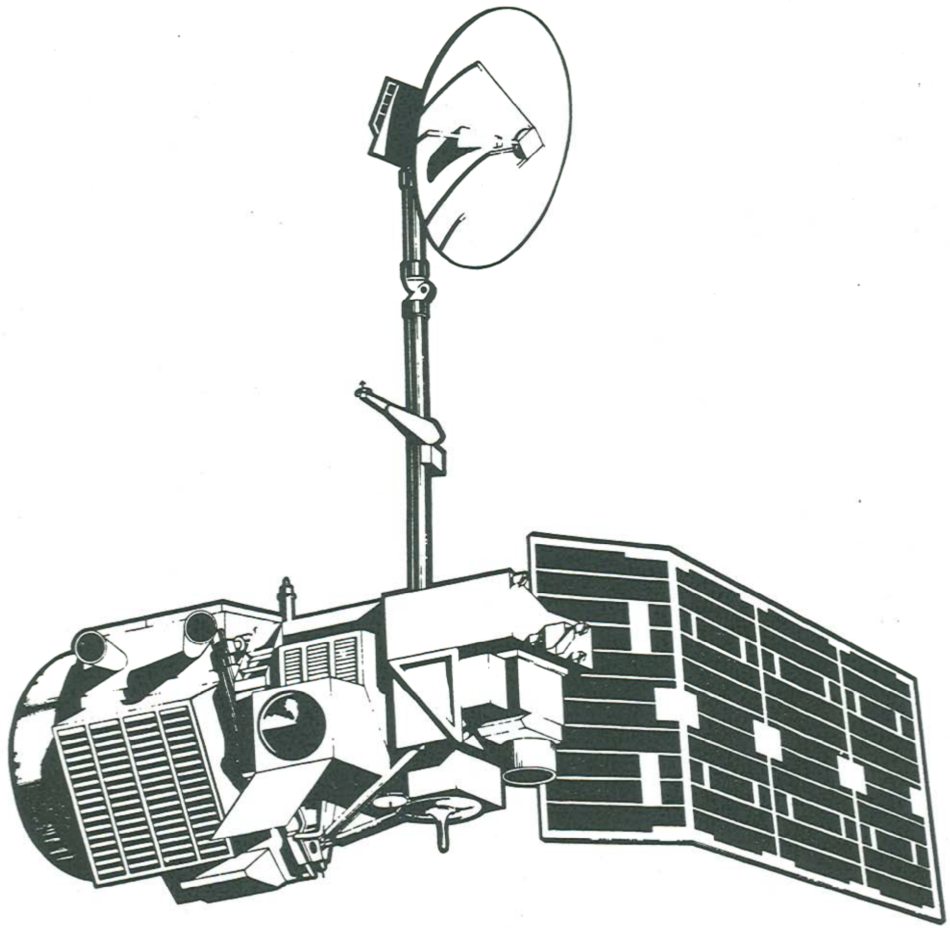

Landsat 4 Data Users Handbook

1984

U.S GEOLOGICAL SURVEY

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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PREFACE

Landsat products are produced and distributed by the Department of the Interior at the U.S. Geological Survey's Earth Resources Observation Systems (EROS) Data Center for the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) which manages the operational Landsat system as of January 31, 1983.

The Landsat Program, originally known as the Earth Resources Technology Satellite (ERTS) Program, is an outgrowth of activities supported by the National Aeronautics and Space Administration (NASA), principally through its Earth Resources Survey Program, and associated Federal agencies. These activities led to the concept of dedicated Earth-orbiting, land-observing satellites, the defining of spectral and spatial requirements for their instruments, and the fostering of research to determine the best means of extracting and using information from the data. The first such Earth Resources Technology Satellite, ERTS 1, was launched on July 23, 1972. Successive satellites of the same series were launched on January 22, 1975, and March 5, 1978. In 1975, the ERTS Program and the satellites were renamed to emphasize the program's prime area of interest: the resources of the Earth's land masses. Landsat 4, the first of the new-generation land-observing satellites, was launched July 16, 1982.

In a parallel program, the EROS Data Center has carried out and continues to support research and applications development in the use of remotely sensed data. The Data Center functions within the National Mapping Division of the U.S. Geological Survey.

This handbook is a joint publication of the National Oceanic and Atmospheric Administration and the U.S. Geological Survey. Technical assistance and information were generously provided by the National Aeronautics and Space Administration.

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INTRODUCTION

The intention of this document is to inform the Landsat 4 data user of how Landsat 4 data are initially acquired and processed, what data products are available, and where and how to get those products.

There have been three previous editions of this handbook: (1) the ERTS Data Users Handbook, issued in September, 1971; (2) a total revision called the Landsat Data Users Handbook, issued in September 1976 and April 1977 installments, and (3) a total revision for Landsat 3 in 1979.

Each of those editions dealt with significant changes in the Landsat Program, such as the launch of new satellites or modifications in data processing. This fourth edition is designed to inform the Landsat data user of the major developments brought about by the launch of Landsat 4, the first of the second-generation civilian Earth-observation satellites.

While some handbook sections deal with the basic design and function of the satellite (or spacecraft) and of the overall Landsat 4 system, user-related topics — such as orbit and coverage, data product availability, and ground processing/product generation — are emphasized. A glossary of remote sensing and satellite system terminology is also included. Acronyms are used throughout the handbook to save space in highly technical parts, but the terms are spelled out in places to aid readability. Highly technical or heavily detailed portions, such as a computer-compatible tape (CCT) format description, are to be found in appendix sections.

This handbook describes the Landsat 4 system and related communication and navigation satellite systems as they were designed to function. Information concerning modification or failure of subsystems can be found in issues of NOAA's "Landsat Data Users Notes" published quarterly and available by contacting: NOAA Landsat Customer Services, Mundt Federal Building, Sioux Falls, SD 57198, U.S.A. — Telephone (605) 594-6151, FTS 784-7151.

As pointed out elsewhere in this handbook, Landsat 5 (designated Landsat D′ until launch) is intended to function as a replacement satellite at failure of Landsat 4. Landsat 5 carries sensors and support systems that are designed to maintain the Multispectral Scanner and Thematic Mapper data flow initiated by Landsat 4. Except for the specific post-launch orbit calendar of Landsat 5 and subsystem engineering modifications, this handbook can serve the users of Landsat 5 data.

LANDSAT 4 SYSTEM

The Landsat 4 system is a major step in the orderly development and application of remotely sensed satellite data to management of the Earth's resources. It provides enhanced remote sensing capabilities, relative to earlier Landsats, through improved sensors, increased acquisition of global data, and more rapid processing of the data for users. An instrument called the Thematic Mapper provides new sensing capability. It is a mechanical scanning radiometer, operating in seven spectral bands, with 30-meter spatial resolution in six bands and 120-meter resolution in a thermal band. Earlier Landsat spacecraft carried radiometers with 80-meter resolution and operated in four or five spectral bands. The Landsat 4 system also incorporates a new, highly automated, ground data processing system at the Goddard Space Flight Center that calibrates and geometrically corrects the sensor data to subpixel accuracies and makes them available for archival or user-product processing only a few days after observation.

Major Program Objectives

The major objectives of the Landsat 4 program are to:

- Implement, under a single Federal agency manager, an operational phase in the Nation's civil land remote sensing satellite activity.
- Provide continued availability of Multispectral Scanner data.
- Maintain a national capability for collecting and distributing satellite remotely sensed land data while decisions concerning transfer of the land satellite responsibility to the private sector are being formed.
- Assess the capability of the Thematic Mapper instrument to provide beneficial and advantageous land data.
- Permit continued foreign data reception.

The Landsat 4 system was developed by the National Aeronautics and Space Administration (NASA). Management and operational responsibilities are transferred to the National Oceanic and Atmospheric Administration (NOAA) in stages as subsystems become operational.

The Landsat 4 mission consists of an orbiting observatory termed the flight segment—consisting of the satellite vehicle, the sensor systems, and the satellite-support systems—and a ground segment that includes the necessary data processing and support systems. The flight segment is designed for a two- year lifetime, with one backup spacecraft available. In addition to the Thematic Mapper (TM) sensor, the flight segment includes a Multispectral Scanner (MSS) designed to provide data similar to what were acquired by the MSS on Landsats 1, 2, and 3.

Data Acquisition and Transmission

The Landsat 4 observatory operates from a nominal 705-km-high, circular, Sun-synchronous orbit, imaging the same 185-km swath of the Earth's surface every 16 days. Digitized TM and MSS data are intended to be received directly from Landsat 4 by foreign or domestic ground stations at X-band. (See fig. 2.1A.) A separate S-band direct link compatible with that of Landsats 1, 2, and 3 is also provided to transmit MSS data to those stations equipped for receiving S-band only. This S-band link serves as the primary communication path prior to the availability of a Tracking and Data Relay Satellite System (TDRSS). Spacecraft telemetry and command communication paths are via TDRSS and through NASA ground stations, both at S-band.

As illustrated in figure 2.1B, image data are transmitted in

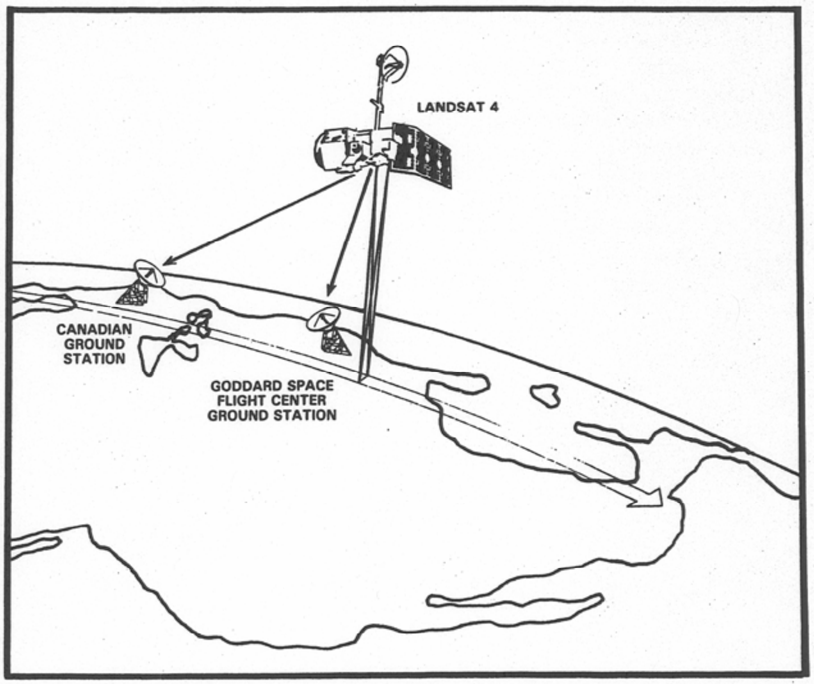


Figure 2.1A FOREIGN AND DOMESTIC GROUND STATIONS CAN RECEIVE DIGITIZED DATA DIRECTLY FROM LANDSAT 4 WHEN IT IS WITHIN RANGE.

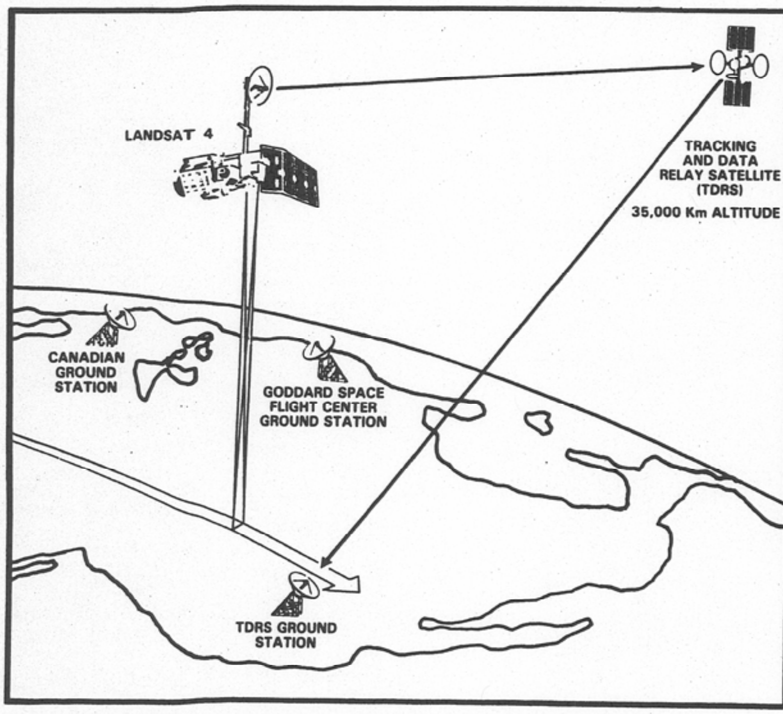


Figure 2.1B SENSOR DATA ARE TRANSMITTED VIA A TRACKING AND DATA RELAY SATELLITE TO ITS GROUND TERMINAL IN WHITE SANDS, NEW MEXICO.

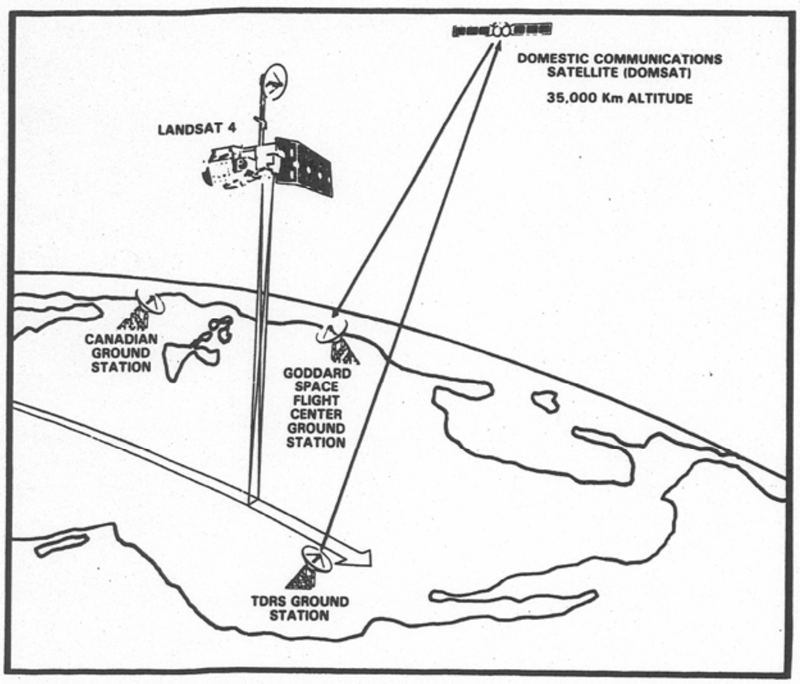


Figure 2.1C RECORDED TM AND MSS DATA ARE RELAYED TO THE GODDARD SPACE FLIGHT CENTER VIA A DOMESTIC COMMUNICATIONS SATELLITE (DOMSAT).

real time via a Tracking and Data Relay Satellite (TDRS) to its ground terminal at White Sands, New Mexico. TM and MSS data are recorded and then relayed via a domestic communications satellite (DOMSAT) to the Goddard Space Flight Center (GSFC) in Maryland for processing (fig. 2.1C). From Goddard, MSS digital data are radiometrically corrected and relayed by DOMSAT (fig. 2.1D)—and TM data are processed onto film and shipped by mail—to the Earth Resources Observation Systems (EROS) Data Center in South Dakota for storage, reproduction into a number of digital and film formats, and distribution to users.

Two Tracking and Data Relay Satellites are designed to be in geosynchronous orbits at 41W and 171W longitudes, respectively. This configuration permits the acquisition of TM and MSS sensor data of nearly all the Earth's surface, except for an area between 50N and 50S latitudes and between 67E and 82E longitudes (which can be covered in part by data recorded at the Thailand and India ground stations).

NOTE: Delays in the launch of the TDRS satellites significantly limited the amount of TM data that could be captured at the beginning of the Landsat 4 mission. A Transportable Ground Station located at GSFC allows TM data acquisition over the eastern half of the United States out to approximately the 100° meridian (fig. 2.2). TM data acquisition capabilities for the remainder of the United States are provided by tape recorders at the Prince Albert Canadian receiving station. MSS data are captured through existing Landsat ground stations until the TDRSS is operational. U.S. ground stations at Goldstone, California, and Gilmore Creek, Alaska, relay MSS data to Goddard as in the past. Selected foreign stations record MSS data and ship the tapes to Goddard. Tracking data for Landsat 4 are obtained via TDRSS or the ground sta-

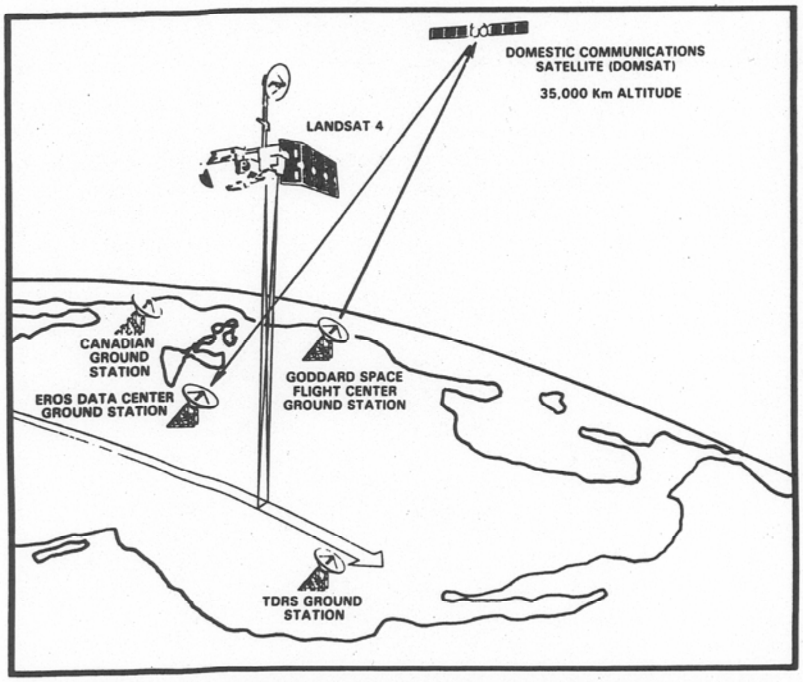


Figure 2.1D RADIOMETRICALLY CORRECTED DIGITAL MSS DATA ARE RELAYED VIA DOMSAT TO THE EROS DATA CENTER.

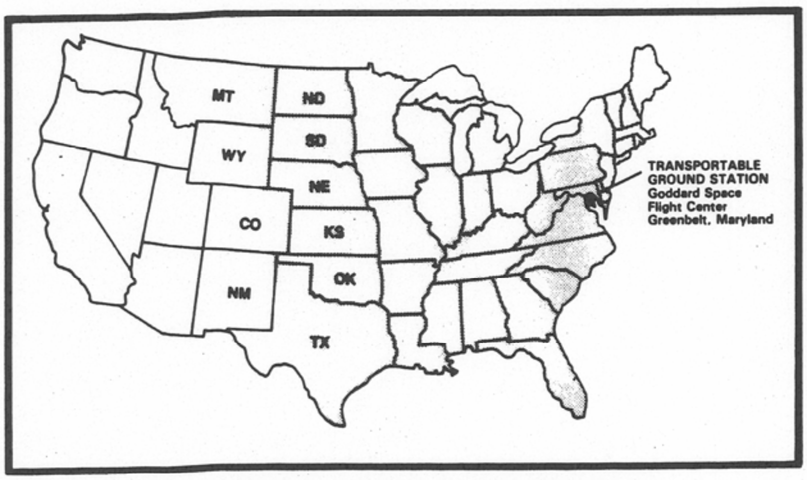


Figure 2.2 APPROXIMATE U.S. RECEPTION RANGE OF TRANSPORTABLE GROUND STATION AT GODDARD SPACE FLIGHT CENTER.

tions. Ephemeris data, required by the spacecraft for attitude control and by the ground segment for image correction processing, are computed at Goddard. The Landsat 4 spacecraft, however, is equipped with a Global Positioning System (GPS) receiver/processor that can provide the spacecraft ephemerides through communication with GPS navigation satellites.

Figure 2.3 depicts the Landsat 4 system and associated elements. Details on the flight segment design and assembly are in Section 3, Spacecraft, of this handbook; details on communications are in Section 6, Data Communications; and details on data processing and support systems, outlined in figure 2.4, are in Section 7, Ground Processing and Product Generation.

Landsat 4 Replacement

Landsat 5 (designated Landsat D′ until launch) is intended to function as a replacement satellite at failure of Landsat 4. Landsat 5 carries sensors and support systems that are designed to maintain the Multispectral Scanner and Thematic Mapper data flow initiated by Landsat 4. Except for the specific post-launch orbit calendar of Landsat 5 and subsystem engineering modifications, this handbook can serve the users of Landsat 5 data.

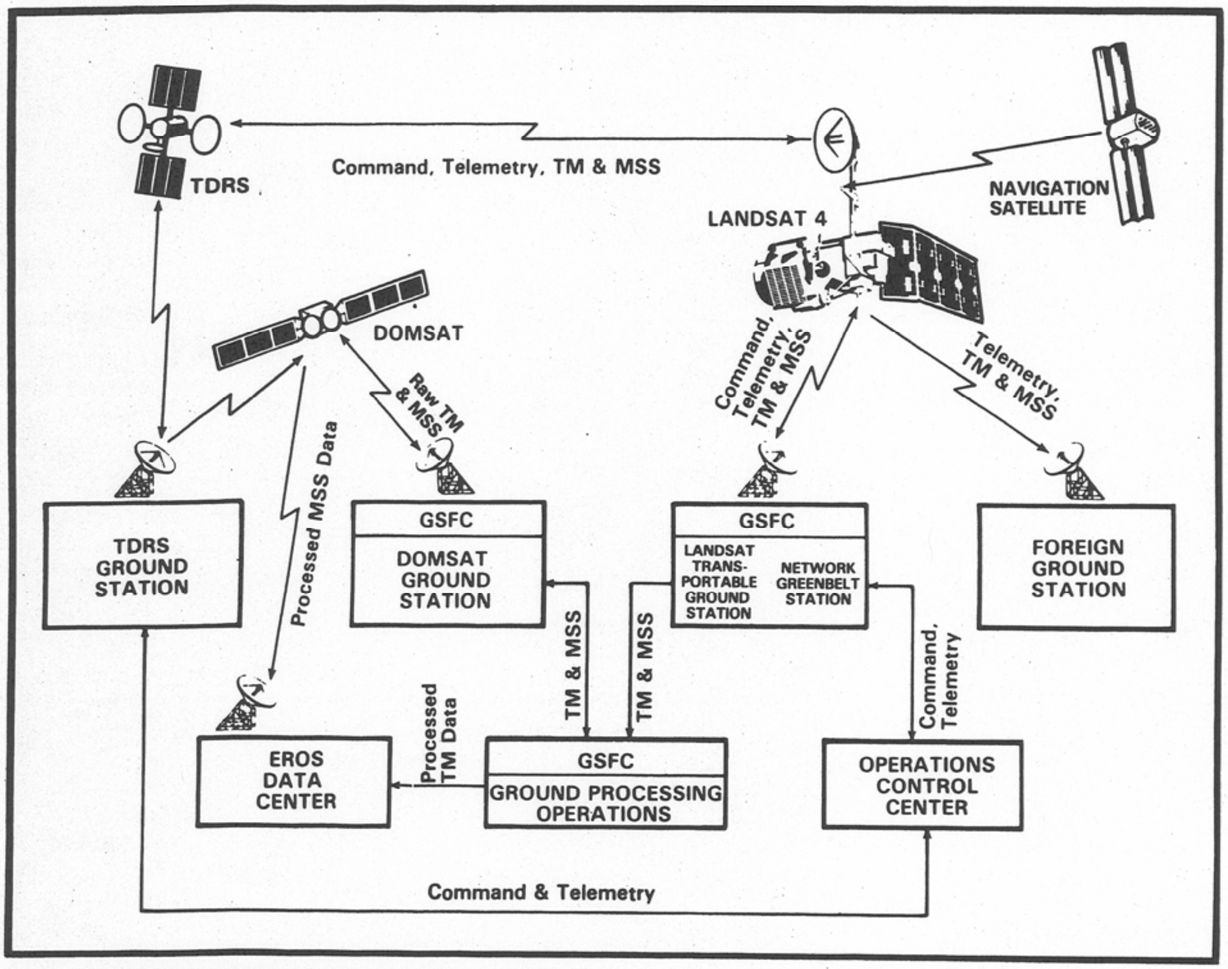


Figure 2.3 LANDSAT 4 SYSTEM OVERVIEW.

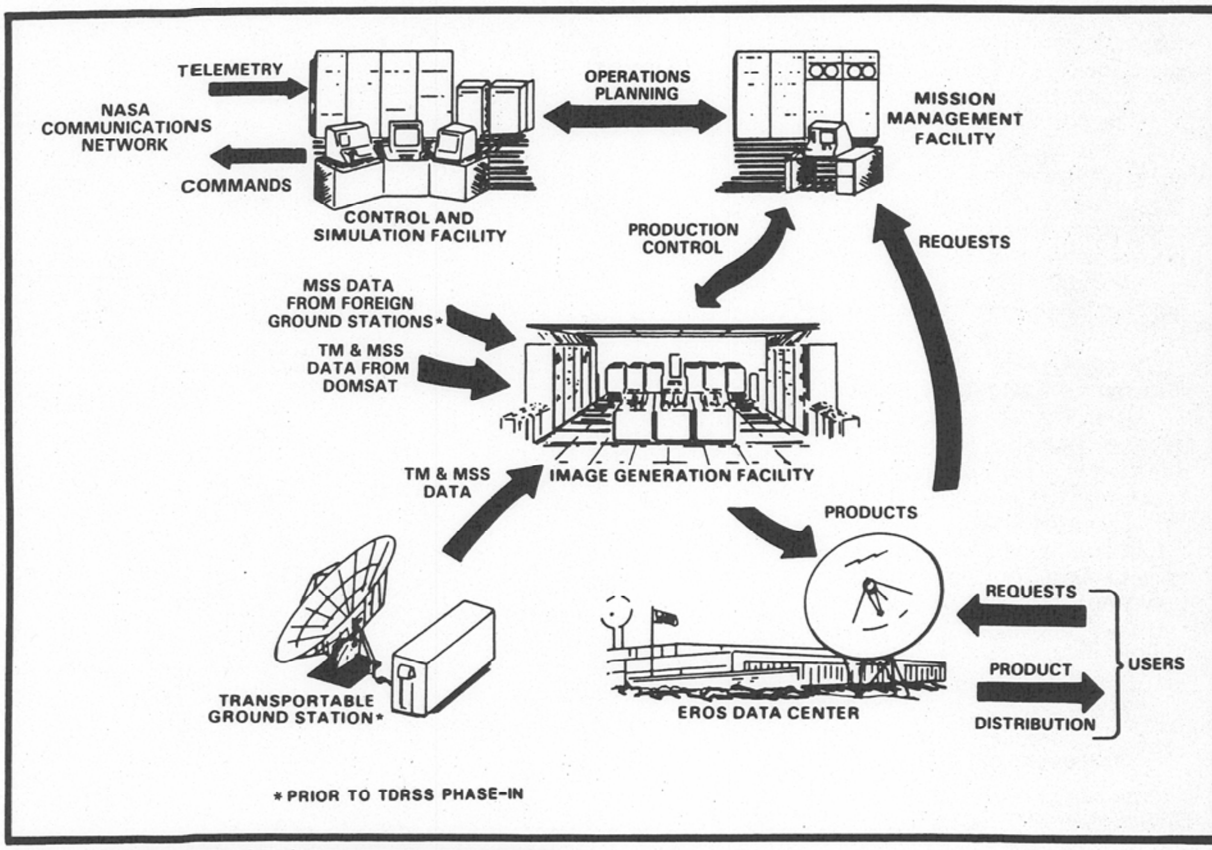


Figure 2.4 LANDSAT 4 GROUND SEGMENT

SPACECRAFT

Functions

The Landsat 4 spacecraft functions to provide:

- Earth images via the Multispectral Scanner and the Thematic Mapper.
- Radio frequency links to transmit the images directly to ground stations or through the Tracking and Data Relay Satellite System (TDRSS).
- Power to the instruments and support equipment.
- Attitude and orbital stability for the instruments.
- Telemetry monitoring of vital spacecraft functions.
- Command capabilities to control spacecraft operation from the ground.

The spacecraft, shown in figure 3.1, is characterized by its tall mast supporting the Tracking and Data Relay Satellite antenna and by its single solar array wing.

The main body of the spacecraft is comprised of NASA's standard Multimission Modular Spacecraft and the Landsat Instrument Module (fig. 3.2). The Multimission Modular Spacecraft includes the Attitude Control, Communications and Data Handling, Power, and Propulsion subsystems. The Instrument Module carries the new Thematic Mapper sensor, the Multispectral Scanner, a wideband communications subsystem, the high-gain TDRS and other antennas, and a solar array capable of generating 2 kilowatts of power. This spacecraft is designed for retrieval by the Space Shuttle.

The long dimension of the spacecraft body (the roll axis) lies in the plane of the orbit; the yaw axis is oriented to the local vertical (parallel to the antenna mast); and the pitch axis is normal to the orbit plane and parallel to the rotation axis of the solar array (fig. 3.1).

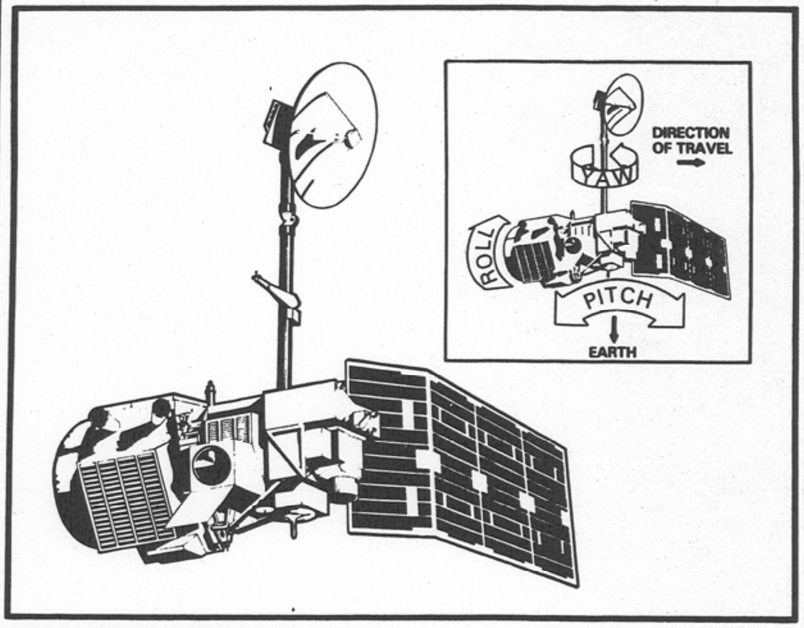


Figure 3.1 LANDSAT 4

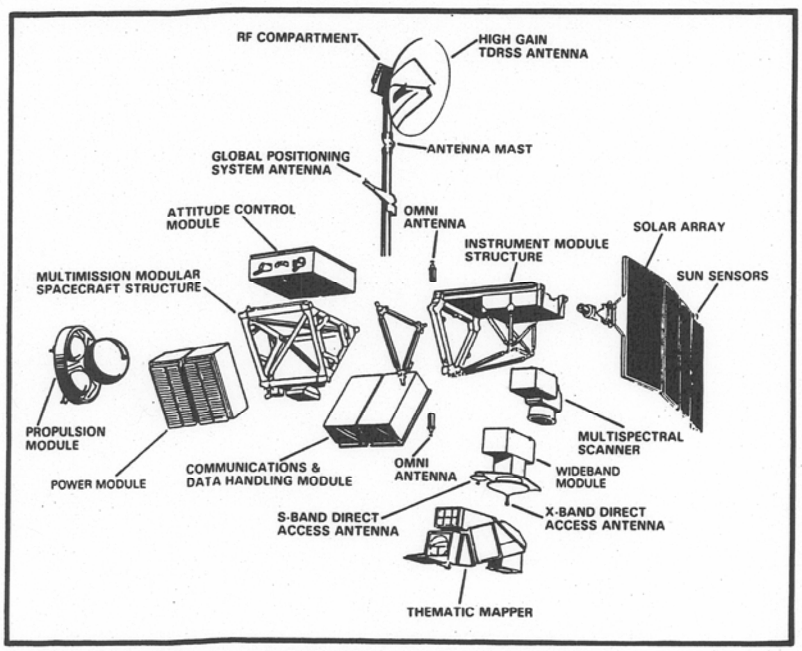


Figure 3.2 MODULAR DESIGN OF LANDSAT 4

Instrument Module

The principal sensing instruments are the Thematic Mapper (TM), located at the base of the Instrument Module, and the Multispectral Scanner (MSS), located at the forward end of the Instrument Module (fig. 3.3). Each instrument uses a moving-mirror assembly to scan in the cross-track direction (perpendicular to the spacecraft ground track) and depends upon the relative motion of the spacecraft to achieve the along-track scan. Details on the sensors are to be found in Section 4, Sensors.

The mast mount for the TDRSS communications assembly ex-

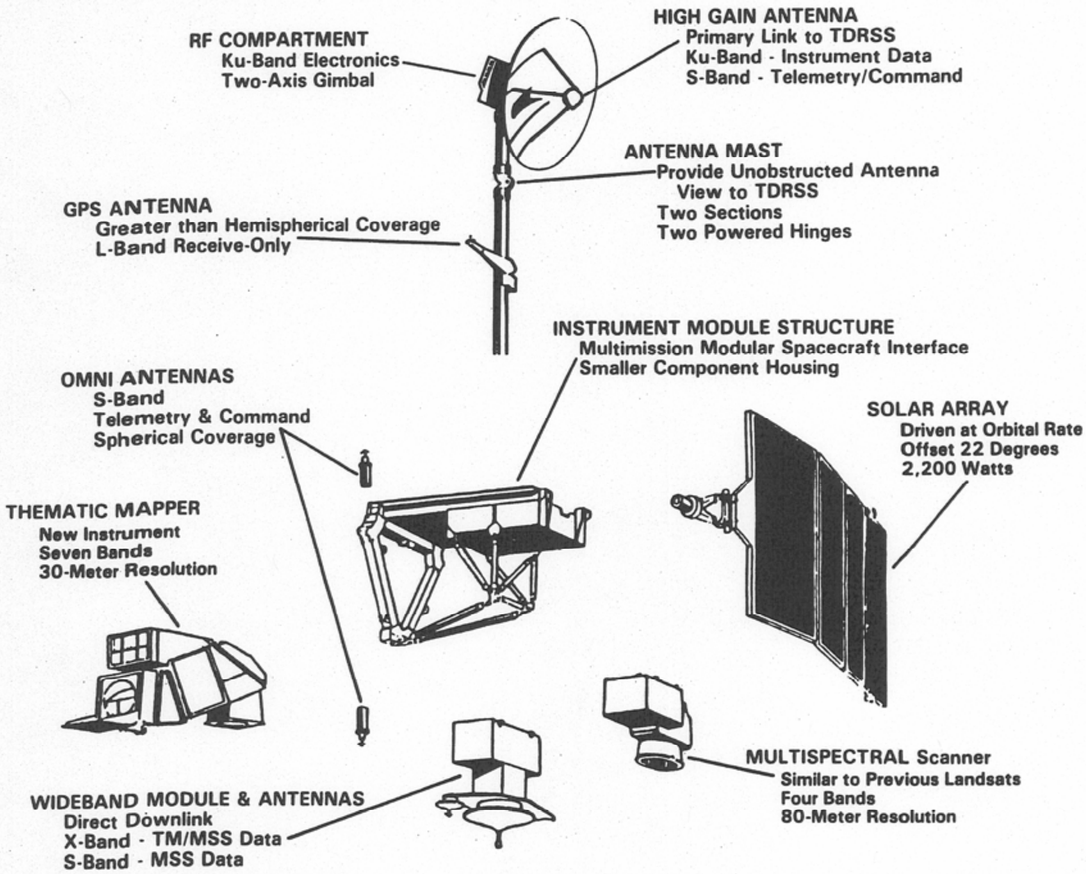


Figure 3.3 INSTRUMENT MODULE

tends 3.7 meters (12.5 feet) above the spacecraft body to provide a clear field of view to the Tracking and Data Relay Satellites.

The Wideband Communication Subsystem enables the spacecraft to transmit MSS and TM instrument data to both TDRSS and ground-based users. The subsystem consists of the radio frequency (RF) compartment, wideband module, and gimbal drive assembly which points the antenna. The RF compartment is integrally mounted on the 1.8-meter (6-foot) diameter Ku-band high-gain TDRSS antenna, and contains the Ku-band autotrack receiver front-end components and all other Ku-band RF components required to transmit to TDRSS. The wideband module, mounted within the Instrument Module structure, contains the mode selection and modulation equipment; this equipment is used for both the Ku-band single-access and X-band links in addition to all the X-band RF equipment required for direct communications with ground stations. The S-band transmitters are mounted in the Instrument Module structure above the wideband module, and the S-band antenna is mounted on the wideband module, adjacent to the X-band antenna.

The Global Positioning System (GPS) on the flight segment includes an antenna for receipt of L-band signals from GPS navigation satellites, a preamplifier, an oscillator, and a receiver/processor assembly. The GPS receives data that are continuously transmitted from a constellation of navigation satellites (fig. 3.4), selects the optimum subset of satellites from which to utilize the data, and calculates three-dimensional position and velocity data of the Landsat 4 satellite.

Every 6 seconds, nominally, updated position and velocity data are output from the receiver/processor assembly to the onboard computer in the Communications and Data Handling Subsystem. These updates are transformed in the computer into the proper coordinate systems and utilized for attitude control and the computation of TDRS antenna pointing angles. The position and velocity data are also downlinked on telemetry for later use in geometric correction of Thematic Mapper and Multispectral Scanner imagery on the ground.

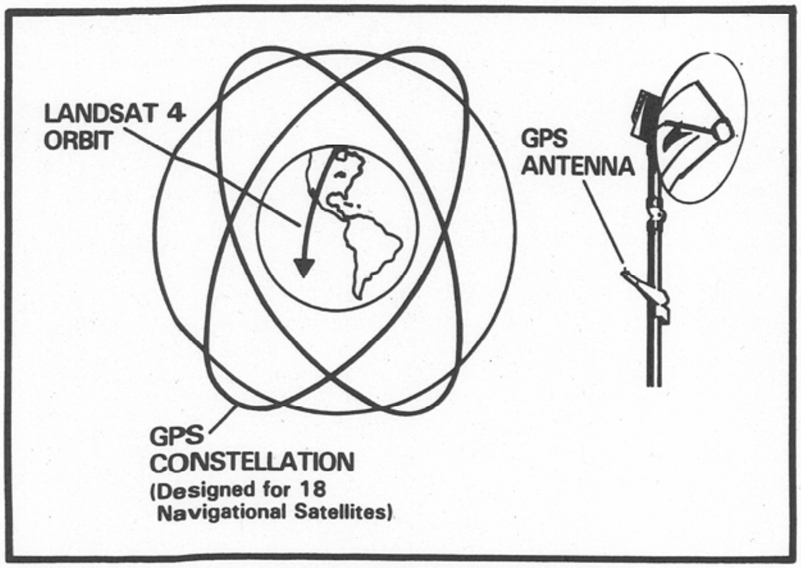


Figure 3.4 GLOBAL POSITIONING SYSTEM (GPS)

In the early 1980's, only five of the planned 18 navigation satellites will be in orbit. Consequently, there will be periods when no navigation satellites are in range of the Landsat GPS antenna. During these periods, the receiver/ processor operates in a "propagate" mode, estimating the position and velocity of Landsat 4 based on past data.

Multimission Modular Spacecraft

The multimission modular spacecraft includes four subsystems: Power, Attitude Control, Communications and Data Handling, and Propulsion (Figure 3.5), all mounted on a triangular structure. Each subsystem is a module, with the first three contained in identical 122- by 122- by 30-cm housings. The forward end of the Multimission Modular Spacecraft provides the mating surface for the Instrument Module and the aft end contains the Propulsion Module.

The Communications and Data Handling Subsystem provides telemetry data output at two data rates: 8 kilobits per second (Kbps) during normal operations (with a 1-Kbps backup for use during launch and in case of contingencies), and a 32-Kbps transmission mode for onboard computer memory dump and payload correction data transmission. Two standard tape recorders are included for recording of telemetry data and subsequent playback at either 128 or 256 Kbps.

The command portion of the subsystem provides serial and pulse command capability. Landsat 4 utilizes three command rates: 125, 1,000, and 2,000 bits per second, depending on the uplink command path. All communications between Landsat 4 and the ground take place via the Communications and Data Handling Module, with the exception of wideband instrument data. The Communications and Data Handling Module also contains an onboard computer with 64,000 words of memory. The capability exists to fully reload the memory via command uplink from the ground, and to dump the memory via telemetry. The computer is used for a variety of functions including attitude control, high-gain antenna pointing/control, spacecraft/TDRS/solar ephemeris computation, failure detection and correction, and housekeeping telemetry monitoring.

The Attitude Control Subsystem is a high-precision, zero-momentum system with a three-axis pointing accuracy of 0.01 degree and a stability of 10^{-6} degree per second. It achieves this precision using an inertial reference unit with attitude updates from two star trackers. Torquer magnets continuously unload the momentum wheels. Backup wheel unloading is provided by the propulsion module. Since the specific pointing modes are mission-unique, all control algorithms are implemented in software executed in the onboard computer. A safe-hold mode is provided that maintains an Earth-pointing attitude without use of the onboard computer. It utilizes redundant scanning Earth-horizon sensors as a two-axis (pitch/roll) reference with a gyrocompass reference in yaw.

The Propulsion Module is mounted at the aft end of the spacecraft and uses hydrazine fuel. Thrusters are used to make orbit adjustments to maintain the 16-day-repeating Landsat 4 ground swath, for backup Attitude Control System momentum-wheel unloading, and for the orbit altitude changes needed for Shuttle rendezvous.

Communication Links

Landsat 4 uses a wide variety of communication links in order to fulfill its mission. There are three kinds of links:

- Narrowband—for housekeeping telemetry, command, and tracking.
- Wideband—for Earth observation (MSS and TM) data
- Global Positioning System—for navigation and time data.

S-band links are used by Landsat 4 for TDRSS narrowband and Ku-band for wideband communications. Both narrowband and wideband communications are transmitted and received through the high-gain TDRSS antenna. The S-band data are also transmitted through omni-directional antennas for ground station or TDRSS narrowband communications.

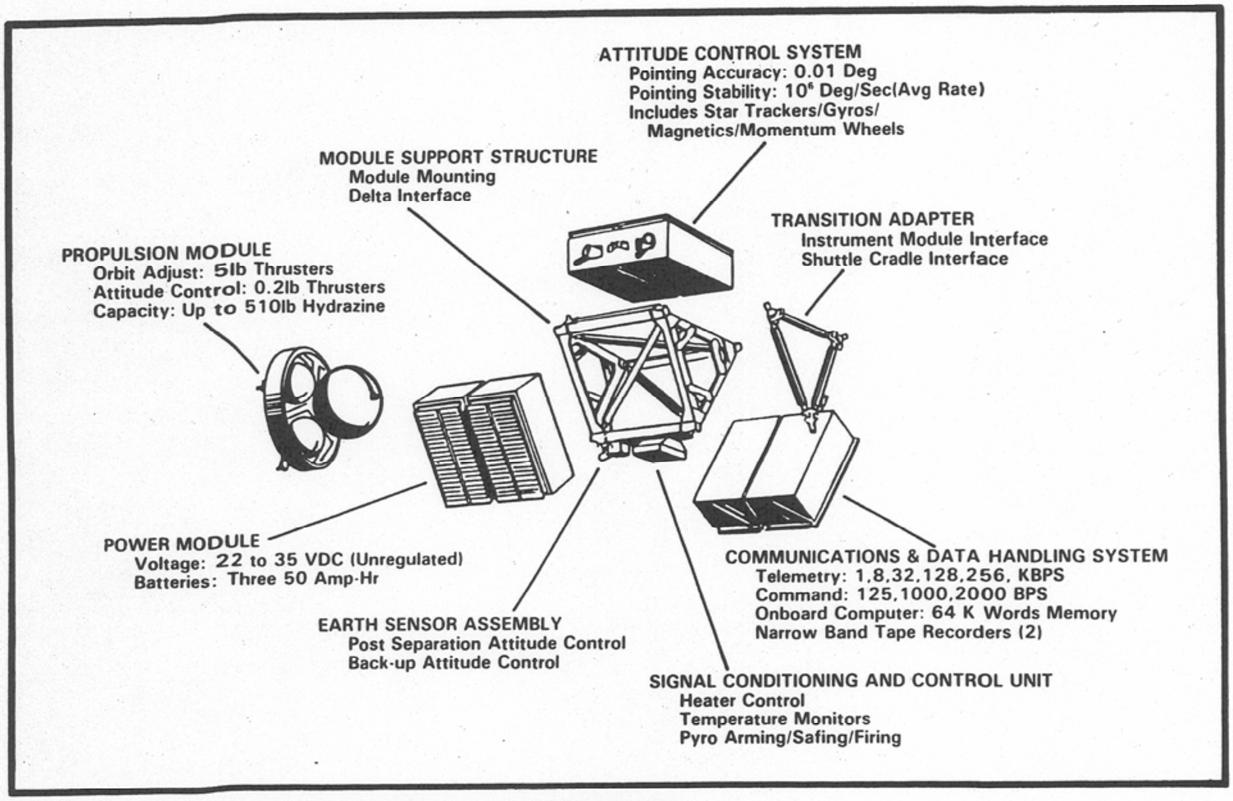


Figure 3.5 MULTIMISSION MODULAR SPACECRAFT

Existing foreign ground stations are equipped to receive 15-megabit-per-second (Mbps) MSS data on S-band. However, the S-band bandwidth is inadequate to handle the 84.9-Mbps data from the Thematic Mapper. An X-band link is provided to permit TM or MSS data to be received by TM-equipped foreign ground stations.

The receive-only links to GPS are at L-band. Details on communication links can be found in Section 6; Data Communications.

SENSORS

The remote-sensor instruments mounted on Landsat 4 are the Thematic Mapper (TM) and the Multispectral Scanner (MSS).

THEMATIC MAPPER

The Thematic Mapper is an advanced, multispectral scanning, Earth resources sensor designed to achieve higher image resolution, sharper spectral separation, improved geometric fidelity, and greater radiometric accuracy and resolution in comparison to Multispectral Scanner performance characteristics. TM data are sensed in seven spectral bands simultaneously. Table 4.1 lists the specific TM spectral bands and their principal applications. Bands 1-5 and 7 have an instantaneous field-of-view (IFOV) equivalent to a 30-meter square when projected to the ground; band 6 has an IFOV equivalent to a 120-meter square on the ground.

The TM (fig. 4.1) is mounted in the spacecraft in a horizontal position with the sun shade pointing toward Earth. Directly above the sun shade aperture is a scan mirror surrounded by its drive mechanisms, control electronics, and scan monitor hardware. The primary mirror mounts about halfway down the length of the telescope of the device, preceded by optical baffling and the secondary mirror. Directly behind the primary mirror are the scan line corrector, internal calibrator, and the visible detector focal plane with its mounting hardware and alinement mechanisms. The radiative cooler (containing the

Table 4.1 TM SPECTRAL BAND APPLICATIONS

BAND	SPECTRAL RANGE	PRINCIPAL APPLICATIONS
1	0.45-0.52 µm	COASTAL WATER MAPPING; SOIL/VEGETATION DIFFERENTIATION; DECIDUOUS/CONIFEROUS DIFFERENTIATION
2	0.52-0.60 µm	GREEN REFLECTANCE BY HEALTHY VEGETATION
3	0.63-0.69 µm	CHLOROPHYL ABSORPTION FOR PLANT SPECIES DIFFERENTIATION
4	0.76-0.90 µm	BIOMASS SURVEYS; WATER BODY DELINEATION
5	1.55-1.75 µm	VEGETATION MOISTURE MEASUREMENT; SNOW/CLOUD DIFFERENTIATION
6	10.4-12.5 µm	PLANT HEAT STRESS MEASUREMENT; OTHER THERMAL MAPPING
7	2.08-2.35 µm	HYDROTHERMAL MAPPING

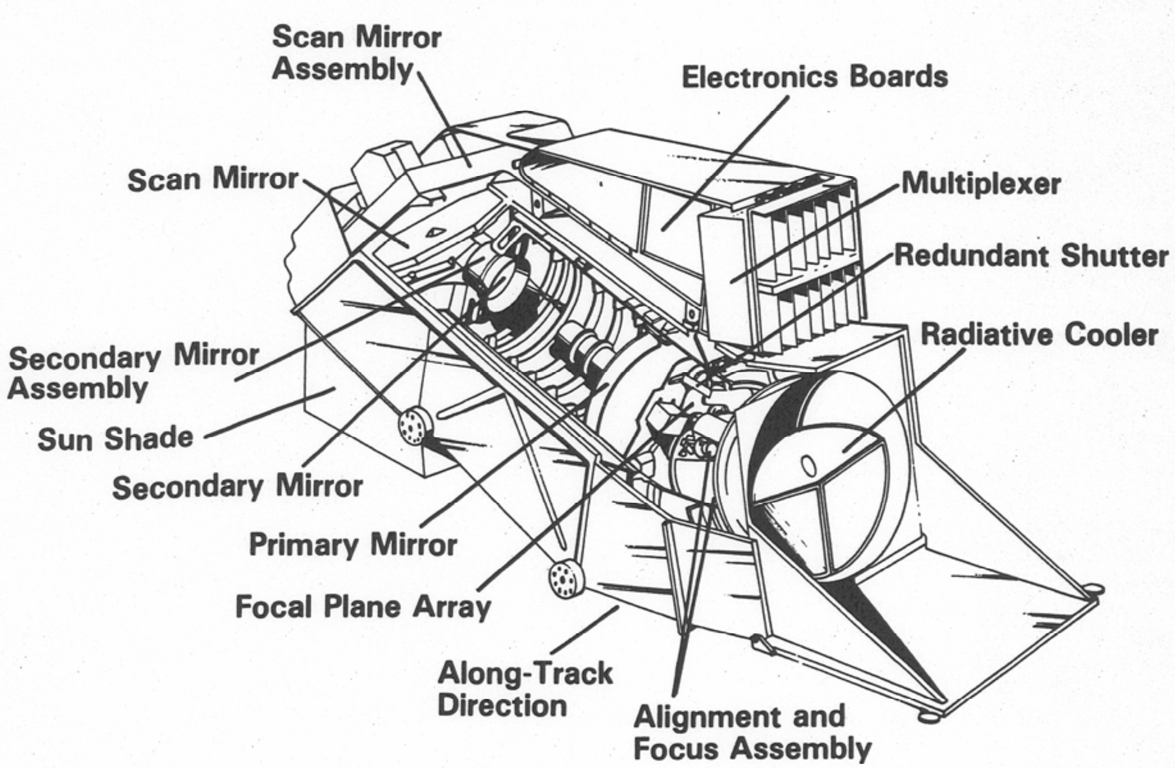


Figure 4.1 CUTAWAY VIEW OF THEMATIC MAPPER

cooled focal plane assembly), relay optics, and infrared detector arrays are located on the instrument's aft end. Electronic equipment is packaged above the telescope in a wedge-shaped box containing the multiplexer, power supplies, signal amplifiers, and filters for all channels.

The detector assemblies for spectral bands 1-4 are located at the primary focal plane and employ 16 detectors for each band. The detector assemblies at the cooled focal plane consist of two near infrared bands (5 and 7) with 16 detectors each and one thermal band (6) with four detectors. Thus, during each scan mirror sweep, 16 scan lines of data are generated for each of bands 1-5 and 7, and four are generated for band 6.

A scan angle monitor on the scan mirror passes signals to the timing mechanism in the multiplexer to indicate the beginning (P_0), midscan (P_1), and end (P_2) of the period in the scan mirror's travel when data are taken in the forward scan direction (fig. 4.2), and equivalent signals (P_3, P_4, and P_5) for beginning, midscan, and end of the reverse scan. A "line stop" signal (P_2 and P_5) indicates the end of the formatting period and is buffered and retransmitted to the scan line corrector to initiate motions that correct for overlap. A second signal, delayed from "line stop" by a programmable period, acts as a synchronization signal to the calibration shutter. These scan angle monitor pulses provide for synchronization of the scan line corrector, calibration shutters, filter shutter, and dc restore circuits.

The scan line corrector (located in front of the prime focal plane) rotates the TM line-of-sight backward along the ground track to generate scan lines that are straight and perpendicular to the ground track. (See figure 4.6.) During each turnaround period of the scan mirror, the internal calibration stimulates the individual channel voltages for all seven spectral bands that provide routine monitoring of detector condition for use in ground processing of images. The calibration signals for bands 1-5 and 7 are derived from three regulated tungsten filament lamps, and the calibration source for band 6 is a commandable blackbody with three selectable temperature settings. A black surface of known temperature is used to restore the outputs of all channels to known levels.

As the scan mirror sweeps the

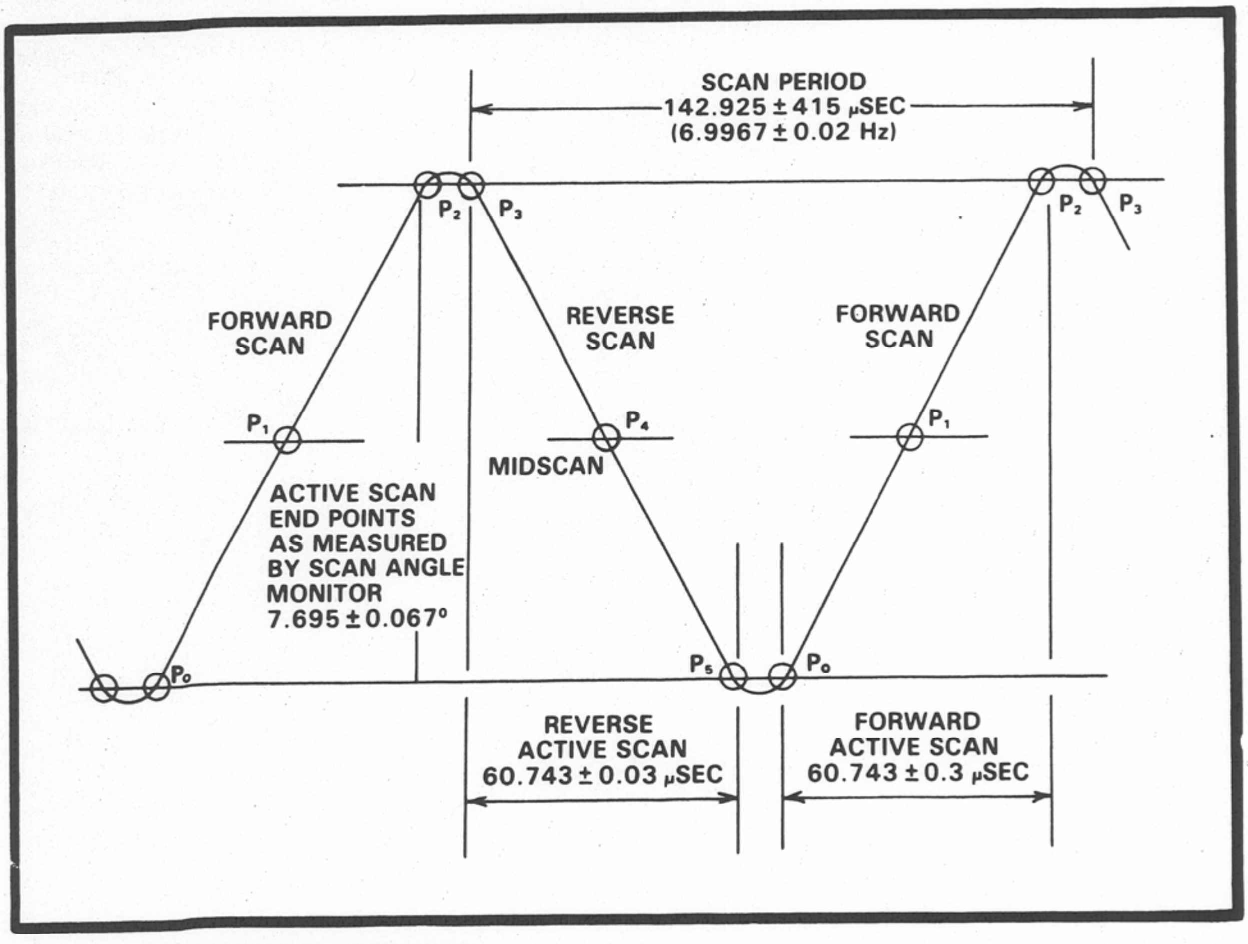


Figure 4.2 SCAN MIRROR DYNAMICS

TM line-of-sight back and forth seven times per second in a direction normal to the ground track, it forms a raster of 16 lines in bands 1-5 and 7, and four lines in band 6 for each sweep direction. Data are collected during both the forward (west-to-east) and reverse (east-to-west) scans. (Note that night-time data are collected in the ascending mode, reversing geographic motion and scanning directions.) The Ritchey-Chretien telescope images the scanned scene energy onto the prime focal plane as the scan line corrector is operating to provide forward and reverse scan swaths adjacent to each other. At the prime focal plane bands 1-4 each employ a 16-element detector array to translate the sensed scene energy into low-level electrical signals that are amplified, converted to 8-bit digital words, and then multiplexed into the 84.9-megabit-per-second (Mbps) data stream transmitted to the ground. A two-mirror, all-reflective relay re-images the incoming energy onto the cooled focal plane located in the radiative cooler, where bands 5 and 7, each utilizing a 16-element detector array and band 6, utilizing a four-element detector array, translate the scene energy into low-level electrical signals. These signals are amplified and converted into 8-bit digital words that are multiplexed into the 84.9-Mbps data stream transmitted to the ground.

THEMATIC MAPPER DESIGN AND FUNCTION

The TM functions as shown in the block diagram (fig. 4.3). Scene energy passes through several major subsystems before it is collected by the solid-state detectors at the focal plane. These subsystems are:

- Scan Mirror Assembly
- Primary Telescope
- Scan Line Corrector
- Primary Focal Plane Array
- Relay Optics
- Cooled Focal Plane Array
- Internal Calibrator

Scan Mirror Assembly

Scene energy enters the system through the Scan Mirror Assembly that moves with the spacecraft in the along-track direction and oscillates across track in the forward (west-to-

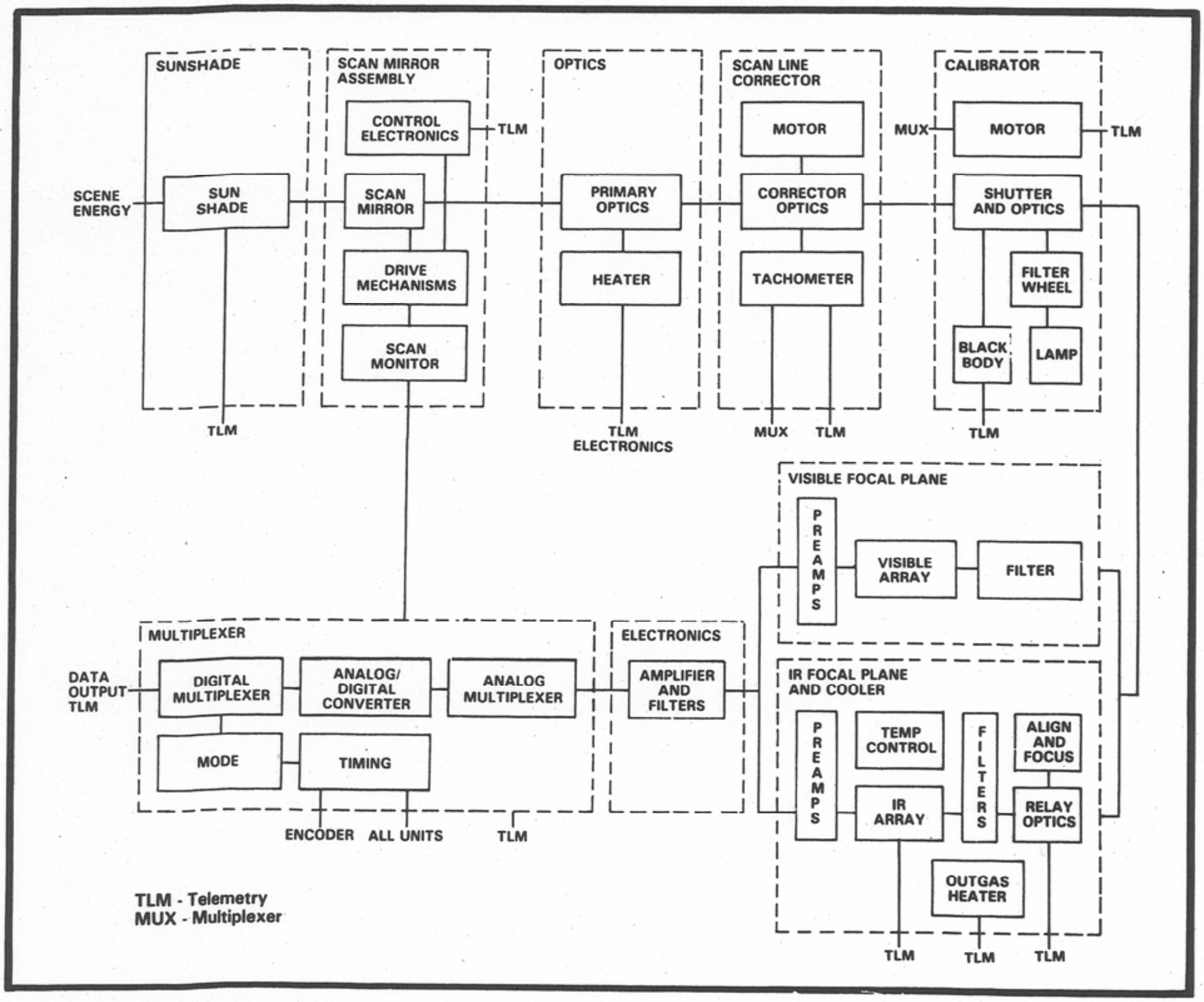


Figure 4.3 TM FUNCTION

east) and reverse (east-to-west) directions during the descending (daylight) portion of the orbit. The scan mirror is designed to operate linearly over a mechanical scan angle of 7.7° at a 7-Hz rate with the required turnarounds at scan end points occurring in 10.7 microseconds. Figure 4.4 illustrates the scan mirror angular position as a function of time, indicating scan angle monitor points. The scan mirror is elliptical (53.47 x 41.28 cm), sized to provide an equal area at all scan angles. The size of the mirror required that a light, brazed-beryllium, egg-crate design be used for its construction (table 4.2) to minimize the mass and moment of inertia of the mirror while making scan turnarounds.

Primary Telescope

The 41-cm Ritchey-Chretien telescope uses primary and secondary mirror surfaces to provide simultaneous correction of spherical aberration and coma. Both primary and secondary mirrors are fabricated from ultra-low expansion glass and incorporate a weight-saving, internal egg-crate structure. Design parameters of the primary telescope are shown in table 4.3.

Scan Line Corrector

The scan line corrector consists of a pair of parallel beryllium mirrors. These mirrors are mounted at an angle of 45° with respect to the optical axis and rotate about an axis normal to the axis of the scan mirror in a sawtooth fashion as shown in figure 4.5. The scan line corrector is located behind the primary optics and compensates for the forward motion of the spacecraft, allowing the scan mirror to produce usable data in both scan directions (scan lines straight and perpendicular to the ground track). The corrector jumps ahead at the mirror turnarounds so that the next set of raster lines is contiguous to the previous set. Figure 4.6 illustrates the scan lines with and without scan line correction.

Prime Focal Plane Array

The prime focal plane, which contains the silicon detectors and preamplifier components for the first four visible spectral bands, is located at the prime focus of the primary telescope. The prime focal plane is packaged in a high-density arrangement to maintain a minimum band-to-band spacing of 2.5 mm, which dictates that the critical first-stage preamplifier field-effect transistors (FET's) and 10^9 ohm feedback resistors be located on substrates behind and normal to the focal plane. The remainder of the preamplifier

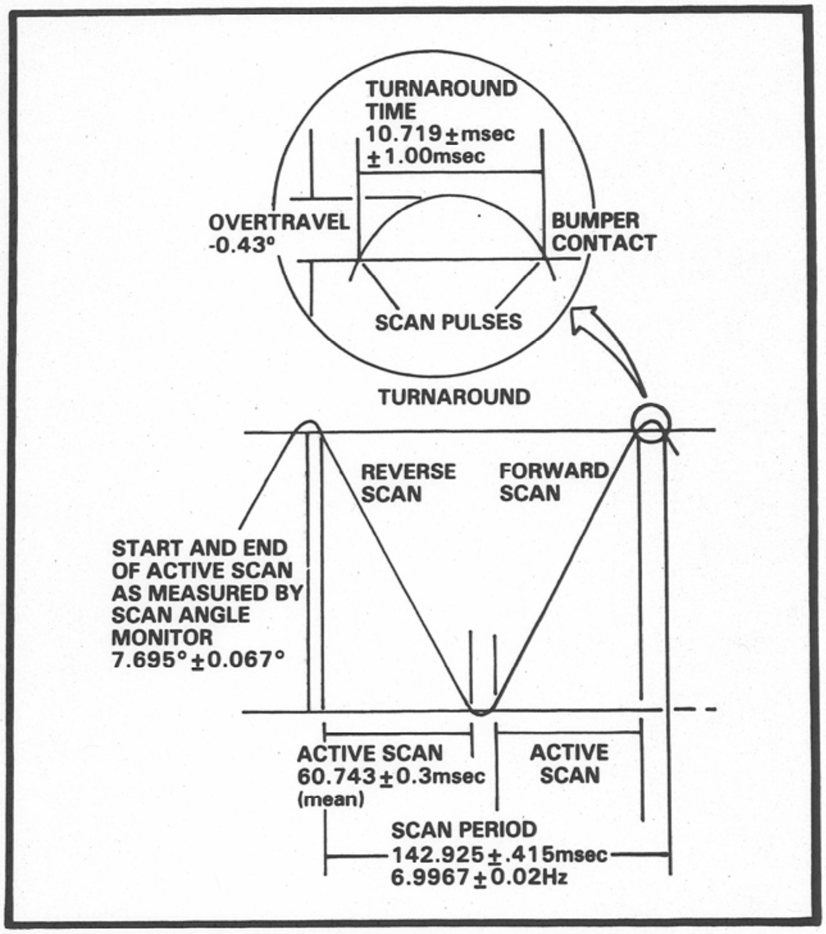


Figure 4.4 TM SCAN MIRROR ANGULAR POSITIONS

Table 4.2 SCAN MIRROR DESIGN PARAMETERS

SWATH LENGTH	185 km
SCAN PERIOD	142.925 msec
SCAN FREQUENCY	6.9967 Hz
SCAN EFFICIENCY	0.85
ACTIVE SCAN TIME	60.743 msec
TURNAROUND TIME	10.719 msec
IFOV DWELL TIME	9.611 msec
LINE LENGTH	6320 IFOV
SIZE	21.050 x 16.250 in. (53.47 x 41.28 cm)
MATERIAL	NICKEL-PLATED BERYLLIUM (EGGCRATE) SILVER COATING WITH SiO_2 OVERCOAT

Table 4.3 PRIMARY TELESCOPE DESIGN PARAMETERS

CONFIGURATION	RITCHEY-CHRETIEN
f/NO.	6.0
MIRROR MATERIAL	GLASS (TITANIUM SILICATE), EGGCRATE CONSTRUCTION, SILVER COATING WITH SiO_2 OVERCOAT
PRIMARY MIRROR CLEAR APERTURE DIAMETER	16.20 in. (41.15 cm)
SECONDARY MIRROR BAFFLE DIAMETER (OBSCURATION)	6.173 in. (15.7 cm)
TELESCOPE CLEAR APERTURE	1056 cm²
EFFECTIVE FOCAL LENGTH	96 in. (243.8 cm)

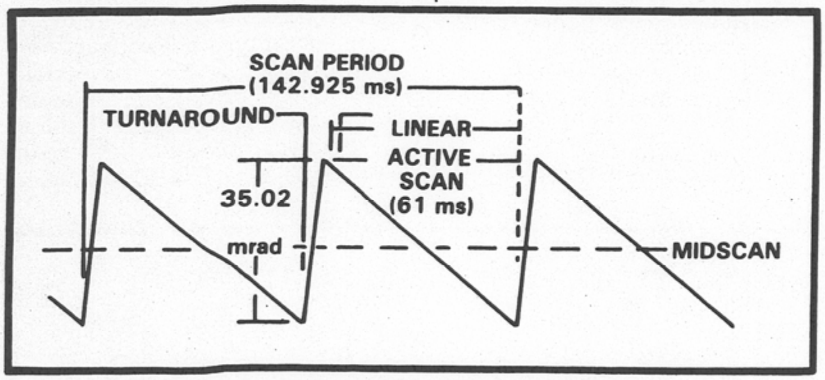


Figure 4.5 TM SCAN LINE CORRECTOR MOTION

components are mounted in hybrid circuits that are connected to the focal plane through flexible cables.

For bands 1-4, each detector assembly uses a 16-element monolithic silicon detector array with an instantaneous field-of-view (IFOV) of 42.5 microradians to convert the sensed scene energy into low-level electrical signals that are then amplified by current mode preamplifiers and frequency boosting post-amplifiers. The odd-numbered detectors are arranged in a row normal to the scan direction (fig. 4.7); even-numbered detectors are aranged in a parallel row, offset one IFOV in the cross-scan direction.

The relative position of detector elements in the focal plane illustrates the spatial relationship of the sensors. Figure 4.8 provides an understanding of relative sensor positions as they are projected on the ground (those detectors that are at the cooled focal plane are shown in their projected positions at the prime focal plane as well as on the ground).

The detector arrays are swept back and forth approximately normal to the ground track by the scan mirror. Sensed energy at each high-resolution band detector (bands 1-5 and 7) is sampled every 9.611 microseconds, which equals one IFOV (42.5 microradians). The detector data are sampled in the following sequence:

Bands 1-5 and 7 — All **odd** detectors of every band sense and are **held** simultaneously every 9.611 microseconds; the resulting samples are read out before the next sample cycle begins.

All **even** detectors of every band sense and are **held** simultaneously one-half sample time later (4.81 microseconds).

With the nominal 2.5-IFOV spacing between odd and even numbered detectors, this creates a 2-IFOV odd-to-even detector spacing on forward scans and a 3-IFOV spacing on reverse scans.

Band 6 — With a detector four times larger than bands 1-5 and 7, band 6 requires only one-sixteenth of the number of samples. The sampling sequence is timed to create this ratio and is performed in the following order:

Detector 1 and detector 3 of band 6 sense and are held simultaneously immediately after scan line start. Detector 1 imagery is then sampled, followed by that of detector 3. The identical sequence then occurs for sampling data from detector 2, followed by detector 4.

In this manner, the data are acquired by holding each one-half (odd or even) detector-set for each band at a specific time. During the hold period, the signal level of the detectors is read out by the multiplexer element for each band. The eight detector outputs per each band are analog-to-digital (A/D) converted by a submultiplexer. The output of the submultiplexer is serialized by the main digital multiplexer, resulting in a digital stream of data and associated telemetry for all of the odd-numbered detectors that will be acquired at time (T_0) and for all of the even-numbered detectors acquired at a time T_0 + 4.81

microseconds.

Relay Optics

The relay optics mechanism, consisting of a folding mirror and a spherical mirror, are used to transfer scene energy onto a second focal plane (cooled focal plane array) located in the radiative cooler. The two mirrors are mounted in a graphite composite structure containing cylindrical assemblies located on 120 centers that provide a capability for on-orbit alinement and focus of the cooled focal plane (with detectors for bands 5 through 7) with respect to the prime focal plane. The relay system has an optimum magnification of 0.5 to allow the use of smaller detectors in the cooled focal plane.

Cooled Focal Plane Array

The detector assemblies at the cooled focal plane consist of bands 5 and 7, arranged as the bands of the prime focal plane array, and band 6, which has four detectors with an IFOV of 170 microradians, located in the radiative cooler.

Bands 5 and 7 each employ a 16-element monolithic indium antimonide (InSb) detector array; band 6 employs a 4-element monolithic mercury-cadmium-telluride detector array. The cooled focal plane has a thin-film heater that maintains the focal plane temperature within ± 0.2K of three selectable temperatures, 90K, 95K, and 105K. (Figure 4.9 shows the cooled focal plane substrate assembly with and without spectral filters.) The focal plane signals are routed off the substrate assembly through a distribution board to extremely thin, flexible, low-thermal conductance cables that interface with the preamplifier assemblies of the radiative cooler.

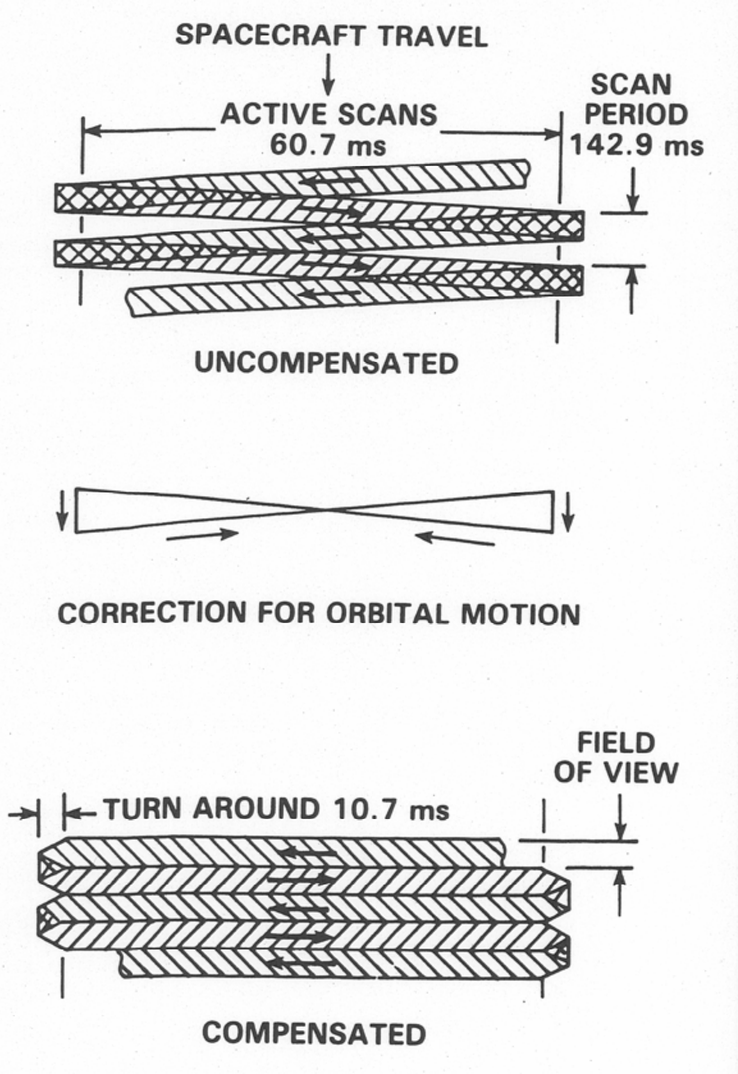


Figure 4.6 TM SCAN LINE CORRECTION

Radiative Cooler

The radiative cooler provides cooling for the detectors of bands 5 through 7. The energy for these detectors passes through the prime focal plane and is refocused by relay optics at the cooled focal plane. The design uses two cooling stages with open-faced honeycomb for the radiator emitting surfaces. The radiations are shielded from direct view of the Sun, Earth, or spacecraft surfaces. Table 4.4 summarizes the radiative cooler design parameters.

Internal Calibrator

The on-board calibrator (fig. 4.9) is mounted in front of the prime focal plane (three tungsten filament lamps for bands 1-5 and 7, a blackbody for band 6, and a flex-pivot-mounted resonant shutter). The shutter oscillates at the same frequency (7 Hz) as the scan mirror assembly. Thus, the shutter introduces the calibration source energy and a black dc restoration surface into the detector fields-of-view during the turn-around time of each scan mirror cycle. An imaging scheme is used on the output end of the shutter to assure uniform calibration without stray radiation; that is, the method for transmitting radiation to the moving calibration shutter allows the lamps to provide radiation independently and to contribute proportionately to il-

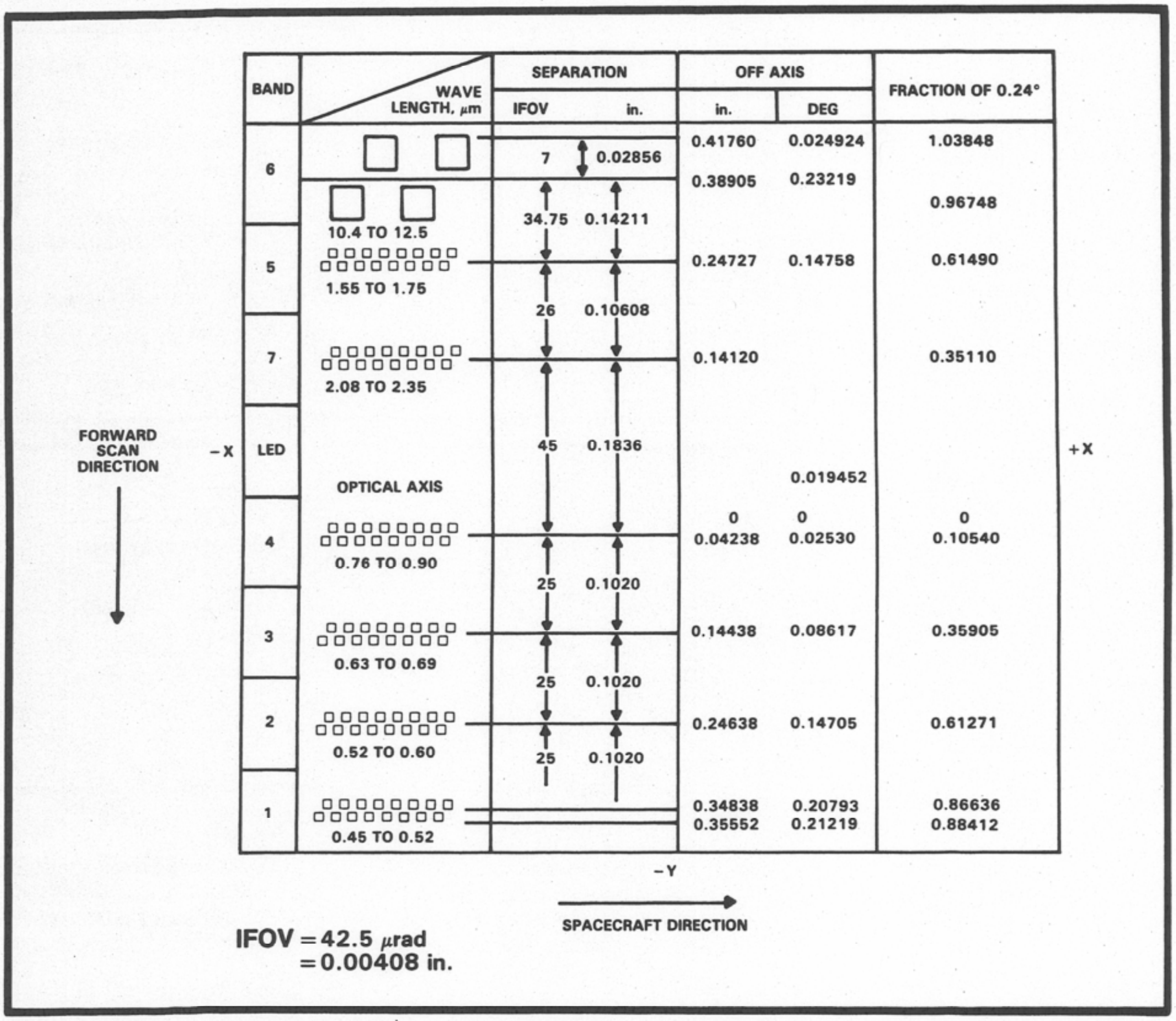


Figure 4.7 VIEW OF DETECTORS AS PROJECTED ON PRIME FOCAL PLANE LOOKING FROM −Z TOWARDS +Z (OPTICAL SYSTEM COORDINATES)

lumination of all detectors.

Electronics Module

The electronics module contains the power supply, the printed wiring boards containing the drives and control electronics for all the mechanisms and heaters, the command and telemetry distribution and collection circuitry, the signal processing postamplifiers that limit the system frequency response, and the multiplexer. The multiplexer encodes all the radiometric data (100 channels of signal data), analog multiplexes all detector channels, makes the A/D conversion, and converts all the radiometric data and telemetry information into 8-bit words that form the 84.9-Mbps data stream transmitted to Earth by the Landsat 4 spacecraft. The multiplexer contains the master clocks that synchronize the system timing for the TM.

THEMATIC MAPPER PERFORMANCE

TM performance results are based on TM/Protoflight (PF) tests conducted at Santa Barbara, California and Valley Forge, Pennsylvania. The TM/PF device is the actual instrument carried on Landsat 4.

The TM/PF performance results are presented in four key areas: (1) spectral response, (2) radiometric sensitivity, (3) square-wave response (modulation transfer function), and (4) band-to-band registration.

Spectral Response

Table 4.5 illustrates the Landsat 4 TM/PF spectral performance. This performance is based on measurements of all protoflight components (mirrors, spectral filters, windows, and detectors) that affect the spectral coverage of the system.

Radiometric Sensitivity

Table 4.6 illustrates radiometric sensitivity for bands 1-5 and 7. Signal-to-noise ratios (SNR) for two levels of scene radiance are shown. The radiometric performance of band 6 is shown in table 4.7 in terms of the noise equivalent

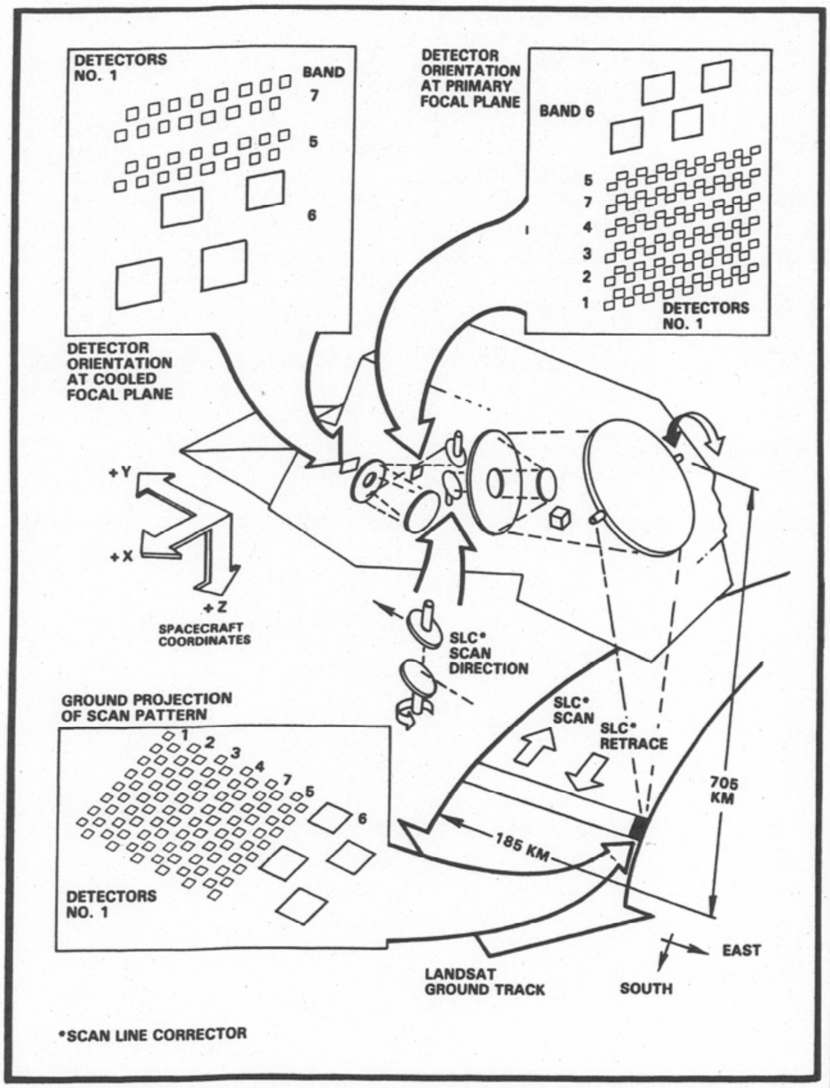


Figure 4.8 RELATIVE POSITIONS OF DETECTOR ELEMENTS

temperature difference (NEΔT).

Square Wave Modulation

Table 4.8 presents the band average response of each spectral band to high-contrast bars of the noted spatial size.The standard deviations (δ) indicate the magnitude of the channel-to-channel response variance for the 16 channels in each of bands 1-5 and 7 and four channels in band 6.

Band-To-Band Registration

Dynamic band-to-band registration was measured at 29 locations throughout both the forward and reverse scan profiles. The data in table 4.9 are the largest registration errors measured throughout either profile. The measured data are presented in terms of fractional IFOV.

MULTISPECTRAL SCANNER

The MSS on Landsat 4 is similar to the MSS instruments that were flown on Landsats 1, 2, and 3. (See fig. 4.10). However, in order to provide MSS data compatible with those acquired from the higher orbits flown by Landsats 1, 2, and 3 (about 920 km), the optics of the Landsat 4 MSS system have been adjusted so that the IFOV size still approximates an 80- x 80-m ground area. In addition, a new numbering system is being used to designate the four spectral bands of the Landsat 4 MSS. What are known as bands 4, 5, 6, and 7 on the previous MSS sensors are now known, respectively, as Landsat 4 MSS bands 1, 2, 3, and 4. This is a change in designation only. The spectral coverage of the instrument remains the same.

Scanning Arrangement

Figure 4.11 illustrates the Landsat 4 MSS scanning geometry. During every mirror MSS retrace period, the radiance from the Earth scene is blanked out by a mechanical shutter. During every other mirror retrace, the individual sensors in bands 1-4 are exposed to a rotating, variable density-wedge optical filter illuminated by an on-board calibration lamp. The resulting calibration data are subsequently utilized to make radiometric corrections on the MSS detector signals.

Fiber Optics Array and Detector Sampling

The MSS electronic subsystem is designed to sample sequentially the individual MSS detectors to produce a serial digital data stream.

Figure 4.12 illustrates the physical arrangement of the square light pipes placed in the focal plane of the MSS telescope. Each light pipe conducts radiance at the focal plane to an individual detector. S1...S24 denotes the order in which the resulting detector signals are sampled. Detectors A, B,...F designate detectors within a given spectral band. The light pipe array dimensions, physical arrangement, and sampling process are directly related to mirror velocity and spacecraft motion. An understanding of this relationship is essential to the calculation of effective field of view as well as to the understanding of computer-compatible tape (CCT) production.

The MSS mirror is driven at a frequency of 13.62 Hz, derived by counting down the frequency of a crystal-controlled clock using a countdown factor of $135 \times 2^{13} = 1{,}105{,}920$. Thus the 13.62 Hz is derived from a frequency of 15.0626 MHz + 0.01%. This frequency is significant in that it represents the maximum bit rate that can be accommodated during detector sampling. Time per bit is 0.0664 microsecond. Each detector represents a channel of data, and 24 such channels (of 25 available) are used on the Landsat 4 spacecraft. Each detector analog output is encoded as a 6-bit digital word, with each word corresponding to one picture element (pixel). The word period is then 0.3983 microsecond (6 X 0.0664),

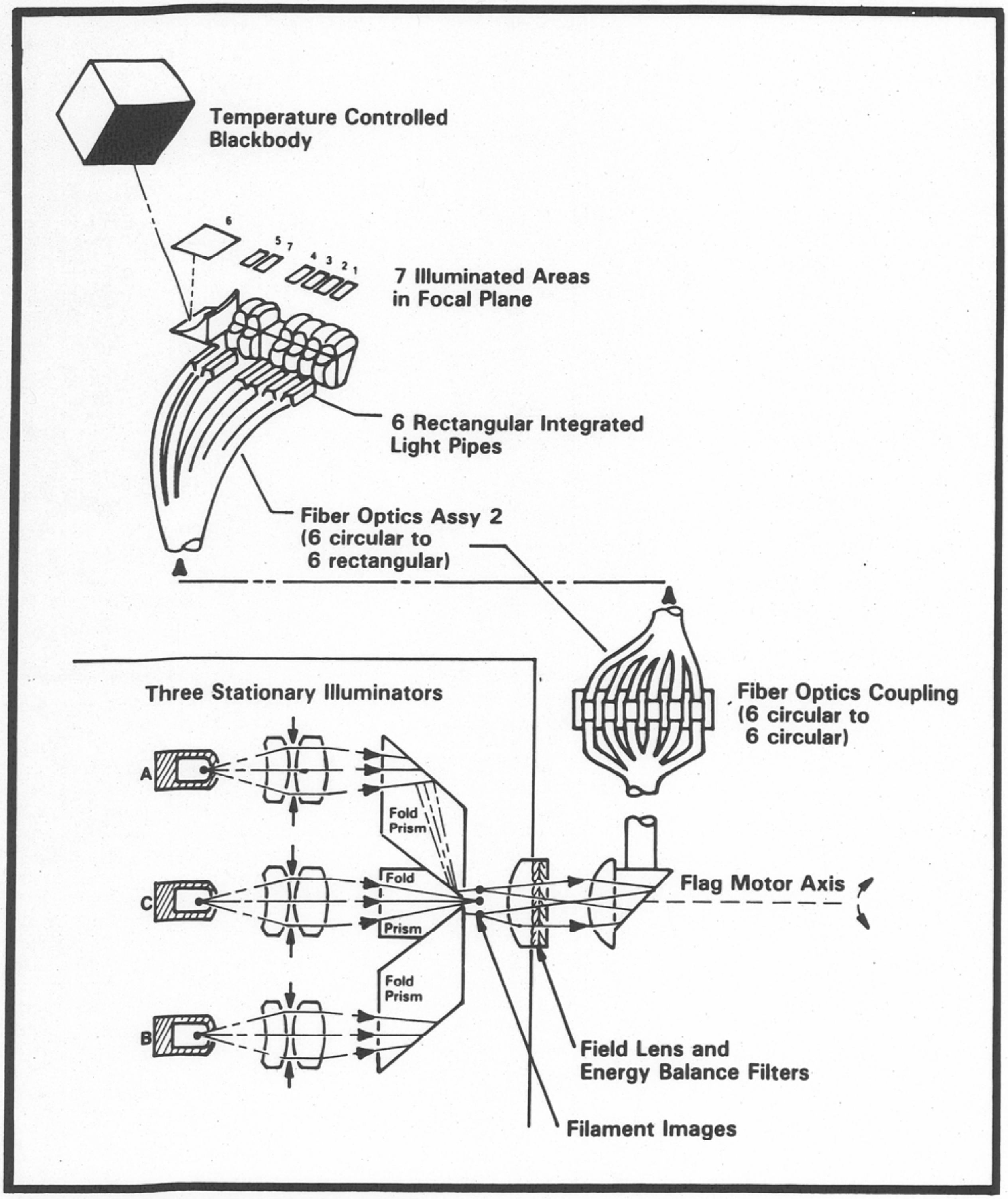


Figure 4.9 CALIBRATOR OPTICAL SYSTEM

which is the sampling time per detector. Because there are 24 channels involved, each detector is sampled once in every 9.958 microseconds.

Consider a ground scene composed of a single 83-by 83-meter object, imaged on detector A, band 1, at a time t = 0. The active scan time during which video is acquired is 33 milliseconds. In the west-to-east active scan period, a scan monitor sensor determines the mirror angular position to start and stop detector sampling. The scan monitor sensor ensures that the cross-track optical scan is 185 km at nominal altitude regardless of mirror scan nonlinearity or other perturbations of mirror velocity. Cross-track image velocity is nominally 6.82 meters per microsecond. After 9.958 microseconds, the 90-by 80-meter image has moved 67.9 meters. The S1 sample taken at this instant represents 15 meters of previous information and 68 meters of new information. Therefore, in practice the "effective" IFOV of a detector in the cross-track direction must be considered to be 68 meters corresponding to a nominal pixel area of 68 by 83 meters (at nadir point). Use of the "effective" IFOV in area calculation therefore eliminates the overlap in area between adjacent samples (pixels).

Table 4.4 TM RADIATIVE COOLER DESIGN PARAMETERS

HORIZONTAL FIELD OF VIEW	160°
VERTICAL FIELD OF VIEW	114°
INTERMEDIATE STAGE RADIATOR AREA	660 cm₂
COLD STAGE RADIATOR AREA	430 cm₂
COLD STAGE MINIMUM TEMPERATURE CAPABILITY (ALL BANDS ON)	84.4K
RADIATION SURFACE	BLACK PAINTED HONEYCOMB
INTERMEDIATE STAGE TEMPERATURE	≃147K
INTERMEDIATE STAGE HEAT LOAD	2.2 watts
COLD STAGE HEAT LOAD	117 mw

Table 4.5 TM PROTOFLIGHT SPECTRAL PERFORMANCE OBSERVED BAND LOCATIONS

	LOWER BAND EDGE AT HALF MAXIMUM		UPPER BAND EDGE AT HALF MAXIMUM		BANDWIDTH AT HALF MAXIMUM	
BAND	OBSERVED λL (NM)	DIFFERENCE λL- λLS (NM)	OBSERVED λU (NM)	DIFFERENCE λU- λUS (MN)	OBSERVED Δλ (NM)	DIFFERENCE Δλ - Δ λS (NM)
1	452	2	518	-2	66	-4
2	529	9	610	10	81	1
3	624	6	693	3	69	9
4	776	16	905	5	129	-11
5	1568	18	1784	34	216	16
7	2097	17	2347	-3	250	-20
6 (μM)	10.422	.002	11.661	-.839	1.239	-.861

Band 1 data precedes band 4 data by 64.926 microseconds. Also, band 2 precedes band 4 data by 44.612 microseconds, and band 3 precedes band 4 by 20.314 microseconds. This spatial misregistration is corrected by inserting the appropriate number of dummy bytes prior to the data in bands 1, 2, and 3 during CCT production. In using the term "byte," it is important to distinguish between "spacecraft" bytes and in-band bytes. For example, band 4 detector A is sampled

Table 4.6 TM PROTOFLIGHT RADIOMETRIC SENSITIVITY BANDS 1-5 & 7

BAND	NOISE EQUIVALENT REFLECTANCE	SIGNAL-TO-NOISE RATIOS: MINIMUM SCENE MEASURED	SIGNAL-TO-NOISE RATIOS: MAXIMUM SCENE MEASURED
1	0.8%	52	143
2	0.5%	60	279
3	0.5%	48	248
4	0.5%	35	342
5	1.0%	40	194
7	2.4%	21	164

once in this time period. The number of bytes generated in all bands during this period is 25. Bands 1, 2, 3, and 4 are offset from each other by two in-band bytes.

Within a spectral band there is also a time delay between the outputs of detector A and F of 3.98 microseconds or 22.3 meters (for a nonrotating Earth), which is compensated for during the production of film images.

Table 4.7 RADIOMETRIC PERFORMANCE OF BAND 6

CFP TEMP	SCENE TEMP	NEΔT, K
95K	300K	0.10
	320K	0.12
105K	300K	0.28
	320K	0.21

Signal compression, via four-segment, quasi-logarithmic amplifiers, is generally employed to improve the signal-to-noise ratio in bands 1, 2, and 3. By compressing high radiance level signals, the quantization noise more nearly matches photomultiplier noise. Band 4 signals, derived from silicon photodiodes, are never compressed because equivalent load resistor noise is best matched by linear quantization. The available ground commandable analog processing options are illustrated in figure 4.13. In the high gain mode applied to bands 1 and 2, amplifier gain is increased by a nominal factor of 3. This increase allows greater use of system dynamic range for those scenes producing low sensor irradiance.

There are two signal compression amplifiers in the spacecraft. One is used to process sensor data from bands 1 and 3, and the second is used exclusively for band 2 data. In subsequent processing, decompression of the signals is performed using separate decompression tables for bands 1 and 3 and for band 2. Calibration-wedge signals from each band are decompressed through the same tables before data calibration.

Table 4.8 TM PROTOFLIGHT SQUARE WAVE RESPONSE (SWR) — (Band Average)

BAND	30 METER BAR SWR	30 METER BAR σ	45 METER BAR SWR	45 METER BAR σ	60 METER BAR SWR	60 METER BAR σ	600 METER BAR SWR	600 METER BAR σ
1	0.46	0.01	0.76	0.03	0.94	0.02	1.0	0.0
2	0.44	0.02	0.72	004	0.96	0.03	1.0	0.0
3	0.41	0.01	0.72	0.02	0.91	0.02	1.0	0.0
4	0.43	0.01	0.76	0.03	0.95	0.03	1.0	0.0
5	0.42	0.02	0.78	0.03	0.89	0.03	1.0	0.0
7	0.44	0.02	0.76	0.02	0.92	0.02	1.0	0.0

BAND	120 METER BAR SWR	120 METER BAR σ	180 METER BAR SWR	180 METER BAR σ	240 METER BAR SWR	240 METER BAR σ	2000 METER BAR SWR	2000 METER BAR σ
6	0.44	0.04	0.78	0.01	0.94	0.00	1.0	0.0

Analog Sensor Signal Processing

The analog sensor samples are to be eventually digitized into a single 15.0626-Mbps data stream; however, analog processing, including amplification, track and hold, and dc restoration are performed before A/D conversion. In addition, provision is made for linear amplification or nonlinear amplification, which can be selected by commands to the spacecraft.

Formation of the Serial Digital Data Stream

After analog processing of sensor data, all data are encoded into 6-bit (1-byte) digital words representing sensor amplitudes in terms of 64 discrete steps, 0-1-2-...63. Six-bit encoding is used regardless of whether the data were linearly processed or compressed. Additional data must be combined with the digital data, so that the sensor data can be properly processed. As an example, the start and end of each active mirror scan time must be indicated. A preamble is added to maintain mirror-scan to mirror-scan bit synchronization. A line-length code that represents the number of pixels encoded from each detector during the mirror active scan time is added.

A vital addition to the sensor data is spacecraft time code. This is essential to identify when and, thereby, where the data were acquired. Time code is basic to framing MSS data to coincide with Worldwide Reference System (WRS) image

Table 4.9 TM PROTOFLIGHT DYNAMIC BAND-TO-BAND REGISTRATION

ALONG SCAN REGISTRATION	
WITHIN PFPA	< 0.1 IFOV
WITHIN CFPA	< 0.08 IFOV
CFPA TO PFPA	< 0.19 IFOV
CROSS SCAN REGISTRATION	
WITHIN PFPA	< 0.13 IFOV
WITHIN CFPA	< 0.10 IFOV
CFPA TO PFPA	< 0.27 IFOV

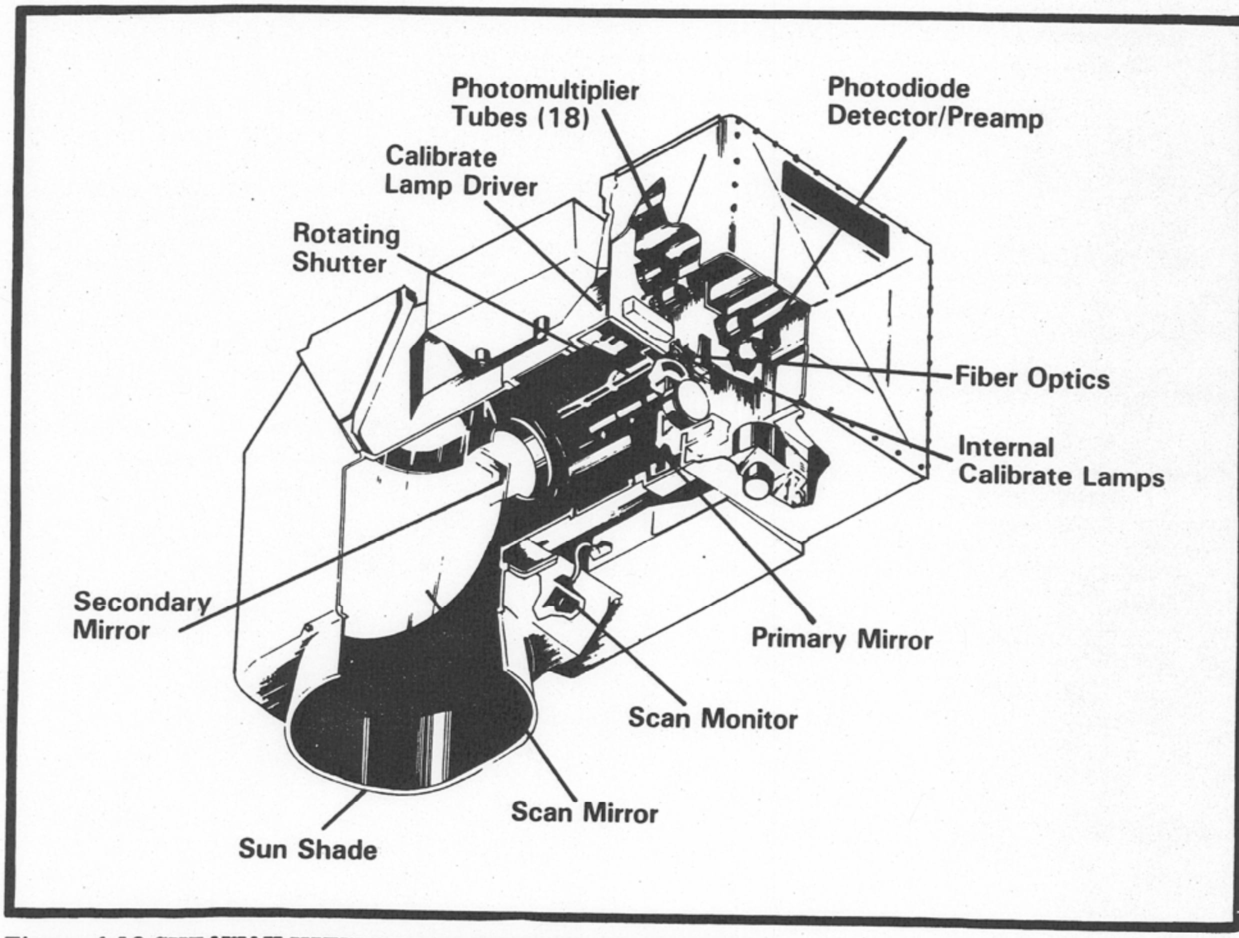


Figure 4.10 CUTAWAY VIEW OF MULTISPECTRAL SCANNER

center points. In addition, scene identification, which is applied to all Landsat photographic and tape products, is derived from spacecraft time code (Greenwich Mean Time).

A typical data sequence may be described as follows: Preamble maintains bit synchronization from scan to scan. As the mirror angular position arrives at the western edge of the area to be imaged, a line-start code is produced. This code interrupts the detector sampling sequence and causes detector A, band 1 to be sampled. A minor-frame synchronizing digital word (MNFS) is also produced (on channel 25). Each time the MNFS or its complement is generated, it indicates that a new sequence of detector video, starting with detector A, band 1, is being produced. In this manner, data are tagged throughout each line scan.

At line start and generation of the first MNFS, video is preempted to permit insertion of 2 bytes of spacecraft time code. The complete time code consists of a 4-byte identifier followed by 44 bytes of time-code data. The first mirror scan contains the four identified bytes followed by 20 bytes of time code. The 24 bytes are distributed, 1 byte per detector (bands 1, 2, 3, and 4) channel. The next line start (mirror scan) contains an alternate 4-byte identifier and the remaining 20 bytes of time code. Therefore, the complete time code can be recovered from two consecutive mirror sweeps. For Landsat 4, the alternate 4-byte identifier is coded to provide spacecraft identification as follows: 0010 = Landsat 4, 0000 = Landsats 1-3.

After time-code insertion, detector video, MNFS and its complement MNFS are transmitted until an end of scan code is produced by a position sensor, which detects that the angular position of the scan mirror has reached the eastern edge of the imaged area. At this time, an end of line code is transmitted. A line-length code (LLC) is computed then for each sensor channel. The code provides information on the number of bytes generated by each detector during active scan time. During ground processing, byte variations between sensors can be eliminated to equalize the line length through the introduction of dummy bytes of synthetic video.

On alternate mirror retraces, after the LLC is completed, calibration data are transmitted in digital form. Precisely 6,060 word-periods after line-start code, the preamble code preempts all data and the process repeats.

The 25 channels with all necessary codes are multiplexed into a 15-megabit-per- second digital stream and transmitted at S-band to ground receiving stations.

At the receiving station, the data are recorded on magnetic tape recorders. Figure 4.14 illustrates a typical channel of data after demultiplexing.

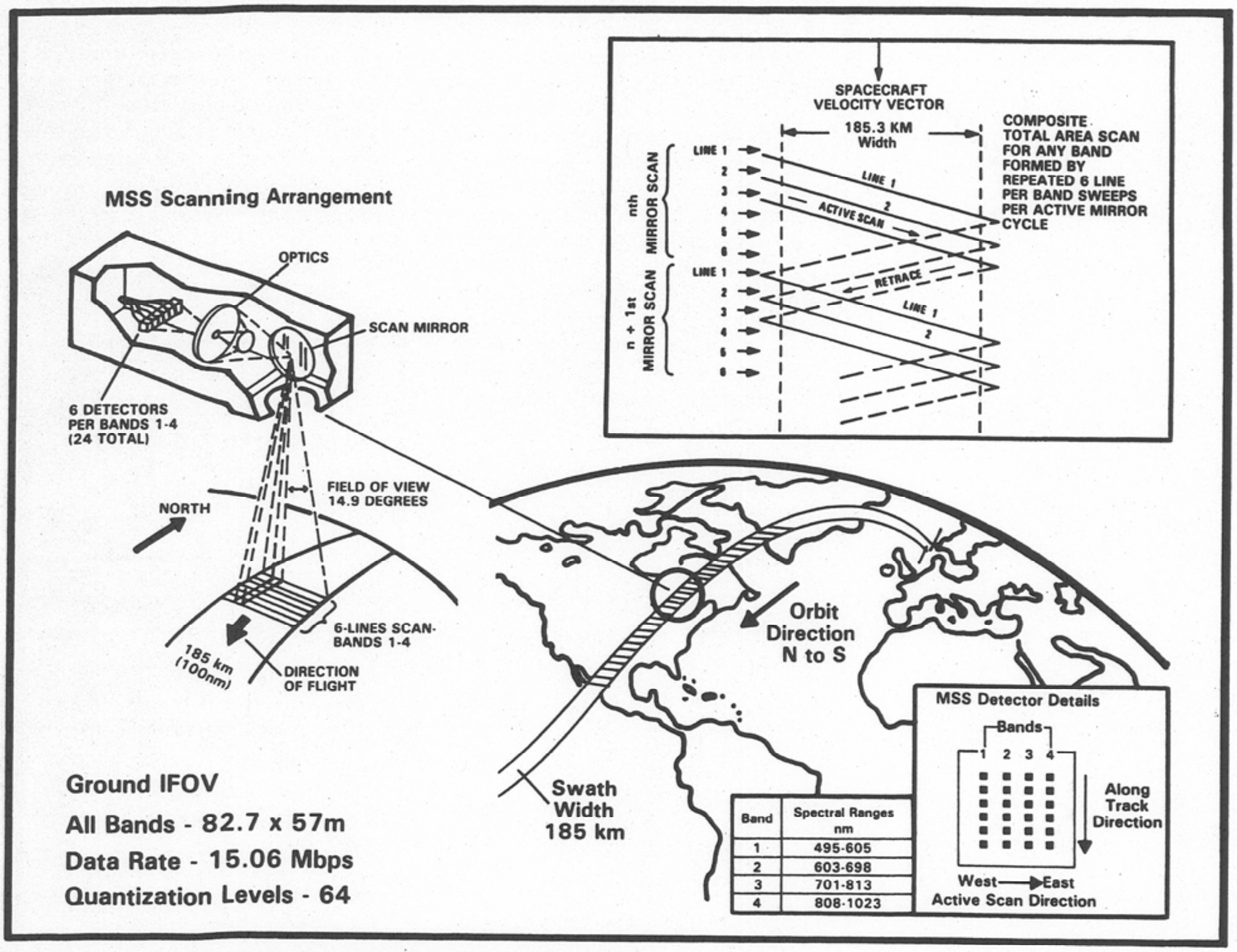


Figure 4.11 LANDSAT 4 MSS SCANNING GEOMETRY

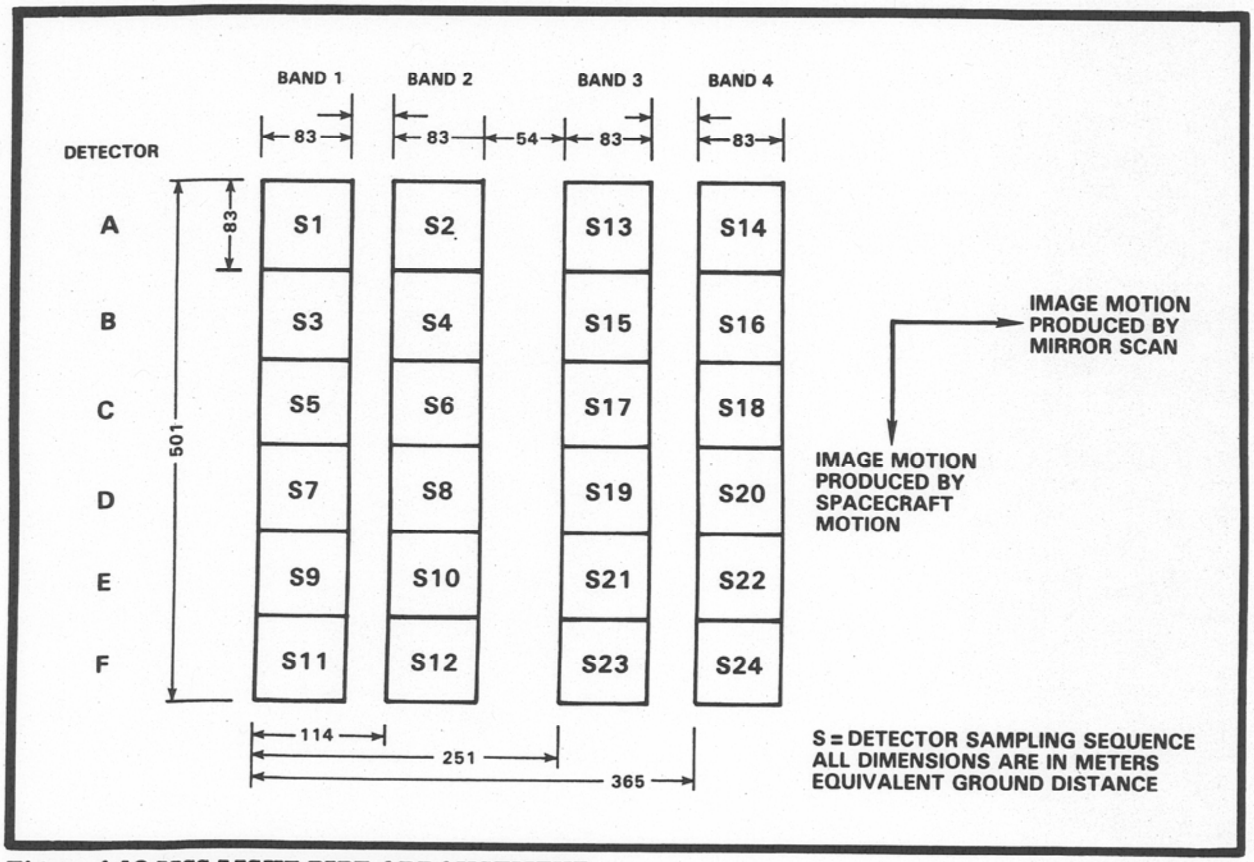


Figure 4.12 MSS LIGHT PIPE ARRANGEMENT

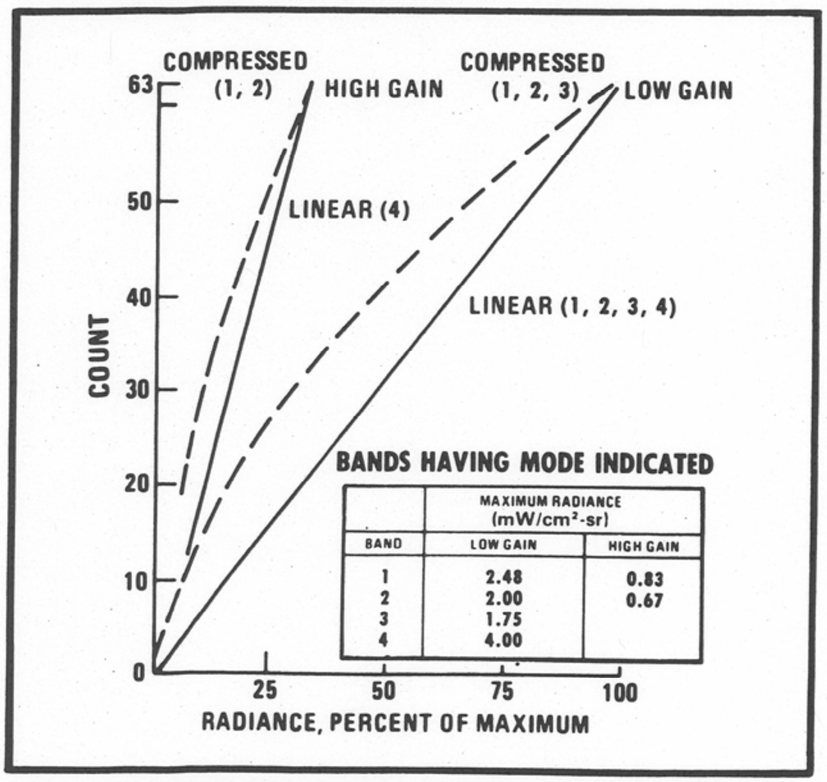
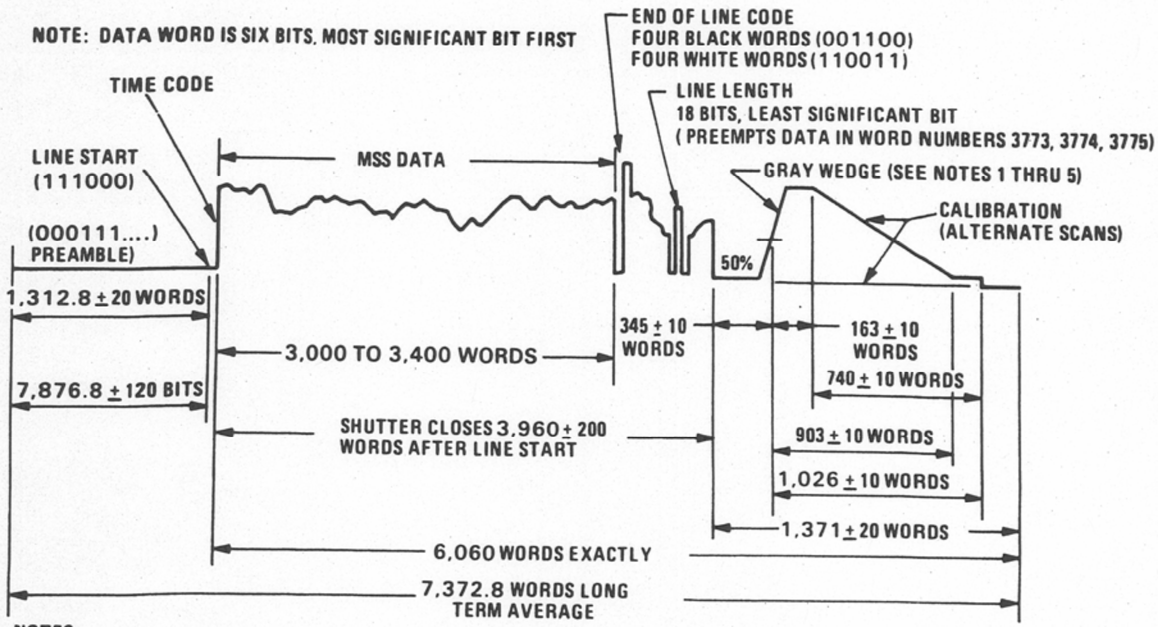


Figure 4.13 MSS DIGITAL OUTPUT COUNT AS A FUNCTION OF RADIANCE, COMPRESSED AND LINEAR MODES



NOTES:

1. GRAY WEDGE RISE TIME APPROXIMATELY 20 WORDS
2. FIRST WORD AFTER LINE START CODE IS WORD NUMBER 0
3. PREAMBLE LENGTH IN BITS WILL NOT BE DIVISIBLE BY 6 EXCEPT BY CHANCE
4. DECOMMUTATED SPACECRAFT TIME CODE IS FOUND IN WORDS 0 AND 1

Figure 4.14 DEMULTIPLEXED DATA CHANNEL

ORBIT AND COVERAGE

Orbit

The orbit of Landsat 4 is repetitive, circular, Sun-synchronous, and near-polar at a nominal altitude of 705 km (438 mi) at the Equator. The satellite crosses the Equator from north-to-south on a descending orbital node at approximately 9:45 a.m. on each pass. Each orbit takes nearly 99 minutes, and the spacecraft completes just over 14 orbits per day, covering the entire Earth (poles excepted) every 16 days. During processing, data obtained is framed into individual scenes of the Earth's surface.

This compares to the higher orbits of Landsats 1, 2, and 3, which were at an altitude of 920 km (570 mi), took 103 minutes to complete (14 times a day), and covered the Earth in 18 days. See table 5.1 for comparing the orbits of Landsats 1-4.

The lower orbit of Landsat 4—necessary for 30-m Thematic Mapper data ground resolution—results in an Earth-coverage pattern significantly different from that of the earlier Landsats. Both the old and the new coverage patterns are discussed and illustrated below, but for more details on Landsats 1, 2, and 3, refer to the Landsat Data Users Handbook, Revised Edition, 1979.

Swathing Pattern

An Earth-observing satellite flies in orbit over a preplanned ground track. (See fig. 5.1.) The sensors onboard the spacecraft obtain data along the ground track at a fixed width or "swath" (fig. 5.2). The 16-day Earth-coverage path for Landsat 4 is known as the swathing pattern of the satellite (fig. 5.3).

As seen in figure 5.3, the adjacent swath to the west of a previous swath is traveled by Landsat 4 one week later (and the adjacent swath to the east occurred one week earlier and will recur nine days later). This is in contrast to Landsats 1, 2, and 3, for which the adjacent swath to the west was established one day later, as illustrated in figure 5.4. Once the user of Landsat data is familiar with the data acquisition cycle, or swathing pattern, it becomes easier to select and obtain whatever Landsat 4 scenes will be required for a specific project.

At the Equator, adjacent swaths overlap at the edges by 7.3 percent (fig. 5.5). For users, this translates as the term image sidelap. Moving from the Equator toward either pole, the sidelap increases, since the swath width of the sensors is fixed at 185 km (115 mi). Table 5.2 shows image sidelap at 0-80° latitude. As discussed below, the data along the ground track of a swath is processed in fixed increments with along-track overlap of about 5.4 percent at the top and bottom of each scene that is processed on film. (For scene overlap on computer-compatible tapes, see Appendix A.)

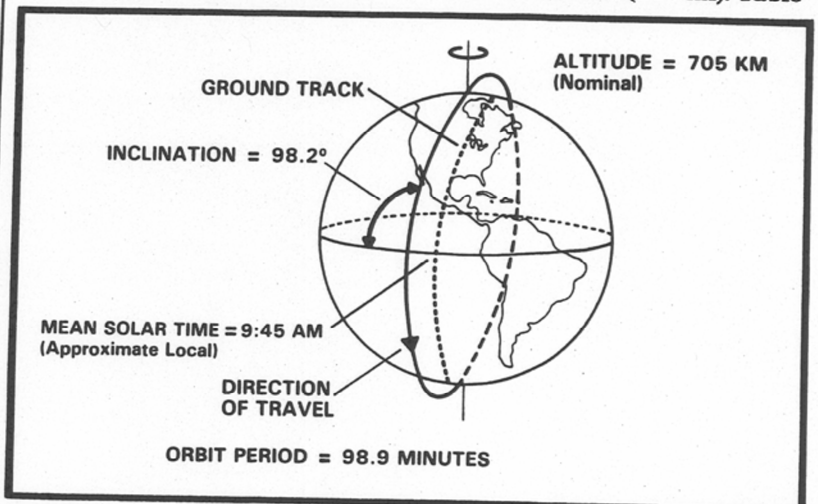


Figure 5.1 LANDSAT 4 ORBIT

ORBITAL PARAMETER	LANDSAT 1	LANDSAT 2	LANDSAT 3	LANDSAT 4 (nominal)
Altitude (Km)	920	920	920	705
Semi-Major Axis (km)	7285.438	7285.989	7285.776	7083.465
Inclination (deg)	99.906	99.210	99.117	98.22
Period (min.)	103.143	103.155	103.150	98.9
Time of Descending Node Equatorial Crossing (local time)	8:50 AM	9:08 AM	9:31 AM	9:45 AM
Coverage Cycle Duration	18 Days (251 revs)			16 Days (233 revs)
Distance Between Adjacent Ground Tracks at Equator (km)	159.38			172

Table 5.1 ORBITS, LANDSATS 1-4

Worldwide Reference System

To make selection of Landsat data manageable and convenient for the user, the swathing pattern of the Landsat 4 sensors is plotted for use in a

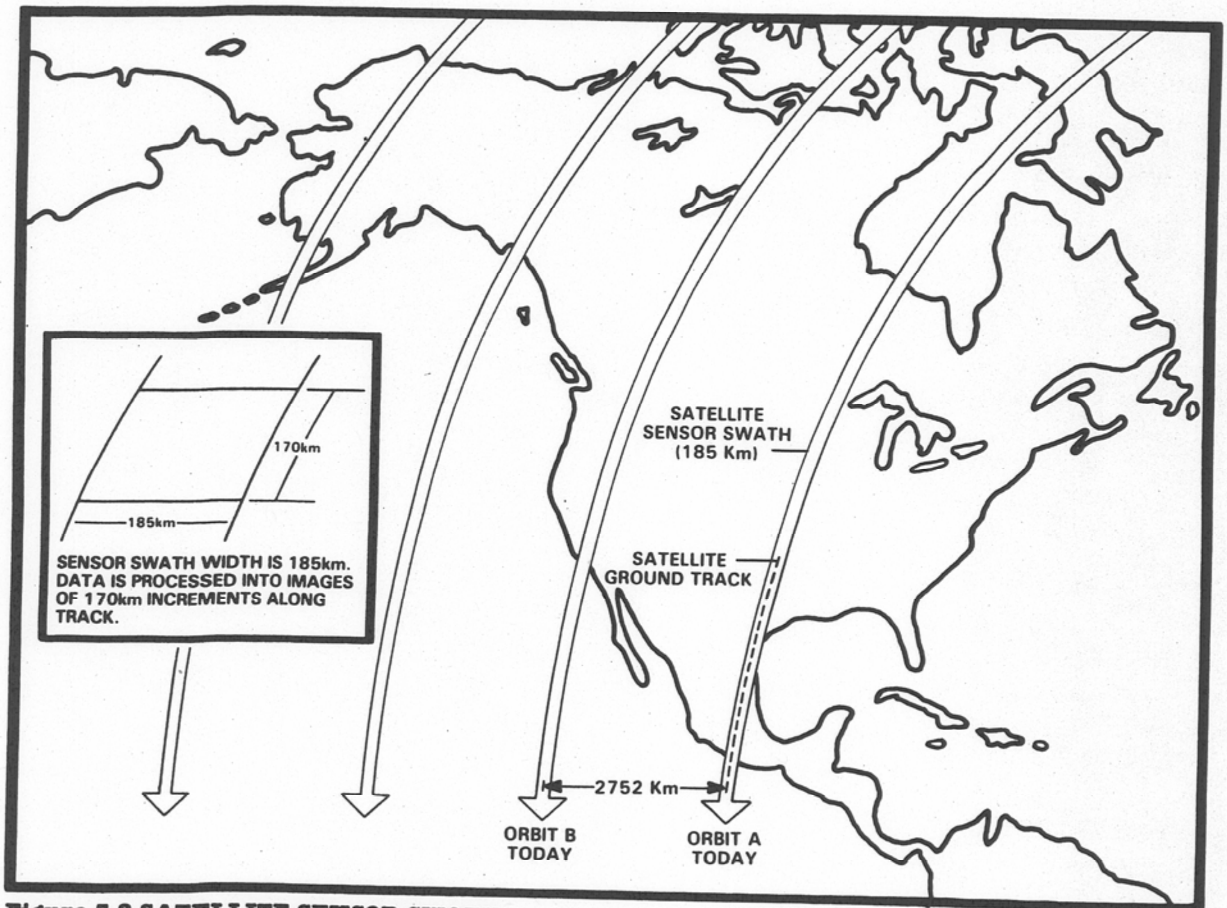


Figure 5.2 SATELLITE SENSOR SWATH

LATITUDE (Deg.)	IMAGE SIDELAP (%)
0	7.3
10	8.7
20	12.9
30	19.7
40	29.0
50	40.4
60	53.6
70	68.3
80	83.9

Table 5.2 SIDELAP OF ADJACENT LANDSAT 4 COVERAGE SWATHS

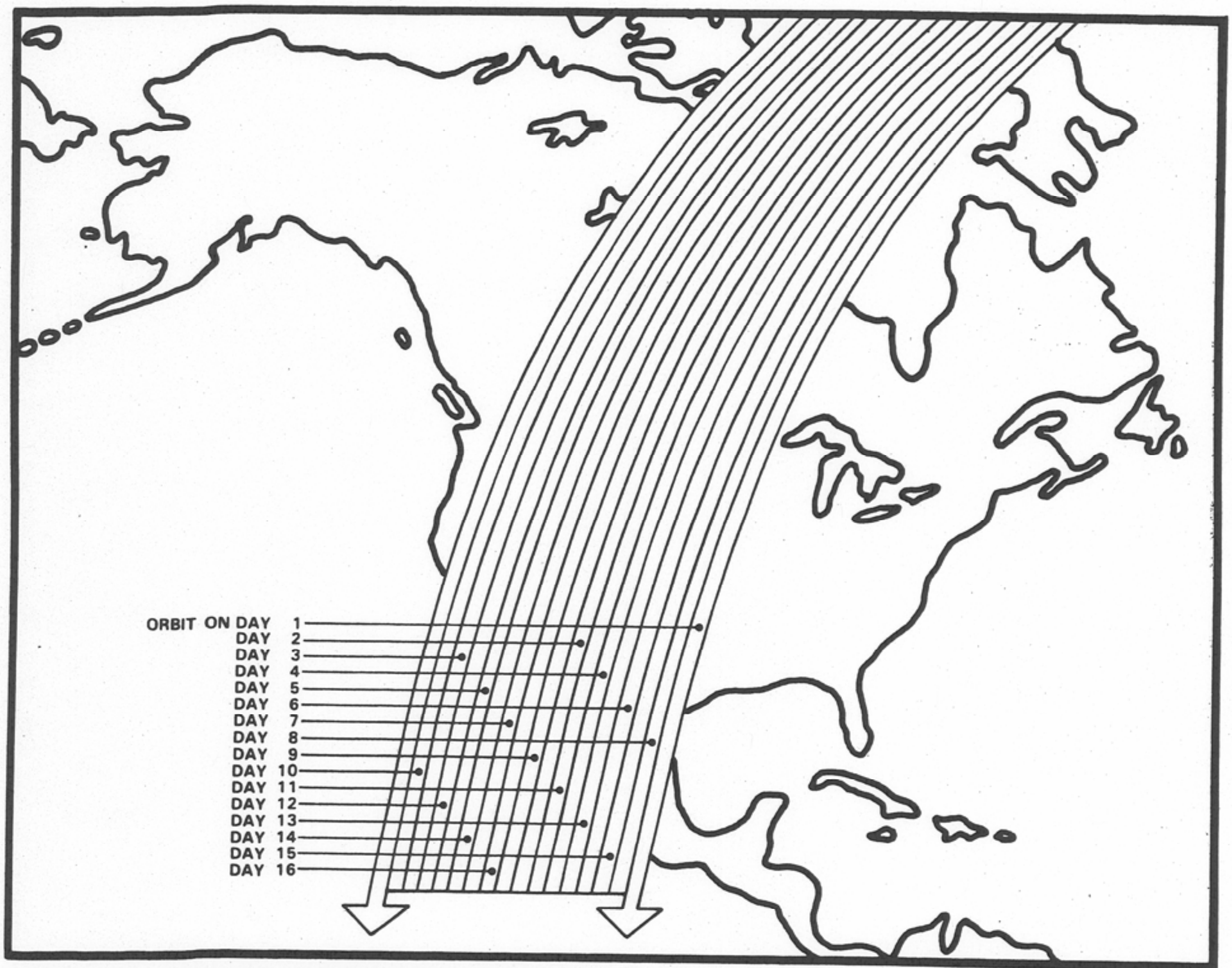


Figure 5.3 LANDSAT 4 SWATHING PATTERN

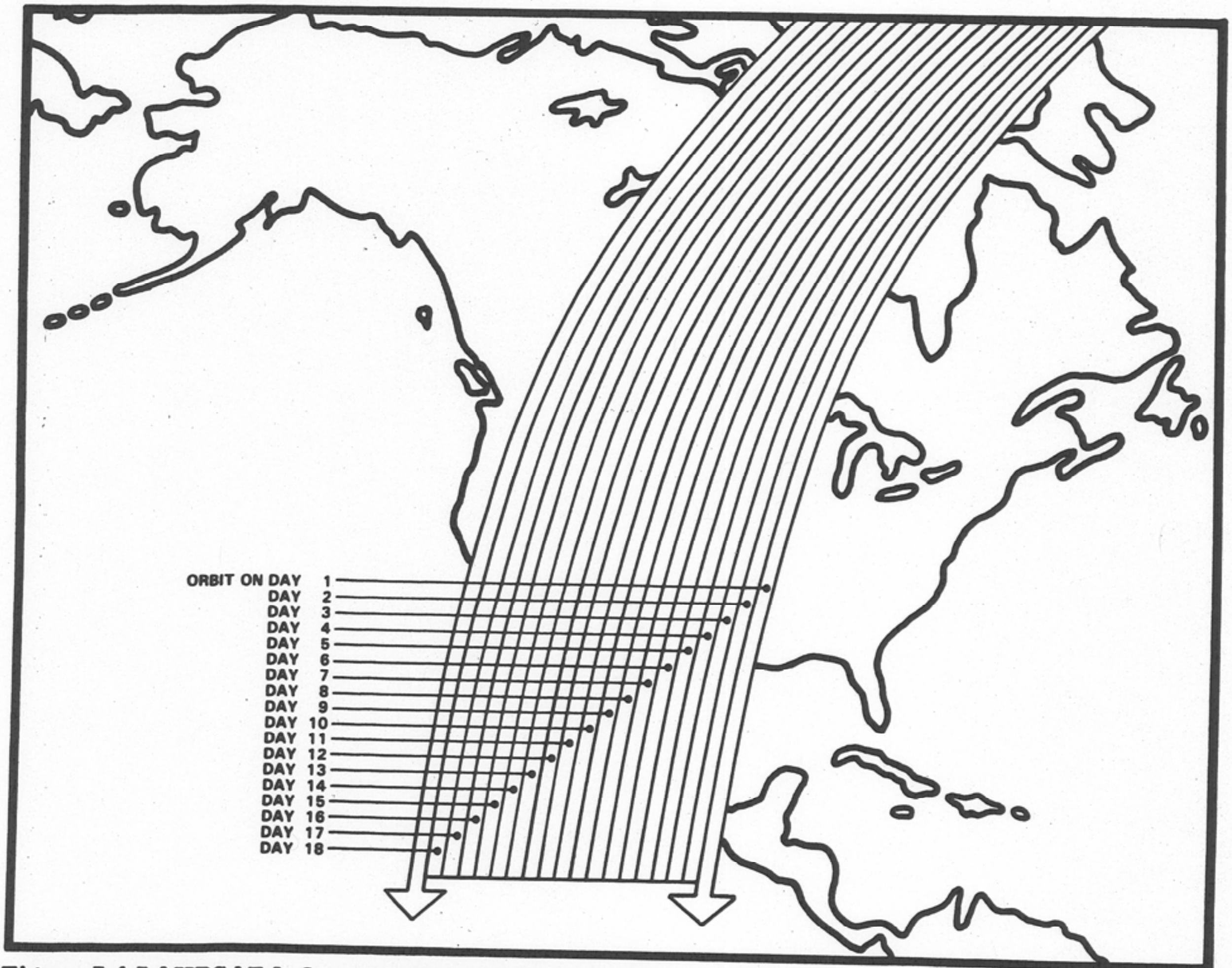


Figure 5.4 LANDSAT 1, 2, and 3 SWATHING PATTERN

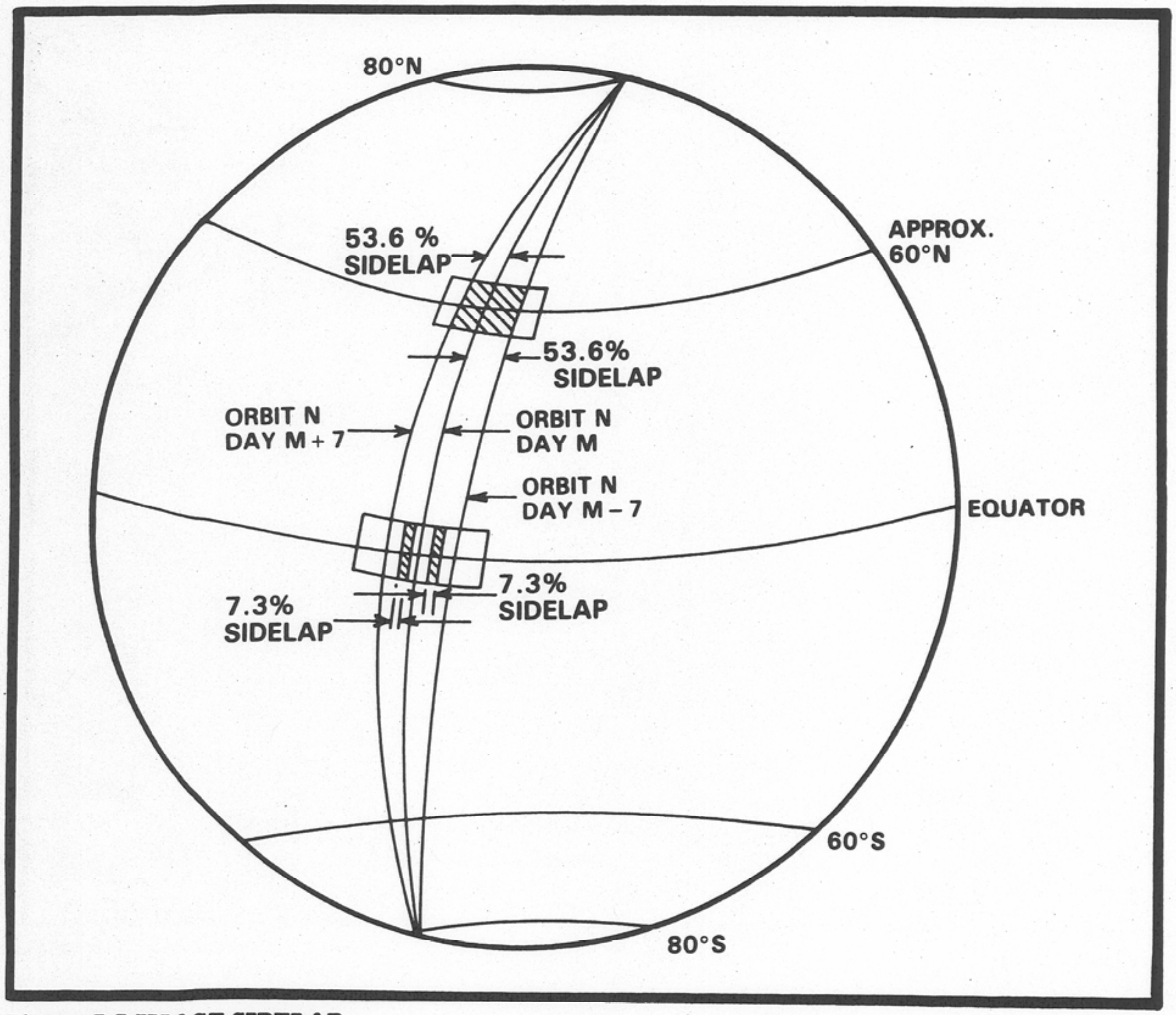


Figure 5.5 IMAGE SIDELAP

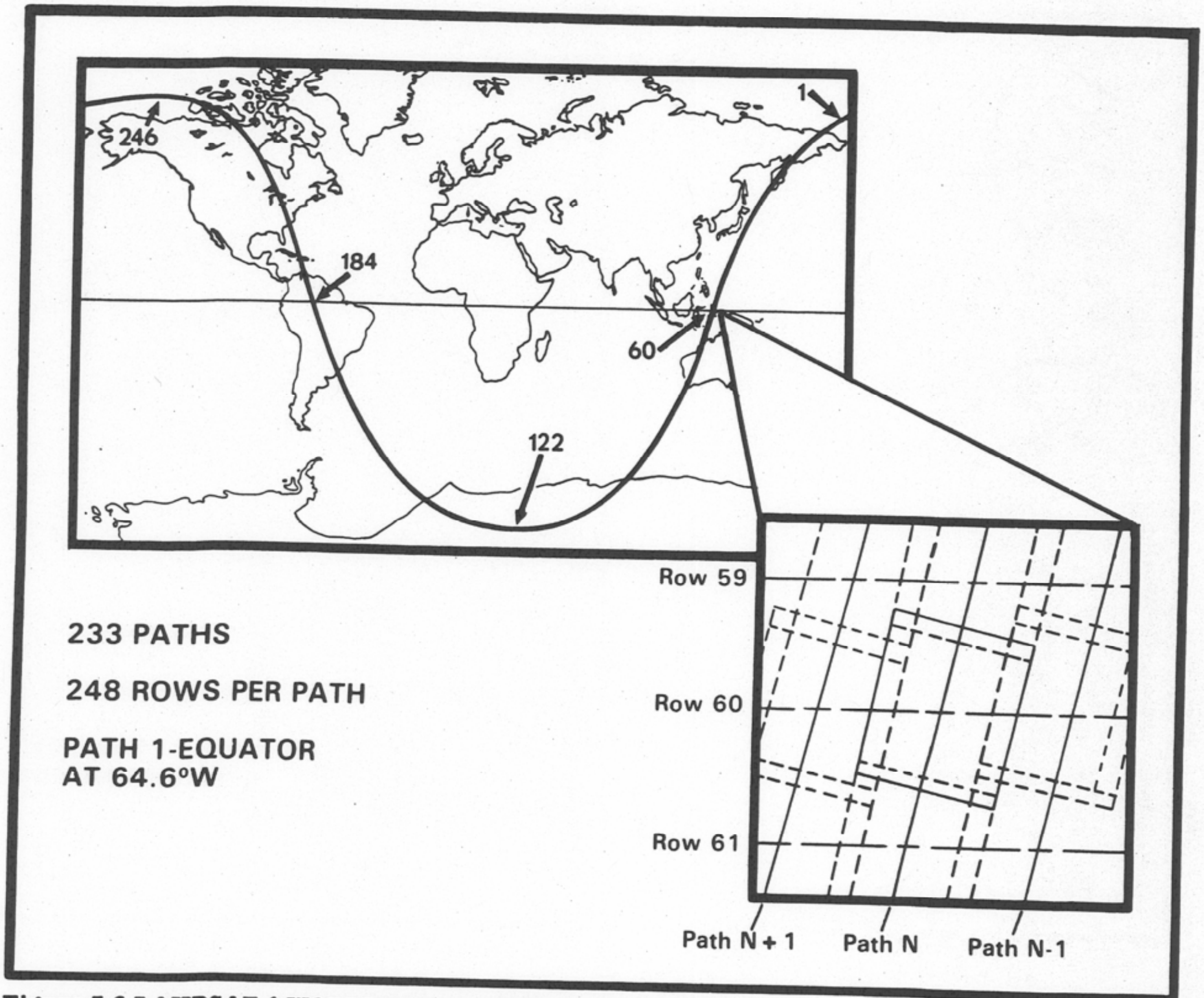


Figure 5.6 LANDSAT 4 WORLDWIDE REFERENCE SYSTEM

Worldwide Reference System (WRS). The WRS indexes orbits (Paths) and frame centers (Rows) for both sensors on each swath. The Path/Row notation eliminates the necessity of using more cumbersome latitude and longitude notations and provides a standard designator for every nominal scene center.

NOTE: Scenes are acquired and processed for an annual Landsat 4 Basic Data Set. Scenes can also be obtained by a user request for coverage. See Section 8, Availability and Ordering of Data, for details.

The 16-day Earth coverage cycle of Landsat 4 is accomplished in 233 orbits. Thus, for Landsat 4, the WRS system is made up of 233 Paths numbered 001 through 233, east to west, with Path 001 crossing the Equator at longitude 64.60W. Landsats 1, 2, and 3 took 251 orbits (Paths) to complete Earth coverage in an 18-day cycle; hence, **there are two different WRS indexes.**

The term Row refers to the latitudinal center line across a frame of imagery along any given Path. As the satellite moves along a Path, either or both Landsat 4 sensor systems scan the terrain below. During ground processing, the continuous data stream is segmented into individual scenes framed in 23.92-second increments of spacecraft time to create 248 Row intervals per complete orbit (fig. 5.6). Note that this Row total is the same as that in the Landsat 1, 2, and 3 WRS system. The Rows have been assigned in such a way that Row 60 coincides with the Equator (descending node). Row one of each Path starts at 80°47'N. latitude, and the numbering increases southward to latitude 81°51'S. (Row 122). Then, beginning with Row 123, the Row numbers ascend northward, cross the Equator (Row 184), and continue to latitude 81°51'N. (Row 246). Row 248 is located at latitude 81°22'N., whereupon the next Path begins. (Because Landsat 4 does not fly in a true polar orbit, but a near-polar orbit, the initial Path/Row numbers do not coincide with latitude 90°N.) A comprehensive list of the specific latitude and longitude values for each

Landsat 4 nominal scene center is available upon request from NOAA (see below).

Successive orbits and framing operations are controlled to assure minimal variation to either side from the intended ground track, and framing of scene centers is controlled through data processing so that successive images of a specific scene can be registered, or overlaid, for comparison of image data.

Ground coverage for orbital Paths at any point on Earth can be determined from Landsat 4 WRS index maps available from NOAA Landsat Customer Services, Mundt Federal Building, Sioux Falls, SD 57198, telephone (605) 594-6151, FTS 784-7151. To determine available coverage over a given area, see Section 8, Availability and Ordering of Data.

Orbit Times

The Landsat orbit is Sun synchronous, as shown in figure 5.7; hence, the geometric relationship between the orbit's descending, or southbound, track and the mean projection of the Sun onto the equatorial plane will remain nearly constant throughout the mission. As a result, the mean Sun time at each individual point in the orbit will remain fixed, and, in fact, all points at a given latitude on descending passes will have the same mean Sun time. For Landsat 4, the nominal mean Sun time of the descending node at the Equator is 9:45 a.m.

A fixed mean Sun time does not mean that local clock time will remain fixed for all points at a given latitude, since discrete time zones are used to determine local time throughout the world. Figure 5.8 illustrates a typical variation between a mean Sun time of 9:45 a.m. and local time for sequential satellite equatorial crossings.

The local time that the satellite

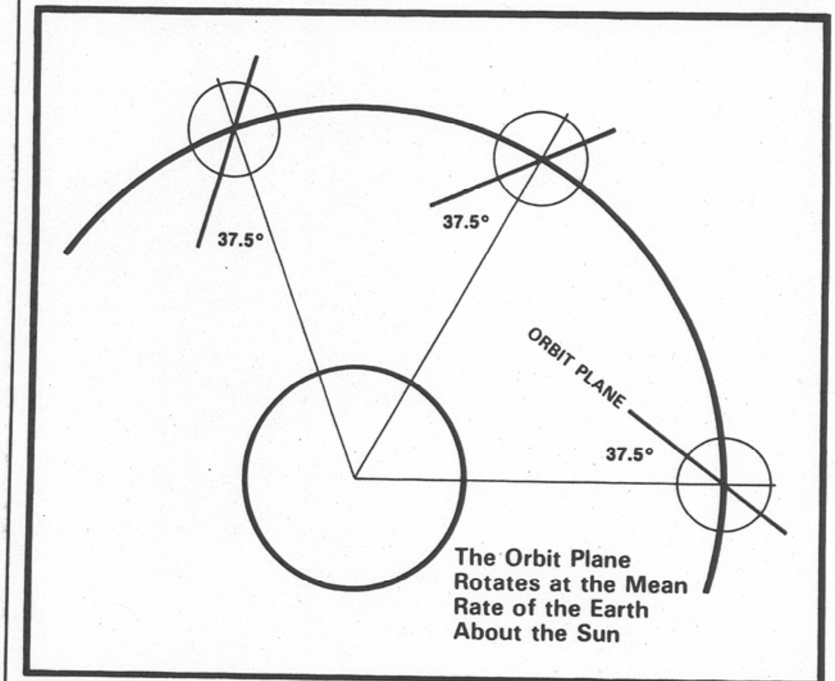


Figure 5.7 SUN-SYNCHRONOUS ORBIT OF LANDSAT 4

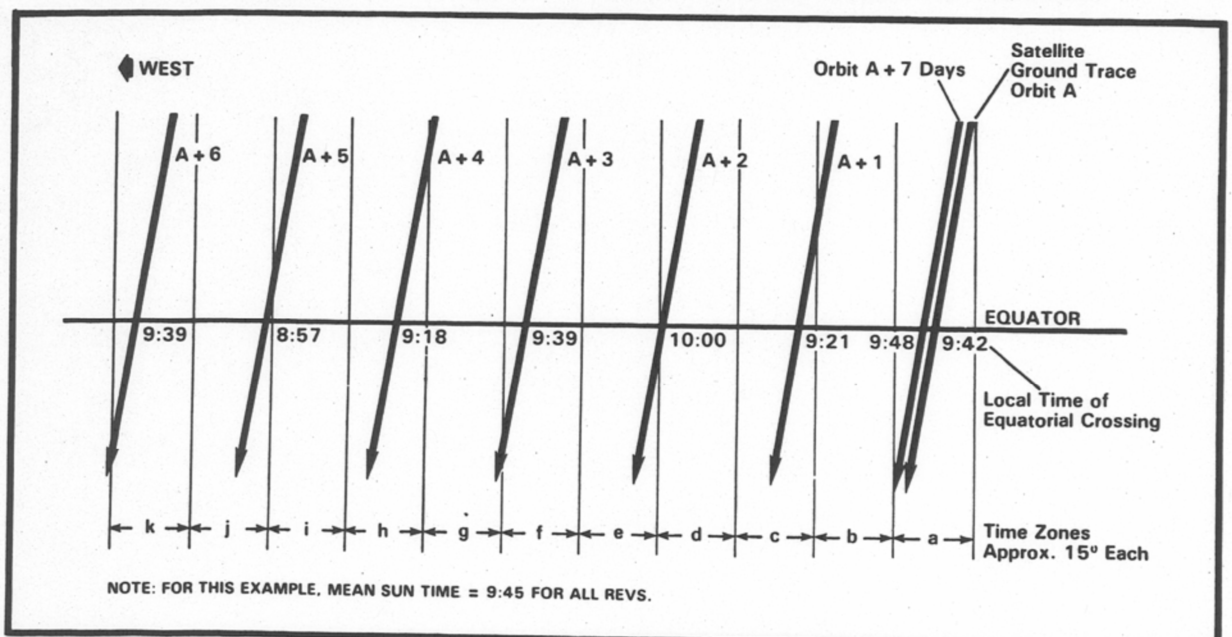


Figure 5.8 VARIATIONS IN LOCAL TIME AT MEAN SUN TIME OF 9:45 A.M.

crosses over a given point at latitudes other than at the Equator also varies due to: (1) the time the satellite takes to reach the given point (98.9 minutes are required for one complete revolution), and (2) the time zones crossed by the satellite relative to its equatorial crossing point (fig. 5.9).

Sun Elevation Effects

While the orbit of Landsat 4 causes the spacecraft to pass over the same point on the Earth at essentially the same local time every 16 days, changes in Sun elevation angle, as defined in figure 5.10, cause variations in the illumination conditions under which imagery is obtained. These changes are due primarily to the north/south seasonal position of the Sun (depicted in fig. 5.11) relative to Earth. Figures 5.12 and 5.13 show how widely the Sun elevation angle can fluctuate throughout a year.

The actual effects of variations in Sun elevation angle on a given scene are very dependent on the scene area itself. The reflectance of sand, for example, is significantly more sensitive to variations in Sun elevation angle than are most types of vegetation. Atmospheric effects also affect the amount of radiant energy reaching the Landsat sensor, and these, too, can vary with time of year. Because of such factors, each general type of scene area must be evaluated individually to determine the range of Sun elevation angles over which useful imagery can be obtained.

Depending on the scene area, it may or may not be possible to obtain useful imagery at the lower Sun elevation angles. At Sun elevation angles greater than 30°, it is expected that all scene areas can be satisfactorily imaged. Normally, no attempt is made to obtain imagery for Sun elevation angles of less than 10°.

Apart from the variability of scene effects, Sun elevation angle is itself affected by a number of perturbing forces on the Landsat orbit. These include forces such as atmospheric drag and the Sun's gravity. They have the effect of shifting the time of descending node throughout the year, and this results in changes to the nominal Sun elevation angle. The effects of orbit perturbations, however, can be considered minor for most applications.

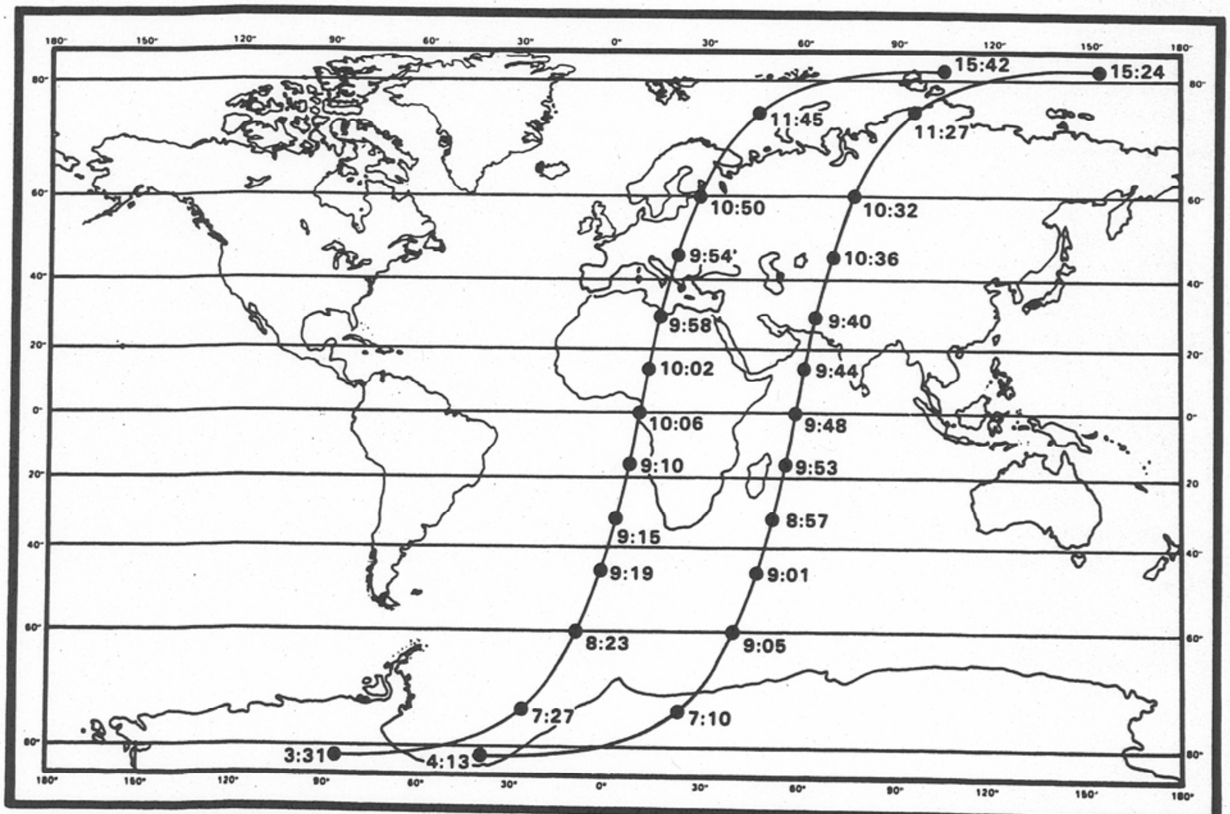


Figure 5.9 VARIATIONS IN LOCAL SATELLITE CROSSING TIME AT INDICATED LATITUDES

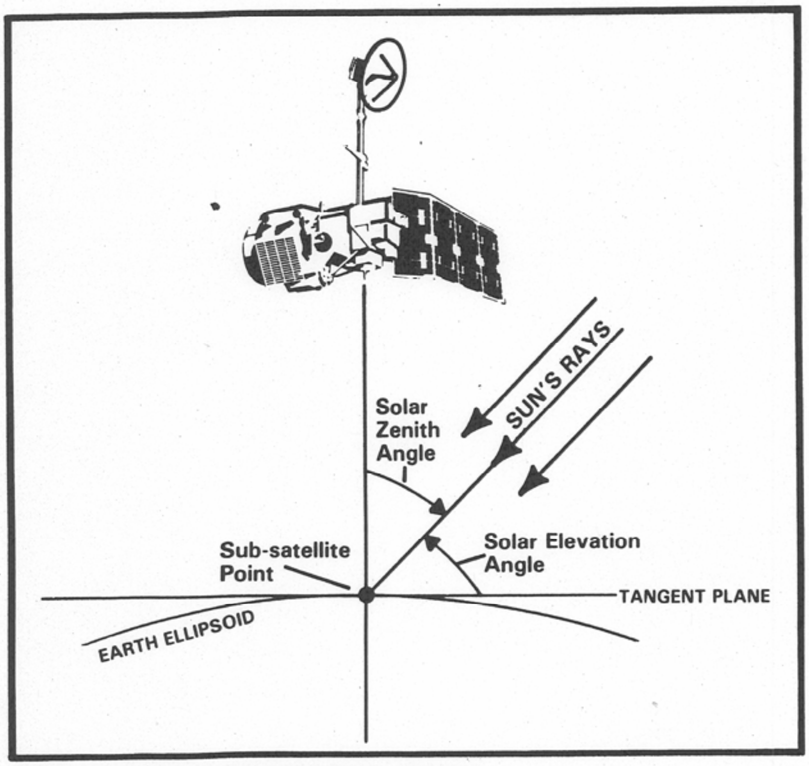


Figure 5.10 SUN ELEVATION ANGLE

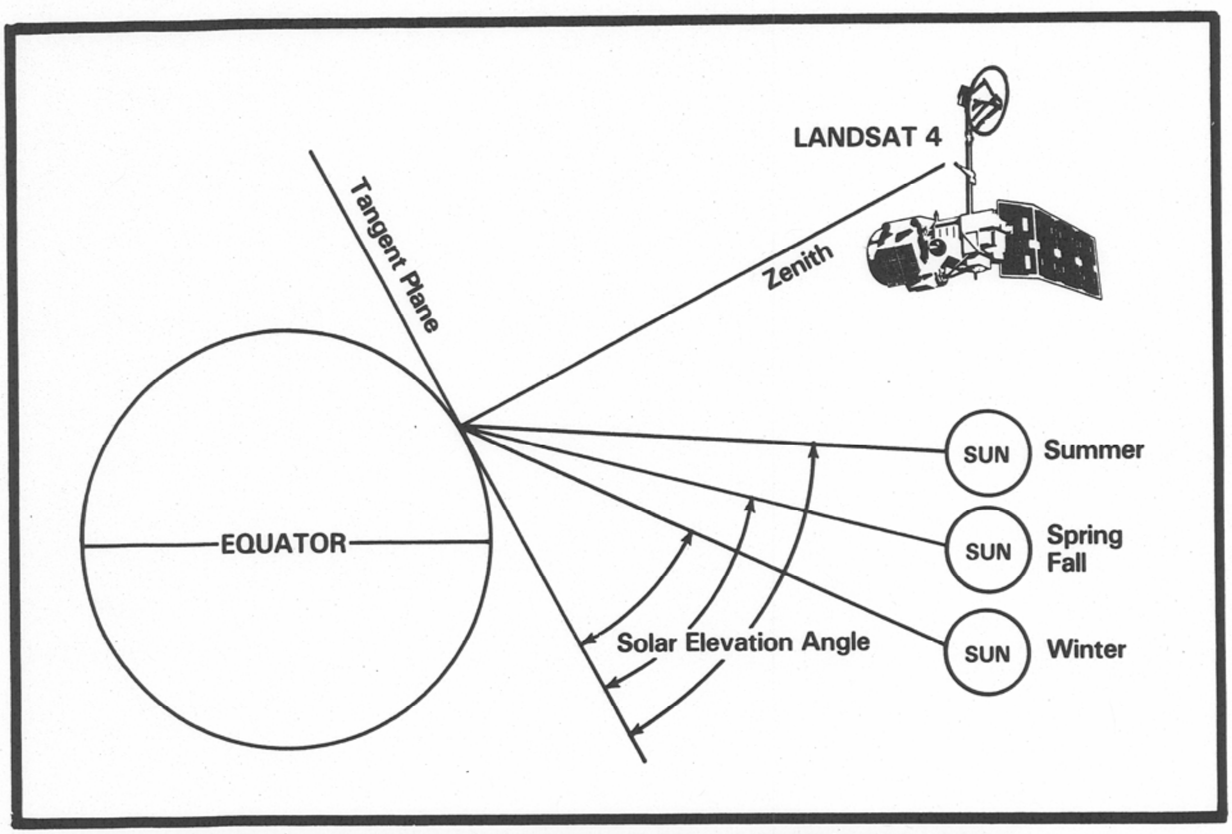


Figure 5.11 EFFECTS OF SEASONAL CHANGES ON SOLAR ELEVATION ANGLE

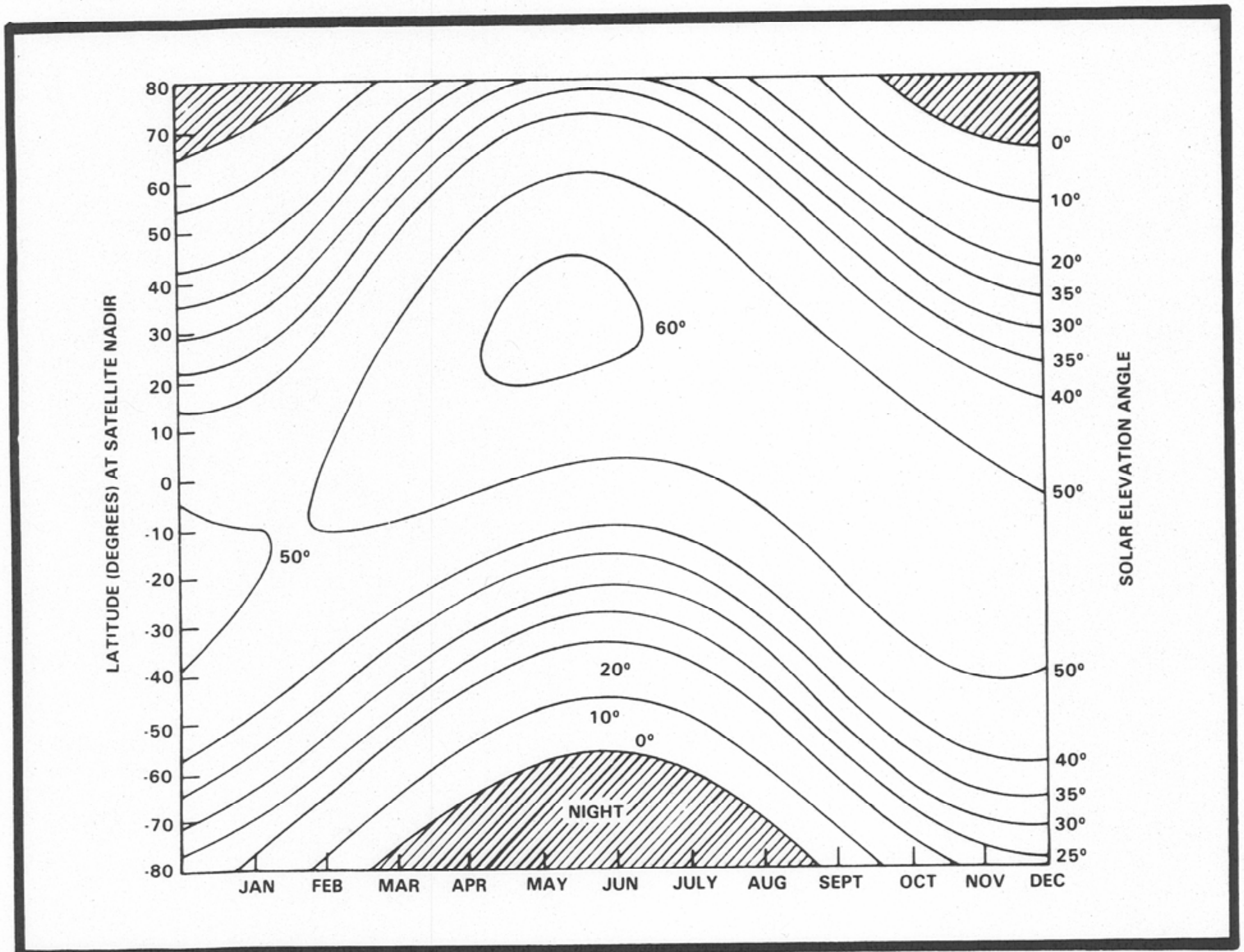


Figure 5.13 SOLAR ELEVATION ANGLE HISTORY AS A FUNCTION OF LATITUDE (at satellite nadir); BASED ON 9:30 A.M. EQUATORIAL CROSSING TIME.

DATA COMMUNICATIONS

The communication links used by the Landsat 4 flight segment are greater in number and sophistication than those on preceding Landsats. To cope with both the real-time transmission requirement and the increased data volume that results from 30-meter-square pixels and three additional spectral bands, a new wideband communications package was designed. Existing receiving stations must upgrade equipment in order to directly receive Thematic Mapper (TM) sensor data from the new communications package carried by Landsat 4, because TM data are transmitted at 85 megabits per second (Mbps) rather than 15 Mbps and at X-band frequency rather than S-band. In order to remain compatible with current receiving stations, Multispectral Scanner (MSS) telemetry and image data will continue to be transmitted at S-band frequency. The capability also exists to transmit both TM and MSS data on a single multiplexed X-band signal.

In another departure from previous Landsat systems, the flight segment does not carry image data recorders. Only real-time data acquisition is supported. Two tracking and data relay satellites in geosynchronous orbit, each permitting coverage of nearly a hemisphere, are designed to relay Landsat data to Goddard. The Tracking and Data Relay Satellite System (TDRSS) can support simultaneous TM and MSS data transmission, and its deployment significantly reduces NASA's dependency on foreign recorders for global coverage. The first of the two satellites was launched in 1983; the satellite pair is to be fully operational in early 1985. The overall system is intended for tracking and data communications use for many satellites in addition to Landsat.

Landsat 4 also carries an L-band omnidirectional anten-

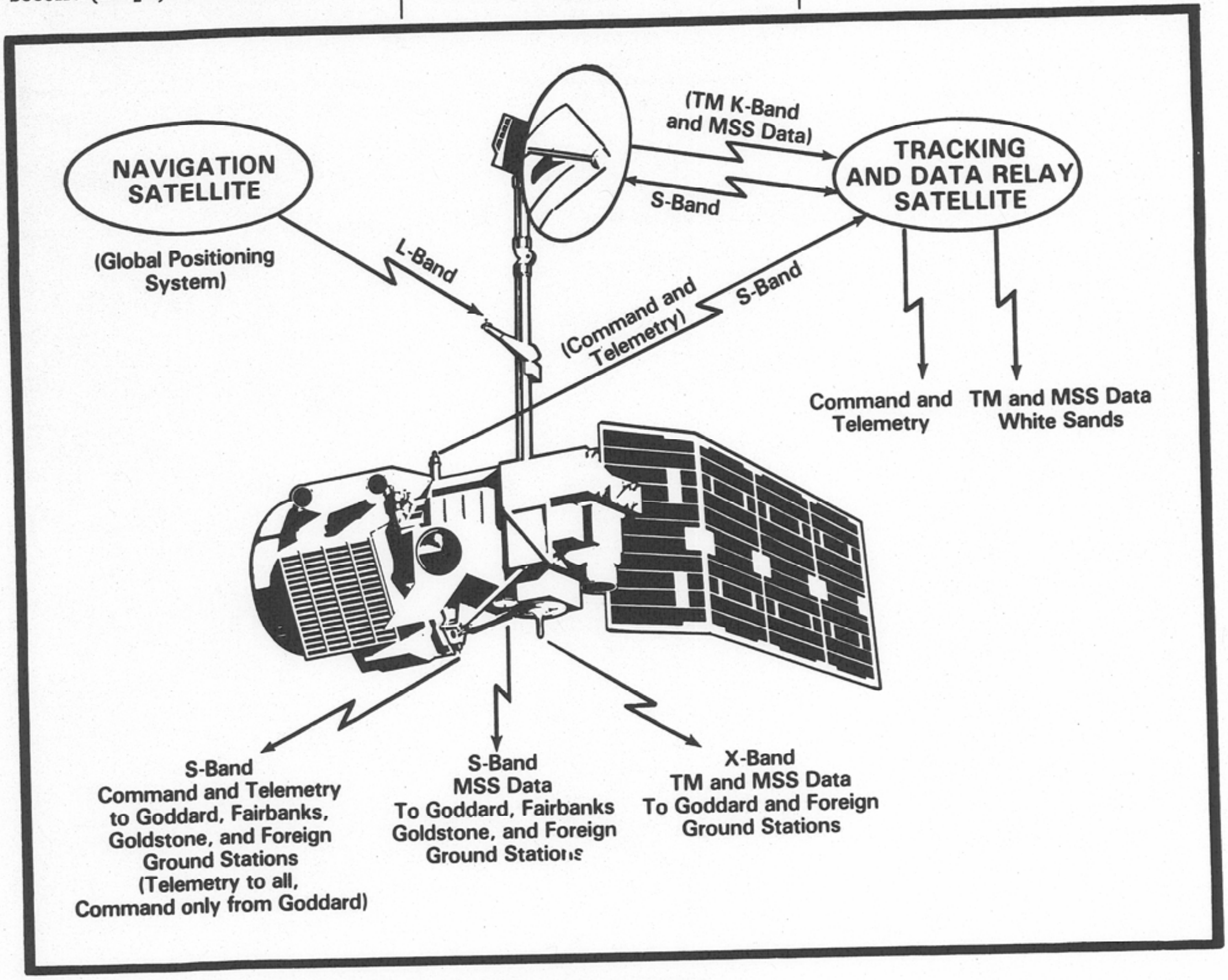


Figure 6.1 FLIGHT SEGMENT COMMUNICATION LINKS

na and receiving system for signals broadcast from a network of navigational satellites. Initially consisting of 5 (later to expand to 18) satellites, the network will provide, through triangulation, extremely precise location (ephemeris) data of the spacecraft. The network, called the Global Positioning System (GPS), is also designed for many applications in addition to Landsat.

The antennas that radiate or receive signals for the communication systems just described are shown in figure 6.1. A few characteristics describing the X-band and S-band data and telemetry transmission are listed in table 6.1.

Because the deployment of the two TDRSS satellites occurs for over a year and full operation will not commence until 1985, the data communication network will be implemented in four phases.

First Phase

The first phase utilizes the start-up configuration shown in figure 6.2. MSS data are received at Goddard, Goldstone, Fairbanks, and four foreign stations (Brazil, Australia, Japan, and Sweden) equipped with U.S. recorders. TM and MSS data acquired over the eastern half of the United States are received directly at Goddard by the Transportable Ground Station (TGS). TM data of the western United States are recorded at the Prince Albert Canadian receiving station. MSS data recorded at foreign stations are mailed to Goddard, and MSS data from Goldstone and Fairbanks are relayed to Goddard by a satellite communications link. Coverage during Phase 1 is shown in figure 6.3.

Second Phase

The second phase commences when the India and Thailand receiving stations become operational. No other changes occur to the network described in Phase 1. Acquisition coverage during Phase 2 is shown in figure 6.4.

Third Phase

The third phase begins after the launch of TDRS-East and completion of the subsequent engineering test period. This phase is a combination of the configurations shown in figures 6.2 and 6.5. TDRS-East will relay—to Goddard via White Sands—MSS and TM sensor data acquired over North and South America, Europe, and Africa as shown in figure 6.6. For a year after launch, TDRS-East will be available typically 2-4 hours per day. Consequently, the TGS at Goddard will still be used to provide eastern U.S. MSS and TM coverage, and Canada will still provide western U.S. TM coverage. Fairbanks, Goldstone, and the foreign ground stations with U.S. recorders will continue to provide MSS coverage.

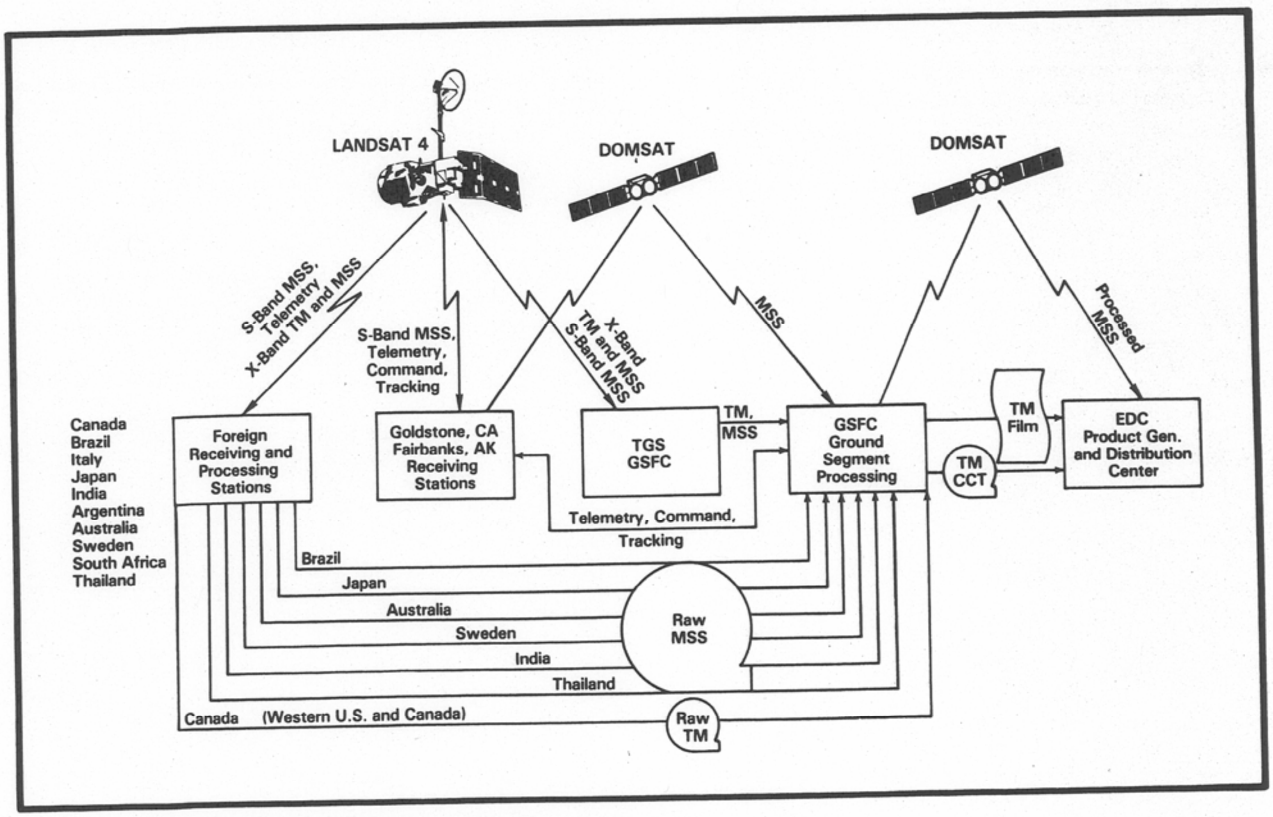


Figure 6.2 PRE-TDRSS GROUND-SEGMENT DATA

6.7. The zone of exclusion is a small segment of the Earth's surface over which neither TDRS is able to relay acquired Landsat 4 data because of orbit and antenna-gimbal geometry constraints.

Because the data stream is received from TDRS at 85 Mbps and can be relayed via communications satellite at a maximum of 50 Mbps, the TM data first are recorded on high density tape before being relayed. MSS data, on the other hand, can be relayed directly at their real-time rate of 15 Mbps.

In this operational phase, partially processed MSS data are transmitted, as before, from Goddard to EDC via a communications relay satellite. Fully processed TM data are sent on both film and digital tape via air freight.

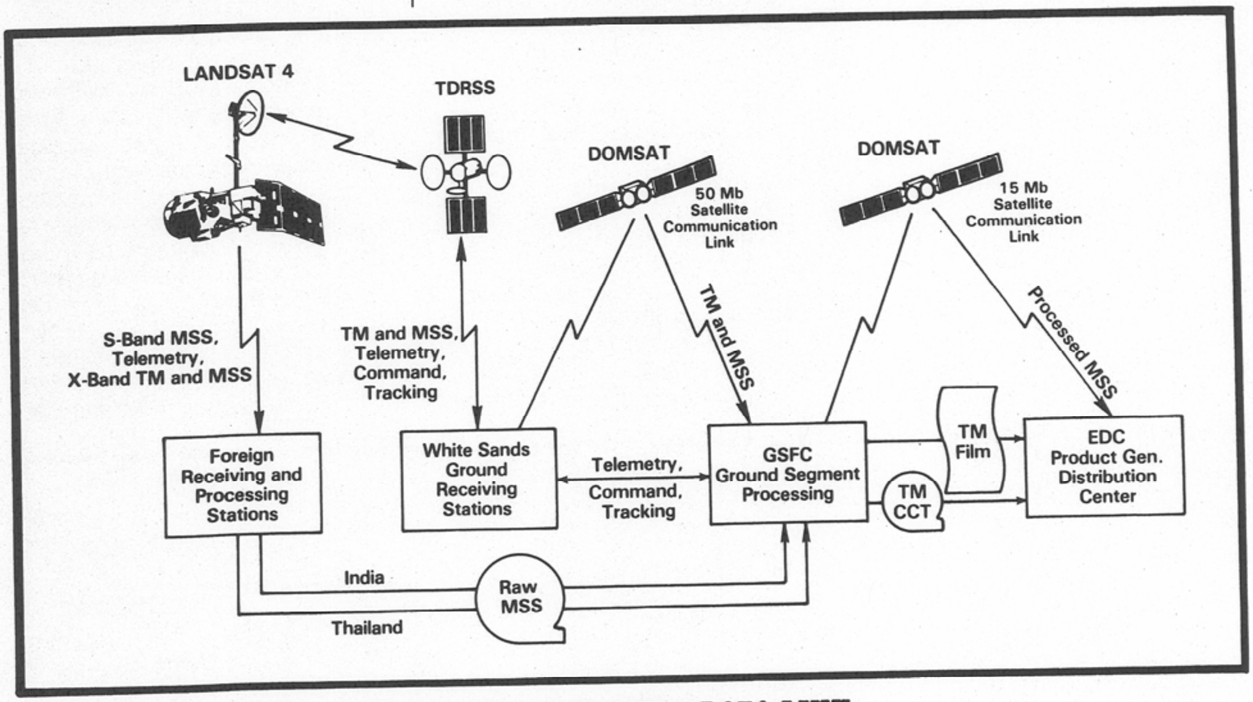


Figure 6.5 OPERATIONAL-TDRSS GROUND-SEGMENT DATA LINK

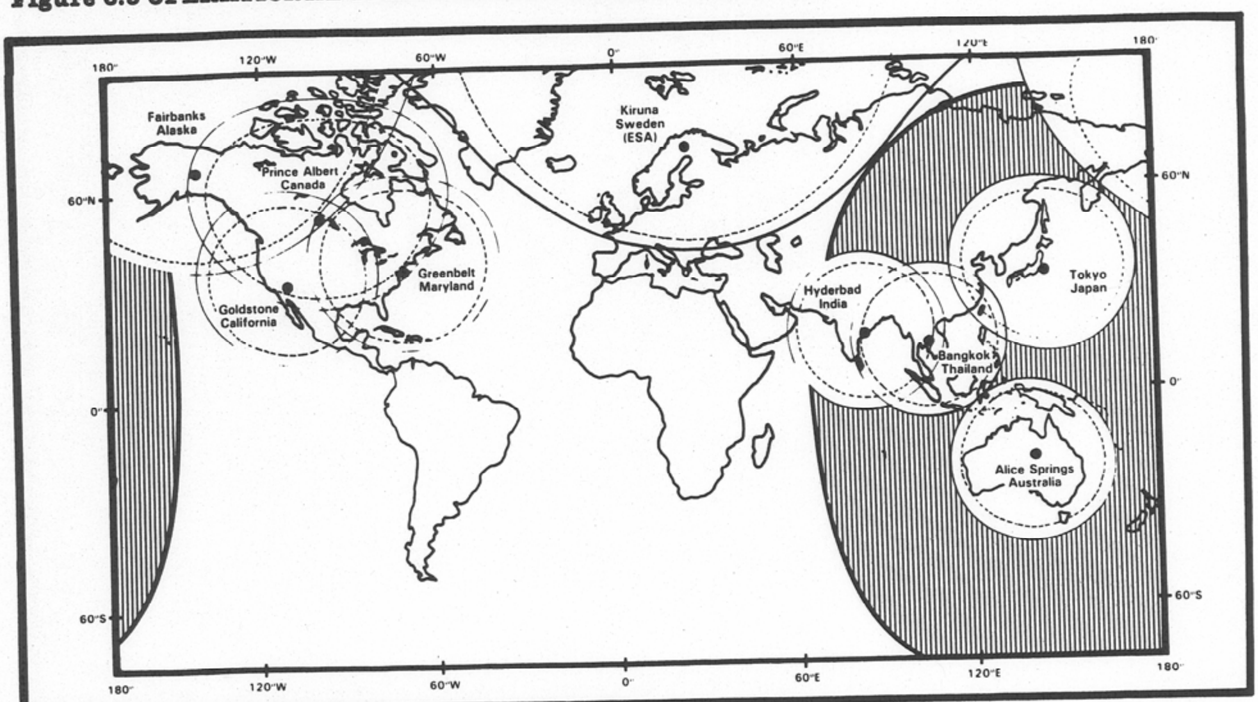


Figure 6.6 THIRD PHASE, DATA COMMUNICATION NETWORK (shaded areas not covered)

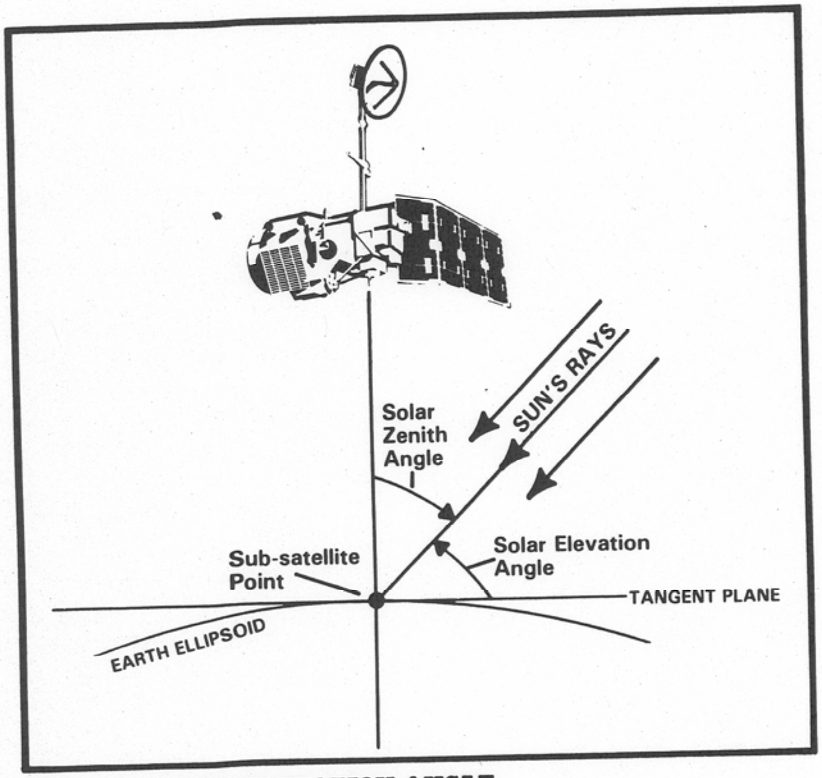


Figure 5.10 SUN ELEVATION ANGLE

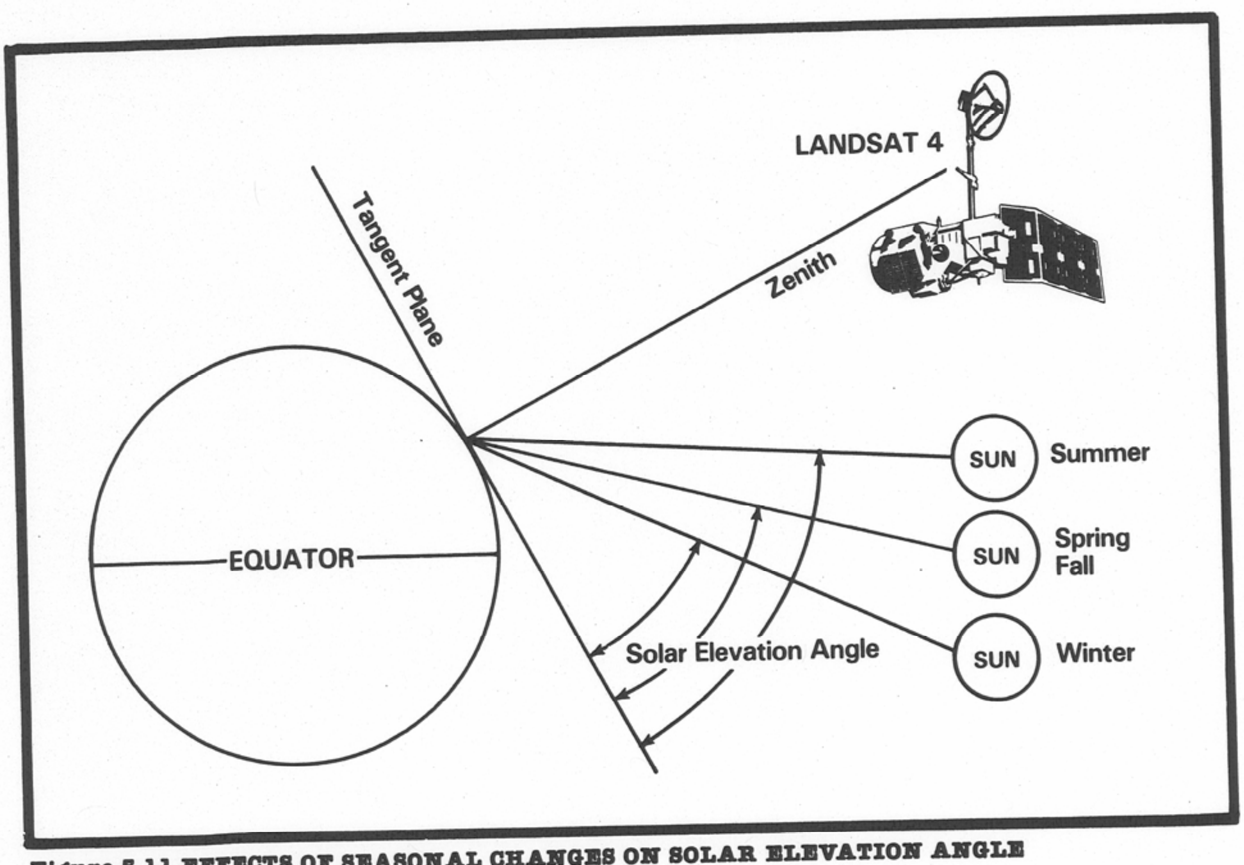


Figure 5.11 EFFECTS OF SEASONAL CHANGES ON SOLAR ELEVATION ANGLE

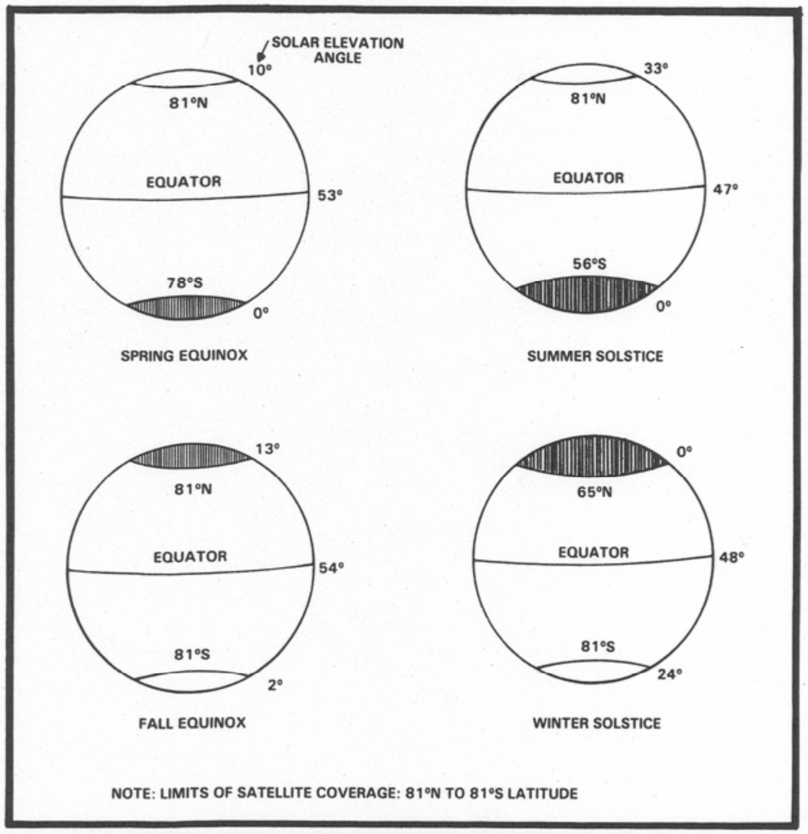


Figure 5.12 SEASONAL VARIATION IN SOLAR ELEVATION ANGLE (based on 9:30 A.M. equatorial crossing time)

Calculation of Sun Elevation Angle

The formula for calculation of Sun elevation angle at any latitude, time of day, and time of year is as follows:

$a = \arcsin(\sin\delta \sin\phi + \cos\delta \cos h \cos\phi)$,

where (1)

a = Sun elevation angle,
δ = solar declination,
h = hour angle (°) to Sun, and
ϕ = latitude.

Exact values for solar declination can be obtained from the "U.S. Naval Observatory Nautical Almanac." A close approximation is given by the following formula:

$\sin\delta = (\sin i)(\sin\lambda)$,

where (2)

i = inclination to ecliptic, which is 23.44°, and
λ = Sun's apparent position (0° at vernal equinox),

or,

$\delta = \arcsin[0.3978 \sin(0.986° d)]$,

where (3)

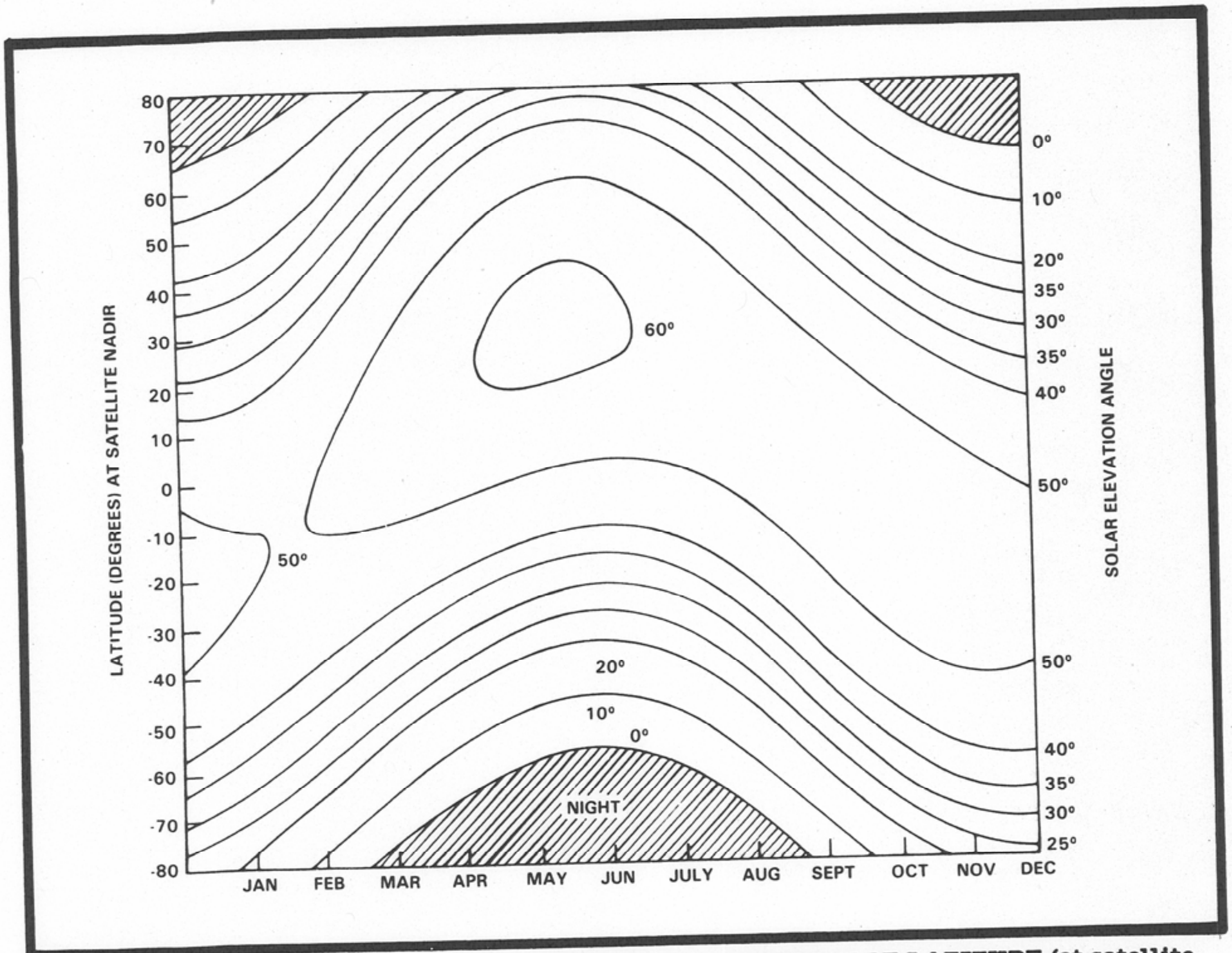
d = days past vernal equinox (approximately 21 March)

Calculation of h

The hour angle, or h in equation (1), is given by the following algorithm:

1. Find the difference, in hours and tenths of hours, between 1200 and the time of interest.
2. Multiply the result obtained in step (1) by 15°.
3. Find the difference, in degrees, between the longitude of interest and center longitude in the same time zone (75°, 90°, 105° or 120° for the conterminous United States).
4. Add the result of step (3) to the result of step (2), if longitude of interest is to the east (of center longitude) and afternoon, or west and morning. Subtract step (3) from step (2) for the converse case. The final value is h.

NOTE: The value for h will be in error (slightly) if the equation of time is not taken into account. This correction can be obtained from the "American Ephemeris and Nautical Almanac." From the "Table of the Sun," find ephemeris transit time for date of interest and use this instead of 1200 in step (1).



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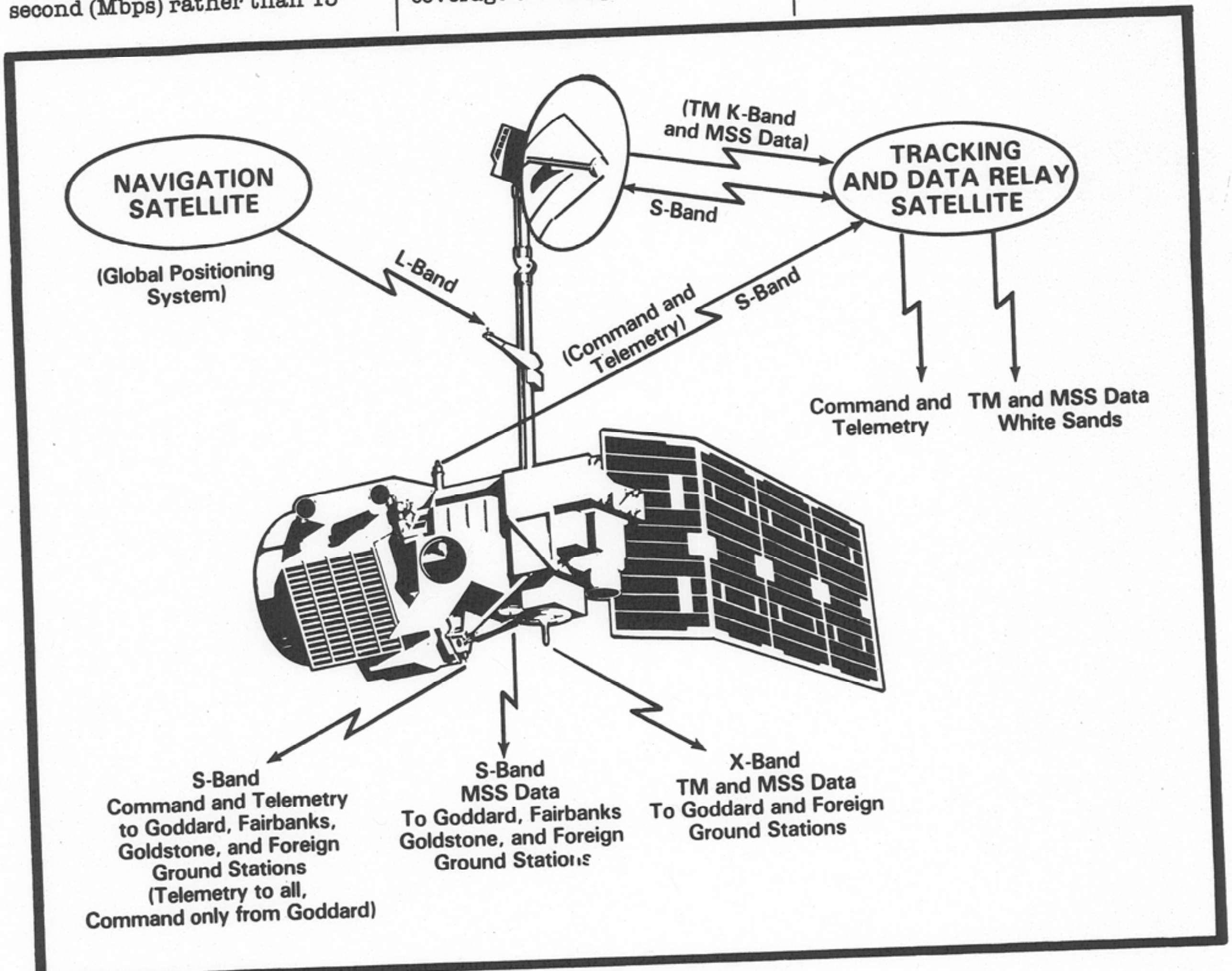

Figure 6.1 FLIGHT SEGMENT COMMUNICATION LINKS

Table 6.1 X-BAND IMAGE DATA TRANSMISSION CHARACTERISTICS

- Frequency: 8.2125 GHz (X-Band)
- Transmitter power: 44 watts
- Shaped-beam antenna
- Unbalanced quadrature phase-shift keyed (UQPSK) modulation
- The TM data are normally on the "I" carrier channel, and the MSS data are modulated on the "Q" carrier channel with a 4-to-1 power split. There are three operational modes as follows:

Mode	I-Channel Data	Q-Channel Data	Modulation
1	PN (84.903 Mbps)	MSS (15.0626 Mbps)	UQPSK
2	TM (84.903 Mbps)	TM (84.903 Mbps)	BPSK
3	TM (84.903 Mbps)	MSS (15.0626 Mbps)	UQPSK

The TM data are replaced with pseudonoise (PN) code for mode 1, in which only the MSS is operating. When only the TM is operating, the MSS data may be replaced with TM data. The TM data are PN-encoded within the instrument electronics. The MSS and TM are differentially encoded by converting from NRZ-L to NRZ-M for downlink transmission.

X- AND S-BAND COMMUNICATIONS TO FOREIGN GROUND STATIONS

Foreign ground stations can acquire TM image data by the X-band link only. TM payload correction data can be acquired either from the X-band image data stream or the S-band 32-Kbps telemetry data link. MSS image data can be acquired from the X-band link in addition to the S-band link. MSS telemetry data can be acquired from the S-band 8-Kbps link. If required, S- and X-band communications links can be operated simultaneously to satisfy foreign ground station coverage requirements for common areas. Simultaneous S- and X-band image data transmissions to one station will not be supported, however.

S-BAND IMAGE DATA TRANSMISSION CHARACTERISTICS

- Carrier frequency: 2265.5 MHz
- Transmitter power: 10 watts
- MSS data rate: 15.0626 Mbps
- Shaped-beam antenna
- NRZ-L PCM/FM modulation
- Deviation ± 5.6 MHz ± 5 percent

S-BAND TELEMETRY DATA TRANSMISSION CHARACTERISTICS

Real-time spacecraft telemetry (housekeeping and GPS data), narrow-band tape recorder telemetry, the payload correction data, and onboard computer data are downlinked by the S-band transponder. S-band telemetry will be commanded on in response to a foreign station's request for telemetry data to support their MSS image data reception (by either S- or X-band). Foreign ground stations can use the real-time spacecraft telemetry or the payload correction data only, or they may use both.

- Frequency: 2287.5 MHz
- Effective isotropic radiation power: +3.2 dBW
- PCM/PSK/PM modulation
  8-Kbps telemetry data on 1.024-MHz subcarrier
- PCM/PM modulation
  32-Kbps PCD (payload correction data) phase-modulated on carrier

na and receiving system for signals broadcast from a network of navigational satellites. Initially consisting of 5 (later to expand to 18) satellites, the network will provide, through triangulation, extremely precise location (ephemeris) data of the spacecraft. The network, called the Global Positioning System (GPS), is also designed for many applications in addition to Landsat.

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Second Phase

The second phase commences when the India and Thailand receiving stations become operational. No other changes occur to the network described in Phase 1. Acquisition coverage during Phase 2 is shown in figure 6.4.

Third Phase

The third phase begins after the launch of TDRS-East and completion of the subsequent engineering test period. This phase is a combination of the configurations shown in figures 6.2 and 6.5. TDRS-East will relay—to Goddard via White Sands—MSS and TM sensor data acquired over North and South America, Europe, and Africa as shown in figure 6.6. For a year after launch, TDRS-East will be available typically 2-4 hours per day. Consequently, the TGS at Goddard will still be used to provide eastern U.S. MSS and TM coverage, and Canada will still provide western U.S. TM coverage. Fairbanks, Goldstone, and the foreign ground stations with U.S. recorders will continue to provide MSS coverage.

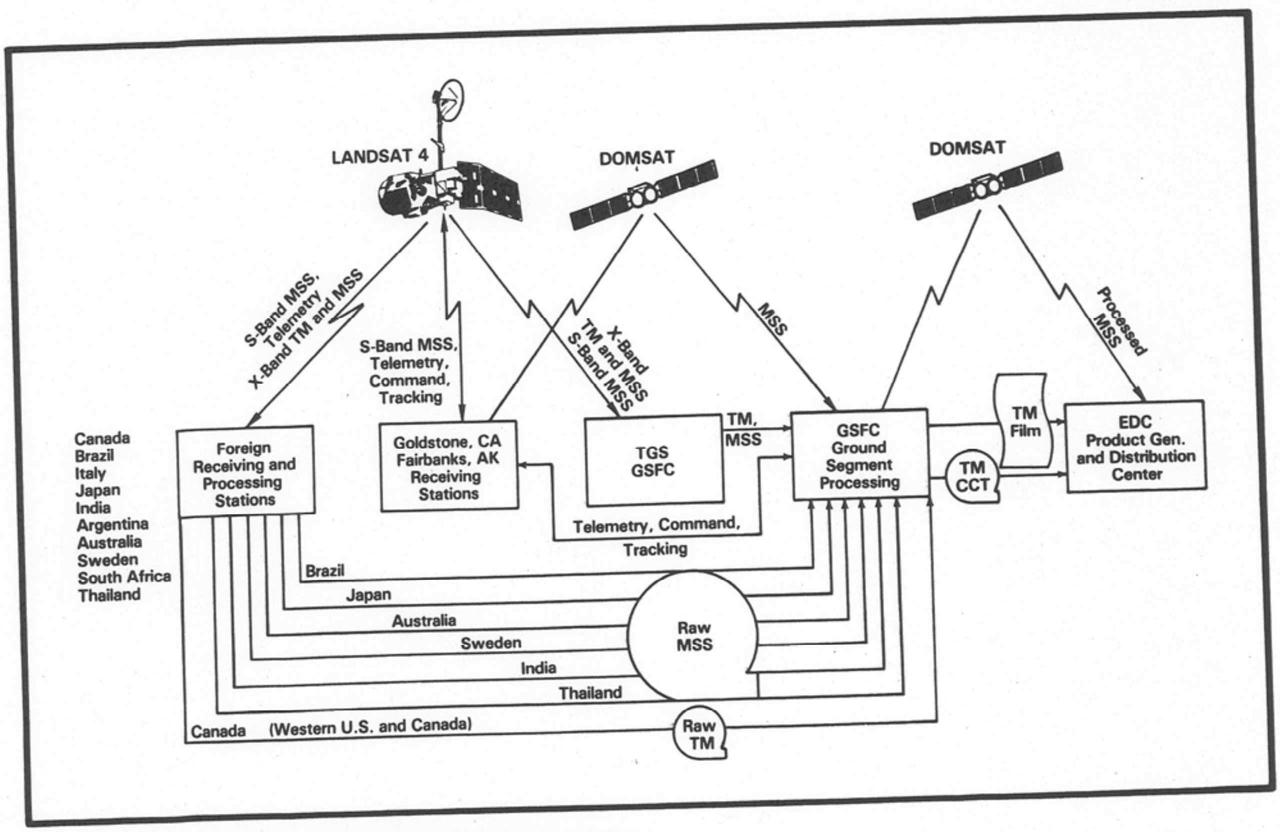

Figure 6.2 PRE-TDRSS GROUND-SEGMENT DATA

Fourth Phase

Following the launch of TDRS-West and the subsequent 90-day engineering test period, Phase 4 will begin. This final phase is configured as shown in figure 6.5 The Fairbanks and Goldstone stations will no longer be used, while the TGS will be used in test modes only. Coverage in this operational phase is worldwide, with two foreign stations providing coverage in the TDRSS zone of exclusion as shown in figure

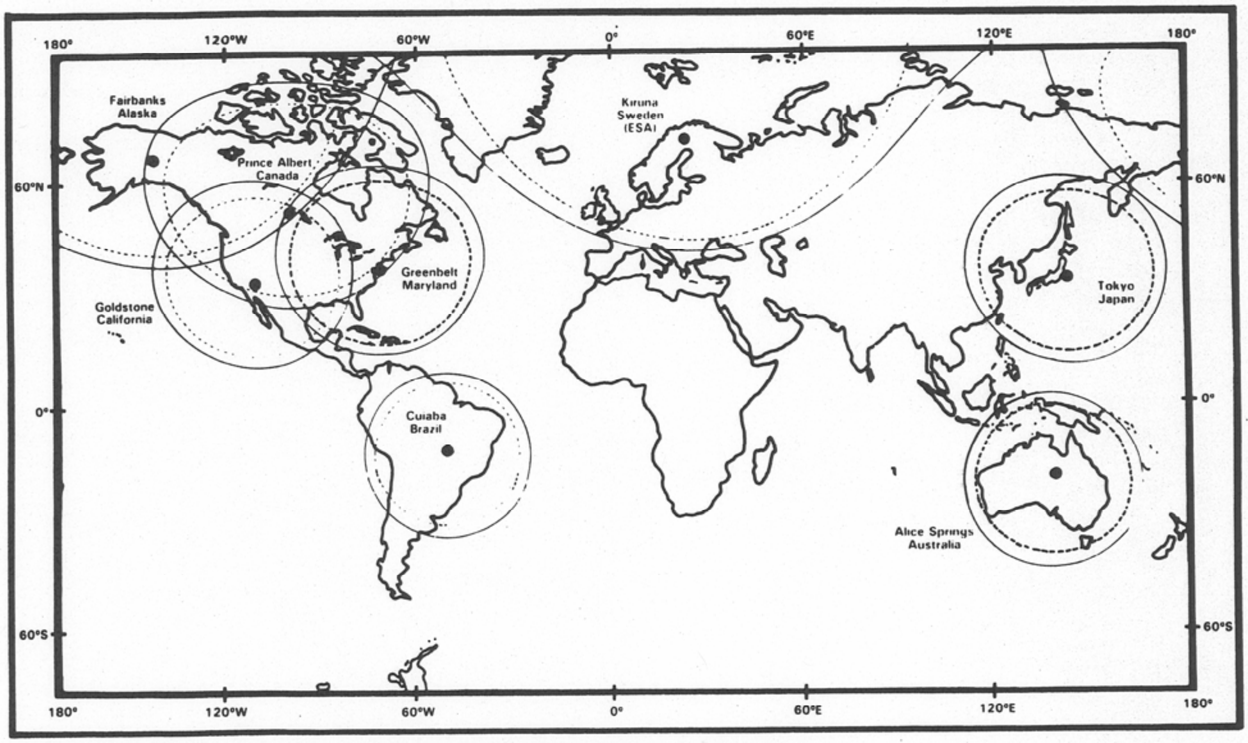

Figure 6.3 FIRST PHASE, DATA COMMUNICATION NETWORK

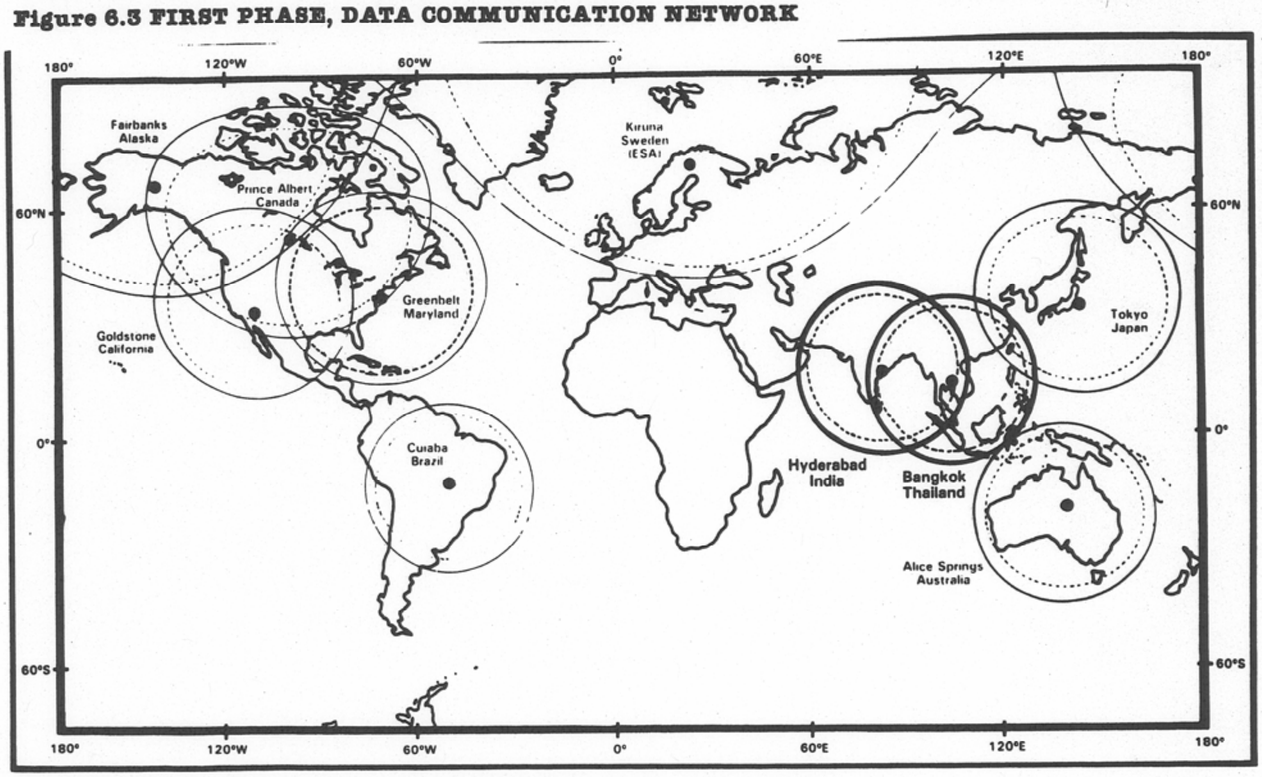

Figure 6.4 SECOND PHASE, DATA COMMUNICATION NETWORK

6.7. The zone of exclusion is a small segment of the Earth's surface over which neither TDRS is able to relay acquired Landsat 4 data because of orbit and antenna-gimbal geometry constraints.

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In this operational phase, partially processed MSS data are transmitted, as before, from Goddard to EDC via a communications relay satellite. Fully processed TM data are sent on both film and digital tape via air freight.

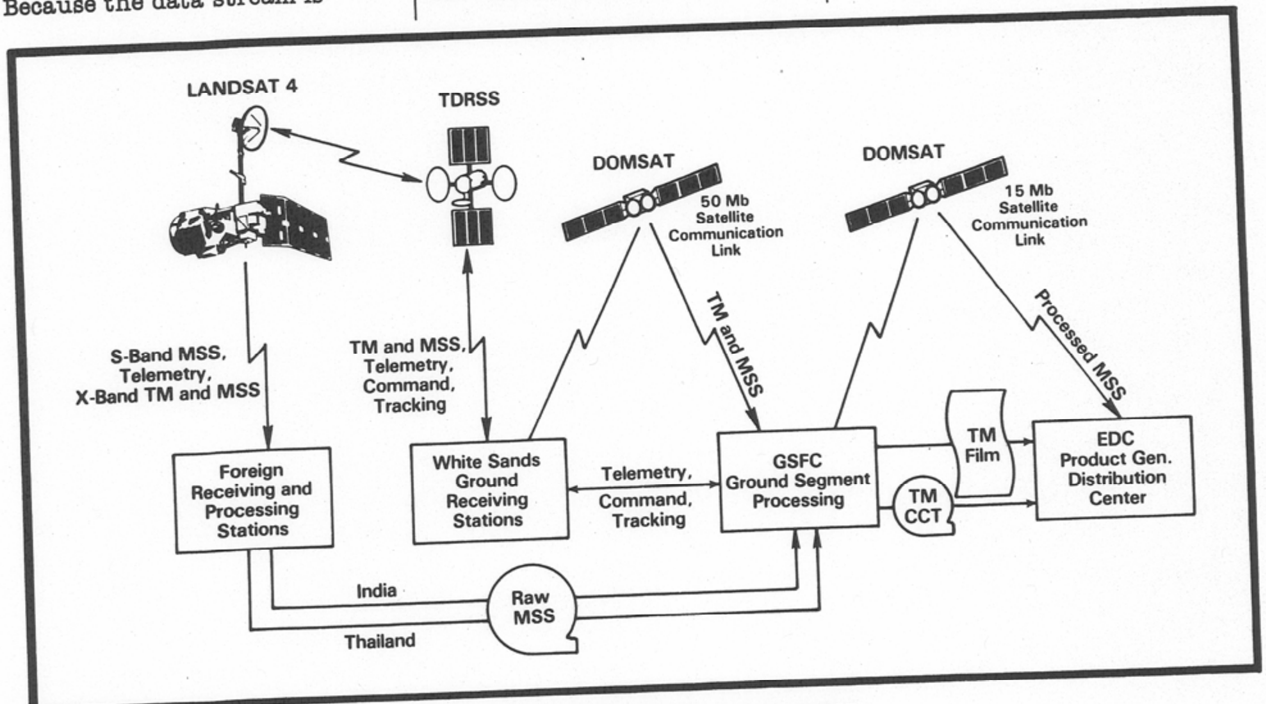


Figure 6.5 OPERATIONAL-TDRSS GROUND-SEGMENT DATA LINK

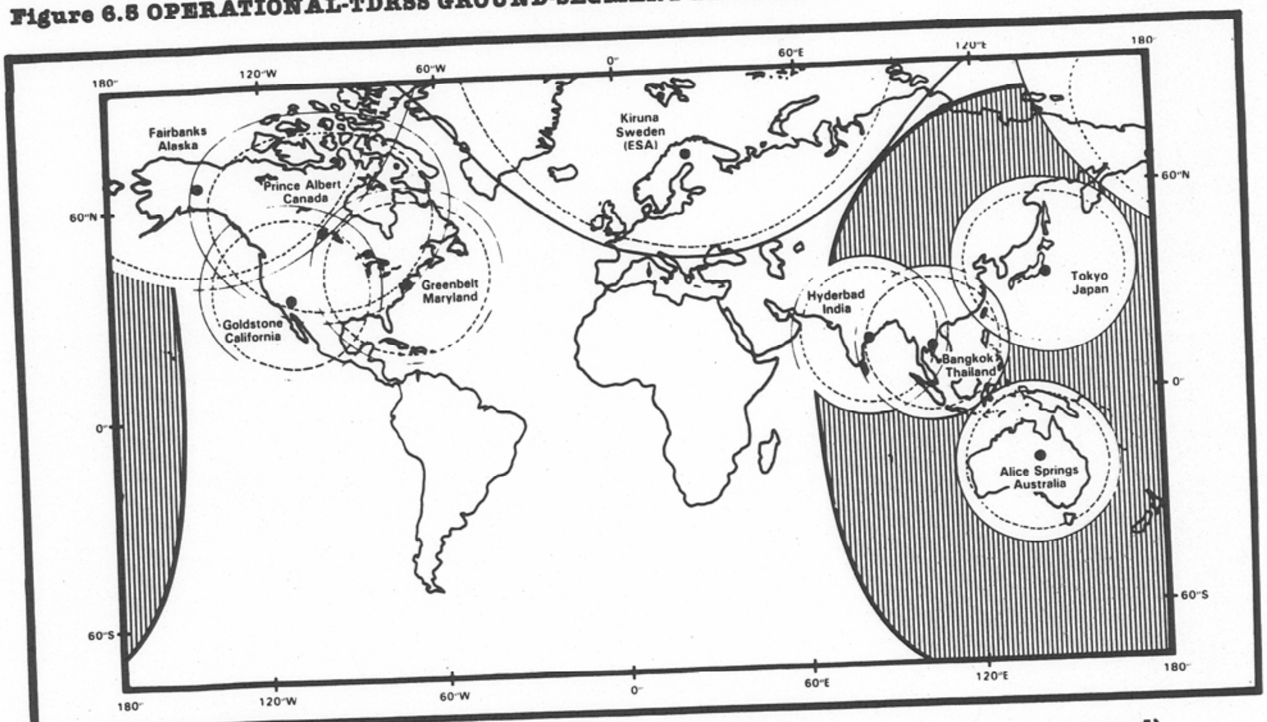


Figure 6.6 THIRD PHASE, DATA COMMUNICATION NETWORK (shaded areas not covered)

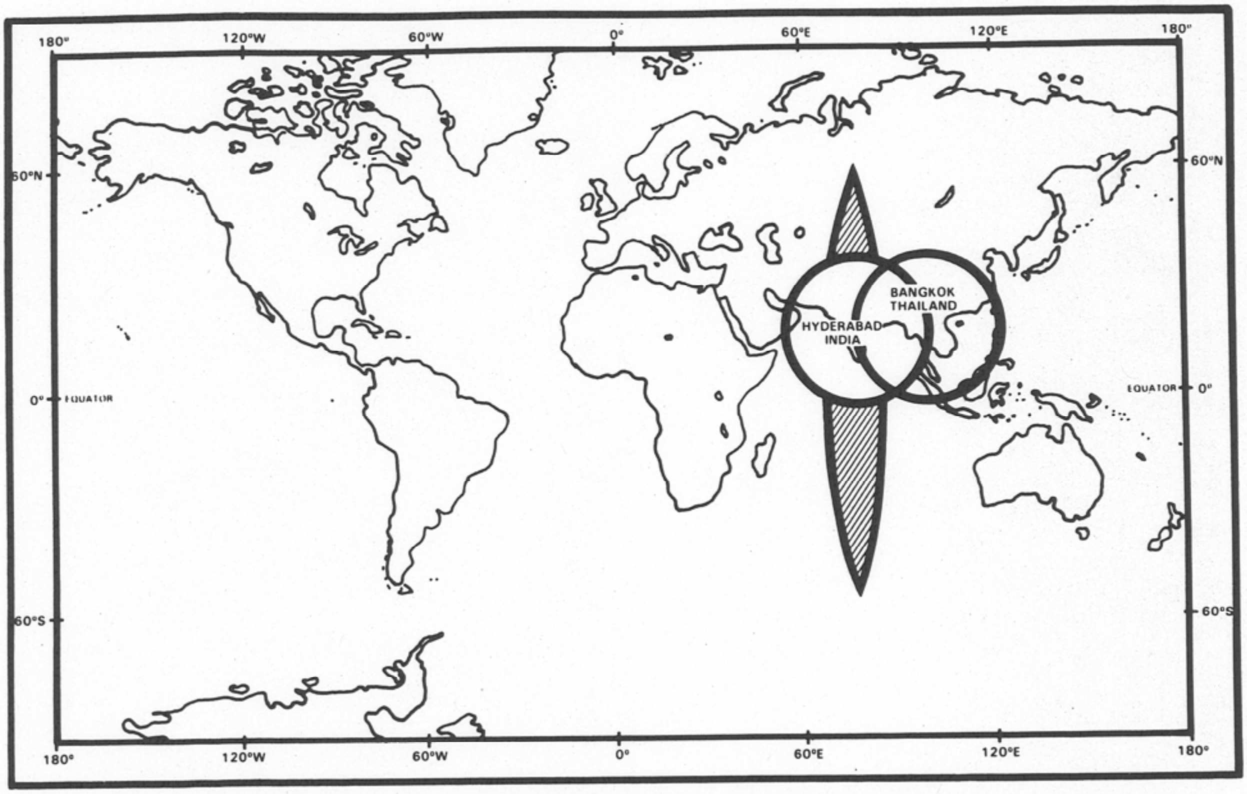


Figure 6.7 FOURTH PHASE, DATA COMMUNICATION NETWORK (shaded areas not covered)

GROUND SYSTEM

GROUND SYSTEM CONFIGURATION

The Landsat 4 ground system includes two major elements: the spacecraft control and image processing portion at Goddard Space Flight Center (GSFC) and the product generation and distribution portion at the EROS Data Center (EDC). The primary GSFC and EDC data and communications paths are noted in figure 7.1.

The new Goddard ground segment for Landsat 4 is partitioned into three separate facilities in which the Mission Management Facility (MMF) performs control, scheduling, production management, and data base maintenance functions for both the Control and Simulation Facility (CSF) and the Image Generation Facility (IGF). The major functions of the MMF, CSF, and IGF are listed in table 7.1. The basic data paths among principal elements (the CSF, MMF, and IGF) of the Landsat 4 system are shown in figure 7.2. More specific information on communication between the flight and ground segments is contained in Section 6, Data Communications.

An overview of the hardware configuration for MMF is shown in figure 7.3 (a CSF configuration is not available for this printing). The hardware configurations for Data Receive Record and Transmit System (DRRTS) and MSS Image Processing System (MIPS) are illustrated in figures 7.4 and 7.5. The TM Image Processing System (TIPS) hardware configuration is now well defined, and software is under development; however, further discussion of TM ground processing will be available as a supplement to this handbook.

GROUND SYSTEM PROCESSING OF MSS DATA

The Landsat 4 ground system commands the flight segment to acquire and transmit image data sensed by the Multispectral Scanner (MSS). The ground system processes the image and telemetry data in several phases, produces high density tape (HDT) products in partially corrected format, and generates film products and computer compatible tape (CCT) products. Except for engineering and quality control verification,

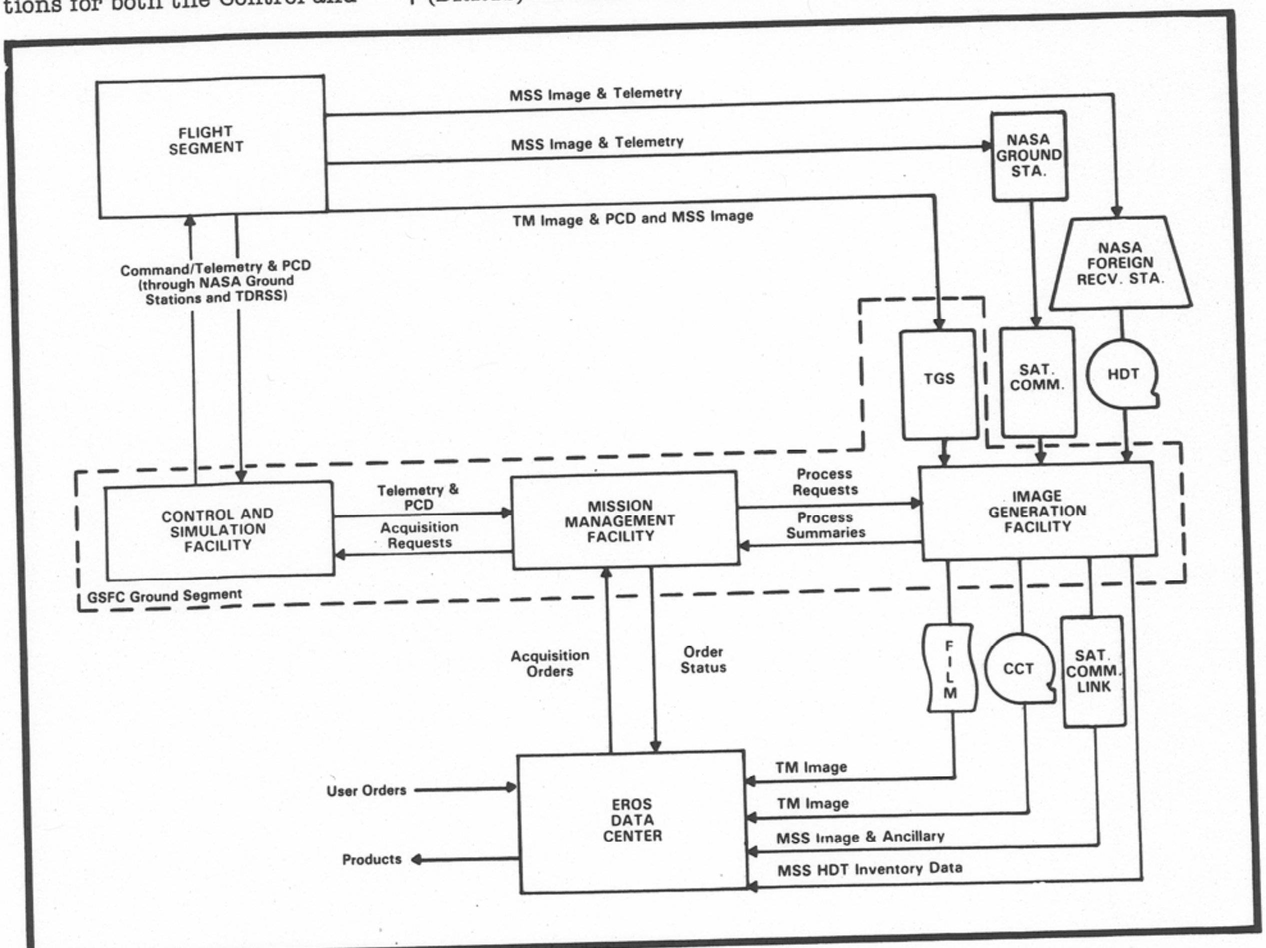


Figure 7.1 GSFC and EDC BASIC COMMUNICATION PATHS

Table 7.1 MAJOR FUNCTIONS OF GODDARD GROUND SEGMENT FACILITIES

Mission Management Facility

- Data Acquisition Support
  - Process Requests for Data Acquisition
  - Provide Candidate Scene Data Acquisition Lists for Satellite Operations Planning and Scheduling
  - Account for Telemetry Data Acquisition
  - Account for Image Data Acquisition
- Archival Data Generation Support
  - Process Requests for Archival Data Generation
  - Schedule and Perform Archival Processing
  - Process Requests for Quality Control (QC) Product Generation
  - Schedule and Perform QC Product Generation
- Ground Segment Management
  - Maintain Ground Segment Supplies Inventory
  - Track Ground Segment Problems
  - Provide Verification and Self Test Capability
  - Provide Management Reports

Control and Simulation Facility

- Plan and Schedule Flight Segment Operations
- Schedule Communication Link Support with Network Control Center
- Command Flight Segment
- Acquire Flight Segment Telemetry
- Monitor, Evaluate, and Report Flight Segment Performance
- Simulate Flight Segment Operation
- Reprogram On-Board Computer
- Perform Flight Segment Self Test

Image Generation Facility

- Acquire Image Data
  - Record Incoming MSS and TM Data
  - Generate Tape Directories
- Process Image-Related Telemetry and Payload Correction Data
  - Calculate Image Framing
  - Generate Systematic Correction Data
  - Generate Geodetic Correction Data if Control Points are Available
- Generate Archival Tapes
  - Apply Radiometric Corrections
  - Append Geometric Corrections
- Create Quality Assurance Products
  - Quick-Look 70mm Film
  - Computer Compatible Tapes
  - Reports
  - Fully Corrected High Resolution Film
- Transmit Archival MSS Data to EROS Data Center

film is generated only from fully corrected data. CCT products, however, are available either partially or fully corrected. The overall ground system acquisition and processing functions can be described in terms of six major activities:

1. User Order Processing
2. Flight Scheduling and Control
3. Ground Segment Image and Telemetry Acquisition
4. Telemetry Processing
5. Digital Archive Generation
6. Image Archive and Product Generation

Activities 1 and 6 are performed primarily at EDC. Activities 2-5 occur at GSFC and are divided among the CSF, MMF, and IGF.

1. User Order Processing

User order requests originate at EDC. User requests are in the form of either a standing order or a retrospective order. Standing orders are requests either for products only (of data as they enter the archive at EDC) or for acquisition of specific data and resultant products. Retrospective orders request products to be made from archived data. Requests for scheduled satellite acquisition of specific data are forwarded to GSFC. Additional information on how to order data is available in Section 8, Availability and Ordering of Data.

Orders for image acquisition are submitted to GSFC on CCT. There the acquisition orders are entered into an MMF data base to form a pool of standing acquisition orders to be satisfied. During the CSF-MMF spacecraft scheduling activity, the MMF data base is searched to identify standing orders requesting acquisition during the scheduled flight period.

2. Flight Scheduling

The CSF accepts candidate acquisition requests from the MMF and integrates these requests with the following data to schedule flight segment activities for image acquisition:

- Ground Station Planning Schedule
- Network Weekly and Daily Planning Schedules, from the Network Operations Control Center (NOCC)
- Predicted Cloud Cover, from the National Weather Service (NWS)
- Ephemeris and Station-Contact Predicts, OBC Load Parameters, from the GSFC Orbit Computation Group (OCG)

The flight scheduling activity uses these input parameters to produce weekly and daily acquisition schedules. Flight scheduling produces:

- A two-week schedule each week, with the second week prepared as a contingency plan.
- A two-day schedule each day, with the second day as a contingency plan.

Acquisition requests are filled on a weekly schedule, beginning on Monday and ending on Sunday. Acquisition orders are due at EDC on the Monday two weeks prior to the acquisition week.

3. Ground System Image and Telemetry Acquisition

DRRTS receives raw image data on HDT from foreign ground stations, directly from TGS, from White Sands via communications satellite relay, or via the Domsat Interface Facility from Goldstone and

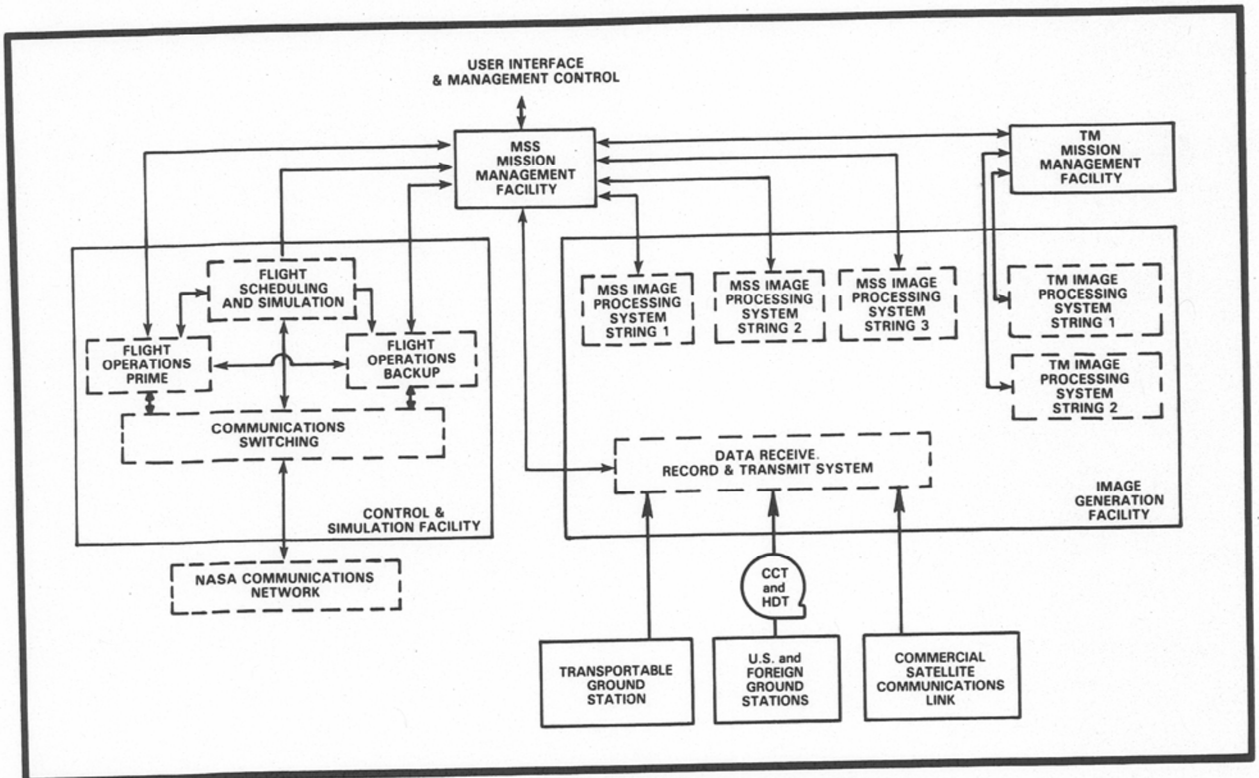


Figure 7.2 LANDSAT 4 GROUND SEGMENT COMMUNICATION PATHS AT GSFC

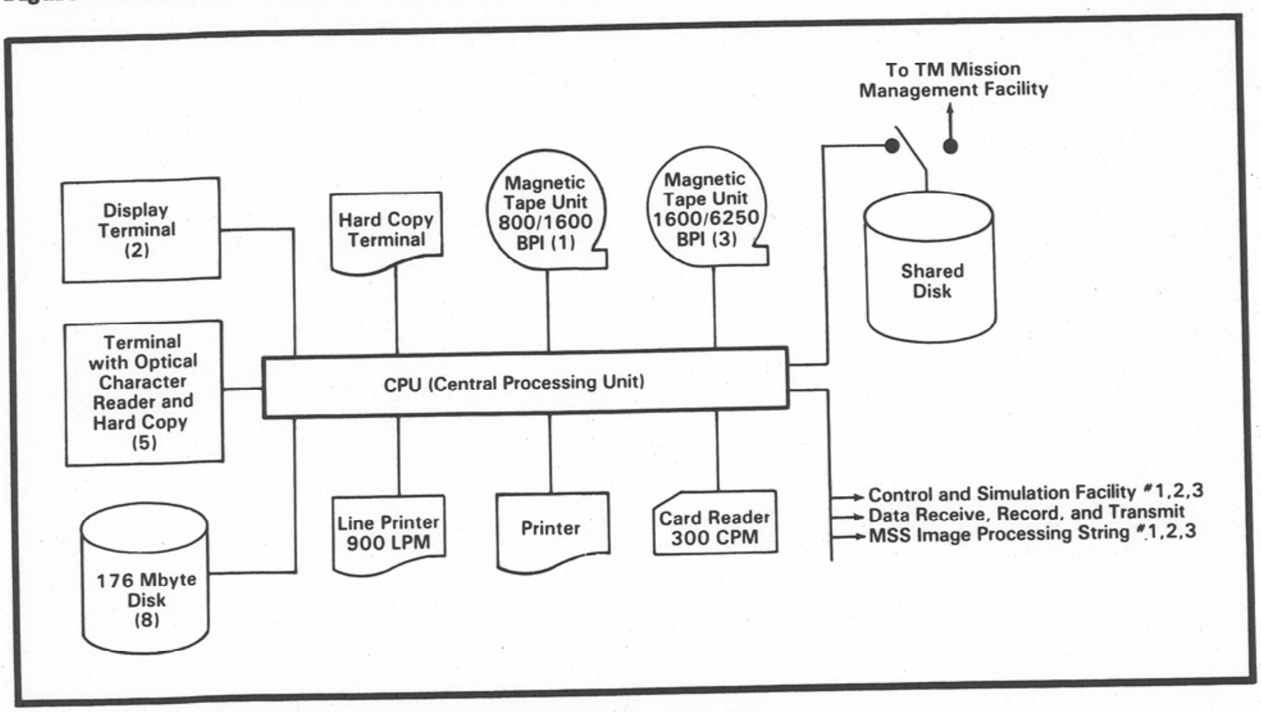


Figure 7.3 MSS MISSION MANAGEMENT FACILITY HARDWARE

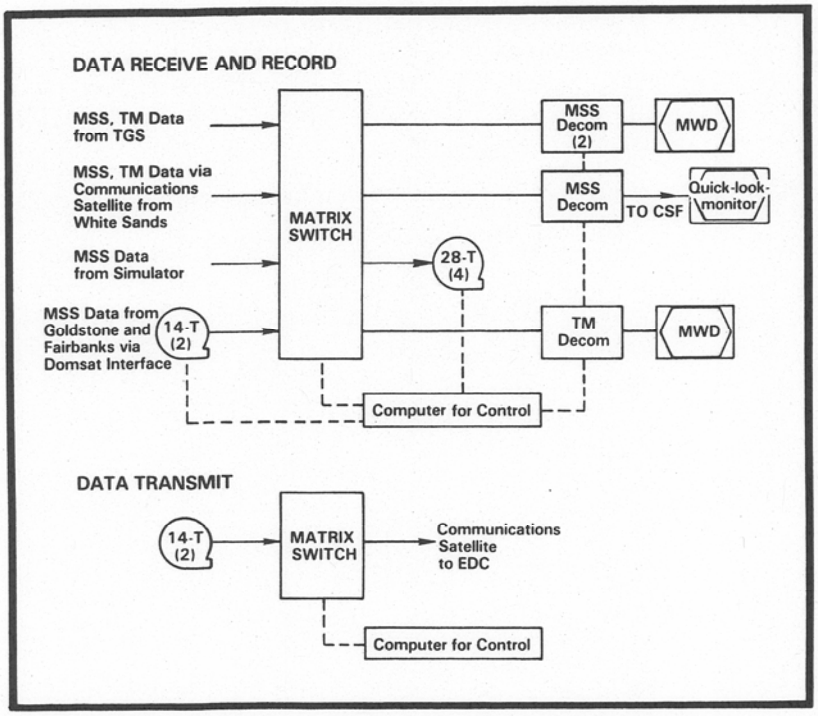


Figure 7.4 DATA RECEIVE, RECORD, AND TRANSMIT SYSTEM

Fairbanks, and records the data on HDT-R, with standard telemetry inter-range instrumentation group (IRIG) time added on the index track of the tape. Incoming data are slightly modified to adjust the line-start codes, to provide bit inversion of imagery and time, and to create and insert line-length code. DRRTS processing extracts spacecraft time, spacecraft ID, sync-loss counts, and sync-fault counts. It generates the HDT-R directory containing scene ID's and IRIG-time indices and creates an image-quality and tape-quality file. These are then transferred to the MMF. Incoming telemetry is received via NASCOM (NASA Communications Network) at the CSF where appropriate data are extracted and formatted into scene-related packets. Telemetry intervals

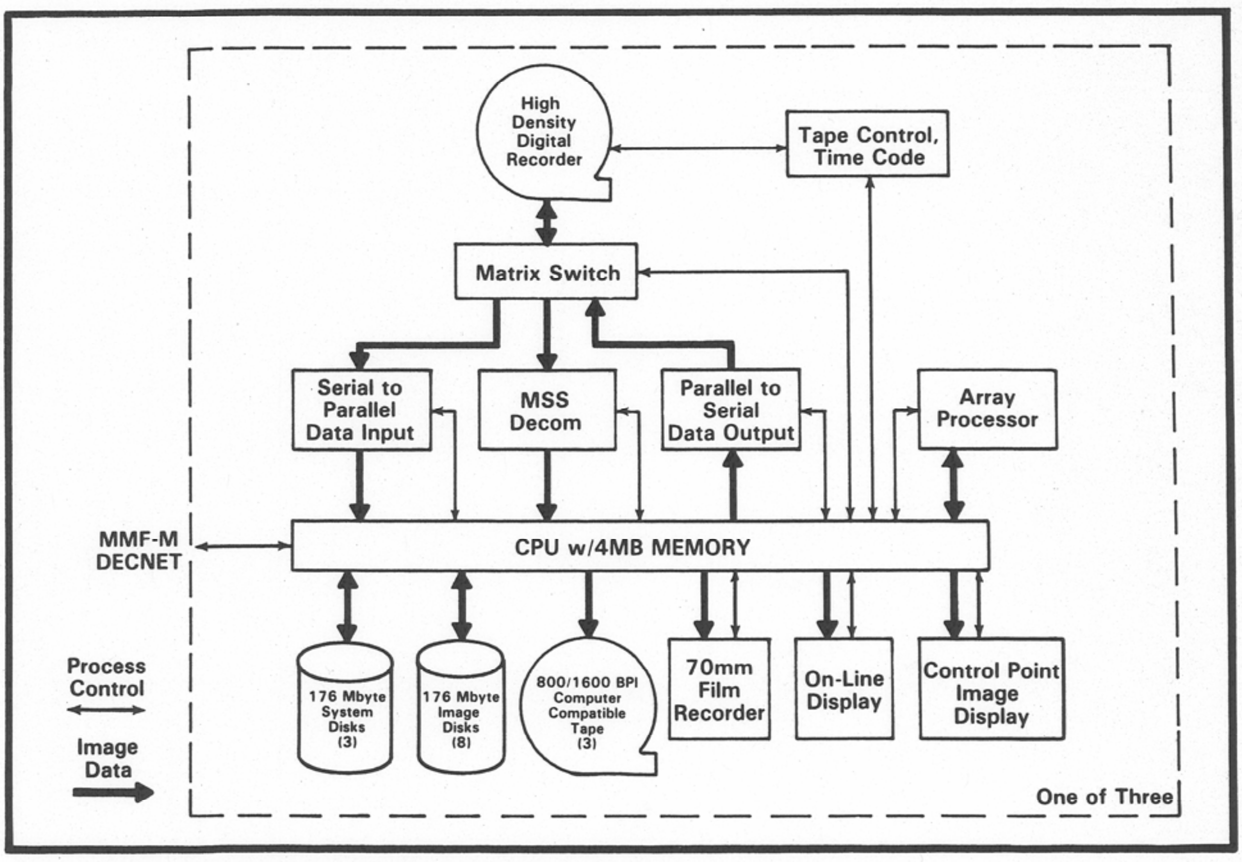


Figure 7.5 MSS IMAGE PROCESSING SYSTEM HARDWARE

relating to "desired scenes" are selected using the acquisition schedule and are transferred with appropriate telemetry start-stop times to the MMF in preparation for processing by the MSS Image Processing System (MIPS) of the IGF.

4. Telemetry Processing

The MMF receives the telemetry data (from CSF) and HDT directories (from DRRTS), updates files, and creates the process request for telemetry processing in MIPS. Payload Correction Data (PCD) is generated from flight-segment telemetry in the first of two phases of correction processing. Systematic Correction Data (SCD) is generated in the second phase from the HDT-R directory information and the PCD. Phase 1 occurs when telemetry is available, whether or not the HDT-R has been recorded. Phase 2 requires information, based on HDT-R directory data, that is provided to the MMF by the DRRTS upon receipt of incoming imagery.

In Phase 1, MMF-M processes the telemetry data to calibrate, validate, enhance, and smooth the On-Board Computer (OBC) attitude and ephemeris information.

Attitude Processing is accomplished in four steps:

- Amplitude and phase compensation of gyro data
- Alinement of compensated gyro data to MSS boresight
- Propagation of Euler parameters and translation of these parameters to roll, pitch, and yaw
- Generation of attitude estimates at 0.512-second intervals.

Ephemeris Processing consists of three steps:

- Comparison of spacecraft ephemeris data (position and velocity) with the ephemeris computed by the ground segment
- Removal of noise, outlier, and bias errors, using results of the spacecraft-to-computed-ephemeris comparison
- Generation of updated ephemeris tables from data created at 2.048 second intervals.

The processed attitude and ephemeris, along with housekeeping and support information, are formatted into a processed PCD file. The content of this file is listed in table 7.2. This file is saved until Phase 2 telemetry processing is initiated, which occurs after receipt of the HDT-R directory at the MMF.

Phase 2 uses information from the processed PCD file and the HDT-R directory to calculate scene-center time and location, scene ID, state-vector departures from nominal, and band/line offset adjustment. These four calculations are described below.

Scene center calculation determines the scene-center location and scene-center time as follows:

- Scene-center time is calculated using processed attitude and ephemeris data files (PCD data), WRS center location, the inertial velocity vector at the WRS center location, and additional parameters from PCD Phase 1 processing.
- Scene-center location is calculated by linear interpolation using two ephemeris data points and scene-center time.
- Processed attitude data (pitch and roll) are linearly interpolated to the time of scene-center and used to correct both

Table 7.2 PROCESSED PAYLOAD CORRECTION DATA FILES

Processed ephemeris data included:
- Time of ephemeris sample (msec)
- Position in Earth-Centered, Earth-Fixed (ECEF) coordinates
- Velocity in ECEF coordinates
- Data quality indicator

Processed attitude data included:
- Time of attitude sample (msec)
- Pitch (radiance)
- Roll (radiance)
- Yaw (radiance)
- Data quality indicator

Housekeeping data included:
- Calibration lamps on/off
- Calibration lamps A/B
- Band 1 low/high gain
- Band 2 low/high gain
- Spacecraft ID
- Scan monitor A/B
- Scan monitor on/off
- Time code

PCD files include the following additional information:
- Orbital elements: the three position and three velocity components of the first ephemeris point in the interval
- Orbital direction (ascending or descending)
- Length of telemetry interval
- Number of ephemeris data points in the interval
- Number of rejected ephemeris points in the interval
- Accuracy of the ephemeris fit
- Number of attitude data points in the interval
- Number of rejected attitude points in the interval
- Accuracy of the attitude fit
- Type of ephemeris (predictive, definitive, GPS)

scene-center time and location.

Scene ID calculation creates, for each scene, a unique scene identifier consisting of the mission number, days since launch, and time of scene center in the form NDDDDHHMMSB where:

N = mission number (4)
DDDD = days after launch at time of observation
HH = hour at time of observation
MM = minute at time of observation
S = tens of seconds at time of observation (at scene center)
B = band identification

The "State Vector Departures from Nominal" calculations create observed-to-nominal difference vectors (deltas) for both ephemeris data (ΔX, ΔY, ΔZ in kilometers) and attitude data (Δroll, Δpitch, Δyaw in radians) in the Earth-centered, Earth-fixed (ECEF) coordinate system. For ephemeris data, the deltas are computed from the nominal along-track, cross-track, and radial spacecraft positions, creating 16 spacecraft-parameter biases. For attitude data, deltas are computed from the nominal values for pitch, roll, and yaw motion, creating 64 spacecraft-parameter biases. The observed-to-nominal difference data are used to create a vector of spacecraft-parameter biases relating to the nominal spacecraft coordinate system as defined at the WRS center. Departures from nominal altitude (in kilometers) and ground velocity (in kilometers per second) are also calculated.

Band/line offset adjustment calculates line shifts required to compensate for:

- Band separation
- Sensor sample timing delay
- Numerical smoothing of the effect of Earth rotation.

Phase 1 and Phase 2 of telemetry processing together produce the Correction Data File, frequently referred to as Systematic Correction Data (SCD), that is needed for MSS archive generation.

5. Digital Archive Generation

Digital archive generation is the ground processing phase that accomplishes the major data handling and computation activities necessary to produce data in archive format. That is, this phase generates data that have been radiometrically corrected and that have associated with them the ancillary data defining geometric correction grids and coefficients. It is these partially processed data that are recorded on high-density tape (HDT) and that are referred to as HDT-Archive MSS (HDT-AM) data.

To initiate archive generation processing, data from a variety of sources, as identified by or provided along with a Process Request (PR) from the MMF, are ingested into the MIPS. One PR is issued per HDT-R. The PR identifies the HDT-R and describes the tape (which contains the raw image data recorded at DRRTS) in terms of the number of swath intervals and scenes as well as by the source of data (TGS, foreign ground station, or NASA receiving station). The PR includes three additional files of information: Interval Ancillary Data File, Systematic Correction Data (SCD) File, and Processed Payload Correction Data (PCD) File.

The Interval Ancillary Data File transfers (from the MMF) information on Control Points (CP's) used in geodetic correction; for example: feature type; elevation, latitude, and longitude of CP; and line and pixel number of the center of the CP chip. It contains the intensity values of the 32- x 32-pixel chip itself, along with correlation histories of the chip. It also contains band and quality information for the image from which the chip was extracted.

The SCD File and Processed PCD File were described in the preceeding section. The PR also identifies those files of parameters stored in the MMF which will be required for archive processing. The MSS Archive Generation (MAG) parameters include WRS-related information, nominal values for ephemeris and detector calibration gains and biases, systematic correction functions (corrections for Earth rotation, etc.), and calibration wedge values.

During the initial data ingest phase, raw data are decoded, and sync and preamble are removed. The data and calibration wedge are decommutated from band interleaved by pixel (BIP) to band sequential (BSQ). Fill pixels are added for band registration purposes, scan lines are substituted to replace bad data, and line lengths are determined from scan pulses.

In the radiometric correction phase, a Radiometric Look-Up Table (RLUT) is generated that is used to translate input scene radiance values to radiometrically corrected output values. From the raw data, six Calibration-Wedge Values (CWV's) per detector per wedge are extracted. Then, histograms of pixel values are calculated from every eighth pixel of every line for each quarter of an image. The extracted CWV's are decompressed (from 0—63 to 0—127), and an average set of wedge values is determined (six per detector per one-fourth scene segment). An intermediate RLUT is generated by modifying these values using prelaunch-measured interval lamp gain and bias data. This RLUT is modified by determining both a multiplicative and an additive factor per detector from the scene radiance histogram extracted from the same quarter scene segment. The resultant RLUT is saved for use during archival HDT generation.

The geometric-correction phase of archive generation produces the data that are used to correct each scene for known systematic distortions. At the same time, geodetic corrections are computed that orient the framed data to one of two map projections, either Spacecraft Oblique Mercator (SOM) or Universal Transverse Mercator (UTM). If ground control points (GCP's) are available for a scene, the geodetic corrections subsequently are refined by data derived from accurately located reference GCP's. Up to 25 GCP's are used to register an image to a map reference. Geometric/geodetic correction is accomplished in four stages.

The first stage of geometric correction models the corrections for systematic distortions. Previously computed PCD and SCD data as well as certain WRS and map-projection-dependent data are used to generate systematic correction functions (SCF's) that associate lines and samples in the modeled image to corresponding lines and samples in the raw image. The parameters modeled in the systematic correction functions are ephemeris, attitude, scan geometry, scan angle profile, Earth geoid, Earth rotation, WRS, band offset, and line-length corrections.

The second stage of geometric correction computation is the generation of geodetic correction functions (GCF's) using control points acquired from the GCP library if available. If ground control points are not available for the WRS being processed, this geodetic correction stage is bypassed, and the image then is corrected for systematic distortions only. In the geodetic correction stage, the systematic correction functions generated in the first stage are updated to reflect ground-control-point correlations. Scene-center time, ephemeris, and attitude information extracted from the SCD file are used to calculate line and pixel locations of 128-line by 128-pixel control-point neighborhoods that are extracted from the raw image data. Difference vectors (ΔX, ΔY), which are used to further enhance the systematic correction functions, are generated for each CP in the raw image. To accomplish this, the CP neighborhoods and the 32-line by 32-sample chips extracted earlier are radiometrically corrected using the RLUTs and geometrically corrected using the SCD. The CP neighborhoods and chips then are enhanced and cross-correlated. The displacement vectors (X, Y) of the CP's in the CP neighborhoods, generated by the cross-correlation process, are filtered to remove outliers. The displacement vectors are used to relate the observed displacement of CP's in a scene to a model of spacecraft motion in order to estimate biases in actual motion from nominal values.

As a byproduct of geodetic correction using control points, fully corrected images are temporally registered. Temporal registration is defined as the inherent registration achieved, in the digital domain, between any two images when both are corrected to the same WRS reference. The control points used to accomplish the registration are either geodetic CP's for which locations were established using a reference map or relative (reference) CP's selected from a previously corrected image. Whenever the set of CP's used to perform the geodetic corrections is selected from a single previously corrected image, that image is referred to as the reference image for the scene being corrected.

The third stage of the geometric correction process uses the geodetic correction functions, or the systematic correction functions if geodetic corrections were not generated, to generate horizontal resampling (HRS) and vertical resampling (VRS) interpolation matrices and coefficients. The coefficients are provided on the archival HDT in two map projections. The first map projection is either Universal Transverse Mercator (UTM) or Polar Stereographic (PS), depending on latitude. The second projection provided is always Space Oblique Mercator (SOM).

The last phase of MSS Archive Generation incorporates those steps required to record an HDT-AM with radiometrically corrected image data as well as the support information necessary to apply geometric corrections to the data. The image data are radiometrically corrected using the RLUTS and are recorded on the HDT in band-sequential format. After the tape is checked for quality, it is transported to the DRRTS, where it is transmitted to EDC via communications satellite.

6. **Image Archive and Product Generation**

The image archive and product generation phase of the ground segment is accomplished at EDC and consists of the following processes:

- Maintaining a digital archive of partially processed data from Goddard Space Flight Center (GSFC)
- Applying geometric-correction transformations and image enhancements to the data
- Recording processed data on photographic film or magnetic tape
- Generating and disseminating customer-requested photographic products and CCT's.

EROS DATA CENTER IMAGE PROCESSING

Partially processed Landsat 4 data are transmitted from the Goddard Image Generation Facility to EDC via a communications satellite. At EDC, the received data are recorded on high-density tape (HDT) using 14-track digital recorders.

After being received but before being archived, Landsat data are processed by a computer-based production system called the EROS Digital Image Processing System (EDIPS). EDIPS is a data processing system that reads digital image data from HDT, applies geometric corrections if requested, optionally performs image enhancement processing, and records the processed data on high-resolution film or computer-compatible magnetic tape (CCT). The HDT is then placed in the EDC digital tape archive.

The labels "HDT" and "CCT" are used to distinguish between two significantly different tape types. An HDT is 1-inch wide and often 9,200-feet long. It is recorded on a sophisticated recorder, and it holds 14 (or 28 or 42) tracks of data at a bit density of 20,000 (or 33,000) bits per inch. A CCT, on the other hand, is one-half-inch wide and generally 2,400 feet long. It is recorded on a conventional data-processing-type tape recorder, and it contains nine tracks of data at a bit density of 1,600 or 6,250 bits per inch.

The label "HDT" or "CCT" is further appended with a two-letter suffix that identifies whether the data is partially (A) or fully (P) processed, and whether the sensor type is MSS (M) (as distinguished from archive tapes for other sensors carried by earlier Landsats). Consequently, the three Landsat 4 CCT types that are available from EDC are a CCT-AM, a CCT-PM, and a CCT-TP.

The term partially processed used above means that the image data has been radiometrically corrected, using spacecraft and sensor systematic parameters, but has not been geometrically corrected. Data in this form are referred to as archive, or A, data. After a geometric-correction transformation is applied at EDC, the image data is referred to as processed, or P, data. Table 7.3 lists a summary of the major steps in EDC's processing of image data to create final products.

EDIPS is normally operated in a production mode referred to as pipeline processing. Sensor data, newly received from GSFC and recorded on HDT-AM, are geometrically corrected and then written to film by the laser-beam film recorder to create negative black-and-white film images of the acquired scenes. In this mode, data are processed in swaths of consecutive scenes in the order that they are contained on the archive HDT, with atmospheric scatter compensation being the only image enhancement performed. After processing, the sensor data are stored in the HDT archive until the data are

Table 7.3 EDC LANDSAT 4 PROCESSING FUNCTIONS

- Receive partially processed image data from GSFC via satellite link and record on HDT-A.
- Using GSFC HDT Inventory data, generate film production requests for all images.
- Read HDT image data; format the serial bit stream; convert to parallel data stream; histogram image data; transfer data to processing computers;
- Apply geometric-correction transformation to partially processed input data;
- Perform, automatically or upon customer request, image enhancement operations such as haze removal, contrast stretch, or edge enhancement.
- Create black-and-white film images for every band of the fully processed data, and archive the frames of film for subsequent customer-product generation.
- Make accession data, including cloud cover and quality assessment, available to customer inquiry via the accession data base.
- Upon customer request, produce final products which may be computer-compatible tapes in one of several formats of both A-and P-data types, paper prints in one of several scales, or film duplicates.
- Collect production data to generate status reports; update order requests; ship products; and invoice customers.

required for CCT or special film production. Approximately 300 MSS scenes can be processed daily, although it is anticipated that just one-third that many scenes will be acquired, preprocessed, and transmitted to EDC by Goddard.

EDIPS also is operated in another mode, termed special order. CCT's containing either original or enhanced data, and film recorded from enhanced data, are generated in the special-order mode. HDT's containing the ordered scenes are retrieved from the archive. Individual scenes are located on the tapes with the aid of an index time-code referred to as the IRIG time. (The IRIG code is recorded on a separate track parallel to the image data.) The ordered scene data are recorded on standard CCT (from either partially or fully processed image data) or on film (from fully processed image data only) with image enhancements applied as requested by each customer. Figure 7.6 shows the different mandatory and optional functions that are available with standard and special-order processing.

Regardless of the operational mode, processing summaries are transferred via tape to the EDC mainframe business computer to stage final product orders to the photographic laboratory.

Figure 7.7 shows the combined data flow for both standard and special-order processing. From data supplied by the Goddard HDT Inventory tape, an order is created for each of the newly acquired partially processed scenes received from Goddard via satellite data link. To satisfy the order, digital data

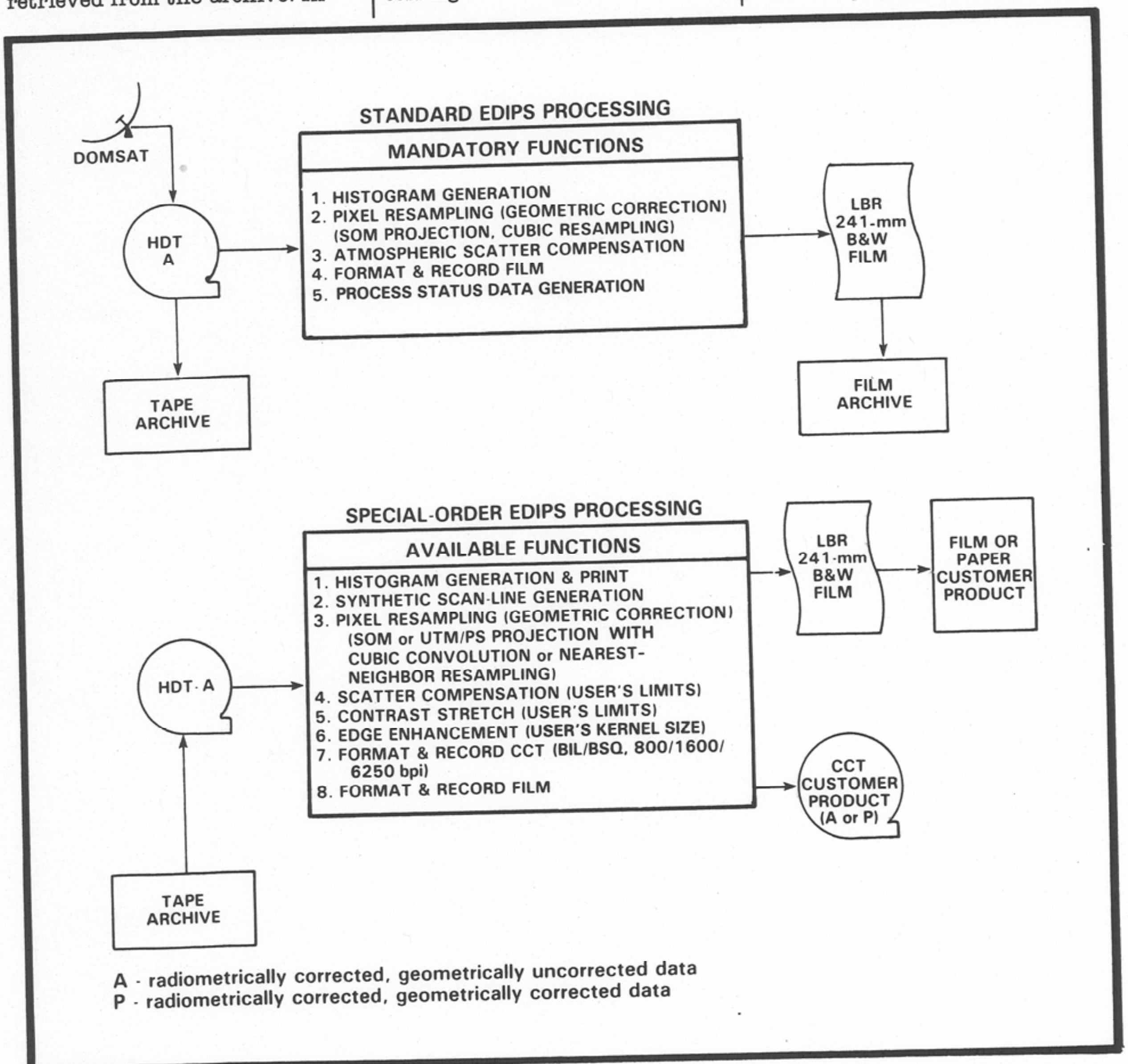


Figure 7.6 EDIPS PROCESSING MODES

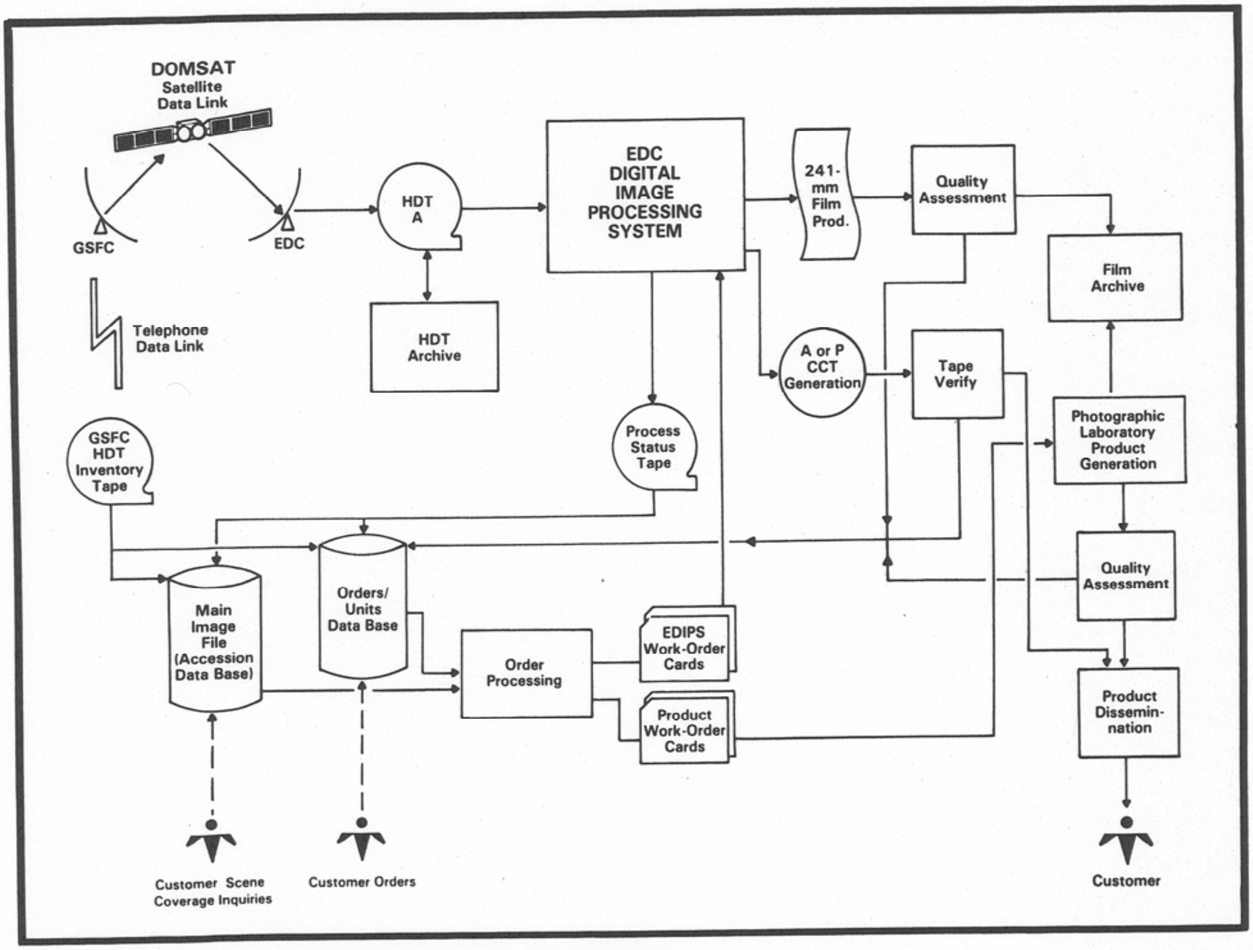


Figure 7.7 CUSTOMER/PRODUCT FUNCTIONAL PROCESSING FLOW

are recorded on film, and then the HDT and film are entered into their respective archives. After quality assessment procedures determine that each image is free of digital and film defects, data describing the accession (image) are made available to NOAA Landsat Customer Services for customer inquiry assistance using the accession data base.

Once a customer finds a scene of interest through data base inquiry, or a scene is found (through a standing request system) to meet specific criteria previously set by a customer, an order is created to initiate product generation by the photographic laboratory. If the ordered product is to be made from a single frame or from an existing false-color composite master, the appropriate master reproducible is retrieved from the film archive and sent to the laboratory for reproduction onto paper or film. If the ordered product is for a false-color composite of a scene for which a master does not already exist, an order is automatically generated for black-and-white duplicates of MSS bands 1, 2, and 4. The three frames are subsequently registered to one another and sequentially exposed on a single sheet of color film. That sheet of film is considered the color master reproducible, and, after being used to generate the color print or transparency ordered by the customer, it is entered into the film archive to be used for any subsequent orders for that scene. After reproduction, the final product is carefully inspected by quality assessment technicians before being shipped to the customer.

If a customer requires a film product or CCT without atmospheric-scattering compensation, with contrast-stretch, or with edge enhancement, an order is generated for special-order EDIPS processing of data contained in the HDT archive. If the ordered product is a 1,600 bpi, the tape will be verified for format and image data readability before shipment. If the ordered product is enhanced film, the special-order master-reproducible will be noted in the accession data base and entered into the film archive after the customer product has been reproduced and inspected.

EDIPS HARDWARE

The system can be separated on a heirarchical basis into four subsystems: input, processing, output, and man/machine interface. The input subsystem consists of two HDT recorders, two microprocessor-based formatters, and a histogrammer/controller. The formatter removes preamble/fill and synchronization data and performs serial-to-parallel data transfer from the HDT recorder to the histogrammer/controller. The last-named device compiles histogram data on a per-band basis to automatically determine atmospheric-scatter bias or contrast-stretch limits and manages data transfer from the formatter to the slave CPU.

The processing subsystem consists of the slave and master CPU's, the inter-CPU data bus and control link, two array processors, three on-line image disks, and two system disks. The slave CPU ingests the data and, together with both array processors, applies the geometric correction transformation. Image enhancement is accomplished by the master CPU through interaction of several devices including the image disk, an array processor (for edge enhancement only), and the table-lookup controller (which is part of the output subsystem). Frame rasterization, field formatting, and image data transfer to film and CCT recorders also is performed by the master CPU. Control over all the process functions is maintained by the master CPU, in conjunction with the man/machine interface devices which include the card reader, operator's terminal, image display, and line printer.

The output subsystem consists of two laser-beam film recorders (LBR's), the table-lookup controller (which performs both radiometric transformation for image enhancement as well as data and control interface to the LBR), and three standard magnetic tape recorders (1,600 bpi). An offline system is used to produce 6,250-bpi CCT's by copying 1,600-bpi CCT's that were recorded on EDIPS.

Figure 7.8 shows the major components of the system.

AVAILABLE PIPELINE AND SPECIAL-ORDER PROCESSING FUNCTIONS

As shown in figure 7.6, special-order processing permits eight different functions to be selected at the customer's option. One function produces image radiance information, two perform image correction, three accomplish image enhancement, and two record digital data on film or magnetic tape. All eight will be briefly described in the following section.

Histogram Generation

The distribution of the 128 (for MSS) brightness values of all input pixels is automatically determined for every frame of HDT image data processed by EDIPS. The radiance histogram is printed and later photocopied for future reference. It also is used to calculate the minimum and maximum brightness values in an image. The minimum brightness value is the radiance bias parameter used in atmospheric scattering compensation. The minimum and maximum brightness values are the stretch factors

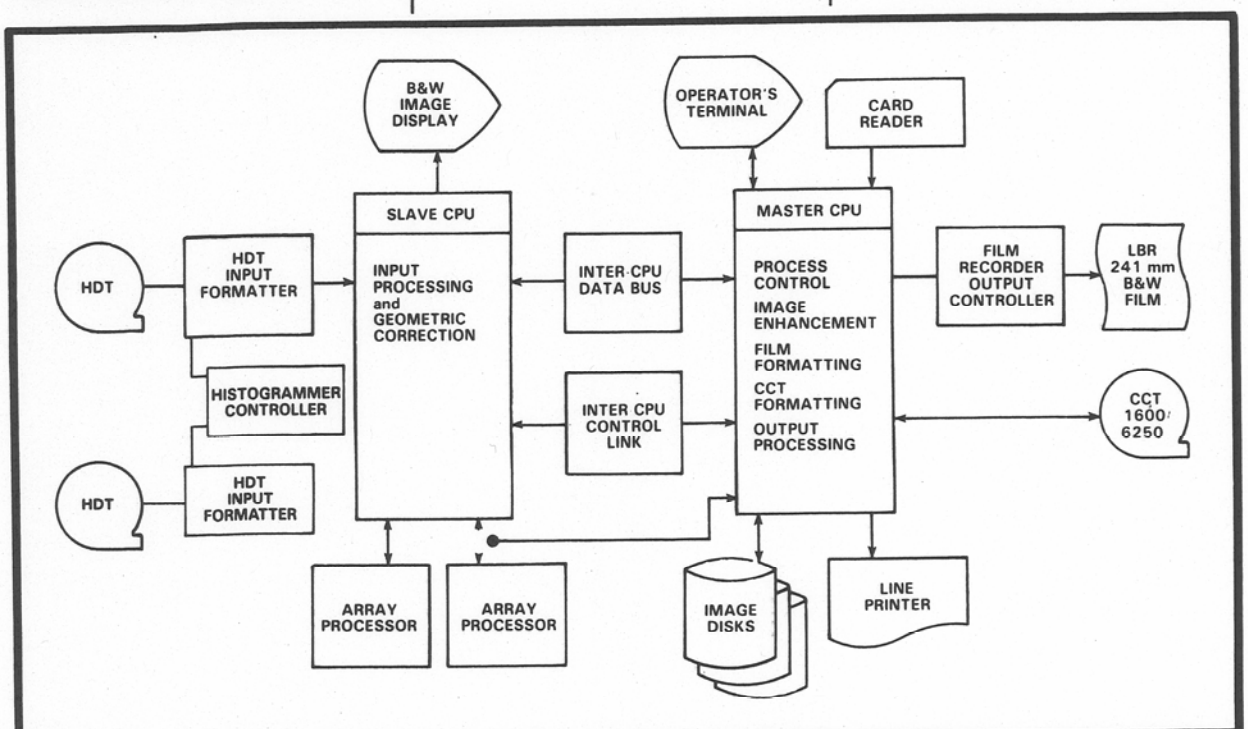


Figure 7.8 EDIPS FUNCTIONAL HARDWARE CONFIGURATION

for contrast enhancement. A histogram is automatically supplied with every CCT order. Figure 7.9 (a) shows a representative band-4 histogram of a scene containing both vegetation and water.

Synthetic Scan Line Generation

In the 24-byte prefix to every image scan line is a quality code that identifies a scan line which has been filled in with a single brightness value in place of actual image data. A quality code of Q0 indicates a good scan line, Q2 indicates a scan line filled on input to GSFC processing, and Q3 indicates a scan line filled on output from GSFC processing. On special order, EDIPS will substitute, for lines with quality Q2 or Q3, a replacement (synthetic) scan line that is a duplicate of a good scan line. EDIPS will search for a good scan line up to three lines above or, if necessary, below the filled scan line.

If a good scan line is not found within the seven-line window, the bad scan line is left unchanged. A replacement scan line retains the original quality code.

Geometric Correction (Resampling)

Extensive corrections are computed and some are applied to the raw image data during the partial processing of MSS data that is performed at Goddard (summarized earlier). At EDC, geometric-correction matrices calculated at Goddard and contained in the HDT ancillary data file are applied to the radiometrically corrected image data to produce a fully corrected P image.

The matrices contain transformation coefficients which specify the location in the input image of each pixel in the output image. The non-linear mapping of input image pixels to the output image, specified by the transformation coefficients, does the warping necessary to accomplish geometric correction. During the mapping process the location in the input image of a particular pixel at a line/sample intersection in the output grid is rarely at the exact intersection of a line and sample. Consequently, the brightness value of the pixel associated with a particular line and sample must be computed by averaging the brightness values of the pixels surrounding it. The averaging method used by EDIPS is either nearest neighbor or cubic convolution.

The map projections available are Space Oblique Mercator (SOM) and either Universal Transverse Mercator (UTM) or Polar Stereographic (PS). The UTM projection is used when the scene latitude is 65° or less, and PS projection is used when the scene latitide is greater than 65°.

Standard processing uses cubic-convolution resampling and produces the SOM projection. Nearest-neighbor resampling and/or the UTM/PS map projection are both available by special order.

Atmospheric Scattering Compensation

To compensate for the component of image brightness that is due to molecular scattering in the atmosphere, a radiance bias is subtracted from all pixels in an image. The amount of the radiance bias is different from scene to scene and is likely to be different for each band of a particular scene. Because the scene radiance due to scattering is inversely proportional to wavelength, the radiance bias is greatest for band 1 and least for band 4.

Radiance bias is equal to the minimum brightness value of the image histogram. The value can either be customer-specified or computer-determined. If specified, the minimum can be expressed either as a particular brightness value (0-127) or as a certain percentage of the total number of pixels in a band. If determined by the computer system, the minimum is the lowest of the first four consecutive brightness values that exceed a frequency count of 600 pixels. It is apparent from the several ways which the minimum brightness value can be specified that the term minimum is relative. This slight corruption or misuse of the word is justifiable because many histograms show pixel counts of from 1 to 50 that are not statistically significant. By selecting a frequency of 600 pixels per brightness value as the arbitrary minimum value, the knee of the histogram curve can be more accurately determined. Scattering compensation linearly shifts the entire distribution to the left so that the minimum value becomes equivalent to brightness value 0.

During standard processing, scattering compensation is applied to all scenes; in special-order mode, it is applied only if the customer so specifies. The shift of the data distribution does more than simply darken the image. Because the recorder/film system transfer curve has higher contrast at lower brightness values, an image to which scattering compensation has been applied typically will show higher contrast. A further explanation of system-transfer-curve concepts will be provided in a forthcoming appendix on photographic products. It is appropriate to note here that the production transfer curve is exponential with an average slope of 3.75, 1.25, and 0.65 for brightness values of 0-16, 16-48, and 48-127, respectively.

Mathematically the operation for scatter compensation is defined by:

$$Y_{ij} = X_{ij} - \text{Bias}$$

where:

Y_{ij} = enhanced pixel at line i and sample j

X_{ij} = input pixel at line i and sample j

Bias = brightness-value-distribution minimum value

See figure 7.9 (b) for a graphic example of this operation.

Contrast Stretch

For other than a strictly mathematical analysis, image data must be reproduced—on a paper printer, film recorder, or cathode-ray-tube display

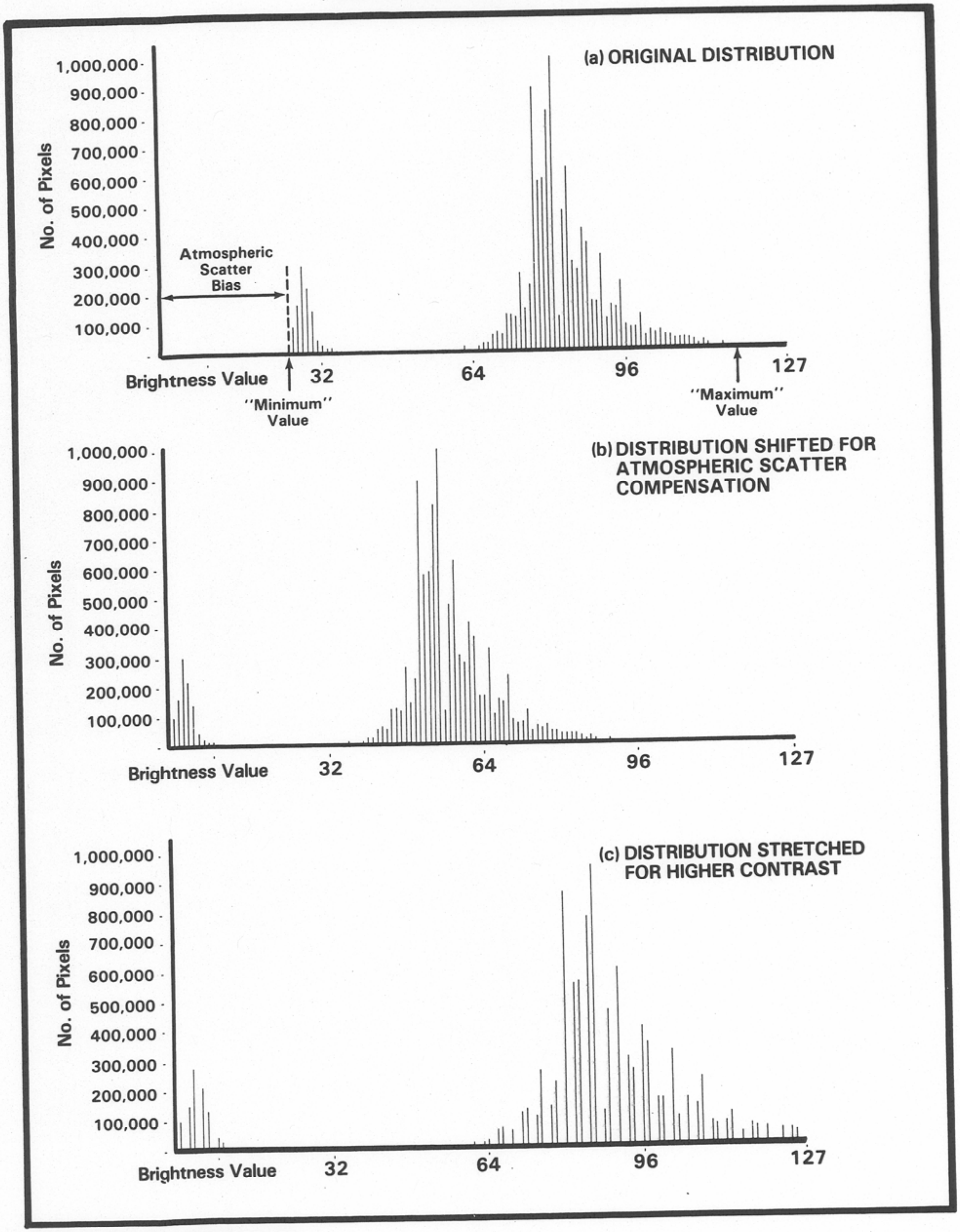


Figure 7.9 BAND 4 HISTOGRAM

device—using a combination of optical, electronic, or mechanical means. Because the transformation from input data value to output film/paper density or screen intensity is scaled to accommodate the full dynamic range of scene reflectance, a typical Landsat scene with a narrow brightness distribution may exhibit insufficient contrast, especially when reproduced on photographic paper. To add distinguishable differences in print density to a scene with flat contrast, the standard unity increment between pixel brightness values must be increased by some scene-dependent factor. A linear stretch accomplishing this objective is done by setting the histogram minimum value equal to brightness value 0, the histogram maximum value equal to brightness value 127, and equally spacing the intervening brightness values. As an unavoidable consequence, all of the brightness values between minimum brightness value and 0 become brightness value 0, and those between maximum brightness value and 127 all are assigned brightness value 127. The preceding limit of 127 is a consequence of the brightness values being 7-bit data for all four spectral bands. Minimum and maximum are relative, not actual, values for the image histogram as was explained in the preceding section on atmospheric scatter compensation.

Unlike scatter compensation, contrast stretch is available only by special order. The user can specify the minimum and maximum brightness values either as specific gray levels or as a percentage (0.0 to 99.99) of the total number of pixels in the image. Or, minimum and maximum values can be automatically determined by a computer-implemented algorithm as before. That is, the lowest and highest brightness values of four consecutive values on the low-brightness (high-brightness) end of the distribution that exceed a frequency count of 600 pixels are designated the minimum (and maximum) values of the image histogram.

The user should be aware that, as with scatter compensation, the mean of the distribution is shifted as a result of stretching the range of the data. Because the limits of the data distribution differ considerably from band to band, the distribution-means of the individual bands may be shifted enough, when contrast stretch is applied, to noticeably affect color fidelity in a color product.

The mathematical operation for contrast-stretch is defined as:

$$Y_{ij} = \frac{(X_{ij} - Min) \times 127}{Max - Min}$$

where:

Y_{ij} = enhanced pixel at line i and sample j

X_{ij} = input pixel at line i and sample j

Min = computed or selected Minimum brightness value in data distribution

Max = computed or selected Maximum brightness value in data distribution

See figure 7.9 (c) for a graphic example of this operation.

Edge Enhancement

The user may request edge enhancement to improve the delineation of the fine structure in an image. Fine image detail consists of high-frequency spatial variations. Spatial frequency can be defined as the number of changes in distinguishable brightness value per unit lateral displacement in an image. For example, from an appropriately low altitude the parallel rails of a railroad track have a higher spatial frequency than the parallel roads of an interstate highway. The intent of edge enhancement is to increase the difference in brightness values at abrupt transitions in brightness value (edges).

To perform edge enhancement, local average value of the neighborhood surrounding a given pixel is subtracted from the subject-pixel brightness value to determine the high-frequency component at that pixel location; that difference value is multiplied by a weighting constant (equal to 1 in EDIPS); and the product is added to the subject pixel value to form the enhanced brightness value. The high-frequency component is positive for pixels brighter than the local average, negative for darker pixels.

It is the user's responsibility to specify the size of the box filter, called the kernel, that determines the local average value in the enhancement process. The larger the kernel size, the lower the low-pass cutoff frequency and the greater the edge-enhancement effect. For example, figure 7.10 shows how image contrast at feature edges is increased by making low brightness values lower and high values higher at abrupt brightness transitions. The example illustrates, for various kernel sizes, how a moderately bright line in an image, which may represent a highway, would be intensified by edge enhancement. A large kernel size intensifies the brightness differential at an edge, but causes the brightness of adjacent pixels to be undesirably affected. It causes edges to be broadened and immediately adjacent features to be modified with highlight and shadow.

Kernel sizes for 1x3 to 9x9 can be specified. Figure 7.10 shows the effect of a 3x3, 5x5, and 9x9 kernel applied to an abrupt brightness differential, although a 1x3, 1x5, 1x7, or 1x9 kernel would have produced this same result because the edge is vertical. A 1x9 kernel will strongly accentuate vertical edges; conversely, a 9x1 will strongly accent horizontal edges.

Mathematically the edge

IMAGE SAMPLE PIXEL VALUES:

L−2:	20	20	20	20	20	60	60	60	60	60	20	20	20	20
L−1:	20	20	20	20	20	60	60	60	60	60	20	20	20	20
L:	20	20	20	20	20	60	60	60	60	60	20	20	20	20
L+1:	20	20	20	20	20	60	60	60	60	60	20	20	20	20
L+2:	20	20	20	20	20	60	60	60	60	60	20	20	20	20

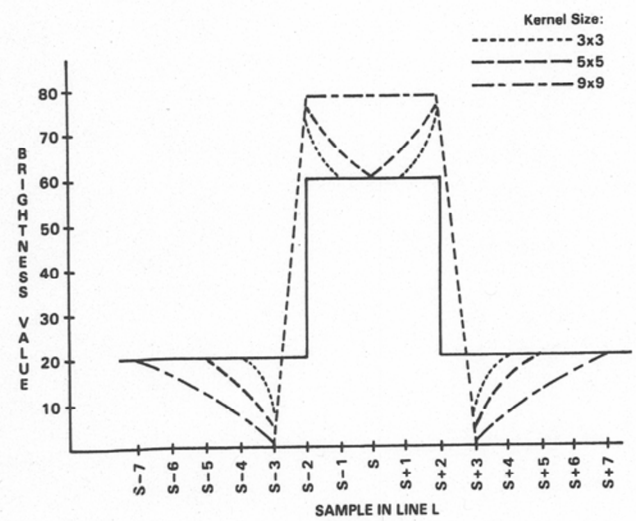


Figure 7.10 EFFECT OF KERNEL SIZE ON EDGE ENHANCEMENT

enhancement algorithm is represented by:

$$Y_{ij} = X_{ij} + C(X_{ij} - X_{ij})$$

where:

Y_{ij} = enhanced pixel value at line i and sample j

X_{ij} = input pixel value at line i and sample j

C = enhancement weighting constant (= 1 in EDIPS)

and:

$$\overline{X}_{ij} = \frac{1}{NM} \sum_{n=i-\frac{N-1}{2}}^{i+\frac{N-1}{2}} \sum_{m=j-\frac{M-1}{2}}^{j+\frac{M-1}{2}} X_{nm}$$

for a kernel size of N lines by M samples, $1 \leq N, M \leq 9$ and N, M always odd.

Computer Compatible Tape Generation

When placing an order for a CCT, the user must specify the data type (A or P), tape bit-density (1,600/6,250 bpi), and the scan-line sequence (band-sequential or band-interleaved by line). The user may also specify that the image data be altered to compensate for atmospheric scatter (histogram-based or user-specified bias), that it be contrast enhanced (histogram-based or user-specified minimum/maximum brightness values), or that it be edge enhanced (user-specified kernel size). The three enhancement operations can be performed only on fully processed (P) data.

Records on a CCT have a one-to-one correspondence to major frames on an HDT. The general format has header, ancillary (for partially processed A data only), annotation, image, and trailer data in fixed record lengths of 3,596 bytes. A complete description of the standard CCT format Version 1.0 is contained in Appendix A. This format is similar to the EDIPS CCT format Version 0.0 produced from February 1979 to September 1982, but quite different from the CCT-X format produced prior to February 1979.

Header data includes scene identification, WRS designator, tape creation date, sensor description, and data-set characteristics of the header, ancillary, annotation, image, and trailer data.

Ancillary data includes modeling data and projection-dependent data. Some of the modeling records include MSS mirror-model coefficients, band-to-band offsets, WRS-format-center latitude/longitude, nadir latitude/longitude, and altitude/attitude coefficients. Projection-dependent data includes HRS pixel coordinates and VRS line coordinates for SOM and UTM/PS projections as well as scan-line and pixel values for temporal-registration and overlap marks. The ancillary file is present only for A data.

The annotation file contains the alphanumeric information that is rasterized and added as border data around the framed image. Such data includes scene-center latitude/longitude, sun elevation, scene identification number, band number, transmission mode, resampling algorithm applied, and sensor gain.

The image file contains sensor data (which ranges in value from 0 to 127), calibration values (if A data), quality codes, and fill counts (if P data). For P data, image pixels have been resampled (interpolated) to 57 X 57 meters. If the format is band-sequential, the image data for each band is in a separate file. In the band-interleaved-by-line format, the image data for all bands is in one large file.

The trailer file contains little else but the values used in any applied enhancement process. The bias value for atmospheric scatter compensation, the minimum and maximum values for contrast stretch, and the edge-enhancement kernel size constitute the fields of interest. For a 1,600-bpi tape, four bands of an A-image are recorded on a single CCT; four bands of a band-sequential P-image are recorded on two CCT's, split two bands per CCT. For a multi-volume CCT set: (1) each volume begins with a tape directory, (2) the breakpoint between volumes is at file or image-record boundaries, (3) all volumes except the last end with an end-of-volume (EOV), and (4) the last volume ends with an end-of-set (EOS).

A summary sheet accompanies the shipped CCT, listing image, sensor, and data identification, data processing codes and enhancements, and data quality summary. A histogram for each band also is included.

Master Film Generation

Black-and-white negative film masters are produced on a laser-beam film recorder (LBR) that uses an argon-ion laser beam, focused to a spot size of 57 micrometers (μ m) in diameter, varied in intensity by an electro-optic modulator to form image pixels. The beam is scanned across the film by a spinning mirror to form one image line while the film is slowly and continuously advanced in a direction orthogonal to the laser scan to form the 2,983 lines that define the complete image. With standard EDIPS operation, only fully processed P data can be recorded on film. The image is produced at a 1:1 aspect ratio and 1:1,000,000 scale because a 57-micron pixel is used to represent a ground subject area of 57 x 57 meters.

One frame, or band, of MSS data on film is formed by 3,385 scan lines, each comprised of 3,620 pixels. Of the 3385 scan lines in a frame, 2,983 lines form the image area, 200 lines form the roll-frame number and coordinate tick-marks above the image, and 202 lines form the coordinate tick-marks, annotation, path-row number, and grayscale below the image. In addition, 660 "blank" gap lines are generated between frames. Of the 3,620 frame pixels, approximately 3,240 pixels form the image, approximately 308 form the left- and right-side zero-fill, and 36 pixels each form the left-and right-side coordinate tick-marks. In addition to the projection coordinate tick marks, registration marks, and annotation data on the film image, scene overlap marks also are normally indicated. The small (1-pixel-wide, 32-pixel-long) L-shaped overlap marks are normally found near the corners of the image in the border area just outside the image. They denote a line along which the leading and trailing scenes in the same swath can be accurately butted. (A swath is a series of scenes along one path that were acquired in a chronologically consecutive and continuous sequence.) Additional tabular and graphic data on film format will be included in the photographic products appendix.

Also, a 15-step (plus border) step wedge is exposed on every frame for radiometric/densitometric verification by the EDC Quality Assurance Section as well as for exposure control during product generation by the Photographic Laboratory.

A more detailed explanation of the film format, production methods, and product characteristics is included in Appendix B, Photographic Products (to be completed).

AVAILABILITY AND ORDERING OF DATA

Multispectral Scanner Data

Landsat 4 MSS data products are similar to those provided by the earlier Landsat MSS systems. A new numbering system, however, is in use for the four spectral bands used in the Landsat 4 MSS system. The bands—known in the Landsat 1, 2, and 3 systems as bands 4, 5, 6, and 7—are now called, respectively, bands 1, 2, 3, and 4. (The former numbering method remains in place for identifying data from the earlier satellites.) Photographic products are generated in black and white or false color from 241-mm (9.5-inch) master positives at a scale of 1:1,000,000.

Landsat 4 MSS data are also available in digital format. Digital products are generated from a high-density digital tape (HDT) containing radiometrically corrected Landsat 4 data (HDT-A). Geometrically and radiometrically corrected—"fully processed"—high density tapes (HDT-P's) and standard computer-compatible tapes (CCT's) are also available. See sample 8.1, Landsat 4 Standard MSS Products Order Form, which lists MSS special-processing services and products.

The MSS digital data are transmitted from the NASA Goddard Space Flight Center, via a domestic communication satellite (DOMSAT), to the EROS Data Center, where the data are recorded in HDT-A format.

An HDT is 14-track, 1-inch-wide magnetic tape with data encoded at 20,000 bits per linear-track-inch (bpi). One track contains a standard telemetry inter-range instrumentation group format A (IRIG-A) time code, 10 tracks contain the MSS data, one track contains vertical parity bit, and the remaining two tracks are unused. Detailed descriptions of HDT-A and HDT-P formats are available as supplements to this handbook for those few users interested in HDT's as digital data sources. These supplements can be obtained by contacting NOAA Landsat Customer Services, Mundt Federal Building, Sioux Falls, SD 57198.

A CCT is a standard 2,400-ft reel of 1/2-inch magnetic tape available in several formats (sample 8.1). A CCT contains data for one MSS scene in four spectral bands and is basically a segment from an HDT, which can hold data for up to 35 Landsat MSS scenes. Depending on the density requested, more than one reel of tape may be required for a complete MSS scene on CCT. A comprehensive description of CCT's containing Landsat 4 MSS data is in Appendix A of this handbook.

Thematic Mapper Data

During the first year after launch of the Landsat 4 satellite, TM data was handled in a test and engineering mode at the Goddard Space Flight Center. Before the TM system was ready for routine operation, a limited number of TM prototype data products in film or CCT format were available. Thematic Mapper data standard products, such as false-color composites, were also under development during the TM test phase. These products are similar to those containing MSS data; that is, a variety of photographic products in black and white and false color (infrared, with the addition of false natural color), based on 241-mm (9.5-inch) master negatives are standard data sources along with digital magnetic tapes in CCT format (see sample 8.2).

Basic Data Set

The MSS Basic Data Set consists of those MSS scenes that are the routine data collection objective of NOAA's operational Landsat MSS system. These scenes will be identified, on a published list, by geographic location and scheduled time of acquisition. NOAA will then make a "best effort" to acquire the data and place them in the Landsat archive where they will be available at regular prices.

Since January 31, 1983, the Landsat 4 preprocessing facility at the Goddard Space Flight Center produces 136 MSS scenes per day. About half of this capacity is used for Basic Data Set acquisitions. This ensures that any higher-priority data can be processed along with Basic Data Set data without exceeding the planned capacity of the system.

In order to accommodate user needs, NOAA focuses the Basic Data Set on the acquisition of good quality data as follows:

- Cover the entire United States (including Alaska, Hawaii, and Puerto Rico) every 16 days. An attempt is made to conserve preprocessing capacity by identifying and eliminating those scenes heavily obscured by clouds.
- Concentrate on the establishment of an MSS worldwide data set. This will be accomplished by scheduling MSS coverage of the world's remaining land masses once a year, with minimum cloud cover.

Procedures for implementing the worldwide data acquisition plan are to be developed. Worldwide climate zones, and their associated vegetation types, are being considered in establishing coverage patterns. Scheduling also must be accomplished within sensor and spacecraft operational constraints. The worldwide coverage scheme and coverage of Hawaii are dependent upon the availability of the Tracking and Data Relay Satellite System (TDRSS).

Recommendations for revisions to the MSS Basic Data Set are expected and will be used by NOAA to update and adjust requirements as may be necessary. Any comments or recommendations concerning the design of the Basic Data Set should be directed to:
Director
User Affairs Division, Sx32
NOAA/NESS
Federal Building 4, Mail Stop D
Washington, D.C. 20233
A parallel TM data acquisition policy will be established for the operational TM system.

User Services

The NOAA Landsat Customer Services Section provides customer assistance and ordering information for all users of NOAA products. Its primary function is to respond to requests for information on availability of Landsat data and to process orders against NOAA holdings. Requests for information may be made to the NOAA Landsat Customer Services Section by letter, telephone, telegraph/telex, or in person. Requests may also be made at offices of NOAA and the U.S. Geological Survey's National Cartographic Information Center (NCIC), which work closely with NOAA. Information about available Landsat data is provided to NCIC offices by NOAA through computer terminals and by telephone; in turn, those offices accept orders from the public and process them through the NOAA system.

Details on all Landsat 4 scenes stored by NOAA are listed in the Main Image File (MIF). This file includes the following information on each issue:

-scene identification number
-geographic coordinates
-cloud cover indicator
-photographic quality for each individual band
-date of acquisition
-image type
-WRS Path-Row indicator
-microfilm reference
-accession format
-high or low gain designator
-digital format availability
-color-composite availability

Data Availability

The availability of Landsat data over a specific area of interest may be determined by several methods. A Landsat scene identification number can be obtained from a catalog, a computer listing, or other accession aids. A computer listing (sample 8.3) of scene identification numbers may be obtained from NOAA after specifying an area of interest. One method of indicating the area of interest is to use geographic coordinates specifying the area. These coordinates can be for either a single point, the corners of a rectangle, a point and radius, or a polygon (for a polygon, up to eight corner points may be used).

A preferred method of indicating an area of interest is to use Path and Row numbers obtained from the Worldwide Reference System (WRS) indexes. These indexes are available from NOAA. To use a WRS index, it is necessary only to locate a map point on the index and then determine which is the closest Path/Row intersection. For example, the intersection nearest Washington, D.C., for Landsat 4 is Path 15, Row 33. See Section 5, Orbit and Coverage, for information on the design of the Worldwide Reference System.

A detailed inquiry form is available for users to provide information on location, dates of coverage, acceptable cloud cover, and image quality desired (sample 8.4).

Micrographic Data Accession Aids

An inexpensive, user-oriented geographic accession aid system has been developed in which the descriptions of all Landsat accessions are stored on microfiche film records. This system is based on the Landsat 4 Worldwide Reference System which is divided into three Zones. Each Zone represents a group of as many as 60 WRS Rows. A 20-Row overlap has been made between the North and South Zones. Each microfiche card represents the Landsat 4 data for one Path in one Zone, and the overlap enables users to confine a microfiche collection to one Zone for any country. (See fig. 8.1 for descending node.)

The Zone/Path/Row notation is the primary storage and retrieval key for the microfiche records. Each microfiche record shows the accession descriptions as computer listings for as many as 60 Landsat Path/Row intersections (nominal scene centers). Users of the Landsat accession aids system will need to consult WRS indexes of their region of interest to identify the Path/Row points for which data are desired.

Landsat Catalog Microfiche

Each microfiche (film card) measures 105 by 148 mm. It contains a large-print header section and micro-image (24 X reduction) computer listings of as many as 60 Landsat WRS scene descriptions.

A diagram of the microfiche layout is shown in figure 8.2. The narrow band of data at the top of the record is the header and shows Path number, Row numbers, Zone designation, date range, accession types, and an indicator of daytime or nighttime coverage.

The microimages of the computer listings are presented in a 10-row by 6-column matrix, which accommodates the 60 potential Path/Row positions. Each micro-image position is

LANDSAT 4 STANDARD MSS PRODUCTS
ORDER FORM

RETURN COMPLETED FORM TO: NOAA/NESS Landsat Customer Services • EROS Data Center Sioux Falls, SD 57198 • Comm: 605/594-6151 FTS: 784-7151 • TWX: 910-668-0310

DATE ____________

NAME ____________ (FIRST) (INITIAL) (LAST) COMPANY ____________

ADDRESS ____________ CITY/STATE ____________ ZIP ________

PHONE (HOME) ____________ (BUSINESS) ____________ EROS ACCOUNT NO. (IF KNOWN) ____________ REF. NO. (P.O., GOV'T ACCT., OR OTHER) ________

SHIP TO: ____________

STANDARD PRODUCTS TABLES

BLACK AND WHITE PRODUCTS

NOMINAL IMAGE SIZE	PRODUCT MATERIAL	PRODUCT CODE	PRICE
18.5cm (7.3 in.)	Paper	23	$ 30.00
18.5cm (7.3 in.)	Film Positive	13	30.00
18.5cm (7.3 in.)	Film Negative	03	35.00
37.1cm (14.6 in.)	Paper	24	58.00
74.2cm (29.2 in.)	Paper	26	95.00

FALSE COLOR COMPOSITE PRODUCTS

NOMINAL IMAGE SIZE	PRODUCT MATERIAL	PRODUCT CODE	PRICE
18.5cm (7.3 in.)	Paper	63	$ 45.00
18.5cm (7.3 in.)	Film Positive	53	74.00
37.1cm 14.6 in.)	Paper	64	90.00
74.2cm (29.2 in.)	Paper	66	175.00

COLOR COMPOSITE GENERATION*

NOMINAL IMAGE SIZE	PRODUCT MATERIAL	PRODUCT CODE	PRICE
18.5cm (7.3 in.)	Printing Master	59	$195.00

*Each MSS Color Composite Printing Master (generated from bands 1, 2, and 4) is retained by EDC. Color Composite product costs must be added to the generation fee.

SCENE IDENTIFICATION	PRODUCT CODE	PHOTOGRAPHS ONLY: MSS BANDS 1 2 3 4	PHOTOGRAPHS ONLY: NO. OF EACH	CCT	QTY.	UNIT PRICE	TOTAL PRICE

SAMPLE 8.1

TOTAL ABOVE A

TOTAL FROM PREVIOUS SHEETS B

TOTAL COST C

PRICES SUBJECT TO CHANGE

COMPUTER COMPATIBLE TAPES (CCT)

These tapes may be ordered either corrected or uncorrected (geometrically).

TRACKS	BPI	FORMAT	MSS All Bands (Band Sequential) PRODUCT CODE	MSS All Bands (Band Sequential) PRICE	MSS All Bands (Band Interleaved) PRODUCT CODE	MSS All Bands (Band Interleaved) PRICE
9	1600	TAPE SET	184-A	650.00	184-B	650.00
9	6250	TAPE SET	185-A	650.00	185-B	650.00

PAYMENT MUST ACCOMPANY ORDER

- CHECK, MONEY ORDER ☐
- PURCHASE ORDER ☐
- GOV'T ACCOUNT ☐

FOR ADDITIONAL SERVICES, PLEASE CONTACT: U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
USER AFFAIRS DIVISION, CODE Sx32, WASHINGTON, DC 20233

Comments: ____________

NOAA FORM 34-1200
October 1982

HOW TO ORDER LANDSAT 4 STANDARD MSS PRODUCTS

This order form is used to order all standard Landsat 4 MSS data. Necessary order information can normally be extracted from a computer listing of available data or from other Landsat references.

Please provide the following information in the indicated areas of the order form:

A. List your complete NAME, ADDRESS, ZIP CODE, and name of your COMPANY if applicable.

B. If you desire to have the products mailed to an address or individual other than yourself, please complete the ''SHIP TO'' address.

C. List a PHONE NUMBER where you can be contacted during business hours.

D. If you have had previous business with the EROS DATA CENTER, please list your EROS ACCOUNT NUMBER if known.

E. Enter the complete SCENE IDENTIFICATION NUMBER. This number can be transcribed directly from the COMPUTER LISTING or from a Landsat catalog.

F. Review the STANDARD PRODUCTS table on the front of the ORDER FORM and determine the type of product desired.

G. Enter the PRODUCT CODE of the type product being ordered from the STANDARD PRODUCTS table.

H. Check columns for bands you desire and also indicate the number of copies you desire of each band in the NUMBER OF EACH column. Check the CCT box only if a digital tape is being ordered. In selecting the tape format, make sure that you consider your equipment and usage. Please complete the QUANTITY column. Count the number of MSS bands checked, multiply by the figure in the NUMBER OF EACH column and enter the RESULT in the QUANTITY column.

SAMPLE 8.1

I. Enter the UNIT PRICE of the type product as reflected in the STANDARD PRODUCTS table.

J. Multiply the figure in the QUANTITY column by the UNIT PRICE, and enter the result in the TOTAL PRICE column.

K. Repeat steps E through J for each product ordered.

L. TOTAL the costs of all products ordered on this order form and enter the net result in BLOCK A (TOTAL ABOVE).

M. For a single order form, enter the Figure from BLOCK A in BLOCK C (TOTAL COST). If more than one order form is required, on the last order form enter the sum of the figures in all BLOCK A's in BLOCK B and then total BLOCK A and BLOCK B in BLOCK C (TOTAL COST).

N. The COMMENTS portion is completed only when special consideration is desired in printing, as in print for water detail, desert detail, etc. which does not necessarily fall in the CUSTOM PRODUCT category. If a CUSTOM PRODUCT is desired, the COMMENTS portion will also be used, and the cost determination will be normally based on three times the standard cost. If an uncorrected tape is desired, it should be noted in the comments portion.

O. PHOTOGRAPHIC and DIGITAL TAPE products are available in other formats but require special ordering procedures. If interested, please call the EROS Data Center for further instructions.

P. Include type of payment (purchase order, check or money order). Make all drafts payable to EROS Data Center. DO NOT SEND CASH.

Q. Mail ORDER FORM(S) and PRE-PAYMENT to the EROS DATA CENTER. IF PAYMENT HAS BEEN PREVIOUSLY FORWARDED TO ANOTHER FACILITY, PLEASE FORWARD THIS ORDER TO THAT FACILITY FOR PROCESSING.

FOR FURTHER INFORMATION OR ASSISTANCE PLEASE CONTACT
U.S. GEOLOGICAL SURVEY
NATIONAL CARTOGRAPHIC INFORMATION CENTER
507 NATIONAL CENTER • RESTON, VA 22092
FTS 928-6045 COMM: 703/860-6045

INFORMATION OR ASSISTANCE MAY ALSO BE OBTAINED FROM THE FOLLOWING U.S. GEOLOGICAL SURVEY, NATIONAL CARTOGRAPHIC INFORMATION CENTER, OFFICES

Eastern Mapping Center
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: 703/860-6336

Mid-Continent Mapping Center
1400 Independence Road
Rolla, MO 65401
FTS: 277-0851
Comm: 314/341-0851

Rocky Mountain Mapping Center
Stop 504, Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: 303/234-2326

Western Mapping Center
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2426
Comm: 415/323-8111

National Space Technology Laboratories
NSTL Station, MS 39529
FTS: 494-3541
Comm: 601/688-3544

LANDSAT 4 THEMATIC MAPPER DATA ORDER FORM

RETURN COMPLETED FORM TO: NOAA/NESDIS Landsat Customer Services • Mundt Federal Building Sioux Falls, SD 57198 • Comm: 605/594-6151 FTS: 784-7151 • TWX: 910-668-0310

DATE ____________

NAME ____________ COMPANY ____________

ADDRESS ____________ CITY/STATE ____________ ZIP ____________

PHONE(HOME) ____________ (BUSINESS) ____________ ACCT. NO. ____________ REF. NO. ____________

SHIP TO: ____________

STANDARD PRODUCTS TABLES

BLACK AND WHITE PRODUCTS

IMAGE SIZE	PRODUCT MATERIAL	PRODUCT CODE	UNIT PRICE
18.5cm (7.3 in.)	Film Negative	03	$ 60.00
18.5cm (7.3 in.)	Film Positive	13	50.00
18.5cm (7.3 in.)	Paper	23	50.00
37.1cm (14.6 in.)	Paper	24	95.00
74.2cm (29.2 in.)	Paper	26	150.00

COLOR COMPOSITE PRODUCTS

IMAGE SIZE	PRODUCT MATERIAL	PRODUCT CODE	UNIT PRICE
* 35mm Slide	Film Positive	50	$ 64.00
18.5cm (7.3 in.)	Film Positive	53	140.00
18.5cm (7.3 in.)	Paper	63	115.00
37.1cm (14.6 in.)	Paper	64	200.00
74.2cm (29.2 in.)	Paper	66	275.00

* FALSE COLOR SLIDE OF EXISTING MASTER INTENDED FOR PROJECTION PURPOSES ONLY.

SCENE I.D. NUMBER	PROD. CODE	TM BANDS 1	2	3	4	5	6	7	COLOR COMBIN.	CCT	QTY.	UNIT PRICE	TOTAL PRICE

SAMPLE 8.2

UNIT PRICES SUBJECT TO CHANGE

TOTAL ABOVE A ____

TOTAL FROM PREVIOUS SHEETS B ____

TOTAL COST C ____

COLOR COMPOSITE GENERATION
(unique band combination)

PRODUCT CODE	UNIT PRICE
59	$305.00

*CUSTOMER MUST DESIGNATE WHICH BAND COMBINATION IS DESIRED. ENTER IN COLOR COMBINATION AREA. PRINTING MASTER IS RETAINED BY NOAA. PRODUCT COSTS MUST BE ADDED TO THE GENERATION FEE.

DIGITAL PRODUCTS

FORMAT	PRODUCT CODE	PRICE
Full Scene 6250 BPI	80	$3400.00
1600 BPI	81	3400.00
Quarter Scene 6250 BPI	82	925.00
1600 BPI	83	925.00

TM CCT QUADRANT NUMBERING EXAMPLE

1	2
3	4

*CUSTOMER MUST DESIGNATE WHICH CCT IS DESIRED IN CCT COLUMN USING (1,2,3,4).

*DIGITAL DATA STANDARD IS BSQ/SOM WITH CUBIC CONVOLUTION CORRECTIONS. OTHER FORMATS MAY BE ORDERED RETROSPECTIVELY.

*800 BPI CCT'S ARE NO LONGER AVAILABLE FROM NOAA/NESDIS.

PAYMENT MUST ACCOMPANY ORDER

- CHECK, MONEY ORDER ☐
- PURCHASE ORDER ☐
- GOV'T ACCOUNT ☐

FOR ADDITIONAL SERVICES, PLEASE CONTACT: U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
USER AFFAIRS DIVISION, CODE E/ER2, WASHINGTON, DC 20233

COMMENTS: ____________

NOAA FORM 34-120
OCTOBER 1983

HOW TO ORDER THEMATIC MAPPER DATA

This order form is used to order all Thematic Mapper data. Necessary order information can normally be extracted from a listing of available data or from other Landsat references.

Please provide the following information in the indicated areas of the order form:

A. List your complete NAME, ADDRESS, ZIP CODE, and name of your company if applicable.

B. List a PHONE NUMBER where you can be contacted during business hours.

C. If you have had previous business with NOAA/NESDIS and EROS DATA CENTER, please list your ACCOUNT NUMBER if known.

D. If you desire to have the products mailed to an address or individual other than yourself, please complete the "SHIP TO" address.

E. Enter the SCENE IDENTIFICATION NUMBER from the list of available data.

F. Review the STANDARD PRODUCTS tables on the front of the ORDER FORM and determine the type of product desired.

G. Enter the PRODUCT CODE of the type of product being ordered from the STANDARD PRODUCTS tables.

H. If you desire that a unique color composite be generated please identify the band combination in the COLOR COMBINATION area, and ENTER PRODUCT CODES 59. Use the COMMENTS section for any detailed instructions. Unique color composites that are not in ascending band order and exposed through blue, green, and red filters in turn are deemed to be custom products and a 3 time processing charge will be incurred.

I. Enter the Spectral BANDS desired when ordering black and white imagery.

J. Complete the QUANTITY column. Count the number of TM bands checked, enter in the QUANTITY column.

SAMPLE 8.2

K. Enter the quadrant desired in the CCT column using (1,2,3,4) when ordering a quarter TM scene. See TM Quadrant numbering example on front.

L. Enter the UNIT PRICE of the type product as reflected in the STANDARD PRODUCTS tables.

M. Multiply the figure in the QUANTITY column by the UNIT PRICE, and enter the result in the TOTAL PRICE column.

N. Repeat steps E through M for each product ordered.

O. TOTAL the costs of all products ordered on this order form and enter the net result in BLOCK A (TOTAL ABOVE).

P. For single order form, enter the figure from BLOCK A in BLOCK C (TOTAL COST). If more than one order form is required, on the last order form enter the sum of the figures in all BLOCK A's in BLOCK B and then total BLOCK A and BLOCK B in BLOCK C (TOTAL COST).

Q. Include type of payment (purchase order, check or money order). Make all drafts payable to NOAA Landsat. PLEASE DO NOT SEND CASH.

R. If a CUSTOM PRODUCT is desired, the COMMENTS portion should be used, and the cost determination will be based on three times the standard cost.

S. Mail ORDER FORM(S) and PRE-PAYMENT to NOAA/NESDIS, Landsat Customer Service, address on the reverse side.

FOR FURTHER INFORMATION OR ASSISTANCE PLEASE CONTACT
U.S. GEOLOGICAL SURVEY
NATIONAL CARTOGRAPHIC INFORMATION CENTER
507 NATIONAL CENTER•RESTON, VA 22092
FTS: 928-6045 COMM: 703/860-6045

FORMATION OR ASSISTANCE MAY ALSO BE OBTAINED FROM THE FOLLOWING U.S. GEOLOGICAL SURVEY, NATIONAL CARTOGRAPHIC INFORMATION CENTER, OFFICES

Eastern Mapping Center
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: 703/860-6336

Mid-Continent Mapping Center
1400 Independence Road
Rolla, MO 65401
FTS: 277-0851
Comm: 314/341-0851

Rocky Mountain Mapping Center
Stop 504, Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: 303/234-2326

Western Mapping Center
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2426
Comm: 415/323-8111

National Space Technology Laboratories
NSTL Station, MS 39529
FTS: 494-3541
Comm: 601/688-3544

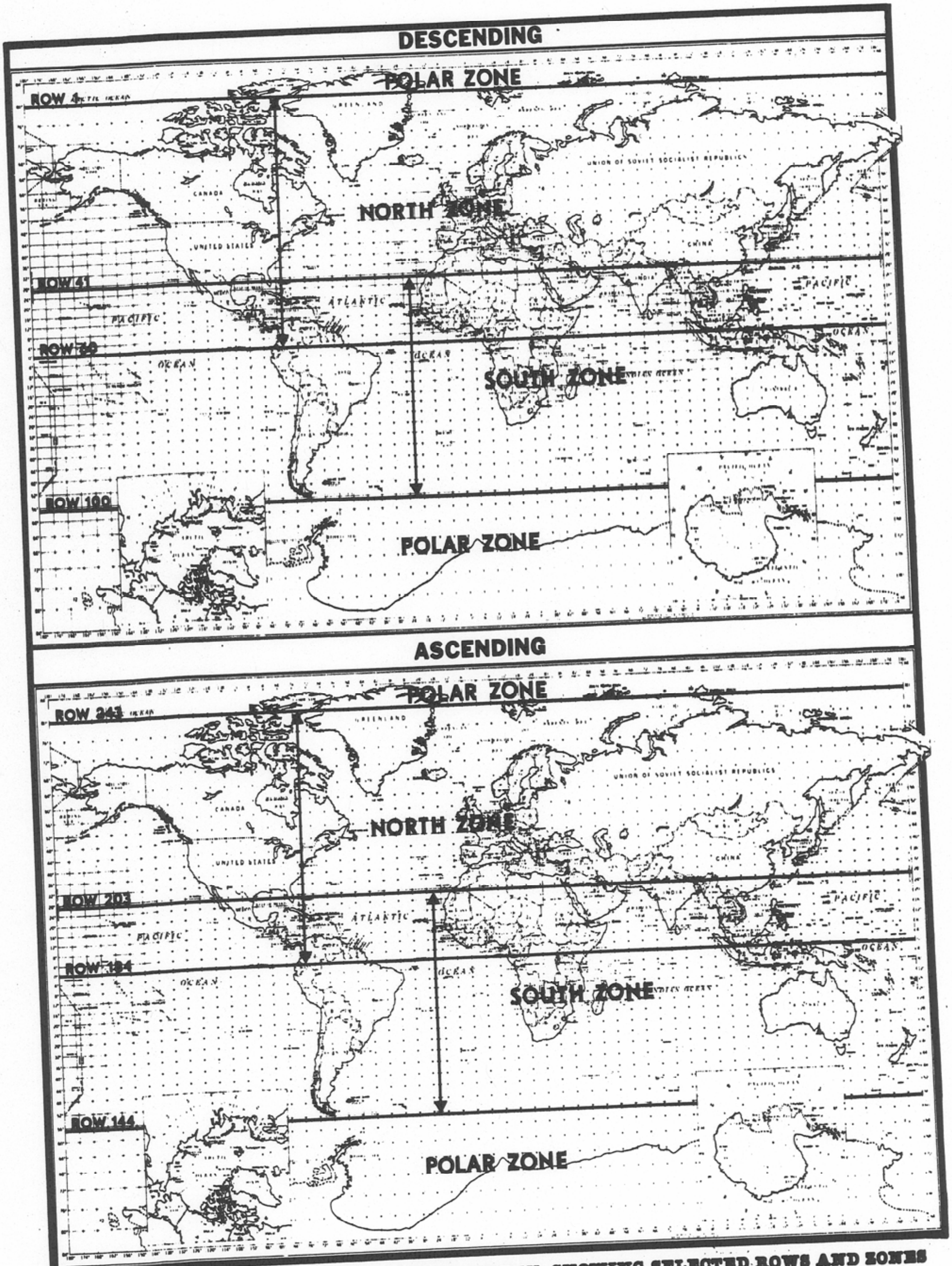
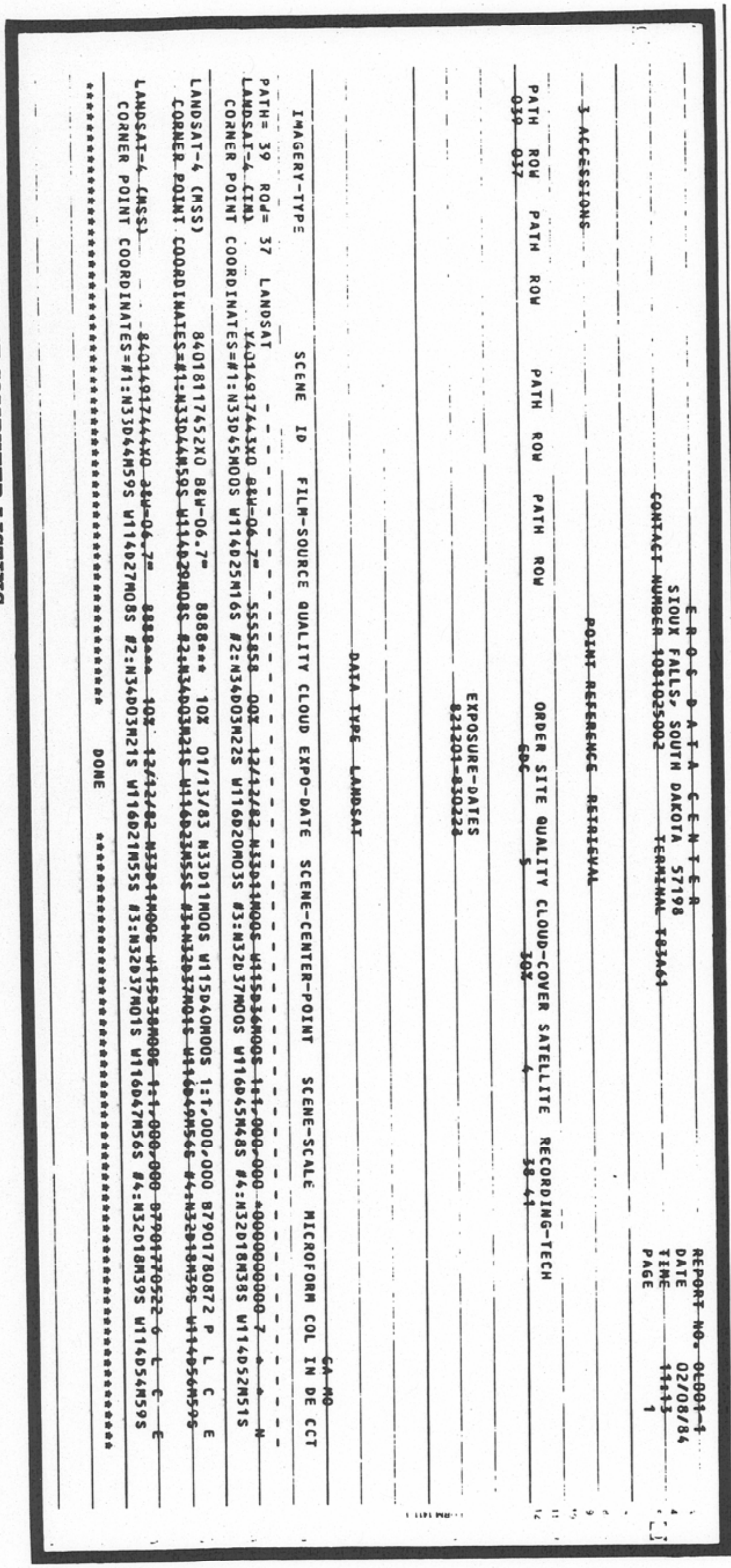


Figure 8.1 LANDSAT MICROFICHE SYSTEMS INDEX, SHOWING SELECTED ROWS AND ZONES



```
E R O S   D A T A   C E N T E R                       REPORT NO. 0L001-1
SIOUX FALLS, SOUTH DAKOTA  57198                       DATE        02/08/84
CONTACT NUMBER 1081025002          TERMINAL T83A61     TIME        11:13
                                                       PAGE            1

3 ACCESSIONS              POINT REFERENCE  RETRIEVAL

PATH  ROW   PATH  ROW    PATH  ROW   PATH  ROW    ORDER SITE QUALITY CLOUD-COVER SATELLITE  RECORDING-TECH
039   037                                            EDC        5       30%          4         38 41

                          EXPOSURE-DATES
                          821201-830223

                          DATA TYPE  LANDSAT

                                                                                                   GA MO
IMAGERY-TYPE          SCENE  ID   FILM-SOURCE QUALITY CLOUD EXPO-DATE  SCENE-CENTER-POINT   SCENE-SCALE  MICROFORM COL IN DE CCT

PATH= 39  ROW= 37  LANDSAT   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
LANDSAT-4 (TM)        Y4014917443X0 B&W-06.7"   5555858  00%  12/12/82 N33D11M00S W115D36M00S 1:1,000,000 *0000000000 7  *  *  N
  CORNER POINT COORDINATES=#1:N33D45M00S W114D25M16S #2:N34D03M22S W116D20M03S #3:N32D37M00S W116D45M48S #4:N32D18M38S W114D52M51S

LANDSAT-4 (MSS)       84018117452X0 B&W-06.7"   8888***  10%  01/13/83 N33D11M00S W115D40M00S 1:1,000,000 B7901780872 P  L  C  E
  CORNER POINT COORDINATES=#1:N33D44M59S W114D29M08S #2:N34D03M21S W116D23M55S #3:N32D37M01S W116D49M56S #4:N32D18M39S W114D56M59S

LANDSAT-4 (MSS)       84014917444X0 B&W-06.7"   8888***  10%  12/12/82 N33D11M00S W115D38M00S 1:1,000,000 B7901770522 6  L  C  E
  CORNER POINT COORDINATES=#1:N33D44M59S W114D27M08S #2:N34D03M21S W116D21M55S #3:N32D37M01S W116D47M56S #4:N32D18M39S W114D54M59S

*********************************************************   DONE   *********************************************************
```

Sample 8.3 LANDSAT SCENE COMPUTER LISTING

allocated to a unique Row number within each Zone. Position No. 1 (upper left-hand corner) is reserved for rows 1, 41, 101, 144, or 184 respectively, in their appropriate Zones.

Landsat Listings

Each micro-image of a computer listing for a dedicated Path and Row intersection is formatted as shown in figure 8.3. The computer listing is explained in the accompanying key. Path/Row scene centers for which no Landsat scenes exist say "NO ACCESSIONS."

System Organization

The key to organizing Landsat microfiche is given in the header. The primary subdivision is by Path, the secondary subdivision is by Zone (implying specific Row groupings), and the third is by date.

A geographic filing system may be based on the Paths crossing and bordering a user's area of interest. Normally, a region will fall within one of the three Zones. The United States, for example, is covered by Paths 10-48 and Rows 25-43, which are enclosed entirely within the North Zone. Non-U.S. coverage obtained from non-U.S. ground receiving stations may be organized in a similar manner.

Several Landsat data reception and processing stations are operated by Government or Government-subsidized organizations or agencies in other countries under agreements with the National Oceanic and Atmospheric Administration. These stations are capable of directly receiving Landsat data acquired over a circular area with a radius of approximately 2,400 km from the station. (See fig. 8.4.)

System Use

Using the Landsat micrographic accession aids system requires only the appropriate WRS index maps, a microfiche reader (24 X magnification is recommended),

GEOGRAPHIC SEARCH FOR LANDSAT DATA
INQUIRY FORM

RETURN COMPLETED FORM TO: NOAA/NESDIS Landsat Customer Services • Mundt Federal Building Sioux Falls, SD 57198 • Comm: 605/594-6151 FTS: 784-7151 • TWX: 910-668-0310

DATE ______

NAME ______ (FIRST) (INITIAL) (LAST) COMPANY ______

ADDRESS ______ CITY/STATE ______ ZIP ______

PHONE (HOME) ______ (BUSINESS) ______ EROS ACCOUNT NO. ______ REF. NO. ______

POINT SEARCH	POINT NO. 1	POINT NO. 2	POINT NO. 3
LAT. / LONG.	LAT. ___ ° ___ ' N or S	LAT. ___ ° ___ ' N or S	LAT. ___ ° ___ ' N or S
	LONG. ___ ° ___ ' E or W	LONG. ___ ° ___ ' E or W	LONG. ___ ° ___ ' E or W
Imagery with any coverage over the selected point will be included.			

WRS NOMINAL SCENE CENTERS (PATH/ROW) ARE DIFFERENT FOR LANDSATS 1-3 VERSUS LANDSAT 4.

PATH ___	PATH ___	PATH ___	PATH ___	PATH ___
ROW ___	ROW ___	ROW ___	ROW ___	ROW ___
PATH ___	PATH ___	PATH ___	PATH ___	PATH ___
ROW ___	ROW ___	ROW ___	ROW ___	ROW ___

AREA RECTANGLE	AREA NO. 1	AREA NO. 2	AREA NO. 3
LAT. / LAT. / LONG. / LONG.	LAT. ___ ° ___ ' N or S to	LAT. ___ ° ___ ' N or S to	LAT. ___ ° ___ ' N or S to
	LAT. ___ ° ___ ' N or S	LAT. ___ ° ___ ' N or S	LAT. ___ ° ___ ' N or S
	LONG. ___ ° ___ ' E or W to	LONG. ___ ° ___ ' E or W to	LONG. ___ ° ___ ' E or W to
	LONG. ___ ° ___ ' E or W	LONG. ___ ° ___ ' E or W	LONG. ___ ° ___ ' E or W
Imagery with any coverage within the selected area will be included.			

If any of the above geographic references cannot be provided, please specify areas of interest by GEOGRAPHIC NAME AND LOCATION (include a map if possible).

PREFERRED TYPE OF COVERAGE

	Black & White	False Color
☐ Landsats 1-3	☐	☐
☐ Landsat 4	☐	☐

☐ MSS ☐ RBV ☐ TM

PREFERRED TIME OF YEAR
Check maximum of three

- JAN-MAR ☐
- APR-JUNE ☐
- JULY-SEPT ☐
- OCT-DEC ☐
- ☐ ALL COVERAGE
- ☐ LATEST COVERAGE
- ☐ SPECIFIC DATES ______

MINIMUM QUALITY RATING ACCEPTABLE

☐ (VERY POOR) ☐ (POOR) ☐ (FAIR) ☐ (GOOD)

NOTE:
Classification of percent of cloud cover is subjective and is relative to the amount of clouds appearing on the imagery and not on their location.

MAXIMUM CLOUD COVER ACCEPTABLE

☐ 10% ☐ 30% ☐ 50% ☐ 70% ☐ 90%

FOR ADDITIONAL SERVICES, PLEASE CONTACT: U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
EXTERNAL RELATIONS, CODE E/ER2, WASHINGTON, DC 20233

COMMENTS: ______

SAMPLE 8.4

NOAA FORM 34-1202
May 1983

HOW TO REQUEST A GEOGRAPHIC SEARCH

This form is used to request a geographic search for Landsat data over a point or area of interest.

Data from this inquiry form will be used to initiate a computer Geosearch. The results will be returned on a computer listing along with a decoding sheet, from which Landsat data can be selected and ordered.

Complete the form as follows:

A. Enter your NAME, ADDRESS, and ZIP CODE clearly. Enter a PHONE number where you can be reached during business hours.

B. Complete the required information for either the POINT SEARCH, or AREA RECTANGLE INQUIRY. The preferred manner of inquiry is to identify the appropriate Landsat Worldwide Reference System (WRS) of PATH and ROW centers. However, if the WRS information is not available, a geographic reference of LATITUDE and LONGITUDE will suffice. It is beneficial that you minimize your area of interest, thereby allowing for a faster and more critical retrieval of information.

C. Complete all other information.

D. Complete the COMMENTS portion of the inquiry. Will it be used for interpretation, analysis, or will it be framed and placed on a wall? This information will assist our technicians in determining whether the products available will satisfy your requirements.

E. Return the completed form to Landsat Customer Services, Mundt Federal Building, Sioux Falls, SD 57198

FOR INFORMATION OR ASSISTANCE PLEASE CONTACT
NOAA/NESDIS
LANDSAT CUSTOMER SERVICES
MUNDT FEDERAL BUILDING
SIOUX FALLS, SD 57198
COMM: 605/594-6151 • FTS: 784-7151

INFORMATION OR ASSISTANCE MAY ALSO BE OBTAINED FROM THE FOLLOWING U.S. GEOLOGICAL SURVEY, NATIONAL CARTOGRAPHIC INFORMATION CENTER, OFFICES

SAMPLE 8.4

E[illegible] Mapping Center
53[illegible] National Center
Reston, VA 22092
FTS: 928-6336
Comm: 703/860-6336

Mid-Continent Mapping Center
1400 Independence Road
Rolla, MO 65401
FTS: 277-0851
Comm: 314/341-0851

Rocky Mountain Mapping Center
Stop 504, Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: 303/234-2326

Western Mapping Center
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2426
Comm: 415/323-8111

National Space Technology Laboratories
NSTL Station, MS 39529
FTS: 494-3541
Comm: 601/688-3544

☆U.S. GOVERNMENT PRINTING OFFICE: 1983—666-493

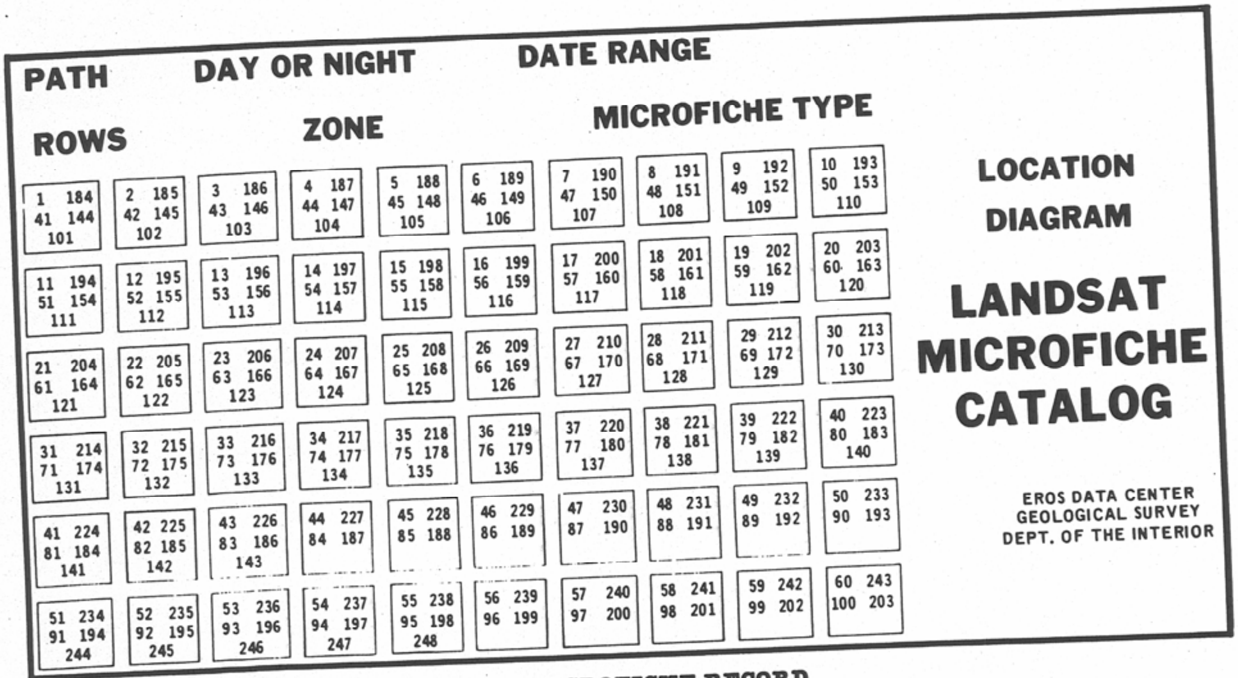


Figure 8.2 FORMAT OF THE LANDSAT MICROFICHE RECORD

and the microfiche accession aids. The following procedure is suggested:

a. Select the proper Landsat 4 WRS index and locate an area of interest.
b. Define the WRS Paths crossing and bounding the selected area.
c. Note the Zone(s): North, South, and (or) Polar.
d. Choose the date range of interest: 1982, 1983, etc.
e. Extract the appropriate microfiche (Path-, Zone-, and date-dependent) from the file and insert in the reader.
f. Note selected accessions for ordering images or viewing in microform.

Ordering Data

Orders may be placed with NOAA Landsat Customer Services by mail, telephone, telegraph/ telex, or in person (see samples). Orders also may be placed at any of the NOAA or NCIC offices listed on sample 8.1. Orders for standard Landsat data products are processed when all of the necessary information (sample 8.1) and payment have been obtained from the customer. Orders for special acquisitions are processed when procedures for this service and payment are received.

Each customer is initially assigned an account number, to which reference should be made in all future transactions.

Payment

All orders for reproduction of data must be accompanied by cash, check, money order, purchase order, or authorized account identification. Checks, money orders, purchase orders, and other instruments must be made payable to NOAA Landsat Customer Services. Currency should not be sent.

Standing or open accounts may be established by users having a need for repetitive and continuing orders. A standing account may be opened by advance deposit of funds with NOAA Landsat Customer Services. The user will be given an account number against which to place all subsequent orders. Status of standing order accounts will be provided by a monthly statement. Accounts may be added to or a refund of the unused portion can be obtained at any time.

Checks drawn on foreign banks will not be accepted due to conversion charges and international documentation requirements; payment should be processed through a U.S. Federal Reserve bank, which will send and make the draft payable to NOAA Landsat Customer Services.

Standing Request System

The NOAA Standing Request System is intended to fill standing Landsat data orders on a regular and timely basis. Automatic reproduction and shipment of data as they become available is an option which provides the most expeditious method for obtaining data that meet the user's criteria over a specified area of interest. A standing account must be established and maintained to satisfy the prepayment requirement for such orders.

Custom Products

Custom processing of Landsat data to unique scales or formats is available. Custom processing must be specified on the order form, and the requirements explicitly identified.

Detailed descriptions of Landsat 4 data product generation can be found in Section 7, Ground Processing and Product Generation.

LANDSAT UNIT RECORD

MICROGRAPHIC ACCESSION AIDS SYSTEM

WRS DATA LISTINGS - Phase I and II

PATH 020 ROW 036 LANDSAT

Phase I Microfiche

DATE	SAT	SEN	IMAGE QUAL 45678	CLD COV	COL	MICROFILM	CCT	CENTER	COORDINATES	SCENE ID	SP
05/21/76	1	MSS	8888	10%		1100510441		N34D33M595	W084D15M00S	854521456050000	
07/14/76	1	MSS	5888	10%		1100500013		N34D33M595	W084D15M00S	853981500050000	
08/10/76	2	MSS	8888	10%		2100210812		N34D37M595	W084D00M00S	825661524150000	

Phase II Microfiche

PATH 020 ROW 036 LANDSAT

DATE	SAT	SEN	IMAGE QUAL 45678	CLS COV	COL	MICROFILM	CCT	DIGIT QUAL 45678	CENTER	COORDINATES	SEN	CLOUD COVER/IMAGE QUAL A	B	C	D	DIG QUAL ABCD	SCENE ID	SP
09/30/78	3	MSS	58888	10%		3100210830	Y	88888	N34D35M00S	W084D10M00S	RBV	10%/8	10%/8	00%/8	10%/8	8888	834531524150000	
10/18/78	3	MSS	55555	20%	7	3100220633	Y	77777	N34D30M59S	W084D00M59S	RBV	10%/8	20%/8	20%/8	10%/8	8888	835621522450000	
11/13/78	3	MSS	58558	10%		3100230438	Y	88888	N34D20M00S	W084D15M00S	RBV	10%/8	10%/7	10%/7	10%/8	8888	835661456050000	
12/01/78	3	MSS	85888	00%		3100240520	Y	88888	N34D33M00S	W084D15M00S	RBV	00%/7	00%/5	00%/7	00%/5	8788	835691500050000	

COMPUTER LISTING KEY

1. DATE.—Indicates the month, day, and year that the images were taken. Dates are listed sequentially, with earliest date first and most recent date last.
2. SAT (Satellite.)—1, 2, or 3 for Landsats 1, 2, or 3, respectively.
3. SEN (Sensor).—MSS for Multispectral Scanner, RBV for Return Beam Vidicon.
4. IMAGE QUAL (Quality).—Each black-and-white band is rated in sequence by a 2 (Poor), 5 (Fair), or 8 (Good). O or M indicates a missing band. Color composites are rated on a 0—9 scale with 9 indicating excellent quality.
5. CLD CLV (Cloud Cover).—Percentage of image obscured by clouds and cloud shadows.
6. COL (Color Composite).—If a color composite has been made from the black-and-white images, its quality designator is shown.
7. MICROFILM.—Indicates (or "shows") the cassette and frame number (for Landsat images acquired prior to the conversion to microfiche records).
8. CCT (Computer Compatible Tape).—Indicates the availability of a CCT by one of the three categories:
   - N, scene cannot be processed and will never be available.
   - Y, scene has been processed and can be ordered.
   - P, scene has not yet been processed; may or may not be processable.
9. CENTER COORDINATES.—The latitude and longitude of the scene center in degrees, minutes, and seconds.
10. SCENE ID.—A 13-character identification number unique to each Landsat scene which is used for product ordering.
11. SP (Special).—Denotes a non-standard product associated with the specific accession, e.g., digital enhanced version available, nonstandard bands used in color composite, and so forth (see STA). Suggest contact with EROS Data Center prior to ordering products.

Figure 8.3 FORMAT OF COMPUTER LISTING FOR A DEDICATED PATH AND ROW AS SHOWN ON MICROFICHE: PHASE I, PRIOR TO IMPLEMENTATION OF IPF/EDIPS; PHASE II, AFTER IMPLEMENTATION OF IPF/EDIPS

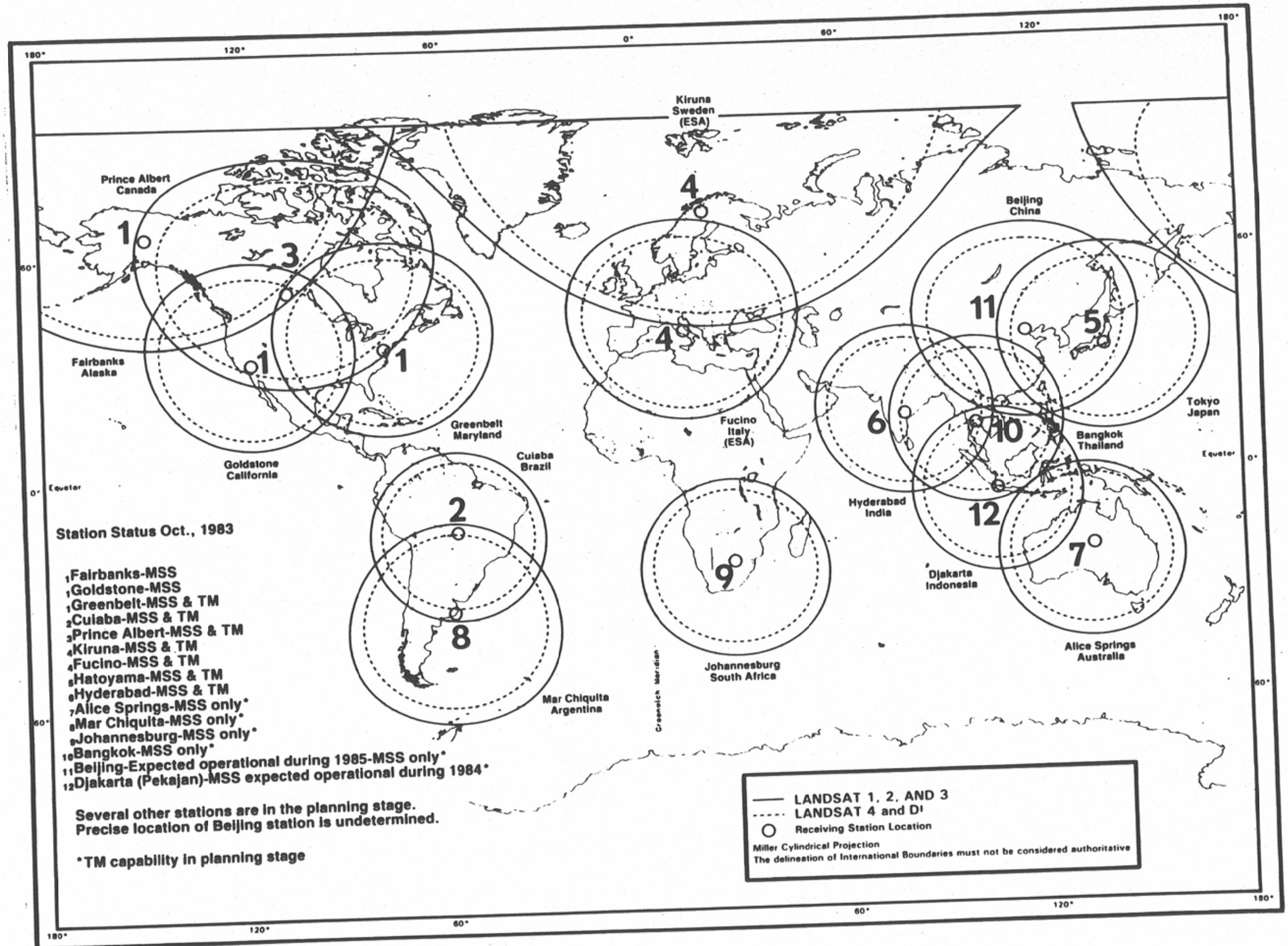


Figure 8.4 LANDSAT RECEIVING STATION COVERAGE

GLOSSARY

This glossary is included to assist the user of this handbook in understanding those relatively uncommon terms that are widely used in remote sensing and space operations. Many of these terms are defined specifically as they are used in remote sensing, space operations, and related activities, and these definitions may differ from standard definitions.

A

absorption. The process by which electromagnetic radiation (EMR) is assimilated and converted into other forms of energy, primarily heat. Absorption takes place only on the EMR that enters a medium, and not on EMR incident on the medium but reflected at its surface. A substance that absorbs EMR may also be a medium of refraction, diffraction, or scattering; however, these processes involve no energy retention or transformation and are distinct from absorption.

absorption band. A range of wavelengths (or frequencies) of electromagnetic radiation that is assimilated by a substance.

acutance. An objective measure of the ability of a photographic system to show a sharp edge between contiguous areas of low and high illuminance. This film property can be measured, using microdensitometric techniques, instead of being qualitatively estimated by means of visual perception. Acutance is correlated to some extent with sharpness, which is the visual impression of edge quality.

albedo. (1) The ratio of the amount of electromagnetic energy reflected by a surface to the amount of energy incident upon it, often expressed as a percentage. Example: the albedo of the Earth is 34 percent. (2) The reflectivity of a body as compared to that of a perfectly diffusing surface at the same distance from the Sun, and normal to the incident radiation. Albedo may refer to the entire solar spectrum or merely to the visible portion.

algorithm. (1) Any method of computation consisting of a comparatively small number of steps, which are specifically adapted to the solution of a problem of some particular type, that are to be taken in a preassigned order, usually involving iteration. In computer terminology, an algorithm is a detailed logical procedure, or statement, which represents the solution of a particular problem. Most commonly, the term is used to indicate an analysis procedure such as that used for evaluation of a square root or for sorting a data file.

altitude. Height above a datum, the datum usually being mean sea level. Not the same as elevation, for it generally refers to points above the Earth's surface rather than those on it. Compare with elevation.

analog. A physical variable which remains similar to another variable insofar as the proportional relationships between the two remain the same over a specified, and usually continuous, range. A temperature, for example, may be represented by a voltage level, which would be its analog. Contrast with digital.

analog computer. A computer that represents variables by physical analogs. Thus, any computer that solves problems by translating physical conditions, such as temperature, pressure, or angular position, into related mechanical or electrical quantities. Different from a digital computer in that it measures continuously, whereas a digital computer counts discretely. An automobile speedometer is an example of an elementary analog device.

analog-to-digital conversion. The process of sampling continuous analog signals in order to convert them into a stream of digital values. Multispectral Scanner data undergo such a conversion prior to digital analysis. Abbreviated as A/D conversion.

ancillary. Auxiliary; accessory. In remote sensing, ancillary data are secondary data pertaining to the area or classes of interest, such as topographic, demographic, or climatological data. Ancillary data may be digitized and used in conjunction with the primary remote sensing data.

angle of drift. The angle between the heading of the axis of a craft and its ground track.

annotation. Any marking on illustrative material for the purpose of clarification, such as numbers, letters, symbols, and signs. Landsat image products are annotated to show date of coverage, Sun angle, scene identification number, and so forth. On photographic image products, these annotations are printed in the border area surrounding the image. On digital products, the annotation is represented in digital form in special records devoted to this purpose on the same file as the image data.

anomaly. A deviation from the norm.

aperture. An opening that admits electromagnetic radiation to a film or detector. An example would be the lens diaphragm opening in a camera.

apogee. The point in the orbit of a heavenly body, especially of a manmade satellite, at which it is farthest from the Earth.

aspect ratio. (1) Of pixels, the numerical ratio of the width of a pixel to its height. (2) Of images, the ratio of two perpendicular axes scales, or the ratio of image length to width.

attenuation. The reduction in the intensity of radiation with distance from its source due to atmospheric absorption and/or scattering; it does not include the inverse-square decrease of intensity of radiation with distance from the source. In a general sense, attenuation can be taken to mean any reduction of a physical variable; see also transmittance.

attitude. The angular orientation of a spacecraft as determined by the relationship between its axes and some reference line or plane or some fixed system of axes. Usually, "y" is used for the axis that defines the direction of flight, "x" for the "crosstrack" axis, perpendicular to the direction of flight, and "z" for the vertical axis. Roll is the deviation from the vertical (the angle between the z-axis of the vehicle and the vertical axis, or angular rotation around the y-axis). Pitch is the angular rotation around the x-axis. Yaw is rotation around the z-axis.

azimuth. The arc of the horizon measured clockwise from the north point to the point referenced. Expressed in degrees. Azimuth indicates direction, and not location.

B

background. Any effect in a sensor or other apparatus or system above which the phenomenon of interest must manifest itself before it can be observed. See background noise.

background noise. (1) In recording and reproducing, the unwanted disturbance within a useful frequency band, independent of whether or not a signal is present. The signal is not to be included as part of the disturbance. (2) In receivers, the random oscillation in the absence of signal modulation on the carrier. Ambient oscillations detected, measured, or recorded with the signal become part of the background noise. Included in this definition is the interference resulting from primary power supplies.

band, spectral. An interval in the elec--tromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers. With Landsat, bands designate the specific wavelength intervals at which images are acquired.

base, film. A thin, flexible, transparent sheet of cellulose nitrate, acetate, or similar material which is coated with a light-sensitive emulsion and used for taking photographs.

batch processing. Pertaining to the technique of executing a set of computer programs such that each program of the set is completed before the next program of the set is started; loosely, sequential processing. Contrast with on-line processing, which see.

bias. (1) In image processing, a persistent difference (not due to sampling error) between the true value of a population characteristic and the value obtained through the estimator used. A systematic distortion in the results. This may be due to a flaw in the measurement, the method of sample selection, or the technique of estimation. (2) A steady voltage inserted in series with an element of an electronic device to signal a desired operation.

bit. (1) An abbreviation of binary digit. (2) A unit of memory corresponding to the ability to store the result of a choice between two alternatives, used especially in connection with digital computing devices.

black body. An ideal body which, if it existed, would be a perfect absorber and a perfect radiator, absorbing all incident radiation, reflecting none, and emitting radiation at all wavelengths. In remote sensing, the exitance curves of black bodies at various temperatures can be used to model naturally occurring phenomena like solar radiation and terrestrial emmitance.

brightness. The attribute of visual perception in accordance with which an area appears to emit more or less light.

brightness value. (Landsat usage) A number in a range of 0-63, 0-127, or 0-255 that is related to the amount of radiance in watts per square centimeter striking a detector in either the Multispectral Scanner or the Thematic Mapper.

buffer. A temporary storage device or circuitry which retains data for transmission between two equipment units, usually in order to compensate for differing data handling speeds of the units.

byte. A group of consecutive bits (usually 6 bits or 8 bits) that is operated upon as a unit in a digital computer. Usually shorter than a word, which see.

C

calibration data. In remote sensing, measurements pertaining to the spectral or geometric characteristics of a sensor or radiation source. Calibration data are obtained through the use of a fixed energy source such as a calibration lamp, a temperature plate, or a geometric test pattern. The application of calibration data to restore measurements to their true values is called rectification, which see.

cell. In remote sensing, an area on the ground from which electromagnetic radiation is emitted or reflected. See instaneous field of view, resolution cell.

characteristic curve. (photography) A curve showing the relationship between exposure and resulting density in a photographic image, usually plotted as the density (D) against the logarithm of the exposure (log E) in candelameters-seconds. It is also called the H and D curve for the sensitometric curve, and the D-log E curve. See Dmax and Dmin.

cluster. In image processing, a homogeneous group of units which are very "like" one another. "Likeness" among units is usually determined by the association, similarity, or distance separating the measurement patterns associated with the units.

collimate. (1) To aline the axes of instruments, especially optical axes of multiple lenses, so that they have the same spatial orientation along a common line. (2) To make parallel rays of light by means of a lens or concave mirror.

color. That property of an object which is dependent on the wavelength of the light it reflects or, in the case of a luminescent body, the wavelength of the light it emits. If, in either case, this light is of a single wavelength, the color seen is a pure spectral color, but, if the light of two or more wavelengths is emitted, the color will be mixed. White light is a balanced mixture of all the visible spectral colors.

color balance. (photography) The proper intensities of colors in a color print, positive transparency, or negative, that give a correct reproduction of the gray scale or of the true color of a scene.

color composite. (multiband photography) A color photograph produced by the combination of (usually) three individual monochrome images in which each is reproduced in a given color. In Landsat Multispectral Scanner imagery, the color blue is ordinarily assigned to band 1 (0.5 to 0.6 μm), green is assigned to band 2 (0.6 to 0.7 μm), and red is assigned to band 3 (0.7 to 0.8 μm) or band 4 (0.8 to 1.1 μm), to form a picture closely approximating a color-infrared photograph.

computer-compatible tape (CCT). The standard 1/2-inch-wide magnetic tape on which Landsat digital data are recorded for distribution to users. A variety of packing densities are available (800, 1,600, or 6,250 bits per inch), as are specific data formats (geometrically corrected, radiometrically corrected, etc.). The term is used in reference to both single tapes and tape sets consisting of single logical volume of data.

contact print. (photography) A photographic print made from a negative or a diapositive in direct contact with a sensitized material.

contrast. (photography) The difference between highlights and shadows. The ratio of reflecting power between the highlights and shadows of a photographic print determines the contrast of the print. Contrast in a negative is determined by the ratio of densities of the parts compared. It is possible to enhance the contrast of Landsat images, when in digital form, by performing a linear stretch of the image gray levels as much as possible to fill the complete dynamic range of the display medium.

cubic convolution. A high-order resampling technique in which the brightness value of a pixel in a corrected image is interpolated from the brightness values of the 16 nearest pixels around the location of the corrected pixel.

D

D-Log E. See density, characteristic curve.

Dmax. The highest density which can be obtained with a particular photographic material; in reference to a particular negative or positive, the highest density recorded. See density.

Dmin. The lowest density on a positive or negative photographic print. See density.

data compression. Any technique that condenses the available data so as to make data storage or transmission more efficient with minimal loss of information. Refers somewhat inappropriately to the mode in which Landsat Multispectral Scanner data are sometimes transmitted from the satellite to the ground; "data compression" in this context refers to a modification of detector response curves to facilitate transmission and is not compression in the true sense. The data are later "decompressed," or returned to their original form, during ground processing.

decompression. A reversal of the process of data compression, which see.

default. A value for a parameter or system characteristic that can take effect if a parameter is omitted, a characteristic is not specified, or no other value is received.

densitometer. A device used to measure the average image density of a small area of specified size on a photographic transparency or print. The measurement may be a meter reading or an electronic signal. When the area is smaller than a few hundred micrometers square, the instrument is called a microdensitometer.

densitometry. The study devoted to the measurement of optical image densities on film or print gray shades usually caused by absorption or reflection of light by a developed photographic emulsion.

density (D). A measure of the light-absorbing capability of a given area or point on a photograph, caused by the comparative amount of silver deposited by exposure and development on that given area or point. Density is expressed as the logarithm of the position's reciprocal transmittance. The density measured should be specified as to whether it is specular or diffuse.

density slicing. A general class of electronic or digital techniques used to assign image points or data vectors to particular classes based on the density or level of the response in a single image or channel; classification by thresholds.

diapositive. A positive image on a transparent medium such as glass or film; a transparency. The term originally was used primarily for a transparent positive on a glass plate used in a plotting instrument, a projector, or a comparator, but now is frequently used for any positive transparency.

digital. Representation of data in the form of discrete bits, or equal integral units. Contrast to analog.

digital computer. A computer in which discrete representation of data is used. In general, any device that performs arithmetic, logical, and comparative functions upon information represented in digital forms, and that operates under the control of an internal program.

digital image. A digital image, or digitized image, or digital picture function of an image, is an image represented numerically in digital form and is obtained by partitioning the area of the image into a finite two-dimensional array of small, uniformly shaped, mutually exclusive regions, called resolution cells or picture elements (pixels), and by assigning a representative gray shade to each such spatial region. A digital image may be abstractly thought of as a function whose domain is the finite two-dimensional set of resolution cells and whose range is the set of gray shades.

disk. A rotating magnetic storage device on which digital data may be held. Used for relatively fast data access in computers.

distortion. A change in scale from one part of an image to another.

dwell time. Refers to the momentary time interval during which a detector is able to, or allowed to, sense incoming electromagnetic radiation within its intended instantaneous field of view.

dynamic range. See scale.

E

electromagnetic radiation. Energy emitted as a result of changes in atomic and molecular energy states and propagated through space at the speed of light. The term radiation, alone, is used commonly for this type of energy, although it actually has a broader meaning. Also called electromagnetic energy. See electromagnetic spectrum.

electromagnetic spectrum. (1) A system that classifies, according to wavelength, all energy that moves, harmonically, at the constant velocity of light. (2) A continuum that is conventionally broken into arbitrary segments (as ultraviolet, visible, radio).

elevation. Vertical distance from the datum, usually mean sea level, to a point or object on the Earth's surface. Not to be confused with altitude, which refers to points or objects above the Earth's surface. Compare with altitude.

emission. With respect to electromagnetic radiation, the process by which a body emits electromagnetic radiation as a consequence of its kinetic temperature only.

emissivity. Ratio of radiation emitted by a surface to the radiation emitted by a black body at the same temperature under similar conditions. May be expressed as total emissivity (for all wavelengths), spectral emissivity (as a function of wavelength), or goniometric emissivity (as a function of angle).

emulsion. (photography) A suspension of a light-sensitive silver salt (especially silver chloride or silver bromide) in a colloidal medium (usually gelatin), which is used for coating photographic films, plates, and papers. The emulsion is the image-forming layer on a photographic material. This same layer, after development of the latent image by reduction of the silver salt to elemental silver, is also called the emulsion.

enhancement. The process of altering the appearance of an image so that the interpreter can extract more information. Enhancement may be done by either digital or photographic means. Some types of digital enhancements commonly applied to Landsat imagery include edge enhancement, noise reduction (filtering), haze removal, and contrast stretch.

ephemeris. Any tabular statement of the assigned places of a celestial body (including a man-made satellite) for regular intervals. Ephemeris data help to characterize the conditions under which remote sensing data are collected and may be used to correct the sensor data prior to analysis.

F

field-of-view. The solid angle through which an instrument is sensitive to radiation. See effective resolution element, instantaneous field of view, resolution.

focal length. In a camera, the distance measured along the optical axis from the optical center of the lens to the plane at which the image of a very distant object is brought into focus.

focal plane. In a camera, the plane occupied by the film and on which the image is focused by the lens. In an instrument such as the Thematic Mapper, the plane occupied by the detectors, and on which the radiances to be sensed are incident.

focal point. The point toward which light rays converge to form an image after passing through a lens or having been reflected by mirrors. The condition of sharpest imagery.

frame. Any individual member of a continuous sequence of images.

fully processed. In reference to Landsat images, those scene data which have been both radiometrically corrected and geometrically corrected through the ground processing system. Contrast with partially processed.

G

gain. A general term used to denote an increase in signal power in transmission from one point to another. Gain is usually expressed in decibels.

gamma. (photography) A numerical measure of the extent to which a negative has been developed, indicating the ratio of the contrast of the negative to that of the subject to which the negative was exposed. A gamma of 1.0 indicates a negative which has the same contrast as the subject photographed. A gamma of 1.2 indicates a negative which has greater contrast than the subject photographed.

generation. The number of reproduction steps in which a negative or positive photographic copy is separated from the original. Thus, the original negative would be the first generation; any positive made from the original negative would be the second generation copy, etc.

geodetic coordinates. Quantities which define the position of a point on the spheroid of reference (for example, the Earth) with respect to the planes of the geodetic equator and of a reference meridian. Commonly expressed in terms of latitude and longitude. Geodetic tick marks are commonly provided in the border surrounding a Landsat photographic data product.

geometric correction. The transformation of image data, such as Landsat data, to match spatial relationships as they are on the Earth. Includes correction for band-to-band offsets, line length, Earth rotation, and detector-to-detector sampling delay. When distributed in digital form, Landsat data that have not been geometrically corrected are accompanied (on the same digital tape) by ancillary data that provide the information necessary for geometric correction to be performed. For Landsat, a distinction is made between data that have been geometrically corrected using systematic, or predicted, values and data that have been geometrically corrected using more precise ground control point data.

geosynchronous. An Earth satellite orbit in which the satellite remains in a fixed position over a geographic location on the Earth. This requires that the orbital plane be in the same plane as the equator, and that the satellite's altitude be high enough for the satellite to revolve about the Earth at a speed equal to that of the Earth's rotation. Geosynchronous orbits are common for most communications satellites, such as the Tracking and Data Relay Satellites.

gray level. (1) A shade of gray representing a given radiometric level, or intensity, on the image. (2) A number or value assigned to a position (x, y) on the image proportional to the integrated output, reflectance, or transmittance of a small area, usually called a resolution cell or a pixel, centered on the x, y position. Gray level can be measured or expressed as: transmittance, reflectance, brightness, radiance, luminance, density, voltage, current, or brightness value.

gray scale. A monochrome strip of shades ranging from white to black with intermediate shades of gray. Such a scale is placed in a setup for a color photograph and serves as a means of balancing the separation negatives and positive dye images. A 15-step gray scale is provided in the border surrounding Landsat photographic data products.

ground control point (GCP). A geographic feature of known location that is recognizable on images and can be used to determine geometric corrections to those images.

ground data. Supporting data collected on the ground, and information derived therefrom, as an aid to the interpretation of remotely sensed data. Ground data typically pertain to weather, soils, and vegetation types and conditions.

ground resolution cell. (1) The area of terrain that is covered by the instantaneous field of view of a detector. The size of the ground resolution cell is determined by the altitude of the remote sensing system and the instantaneous field of view of the detector. (2) The smallest area on the ground that can be resolved on a Landsat image. Compare with resolution cell.

ground track. The vertical projection of the actual flight path of an aerial or space vehicle onto the surface of the Earth.

ground truth. Data which are acquired from field checks, high-resolution remote sensing data, or other sources of "known" data. Ground truth is used as the basis for making decisions on training areas and evaluating classification results. See ground data.

H

H and D curve. A graph of density plotted against the logarithm of the exposure. See characteristic curve.

hardcopy. Any map, picture, chart, or graphic representation physically recorded on a sheet of paper or other such visual medium in such a manner that it may be stored or transported.

hardware. The physical components of a computer, or remote sensor system, and its peripheral equipment. Contrast with software.

hardwired. Describing a logic function or algorithm that is "built-in" to a system, enabling rapid execution.

histogram. A graphical representation of a frequency distribution by means of lines or rectangles that represent class intervals along the x-axis, and corresponding class frequencies along the y-axis; a frequency distribution plot, often of a classification training area. With each order for a Landsat computer-compatible tape (CCT), a histogram plotting scene brightness values is provided.

histogram cutoff points. The lowest and highest values of a histogram display, usually in reference to a histogram plot of brightness values in a Landsat scene.

Hotine Oblique Mercator (HOM). A variation on the basic Mercator map projection based on north-south strips that are oblique, or inclined away from, the polar axis, thereby matching the orientation of the Landsat ground tracks more nearly. The HOM is a conformal projection and nearly distortion-free. In it, the Earth is divided into five zones of latitude; within each of these zones, the number of north-south projection axes is equal to the number of Landsat paths that are traced such that each projection axis approximates the path of nominal scene centers. See Universal Transverse Mercator.

hue. The attribute of a color that differentiates it from gray of the same brilliance and that allows it to be classed as blue, green, red, or intermediate shades of these colors.

I

image. (1) The recorded representation of an object produced by optical, electro-optical, optical-mechanical, or electronic means. It is the term generally used when the electromagnetic radiation emitted or reflected from a scene is not directly recorded on photographic film. (2) The optical counterpart of an object, or scene, produced by a lens, mirror, or other optical system.

image enhancement. Any one of a group of operations which improves the interpretability of an image or the detectability of targets or categories in the image. These operations, in the case of Landsat images, include: contrast stretch, edge enhancement, spatial filtering, noise suppression, image smoothing, and sharpening of image detail.

image processing. Encompasses all the various operations which can be applied to photographic or image data. These include, but are not limited to: image compression, image restoration, image enhancement, preprocessing, quantization, spatial filtering, and pattern recognition techniques. The term usually refers to the application of such operations by digital means, requiring a computer.

image restoration. A process by which a degraded image is restored to its original condition. Image restoration is possible only to the extent that the degradation transform is mathematically invertible.

image transformation. A function or operator which takes an image as its input and produces an image as its output. Depending on the transform chosen, the input and output images may appear entirely different and have different interpretations. Fourier, Hadamard, and Karhunen-Loeve transforms, as well as various spatial filters, are examples of frequently used image transformation procedures.

imagery. The products of image-forming instruments (analagous to photography). Used loosely, but acceptably, to refer to Landsat image data products of all types, both photographic and digital.

infrared (IR). Pertaining to or designating the portion of electromagnetic spectrum with wavelengths from the red end of the visible spectrum to the microwave portion of the spectrum, or from 0.7μm to 1 mm.

instantaneous field of view (IFOV). (1) The solid angle through which a detector is sensitive to radiation. In a scanning system this refers to the solid angle subtended by the detector when the scanning motion is stopped. Instantaneous field of view is commonly expressed in milliradians. (2) The ground area covered by this solid angle (see ground resolution cell).

interface. (1) The junction or relationship between the components of a data processing system. (2, verb) To join or work together, coordinate, either physically or logically.

irradiance. The measure, in units of power, of radiant flux incident on a surface; it has the dimensions of energy per unit time.

isarithm. A line connecting points of equal quantity on a map. A contour line is an isarithm.

isocenter. The point of a photograph intersected by the bisector of the angle between the plumb line and the photograph perpendicular. The isocenter is significant because it is the center of radiation for displacement of features due to tilt.

J

jitter. Small rapid variations in a variable (such as a waveform) due to deliberate or accidental electrical or mechanical disturbances or to changes in the supply voltages, in the characteristics of components, etc. Jitter effects arising from the oscillating mirrors and other movable components aboard Landsat are often a cause of certain anomalies in the image data received and must be compensated for by the ground processing system.

K

K band. A radio frequency band extending from approximately 12.5 to 36 gigahertz.

kilobyte. In data processing terminology, refers to 1,024 bytes of data, usually of core memory storage.

L

L band. A radio frequency band extending from approximately 1.0 to 2.0 gigahertz.

laser. (From Light Amplification by Stimulated Emission of Radiation). A device for producing light by emission of energy stored in a molecular or atomic system when stimulated by an input signal. Electronically modulated laser optical recording systems are used to transform digital brightness values on Landsat high-density digital tapes (HDT's) into analog gray shades on photographic films to produce master reproducible images of Landsat scene data.

latent image. An invisible image produced by the physical or chemical effect of light upon matter (usually silver halide) which can be rendered visible by the subsequent chemical process of photographic development.

light, transmitted. Light that has traveled through a medium without being absorbed or scattered.

line scanner. A scanning radiometer, which by use of a rotating or oscillating plane mirror, can scan a path normal to the movement of the radiometer. The mirror directs incoming radiation to a detector which converts it into an electric signal.

linear quantizing. The range of gray shades from maximum to minimum is divided into contiguous intervals, each of equal length, and each gray shade is assigned to the quantized class which corresponds to the interval within which it lies.

linear spatial filter. A spatial filter for which the gray shade assignment at coordinates (x, y) in the transformed image is made by some weighted average (linear combination) of gray shades located in a particular spatial pattern around coordinates (x, y) of the domain image. The linear spatial filter is often used to change the spatial frequency characteristics of the image. For example, a linear spatial filter which emphasizes high spatial frequencies will tend to sharpen the edges in an image. A linear spatial filter which emphasizes the low spatial frequencies will tend to blur the image and reduce noise.

lookup table. A file of values from which functions corresponding to a given argument can be obtained. A table lookup procedure is employed, for example, during conversion of Landsat digital image data to a latent image on film.

M

magnetic tape. A method of storing data by selective polarization of the surface of a ferrous-coated tape. A reel of magnetic tape can store a large amount of data, but must be accessed sequentially.

map projection. Any systematic arrangement of meridians and parallels portraying the curved surface of a sphere or spheroid upon a plane.

mask. Any material or digital procedure used to obscure or define a part of the image.

master reproducible. (1) The film negative or positive that is used for the printing of sensitized material, paper, or film, positive or negative. (2) Any computer tape or any other medium that serves as a source in a duplicating process.

modulate. To vary, or control, the frequency, phase, or amplitude of an electromagnetic wave or other variable.

modulation transfer function (MTF). The modulation transfer function of an imaging system or component measures the spatial frequency modulation response of the system or component. As an imaging system or component processes or records an image, the contrast modulation of the processed or recorded image is different from the input image. The modulation transfer function can be thought of as a curve, indicating for each spatial frequency the ratio of the contrast modulation of the output image to the contrast modulation of the input image. It is formally defined as the magnitude of the Fourier transform of the line spread function of the imaging system or component.

mosaic. An image or photograph made by piecing together individual images or photographs covering adjacent areas.

mosaic, controlled. A mosaic oriented and scaled to horizontal ground control, usually assembled from rectified photographs.

multiband system. A system for simultaneously recording electromagnetic radiation from the same scene in several bands from essentially the same spectral region, such as the visible or visible and near infrared. May be applied to cameras with different film/filter combinations or scanning radiometers that use disparate optics to split wavelength bands apart for viewing by several filtered detectors.

multiplexer. An electronic device which permits the transmission of multiple messages simultaneously on one communication channel.

multispectral. Generally denotes remote sensing in two or more spectral bands, such as visible and infrared.

Multispectral Scanner (MSS). (1) A non-photographic imaging system which utilizes an oscillating mirror and fiber optic sensor array. The mirror sweeps from side to side, transmitting incoming energy to a detector array which sequentially outputs brightness values (that is, signal strengths) for successive pixels, one swath at a time. The forward motion of the sensor platform carries the instrument to a position along its path where an adjacent swath can be imaged. The recorded signal can be played back through a device which will convert signal strength to brightness on a photographic emulsion, thereby producing a photo-like image of the terrain that has been sensed. (2) For Landsats 1, 2, 3, and 4, the Multispectral Scanner sensed radiation simultaneously by an array of six detectors in each of four spectral bands from 0.5 to 1.1μm. See scanning radiometers.

N

nadir. That point on the celestial sphere vertically below the observer, or 180° from the zenith.

near infrared. The preferred term for the shorter wavelengths in the infrared region extending from about 0.7μm (visible red) to about 3μm. The longer wavelength end grades into the middle infrared. Sometimes called solar infrared, as it is only available for use during the daylight hours. Also known as the shortwave infrared (SWIR).

negative, photographic. A photographic image in which the subject tones to which the emulsion is sensitive are reversed or complementary. Contrast with positive, photographic.

node. Either of the two points at which the orbit of a heavenly body intersects a given plane, especially the plane of ecliptic. With respect to Landsat, the orbital nodes occur at the equator, one on the descending, or daylight, track of the orbit and the other on the ascending, or nighttime, track.

noise. Any unwanted disturbance affecting a measurement (as of a frequency band), especially that which degrades the information-bearing quality of the data of interest. See signal-to-noise ratio, background noise.

nominal. (1) In name only; so- called. (2) Loosely, a rough designation or an approximation.

nonsystematic distortion. Geometric irregularities on images that are not constant and cannot be predicted from the characteristics of the imaging system.

O

observatory. A place or structure, such as the Landsat satellite, equipped and used for making observations of astronomical or other natural phenomena; a place or structure affording an extensive view.

off-line. (1) Describing a processing mode in which processing is done in the absence of any operator intervention. Contrast with on-line processing. (2) Describing equipment not connected to a computer, or temporarily disconnected from one. Off-line equipment is either idle, undergoing repair, or performing a task under its own direction.

on-line. (1) Describing a processing mode in which processing is done directly under the control of a human operator, via terminal, or a control program, permitting the controlling agent to affect or change the operation being performed simultaneously with the execution of that operation. Sometimes called "interactive" processing or real-time processing, which see.(2) Describing equipment capable of interacting with a computer. On-line equipment operates at the same time as the computer, or in cooperation with the computer, in accomplishing a task.

optical axis. An imaginary line drawn directly through the optical center of the camera lens to the geometric center of the film. In this case of TM or MSS imagery, the point in the image where geometric distortion is at a minimum.

orbital period. The interval in time between successive passages (orbits) of a satellite through a reference plane.

orthophotographic. Describing a photograph in which image displacements due to tilt and relief have been removed.

overlap. (photography) The amount by which one photograph overlaps the area covered by another, customarily expressed as a percentage. The overlap between adjacent Landsat images (that is, two adjacent paths) is called sidelap, which see.

overlay. (1) A transparent sheet giving information to supplement that shown on maps. When the overlay is laid over the map or image on which it is based, its details supplement the map. (2) A tracing of selected details on a photograph, mosaic, or map to present the interpreted features and the pertinent detail, or to facilitate plotting.

P

panchromatic. Describing films or detectors that are sensitive to broadband electromagnetic radiation (the entire visible part of the spectrum).

parallax. The apparent change in the position of one object, or point, with respect to another, when viewed from different angles.

parameter. Any quantity of a problem that is not an independent variable. More specifically, a term which distinguishes, from dependent variables, quantities which are constants or which may be assigned more or less arbitrary values for purposes of the problem at hand.

parity check. A check for whether the number of ones or zeros in a word of binary data is odd or even, for comparison with a previously computed digit.

partially processed. In reference to Landsat images, those scene data which have been radiometrically corrected, only, through the ground processsing system. Contrast with fully processed. Also see levels of processing.

path. The longitudinal center line of a Landsat scene, corresponding to the center of an orbital track. Sequential numbers from east to west are assigned to 233 nominal satellite tracks for Landsat 4. Path numbers can be used with row numbers to designate nominal scene center points. See **row** and scene center, nominal.

payload. Originally, the revenue-producing portion of an aircraft's load (passengers, cargo, mail); by extension, that which a spacecraft carries that is separate from the equipment or operations necessary to maintain the spacecraft in orbit.

perigee. The point in the orbit of heavenly body, especially of a man-made satellite, at which it is nearest the Earth.

perturbation. Irregular variation in, or deviation from, what is usual or expected, as in the orbital motion of a satellite being affected by extraordinary gravitational pull.

picture element (pixel). A unit whose first member is a resolution cell and whose second member is the gray shade assigned to that resolution cell by a digital count. A Landsat MSS pixel represents about 0.44 hectares (1.09 acres) on the ground. One Landsat MSS frame contains about 7.36 x 10^6 pixels, each described by one of 64 radiance values. A Landsat TM pixel represents about 0.09 hectares (0.22 acres) on the ground. One Landsat TM frame (quarter scene) contains about 35.8 x 10^6 pixels, each described by one of 256 radiance values. (All values given for uncorrected data only.)

pitch. The rotation of a spacecraft about the horizontal axis normal to its longitudinal axis (in the along-track direction) so as to cause a nose-up or nose-down attitude. The pitch axis is referred to as the "x" axis. See attitude.

pixel. Abbreviation of picture element, which see.

Polar Stereographic (PS). An azimuthal stereographic projection commonly used with Landsat data acquired above 65° latitude. In this projection, the meridians are straight lines converging at the pole (central point), and lines of latitude are concentric circles about this point. Like the UTM projection, the Polar Stereographic is a conformal projection, meaning that angular relationships are preserved.

positive, photographic. A photographic image having approximately the same rendition of light and shade as the original subject. Contrast with negative, photographic.

primary color. One of the three colors, either additive (blue, green, and red) or subtractive (cyan, yellow, and magenta) that may be combined to produce the full range of colors.

Q

quantize. (1) To restrict a variable to discrete values, each of which is normally an integral multiple of the same quantity. (2) To process a range of gray shades, from maximum to minimum, such that the entire range is divided into contiguous intervals of normally equal lengths, each being assigned an integer value unique to the gray shade corresponding to it. Output voltages from the Thematic Mapper sensor aboard Landsat 4 are quantized into 256 discrete values prior to transmission to the ground. A total of 256 brightness values are therefore possible in each band of Thematic Mapper imagery. With Landsat MSS data, the data from bands 1, 2, and 3 may be quantized in a non-uniform or "compressed" manner. These data are then "decompressed" during ground processing.

quantization level. The number of numerical values used to represent a continuous quantity.

R

radian. The angle subtended by an arc of a circle equal in length to the radius of the circle: 57.3°

radiance. Measure of the energy radiated by an object. In general, radiance is a function of viewing angle and spectral wavelength and is expressed as energy per solid angle.

radiation. The process by which electromagnetic energy is propagated through free space by virtue of joint undulatory variations in the electric and magnetic fields in space. This concept is to be distinguished from conduction and convection. Also, the process by which energy is propagated through any medium by virtue of the wave motion of that medium, as in the propagation of sound waves through the atmosphere. Also called radiant energy. Also called electromagnetic radiation, which see.

radiometer. An instrument for detecting and measuring electromagnetic radiant energy.

random access. Process of obtaining information from, or placing information into, storage where the time required for such access is independent of the location of the information most recently obtained or placed in storage. A digital tape containing Landsat data is not a random-access storage medium.

range, brightness. Variation in light intensity from maximum to minimum.This generally refers to a subject to be photographed.

range, dynamic. The difference between maximum measurable signal and minimum detectable signal. The upper limit usually is set by saturation and the lower limit by noise.

raster. In television, a predetermined pattern of scanning lines which provides substantially uniform coverage of the area being televised. Also used to designate the two-dimensional array of pixels in an image.

ratio image. An image prepared by processing digital multispectral data. For each pixel the value for one band is divided by that of another. The resulting digital values are displayed as an image. The term **ratioing** refers to the process by which a ratio image is produced.

read-only memory. Information which is stored permanently or semi-permanently and is read out but not altered in operation.

real time. Time in which the recording of an event is simultaneous with the event. The real time of a satellite is that in which it simultaneously reports on its environment as it encounters it. The real time of a computer is that time during which it is accepting data and simultaneously performing operations on it.

rectification. A process by which a tilted oroblique photograph is projected onto a horizontal reference plane, the angular relation between the photography and the plane being determined by ground reconnaissance. For example, if the image is taken of an equally spaced rectangular grid pattern, then the rectified image will be an image of an equally spaced rectangular grid pattern.

reflectance. The ratio of the radiant energy reflected by a body to that incident upon it. In general, reflectance is a function of the incident angle of the energy, viewing angle of the sensor, spectral wavelength and bandwidth, and the nature of the object.

registration. The translation-rotation-rectification alignment process by which two images of like geometries and of the same set of objects are positioned coincident with respect to one another so that corresponding elements of the same ground area appear in the same place on the registered images. In this manner, the corresponding gray shades of the two images at any (x, y) coordinate or resolution cell will represent the sensor output for the same object over the full image frame being registered. In digital registration, the digital grids also must be superimposed at the same time the ground elements are superimposed.

remote sensing. In the broadest sense, the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study; for instance, the utilization at a distance (as from aircraft, spacecraft, or ship) of any instrument and its attendant recording and display devices for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy. The technique employs such devices as cameras, lasers, radio frequency receivers, radar systems, sonar seismographs, gravimeters, magnetometers, multispectal scanners, and scintillation counters.

resolution. The ability of an imaging system to distinguish closely spaced objects in the subject area. Can be expressed as the spacing, in line-pairs per unit distance, of the most closely spaced lines that can be distinguished. See instantaneous field of view, resolution cell, effective resolution element.

resolution cell. The smallest, most elementary areal constituent of the gray shades considered by an investigator in an image. A resolution cell is referenced by its spatial coordinates. The resolution cell or formations of resolution cells can sometimes constitute the basic unit for pattern recognition in image data.

return beam vidicon (RBV). As used on Landsats 1 and 2, a camera system which operated by shuttering three independent cameras simultaneously, each sensing a different spectral band in the range of 0.48 to 0.83 μm. The RBV system for Landsat 3 contained two identical cameras which operated in the spectral band from 0.50 to 0.75 μm. The cameras were aligned to view adjacent nominal 99 by 99 km square ground scenes with a 15-km sidelap yielding 183 by 99 km scene pairs. Two successive scene pairs will nominally overlap an MSS scene.

roll. The rotation of a spacecraft about its longitudinal axis (in the along-track direction) so as to cause a side-up or side-down attitude. The roll axis is referred to as the "y" axis. See attitude.

row. The latitudinal (nominal) center line of a Landsat scene. Row 60 corresponds to lat. 0° (the equator), row 1 is at lat. 80°47'N, and row 122 is at lat. 81°51'S. There are 248 rows, altogether, for Landsat 4, the same as for the earlier Landsats.

S

S band. A radio frequency band extending from approximately 2.0 to 4.0 gigahertz.

saturation. (1) In general, the point at which a further increase in input yields no further increase in output. (2) (optics) The presence of the maximum number of wavelengths over the spectral region contributing to a particular color. Contrast with hue (tint) and brightness (intensity), the other two components of a color.

scale. (1) The ratio of a distance on a photograph or map to its corresponding distance on the ground. The scale of a photograph varies from point to point because of tilt and relief, but is usually taken as f/H where f is the principal distance (focal length) of the camera and where H is the height of the camera above mean ground elevation. Scale may be expressed as a ratio, 1:24,000; a representative fraction, 1/24,000; or an equivalence, 1 in = 2,000 ft. (2) The full range of tones which a photographic paper is capable of reproducing; also termed dynamic range.

scanner. Any device which systematically breaks up an image into picture elements (or pixels) and records some attribute of each picture element. The sweep of a scanner's mirror, prism, antenna, or other element across the track (direction of flight) may be straight, circular, or another shape.

scan line. The ground trace of a narrow strip that is recorded by the instantaneous field of view of a detector in a scanner system.

scene center, nominal. The center of the cluster of scene centers of scenes imaged over the same area but at different times. Useful as an indexing tool in view of the fact that slight changes in the Landsat orbit, in addition to difficulties in timing or framing individual Landsat scenes, cause scenes acquired on different dates over the same area to coincide inexactly.

sensor. Any device which gathers energy and presents it in a form suitable for obtaining information about the environment. Passive sensors, such as thermal infrared and microwave, utilize electromagnetic radiation produced by the surface or object being sensed. Active sensors, such as radar, supply their own energy source.

sidelap. The extent of lateral overlap between images acquired over adjacent ground tracks. See overlap.

signal. The effect (for example, a pulse of electromagnetic energy) conveyed over a communications path or system. Aboard Landsat, signals from the scene being sensed are received by the sensors and converted to another form prior to transmission to the ground.

signal-to-noise ratio. The ratio of the level of the information-bearing signal power to the level of the noise power. Abbreviated as S/N ratio.

signature. Any characteristic or series of characteristics by which a material may be recognized. Used in the sense of spectral signature, as in photographic color reflectance. A category is said to have a signature only if the characteristic pattern is highly representative of all units of that category.

skew. The degree of asymmetry or deviation from symmetry of a distribution. Distribution skewed to the right has a positive skew. Distribution skewed to the left has a negative skew.

skew correction. A geometric correction made on Landsat imagery to offset the skewing effect of the Earth's rotation during scene acquisition. This is accomplished by shifting the data to the left on the average of one pixel every **n**th line as it is read into memory, n being dependent on the latitude of image acquisition.

slope. (topography) Inclination of the terrain from horizontal. It is expressed in convenient units, such as percent, feet per mile, etc.

software. Written instructions, or programs, used to control the operation of computers. Originally the term included program compilers but was extended to programs in general and even to machine-generated reports. Contrast with hardware.

Space Oblique Mercator (SOM). A variation on the basic Mercator map projection based on the dynamics of satellite motion. The movements of the Landsat platform, sensors, and the Earth, expressed as functions of time, are used to calculate which latitudes and longitudes on the Earth correspond to locations in the projection plane. Thus, a continuous projection of the entire area of coverage is obtained. The SOM projection will be standard for Landsat 4 data. It is conformal and nearly totally distortion-free. See Universal Transverse Mercator, Hotine Oblique Mercator.

Space Shuttle. Any of the series of manned, reusable space vehicles that are periodically placed into orbit by NASA to accomplish specific missions and are subsequently piloted back to Earth. Current Space Shuttle design incorporates a cargo bay and manipulative mechanical arm which potentially could be used to retrieve in-orbit satellites such as Landsat 4 and return them to the ground for repair and/or refurbishment. Also known as the Space Transportion System (STS).

spatial filter. An image transformation, usually a one-to-one operator used to lessen noise or enhance certain characteristics of the image. For any particular (x,y) coordinate on the transformed image, the spatial filter assigns a gray shade on the basis of the gray shades of a particular spatial pattern near the coordinates (x,y).

spectral band. An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

spectral interval. The width, expressed either in wavelength or frequency, of a particular portion of the electromagnetic spectrum. A given sensor, such as radiometer detector or camera film, may be designed to measure or be sensitive to energy from a particular spectral interval. Also termed spectral band, which see.

spectral response. The response of a material as a function of wavelength to incident electromagnetic energy, particularly in terms of the measurable energy reflected from and emitted by the material.

spectral signature. The quantitative measurement of the properties of an object at one or several wavelength intervals. Spectral signature analysis techniques use the variation in the spectral reflectance or emittance of objects as a method of identifying the objects.

spike. The sharp deviation from a line (such as in a histogram) that can be caused by erroneous or undesirable data.

standard deviation (SD). The square root of the variance. The value is expressed in the units of measure in which the observations were taken.

steradian. A unit of measure of solid angles. Formally, it is the angle subtended at the center of the sphere by a portion of the surface whose area is equal to the square of the radius of the sphere. There are 4π (pi) steradians in a sphere.

Sun angle. The angle of the Sun above the horizon. Both the quantity (lumes) and the spectral quality of light being reflected to a remote sensor are influenced by Sun angle. Also called Sun elevation and Sun elevation angle.

Sun synchronous. An Earth satellite orbit in which the orbital plane remains at a fixed angle with respect to the Sun, precessing through 360° during the period of a year. Landsat 4 is in near-polar orbit of this type and maintains an orbital altitude such that each pass over a given latitude on the Earth's surface occurs at the same mean Sun time. Compare with geosynchronous.

swath. A strip, belt, or long narrow extent of anything. Refers to the ground track, or trace, followed by Landsat 4, which images a continuous swath 189 km wide.

T

tape drive. A synonym for a magnetic tape deck, including a tape transport and read/write heads.

telemetry. The science of measuring a quantity or quantities, transmitting the measured value to a distant station, and there interpreting, indicating, or recording the quantities measured. A telemetry link, such as the Tracking and Data Relay Satellite (TDRS) system, is a system for transmitting data over long distances using radio techniques.

temporal. Pertaining to, concerned with, or limited by time.

thermal band. A general term for intermediate and long wavelength infrared-emitted radiation, as contrasted to short wavelength reflected (solar) infrared radiation. In practice, generally refers to infrared radiation emitted in the 3- to 5-μm and 8- to 14-μm atmospheric windows.

thermal infrared. The preferred term for the middle wavelength ranges of the infrared region extending roughly from 3μm at the end of the near infrared, to about 15 or 20μm where the far infrared commences. In practice the limits represent the envelope of energy emitted by the Earth behaving as a graybody with a surface temperature around 290 K (27° C). Seen from any appreciable distance, the radiance envelope has several brighter bands corresponding to windows in the atmospheric absorbtion bands. The thermal band most used in remote sensing extends from 8 to 14 μm.

Thematic Mapper (TM). One of the two Earth-sensing payloads carried aboard Landsat, the Multispectral Scanner being the other. It is a nonphotographic imaging system which utilizes an oscillating mirror and seven arrays of detectors which sense electromagnetic radiation in seven different bands. The recorded detector signals can be played back through a device which will convert signal strength to brightness on a photographic emulsion, thereby producing a photo-like image of the terrain that has been sensed. The Thematic Mapper is a derivative of the Multispectral Scanner generation of sensors, but it achieves much greater ground resolution, better spectral separation, improved geometric fidelity, and greater radiometric accuracy and resolution. See Multispectral Scanner and scanning radiometer.

threshold. The boundary in spectral space beyond which a data point, or pixel, has such a low probability of inclusion in a given class that it is excluded from that class.

time, Greenwich mean. Mean solar time of the meridan of Greenwich, England (longitude 0), used by most navigators and adopted as the prime basis of standard time throughout the world. Abbreviated GMT.

time, mean Sun. The mean Sun time at a given location on the Earth is determined by the distance in longitude from the Greenwich meridian. The mean Sun time at any location is determined by dividing the difference in longitude from Greenwich (in degrees, moving east) by 15 and adding the result to the current GMT. This will be the mean Sun time relative to Greenwich, expressed in hours.

tone. Each distinguishable variation of shade from black to white.

Tracking and Data Relay Satellite System (TDRSS). A system of two geosynchronous communications satellites launched for the purpose of receiving and relaying data, command, and telemetry signals to and from all NASA orbiting satellites, including the Space Shuttle. The TDRS system will reduce the number of ground stations needed and will simplify the handling of a growing volume of satellite telecommunications traffic.

transformation. (1) The process of projecting a photograph (mathematically, graphically, or photographically) from its plane onto another plane by translation, rotation, and/or scale change. (2) The process of defining such a plane through mathematical operations. See image transformation.

transmittance. The ratio of the energy per unit time per unit area (radiant power density) transmitted through an object to the energy per unit time per unit area incident on the object. In general, transmittance is a function of the incident angle of the energy, viewing angle of the sensor, spectral wavelength and bandwith, and the nature of the object.

transparency. Photographic positive image upon glass or film, intended to be viewed by transmitted light, in either black and white or color. A 35-mm slide is a transparency. Also called a diapositive.

truncate. To shorten by or as if by cutting off.

U

ultraviolet radiation. Electromagnetic radiation of shorter wavelength than visible radiation but longer than X-rays; roughly, radiation in the wavelength interval between 10 and 4,000 angstroms.

umbra. The complete or perfect shadow of an opaque body, as a planet, where the light from the source of illumination is completely cut off.

uncontrolled mosaic. A mosaic made without correction for distortion or displacement of any type.

uniform grid. Square, rectangular, or, more rarely, hexagonal lattice for recording geographical data. The simpler grids are usually not related to geodetic coordinate systems.

Universal Transverse Mercator (UTM). A widely used map projection employing a series of identical projections around the world in the intermediate latitudes, each covering 6° of longitude and oriented to a meridian. The UTM projection is characterized by its property of conformality, meaning that it perserves scale and angular relationships well, and by the ease with which it allows a useful rectangular grid to be superimposed on it. Extensively used in navigational applications, the UTM has been the most common projection used with Landsat data. It is sometimes called the Gauss-Kruger projection.

V

vector. In image processing, the coordinate in **n** space (where **n** is the number of features, bands, or channels), determined by the intensity value of each band.

video. A term pertaining to the bandwidth and spectrum position of the signal which results from television scanning and which is used to reproduce a picture.

video tape recording. A magnetic recording of the composite video signal.

vidicon. A storage-type, electronically-scanned, photoconductive, television camera tube, which often has a response to radiation beyond the limits of the visible region. Particularly useful in space applications, as no film is required. See return beam vidicon.

visible radiation. Electromagnetic radiation of the wavelength interval to which the human eye is sensitive; the spectral interval from approximately 0.4 to 0.7μm (4,000 to 7,000 angstroms).

W

wave. A disturbance which is propagated in a medium in such a manner that at any point in the medium the quantity serving as the measure of the disturbance is a function of time, while at any instant the displacement at a point is a function of the position of the point. Any physical quantity having the same relationship to some independent variable (usually time) that a propogated disturbance has, at a particular instant, with respect to space, may be called a wave.

An electromagnetic wave is one in which the disturbance is the change in the electric and magnetic field intensities from their equilibrium values in space.

wavelength. (symbol λ). Wavelength = 1/frequency. In general, the mean distance between maximums (or minimums) of roughly periodic pattern. Specifically, the shortest distance between particles moving in the same phase of oscillation in a wave disturbance. Optical and infrared wavelengths are measured in nanometers (10^{-9}m), micrometers (10^{-6}m) and angstroms (10^{-10}m).

word. (1) Ordered set of characters stored and transferred as a unit by the computer. (2) A set of bits comprising the smallest addressable unit of information in a programmable memory. See byte.

Worldwide Reference System (WRS). A global indexing system for Landsat data, first developed in Canada, which is based on nominal scene centers defined by path and row coordinates. See path, row.

X, Y, Z

X band. A radio frequency band extending from approximately 8.0 to 12.5 gigahertz.

yaw. The rotation of a spacecraft about its vertical axis so as to cause the spacecraft's longitudinal axis to deviate left or right or left from the direction of flight. The Yaw axis is referred to as the "Z" axis. See attitude.

zenith. The point in the celestial sphere that is exactly overhead. Contrast with nadir.

ABBREVIATIONS

— A —

A/D	analog-to-digital

— B —

B/W	black-and-white
BBR	band-to-band registration
BIP	band interleaved by pixel
bpi	bits per inch
BSQ	band sequential

— C —

CCT	computer-compatible tape
CCT-A	computer-compatible tape, archival
CCT-AM	computer-compatible tape, archival, Multispectral Scanner
CCT-P	computer-compatible tape, processed
CCT-PM	computer-compatible tape, processed, Multispectral Scanner
CCT-PT	computer-compatible tape, processed, Thematic Mapper
CCT-X	computer-compatible tape, X-format (band interleaved by pixel pairs)
CP	control point
CPU	central processor unit
CSF	Control and Simulation Facility
CWV	calibration wedge value

— D —

D	density
DEMUX	demultiplexer
DOI	Department of Interior
DOMSAT	Domestic Communications Satellite
DRRTS	Data Receive, Record, and Transmit System

— E —

ECEF	Earth-centered, Earth-fixed
EDC	EROS Data Center
EDIPS	EROS Digital Image Processing System
EMR	electromagnetic radiation
EOS	end-of-set
EOV	end-of-volume
EROS	Earth Resources Observation Systems
ERTS	Earth Resources Technology Satellite

— F —

FET	field-effect transistor
FM	frequency-modulated

— G —

GCD	geodetic control data
GCF	geodetic correction function
GCP	ground control point
GHIT	Goddard HDT Inventory Tape
GHIT-AM	Goddard HDT Inventory Tape, archival
GMT	Greenwich Mean Time
GPS	Global Positioning System
GSFC	Goddard Space Flight Center

— H —

HDT	high-density tape
HDT-A	high-density tape, archival
HDT-AM	high-density tape, archival, Multispectral Scanner
HDT-AR	high-density tape, archival, return beam vidicon
HDT-P	high-density tape, processed
HDT-PM	high-density tape, processed, Multispectral Scanner
HDT-PR	high-density tape, processed, return-beam vidicon

HOM	Hotine Oblique Mercator
HRS	horizontal resampling

— I —

ID	identification
IGF	Image Generation Facility
IFOV	instantaneous field of view
IR	infrared
IRIG	inter-range instrumentation group
IRIG-A	inter-range instrumentation group format A

— K —

Kbps	kilobits per second

— L —

LBR	laser-beam recorder
LLC	line-length code

— M —

MAG	MSS archive generation
Mbps	megabits per second
MIF	Main Image File
MIPS	MSS Image Processing System
MMF	Mission Management Facility
MNFS	minor-frame synchronizing digital word
MSS	Multispectral Scanner
MTF	modulation transfer function
MUX	multiplexer

— N —

NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NCIC	National Cartographic Information Center
NDPF	NASA Data Processing Facility
NEΔT	noise equivalent temperature difference
NOAA	National Oceanic and Atmospheric Administration
NOCC	Network Operations Control Center
NWS	National Weather Service

— O —

OBC	onboard computer
OCG	orbit computation group

— P —

PCD	payload correction data
PCM	pulse-code modulated
PCS	payload correction system
PE	product evaluation
PF	protoflight
PM	phase modulated
PN	pseudonoise
PR	process request
PS	Polar Stereographic

— Q —

QC	Quality Control

— R —

RBV	return-beam vidicon
RF	radio frequency
RLUT	radiometric look-up table

— S —

S/C	spacecraft
SCD	systematic correction data
SCF	systematic correction function
SD	standard deviation
SNR	signal-to-noise ratio
SOM	Space Oblique Mercator
SWIR	Shortwave Infrared
SWR	square wave response

— T —

TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TGS	Transportable Ground Station
TIPS	Thematic Mapper Image Processing System
TM	Thematic Mapper

— U —

ULE	ultra-low expansion
UQPSK	unbalanced quadrature phase-shift keyed
UTM	Universal Transverse Mercator

— V —

VRS	vertical resampling

— W —

WRS	Worldwide Reference System

APPENDIX A

LANDSAT MULTISPECTRAL SCANNER

COMPUTER-COMPATIBLE TAPE FORMAT

VERSION 1.0

This draft document is periodically updated. Any new version will be announced in NOAA's "Landsat Data Users Notes" available by subscription from NOAA Landsat Customer Services, Mundt Federal Building, Sioux Falls, SD 57198.

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ABBREVIATIONS

ANSI	American National Standards Institute
ASCII	American standard code for information exchange
BIL	band interleaved by line
BOT	beginning of tape
BPI	bits per inch
BSQ	band sequential
CCT	computer-compatible tape
CCT-AM	computer-compatible tape, archival MSS
CCT-PM	computer-compatible tape, processed MSS
CWV	calibration wedge value
DQI	digital quality indicator
EBCDIC	extended binary coded decimal interchange code
EDC	EROS Data Center
EOF	end of file
EOS	end of set
EOT	end of tape
EOV	end of volume
EROS	Earth Resources Observation System
FL	floating-point format, double precision
FLS	floating-point format, single precision
FP	fixed-point format
FPG	fixed-point grid value format
GMT	Greenwich mean time
GPS	global positioning system
HOM	Hotine Oblique Mercator
HRS	horizontal resampling

ID	identification number
IRG	inter-record gap
LGSOWG	Landsat Ground Station Operations Working Group
MSS	multispectral scanner
NASA	National Aeronautics and Space Administration
PS	Polar Stereographic
RCA	relative calibration accuracy
RMS	root mean square
SCD	systematic correction data
SOM	Space Oblique Mercator
UTM	Universal Transverse Mercator
VRS	vertical resampling
WRS	Worldwide Reference System

ILLUSTRATIONS

CONTENTS

TABLES

1.0 INTRODUCTION

After digital processing systems for Landsat 3 became operational, discussion among personnel from several of the Landsat processing centers resulted in an agreement that a universal Computer Compatible Tape (CCT) format should be developed. This general agreement caused the formation of a Tape Standards Working Group as a subgroup of the international Landsat Ground Station Operations Working Group (LGSOWG). The format design began in 1978 with the objective of implementing the new format prior to or with the launch of Landsat 4. This document defines the EROS Data Center's Landsat CCT Version 1.0 product, conforming to the concepts of the "Standard" format as much as is possible using existing EDC systems.

Unlike previous Landsat CCT formats, the new CCT's will include a comprehensive field location and data description information "superstructure". This superstructure consists of:

- a volume directory file which generally describes the data configuration and provides pointers to each data file.
- a file descriptor record for each data file which describes the data structure within the file and provides pointers to certain fields within the file.

Once a data user becomes familiar with the superstructure, it becomes possible to read any CCT whose format conforms to the superstructure concept and identify the data type and source, locate and read desired data and support information, and, in most cases, use the data without need of further documentation or software modification.

The impact to the established Landsat CCT format of adding superstructure requirements is minor. In figure 1, the additional records required for a one-tape data set of one band of multispectral scanner (MSS) imagery are illustrated. The entire superstructure is composed of four records. Three records, the volume descriptor record, the text record, and the file pointer record, reside in a Volume Directory File. The fourth record is the file descriptor record which is the first record of each data file.

The four superstructure records are similar to one another in content as well as in format. The purpose of these records is to identify, describe, and locate data in the data files. Thus, superstructure records primarily supply information about the data on the CCT rather than carrying data themselves.

The data records within the data files will be very similar in format and content to those of previous Landsat CCT's with changes, for example, in record lengths, in data encoding, and in the addition of new special-purpose fields in the header and ancillary data records. Overall, however, the general type and format of the data will remain unchanged. Two types of MSS image data will continue to be offered:

- o fully processed MSS data with both geometric and radiometric corrections applied (CCT-PM)

- o partially processed MSS data with only radiometric corrections applied (CCT-AM).

These will be offered in either a Band-Interleaved-by-Line (BIL) or a Band-Sequential (BSQ) image data format.

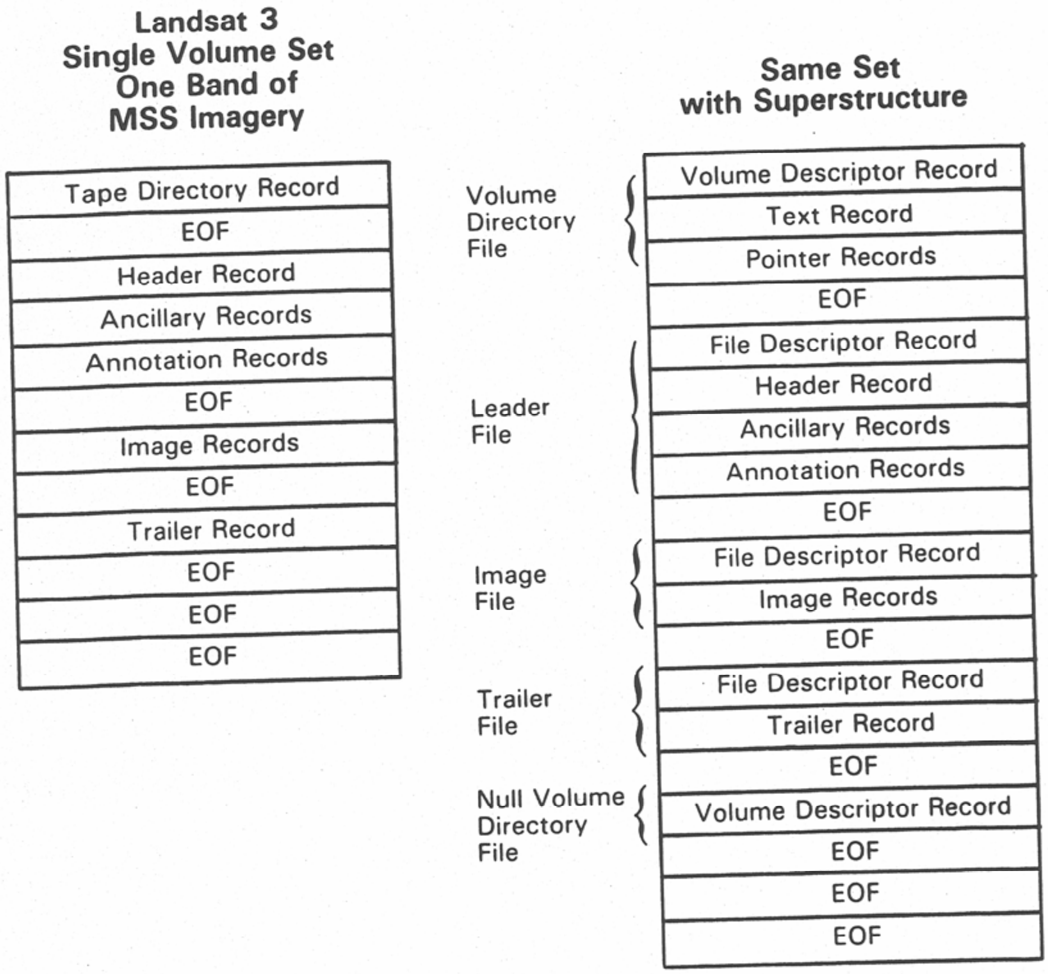

Figure 1. --Comparison of Tape Layout, Before and After Adding Superstructure Records

2.0 COMMON CONVENTIONS

2.1 Byte

A byte is eight bits in length and may contain any type of data. The most significant bit occurs first and is the left-most bit of the byte.

2.2 Image Data Representation

Image data will be right-justified in a byte with the most significant bit zero-filled. A data range from 0 to 127 is allowed with zero as low radiance.

2.3 Non-Image Data Representation

Non-image data fields are byte multiple in length and represented in one of several data types. "Alphanumeric" data fields are ASCII coded and left-justified within the field. "Numeric" data fields are ASCII coded and right-justified within the field. Unless otherwise specified, all fields referred to simply as "binary", are uncoded, unsigned, integer binary numbers. Many fields of the header and ancillary data records are represented in one of four "special" fixed, and floating-point formats--fixed-point binary (FP), double precision floating-point binary (FL), single precision floating-point binary (FLS), or fixed-point binary grid value (FPG)--which are described in more detail in section 4.0.

2.4 Record, Logical and Physical

A logical record is a collection of related data items and is treated as a unit of information. A physical record is a physical collection of data written to or read from a tape as a unit in a single operation. On Landsat CCT's, a physical record is equivalent to a logical record. Volume descriptor, file pointer, file descriptor, header, ancillary, annotation, image, trailer, and text data are the different types of records. Records are structured to contain a record number, a record type code, the record length in bytes, data, and optional zero fill as shown in figure 2. Records are separated by inter-record gaps (IRG), and records are not split between physical tape volumes. These attributes are elaborated upon below.

2.4.1 Record Number

This is a four-byte binary number which indicates the sequence of the record within the file. The first record of the file is numbered one, and the record number increments by one per record.

2.4.2 Record Type Codes

Bytes five through eight of every record contain four one-byte codes which classify the data content of the record. The 12 basic record type codes which apply to Landsat Version 1.0 CCT's are listed in table 1.

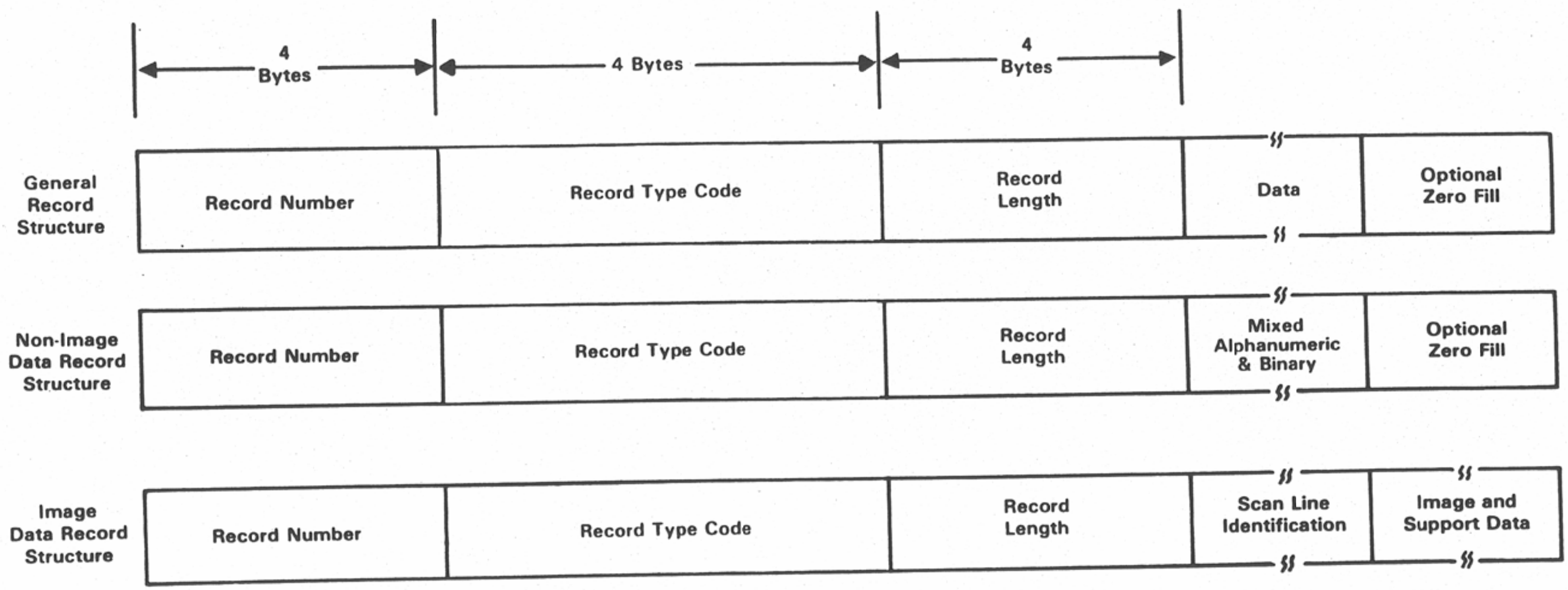

Figure 2.--LANDSAT-D CCT RECORD STRUCTURE

Table 1.--Record Type Codes

Record Type	Byte 5	Byte 6	Byte 7	Byte 8
Volume Descriptor	$300)_8$*	$300)_8$	$022)_8$	$022)_8$
File Pointer	$333)_8$	$300)_8$	$022)_8$	$022)_8$
File Descriptor	$077)_8$	$300)_8$	$022)_8$	$022)_8$
Null Volume Descriptor	$300)_8$	$300)_8$	$077)_8$	$022)_8$
Text	$022)_8$	$077)_8$	$022)_8$	$022)_8$
Header	$022)_8$	$022)_8$	$022)_8$	$022)_8$
Annotation	$022)_8$	$333)_8$	$022)_8$	$022)_8$
Ancillary, General	$022)_8$	$044)_8$	$022)_8$	$022)_8$
Ancillary, Universal Transverse Mercator or Polar Stereographic Map Projection Data	$044)_8$	$044)_8$	$333)_8$	$022)_8$
Ancillary, Space Oblique Mercator or Hotine Oblique Mercator Map Projection Data	$044)_8$	$044)_8$	$355)_8$	$022)_8$
Image	$355)_8$	$355)_8$	$022)_8$	$022)_8$
Trailer	$022)_8$	$366)_8$	$022)_8$	$022)_8$

*Denotes octal radix, $10)_8$ is actually a decimal 8.

2.4.3 Record Length

The record length in bytes for each record is recorded in bytes nine through 12. This is a binary, right-justified number with the left-most bit being the most significant. Volume directory and null volume directory records are 360 bytes in length. All other records on the CCT are 3600 bytes in length.

2.5 File, Logical and Physical

A file is a collection of physical records preceded and followed by end-of-file (EOF) indicators. All files, except for the volume directory, have a file descriptor record as the first record. This is followed by the data records of the file. All records of a file are of constant record length. On MSS CCT's there are four types of files:

- o Volume Directory
- o Leader (header, ancillary, and annotation)
- o Image
- o Trailer

A logical file is equivalent to a physical file except in the case of image files. An image file (and no other file) may be split between reels of CCTs on record boundaries. Thus, when image files are split between CCT reels, the logical image file is not equivalent to the physical image file. It should be pointed out that one image file equals <u>either</u> one image (one band) of data when the format is BSQ, or all bands in the BIL format. Recording methods for files spanning physical volumes are discussed in section 3.0.

2.6 File Classes and Codes

The volume directory file is described in section 4.2. The file pointer records of the volume directory file contain the names and codes of the data file classes which follow. There are three data file classes, named and coded as follows:

Class Name	Class Code	File Content
Leader File	LEAD	Header, annotation and ancillary records
Imagery File	IMGY	Image data record
Trailer File	TRAI	Trailer records

Each file class has associated with it a particular file format and file descriptor record variable segment. These are defined in section 4.

2.7 Logical Volume

A logical volume is a logical collection of one or more files recorded consecutively. A logical volume contains one scene of one or more images (bands).

All logical volumes have a volume directory as the first file. This is followed by leader, image and trailer data files and is concluded with a null volume directory. When a logical volume is split between physical volumes, the volume directory is repeated at the start of the continuation tape. (See section 3.0 for discussion on how logical volumes are split). All logical volumes conclude with a null volume directory (one per logical volume in all cases).

2.8 Physical Volume

A physical volume is a dismountable physical reel of magnetic medium. A physical volume may contain one, more than one, or part of one file. Physical volumes always start with a volume directory file. The last record of a physical volume is followed by an end-of-volume (EOV) indicator.

2.9 CCT Volume Set

A CCT volume set consists of one or more physical volumes and contains one logical volume.

2.10 Tape Gaps and Marks

American Nationals Standards Institute (ANSI) specifications define all tape gaps, marks, and indicators used on CCT's. A brief description of some of the housekeeping conventions used on CCT's follows. However, final and complete definitions are contained in the appropriate ANSI specification referenced in Section 5.0.

2.10.1 Beginning-of-Tape Marker

A small piece of reflective tape is located on the non-recording side of a CCT several feet from the beginning of each reel. This beginning-of-tape (BOT) indicates the beginning of the tape for reading and writing.

2.10.2 Initial Gap

An initial gap of 8 centimeters (3 inches) minimum, 7.62 meters (25 feet) maximum, separates the first record on a CCT from the BOT.

2.10.3 Interrecord Gap

An interrecord gap (IRG) of nominally 1.5 centimeters (0.6 inches) separates multiple records in a file.

2.10.4 End-of-File Mark

The end-of-file (EOF) mark is a specially coded block of data which separates files on a CCT. The EOF is the tape mark described in the referenced ANSI standard.

2.10.5 End-of-Volume Mark

The end-of-volume (EOV) indicator consists of two consecutive EOF's and marks the end of recorded data on the physical volume.

2.10.6 End-of-Tape Marker

A small piece of reflective tape is located on the non-recording side of a CCT several feet from the end of each reel. This end-of-tape (EOT) marker indicates the end of the permissible recording area.

2.10.7 End-of-Set Mark

The end-of-set (EOS) mark consists of three consecutive EOF's and occurs on the last physical volume of a volume set.

3.0 TAPE LAYOUT

A standard Landsat MSS Version 1.0 CCT tape set contains image data for one MSS scene (one logical volume). If the tape set is one physical volume (that is, the data for one scene are contained on one tape reel) the tape format is as shown in figure 3. The physical and logical volume begin with a volume directory file followed by one or more sets of leader, image, and trailer files. The image data format of the CCT shown in figure 3 is BSQ, with as many sets of leader, image, and trailer files as there are images (bands) in the scene. If the CCT image data format is BIL, there is only one such file set. Records are separated by IRG's. Files are separated by EOF's. The logical volume is followed by an EOS.

When a logical volume requires more than one physical volume, the transition between tapes is accomplished in one of two ways: (1) the split between volumes occurs on file boundaries, or (2) the split occurs on record boundaries within an image data file. Figure 4 illustrates these two cases. When the break is between files, the last file before the break is followed by two EOF's (an EOV), and the next tape starts with another volume directory. This subsequent volume directory is the same as the one which initiated the logical volume but with appropriate fields updated to indicate the change of physical volume. After an EOF, the next data file then continues.

2.4.3 Record Length

The record length in bytes for each record is recorded in bytes nine through 12. This is a binary, right-justified number with the left-most bit being the most significant. Volume directory and null volume directory records are 360 bytes in length. All other records on the CCT are 3600 bytes in length.

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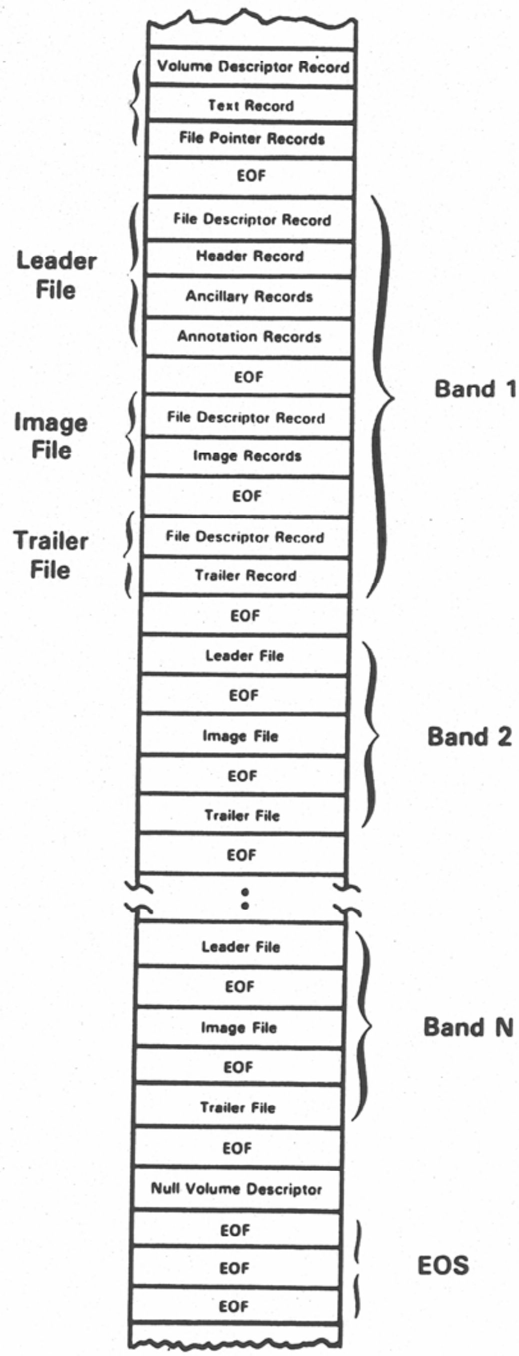


Figure 3. --Tape Layout of a CCT of N Bands of Band Sequential Data

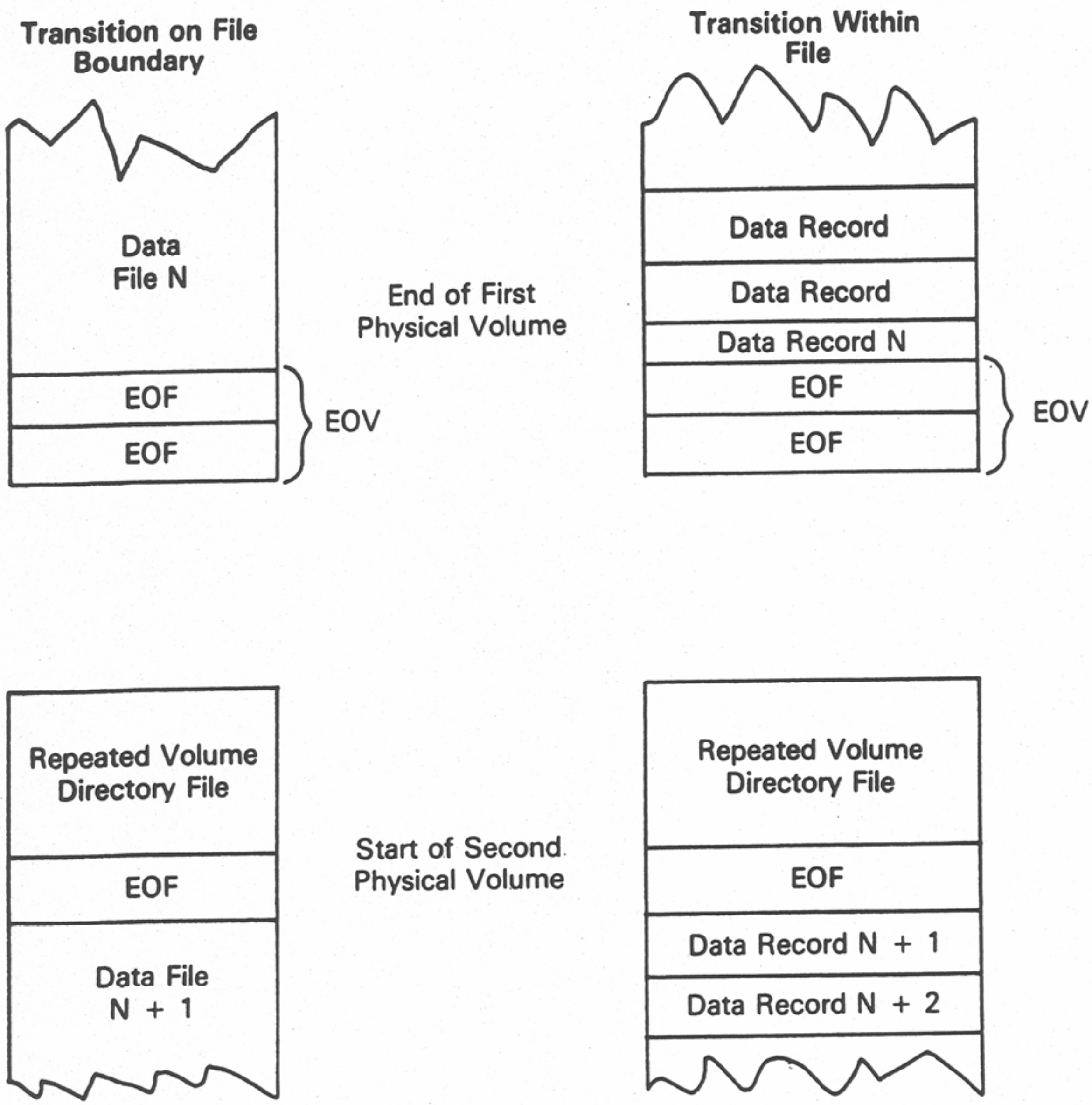


Figure 4.--Illustration of the Two Types of Transition Between Physical Volumes of a Logical Volume

When the break falls within an image file, the last record before the break is followed by an EOV. The next tape starts with the repeated, updated volume directory. This is followed by an EOF and the remaining image records of the previous file.

Table 2 is provided here as a reference guide on the distribution of MSS image data on CCTs. The MSS data are categorized by the type of interleaving, by whether or not geometric corrections are applied and by the number of bands of data. The distribution of these data types is then presented for CCT's with densities of 800, 1600 and 6250 bits-per-inch (BPI).

Table 2. --CCT Physical Volume Distribution of MSS Data

Data Type and Tape Number		Image Distribution by Density: 800 BPI	1600 BPI	6250 BPI
MSS BSQ				
Geometrically Uncorrected				
(1 band)	Tape 1	entire image	entire image	entire image
(2 bands)	Tape 1	band 1	all images	all images
	Tape 2	band 2		
(3 bands)	Tape 1	bands 1 and 2	all images	all images
	Tape 2	band 3		
(4 bands)	Tape 1	bands 1 and 2	all images	all images
	Tape 2	Bands 3 and 4		
(5 bands)	Tape 1	bands 1 and 2	bands 1, 2 and 3	all images
	Tape 2	bands 3 and 4	bands 4 and 5	
	Tape 3	band 5		
Geometrically Corrected				
(1 band)	Tape 1	entire image	entire image	entire image
(2 bands)	Tape 1	band 1 and 1491 lines of band 2	all images	all images
	Tape 2	1492 lines of band 2		
(3 bands)	Tape 1	band 1 and 1491 lines of band 2	all images	all images
	Tape 2	1492 lines of band 2 and band 3		
(4 bands)	Tape 1	band 1 and 1491 lines of band 2	bands 1 and 2	all images
	Tape 2	1492 lines of band 2 and band 3	bands 3 and 4	
	Tape 3	band 4		
(5 bands)	Tape 1	band 1 and 1987 lines of band 2	bands 1, 2 and 3	all images
	Tape 2	996 of 2, band 3 and 966 of 4	bands 4 and 5	
	Tape 3	1987 lines of band 4 and band 5		
MSS BIL				
Geometrically Uncorrected				
(4 bands)	Tape 1	4800 lines	all lines	all lines
	Tape 2	4800 lines		
(5 bands)	Tape 1	4000 lines	6000 lines	all lines
	Tape 2	4000 lines	6000 lines	
	Tape 3	4000 lines		
Geometrically Corrected				
(4 bands)	Tape 1	3976 lines	5964 lines	all lines
	Tape 2	3976 lines	5968 lines	
	Tape 3	3980 lines		
(5 bands)	Tape 1	4970 lines	7455 lines	all lines
	Tape 2	4970 lines	7460 lines	
	Tape 3	4975 lines		

4.0 FILE FORMATS

A standard CCT with MSS data contains two general categories of records: superstructure records and data records. Combined, these categories provide nine types of records: volume descriptor, text, file pointer, file descriptor, header, ancillary, annotation, image, and trailer. These records are grouped into four file types: volume directory, leader, image and trailer. The grouping of these records into these file types is illustrated in table 3. Figure 5 shows the overall structure of Landsat CCT's in both BSQ and BIL data format. The remainder of this section is concerned with defining the format for each of these record and file types.

4.1 Record Rules and Content

4.1.1 Superstructure Records

The following rules apply to the record format and content of the volume descriptor, file pointer, file descriptor, and text records.

1. The first 12 bytes (3 fields) of all records contain only binary numbers and predefined bit-pattern codes.

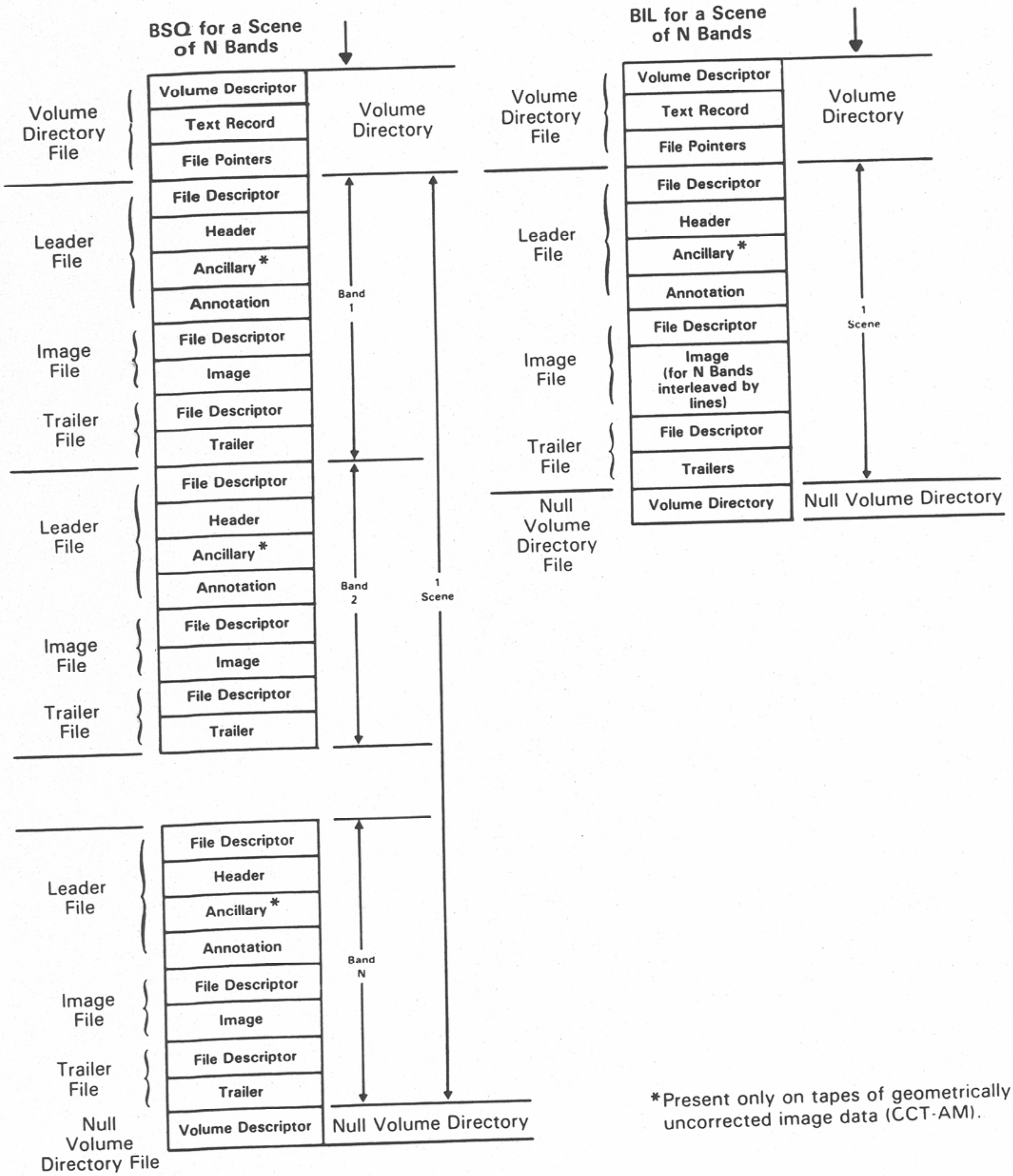
2. The fields assigned to the first 16 bytes are similar for all four types of records.

3. From byte 13 to the end of the record, fields are numeric or alphanumeric and are coded in ASCII.

Table 3. --Record Groupings by File Type

FILE TYPE	RECORD TYPES CONTAINED
Volume Directory File	• Volume Descriptor Record • Text Record • File Pointer Records
Leader File	• File Descriptor Record • Header Record • Ancillary Records * • Annotation Record(s)
Image File	• File Descriptor Record • Image Records
Trailer File	• File Descriptor Record • Trailer Record(s)
Null Volume Directory File	• Volume Descriptor Record

* Present only on tapes of geometrically uncorrected imagery (CCT-AM).



*Present only on tapes of geometrically uncorrected image data (CCT-AM).

Figure 5. --Data Format of Landsat MSS

4. Numeric data are right-justified and alphanumeric data are left-justified.

5. In fields containing data and blanks, the blanks are represented by the ASCII blank character (b̸).

6. Data fields are assigned so as to follow 4-byte boundary alignments.

7. Records in the volume directory file and null directory file are 360 bytes in length. Records in the other files--leader, image, and trailer--are 3600 bytes in length.

The 12 bytes referred to in rule 1 are illustrated in figure 6. They contain record number, record type codes, and record length. These fields are as defined in section 2.4.

The similarity of the next four bytes among superstructure records (rule 2) can be seen in figure 6. The first two of these bytes (record bytes 13 and 14) are ASCII/EBCDIC flags. The next two (bytes 15 and 16) are blank. These fields will be described on a per-record basis in the sections which follow.

The three non-text superstructure records are similar in content as well as in format. The purpose of these records is to identify, describe, and locate data in the data files. The general blocking of this type of information within superstructure records is also shown in figure 6. Superstructure records primarily supply information about the data on the CCT, rather than carrying data themselves.

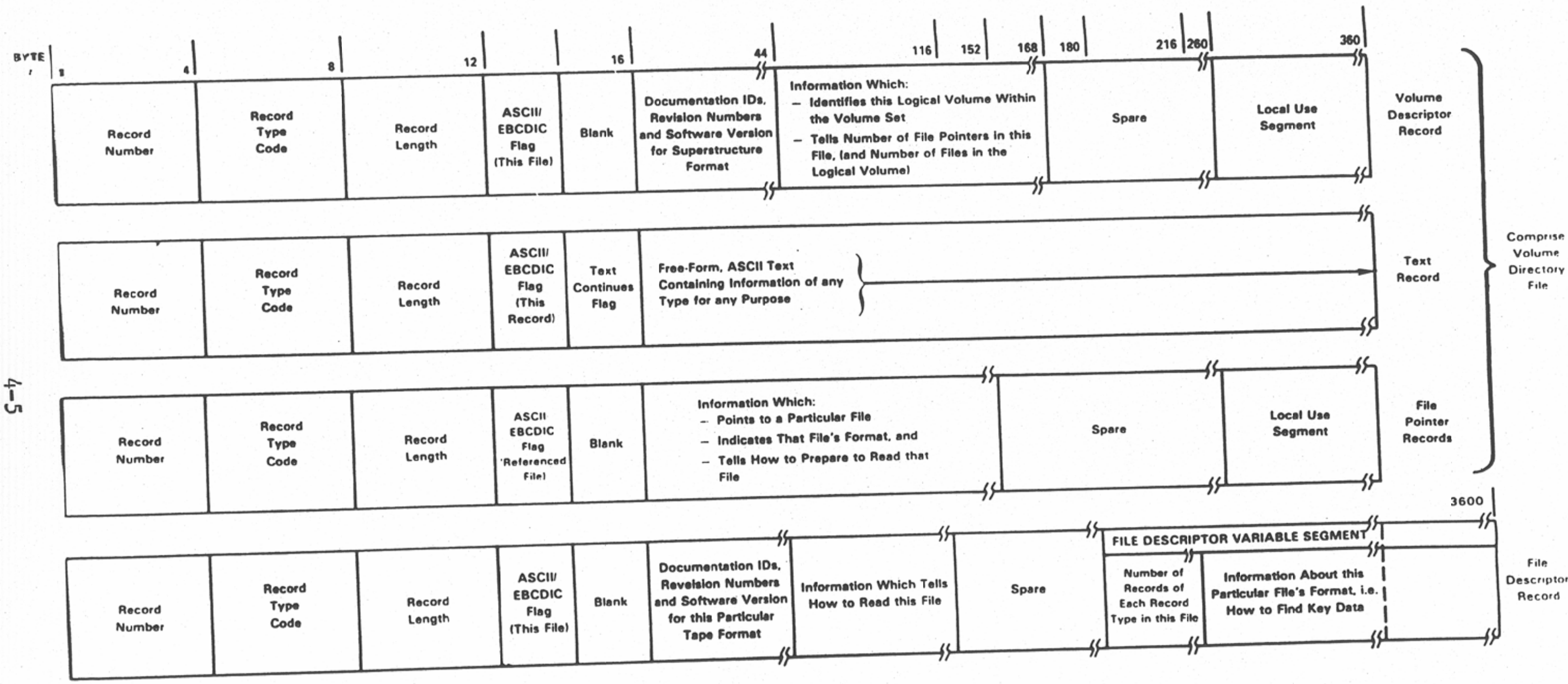


Figure 6.--Layout of Superstructure Records

4.1.2 Data Records

The following rules apply to the record format and content of the header, ancillary, annotation, image, and trailer records.

1. The first 12 bytes (3 fields) of all data records contain only binary numbers and predefined bit-pattern codes of record introduction information.

2. The remainder of all data records contain data, blank fill,or zero fill.

3. All data records are 3600 bytes in length.

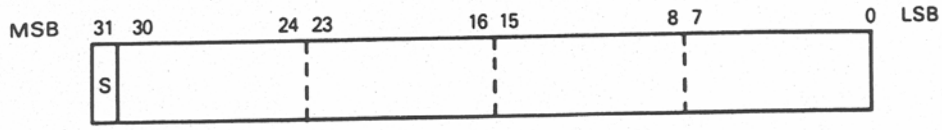
4. Numeric data are right-justified and alphanumeric data are left-justified.

5. In alphanumeric fields containing data and blanks, the blanks are represented by the ASCII blank character (b̸).

6. Binary fields representing values containing fractional components are given in one of the four formats shown in figure 7, unless a unique data representation format is designated for a specific field.

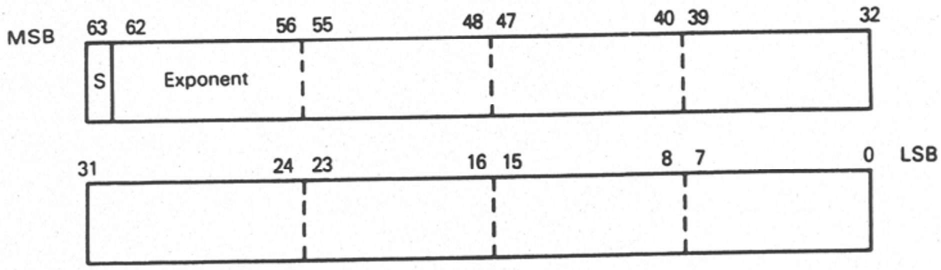
The 12 bytes referred to in rule 1 contain the record number, record type code, and record length. They are as defined in section 2.4.

Fixed Point Binary Format (FP),
a number is represented in four bytes, as follows:



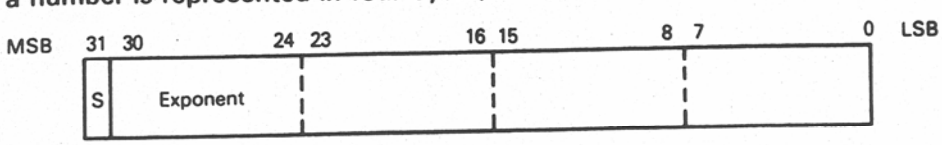
Bit 31 S(Sign) = 0(+), 1(−)
Bits 30:0 Magnitude

Floating Point Binary Format (FL),
a number is represented in eight bytes, as follows:



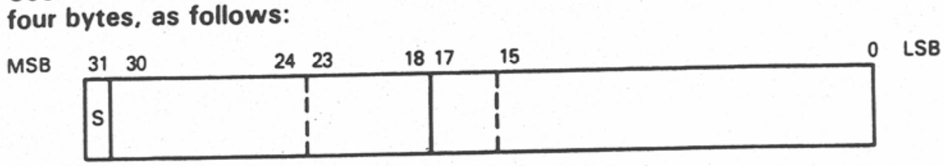
Bit 63 S(Sign) = 0(+), 1(−)
Bits 62:56 Exponent, Range of −64 Through +63. Treated as Excess 64.
Bits 55:0 Fraction Magnitude, 14 Hexidecimal Digits. The Value is found by Multiplying the Factional Part by the Power of 16.

Single Precision Floating Point Binary Format (FLS),
a number is represented in four bytes, as follows:



Bit 31 S(Sign) = 0(+), 1(−)
Bits 30:24 Exponent, Range of −64 Through +63. Treated as Excess 64
Bits 30:24 Fraction Magnitude, 6 Hexidecimal Digits. The Value is Found by Multiplying the Fractional Part by the Power of 16.

Fixed Point Grid Format (FPG) for Resampling Grid Coordinates, and Fill Counts; a number is represented in four bytes, as follows:



Bit 31 → (Sign) = 0(+), 1(−)
Bits 30:18 → Integer Magnitude (two's compliment)
Bits 17:0 → Fraction Magnitude (two's compliment)
Fixed Binary Point Between Bits 18 and 17.

Figure 7. --Data Representation Formats for Fractional Binary Numbers

4.2 Volume Directory File

The volume directory file is the first file of every logical volume. It is composed of a volume descriptor record, a text record, and a series of file pointer records. Every physical volume (tape) also starts with a volume directory file since the tape is either the start of a logical volume or else a logical volume is continued on the tape, in which case the updated volume directory is recorded at the start of the physical volume. The volume descriptor record identifies the logical volume and the number of files the logical volume contains. A text record follows the volume descriptor record and identifies the type of data contained in the logical volume. There is a file pointer record for each data file of the logical volume, indicating each file's class, format, and attributes.

4.2.1 The Volume Descriptor Record

The volume descriptor is the first record of the volume directory file. This record identifies the logical volume and the number of files the logical volume contains. It is composed of five segments. The first segment (bytes 1-16) contains record identification information. The second segment (bytes 17-44) gives format documentation and software identification for the format in which the superstructure is recorded on tape. The third segment (bytes 45-168) provides basic information about the logical volume and gives the number of pointer records in the volume directory file. The fourth segment (bytes 169-260) is spare and is reserved for expansion of control information in future volume descriptor record format revisions. The fifth segment (bytes 261-360), the local use segment, provides space for whatever notation or information the tape user wants to place in it. A breakdown of the individual data items of the volume descriptor record is given in table 4.

Table 4.--Volume Descriptor Record Format

Byte	Type*	Description
1-4	B	Record number = $1)_{10}$.
5-8	B	Record type code: byte 5 = $300)_8$ byte 6 = $300)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Length of this record = $360)_{10}$.
13-14	A	ASCII/EBCDIC Flag for this file = "Ab̸" for ASCII. (EBCDIC not available.)
15-16	A	Blank.
17-28	A	Superstructure control document number: 12 bytes, always CCB-CCT-0002.
29-30	A	Superstructure control document revision number: 2 bytes indicating the revision letter of the document identified in bytes 17-28, coded "b̸C" initially.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 4.--Volume Descriptor Record Format--Continued

Byte	Type*	Description
31-32	A	Superstructure record format revision: 2 bytes, coded "ƀA" unless this record format is modified.
33-44	A	Software release number for this logical volume.
45-60***	A	ID for physical volume containing this volume descriptor: 16 character tape ID of the form: LNSTTYYDDDXXNVƀƀ where L = Mission designator coded 'L' for Landsat N = Mission number, '2', '3' or '4' S = Sensor type, coded 'M' for MSS TT = Tape type, coded 'CP' (data with geometric correction) or 'CA' (data without geometric correction).

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Fields to be updated when a volume directory is repeated on a subsequent physical volume

***Blank filled in a null volume descriptor record.

Table 4.--Volume Descriptor Record Format--Continued

Byte	Type*	Description
		YY = Last two digits of year in date of generation DDD= Julian day of generation XX = Sequence number within day for each tape type N = Physical volume number V = Number of volumes in set.
61-76**	A	Logical volume ID, 16 characters of the form: ADDDDHHMMSbbbbbb where A = Landsat mission number DDDD = Day number, relative to launch, at time of observation HH = Hour at time of observation MM = Minutes at time of observation S = Tens of seconds

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Blank filled in a null volume descriptor record.

Table 4.--Volume Descriptor Record Format--Continued

Byte	Type*	Description
77-92	A	Volume set ID: 16 character coded "LANDSATNbMSSbXXX" where N is the mission number and XXX is either BIL or BSQ.
93-94	N	Number of physical volumes in the set: 2 bytes indicating 1, 2 or 3 tapes per set ("b1", or "b2" or "b3").
95-96	N	Physical volume number, start of logical volume: always "b1".
97-98	N	Physical volume number, end of logical volume: same as bytes 93-94.
99-100**	N	Physical volume number containing this volume descriptor: sequence number of this tape within tape set = "b1", "b2" or "b3".

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Fields to be updated when a volume directory is repeated on a subsequent physical volume.

Table 4.--Volume Descriptor Record Format--Continued

Byte	Type*	Description
101-104**	N	First referenced file number in this physical volume: this 4 byte field gives the file number of the first data file which follows this volume directory file. If a file spans two or more physical volumes each portion of the file is referenced by the same number (because each portion is using the same file pointer record). Volume directory files are not included in the file sequence number count.
105-108	N	Logical volume number within volume set: coded "bbb1" except for null volume descriptor which is coded "bbb2".

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Fields to be updated when a volume directory is repeated on a subsequent physical volume.

Table 4.--Volume Descriptor Record Format--Continued

Byte	Type*	Description
109-112***	N	Logical volume number within physical volume: same as bytes 105-108.
113-120**	A	Logical volume creation date: 8 bytes of form YYYYMMDD.
121-128**	A	Logical volume creation time: 8 bytes of form HHMMSSXX, where XX indicates hundredths of seconds.
129-140**	A	Logical volume generating country: "USAb̸b̸b̸b̸b̸b̸b̸b̸b̸".
141-148**	A	Logical volume generating agency: coded "USGSb̸b̸b̸b̸".
149-160**	A	Logical volume generating facility: coded "EDC̸b̸b̸b̸b̸b̸b̸b̸b̸b".

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Blank filled in a null volume descriptor record.

***Fields to be updated when a volume directory is repeated on a subsequent physical volume.

Table 4.--Volume Descriptor Record Format--Continued

Byte	Type*	Description
161-164**	N	Number of pointer records in volume directory: equals number of data files in CCT tape set: coded $3)_{10}$ for BIL; up to three times number of bands for BSQ.
165-168**	N	Number of records in volume directory: the number of pointer records + 2.
169-260	A	Volume descriptor spare segment (reserved) (Blank filled).
261-360	A	Local use segment (Blank filled).

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Blank filled in a null volume descriptor record.

4.2.2 Text Record

A text record occurs as the second record of the volume directory file. After the first 16 bytes of basic superstructure record identification information, the remainder of the record is free-form ASCII text. It may be used to carry any type of information for any purpose. Standard Landsat CCT products will carry information about the contents of the tape such as sensor, scene ID, date, and type of processing. These are intended for the convenience of the user. The format and content of the text record are given in table 5.

Table 5.--Text Record Format

Bytes	Type*	Description
1-4	B	Record number = the sequence number of this record within this file = $2)_{10}$.
5-8	B	Record type code: byte 5 = $022)_8$ byte 6 = $077)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Record length = $360)_{10}$.
13-14	A	ASCII/EBCDIC flag for this record, indicating whether the alphanumeric information of this record is coded ASCII or EBCDIC. Coded "AƀE" for ASCII (EBCDIC not available).
15-16	A	Blank filled.
17-360	A	Field to be used for free-form text (alphanumeric information of any kind desired by the tape producer).

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

4.2.3 File Pointer Record

File pointer records reside in the volume directory file. There is one file pointer record for each data file of the logical volume; it identifies the file by class, indicates that file's format, and provides file attribute information such as record lengths and data type. These file pointer records are recorded in the same sequence as the files to which they point.

After the first 16 byte segment of record identification information, there are three data segments. The second segment (bytes 17-152) supplies specific file attribute information such as file class, format and data type. The third segment (bytes 153-260) is spare and is reserved for expansion of the file pointer information segment in future format revisions. The fourth segment (bytes 261-360) is provided for local use. The format of a file pointer record is given in table 6.

Table 6.--File Pointer Record Format

Bytes	Type*	Description
1-4	B	Record number: sequence number of this record in this file; first pointer record = $3)_{10}$.
5-8	B	Record type code: byte 5 = $333)_8$ byte 6 = $300)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Length of this record = $360)_{10}$.
13-14	A	ASCII/EBCDIC flag for the referenced file: coded "Ab̸" for ASCII (EBCDIC not available).
15-16	A	Blank.
17-20	N	Referenced file number: sequence number of data file within logical volume; 1st data file is numbered $1)_{10}$.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 6.--File Pointer Record Format--Continued

Bytes	Type*	Description
21-36	A	Referenced file identification: 16 characters indicating nature of the data of the form: LLNbSSSTFFFFXXXB, where LL = Satellite coded 'LS' N = Mission number, coded '2', '3', or '4' SSS = Sensor type, coded 'MSS' T = Data type, coded 'A' for geometrically uncorrected data or 'P' for geometrically corrected data FFFF = File type, coded: "LEAD' for leader file 'IMGY' for imagery file 'TRAI' for trailer file XXX = Image data format, coded 'BIL' or 'BSQ'.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 6.--File Pointer Record Format--Continued

Bytes	Type*	Description
		B = Band number associated with file, coded 'b̸' for BIL or '1','2','3' or '4' for Landsat-4 BSQ or '4', '5', '6', '7', or '8' for Landsat-2/3 BSQ.
37-64	A	Referenced file name: 28 bytes coded "LEADER FILE", "IMAGE FILE", or "TRAILER FILE" with trailing blanks.
65-68	A	Referenced file class code: coded 'IMGY' for files containing image data 'LEAD' or 'TRAI' for all other files.
69-96	A	Referenced file data type: 28 bytes coded 'BINARY ONLY' (with trailing blanks) for files of image data, and 'MIXED BINARY AND ASCII' (with trailing blanks) for all other files.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 6.--File Pointer Record Format--Continued

Bytes	Type*	Description
97-100	A	Referenced file data type code: coded 'BINO' for image data or 'MBAA' for all other files.
101-108	N	Number of records in referenced file including file descriptor record.
109-116	N	Referenced file 1st record length: always = $3600)_{10}$.
117-124	N	Referenced file maximum record length: always = $3600)_{10}$.
125-136	A	Referenced file record length type: always coded "FIXED LENGTH".
137-140	A	Referenced file record length type code: always coded "FIXD".
141-142	N	Referenced file physical volume number, start of file: coded "b̸1", "b̸2" or "b̸3", indicating the sequence number of the tape of a tape set containing the 1st record of the file.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 6.--File Pointer Record Format--Continued

Bytes	Type*	Description
143-144	N	Referenced file physical volume number, end of file: coded "b1", "ƀ2", or "ƀ3", indicating the sequence number of the tape of the tape set containing the last record of the file; will be the same as field directly above unless the file is split across physical volumes (tapes).
145-152**	N	Referenced file portion, the sequence number of the first record of the file on this physical volume: coded "ƀƀƀƀƀƀƀ1" for all files unless the referenced file is a continuation (that is, was started on a previous tape). In this case, the field contains the sequence number of the first record of the file recorded on this tape.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

**Updated in repeated volume directory if logical volume is split within a file

Table 6.--File Pointer Record Format--Continued

Bytes	Type*	Description
153-160**	N	Referenced file portion, the sequence number of the last record of the file on this physical volume.
161-260	A	Pointer spare segment (Blank filled)
261-360	A	Local use segment (Blank filled)

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Updated in repeated volume directory if logical volume is split within a file

4.3 Leader File

The leader file is composed of a file descriptor record and up to three types of data records: header, ancillary, and annotation. The leader file is the first file of a block of data which represents a single band of a scene for a BSQ tape or the entire scene for a BIL tape. This was illustrated earlier in figure 5. The leader file preceeds image data files and supplies information associated with the image such as image product annotation, ephemeris/attitude data, processing information, and other support information.

4.3.1 File Descriptor Record

The file descriptor record is the first record of a leader file, and introduces that file. (It is also the first record of an image data file and a trailer file). Following the first 16 byte segment of record identification information are four data segments. The second segment (bytes 17-44) identifies the format, and the software version used to produce the file. The third segment (bytes 45-116) provides basic information necessary to locate and read the data records of the file. The fourth segment (bytes 117-180) is a spare which is reserved for expansion in future file descriptors revisions. These first four segments are known as the file descriptor fixed segments. They provide information on how to read the particular file being introduced by the file descriptor record.

The fifth segment (bytes 181-3600) is referred to as the file descriptor variable segment because its format varies with the type of file being described. The fifth segment starts with values indicating the number of records of each record type in the file. This is followed with locator information particular to the format of the data file, that is, how to access and display essential data. Specific field locator information in bytes 217 through 360 is given in a series of 16-byte codes, each of which are structured as follows:

Bytes	Description
1-6	The record number of the record containing the field
7-12	The record byte number of the first byte of the field
13-15	Length of the field in bytes
16	A code indicating the type of data in the field, coded 'A' for alphanumeric; 'N' for numeric; 'B' for binary.

The format of the fixed and variable segments of the leader file descriptor record is given in table 7.

Table 7.--File Descriptor Record for Leader File

Bytes	Type*	Description
1-4	B	Record number = $1)_{10}$.
5-8	B	Record type code: byte 5 = $077)_8$ byte 6 = $300)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Length of this record = $3600)_{10}$.
13-14	A	ASCII/EBCDIC flag for this file = "Ab̸" indicating ASCII. (EBCDIC not available).
15-16	A	Blanks.
17-28	A	Control document number for this embodiment (that is, this document's number).
29-30	A	Control document revision number.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 7.--File Descriptor Record for Leader File--Continued

Bytes	Type*	Description
31-32	A	File design descriptor revision letter: 2-bytes giving the revision letter of the file format (as opposed to revisions which affect the control document without affecting the file format). Coded "ɃA" unless this record format is modified.
33-44	A	Software release number for this file.
45-48	N	File number: sequence number of this file within the logical volume. The volume directory file is not included in this count.
49-64	A	File identification: same as file pointer record, bytes 21-36.
65-68	A	Record sequence and location type flag: always coded "FSEQ" indicating a fixed record location of record sequence number.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 7.--File Descriptor Record for Leader File--Continued

Bytes	Type*	Description
69-76	N	Record number location: always coded "ƀƀƀƀƀƀƀ1" indicating that record number starts in record byte one.
77-80	N	Record number field length: always coded "ƀƀƀ4" indicating a 4 byte record number field.
81-84	A	Record code and location type flag: always coded "FTYP" indicating a fixed record location of the type code field.
85-92	N	Record code location: always coded "ƀƀƀƀƀƀƀ5" indicating that record code starts in record byte five.
93-96	N	Record code field length: always coded "ƀƀƀ4" indicating a 4 byte record field.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 7.--File Descriptor Record for Leader File--Continued

Bytes	Type*	Description
97-100	A	Record length and location type flag: always coded "FLGT" indicating a fixed record location of the record length field.
101-108	N	Record length location: always coded "ƀƀƀƀƀƀƀ9" indicating that record length field starts in record byte nine.
109-112	N	Record length field length: always coded "ƀƀƀ4" indicating a 4 byte record length field.
113	A	Flag indicating that data interpretation information is included within file descriptor record: coded "N" indicating NO.
114	A	Flag indicating that data interpretation information is included within records other than the file descriptor record: coded "N".

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 7.--File Descriptor Record for Leader File--Continued

Bytes	Type*	Description
115	A	Flag indicating that data display information is included with the file descriptor record: coded "N".
116	A	Flag indicating that data display information is included within the file in record(s) other than the file descriptor: coded "N".
117-180	A	Reserved segment (Blank filled)
181-186	N	Number of header records: always = $1)_{10}$.
187-192	N	Header record length: always = $3600)_{10}$.
193-198	N	Number of ancillary records: coded $0)_{10}$ for leader files preceding imagery that has been geometrically corrected; coded $18)_{10}$ if imagery is geometrically uncorrected.
199-204	N	Ancillary record length: always = $3600)_{10}$.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 7.--File Descriptor Record for Leader File--Continued

Bytes	Type*	Description
205-210	N	Number of annotation records: coded = $1)_{10}$ for fully processed data; $2)_{10}$ for partially processed.
211-216	N	Annotation record length: always = $3600)_{10}$.
		<u>Field Locator Information</u>
217-232	A	Scene identification field locator: coded "ƀƀƀƀƀ2ƀƀƀƀ13ƀ11A".
233-248	A	World Reference System identification locator: coded "ƀƀƀƀƀ2ƀƀƀƀ25ƀƀ8A".
249-264	A	Mission identification field locator: coded "ƀƀƀƀƀ2ƀƀƀƀ49ƀƀ4N".
265-280	A	Sensor identification field locator: coded "ƀƀƀƀƀ2ƀƀƀƀ45ƀƀ4A".
281-296	A	Exposure date-time field locator: coded "ƀƀƀƀƀ2ƀƀƀ109ƀ16N".

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 7.--File Descriptor Record for Leader File--Continued

Bytes	Type*	Description
		Field Locator Information--Continued
297-312	A	Geographic reference field locator (format center): coded "ȸȸȸȸȸ3ȸȸȸȸ21ȸ17A" for geometrically corrected imagery and "ȸȸȸȸ21ȸȸȸȸ21ȸ17A" for geometrically uncorrected imagery.
313-328	A	Image processing performed field locator: coded "ȸȸȸȸȸ2ȸȸȸ169ȸȸ1A".
329-344	A	Imagery format (interleaving) indicator: coded "ȸȸȸȸȸ2ȸȸȸ173ȸȸ4A"
345-360	A	Band indicator locator: coded "ȸȸȸȸȸ2ȸȸȸ206ȸȸ1A".
361-3600	A	Blanks.

*Denotes field type:

A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

4.3.2 Header Record

The header record identifies the content and format of the data of the leader file and of the image and trailer files that follow. There is only one header record per leader file. Header record data are subdivided into six groups:

a) Record Introduction: record number, type, and length.

b) Image Identification: scene ID, and WRS path/row indicator.

c) Spacecraft Description: sensor, mission number, and detector status.

d) Time of Exposure: WRS frame center location and exposure time.

e) Data Identification/Characteristics: general header, annotation, ancillary, image and trailer data characteristics such as number of records, interleaving type, resampling technique, map projection, and WRS offset.

f) Special Purpose Fields: transmission mode, temporal registration data, overlap mark information, geometric correction quality codes, radiometric correction accuracy, telemetry and control point quality indicators, and image enhancement indicators.

The header record format is given in table 8. It should be noted that significant modifications in the format of the header record have been made from the previous Landsat CCT format. The general order of appearance of specific data fields, however, has not changed. Attempts have been made to convert as many binary fields as possible to ASCII and to place the fields on 4-byte boundaries to ease field access and interpretation.

Table 8.--Header Record Format

Bytes	Type*	Description
A. Record Introduction		
1-4	B	Record number = $2)_{10}$
5-8	B	Record type code: byte 5 = $022)_8$ byte 6 = $022)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$
B. Image Identifiers		
13-24	A	Image Identification (ASCII) - unique image identifier of the form: b̸NDDDDHHMMSB where N = Landsat mission number: 2, 3, or 4 DDDD = Days after launch at time of observation HH = Hour at time of observation MM = Minute at time of observation S = Tens of seconds at time of observation, where time of observation is universal time (GMT)

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
B. Image Identifiers--Continued		
		B = Band Identification Code: 1, 2, 3, or 4 for Landsat-4 BSQ; 4, 5, 6, 7, or 8 for Landsat-2/3 BSQ; or blank for BIL
25-32	A	WRS Designator - unique terrestrial image identifier of the form: ɃMPPPRRR where M = A (for ascending node) or D (for descending node) PPP = WRS path number RRR = WRS row number
33-38	A	Date of Tape Generation of the form: DDMMYY where DD= day, MM = month, YY = last two digits of year.
39-44	A	Blank Fill (not used)
C. Spacecraft Description		
45-48	A	Sensor Identification: always coded "MSSɃ"
49-50	N	Mission Number: $2)_{10}$, $3)_{10}$, or $4)_{10}$

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
C. Spacecraft Description--Continued		
51-56	N	Spacecraft orbit number during which the image was acquired
57-84	A	Active Detector Status - contains detector status for the 24 (26 for Landsat-3) MSS detectors. One byte per detector, six detectors for each of the four bands starting with the status of detector 1 of the first band in byte 57 through detector 6 of the fourth band in byte 80. In the case of Landsat-3, band 8 detectors A and B are in bytes 81 and 82, respectively. Bytes not used are blank filled. A "1" in the byte indicates the detector is active. If a detector was disabled or inactive during the data acquisition pass, the status will be "0".
85-88	N	Active Detector Count - the number of active detectors

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
C. Spacecraft Description--Continued		
89-92	N	Nominal number of image data pixels per scan line in original geometrically uncorrected image
93-96	A	Blank fill (not used)
D. Time of Exposure/WRS Designator		
97-100	A	Blank fill (not used)
101-104	N	Scan line number containing WRS frame center in fully processed image
105-108	N	Pixel number of WRS frame center in fully processed image. (Blank filled in partially processed CCT-AM.)
109-124	A	Center picture exposure time, in GMT: Last 2 digits of year (00-99) Day of year (3 digits: 001-366) Hour (2 digits: 00-23) Minutes (2 digits: 00-59) Seconds (2 digits: 00-59) Milliseconds (3 digits: 000-999) Blanks (2 digits)

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
E. Data Identification and Characteristics		
		Header Data Characteristics
125-128	N	Header record length = $3600)_{10}$
129-132	N	Number of header records = $1)_{10}$
133-136	N	Number of bytes of Group "F" (special purpose fields) header data
		Annotation Data Characteristics
137-140	N	Annotation record length = $3600)_{10}$
141-144	N	Number of annotation records = $1)_{10}$ for fully processed data; $2)_{10}$ for partially processed data
		Ancillary Data Characteristics
145-148	N	Ancillary record length = $3600)_{10}$
149-152	N	Number of ancillary records = $18)_{10}$ for partially processed imagery; = $0)_{10}$ for fully processed imagery
153	A	Geometric corrections applied, "Y" = Yes; "N" = No
154	A	Geometric correction data present, "Y" = Yes; "N" = No

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
E. Data Identification and Characteristics--Continued		
		Ancillary Data Characteristics--Continued
155	A	Radiometric correction applied, "Y" = Yes; "N" = No
156	A	Radiometric correction data present, "Y" = Yes; "N" = No
157-160	N	Image record length = $3600)_{10}$.
161-166	N	Number of image records = $2400)_{10}$ for partially processed BSQ imagery; = $2983)_{10}$ for fully processed BSQ; = $11,932)_{10}$ for fully processed Landsat-2/4 four band BIL imagery; = $14,915)_{10}$ for fully processed Landsat-3 five band BIL imagery; = $9600)_{10}$ for partially processed Landsat-2/4 four band BIL imagery; = $12,000)_{10}$ for partially processed Landsat-3 five band BIL imagery.
167-168	N	Number of calibration/quality support data bytes per scan line of image data = $28)_{10}$ for fully processed imagery, = 0 for partially processed.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
E. Data Identification and Characteristics--Continued		
		Image Data Characteristics
169	A	Image data format = "A" for partially processed data, = "P" for fully processed data
170-172	A	Blank Fill (not used)
173-176	A	Interleaving type indicator, "BSQ␢" or "BIL␢"
177	N	Line interleaving count, = $0)_{10}$ for noninterleaved (BSQ) data; = $4)_{10}$ for Landsat-2/4 BIL data; = $5)_{10}$ for Landsat-3 BIL data
178	N	Number of bits per pixel, always $8)_{10}$
179-180	A	Resampling Applied: "␢␢" = none "CU" = cubic convolution "NN" = nearest neighbor

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
E. Data Identification and Characteristics--Continued		
181-184	A	Map projection: corresponds to that applied to fully processed data (UTM, PS or SOM) or to the first map projection set in the ancillary and annotation sections for partially processed data (UTM or PS) "UTMƀ" = Universal Transverse Mercator (UTM) "PSƀƀ" = Polar Stereographic (PS) "SOMƀ" = Space Oblique Mercator (SOM) "HOMƀ" = Hotine Oblique Mercator (HOM).
185-190	N	WRS offset from fully processed image center. Contains right (positive) or left (negative) pixel displacement of the WRS designation with respect to the picture center pixel (scan line 1492, pixel 1774). (Zero filled for partially processed data).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
E. Data Identification and Characteristics--Continued		
191-192	A	Blank Fill (not used).
193	A	Image data justification, always "R" indicating right justification.
194-196	N	Location of most significant bit, always 0, indicating left.
197-200	N	Number of pixels per scan line, in both partially processed and fully processed image data, always $3548)_{10}$ (including fill pixels).
201-204	A	Blank Fill (not used).
205	N	Number of usable images per scene: = $1)_{10}$, $2)_{10}$, $3)_{10}$, $4)_{10}$, or $5)_{10}$.
206	N	MSS band number = $1)_{10}$, $2)_{10}$, $3)_{10}$ or $4)_{10}$ for Landsat-4 BSQ data; = $4)_{10}$, $5)_{10}$, $6)_{10}$, $7)_{10}$ or $8)_{10}$ for Landsat-2/3 BSQ data, = $0)_{10}$ if BIL data.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
E. Data Identification and Characteristics--Continued		
207-212	A	Blank Fill (not used).
		Trailer Data Characteristics
213-216	N	Trailer record length = $3600)_{10}$.
217	N	Number of Trailer Records: $1)_{10}$ for BSQ, $4)_{10}$ or $5)_{10}$ for BIL.
218-224	A	Blank Fill (not used).
F. Special Purpose Fields		
225	A	Orbital direction: "D" = descending node "A" = ascending node
226-228	A	Lat./Long. tick mark flag: a code of 'ƀƀX' in the bytes indicates that the latitude and longitude tick marks are provided in the annotation record. (Blank fill indicates exclusion of lat./long.)

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields		
229-236	FL	Image Orientation Angle: Orientation of map projection coordinate system with respect to center line of fully processed image (in radians). (Zero filled for partially processed data as is contained in ancillary data records).
237-240	A	Sensor mode: "LLbb" = low gain linear "LCbb" = low gain compressed "HLbb" = high gain linear "HCbb" = high gain compressed.
(241-356)		Blank fill for partially processed imagery (CCT-AM) OR Temporal Registration Data for fully processed imagery (CCT-PM). Byte assignments 241-356 are as follows:

* Denotes field type:

A = Aphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see figure 7 for explanation)

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
241-252	A	Scene ID of reference image used for temporal registration processing of the form: ƀADDDDHHMMSB where A = Landsat mission 2, 3, or 4 DDDD = Day number, relative to launch, at time of observation HH = Hour at time of observation MM = Minute at time of observation S = Tens of seconds at time of observation B = Band ID code: 1, 2, 3, or 4 for Landsat-4 BSQ; 4, 5, 6, 7, or 8 for Landsat-2/3 BSQ; or blank for BIL.

* Denotes field type:

A = Aphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
253-260	A	WRS Designator - 8 bytes of unique terrestial identifier of the form: ⱀMPPPRRR where M = A (for ascending node) or D (for descending node) PPP = nominal WRS path number RRR = nominal WRS row number.
261-324	N	Scan line and pixel numbers of the common temporal registration region of the reference image and current image (image under processing, see figure 8). Temporal registration points P_1 through P_4 are in the tabular form given below. Entries denote byte assignments scan line numbers and pixel numbers.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		

Temporal Registration	Current Image		Reference Image	
	Scan Line Number	Pixel Number	Scan Line Number	Pixel Number
P_1	261-264	265-268	269-272	273-276
P_2	277-280	281-284	285-288	289-292
P_3	293-296	297-300	301-304	305-308
P_4	309-312	313-316	317-320	321-324

Bytes	Type*	Description
		Overlap Data: scan line and pixel numbers (in fully processed image) of the four overlap marks (see figure 9) as follows:
325-328	N	Scan Line of First Overlap Mark (Upper Left).
329-332	N	Pixel Number of First Overlap Mark.
333-336	N	Scan Line of Second Overlap Mark (Upper Right).
337-340	N	Pixel Number of Second Overlap Mark.

*Denotes field type:
A = Alphanumeric
N = Numeric
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
341-344	N	Scan Line of Second Overlap Mark (Lower Left).
345-348	N	Pixel Number of Third Overlap Mark.
349-352	N	Scan Line of Fourth Overlap Mark (Lower Right).
353-356	N	Pixel Number of Fouth Overlap Mark.
357-360	N	Nominal overlap mark pixel offset in fully processed image data (see figure 9).
361-364	A	Geometric correction quality code: quality assessment of appended (CCT-AM) or applied (CCT-PM) geometric modeling data. For Landsat-2/3, coded as "9" for highest to "0" for lowest quality based on the number of control points applied by setting the code equal to the truncated integer value of the expression $\frac{N+7}{8}$ where 'N' is the number of control points. For Landsat-4, represents the number of parameters modeled in the processing (see table below).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description

F. Special Purpose Fields--Continued

Code	Parameters Modeled	Geometric Correction Quality
0	None, correction is SCD only	Acceptable
2	Along track, across track (control points used to calculate translation errors)	Good
3	Along track, across track and yaw	Good
4	Along track, across track yaw, altitude	Excellent
6	Along track, across track, yaw, altitude, along track rate, across track rate	Excellent

Bytes	Type*	Description
365-368	N	Actual number of Tick Marks for Top (T), Left (L), Right (R) and Bottom (B) Annotation zones (Blank fill for partially processed data).
(369-3568)		Blank filled for Landsat-2/3, following for Landsat-4:

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
369-372	A	Overall Band Quality Indicator (see table 9). The assessment of the overall quality of a band of imagery based on the combined geometric, radiometric and image data quality. Four bytes, one code for each of four bands starting with band 1 in byte 369. Bytes not used are blank filled.
373-376	A	Radiometric Calibration Method "b̸b̸b̸b̸" = No corrections applied (engineering test mode) "HIST" = Histogram method "CALW" = Cal wedge values only (no histograms) "NSTA" = Non-standard corrections applied (engineering test mode).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see figure 7 for explanation)

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
377-380	FLS	Relative Calibration Accuracy (RCA), maximum difference between detector means for the image. $0 \leq RCA \leq 1.0$ Excellent $1.0 \leq RCA \leq 2.0$ Good $2.0 < RCA$ Acceptable
381-384	A	Blank filled.
		<u>Input Data Quality Indicators</u> <u>Telemetry</u>:
385-388	N	Number of ephemeris data points sampled in the telemetry interval.
389-392	N	Number of rejected (outlier) ephemeris data points in the telemetry interval.
393-396	N	Number of attitude data points sampled in the telemetry interval.
397-400	N	Number of rejected (outlier) attitude data points in the telemetry interval.
401-404	FLS	Length of telemetry interval in seconds.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 8.--Header Record Format--Continued

Byte	Type*	Description
F. Special Purpose Fields--Continued		
405-408	A	Blank filled.
409-420	FLS	Accuracy of ephemeris fit, RMS difference in meters between fit and data points. 3 four-byte values, one each for altitude, along-track position, and across-track position.
421-424	A	Blank filled.
425-436	FLS	Accuracy of attitude fit, RMS difference in radians between fit and data points. 3 four-byte value, one each for pitch, roll and yaw.
		Control Points:
437-440	A	Overall Band Quality codes of reference scene from which control points were extracted (see table 9); four bytes giving one code for each of four bands starting with band 1 in byte 437. Bytes not used are blank filled.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
		Control Points--Continued
441-444	N	Number of geodetic control points used to correct reference image control point extraction process (control point library build).
445-448	N	Average** previous registration success; average percent previous successful registrations of control points.
449-452	A	Blank filled.
453-456	FLS	Average** autocorrelation peak value in control point generation process
457-464	FLS	Ninety percent error ellipse of geodetic control point location in corrected reference image from which control points are extracted; two values, along-track and across-track, (in meters).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

**Average of only those control points used in calculations for present scene

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
		Control Points--Continued
465-468	FLS	Correlation Factor; average** autocorrelation peak values of control points used in the correction of the reference image from which control points are extracted
469-472	FLS	Average** control point suitability measure; average of autocorrelation surface peak curvatures
473-484	A	Blank filled (not used)
485	A	Data Source (ASCII) "G" = GSTDN, "W" = TDRSS/White Sands, "T" = Transportable Ground Station
486	A	Blank filled (reserved for processing anomaly indicator)
487-492	A	Blank filled

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see Figure 7 for explanation)

**Average of only those control points used in calculations for present scene

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
493-496	FP	Uncorrectable ECC count for the scene; total count accumulated during input of data in HDT-AM creation process.
497-500	FP	Indication of bit error rate for the scene; number of sweeps which had a least one minor frame sync loss (more than three consecutive minor frame sync words containing at least one bit error). There are 6 bits per sync word, including calibration data. There are about 2100 sync words per sweep.
501-504	A	Blank filled.
505-508	N	Use of Nominal Calibration Wedge values (CWV) $0)_{10}$ = Not used $1)_{10}$ = Used for comparison only $2)_{10}$ = Used to replace CWV's outside window and used in radiometric calibration.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
509-512	N	Window Size; the neighborhood of the nominal values to which the actual CWVs are compared.
(513-1088)		Nominal Calibration Wedge Values; 144 four-byte values, six values for each of six detectors per each of four bands. Fields for bands not present are blank filled.
513-656	N	Band 1 Nominal Calibration Wedge Values.
657-800	N	Band 2 Nominal Calibration Wedge Values.
801-944	N	Band 3 Nominal Calibration Wedge Values.
945-1088	N	Band 4 Nominal Calibration Wedge Values.
(1089-1664)		Calibration Wedge Quality; total number of times CWV did not fall into nominal (±) window neighborhood. 144 four-byte values, one for each cal. wedge sample. Fields for bands not present are blank filled.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see figure 7 for explanation)

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
1089-1232	N	Band 1 Calibration Wedge Quality.
1233-1376	N	Band 2 Calibration Wedge Quality.
1377-1520	N	Band 3 Calibration Wedge Quality.
1521-1664	N	Band 4 Calibration Wedge Quality.
1665-1672	FL	WRS scene center latitude in radians.
1673-1680	FL	WRS scene center longitude in radians.
1681-3568	A	Blank filled.
3569	A	EDIPS performed contrast stretch; coded: "F" = False, "T" = True.
3570	A	EDIPS performed haze removal; coded: "F" = False, "T" = True.
3571	A	EDIPS performed edge enhancement; coded: "F" = False, "T" = True.
3572	A	Blank filled.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
(3573-3600)		Blank filled for MSS BSQ. The following for MSS BIL:
3573-3577	A	Indication of data present by band--actual data is indicated as present by an "X" in the proper byte location starting with band 1 (Landsat-4) or band 4 (Landsat-2/3) in byte 3573. When data for a given band is not present, it's position will contain a blank rather than an "X".
3578-3580	A	Blank filled.
3581-3585	A	A five-byte field, with one byte for each of the MSS bands to indicate sensor gain options, coded: "H" = High Gain "L" = Low Gain.
3586-3588	A	Blank filled.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 8.--Header Record Format--Continued

Bytes	Type*	Description
F. Special Purpose Fields--Continued		
3589-3593	A	A five-byte field, with one byte for each of the MSS bands to indicate the type of MSS transmission, coded: "1" = Linear Mode "2" = Compressed Mode.
3594-3600	A	Blank filled.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 9. --Overall Band Quality Codes

Code	Relative Quality	Geometric* Correction Quality Code (Bytes 361-364 of Header)	Radiometric* Correction Quality Code (Bytes 377-380 of Header)	Image** Data Quality Code
C	Best	E	E	E
B		E	E	G
A		E	G	E
9		G	E	E
8		E	G	G
7		G	E	G
6		G	G	E
5		G	G	G
4		A	E	E
3		A	E	G
2		A	G	E
1		A	G	G
0		A	E or G or A	A
0	Acceptable	A	A	E or G or A

*E = EXCELLENT
G = GOOD
A = ACCEPTABLE

**The Image Quality Code is defined as follows:

$$0 \leq DQI \leq 1.5 = E$$

$$1.5 < DQI \leq 4.5 = G$$

$$4.5 < DQI = A$$

Where DQI is defined as DQI = Major frame synch losses + Minor frame synch losses/20 + Unrecoverable ECC count errors/20.

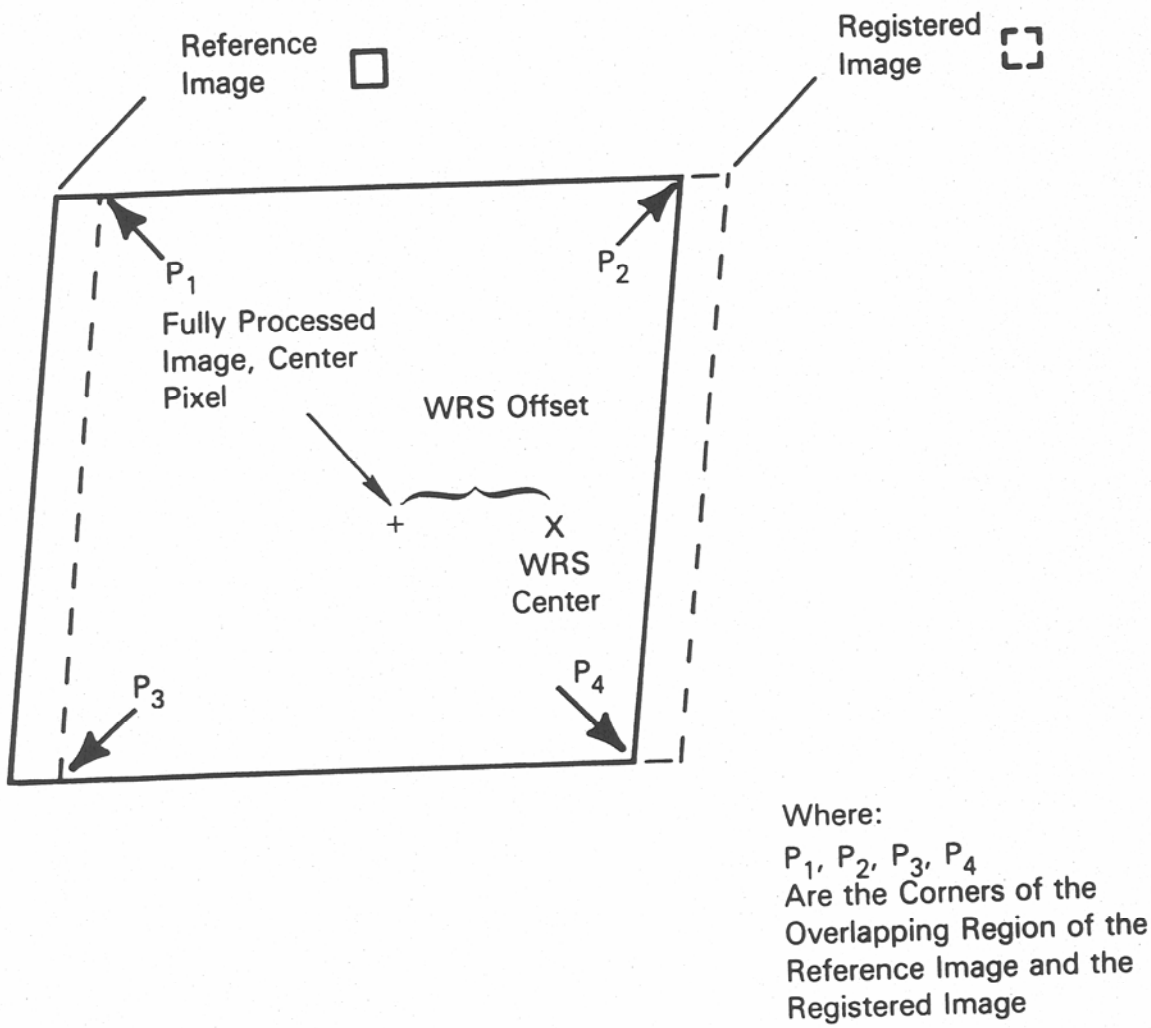


Figure 8. --Symbolic Representation of Temporal Registration

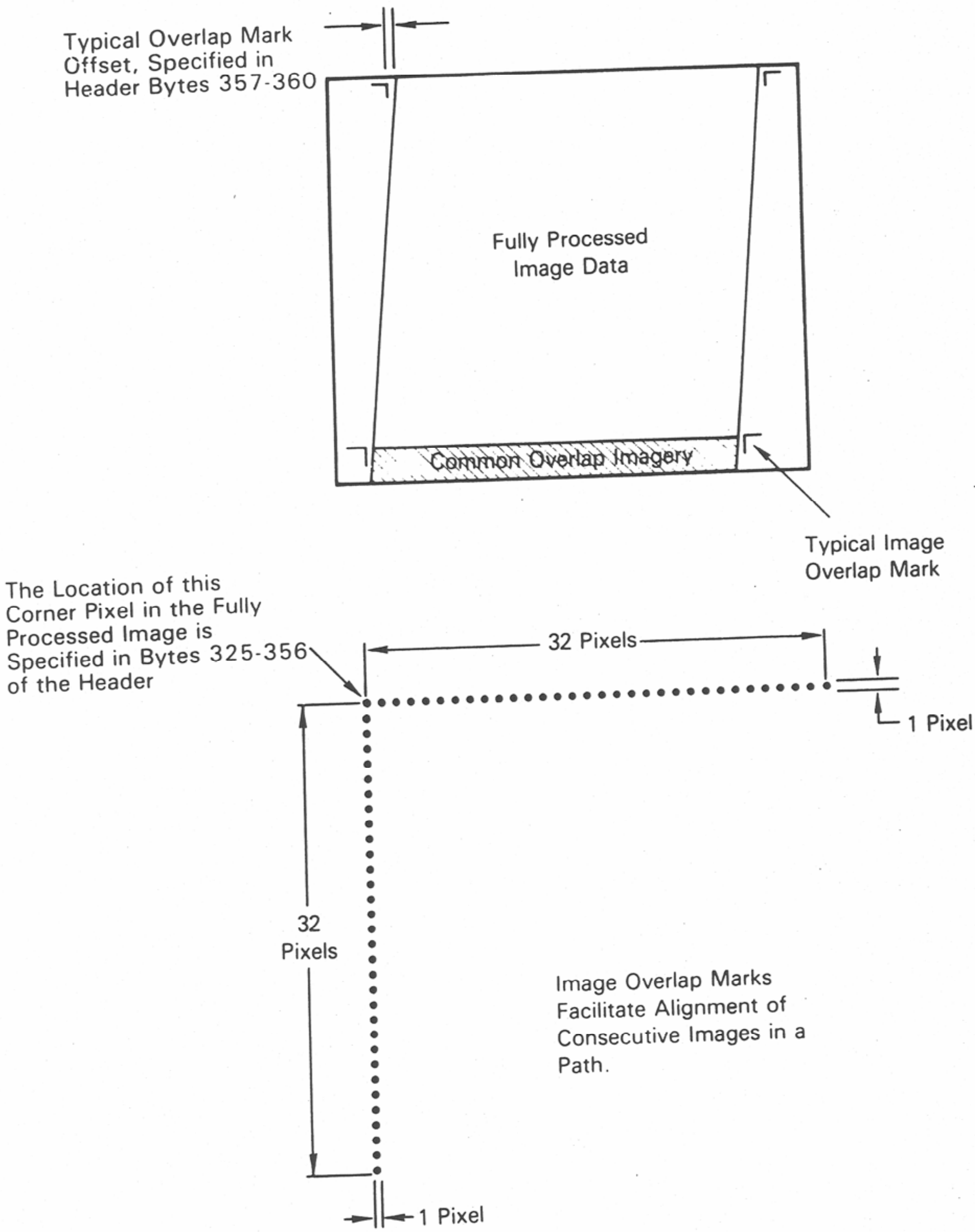


Figure 9. --Image Overlap Marks and Common Overlapping Imagery

4.3.3 Ancillary Record

Ancillary records occur only on partially processed CCT's (data without geometric corrections applied). The ancillary records contain various kinds of correction data which can be applied to the image data to produce a geometrically correct image. For each image, ancillary information for two map projections is provided with the first projection being either Polar Stereographic (PS) or Universal Transverse Mercator (UTM) and the second projection being either Hotine Oblique Mercator (HOM) or Space Oblique Mercator (SOM). There are a total of 18 ancillary records arranged on the tape in the following order:

1. Two general ancillary records.
2. Eight PS/UTM map projection records.
3. Eight HOM/SOM map projection records.

The two general ancillary records contain geometric modeling data. The first of the two general records contains a set of spacecraft dependent constants, whereas, the second record contains image dependent spacecraft parameters. The format and content of the general ancillary records are given in tables 10 and 11.

The 16 map projection records contain horizontal resampling (HRS) and vertical resampling (VRS) geometric transformation grids as well as other projection dependent information. Since the eight PS/UTM and eight HOM/SOM projection records are identical in format and different only in content, their format and content description are given in a single table 12. Note that table 12 begins with records 5 and 13, due to the occurrence of four prior records (file descriptor, header, and two general ancillary) in the leader file.

Table 10.--General Ancillary Record #1 Format.

Bytes	Type*	Description
1-4	B	Record number = $3)_{10}$.
5-8	B	Record type code: byte 5 = $022)_8$ byte 6 = $044)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Record Length = $3600)_{10}$.
13-16	FP	Nominal number of pixels per input image scan line.
17-20	FP	Number of scan lines in the partially processed input image.
21-28	FL	Nominal scale of inter-pixel distance in meters per pixel in the partially processed input image.
29-36	FL	Nominal scale of inter-line distance in meters per pixel in the partially processed input image.
37-40	FP	Number of pixels per line of fully processed output image.

*Denotes field Type:

A = Alphanumeric (ASCII)

N = Numeic (ASCII)

B = Binary

FP, FLS, FL (see figure 7 for explanation)

Table 10.--General Ancillary Record #1 Format--Continued

Bytes	Type*	Description
41-44	FP	Number of lines per band of fully processed output image.
45-52	FL	Scale of inter-pixel distance in meters per pixel in fully processed output image.
53-60	FL	Scale of inter-line distance in meters per pixel in fully processed output image.
61-68	FL	Nominal spacecraft altitude in meters.
69-76	FL	Nominal input swath width in meters.
77-108	FL	MSS mirror model coefficients (4 values, 8 bytes each).
109-116	FL	MSS maximum mirror angle in radians.
117-124	FL	Scan skew constant (as a result of finite scan time).
125-132	FL	Time between successive MSS mirror sweeps in seconds.
133-140	FL	Time for the active portion of an MSS mirror sweep in seconds.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 10.--General Ancillary Record #1 Format--Continued

Bytes	Type*	Description
141-148	FL	Semi-major axis of Earth ellipsoid (International Spheroid) in meters.
149-156	FL	Semi-minor axis of Earth ellipsoid (International Spheroid) in meters.
157-164	FL	Earth curvature constant (dependent on spacecraft's nominal altitude and Earth radius) in meters $^{-2}$ (one over square meters).
165-268	FLS	MSS sampling delay constants (up to 26 values, one for each detector) measured in input image along-scan pixel units (4 bytes each).
269-288	FLS	MSS band-to-band offsets with respect to band 1 (Landsat-4) or band 4 (Landsat-2/3) measured in input image along-scan pixel units. For Landsat-4, 3 values, 4 bytes each starting at byte 269 (one value for each of bands 2, 3, and 4). For Landsat-2/3, 5 values, 4 bytes each (one value each for 5, 6, 7, 8A and 8B).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see figure 7 for explanation)

Table 10.--General Ancillary Record #1 Format--Continued

Bytes	Type*	Description
289-3600	B	Zero Fill (not used).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 11.--General Ancillary Record #2 Format.

Bytes	Type*	Description
1-4	B	Record number = $4)_{10}$.
5-8	B	Record type code: byte 5 = $022)_8$ byte 6 = $044)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
13-20	A	WRS path and row numbers: eight characters in the form "ƀPPPƀRRR" where PPP = path number, RRR = row number.
21-28	FL	WRS frame center latitude in radians.
29-36	FL	WRS frame center longitude in radians.
37-52	A	Spacecraft time of frame center (Universal time), same format as bytes 109-124 in Header.
53-60	B	Zero Fill (not used).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see Figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
61-68	FL	Scene center latitude in radians.
69-76	FL	Scene center longitude in radians.
77-100	FL	Scene center in Earth-centered, Earth-fixed coordinates in meters (3 values X, Y and Z, 8 bytes each).
101-108	FL	Spacecraft heading angle at scene center (beta) in radians.
109-116	FL	Scan line coordinate of scene center in partially processed input image.
117-124	FL	Pixel coordinate of scene center in partially processed input image.
125-132	FL	Normalized spacecraft velocity error from nominal at nadir.
133-140	FL	Earth rotation velocity at nadir in meters per second.
141-144	FLS	Earth rotation parameter (image skew), in radians.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
		<u>Spacecraft state vector at scene center:</u>
145-152	FL	Pitch in radians.
153-160	FL	Roll in radians.
161-168	FL	Yaw in radians.
169-176	FL	X in Km.
177-184	FL	Y in Km.
185-192	FL	Z in Km.
193-200	FL	Delta pitch in radians/sec.
201-208	FL	Delta roll in radians/sec.
209-216	FL	Delta yaw in radians/sec.
217-224	FL	Delta X in Km/sec.
225-232	FL	Delta Y in Km/sec.
233-240	FL	Delta Z in Km/sec.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
		Spacecraft state vector at scene center:
241-256	FL	Zero fill.
257-260	FP	Total number of control points used in geometric correction model.
(261-3600)		Zero filled for Landsat-2/3. Following for Landsat-4:
261-264	FP	Number of geodetic control points used in geometric correction model.
265-268	FP	Total number of control point correlations attempted.
269-272	FP	Number of correlated control points rejected during modeling process (that is, outside predefined limits, indicating an undesirable control point for some reason).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
273-276	FP	RMS along-track geometric modeling error (that is, how well the geometric model matched the control point data), in meters.
277-280	FP	RMS across-track geometric modeling error, in meters.
281-287	B	Zero fill.
288-312	B	Distribution of control points used. The number of control points in each zone of the WRS frame (used in the geometric correction model) is given (one byte per zone).
313-512	A	Identification of control points used. Up to 25 control points, each using eight bytes of the format b̸BtXXYYY where b̸ = blank; B = band number 1, 2, 3 or 4; T = Type (G,S,R); XX = Zone 01-25; YYY = Sequence within Scene 001-999.
513-672	B	Zero fill.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
		Geometric Correction Parameters Ephemeris Data:
673-686	A	Time of the first set of ephemeris entries of the form: "YYDDDHHMMSSmmm" where YY = last two digits of year DDD = julian day of year HH = Hour MM = minutes SS = seconds mmm = micro-seconds
687-690	FLS	Time interval between successive sets of ephemeris entries (in seconds).
691-694	FP	Number of sets of ephemeris entries.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
695-1142	FLS, FP	Up to 16 sets of ephemeris entries, each set consists of seven values: spacecraft location (x,y,z) in FLS format, spacecraft velocity (V_x, V_y, V_z) in FLS format and a data quality indicator Q in FP format. Where Q can take on the values: $0)_{10}$ - corresponding input data--valid. $1)_{10}$ - no corresponding input data. $2)_{10}$ - corresponding input data--not valid. Coordinate system is Earth-centered, Earth-fixed.
		Attitude Data:
1143-1156	A	Time of the first set of attitude entries of the form: "YYDDDHHMMSSmmm" where YY = last two digits of year DDD = julian day of year HH = hour MM = minutes SS = seconds mmm = micro-seconds

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
		<u>Attitude Data:</u>
1157-1160	FLS	Time interval between successive sets of attitude entries, in seconds.
1161-1164	FP	Number of sets of attitude entries.
1165-2124	FLS, FP	Up to 60 sets of attitude entries, each set consists of four values: pitch angle (radians) in FLS format, roll angle (radians) in FLS format, yaw angle (radians in FLS format, and a data quality indicator Q in FP format. Where Q can take on the values: $0)_{10}$ - valid data. $1)_{10}$ - angular increment data not valid; replaced by last good value. $2)_{10}$ - angular increment data not valid; replaced by 0. $3)_{10}$ - no valid drift bias; replaced by 0. $4)_{10}$ - angular increment data not available; initial attitude information used. $5)_{10}$ - initial attitude information not available; replaced by 0.

*Denotes field type:
FP, FLS, FL (see figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
		Attitude Data.--Continued
2125-2844	FLS	Partial derivatives for SOM projection. There are 12 matrices, each matrix is 3x5. The 12 matrices are partial derivatives of X and Y with respect to each of six spacecraft parameters; along-track location; across-track location, altitude, pitch, roll, yaw.
2845-3012	B	Zero fill - not used.
(3013-3204)	FLS	Multiplicative gain and additive (bias) radiometric correction constants, two values for each of six detectors in the order: Detector 1 multiplicative constant, Detector 1 additive constant, Detector 2 multiplicative constant, etc. Fields for bands not present are zero filled.
3013-3060	FLS	Band 1 multiplicative and additive radiometric correction constants.
3061-3108	FLS	Band 2 multiplicative and additive radiometric correction constants.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FLS, FL (see figure 7 for explanation)

Table 11.--General Ancillary Record #2 Format--Continued

Bytes	Type*	Description
		Attitude Data.--Continued
3109-3156	FLS	Band 3 multiplicative and additive radiometric correction constants.
3157-3204	FLS	Band 4 multiplicative and additive radiometric correction constants.
3205-3600	B	Zero fill.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FLS, FL (see figure 7 for explanation)

Table 12.--Ancillary Map Projection Record Formats.
(records numbered 5 through 12 refer to UTM/PS, records numbered 13 through 20 refer to SOM/HOM)

Records 5 and 13

Bytes	Type*	Description
1-4	B	Record number = $5)_{10}$ for UTM/PS; = $13)_{10}$ for SOM/HOM.
5-8	B	Record type code: byte 5 = $044)_8$ byte 6 = $044)_8$ byte 7 = $333)_8$ for UTM/PS $355)_8$ for SOM/HOM byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
13-256	FPG**	HRS Pixel Coordinates (Row number 1).
257-260		Line Fill Left Count (Row number 1).
261-264		Line Fill Right Count (Row number 1).
265-508		HRS Pixel Coordinates (Row number 2).
509-512		Line Fill Left Count (Row number 2).
513-516		Line Fill Right Count (Row number 2).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Each coordinate and grid line fill count (for all rows) is in the Fixed Point Grid Format (see figure 7).

Table 12.--Ancillary Map Projection Record Formats--Continued

Records 5 and 13.--Continued

Bytes	Type*	Description
517-768	FPG**	HRS Coordinates and Fill Counts (Row number 3.
769-3036		HRS Coordinates and Fill Counts (Row numbers 4-12).
3037-3600	B	Zero Fill (not used).

Records 6 and 14

Bytes	Type*	Description
1-4	B	Record number = $6)_{10}$ for UTM/PS; = $14)_{10}$ for SOM/HOM.
5-8	B	Record type code: byte 5 = $044)_8$ byte 6 = $044)_8$ byte 7 = $333)_8$ for UTM/PS $355)_8$ for SOM/HOM byte 8 = $022)_8$

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

**Each coordinate and grid line fill count (for all rows) is in the Fixed Point Grid Format (see figure 7).

Table 12.--Ancillary Map Projection Record Formats--Continued

Records 6 and 14.--Continued

Bytes	Type*	Description
9-12	B	Record length = $3600)_{10}$.
13-3036	FPG**	HRS Coordinates and Fill Counts (Row numbers 13-24).
3037-3600	B	Zero Fill (not used).

Records 7 and 15

Bytes	Type*	Description
1-4	B	Record number = $7)_{10}$ for UTM/PS; = $15)_{10}$ for SOM/HOM.
5-8	B	Record type code: byte 5 = $044)_8$ byte 6 = $044)_8$ byte 7 = $333)_8$ for UTM/PS $355)_8$ for SOM/HOM byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

**Each coordinate and grid line fill count (for all rows) is in the Fixed Point Grid Format (see figure 7).

Table 12.--Ancillary Map Projection Record Formats--Continued

Records 7 and 15.--Continued

Bytes	Type*	Description
13-3036	FPG**	HRS Coordinates and Fill Counts (Row numbers 25-36).
3037-3600	B	Zero Fill (not used).

Records 8 and 16

Bytes	Type*	Description
1-4	B	Record number = $8)_{10}$ for UTM/PS; = $16)_{10}$ for SOM/HOM.
5-8	B	Record type code: byte 5 = $044)_8$ byte 6 = $044)_8$ byte 7 = $333)_8$ for UTM/PS byte 8 = $355)_8$ for SOM/HOM
9-12	B	Record length = $3600)_{10}$.
13-3036	FPG**	HRS Coordinates and Fill Counts (Row numbers 37-48).
3037-3600	B	Zero Fill (not used).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

**Each coordinate and grid line fill count (for all rows) is in the Fixed Point Grid Format (see figure 7).

Table 12.--Ancillary Map Projection Record Formats--Continued

Records 9 and 17

Bytes	Type*	Description
1-4	B	Record number = $9)_{10}$ for UTM/PS; = $17)_{10}$ for SOM/HOM.
5-8	B	Record type code: byte 5 = $044)_8$ byte 6 = $044)_8$ byte 7 = $333)_8$ for UTM/PS $355)_8$ for SOM/HOM byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
13-768	FPG**	HRS Coordinates and Fill Counts (Row numbers 49-51).
769-1020	B	Zero Fill (not used).
1021-1264	FPG**	VRS Line Coordinates (Row number 1).
1265-2972		VRS Coordinates (Row numbers 2-8).
2973-3600	B	Zero Fill (not used).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

**Each coordinate and grid line fill count (for all rows) is in the Fixed Point Grid Format (see figure 7).

Table 12.--Ancillary Map Projection Record Formats--Continued

Records 10 and 18

Bytes	Type*	Description
1-4	B	Record number = $10)_{10}$ FOR UTM/PS; = $18)_{10}$ for SOM/HOM.
5-8	B	Record type code: byte 5 = $044)_8$ byte 6 = $044)_8$ byte 7 = $333)_8$ for UTM/PS $355)_8$ for SOM/HOM byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
13-2940	FPG**	VRS Coordinates (Row numbers 9-20).
2941-3600	B	Zero Fill (not used).

Records 11 and 19

Bytes	Type*	Description
1-4	B	Record number = $11)_{10}$ for UTM/PS; = $19)_{10}$ for SOM/HOM.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

**Each coordinate and grid line fill count (for all rows) is in the Fixed Point Grid Format (see Figure 7).

Table 12.--Ancillary Map Projection Record Formats--Continued

Records 11 and 19.--Continued

Bytes	Type*	Description
5-8	B	Record type code: byte 5 = $044)_8$ byte 6 = $044)_8$ byte 7 = $333)_8$ for UTM/PS $355)_8$ for SOM/HOM byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
13-2940	FPG**	VRS Coordinates (Row numbers 21-32).
2941-3600	B	Zero Fill (not used).

Records 12 and 20

Bytes	Type*	Description
1-4	B	Record Number = $12)_{10}$ FOR UTM/PS = $20)_{10}$ for SOM.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

**Each coordinate and grid line fill count (for all rows) is in the Fixed Point Grid Format (see figure 7).

Table 12.--Ancillary Map Project Record Formats--Continued

Records 12 and 20.--Continued

Bytes	Type*	Description
5-8	B	Record type code: byte 5 = $044)_8$ byte 6 = $044)_8$ byte 7 = $333)_8$ for UTM/PS $355)_8$ for SOM/HOM byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
13-2940	FPG**	VRS Coordinates (Row numbers 33-44).
2941-3084	B	Zero Fill (not used).
3085-3086	B	Pixel number of WRS center in fully processed image.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Each coordinate and grid line fill count (for all rows) is in the Fixed Point Grid Format (given in Figure 7).

Table 12.--Ancillary Map Project Record Formats--Continued

Records 12 and 20.--Continued

Bytes	Type*	Description
3087-3088	B	Offset of WRS center from fully processed image center pixel (in pixel units). Displacement of the WRS designation with respect to the picture center pixel (scan line 1492, pixel 1774). Most significant bit indicates the sign; "0" = positive with WRS center to right of picture center and 1" = negative with WRS center to left of picture center.
3089-3108	A	Temporal Registration Scene Identification. Same format as bytes 241-260 of Header.
3109-3140	B	Scan line and pixel numbers for temporal registration marks for referenced image and current image (image under processing, see Header bytes 261-324 and figure 8).
3141-3156	B	Overlap Data: scan line and pixel numbers (in binary) of the four overlap marks as given in Header bytes 325-356, table 8.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

FP, FL, FLS (see figure 7 for explanation)

Table 12.--Ancillary Map Project Record Formats--Continued

Records 12 and 20.--Continued

Bytes	Type*	Description
3157-3160	B	Actual number of tick marks. One byte for each edge: top, left, right and bottom.
3161-3168	B	Input sample value of four corner points in output image (band independent).
3169-3176	FLS	Image Orientation Angle - orientation of map projection coordinate system with respect to center line of fully processed image in radians.
3177-3178	B	NSWEEPS - number of sweeps prior to scene center at which the HRS, VRS grid points begin.
3179-3600	B	Zero Fill (not used).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
FP, FL, FLS (see figure 7 for explanation)

4.3.4 Annotation Record

The annotation record data contain the alphanumeric information printed by the film recorder at the bottom of the film product and the tick mark information that surrounds the corrected and framed image. For partially processed data, there will be two annotation records, the first with tick marks given in either the UTM or PS formats and the second with tick marks given in either the SOM or HOM formats. The format of the annotation record is given in table 13.

Segment C (bytes 413-3600) of the annotation record contains tick mark coordinates in either UTM, PS, SOM, or HOM projection formats. As indicated in header bytes 226-228, it may also include tick mark coordinates in latitude-longitude format with one tick mark coordinate value for each of the top, left, right and bottom tick mark zones (see figures 10, 11 and 12 for allowed tick mark formats).

Table 13.--Annotation Record Format

Bytes	Type*	Description
A. Record Introduction		
1-4	B	Record number = $3)_{10}$ for files preceeding fully processed image data: = $21)_{10}$ and $22)_{10}$ for files preceding partially processed image data.
5-8	B	Record type code: byte 5 = $022)_8$ byte 6 = $333)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
B. Image Annotation Data		
13-20	A	Day, month and year of image acquisition: 8 bytes of the form "DDMMMYYb̸" where MMM is a standard alpha abbreviation for month (ASCII).
21-37	A	Image format center - latitude and longitude of the center of the MSS image format in degrees and minutes; for example "Cb̸N33-05/W115-18".

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 13.--Annotation Record Format--Continued

Bytes	Type*	Description
B. Image Annotation Data--Continued		
38-46	A	WRS path and row identifier and orbital direction indicator: of form "XPPP-RRRȸ" where X indicates ascending (A) or descending (D) node, and PPP-RRR indicates WRS path & row numbers.
47-63	A	Nominal WRS center latitude and longitude; for example: "NȸN33-03/W115-42".
64-73	A	Sensor (MSS) and spectral band identification code of the form "SȸBBBBȸȸN" where: S = sensor, coded 'M' BBBB = Band by position, e.g., ȸ2ȸȸ indicates band 2 N = node; 'A' for ascending, 'D' for descending

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 13.--Annotation Record Format--Continued

Bytes	Type*	Description
B. Image Annotation Data--Continued		
74-87	A	Sun Angles - the sun elevation angle and sun azimuth angle measured clockwise from true North at time of midpoint of MSS frame is specified to the nearest degree (blank for ascending node coverage), for example "SUNbEL30bA015".
(88-99)		Processing Codes. These codes apply to the geometric correction matrix values and to the final geometrically corrected image data, and are as follows:

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 13.--Annotation Record Format--Continued

Bytes	Type*	Description
B. Image Annotation Data--Continued		
88	A	Defines the type of geometric correction applied to the data: "U" = uncorrected (engineering test mode) "S" = system level corrected (Systematic Correction Data (SCD) only, no control point correction applied) "G" = geometrically corrected based on geodetic information (no temporal registration performed since geodetic control points used were not from a single reference image) "T" = temporal registration to a single reference image (reference image corrected using geodetic control points) "R" = temporal registration to a single reference image (no geodetic information available when correcting reference image)
89	A	Blank (b̸).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 13.--Annotation Record Format--Continued

Bytes	Type*	Description
B. Image Annotation Data--Continued		
90	A	Defines the map projection: "P" = Polar Stereographic projection "S" = Space Oblique Mercator projection "U" = Universal Transverse Mercator projection "H" = Hotine Oblique Mercator projection
91	A	"_"
92	A	Indicates the resampling algorithm applied: "C" = cubic convolution "N" = nearest neighbor "b̸" = geometrically uncorrected imagery
93	A	Indicates the type of ephemeris data used to compute the geometric correction matrices: "P" = predictive "D" = definitive "G" = Global Positioning System (GPS)
94	A	"_"

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 13.--Annotation Record Format--Continued

Bytes	Type*	Description
B. <u>Image Annotation Data</u>--Continued		
95	A	Gives the processing procedure: "N" = normal processing procedure "A" = abnormal processing procedure (engineering test mode)
96	A	Blank (ƀ).
97	A	Indicates the sensor gain: "H" = high gain "L" = low gain
98	A	Shows the type of MSS transmission: 1 = linear mode 2 = compressed mode
99	A	Blank (ƀ).
100-112	A	Agency and Project identification: alpha characters, coded "NASAƀLANDSATƀ".

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 13.--Annotation Record Format--Continued

Bytes	Type*	Description
B. Image Annotation Data--Continued		
113-127	A	Frame identification number - each image or frame will have a unique identifier which will contain encoded information consisting primarily of time of acquisition (Universal Time) relative to launch. Its format is E-NDDDD-HHMMS-B and is interpreted as follows: E = Encoded project identifier N = Landsat mission number DDDD = Day number relative to launch, at time of observation HH = Hour at time of observation MM = Minute at time of observation S = Tens of seconds at time of observation B = Band identification code: 1, 2, 3 or 4 for Landsat-4; 4, 5, 6, 7 or 8 for Landsat-2/3
128-410	B	Zero Fill (not used).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

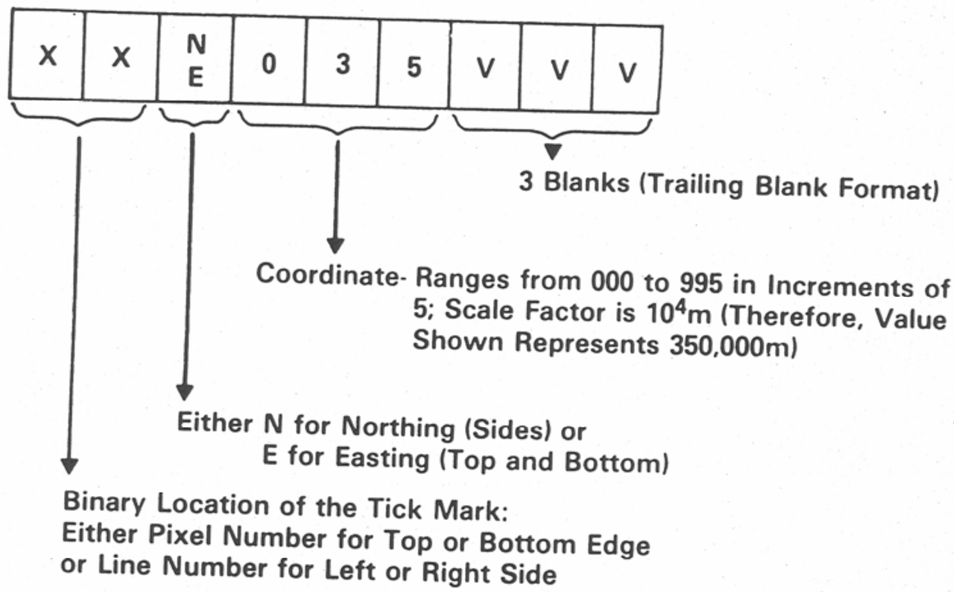
B = Binary

Table 13.--Annotation Record Format--Continued

Bytes	Type*	Description
C. Tick Mark Coordinate Data		
411-554	B,A	Top edge tick mark data.
555-808	B	Zero Fill (not used).
809-970	B,A	Left side tick mark data, first.
971-1206	B	Zero Fill (not used).
1207-1269	B,A	Left side tick mark data, concluding.
1270-1604	B	Zero Fill (not used).
1605-1766	B,A	Right side tick mark data, first.
1767-2002	B	Zero Fill (not used).
2003-2065	B,A	Right side tick mark data, concluding.
2066-2400	B	Zero Fill (not used).
2401-2544	B,A	Bottom edge tick mark data.
2545-3600	B	Zero Fill (not used).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

UTM Tick Mark (ASCII Notation)



Polar Stereographic Tick Mark (ASCII Notation)

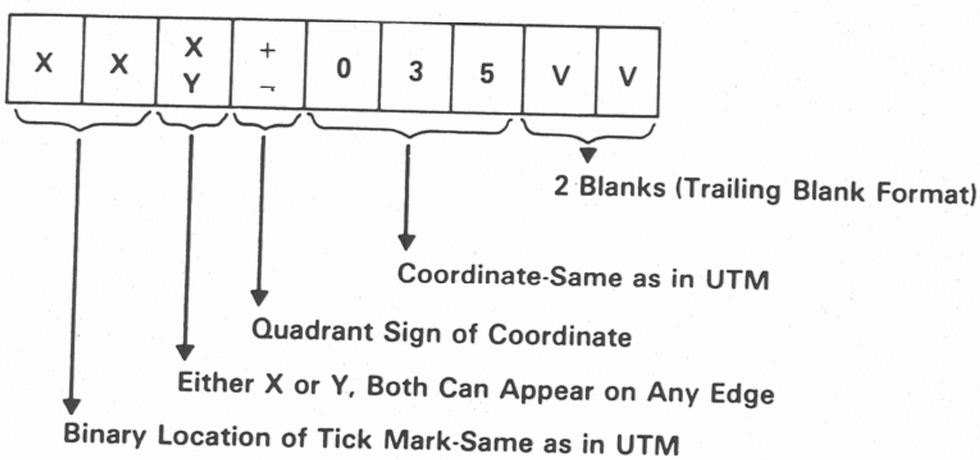


Figure 10. --Annotation Tick Mark Formats for UTM and PS

SOM/HOM Tick Mark (ASCII Notation)

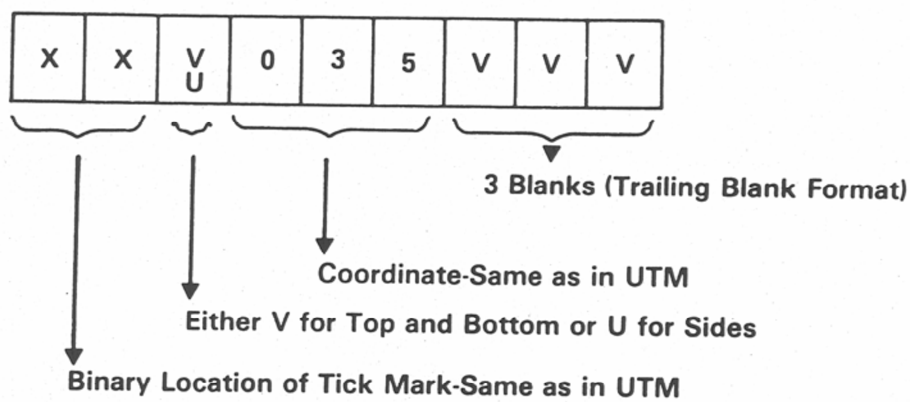


Figure 11. --Annotation of Tick Mark Formats for SOM/HOM

Latitude, Longitude Tick Mark

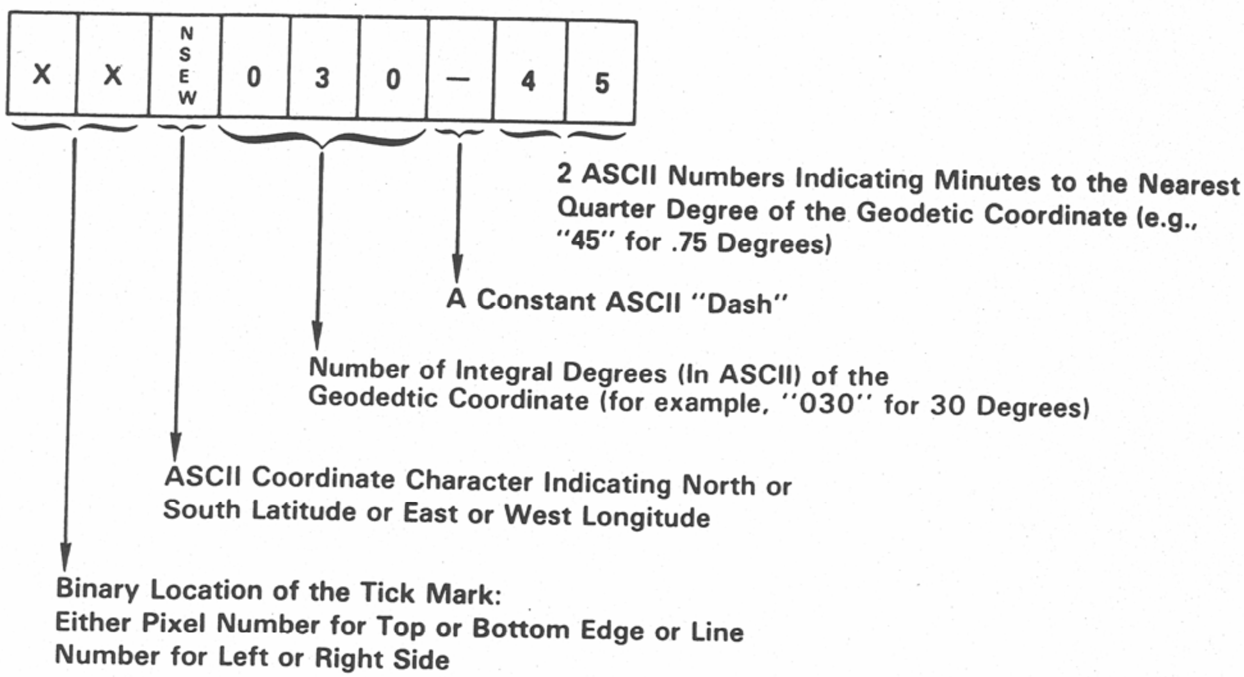


Figure 12. --Annotation Tick Mark Formats for Latitude and Longitude

4.4 Image File

The image file is composed of a file descriptor record and image data records. It follows the leader file as illustrated in figure 5. The image file contains the actual image data, along with data format information and per-line support data such as quality codes, fill pixel counts, and scan line identifications.

4.4.1 File Descriptor Record

The file descriptor record is the first record of each image file, and it introduces that file. The image file descriptor record variable segment (bytes 181-448) gives the number and length of the image records; describes the data format in terms of the pixel group, the data content, and the overall image; and gives the location of significant data fields in the record prefix and suffix. Specific field locator information in bytes 297 through 448 is given in a series of 8-byte codes each of which are structured as follows:

Bytes	Description
1-4	The byte number within the prefix or suffix of the first byte of the field.
5-6	The length, in bytes, of the field.
7	Coded "P" or "S" indicating that the information is in the scan line prefix or suffix, respectively.
8	Indicates the type of data in the field. Codes "A" for alphanumeric; "N" for numeric; "B" for binary.

The format of the image file descriptor record is given in table 14.

Table 14.--The File Descriptor Record Format for the Image File.

Bytes	Type*	Description
1-4	B	Record number = $1)_{10}$
5-8	B	Record type code: byte 5 = $077)_8$ byte 6 = $300)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Length of this record = $3600)_{10}$.
13-14	A	ASCII/EBCDIC flag for this file = "Aƀ" indicating ASCII. (EBCDIC not available.)
15-16	A	Blanks.
17-28	A	Control document number for this embodiment (i.e., this document's number)
29-30	A	Control document number for this embodiment revision number (i.e., this documents revision number).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 14.--The file Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
31-32	A	File design descriptor revision letter: 2-bytes giving the revision letter of the file format (as opposed to revisions which affect the control document without affecting the file format). Coded "ȸA" unless this record format is modified.
33-44	A	Software release number for this file.
45-48	N	File number: sequence number of this file within the logical volume. The volume directory file is not included in this count.
49-64	A	File identification: same as file pointer record, bytes 21-36.
65-68	A	Record sequence and location type flag: always coded "FSEQ" indicating a fixed record location of record numbers.
69-76	N	Sequence number location: always coded "ȸȸȸȸȸȸȸ1" indicating that record number starts in record byte one.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 14.--The File Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
77-80	N	Sequence number field length: always coded "ƀƀƀ4" indicating a 4 byte record number field.
81-84	A	Record code and location type flag: always coded "FTYP" indicating a fixed record location of the type code field.
85-92	N	Record code location: always coded "ƀƀƀƀƀƀƀ5" indicating that record code starts in record byte five.
93-96	N	Record code field length: always coded "ƀƀƀ4" indicating a 4 byte record code.
97-100	A	Record length and location type flag: always coded "FLGT" indicating a fixed record location of the record length field.
101-108	N	Record length location: always coded "ƀƀƀƀƀƀƀ9" indicating that record length field starts in record byte nine.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 14.--The File Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
109-112	N	Record length field length: always coded "ƀƀƀ4" indicating a 4 byte record length field.
113	A	Flag indicating that data interpretation information is included within file descriptor record: coded "N" indicating NO.
114	A	Flag indicating that data interpretation information is included within records other than the file descriptor record: coded "N".
115	A	Flag indicating that data display information is included with the file descriptor record: coded "N".
116	A	Flag indicating that data display information is included within the file in record(s) other than the file descriptor: coded "N".
117-180	A	Reserved segment (Blank filled).

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 14.--The File Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
181-186	N	Number of image records = $2983)_{10}$ for fully processed BSQ; = $2400)_{10}$ for partially processed BSQ; = $11,932)_{10}$ for fully processed Landsat-2/4 BIL; = $14,915)_{10}$ for fully processed Landsat-3 BIL; =$9600)_{10}$ for partially processed Landsat-2/4 BIL; = $12,000)_{10}$ for partially processed Landsat-3 BIL.
187-192	N	Image record length = $3600)_{10}$.
193-216	A	Reserved (blanks).
		<u>Pixel Group Data</u>
217-220	N	Number of bits per pixel = 8.
221-224	N	Number of pixels per data group = 1.
225-228	N	Number of bytes per data group = 1.
229-232	A	Justification and order of pixels within data group: coded "RJLR".

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 14.--The File Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
		Image Data in this File
233-236	N	Number of (images) bands = 1 for BSQ; = 4 for Landsat-2/4 BIL; 5 for Landsat-3 BIL.
237-244	N	Number of lines per image (excluding border lines) = 2983 for fully processed image data; = 2400 for partially processed image data.
245-248	N	Number of left border pixels per line: coded zero indicating no constant border.
249-256	N	Number of image pixels per line (includes pad pixels).
257-260	N	Number of right border pixels per line: coded zero indicating no constant border.
261-264	N	Number of top border lines: coded zero indicating no constant border.
265-268	N	Number of bottom border lines: coded zero indicating no constant border.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 14.--The File Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
		Image Data in this File--Continued
269-272	A	Interleaving indicator coded "BSQ$\not{b}$" or "BIL$\not{b}$".
		Record Data in this File
273-274	N	Number of physical records per line = 1.
275-276	N	Number of physical records per multispectral line in this file = $4)_{10}$ if Landsat-2/4 BIL; = $5)_{10}$ if Landsat-3 BIL; = $1)_{10}$ if BSQ.
277-280	N	Number of bytes of prefix data per record = $12)_{10}$.
281-288	N	Number of bytes of image data per record = $3548)_{10}$ (includes pad pixels).
289-292	N	Number of bytes of suffix data per record $28)_{10}$ (note that suffix is "Ø" filled for fully processed imagery)
293-296	A	Blanks

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 14.--The File Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
		<u>Prefix/Suffix</u> <u>Data</u> <u>Locators:</u>
297-304	A	Scan line number locator: coded "b̸b̸b̸1b2PB" for fully processed image data or blanks for partially processed image data.
305-312	A	Image (band) number locator: coded blanks for fully processed image data or "b̸b̸11b̸1PB" for partially processed image data.
313-320	A	Time of scan line locator: coded blanks for fully processed image data or "b̸b̸b̸110PA" for partially processed image data.
321-328	A	Left-fill count locator: coded blanks for partially processed image data, "b̸b̸b̸5b̸4PB" for fully processed image data.
329-336	A	Right-fill count locator: coded blanks for partially processed image data, "b̸b̸b̸9b̸4PB" for fully processed image data.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 14.--The File Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
		Prefix/Suffix Data Locators--Continued
337-368	A	Blanks
369-376	A	Scan line quality code locator: coded "ƀƀƀ3ƀ2PA" for fully processed image data or "ƀƀƀ4ƀ1SB" for partially processed image data.
377-384	A	Calibration information field locator: coded blanks for fully processed image data or "ƀƀƀ5ƀ6SB" for partially processed image data.
385-392	A	Gain values field locator: coded blanks for fully processed image data or "ƀƀ13ƀ2SB" for partially processed image data.
393-400	A	Bias values field locator: coded blanks for fully processed image data or "ƀƀ17ƀ2SB" for partially processed image data.
401-432	A	Blanks

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 14.--The File Descriptor Record Format for the Image File--Continued

Bytes	Type*	Description
		Prefix/Suffix Data Locators--Continued
433-436	N	Number of left fill bits within pixel: coded "ƀƀƀ1".
437-440	N	Number of right fill bits within pixel: coded "ƀƀƀ0".
441-448	N	Maximum data range of pixel values: coded "ƀƀƀƀƀ127".
449-3600	A	Blanks.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

4.4.2 Image Data Records

An image data record contains one scan line of MSS imagery plus associated support data such as calibration, pad pixels, and quality. The 12 bytes of standard record introductory data (record number, record type code and record length) are followed by a 12-byte scan line identifier. The scan line identifier has a different format depending on whether the image data have or have not been geometrically corrected. The scan line identifier is followed by image data, and these are followed by support data when the image has not been geometrically corrected. The per-scan-line support data are defined in the file descriptor record variable segment and described in the header record, as are the length, justification, and pixel content of image data groups. It should be repeated that end-of-line support (suffix) data only accompany data that do not have geometric corrections applied; the support-data section of geometrically corrected image data is zero-filled (that is, not used). The format and content of the image data record are given in table 15 for geometrically uncorrected image data (CCT-AM) and table 16 for geometrically corrected image data (CCT-PM).

Table 15.--Image Record Format for Geometrically Uncorrected Data (CCT-AM).

Bytes	Type*	Description
A. Record Introduction		
1-4	B	Record number = $2)_{10}$ for 1st image record and incremented by one for each subsequent record.
5-8	B	Record type code: byte 5 = $355)_8$ byte 6 = $355)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
B. Prefix Data		
13-22	A	Scan line time in the form: "DDDHHMMSST" where DDD = day of year HH = hour MM = minutes SS = seconds T = tenths of second
23	N	Band indicator.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 15.--Image Record Format for Geometrically Uncorrected Data (CCT-AM)--Continued

Bytes	Type*	Description
B. Prefix Data--Continued		
24	B	Scan line count reset to 1 every other mirror sweep cycling 1-12)$_{10}$ throughout image.
C. Image Data		
25-3572	B	Image pixels.
D. Suffix (Support) Data		
3573-3574	B	Original line length - the actual number of pixels in the original geometrically uncorrected image scan line.
3575	B	Time Code Indicator - contains a 1)$_{10}$ if time code in SLID was calculated (i.e., was not obtained from video data stream) otherwise zero.
3576	B	Quality Code: 0)$_{10}$ - Good Quality 1)$_{10}$ - Not used in Landsat 4 2)$_{10}$ - Filled line on Input 3)$_{10}$ - Filled line on Output

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 15.--Image Record Format for Geometrically Uncorrected Data (CCT-AM)--Continued

Bytes	Type*	Description
D. Suffix (Support) Data--Continued		
3577-3582	B	Selected Calibration Wedge Values (CWV's) - six 1 byte binary numbers; one for each Calibration Wedge sample (Binary values ranging from 0 to 63).
3583	B	Nominal Cal. Indicator of Calibration Wedge substitution: of the form ØØ$X_1X_2X_3X_4X_5X_6$ where bits X_1 thru X_6 are flags for each wedge sample, e.g., 00000100 indicates that sample #4 was replaced by a nominal value.
3584	B	Zero fill.
3585-3586	B	Calibration Wedge Gain Value applied in the radiometric correction process. A 16-bit binary number** with bit 15 being the left-most bit and bit 0 the right-most. The value has a fixed binary point between bits 10 and 9.
3587-3588	B	Zero fill.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

**Negative numbers (bit 15=1) are represented in two's complement form.

Table 15.--Image Record Format for Geometrically Uncorrected Data (CCT-AM)--
Continued

Bytes	Type*	Description
D. Suffix (Support) Data--Continued		
3589-3590	B	Calibration Wedge Bias Value applied in the radiometric correction process. A 16-bit binary number** with bit 15 the left-most bit and bit Ø the right-most. The value has a fixed binary point between bits 2 and 1.
3591-3592	B	Zero fill
(3593-3600)	-	Zero filled for Landsat-2/3. Following for Landsat-4:
3593-3594	B	Histogram Gain Value - (same format as Calibration Wedge Gain Value).
3595-3596	B	Zero fill
3597-3598	B	Histogram Bias Value - (same format as Calibration Wedge Bias Value).
3599-3600	B	Zero fill

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary
**Negative numbers (bit 15=1) are represented in two's complement form.

Table 16.--Image Record Format for Geometrically Corrected Data (CCT-PM).

Bytes	Type*	Description
A. Record Introduction		
1-4	B	Record number = $2)_{10}$ for 1st record incremented by one for each subsequent record.
5-8	B	Record type code: byte 5 = $355)_8$ byte 6 = $355)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
B. Prefix Data		
13-14	B	Scan line count, $1\text{-}2983)_{10}$.
15-16	A	Scan line quality code of the form: "QØ" - Good Quality "Q1" - Synthetically generated on input (not used in Landsat 4) "Q2" - Filled line on Input "Q4" - Filled line on Output
17-20	B	Left fill pixel count.
21-24	B	Right fill pixel count.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 16.--Image Record Format for Geometrically Corrected Data (CCT-PM)--
Continued

Bytes	Type*	Description
C. <u>Image Data</u>		
25-3572	B	Image pixels.
D. <u>Suffix (Support) Data</u>		
3573-3600	B	Zero fill.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

4.5 Trailer File

The trailer file follows the image data file. The trailer file is composed of a file descriptor record and one trailer record in the case of BSQ or one trailer record for each band in the case of BIL.

A trailer file descriptor record (the first record of each trailer file), introduces and describes the trailer file. The general record format and content of the trailer file descriptor record is given in table 17.

Following the file descriptor, the trailer data records provide space for user information and/or control fields. The first 12 bytes are the standard introductory data (record number, record type code, and record length). The format for a trailer record is given in table 18.

Table 17.--The File Descriptor Record Format for the Trailer File.

Bytes	Type*	Description
1-4	B	Record number = $1)_{10}$.
5-8	B	Record type code: byte 5 = $077)_8$ byte 6 = $300)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Length of this record = $3600)_{10}$.
13-14	A	ASCII/EBCDIC flag for this file = "Ab̸" indicating ASCII (EBCDIC not available).
15-16	A	Blanks.
17-28	A	Control document number for this embodiment (i.e., this document's number).
29-30	A	Control document number for this embodiment revision number (i.e., this documents revision number).

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 17.--The File Descriptor Record Format for the Trailer File--Continued

Bytes	Type*	Description
31-32	A	File design descriptor revision letter: 2-bytes giving the revision letter of the file format (as opposed to revisions which affect the control document without affecting the file format). Coded "b̸A" unless this record format is modified.
33-44	A	Software release number for this file.
45-48	N	File number: sequence number of this file within the logical volume. The volume directory file is not included in this count.
49-64	A	File identification: same as file pointer record, bytes 21-36.
65-68	A	Record sequence and location type flag: always coded "FSEQ" indicating a fixed record location of record numbers.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 17.--The File Descriptor Record Format for the Trailer File--Continued

Bytes	Type*	Description
69-76	N	Sequence number location: always coded "b̸b̸b̸b̸b̸b̸b̸1" indicating that record number starts in record byte one.
77-80	N	Sequence number field length: always coded "b̸b̸b̸4" indicating a 4 byte record number field.
81-84	A	Record code and location type flag: always coded "FTYP" indicating a fixed record location of the type code field.
85-92	N	Record code location: always coded "b̸b̸b̸b̸b̸b̸b̸5" indicating that record code starts in record byte five.
93-96	N	Record code field length: always coded "b̸b̸b̸4" indicating a 4 byte record field.
97-100	A	Record length and location type flag: always coded "FLGT" indicating a fixed record location of the record length field.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 17.--The File Descriptor Record Format for the Trailer File--Continued

Bytes	Type*	Description
101-108	N	Record length location: always coded "ƀƀƀƀƀƀƀ9" indicating that record length field starts in record byte nine.
109-112	N	Record length field length: always coded "ƀƀƀ4" indicating a 4 byte record length field.
113	A	Flag indicating that data interpretation information is included within file descriptor record: coded "N" indicating NO.
114	A	Flag indicating that data interpretation information is included within records other than the file descriptor record: coded "N".
115	A	Flag indicating that data display information is included with the file descriptor record: coded "N".

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 17.--The File Descriptor Record Format for the Trailer File--Continued

Bytes	Type*	Description
116	A	Flag indicating that data display information is included within the file in record(s) other than the file descriptor: coded "N".
117-180	A	Reserved segment (Blank filled).
181-186	N	Number of trailer records = $1)_{10}$ for BSQ, $4)_{10}$ for Landsat-2/4 BIL, or $5)_{10}$ for Landsat-3 BIL.
187-192	N	Trailer record length = $3600)_{10}$
193-3600		Reserved (blanks)

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

Table 18.--Trailer Record Format

Bytes	Type*	Description
1-4	B	Record number = $2)_{10}$ (also records 3, 4, 5 and/or 6 if BIL).
5-8	B	Record type code: byte 5 = $022)_8$ byte 6 = $366)_8$ byte 7 = $022)_8$ byte 8 = $022)_8$
9-12	B	Record length = $3600)_{10}$.
13	A	Flag indicating last scene (each image) in a data acquisition interval: "N" = No "Y" = Yes
14-3580	B	Zero fill.
3581-3582	A	Destriping indicator: "N" = none applied "Y" = applied.
3583-3584	A	Units of following contrast stretch values: "P" = percentage "G" = gray levels.

*Denotes field type:
A = Alphanumeric (ASCII)
N = Numeric (ASCII)
B = Binary

Table 18.--Trailer Record Format--Continued

Bytes	Type*	Description
3585-3588	B	Minimum cut-off value of contrast stretch
3589-3592	B	Maximum cut-off value of contrast stretch
3593-3596	B	Radiance value used for atmospheric scatter compensation (haze bias value).
3597 - 3600	B	Edge enhancement kernel size X,Y. Two values two bytes each.

*Denotes field type:

A = Alphanumeric (ASCII)

N = Numeric (ASCII)

B = Binary

4.6 Null Volume Directory File

The file which terminates a logical volume is the null volume directory file. This file is referred to as "null" because it defines a non-existant (empty) logical volume. This file consists of a volume descriptor record only. The format and content of a volume descriptor record is described in section 4.2.1.

5.0 APPLICABLE DOCUMENTS

American National Standards Institute, 1973a, Recorded Magnetic Tape for Information Interchange (800 CPI, NRZI): ANSI X3.22-1973.

American National Standards Institute, 1973b, Recorded Magnetic Tape for Information Interchange (1600 CPI, PE): ANSI X3.39-1973.

Landsat Ground Station Operations Working Group, 1979, The Standard CCT Family of Tape Formats: LGSOWG Doc. CCB-CCT-0002-C.

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