Landsat 7 Flight Operations Plan

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Document Section Reference

Table of Contents

Index of Figures and Illustrations

Index of Figures and Illustrations continued

Index of Tables

Section 1 INTRODUCTION

Table of Contents

1.1 Purpose and Scope

The purpose of the Landsat 7 Flight Operations Plan (FOP) is to serve as a comprehensive baseline document reflecting how the Flight Operations Team (FOT) operates and interacts with other elements and the spacecraft in order to achieve the mission objectives. Operations internal to the segment will also be described. Scientific objectives, subsystem and instrument design, mission operations philosophy, past flight operations experience, and ground system architecture all serve as a foundation for the development of the FOP. The plan provides a basis for the development of detailed flight and ground system operating procedures. In addition, the FOP is used as a training tool for the FOT.

To put the FOP in to perspective with other operations documents, consider this overview:

FOP - (Flight Operations Plan) - provides an outline of operations including plans, timelines, configurations, and interfaces necessary to coordinate flight and ground resources.

FPD - (Flight Procedures Document) - provides low-level detail (work instructions in most cases) on how to perform activities laid out in the FOP.

OOH - (On Orbit Handbook) - provides detail of spacecraft design, normal and contingency spacecraft activities, operational constraints, and LAA activities.

1.2 Document Organization

The Landsat 7 FOP is comprised of eleven separate sections. A brief description of each follows:

Section 1: Introduction - Provides a brief introduction including document purpose, scope, and organization. This section also includes a list of all referenced documents.

Section 2: Mission Overview - This section is meant to provide the reader with an overview of the entire Landsat 7 mission, including the mission objectives.

Section 3: Flight Operations Team - The FOT objectives, organization, and job responsibilities are described. In addition, a staffing profile is given for the team as well as a brief overview of their training and certification.

Section 4: Facilities - This section gives a brief overview of the Mission Operations Center (MOC) including the logistics, maintenance, contingency plans, and configuration control of the facility. A description of the MOC hardware architecture is also given.

Section 5: Mission Phases - This section provides an overview of the operations that will be required of the FOT during each of the Mission phases. Pre-launch Planning and Testing, Launch, Ascent, and Activation, On-Orbit, and EOL phases are discussed.

Section 6: Satellite Subsystems and Operations - This section provides a description of the Landsat 7 spacecraft and payload along with the operations associated with each system.

Section 7: Realtime and Support Operations - This section describes the components of realtime operations (pass operations, command and telemetry operations), and support operations (planning and scheduling, spacecraft clock and center frequency maintenance, ephemeris and leap second updates, and maneuver planning). In addition, two realtime scenarios and a MOC activity timeline are given.

Section 8: Anomaly Detection, Isolation, and Recovery - Anomaly handling philosophy along with the tools used to detect and react to anomalies are discussed.

Section 9: Offline Engineering, Trending and Analysis - This section provides an overview of the offline engineering activities necessary for spacecraft operations (routine and non-routine).

Section 10: Software and Database Configuration and Maintenance - A plan for the configuration control and maintenance of the numerous databases, procedures, and software components is referenced.

Section 11: Operational Interfaces - A chart showing the external interfaces of the MOC is presented. The chart shows products, frequencies, and exchange media.

Section 12: Acronym List

Appendix A: FDF Products and Timelines

1.3 Referenced Documents

The Landsat 7 FOP has been developed using a combination of mission, spacecraft, science, and ground system documentation, in addition to meeting with subsystem and instrument engineers, science representatives, and system developers. The FOP supercedes other operational documents as of the published date. Specific documents used in this process include the following:

(1) Practical Applications of Landsat Data by P.K. Conner and D.W. Mooneyhan as it appeared in Monitoring Earth's Ocean, Land, and Atmosphere from Space-Sensors Systems, and Applications, an AIAA publication.

(2) Detailed Mission Requirements (December 1996) 430-11-01-003-1

(3) Mission Operations Concept Document (April 1997) MOSDD-L7-MOP-002

(4) Spacecraft Subsystem Critical Design Review Packages

(5) Space Segment Satellite Critical Design Packages (October 10-11, 1995)

(6) Solid State Recorder Operations Concepts (April 1996)

(7) Mission Operations Center System User's Guide (April 1998) 511-4SUG/0696

(8) On-Orbit Handbook (July 1999) PS23007555 (II, III, IV, V, VI)

(9) Training material presented to the FOT by NASA Code 700 engineers

(10) Training material presented to the FOT by LMMS engineers

(11) Flight Dynamics to Landsat 7 ICD (September 1997) 430-11-06-006-1

(12) Data Formats Control Book Vol. II, III (June 1999) 23007702-IIAA, IIIAA

(13) Early Orbit Operations TIM Package (May 1995)

(14) FOT Training & Certification Plan (December 1999) FCS-L7-LOP.002

Section 2 MISSION OVERVIEW

Table of Contents

2.1 Mission Introduction

Landsat 7 is the seventh in a series of land remote-sensing satellites. The Landsat satellites have been designed to provide a varied user community with timely visible and infrared imagery of the Earth's surface. The first Landsat satellite was launched in 1972 and contained return beam vidicon cameras and a multispectral scanner for Earth imaging. Landsat 2 and 3 (launched in 1975 and 1978 respectively) carried similar instrumentation. In 1982 when Landsat 4 was launched it marked the first use of the Thematic Mapper (TM), a 7-band, mechanically scanned radiometer with 30 meter (m) ground resolution. In addition to using an updated instrument, Landsat 4 made use of the multimission modular spacecraft (MMS) to replace the Nimbus based spacecraft design of Landsats 1-3. Landsat 5, launched in 1984, was designed to be much like Landsat 4, containing only minor upgrades. Landsats 4 and 5 are still operational. Landsat 6 was lost shortly after launch in 1993.

Landsat 7 represents a new generation of Landsat spacecraft. It carries the Enhanced Thematic Mapper Plus (ETM+), improving on the resolution and bandwidth obtained by past and current Landsat missions. Also, unlike Landsats 1-5 which were driven by user requests, Landsat 7 will operate largely as a survey mission, continually refreshing an existing Landsat database. Users of Landsat 7 will be able to obtain their desired data from a continuously updated archive rather than requesting the imaging of specific scenes on an as needed basis. This archive will be available to users for browsing and ordering of products.

Data input into the system by Landsat 7 is sufficiently consistent with past Landsat missions in terms of acquisition geometry, calibration, coverage, and spectral characteristics to allow comparison for global and regional change detection and characterization. The Landsat 7 goal is to fully refresh the global archive of all landmass and near coastal images on a periodic basis. The Landsat 7 project continues to make Landsat data available for U.S. civil, national security, and private sector use as well as academic, foreign, and commercial uses. Another goal of the project is to expand the uses of such data. Landsat 7 is to have a design lifetime of five years.

The National Aeronautics and Space Administration (NASA) was responsible for development of the Landsat 7 spacecraft and ground system and currently manages the spacecraft operations until transfer of such responsibilities to the United States Geological Survey (USGS) are completed (currently planned for 10/1/2000). USGS is responsible for the capture, processing, and archiving of all instrument and necessary ancillary data. USGS will also provide customer services to the user community.

2.2 Landsat 7 Ground System

Below is a list of the elements contained in the Landsat 7 Ground System, followed by a brief description of each element. Figure 2-1 illustrates the relationships between these elements.

- Mission Operations Center (MOC)
- Network Control Center (NCC)
- Landsat Ground Station (LGS)
- Alaska Ground Station (AGS)
- Svalbard Ground Station (SGS)
- Wallops Flight Facility (WPS)
- Space Network (SN)
- Flight Dynamics Facility (FDF)
- Landsat Processing System (LPS)
- Image Assessment System (IAS)
- International Ground Stations (IGS)
- EDC Distributed Active Archive (EDC-DAAC)

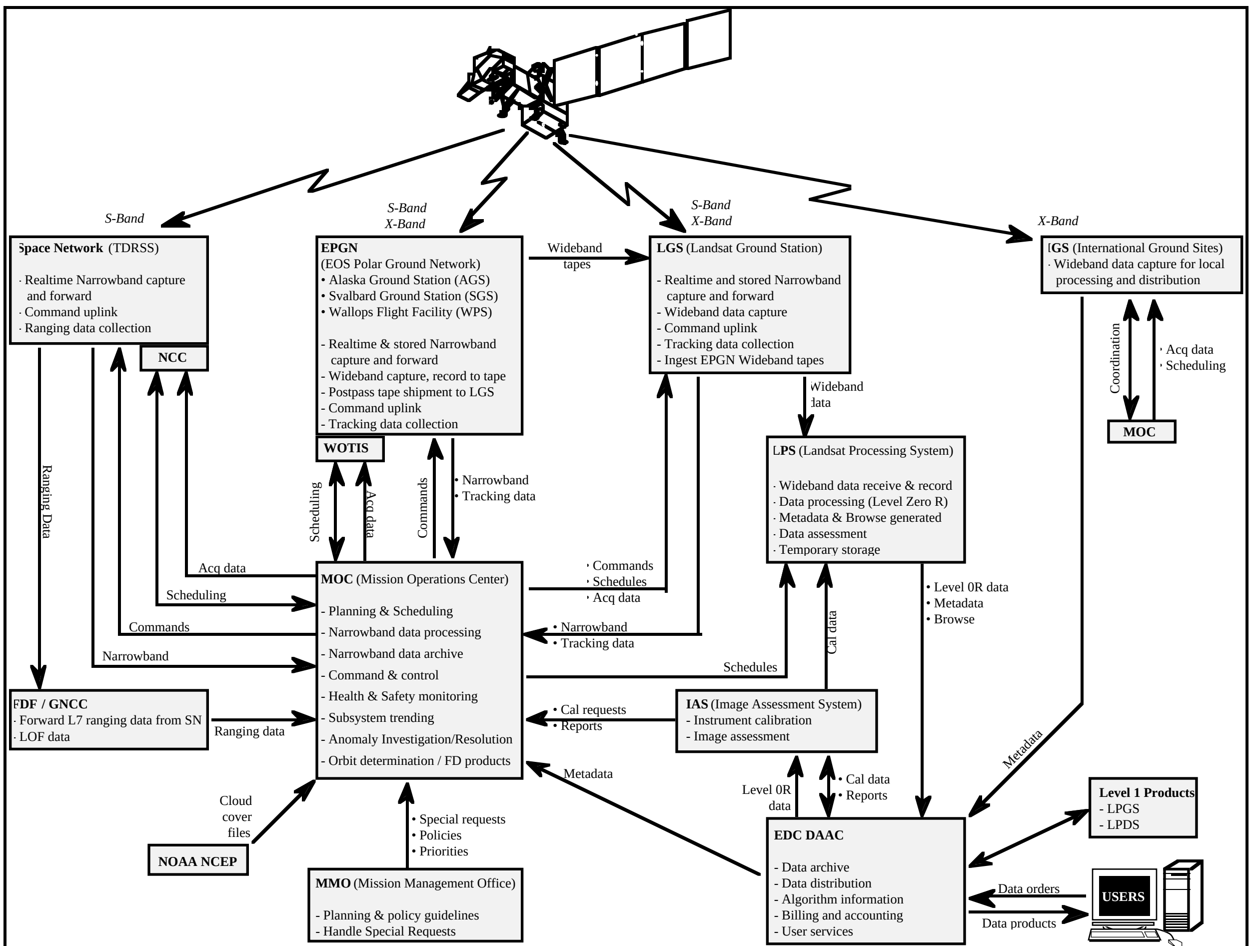


Figure 2-1 Landsat 7 Ground System

• **Ground Communications System**

The Landsat ground communications system provides for the receipt of S-Band housekeeping telemetry (realtime and recorded data) and X-Band instrument data (realtime and recorded data) and the transmission of commands (realtime and stored loads) to the spacecraft. All stations receiving realtime housekeeping telemetry also support the calculation of spacecraft clock drift. See Table 2-1 for an overview of station usage for normal operations, and Figure 2-2 for a graphic showing representative ground station passes scheduled for normal operations.

• **Space Network**

The NASA Space Network (SN) Tracking and Data Relay Satellite System (TDRSS) provides Doppler and ranging services for Landsat 7. Realtime housekeeping telemetry and command operations can also be provided during ranging supports. Command and data rates are limited through SN as Landsat 7 does not use a TDRSS high-gain antenna. Housekeeping recorder dumps (256 Kbps) cannot be supported by SN. Transponder center frequency measurements are also performed using SN support.

• **Alaska, Svalbard, and Wallops Stations**

Wallops Flight Facility manages three ground stations being used by Landsat 7 - the Alaska Ground Station (AGS) at Poker Flat; Svalbard Ground Station (SGS) in Norway; and Wallops Island, Virginia (WPS). These sites are collectively known as the EOS Polar Ground Network (EPGN). These sites all provide housekeeping telemetry support, both realtime and playback, command capabilities, and 2-way Doppler tracking. To augment data collection at the Landsat 7 Ground Site (LGS) and provide realtime imaging of Alaska, AGS and SGS also capture payload data on tape. These tapes are sent to LGS for playback and processing. WPS does not provide payload data capture services and is used only as a backup to the other EPGN sites.

• **Landsat 7 Ground Station**

The Landsat Ground Station (LGS) is located at the EROS Data Center (EDC) in Sioux Falls, SD. LGS is the prime United States site for receiving payload data. Housekeeping telemetry and command operations, and 2-way Doppler tracking are also conducted through LGS. LGS acts as the ‘front end’ of the Landsat 7 Processing System (LPS), providing payload data for processing either through realtime contacts with Landsat 7 or playback of tape recorded data from AGS, SGS, or LGS.

Stations	Purpose	Band @ Rate	Passes/Day	Pass Duration
WPS AGS SGS	• uplink stored cmd/memory loads • uplink realtime cmds • downlink of recorded H/K tlm • downlink of realtime H/K tlm • downlink of stored payload data • downlink of realtime payload data • 2-way Doppler data collection • s/c clock maintenance	• omni S-band @ 2 Kbps • omni S-band @ 2 Kbps • omni S-band @ 256 Kbps • omni S-band @ 4.864* Kbps • gimbaled X-band @ 150 Mbps (AGS) • gimbaled X-band @ 300 Mbps (SGS) • gimbaled X-band @ 150 Mbps (AGS only) • omni S-band, coherent • omni S-band	0 at WPS 2 at AGS 2 at SGS	≈15 minutes maximum
LGS	• uplink stored cmd/memory loads • uplink realtime cmds • downlink of recorded H/K tlm • downlink of realtime H/K tlm • downlink of stored payload data • downlink of realtime payload data • 2-way Doppler data collection • s/c clock maintenance	• omni S-band @ 2 Kbps • omni S-band @ 2 Kbps • omni S-band @ 256 Kbps • omni S-band @ 4.864* Kbps • gimbaled X-band @ 150-300 Mbps • gimbaled X-band @ 150 Mbps • omni S-band, coherent • omni S-band	6 (all available)	≈15 minutes maximum
IGSs	• downlink of realtime payload data	• gimbaled X-band @ 150 Mbps	1-3 per station	≈15 minutes maximum
NASA SN (TDRSS)	• Doppler & PN ranging operations • frequency drift determination • s/c clock maintenance • uplink of realtime cmd • downlink of realtime H/K tlm	• omni S-band, coherent @ 4.864* K • omni S-band, noncoh. @ 4.864* K • omni S-band • omni S-band @ 1** Kbps • omni S-band @ 4.864* Kbps	2-3	≈20 minutes maximum

* These sites are also capable of providing 1.216 Kbps realtime H/K downlinks.

** SN is also capable of supporting 125 bps command rate.

Table 2-1 Landsat 7 Space - Ground Communications for Normal Operations

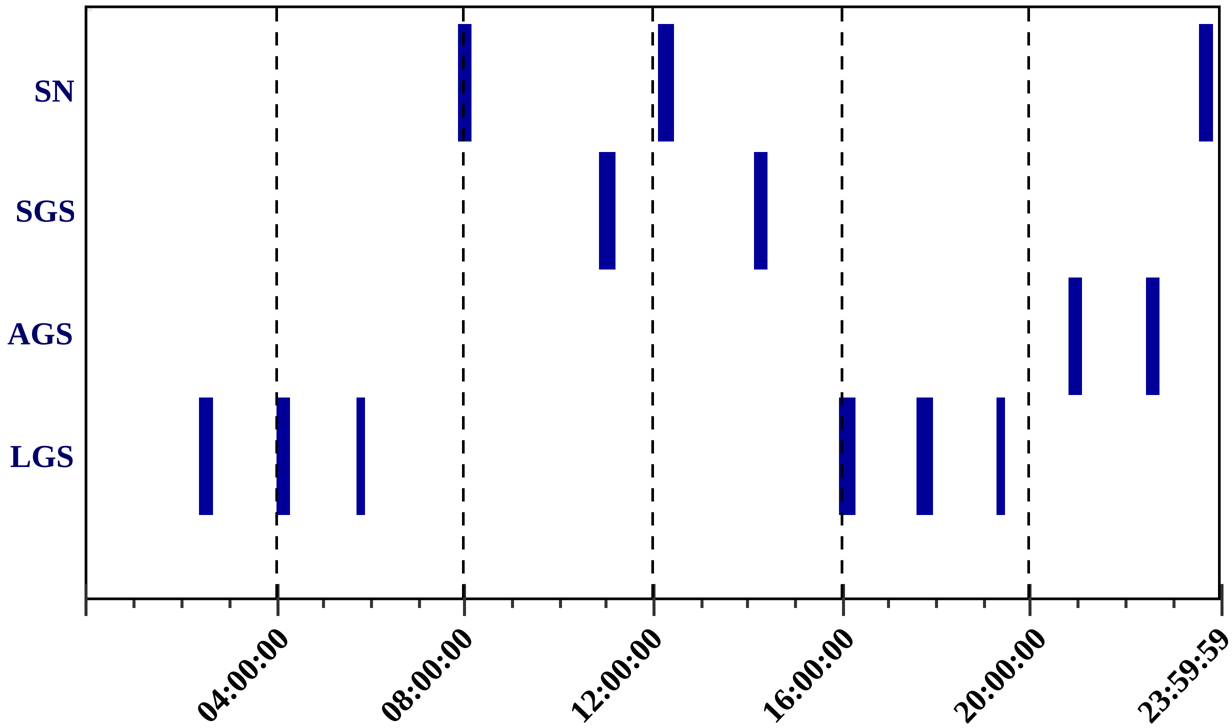


Figure 2-2 Ground Station Contacts for Normal Operations

- **Flight Operations Support**

- **<u>Mission Operations Center</u>**

The Landsat 7 MOC is located in Building 32 at GSFC. It provides the hardware and software systems necessary for the successful execution of realtime supports and off-line engineering activities. From here, the Flight Operations Team (FOT) performs realtime command and control operations of the spacecraft as well as assessing spacecraft performance through the analysis of captured housekeeping data. The FOT is also responsible for scheduling ground communication resources, managing the capture, storage, and downlink of all payload data, and generating the necessary command loads. In addition, flight software maintenance facilities are provided and orbit determination and flight dynamics functions are executed. All housekeeping telemetry is processed, analyzed, and archived in the MOC. The MOC facilitates interfacing with all appropriate elements required to conduct mission operations.

• **Flight Dynamics**

While many of the necessary flight dynamics functions are provided by the FOT, some remaining functions are provided by NASA flight dynamics personnel. Support for tracking data evaluation and Local Oscillator Frequency (LOF) reporting is supplied by personnel in the FDF. In addition, NASA personnel assist in the planning of major maneuvers such as Δ-i burns. The FOT performs most other daily flight dynamics functions. Software used for this support is described in Section 7.4.2. The interface between the NASA flight dynamics team and the FOT is detailed in the Landsat-7 to FD ICD. A listing of flight dynamics functions and who provides them is shown in Table 2-2.

Function	FOT	FDF
Ephemeris Generation	*	
Orbit Maintenance and Attitude Maneuver Support	*	*
Tracking/Doppler Data Quality Assessment		*
Transponder Center Frequency Assessments	*	*
Planning and Scheduling Product Generation	*	

Table 2-2 Flight Dynamics Functions

Network Control Center

The NCC provides scheduling, configuration control, performance monitoring, and realtime operations support for the Space Network (SN).

• **Wallops Orbital Tracking Information System**

The Wallops Orbital Tracking Information System (WOTIS) provides the scheduling interface for the EPGN ground stations (AGS, SGS, WPS).

• **X-Band Data Processing**

• **EDC Elements**

The EDC at Sioux Falls contains the LPS, EDC-DAAC, IAS, LPGS and LPDS along with LGS. A functional diagram of the EDC facilities is given in Figure 2-3. LGS is described above in the *Ground Communications System* section.

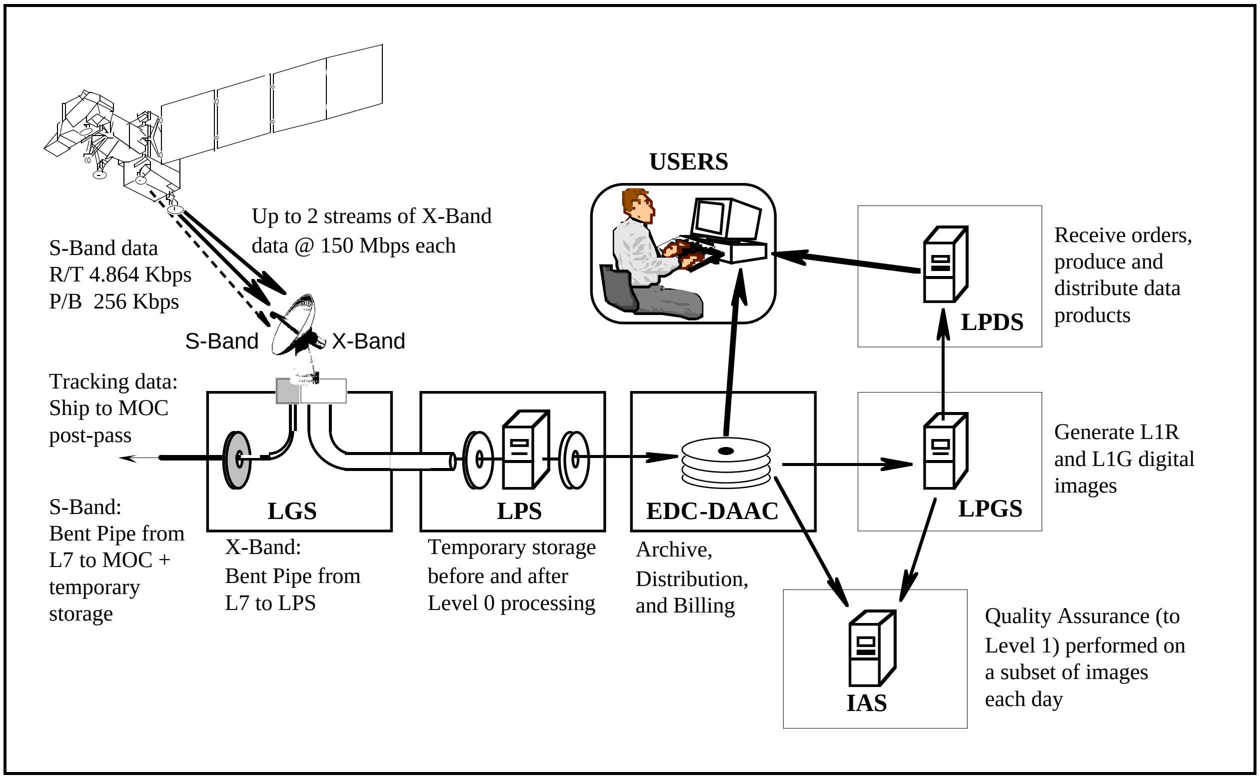


Figure 2-3 EDC Elements and Functions

• **Landsat Processing System**

The LPS is responsible for processing the captured payload data to a Level Zero R product, and creating appropriate metadata and browse data to compliment the payload data. LGS supplies LPS with data at the time of receipt (realtime imaging or recorder playbacks) or through playback of tapes from AGS or SGS. LPS is required to be capable of processing an average (over two days) of 250 scenes per day. After processing is complete, the data is temporarily stored and the EDC-DAAC is notified that the data is ready for archive.

• **EDC - Distributed Active Archive Center**

The EDC-DAAC provides the archive, distribution, and user interface functions for the Landsat 7 system. EDC-DAAC coordinates and manages user accounts, billing, and services for Landsat users. Products are distributed to users via both electronic means and a standard archive format (CD, 8mm tape, etc.)

• **Level-1 Product Generation System**

The LPGS produces Level-1 radiometrically corrected and geometrically corrected digital images for distribution by LPDS and analysis by IAS.

• **Level-1 Product Distribution System**

The LPDS produces Level-1 radiometrically corrected and geometrically corrected data products and distributes them to users.

• **Image Assessment System**

The IAS has been tasked with providing image quality assurance for Landsat 7. Between one and ten images are taken from the DAAC and LPGS each day and used to provide a quality check on the image product, evaluate ETM+ calibration data, and update image processing parameters. The IAS also trends the ETM+ performance from data derived from these daily operations. Health and performance of the instrument will be tracked and notification of degraded performance will be provided to Landsat 7 users and operators.

• **International Ground Stations**

In addition to sending payload data to the EDC facilities, the spacecraft will also downlink science data to several IGS. These stations will receive realtime science data only; each IGS can receive images of the territories within their respective acquisition circles only. Each IGS will sign a Memorandum of Understanding (MOU) with the Mission Management Office (MMO) which will specify certain terms of agreement relating to the scheduling and operations effecting their image capture. A list of current IGS is shown in Table 2-3.

Site	Location	Site	Location
COA	Cordoba, Argentina	NSG	Neustrelitz, Germany
ASA	Alice Springs, Australia	FUI	Fucino (Avezzano), Italy
HOA	Hobart, Australia	HIJ	Hiroshima, Japan
CUB	Cuiaba, Brazil	BJC	Beijing, PRC
GNC	Gatineau, Canada	KIS	Kiruna, Sweden
PAC	Prince Albert, Canada		

Table 2-3 International Ground Stations

2.3 Spacecraft Overview

This section will provide a brief overview of the Landsat 7 spacecraft. A more detailed description of the spacecraft systems can be found in Section 6 - *Spacecraft Subsystems and Operations* or in the On Orbit Handbook (OOH). The OOH takes precedence over the FOP in the event of conflicting information.

These subsystems comprise the spacecraft:

- Command and Data Handling (C&DH)
- Attitude Control Subsystem (ACS)
- Electrical and Power Subsystem (EPS)
- Enhanced Thematic Mapper Plus (ETM+)
- Thermal Control Subsystem (TCS)
- Reaction Control Subsystem (RCS)
- RF Communications (Comm)
- Deployables

Landsat 7 was launched on a Delta II-7920-10 from Vandenburg Air Force Base (VAFB) April 15 1999 at 1:32 PM and after eight ascent maneuvers, achieved a 705 km circular mission orbit. The orbit is sun-synchronous with an inclination of approximately 98.2° and a descending node crossing at 10:00 (± 15 min) AM local solar time. This orbit gives the spacecraft near full Earth coverage and allows it to pass over any point on the Earth every 16 days. The ground track of the spacecraft follows the standard World-Wide Reference System (WRS) used by Landsat 4 and 5.

Landsat 7 is a three-axis stabilized platform carrying a single nadir-pointed instrument, the Enhanced Thematic Mapper Plus (ETM+). The ETM+ senses radiation in seven unique spectral bands and one panchromatic band. S-Band is used for commanding and receiving housekeeping telemetry. X-Band is used for instrument data downlink. The payload data (instrument data and engineering data necessary for image processing) may be downlinked via any one of three unique X-Band frequencies. A 378 Gigabit Solid State Recorder can hold 42 minutes of instrument data and 29 hours of housekeeping telemetry concurrently. Power is provided by a single Sun-tracking solar array (1550 watts EOL) and two 50 amp-hour Nickel-Hydrogen batteries. Attitude control is provided through four reaction wheels (roll, pitch, yaw, skew), three 2-channel gyros with celestial drift updating, a static Earth sensor, 1750A processor, and torque rods and magnetometers for momentum unloading. Orbit control, backup momentum unloading, and backup attitude control are provided through a blow-down monopropellant hydrazine system with a single tank containing (at launch) 270 pounds of hydrazine, associated plumbing, and 12 one pound-thrust jets. Spacecraft weight was approximately 4632 pounds at launch.

Figure 2-4 provides a graphical description of the Landsat 7 spacecraft.

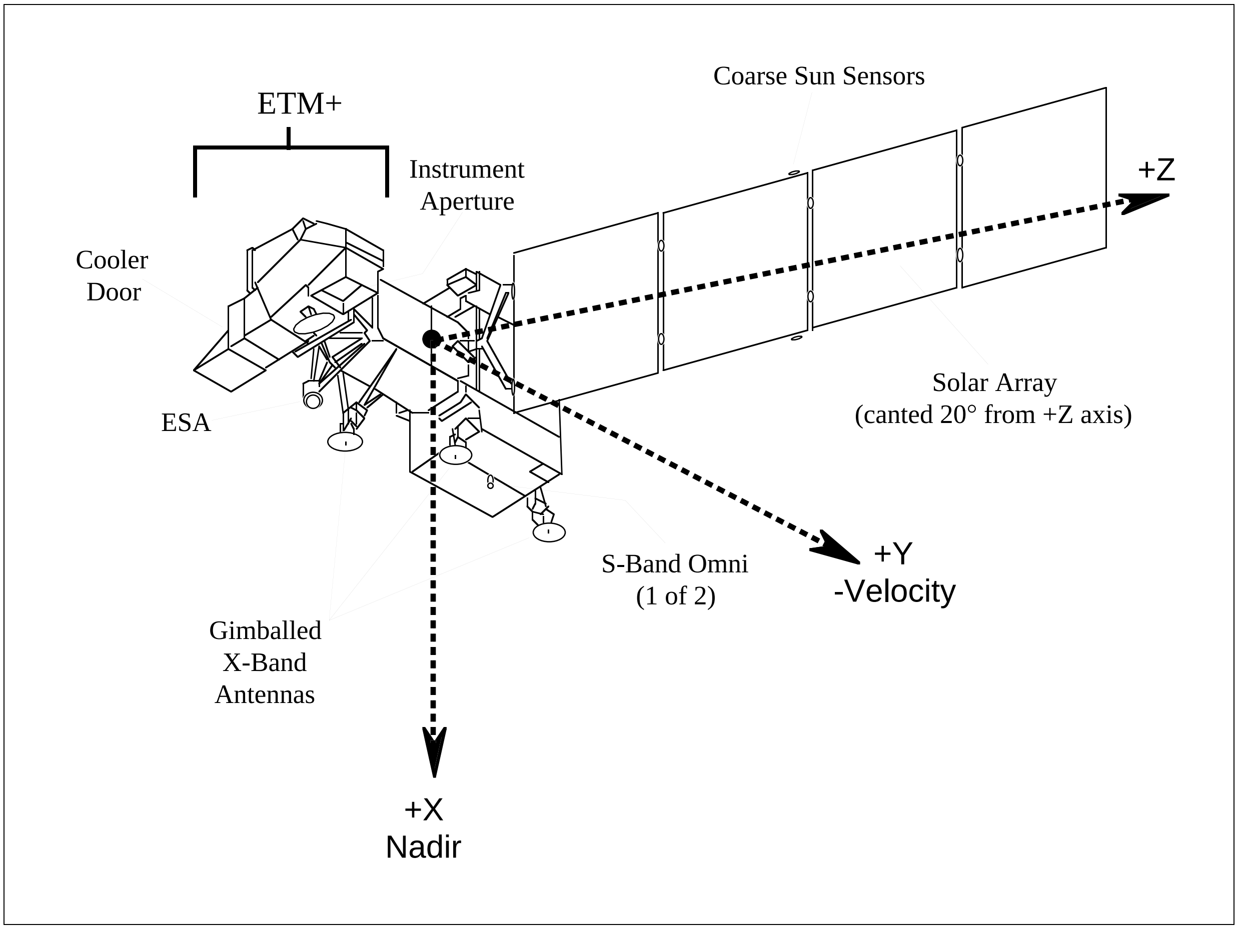


Figure 2-4 Landsat 7 Spacecraft

Section 3 FLIGHT OPERATIONS TEAM

Table of Contents

3.1 FOT Objectives

Mission operations will be performed by the Flight Operations Team (FOT), organized in accordance with the staffing structure illustrated in Figure 3-1. Reference to the FOT, either in general or by specific staff position, relates to this organizational outline. Prime responsibilities of the FOT are to:

- Ensure spacecraft health and safety
- Provide spacecraft operations as required to meet established mission objectives
- Interface with external support facilities to coordinate mission operations
- Maintain daily operational continuity
- Perform contingency operations as needed
- Investigation, resolution, and documentation of s/c anomalies
- Performance trending, analysis, and prediction

3.2 FOT Organization

The Landsat 7 staffing structure is based on flight-proven and effective realtime operations designs. The team organization encompasses key operational needs such as position back-ups and integral cross training capability.

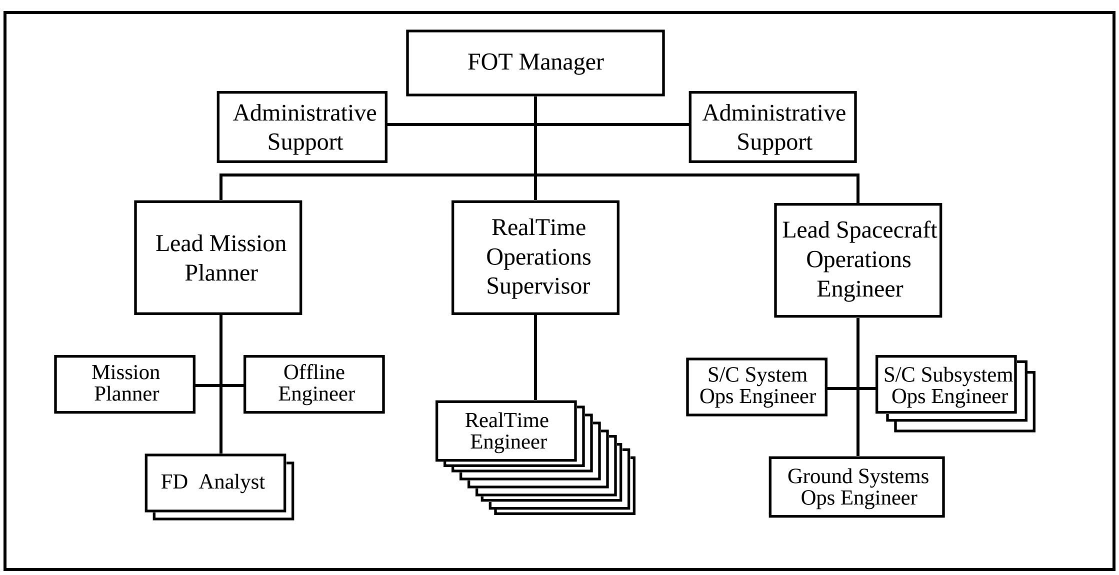


Figure 3-1 Landsat 7 FOT Organization

3.3 FOT Roles and Responsibilities

The following section provides a brief description of each FOT position. In addition, this section attempts to correlate mission responsibility to each position. As illustrated in Figure 3-1, the FOT consists of the following positions:

• Flight Operations Team Manager

The FOT Manager is responsible for staffing and overall management of the FOT. The manager will also hold the additional technical role of maximizing cross-mission reuse with other ATSC supported missions. Specific responsibilities include:

a. Provide NASA and USGS-to-contractor task management interface.
b. Provide hiring (including coordinating hiring panel) and overall management of FOT staff.
c. Provide employee performance evaluation and salary administration.
d. Provide FOT task cost management and contract modification coordination as necessary.
e. Provide operations status reporting to the NASA, USGS, and ATSC management.
f. Support working groups and meetings as necessary to effectively plan, coordinate, and carry out Landsat 7 mission operations.
g. Identify opportunities for cost reductions through mission reuse, continuous process improvements, new operations strategies, new technologies, and other innovations.

• Operations Engineers (Spacecraft Systems and Subsystems Engineers)

The Lead Operations Engineer has overall responsibility for all technical aspects of Landsat 7 flight operations under direction of the FOT Manager. The Operations engineers consist of two system engineers (one of whom is the lead) and several subsystem engineers. Specific responsibilities are listed below. If a particular responsibility is isolated to the Lead or the support engineers, it is noted.

a. Provide overall coordination of spacecraft operations and provide technical direction to the FOT staff. (Lead)
b. Support development and administration of FOT training and certification program.

c. Act as FOT's point-of-contact to NASA and other contractor subsystem engineers for sustaining engineering support.

d. Coordinate configuration control of Landsat 7 command procedures and telemetry displays. (Lead)

e. Assist in Landsat 7 telemetry, command, and Network Control Center (NCC) database maintenance in the MOC.

f. Evaluate operational procedures and monitor them for process improvement.

g. Perform special investigation and troubleshooting efforts as related to spacecraft performance and anomaly recovery.

h. Provides technical and operational support to FOT on spacecraft and ground subsystems.

i. Coordinate nominal, contingency, and special operations of the spacecraft.

j. Plan and coordinate special observatory operations such as maneuvers.

k. Coordinate and support detailed procedure generation and testing for observatory commanding during all mission phases.

l. Perform in-depth observatory analysis, subsystem trending, performance evaluation, and reporting.

m. Perform orbit maneuver planning, coordination, and execution as required.

n. Coordinate the generation of periodic spacecraft and ground performance reports.

o. Provides point-of-contact to other elements such as EDC as necessary to coordinate any engineering efforts or deviations from operations baseline. (Lead)

p. Provide MOC Project Data Base (PDB) configuration management.

• Ground System Ops Engineer

a. Lead operations acceptance testing of MOC software

b. Provide FOT with end-to-end ground system expertise regarding operations element configuration, capabilities, and interfaces

c. Support development of a training/certification plan for FOT Realtime Engineers and train FOT members.

d. Perform ground system parameter analysis and trending

e. Coordinate interaction between FOT and various software development/maintenance teams to ensure FOT needs are met.

• Realtime Operations Supervisor

The Realtime Operations Supervisor is primarily concerned with maintaining the operational status of the control center systems and staff as required to conduct scheduled realtime interaction with the Landsat 7 observatory. Specific responsibilities include:

a. Supervise the realtime console personnel in order to support daily operations.
b. Ensures that realtime console personnel are advised and have necessary resources to execute Landsat 7 operations.
c. Provides point-of-contact to support facilities such as EDC, Wallops, and the NCC as needed to coordinate realtime operations.
d. Maintains FOT work schedules to ensure adequate staffing for accepted operational baseline.
e. Provides operations status reporting.
f. Generates and implements the FOT training plan.
g. Assist in coordinating all realtime operations and various offline operations (trending etc.)

• Mission Planner

The Landsat 7 Mission Planners are primarily responsible for planning, coordination, and scheduling of mission activities. Mission Planners and FD Analysts are cross-trained to provide redundancy in these areas. Personnel who achieve this level are classified as Offline Engineer. Specific responsibilities of a mission planner include:

a. Operate MOC offline system as required to perform Landsat 7 mission planning, command management, and scheduling functions.
b. Coordinate all planning and scheduling inputs from FDF, EDC, NCC, Wallops, IGS, NCEP, MMO.
c. Ensure proper population and maintenance of MOC Mission Operations Planning & Scheduling System (MOPSS) database.
d. Coordinate scheduling of all ground and space contacts.
e. Operate TDRSS User Planning System (UPS) as required to ensure TDRS resources are scheduled to meet Landsat 7 tracking requirements.

f. Maintain general records of MOC ground system operations as related to mission planning, command management, and scheduling.

g. Perform stored command load management functions validation, load generation, and report generation.

h. Generate reports on Global Archive Refresh success and Cloud Clover Prediction success.

- Realtime Engineer

The Realtime Engineers are primarily responsible for the realtime telemetry and command interaction with the observatory. This position is broken down into two certification levels: command controller (CC) and spacecraft analyst (SA). At the CC certification level, the engineer is qualified to perform ground system configuration activities, run spacecraft operations procedures, and verify command receipt onboard the spacecraft. The SA is qualified to perform all CC tasks and the remaining Realtime Engineer responsibilities. Specific responsibilities include:

a. Perform realtime evaluation of spacecraft engineering parameters to ensure observatory health and status is maintained. (SA)

b. Uplink required stored command and ephemeris loads and verify execution and/or successful on-board storage. (CC)

c. Uplink commands as necessary to perform normal housekeeping activities. (CC)

d. Perform command and control activities as necessary to ensure spacecraft safety. (CC,SA)

e. Coordinate with the NCC and ground stations during all contacts to maintain realtime telemetry, command, and/or tracking operations. (SA)

f. Perform off-line telemetry playbacks as required for performance trending, power analysis, plot generation, etc. (CC,SA)

g. Maintain general console records documenting both realtime spacecraft and MOC ground system operations. (SA)

• <u>Flight Dynamics Analyst</u>

Flight Dynamics Analysts are responsible for flight dynamics products and analysis necessary to support the mission. Specific responsibilities include:

a. Perform daily orbit determination.

b. Generate products needed for scheduling and uplink.

c. Perform analysis and quality assurance on products generated on MOC FD system.

d. Assist in maneuver planning; Generate maneuver command sheets.

e. Develop automation relating to MOC FD system.

f. Perform routine maintenance on MOC FD system.

g. Perform analysis necessary for short and long term orbit maintenance.

3.4 FOT Staffing Profile

The FOT provides 24 hour, 7 day per week support of spacecraft health and safety activities. Realtime engineers are on duty around-the-clock in the MOC to support pass activities and provide the first point of reaction in the event of spacecraft emergencies. Mission Planner, FD Analyst, and Operations Engineer positions will be staffed during day shift unless special activities require off-hours coverage. In addition, Ops Engineers will be on-call around-the-clock, and Mission Planners are scheduled for 7-day operations. Figure 3-2 shows FOT scheduling.

	M	T	W	Th	F	Sa	Su
Real-time Engineers	2	2	2	2	2	2	2
	2	2	2	2	2	2	2
	2	2	2	2	2	2	2
Mission Planners	1	1	2	2	2	1	1
FD Analysts	2	2	2	2	2		
Operations Engineers (on-call 24 hours)	8	8	8	8	8		

= Day Shift
= Swing Shift
= Mid Shift

Figure 3-2 FOT Scheduling

3.5 FOT Training

Training will be accomplished in a number of areas so the FOT can acquire the spacecraft knowledge and system expertise necessary to effectively conduct mission operations. Such areas include spacecraft and instrument subsystems, MOC systems, ground element interfaces, and operational scenarios for realtime and off-line activities. A detailed description of the training approach for the FOT is documented in the FOT Training and Certification Plan.

Spacecraft subsystem training is administered by the Operations Engineers. Generation of training packages covering specific subsystems, functions, or functional areas of the spacecraft design and/or operation is the responsibility of the FOT. In addition to these packages, this document, classroom style training, on-the-job training, and training runs using the L7 simulator are used to help team members achieve the desired skills. Documents generated external to the FOT are also used. The On-Orbit Handbook contains detailed spacecraft design information, operational constraints and restrictions, and operational guidelines for on-orbit mission phases. Various interface and design documents created for specific spacecraft components and systems are also used. In addition, spacecraft Critical Design Review packages are available to the FOT.

MOC facility familiarization and training is an integral part of FOT training. This training will include all facets of the MOC (specific training for an individual will be tailored to that persons intended position) including realtime operations, off-line activity, use of support tools such as the database management tool (Oracle), the mission planning and scheduling interface (MOPSS), the Generic Trend Analysis System (GTAS), flight dynamics tools, etc. Interface activities with other support elements external to the MOC will also be exercised. Key documentation for this training is contained in several documents, one of which is the MOC System User’s Guide which describes the capabilities and functions of all MOC systems.

Certification is the verification, through performance and/or written evaluation, that an individual meets the minimum level of proficiency necessary to perform the duties associated with their position. A formal certification process is used for many FOT positions and utilizes a Skills Catalog that contains a measurable description of all the tasks, skills, and knowledge involved in performing the duties of a particular position. Once the required performance is verified, final certification is accomplished by successful completion of a written test. Training methods and documents mentioned above are all used in accomplishing this task. Training and certification will be an ongoing process for the FOT to assure a consistent and sustained level of proficiency and knowledge.

Section 4 FACILITIES

Table of Contents

4.1 Description

The MOC is located at GSFC, Building 32 and is comprised of a Mission Operations Room (MOR) and support facilities. Figure 4-1 shows the MOR facility as planned for normal operations.

Facility management for the MOC will be provided by the GSFC Building 32 Facility Operations Manager (FOM). Procedures for facility operations (temperature control, etc.) and contingency plans (fire response, bomb threat, etc.) have been made available to the FOT.

MOC facility operations will also be generated by the FOT. In addition to the contingency plans mentioned, there will be standard operating procedures that deal with facility issues (Preventative maintenance on MOC hardware, for example).

4.2 Logistics

Established systems, procedures, and institutional service are utilized to fulfill logistical requirements.

4.3 Maintenance

Arrangements for general facility maintenance and janitorial services are provided by NASA.

4.4 Configuration Control

Configuration management of the facility will be provided by the FOT and the FOM. Configuration of the hardware and software within the MOC will be controlled by the FOT. The System Administrator will be responsible for this function.

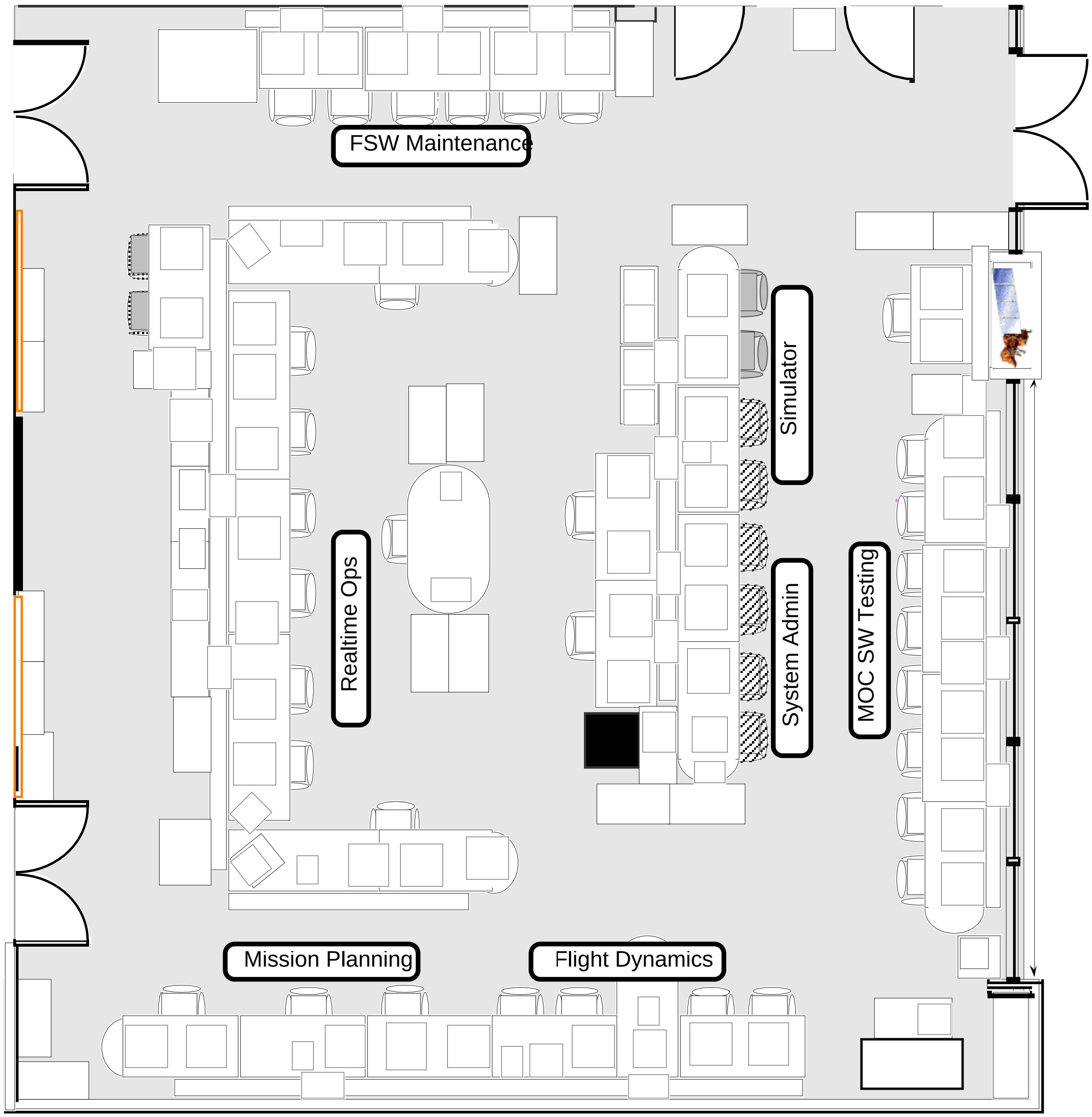


Figure 4-1 MOR Facility

4.5 MOC Hardware Architecture

The MOC system is set up as a distributed network. Although any workstation and any X-terminal can perform any necessary function, they have been divided up functionally and are used in this manner during nominal operations. Figure 4-2 shows the MOC hardware architecture.

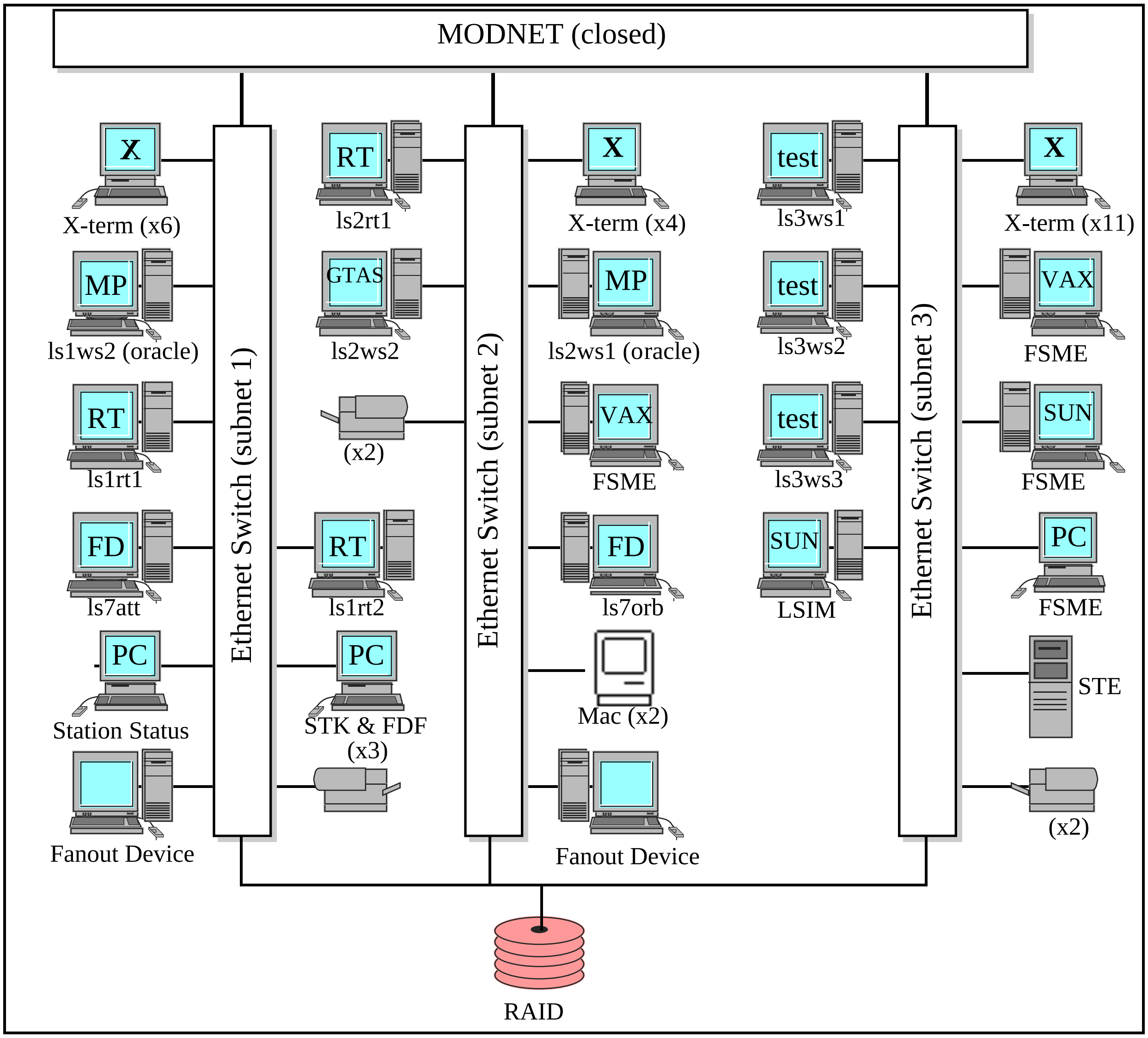


Figure 4-2 MOC Hardware Architecture

Realtime Operations, planning and scheduling, trending, and flight dynamics work are all accomplished using HPJ210 workstations with dual 120Mhz processors and 4GB disk drives. For a realtime contact, only one realtime workstation and its associated X-terminals are used per receive site. It is possible for two realtime workstations to be in use, receiving data from two separate receive sites.

Section 5 MISSION PHASES and ACTIVITIES

Table of Contents

5.1 Pre-Launch Development and Testing

The Pre-launch Development and Testing phase of the mission extended from the program acceptance until launch. This phase involved development and testing of software, hardware, and test plans for both the ground and spacecraft. In addition, operations development took place prior to launch.

During this phase, the FOT was partly or fully responsible for the following:

- Operations Concept, Plans, and Procedure development
- Spacecraft and Ground system knowledge capture
- Training of all personnel for Launch and On-Orbit operations
- Command procedure and telemetry display generation
- Verification and Validation of developed procedures and displays
- Validation of MOC system and support systems
- Support of appropriate Ground and Spacecraft System tests
- Support Operation Reviews
- External Interface testing

5.2 Launch and Ascent Operations

The L&A phase of the mission began four hours before liftoff and continued until AOS at SGS. A telemetry link was established just after liftoff and, using TDRS W, McMurdo, and TDRS Z, almost continuous coverage was be maintained throughout the phase.

During this phase, the FOT was responsible for the following:

- Verifying proper MOC configuration prior to launch
- Providing status of appropriate launch critical items to the Operations Manager for Launch GO/No-GO decision
- Support verification of proper spacecraft configurations at Launch and Separation
- Verify the completion of specific L&A events including
    - --S-Band, RWA, and Catbed ON
    - --RWA ENABLE
    - --Separation
    - --Solar Array Deployment and Slew
    - --Attitude Control Mode transitions

--All planned station contacts

- Provide anomaly response for all above listed events if necessary
- Provide command and telemetry operations after liftoff

5.3 Activation and Verification Operations

Once successful RF communication was established at SGS, a thorough analysis was performed to determine the success of launch. Stored housekeeping data was be downlinked and processed in the MOC. From these data R/T plots, statistics files, and archive files were created for data analysis. The history files and all off-line data during this phase will be stored for the remainder of the mission. Ranging and Doppler operations will began as soon as possible.

After initial checkout, the spacecraft was configured for the Activation phase, at which time various components and subsystems were powered ON for checkout and calibration activities. Performance of the ACS sensors, GXAs, and other components were characterized during this period. The release of components restrained during Launch, including all GXAs and the Full Aperture Calibrator (FAC) Paddle, will took place. In addition, the FOT will began gathering empirical data on spacecraft and ground performance, including communications performance. The spacecraft was placed onto the WRS using eight separate thruster burns during this phase. During the drift onto the WRS, Landsat 7 performed an underfly of Landsat 5 for about 26 orbits. Coincident imaging was scheduled between the two spacecraft to provide an opportunity for calibration and comparison of data. Commissioning of the ETM+ also took place during the this phase. Activities during these 90 days were be detailed in the On-orbit Initialization and Verification Plan (OIVP), and Launch Handbook.

During this phase, the FOT was also responsible for the following:

- Providing all command and telemetry operations
- Executing all activation, checkout, and commissioning procedures
- Provide anomaly response during the entire phase as necessary
- Provide trending and analysis of spacecraft and ground performance

5.4 On-Orbit Mission Operations

On-Orbit mission operations consists of executing the long-term science plan, maintaining spacecraft and instrument health and safety, providing routine control of the spacecraft and instrument systems, and collecting science data. Also included in these operations is the planning and scheduling of image collection and communications, sustaining engineering efforts, software and hardware maintenance activities, and contingency operations.

During this phase, the FOT is responsible for the following:

- Providing all command and telemetry operations
- Provide anomaly response as necessary
- Provide trending and analysis of spacecraft and ground performance
- Conduct all planning and scheduling necessary to fulfill the mission objectives
- Conduct all engineering operations (FD operations, spacecraft clock and center frequency maintenance, performance analysis and prediction, etc.)
- Provide management with necessary reports
- Interact with all external interfaces as necessary to support daily operations

5.5 End of Life

At some point a government decision will be made to terminate the mission. At that time a NASA and/or USGS EOL plan will be generated and executed.

Section 6 SPACECRAFT SUBSYSTEMS and OPERATIONS

Table of Contents

Note to the Reader

Section 6 is meant mainly as a training aid. The OOH takes precedence over the FOP in the event of conflict.

6.1 Command and Data Handling Subsystem (C&DH)

C&DH contains the hardware and software necessary to accomplish the following tasks:

- Command processing (realtime and stored)
- Collection, formatting, and distribution of all mission data (Payload and Housekeeping)
- Computational resource (attitude control and health and safety computations)
- Time generation and distribution
- Power supply and switching for selected components

In order to successfully operate, the C&DH must interface with every other spacecraft subsystem. Twelve separate components make up the C&DH and are necessary to accomplish the above listed tasks.

- ADA (Angular Displacement Sensor Assembly) measures angular jitter at the ETM+
- BSU (Baseband Switching Unit) routes payload data and clock between the ETM+, SSR, and X-Band Communications system
- CIU (Controls Interface Unit) provides CCSDS command decoding, command counter, hardware decoded command execution, Flight Software (FSW) input/output, Attitude Control Electronics Circuits (RWA tach D/A converter), and clock divider
- LMI (Lower Equipment Module Interface Unit) provides remote command and telemetry distribution for the Lower Equipment Module (LEM)
- PDF (Payload Data Formatter) collects and formats Payload Correction Data (PCD) and time code for ETM+
- RTC (Remote Telemetry and Command Unit) provides remote command and telemetry distribution for the Equipment Support Module
- RXO (Redundant Crystal Oscillator) is a temperature controlled 5.12 MHz time source
- SCE (Signal Conditioning Unit for ESM) provides power switching, torquer rod, heater control, SBT
- SCL (Signal Conditioning Unit for LEM) provides thruster, EED, heater control, XTX

- SCP (Standard Controls Processor, or 'skip') is a 1750A processor, 290 KIPS, 192K RAM, 64K ROM, EEPROM. The SCP executes flight software (FSW) including attitude control processing and execution of stored command loads.
- SSR (Solid State Recorder) records payload data (378 Gigabit capacity, ≈42 minutes) and housekeeping data (520 Mb capacity, ≈29 hours) for later playback.
- TDF (Telemetry Data Formatter) multiplexes and formats all housekeeping data for downlink, and creates CCSDS packets.

The primary operations with which the FOT will interact with the C&DH subsystem include table and memory operations, stored command processing, clock maintenance, and recorder management. Figure 6-1 shows an overview of the C&DH system components.

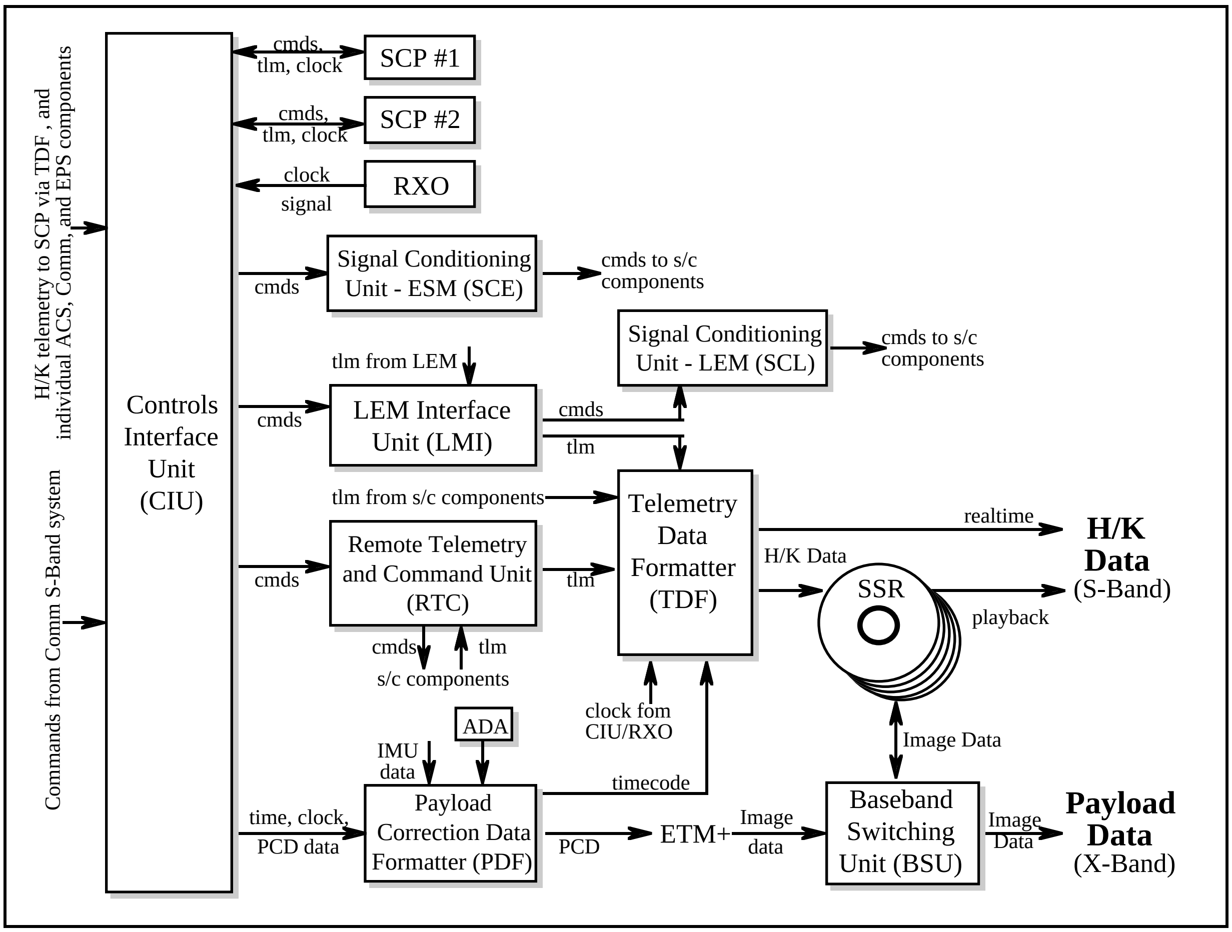


Figure 6-1 C&DH Components

• Angular Displacement Assembly

ADA - Description

The ADA is an accelerometer package that measures angular “jitter” at the ETM+ and provides this information to the PDF to be included in the ETM+ datastream. The ADA has been included as part of the C&DH system, although it resembles an ACS component and is utilized as a payload component. The ADA sensors are fluid rotor angular accelerometers that produce a linear output signal in response to dynamic angular displacements about one spacecraft axis. Three sensors are mounted on the ETM+ telescope frame. The sensors can detect ‘jitter’ below 1 nanoradian (0.002 arcsecond). This data is used for image motion compensation during processing. ADA data is included in the payload data, but is not part of the h/k telemetry.

ADA - Operation

The ADA requires no operations apart from being powered. The PDF provides power directly to the ADA, and the PDF is planned to be continuously powered on-orbit.

• Baseband Switching Unit

BSU - Description

The BSU collects and distributes data between the ETM+, the SSR, and the X-Band system. The BSU also provides 75 MHz reference clock to the ETM+ and SSR. All payload data must flow through the BSU. The BSU also contains a generator for pseudorandom noise (PN) signals. The data path combinations between the BSU, ETM+, SSR, and X-Band system are numerous. The set of ‘normal’ connections is more limited but still non-trivial (see Figure 6-2).

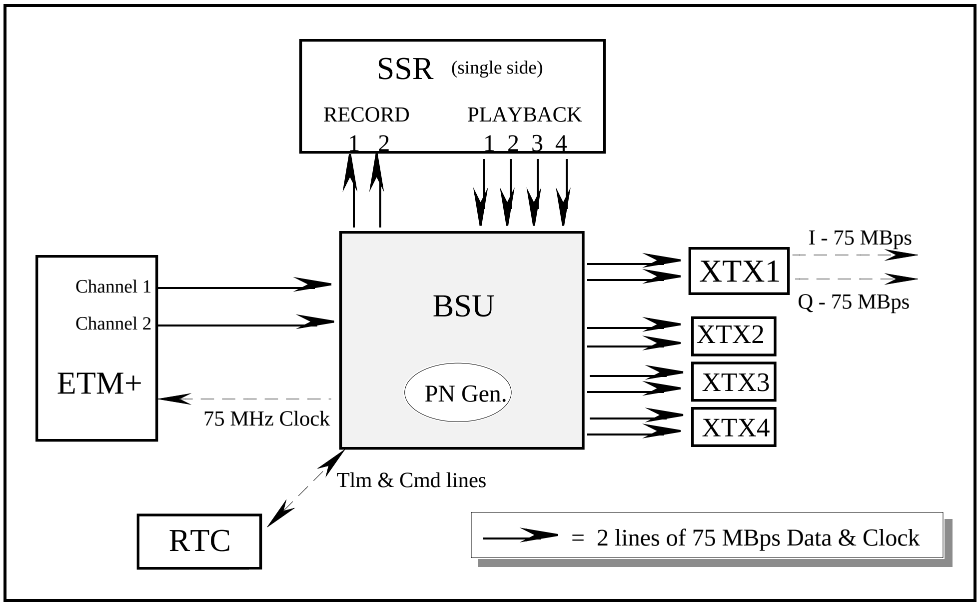


Figure 6-2 BSU Interconnection to C&DH

BSU - Operations

When no wideband activity is scheduled during a certain minimum period, the BSU will be powered down to avoid getting it too warm. When the BSU is powered up, it retains no knowledge of its previous configurations, so all data paths must be re-commanded for each imaging session. The commands for powering up and configuring the BSU are handled by the MOC scheduling software. Prior to each wideband session (realtime imaging and/or SSR playback or record), the BSU is turned on and commanded to flow the ETM+ and/or playback data to the SSR and/or X-Band transmitter(s). During a ground station contact, the data flow may need to be reconfigured - i.e. to switch from SSR playback to live ETM+ data and back to playback. The timeline of events and their commands are handled by the scheduling software.

• **Control Interface Unit**

CIU - Description

The CIU is responsible for accepting all commands from the RF system and passing them along to their intended component. Other important functions of the CIU include; all I/O functions for the SCP, providing clock frequencies to the SCP, and providing processing functions allowing the SCP to receive ACS component telemetry and command ACS components. The CIU also performs command structure validation (including CCSDS syntax checking) in the form of telecommand codeblock BCH checking, and transfer frame header validation. Spacecraft Command Counter (SCC) checking and incrementing is also done in the CIU. When the CIU receives one of the “special hardware commands”, otherwise known as “CIU decoded commands", it passes validation information to the SCP so FSW may create a Command Validation (CV) word and the CIU then passes the command along to the appropriate hardware. When the CIU receives a "FSW decoded command", it is passed to FSW where it is received, processed and queued for execution.

CIU - Command Validation

The CIU validates the command structure during uplink. Command syntax is checked just prior to execution by the SCP and is covered in Section 7.3. The CIU validates CLTU and transfer frame structure (shown in Figure 7-6) and also checks the command counter value. The list of checks include:

a) Carrier and detector lock
b) CLTU start sequence detected
c) Perform BCH on codeblock
d) CLTU tail sequence detected
e) Transfer frame version number, spacecraft ID, and length
f) SCC Enable
g) Compare commanded and expected value of SCC

If the command fails any of the checks mentioned in "a" through "e", the command is rejected and the FOT notified in realtime telemetry via the CIU Status word. If the structure of the command is correct, but the command counter value embedded in the command differs from the one the CIU expects, the command buffer is emptied and no further commands are accepted unless their SCC value is correct. The MOC may or may not automatically retransmit the failed command depending on the selected command mode - Section 7.3 outlines how the MOC handles command failures. When a command is not accepted by the CIU, the MOC must retransmit the entire CLTU that contains that command. If there are other commands in the CLTU that were already accepted by the CIU, they will be ignored as their embedded SCC value is less than the current CIU counter value. When the rejected command reaches the CIU with the correct counter value, command execution resumes and that command and the ones following it are processed. The CV is generated by the SCP and is discussed below.

• Redundant Crystal Oscillator / Spacecraft Clocks

RXO / Clocks - Description

The RXO is a 5.12 MHz (one cycle every 0.195 μsec) oven-controlled oscillator that drives all satellite digital timing chains via the CIU. The RXO drives command and telemetry serial data transfers and distributes its frequency to the other subsystems. The Software clock, maintained in FSW, is synchronized to the RXO. It has a 999 day rollover and is incremented in 0.5 second units (2 Hertz). The Hardware clock, in the PDF, is also synchronized to the RXO and is updated by FSW using the Software clock as a reference. The Hardware clock is used to timestamp ETM+ scan line starts and housekeeping telemetry minor frames. It has a 999 day rollover and is incremented in 1/16 millisecond units (16 kiloHertz). Timing signals from the RXO are also used by the SCP to time the execution of stored commands. The RXO is powered from the essential bus and cannot be turned off. Two oscillators are provided for redundancy. Figure 6-3 shows the complete timing system.

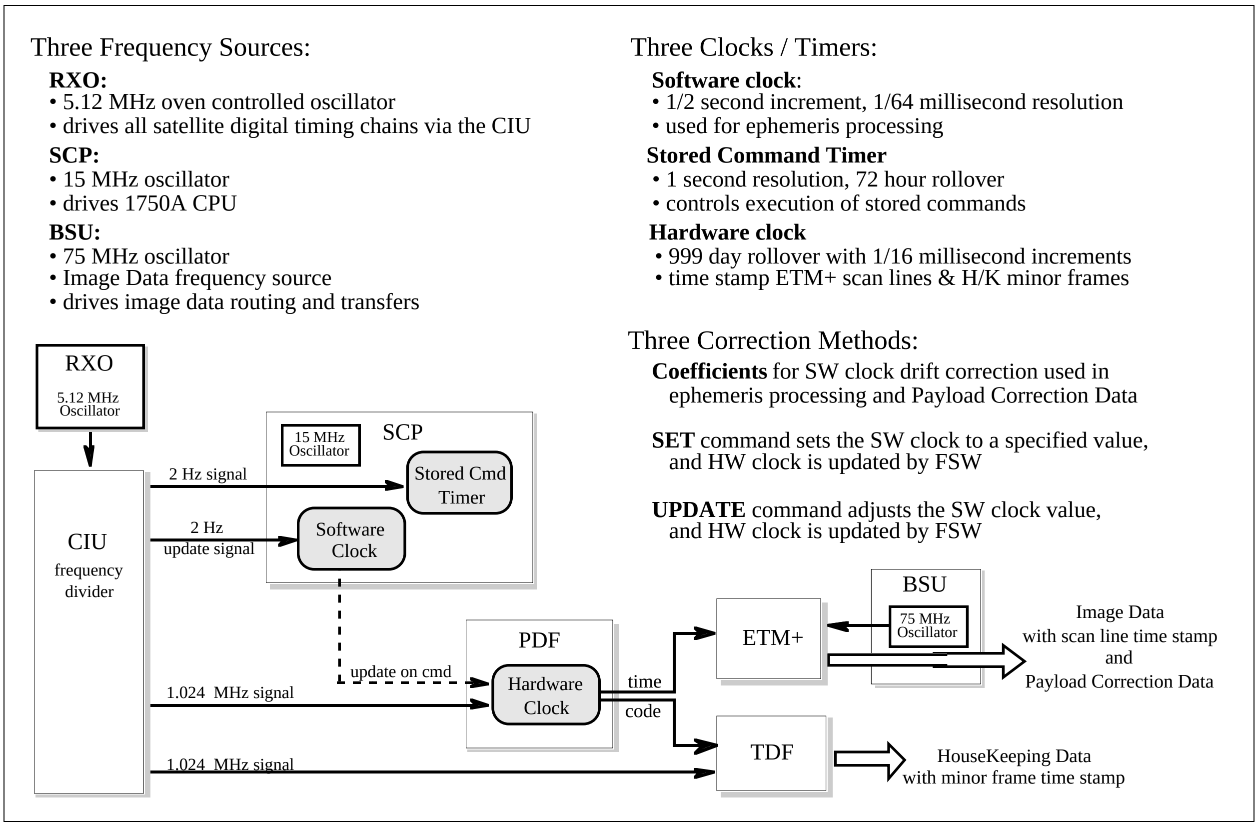


Figure 6-3 Timing System

RXO / Clocks - Operations

The RXO is used as a reference for the Software and Hardware clocks. The clocks' accuracy must be known (and maintained) to within very specific limits to allow accurate image processing, CSA processing, and other precision operations. The FOT updates the Software clock and uplink correction coefficients; FSW uses the update value to correct the Hardware clock. The update values compensate for the clock drift and restore the clocks value to within the required 15 msec of true GMT. Although 15 msec is the required accuracy of the clock, it can typically be set to within 5 msec of true GMT. The correction coefficients are used by FSW and image processors (the coefficients are included in the payload data) to adjust the spacecraft time to within the required 15 msec even hours after the clock has been corrected. Figure 6-4 shows clock coefficient calculation at a high level; a detailed description can be found in Section 7.5.

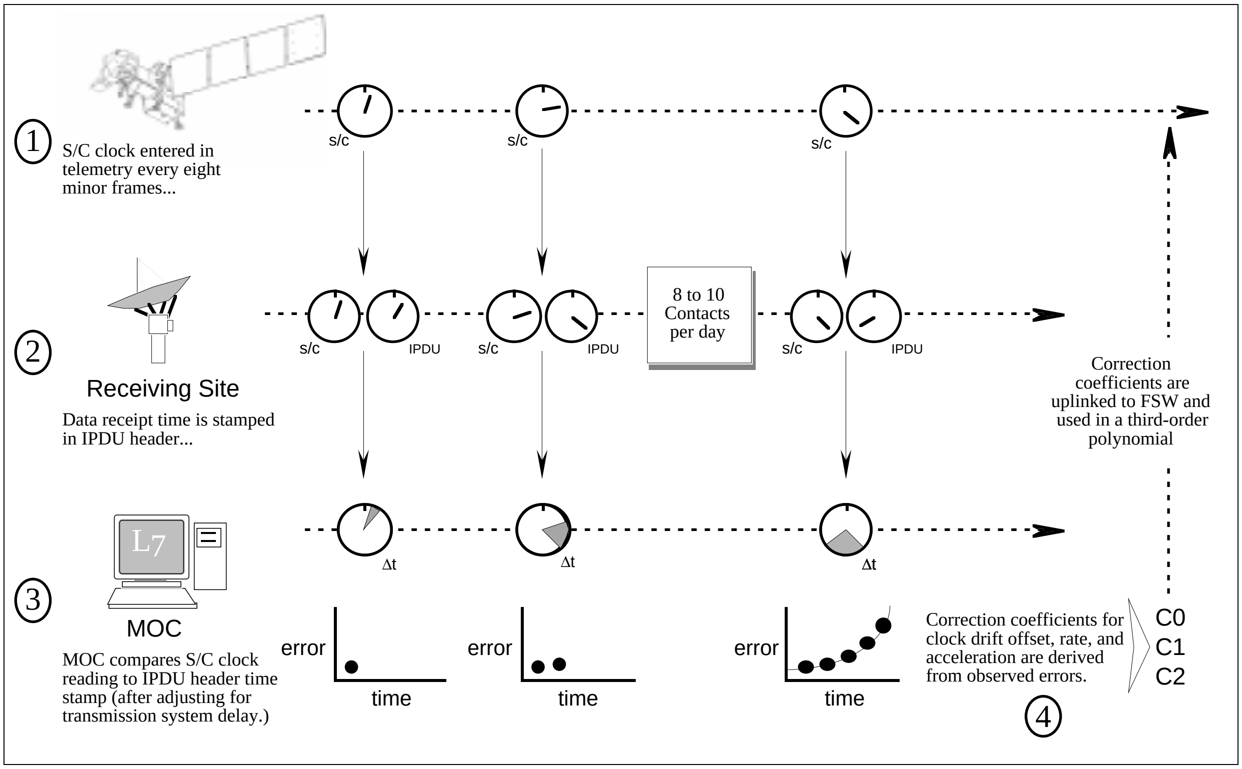


Figure 6-4 Clock Coefficient Calculation

The primary RXO has its temperature and amplitude monitored. If either is detected as bad, a switch to the redundant RXO is made. The redundant RXO is monitored for amplitude only. Switches to and from the primary RXO are done autonomously (when the primary RXO parameter(s) are back in limits, it will switch back to the primary autonomously). This may be ground disabled so the backup RXO is used no matter what the prime RXO does. RXO temperature monitoring is done via an analog signal that is hysterisis damped to avoid unnecessary switching.

• Standard Controls Processor

SCP - Description

Landsat 7 has two identical SCPs. One is used as a warm backup to the other. The SCP is responsible for attitude control processing, most command processing, storage and execution of all stored commands, and spacecraft failure detection and correction among other duties. The FOT will be interacts with the SCP more than with most components onboard as it performs many of the daily functions needed during routine operations. Each SCP consists of a 1750A processor, memory cards, various I/O boards, a power converter, and backplane, and weighs 11.1 pounds. The SCP is powered from the essential bus and cannot be turned off.

If a "Brown-Out" occurs (the bus voltage drops below 22V for more than 100 μs) the SCP will produce a machine error and enter a no-op loop (idle). When the Brown-Out condition clears (bus voltage above 22V) FSW is re-initialized (and re-entered from the idle state), but the Control SCP is not switched. If the bus voltage drops below 14V, the SCP will shut down, and when power is restored it will enter SHP.

Each SCP is capable of running in either of two Flight Software (FSW) packages; Flight Load Package (FLP) and SafeHold Package (SHP). Flight Load Package contains code necessary to do the following:

a. operate in all primary, backup and safehold ACS modes; including transition between modes, momentum management, star processing, etc.

b. control power management and fault protection above and beyond what the flight hardware provides

c. provide fault detection, correction, and reporting for specific hardware and software problems

d. accept and execute stored commands using either an absolute or relative time reference

SafeHold Package contains code necessary to do the following:

a. operate in ascent or safehold ACS modes; including transition between modes, momentum management, etc.

b. control power management and fault protection above and beyond what the flight hardware provides

c. provide very limited fault detection, correction, and reporting for specific hardware and software problems

A copy of SHP resides in Read Only Memory (ROM) onboard and, if configured to do so, upon power reset of the SCP, it is copied into RAM for execution.

Each SCP puts out a "ME OK" signal to the CIU every 0.5 seconds. Whenever a FSW package witholds its "ME OK" signal for three consecutive cycles (1.5 seconds), the CIU will mark that SCP “BAD” and command a switch in Control SCPs (assuming the other SCP is OK). The SCP that is newly in control will receive information from the now Standby SCP. This information will tell the new Control SCP which FSW package to attempt to use first, and whether to attempt a Sun or Earth pointing attitude submode. Once a SCP has been marked NOT OK, ground action is required to mark it OK. If both SCPs are NOT OK, the CIU selects the Ground Preferred SCP and places it in control. The Ground Preferred SCP selection is stored in EEPROM.

Residing on each SCP I/O board is an Electrically Erasable Programmable Read-Only Memory (EEPROM) chip, consisting of 4096 8-bit words. Because EEPROM memory is non-volatile (retained after a power loss) it is used to store important spacecraft hardware and software configurations. 64 of the 4K words contain flags and keywords that are used by FSW for configuration upon power up. The rest of the locations represent an area that is used to store patches to the SHP. Upon power up, these patches to SHP are loaded into RAM after the SHP code has been loaded from ROM. Though the chip is defined as read-only memory, the capability exists to electronically erase and update any of its stored memory contents via ground command. This function is operationally constrained while over the South Atlantic Anomaly Region as high proton flux may lead to an EEPROM bit sticking high.

<u>SCP</u> - Initialization and Resets

Upon initialization (or any power interruption) the copy of the Safe Hold Package (SHP) stored in ROM is loaded into RAM (if configured to do so) and the spacecraft is placed into Sun Pointing Attitude Mode (SPAM). Upon powerup the SCP uses a non-volatile configuration memory (EEPROM auto-configuration table), maintained by the FOT, to reference and set the various default states, settings and parameters of the spacecraft.

After any initialization, the FOT will have to perform numerous operations to return the SCP to its nominal configuration. For example, the Flight Load Package (FLP) must be reloaded after any loss of power.

SCP - EEPROM Operations

Upon a SCP power reset or entry into the SHP, safehold uses values in EEPROM to configure spacecraft hardware and software. EEPROM contents must be kept updated with the current desired configuration of the spacecraft. Anytime there is a component failure and/or switchover, it must be reflected in these tables. A complete list of the EEPROM contents were documented pre-launch in PIR U-S/C-L7-1080-SYS-A, however several values in EEPROM were changed post launch. An updated copy of the current values is kept by the FSW maintenance group. The EEPROM has a rated lifetime of 10,000 write cycles per byte.

Three types of operations which can be conducted with EEPROM: write, read and dump. To check EEPROM data contents, FSW employs triple voting logic during read operations. As a result, three copies of EEPROM data contents are always stored. (See Figure 6-5 for clarification.) Writing to EEPROM requires closing the relay leading to the non-volatile memory write line prior to uplinking the memory update. Commands to write to EEPROM consist of a data value written to 3 separate address locations. The procedure is then repeated for the standby SCP. Values cannot be read from EEPROM directly. The desired EEPROM locations are transferred from EEPROM to a FSW table. This table (DMPEETBL) is then dumped from FSW memory to the ground in the form of a SCP diagnostic dump. Another table in FSW(SHP) exists to hold EEPROM contents. This table (RDEETBL) is used by SHP and may be updated by ground command or by FSW autonomously. FSW will perform this function upon a SCP reboot if the FEEPROM flag is set to TRUE. A third table (EETRIPLE) is used by SHP to store the results of its triple voting process. After any update of the EEPROM, the FOT commands a transfer of the entire EEPROM contents into the DMPEETBL where they are then downlinked to the ground.

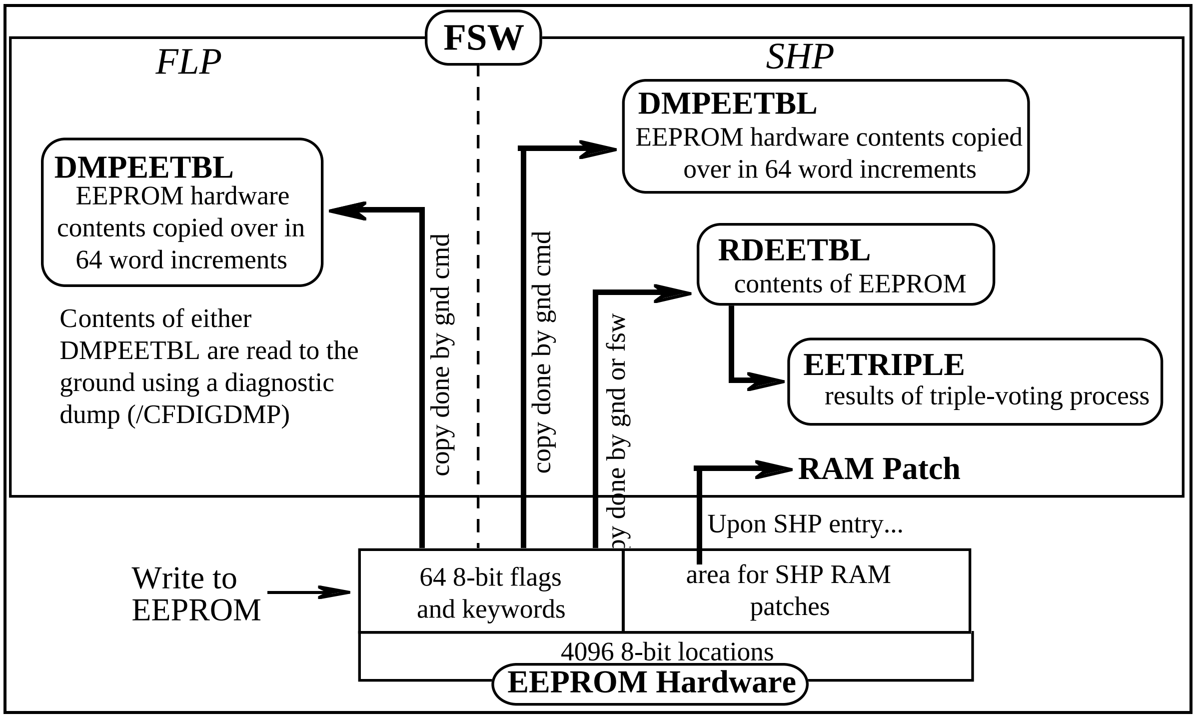


Figure 6-5 EEPROM Reading and Writing

<u>SCP</u> - Telemetry into the SCP

In addition to receiving data from various spacecraft components directly, the SCP receives 18 eight-bit data words from the Telemetry Data Formatter (TDF). This data is present in each minor frame regardless of the TDF telemetry format. Of these 18 words, only 10 are used during the FSW execution. FSW routines such as Failure Detection and Correction (FDAC), Power Status Monitor (PMON), and Payload Correction Data (PCD) rely on these “TDF-to-SCP” words to check the status of the spacecraft subsystems, so it is very important that the order and location of these words in the minor frame layout remain the same in all TDF formats. The SCP expects certain parameters in specific locations and if they are incorrect, autonomous action may be triggered by false data. If the TDF “Flex” format is utilized, the “fixed” portions of the minor frame must not be altered from the layout of the pre-programmed TDF formats (see *TDF - Formats* section below).

<u>SCP</u> - Telemetry out of the SCP

• <u>DATABs</u>

The SCP outputs telemetry words to the TDF to be included in the housekeeping datastream. The number of words depends on the TDF format, and the contents of the words depends on the Data Table (DATAB) selected (except for Rolling Dump and Dump format, see below.)

The DATAB is a table in FSW that defines what values the FSW is to send the TDF for inclusion into each minor frame of telemetry. The number of words contributed to each TDF minor frame by FSW is dependant on the TDF telemetry format chosen. All formats use five DATAB words for the SMON, DATAB ID, and Control SCP words. Dump format uses four additional DATAB words, Normal format uses 16 additional words, and Extended FSW format uses 24 additional DATAB words. The Backup SCP also uses a smaller DATAB to contribute one word in all telemetry formats.

There are two default DATABs in each FSW package initially and these may be changed post-launch by ground command if necessary. DATAB1 is used primarily during maneuvers as it contains more jet and ACS parameters. DATAB2 is used during normal operations as it contains information on GXA control, etc. For complete listing of default telemetered parameters and their subcommutation scheme, see the DFCB Volume 3 (Telemetry).

• Memory Dumps

The contents of FSW can be dumped to the ground using either the Dump telemetry format or the Rolling Dump scheme in Normal format. In Dump format, 32 words of every minor frame are dedicated to FSW dump contents of the control or backup SCP and limited telemetry is available on subsystem hardware parameters. A separate command is sent to the SCP specifying the staring and ending address of the desired dump.

The SCP can also contribute data to telemetry via a “Rolling Dump” capability in Normal format. The Rolling Dump provides a continuous dump of a ground selectable region of memory. Each minor frame contains six words of data corresponding to six consecutive SCP memory locations and two words specifying the start address of the data in that minor frame. The number of memory locations selected for Rolling Dump should be divisible by six.

A full memory dump (196,608 words) will take approximately 25.6 minutes to downlink in Dump format at 4 Kbps. A dump of 6,000 words (to verify a Stored Command or Ephemeris Load for example) will take about 47 seconds (Dump format, 4 Kbps). Full memory dumps can be commanded to begin near the end of a realtime pass and allowed to continue as the spacecraft passes beyond the station’s view. The SCP dump will be captured on the SSR, the SSR played back at the next ground contact, and the dump contents extracted and analyzed offline.

SCP – FSW Autonomous Safing of the S/C

• Failure Detection and Correction (FDAC) and Status Monitor (SMON)

The FDAC software in the SCP provides the autonomous detection of the onset of unsafe conditions and configures the spacecraft components as necessary to reestablish and/or maintain the safety of the spacecraft. A “safe” condition is defined as a state from which, after 72 hours of no ground contact, the ground can configure the spacecraft to resume mission operations. FDAC realizes these objectives via the switching of A/B hardware selections and configuration/mode changes. FDAC runs a series of tests on selected component states and modes and uses the results of these tests to decide whether or not a corrective action is necessary. Actions taken and errors flagged by FDAC will be reported in telemetry via Status Monitor (SMON) messages. The FOT will use SMON messages along with noticed changes in the state of the spacecraft during realtime contacts to identify and isolate these anomalies. FDAC can be separated into two separate functional areas; Component level FDAC and System/Path level FDAC. All FDAC actions may be ground enabled/disabled.

REDMN (REDundancy MaNagement) is the FDAC module that is responsible for executing the switch of individual hardware components based on software flags set by the many FDAC status/logic tests. REDMN monitors the ESA, IMU, LMI, ADE, RWA, RTC, TDF, CSS, and TAM for specific problems. If a problem is flagged, actions are taken in order until positive results are obtained. Actions are: component switch, bus switch in CIU, clock switch in CIU, SCP switch.

ICMON (InterConnect MONitor) is the module responsible for monitoring software flags in groups corresponding to interconnection pathways, to detect and correct pathway faults. ICMON will reconfigure the data pathway before multiple components are switched (before REDMN begins switching components). ICMON will switch the following pathways or interconnects in turn until positive results are obtained; CIU I/O bus, Clock divider, LMI, RTC, TDF, SCP (via MEOK control).

• Power Status Monitor (PSMON)

PSMON (or PMON) software performs several monitoring, alert, and autonomous action tasks on the spacecraft power subsystem. These functions are briefly described below.

- Monitor battery temperatures – Temperature, average temperature and gradient temperature are monitored for each battery pack. If any of these exceed a defined limit, autonomous action is taken.. The action taken, either a hardware switch or a switch to V/T 8, depends on the faulty temperature.

- Monitor battery charge currents – PSMON verifies that charge currents on each battery are within specified limits.
- Performs battery state-of-charge calculation – Both theoretical and actual state-of-charge values are calculated.
- Provides battery charge control – PSMON commands V/T curve selection and charge rate based on actual state-of-charge and the spacecraft orbital position (described below in more detail).
- Performs load shedding as necessary - PSMON will detect specific conditions relating to battery state of charge and initiate load shedding. Load shed is an autonomous reduction of s/c power load to compensate for a power emergency and is done in two phases (described below in more detail).

PSMON automatically commands a change in V/T charging curve if it detects that a battery has not reached full charge in one daylight period. The battery state of charge is checked every time FSW believes the spacecraft has passed from daylight to shadow. If the battery has not reached full charge at this point, the next most “aggressive” V/T curve is selected for use during the next charging cycle (i.e. from V/T 5 to V/T 4). On the first day/night transition where the battery has reached full charge, the normal V/T curve (#5) is selected.

Phase 1 load shed is commanded in response to a battery state of charge below predicted or absolute threshold. In a Phase 1 loadshed the following actions are taken; ETM+ shutdown, SSR to low power, BSU off, XTXs off, GDE off, catbed heaters OFF, S-Band to “Auto-on” mode with transmitters OFF. Phase 2 is commanded in response to a worsening SOC, and/or invoked after transition to SHP. In a Phase 2 loadshed the following actions are taken; S-Band transmitters OFF, “Auto-On” disabled, BCRs to backup-high rate, all heaters OFF except RCS, IMU, ETM+, and Battery.

- <u>ETM+</u> <u>Protection</u>

FSW provides three separate areas of protection for the ETM+. FSW detects when the instruments power supplies have been turned on. At this time, it begins to count down from 4200 half-seconds. The operational constraint for continuous ETM+ on-time is 34 minutes. Once the timer reaches zero, an automatic shutdown of the instrument takes place (via RTCS).

At any point during operation, if the ETM+ power supplies rise above their FSW trigger value, the instrument will be shut down automatically. This is a separate check than the one performed by the ETM+ hardware.

If at any time a loss of Earth pointing attitude is thought to have occurred, FSW will automatically close the cooler door by one position (i.e. from OPEN to OUTGAS) to protect the Cold Focal Plane radiator from sun impingement.

•Status Monitor (SMON)

The Status Monitor (SMON) is a table in FSW that contains the 64 most recent events detected or implemented by FSW. Most of the "events" reported by SMON include FDAC related tests and/or actions. Events such as an autonomous change of V/T curve, dropping out of precision ACS mode, ESA interference, etc, may be reported. For each event, a six word report is filed by FSW and includes the following information:

- Report Number - unique ID for each report filed
- Time of Report - spacecraft time at which the report was filed (uses three words)
- Report Source – gives an indication of the component/FSW module from which the report was filed, or to which the report applies
- Reason Code – the indication of the specific test that failed or action taken

Three words of the SMON table are dumped every minor frame. This continuous dump of the 64x6 word area repeats every 32 seconds when in 4K telemetry rate. The SMON table is read out from oldest to newest report. When a new report is filed, the rolling dump is interrupted at the next report boundary, and the new report is inserted into the next two minor frames. The continuous dump of the SMON buffer hen resumes at the point of interruption.

SCP - Command Execution

The SCP FSW provides for four different methods of sending commands to the rest of the spacecraft. These methods are realtime commanding, Absolute Time Command Sequences (ATCS), Relative Time Command Sequences (RTCS), and FSW generated commands. Each of these methods is handled differently by FSW.

• Realtime Commands

Realtime commands entering FSW are handled at the highest priority level. After the commands validity is verified, a Command Verification word(s) is generated (see the next topic for CV information), and the command is executed. If the command is meant for a component other than the SCP/FSW, it is sent out via the CIU to the RTC, LMI, SCE, or specific component.

• Absolute Time Command Sequences (ATCS)

ATCS commands are uplinked to FSW in a load generated in the MOC. The load is placed into a "Scratch" area until activation when it is moved to its "working area". There are two tables onboard that ATCS loads can be executed from. They are called the Bus and Payload tables. When the ATCS is built, the table it is going to must be specified. Currently the Bus table is used for normal daily ATCS loads, with each day's load overwriting any unexecuted commands still resident in the active table area.

Each command is tagged with a time of execution. This execution time is specified not in hh:mm:ss, but rather in seconds past 00:00:00 GMT of the day the load was activated in FSW. The working area has a command index pointer. This pointer is normally set to location zero in the working area when a load is activated, causing the load to begin execution with the first command in the load. The table pointer evaluates the time tag on the command word and if it matches the current stored command timing counter, it will send the command out to be executed. If the current "time" is after the execution time tag, the command will be executed if the Late Execute bit is set, otherwise it is skipped. If the current time is before the command time tag, the pointer will wait until the times match. After execution of a command, the pointer moves to the next command and repeats the process. Because of this method, commands must be contained in the load in chronological order. Execution time tags have a resolution of one second.

• Relative Time Command Sequence (RTCS)

FSW allows for the existence of 75 command macros. These sequences contain commands and wait times. Once a sequence is activated, each command is executed after its specified wait time. The wait time is specified in integer seconds and is relative to the execution of the previous command. The delay between commands in an RTCS may be anywhere from 0 seconds to 9.1 hours. An RTCS may be started by a realtime command, stored command, or another RTCS. An RTCS cannot activate itself. Multiple RTCS may run at the same time.

When loading an RTCS, two loads are actually necessary. An information table must be uplinked and moved in addition to the RTCS memory load. The "info" table contains each sequences id number, the beginning location of the command sequence in FSW, and the number of commands in the sequence. The "memory" load contains the actual commands and wait times. No RTCS should be running when a new RTCS load is activated.

Each RTCS may be in any one of three configurations. These configurations are made up of two separate states. The invalid/valid state indicated whether or not the RTCS is available to be executed. An invalid RTCS cannot be executed. The invalid/valid states are used by the ground as a "safety switch", and in fact, certain sequences are kept invalid until needed for operations when they are made valid just prior to being Activated. The inactive/active state indicates whether or not the RTCS is in fact currently executing. Using these states, the three attainable configurations for any RTCS are as follows: invalid-inactive, valid-inactive, and valid-active.

The RTCS table is equipped with a firewall. Any RTCS below this firewall is not allowed to be active if RTCS processing is disabled. RTCS above the firewall may be activated regardless of the RTCS processing status. Currently, the firewall is kept at slot 35, meaning that RTCS 1-34 may not be activated if processing is disabled. Many of the sequences kept above 34 are used for safing of the spacecraft in anomalous situations and must be capable of being activated at any time.

SCP - Command Verification

While the CIU is responsible for checking whether or not a command has reached the spacecraft successfully (proper CLTU format, Transfer frame format, and SCC number), the SCP is responsible for validating the syntax of the command and outputting a Command Verification (CV) word to the TDF.

The SCP puts out at least one CV word for every command that it processes. The Control and Standby SCP each contribute one CV word per minor frame. The CV word may contain error codes, opcodes, complimented opcodes, checksums, or any possible data word for any possible realtime command (possibly inverted).

Each time a command is successfully received by the SCP, it places the opcode (and data words for realtime commands) into the CV queue for downlink. If an error is detected, the SCP will invert the offending opcode (and data words for realtime commands) and put it into the CV queue for downlink. The next CV word will contain a 16-bit error code. Error codes are also generated for load checksum mismatches, load starting/ending address errors, RTCS execution errors, etc.

The Table 6-1 summarizes the contents of the CV word for commands.

Cmd Type	CV Contents for Successful Command*	CV Contents for Unsuccessful Command
Realtime	Op Code & Datawords	Compliment of Op Code & Dataword and Error msg
ATCS	Op Code	Compliment of Op Code and Error msg
RTCS	Op Code	Compliment of Op Code and Error msg

*A CV code word (092A or 092B) will follow each of these responses.

Table 6-1 CV Code Word Contents

If a CV error is generated on an ATCS command, the ATCS continues to operate normally (except that the bad command is skipped). If an RTCS command generates a CV error, the RTCS is disabled and marked as invalid. This is important and must be kept in mind when generating command loads and building RTCS. Commands that must be executed in a specific order should be put in an RTCS. In addition, a CV word is generated when an RTCS completes successfully.

The first hex number (first 4 bits) in any command opcode is an indication of the origin of that command. For example, the CV'd opcode for a realtime "noop" command will appear as x'881A'. If that same noop command were to be sent from an RTCS, the CV'd opcode would read x'381A'. A noop command executed from the Bus stored command table (from the ATCS) would produce a CV of x'281A'. That same command built and issued from a FSW routine would yield x'481A'.

A complete listing of CV Error Messages and Keywords are defined in DFCB Volume 3. In addition, the CV tstol proc may be used to find the text message associated with any CV keyword.

FSW has a queue 60 words long where it can store CV words until they can be put into telemetry. If this queue fills up, the last CV in the queue will be replaced by an error code indicating a full queue. Upon initialization, the CV queue output will be "0". All other times, the last CV word written to the queue will be repeated until a new one is generated.

The CV is generated just prior to the command execution, so a command uplinked in a stored load may not be verified (and CV generated) by the SCP for hours. How the SCP reacts to a failed command differs depending on the type of command.

SCP – Standby SCP Operations

Because the Standby SCP is used as a warm backup to the Control SCP, certain changes in one SCP should be reflected in the other. The operations listed below should be performed on the Standby SCP whenever they are performed on the Control SCP.

- Clock corrections
- DATAB changes
- RTCS changes (not related to maneuver operations)
- EEPROM changes
- Star Catalog updates
- Preferred Bus/Clock switches
- FSW code changes

• **Solid State Recorder**

SSR - Description

The SSR is a 378 Gigabit storage device used to store both payload and housekeeping data until it can be downlinked to the ground. 520 Mbits of the storage capacity is a nested partition designated for housekeeping data. The SSR is capable of either recording or playing back payload data (but not both simultaneously) while simultaneously recording and/or playing back housekeeping data.

SSR memory is addressed in blocks, both logical and physical blocks. The ETM+ produces data on two 75 Mbps channels. The SSR records these two streams of data into two separate physical blocks. In order to locate these blocks in memory and access them, the SSR must "link" the two physical blocks together. These two physical blocks that are linked are referred to as one logical block. A logical block is two physical blocks long. The SSR contains 6144 wideband physical blocks – 6136 blocks for image data, and eight blocks for housekeeping data. (A physical wideband block is 67,108,864 bits.)The SSR logic further breaks the eight housekeeping blocks into 128 smaller housekeeping blocks. The housekeeping data which is stored on eight wideband blocks is equivalent to (8*128)= 1024 housekeeping blocks.

There are several operational modes for the SSR, which combine into many possible operations scenarios. The SSR has three power modes: Off, Low Power Standby, and Wideband Power Standby. In off mode, data (both housekeeping and wideband) cannot be recorded or played back. In low power standby only part of the SSR is powered. Housekeeping data record and playback can occur, but wideband data operations are disabled. Wideband power standby is the normal, fully powered configuration. All wideband and housekeeping record and playback operations can occur. There is also a built in test mode and a configuration mode that can be used during special operations. The SSR is autonomously commanded from wideband standby to low power standby during phase 1 loadshedding. Further loadshedding will not switch low power standby to off - housekeeping data collection and playback is maintained to assist in anomaly correction activities.

SSR Operations - Housekeeping Normal Operations

The housekeeping partition in the SSR can both write and playback data simultaneously. The standard operation is to use the housekeeping partition as a circular buffer - constantly writing new data into the memory and periodically reading out all the data up to the block currently being written. Housekeeping data can be recorded at 1k or 4k. The rate of record depends on the TDF setting. Our nominal record rate is 4k. Playback data is initiated by the CC and transmitted to the ground on the S-Band carrier at 256 Kbps - about 64 times faster than it is recorded (assuming 4Krecord rate). Housekeeping data is only dumped at ground sites, not during TDRS supports. Given a normal ground station contact of 8 - 10 minutes, there will be adequate time to playback seven or eight hours of recorded data. Ground station supports will be arranged so than no more than five hours of data is stored on-board.

SSR Operations – Wideband Normal Operations

The wideband partition of the SSR is used to record image/payload data. The SSR can record or playback wideband data, but not both at the same time. Wideband data is transmitted to the ground on a X-Band signal. All SSR wideband commanding is done out of the ATCS load. The MOC scheduler keeps track of data recorded, what blocks the data was recorded to and when it needs to be played back. The scheduler plays back all recorded data to ground stations. Each wideband SSR block has two flags that can be set when the data is recorded. One is the allocate flag, the other is a write protect flag. These will be discussed in a later section.

SSR Operations - Wideband Logical Block Allocation

As mentioned before, two physical blocks are ‘linked’ to one logical block. Each day these logical to physical block assignments(or links) will be changed. This is called the rename function. Assuming there are still physical blocks of data left on the SSR at the end of a day, their corresponding logical blocks are ‘renamed’. While the process is almost instantaneous and is initiated by the stored command load, it will not be done while the SSR is handling wideband data. Figure 6-6 represents how the logical block designations for “leftover” data are changed at the end of each day. As can be seen in the figure, the physical block designations are not affected by this process. As with other figures in this document, this figure is a simplified example, in reality one scene will occupy 27 blocks of SSR memory. The FOT will not schedule a downlink of less than one scene.

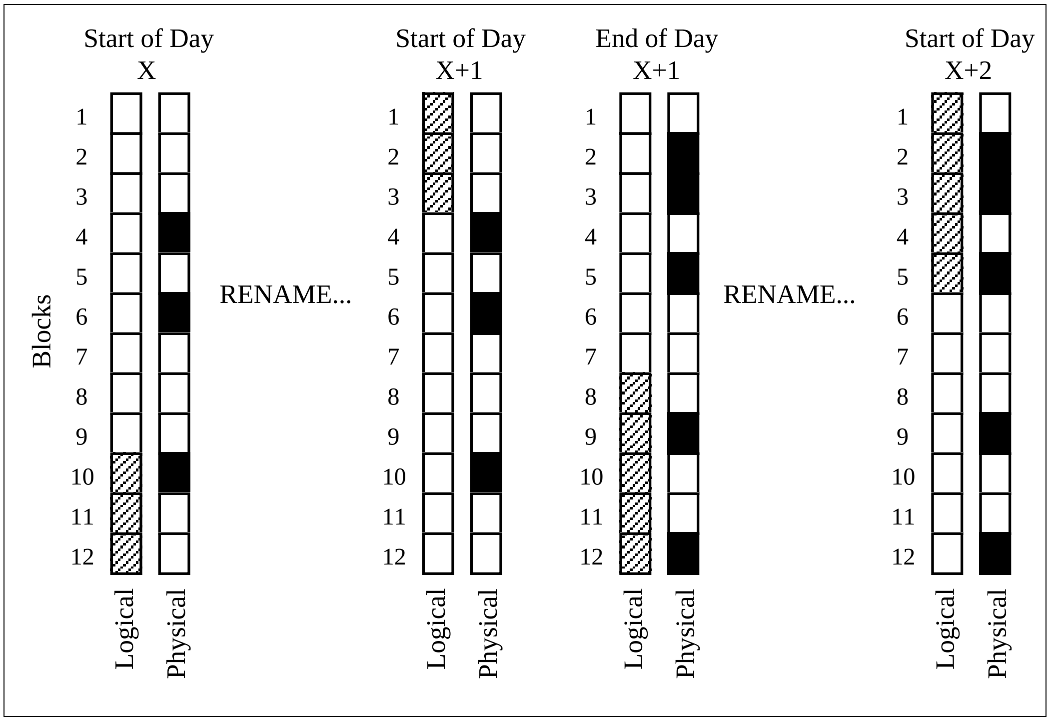


Figure 6-6 SSR Logical Block Renaming

SSR Operations - Write Protect and Allocate Flags

The "Allocate" flag is one of two flags that exist for each SSR block. Whenever data is written into a block, the SSR automatically sets that blocks allocate flag to ensure that it is not written over prior to downlink. When that block is read out for downlink, the SSR automatically resets the allocate flag to free that block for future data recording. The FOT also has the option of write protecting a block by setting a “write protect” flag on the blocks when their “Record” command is sent. Once a block has been write protected, it remains protected until the FOT resets its flag. This would be done in the case of special request data to ensure that it is not written over until successful capture on the ground is verified. The difference between the allocate flag and the write protect flag is that the write protect flag must be controlled completely from the ground while the allocate flag may be manipulated by either the SSR or the ground.

When breaking an interval (a group of contiguous scenes) up into 2 or more sub-intervals and the sub-intervals are downlinked over different contacts, the "allocate" flag must be reset (by stored command)for the "overlap" portion of the data so it is not written over. For example, if the interval covers scenes 1-8 (see Figure 6-7) and 1-4 are to be downlinked on orbit X and 5-8 are to be downlinked on orbit X+1 the following must happen: scenes 1-4 are downlinked, but 1/2 a scene must be added on the beginning and end of sub-interval #1 for processing. The sub-interval actually ends 1/2 scene into scene 5. When the SSR reads a block for downlink, it "de-allocates" it so it is free to be written over. So in the example, after sub-interval #1 has been read down, all the blocks that contained scenes 1-5.5 are free to be written over. However, the next sub-interval is to contain scenes 4.5 - 8 (plus 1/2 scene on the end), so that leaves the blocks containing scenes 4.5 to 5.5 that will need to have the allocate flags set on all the corresponding blocks. All of the intervals and sub-intervals are kept track of by the scheduling software. It will generate the appropriate commands and put them in the ATCS load.

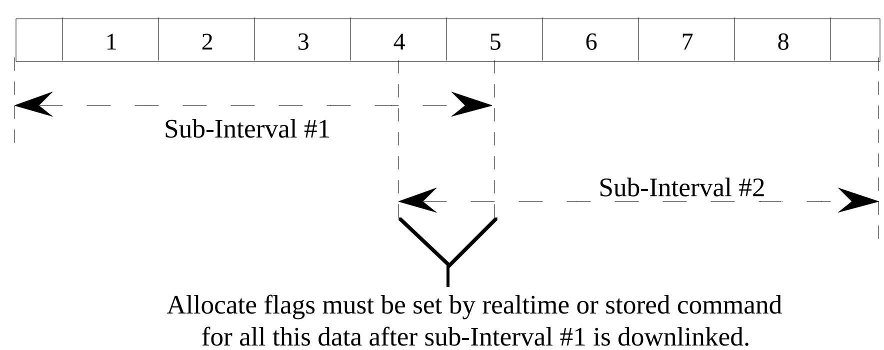


Figure 6-7 Sub-Interval Downlink

SSR Operations - Operational Constraints

There are several SSR constraints the FOT should be aware of. The first involves sending commands from the ground to the SSR. Any ground commanding to the SSR (for example housekeeping dumps or mass memory dumps) may not be performed while SSR commanding is being done from the stored command load. The reason for this is how the SSR handles stored commands. For example, it takes a minimum of 4 commands to start a wideband playback. The SSR treats these four commands as one group of commands. Any interruption in the execution sequence of these commands would cause an error in the SSR and the playback would not occur. Once this sequence of commands has occurred, the SSR may be commanded from the ground.

The second constraint involves commanding the SSR to a telemetry format other than the 'normal' output. The TDF MUST be in 'ext_fsw' or 'nor_ctl' mode before/during/while the SSR is being commanded to a telemetry mode other than 'normal' mode. (The SCP/TDF dump and SSR dump procedures cannot be run concurrently.)

• Telemetry Data Formatter

TDF - Description

The TDF gathers, formats, and distributes spacecraft housekeeping data at 1 or 4 Kbps. The TDF has in it several selectable telemetry downlink formats, each available regardless of rate. Telemetry is sent from the TDF to the S-band transmitter for downlink and/or to the SSR for temporary storage. Some telemetry (the "TDF-to-SCP" words) is also sent to the CIU for relay to the SCP; see the SCP section above. The TDF weighs 36 pounds and draws 9.01 watts.

The TDF uses a time-division multiplexing system (TDM) of fixed length minor frames (mf) that contain data in a known format. Each minor frame contains 64 16-bit telemetry words, and 256 minor frames are collected into a major frame. Every minor frame contains certain fixed parameters, including:

- Frame sync pattern,
- Format and rate in which the minor frame was created,
- the count of the minor frame (0 to 255),
- Spacecraft clock (the PDF/Hardware Clock) - takes 8 minor frames downlink,
- Command verification words,
- Command counter and CIC (CPU interrupt code),
- CCSDS telemetry status words,
- TDF-to-SCP words.

The remainder of the minor frame is packed with housekeeping data from either hardware or software origins.

The data contained in each minor frame is defined by the telemetry format selected by the FOT. Five format definitions exist within the TDF and each provides specifically formatted minor frames. Figure 6-8 shows a generic minor frame layout. When 256 minor frames have been output by the TDF, the cycle begins again with the first minor frame.

At a telemetry rate of 4K, one minor frame is output from the TDF every 1/4 second. At a rate of 1K, one minor frame is output every 1 second.

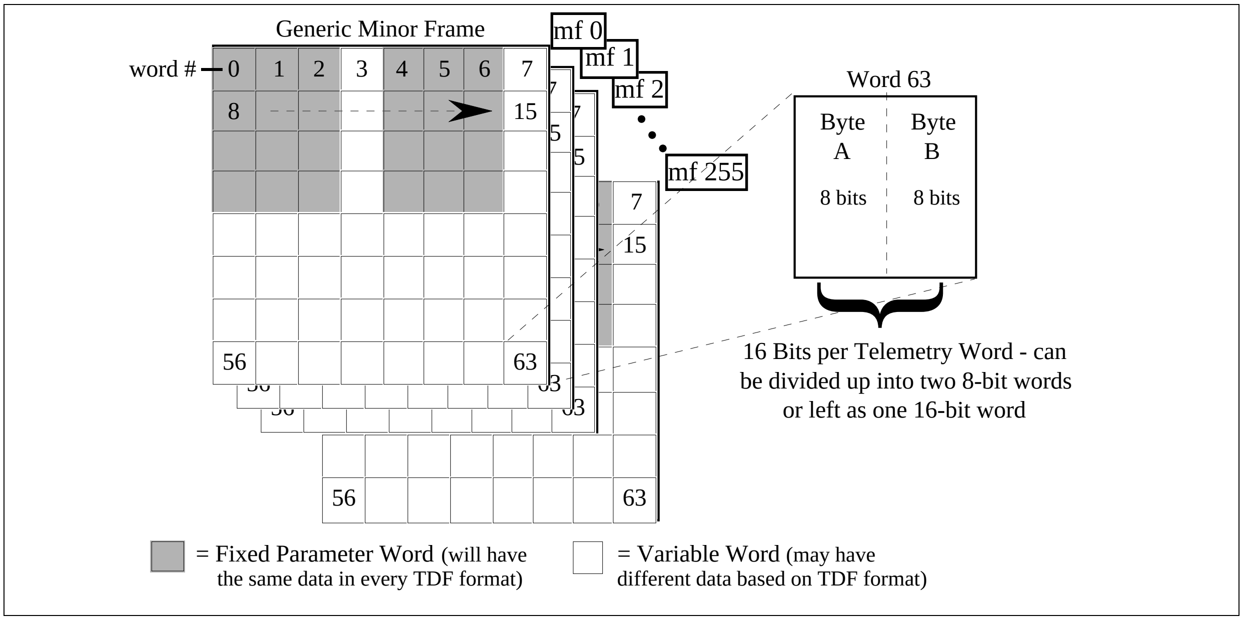


Figure 6-8 Generic Housekeeping Minor Frame

Housekeeping telemetry is formatted into CCSDS-compliant Channel Access Data Units (CADUs) by the TDF for transmission to the ground and/or recording onto the SSR. Figure 6-9 illustrates how minor frames are collected and packed into CADUs.

As mentioned before, five telemetry formats are defined in TDF ROM. These formats exist in TDF ROM along with other information, and are automatically copied into RAM upon a TDF side switch or power up. These formats are Normal, FSW Dump, Dwell, TDF RAM Dump, and Extended FSW. No matter which format is chosen, a minor frame will always consist of 64 16-bit words. For a detailed description of what telemetry is contained in each of these formats, refer to the DFCB Volume 3.

In addition to providing these five formats, the TDF allows the RAM copy of the Normal format definition to be changed by ground command. This is referred to as Flex Mode. When the TDF is commanded into Normal, SCP Dump, FSW Extended, Dwell, or TDF Dump Modes, definitions existing in ROM are used to structure the telemetry stream. When commanded into Flex mode, the TDF uses words 0-127 in RAM to structure the telemetry stream. When first entering Flex mode, the telemetry stream is formatted as if it were Normal mode because the Flex RAM area is an exact copy of the Normal ROM area (Flex mode does not exist in ROM).

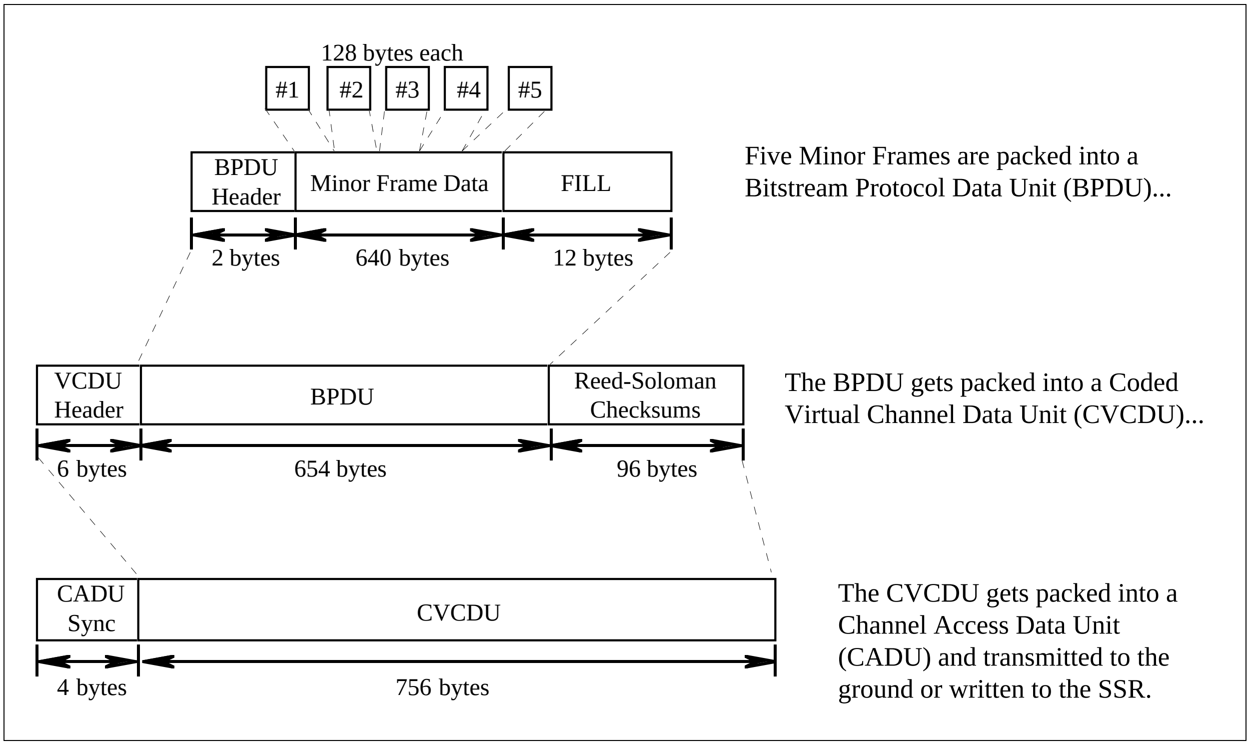


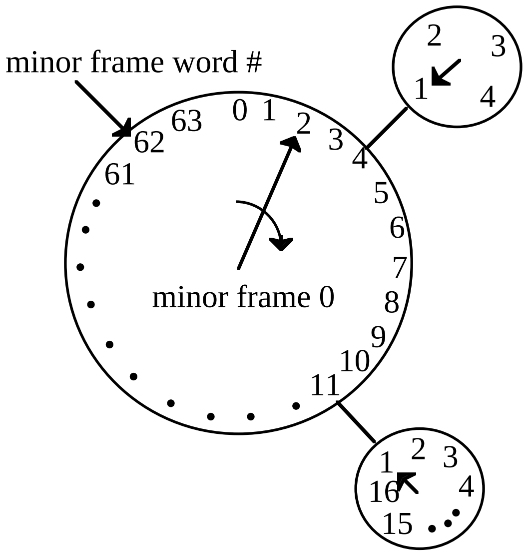
Figure 6-9 Packing Minor Frames into CCSDS CADUs

Certain words in the telemetry format definitions point to tables that specify data to be subcommutated (subcom tables). These tables, defined in the TDF ROM/RAM, provide the ability to increase the number of points contained in the telemetry stream and define varying rates at which they are brought to the ground. The TDF ROM defines two subcoms that are 256 “deep”, 30 subcoms that are 64 “deep”, 36 subcoms that are 16 “deep”, and nine subcoms that are 4 “deep”. The notation ‘x’ “deep” tells how many parameters can be placed within that subcom. For example, there may be a word in the telemetry format definition that points to a subcom that is 16 “deep”. This minor frame word in telemetry may, over the course of 16 minor frames actually contain 16 separate telemetry parameters. The FOT may specify whether the subcom tables in RAM or ROM are used. Subcom tables in RAM may be altered using ground commands. A simplified explanation of data subcom is shown in Figure 6-10. Dwell word assignments are also contained in the TDF ROM as well as 2 words of sync pattern.

Several of the formats contain FSW dump words (including the Rolling dump). The FOT may specify whether these FSW dump words are obtained from the Control or Standby SCP.

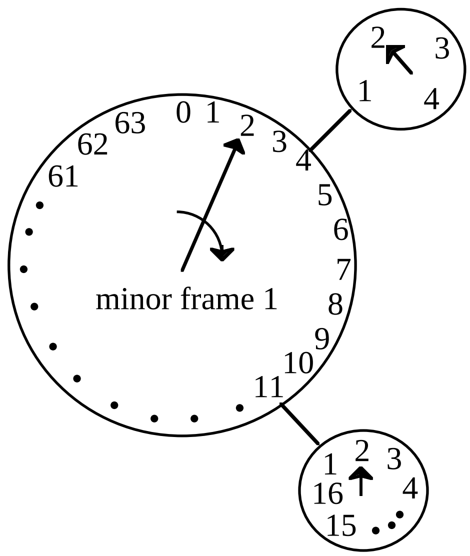
On any timing or format switch, the switch will take effect on the next minor frame boundary (coincident on the 2 Hz clock pulse) and then begin a new Major Frame. Upon TDF reset, a new Major Frame is begun and the TDF defaults to Normal format in 1 Kbps.

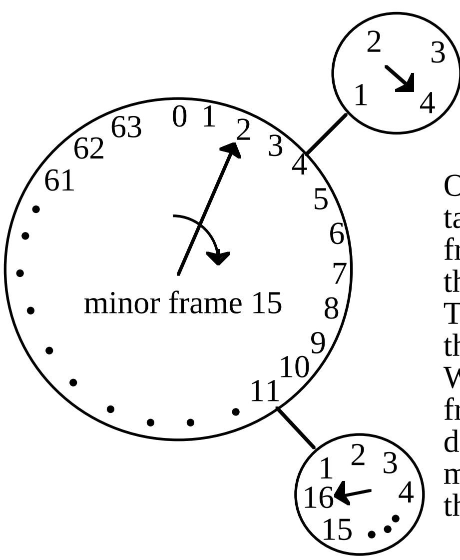
The picture below shows a theoretical minor frame/subcom setup. The minor frame has 64 words, and uses 2 subcom tables, one 4 "deep" and one 16 "deep".



Minor frame 0. As the pointer sweeps through minor frame words 0 to 63 putting out data for each word, it passes two words (4 and 11) that point to different subcom tables. On this first minor frame, it will receive values stored in subcom data word 1 from each subcom table.

On minor frame 1, each pointer in the subcom tables advances 1 word. When the minor frame word pointer sweeps past word 4 this time, it will receive a value stored in subcom data word 2. The same will happen when the pointer sweeps past mf word 11. NOTE: Different subcom tables may contain different parameters.





On minor frame 15, each pointer in the subcom table has advanced 15 times. When the minor frame pointer sweeps past minor frame word 4 this time, it will receive subcom data word 4. This will be the 4th time since minor frame 0 that this value has been placed into the minor frame. When the minor frame pointer sweeps past minor frame word 11 this time, it will receive subcom data word 16. This will be the 1st time since minor frame 0 that this value has been placed into the minor frame.

Figure 6-10 Telemetry Subcom Explanation

TDF - Operations

Under normal conditions the TDF is operated in Extended FSW format using RAM subcom definitions. Following is a list of the six possible formats and what they are used for.

Extended FSW - Routine Operations
Normal - Special Operations
FSW Dump – Weekly and special dumps of FSW locations and tables
TDF Dump - Verification dumps of TDF RAM
Dwell - Launch and Ascent
Flex - Used as needed during Non-routine operations

TDF - Operations : Subcom RAM Patches

Currently, there are two patches necessary to TDF RAM prior to executing normal operations. The first change to the RAM image is necessary in order to compensate for a hardware error. A TDF subcom table needs to be altered to provide proper telemetry readings on certain X-Band parameters. The second patch is necessary to place ETM+ cal lamp current into the telemetry stream for image processing. Because of these two patches, it is necessary to run the TDF using the RAM subcom definitions during all normal operations. Two RTCSs are dedicated to holding all TDF RAM patches necessary for normal operations. In the event of a TDF side switch, the RTCS will be used to restore the normal operating RAM image.

6.2 Attitude Control Subsystem (ACS)

The purpose of the Attitude Control Subsystem (ACS) is:

- establish and maintain a stable platform from which the instrument may perform accurate remote sensing
- maintain the spacecraft-Sun-Earth orientation to preserve spacecraft safety and health

The ACS uses a closed loop system with sensors feeding any measured attitude errors to a processing function which calculates the necessary restorative torques and commands the appropriate actuators to create those torques. The effects of these torques are measured by the sensors and sent to the processor as the cycle, or loop, is repeated.

The ACS is required to maintain attitude pointing within ±60 arcseconds (0.01667°) (1σ) of the calculated position in Precision Mode. These sensors and actuators are used in various combinations for different ACS modes:

- IMU (Inertial Measurement Unit) measures inertial rates of the spacecraft body
- CSA (Celestial Sensor Assembly) provides star crossing information
- ESA (Earth Sensor Assembly) provides Earth position data relative to the spacecraft
- TAM (Three Axis Magnetometers) sense the local magnetic field for use with the MTR
- CSS (Coarse Sun Sensors) provide Sun location information
- RWA (Reaction Wheel Assemblies) create restorative torques in response to commands from the SCP. Creates necessary torque to slew the spacecraft during special operations
- MTR (Magnetic Torque Rods) create external torques for momentum unloading
- REA (Reaction Engine Assembly) provides thrust for orbit maintenance. Creates external torques for backup reaction wheel unloading

All ACS sensors and actuators are either internally or block redundant. The interface between the sensors and the actuators is the SCP FSW which provides attitude control processing and commanding. Included in FSW is a star catalog containing 700 entries and an ephemeris table with predicted locations and speeds of the spacecraft throughout its orbit.

Commands from the ground may enter the control loop and affect the sensors or actuators, however this will not be the case during normal operations. Figure 6-11 provides a high level block diagram of the ACS.

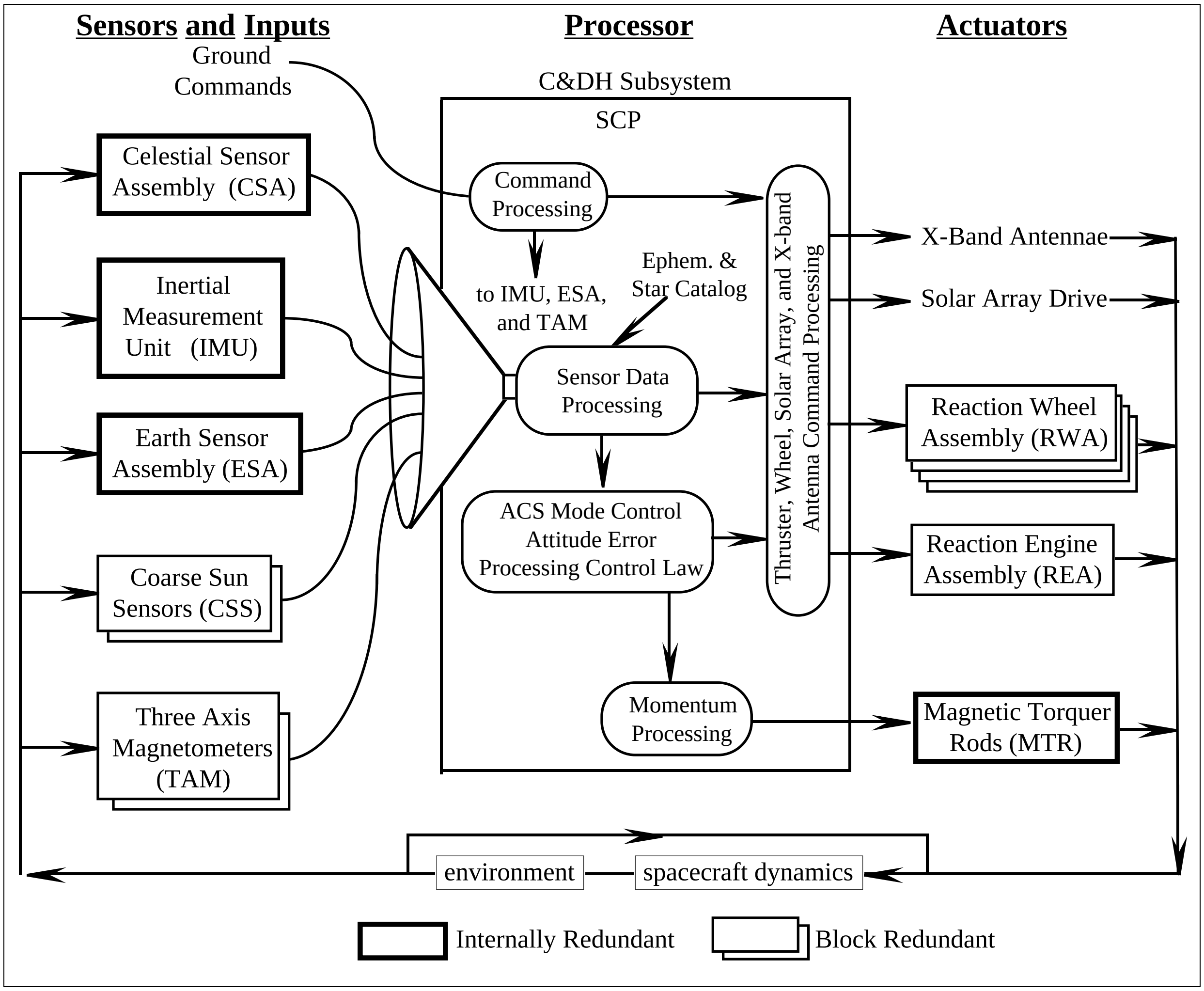


Figure 6-11 ACS Block Diagram

In the following sections, operational considerations of some of the ACS components are discussed. Although many of the attitude control functions are automated and require little if any operator intervention, trending will be done in order to assess the subsystem and component performance.

• Earth Sensor Assembly

ESA - Description

The ESA is a static infrared horizon sensor designed to operate at 705 km altitude with optimum sensitivity to radiation in the 14 to 16 micron (CO_2) range. Because the sensor detects infrared energy, its data is useful over both sunlight and shadow portions of the Earth. Four Quadrants, each with four sensors, are used to detect the horizon (or limb) of the Earth's disk. Data from the 16 sensors measure the difference between radiated energy from the Earth and the energy present in space and are used to calculate the Earth's position under the s/c. The ESA is used as a prime control sensor in ACS backup modes to calculate roll and pitch errors. ESA data is also used in primary ACS mode, but only as an abort criteria (it does not contribute to the control algorithm). Each of the four detectors (in each quadrant) contributes data (counts) to FSW on the amount of energy being sensed. Of the four detectors, there are two "A" detectors wired in parallel, one "B" detector, and one "S" detector. The "S" detector should sense a background level of energy from space while the "A" and "B" detectors should each be sensing energy from the horizon of the Earth's disk. The ESA has a field of view of approximately 128°. Processing ESA data yields an output of the Earth position within the field of view that is accurate to within 0.10°. When using only three of the four quadrants, the accuracy drops to 0.14°. It weighs 8.9 pounds and draws 1.35 watts maximum.

ESA - Operations

Once the ESA is powered on, it should require no further ground actions. ESA outputs are used actively by the FSW ACS control law in Local Vertical Acquisition (LVA), Yaw GyroCompassing (YGC,) and Earth Search modes, and as an abort criteria in Precision, Yaw Slew, and Maneuver modes. In any of these modes, loss of Earth presence will cause the spacecraft to automatically transition into Sun Pointing Safehold mode.

FSW calculates the position of the Sun and Moon relative to the spacecraft. Whenever the Sun and/or Moon are calculated to be within a specified distance of an ESA quadrant, FSW will mark that quadrant "BAD" until the interference is over. These Sun and Moon interference checks may be disabled. There is a seasonal phenomena that causes ESA quadrants 2 and 4 to be marked BAD due to Sun interference. The spacecraft orbit to Sun geometry is such that this interference occurs for several months each year and causes each of the two quadrants to be marked BAD once each orbit. In addition, every 28 days, the ESA experiences Moon interference during the full moon. Neither of these interference cases interrupts normal operations. A quadrant may also be marked "BAD" from the ground if it is determined that its data is no longer reliable. FSW will mark a quadrant "LOST" if it no longer senses sufficient Earth radiation (penetration < 10%).

There is a phenomena experienced by the ESA on other missions which causes the lenses to darken with a corresponding drop in sensor sensitivity. Landsat 7's ESA has been built with a lens coating supplied by a different manufacturer to avoid this situation. The FOT monitors ESA long term performance, in part, to watch for this phenomena. Any change in performance over time may be associated with the lens darkening, and there are offset adjustments in the FSW that will help bias the system to minimize the effect of this problem.

• Inertial Measurement Unit

IMU - Description

The IMU contains three 2-axis Teledyne gyros providing six channels of gyro data that are always available to the SCP for processing. All six channels, however, are not available to the ground at the same time. The IMU also houses the Celestial Sensor Assembly (CSA) processing boards, meaning that the CSA will not function unless the IMU is powered. The gyros have a low and high range of operation. In low range (their normal operating configuration), their scale factor is 0.061 arcsec/pulse with a rate range of 0.5°/sec. In high range they have a scale factor of 1.83 arcsec/pulse and a range rate of 15°/sec. The IMU weighs 38.5 pounds (not including 3.35 pound mount) and draws 50.3 watts in low range and 68.2 watts in high range.

IMU drift calibrations are performed automatically by FSW using the star-transit data from the CSA. The IMU is used actively in Precision, Yaw slew, and Maneuver modes when calibrated. In an uncalibrated state, the IMU may support the Rate Nulling, LVA, YGC, and Earth Search modes.

IMU - Operations

Like the ESA, the IMU will have very few operational needs during nominal conditions. The FOT will trend the calculated gyro drifts, biases and temperatures.

• Celestial Sensor Assembly

CSA - Description

The CSA is a static star sensor used to provide attitude information relative to an external, relatively fixed source (the stars). The CSA neither tracks stars nor measures their relative brightness, it simply registers a stars crossing in front of one of its sensing slits. The time of the star crossing and information included in the star catalog, ephemeris file (both described further on in this section), and other FSW input are used to calculate an attitude error and a gyro bias.

The CSA contains a celestial sensor, a sunshield, and a connecting sleeve or “boot.” The celestial sensor is comprised of a reticle and optics package which focus objects on a silicon detector array. Timing circuits and a power supply reside in the IMU, but are a functional part of the CSA and a light emitting diode is included for performing self tests. The sunshield provides protection against off-axis light sources.

The optical system focuses the light of a star on the silicon detector array through a 6-slit reticle. The star position, based on the slit through which it is detected, is conditioned and converted to a pulse which indicates the star's position as a function of the time of the transit across the reticles. This position is compared to predicted star locations in order to determine the attitude error.

CSA - Operations

Like the ESA and IMU, the CSA will have very few operational needs during nominal conditions. FSW calculates the spacecraft-to-moon geometry. If the moon is predicted to interfere with the CSA, FSW will disable CSA output for a given time span until the moon has safely moved away from the CSA FOV. The FOT may disable this function, however it is normally enabled. Planets are not accounted for, however the CSA will recognize that they are not acceptable stars and a "False" detection will be noted.

Because the FSW only has 700 stars to choose from (See the FSW Reference Table section below) and the CSA senses many more than that number, a large number of "unidentified" stars are detected.

Several unidentified stars in a row within a certain timespan, or on the same slit may be flagged by FSW by either setting the "proton storm" flag or by marking part of the CSA as "bad". Both of these situations have occurred since launch, and in fact, the proton storm flag is set and cleared fairly routinely by FSW.

- **Three Axis Magnetometer**

TAM - Description

Redundant TAMs are provided to sense the local strength and direction of the Earth's magnetic field. Each TAM consists of a sensor and a separately packaged electronics unit. The analog outputs provided by the TAM allow for sensing magnetic field data in three orthogonal axes.

TAM - Operation

Once the TAM is powered there will be no ground interactions necessary. The TAM data is used by the FSW ACS routine to determine the local magnetic field when reaction wheel momentum unloading is deemed necessary via the magnetic torque rods.

• FSW Reference Data (Star catalog and Ephemeris)

Among the inputs to ACS processing, FSW uses many or all of the sensors described above, and in addition, many inputs from FSW itself are used. Constants, tables, algorithms, etc are all part of the input to ACS processing, but there are two tables of information in particular that require FOT maintenance. These tables contain information on the location of the stars used for external attitude reference and the location of the spacecraft in its orbit.

The star catalog is a table consisting of information (Right Ascension and Declination) for 700 selected stars. When a star transit is logged by the CSA, FSW checks the star catalog to verify that an acceptable star should have been seen by the CSA, given the time of the transit, the s/c attitude at that time, and the s/c orbital position. Candidate stars in the catalog meet specific criteria to be included and must be reviewed and updated. For example, several of the stars included have a relative motion over the years and so their position in the sky must be updated periodically. Performance of the ACS in precision control mode is effected by the accuracy and completeness of the star catalog.

The ephemeris table is a time ordered listing of the predicted location of the spacecraft within its orbit on 12 minute intervals. The location is given in Earth centered coordinates (ECI) and consist of an x, y, and z position. In addition, the predicted velocity of the spacecraft in each ECI axis is given (xdot, ydot, zdot). Ephemeris is used in several areas of FSW. Xband antenna pointing, solar array pointing, and CSA data processing all use information in the ephemeris. When FSW needs the s/c position at any time other than what is provided in the table, it interpolates between the given values. Typically, the ephemeris onboard is updated once each day with a file that covers a three day time span (in 12 minute centers). Further operational considerations are explained in section 7.6 Ephemeris Operations.

• Attitude Processing Function

Input from the appropriate sensors is sent to the SCP/FSW where it is passed through algorithms to determine the current state (position, velocity, and possible acceleration) of the spacecraft. These values are then used to determine the appropriate response to the spacecraft state. Normally the response will be an output voltage to the reaction wheel assembly (RWA).

• Reaction Wheel Assembly

RWA - Description

The RWA consists of four reaction wheels (Roll, Pitch, Yaw, Skew) with three phase, six pole DC torque motors, and the necessary support electronics and housing hardware. The spinning wheels represent a reservoir of angular momentum distributed along all three spacecraft axes, and respond to voltage commands from the SCP by adjusting their spin rates. These changes in the wheel angular momentum are used to counteract any disturbance torques experienced by the spacecraft and keep the satellite within the attitude stability requirements. The RWA weighs 18.25 pounds and consumes 23 watts on average (3500 RPM) or 209 watts (worst case). Wheel saturation speed is 6500 RPM.

RWA - Operation

FSW commands the wheels to maintain attitude control and performs momentum unloading autonomously. The skew wheel is powered on and set to spin at a default value (currently, this value is approximately 1280 rpm). This configuration adds a momentum bias to all three axes and normally precludes any of the other wheels from passing through zero RPM during a normal orbital cycle. It is desirable to do this as wheels changing spin directions may cause unwanted attitude transients. FSW SHP utilizes only three of the four wheels. Ground interactions are not normally required, with the exception of Yaw slews for Delta-I orbit adjust maneuvers when the skew wheel bias is disabled.

- **Magnetic Torquer Rods**

MTR - Description

Torque for performing wheel unloading is produced through the MTR. Two rods are provided, one along the X_{nav} axis and the other along the Y_{nav} axis. Each consists of a 36 inch cylindrical magnetic core wrapped with 6 layers of 28 gauge copper wire with each layer separated by heavy polyester-amide-imide insulation. Redundant windings on each rod allow for single failures without loss of function.

MTR - Operations

Interaction between the MTR and local magnetic field will create a torque on the spacecraft structure. The MTR are used in conjunction with the TAM by FSW for autonomous momentum unloading. See the subsection *Momentum Management* below.

- **Reaction Control System**

RCS - Usage

The RCS (described in Section 6.6) can be used by FSW for autonomous momentum unloading. See the subsection *Momentum Management* below.

• Momentum Management

Periodically throughout the orbit, the wheels will have absorbed enough momentum from the environment that they will need to be "unloaded". This will manifest itself in telemetry as high or low wheel speeds. Unloading momentum is the process of exerting an external force on the spacecraft and forcing it to respond. The FSW, sensing this external force (via the IMU) reacts to it as normal by adjusting the wheel speed to counteract the disturbing torque. If the external force is selected correctly, the resulting action of the FSW will lower the wheel speeds (if they were too high) or raise them (if they were too low). Because the force was applied externally, the total momentum of the spacecraft has actually been changed. This external force, or torque, is applied nominally by the MTR. They take advantage of the Earth's magnetic field and use its force to impart a torque on the spacecraft. This operation on Landsat should be fairly transparent to the FOT, although it will have some trending associated with it to assess the performance of the MTR and wheels.

It is possible for the RCS thrusters to be used to control spacecraft momentum. The spacecraft must be manually enabled (by ground command) to be allowed to autonomously switch to thruster unloading in the event of a MTR failure or other momentum management anomaly.

• Attitude Control Modes

The spacecraft has three different modes of attitude control in the FSW Flight Load Package: Backup, Primary, and Sun Pointing Attitude Mode (SPAM). Backup and Primary contain several submodes. A listing and description of these modes and submodes is given below. FSW Safehold Package contains Rate Nulling and Sun Pointing Attitude Mode. For a graphical look at the modes and submodes, and their interactions, see Figure 6-12. Table 6-2 shows the relationship between sensors and actuators in each mode.

Primary Mode

Precision - This submode is used during most of the mission and performs precise attitude control necessary for image operations. A major part of the Precision ACS code is made up of a Precision Attitude Determination System (PRADS) Kalman filter. PRADS calculates estimates of attitude and gyro bias errors.

Yaw Slew - This is used to orient the spacecraft prior to inclination adjust maneuvers and is entered only by ground or stored commands. A slew in the yaw direction of up to $\pm$ 180° is allowed at a controlled rate. In this mode, the Kalman filters and CSA processing are inhibited.

Maneuver - This mode is used to perform orbit maintenance and acquisition burns (ΔV and Δi). Attitude control is done using on and off pulsing of the thrusters during the maneuver. At burn completion, the spacecraft automatically reverts into precision mode. This mode may be entered only by ground or stored commands. In this mode, the Kalman filters and CSA processing are inhibited.

Backup Mode

Local Vertical Acquisition - This submode controls the roll and pitch axis position (inertially fixed), but lets the yaw axis drift within a set rate. The spacecraft stays in this configuration until the ESA locks onto the Earth. At this point, LVA is complete and the spacecraft automatically transitions into Yaw Gyrocompass submode. To bring the spacecraft out of Sun Pointing Safehold mode, it is commanded to LVA from the ground.

Yaw Gyrocompass - YGC maintains rates and positions on all three axes to within specified limits. YGC is “complete” when the Yaw error is under the threshold limits. The FOT will command the spacecraft from YGC into Precision mode.

Earth Search - Earth Search induces a small roll and/or pitch motion in the spacecraft and is entered only by ground command. This motion continues until the ESA locks onto Earth presence and is used as an alternative way to acquire the Earth when transitioning into LVA.

SPAM - This mode is entered when the spacecraft does not have Earth presence. After the solar array is rotated to the Index position (0°), the entire spacecraft rotates to orient the cell side of the array towards the Sun (± 10°) using the CSS and RWA. While the array is rotating to the index position, the s/c will have a slight roll rate. When the array reaches the index position, the roll rate is zeroed out. Among other actions automatically taken upon SPAM entry, a phase 1 load shed is executed and the ETM+ cooler door is moved to the outgas position. SPAM is exited by ground command, putting the spacecraft into the LVA submode. A copy of SPAM exists in the FLP and SHP.

Rate Nulling - (SHP only) This submode was used after separation from the launch vehicle to lower the spacecraft rates and maintain them low enough for solar array deployment and successful transition into FLP and Local Vertical Acquisition submode. Thrusters were used to lower the spacecraft rates.

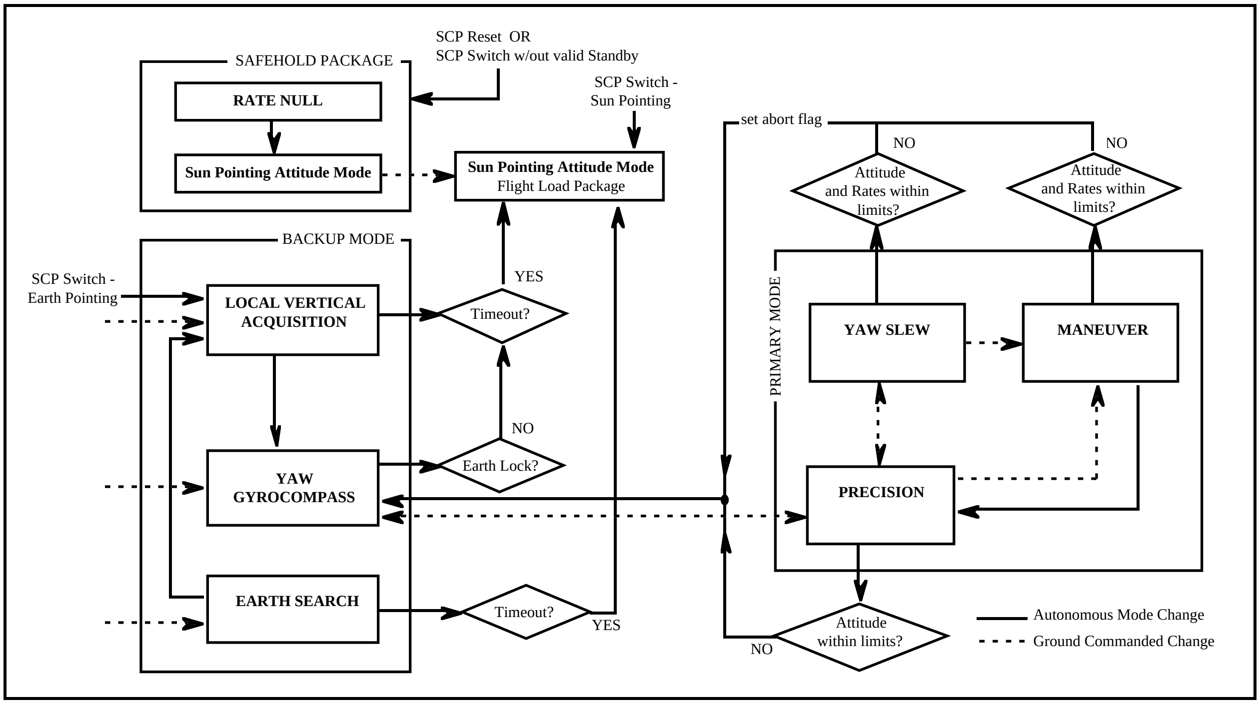


Figure 6-12 ACS Mode Interactions

ACS MODE	ACTUATORS: RWA	ACTUATORS: REA	SENSORS: CSS	SENSORS: ESA	SENSORS: RAW IMU	SENSORS: CSA	SENSORS: CALIBRATED IMU
Local Vertical Acquistion	√			√	√		
Yaw Gyro Compass	√			√	√	*	*
Earth Search	√			√	√		
Precision	√			†		√	√
Yaw Slew	√			†			√
Maneuver		√		†			√
Rate Nulling	√	√			√		
SPAM	√	B	√		√		

√ = Active Component
B = backup
* = monitored for convergence, not used control
† = monitored for Earth lock

Table 6-2 ACS Modes / Sensors / Actuators

6.3 Electrical Power Subsystem

The Electrical Power Subsystem (EPS) generates, stores, switches, and distributes power as needed by the spacecraft. Pyrotechnic system, launch vehicle interface support, and special test interfaces are also provided.

The EPS is comprised of:

- Solar Array provides electrical power to spacecraft
- SAD (Solar Array Drive) and ADE (Array Drive Electronic) –rotates the Solar Array towards the Sun
- Nickel-Hydrogen (NiH) batteries - store surplus power for use when the Solar Array cannot meet the spacecraft power needs
- PCU (Power Control Unit) - regulates the spacecraft bus voltage and controls battery charging and discharging
- SDA (Shunt Dissipater Assembly) - converts excess power to heat under the control of the PCU in order to maintain bus voltage

Figure 6-13 provides a block diagram of the EPS.

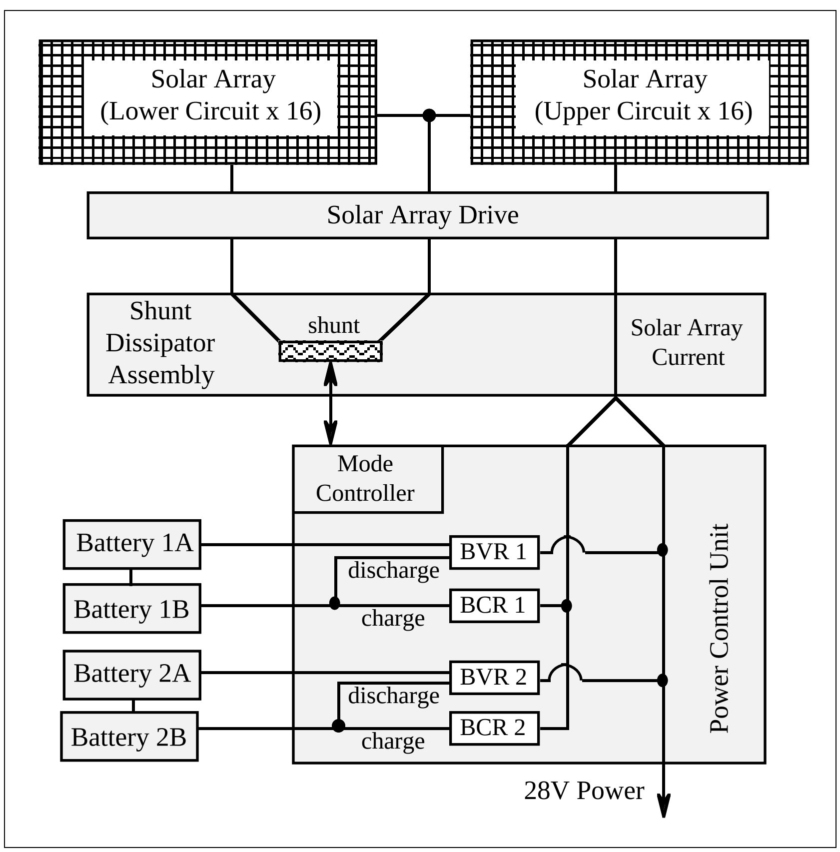


Figure 6-13 Electrical Power Subsystem (EPS)

• Solar Array and Drive

Solar Array - Description

The Landsat 7 solar array is a 26 foot rotating solar array that tracks the sun. It is assembled as four panels with a total of 16 circuits, each with an upper and lower section. Each circuit contains 5 strings, each string contains 83 solar cells. The hinged panels form a rigid 'wing' canted 20° to the spacecraft +Z-axis (see Figure 6-14). The array is required to provide 1550 watts of power at EOL. BOL power is approx. 1900 watts.

SAD and ADE - Description

The SAD assembly consists of a four phase stepper motor with redundant windings, a helicon reduction gearbox, torque limiting clutch, slip ring assembly, and position resolver. Given the 20° cant of the array yoke, the solar array sweeps out a 'cone' as it rotates about the +Z-axis. The stepper motor rotates the solar array at one of four commandable motor rates from the Array Drive Electronics (ADE) -

- Slew - 0.30918 degrees / second
- Normal - 0.060677 degrees / second
- Fast - 0.061568 degrees / second
- Slow - 0.059757 degrees / second

The ADE can be commanded to rotate forward, reverse, or stopped. The ADE will 'ramp' up or down to a newly commanded rate, providing smooth rotation of the array. Slip rings transfer electrical power (48 rings) and control signals (12 rings) across the SAD's rotating hub. The position resolver indicates in telemetry the array's rotated position with respect to an index point to an accuracy of 0.25°. FSW receives the position telemetry and sends commands to the ADE based on the selected control method (see Operations section below.)

Solar Array /SAD/ADE –Operations

The solar array is driven by FSW to keep it at an optimal angle to the Sun. The FSW routine controlling the SAD can operate in five modes: ephemeris closed loop, CSS closed loop, open loop, commanded position, and stop. Ephemeris closed loop will be the nominal control method, whereby the FSW determines the correct position of the array using ephemeris data, determines the true current position based on the resolver data, and commands the ADE to rotate the array to make up the difference. In CSS closed loop control the array is driven to null out the CSS determined error and keep the array pointing normal to the Sun. In open loop the array is slewed at one of the four predetermined rates without regard to position. Commanded position control rotates the array to a desired position using resolver data and stops the array at that point. Stop mode stops the array at the current location.

Nominally, there is no ground interaction with the solar array or its drive. However, it may necessary to slew the solar array to specific positions prior to performing maneuvers. Positions will be chosen to minimize the torque created on the array by the firing of the jets. Plans for these operations are detailed in PIR U-S/C-L7-1062-SYS.

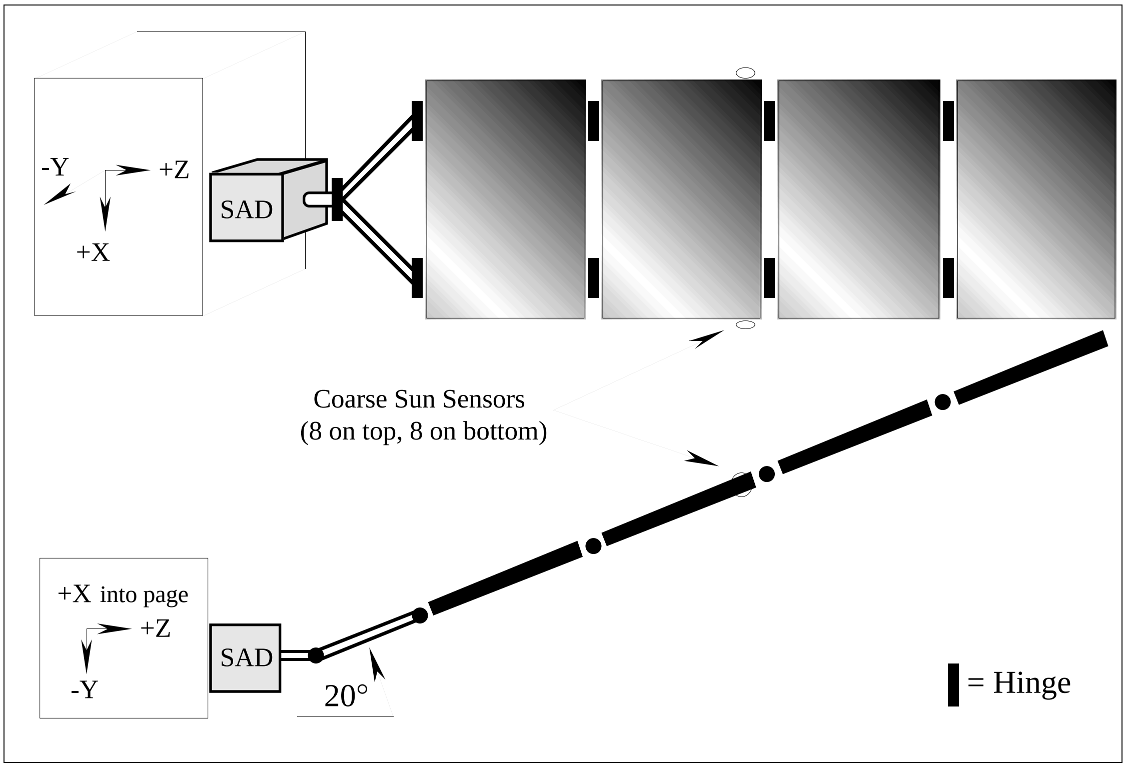


Figure 6-14 Solar Array and Drive Orientation

- **Batteries**

Batteries - Description

Two 50 amp-hour rated Nickel Hydrogen (NiH) batteries provide power during eclipse and other times when the solar array cannot provide power to meet the spacecraft bus load. Flight battery capacity is 5-10% above the 50 amp-hour spec. Each battery consists of 17 cells, each contained in its own pressure vessel with 750 PSI operating pressure and 3000 PSI burst limit. Two cells in each battery pack provide pressure telemetry. Total battery weight is approximately 140 pounds.

Batteries - Operations

The battery charging and discharging is controlled by hardware (PCU), but the state-of-charge is managed by the FSW PMON routine. Charge rates and V/T curves are autonomously selected by PMON in response to state-of-charge conditions. PMON is discussed in detail in the C&DH section of this document. The FOT will monitor the performance of the batteries, state-of-charge, temperature, etc. It is possible for the FOT to override the FSW selection of battery V/T curves and charge rates, but this is not done during normal operations. The EPS design does not require the batteries to reach a 100% state-of-charge during each orbit, only once per day as a minimum. If the batteries do not return to 100% state-of-charge after one orbit, the FSW (PMON) will take action and change VT curves. This is done autonomously. (PMON is discussed in more detail in the C&DH section of this document). Battery depth-of-discharge should never exceed 32% during normal operations. Battery life is considerably reduced if excessive deep discharging is allowed. No reconditioning of the batteries is required.

• Power Control Unit / Shunt Drive Assembly

PCU - Description

The PCU regulates the spacecraft bus to 28± 0.56 volts by battery charging, discharging and shunting solar array power.

The control devices internal to the PCU are:

Battery Charge Regulator (BCR) - a V/T controlled charger for the batteries
Bus Voltage Regulator (BVR) - discharges the batteries to boost the bus voltage
Mode Controller (MC) - operates the BCR, BVR, and Shunt Drive Assembly (SDA) to maintain the 28V bus regulation.

The BCR provides charging for the batteries. Batteries are used during eclipse periods when the solar array does not provide power. After the spacecraft comes out of eclipse and back into full sun, the solar array will provide power for the spacecraft and the batteries will begin to charge. Battery charging is controlled by both software and hardware. The batteries are charged at 13.6 A. When the battery reaches the voltage limit for a particular temperature (as defined by the V/T curves), the charge current will begin to ramp down, eventually switching to trickle charge (.85 A). Landsat has 16 V/T curves, 8 for normal cell operation, 8 shifted limits for a single shorted cell operation. V/T 5 is our nominal on-orbit limit.

SDA –Description

The SDA dissipates excess power from the solar array in response to signals from the PCU. When the solar array produces more current than the spacecraft needs, the excess is dissipated by the shunts. Landsat has 16 partial shunts located on one of the walls of the lower equipment module. Each shunt circuit has three states- off, active or saturated. During nominal conditions, the shunts are activated on a linear basis -meaning the first shunt comes on and becomes saturated before the second shunt will come on.

Shunt taps are in the middle of the string of cells between the 51st and 52nd cell (there are 83 cells in the string). The lower half of the string (cells 1-51) are controlled by the power control unit and shunt circuit. The top half of the string (cells 52-83) is not shunted. The SDA is the junction point for the solar array harness and current sensing.

PCU / SDA - Operations

Bus voltage regulation is autonomously provided by the PCU and SDA. The PCU Mode Controller will switch between primary and backup units if a failure condition is detected.

6.4 Radio Frequency Communications Subsystem (Comm)

The Radio Frequency (RF) Communications subsystem is designed to provide housekeeping telemetry, command uplink, and tracking ability through an S-Band system and payload data through an X-Band system (see Figure 6-16) . The following components are used:

- Two SBT (S-Band Transponders) for command uplink and housekeeping downlink
- Two S-Band Omni Antennas to support the SBT • S-Band Hybrids, Diplexers, and Baseball Switches in the SBIU to route and switch S-Band RF signals
- Four XTX (X-Band Transmitters) to downlink Payload data over four frequencies
- Three GXA (Gimbaled X-Band Antennas) and Gimbal Drive Electronics (GDE) track ground sites while broadcasting Payload data
- X-Band Triplexers and Baseball Switches route, switch, and condition X-Band RF signals.

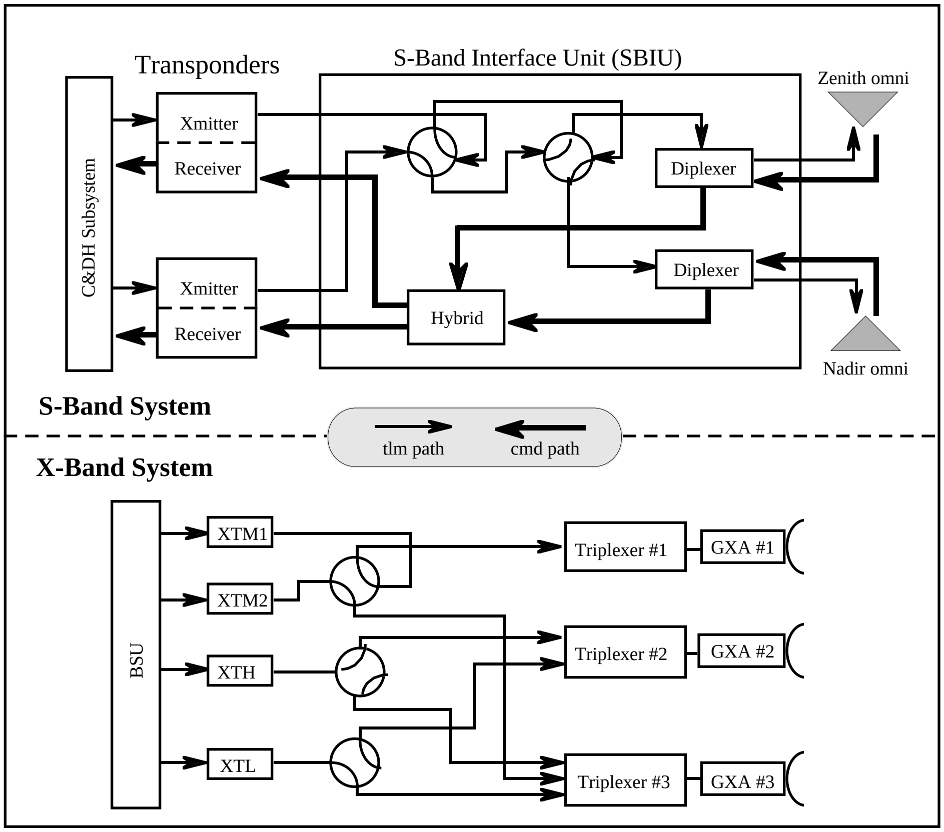


Figure 6-16 RF Communications Subsystem Block Diagram

- **S-Band System**

The S-Band system transmits all housekeeping telemetry and accepts all commands. The S-Band system also provides SN tracking and SN and ground doppler capabilities. The output from the S-Band system is Left-Hand Circular Polarized (LHCP).

<u>SBT</u> - Description

The S-Band transmitter produces a 5 Watt RF signal at 2287.5 MHz(nominal). The transmitters can be commanded to operate in coherent or non-coherent mode. Non-coherent transmission uses the 2287.5 MHz internal oscillator as the frequency reference; coherent transmission uses the received uplink frequency(240/221) as the frequency reference. The transmitters receive realtime H/K data from the TDF and playback H/K data from the SSR. The realtime data rate is dependent on the TDF setting; the transmitter is not configured separately. The modulation method for broadcast depends on whether the SBT is in TDRS or STDN mode - see Table 6-3.

HouseKeeping Data Source	STDN Mode		TDRS Mode	
	Rates	Modulation	Rates	Modulation
TDF (RealTime)	1.216 Kbps / 4.864 Kbps	BPSK on 1.024 MHz subcarrier	1.216 Kbps / 4.864 Kbps	QPSK on I and Q channels (1:1)
SSR (Playback)	256 Kbps	Phase modulated on carrier	N/A	N/A

Table 6-3 S-Band System Modes

In STDN Mode, realtime data is modulated onto a 1.024 MHz RF subcarrier at 1.216 or 4.864 Kbps. When commanded, playback data is modulated onto the base carrier at 256 Kbps .

In TDRS Mode, realtime data is convolutionally encoded and modulated onto the I and Q channels at 1.216 or 4.864 Kbps. Each channel carries the same data at the same rate. The data is re-combined on the ground for error detection and correction. The MOC will receive one data stream at the original rate. SSR and wideband playbacks are not possible using TDRSS as the omni antenna does not provide sufficient link margin.

The S-Band receiver receives 2106.40625 MHz (nominal) signals passed from the omni antenna through the diplexer and hybrid. Because of the hybrid, both receivers will see the signals from both antennas. The receivers are automatically set to either TDRS or STDN mode based on the received sign al. Once the mode is selected, it remains until receiver lock is broken. In STDN mode the command rate is 2000 bps. In TDRS mode the command rates are 125 bps and 1000 bps. TDRS command rates are commandable. For normal operations one receiver will be set to 125 bps and the other to 1000bps. This will allow either command rate to be used during TDRS passes. The receivers are powered from the essential bus and cannot be turned off.

Omni Antennas - Description

The omni antennas are mounted on the Nadir (+X) and Zenith (-X) sides of the spacecraft. Although either antenna is available to either SBT based on the RF baseball switch settings, one transponder is set to transmit on the zenith antenna (for TDRS operations), while the other transponder transmits to the nadir antenna (for ground station operations).

Using omni antennas for TDRS support imposes limitations on the orientation allowed between the two spacecraft for a successful RF contact. “Constrained Geometry” refers to the relationship between TDRS and a 45° or 70° cone projected from the Landsat zenith antenna. When a TDRS is located within the boundaries of this cone it is said to be “within the constrained geometry." Any visibility outside of the cone is "outside of the constrained geometry." Normally, only TDRS contact time within the constrained geometry will be scheduled, lowering the useful length of contacts to 15 minutes, but guaranteeing proper gains for solid RF lock. Figure 6-17 illustrates constrained geometry.

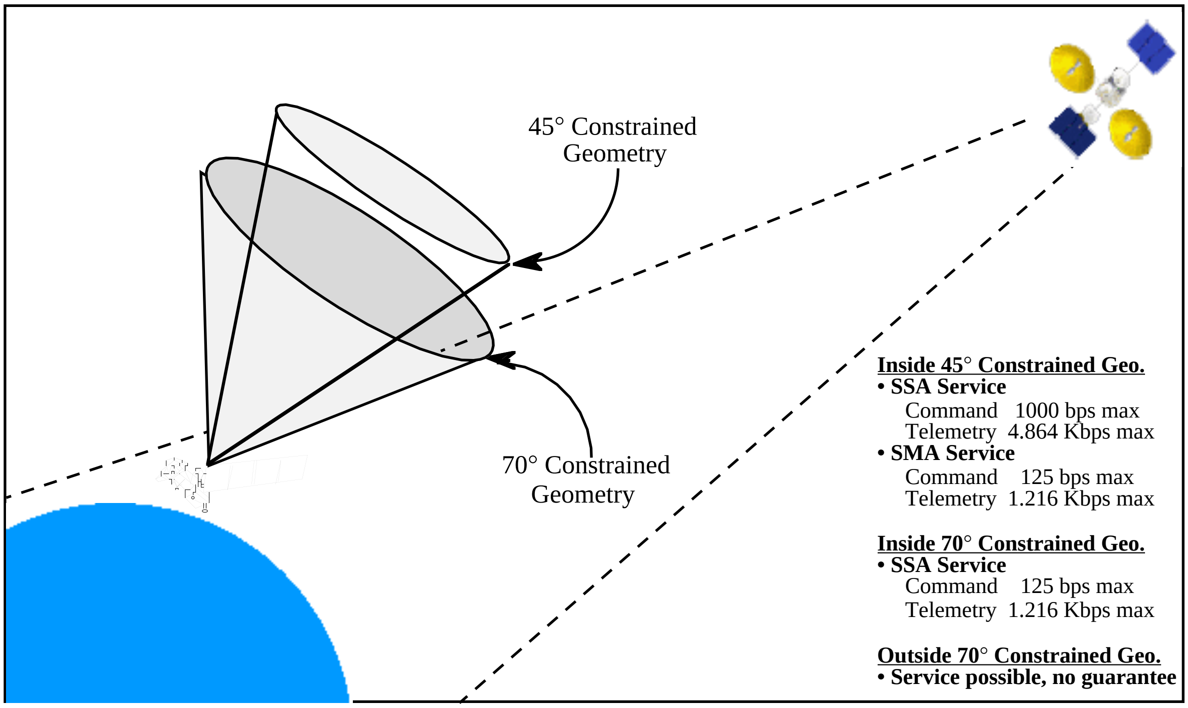


Figure 6-17 Constrained Geometry

S-Band System - On-Orbit Operations

Almost all of the commanding associated with the S-Band system will be conducted via stored commands. For each pass, RTCSs will be used to turn on the transmitter in TDRS or STDN mode and in either coherent or non-coherent mode. RTCSs are also used to turn the transmitter off at LOS.

The SBTs have a capability called "AUTO-ON" which allows the transmitter to come on automatically whenever the receiver detects an uplink signal. This is a commandable feature that will DISABLED during normal on-orbit. Auto-On is enabled during a phase 1 loadshed or when the end of a stored command load has been reached.

If the spacecraft is in safemode with the transponder in auto-on and the FOT contacts the spacecraft via TDRSS, the transmitter will automatically turn on in TDRS mode. The transmitter will remain in TDRS mode until commanded otherwise by the ground. Given this situation, three different scenarios are laid out below.

Scenario 1: If the TDRS contact ends and the FOT has not been able to reconfigure the transponder, the transponder will remain in auto-on mode with the transmitter in TDRS mode. If the next contact with the spacecraft is through LGS, the FOT will have to blindly command the transponder off (during the LGS contact) and back on in STDN mode before receiving valid telemetry.

Scenario 2: If the FOT is able to turn off the transmitters prior to the end of the TDRS contact, they will revert back to the auto-on mode. When the spacecraft is radiated with a STDN signal from a ground station, the transmitters will turn on in the STDN mode.

Scenario 3: If the FOT switches the transponder to TDRSS mode (auto-on disabled) during the TDRS contact, the transponder operations are then conducted as they are during normal operations

- **X-band System**

The X-band system conditions and downlinks high-rate payload data to US and international ground stations.

<u>XTX</u> - Description

Four X-Band Transmitters (XTX) provide QPSK modulated data at 150 MBps. Data is received from the BSU in two 75 MBps streams and formatted onto the I and Q channels at a 1:1 ratio. Transmit power is 3.5 Watts. Three frequencies are used: High (8342.5 MHz), Low (8082.5 MHz), and Mid (8212.5 MHz). Two of the transmitters use the same mid frequency, the others are fixed at either high or low. Due to the RF “baseball” switch layout and triplexer capabilities, it is possible that all four XTX can be operating simultaneously through three or fewer antennas (see Figure 6-16.)

<u>GXA</u> - Description

Three Gimbaled X-Band Antennas (GXA) radiate narrow beam-width X-Band signals and track ground stations. Each 14.5 inch diameter parabolic dish is steered by across-track and along-track stepper motors with 100:1 harmonic drive gear reduction. The 3-phase drive motors have redundant windings and rotate the dish 0.034° per step. The Gimbal Drive Electronics (GDE) provide control signals to the motors and return status telemetry on the motor status and drive positions. The RF output from the GXA is right-hand circular polarized (RHCP).The GXAs are controlled by FSW.

The GXAs are mounted on the Nadir (+X) side of the spacecraft. GXA2 and GXA3 are attached to the LEM while GXA1 is mounted to a tripod-strut assembly projecting below the ESM. The GXAs have "hard stops" at ±67.6° (along and across) which physically block the antenna travel (the harmonic drive design allows indefinite time driving into the hard stop, but this is not recommended operationally)."Soft stops" at ±66° are controlled by the FSW routine that guides the GXAs. A "home" position at +67° across and along is used by FSW to calibrate the GXA pointing. FSW uses an open-loop control routine to point the GXAs within 0.102 degrees of their intended position. Physical measurement of GXA position is provided by potentiometers in the GDE and is accurate to within 1.2 degrees. The maximum physical slew rate of the GXAs is 2.5 degrees/second. This rate is limited by FSW to avoid unwanted affect on the ACS (maximum station tracking rate is 0.55 degrees/second). Accuracy of the GXAs RF boresight referenced to its mechanical interface with the spacecraft is less than 0.55°.

The GXAFSW routine has four modes of operation: tracking, position, calibration and stop mode. In tracking mode, a ground station is tracked by commanding the GDE to step the gimbal motors at a fixed rate. This mode is used to track all ground sites. In calibration mode, the GDE is commanded to slew the gimbals to the home position. This is done periodically to zero out any accumulated position errors in the GXA position. In stopmode, the GXAs are commanded to stop slewing. In position mode, the GXAs are given an along track and across track position. The GXAs move to that position and stay there.

<u>Triplexers</u> <u>and</u> <u>RF</u> <u>Switches</u> - Description

Three triplexers allow multiple RF signals to reach a single GXA. By the layout of the system, GXA1 can receive one RF signal (from either mid XTX), GXA2 can connect to the high and/or low XTX, and GXA3 can receive high and/or mid and/or low (see Figure 6-16.) A triplexer is necessary at each antenna to handle all the combinations of incoming RF signals. In addition, the triplexers filter and perform pulse shaping on the RF signals to avoid spectral overlapping.

The RF Switches ("BaseBall Switches") direct the flow of RF signals to the triplexers and GXAs. Reconfiguration of the switches is not needed unless there is a failure of some component. Figure 6-16 shows the baseball switches in their nominal positions.

X-Band - Normal Operations

The operation of the X-band system is slightly more involved than the S-Band system due to the GXA pointing requirements. All commands for the X-Band system are built into the stored command load by the MOC scheduling software. These commands go to the FSW, where calculations of GXA pointing angles are done. FSW issues the commands to the GDE, but there are still scheduling considerations that must be taken into account on the ground.

The GXAs will be calibrated every other day. Calibrations are done by a RTCS that is called from the stored command load. Calibrations are done when the GXAs are not being used.

6.5 Thermal Control Subsystem (TCS)

The Thermal Control subsystem (TCS) maintains the spacecraft components and equipment within the thermal requirements of the mission. There are two types of components included in the TCS design: *passive* and *active* components.

Passive Components

- thermal blankets
- louvers
- isolating stand-off struts
- thermal coatings
- radiators

Active Components

- heater elements
- thermostats
- proportional thermal controllers (PTC)

PTC - Description

A PTC is a fully redundant active temperature controller system consisting of heaters, Heater Control Modules (HCM), thermistors, and a Dual Thermal Controller (DTC) board. Each DTC contains either two or four redundant Thermal Control Amplifiers (TCA). PTC operates as a feedback loop, increasing or decreasing the HCM drive current and therefore the heater current when the thermistor-sensed temperature falls to the preset temperature setpoint (Tsp). The PTC provides a potential temperature range of Tsp+1.5°C to Tsp-4.5°C for the component or panel being controlled.

The thermal control subsystem operations are minimal. RCS catalyst bed heaters will be under FOT control - normally the heaters will be off. They will be turned on approximately 60minutes before scheduled use (113°C minimum before firing.)

6.6 Reaction Control Subsystem (RCS)

The Reaction Control Subsystem (RCS) provides the propulsion capability required for orbit maintenance and attitude control during orbit maneuvers. The RCS also provides the capability to perform back-up momentum wheel unloading. Landsat has a Hydrazine Monopropellant blowdown system using Helium as a pressurant. The pressure is unregulated. The RCS consists of

- REA (Rocket Engine Assemblies) or Thrusters- eight for attitude control and four for orbit adjust
- Latch Valves - two parallel latch valves control the propellant flow from the tank to the REA
- Fill and Drain Valves - three valves to allow fuel and unfueling (prior to launch)
- Pressure Transducer - measures system pressure across a 0 - 450 PSI range
- Filters - two 15 micron parallel filters provide filtering of fuel
- Propellant and Propulsion tank - a single bladder-divided tank contains the Hydrazine (N_2H_4) and Helium pressurant.
- Titanium Lines and Manifolds - all titanium plumbing with welded junctions and Ti-CRES transition joints at REAs and pressure transducer.

The entire system (dry) weighs approximately 57 pounds. The system will be loaded with 269 pounds of Hydrazine prior to launch - enough fuel for approximately 10 years of on-orbit operations. Figure 6-18 provides a functional diagram of the RCS.

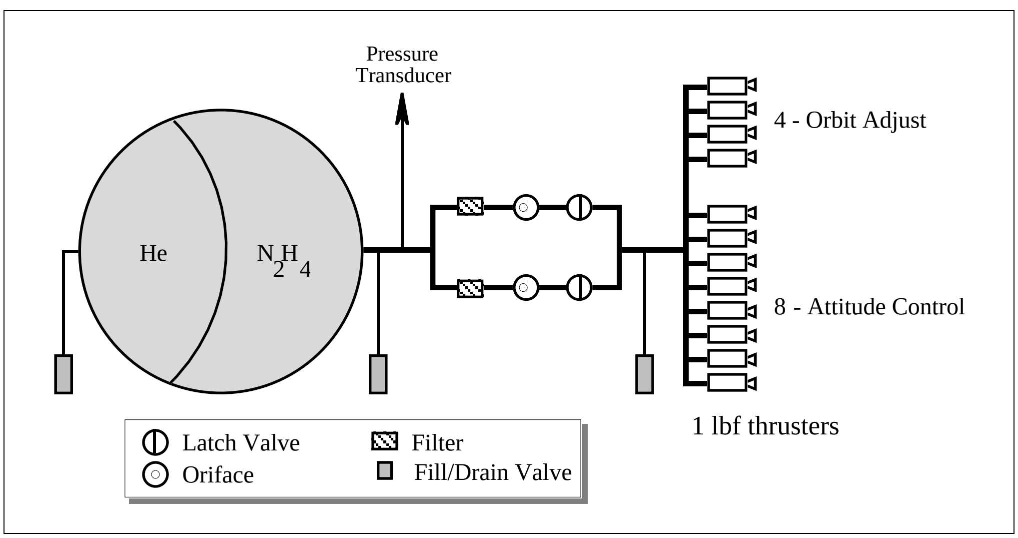


Figure 6-18 Reaction Control Subsystem

REA - Description

Twelve REA provide a nominal 1 pound-force of thrust through the catalytic decomposition of Hydrazine. Maximum inlet pressure is 1500 PSI, and the thruster has a rated lifetime of 420,000 pulses (0.1 second pulses). Each thruster has associated with it two 2-watt catalyst bed heaters. Nominally, both heaters will be used so if one fails while out of ground contact, the thrusters will remain warm. Catbed heaters will be powered on for scheduled thruster usage and turned off for nominal operations. The thruster valve has redundant heaters, operated under thermostatic control. Figure 6-19 shows the locations of the REAs.

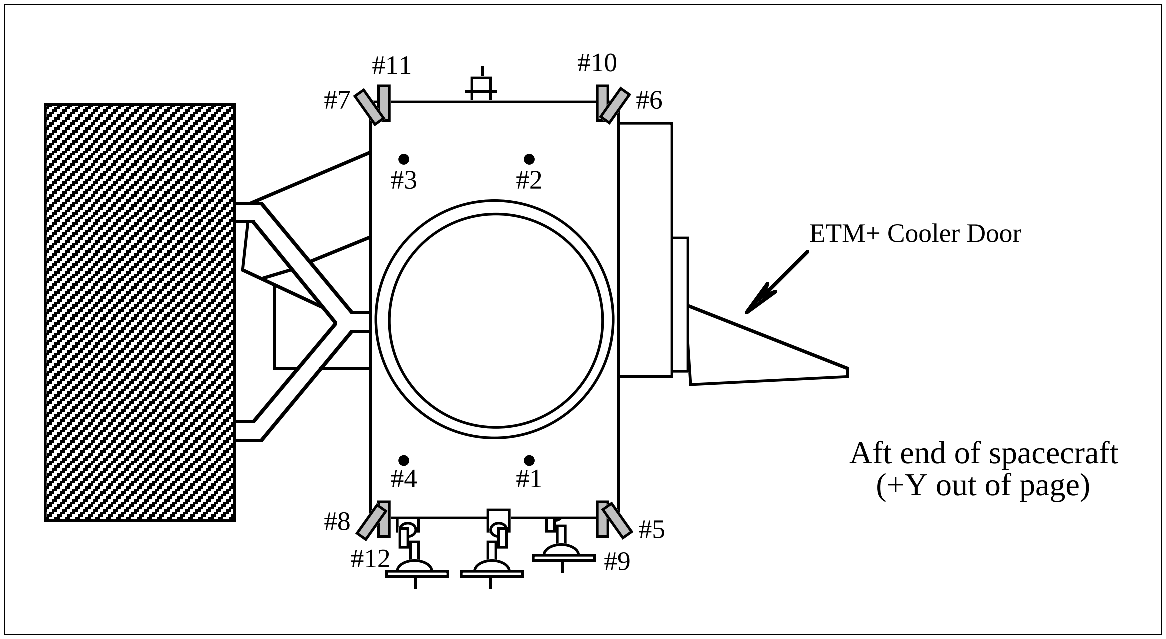


Figure 6-19 Thruster Locations

Latch Valves - Description

Two parallel latch valves provide isolation of the propellant tank from the REA manifold. The parallel design isolates a valve that may fail in the closed position. The torque-motor actuated valves will relieve pressure from the outlet side of the valve if the outlet pressure is 200 PSI greater than the inlet pressure. The latch valves may be closed through ground command, but once on-orbit they will not be cycled during nominal operations.

Fill and Drain Valves - Description

The F&D Valves are manually actuated valves used for fueling and pressurizing the RCS prior to launch. Internal and external caps further seal the valves to ensure no leakage of Hydrazine or Helium.

Propellant Tank - Description

The Propellant Tank is a 28 inch diameter titanium sphere with a rubber diaphragm isolating the Helium pressurant from the Hydrazine fuel. The tank is sized to hold the 270 pounds of fuel, pressurized to 250 PSI @21°C. Absolute tank capacity is 347 pounds of fuel.

RCS - Thermal Control

The issue of freezing Hydrazine is critical. In order to avoid this condition, the RCS is well-equipped with heaters on the tank, supply lines, REA valves, and latch valves. These heaters are all under thermostatic control and require no ground attention other than thermal monitoring.

RCS - Operations

The RCS will be used for orbit adjust maneuvers (Δ-V and Δ-i) and for backup momentum wheel unloading. Prior to thruster usage, the FOT will assure that the catbed heaters are powered on and the beds have reached their minimum operating temperature of 113°C. The commands enable the thrusters and begin firing (for maneuvers) will be issued from a RTCS. FSW maintains attitude control during the burn by firing Roll and Pitch jet pairs and by off-pulsing the Yaw jets.

Momentum wheel unloading will nominally be performed using the magnetic torquer rods, but the RCS is available as backup. Using the RCS significantly impacts operations as the ETM+ cannot be imaging when the thrusters are fired due to the ACS disturbance and settling time.

6.7 Enhanced Thematic Mapper Plus (ETM+)

ETM+ - Description

The ETM+ is a fixed position, nadir viewing, "whisk-broom", multispectral scanning radiometer and is capable of providing high-resolution imaging information of the earth's surface. Radiation in both the visible and infrared regions of the spectrum are detected by the instrument in eight distinct spectral bands. The ETM+ is an updated version of the Landsat 4/5 Thematic Mapper (TM) payloads, but still provides data continuity with all prior Landsat missions. Improvements in the instrument include increased spatial resolution of the thermal IR band (Band 6), improvement of the radiometric calibration equipment, and the addition of a panchromatic band (Band 8). Figure 6-20 shows a simplified diagram of the ETM+.

The ETM+ is designed to collect, filter, and detect radiation from the earth in a 185 km wide swath as it passes overhead. The viewing swath is produced by means of an oscillating mirror system that sweeps across track as the sensor field of view moves forward along track due to spacecraft motion. The data from the ETM+ is output on two channels, each at 75 Mbps. Each of the channels is multiplexed to contain data from several detectors along with Payload Correction Data (PCD), time stamp, and instrument status. The data channels contain:

Format 1 » Band 1-3 (Visible), Band 4 (VNIR), Band 5 (SWIR), Band 6 (LWIR), time, PCD, status data

Format 2 » Band 6 (LWIR), Band 7 (SWIR) and Band 8 (Pan), time, PCD, status data

Data from each band can be selected for output in High or Low gain, a commandable setting to adjust the multiplexer reference voltage. Band six appears in both channels, with the data in format 1 fixed in high gain and the band six data in Format 2 fixed in low gain.

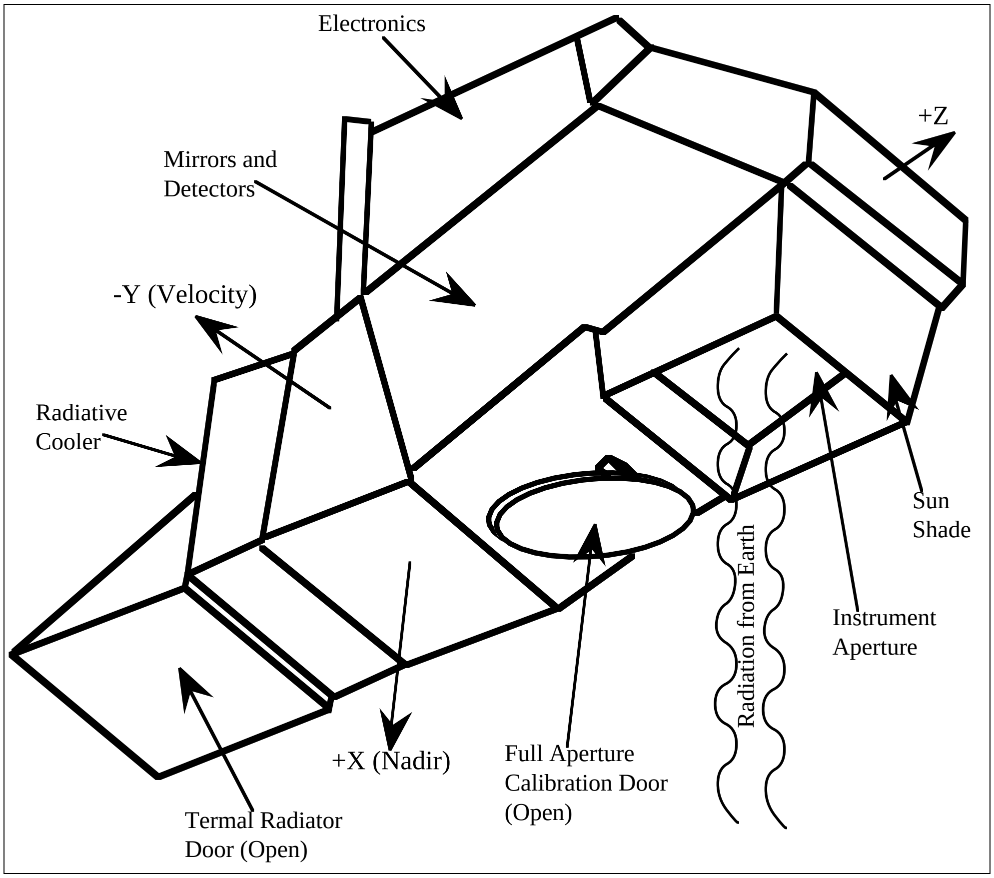


Figure 6-20 Enhanced Thematic Mapper Plus

The ETM+ contains two pieces of external moving hardware: the Full Aperture Calibration Door and the Cold Focal Plane Radiative Cooler Door. Both were restrained during launch and ascent and were freed within the first two days after launch.

The ETM+ optics contain the scan mirror and scan line correction assembly among other components. The Scan mirror, scanning at 7Hz, provides the across track motion for the imaging while the forward velocity of the spacecraft provides the along track motion. The Scan Line Correction (SLC) assembly is used to remove the “zig-zag” motion of the imaging FOV produced by the combination of the along and across track motion. The ETM+ optics are shown in Figure 6-21.

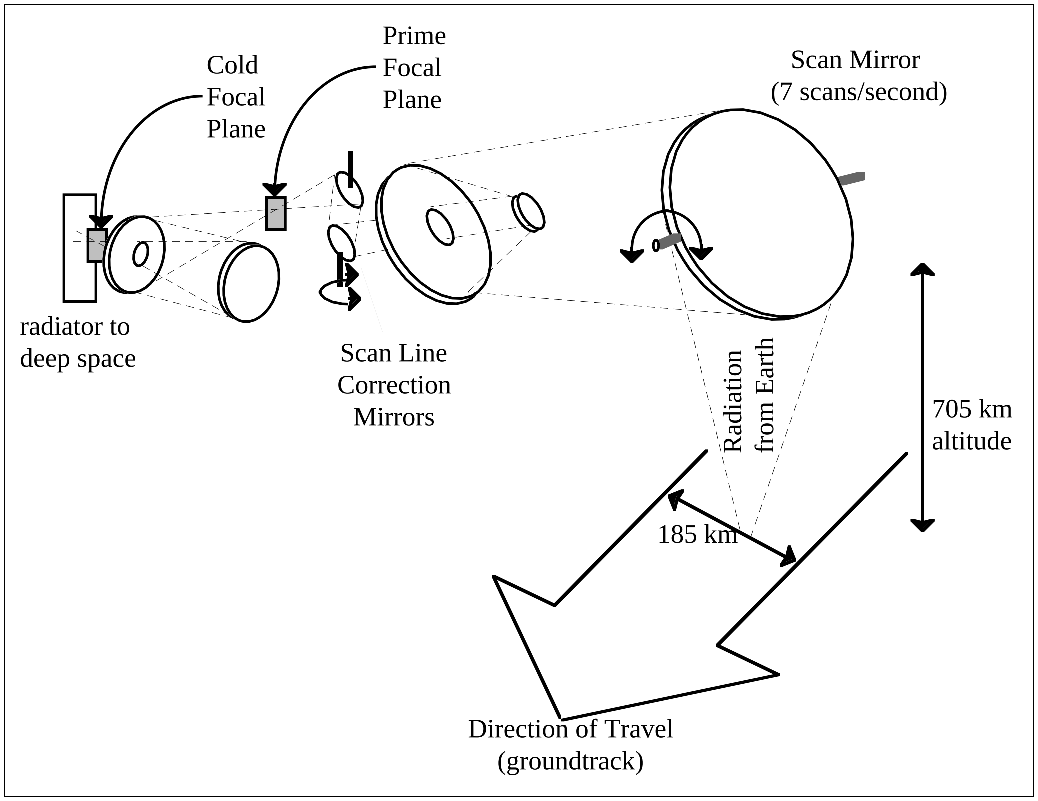


Figure 6-21 ETM+ Optics

There are two focal planes used by the ETM+. The primary focal plane uses silicon photodiode material as a sensor and is arranged into five detector arrays on a monolithic substrate. There is one array each for bands 1-4 and one for the Pan band (band 8). The arrays making up bands 1-4 each consist of 16 detectors. Each detector is 0.00408 in x 0.00408 in. The Pan band consists of 32 detectors, each 0.00204 in x 0.00177 in. The cold focal plane assembly (CFPA) uses detectors of indium antimonide (InSb) for bands 5 and 7, and mercury cadmium telluride (HgCdTe) for band 6. Bands 5 and 7 each have 16 detectors and each detector is 0.00190 in x 0.00204 in. Band 6 contains 8 detectors, each 0.00408 in x 0.00408 in. The photovoltaic InSb material works best at temperatures in the 90K to 105K range and shows very little degradation in response over this range. The photoconductive HgCdTe material works best at 90K to 91K and shows much greater degradation in response when operating in temperatures rising to 105K. Because of this, band 6 (the thermal band) output is very sensitive to the operating temperature of the CFPA. The CFPA must be radiated into space to maintain proper thermal balance for routine operations. The CFPA is kept at a nominal temperature of 91K using a balance of radiators and heaters. Exposure of the CFPA radiative cooler to direct sunlight will cause permanent damage to the ETM+.

The ETM+ contains several survival heaters that are necessary during backup attitude control modes to keep it thermally stable. These heaters will not be disabled during normal operations.

Calibration of ETM+ data is accomplished using several types of calibration schemes. The ETM+ is equipped with an internal calibration paddle that moves into the path of the incoming radiation once each scan line. This paddle has two calibration lamps with known energy signatures that, when turned on, will be sensed by the detectors and supply calibration data at the end of every scan line. In addition, the ETM+ is built to perform two types of calibration that use the Sun as a radiation source. Full Aperture Solar Calibration (FAC) and Partial Aperture Solar Calibration (PAC) will be performed periodically (at IAS request). See ETM+ -*Calibration* for a more detailed description of how these calibrations will be performed. Ground Look Calibration (GLC) will also be performed on scenes identified and requested by the IAS.

ETM+ - General Operations

There will be no realtime operations of the ETM+, everything done with the instrument during normal operations will be accomplished via stored commands (ATCS and RTCS).

The ETM+ has these defined modes (see Figure 6-22):

1) Initialization Mode - ETM+ is not imaging in this mode. All relays are set to default or Off positions and Power Supplies 1 and 2 are off. It is a starting state from which other modes are commanded.

2) Standby Mode - ETM+ is not imaging in this mode, but is ready to begin imaging when the power supplies are turned on. The relays required for imaging are set in the proper configuration and heater controllers are enabled, and Power Supplies 1 and 2 are off.

3) Imaging Mode - ETM+ is powered and scanning. Imaging almost always will be done during the day, but may be done at night. All eight bands will be enabled when imaging. Individual band gains may be altered as needed.

4) FAC Imaging Mode – Imaging Mode with the FAC panel deployed. FAC calibration operations are described below in *ETM+ - Calibration.*

5) Outgas Mode – Outgas heaters are powered to drive contaminates from the cooler area. Cooler door is moved to outgas position (5° from closed). Scanner and bands are powered off.

6) Sun Pointing Safestate - When the spacecraft enters SPAM, the ETM+ cooler door is placed into the outgas position and the ETM+ is powered down in an orderly fashion. Closing the cooler door prevents Sun impingement on the cold focal plane and radiator. It is imperative that the door is moved properly to this position. The restrictions on solar intrusion within 15° of the ETM+ boresight are: 40 seconds if the calibration shutter is operational or 0.4 seconds if the shutter is disabled.

7) Earth Pointing Safestate - Entry into this mode sets the standby and baffle heaters on to maintain thermal stability and powers down the ETM+ in an orderly fashion.

The gains for each band are ground selectable (high and low) and default values will be specified on a scene by scene basis in the long term plan. Gains will be set on a scene-by-scene basis depending on season, Sun angle, and ground cover conditions. The Long Term Plan determines the gain settings for individual scenes, and the MOC scheduling software and onboard RTCSs provides the commands necessary to reconfigure gain settings during imaging.

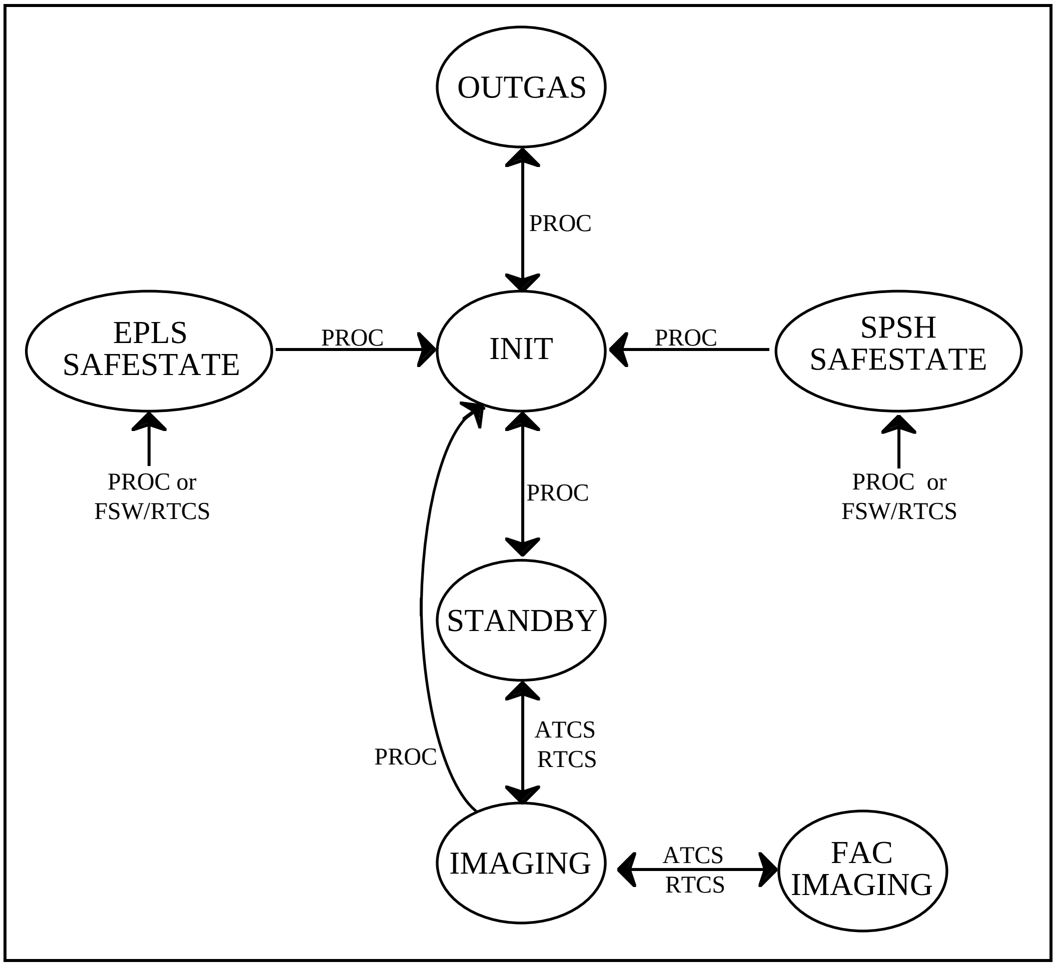


Figure 6-22 ETM+ Modes

The currently enforced duty cycles on the ETM+ are as follows:

a) Long term duty cycle = 230 min of operation during any 23 hr timespan

b) Mid/Long term duty cycle = 131 min of operation during any 10 hr timespan

c) Mid term duty cycle = 52 min of operation during any 200 min timespan

d) Short term duty cycle = 34 min of operation during any 100 min timespan

e) Shadow duty cycle = 15 min of operation during any 100 min timespan

<u>ETM+</u> - Normal Imaging

Normal imaging operations will be conducted via stored command loads produced by the MOC scheduling software. The scheduling software works in concert with the Long Term Plan to determine which scenes will be imaged and at which gain settings. The scheduling software also manages the amount and locations of payload data stored on the SSR. ETM+ data is routed to the SSR for capture and future playback or directly to the X-band system for realtime downlink.

Certain rules govern the operations of the ETM+:

- Duty cycle limitations - see previous section
- "Flywheeling" - desired scenes may not be contiguous along the orbital path. In order to limit power cycling of the ETM+, scenes that are interspersed between desired scenes will also be imaged, but not recorded. Up to 7 filler scenes will be scheduled between desired scenes. If there are more scenes than that between the two desired scenes, the ETM+ will be power cycled.
- Payload data can be sent to the ground in realtime or recorded on the SSR for later playback. International Ground Stations will receive realtime data only.
- Before each scene, a minimum of 5.21 seconds of PCD must be included for image processing.
- After each scene, a minimum of 17.36 seconds of PCD must be included for image processing.
- In order to geographically align a scene properly during image processing, the last half of the previous scene and the first half of the next scene must be available. For the first and last scene in an interval, extra data must be collected. For scenes inside an interval there is no impact as the pre- and post-scene data is already available.
- To ensure the image data is downlinked and/or recorded properly, the configurations of the SSR, BSU, XTXs, and baseball switches must all be correct.

Below is a typical command series for a realtime ETM+ imaging session:

- (Start of 1st scene – 126 seconds)
  GXA is commanded to track the supporting ground station(s) if realtime imaging
- (S-69) BSU powered on if previously off
- (S-66) ETM+ imaging RTCS begins - power supplies on, warmup begins
- (S-8) BSU configured to route ETM+ data to proper XTX
- (S-6) XTX on - pre-scene PCD flow begins
- (S-0) Valid scene data flow
- (During imaging) Band Gains may be reconfigured for individual scenes
- (End of session) End of data for final scene
- (E+18) XTX powered off - End of post-image trailer (17.36 seconds)
- (E+19) ETM+ standby RTCS begins - power supplies turned off

<u>ETM+</u> - Outgassing

For peak performance of the thermal bands (especially Band 6), the CFPA must be kept at a very specific, tightly controlled temperature. Because energy from the CFPA is radiated to deep space, left unheated, it would cool to a temperature below its optimum operating temperature.

The current needed by the CFPA heater is proportional to the amount of energy needed to raise the CFPA temp to the desired set point (91°K). As the radiator becomes dirty, it will dissipate heat less efficiently, thereby less energy is required to warm the CFPA. This will be reflected by a steadily dropping CFPA heater current. Over the course of days or weeks, the current will slowly drop until it reaches 0 amps. At this point, the CFPA temperature will begin to rise. Sometime before this occurs, outgassing operations must occur. This constitutes placing the ETM+ into its Initialized state, moving the Cooler door to its outgas position, and turning on the outgas heaters. Outgassing must take place for six days. If, 36 hours after turning off the outgas heaters, the CFPA reaches set point, and the heater is needed to maintain that temperature, outgassing has been successful.

ETM+ - Calibration

There are two special types of operations associated with the calibration of the ETM+. They are Full Aperture Calibration (FAC) and Partial Aperture Calibration (PAC). Both of these operations must take place in specific orbital positions and involve special calibration equipment on-board the spacecraft.

PAC will be scheduled once every day during normal operations and is used for radiance calibration of Bands 1-5, 7, and 8. Approximately one minute after the spacecraft passes into sunlight and while its subsatellite point is still in darkness (see Figure 6-23), the ETM+ is commanded to image. The PAC calibrator consists of four small prisms housed in the ETM+ sunshade. This device reflects sunlight off of two of its surfaces through a small aperture when the spacecraft is in the orbital position described above and shown in Figure 6-23 (upper). Sunlight is used because the Sun is a well known, well characterized source of radiation. The ETM+ is then commanded to image just as it would be during normal operations and effectively creates an image of the Sun. The IAS will be notified of the operation so that they may obtain the image data from EDC-DAAC for processing. Additional operations will be done at the request of the IAS.

FAC will be scheduled at IAS request (approximately once every four to six weeks). FAC performs the full aperture radiance calibration for Bands 1-5, 7, and 8. FAC operations involves positioning the FAC paddle in front of the ETM+ aperture to reflect sunlight into the field of view. The ETM+ will then image with the band gain settings configured per the IAS request. This operation will take place over the North Pole terminator (see Figure 6-23 lower). The IAS will be notified of the operation so that they may obtain the image data from EDC-DAAC for processing. Additional operations will be done at the request of the IAS.

In addition to PAC and FAC operations, calibration data will be extracted from normal ETM+ images taken over specified calibration targets. These targets consist of landmass scenes with well known, well characterized features and/or properties and will be supplied to the FOT by the IAS. Ground Look Calibration (GLC) will be done using ground truth images to help characterize the effective radiance seen by the ETM+. GLC will occur at IAS request. Geometric calibration will also be done using normal ETM+ images of specified scenes. Calibration data is also injected into the normal data stream during all imaging operations. This data includes internal shutter, lamp, blackbody, and cold focal plane array temperatures.

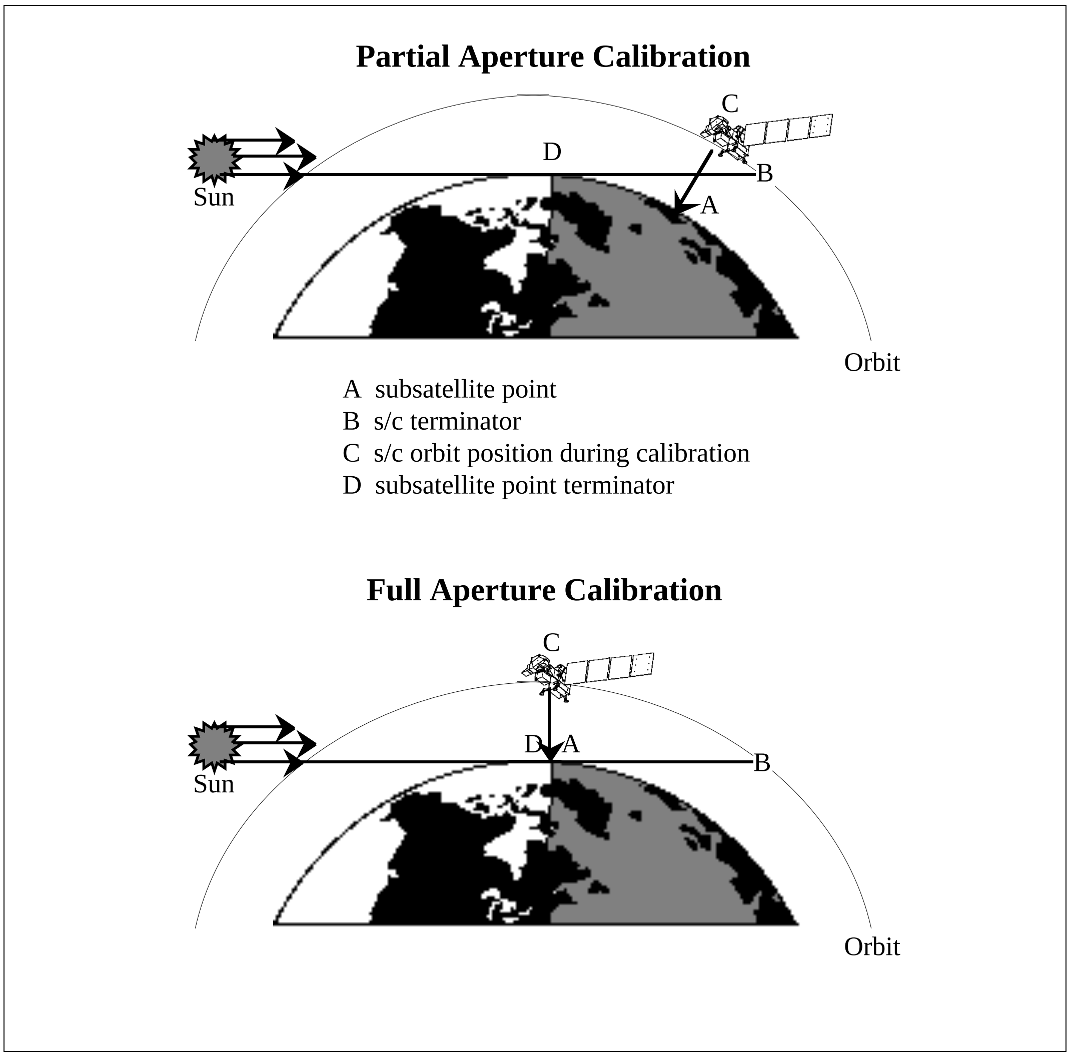


Figure 6-23 ETM+ Calibration Orbital Geometry

Section 7 REALTIME and SUPPORT OPERATIONS

Table of Contents

7.1 Introduction

This section provides a brief overview of realtime and support activities. The Landsat FOT will conduct all operations from the Mission Operations Room (MOR) located within the Mission Operations Center (MOC) at GSFC.

Realtime operations consist of those activities that are necessary to support direct communication with the spacecraft and include system configuration, housekeeping telemetry processing, command uplink and verification, and table and memory load/dump operations. Support operations are those offline activities that are necessary to support the safe and nominal operation of the spacecraft and include planning and scheduling, orbit determination, stored command load generation, ephemeris generation and spacecraft clock maintenance.

During realtime operations the FOT may or may not be in voice contact with a station operator. AGS, SGS and WPS will send station status information to the MOC in realtime so the FOT will have an indication of any station trouble during the contact. This status information will be displayed in the MOC on a PC. SN contacts require the FOT to configure the LIPPS (Landsat IP Processing System) at WSC via a Telnet session.

Realtime operations may be broken up into three main phases: pre-pass, pass, and post-pass operations. These phases are described below.

- **Pre-Pass Operations**

The first step in getting ready for a spacecraft pass is to make sure all necessary equipment in the MOC is functioning properly and will be able to support a spacecraft contact. After the appropriate MOC hardware and software are initialized, a startup TSTOL procedure is executed on the workstation that will be supporting the contact. This procedure will initialize the pass, open all history files, provide operator privileges, establish forward and return ENIF connections, and set the opmode, command and telemetry site, and orbit. If a command load is to be sent during the contact, the FOT will verify that the proper load is residing on the system and has been approved. Once the MOC system is configured properly, the station may request the MOC to send a No-op command to the site and verify receipt to check the command line. Pre-pass operations at WPS, AGS, and SGS will be performed automatically by equipment and scheduling software at each site.

The entire set-up and configuration process should not take more than 10 - 15 minutes, and is completed approximately 15-20 minutes prior to the scheduled pass. This allows a block of time for the FOT to troubleshoot any problems with the ground system or its configuration before AOS.

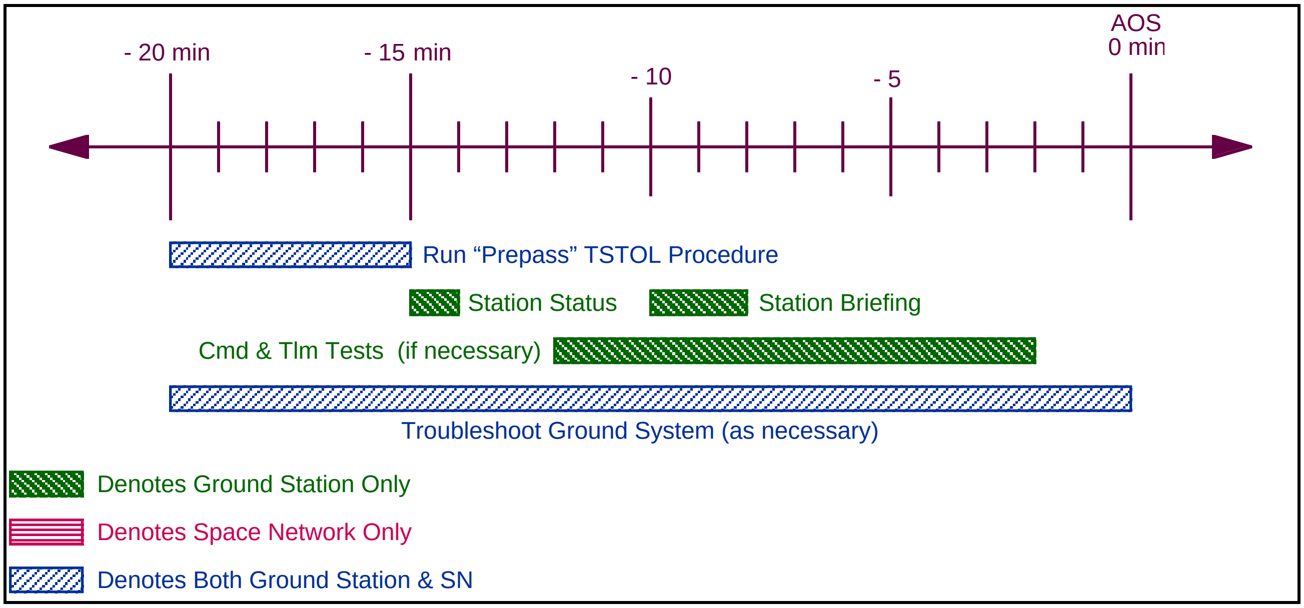


Figure 7-1 Pre-Pass Activities

- **Pass Operations**

Between AOS and LOS, the FOT performs all scheduled commanding and telemetry operations planned for that contact, in addition to confirming the spacecraft state of health. Scheduled operations for a support could include, but are not limited to, the following: command loads (ATCS, RTCS, ephemeris), SSR housekeeping dumps, clock adjusts or weekly spacecraft software dumps. Unscheduled operations in response to anomalous conditions will also take place during realtime passes as necessary.

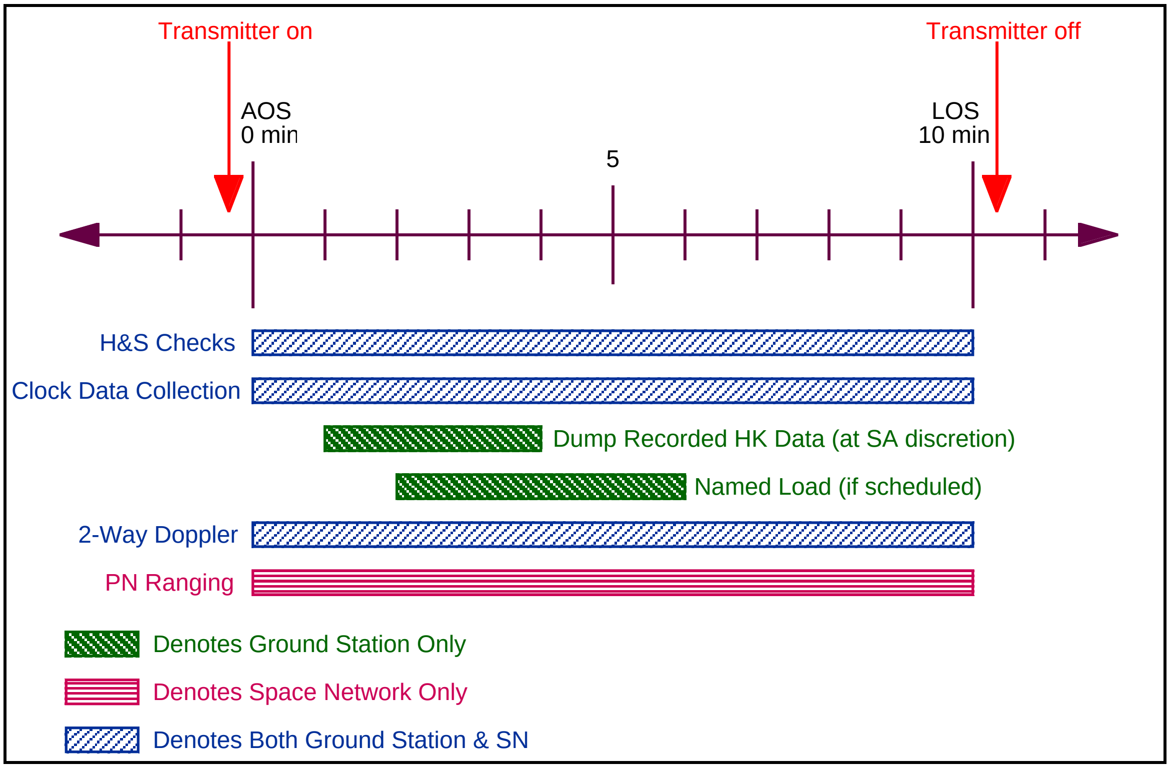


Figure 7-2 Pass Activities

- **Post-Pass Operations**

After the pass has finished the FOT will perform any "clean up" operations needed on the MOC system. This may include terminating IP connections, closing out files, archiving data, etc. If the pass included the capture of recorded housekeeping data, it is processed during this post-pass time. The data is run through the system just as the realtime data is, although at a higher rate (up to 32 Kbps), with the identical checks and processes being run. This process is monitored by the FOT so that they may flag any anomalous conditions that may have occurred while the spacecraft was out of view. Data subsetting is enabled during the playback to create input files for offline trending. All housekeeping data received from the spacecraft will be archived for the life of the mission.

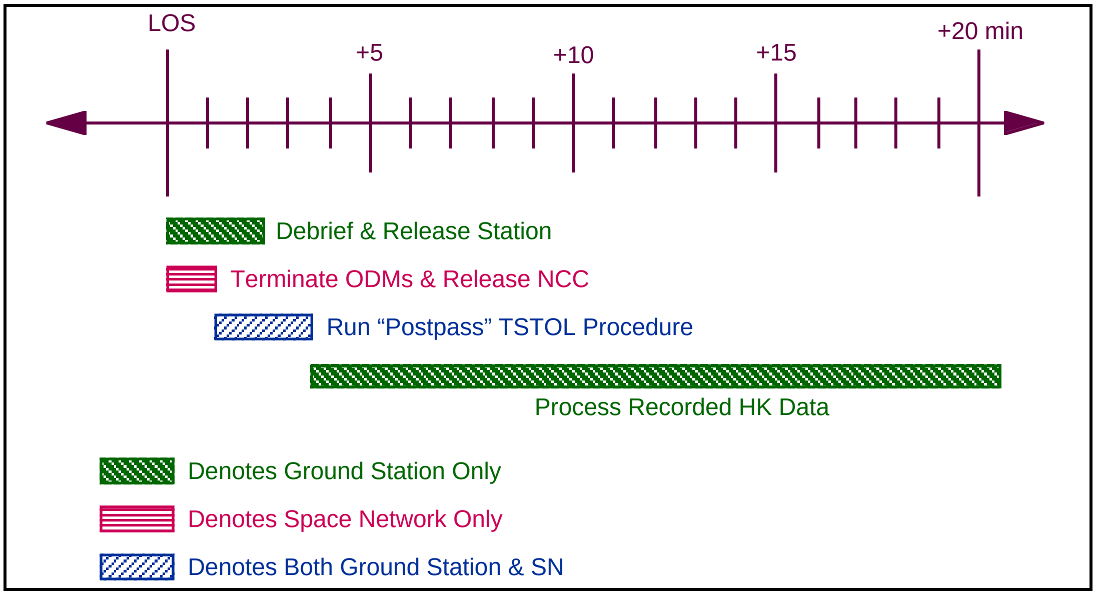


Figure 7-3 Post-Pass Activities

7.2 Telemetry Operations

Both realtime and SSR recorded housekeeping telemetry is ingested by the MOC. Realtime telemetry is downlinked during all contact periods and used to ensure the health and safety of the spacecraft and payload. SSR recorded data is downlinked only during ground station passes and is used for trending and subsystem performance analysis as well as anomaly recognition.

Housekeeping playback data is downlinked at 256 Kbps, passed to the MOC in bent-pipe fashion and processed in the MOC post-pass. Processing rates for the playback data can be maximum 32 Kbps. When filled to capacity, it takes approximately 28 minutes to dump the housekeeping portion of the SSR. Several housekeeping dumps are scheduled daily in order to minimize the latency of the stored data. The goal in scheduling these dumps is to have data stored on the SSR for no longer than six hours (nominally, the amount of stored data will be three hours or less). Housekeeping playback data is processed as soon as it is fully captured in the MOC (post-pass) and is checked for out-of-limit violations, and used for anomaly investigation, subsetting and trending, etc. Downlinked data (both playback and realtime) is captured at the ground site on tape and stored for 72 hours. The FOT will contact the station to arrange for a playback of the data tape if necessary. Operations dealing with the dumping of housekeeping data from the SSR are discussed further on in this section.

Realtime telemetry is downlinked at a rate of 1.216 Kbps or 4.864 Kbps, passed to the MOC, and processed in realtime. The data is displayed for the FOT by the TPOCC ground system. This telemetry will also be captured digitally at LGS by the PTP, and on tapes at AGS, SGS, and WPS.

Realtime housekeeping telemetry enters the MOC via two NISN routers and is sent to two Ethernet switches. From here, the data may be routed to any of the equipment on the closed side of MODNET. Data may be sent to a single workstation for processing or to a “fanout” device, which in turn allows multiple workstations to receive the data. Once a workstation is receiving data, it is capable of performing decommutation. A Current Value Table (CVT) resides on each workstation and is updated synchronously with the incoming telemetry. X-terminals can then tie into the workstation and access the CVT. The MOC system provides a number of realtime functions including:

- Telemetry decommutation
- Telemetry displays (mnemonic and graphical)
- Telemetry limit checking
- Configuration monitors
- State recognition
- Subset generation
- Hardcopy reports
- Memory/table dump collection
- Data accounting/archival

• Telemetry Decommutation

Telemetry decommutation will be provided by an active realtime workstation. Based on telemetry format definitions in the operational database, the workstation will decommutate the incoming realtime telemetry stream and update its current values table. Housekeeping playback data will be written to a history file in raw form, and replayed post-pass. All telemetry is converted using definitions in the operational database.

• Page Displays

The visual display terminals on both the workstations and X-terminals provide the means to display decommutated data. These may be generic pages provided by MOC software or unique pages developed by the FOT using page building software. TPOCC allows the FOT to create and maintain unique page displays. Telemetry values will be displayed using information provided in the operational database (ODB). All display pages can be displayed on any workstation or X-terminal.

- **Telemetry Limit Checking**

TPOCC will compare current values of telemetry to the limits defined in the operations database. The TPOCC displayed values will be color -coded depending on their value. The telemetry will be shown in green (limits are not being exceeded), yellow (low limit being exceeded) or red (high limit being exceeded). In addition, the limit being exceeded (yellow low, yellow high, red low, red high) will be displayed. Limits may be adjusted, and limit checking may be turned off by the FOT.

- **Configuration Monitors**

Configuration monitors are procedures built and maintained by the FOT and used to check specific, expected configurations on the spacecraft or ground. The configuration monitors are run by the FOT (usually at the beginning of a realtime contact) to aid in verification of the state of the spacecraft. Configuration monitors may be run at any time during the contact.

- **Special Processing**

Special processors are provided which perform calculations that are beyond the capabilities of nominal telemetry decommutation. These can be enabled or disabled via TSTOL directives. Results are available to the FOT. Examples of special processing for Landsat include clock correlation, CV display, and super-commutated data processing.

- **Subset Generation**

The MOC system has the capability to create a subset file (in realtime) containing specific telemetry mnemonics, their values and a time stamp. These subset files will be used for trending purposes, ETM+ housekeeping data capture for image processing, spacecraft performance assessment, and anomaly investigation. The telemetry mnemonics included in the file are specified by the FOT. The MOC will allow for several subset definition files.

- **Hardcopy Reports**

The capability exists to generate a variety of hardcopy reports including display snapshots, sequential prints, and various other MOC reports. The hardcopy report function can be performed in realtime or during off-line activities.

- **Memory/Table Dump Collection**

The MOC provides the capability to collect dump data from onboard images, process the memory images and generate reports. The MOC will maintain a Ground Reference Image (GRI) and make it available to the FSW maintenance group. This MOC function may also compare the most recently uplinked stored command load with the GRI for mis-compares.

- **Data Accounting and Archival**

Several different files may be generated during a realtime contact. These include history event logs, frame and block files, NCC files, command and command echo history logs. Nominally, all logs will be open and collecting data during a realtime contact. All history data will be retained on the RAID for approximately 7 days before it is removed to permanent storage on 4mm tape. A file maintenance utility provided by the MOC will be available to the FOT to aid in system file archiving and deletion.

- **SSR Housekeeping Data Management**

Management of the SSR housekeeping memory will be done in realtime by the FOT. A combination of operational and command procedures will be used to manage and playback housekeeping data stored on the SSR.

The SSR has approximately 520 Mbits allocated for the storage of housekeeping data. Since the housekeeping dump rate will be 64 times the nominal record rate (256 Kbps vs 4 Kbps), for every 1 minute of playback, approximately 1 hour of recorded data may be downlinked. Housekeeping data comes down in S-Band and is only dumped to ground sites. The FOT does not dump housekeeping telemetry on TDRS supports.

There are several relevant parameters available in the normal telemetry format that will be used for the management of the stored data. These parameters are listed below and shown in Figure 7-4.

Record Pointer - current block being written to
Playback Pointer - last block played back by the recorder
Record Counter - number of blocks recorded, but not played back
Playback Counter - number of blocks remaining to be played back in the current dump

The SSR housekeeping partition operates with ‘overwrite’ enabled. This means if the SSR housekeeping partition fills up, it may begin overwriting data that has not yet been played back.

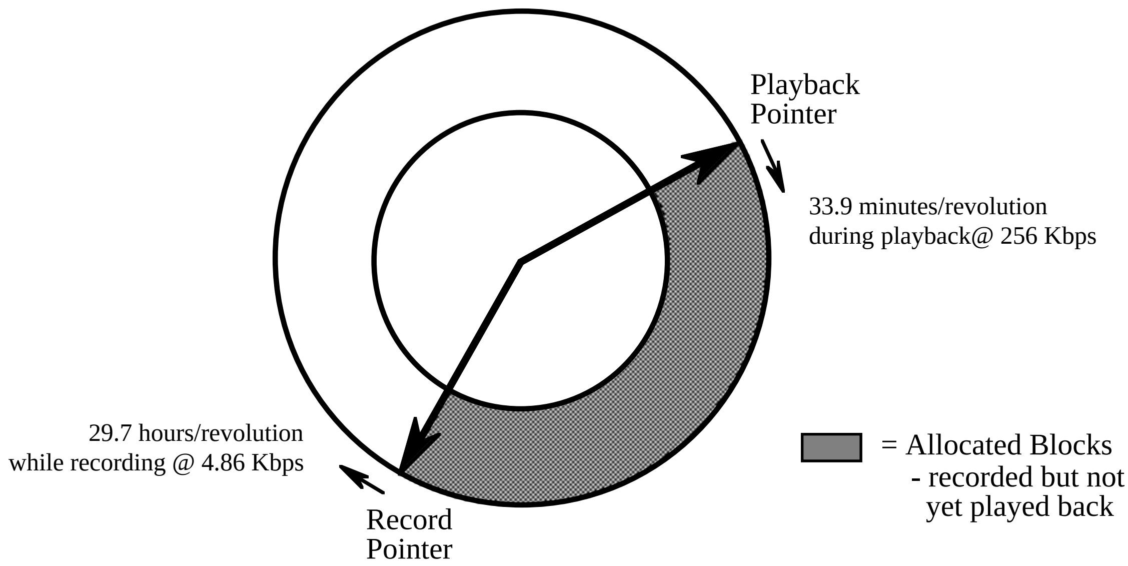


Figure 7-4 SSR Housekeeping Pointers

Unlike dumping wideband data (where a start and end block are specified within the playback command), housekeeping dumps are commanded using the starting block of the playback and the total number of blocks desired in the playback. The housekeeping partition of the recorder deals with physical blocks on the SSR, not logical blocks like the payload side. It is possible to begin a playback and allow the playback pointer to catch up to the record pointer. When this happens, the playback will automatically stop at the next block boundary, however, there is an operational concern with this method that is shown in Figure 7-5.

A playback may be stopped by the FOT at any time using a realtime command. After execution of the command, the playback will discontinue after the SSR has finished playing back that block. For housekeeping data, 1 block ≈ 104.4 seconds of realtime telemetry at the 4K rate, and will take about 1.6 seconds to dump at 256 Kbps.

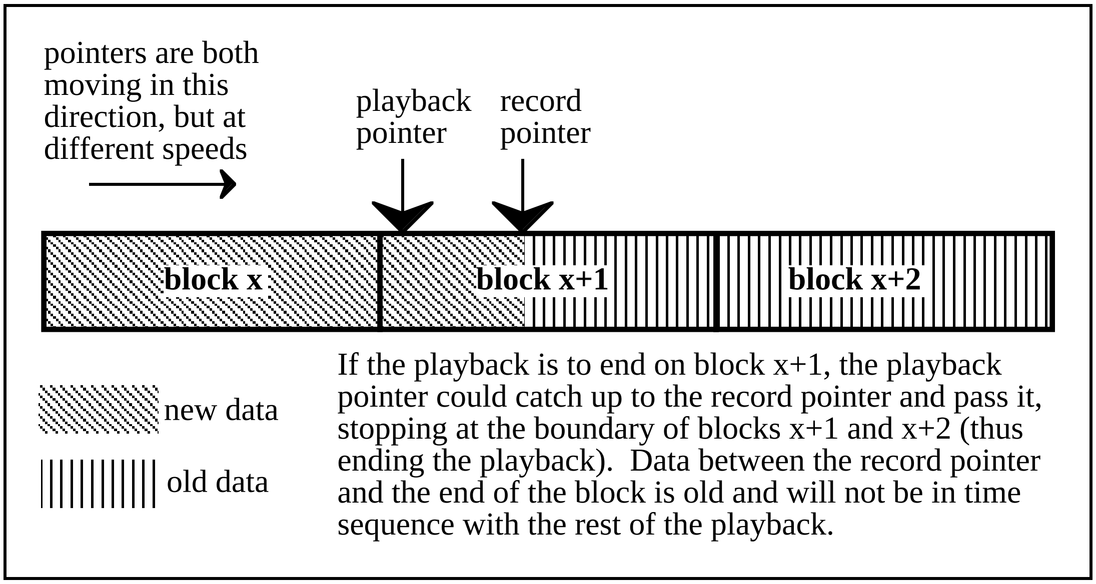


Figure 7-5 SSR Housekeeping Pointers

While the wideband partition of the recorder is to be closely "managed" by the scheduling software, similar plans are not needed for the narrowband partition. During nominal operations, data on the narrowband recorder will be handled in a "first-in-first-out" (FIFO) manner. This minimizes the time that the data spends on the recorder. There will be times however, when this scenario may not be desirable. If the FOT finds the spacecraft in some non-nominal state upon AOS, it may be conceivable that they would want to dump a portion of the recorded data in a non-FIFO manner (for example, dumping the most recent 45 minutes of recorded data). In order to access any of the housekeeping data, there are several options available for a housekeeping dump. These are accessed via the 'hkdump' TSTOL procedure.

a) Dump all blocks between the record and PB pointers (this will not dump the block currently being written to by the record pointer)

b) Dump the maximum number of blocks possible between the current time and the supplied LOS time.

c) Dump the blocks within the given GMT range. This option assumes recording was done at 4K.

d) Dump the given block range.

The playback is automatically terminated when the recorder has dumped the specified number of blocks or when the playback pointer meets the record pointer. While the housekeeping data is being dumped, the FOT may execute any command loads or perform other operations that are planned for that contact. There are however, some very important operational commanding constraints that can be found in section 6 (SSR) of this document.

Along with the record and playback pointers/counters, pseudo-telemetry will be generated that calculates the GMT of the last recorded block and the total duration of telemetry stored on the page. (Ex. Oldest recorded block is 12:34:56 GMT, and there is 5.3 hours of narrowband data on the recorder.)

- **Station Status**

In addition to telemetry coming to the MOC from the spacecraft, WPS, AGS, and SGS will electronically send their equipment status to the MOC in realtime. This status will be viewed, via telnet session, on a PC in the MOC. A list of status parameters follows:

- Antenna azimuth and elevation angles
- Tracking control mode (program track, autotrack)
- Transmitter mode (antenna or dummy load)
- Exciter mode (carrier modulation status)
- . Exciter/receiver coherency
- Receiver automatic gain control level (S- and X-Bands)
- Demodulator lock status (S- and X-Bands)
- Bit synchronization status (S- and X-Bands)
- PTP status

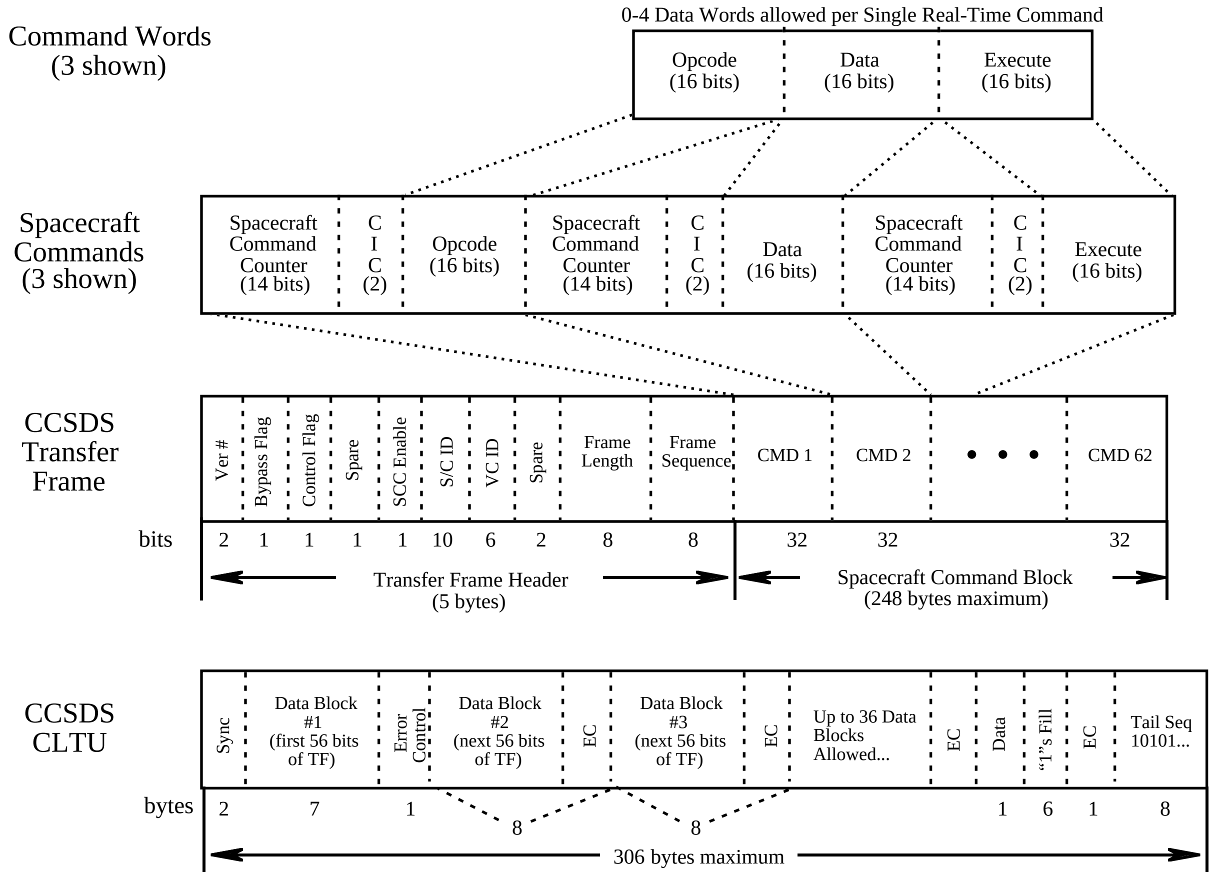
7.3 Command Operations

- **Command Description**

The Landsat 7 command structure follows a multilayered approach. Command Words are mapped into Spacecraft Commands. One Command Word may be mapped into two or more Spacecraft Commands depending on the Command Word length. Spacecraft Commands (collectively known as a Spacecraft Command Block) are then put into a CCSDS Transfer Frame. While a Spacecraft Command Block may be anywhere from 4 to 248 bytes in length, only one Command Block is allocated for each Transfer Frame. The frame(s) are then encoded into CCSDS Telecommand Codeblocks, and placed into a CCSDS Command Link Transmission Unit (CLTU). Figure 7-6 provides an illustration of the Landsat 7 command structure. For transportation between the MOC and the ground sites, the MOC further encodes the CLTUs into Internet Protocol Data Units (IPDU) Packets. All transportation of command and telemetry data is accomplished via the use of IP.

While all commands adhere to a standard CCSDS protocol, no Frame Acceptance and Reporting Mechanism (FARM), Command Link Control Word (CLCW), or CCSDS Control Commands will be used. Landsat 7 will use a custom mechanism in place of the CCSDS Control Command, and utilizes the SCC (Spacecraft Command Counter) to meet the intent of the CLCW.

A forward link or command uplink will normally be scheduled during every realtime support (ground station and SN passes). Commands can be uplinked to the spacecraft in realtime or as part of a memory or table load. The MOC provides the capability to generate, format, and verify syntax of both realtime and stored commands. Command data is transmitted to the scheduled ground station to be uplinked to the spacecraft.



Transfer Frame Header Information:

- Version # set to B'00' to signify version 1 header.
- Bypass Flag set to B'1' to signify Type-B Transfer Frame
- Control Command Flag set to B'0'; Landsat will not use control commands
- Spare set to B'00'
- SCC Enable set to 1 or 0 depending on status of Spacecraft Command Counter function
- S/C ID set to B'0001010101' for Uplink Processor 1, or B'0001010110' for Uplink Procesor 2
- Virtual Channel ID set to B'010000'; Landsat has only 1 VC for commanding
- Frame Length is one less than the total byte count of the Transfer Frame: maximum 253-1 = 252
- Frame Sequence Number set to B'00000000'; Type-B Transfer Frames do not use this

Notes:

- Up to 62 16-bit commands are allowed per Transfer Frame
- 1 Transfer Frame is allowed per CLTU
- Maximum CLTU size is 306 bytes
- Each CLTU is wrapped with 16 bytes of Preamble fill ("1010") and 1 byte Trailer fill, then a 32 byte IPDU header is placed in front of the CLTU and the entire "IP Block" is sent from the MOC

Figure 7-6 Landsat Realtime Telecommand Format

For the Landsat spacecraft there exists two distinctive command types: Software and Special Hardware. Software commands, sometimes called SCP commands, include all but 15 of the defined commands for Landsat 7. Special hardware commands (often called CIU decoded commands) are executed directly by the CIU and do not require a functioning SCP and flight software. The SCP does however generate a CV word for hardware commands.

Every realtime command sent to Landsat 7 must be followed by an “execute” command. For software commands, this “execute” is sent automatically by the MOC system. For Hardware commands, the “execute” will not be sent automatically and the FOT must do this manually. Many of the hardware commands are critical and execution of them could have serious repercussions. The manual execution of these commands is used as an additional safety measure.

All commands are assigned a criticality. Critical commands are those that may cause damage to the spacecraft or payload if sent at an inappropriate time. All critical commands will require additional intervention of an FOT member before transmission (the /ALLOW directive).

Different execution methods for commands are used depending on the operation being performed. Realtime, Stored, and Relative Time commands are all handled differently by the spacecraft. Refer to section 6.1 SCP Command Execution for information on how the spacecraft handles these different types of command execution. Refer to the following section Command Uses for information on which execution method is used for various operations. Despite how they are to be executed, all commands sent to the spacecraft are built by the MOC system.

Realtime commands consist of the command opcode and optional data words, and must be followed by a separate Execute command. Stored commands (ATCS) consist of a leading bit indicating a command word, a time tag (number of seconds past 00:00 GMT, starting the day the load was activated), a late execution indicator, command word, a bit indicating a data word, and optional data words. Figure 7-7 illustrates the command structure of realtime and stored commands. RTCS commands consist of a 16 bit field indicating that commands “wait time”, 16 bits for the command opcode, and optional 16 bit command data word(s).

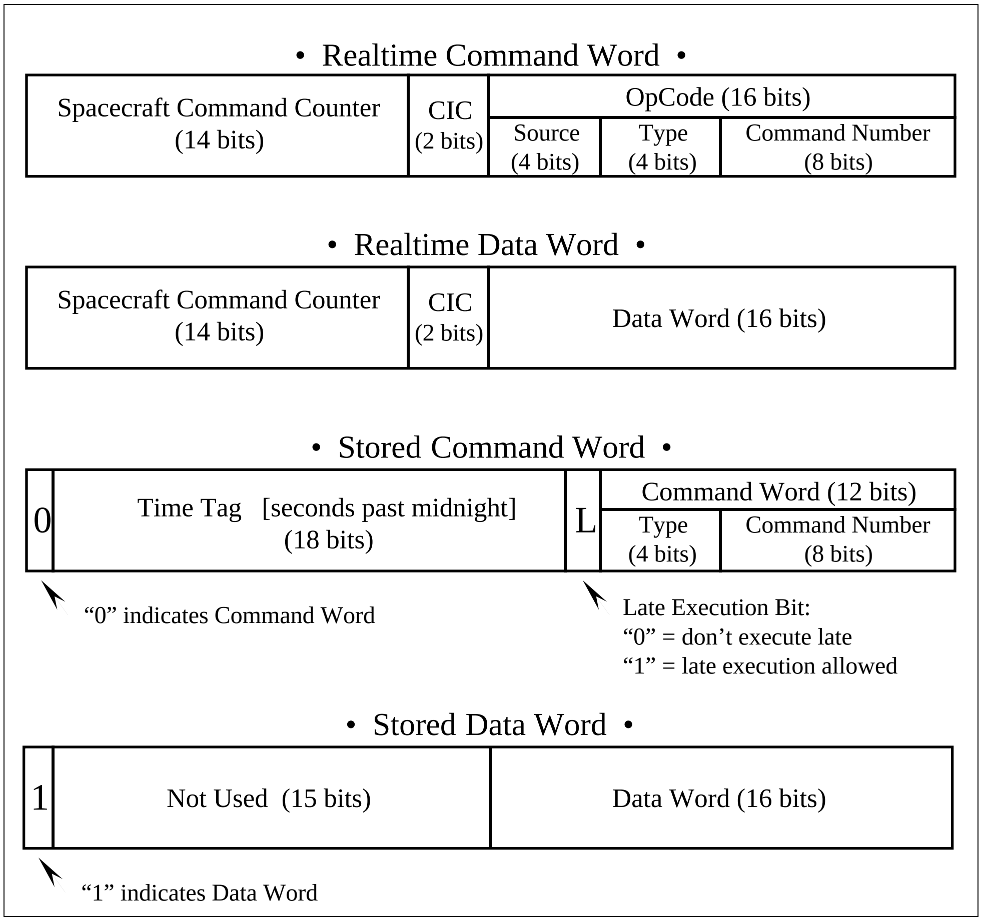


Figure 7-7 Realtime and Stored Command Formats

Detailed descriptions of command structure and command settings (late bit, criticality, opcode, datawords, etc) are contained in the DFCB, volume 3. This information is shared with the MOC via the Operational Database (ODB).

• Command Uses

As described above and in section 6.1, there are three modes of command execution used by the FOT. Each of these methods are used for specific operations and situations. The information below is meant for reference only and differences in the stated approach may occur.

Realtime (includes TSTOL procs)

- SSR housekeeping data dumps
- FSW and SSR RAM dumps
- S/C clock maintenance
- Uplinking command loads
- Activating RTCSs used for FSW RAM dumps, FSW scratch buffer management, FSW counter resets

Maneuver operations
Non-routine operations

ATCS
BSU on/off
SSR wideband playback and record operations
GXA tracking and calibration
Xband transmitter on/off
ETM+ gain changes
RTCS activation

RTCSs
ETM+ imaging <--> standby transition
ETM+ gain changes
BSU/SSR/ETM+ configuration
Sband transmitter configuration
Maneuver operations
FSW maintenance (dumps, counter resets)
FSW scratch buffer management

- **Command Privileges**

Command operations of the Landsat spacecraft is provided through a set of TSTOL privileges. The Command Control (CC) privilege is used by the FOT for full command capability. Only one workstation can be configured for the CC privilege. The CC, and only the CC, is provided with the capability to send realtime Telecommands, Raw Bit commands, and uplink table/memory loads to the spacecraft. For Landsat 7, all spacecraft command transmissions will originate from the MOC.

The CC workstation also possesses the capability to set various command modes, and control command processing within the MOC. The MOC privileges are noted in Table 7-1.

Privilege	Description	Function
MC	Master Control	Overall control of all MOC configuration.
CC	Command Control	Command capability for any type of command activity.
FC	Flight Controller	Restricted from commanding and reconfiguring MOC. Page call & procedure execution capability.
TSTOL	Display	Restricted to displays ONLY.

Table 7-1 Command Privileges

• **Command Modes**

The MOC will provide various command modes required to support the mission. Command modes can be user controlled via TSTOL directives. The TPOCC system is initialized with a default set of command modes however, the Command Controller (CC) has control over selecting command modes. The command modes and default settings are listed in Table 7-2:

Command Mode	Default Setting
Transmission mode	Two Step
SCP	SCP 1
SCC Bypass Commanding	Disabled
End Item Verification	Enabled
Command Receipt Verification	Enabled
Wait for Verification	Disabled
Automatic Restransmission	Enabled
CLTU Verification Messages	Enabled
IPDU Transmission Messages	Enabled
Automatic GRI Updates	Enabled
Verification Delay	30 Seconds
Number of Retransmissons	3
Metering Rate Commanding Uplink Rate	Defaults depends on command site selected

Table 7-2 MOC Command Modes and Defaults

In addition, the Command Controller is able to set the command receipt verification delay, the end–item verification period, and the command IP data unit metering rate.

When commanding in the one-step mode, realtime command blocks are generated and sent to the External Network Interface (ENIF) immediately after a command or load enters the command buffer. Manual intervention is not required, unless a critical command is being transmitted. When commanding in two-step mode, commands will be transmitted only after the /send TSTOL directive is entered.

The default set up in the MOC will have two-step commanding with command receipt verification enabled for all commands. The system will not wait for one command to verify before sending the next command, but if a command does not verify, it will automatically resend it (non-critical commands only).

- **Realtime Commanding**

Realtime commands are routed to the flight software for syntax checking and are either sent back to the CIU for immediate execution, or executed within FSW itself. Syntax errors stop the processing of the command and are flagged in the Command Verification (CV) word placed in telemetry. Realtime commands have the highest priority of the three commanding methods and are executed immediately upon acceptance. Uses for realtime commands are discussed above in the Command Uses section. The mechanism of CV is discussed in section 6.1 and below in Command Verification. The FOT may send realtime commands either embedded in a pre-built command procedure, or discretely. Discrete commands may be sent either by typing the command mnemonic into the system, or by typing in the hex code for a command. Discrete commanding will be avoided in favor of the safer, more efficient command procedure method. Groups of commands that accomplish a specific task will be executed by using TSTOL procedures (procs) that have been pre-built and tested by the FOT. This type of operation not only lightens the workload of the FOT, but also ensures a standard, tested sequence of commands is always used for a given situation. In addition to commands, telemetry checks, timed waits, and other constraints may be checked automatically by the proc while it is running. Procs are coded by the FOT and tested before being signed and approved for operational use.

- **Command Loads**

Command loads are broken down into two main categories: Named and General. They may be separated further into seven possible types and are shown in Table 7-4. Named loads must be uplinked to a FSW scratch buffer in the SCP prior to being moved to their final destination. General loads are sent directly to their final destination in FSW.

Load	Description
Absolute Time Command Sequence (ATCS, Stored Command)	Named Load - Provides payload and bus commands for subsequent execution by FSW command processing. This load typically contains commands necessary for imaging operations (BSU, SSR, X-Band commands, and ETM+; see "Command Uses" section). Commands to start RTCS are also contained in ATCS loads. One ATCS load is uplinked each day covering 36 to 48 hours of operations.
Ephemeris Table (Ephem)	Named Load - Contains s/c position and velocity information for use by the FSW for attitude control, solar array positioning, and GXA pointing. This load contains 72 hours of orbital state vector information on 12 minute centers. One load covering 72 hours is uplinked each day.
Data Tables (DATABs)	Named Load - Updates DATABs used by the SCP FSW as a reference for what telemetry it contributes to the TDF for inclusion in each minor frame. There are 2 DATABs in FLP and 2 in SHP. This load is uplinked as needed (not frequently).
Relative Timed Command Sequence (RTCS)	Named Load(s) - Two loads are needed. The RTCS Information Table and the RTCS ID Command Sequence Table must both be uplinked. RTCSs contain set command sequences (macros) with specified time delays between each command in the sequence. They are used to control S-Band, ETM+, and BSU operations (see "Command Uses" section). These loads are uplinked as needed.
Compression Table	Named Load - Updates either the 32-bit or 48-bit compression table contents (logical addresses) used by the FSW for data tables; updates scale and MSB tables. This load is uplinked as needed (very infrequently).
ICMON Table Load	Updates the FDAC ICMTEST Weight Table. This load is uplinked as needed (very infrequently).
Packing Table	Named Load - Updates the packing table for flags and indicators for use by the FSW for data tables. This load is uplinked as needed (very infrequently).
General Memory	General Load - Changes any contiguous sequence of memory locations beginning with a designated physical starting address through to a physical ending address. A General Memory Load changes any area of memory and is used for FSW update and Star Catalog updates. This type of load is uplinked as needed.

Table 7-4 Spacecraft Command Tables

Loads reside in a specific directory in the MOC after they have been "Approved" by the planning and scheduling system. The TPOCC command window will access this directory via a pull down menu and present the user with a list of approved loads. Double clicking on the load will place it into the command buffer. Every load must be preceded by a specific realtime command that contains information about the load. The MOC will automatically precede the load in the buffer with the appropriate realtime command. When uplinked, the realtime command will be verified by FSW and notification will be placed in telemetry (CV=x'092A'). The load itself will NOT increment the SCC, and upon load completion FSW will put out a CV word (for Named loads) that signifies a successful load (x'092B'). FSW will automatically calculate a checksum for Named loads and compare it against the checksum uplinked with the load. If the checksums agree, no further notification is given, however if they do not match, a CV word is generated.

Normally, there will be two command loads needed in a given Landsat day - ATSC and Ephemeris load. The loads that need to be uplinked for a certain pass will reside on the MOC system with appropriate names prior to the planned pass. ATCS, ephemeris, and RTCS loads are explained in more detail below.

Command Loads - ATCS

The ATCS is built each day by the mission planner. After completion, the load is verified by visual inspection of the mission planner, the SA, and by offline software written by the FOT. When approved by the mission planner, the load is place onto the realtime command system and is ready for uplink at the appropriate site.

ATCS loads are built by the mission planners to be activated during a very specific timeframe. For a new ATCS load to continue operations in a seamless manner after taking over from an old load, the scheduler must know when the new load is to be activated (i.e. when it will "take over" from the current load). The scheduler uses the state of the SSR, ETM+, BSU, etc at this time (as commanded from the old load) as a starting point for the new load. After this starting point the new load may quickly diverge from what the old load would have commanded, as the new load is based on updated cloud cover data and other dynamic scheduling inputs. If the prime uplink opportunity is missed, the load will be re-generated for a new uplink time.

The current operation is to uplink the ATCS load from an AGS contact during a descending node pass late in the GMT day (between 2000z and 2359z). An RTCS is then activated. The RTCS waits 12 minutes, stops stored command processing, moves the load to the Active Command

Table, resets that table's index to "0" (making the table available for execution), and restarts stored command processing. The act of resetting the table index resets the stored command timer (for both Active Command Tables) to the number of seconds past 00:00 GMT. The RTCS uses a 12 minute delay before moving the load out of the Scratch Buffer to ensure the spacecraft is not imaging when the load is activated. A 12 minute delay from a descending AGS or LGS pass ensures that the spacecraft will be over the Pacific Ocean and not imaging. If necessary, it is also possible to uplink and activate the ATCS at other sites.

Command Loads - Ephemeris

The ephemeris load is built each day by the mission planner using inputs from the FOT flight dynamics engineer. A software check is run that validates the first node of ephemeris data relative to the previous days load (this check is similar to one done onboard). When approved by the mission planner, the load is place onto the realtime command system and is ready for uplink at the discretion of the SA.

The Ephemeris load does not require a specific contact for uplink and may be loaded to the s/c anytime after its valid data begins. After the ephemeris has been accepted into the scratch buffer, FSW compares the values in the 1st node of the newly uplinked ephemeris to the corresponding node in the ephemeris being referenced. If the two do not compare within a specified value, the 1st node check fails and is flagged in telemetry. This flag is one of several points used by the FOT to verify successful uplink.

The ephemeris is uplinked and an RTCS is used to move and activate it after a 12 minute delay. The reason for this delay is that it is not desirable to switch to a new ephemeris file while ETM+ operations are underway. Any resultant attitude transients due to the switch may degrade the ETM+ image. Since the ephemeris file is normally uplinked at an LGS descending pass, the 12 minute wait helps to ensure activation over the Gulf of Mexico or Pacific.

Command Loads - RTCS

RTCS loads are built by the mission planner using inputs from the FOT engineers. This is done on an as needed basis. Changes are input to the system and the resultant loads are inspected and approved by the mission planner and system engineer. As mentioned in section 6.1 "SCP-Command Execution", two loads are necessary to alter the RTCSs. When moving these two files into their working areas from the scratch buffer it is necessary to ensure that no RTCS is accessed while the tables are being overwritten. To do this, two steps are take. First, the "firewall" must be moved to location 75 since any RTCS above the firewall may be activated even when RTCS processing is disabled. Second, RTCS processing must be disabled. After both tables are moved to their working areas, the firewall is returned to its proper location (normally slot 35) and processing is enabled.

- **Command Buffer Management**

The SCP has one scratch buffer (6200 words) where all Named loads are placed after being accepted by the CIU. Only one Named load can occupy the scratch buffer at any time. The loads stay in this buffer until the FOT moves them to their final destination and moving them from the scratch buffer does not remove their contents from the buffer.

For ATCS loads, that final destination is the Active Command Table. While the SCP contains two Active Command Tables (Bus and Payload), the current baseline is to make use of only one of them. The stored command load, holding enough commands for 36-48 hours, will be uplinked to the scratch buffer and moved to the Bus Table.

- **Command Verification**

The FOT will use the Spacecraft Command Counter (SCC), Command Verification (CV) Word, Checksum, and End-Item verification to verify successful transmission/execution of commands. A more detailed description of on-board command processing and validation is provided in Section 6.1 (CIU). Telemetry end-item verifiers will be defined in the PDB and are used by the MOC for command verification during realtime operations. The MOC is normally configured to automatically check the End Item Verifier status for realtime commands. Command status will also be verified by FOT monitoring of telemetry display pages. In addition, if necessary it is possible to dump all Named loads from the SCP scratch buffer for comparison against a ground reference image prior to moving them to their working area.

Verification of commands during specific operations (ATCS loads, Ephemeris loads, maneuver operations, etc) are detailed in the specific flight procedures.

Occasionally, a data word may be generated for a realtime command that, when returned to the ground in CV, may match an assigned CV error code and trigger a false CV error notification from the MOC.

- **Configuration Control**

Configuration control procedures differ for each specific command product. The processes for some of the products are outlined in the above sections for Realtime Commands and Command

Loads. The specific processes used for each product are detailed in the specific flight procedures and the configuration control plan.

7.4 Mission Planning and Scheduling

The planning and scheduling process may be broken up into three distinct phases. These phases are shown below in Figure 7-9 and explained in the rest of the section.

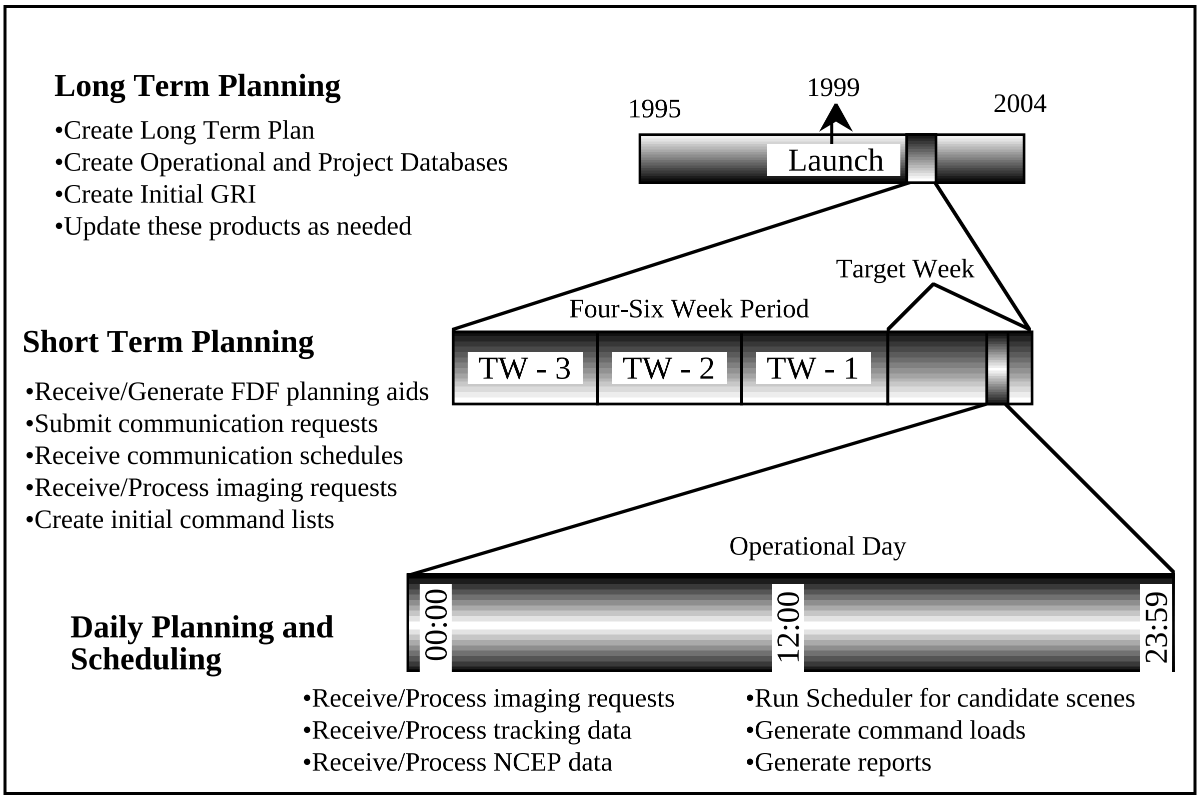


Figure 7-9 Planning and Scheduling

7.4.1 Long Term Planning

• Long Term Plan Database

Unlike previous Landsat missions, Landsat 7 is being run as a survey mission. This fact means that users, as a whole, do not drive the day-to-day scene acquisition schedule. Pre-launch, a working group was formed that included the Project Scientists, MOC developers, FOT, Systems Engineering, and User Community representatives. A Long Term Plan was developed that is meant to be referenced each day by the scheduling software. The plan, in conjunction with other planning aids and software, helps produce a conflict free imaging schedule that is populated with scientifically useful images.

This plan includes a database of all landmass and near-coastal WRS scenes on Earth, with additional information on each scene. Examples of the scene information included is shown below.

- Default Scene priority
- Seasonality of Scene (When are the scenes “in season”)
- Repeat Factor (How many times, per season, should the scene be imaged)
- Maximum acceptable cloud cover
- Acceptable Sun Angle limits
- Default gain settings (each scene may have several default settings that are time dependent)

The long–term plan can take into account the calibration plan, planned satellite maneuvers, and international imaging needs. The FOT will have the capability to modify the LTP after launch as needed and directed.

7.4.2 Short Term Planning and Scheduling

- **FD Planning Aids**

FD planning aids are generated in the MOC by the FOT on a daily and weekly basis. These products will be generated prior to performing the daily scheduling and are created by a combination of commercial and Landsat 7 specific software provided and maintained by FDF. Software used for FDF planning aid generation includes commercial software such as Satellite Tool Kit (STK), and FreeFlyer, government supplied software, and FOT generated scripts and programs. FD activities necessary on a daily and weekly basis are shown in Appendix A.

Throughout the day, the MOC will be collecting Doppler and ranging data. Data from the SN will be sent to the FD Orbit workstation in near realtime after being filtered by FDF in Building 28 (The SN data is sent in UDP/IP format which is not compatible with the TCP/IP MOC set-up). In addition to changing the transport protocol, FDF will strip out all non-Landsat 7 data. Doppler data from the ground sites will be sent via FTP to the FD Orbit workstation post-pass. The baseline contact schedule of five LGS, two AGS, two SGS, and two SN tracking passes per day should provide the geographic and ephemeral diversity necessary for an accurate orbit determination.

Using the tracking data over the last 30 to 50 hours, a definitive orbit vector is generated. This “Orbit Determination (OD)” is the first step in generating the daily FD products. This vector is used for, among other things, generation of a predicted ephemeris (spacecraft location and velocity at 12 minute intervals over the next three days). This file is taken by the MOC and translated into a suitable format for uplink to the spacecraft. For further descriptions of ephemeris file use and operations, see sections 6.1 SCP - Command Execution and 7.3 Command Operations – Command Loads. The predicted ephemeris must meet specific accuracy requirements as reflected in Figure 7-10.

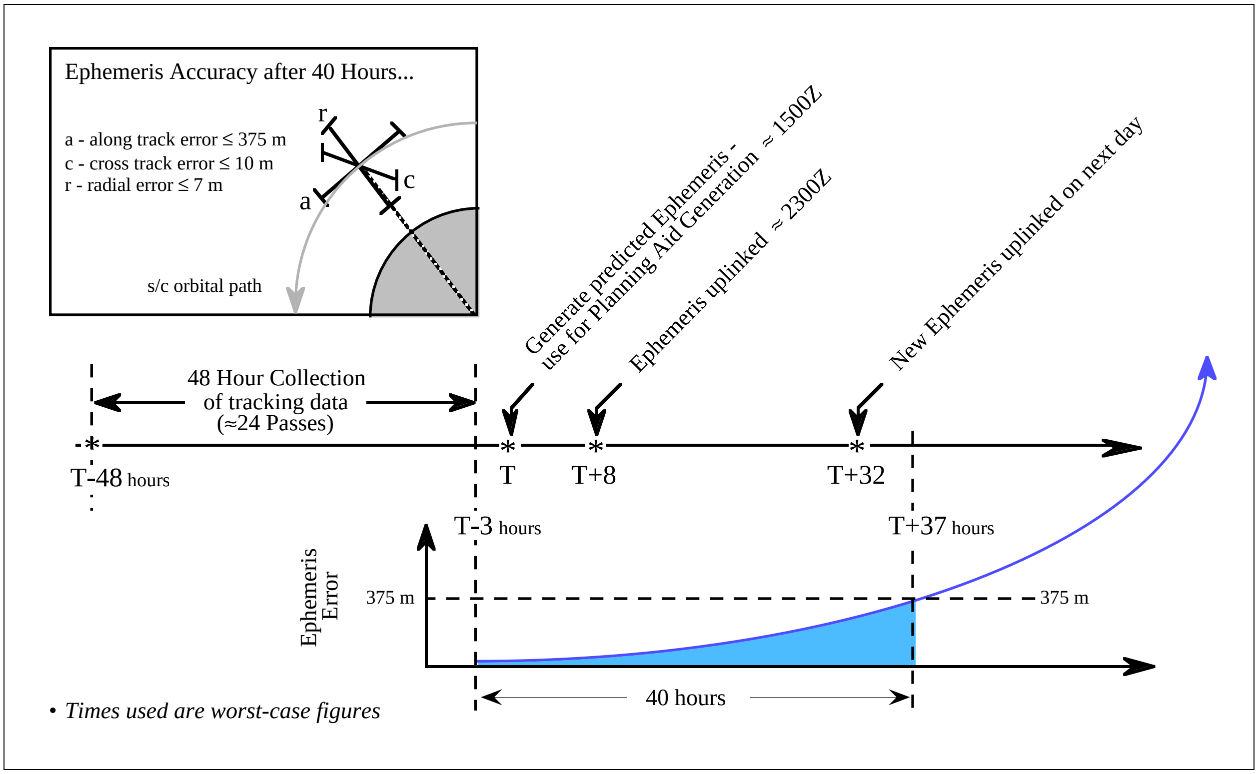


Figure 7-10 Ephemeris Accuracy and Timeline

A diagram showing how the various FDF components work together is shown in Figure 7-11.

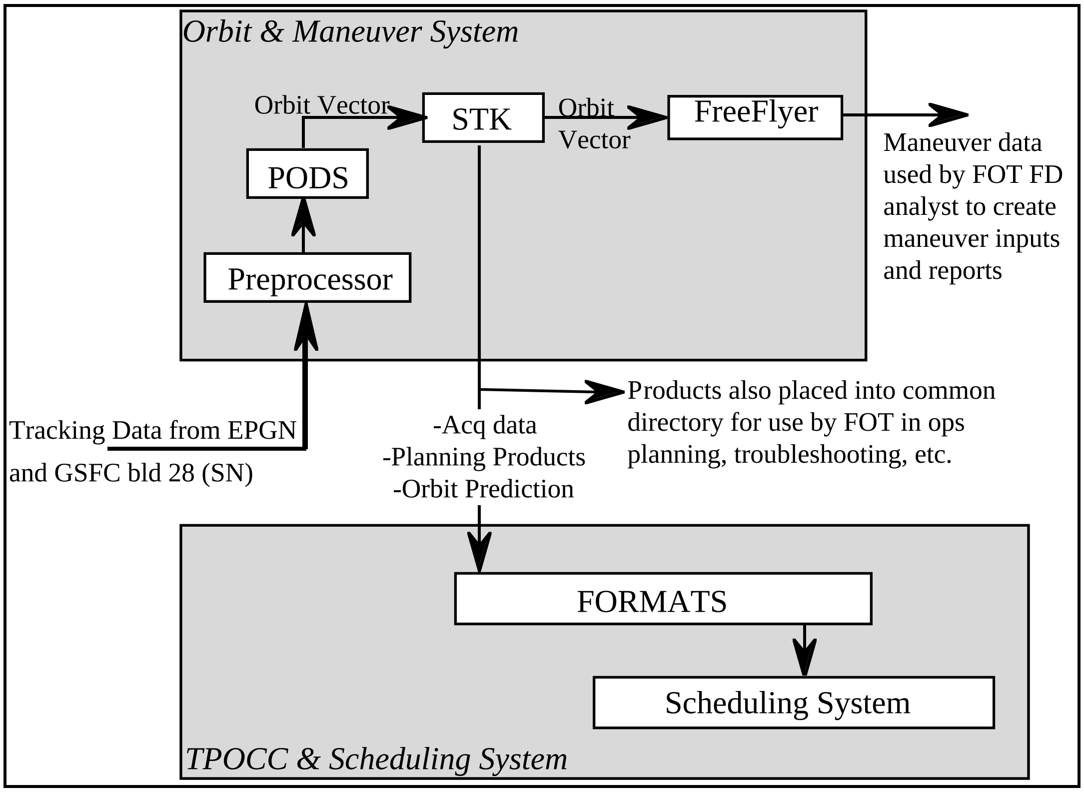


Figure 7-11 FD System Architecture

- **Ground Communications Scheduling**

For normal operations, the FOT will have to schedule support from five different communications elements: LGS, AGS, SGS, WPS, and SN. SN is scheduled by the NCC, LGS scheduling is performed directly with the station, and the remaining stations are scheduled through Wallops Orbital Tracking Information System (WOTIS).

<u>WOTIS Scheduling</u>

The scheduling strategy maximizes LGS usage and fills coverage gaps with AGS, SGS, and SN. The specifics regarding LGS scheduling, including file formats and naming conventions, are covered in the *Interface Control Document Between the Landsat 7 MOC and the LGS*.

Approximately three weeks before the interval being scheduled, the scheduling process begins with the FOT/MOC sending a strawman request file to WOTIS. The views for AGS, SGS, and WPS are filtered by the MOC based on several criteria, including coverage availability at the LGS and pass duration. These resulting views represent a more accurate prediction of actual Landsat 7 support needs and, therefore, are sent to WOTIS as the first step in the scheduling process. Once

WOTIS receives the file, a preliminary schedule is generated based on the Landsat 7 views and the support requirements of other EPGN-supported spacecraft.

WOTIS returns a forecast schedule file which is FTP'd to the MOC approximately 2.5 weeks before the target week, and contains entries for each request that AGS, SGS, and WPS resources can support. Based on agreements between AGS, SGS, and WPS and the Landsat 7 project, support entries for both X-Band and S-Band are generated for the sites since two RF equipment chains are used. The WOTIS scheduling system generates tags that are used to uniquely identify each X-Band and each S-Band support in a schedule. Any subsequent actions relevant to a given support by either the MOC/FOT or the sites make use of this tag.

After the forecast file is sent to the MOC, the FOT may return a confirmed file to WOTIS to add or delete contacts. Entries that were in the forecast schedule but do not appear in the confirmed schedule are effectively deleted. In addition to adding and deleting contacts, the MOC/FOT can make any necessary changes to the support entries via the confirmed schedule. For example, specific on and off times for S-Band station resources can be given by adjusting the times associated with the contact and tracking support can be changed from one-way to two-way or vice versa.

Each day, the MOC/FOT sends a daily schedule file to WOTIS by 2000z. The file begins with the current local time and ends at the chosen stop time of the scheduling run. The parameters that will be given at this time are X-Band frequency (i.e. which of Landsat 7's three frequencies will be in use) and specific equipment on/off times. As with the other transmissions, FTP provides acknowledgment that the daily schedule arrived successfully at WOTIS. The transfer of the daily schedule is the final electronic exchange in the scheduling process. Any modifications after this point, including requests for emergency support, are accomplished via voice coordination between the FOT and WFF operations staff, with confirmation via electronic mail.

Space Network Scheduling

Two or three TDRSS passes per day will be scheduled to collect either tracking data, each being about 15 minutes long. One additional contact will be needed for center frequency measurement. Coverage for orbit adjust maneuvers and other special events will be scheduled as needed.

SN - Service Specification Codes and Prototype Events

Service Specification Codes (SSC), formerly known as SSCs are a standard interface tool used between the FOT and NCC to specify the characteristics of a planned TDRSS support. These codes provide specific information on the telecommunications link including carrier frequency, data rates, and other interface requirements for any TDRSS support request.

Changes to any code must be reflected in the NCC database before they can become part of the daily operational scheduling scenario. Changes to any SSC will be implemented by the NCC after receipt of a written request from the FOT. These changes must be coordinated with both the NCC and UPS database administrators. An example of the information specified in the SSCs is shown below.

a) Initial and maximum data rates
b) Receive frequency
c) Polarization
d) Service configuration (SSA, etc.)

Following SSC definition, prototype events can be defined which specify a fixed combination of service SSCs and their associated timing. The prototype event (PE) allows a more convenient method of describing contacts that always involve the same combination of services. The definition of PEs allows a much easier method of TDRS scheduling (since all detailed information is not required to be specified for each schedule requests).

Like SSCs, PEs are defined in the NCC and UPS databases. In addition, the UPS supports locally defined events that allow the user to specify the desired combination of SSCs but without specifying fixed duration and offset times.

SN - Scheduling Interfaces

The TDRSS network is scheduled by submitting requests to the NCC scheduling facility. The User Planning System (UPS) will be used to interface with NCC during scheduling. The UPS allows each mission to develop databases of service configurations and their associated scheduling criteria. The UPS is integrated into the MOC and will be connected to the TPOCC LAN, allowing the FOT to run UPS functions with an X-terminal interface. The FOT submits scheduling requests to NCC via the UPS, and after the NCC has accepted or rejected the requests, schedules are transmitted back to the FOT through the UPS.

SN - Scheduling Process

The scheduling process for Landsat begins three weeks prior to the event week. At this time inview files will be sent to the MOC and are made available to the UPS. A session is established on the UPS, and the automatic request generation function (initiate orbital process) is called. For routine scheduling, Landsat events are scheduled following the previously defined scheduling guidelines and will be sent electronically to the NCC.

During the following week, the NCC performs conflict resolution for all users based on a priority criteria and TDRS availability. The NCC contacts the FOT in an attempt to resolve any conflicts. An attempt to resolve conflicts is accomplished using a variety of methods, such as sliding a contact to an earlier or later time, or accepting a support of less than 10 minutes in duration. The user can attempt conflict resolution with the UPS graphical displays, which depict “problem” contacts in red. After reviewing the appropriate reports, the adjusted requests are electronically sent to the NCC.

By the end of the week, the NCC sends User Scheduling Messages (USMs) for all supports to the UPS. On the UPS, the USMs are merged into a single schedule for the week and are relayed to the MOC scheduling system.

SN - Changes in the TDRSS Schedule

Schedule changes can occur anytime between event confirmation receipt and event start. Schedule changes can be initiated by either the FOT or the NCC. For both situations, the processing steps are essentially the same. The significant difference is that for FOT-requested changes, the appropriate schedule modification requests must be coordinated and then submitted via the UPS. For many NCC changes, such as pass deletion, the NCC will notify the FOT (usually a phone call) and transmit the USM containing the deleted pass. If for NCC requested changes, an acceptable alternate time (or alternate TDRS) is available, the FOT must submit the appropriate requests and then wait for the USMs reflecting the changes.

- **Scheduling Image Requests**

Requests for imaging will enter the MOC in a number of different ways. The long term plan, MMO inputs (Special Requests, Individual User Requests), IAS inputs (calibration requests), and IGS inputs will be the largest sources of imaging requests.

Special Requests

Landsat 7 users may request that specific images be included in the daily imaging schedule. These image requests must be in response to an environmental emergency, related to national security, or be part of some sort of time-critical observation and will be directed at the MMO.

Once the special requests are accepted by the MMO, they are passed along to the MOC where they are ingested into the planning system and scheduled on the appropriate day. These scenes pass through the scheduling process and are placed in the daily schedule regardless of predicted cloud cover. In addition, they are write-protected on the SSR and will not be released until the FOT confirms a successful downlink and capture by LGS/LPS.

Individual User Requests

These images are similar to Special Requests in that they are individually requested via the MMO. Even though these images have a much elevated priority going into the scheduling process, they are not write-protected on the SSR and in the initial scheduling process, cloud cover filters are used (i.e. they will not be scheduled if cloud cover predictions are too high).

Calibration Requests

These requests for Ground Look Calibration scenes, PACs, or FACs come from the IAS and are input into the scheduling process.

IGS Image Requests

The individual IGSs submit service requests to the MOC and are accommodated as resources allow.

7.3.3 Daily Planning

There are several activities that take place on a daily basis that lead up to, and include, the actual generation of useable command loads. The MOC ingests the newest version of any perishable planning aids that are to be used before the actual scheduler may be run.

- **Daily Planning Aids**

The daily definitive orbit vector and other planning aids are generated by the Flight Dynamics engineer and passed along to the scheduling system (see Section 7.4.2). This vector is used in several different ways during the scheduling process. For example, the scheduling software uses these products to establish spacecraft position over the Earth in order to know which scenes to consider for imaging.

The Cloud Cover predictions come into the MOC from the National Center for Environmental Prediction (NCEP) in a form that must be processed and manipulated before it may be included in the scheduling process. The NCEP makes these files available to the MOC (and other users) several times a day and the scheduling software will use the files most appropriate for that time span. The predicts are used in the scheduling process to maximize the number of "substantially cloud-free" scenes that are captured. Due to the dynamic nature of weather conditions, the accuracy of the predicts begins to diminish immediately after creation.

- **Activity/Scene Scheduling Process**

At the beginning of the scheduling process, all scenes that the spacecraft will be passing over during that 48 hours will be extracted from the long term database. The number of scenes extracted will greatly outnumber the scenes that can fit onto the recorder and be played back, so a filtering algorithm is used to lower the number of candidate scenes to a manageable level. Several parameters such as predicted Cloud Cover, Sun Angle, and historical scene data are used. These filters do not actually eliminate a scene from the process, but are used to adjust an individual scene's priority. Each scene has associated with it a default priority which is adjusted up or down during the filtering process. If for example it is found that a particular scene is predicted to be covered in clouds during the imaging period, its priority will be lowered (lowering its chances to be scheduled) so it will not take up space that may be utilized by a cloud free image.

The software runs through the day, trying to schedule every land image the spacecraft flies over. The only exception to this are those scenes whose Long Term Plan request(s) have already been filled. The requirements for these scenes during the given time period have been fulfilled and the scene will not be scheduled until a new "season" has begun. When the software tries to schedule a scene, but finds that the SSR is full, it will "unschedule" a different scene previously planned for the SSR but with a lower priority, thus freeing up the space. Similar action is taken in order to stay within ETM+ duty cycle limits. As the scheduling software sweeps through the designated scheduling time span, it constantly trades lower priority scenes for higher priority scenes. In this way, the software ends up scheduling only those scenes with the highest priorities.

Once a conflict free schedule is produced by the scheduler, ETM+ imaging sessions are analyzed and fly–wheel scenes (which will not be sent to the SSR) are added to the scheduler as necessary to prevent turning the ETM+ on and off too frequently. If the scheduler can not arrive at a conflict free schedule, FOT intervention is required.

The scheduler enforces the ETM+ instrument duty cycle limits. Scheduled ETM+ on/off cycles will be monitored by the scheduler, and a duty cycle check of ETM+ on time will be calculated.

In addition to scheduling ETM+ imaging, this process will also make use of MOPSS and PARR in order to schedule housekeeping activities. S-Band, X-Band, and BSU ON/OFF commands, and any configuration commands that are necessary, will be entered into the schedule at this time. Rules and macros may be set up by the FOT to control the placement of these commands and cause them to be included in the activity list automatically.

In cases where the FOT becomes involved in influencing the schedule manually, agreed upon policies from the MMO, set procedures, and FOT judgment will be used. The final output of the scheduler is a time-ordered stored command list for the stored command load.

• **Load Generation**

The stored command list will then be made available to the load generation function to incorporate the time-ordered stored command lists into a time tagged satellite command load to be uplinked to the satellite. The FOT uses the load generation function to produce the binary images that are loaded into the SCP memory. The load generation function produces memory map reports.

7.5 Spacecraft Clock Maintenance

The performance of the spacecraft clock will need to be monitored and trended on a daily basis. In addition, correction factors and updates to the Software clocks in both SCPs will have to be uplinked as needed (probably once a day). Updating or setting the Software clock will change (increment or decrement) the Software clock value and will in turn will have an identical effect on the PDF Hardware clock. The correction factors (or coefficients) are applied by FSW to the Software clock value and are used in ephemeris processing. In addition, these coefficients are downlinked in PCD and used for image processing. For information on the frequency source of the spacecraft clock and its operations, see Section 6-1 and Figure 6-4.

A time tag is generated and brought down across eight minor frames. Thus the time of generation of every eighth minor frame can be established. The spacecraft clock will have associated with it two types of drift. A long term drift that will be predictable, trendable, and correctable by the FOT, and a short term random drift. Data captured during realtime ground contacts (not SN) will be used to characterize and calculate clock and coefficient updates. Updates are normally calculated and uplinked twice a week. The difference between the

Hardware clock value and GMT will be trended and is required to be less than 145 ms (operationally, it is kept below 15 ms). This change is then applied to the Hardware clock by FSW. Hardware and Software clock values are required to be correctable to within ± 15 ms of GMT (operationally, they are correctable to within 5 ms).

The Range Data Determination (RDD) method will be used by the MOC to calculate the difference between the Hardware clock value and GMT. This approach uses ground receipt time of telemetry, spacecraft time, known equipment delays, and range data to relate the spacecraft clock to UTC. The general formulas needed for this method are shown below:

Clock Delta = $T_{GRT} - T_{RFT} - T_{HW} - T_{S/C}$
T_{GRT} = ground receipt time of the time tagged tlm
T_{RFT} = Radio frequency signal transmission (range) delay
T_{HW} = Landsat 7 internal telemetry delay (difference between the generation and sending times of the reference VCDU) + Ground station hardware delays
$T_{S/C}$ = spacecraft time converted to UTC

At each ground contact, RDD collection is turned on in the MOC by the default setup routine. This initiates the MOC calculation of the GMT error. The error is trended vs time and characterized using a polynomial. A duplicate polynomial resides onboard the spacecraft. In addition, the polynomial is included in PCD so that the correct spacecraft time may be used during image assessment. The polynomial is as follows:

$$T_{UTC} = T_{s/c} + C_0 + C_1(\Delta t) + 0.5(C_2)(\Delta t^2)$$

where:

$\Delta t = T_{s/c} - t_{update}$ (Δt is the time elapsed since the coefficients were last updated)
$T_{s/c}$ = Software Clock value
C_0 = clock correction bias term
C_1 = clock drift rate
C_2 = clock drift rate acceleration

The coefficients C_0, C_1, and C_2 are calculated using the RDD COMPUTE MOC directive. The onboard correction algorithm is applied against the Software clock value and is <u>not</u> used on Hardware clock output (therefore, not applied to the clock time stamped on the housekeeping or payload telemetry) although the correction coefficients are reported in PCD.

To correct the Hardware clock output, the value of the C_0 coefficient will be backed out of the PDF using a Clock Update command. This also has the effect of reducing the Software clock error by the same amount. Since the first order error of the Software clock would then be near zero, only the C_1 and C_2 coefficients need to be updated (C_0 can be uplinked as 0).

Typically, the clock correction parameters are calculated and uplinked twice each week. For more information on RDD directives and their options, see the *Landsat 7 MOC SUG.*

7.6 Spacecraft Operations Summary

The following list of activities represents a simplified subset of FOT activities used to successfully operate the Landsat 7 spacecraft. This is not meant to be an all inclusive list, and over time, some of the specifics involved with these activities may change. This list is merely meant as a representative tasking list.

- **Routine Daily Activities**

1. Generate the flight dynamics products specified for that day. Products include, but are not limited to orbit vectors, predicted ephemeris file, station inviews, s/c shadow report, south atlantic anomaly report, etc.
2. Process the ephemeris file and move onto realtime MOC system load directory.
3. Generate and check a conflict free stored command load (ATCS) and move onto realtime system load directory.
4. Perform short and long term resource planning for the GN and SN support sites.
5. Conduct scheduled contacts with STDN and SN resources.
6. Perform dumps of the housekeeping data from the SSR. Frequency of these dumps are at the discretion of the SA.
7. Process the captured housekeeping playback files.
8. Receive ephemeris file and ATCS file from mission planner and verify contents as specified in the Flight Procedures Document.
9. Uplink and activate the daily ephemeris file following the directions in the Flight Procedures Document. The contact used for this operation is at the discretion of the SA.
10. Uplink and activate the daily ATCS file following the directions in the Flight Procedures Document. The contact used for this operation is dictated by the ATCS file. If for any reason the load cannot be uplinked at the specified contact, a new load must be generated.

11. Perform trending of previous GMT day data. (create specified daily plots and/or special reports as specified in the Flight Procedures Document).
12. Review generated plots and/or reports for previous GMT day. This operation is required of the operations engineers, and encouraged of the r/t engineers.
13. Assess the past, present and predict the future performance of the s/c.
14. Contribute to training the team by generation of training material, one-on-one training, or support of training simulations.

- **Non-Daily Routine Activities**

1. Calculate and uplink values of s/c clock error, drift, and acceleration for uplink to the spacecraft. Typically, this is done twice each week.
2. Dump an image of the SCP RAM (Stby or Control) and TDF RAM as specified in the Flight Procedures Document. This is typically done once a week (on Monday). The contact where this operation is performed is chosen by the SA, following guidelines in the FPD.
3. Transfer the SCP RAM image file (extracted by the MOC during subsetting) to FSME.
4. Dump an image of the SSR mass memory status per the FPD. This is typically done once a week (on Monday). The contact where this operation is performed is chosen by the SA, following guidelines in the FPD.
5. Plan and generate a procedure for routine Orbital Maintenance (OM) maneuvers.
6. Execute maneuver procedures as planned. This typically will be done once every two to four weeks as orbital decay dictates. A new procedure will be generated and distributed prior to each maneuver. Typical steps in this procedure currently include uplinking RTCS files, running the maneuver procs, making specific RTCSs valid, and verifying specific telemetry.

- **Non-Routine Activities**

1. Gather and analyze the appropriate data for investigation, resolution, and documentation of all anomalies.
2. Plan, simulate, and document all special operations and engineering tests.

The Figure 7-14 summarizes some of the routine realtime activities and a possible timeline within the week.

Sun	Mon	Tues	Wed	Thur	Fri	Sat
Daily R/T Activities	Daily R/T Activities SCP, TDF RAM dumps SSR mem dump	Daily R/T Activities s/c clock ops OM (every 2-4 weeks)	Daily R/T Activities	Daily R/T Activities s/c clock ops	Daily R/T Activities	Daily R/T Activities

Figure 7.14 Possible Timeline for Operations Activities

Section 8 ANOMALY DETECTION, ISOLATION, and RECOVERY

Table of Contents

8.1 Introduction

There are two basic types of anomalies:

Safety - Malfunction in a component or pathway that is required to maintain a safe spacecraft, or, by its failure, causes an unsafe state on the spacecraft. An unsafe state is one where either the attitude of the spacecraft or its thermal balance is not stable, or the spacecraft is in a state or configuration that it cannot sustain for 72 hours without ground contact, and without causing permanent damage. These types of anomalies can be detected by the on-board Failure Detection software (FDAC), the MOC software and the FOT. The spacecraft can react autonomously to specific safety related conditions.

Health - Malfunction in a component that causes the interruption of mission operations, but does not jeopardize the spacecraft safety. These types of anomalies can be detected by the MOC software and the FOT.

8.2 Spacecraft Self-Protection

The Landsat spacecraft was designed and built to be highly autonomous and take care of itself while it is out of view (approx.90% of the time). It has several 'safety features'. More detail about all the items listed below can be found in section 6 (C&DH) of this document.

- FDAC (Failure Detection and Correction Software). Specific components and pathways are monitored for failures. If a failure is detected, the FDAC software is designed to switch component side and/or command and clock pathways.

- ACS Faults. The ACS FSW will detect specific conditions and switch ACS control modes.

- Power Faults. The power status monitor will detect specific conditions and switch component sides or initiate loadshedding.

- ETM+ Safing. FSW and ETM+ hardware will safe the instrument in response to specific conditions.

In addition to the spacecraft safing features, the ground software also aids the FOT in recognizing anomalies. TPOCC software provides limit checking on all spacecraft telemetry mnemonics and the ability to build configuration monitoring files. Configuration Monitors are used to check expected values of spacecraft telemetry mnemonics and alert the FOT to any non-matching telemetry values.

8.2 Identification, Isolation, and Response

The opportunity to capture and resolve anomalies in real-time is rare and infrequent due to the fact the spacecraft is out of FOT view approx. 90% of the time(during a 24 hour period). Since anomalies are unique in most situations, caution usually prevails over firing from the hip. Real-time immediate command response to anomalies is not the number one priority. The philosophy for anomaly identification, isolation and response can be found in the following diagram:

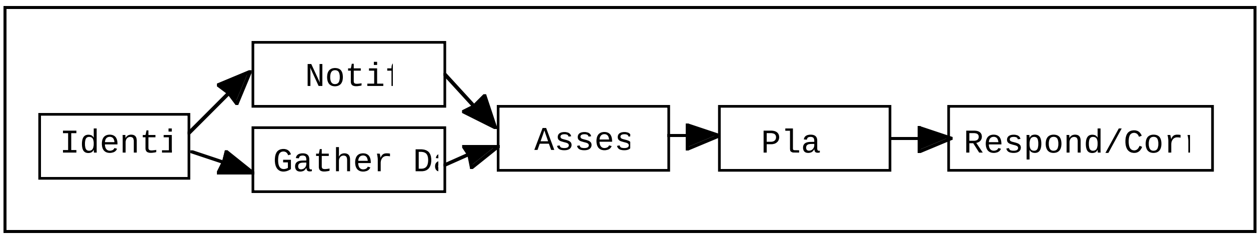


Figure 8-1 Identification, Isolation, and Response for Spacecraft Anomalies

When an anomalous condition is recognized, the FOT will react to it using established procedures whenever possible. The FOT has developed an ‘Escalation Procedure’ that lists anomalies the FOT is prepared and pre-authorized to react to. In addition, the procedure lists anomalies that require immediate notification of the lead Operations Engineer and anomalies that require notification to the lead OE within 48 hours. In the event of an anomaly, the FOT will also notify the following personnel: the Real Time Ops Supervisor, FOT Manager, NASA and USGS, Honeywell Management and any other technical personnel. Depending on the type and severity of the anomaly, the personnel in the above list may not be notified immediately, but during the next set of business hours. The Escalation Procedure is not contained in this document.

The FOT also maintains an Anomaly Report database that archives all ground station and spacecraft related anomalies. There are also TSTOL procedures available for response to anomalies. These procedures have been tested and have received the proper signatures.

8.4 Investigation and Recovery

- **Investigation Process**

Once an anomaly is detected, a judgment will be made in real-time as to whether the condition may be allowed to exist or if immediate action will be needed. Additional supports from the ground stations and SN may be requested. As soon as is feasible, the FOT will open an Anomaly Report so that the event may be archived in the anomaly database.

Once an anomaly is detected, the event is investigated by the FOT. The goal of the investigation is to isolate the root cause of the anomaly, determine how and when mission operations may be resumed (if they have not already), and how to avoid repeating the anomaly on this or any other component in the system. The output of the investigation should include the following:

- Detailed account of what happened from anomaly occurrence to investigation close
- The current configuration of the spacecraft and/or ground system (if different than prior to the anomaly)
- Recommendations for necessary changes in operational procedures, command procedures, displays, databases, spacecraft constraints, etc.
- Recommendations or specific procedures to follow if the anomaly occurs again
- Predictions of future spacecraft performance if affected by the anomaly

The results of the investigations will be placed into an anomaly database and saved for the life of the mission.

Section 9 OFFLINE ENGINEERING, TRENDING, and ANALYSIS

Table of Contents

9.1 Offline Engineering Activities

While it is impossible to completely separate spacecraft operations into realtime (Section 7) and offline (Section 9) because of the many overlaps and dependencies, the two categories do sometimes offer a convenient, if not imperfect, way to group operations. Offline activities of the FOT include the following:

1. Planning and scheduling SN, EPGN, and certain spacecraft resources (mainly wideband)
2. Generating command loads for routine and non-routine operations
3. Generating orbital products for planning, scheduling, troubleshooting, and operations
4. Performing isolation, analysis, and resolution for all anomalous spacecraft performance
5. Analysis of spacecraft performance (past and present) and predicting future performance
6. Planning and performing preventative maintenance on the spacecraft
7. Planning and implementing special (routine and non-routine) operations
8. Training the Landsat 7 team on spacecraft design and operations
9. Generating documentation and reporting as necessary

Activities 1-3 are discussed in Section 7 of this document because of their close relationship with realtime operations. Activity 4, spacecraft anomaly response is covered in Section 8. Activities 5-9 are discussed below.

9.2 Trending and Performance Analysis

• Daily Trending, Data Flow, and Analysis

Several times each day, the FOT will dump collected housekeeping data from the SSR. This data is collected on the MOC system and used for periodic trending and analysis. The data is processed, and once each day a set of daily trend plots is created. Several plot files exist, and although the routine operation is to create only the plots defined in the "daily" definition, it is possible to create plots of other spacecraft parameters by using other defined plot definition files. Along with the daily plots, statistics are generated (max, mean, min, standard deviation) on each parameters values over the given day. Special text reports may also be generated of any of the parameters if deemed necessary. These text reports may be used as is, or transferred to one of the offline desktop computers for use in commercial spreadsheet or graphing software. Figure 9-1 shows the data flow in the daily trending process.

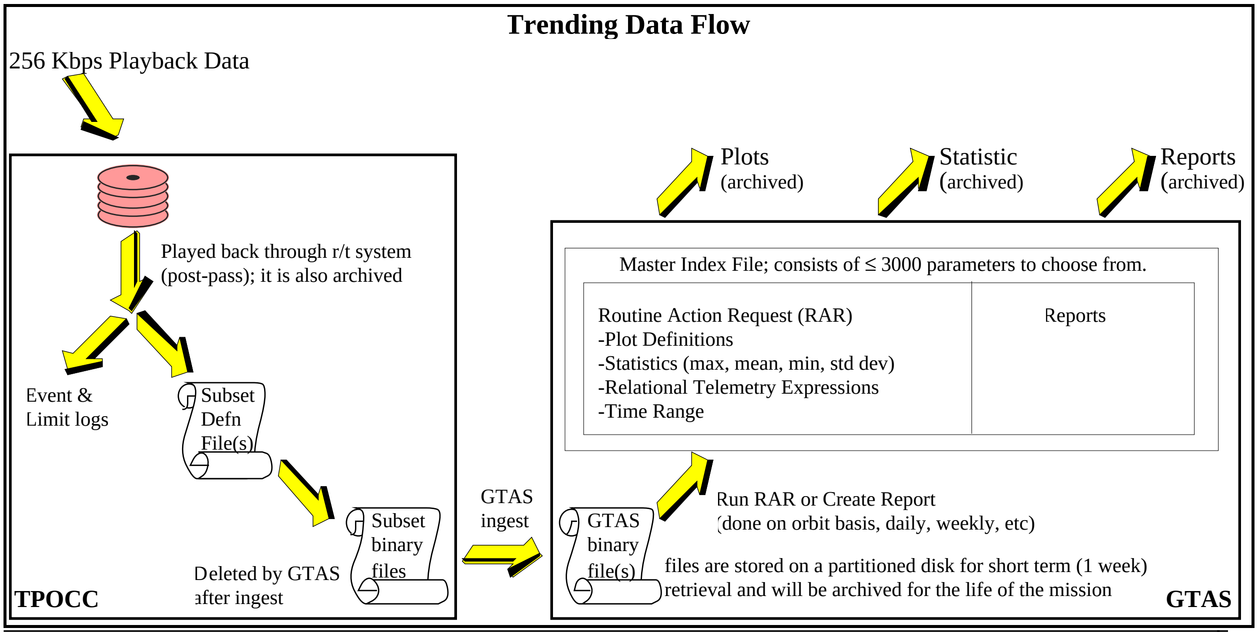


Figure 9-1 Trending Data Flow

The FOT worked with the spacecraft and component builders pre-launch to identify desirable parameters for daily trending. The list of parameters plotted each day continues to be refined as more empirical data on the spacecraft is gathered.

As stated earlier, once each selected parameters (currently numbering in the hundreds) are plotted. The parameters are plotted with fixed Y-axis scales appropriate to the individual parameter and with X-axis values spanning 00:00 GMT of day x to 00:00 GMT of day x+1.

It is the responsibility of the offline engineers to review these plots each day and assess the performance of the spacecraft over the past 24 hours. Any irregularities in a parameters performance are investigated, characterized, analyzed, and elevated as necessary. Hardcopies of the daily plots are archived in the MOC for several months (and elsewhere permanently). The raw data used to create the plots is archived permanently as well.

- **Long Term Trending and Analysis**

In addition to the daily graphs generated by the FOT, plots used to assess the long term performance of the spacecraft are generated. These plots are comprised of statistical data (max, mean, min) on selected parameters. These plots allow the FOT to analyze long term trends in the system that may be caused by seasonal changes, shifting orbital geometry, or degraded component performance. As with the daily trends, any irregularities or unexpected behavior in a parameters performance are investigated, characterized, analyzed, and elevated as necessary.

For long term trending, the parameters are plotted with fixed Y-axis scales appropriate to the individual parameter and with X-axis values spanning weeks, months, or years depending on the trend being analyzed.

The parameters selected for long term trending are not the same parameters used in daily trending, although there is considerable overlap.

9.3 Spacecraft Preventative Maintenance

- **Center Frequency Maintenance**

It is necessary to characterize the transmit frequency of the S-Band system. The transmit frequency is calculated by FDF using data obtained during non-coherent TDRS supports. Currently, one non-coherent TDRSS contact is scheduled each day. The number of non-coherent supports could be changed by the FOT if they deem one contact a day is too much or not enough, depending on the rate of the drift.

After a non-coherent support, FDF will calculate the center transmit frequency from the event and produce a Local Oscillator Frequency (LOF) report. This report is sent to the FOT, who will in turn notify NCC if needed. NCC must know our frequency within ±1500 Hz of the actual center frequency.

- **Spacecraft Clock Maintenance**

Although this is a preventative maintenance task, operational process improvements and streamlining have allowed it to also become a fully realtime operation. The actual process of calculating and uplinking correction parameters to the spacecraft clock is accomplished via a fully realtime process and is described in Section 7.5. The results of the process are trended and analyzed offline.

- **RAM Image Maintenance**

Each week a dump of the full SCP RAM is commanded. These dumps alternate between SCP 1 and SCP 2 so that every two weeks, the contents of a particular SCP is dumped. The dump file is transferred to the FSW maintenance area (housed within the MOC) where it is compared to a reference image to verify that no static area of memory has changed unexpectedly. Such changes may be the result of a high energy environment ("bit flips").

In addition, the RAM area of the TDF is also dumped every week for comparison against a reference image. The entire contents of the TDF RAM should remain static unless changed by the FOT.

- **Leap Second and Year Rollover**

The U.S. Naval Observatory in Washington, D.C. maintains a Cesium standard atomic clock which provides the master reference for all official NASA time. Due to the inherent irregularity of solar time, atomic and solar clocks do not maintain synchronization over time. This irregularity is compensated for by periodic one-second adjustments to the atomic clock. Leap-second adjustments are typically made once per year and are always implemented on either June 30th or December 31st. Notification of such adjustments will be provided to the FOT by the GSFC Networks Division Timing Frequency Office, Code 531, at least two weeks in advance.

Adjusting the software and hardware clocks for leap-seconds is easily accomplished using the 'PDF Time Code Update' command, however, the timing of the update is crucial. Changing the system time by an amount as large as one second will create attitude disturbances when the active ephemeris is suddenly offset by a second. Additionally, the active ephemeris would be propagating based on a different time frame as the system time, resulting in a constant attitude error once the attitude disturbance had passed. Leap-second updates need to be performed during a non-imaging period (to avoid attitude disturbances) and the ephemeris needs to match the time-frame after the leap-second has been added to the system (to avoid attitude errors.)

Every year rollover operations must be performed on the spacecraft clock. At the rollover to the new year, three FSW parameters are altered. As discussed in Section 6, the spacecraft clock will count up to 999 days without rolling over, so at each year rollover, the clock must be bumped backwards to reset its day count to 1. In addition, FSW contains a parameter that indicates the modified Julian day of the current year. This variable is altered at the same time the day count is rolled back. At the same time, the third variable, related to ephemeris processing, is altered. FSW contains a parameter that it uses as a reference time for the beginning of the currently active ephemeris file. This time is used to calculate which ephemeris node should be used. This parameter is altered to ensure a smooth transition from the pre 00:00:00 GMT node to the post 00:00:00 GMT node. All three of these parameters are altered using an RTCS that is activated at 00:00:00 GMT of day 001 from the ATCS.

9.4 Engineering Operations Planning and Implementation

• Orbit Maintenance

The ground track of Landsat 7 follows the Worldwide Reference System (WRS) followed by Landsats 4 and 5. In addition, the ETM+ and ESA are designed to perform in specific orbital conditions. In order to maintain this mission orbit, periodic maneuvers must be performed, and the planning of these maneuvers falls to the FOT. A listing of the planned orbital parameters and requirements is given in Table 9-1 below:

Parameter	Value
Semi Major Axis (Altitude)	7077 km ± 5 km (705 km ± 5 km)
Inclination	98.21° ± 0.028°
Eccentricity	0.001
Arg. of Perigee	90° ± 40°
Period	98.88 min
Descending Equatorial Crossing Time	10:00 AM± 15 min (mean local solar time)
WRS Across Track Error	± 5 km

Table 9-1 Orbital Parameters

Orbital parameters and errors are trended (ground track error, mean local time, inclination, etc.) by the FOT and maneuvers are planned accordingly. Δ-V maneuvers, used to counteract atmospheric drag, are necessary every one to six weeks depending on solar flux values. The FOT will trend the error between the ground track and the true WRS. Maneuvers will be planned and executed in order that this error does not grow larger than the maximum allowed ± 5 km. Operationally, an effort will be made to keep this error lower than ± 3 km.

Once it is decided that a maneuver is necessary, software residing in the MOC will be used to plan maneuver execution time and duration. FOT personnel execute this software, then using the output, plan the specific maneuver operations. Timelines for catbed heater turn on, proc execution, in addition for estimates of solar array position and ACS filter values are calculated. This information is then used in the various products necessary for the maneuver. ATSC, RTCS, and TSTOL procs are all involved with the execution of the maneuver. The procs are used to setup FSW values, and the actual firing commands and catbed heater commands are sent from RTCSs. Some of the parameters necessary to specify in the RTCS are the maneuver mode, thruster configuration to be used, total time of thruster firing (resolution of 0.1 seconds), and total number of orbit adjust pulses (resolution of 0.1 sec). While it will be desirable to have contact with the spacecraft during the execution of the maneuver, this may not always be possible.

An updated ephemeris file (predicted spacecraft position assuming a nominal maneuver) may be loaded onto the spacecraft and activated upon successful completion of the maneuver. In addition, new planning aids are generated, including new acquisition data for the ground sites, and will be distributed as appropriate (usually the next day). A post-maneuver report is generated that describes the results of the maneuver and a special set of maneuver plots are generated for analysis.

Inclination maneuvers will be required about every 12 months. The orbits inclination change over time will alter the descending node time (to be kept at 10:00 AM ±15 min). The FOT will begin planning maneuvers several weeks in advance and will involve Flight Dynamics engineers when necessary. Inclination maneuvers involve slewing the spacecraft approximately 90° in yaw to orient the thrusters perpendicular to me spacecraft velocity direction. In addition, the ETM+ cooler door is closed to protect the radiative cooler. After the burn is complete, the spacecraft is slewed back to a nominal attitude and the cooler door is opened. From this point, approximately 24 hours are needed to cool the ETM+ back to its operating temperature. Because at least one day of science operations are lost executing a Δ-i, they will normally be planned for the fall months as this minimizes the impact to the yearly data collection (avoiding the spring and summer growing seasons). Special packages, including training information, timelines, and updated procedures are distributed to the FOT prior to the operation and special training and/or simulations may take place.

- **Special Operations**

There are occasions where operations are necessary that deviate from the normal daily plan. These operations may be requested in support of the following situations:

- Anomaly recovery

- Change in FSW code necessary to optimize, update, or fix existing code
- Change in baseline operations or part of a study to do so
- Test of another part of the Landsat 7 system or approved test of an external system
- Measuring and documenting spacecraft performance for future reference or in support of an ongoing study

Often, the FOT will generate a request for such operations, either in the form of an Engineering Request, Command Request Form, or special memo. Once reviewed and approved by appropriate parties (this process may take hours to weeks depending on the operation/change being discussed) implementation is planned. Special operations are also “dry-run” on LSIM prior to implementation whenever possible to verify the process.

9.5 Offline Analysis and Planning Tools

A collection of tools exist in the Landsat 7 MOC for use in offline operations. Except where noted, these are FOT developed tools, are not part of the delivered “MOC” system, and run on Mac OS-based computers.

SSR Tlm Tool – This tool was developed to assist the FOT in the display of many of the SSR “special” telemetry output formats. The tool opens and reads six text files produced on the TPOCC system during a SSR special telemetry dump. The target data type is stripped from the files, processed and formatted, and written to an output file and made available for printing. These special telemetry formats are used during the weekly diagnostic dumps of SSR RAM and during anomaly investigations.

LoadChecker – Prior to uplinking the ATCS, this tool is used to syntax and logic check the daily load, primarily as a way of validating the operations performed on the wideband data chain. The ATCS Memory Map (the output from another Mission Ops Tool) file is opened and read, and the command data is interpreted for its affect on certain spacecraft components. The interactions of the components are compared to established rules of operations, and any violation of said rules are flagged and posted to the user. LoadChecker also provides the user with information on possible load activation times and possible false error messages that may be seen in the MOC’s Command Verification (CV) messages.

Auto Merger / Receiver – a pair of Mission Ops Tools used together for transferring and processing several types of data files. Auto Merger has a polling function that periodically checks a local FTP directory for new files. Files are checked for their processing type based upon file name, opened and processed, processed data is saved to file, and printed and/or transferred to another computer which is hosting the Receiver tool. Receiver accepts the data from Auto Merger and saves it to file on designated host Macintoshes. This tool combination provides the following processing (at this time):

ATCS Memory Map – convert to human readable form, print, and transfer to LoadChecker host computer.

RTCS Memory Map – convert to human readable form and print.

Orbital Element File – reformat as HTML file and transfer to FOT web server.

Scene Schedule – reformat as HTML and transfer to FOT web server.

NRZ-M Tool – used to interpret TPOCC's spacecraft command delog data. Opens and reads delog files, converts hex data from NRZ-M encoding to NRZ-L, locates CCSDS sync and packetizing parameters, evaluates CLTU header for validity, and breaks out command op-codes and datawords for inspection.

Inview Tool – converts GN and SN inview data and station schedule to a graphical timeline format. Opens and reads text files from MOPSS, interprets data, and produces graphical display covering a selected two hour window. Display shows inview versus scheduled passes, times of AOS and LOS, and overlapping contact relationships. Displays can be produced and printed in individual or batch mode.

TUT – provides graphical display of NCC TUT data files. Opens and reads text files that are emailed from NCC, breaks out the periods of available SN coverage, and displays the twelve SN data services that are available for Landsat 7 to schedule. The user selects a two-hour time window for display, and can move sequentially through the TUT data to view desirable services at a specified time.

Generic Trending and Analysis System (GTAS) - provides graphing and text report capability for daily spacecraft performance data. GTAS runs on Hewlett Packard platform and is provided by a group external to the FOT. For a data flow diagram involving GTAS, see Figure 9-1.

Landsat 7 Simulator (LSIM) - Models the spacecraft and varying degrees of spacecraft environment for use in TSTOL proc development, procedure validation, FOT training, and anomaly investigation. LSIM executes Landsat 7 FSW packages, and provides dynamic models of all major spacecraft systems and components. LSIM runs on Sun platform and is provided by a group external to the FOT.

9.6 Documentation and Reporting

The FOT is responsible for documenting and reporting all operations of the Landsat 7 spacecraft.

• Daily Operations Documentation

Daily operations of the spacecraft are documented in the shift logbook. All routine and non-routine activities are recorded here and support information such as page display snaps and contact schedules are archived in a separate book.

• Weekly Status Report

The Weekly Status Report is a standard electronic format Each report will include the following information:

Ops Activities
- special ops
- non-standard ops
- special requests or activities fulfilled

Anomalies
- S/C anomalies
- significant Ground System anomalies
- operator errors

Schedule Info
- upcoming special or non-routine events

Scene Acq Stats
IGS Total
EDC (LGS, EPGN) Total

• Monthly Status Review

The Monthly Status Review is a status presentation to the customer reviewing the information contained in the past four weeklies and a discussion of any open items or concerns.

- **Quarterly Status Review**

The Quarterly Status Review is a status presentation to the customer, along with all other elements of the Landsat 7 system, reviewing current status, past performance, and a discussion of any open items or concerns.

- **Spacecraft Performance Report (released periodically)**
  - Subsystem and component performance (current and historical)
  - Orbital history
  - Spacecraft Anomaly review and status
  - Predictions of future performance and constraints
  - Recommendations for operational changes (if necessary)

- **Post-Maneuver Report (distributed after each maneuver)**
  - Maneuver data, thruster efficiency, etc
  - Orbit and jet predictions vs actuals
  - NOTE: A special report is generated after Δ-i burns

- **Anomaly Report (distributed as necessary)**
  - Account of all events from anomaly occurrence to close of investigation
  - Current configuration of the spacecraft and/or ground system
  - Recommendations for necessary changes in operational procedures, command procedures, displays, databases, spacecraft constraints, etc
  - Recommendations or specific procedures to follow if the anomaly occurs again
  - Recommendations to prevent future occurrence of similar anomalies
  - Spacecraft performance predictions if affected by anomaly

Section 10 SOFTWARE and DATABASE CONFIGURATION and MANAGEMENT

10.1 Configuration Management and Product Control

Many products and resources are generated and used by the FOT in the course of supporting and operating the spacecraft. These resources and products must be managed to ensure that they remain up to date, accurate, and consistent. In addition, changes to these sources must be controlled to ensure that proper review and agreement or concurrence has been reached by the FOT, NASA, USGS, and any other elements effected by the change.

To this end, the FOT has in place configuration management (CM) processes for all critical resources and products used. Many of these processes are discussed throughout this document. In addition, the FOT is held to ISO 9000 compliance by Honeywell through training and periodic audits.

Documentation separate from the FOP is maintained by the FOT to explain the processes used, and track and manage any changes to all key products.

Section 11 OPERATIONAL INTERFACES

Numerous interfaces exist between the MOC and the other elements necessary for day-to-day operations. The following charts outline the products passed between the MOC and the elements, the frequency of the interfacing, and the methods of transmission.