port is normally powered. The port inputs a 1.024 second pulse synchronized to the TT&C main frame sync pulse and six other clock frequencies for all bus users.

6.7 Nuclear Event Detector Ports

There are two ports, one is normally powered. The port inputs a one-bit status indication of the occurrence of a radiation event when polled by the CPU. When the event signal is read, the status indicator is automatically reset, making the port ready to input the next event occurrence. Special CPU processing is initiated when the event is sensed.

6.8 BFN Ports

There are two ports. Only one is normally powered. Each port is dedicated to one of two BFN central electronics packages. This port operates differently from other ports, in that no feedback signal is returned by the port. The transmitted commands are assumed to be completed in open-loop fashion, in a prespecified time.

6.9 Telemetry Ports

There are two telemetry ports, each consisting of a 64 word by 8 bit RAM which buffers data from the CPU and holds it until removed by the TT&C. Only one port is normally powered. The port outputs serial, digital data of selected ACS and BFN operating and commanded values, stored in RAM, from the CPU to the TT&C. Bi-level and analog data is not provided through the port. Insuring that the port RAM is loaded with the correct data, prior to the point in time the TT&C sampling operation begins, is a responsibility of the CPU under ROM control. A port 'RAM not empty' status indicator is input to the CPU when the port is polled, and is used to reload the port RAM after being emptied by TT&C. The read command sets flip-flops indicating master frame (one/61.44 sec.), main frame (one/2.048 sec.), and interrupt mode status for use by the ACS software; and the timing is synchronized with the TT&C subsystem.

6.10 Command Ports

There are two message command ports, each consisting of a 16-word by 20 bit RAM which buffers message commands from the TT&C command decoders (CD's) to the CPU. Only one port is normally powered. The CPU and the TT&C CD's share access to the port RAM on an asynchronous basis. The CPU can command a request for uninterrupted access to the port RAM to empty it each execution cycle. The port inputs 18 bits of message command data and two bits of abort and enable status indicators, hence 20 bits. The message command data is used to modify RAM. The status indicators are used to control the processing of sequences of message commands. Two input operations are required to obtain each 20 bit message command from the port.

145

6.11   DC Matrix

Two identical diode latching relay matrices provide nonvolatile storage of discrete commands issued by the TT&C CD's. Both are always active. Approximately 60 of these discrete commands generate status indicators which are ready by the CPU and are used to control various processing algorithms. Discrete commands are used to select redundant bus elements, enable/disable for automatic modes (e.g., auto earth acquire), and for selection of processing parameters in ROM or RAM.

7.0   ROM PROGRAM

The ACS and BFN programs, stored in nonvolatile ROM and executed by the CPU, give the ACS its character. The ACS program is executed to completion each CPU execution cycle. This is assured by the use of the 1.024 second CPU/ROM power strobe and the careful sizing and programming of the ROM so that control functions are processed, ports are serviced and the ROM 'halt' instruction is executed (to terminate the power strobe) within a time period less than the CPU execution cycle. Some port processing, such as command and telemetry, requires special timing within each execution cycle. When the CPU is powered, the ROM program executes in a functional, straight-line manner. Within each functional area, loops and subroutine calls are used. Higher priority functions such as circumventive, telemetry, and input conditioning are processed first. Ports are serviced in a polling fashion, i.e., they are written to and read from at the discretion of the ROM program execution and are not allowed to initiate their own request for service, which would interfere with ROM program timing. Program interruption is used sparingly to handle CPU memory, port faults or is under ROM program control to accomplish RAM patching. Message commands from TT&C can be used to modify RAM contents (variables). Discrete commands (DC's) from TT&C (to the latching relay matrix) are used to configure redundant units on the bus, select a limited set of control algorithm and port processing modes, constants stored in ROM or variables stored in RAM. ROM 'reprogramming' can be performed by using the redundant RAM to house the patch program and establishing a link from ROM.

7.1   MAJOR ROM PROGRAM PROCESSES

7.1.1   Power Up

The CPU/ROM is powered off/on each 1.024 second cycle. The determination that this is the normal CPU/ROM strobe power, or a power off/on condition which could seriously affect subsequent processing, is made by checking RAM memory for the presence of special 'sync' words. When the sync words are not intact (indicating a non-normal power off/on or possible nuclear event), the RAM is cleared, the RAM sync words are reestablished, HRAM values are written to RAM, RAM patching is disabled and the telemetry and command ports are initialized.

146

7.1.2 Circumventive

This logic is executed if nuclear event detection or CPU address instruction faults have occurred during the last CPU execution cycle. Event detection and CPU address instruction faults disable RAM patching and cause the bypassing of subsequent attitude control algorithms which use the sun sensors for a period of 32 CPU execution cycles.

7.1.3 Telemetry

There are two telemetry functions: normal and interrupt telemetry processing. Normal processing consists of providing 34 bytes (1 byte = 8 bits) of data, each CPU execute cycle to the port RAM. Data contents vary between two CPU execution cycles which comprise the 2.048 second TT&C main frame. In addition, twelve different processing modes and five different formats are available to convert data for the output telemetry stream. Interrupt telemetry is from BFN only. The processing consists of providing 64 bytes of data four times each CPU execute cycle, to the port RAM. The TT&C reads the port RAM after each load.

7.1.4 Attitude Control

This processing commands the thrusters, RW, SAD and GDA ports based upon sensor, RW tach, and command inputs. Processing starts by reading sensors, RW tachs and discrete command status, accessing ROM and RAM operating values and then decoding and scaling this data for subsequent control-loop processing. Inner and outer control-loop processing is then performed. Inner control-loop processing is performed each CPU execute cycle. Inner control accepts outer loop attitude error estimates and commands the RW port to null the estimates, senses the RW tach response, calculates the corrected error factors achieved and updates the attitude error estimates. Attitude estimates are comprised of pitch, yaw, roll and RW momentum elements. The outer control loop processing is done every 16 CPU execute cycles for normal on-orbit operations or every 2 CPU execute cycles for maneuvers. Outer loop processing uses read-sensor data to calculate attitude and rate errors, and updates the attitude and RW momentum error estimates. Errors are the difference between estimated and sensed attitude. The outer loop also drives the thruster ports for maneuvers and RW unloading. SAD and GDA port processing is performed last.

7.1.5 Message Command

Command processing reads message commands from the RAM port, stores them into an intermediate RAM buffer, checks for any command abort status, and dispatches processing to the specific routine designed to handle one of the ten different command types.

7.1.6 BFN

Not examined.

147

7.1.7   HRAM

Processing is performed each CPU execute cycle and writes certain RAM parameters to the HRAM. Attitude control processing sets a control word as new RAM parameters are computed which require writing to HRAM. This control word is used at the next CPU executive cycle to update only those HRAM words required. CPU time and power is saved by not writing all values to HRAM each CPU execution cycle.

7.1.8   Traps

Four trap types are processed: CPU odd-address, CPU illegal instruction, port time-out, and software triggered. Traps are special hardware interrupt vectors. The odd-address trap occurs when the CPU executes from an odd memory address for some reason (hardware fault, bad programming). The ROM program cannot decide what address value should be used, therefore a software status bit is set and the CPU is halted ('halt'instruction terminates CPU/ROM power strobe). The software status bit is then recognized by subsequent circumventive processing at the next CPU execute cycle (see circumventive processing, above). The illegal instruction trap occurs when the CPU tries to decode a word from memory which is not a defined, machine operation code. The processing sets a software status bit and the CPU is halted. The software status bit is then recognized by subsequent, circumventive processing. Time-out traps occur when addressed peripheral devices do not respond within several microseconds. This could occur if a nonexistent port of memory is addressed. Trap processing sets a software status flag, which goes to telemetry, and returns to the interrupted program. Software triggered traps occur when a 'trap' instruction is executed in the presence of 'integer overflow' or 'divide by zero' conditions. This is used in double precision subroutines to detect computational errors. Recovery processing consists of setting a software status bit and returning to the interrupted routine where the faulty calculation is set to zero.

7.1.9   RAM Patch

'RAM patching' uses the redundant RAM. It allows changing the ROM program flow by storing into the redundant RAM a modification which has been previously checked out and ground verified. At the time that the ROM program is installed, 'hooks' ('breakpoint trap' (bpt) instructions) are interleaved at preselected locations throughout the ROM software to facilitate later RAM patching. All patches contain a patch table which is stored in to reserved RAM locations. The patch table contains: old program location for bpt instruction, entry point location for the uplinked patch, and the new ROM program location return point. Multiple patches can be in effect, using the patch table. Execution of the ROM bpt instructions causes trap interrupt processing. This processing checks for the presence of the correct ground commanded enable and execute discrete commands, and the patch table located in the proper place in the RAM. If all is enabled and ready, the patch is executed, after which the program flow returns to the ROM program. Patches can be used up to the limit of the redundant IK RAM's ability to hold them and the limit in running time of the ACS program that can be tolerated.

148