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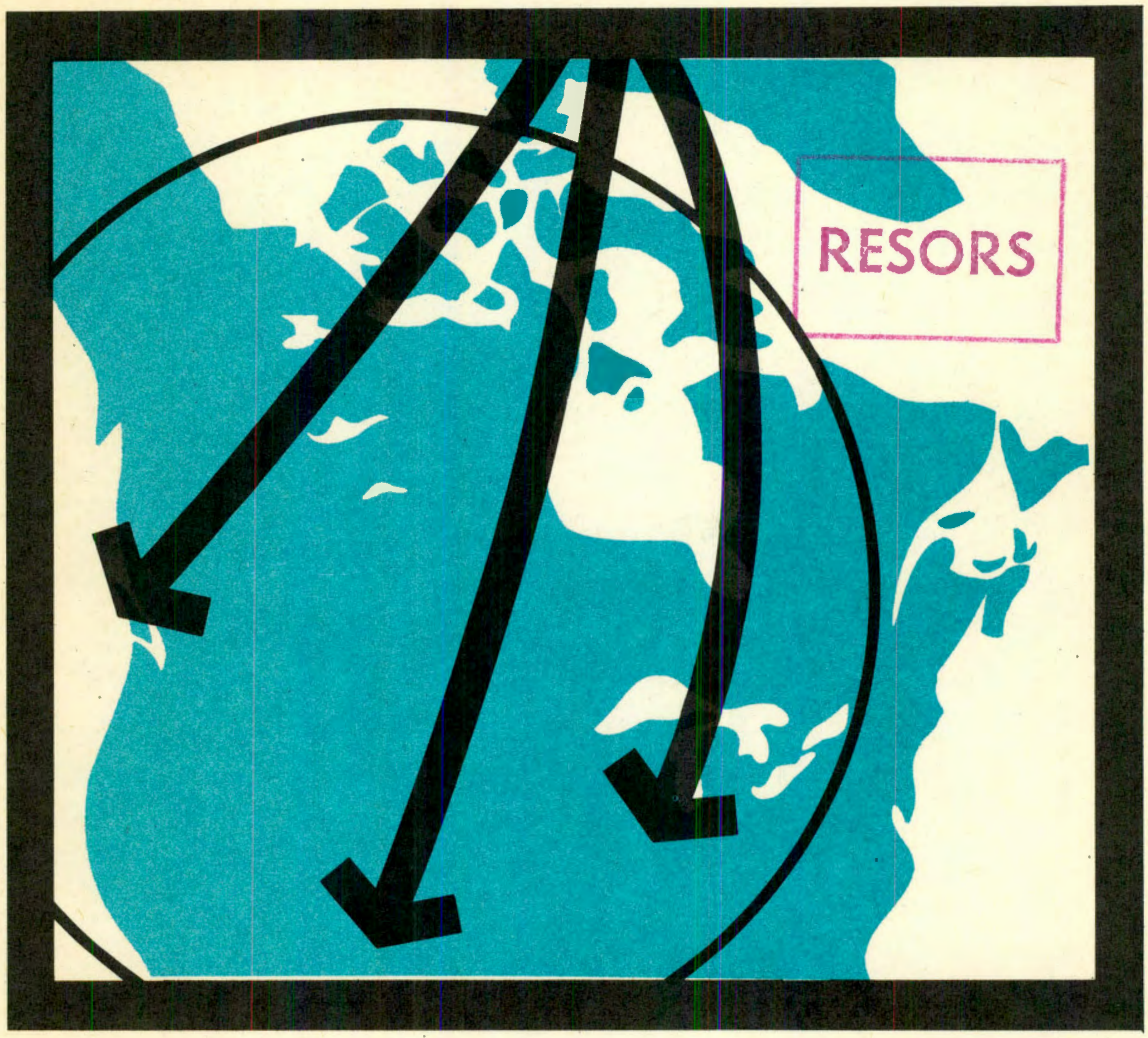
EARTH RESOURCES TECHNOLOGY SATELLITE DATA USER'S HANDBOOK



DEPARTMENT OF ENERGY,
MINES AND RESOURCES
CANADA CENTRE FOR REMOTE SENSING

The Canada Centre for Remote Sensing gratefully acknowledges the permission granted by the United States Government for the use of large extracts from the NASA Earth Resources Technology Satellite Data Users Handbook in the preparation of this publication.

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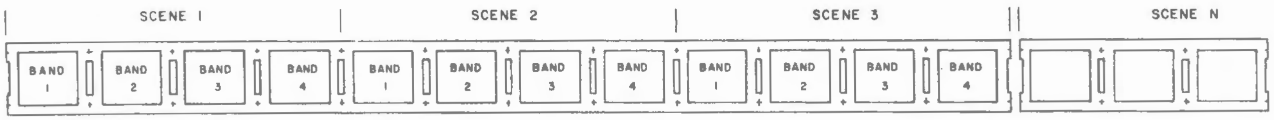
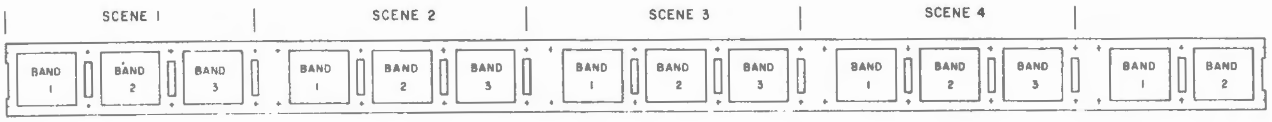


MSS FILM ROLL LAYOUT



RBV FILM ROLL LAYOUT

MSS AND RBV VIDEO TAPE TO FILM CONVERSION IS PERFORMED BY THE ELECTRON BEAM RECORDER (EBR). THE EBR "GROUPS" THE IMAGES ON THE ARCHIVAL FILM ROLL BY SCENES, AS ILLUSTRATED. A SCENE IS ONE 25-SECOND, 100 BY 100 NAUTICAL MILE OBSERVATION.

Figure 3-3 Roll Form Scene/Band layout

SECTION 1
INTRODUCTION

The Earth Resources Technology Satellite (ERTS) program is a major first step in the merger of space and remote sensing technologies into an R&D system for developing and demonstrating the techniques for efficient management of earth's resources. To establish the feasibility of these techniques, NASA launched the experimental ERTS-1 satellite into orbit on July 23 1972 and will launch a second satellite, ERTS B, early in 1976. Each will acquire multispectral images of the earth's surface and transmit this raw data through ground stations to data processing centers at the NASA Goddard Space Flight Center and the Canada Centre for Remote Sensing (CCRS) for conversion into black-and-white or colour photographs and computer tapes to fulfill the varied requirements of investigators and user agencies. In addition, ERTS Systems will collect environmental data from remote, earth-based instrument platforms and relay this information to the data processing center at Goddard for final processing and dissemination to investigators. The role of the "user" is an integral and indispensable part of the ERTS program. Investigator's experimentation with, and analysis of, the ERTS data products is the only meaningful route to developing and demonstrating the utility of data acquired by satellite systems of this type for use in earth resources management. Future operational earth resources satellite and data system requirements will be derived from user experience with ERTS 1/B data.

This handbook has been designed to satisfy Canadian user needs for pertinent and sufficient information about ERTS data products, and how to acquire them. The main body of the handbook provides information required by all investigators. The appendices provide more detailed treatment of topics required by many investigators to varying degrees. A brief description of the section contents follows:

Section 2 ERTS Program Description

Provides a concise explanation of the total ERTS system and its mission. An overview of the various major system elements and their characteristics, the observatory, payloads, orbit and coverage, ground facilities and services available to users is included in this section.

Section 3 Output Data Products

Provides a detailed description of each type of data that is available to Canadian user with information on data format, content, annotation, and pertinent characteristics.

Section 4 User Services

Provides a discussion of how ERTS output data products are obtained, and what catalogs, listings, facilities, and other materials and services are available to assist the user in identification, selection and use of these products.

APPENDICES

These provide in-depth treatment of selected topics considered to be of special interest to many users. These topics are:

A. Payload — Describes equipment, characteristics, and operating modes of RBV (Return Beam Vidicon), MSS (Multi Spectral Scanner), and DCS (Data Collection System) payloads.

B. Observatory — Describes spacecraft configuration and subsystems which control and support payload and mission activities.

C. Ground Stations and Ground Communication — Describes STADAN (Space Tracking and Data Acquisition Network) stations and PASS (Prince Albert Satellite Station) which support the ERTS mission, and the transfer of data to the CCRS Data Processing Division in Ottawa.

D. Operations Control Center — Describes the function performed by this facility in planning and conducting the flight operations and its role in the collection of payload data.

E. CCRS/NAPL Data Processing Facility — Describes the conversion and correction of raw video tapes into useful photographic and digital tape products. The different types of processing at the CCRS and NAPL are considered and the equipments that perform these processes are described.

F. System Performance — Describes the expected quality of the various imagery and data tapes principally in terms of resolution, geometric accuracy and radiometric fidelity.

G. Data Calibration — Describes the source of data and application of the corrections made to the data products prior to distribution by the NAPL.

H. Film and Developer Characteristics — Describes the intermediate and final film products and their processing characteristics.

I. Orbit and Coverage — Describes the orbital constraints on the collection of data and the systematic coverage which results.

J. Orbit Control — Describes the process of establishing and maintaining the desired orbital coverage and its limitations.

K. Mission Planning — Describes the system used to obtain the maximum amount of useful data within overall system constraints and environmental conditions.

L. Sun Illumination — Describes the earth illumination conditions and their variability with latitude and season of the year.

M. Sample Products — Provides samples of actual ERTS-1 imagery.

N. CCRS Interpretative Aids — Describes the equipment available at CCRS to aid in the development of automatic interpretation methods.

Acronyms, Glossary and References

Provides suggested reference materials for further treatment of selected topics; a definition of terms used throughout this handbook which may require explanation to avoid misinterpretation; and a list of acronyms frequently used to minimize repetition of multiple-word titles.

Development of the ERTS Observatory and the Ground Data Handling Systems are proceeding concurrently with preparation of this handbook. Consequently, the document is bound in looseleaf form to facilitate continuous updating. Each page is identified in the lower outside corner as an original or a revised page (including the revision number and date). New or changed information affecting users' participation in the program will be issued periodically. A change bar will be printed in the left-hand margin, opposite revised information. Sample data products of the Ground Data Handling System are provided in Appendix M of the handbook.

Distribution of this handbook and subsequent update material will be made in accordance with a controlled list established by CCRS. Each recipient is assigned a control number for each handbook. To insure rapid response, this control number must be used for all ERTS correspondence. For additional information or related inquiries regarding this handbook or its contents, please address all correspondence to:

Canada Centre for Remote Sensing
Department of Energy, Mines and
Resources,
2464 Sheffield Road,
Ottawa, Ontario.
K1A 0E4
Attention: ERTS User Liaison

SECTION 2
ERTS PROGRAM DESCRIPTION

The Earth Resources Technology Satellite (ERTS) Program has been designated as a research and development tool to demonstrate that remote sensing from space is a feasible and practical approach to efficient management of the earth's resources. The knowledge gained from the application of data acquired by the two satellites [ERTS 1 (designated ERTS-A prior to launch) and ERTS B] will point the way toward development of fully operational and more effective systems for earth resources management.

Figure 2-1 shows examples of ERTS-1 photographs to give the user an appreciation of the scale and image quality that can be expected.

These and other types of ERTS data products will be used by investigators for developing practical applications in the various earth resources study disciplines including agriculture, forestry, geology, geography, hydrology and oceanography. With the knowledge gained from the application of ERTS data in these and other disciplines over the next few years, it is anticipated that mankind can realize widespread benefits.

2.1 ERTS MISSION

To achieve its broad objectives, the mission of ERTS-1 and B provides for the repetitive acquisition of high resolution multispectral data of the earth's surface on a global basis. Two sensor systems have been selected for this purpose: a four-channel Multispectral Scanner (MSS) subsystem for ERTS 1 (five channels for ERTS B), and a three-camera Return Beam Vidicon (RBV) system. In addition, the ERTS Observatory is utilized as a relay system to gather data from remote, widely distributed, earth-based sensor platforms equipped by the individual investigators. The data acquired by the total ERTS System will thus permit quantitative measurements to be made of earth-surface characteristics on a spectral, spatial, and temporal basis.

The overall ERTS 1/B System is illustrated in Figure 2-2. The Observatory carries a payload of imaging multispectral sensors (MSS and RBV), wideband video tape recorders, and the spaceborne portion of a Data Collection System (DCS). The spacecraft "housekeeping" telemetry, tracking, and command subsystems are compatible with stations from either NASA's Manned Space Flight Network (MSFN) or its Space Tracking and Data Acquisition Network (STADAN). Wideband payload video data is received at one STADAN site at Fairbanks, Alaska; at two MSFN sites: Goldstone, California, and the GSFC Network Test and Training Facility (NTTF) at Greenbelt, Maryland; and at the Prince Albert Satellite Station (PASS) located near Prince Albert, Saskatchewan. The Operations Control Center (OCC) is the focal point of mission orbital operations. Here the overall system is scheduled, spacecraft commands are originated and orbital operations are monitored and evaluated. DCS, telemetry, and command data transfer between OCC and remote ground sites is accomplished by NASA Communications (NASCOM). Orbital parameters and calibration information are sent to the CCRS via this network.

The CCRS accepts payload video and housekeeping data in the form of magnetic tapes which are shipped via air from Prince Albert, or, in the case of East Coast data, from the NASA Goddard Space Flight Center. CCRS/NAPL then perform the video-to-film conversion and correction, producing black and white images from individual spectral bands and colour composites from several spectral bands.

CCRS maintains an information retrieval system for all ERTS data collected over Canada. The NAPL provides for the processing, reproduction and delivery of photographic products and special computer services.

PRECISION PROCESSED IMAGE

Figure 2-1. Color Composite of ▶
Precision Processed Image

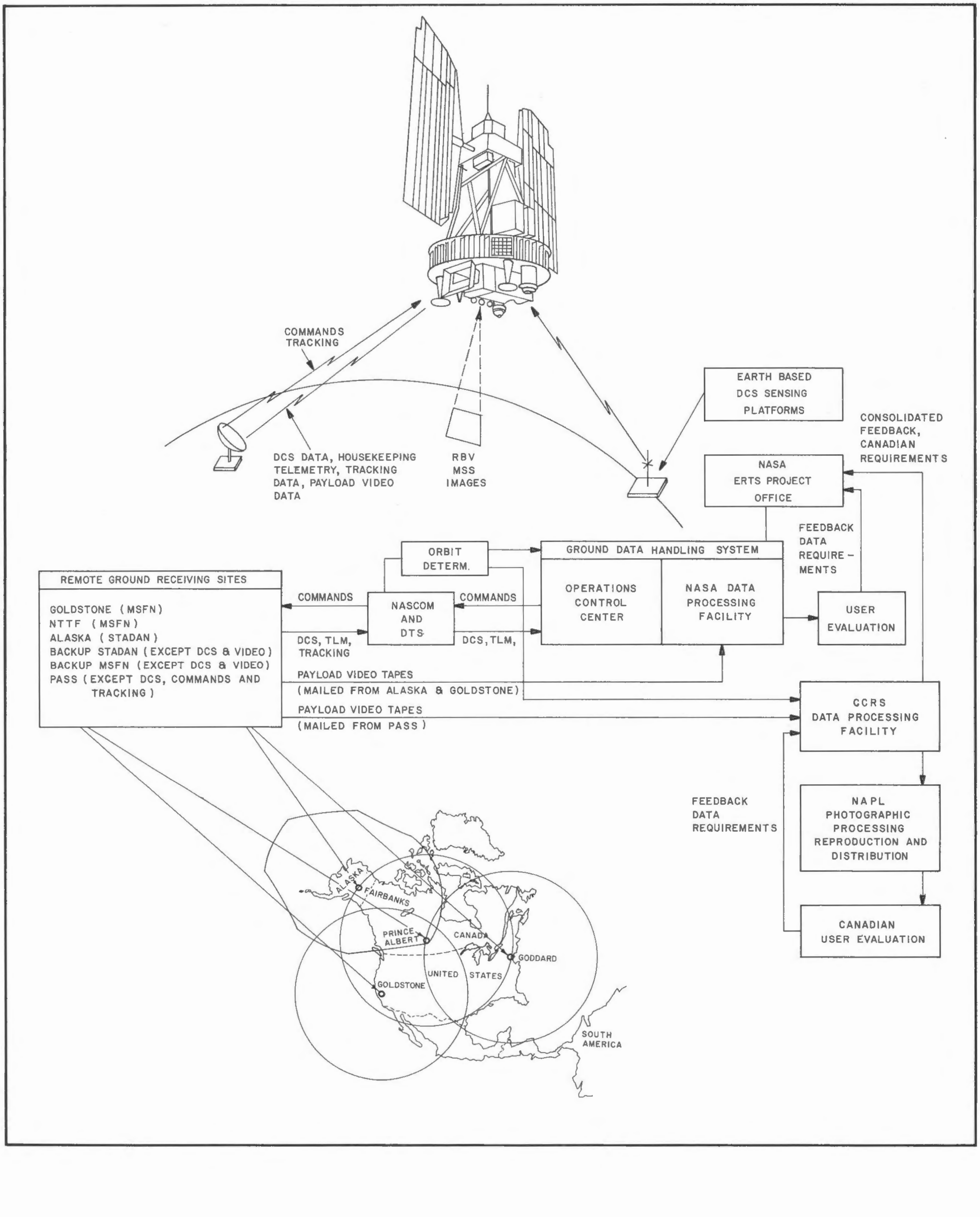


Figure 2-2. Overall ERTS System

2.2 OBSERVATORY SYSTEM

The elements of the Observatory system include the payload subsystems and the various support subsystems comprising the spacecraft vehicle. The Observatory configuration is shown in Figure 2-3.

Control of observatory attitude to the local vertical and orbit velocity vectors within 0.7 degree of each axis is achieved by a three axis active Attitude Control Subsystem. It uses horizon scanners for pitch and roll control, and a gyro-compassing mode for yaw orientation. An independent passive Attitude Measurement Sensor (AMS), operating over a narrow range of about 2 degrees, provides pitch and roll attitude data accurate to within 0.07 degree to aid in image location. Orbit adjustment capability is furnished by a monopropellant hydrazine subsystem employing one-pound force thrusters. This system is used to remove launch vehicle injection errors, and to provide periodic trim to maintain a precise orbit.

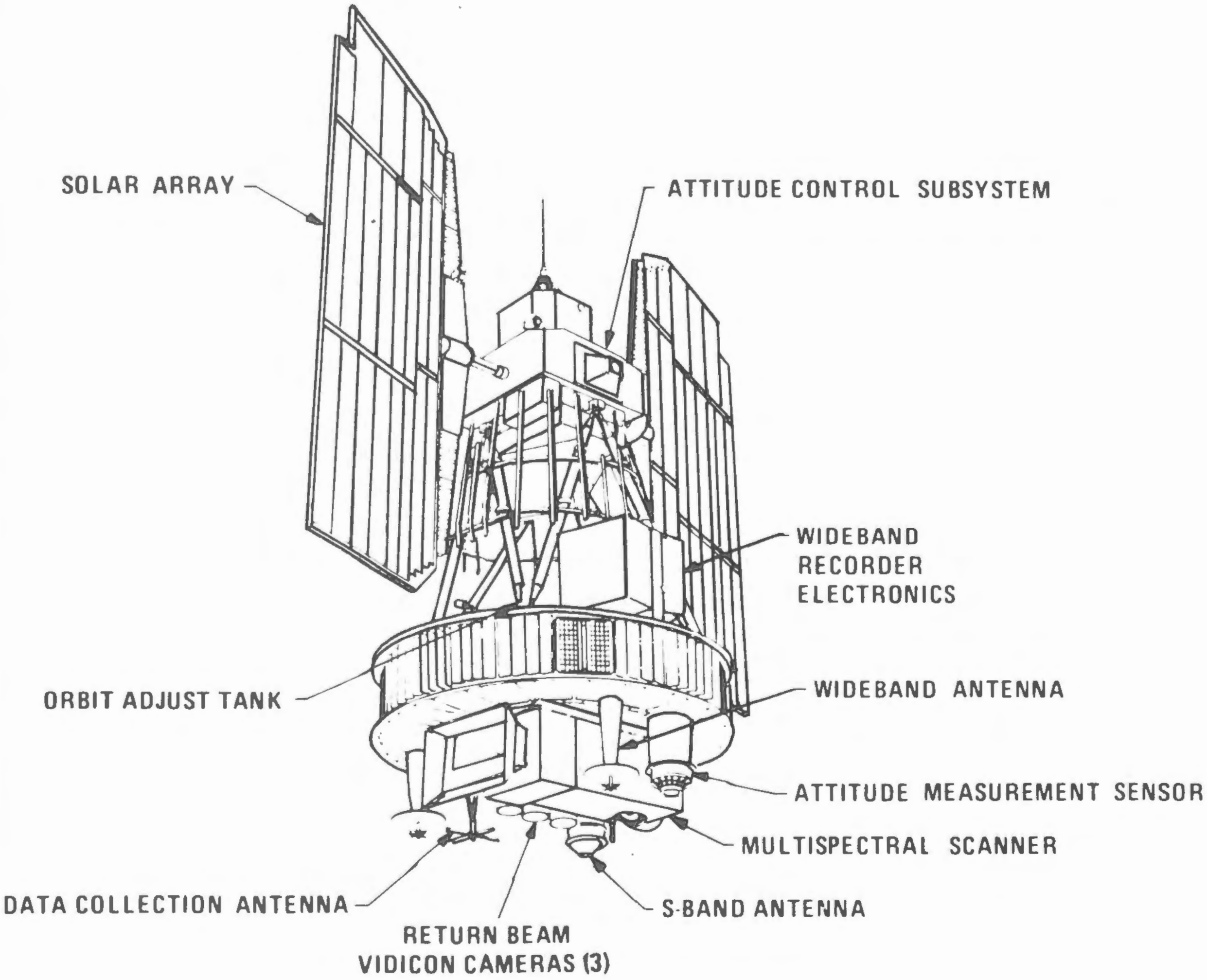


Figure 2-3. Observatory Configuration

Payload video data are transmitted to ground stations over two wideband S-Band data links. Traveling Wave Tube amplifiers, with commandable power output and shaped beam antennas, are used in this subsystem to provide maximum fidelity of the payload data at minimum power. The two links are identical and interchangeable, compatible with data from either of the two imaging sensors (the RBV and MSS). Cross-strapping and dual mode operation with a single amplifier is provided to assure system operation even in the event of some hardware failures. Telemetry, tracking, and command capability, fully compatible with both the STADAN and MSFN systems, is achieved with a subsystem design synthesized largely from existing hardware and designs used on various NASA programs.

Electrical power is generated by two independently driven solar arrays, with storage provided by batteries for spacecraft eclipse periods and launch. Independent conversion and regulation equipment is used to supply payload and spacecraft power.

The spacecraft configuration packages payload equipment centrally in a circular structure at the base of the spacecraft, providing close proximity between the payload sensors, their electronics, and wideband communications equipment. The three RBV camera heads are mounted to a common baseplate, structurally isolated from the spacecraft, to maintain accurate alignment. A superinsulation thermal blanket surrounds equipment on the circular structure, except for specified radiator areas, where heat is rejected from the center section. During minimum operating periods heaters are used to maintain temperature levels.

2.3 PAYLOADS

2.3.1 Return Beam Vidicon Camera

The Return Beam Vidicon (RBV) camera system operates by shuttering three independent cameras simultaneously, each sensing a different spectral band in the range of 0.48 to 0.83 micrometers. Since these are visible wavelengths, the RBV is operated only in daylight. The viewed ground scene, 100 by 100 nautical miles in area, is stored on the photosensitive surface of the camera tube and, after shuttering, the image is scanned by an electron beam to produce a video signal output. Each camera is read out sequentially, requiring about 3.5 seconds for each of the three spectral images. To produce overlapping images along the direction of spacecraft motion, the cameras are reshuttered every 25 seconds. The video bandwidth during readout is 3.2 MHz. Orientation of the three camera heads is shown in Figure 2-4.

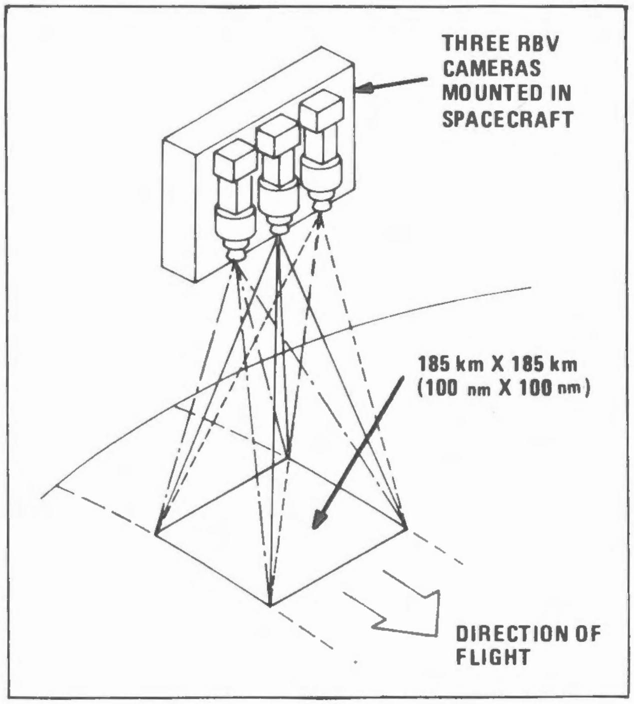


Figure 2-4. RBV Camera Head Orientation

2.3.2 Multispectral Scanner

The Multispectral Scanner (MSS) is a line scanning device which uses an oscillating mirror to continuously scan perpendicular to the spacecraft velocity as shown in Figure 2-5. Six lines, with the same bandpass, are scanned simultaneously in each at the four spectral bands for each mirror sweep. Spacecraft motion provides the along-track progression of the six scanning lines. Optical energy is sensed simultaneously by an array of detectors in four visible spectral bands from 0.5 to 1.1 micrometers for daylight operation of ERTS A. A fifth band in the near (thermal) infrared from 10.4 to 12.6 micrometers is included on ERTS B. The detector outputs are sampled, encoded to six bits and formatted into a continuous data stream of 15 megabits per second. During image data processing in the Ground Data Handling System facility, the continuous strip imagery is transformed to framed images with a 10 percent overlap of consecutive frames and an area coverage approximately equal to that of the RBV images.

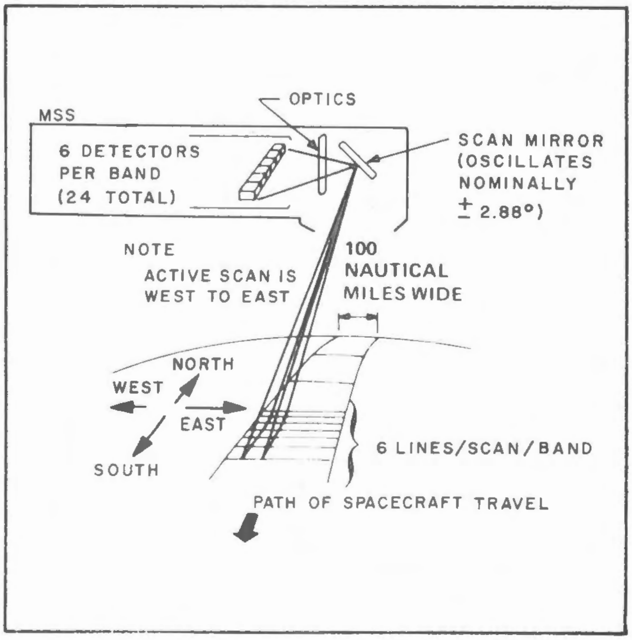


Figure 2-5. MSS Ground Scan Pattern

2.3.3 Wideband Video Tape Recorders

The uses of data from the RBV and MSS sensors are complementary in several respects, and both sensors are generally operated simultaneously over the same terrain during daylight hours. When operated over a ground receiving station, their data are transmitted in real time to the ground receiving site and recorded there on magnetic tape.

When the RBV and MSS sensors are operated at locations remote from a ground receiving station, two wideband video tape recorders (WBVTR), included as part of the observatory payload, are used to record the video data. Each WBVTR records and reproduces either RBV or MSS data upon command and each has a recording capacity of 30 minutes.

2.3.4 Data Collection System

The Data Collection System (DCS) obtains data from remote, automatic data collection platforms, which are equipped by specific investigators, and relays the data to ground stations whenever the ERTS spacecraft can mutually view any platform and any one of the ground stations, as shown in Figure 2-6. Each DCS platform collects data from as many as eight sensors, supplied by the cognizant investigator, sampling such local environmental conditions as temperature, stream flow, snow depth, or soil moisture. Data from any platform is available to investigators within 24 hours from the time the sensor measurements are relayed by the spacecraft.

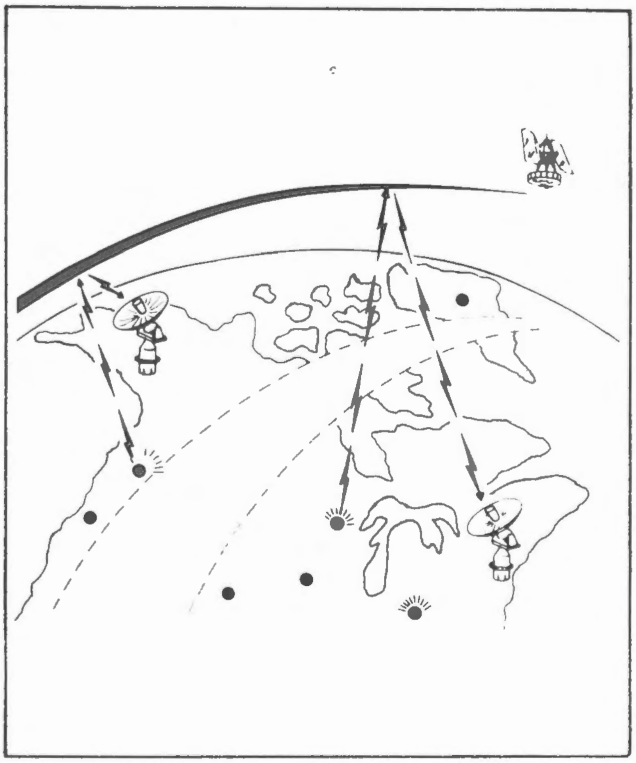


Figure 2-6. Data Collection System

2.4 ORBIT AND COVERAGE

Systematic, repeating earth coverage under nearly constant observation conditions is provided for maximum utility of the multispectral images collected by ERTS A and B. The Observatory operates in a circular, sun synchronous, near-polar orbit at an altitude of 494 nautical miles. It circles the earth every 103 minutes, completing 14 orbits per day and views the entire earth every 18 days. The orbit has been selected and will be trimmed so that the satellite ground trace repeats its earth coverage at the same local time every 18 day period within 20 nautical miles. A typical one-day ground coverage trace is shown in Figure 2-7 for the daylight portion of each orbital revolution.

2.5 OPERATIONS CONTROL CENTER

The Operations Control Center (OCC) is the hub of all ERTS mission activities; it provides control of the spacecraft and payload orbital operations required to satisfy the mission and flight objectives. The OCC operates 24 hours per day, and its activities are geared to the operations timeline dictated by the 103-minute spacecraft orbit and the network coverage capability. The primary receiving stations in Alaska; Goldstone, California; and the NTTF at NASA Goddard provide contact with the spacecraft on 12 or 13 of the 14 orbits each day.

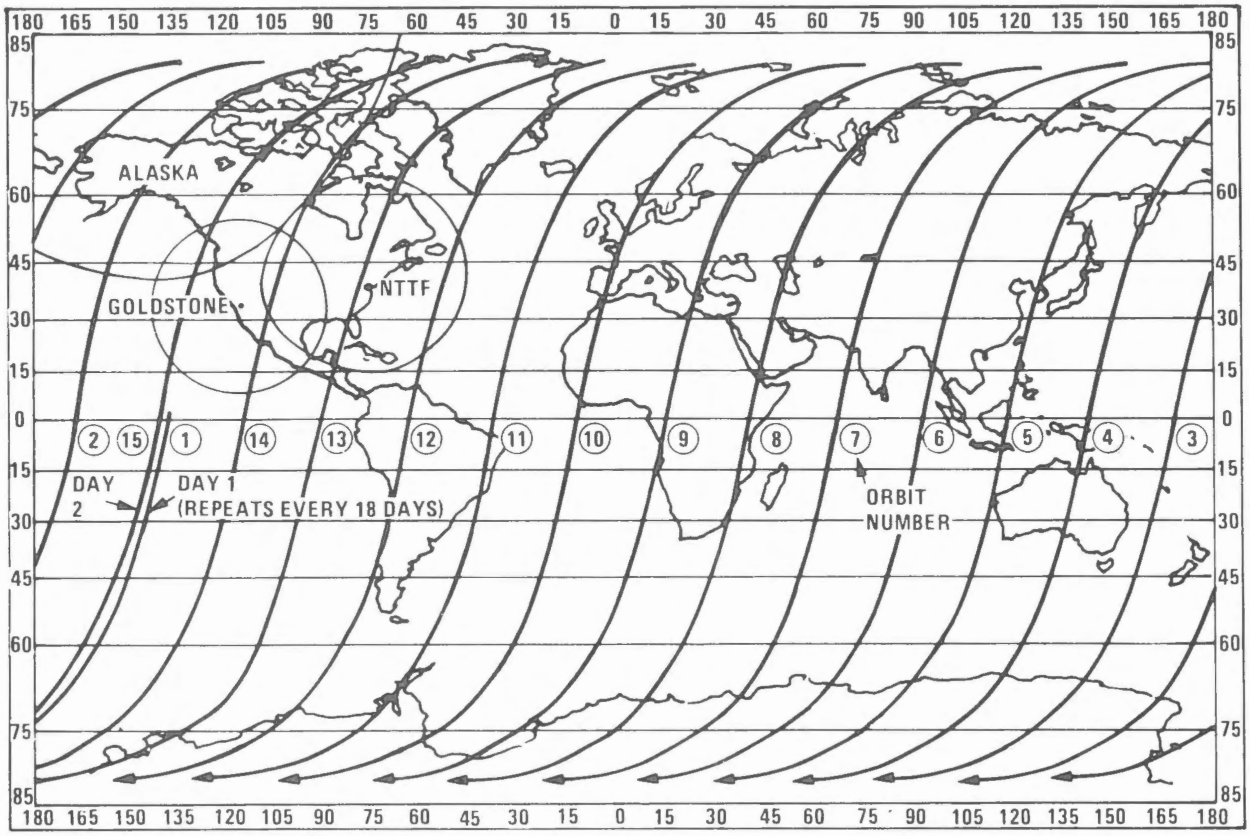


Figure 2-7. Typical ERTS Daily Ground Trace (Daylight Passes Only)

OPERATIONS CONTROL CENTER

The Operations Control Center system is shown in Figure 2-8. The OCC computer performs spacecraft and sensor "housekeeping" telemetry processing, command generation, display processing, system scheduling, and processing of DCS information. Interacting with the computer and its software are the OCC operations consoles; each console has a cathode ray tube display and other station and alarm indicators. The consoles provide the operations personnel with all the information required to assess the health of the spacecraft and payloads, and to make and implement rapid command and control decisions. Each cathode ray tube is under control of the computer, and an operator can display any data in the computer system library, by immediate keyboard request, to evaluate the performance of any subsystem or payload on board the spacecraft.

The RBV and MSS ground station equipment provides the capability to record, process and quickly display video data acquired locally by the NTTF station during orbits which pass over the eastern part of the United States. DCS data is received from the three primary stations and pre-processed in the OCC for subsequent formatting and cataloging in the NDPF.

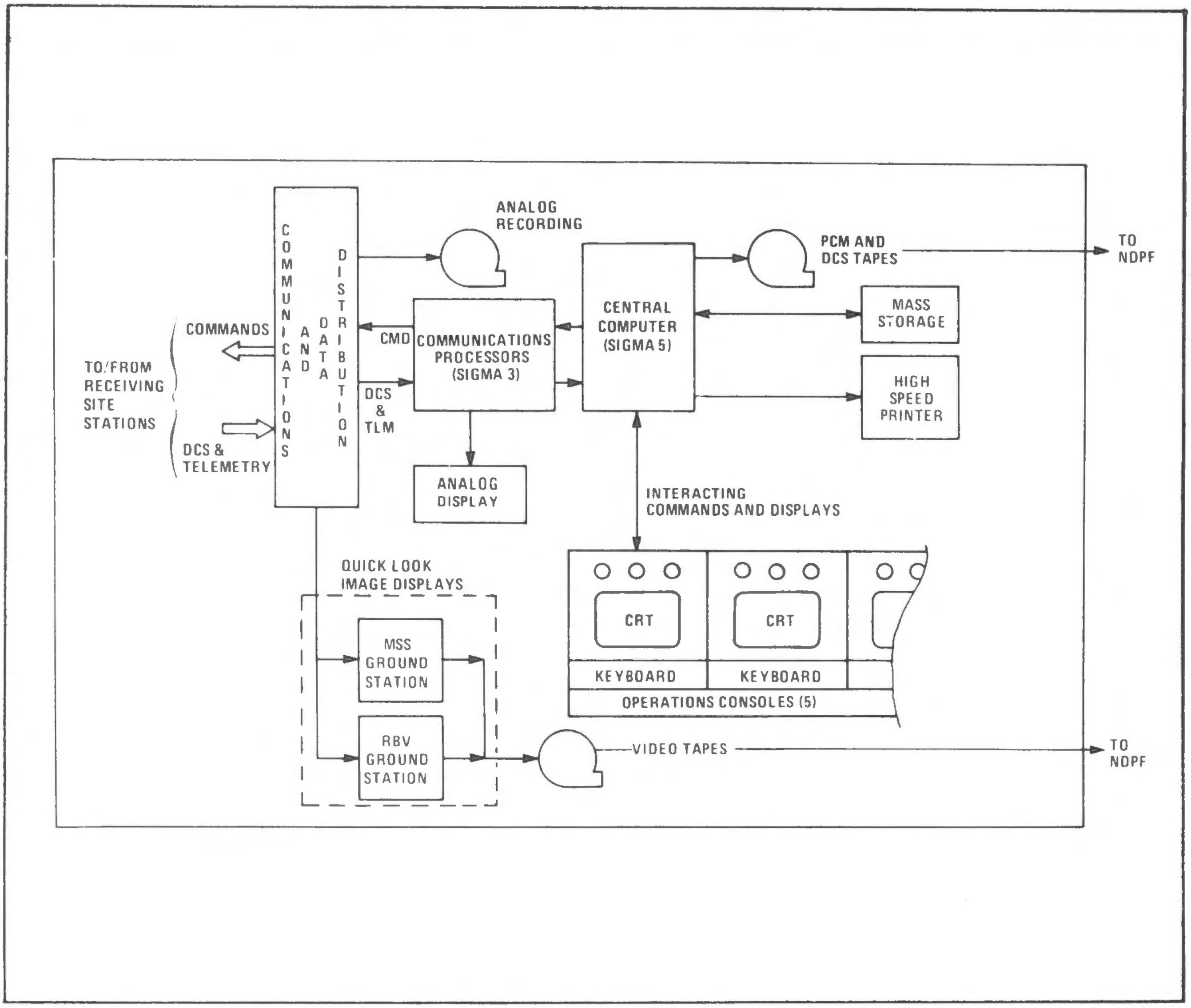


Figure 2-8. OCC System

2.6 CCRS DATA PROCESSING FACILITY

The CCRS Data Processing Facility produces high quality data for distribution to investigators. Figure 2.9 shows the system functional configuration. Spacecraft ephemeris, derived from tracking data acquired by the data acquisition stations, is provided to the CCRS from the Operations Control Center. This data, along with telemetry housekeeping data containing spacecraft attitude and sensor operation information, is used to produce an Image Generation Control Tape for identification, location and annotation of all imagery during image processing. There are three types of image processing performed: Initial, Precision and Digital Tape. All data are Initial Pass processed while only selected data are Precision or Digital Tape processed.

2.6.1 Initial Processing

Payload video data tapes are the principal input to Initial Processing. Here two electron beam image recorders (EBIR) produce corrected 50 mm images on 70 mm film of data from all video tapes. During video-to-film conversion, alphanumeric annotation data, image location, and a grey scale for calibration are recorded. Initial radiometric and geometric corrections are also made to the image. The 70 mm film images produced by Initial Pass Processing are developed in the NAPL Photographic Processing section and inspected for quality and cloud cover.

2.6.2 Precision Processing

Precision Processing is performed on selected image data. Photographs, which are 9.5 inch enlargements of the 70 mm film images produced by Initial Processing, are digitized to generate a corrected Image Generation Control Tape. This control tape which specifies the additional geometric and radiometric corrections is run simultaneously with the video data tape to produce precision imagery. This second production pass removes errors not corrected in Initial Processing and performs precision location and orthographic projection of the corrected image relative to Universal Mercator (UTM) map coordinates.

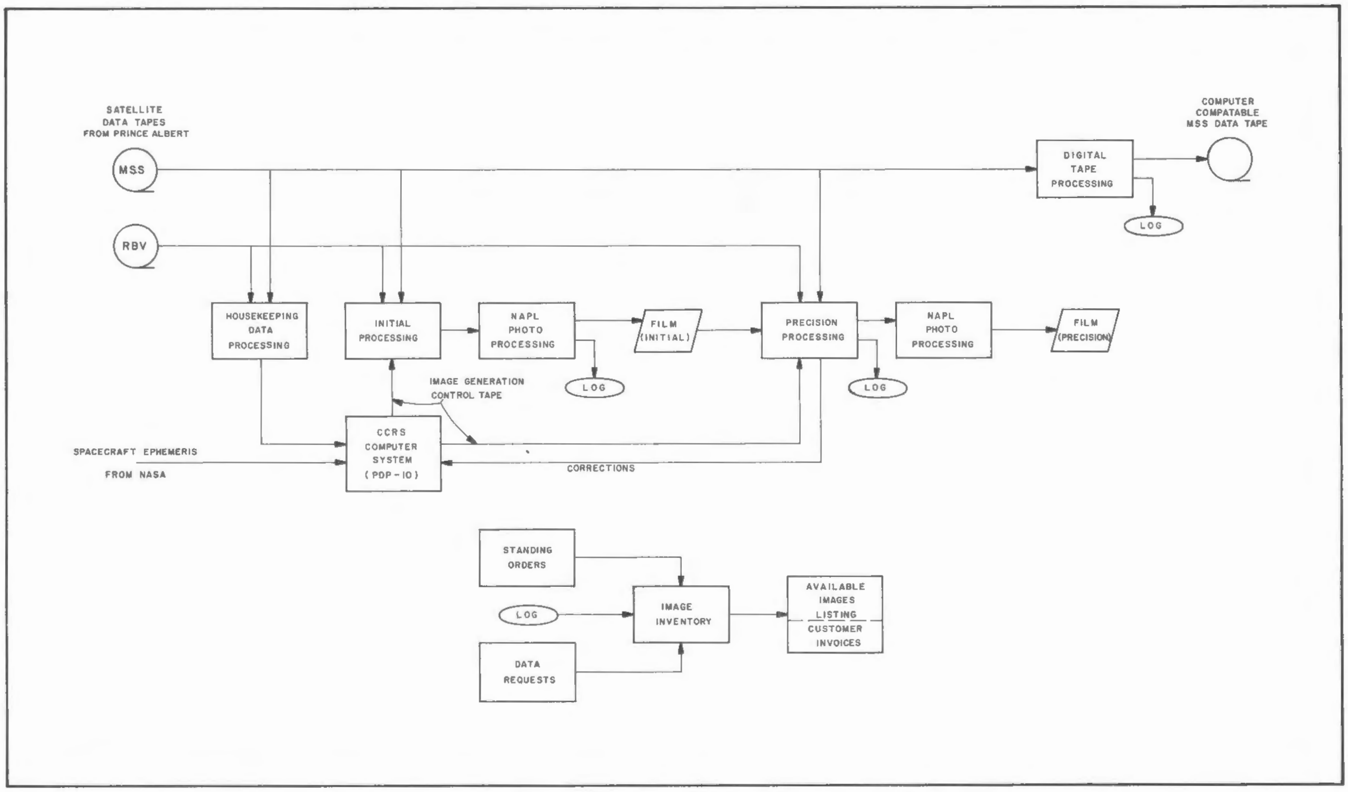


Figure 2-9 ERTS System Flow

2.6.3 Digital Tape Processing

Digital Tape Processing is performed on selected image data when requested by investigators. Digital Tape Processing edits, calibrates, corrects, and formats digital data produced from Initial or Precision processing and outputs this data on a computer compatible digital tape for distribution.

2.6.4 DCS Data Processing

Data Collection System data is processed, formatted and distributed to investigators by NASA on magnetic tapes, computer listings or punched cards within 24 hours from the time data collection platform sensor measurements are relayed by the spacecraft to the US ground receiving sites. All Canadian data is also transmitted to CCRS via teletype. At CCRS the data is sorted by platform number and stored in on-line computer files. Each DCS user has an account number which allows him to interrogate the CCRS computer at any time using Telex or an ASCII teletype terminal to obtain a printout of all data received since the last interrogation.

CCRS performs an error check using the data check-sum supplied by NASA. In addition, the data can be further processed by CCRS to provide, for example, conversion to engineering units. This processing varies from platform to platform.

2.6.5 Support and User Services

All of the CCRS and NAPL/RC equipment and processes are scheduled by work orders which are generated to match investigator requests against received data through the CCRS information system. The information system also serves as a data base to generate catalogues of image coverage, microfilm, abstracts, and DCS data for distribution to Canadian investigators.

It is anticipated that close to 150,000 master images will be processed and stored at the NAPL each year. The storage and retrieval system aids the investigator to select only those images that are of significance to him. Investigators have access to all CCRS/NAPL data through several files to provide efficiency in searching areas of interest. These aids include:

Browse Files — Complete file of all available images arranged by frame, with a data base query and search system to provide a cross reference by geographic position and date.

Coverage Catalogues — a listing of all Canadian images that are processed each month. These catalogues are updated on a regular schedule.

DCS Catalogue — Listing stored in CCRS computer of information available from the remote, instrumented data collection platforms.

Imagery requested by investigators by either Standing Order or specific Data Requests are processed in either black and white or colour from archival images stored in the master file. Samples of this imagery are available at NAPL to permit the investigator to select the material most useful for his purposes.

SECTION 3
OUTPUT DATA PRODUCTS

Canadian ERTS data will be distributed by the National Air Photo Library (NAPL) in two forms, as photographic products, and, for MSS data, as computer compatible tapes. CCRS receives the Data Collection System data for Canadian investigators via the NASCOM network. This data is then converted to engineering units as specified by the user and made available to him by teletype.

3.1 PHOTOGRAPHIC PRODUCTS

All photographic products, with the exception of "quick-look" products, will be geometrically and radiometrically corrected as fully as possible. The geometric corrections will conform the imagery to current UTM maps in the 1:250,000 series. The radiometric corrections will allow a direct correlation of film density with scene radiance. The details and the accuracy of these corrections are described in Appendix F. Fully corrected and annotated photographs will be distributed within ten days of acquisition to users who have submitted standing orders.

3.1.1 Standard Photographic Products

The standard products will be 9.5-inch-format positive paper-prints and transparencies, in black and white for the individual spectral bands, and as colour composites. It is expected that the black and white transparencies will have the greatest geometric and radiometric accuracy and should be used for any work involving detailed measurements. The scale of the image will be accurately controlled to 1:1,000,000 to allow direct comparison with maps.

3.1.2. Image Format and Annotation

A sample of the MSS image format and annotation is shown in Figure 3-1. The RBV products will be similar, but square and with fiducial references (reseau and anchor marks). The spacecraft heading is always from top to bottom.

Registration Marks. Four registration marks are placed beyond the image corners to facilitate alignment of different spectral images of the same scene from the same payload sensor. The image is positioned within the writing area so that when the registration marks from two or more spectral images are superimposed, the imagery will be registered. The intersection of diagonals drawn through the four registration marks is the format centre of the image. The format centre of a scene imaged at the same time by both the RBV and MSS will be identical. Annotation not otherwise specified refers to properties at the format centre.

Tick Marks. Latitude and longitude tick marks are placed along the edge of the image at intervals of 30 arc minute. The geographic reference marks are annotated in degrees-minutes with the appropriate direction indicator. At latitudes above 60 degrees north, tick marks are spaced at one-degree intervals to prevent crowding.

Grey Scale. A 15-step grey scale tablet is exposed on every frame of imagery as it is produced on the Electron Beam Image Recorder (EBIR). This scale is subject to the same copying and processing as the image to which it is attached. The grey scale gives the relationship between a level of grey on the image and the electron beam density used to expose the original image. The electron beam density is related to the sensor signal voltage which, in turn, is related to the energy incident on the sensor.

The grey scale tablet is a macroscale tablet and cannot be used reliably for microscale image radiometry, because the areas on the order of a few picture elements are subject to influence by neighbouring areas (modulation transfer function effects, chemical development adjacency effects) and do not supply enough data points to average noise down to a low figure.

Alphanumeric Annotation. Figure 3-2 explains a typical example of imagery alphanumeric annotation. Paragraphs (a) through (i) explain the data contained in this annotation.

3.1.3 Delivered Form

Most photographic products will be delivered in cut form. When the order is for a large number of consecutive images, products will be delivered in roll form. The sequences of imagery in rolls is illustrated in Figure 3.3. A complete set of imagery from one orbit will consist of one roll of RBV imagery and two rolls of MSS imagery.

3.2 COMPUTER COMPATIBLE TAPES

Digital MSS data will be available as computer compatible tapes in the following formats on 2400 ft. reels:

- 7 track 200, 556 or 800 bpi
- 9 track 800 or 1600 bpi

All data is binary and will be framed. Each tape will contain any or all of the four spectral bands as selected by the user, each line will be preceded by radiometric correction parameters and each frame preceded by radiometric correction parameters and each frame preceded by geometric correction parameters. The data for a frame will consist of about 2400 lines in each of four spectral bands, radiometric calibration, geometric correction data, and frame identification data.

The tapes will contain the following amounts of data:

9 track 1600 bpi	2400 lines (full frame)
9 track 800 bpi	1200 lines (1/2 frame)
7 track 800 bpi	800 lines (1/3 frame)
7 track 556 bpi	600 lines (1/4 frame)
7 track 200 bpi	275 lines (1/4 frame)

SECTION 4
USER SERVICES

There are two agencies which will handle the distribution of ERTS data products, the National Air Photo Library and the Canada Centre for Remote Sensing. The National Air Photo Library (NAPL) will have catalogues and orbital maps for all ERTS data and a browse file of selected imagery, and will accept standing orders or orders for specific frames of photographic imagery at the following address:

National Air Photo Library
615 Booth Street,
Ottawa, Ontario K1A 0E4
Attention: Remote Sensing

Requests for computer compatable tapes, special products or services and questions concerning ERTS may be submitted to either NAPL or to the following address:

Canada Centre for Remote Sensing
Department of Energy, Mines
and Resources
2464 Sheffield Road
Ottawa, Ontario K1A 0E4
Attention: ERTS User Liaison

4.1 ORDERING PROCEDURES

Orders will be of four types:

1. Standing orders
2. Data Requests
3. Computer Compatible Tape orders
4. Requests for special products or services

Standard order forms exist for the first two order types, but requestors do not necessarily have to submit these forms providing they supply all necessary information. This information may be provided by mail, telephone call, or personal visit to NAPL.

4.1.1 STANDING ORDERS FOR IMAGES

The Standing Order is designed to provide fast delivery to users who can define their requirements in advance of reception of data from the satellite. Once generated, the Standing Order applies unless cancelled or changed by the investigator.

A Standing Order may specify a particular product according to geographic area, period of time, cloud cover limits and image quality. When imagery that meets these criteria is received from the satellite, it will be reproduced and mailed to the user within a week. No prior notification of intent to distribute data will be mailed out, thus it is imperative that the user keep his standing orders up to date and consistent with his requirements. Figure 4-1 shows the form used in placing Standing Orders for all imagery, the form includes an explanation of each entry on the reverse side. The Figure includes an illustrative example of a completed form.

4.1.2 DATA REQUESTS FOR IMAGES

To order imagery that is already in the catalogue, the user should specify frame identification, sensor (RBV OR MSS), spectral band and film type.

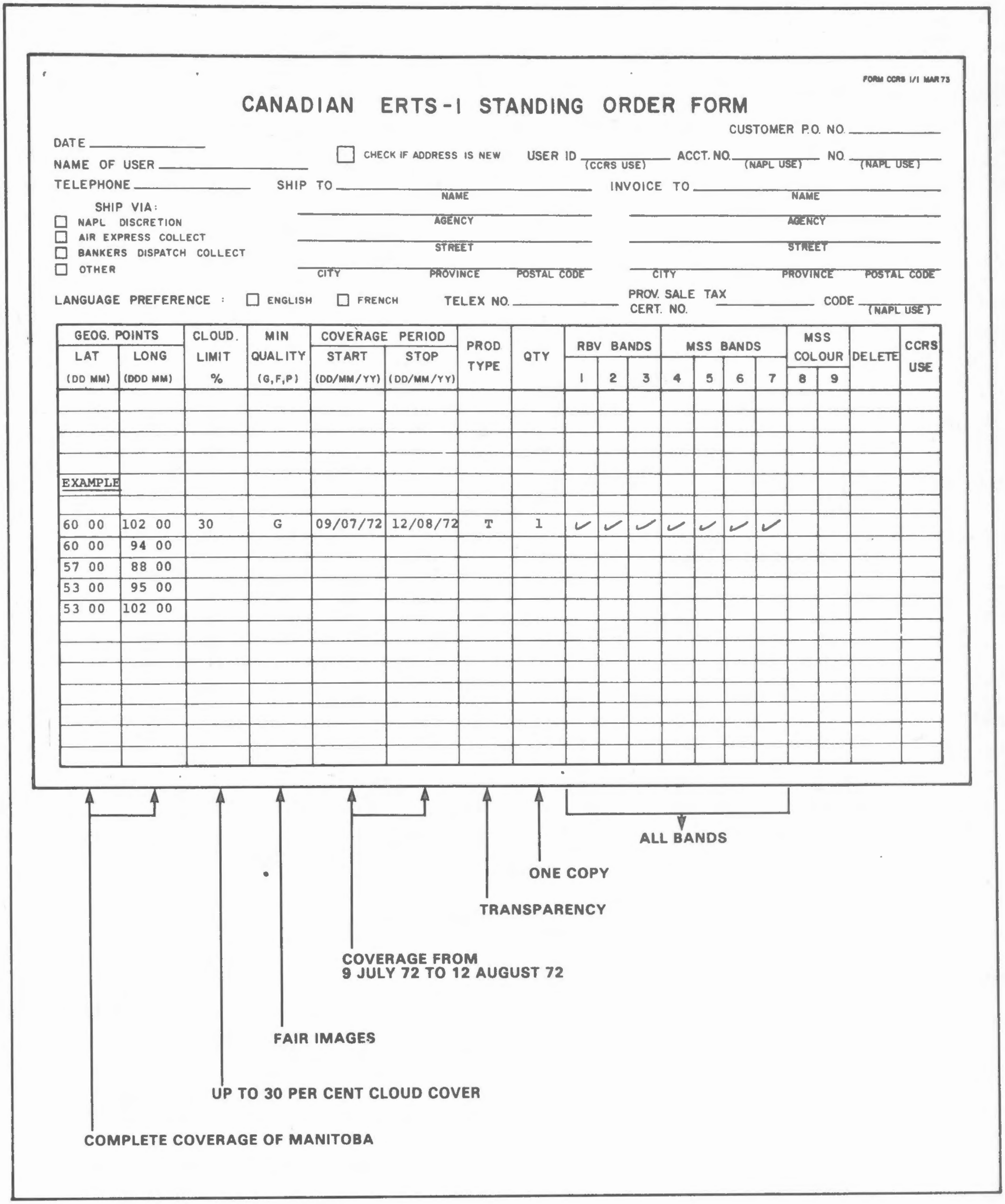
Figure 4-2 shows the form used in placing Data Requests, the form includes an explanation of each entry on the reverse side. Again, it is emphasized that the National Air Photo Library will provide assistance in completing the order form. Data Requests are normally filled within two weeks.

4.1.3 COMPUTER COMPATIBLE TAPES

Users may order MSS digital tapes through the Canada Centre for Remote Sensing by specifying the frame identification number given in the photographic product catalogue. The order may consist of one or more frames, a portion of a frame or continuous data (without overlap between frames) covering more than one frame. It should be noted that only tapes that start at the top of a frame, or end at the bottom of a frame will contain the top or bottom margin geographic annotation.

4.1.4 REQUESTS FOR SPECIAL PRODUCTS OR SERVICES

CCRS may have the capability of conducting a limited amount of special processing (e.g. special mixing of spectral bands). A request for such services should include a description of the processing and an outline of the investigation for which it is required.



FORM CCRS 1/1 MAR 73

CANADIAN ERTS-1 STANDING ORDER FORM

CUSTOMER P.O. NO. ____________

DATE ____________

NAME OF USER ____________

TELEPHONE ____________

☐ CHECK IF ADDRESS IS NEW

USER ID ____________ (CCRS USE)

ACCT. NO. ____________ (NAPL USE)

NO. ____________ (NAPL USE)

SHIP TO ____________ NAME ____________ AGENCY ____________ STREET ____________ CITY PROVINCE POSTAL CODE

INVOICE TO ____________ NAME ____________ AGENCY ____________ STREET ____________ CITY PROVINCE POSTAL CODE

SHIP VIA:
☐ NAPL DISCRETION
☐ AIR EXPRESS COLLECT
☐ BANKERS DISPATCH COLLECT
☐ OTHER

LANGUAGE PREFERENCE : ☐ ENGLISH ☐ FRENCH

TELEX NO. ____________

PROV. SALE TAX CERT. NO. ____________

CODE ____________ (NAPL USE)

GEOG. POINTS		CLOUD. LIMIT	MIN QUALITY	COVERAGE PERIOD		PROD TYPE	QTY	RBV BANDS			MSS BANDS				MSS COLOUR		DELETE	CCRS USE
LAT (DD MM)	LONG (DDD MM)	%	(G,F,P)	START (DD/MM/YY)	STOP (DD/MM/YY)			1	2	3	4	5	6	7	8	9		
EXAMPLE																		
60 00	102 00	30	G	09/07/72	12/08/72	T	1	✓	✓	✓	✓	✓	✓	✓				
60 00	94 00																	
57 00	88 00																	
53 00	95 00																	
53 00	102 00																	

ALL BANDS

ONE COPY

TRANSPARENCY

COVERAGE FROM
9 JULY 72 TO 12 AUGUST 72

FAIR IMAGES

UP TO 30 PER CENT CLOUD COVER

COMPLETE COVERAGE OF MANITOBA

Figure 4-1 Standing Order Form

ERTS orders should be submitted to:

NATIONAL AIR PHOTO LIBRARY
615 Booth Street
Ottawa, Ontario K1A 0E4

Attention: Remote Sensing

(1) Geographic Points

Latitude (DD MM)	North assumed
Longitude (DDD MM)	West assumed

DD(D) = Degrees
MM = Minutes

The latitude and longitude of 1 to 12 points defining a point, line (2 end points) or area (3-12 corner points) for which coverage is desired. The corner points of an area should be arranged cyclically.

(2) Cloud Cover Limit

The maximum acceptable cloud cover in %.

(3) Minimum Quality

The poorest quality imagery acceptable, specified by:

G = Good.	Complete images with good tone, resolution and granularity. Little or no noise.
F = Fair.	Lighter or darker than good imagery, or noticeable noise.
P = Poor.	Imagery which is too light or too dark, partial images or significant noise.

A user who specifies "F", for example, would receive all fair and good imagery.

(4) Coverage Period

DD = Day
MM = Month
YY = Year

The beginning and end dates of the time period for which imagery is desired.

(5) Product Type

The two standard product types available on standing order are 9"x 9" positive film transparency (T) and 9"x 9" positive paper print (P).

(6) Quantity

The number of copies of each image desired.

(7) RBV and MSS Bands

The sensor and spectral band from which black and white imagery is desired:

RBV	Band 1	475 - 575 nm.	(blue green)
	Band 2	580 - 680 nm.	(red)
	Band 3	690 - 830 nm.	(near infrared)
MSS	Band 4	500 - 600 nm.	(blue green)
	Band 5	600 - 700 nm.	(red)
	Band 6	700 - 800 nm.	(near infrared)
	Band 7	800 -1100 nm.	(near infrared)

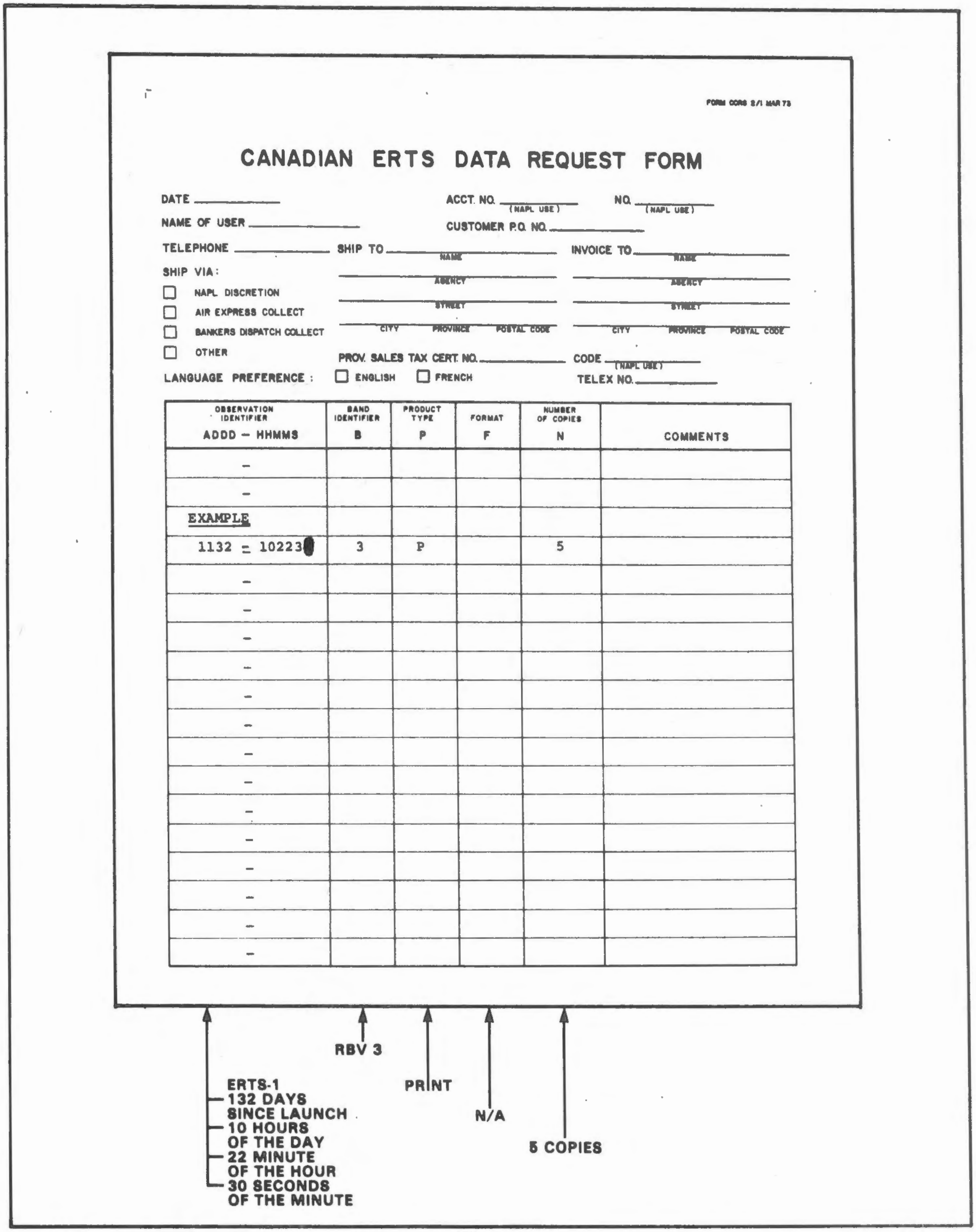
(8) MSS Colour

The MSS false colour composite prints desired:

8. Bands 1, 2, and 3
9. Bands 2, 3, and 4

(9) Delete

The standing order form should be used for changing or cancelling as well as placing an order. To cancel an order, write in the order and place an "X" in the "delete" column. To change an order, delete it and place a new order on the same form.



FORM CCRS 2/1 MAR 73

CANADIAN ERTS DATA REQUEST FORM

DATE ____________

ACCT. NO. ____________ (NAPL USE)

NO. ____________ (NAPL USE)

NAME OF USER ____________

CUSTOMER P.O. NO. ____________

TELEPHONE ____________

SHIP TO ____________ NAME / ____________ AGENCY / ____________ STREET / ____________ CITY PROVINCE POSTAL CODE

INVOICE TO ____________ NAME / ____________ AGENCY / ____________ STREET / ____________ CITY PROVINCE POSTAL CODE

SHIP VIA:

☐ NAPL DISCRETION
☐ AIR EXPRESS COLLECT
☐ BANKERS DISPATCH COLLECT
☐ OTHER

PROV. SALES TAX CERT. NO. ____________

CODE ____________ (NAPL USE)

LANGUAGE PREFERENCE : ☐ ENGLISH ☐ FRENCH

TELEX NO. ____________

OBSERVATION IDENTIFIER ADDD – HHMMS	BAND IDENTIFIER B	PRODUCT TYPE P	FORMAT F	NUMBER OF COPIES N	COMMENTS
–					
–					
EXAMPLE					
1132 – 10223[illegible]	3	P		5	
–					
–					
–					
–					
–					
–					
–					
–					
–					
–					
–					
–					
–					
–					

ERTS-1
– 132 DAYS SINCE LAUNCH
– 10 HOURS OF THE DAY
– 22 MINUTE OF THE HOUR
– 30 SECONDS OF THE MINUTE

RBV 3

PRINT

N/A

5 COPIES

CANADIAN ERTS DATA REQUEST FORM
(Instructions)

1. Complete the header information

2. Order data as follows:

ADDD-HHMMS -Observation Identifier - the unique identification for each scene observed by the satellite. This information is available on all images and on invoices for standing order items.

A = Satellite Number
DDD = Days since launch
HH = Hour of Day (GMT)
MM = Minutes of Hour (GMT)
S = Tens of seconds of minutes (GMT)

List separately for each individual scene ordered.

B -Sensor Band Identification Code

1 = RBV1
2 = RBV2
3 = RBV3
4 = MSS1
5 = MSS2
6 = MSS3
7 = MSS4
8 = Colour MSS 1, 2 & 3
9 = Colour MSS 2, 3 & 4
R = All RBV Bands
M = All MSS Bands, including colour
X = All Bands, including MSS colour

P -Product Type where:

P = 9.5 inch paper print
T = 9.5 inch film transparency
S = 70 mm strip B&W transparency (all 4 bands, MSS; all 3 RBV)
D = Digital Magnetic Tape
E = Paper Enlargement
C = Catalogue of available imagery

F -Format of the Product where:

Blank = not applicable(P,T,S and C do not require format specification)

D product formats:

72 = 7-track, 200 bpi
75 = 7-track, 556 bpi
78 = 7-track, 800 bpi
98 = 9-track, 800 bpi
8H = 9-track,1600 cpi

E product formats:

10 = 10" x 10"
15 = 15" x 15"
20 = 20" x 20"
30 = 30" x 30"
40 = 40" x 40"
60 = 40" x 60"

N -Number of copies of the Product

3. Mail to: National Air Photo Library
615 Booth Street
Ottawa, Ontario K1A 0E4
Attention: Remote Sensing

Telephone: 994-5457
Telex: 053-4328

APPENDIX A
PAYLOAD

The Earth Resources Technology Satellite payload includes: a Return Beam Vidicon (RBV) camera subsystem, a Multispectral Scanner Subsystem (MSS) and a Data Collection System (DCS). The RBV and MSS furnish independent views of the earth beneath the Observatory, while the DCS relays local environmental information from remote platforms to the ground stations for processing and delivery to users. This appendix contains a description of the characteristics of each of these payloads which are informative in understanding and interpreting the data which they produce.

A.1 RETURN BEAM VIDICON CAMERA

The Return Beam Vidicon (RBV) camera subsystem contains three individual cameras that operate in different nominal spectral bands. The measured spectral response of the three cameras is shown in Figure A.1-1.

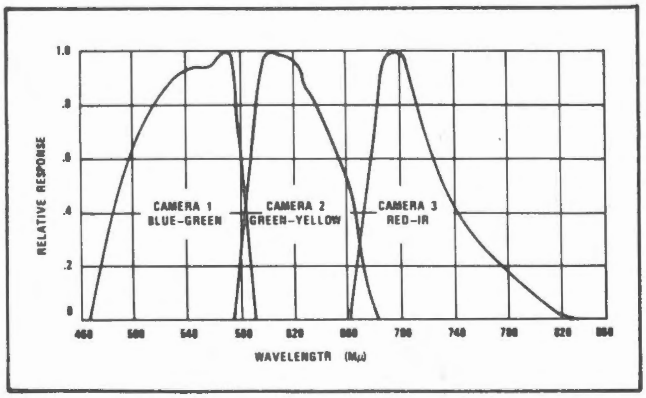


Figure A.1-1. Spectral Response, RBV Camera System

Each camera contains an optical lens, a shutter, the RBV sensor, a thermoelectric cooler, deflection and focus coils, erase lamps and the sensor electronics. The cameras are similar except for the spectral filters contained in the lens assemblies to provide separate spectral viewing regions. The sensor electronics contain the logic circuits to program and coordinate the operation of the three cameras as a complete integrated system and provide the interface with the other spacecraft subsystems. Table A.1-1 shows the major camera parameters and their expected performance.

Table A.1-1 RBV Camera Parameters

Item	Camera 1	Camera 2	Camera 3
Nominal Spectral Band (Micrometers)	.475-.575 Blue-Green	.580-.680 Green-Yellow	.698-.830 Red-IR
Abbreviated Band Reference	Blue	Yellow	Red
Edge Resolution (% of center)	80%	80%	80%
Video Bandwidth (MHz) without Aperture Correction	3.2(−20dB)	3.2(−20dB)	3.2(−20dB)
Signal-to-Noise Ratio (at 100% highlight) Aperture Correction Out	33dB	33dB	31dB
Horizontal Scan Rate (lines/second)	1250	1250	1250
Number of Scan Lines (active video)	4125	4125	4125
Readout Time (seconds of active video)	3.5*	3.5*	3.5*
Readout Sequence	3	2	1
Focal Length of Lens (mm)	125.865	125.824	125.979
Exposure Set Time (msec)			
No. 1	4.0	4.8	6.4
No. 2	5.6	6.4	7.2
No. 3	8.0	8.8	8.8
No. 4	12.0	12.0	12.0
No. 5	16.0	16.0	16.0

*Readout time includes 3.3 seconds ground video, and 0.2 second sync and time code information.

A.1.1 Operation

The three RBV cameras are aligned in the spacecraft to view the same nominal 185 kilometers (100 nautical mile) square ground scene as depicted in Figure A.1-2. When the cameras are shuttered, the images are stored on the RBV photosensitive surfaces, then scanned to produce video outputs. As shown in the RBV timing relationships illustrated in Figure A.1-3, the three cameras are scanned in sequence during the last 10.5 seconds of the basic 25 second picture time cycle. The video from each is serially combined with injected horizontal and vertical sync. The readout sequence is camera 3, then camera 2, then camera 1.

The video data interval for each camera lasts for 3.3 seconds, lines 251 through 4375 of the composite video output. The format of

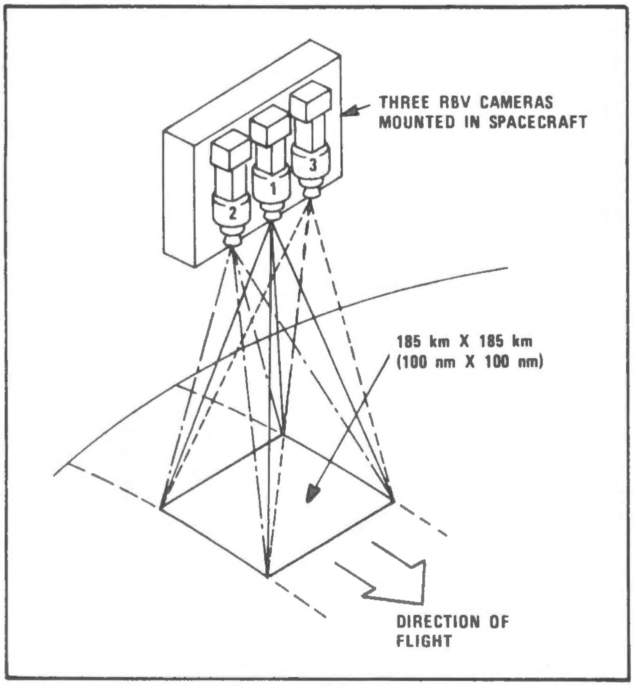


Figure A.1-2. RBV Scanning Pattern

the video data is presented in Figure A.1-4. The 720 microseconds of active video in each of the lines is replaced with 1.6 MHz sine wave when a camera is turned off and the camera controller-combiner is still operating.

Two modes of operation are possible and are selectable by ground command. Normally the continuous cycle mode is used.

1. Continuous cycle — This mode is the normal operating mode of the three-camera system. The system continues to take pictures every 25 seconds, the three cameras operating by one command, until the system is commanded off.

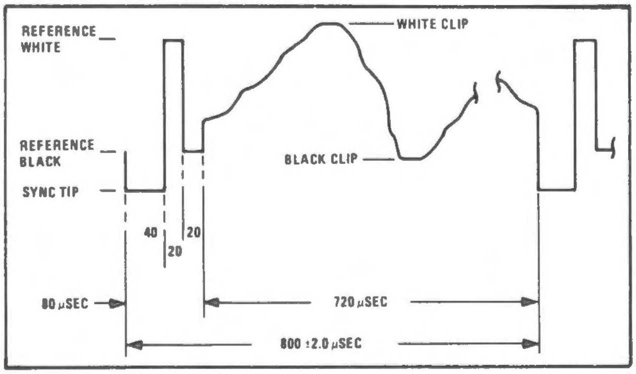


Figure A.1-4. Video Data Format for One Horizontal Line

2. Single cycle — The camera will take one picture and then revert back to hold mode until a "start prepare" command is received. This mode allows a single 25-second picture cycle to be taken of selected areas with the enabled cameras.

In addition a calibration mode is provided and is exercised by ground command. In this mode the erase lamps provide three different exposures to each camera which are nominally 0, 15 and 100 percent of the maximum specified input radiance for each camera (designated as Cal 0, 1 and 2 respectively).

The calibration command exercises the sequence depicted in Figure A.1-5. The shutters of each camera are inhibited and the cameras then proceed through three 25-second picture cycles producing 9 images corresponding to three illumination levels for each of the three cameras.

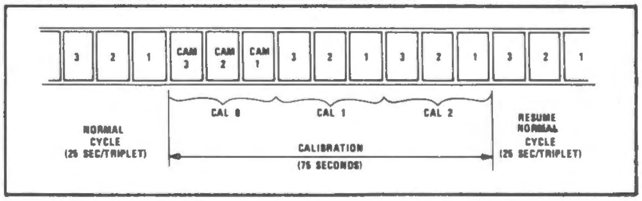


Figure A.1-5. Calibrate Mode Operation

A.1.1.1 Reseau Marks and Scan Orientation

A reseau pattern is inscribed on the photoconductive surface of the RBV tube. Figure A.1-6 shows the reseau pattern as it projects into the scene being viewed by the camera. The orientation of the pattern is indicated by using unique anchor marks in the pattern. These reseaus and anchor marks are detailed in Figure A.1-7. All dimensions shown in the figure are in millimeters measured on the faceplate of the RBV camera (Multipliers for 70mm: 2.165; 242mm: 7.362). The arrows in Figure A.1-6 marked "H" and "V" (upper left hand corner) indicate the direction of the line and frame scan. The two digit numbers are assigned to identify each cross in the reseau pattern; the first digit is a row number and the second digit is a column number.

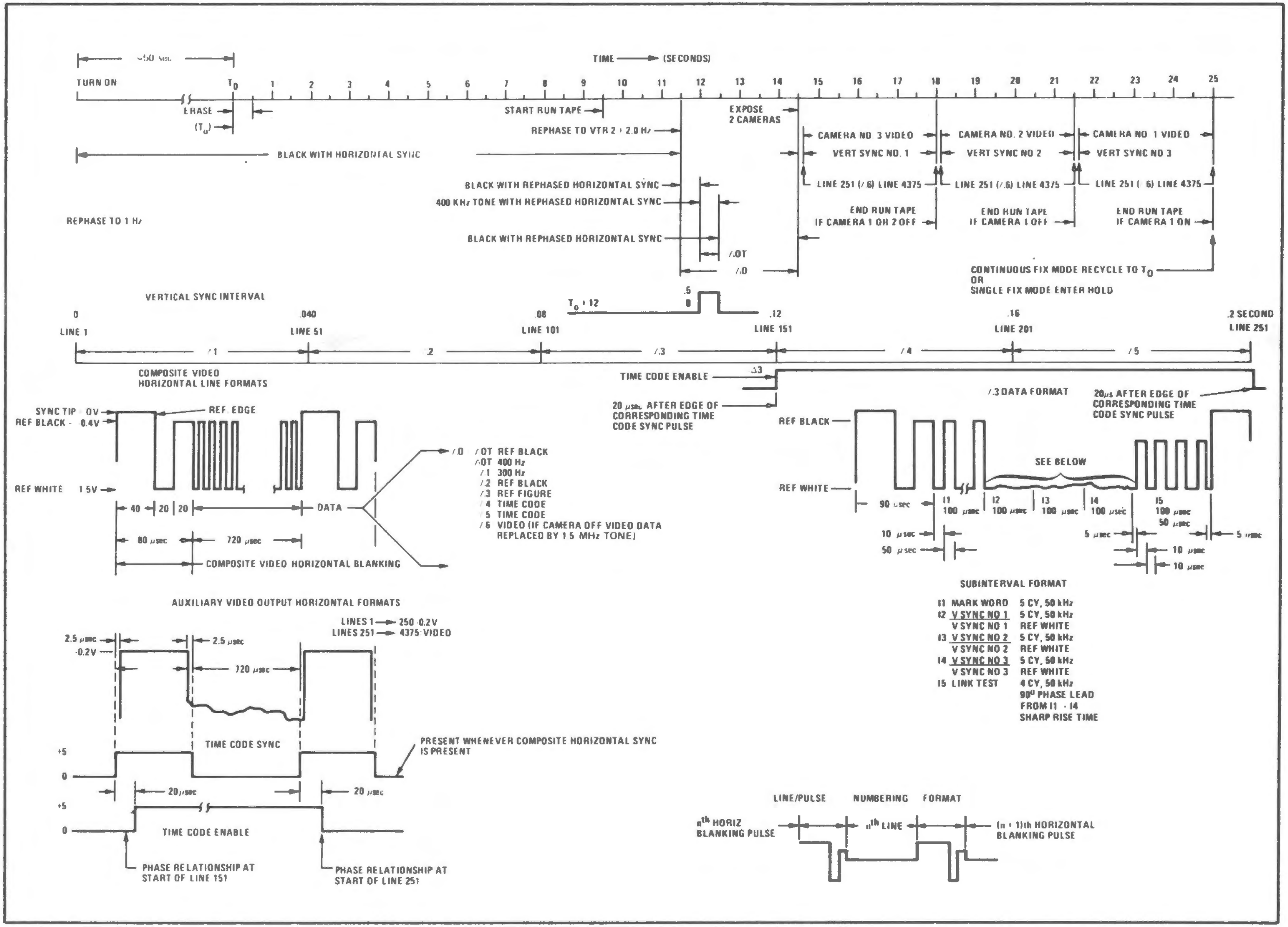


Figure A.1-3. RBV Camera Subsystem Timing Relationship

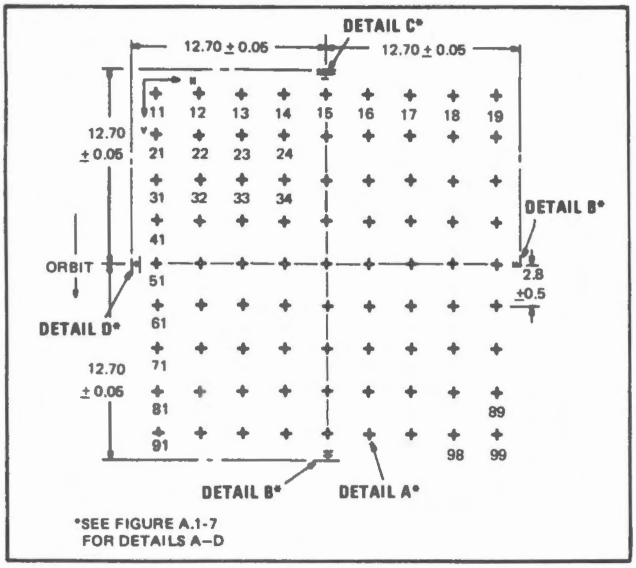


Figure A.1-6. Reseau Marks on Scene

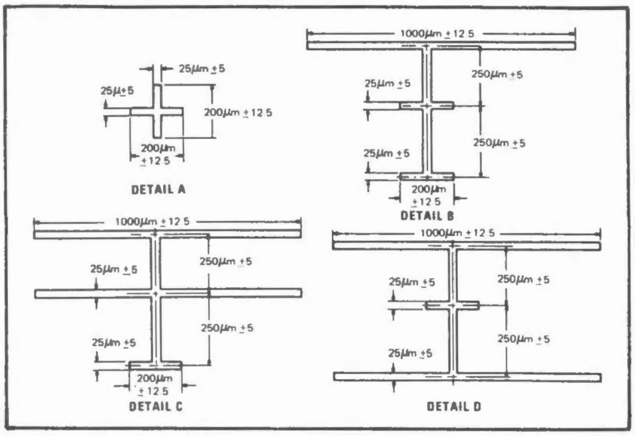


Figure A.1-7. Details of Reference Marks

The orientation of the whole camera with respect to the projection of the reseau pattern into the scene is given by the "camera feet" indication in Figure A.1-8. The camera lens reverses and inverts the scene, so that the actual orientation of the reseau pattern on the vidicon in the camera is also inverted and reversed. The orbit track direction and shutter motion direction are also shown. The shutter mechanism in each RBV camera consists of two adjacent blades with offset cutouts which sweep across the vidicon aperture to provide the pre-commanded exposure time to each portion of the photoconductor. The shutter provides uniform exposure over the photoconductor within a maximum variation of ±5 percent.

The unique anchor marks are located at the (nominal) edges of the scans. The edges will drift somewhat because of circuit tolerances (the overall size-centering tolerance is ±2 percent); however, the starting point of the scan is somewhat tighter. The reseau locations have been mapped on the vidicon faceplate with approximately 3 micrometer accuracy and are used during image generation to remove geometric distortions.

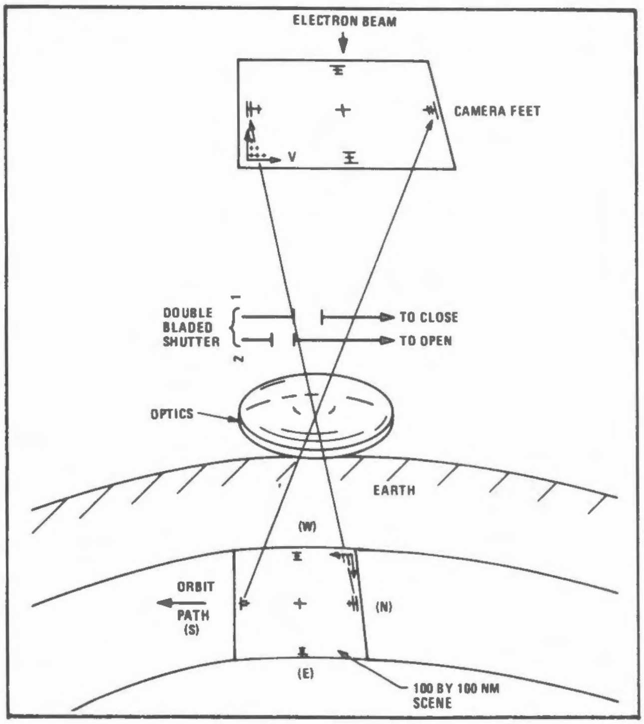


Figure A.1-8. Camera-Scene Orientation

A.1.2 Performance

A.1.2.1 Resolution

Measured square wave response for the RBV (lens, vidicon and amplifier) are shown in Figure A.1-9. An improvement in response, with a corresponding decrease in signal-to-noise ratio, is possible by utilizing the aperture compensation command. With this command each RBV camera employs a secondary amplifier system for the raw video which incorporates specific frequency response shaping networks. It is important to note that this improvement applies to the cross-track direction only and cannot compensate for smear degradations occurring in the along-track direction. Annotation on each image will state if aperture compensation was

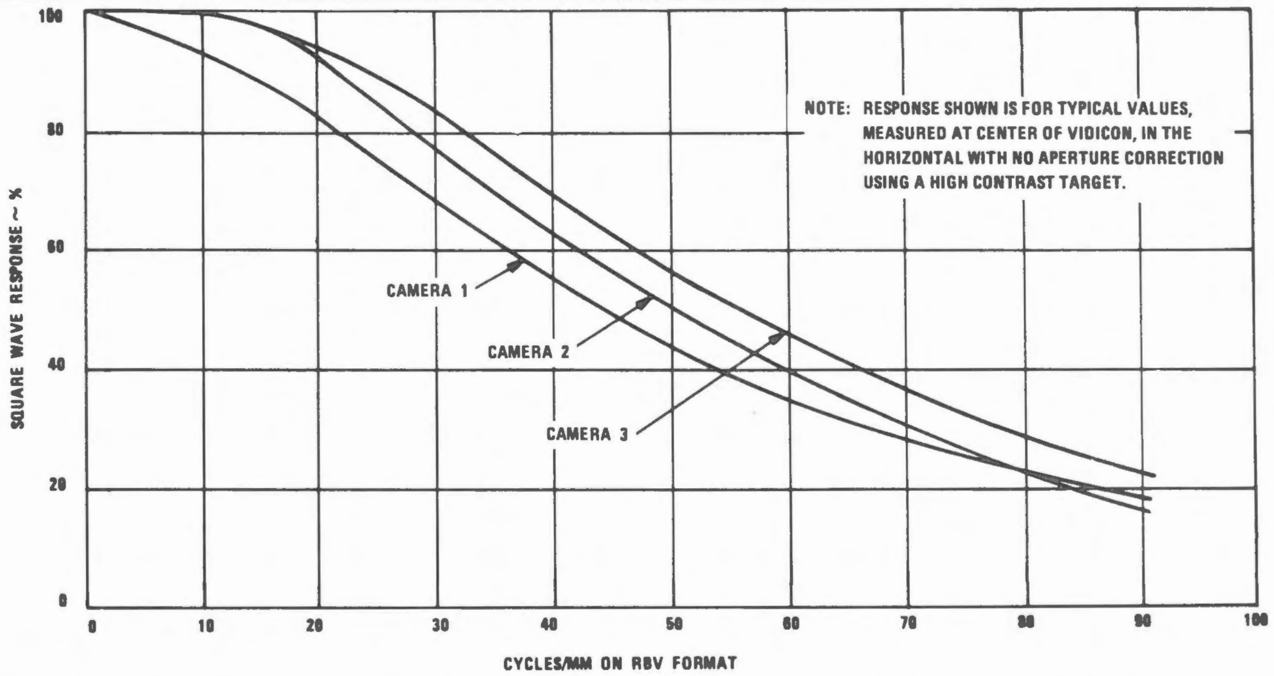


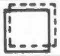
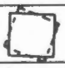
Figure A.1-9. Typical Sine Wave Response - RBV Camera

"in" or "out". A discussion of expected resolution for RBV data for typical space contrast targets can be found in Paragraph F.3.2 of Appendix F.

A.1.2.2 Geometric Fidelity

Table A.1-2 shows the raw internal RBV errors observed during test and includes, for reference only, the positional effect of these errors on the output image. All errors are effects associated with the electromagnetic characteristics of the vidicon camera.

Table A.1-2. Positional Effects of Raw Internal RBV Errors

ITEM	NAME OF ERROR	ILLUSTRATION OF ERROR TYPE	OBSERVED VALUE	IMAGE POSITIONAL EFFECT (m) 1σ
1	MAGNETIC LENS DISTORTION		1% OF MAXIMUM	432
2	S CURVE		0.200 MM AT CORNERS	418
3	SCALE		< ±1%	< 432
4	CENTERING		<0.75% EACH AXIS	< 982
5	NONLINEARITY		±1% MAXIMUM EACH AXIS	518
6	SKEW		< 0.26 DEGREE	< 210
7	RASTER ROTATION		< 0.1 DEGREE	< 75

A.1.2.3 RBV Exposure Capabilities

The capability of the RBV cameras to recognize specific scene radiance is a function of the light transfer characteristics (LTC) and time of exposure of each camera. The LTC relates voltage output to radiance for mean levels or levels in large areas (near zero spatial frequencies). Figure A.1-10 is the measured LTC for the three cameras for the on-axis (center) location of the vidicon. The radiance is the equivalent spectrally-flat radiance in front of the lens within the bandpass of each camera.

The equivalent spectrally flat radiance is obtained by integrating the scene radiance and camera spectral responses.

$$N = \frac{\int R(\lambda)\ N_S(\lambda)}{\int R(\lambda)}$$

where

$R(\lambda)$ = Camera spectral response
$N_S(\lambda)$ = Scene spectral radiance

The camera spectral response is shown in Figure A.1-1.

The exposures for the various spectral bands corresponding to one volt video output (white reference, defined as saturation exposure) are:

RBV EXPOSURE CAPABILITIES

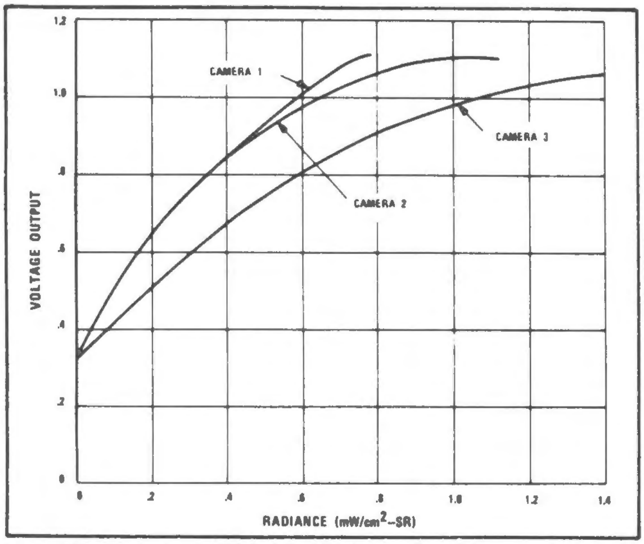


Figure A.1-10. RBV Light Transfer Characteristics

Band	
1	0.552 μjoules/cm^2
2	0.598 μjoules/cm^2
3	0.985 μjoules/cm^2

The maximum mean radiance of a scene at the vidicon faceplate is related to the saturation exposures and exposure time by:

$$N = \frac{4T^2Ex}{\pi t} \text{ (watts/cm}^2 - \text{ster)}$$

where

N = Mean radiance of scene at vidicon faceplate
T = Effective f number of lens
t = Exposure time
Ex = Saturation exposure

Based on this equation, Table A.1-3 delineates the exposure time settings along with the value of scene radiance at saturation of the vidicon.

Table A.1-3. Scene Radiance at Saturation for Various Exposure Times

Exposure Set	Band 1		Band 2		Band 3	
	t	N_{SAT}	t	N_{SAT}	t	N_{SAT}
	(ms	(mw/cm^2-sr)	(ms)	(mw/cm^2-sr)	(ms)	(mw/cm^2-cr)
A	4	1.80	4.8	1.62	6.4	2.01
B	5.6	1.29	6.4	1.22	7.2	1.78
C	8	0.90	8.8	0.89	8.8	1.46
D	12	0.60	12	0.65	12	1.07
E	16	0.45	16	0.49	16	0.80

Table A.1-4 shows calculated values of scene radiance at sensor input for various solar zenith angles and typical ERTS scenery.

Table A.1-4 Total Scene Radiance (N) mW/cm^2–sr

Typical Scene	Band 1 (Zenith Angle)				Band 2 (Zenith Angle)				Band 3 (Zenith Angle)			
	0	30	45	60	0	30	45	60	0	30	45	60
Specular	4.21	3.83	3.01	2.21	3.39	3.38	2.79	2.02	3.04	2.63	2.16	1.54
Fresh Snow		2.91	2.32	1.61		2.56	2.12	1.54		1.85	1.52	1.09
Icy Snow		2.82	2.43	1.78		2.69	2.22	1.62		2.07	1.70	1.22
Clay		2.23	2.16	1.67		2.37	1.97	1.44		1.91	1.58	1.13
Sand		1.02	0.88	1.08		1.07	0.90	0.68		1.16	0.96	0.69
+1σ Plants		0.70	0.62	0.99		0.53	0.46	0.37		1.04	0.86	0.62
-1σ Plants		0.47	0.43	0.64		0.31	0.28	0.25		0.57	0.48	0.29
H_2O		0.60	0.54	0.46		0.33	0.3	0.26		0.25	0.22	0.17
Overcast	2.37	2.81	2.35	1.74	3.42	2.94	2.43	1.76	2.76	2.38	1.96	1.40

NOTE: Typical values, not to be taken as absolute.

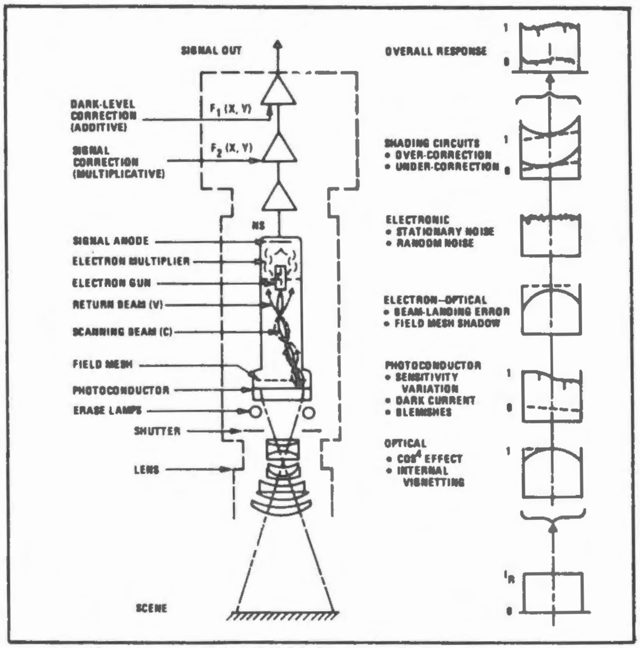


Figure A.1-11. RBV Camera Subsystem and Radiometric Error Sources

These values were calculated with a solar constant of 0.1322 W/cm^2, two atmosphere traverse and an atmospheric transmission of 0.8. These data are shown only as representative examples and should not interpreted as precision values.

A.1.2.4 Radiometric Fidelity

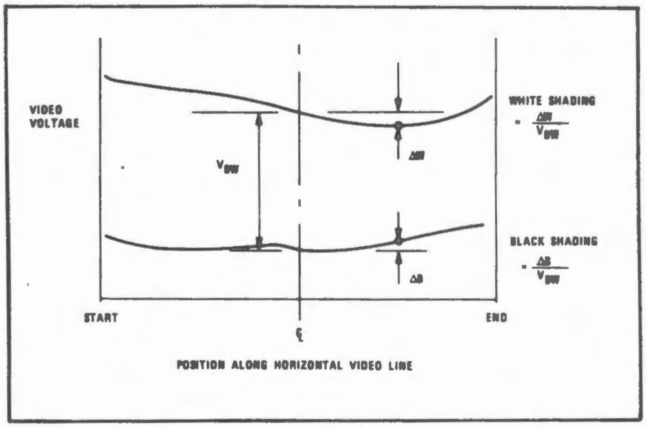


Figure A.1-12. Shading Definitions

Figure A.1-11 illustrates the RBV camera subsystem and graphically shows the effects of radiometric errors as an input is processed through the camera subsystems. The relationship of camera voltage output to exposure varies for different spatial locations on the face of the vidicon, a phenomena called shading. Shading also varies with signal level. The definition of black and white level shading is given in Figure A.1-12.

Figure A.1-13 shows the measured shading for the three cameras at black and approximately white levels. As described in Appendix F and G, shading is largely removed by corrections applied as images are generated on film in the NDPF.

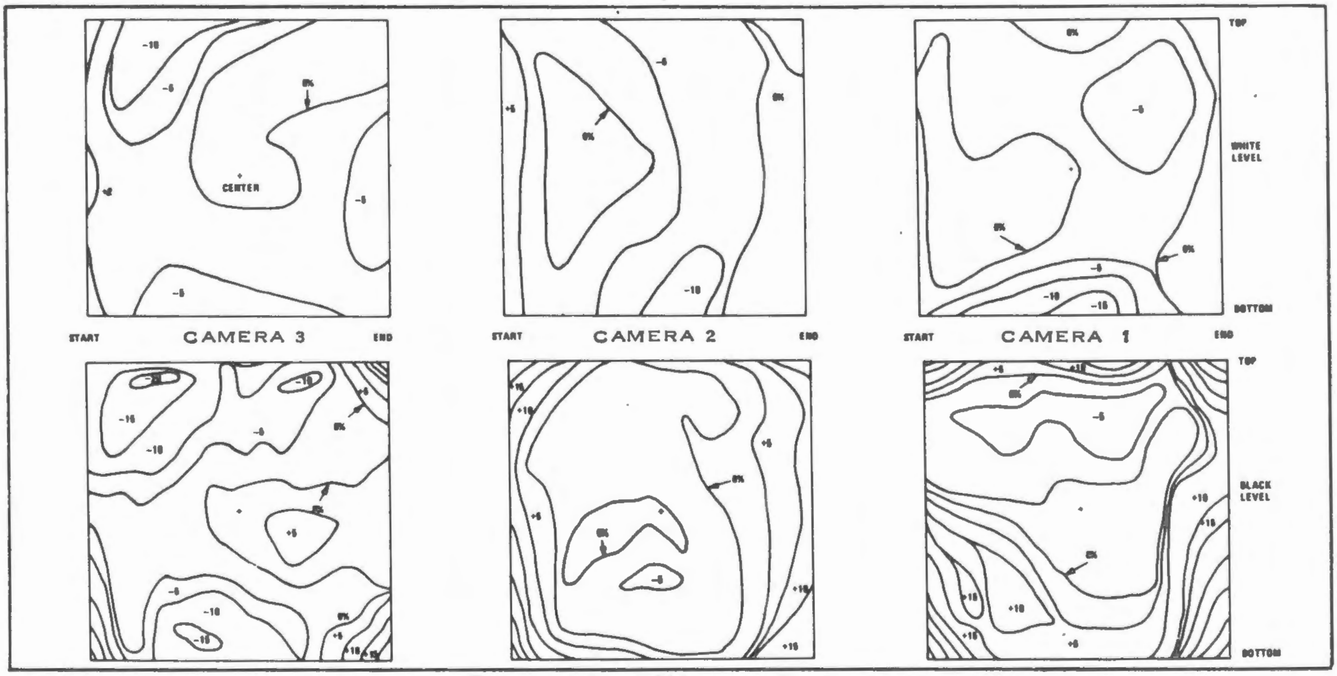


Figure A.1-13. RBV Camera Shading

A.2 MULTISPECTRAL SCANNER SUBSYSTEM

The Multispectral Scanner Subsystem (MSS) gathers data by imaging the surface of the earth in several spectral bands simultaneously through the same optical system. The MSS for ERTS A is a 4-band scanner operating in the solar-reflected spectral band region from 0.5 to 1.1 micrometer wavelength. It scans cross-track swaths of 185 kilometers (100 nm) width, imaging six scan lines across in each of the four spectral bands simultaneously. The object plane is scanned by means of an oscillating flat mirror between the scene and the double-reflector, telescope type of optical chain. The 11.56 degree cross-track field of view is scanned as the mirror oscillates ±2.89 degrees about its nominal position as shown in Figure A.2-1.

The instantaneous field of view of each detector subtends an earth-area square of 79 meters on a side from the nominal orbital altitude. Field stops are formed for each line imaged during a scan, and for each spectral band, by the square input end of an optical fiber. Six of these fibers in each of four bands are arranged in a 4 by 6 matrix in the focused area of the telescope.

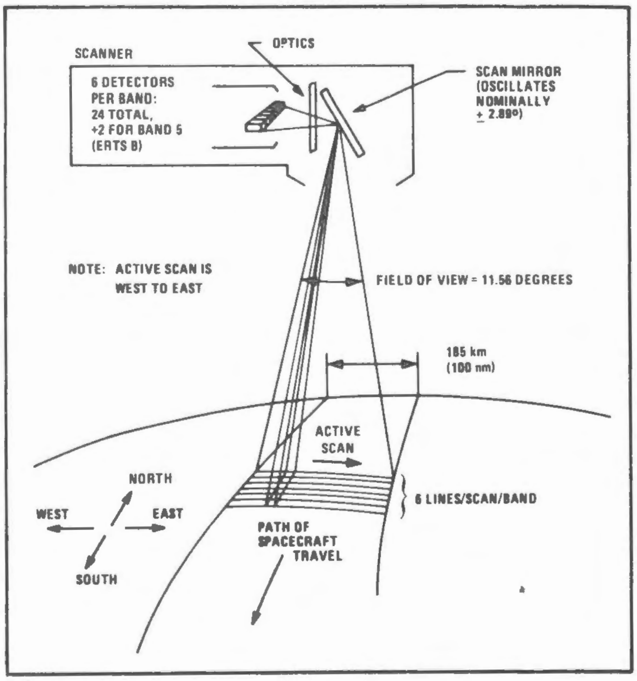


Figure A.2-1. MSS Scanning Arrangement

Light impinging on each glass fiber is conducted to an individual detector through an optical filter, unique to the spectral band served. An image of a line across the swath is swept across the fiber each time the mirror scans, causing a video signal to be produced at the scanner electronics output for each of 24 channels. These signals are then sampled, digitized and formatted into a serial digital data stream by a multiplexer. The sampling interval is 9.95 μsec, corresponding to a cross track motion of the instantaneous field of view of 56 meters.

The along-track scan is produced by the orbital motion of the spacecraft. The nominal orbital velocity causes an along-track motion of the subsatellite point of 6.47 km/sec neglecting spacecraft perturbation and earth rotation effects. By oscillating the mirror at a rate of 13.62 Hz, the subsatellite point will have moved 474 meters along track during the 73.42 millisecond active scan and retrace cycle. The width of the along-track field of view of six detectors is also 474 meters. Thus, complete coverage of the total 185 kilometer wide swath is obtained. The line scanned by the first detector in one cycle of the active mirror scan lies adjacent to the line scanned by the sixth detector of the previous mirror scan. Figure A.2-2 shows this composite scan pattern.

The MSS subsystem is used on two missions; for the first mission (ERTS A), the four selected spectral bands are:

Band 1	0.5 to 0.6 micrometers
Band 2	0.6 to 0.7 micrometers
Band 3	0.7 to 0.8 micrometers
Band 4	0.8 to 1.1 micrometers

Bands 1 through 3 use photomultiplier tubes as detectors; Band 4 uses silicon photodiodes.

For the ERTS B mission, a fifth band is added that operates in the thermal (emissive) spec-

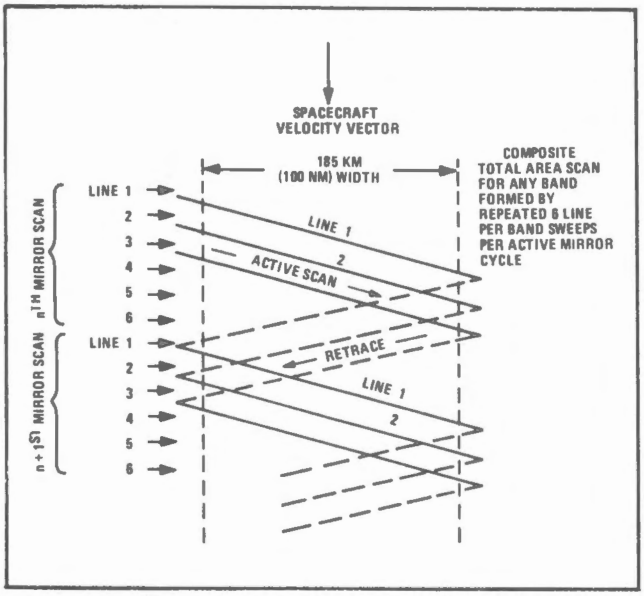


Figure A.2-2. Ground Scan Pattern for a Single MSS Detector

tral region from 10.4 to 12.6 micrometers. This band uses mercury-cadmium-telluride, long wave IR detectors that are cooled to approximately 100°K by a passive radiation cooler. Energy is accepted through a slit near the fiber matrix and conducted by relay optics onto the detectors which form the field stops. The IFOV dimensions are three times greater than for Bands 1 through 4.

A.2.1 Operation and Calibration

A.2.1.1 Operation

The analog video outputs of each detector are sampled by the multiplexer during the active portion of the west-to-east sweep of the mirror. Since the sampling rate is constant (derived from an internal clock) and the mirror motion is not exactly constant, a variable number of samples per scan line results. This is accommodated by using mirror scan position monitors which detect the angular positions of the mirror corresponding to the edges of the 185-kilometer ground swath. Sampling of the detectors is initiated at the mirror position corresponding to the westward edge of the swath. Sampling is preempted as the mirror reaches the position corresponding to the eastward edge of the swath. By this method the scan lines may be corrected by NDPF processing to contain the same number of samples for each scan line with each line corresponding to 185 kilometers in length.

The video outputs from each detector in the scanner are sampled and commutated once in 9.95 microseconds and multiplexed into a pulse amplitude modulated (PAM) stream. The commutated samples of video are either transmitted directly to the analog-to-digital (A/D) converter for encoding or, for Bands 1 through 3, are directed to a logarithmic signal compression amplifier and then to the encoder. This selection is made by ground command. Encoding for either the linear or compressed mode is to 6 bits.

The signal compression mode is normally used since the photomultiplier detectors have a better signal-to-noise performance. By compressing the high light levels and expanding the lower light levels, the quantization noise more nearly matches the detector noise. Noise for the channels of Band 4 is established by the equivalent load resistor noise and is best matched by the linear quantization. Thus, no signal compression is performed on Band 4.

A high gain mode is also selectable by ground command. In this mode a gain of three is applied to Bands 1 and 2 prior to A/D conversion, and allows use of the large dynamic range of the detectors for scene/illumination conditions producing low irradiance into the sensor. Annotation on each image will indicate the setting of compression and gain.

Figure A.2-3 shows the MSS multiplexer output count versus scene radiance for the four possible mode combinations. The bands which can be placed in each mode are indicated next to the curves presented in the figure. Bands 1 and 2 can be placed in the high gain mode individually. The compressed mode command applies to Bands 1, 2, and 3 jointly.

"Maximum radiance" is the scene radiance in front of the lens which gives count 63, the

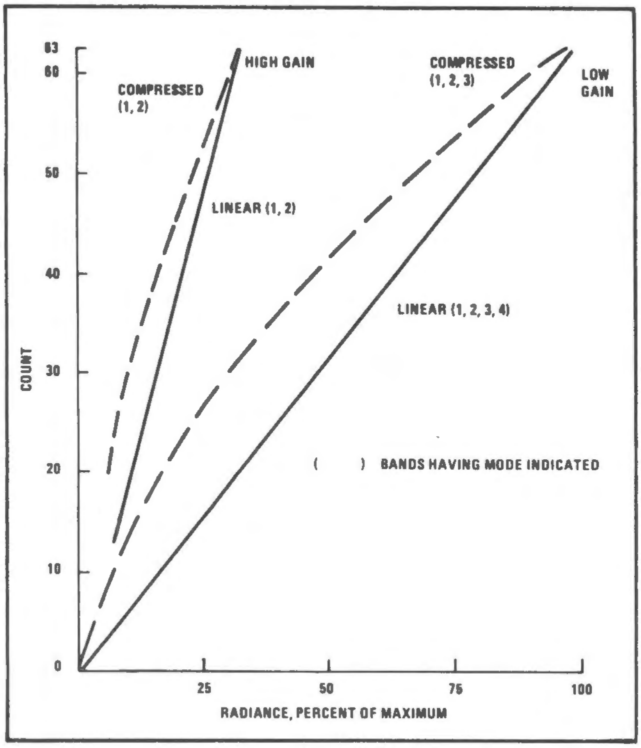


Figure A.2-3. MSS Output Count vs Radiance, Compressed and Linear Modes

highest count. Table A.2-1 gives the maximum radiance in each band for both high and low gain. The same maximum values apply for either the linear or compressed modes. The tabulated values are from tests made using a calibrated light integrating sphere as a source of radiance.

Table A.2-1. MSS Maximum Radiance

	Maximum Radiance (milliwatts/cm^2–SR)	
Band	Low Gain	High Gain
1	2.48	0.83
2	2.00	0.67
3	1.76	–
4	4.60	–

A.2.1.2 Calibration

During the retrace interval, when the scan mirror makes the transit from east to west, a shutter wheel closes off the optical fiber view to the earth and a light source is projected onto the fibers through a variable neutral density filter on the shutter wheel. This process introduces a calibration wedge into the video data stream of Bands 1 through 4 during this retrace interval. The nominal shape of the calibration or gray wedge is as shown in Figure A.2-4. The actual shape and level varies somewhat for the detectors in the various spectral bands.

Knowledge that the calibration lamp intensity is constant makes it possible to obtain a check of the relative radiometric levels and also to equalize gain changes which may occur in the six detectors of a spectral band. Experience has shown that the eye discerns very slight variations among adjacent lines. Corrections will be performed in the NDPF processing equipment to equalize these levels so that striping will be avoided.

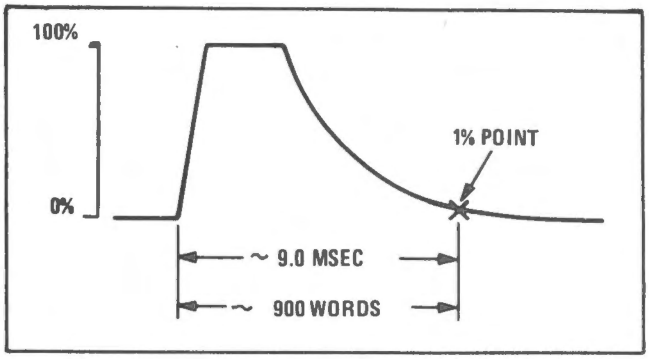


Figure A.2-4. Nominal Calibration Wedge Output

A.2.2 Performance

The characteristics by which the quality of the Multispectral Scanner are measured include:

1. Amplitude resolution which is determined by signal-to-noise ratio (SNR)
2. Spatial resolution which is nominally defined by square wave response

3. Band-to-band registration
4. Geometric fidelity

The amplitude resolution and square wave response are inherent characteristics of the sensor system and cannot be improved by ground processing. The remaining characteristics are representative of properties which are amenable to ground processing correction if errors are systematic or slowly time variant. These four characteristics are treated in Paragraphs A.2.2.1 through A.2.2.4.

A.2.2.1 Signal-to-Noise Ratio (SNR)

Parameters which enter into the voltage SNR calculations at the scanner output are tabulated in Table A.2-2. The minimum system

Table A.2-2. MSS Parameters Affecting Signal-To-Noise Ratio

Parameter (Units)	Band	Nominal
Instantaneous Field-of-View (mr)	1-4	0.086
	5	0.258
Mean photocathode sensitivity over spectral band 9 ma watt-1)	1	34.5
	2	25.0
	3	12.0
PMT sensitivity enhancement factor	1-3	2.40
Electrical Bandwidth (kHz)	1-4	42.3
	5	14.1
Optical efficiency, including obscuration	1-4	0.26
	5	0.34
Electron multiplier noise factor	1-3	1.40
Preamplifier noise factor	4	1.35
	5	1.30
Noise equivalent power (10^{-14} watts Hz$^{-½}$)	4	11.0
	5	1.0
Radiance into sensor to produce full scale output (milliwatts cm^{-2} ster^{-1})	1	2.48
	2	2.00
	3	1.76
	4	4.60
Entrance aperture (cm)	1-5	22.82
Ratio of filter effective noise bandwidth to information bandwidth	1-5	1.05
f Number	5	2
Black body radiance change per unit temperature change (10^{-4} watts cm^{-2} ^{o}K^{-1} ster^{-1} μm^{-1})	5	0.131

voltage SNR output, in both the compression and linear modes of operation, versus input radiance levels are shown in Figure A.2-5. A comparison with test values is also shown.

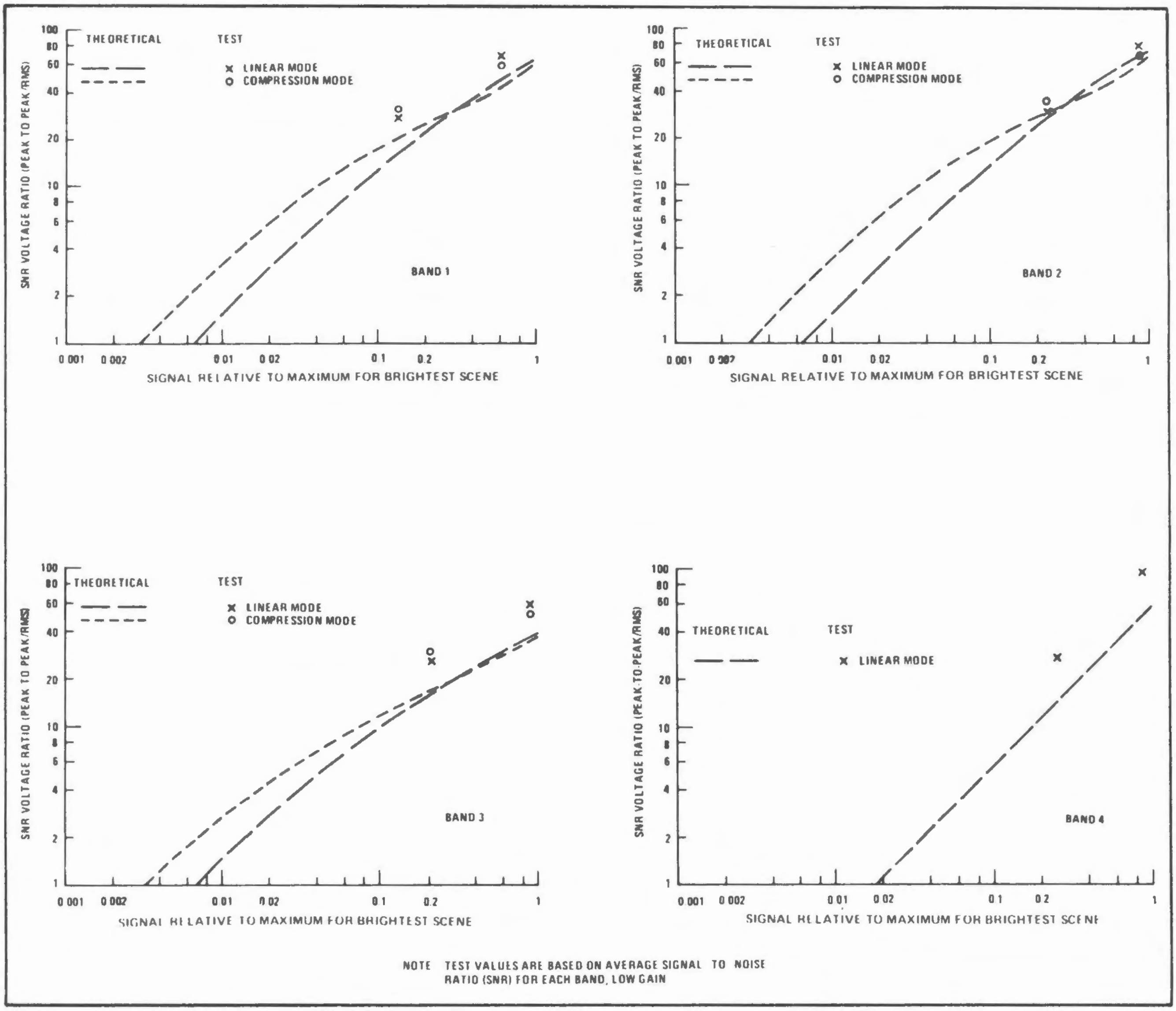
A.2.2.2 Square Wave Response

The square wave response for the MSS determined by test is shown in Figure A.2-6. Not included are responses of ground processing equipment and target contrast modulation at the MSS image plane.

A.2.2.3 Band-to-Band Registration

The utility of the scanner for signature analysis is largely dependent upon the accuracy with which points can be sampled or registered from one spectral band to another. The single optics nature of the scanner makes excellent registration possible.

Due to the fiber optics physical separation and the detector time sampling, the spacing between fibers is set for different spectral bands to permit the radiometric levels to be



NOTE TEST VALUES ARE BASED ON AVERAGE SIGNAL TO NOISE RATIO (SNR) FOR EACH BAND, LOW GAIN

Figure A.2-5. Signal Relative to Maximum for Brightest Scene

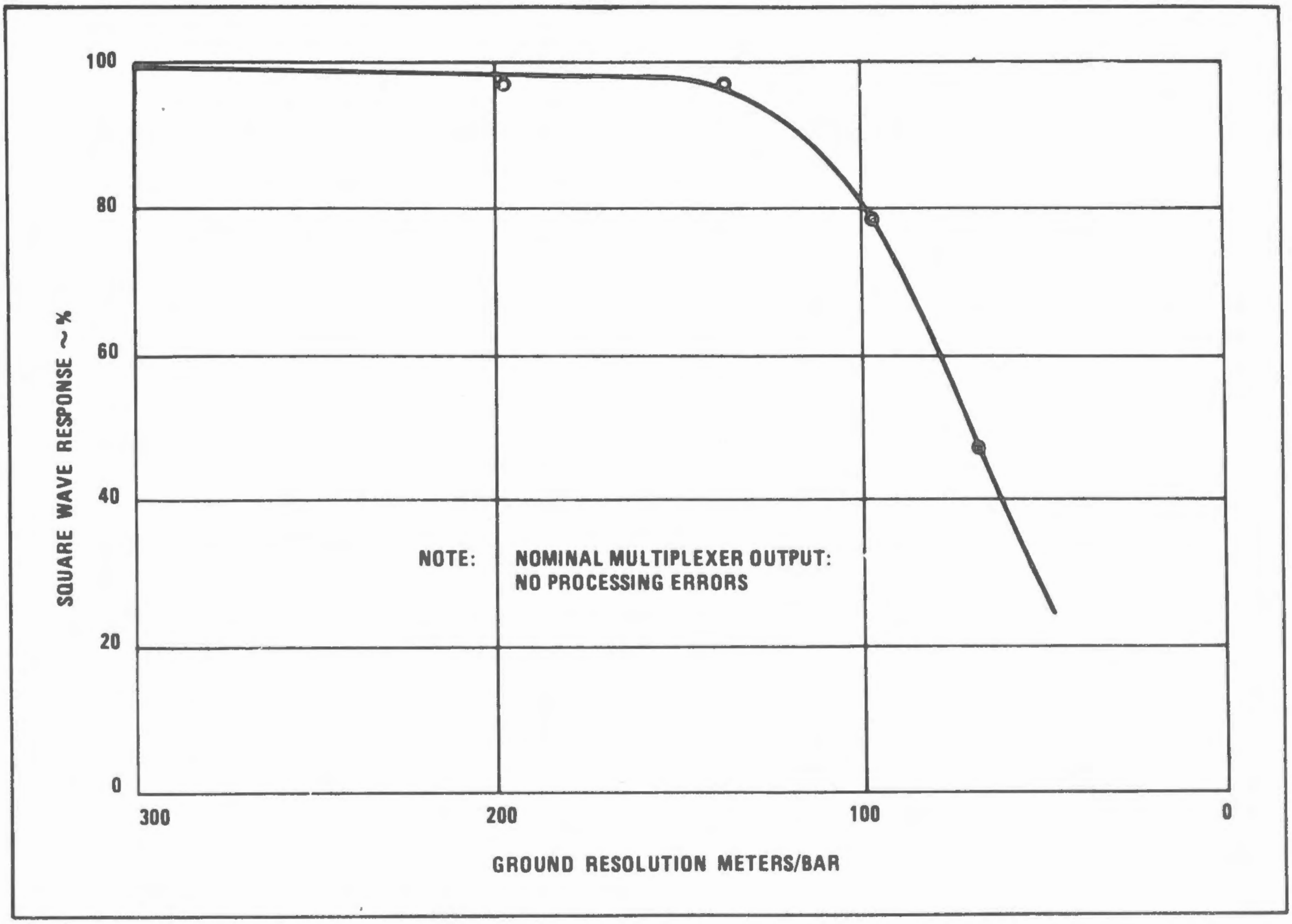


Figure A.2-6. MSS Square Wave Response, Typical Measured for All Bands

compared without interpolating data. For a given selected spacing, this time interval between commutator samples in adjacent bands is "ideally" (under the assumption of a constant velocity during active scan) made to coincide with the time interval between instantaneous fields of view. The commutator will then sample exactly the same point on the ground in each band a known number of samples apart (known time interval).

Figure A.2-7 shows the detector layout and sampling sequence while Figure A.2-8 shows the band-to-band registration delays required to yield the sample on the ground under the assumption of a constant scan velocity.

The primary sources of registration error lies in the accuracy with which the optical fibers are aligned and the variation in scan rate across the swath. The combined effects of the tolerances of the optical fibers and the mirror scan rate variation are small as shown below:

Direction	Magnitude (Peak)
Across Track	± 15 meters
Along Track	± 3 meters

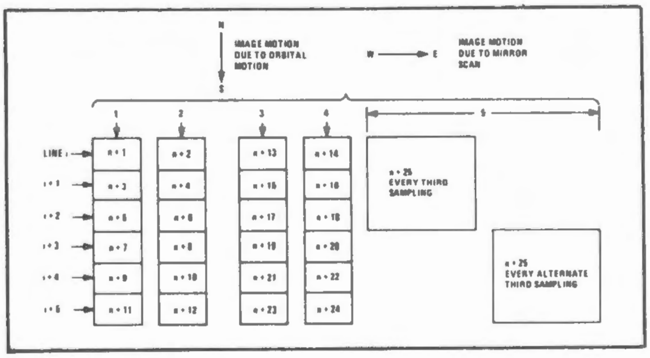
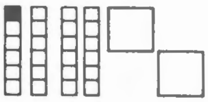
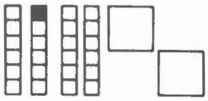
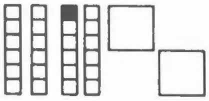
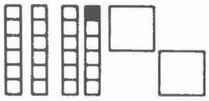
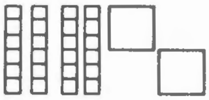


Figure A.2-7. Detector Spatial Layout and Sampling Sequence

POSITION OF IMAGE ELEMENT RELATIVE TO DETECTOR	RELATIVE ELAPSE TIME (μSEC)	RELATIVE DELAY IN SAMPLING SEQUENCE
	0	0 COMPLETE SCAN SEQUENCE PLUS 0 SEQUENTIAL SAMPLE
	20.278	2 COMPLETE SCAN SEQUENCES PLUS 1 SEQUENTIAL SAMPLE
	44.576	4 COMPLETE SCAN SEQUENCES PLUS 12 SEQUENTIAL SAMPLES
	64.874	6 COMPLETE SCAN SEQUENCES PLUS 13 SEQUENTIAL SAMPLES
	—	COMPLETE SCAN SEQUENCES PLUS SEQUENTIAL SAMPLES

NOTES: 0.398 μ SEC PER SEQUENTIAL SAMPLE
9.95 μ SEC PER COMPLETE SAMPLING SEQUENCE (25 SAMPLES)

Figure A.2-8. Band-to-Band Registration Delay

A.2.2.4 Geometric Fidelity

A tabular summary of internal scanner errors which introduce positional errors in the imagery is shown in Table A.2-3.

The scan nonlinearity arises from the torque due to the mirror support pivots. This error is largely systematic and compensated for in generating imagery on film in the NDPF. Most of the remaining error sources are random and will not be removed in ground processing; however, their combined effect of ± 26 meters rms is quite small compared with other spacecraft related positional error sources.

Table A.2-3. MSS Geometric Errors

Error Source	Observed Value
Scan Linearity	+1.4 to −3.9% peak (largely systematic)
Random Cross Scan Jitter	2 μrad rms 5 μrad peak
Scan to Scan Repeatability	4 μrad rms 8 μrad peak
Scan Start and Scan End Variation	1 μsec
Sampling Uncertainty	10^{-4} crystal error
Detector Alignment	0.1 resolution element (systematic error)

A.3 DATA COLLECTION SYSTEM

The Data Collection System (DCS) provides the capability to collect, transmit, and disseminate data from remotely located earth-based sensors. As shown in Figure A.3-1, the system involves remote Data Collection Platforms (DCP), satellite relay equipment, ground receiving site equipment, and a ground data handling system.

The DCP is connected to individual environmental sensors which are selected and provided by the investigator or user agency to satisfy his own particular needs. Up to eight individual sensors may be connected to a single DCP. The sensors may provide digital or analog outputs to the DCP. The DCP transmits the sensor data to the satellite which in turn relays the data to the ground receiving site through an on-board receiver/transmitter.

The ground receiving site equipment accepts the data and decodes and formats it for transmission to the Ground Data Handling System (GDHS) at Greenbelt, Maryland. The data is received in the Operations Control Center (OCC) where it is reformatted and written on magnetic tape and then either transmitted direct to the user or passed on to the NASA Data Processing Facility (NDPF) for further processing and cataloging required for dissemination to the user agencies.

The geometry involved in relaying DCS data is shown in Figure A.3-2. The satellite is at an altitude of approximately 500 nautical miles. The transmitting antenna of the DCP subtends an angle of ±70 degrees from the vertical and the ground receiving site visibility is nominally ±85 degrees from the vertical. When the satellite is in mutual view of a transmitting DCP and one or more of the

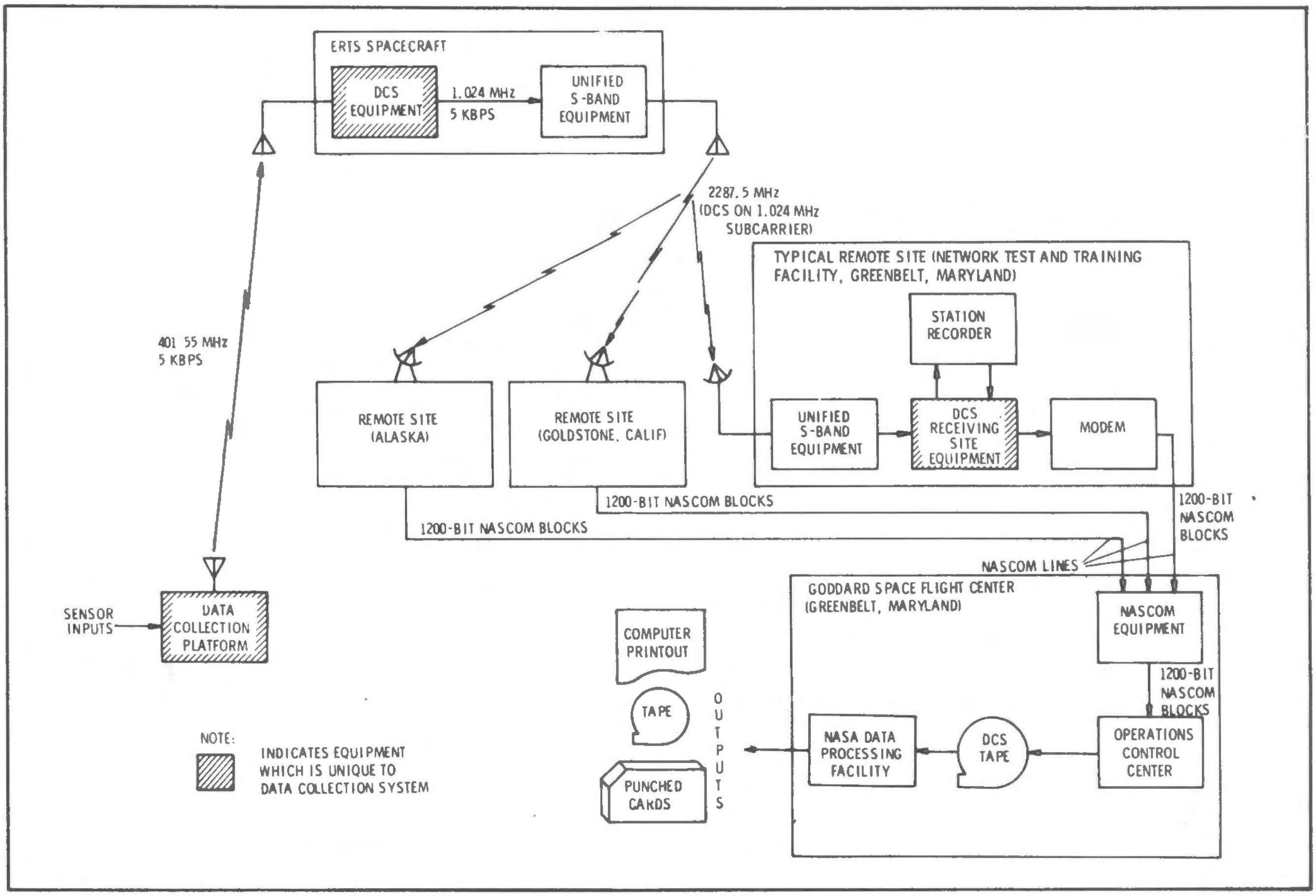


Figure A.3-1. Data Collection System Block Diagram

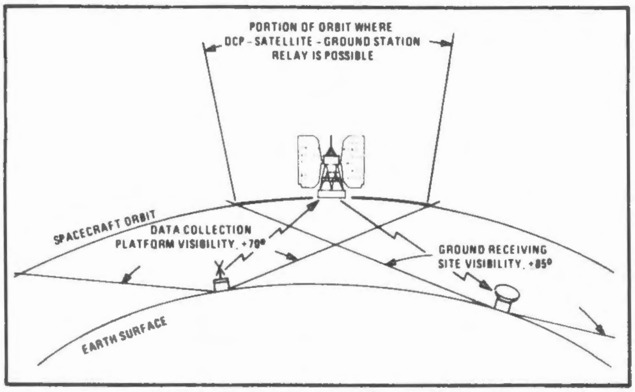


Figure A.3-2. DCS Data Relay Geometry

ground receiving sites, the message from the DCP is relayed to the receiving site and transmitted over land lines to the OCC. The DCP's operate continuously, sampling the sensors periodically and transmitting a 38-millisecond burst of data containing all sensor channels at intervals of about every three minutes. Note that the satellite acts as a simple real time relay with no on-board data storage. The DCP transmissions are received at the ground receiving site immediately except for propagation and fixed system time delays.

The orbit parameters (the orbital period is ~103 minutes) allow for up to 9 minutes of mutual visibility for some DCP's. Figure A.3-3 shows the potential area of mutual visibility for one orbital pass. In these cases it is possible to receive up to three separate transmissions from a DCP for each orbital pass of the satellite. The use of three receiving sites, Alaska, Goldstone, and NTTF, provides nine active passes over the North American Continent each day. It is expected that there will be five daylight passes and four night time passes.

For a particular DCP, the orbit parameters and the receiving site locations cause the spacecraft to be in mutual view of a platform located almost anywhere in North America and at least one of the three ground receiving sites during at least two orbits per day—one about 9:30 in the morning and the other about 9:30 in the evening. At least one message is relayed from each platform every 12 hours.

The Data Collection System is designed to assure that the probability of receiving at least one valid message from any DCP every 12 hours is at least 0.95 for as many as 1000 DCP's located throughout the United States.

Interference of signals from two or more DCP's transmitting simultaneously may cause incorrect or partial messages to be received. To minimize this possibility, the system uses error coding and other schemes to correct or identify messages containing errors and to identify incomplete messages. The probability of erroneously indicating that a given message is valid (i.e., stating that a message which contains an error does not) is less than 0.001.

In order to improve performance for locations where there is a relatively short period of mutual DCP-ground station visibility from the Observatory, the average rate of DCP message bursts can be switched to a more rapid rate: One message burst each 90 seconds. Using this feature, DCP's may be located anywhere in Continental U.S. or Alaska and achieve this performance. DCP's may be deployed beyond these bounds, however, with degraded performance in terms of probability of receiving a valid message each 12 hours.

As shown in Figure A.3-1, operation of the Data Collection System requires three hard-

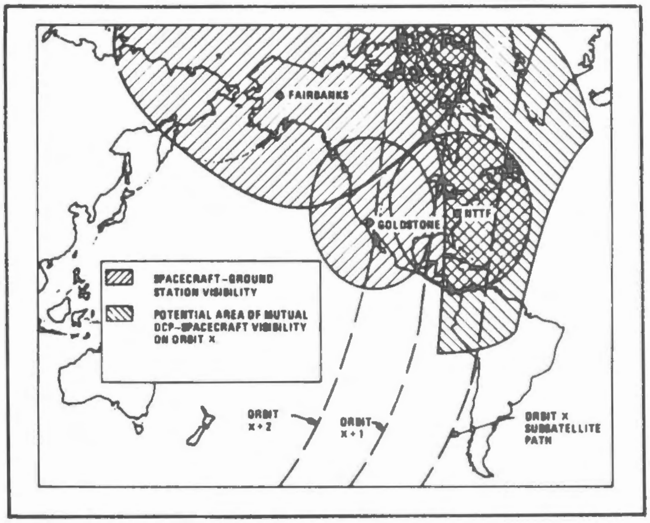


Figure A.3-3. Mutual DCP-Receiving Site Visibility ware subsystems—the Data Collection Platforms, the receiving and transmitting equipment in the satellite, and special receiving and preprocessing equipment located at each of three ground receiving sites. In addition, the system uses existing ground communication facilities and the hardware/software capabilities of the OCC and NDPF at Goddard. These facilities are described in the following sections.

A.3.1 Data Collection Platform

The Data Collection Platform (DCP) collects, encodes, and transmits ground sensor data to the ERTS Observatory. A block diagram is shown in Figure A.3-4 and a sketch in Figure A.3-5.

The DCP will accept analog, serial-digital, or parallel-digital input data as well as combinations of those. Eight analog inputs or 64 bits of digital input can be accepted. Combined inputs are selected by individual analog inputs and groups of 8 bits of digital input up to a total equivalent to 64 bits.

Selection of the type of input is made by the switch positions on the front panel of the platform. For all types of inputs the nominal signal amplitude range is from 0 to +5 Vdc. The source impedance must be less than 10,000 ohms resistive and less than 1000 picofarads capacitive. Input impedance is greater than 1 megohm.

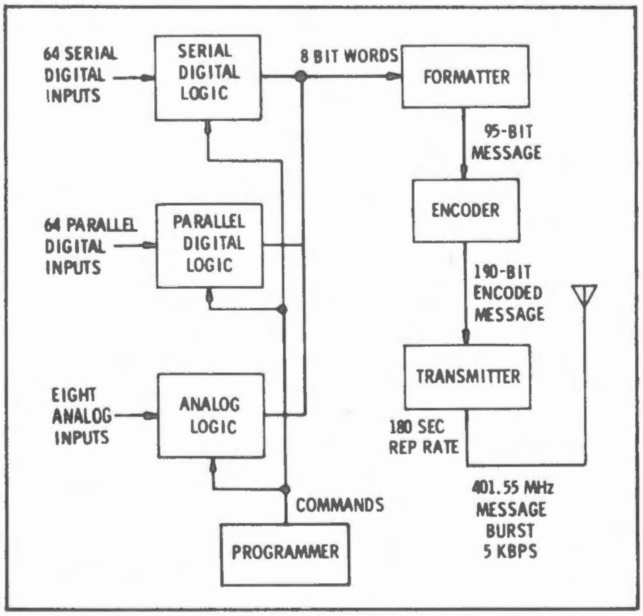


Figure A.3-4. Data Collection Platform Block Diagram

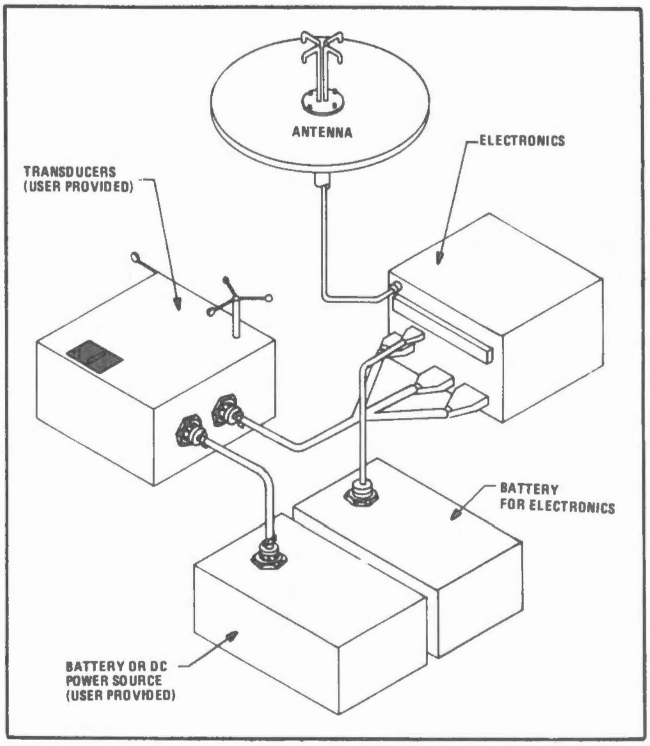


Figure A.3-5. Data Collection Platform

For analog inputs, the analog-to-digital converter converts the normal signal range of 0 to +5 Vdc into eight bits of binary with a resolution of 19.53 millivolts per bit; conversion error is less than one percent of full scale, including quantization.

Serial digital data (of up to 64 bits) is accepted as a single input. An enable command and a 2.5 kHz clock is supplied to enable the transfer of the serial digital data.

Up to 64 parallel digital bits can be accepted by the DCP. These parallel bits are sampled in 8-bit groups insequence during a 68-millisecond period corresponding to the entire platform "on" time (warm-up and message transmission). A data gate is provided during this period.

Format of a DCP message prior to encoding consists of 95 bits in the format of Table A.3-1.

Table A.3-1. DCP Message Format

Bits		
1-15	Preamble	
16-17	Synchronization	
18-27	Platform ID	
28-35	Data Word Number 1	Sensor 1 through 8 occupy 64 bits
36-43	Data Word Number 2	
44-51	Data Word Number 3	
52-59	Data Word Number 4	
60-67	Data Word Number 5	
68-75	Data Word Number 6	
76-83	Data Word Number 7	
84-91	Data Word Number 8	
92-95	Encoder run-out bits	

Before transmission, each DCP message is encoded using a rate 1/2 constraint length five convolutional code, to produce a 190-bit message output. A message is sent every 90 or 180 seconds, depending on the setting of the time selection switch on the front panel of the equipment.

A.3.2 DCS Spacecraft Equipment

The spacecraft acts as a simple relay: receiving, frequency translating and retransmitting the burst messages from the DCP's. No onboard recording, processing or decoding of the data is performed. A DCS unique UHF antenna and redundant receivers are provided. The output of the DCS receiver is applied to the Premodulation Processor where the DCS data is put on a subcarrier of the Unified S-band (USB) equipment. USB equipment, used for narrow band telemetry, is used to retransmit the DCP messages to the three primary receiving sites.

A.3.3 Treatment of Data at the Receiving Site

At the receiving site, the composite S-Band signal is received, the DCS subcarrier extracted and inputted to special DCS Receiving Site Equipment (DCS/RSE). The DCS/RSE performs a matched filter operation on each encoded bit received, and quantitizes the output of that operation to three bits. Each bit reprsentation recovered from the DCP transmission is in the form of a four-bit byte; one bit, indicating the presence or lack of signal (squelch), and the three-bit quantization of the matched filter. When no signal is present, the output byte is set to all zeros. The quantized bits are decoded, and quality bits are assigned to each decoded bit and the overall message to indicate the decoding confidence level.

The DCS/RSE formats the decoded data with the quality indicators and a 30-bit site time code, which was converted from the NASA 36-bit time code. The data is buffered and formatted into a 1200-bit NASCOM block and outputted to a site modem in real time as messages are received. The DCS/RSE adds the NASCOM header and the filler and check bits, along with buffering the data and site-time information. In the event of equipment problems, the data is also recorded for post-pass playback. The NASCOM blocks are transmitted to the OCC by the modem.

A.3.4 Treatment of Data at the GDHS

The NASCOM data blocks are received at the OCC where the NASCOM header is stripped and DCS data messages are written, in the order received, on a magnetic tape. One magnetic tape may contain messages from one or more receiving sites. At the conclusion of one or more station passes, this tape is transferred to the NDPF. The usual mode of operation involves the transfer of data to the NDPF at the conclusion of each pass.

When the DCS tapes arrive at the NDPF from the OCC, they are read, edited, reformatted, and the data is sorted according to platform identification and the time the data was received. Redundant data resulting from overlapping station coverage is removed. The criteria for determining redundant data is an exact match between the messages except for receiving site (station ID). An active data file is generated which maintains a record of the most recent 24-48 hours of DCS messages. This resides in random-access storage in the NDPF computer.

The active data file contains the platform message data in addition to the results of the editing checks and certain identifying information. Four editing checks are performed: the station code is checked to assure that it is one of the three valid codes for Goldstone, Alaska, or NTTF; the platform ID is checked to assure that it matches a valid ID maintained in a platform ID file; a flag is set if any one of the quality bits associated with the platform ID is zero; a fourth check is made on the time of reception. If any part of the time code exceeds possible values for day, hour, minute, or seconds, a flag is set in the active data file. These checks and flags do not cause any messages to be rejected.

An active data file entry is made for each platform message and consists of eight words as shown in Table A.3-2. The platform ID is a binary coded decimal from 1 to 1000. Each platform has a unique designator. The platform ID quality bits are those that were associated with the platform ID during transmission. Words 5 and 6 contain the actual data bits in the order in which they were received. For convenience, the associated quality bits have been separated and put in words 7 and 8.

Table A.3-2. DCS Active Data File Entry

Word	Bits	Item	Mode	Format
1	0-15	Platform ID	Binary	XXXX
	16-23	Satellite ID	EBCDIC*	1/2 (1 for ERTS A, 2 for ERTS B)
	24-31	Station ID	EBCDIC	A/G/N (Alaska, Goldstone, NTTF)
2	0-15	Days (GMT)	Binary	1-366
	16-31	Days Since Launch	Binary	1-N
3	0-7	Hours (GMT)	Binary	0-23
	8-15	Minutes (GMT)	Binary	0-59
	16-23	Seconds (GMT)	Binary	0-59
	24-31	Year (GMT)	EBCDIC	0-9
4	0-5	Not Used	Binary	0
	6-15	Platform ID Quality	Binary	All Ones
	16-17	Not Used	Binary	0
	18-23	Error Flags:		
		Invalid Station Code	Bit 18	(1 = set)
		Invalid Platform ID	Bit 19	(1 = set)
		Poor Platform ID Quality	Bit 20	(1 = set)
		Invalid Time Code	Bit 21	(1 = set)
		Duplicate Message	Bit 22	(1 = set)
		Redundant Message	Bit 23	(1 = set)
	24-28	Not Used		
	29-31	Message Quality	Binary	0-7
5	0-31	Data Bits	Binary	
6	0-31	Data Bits	Binary	
7	0-31	Quality Bits	Binary	
8	0-31	Quality Bits	Binary	

*Extended Binary Decimal Interchange Code

Available products consist of magnetic tapes, punched cards, or computer listings. All products are limited to uncalibrated data; that is, data bits are disseminated to the user without conversion to engineering units. Magnetic tapes contain message data records ordered according to platform ID and time with ID, and in the same 8-word format as the active data file entry. The entries are blocked 60 to a tape record. A tape header is included for identification. The details of this tape format are contained in Figure 3-22 of Section 3.

The data card format for DCS products is shown in Figure 3-20. Entries for these cards are also given in Table A.3-3. The listing for-

Table A.3-3. DCS Data Card Entries

Column	Item	Format
1-2	Card ID for Standing Requests for Variable Requests	SC VC
3-6	User ID	AAAA
7-10	Platform ID	1-1000
11	Satellite ID (1 for ERTS A, 2 for ERTS B)	N
12	Year of Reception	1-9
13-21	Time Code (GMT)	DDDHHMMSS
22	Station ID	A/G/N
23,24	Encoded Error Flag: 32 = Invalid Station ID 16 = Invalid Platform ID 8 = Poor Platform ID Quality 4 = Invalid Time Code 2 = Duplicate Message 1 = Redundant Message (Or any combination of the above; e.g.:) 63 = All Conditions Exist	0-63
25	Message Quality Level 0 = Long or short message 1—7 indicates lowest to highest quality	0-7
26	Data Format Indicator O = Data in octal digits (22 columns) H = Data in hexadecimal digits (16 columns)	O/H
28/34-49	Data in Octal or Hexadecimal Digits	
51/57-72	Data Quality in Octal or Hexadecimal Digits	

NOTE: If quality bits are included, they will be in the user format as the data bits. Columns 51/57-72 are optional depending on the use of data quality bits.

mat is given in Figure 3-21. DCS data products may be requested in two ways. A standing order may be permanently established with the NDPF to require that all data from a set of platforms be sent to the user agency. The capability is provided in a standing request either to keep or eliminate the quality bits for card or listing outputs. It is also possible for the investigator to designate the level of message quality which is acceptable to him.

A variable request allows the investigator to do retrospective searches. The capability is provided to search the archives based on user ID (all platforms listed for this user are retrieved), or individual platform ID. It is possible to qualify the search based on a given time period or geographical area. All three product media are available and data can be qualified as to message quality.

A.3.5 · Treatment of DCP Data at the CCRS

ERTS messages and DCP data are received at CCRS, Ottawa, Canada, via the telephone link with GDHS at Greenbelt, Maryland. All information is recorded simultaneously on a magnetic tape and a teletype printer.

The CCRS retransmission system for the DCP data is implemented using the CCRS computer system. The source magnetic tape is periodically transferred to a permanent magnetic tape file. The software data handling system collects the DCP data which are then separated using the PID numbers; they are stored on separate user disk files. The data are formatted into the desired engineering units and the checksum is verified for each line. An asterisk at the end of a line indentifies a checksum error within that line.

Each user may access his DCP data file by dialing into the CCRS computer system on a remote terminal. By using either of the two numbers assigned to him, the user gains access to his data file on disk which is output on to his terminal. One access number types the data at the remote terminal leaving the file unaltered. The other access number types the data file and then deletes it.

In order to prevent accumulation of excessively large data files, all DCP data are transferred to hardcopy and deleted on a weekly basis.

All DCP data files are updated each time the source magnetic tape is input into the CCRS retransmission system. Any previously retransmitted data may be retrieved from the permanent magnetic tape file. This retrieval is done by user request, specifying the date on which the data was originally transmitted by CCRS.

APPENDIX B
OBSERVATORY

The ERTS observatory (Figure B-1) is an earth-pointing stabilized spacecraft consisting of integrated subsystems that provide the power, environment, orbit maintenance, attitude control, and information flow required to support the payloads for a period of one year in orbit. It weighs approximately 2100 pounds (953 kg) and has an approximate overall height of 10 feet (3.04 m) and a diameter of 5 feet (1.52 m), with solar paddles extending out to a total of 13 feet (3.96 m).

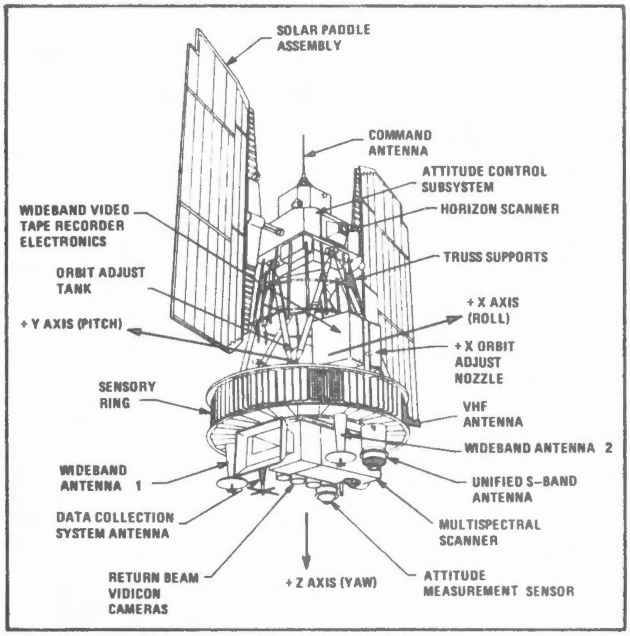


Figure B-1. ERTS Observatory

B.1 ATTITUDE CONTROL SUBSYSTEM

The Attitude Control Subsystem (ACS) provides spacecraft alignment with both local earth-vertical and orbit velocity vectors, and provides rate control about the pitch, roll and yaw axes. The ACS achieves pointing accuracies of the spacecraft axes within 0.4 degrees of the local vertical (about the pitch and roll axes) and within 0.6 degrees of the velocity vector (about the yaw axis). The expected rotation rates encountered during Multispectral Scanner (MSS) and Return Beam Vidicon (RBV) operations are less than 0.015 degree per second about all axes. These rates produce image motions which are negligible during the short exposure of the RBV cameras, but cause a slight distortion in the MSS images. Compensation for these distortions is provided during ground image processing in the NASA Data Processing Facility (NDPF) by applying correction factors for the measured attitude rates.

The 3-axis active ACS uses horizon scanners for roll and pitch attitude error sensing. The rate gyros sense yaw rate and, in a gyro compassing mode, sense yaw attitude. A torquing system uses a combination of reaction jets to provide spacecraft momentum control and large control torques when required; flywheels are utilized for fine control and residual momentum storage.

B.2 ATTITUDE MEASUREMENT SENSOR

The Attitude Measurement Sensor (AMS) is an independent component (not used for attitude control purposes) that determines precise spacecraft pitch and roll attitude. This data is used for image location and correction during ground processing. The AMS detects the radiation level change in the 14 to 16 micron range between the earth's atmosphere and the spatial background and establishes the spacecraft pitch and roll axis positions relative to the local vertical. After ground compensation of telemetry data for variations due to seasonal radiance and other effects, the pitch and roll attitude can be determined to within about 0.07 degree.

B.3 WIDEBAND VIDEO TAPE RECORDER SUBSYSTEM

Two Wideband Video Tape Recorders (WBVTR) record, store, and reproduce the data outputs from either the RBV or MSS during remote sensing operations. Each recorder can record 30 minutes of either 3.2-MHz video analog data from the RBV or 15-Mbps digital data from the MSS. Data are recorded by four heads (on one wheel) rotating across the 2-inch wide tape. Recording and playback are each at 12 inches per second (30 cm/sec) and in the same direction. Total usable tape length is 1,800 feet (548 m) for each recorder.

The RBV analog video signal is transformed into the FM domain by video circuitry in the WBVTR. The signal is received as a negative analog signal, is dc level shifted, frequency modulated, amplified and recorded. To insure head switching during the horizontal blanking interval of the video signal during playback, the RBV signal is rephased to the WBVTR headwheel at the beginning of each triplet exposure during recording. In playback, the RBV signal is read out sequentially by the same four rotating heads, with appropriate switching, producing a continuous RBV signal in the FM domain. The signal is then demodulated on the ground, producing the original analog video waveform.

The MSS digital video data is received as a Non-Return to Zero Level (NRZ-L), 15-Mbps data stream. In the WBVTR, the data stream is re-clocked and then frequency modulates an FM carrier. The resulting frequency-shift keyed (FSK) signal is recorded by four rotating heads. The MSS data are recorded asynchronously; that is, the data stream and rotating heads are not synchronized. In playback, the MSS signal is read out sequentially by the same four rotating heads, with switching and demodulation producing a continuous NRZ-L, 15 Mbps data stream.

Each WBVTR can record and playback either RBV or MSS data at any given time. The selection of RBV data or MSS data for each WBVTR during record or playback, plus appropriate tape motion to select the proper tape location, is made by appropriate ground commands which can be stored by spacecraft equipment for subsequent remote execution.

B.4 POWER SUBSYSTEM

The Power Subsystem supplies the electrical power required to operate all spacecraft service and payload subsystems. During sunlight periods the subsystem delivers a maximum output of 980 watts of regulated -24 volts for short periods. This power is derived from the load sharing of the 550-watt solar array panels and the eight, 4.5-amp batteries. The expected power requirements during payload operation is 480 watts for real-time operation and 521 watts for remote operation. Considering the subsystem as an energy balanced system, it can support an average of 20 minutes of payload (both RBV and MSS) "ON — time" per orbit initially and 12.1 minutes after one year. The reduction in "ON — time" is mainly due to efficiency loss of the solar arrays from small particle impact during the year in orbit. However, the actual payload "ON — time" is limited by other system constraints (such as station pass time, record capability, etc.) to an average of 12 minutes per orbit.

All power is provided from the batteries during the launch phase and while the spacecraft is within the earth's umbra. Energy from the solar array not required for spacecraft loads during the lighted periods is used to recharge the batteries and any excess power is dumped via auxiliary loads.

B.5 COMMUNICATIONS AND DATA HANDLING SUBSYSTEM

The Communications and Data Handling Subsystem (Figure B-2) provides for all spacecraft information flow and is composed of the Wideband Telemetry Subsystem and the narrowband Telemetry, Tracking and Command Subsystem.

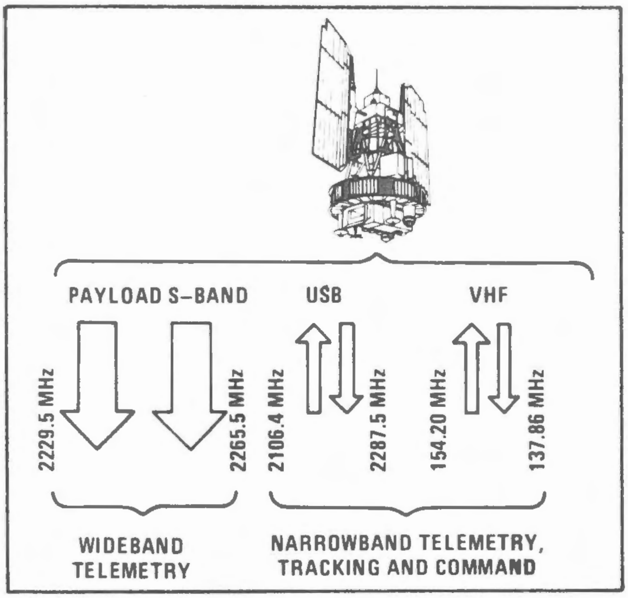


Figure B-2. ERTS Communication Links

B.5.1 WIDEBAND TELEMETRY SUBSYSTEM

The Wideband Telemetry Subsystem accepts and processes data from the RBV, the MSS, and both Wideband Video Tape Recorders, and transmits it to the ground receiving sites.

The subsystem consists of two, 20-watt S-Band FM transmitters and associated filters, antennas, and signal conditioning equipment. As shown in Figure B-3 the subsystem permits transmission of any two data sources simultaneously, either real time or recorded, over either of the two down links (one data source each). Commandable power level traveling wave tube (TWT) amplifiers and shaped beam antennas provide maximum fidelity of the sensor data at minimum power. Cross-strapping and dual mode operation (two data sources) with a single TWT amplifier is available in the event of hardware malfunctions.

A total of 912 telemetry points (576 analog; 16, 10-bit digital words; and 320, 1-bit binary words) can be sampled at rates between once per 16 seconds to five times in one second. The data is pulse code modulated (PCM) and can then be transmitted in real time either over the VHF or Unified S-Band (USB) links at a 1-Kbps rate. Up to 210 minutes can be stored on each of two narrowband tape recorders (NBTR) for subsequent playback at a 24-Kbps rate. Analog data has 8-bit accuracy or 1 part in 256.

The USB equipment has the capability to transmit on separate subcarriers real-time telemetry (768 KHz), playback data (597 KHz), DCS data (1.024 MHz) and pseudo-random ranging information simultaneously over the same 2,287.5 MHz carrier. The playback data can be derived from either of the NBTR's or either of the auxiliary tracks of the WBVTR's.

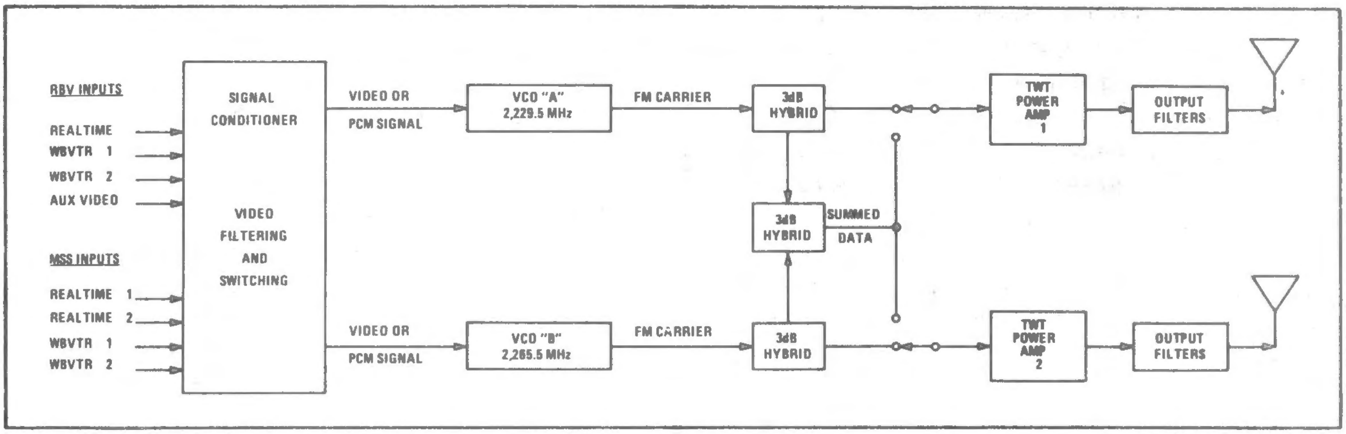


Figure B-3. Wideband Telemetry Subsystem Functional Block Diagram

B.5.2 TELEMETRY, TRACKING AND COMMAND SUBSYSTEMS

The Telemetry, Tracking and Command Subsystem collects and transmits spacecraft and sensor housekeeping data to the ground sites, provides tracking aids, receives commands from NASA'S Space Tracking and Data Network (STDN), and implements those commands on board the spacecraft. In addition it provides the link for transmitting the Data Collection System data.

Only real-time or playback data (from either of the NBTR's) can be transmitted at one time over the 137.86 MHz VHF equipment. All three of the ERTS receiving sites will normally use the USB downlink.

Commanding can be performed via either the STADAN VHF link at 154.20 MHz or by the MSFN USB link at 2,106.4 MHz into redundant sets of receivers on the spacecraft. These commands can be any of the 512 possible commands executable by the command/clock or any of the 8 commands recognizable by the Command Integrator Unit. A total of 30 command/clock commands can be "stored" for execution outside of the range of the ground stations. All remote payload operations are performed using stored commands.

B.6 THERMAL CONTROL SUBSYSTEM

The Thermal Control Subsystem provides a controlled environment of 20 ± 10°C for spacecraft and sensor components. Thermal control is accomplished by both semipassive (shutters and heaters) and passive (radiators, insulation, and coatings) elements. Shutters are located on each of the peripheral compartments on the sensory ring, and are actuated by two-phase, fluid-filled bellows assemblies. These assemblies are clamped tightly to heat dissipating components and position the shutter blades to the proper heat-rejection level. Heaters are bonded at various locations in the sensory ring to prevent temperatures from falling below minimum levels during extended periods of low equipment-duty cycles. The heaters are energized selectively by ground command when the temperature level at these locations falls below a predetermined value. The upper and lower surfaces of the sensory ring are insulated to prevent gain or loss of heat through those areas. External structure and radiating surfaces are coated to provide the required values of emissivity and absorptivity.

Passive radiators coated with a low-absorptivity, high-emissivity finish are used to assist the shutters in rejecting the heat from the sensory ring. Radiators are provided for the RBV, the MSS, the Wideband Video Tape Recorders, and the Narrowband Recorders.

B.7 ORBIT ADJUST SUBSYSTEM

The Orbit Adjust Subsystem (OAS) establishes the precise ERTS orbital parameters after orbit insertion and makes adjustments throughout the life of the mission to maintain overlapping coverage of sensor imagery and long-term repeatability.

The OAS is a monopropellant, hydrazine-fueled, propulsion system constructed as a single module consisting of three rocket engines, a propellant tank and feed system, a support structure and the necessary interconnect plumbing and electrical harnessing. The OAS is mounted to the spacecraft sensory ring with a thruster located along each of the (+) roll, (-) roll, and (-) pitch axes, such that each thrust vector passes approximately through the spacecraft center of mass. With these thrust vectors, the orbit adjust subsystem can impart incremental velocities to the spacecraft to correct in-plane injection errors, inclination injection errors, and orbit perturbations due to atmospheric drag and other error sources over an orbital life of one year.

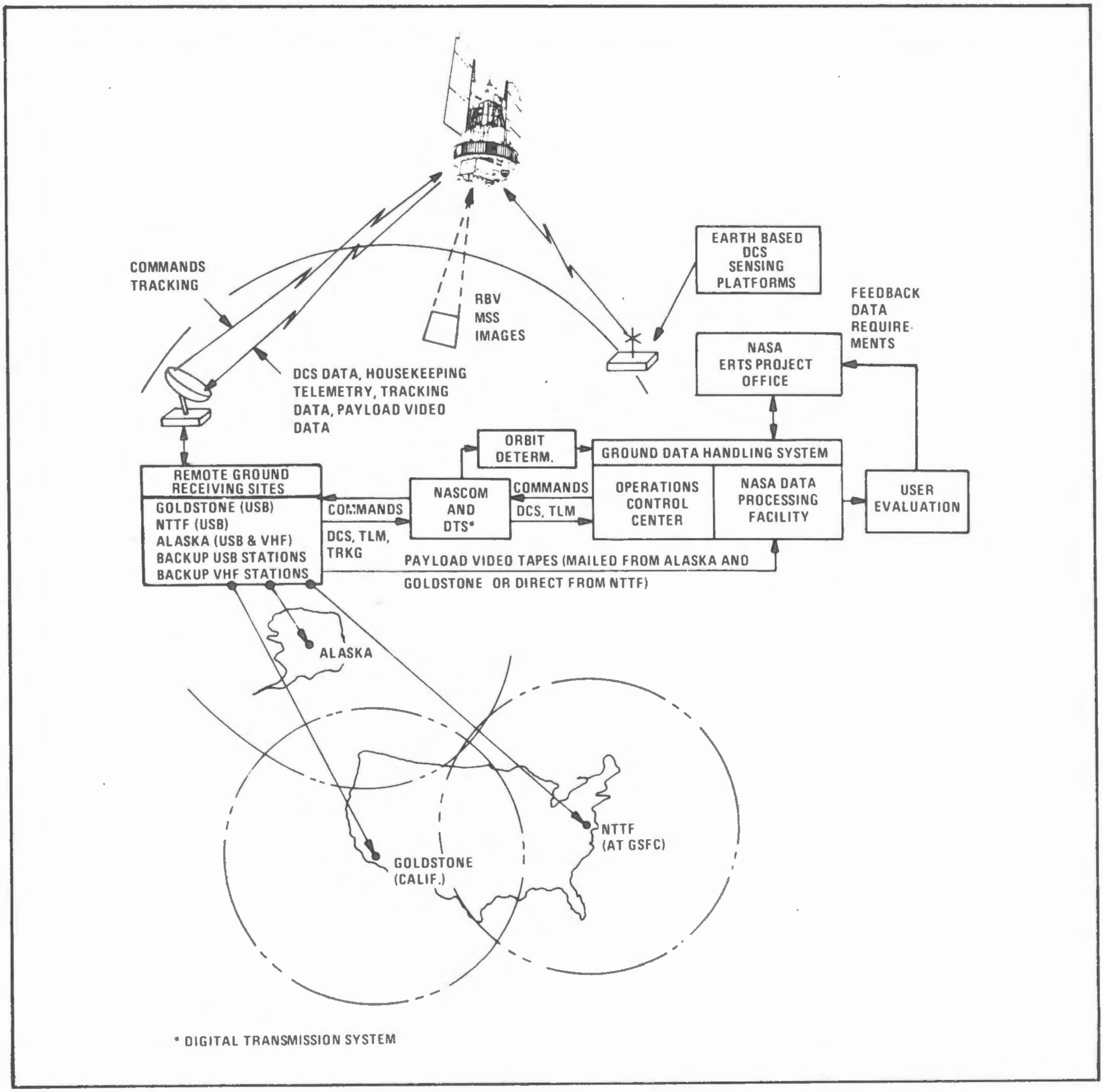
B.8 ELECTRICAL INTERFACE SUBSYSTEM

The Electrical Interface Subsystem functions include power switching, telemetry signal generation, switching logic, power fusing, data routing, time-code processing and automatic "shut-off" of equipment. Time-code data are received from the command/clock, assembled into storage registers and relayed to the RBV and MSS, when requested. Timers associated with the payloads, WBVTR and S-Band Transmitter are provided to automatically remove power after 32 minutes of operation if the normal turn-off does not occur. Power switching (regulated and unregulated), transient load circuitry, and fusing are included in this subsystem for the RBV, MSS, WBVTR's and the Orbit Adjust Subsystem.

APPENDIX C
GROUND STATIONS AND GROUND COMMUNICATIONS

C.1 GENERAL DESCRIPTION

Communications between the spacecraft and the ground are handled via ground stations which are parts of NASA's Space Tracking and Data Network (STDN). The NASA Communications (NASCOM) network provides the necessary communication of data between these ground stations and the Ground Data Handling System (GDHS) located at Goddard Space Flight Center (Figure C-1). The Canadian receiving station at Prince Albert, Saskatchewan, has receive capability only.



* DIGITAL TRANSMISSION SYSTEM

Figure C-1. Communications and Data Flow Configuration

Four primary ground stations accomplish all of the necessary communications in support of the mission:

STATION	COMMAND AND TELEMETRY RF CAPABILITY
Goldstone (Calif) and PASS	Unified S-Band (USB)
NASA Test and Training Facility (NTTF)	USB
Alaska	Very high Frequency (VHF) and USB

These are the only sites equipped to receive the Multispectral Scanner (MSS) and Return Beam Vidicon (RBV) data. Only the three United States stations receive Data Collection System (DCS) data, and perform all narrowband telemetry, tracking and command functions. Other STDN stations will be used as a backup for narrowband telemetry, tracking or command functions only.

Figure C-2 summarizes the various spacecraft to ground communications links and Table C-1 lists the capabilities of the ground stations to receive and transfer the various types of data.

Table C-1. Spacecraft/Ground Communications Summary

CAPABILITY	PASS	STATION				
		Goldstone	Alaska	NTTF	Backup USB	Backup VHF
Payload Data						
Receive RBV/MSS Video	X	X	X	X		
Receive DCS Data (USB)		X	X	X		
Transfer RBV/MSS Video to OCC				X		
Mail RBV/MSS Video Tapes to NDPP and CCRS	X	X	X			
Transfer DCS Data to OCC		X	X	X		
Command Data						
USB Command		X			X	
VHF Command			X	X		X
Computer Controlled Commands		X	X	X	X	
Manual Commands			X			X
Housekeeping Telemetry Data (Narrowband)						
Receive USB PCM	X	X	X	X	X	
Receive VHF PCM			X			X
Transfer Real Time PCM to OCC		X	X	X	X	X
Transfer Playback PCM to OCC			X	X		
Tracking Data						
USB Tracking		X		X*	X	
Mini-track Tracking			X			X

*Receive Only

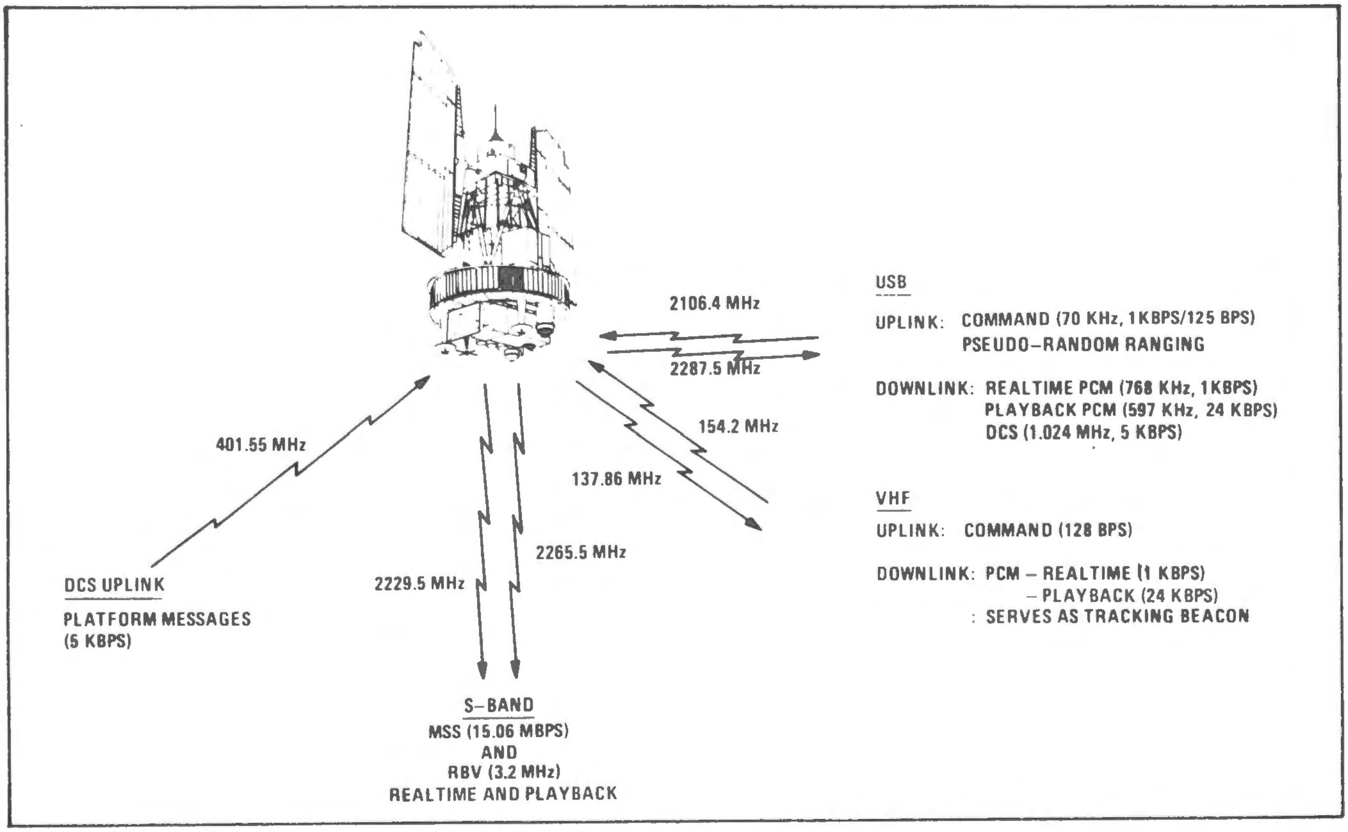


Figure C-2. Spacecraft/Ground Communication Links

C.2 PAYLOAD WIDEBAND COMMUNICATIONS

C.2.1 Spacecraft to Ground Communication

RBV and MSS wideband data are normally telemetered simultaneously to the ground stations over two S-Band links operating at center frequencies of 2229.5 MHz and 2265.6 MHz. The RBV camera has a video bandwidth of 3.2 MHz and is used to frequency modulate the carrier within an RF bandwidth of 20 MHz. The MSS output is a single Pulse Code Modulation-Non-return to Zero Level (PCM-NRZL) encoded bit stream at a bit rate of 15.06 Mbps. This PCM signal Frequency Shift Key (FSK) modulates the carrier.

Both RF links contribute a small degradation to the data. For the RBV the degradation in signal-to-noise ratio is less then 1 dB. The MSS bit error rate is less than 1 in 10^5. These are worst-case values expected at the 2^{o} elevation limit of the three primary ground station viewing cones.

C.2.2. Ground Receiving and Recordings

Figure C-3 illustrates the flow of the wideband data as it is received and recorded. At the Alaska, Goldstone and Prince Albert stations the data is received and demodulated and then hardwired into special Remote Site Equipment where it is processed and recorded. For the NTTF station at GSFC, the Receiving Site Equipment is physically located in the Operations Control Center rather than at the station. This permits operations personnel to directly monitor the display equipment during data reception from NTTF.

The Receiving Site Equipment for the RBV includes equipment to resynchronize and reclamp the video, a video display CRT, and various test equipment. This equipment monitors the data as it is received and supplies the necessary timing and control signals to the video tape recorder. The recorder, an RCA TR-70, records the composite video signal on tape for physical transfer to the NDPF.

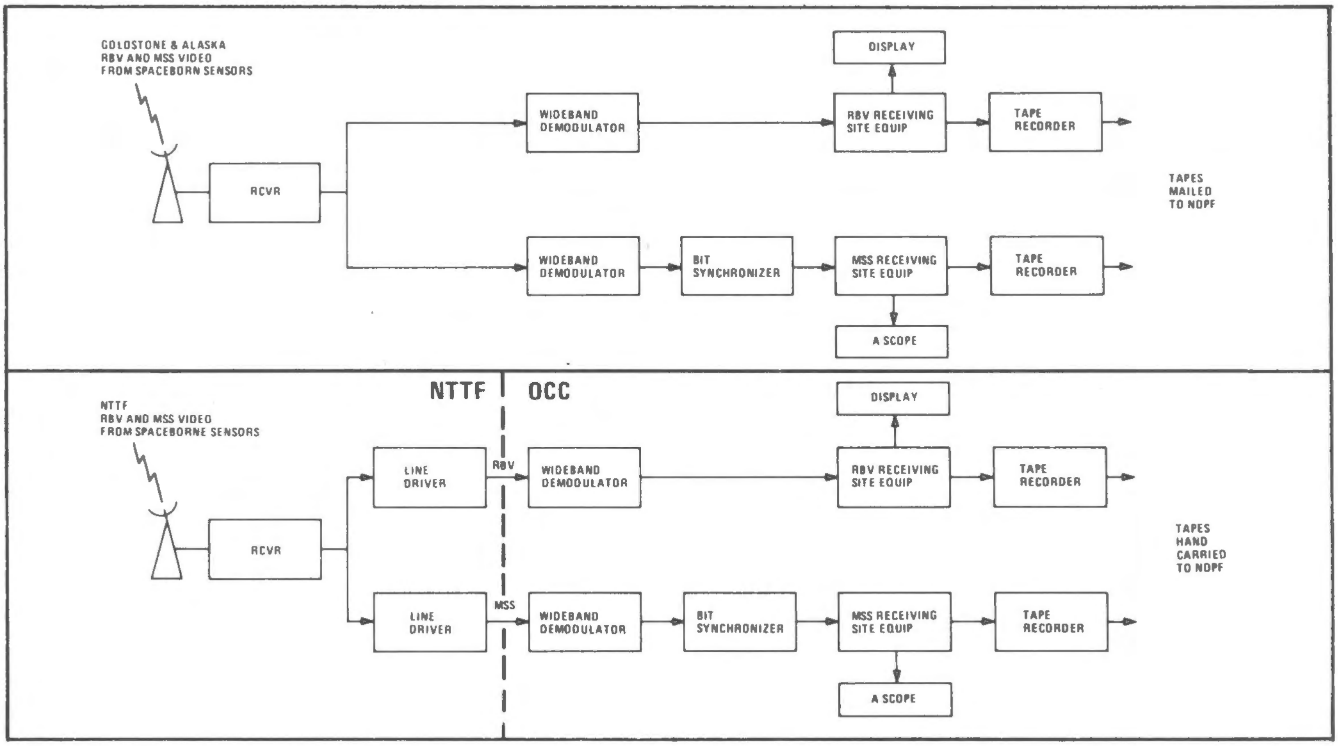


Figure C-3. Wideband Video Data Flow

The Receiving Site Equipment for the MSS demultiplexes the serial bit stream into individual data channels corresponding to each of the detectors in the sensor. It adds a preamble, line start code, line length code, and other data to each channel, and outputs the digital data on parallel lines for recording on an Ampex FR1928 tape recorder. An A-scope provides the capability to monitor one of the output channels after demultiplexing.

C.3 TELEMETRY, TRACKING AND COMMAND DATA HANDLING

The spacecraft telemetry, tracking and command equipment operates with either the USB or VHF type stations. The stations and the NASA ground communication facilities provide the link for the transfer of this data between the spacecraft and the Operations Control Center at GSFC.

C.3.1 Telemetry Data

The spacecraft transmits real-time telemetry data at 1 Kbps, using the VHF downlink to VHF stations or a subcarrier of the Unified S-band (USB) downlink to USB stations. This data is received whenever the spacecraft is in view of one of the three prime ground stations, and is directly relayed to the OCC.

The spacecraft also continuously records telemetry data on one of two on-board narrowband tape recorders. This data is played back at 24 Kbps using another of the USB subcarriers (or VHF backup downlink). This data is normally received during station contacts at Alaska or NTTF and is transferred in real time to the OCC. This stored data provides a continuous history of the spacecraft and sensor status.

C.3.2 Command Data

Normally all commands are generated in the OCC and relayed to the spacecraft from one of the three prime stations. These commands may be real-time commands executed immediately upon receipt, or time-tagged commands that are stored for execution at a prescribed later time. In emergency situations commands may be sent from other stations. Commands from USB stations are transmitted on a subcarrier of the USB link and from VHF type stations on the VHF link.

C.3.3 Tracking Data

Primary tracking data is obtained using the MSFN USB range/range rate system. Tracking data is processed at the ground stations to determine range, velocity and direction parameters. These are then transmitted by teletype to GSFC where the orbital parameters and spacecraft ephemeris are computed.

Secondary tracking can be provided by the VHF minitrack interferometer tracking system located at VHF stations.

C.3.4 DCS Data

Data from individual Data Collection Platforms is transmitted to the spacecraft at UHF where it is received, frequency translated, and retransmitted over the USB downlink to one of the three prime stations. Special DCS receiving site equipment at these stations decodes and processes the data as it is received and reformats it for transmission to the OCC. (Refer to Appendix A.3 for a more complete discussion of the Data Collection System.)

APPENDIX D
OPERATIONS CONTROL CENTER

The Operations Control Center (OCC) is the focal point of all communications with the ERTS spacecraft. All spacecraft and operations scheduling, commanding and spacecraft related data evaluation for the ERTS mission is controlled by the OCC. Its 24-hour-a-day activities are geared to the operational timeline dictated by the orbit and ground station coverage capabilities. The major elements of the OCC are shown in Figure D-1.

D.1 SYSTEM SCHEDULING

At the beginning of each spacecraft day the activity plans for that day are generated by the OCC for each orbit's operation, based on sensor coverage requirements, spacecraft and payload status, network availability and the current cloud-cover predictions. Priorities are assigned to coverage requirements for selecting the data to be collected over various geographic locations as described in Appendix K. Sensor operations including real-time, remote coverage, and calibrations are scheduled. Current spacecraft and payload status are examined to ensure effective utilization of the observatory capabilities. Tracking and orbit adjust requirements are obtained from the NASA Orbit Determination Group when required and integrated with the coverage planning. Scheduling is coordinated with the network operations center and station availability is determined for both routine contact operations and orbit-adjust maneuvers. After integration of all the required data sources and support activities, a final activity plan is issued. This plan is the integrated time-ordered sequence of events defining the spacecraft, payload, and ground system operations for each orbit, and serves as the basis for the compilation of spacecraft command lists.

D.2 DATA ACQUISITION

After acquisition of telemetry signals from the spacecraft, the narrowband housekeeping data (real time and playback) and Data Collection System (DCS) information are routed via the NASA Communication (NASCOM) network to the OCC. The real-time spacecraft data are then displayed on five operations consoles where computer-driven status lights and CRT displays provide the spacecraft evaluators with a complete on-line determination of vehicle and payload status, performance, and health, as well as command verification. DCS data are also processed in the OCC on-pass and placed on magnetic tape. These tapes are available immediately post-pass for continued processing in the NASA Data Processing Facility (NDPF).

In-depth spacecraft evaluation and image annotation information are derived from the data stored on the narrowband tape recorders. These data contain all the satellite telemetry for the entire orbit, including all remote areas. Playback data are received during the station post-pass to produce detailed spacecraft evaluation parameters and trends. The Spacecraft Performance Data Tape is also generated from this playback data and given to the NDPF for use in generation of image annotation parameters.

Video data received during Network Test and Training Facility (NTTF) station passes are relayed directly to the OCC where they are processed in the identical manner as at other remote sites as outlined in Appendix C. The video tapes generated in the OCC are hand-carried to the NDPF for image processing.

D.3 COMMAND GENERATION

Commanding of the ERTS spacecraft is performed by an operator at either of two operations consoles located in the OCC. All commands are checked and then routed by the OCC computer system to the remote receiving site that is in contact with the satellite. At the site an "as transmitted" command check is performed and command acknowledgements are relayed back to the OCC. Final command verification is made through analysis of telemetry data.

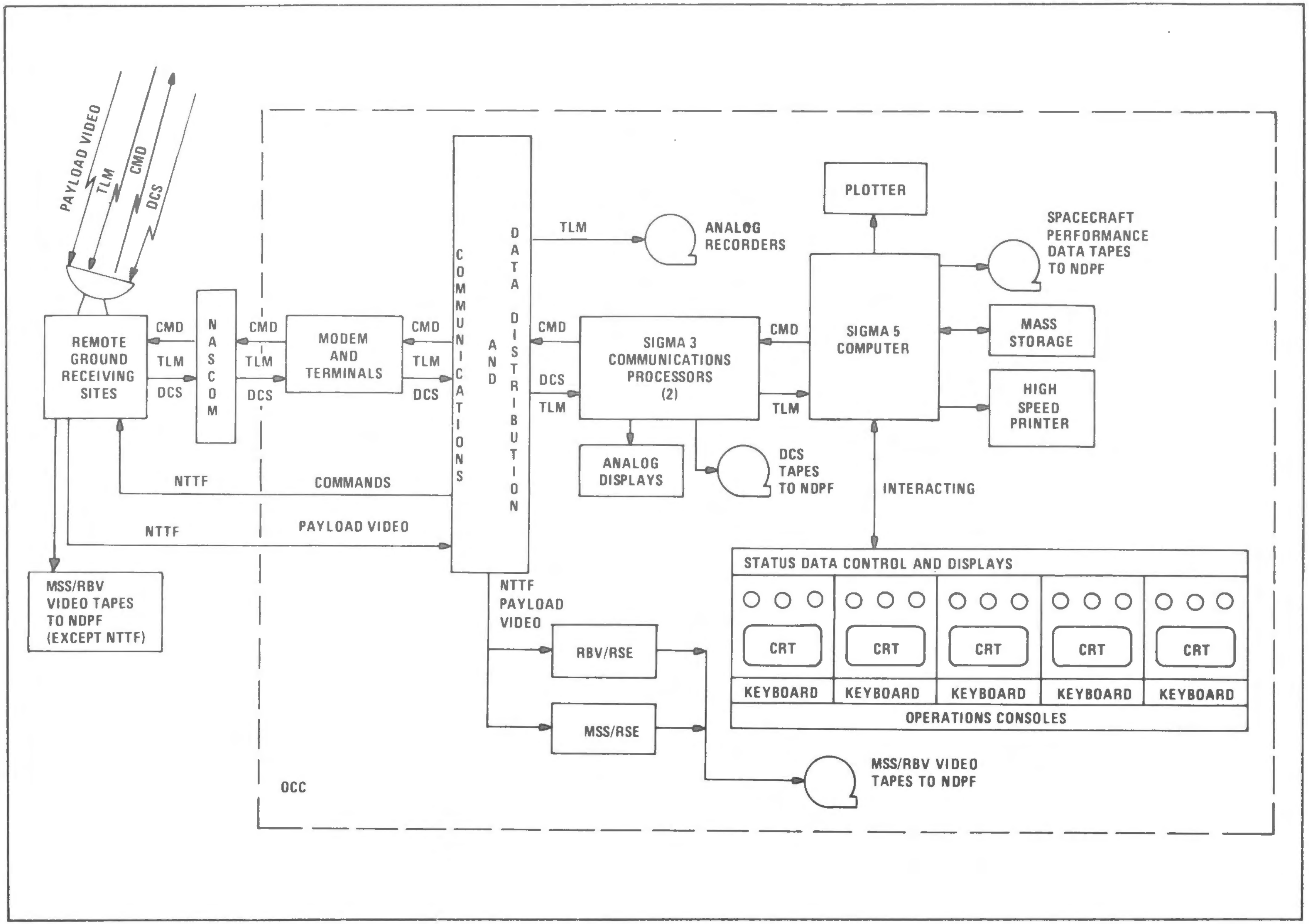


Figure D-1. Major Elements of Operations Control Center

APPENDIX E
CCRS DATA PROCESSING FACILITY

The data processing facility of CCRS has been designed to meet all the specialized data processing needs of the Centre. In addition to the requirement to process the data from the ERTS satellite the system will be required to process widely varying types of data obtained by airborne remote sensors and must also serve as a research tool for the development of automated interpretation techniques. The computational load, special equipment and reliability requirements for the processing of ERTS data are quite demanding, but well defined. The remaining requirements are much less rigidly defined and are expected to change rapidly as new sensors, interpretation instruments and recording systems are developed. Thus a highly flexible and reasonably powerful computing facility is needed.

A block diagram of the Data Handling System is shown in Figure E-1. In order to meet the conflicting demands of high system reliability for ERTS data processing and maximum flexibility for the remainder of the Centre's needs, a dual processor computer system was selected. This configuration also provides a measure of redundancy for the ERTS production since most components can be quickly and efficiently switched from one Central Processing Unit (CPU) to the other. The computer chosen for the system is a Digital Equipment Corporation PDP-10.

The equipment is normally operated as if it consisted of two entirely separate and independent systems. The first is the dedicated, on-line ERTS production facility, which is used to control the processing of the video data. The second is the utility system. It is used for all general software and hardware development in support of the airborne and interpretation requirements, as a research tool for the Centre scientists, and for the off-line data processing tasks which are necessary to prepare for the ERTS production runs. As experimental systems reach operational status, they can be moved over to the production system.

E.1 UTILITY SYSTEM

In Figure E-1, the utility system is that portion to the right and below the heavy dotted line. The utility portion of the facility is operated under a standard time-sharing monitor system which allows a number of users simultaneous access to the system. Standard software available to the timesharing user includes Assembler, Extended Fortran IV, Algol, Basic, Cobol, Interactive Text Editor, and a large number of special utilities. It is relatively easy to add non-standard devices to this system. This is the case with respect to both the hardware interface required and the software modifications required in the monitor.

The utility system will be used primarily to support the airborne and interpretation requirements, although some of the off-line ERTS production is also done on this system. Normally the utility configuration consists of a PDP-10 CPU with 124K words (36-bit) of core memory, 90K characters of on-line disc storage, line printer, card reader, paper tape reader/punch, *DEC-tape, magnetic tape drives and keyboard terminal equipments. Magnetic tape equipment include 7-track multiple density, 9-track 800 c.p.i. and 9-track 200 i.p.s. 1600 c.p.i. tape drives. A large number of speeds can be accommodated in the keyboard terminals from 110-2400 baud. An analogue-to-digital converter is provided mainly to allow the processing of analogue tapes recorded in the aircraft program. A high resolution, full colour video display system has been provided as an interactive aid for the development of automated interpretation methods.

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*DEC-Tape is a registered trademark of the Digital Equipment Corporation.

E.2 ERTS PRODUCTION SYSTEM

The portion of the system used for the production processing of ERTS data is shown to the left and above the heavy dotted line in Figure E-1. The standard computer portion of the system consists of a PDP-10 CPU with 32K 36-bit words, paper tape reader/punch, DEC-tape, and two 1600 c.p.i. 200 i.p.s. magnetic tape drives. The remaining equipment was specified and built especially for the processing of ERTS data.

E.2.1 RBV VIDEO PROCESSING

The RBV tapes from PASS are played back at full speed on a recorder system which is identical to that used to record the tape at the receiving station. This unit is a modified TV helical scan analogue recorder with a 3,5 MHz bandwidth. A special Video Processor and Sync Separator (VPASS) has been added to the recorder to accommodate the non-standard line rate associated with the RBV.

The video signal is modified by the Radiometric Correction Unit (RCU). This unit corrects the RBV signal in a continuous fashion for the severe non-linear radiometric response of the satellite sensors. For a scene of uniform brightness, the video signal can change by more than 2:1 from the centre of the scene to the corners. Calibration data for each camera will be available before satellite launch and periodically throughout the ERTS mission. Essentially, this unit linearly interpolates the black level offset and the gain factor in two dimensions between the values at spot points of an 18 × 18 array supplied by the computer. These offset and gain values are then used to correct the incoming video signal.

Annotation and calibration information is added to the video signal in the Electron Beam Image Recorder (EBIR) Controller. This data is provided by the PDP-10. In addition the controller acts as an interface between the computer and the EBIR. This provides the mechanism for digitally controlling the deflection wave-forms of the EBIR to smoothly correct for all geometric errors. Sources of these errors include those due to the electromagnetic scanning system in the RBV cameras and attitude errors in the spacecraft as well as geometric distortion within the EBIR and the NAPL enlarging system.

The EBIR's are precision film recording devices. In operation, each resembles a Cathode Ray Tube (CRT). However instead of a phosphor-coated face-plate, a 70mm photographic film is bombarded directly by electrons. Of course, this means that the film must be placed in a vacuum. Photographic film is extremely sensitive to electron bombardment. Thus, it is possible to use a very slow, ultra-fine-grain film. In addition, very low beam currents are required (70 na) resulting in a very small spot diameter. Furthermore, the problems associated with light scattering which occur with electron bombardment of phosphors are avoided. The EBIR has a nominal resolution of 6,000 lines with 0.1 per cent non-linearity of scan and 0.05 per cent pincushion distortion.

E.2.2 MSS VIDEO PROCESSING

The MSS data from PASS is played back on a specially modified 28-track instrumentation recorder. The digital recording density of 10,000 bits/inch creates a large amount of skew from track to track. The method of scanning six lines simultaneously for each spectral band poses a major reformatting task, since imaging devices may record only one line at a time. The primary task of the MSS data Processor (MDP) is to perform the deskewing and reformatting of the MSS data.

The format of the data on each channel of the tape recorder is essentially the same. Prior to the start of line, a preamble consisting of the binary pattern ...0101... is recorded for approximately 10 milliseconds (7800 bits). This is followed by a 6-bit line start code 111001. This is followed by 6,060 6-bit words of data. The first two words provide satellite time information. The next, approximately 3,300 words, contain scene information. Words 3773, 3774 and 3775 provide the line length code which defines the total number of words from all sensors sampled during the active portion of the MSS mirror scan cycle. This will be approximately 25 times the number of data words in the active sweep portion of each tape track. Following the line length code is the calibration information. On alternate sweeps this takes the form of a black level and a grey-scale wedge.

Each channel of the MDP searches for and locks onto the preamble, awaiting the line start code. Upon detection, the time code data is extracted and the scene data is dumped into core memory. The line length data is extracted from each channel as it becomes available until two channels provide identical line length data, whereupon it is transferred to the PDP-10 computer.

The calibration data can be extracted for presentation to the computer in one of the following ways. In uncompressed mode, all data from any one sensor may be requested by the computer for any given MSS scan. This will consist of approximately 1,600 words. In the compressed mode, calibration data from all sensors are transferred to the computer. The data from each channel are compressed into 25 twelve-bit words by summing blocks of 64 consecutive original data words.

As the data is entering the MDP on one MSS sweep for all sensors in parallel, the data from the previous sweep is extracted on a line-by-line basis. The output section of the MDP contains a 64-word Random Access Memory (RAM) for each sensor. Every 6-bit data word is used as an address to select a specific 8-bit word in its RAM. This 8-bit word is used as the output signal for the image recorder. The RAM's are loaded by the computer with those values necessary to perform full radiometric correction as determined from the calibration data. In addition, the RAM's may be used to perform radiometric transformations such as linear-to-logarithmic and logarithmic-to-linear.

Unless the effective gain and offset of each channel are the same within a given spectral band, a repetitive intensity change will occur every six scan lines on the photographic image. The human visual system is especially sensitive to such patterns which would appear as banding or striping in the photographs. It has been found that the stability and accuracy of the on-board calibration system is unlikely to provide sufficient accuracy in the sensor gain values to eliminate banding using the above calibration scheme. To improve the MSS performance, a Digital Video Analyzer (DVA) has been added to the MDP. This unit consists of 26 separate microprocessors which compute the sum and sum of squares of the scene data for each sensor and present these values to the computer. These data can then be used to determine very accurately the relative gain of each sensor with respect to every other within a spectral band. In addition, the error in the absolute accuracy of the gain for each band can be reduced.

There are three data paths from the MDP. In the first mode of operation, data are directed to the EBIR controller, at a data rate of approximately 6 million 8-bit words/second. The EBIR controller controls the timing of the readout in order to synchronize the EBIR system to the tape recorder, to correct for attitude changes in roll and to correct for the non-linearity and variable rate of the MSS scanning system. Correction for yaw, pitch rate and scale are also performed.

A second mode of operation allows scene data to be transferred to the PDP-10 mainframe core. Normal operation for this mode is at one-quarter of the real-time speed. The data are transferred to the standard tape drives for preparation of computer compatible tapes. By adding three additional tape controllers with two drives per controller, the system is capable of operating in real-time speeds. It is also possible to transfer data from the PDP-10 system to the MDP for image recording.

In the third mode of operation, the MDP output is directed to a 9.5-inch format, fully correcting Laser Beam Image Recorded (LBIR). The unit contains four film transports which allows two independent sets of false-colour images to be recorded from the same MSS data. Each set is framed so that sequential images contain the same scene information. The LBIR is equipped with a digital video mixing capability so that each of the three primary colours exposed on the film can be made up of linear combination of five spectral bands of ERTS-B. The LBIR contains all the circuitry required to synchronize its scanning rate to that of the tape recorder and to readout the data from the MDP at a variable rate to compensate for scale, roll and scan rate variations. The LBIR also contains a set of RAM's at the output to the beam modulators which may be loaded with values to compensate for non-linear exposure characteristics of the film being exposed.

The LBIR controller provides the interface between the LBIR and the computer. In addition, the annotation information is generated here. Digital scene data can also be directed to the LBIR through the controller from the computer or from an external digital source. Five channel analogue-to-digital conversion will provide an analogue input capability.

In addition to its recording capability, the LBIR can be used to scan a photographic transparency, producing a digital representation which is directed to the computer.

Colour composites can also be made from the 70mm EBIR film using a semi-automatic colour composite printer/enlarger developed for the NAPL to support the ERTS program. Identical precision pin-registered framing mechanisms are used in the EBIR and the NAPL printer which allow very precise registration of images with respect to the film sprocket holes.

E.2.3 HOUSEKEEPING DATA PROCESSING

Information on the sensor status, spacecraft attitude and time is recorded on auxiliary narrow-band tracks of both the RBV and MSS tape recorders. These data are extracted during a preliminary tape pass to provide preliminary annotation and correction information.

E.3 INITIAL AND PRECISION PROCESSING

A preliminary set of ERTS images are produced during the initial processing production pass with all known, systematic geometric and radiometric distortions removed. Crude annotation is generated on the basis of the attitude information provided from the satellite and altitude and positional information predicted from orbital parameters which are supplied from NASA via teletype. These preliminary images are then processed and in the case of the EBIR system enlarged to a 9.5-inch format. The resulting transparencies are then examined to identify ground control points. The positions of these are determined from the 1:250,000 scale topographic maps which are available for all of Canada. The exact position of each ground control point with respect to all others in the image is determined quickly with the aid of a graphic digitizer which is on-line to the utility system. This information is used to produce a corrected image tape, which in turn is used to control the EBIR and LBIR controllers during the precision production pass. The precision corrected imagery will be at an exact scale of 1:1,000,000 and will be corrected and annotated to an accuracy of a few hundred metres.

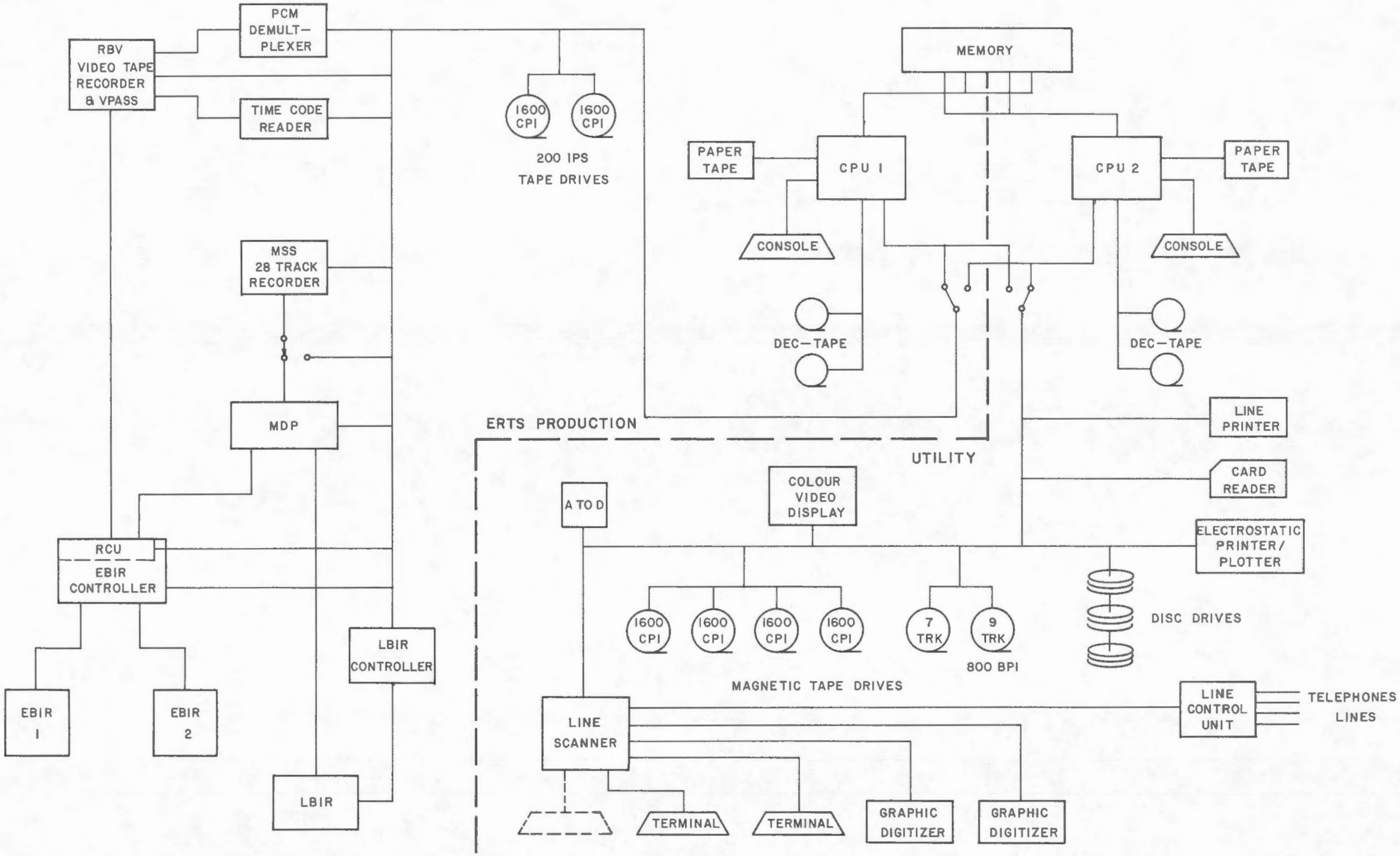


FIGURE E-1

BLOCK DIAGRAM DATA HANDLING SYSTEM

APPENDIX F

SYSTEM PERFORMANCE

(This Appendix is in preparation)

APPENDIX G

CALIBRATION

(This Appendix is in preparation)

APPENDIX H

FILM AND DEVELOPER CHARACTERISTICS

(This Appendix is in preparation)

APPENDIX I
ORBIT AND COVERAGE

Systematic, repeating, global earth coverage under nearly constant observation conditions is required for maximum utility of the multispectral images collected by ERTS. ERTS-1 has been launched into a circular sun-synchronous orbit with a 9:42 a.m. descending node (equatorial crossing). The orbital parameters are given in Table I-1.

I.1 EARTH COVERAGE

The ground coverage pattern selected is shown in Figure I-1 for two orbits on two consecutive days. The orbit causes the daily coverage swath to be shifted in longitude at the equator by 1.43 degrees corresponding to 159 kilometers. The revolutions progress in a westwardly direction and the pattern continues until all the area between orbit N and orbit N+1 on day M is covered. This constitutes one complete coverage cycle, consisting of 251 revolutions, takes exactly 18 days, and provides complete global coverage between 81 degrees north and 81 degrees south latitude. On any given day, the satellite makes approximately 14 revolutions of the earth as shown by the typical ground trace in Figure I-2

Table I-1. ERTS-1 Orbit Parameters

Orbit Parameter	Actual Orbit
Semi-major axis	7285.82 km
Inclination	99.114 deg
Period	103.267 min
Eccentricity	.0006
Time at descending node (equatorial crossing)	9:42 a.m.
Coverage cycle duration	18 days (251 revs)
Distance between adjacent ground tracks (at equator)	159.38 km

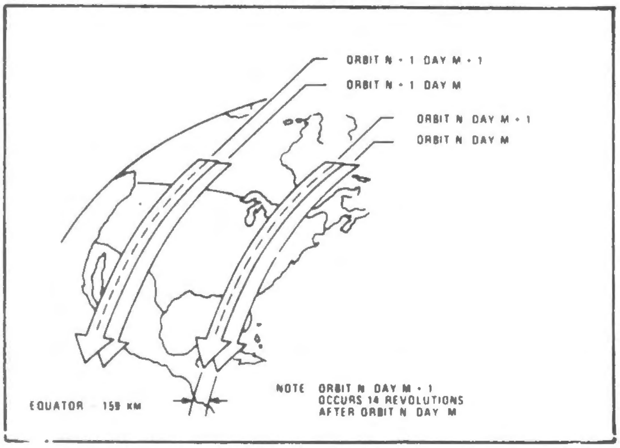


Figure I-1. Ground Coverage Pattern

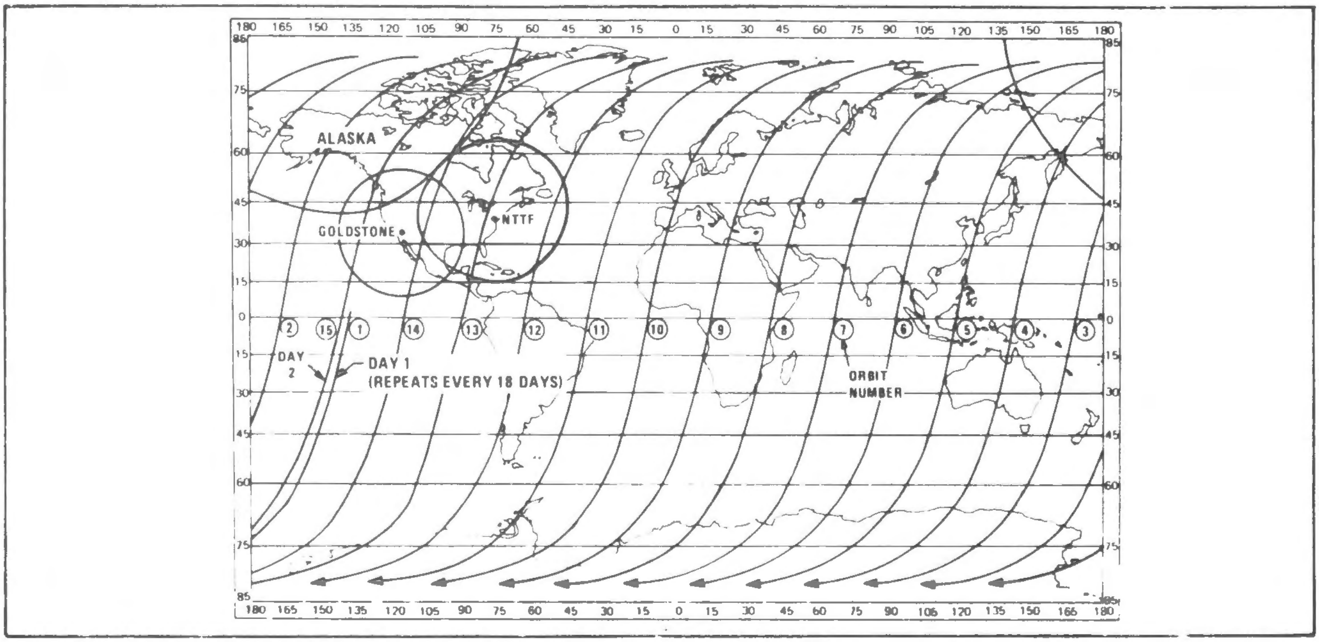


Figure I-2. Typical ERTS Ground Trace for One Day (Only Southbound Passes Shown)

Coverage over Canada is depicted in Figure I-3. The observatory proceeds along each swath from top to bottom in the illustration and the orbits proceed from right to left. On the first day, coverage is provided in Orbit Numbers 1, 2, and 3. On the second day, images are returned during Orbit Numbers 15, 16, and 17. Adding 14 orbits for each succeeding day, Canadian coverage is completed after orbit 251, and is repeated beginning with Orbit Number 1. With the two ground stations used for ERTS, data covering Canada is obtained in approximately 18 minutes of operation per day.

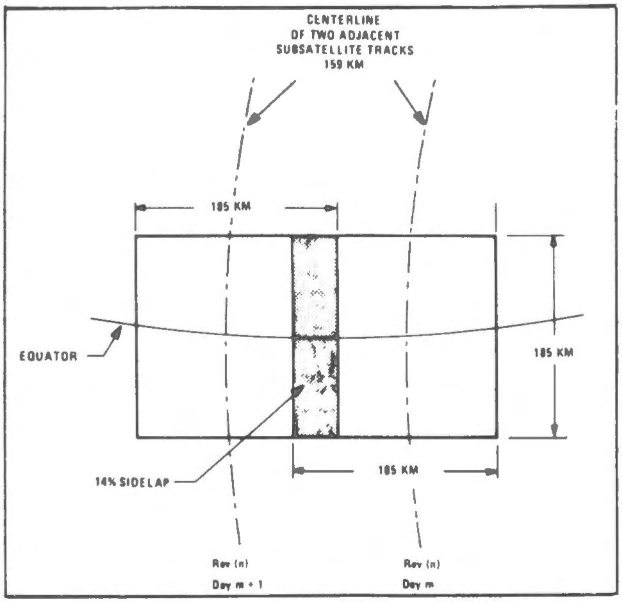


Figure I-4. Imagery Sidelap at the Equator

I.2 IMAGERY OVERLAP

The coverage pattern provides 14 percent cross-track imagery overlap at the equator as shown in Figure I-4. Table I-2 indicates the increase in cross-track overlap of the swaths as higher latitudes are reached. At latitudes with greater than 50 percent overlap, complete duplicate coverage is achieved on sequential days. The duplicate coverage affords the possibility of obtaining images of a given ground area via portions of images taken on days M-1 and M+1 even though an image was not obtained on day M (Figure I-5).

Table I-2. Overlap of Adjacent ERTS Coverage Swaths

Latitude (deg)	Image Sidelap (%)
0	14.0
10	15.4
20	19.1
30	25.6
40	34.1
50	44.8
60	57.0
70	70.6
80	85.0

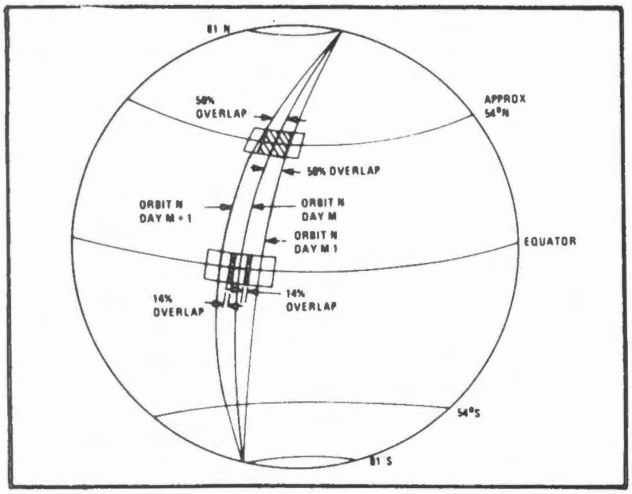


Figure I-5. ERTS Overlapping Coverage

I.3 REPEATABILITY

The ERTS orbit has also been designed so that the swaths viewed during one 18-day coverage cycle repeat or overlay the corresponding swaths viewed on all subsequent coverage cycles. This facilitates comparison of imagery of a given area collected during different coverage cycles. In addition, picture-taking sequences will be scheduled such that centers of images taken every 18 days are aligned along the in-track direction. This is accomplished by referencing all payload operation to the equator as indicated in Figure I-6. For example, if imagery of Region A were desired in the orbit shown in Figure I-6, it will not be obtained as one picture centered over the region, but will consist of two pictures taken 125 and 100 seconds prior to the equatorial crossing. The repeating orbit characteristics are such that no more than 37 kilometers cross-track picture-center variation will occur over the one-year mission life. The in-track scheduling will assure that no more than 30 kilometers in-track picture-center variation will occur.

I.4 ALTITUDE VARIATIONS

Selection of a circular orbit minimizes the variations in the altitude of the spacecraft. However, even a pure circular orbit cannot maintain a constant altitude profile due both to the oblate characteristics (polar flattening) of the earth and to perturbing forces upon the satellite such as the gravitational effects of the earth, sun and moon. The combined effects of

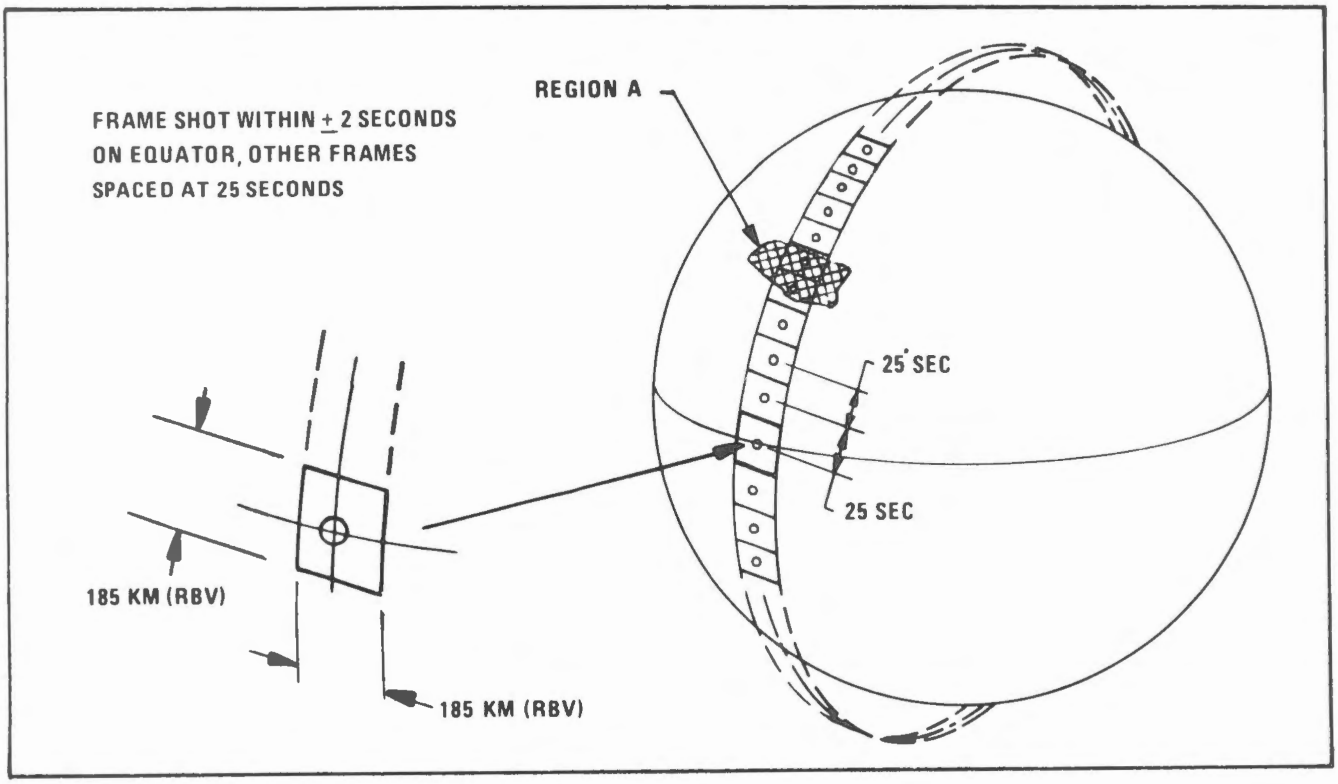


Figure I-6. In-Track Picture Scheduling oblateness and perturbing forces will cause the altitude of the satellite to vary periodically within the range of 900 to 950 km throughout the mission life.

1.5 DETERMINATION OF LOCAL OBSERVATION TIME

The ERTS orbit is sun-synchronous, as shown in Figure 1-7; hence, the geometric relationship between the orbit's descending node (southbound equatorial crossing) and the mean sun's projection into 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 ERTS A and B the mean sun time at the descending node will be established at launch and will be between 9:30 and 10:00 a.m. The actual mean sun time at descending node achieved for ERTS-1 is 9:42 a.m. A fixed mean sun time does not mean that the local clock time will remain fixed for all points at a given latitude, because of the fact that discrete time zones are used to determine local time throughout the world. Figure I-8 illustrates a typical variation in local time for sequential satellite equatorial crossings.

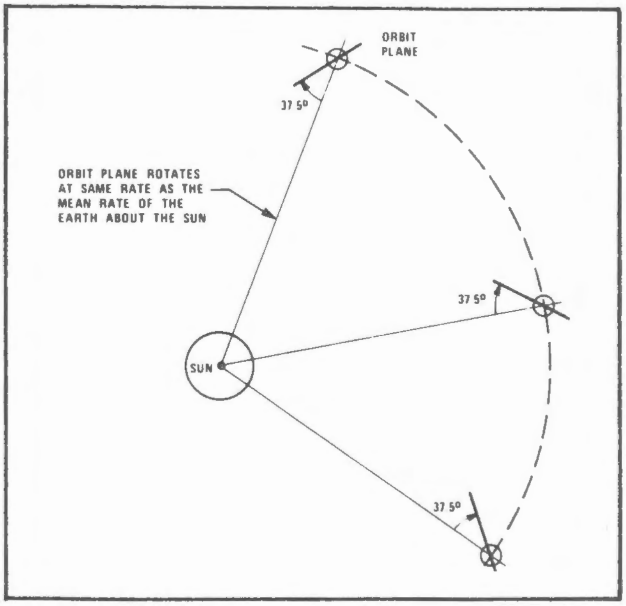
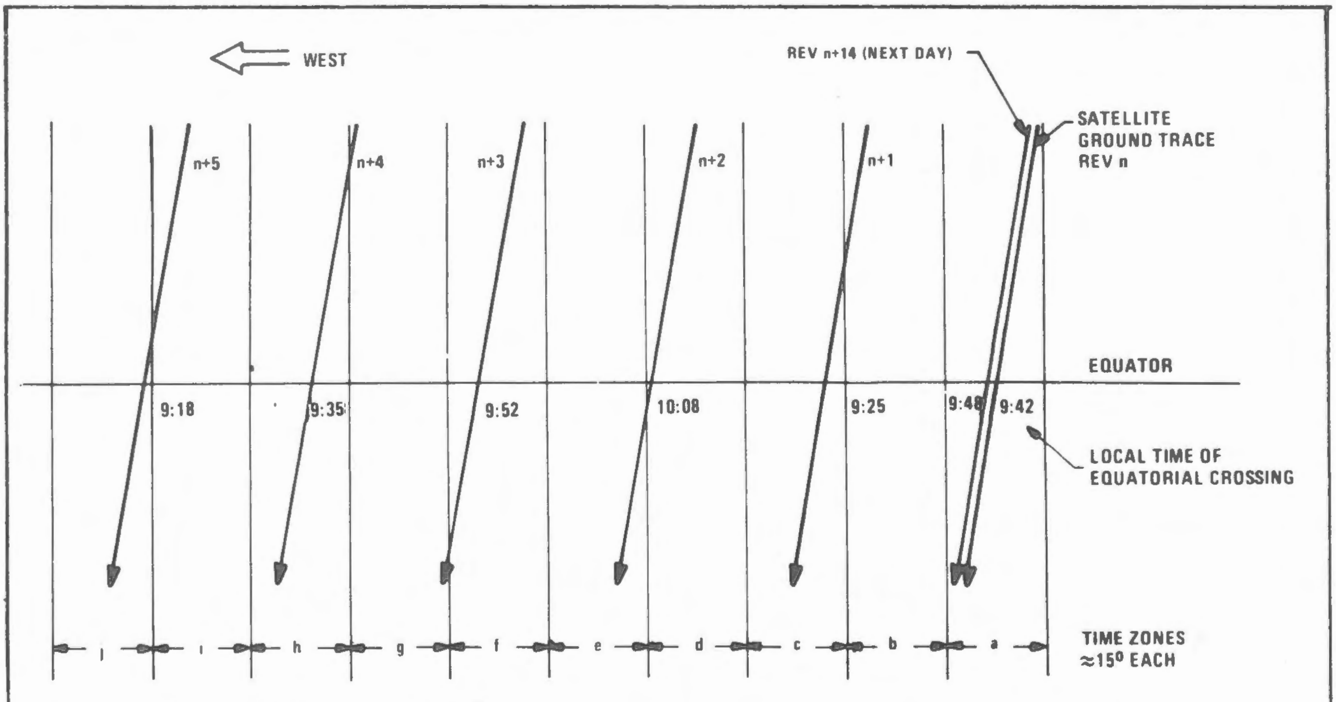


Figure I-7. Motion of Orbit Plane in Sun-Synchronous Orbit



NOTE: MEAN SUN TIME = 9:42 FOR ALL REVS.

Figure I-8. Variation in Local Time of Equatorial Crossing

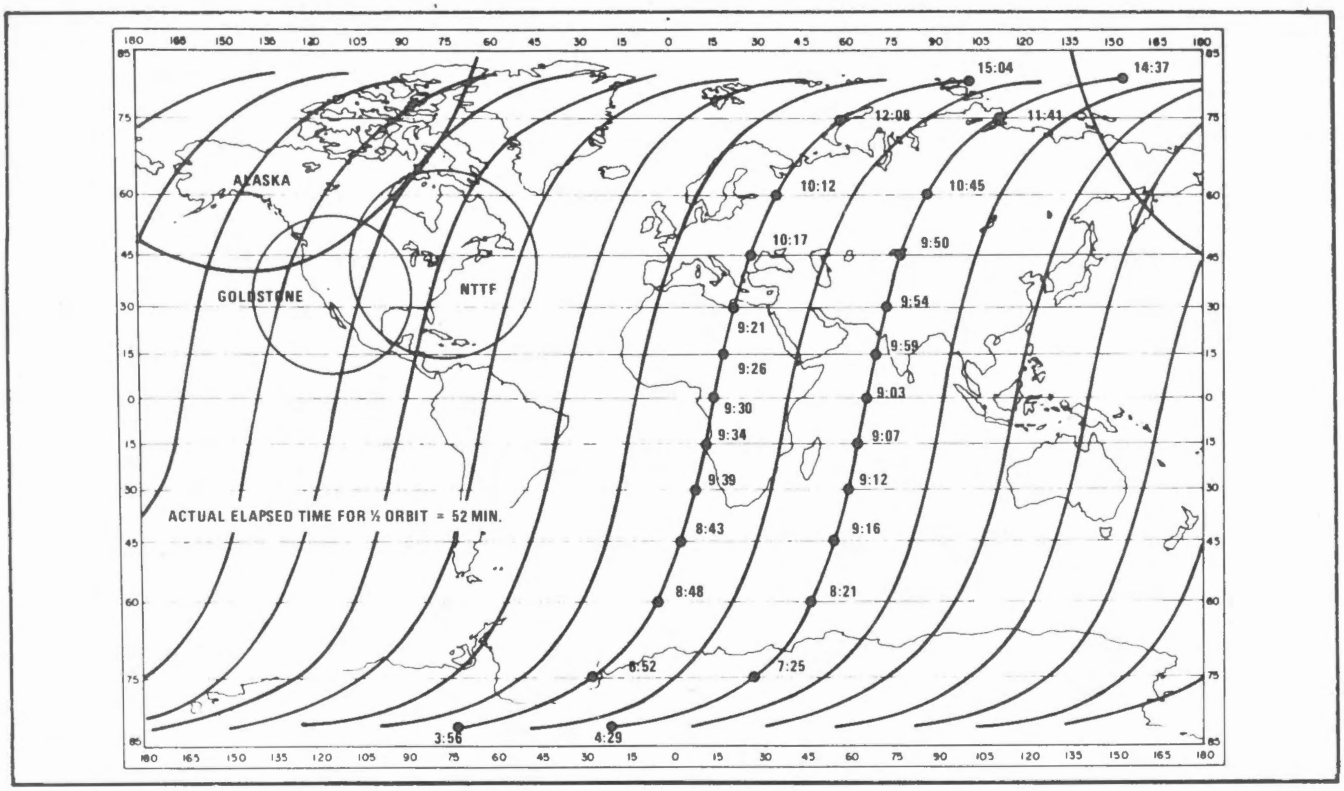


Figure I-9. Local Time — Variations Within an Orbit

The local time that the satellite crosses over a given point at latitudes other than at the equator will also vary due to (1) the time the satellite takes in orbit to reach the given point (103 minutes is required for one complete revolution), and (2) the time zones crossed by the satellite as it transverses its orbit.

Figure I-9 illustrates these effects on local clock time for various points in a typical orbit as a function of latitude.

The following procedure can be used to determine the local clock time and the day when the satellite will pass over any position in the world:

1. Define the latitude (81° N to 81° S) and longitude (+180° to −180°) of the position of interest (+ is East).
2. Define the approximate descending node as follows:
   a. Locate the latitude of the point of interest in Table I-3.
   b. Read the value of Δ longitude from the table.
   c. Add the Δ longitude to the longitude of the point of interest. If the value of the result is more negative than −180°, add 360° to the result.

      or

      If the value of the result is more positive than +180°, add 360° to the result, carefully noting algebraic signs.
3. Find the actual descending node as follows:
   a. Using Table I-4, find the value of descending node nearest to the value determined in step 2-c This represents the descending node of the actual satellite orbit revolution that will image the point of interest.

Table I-3. Satellite Longitude Corrections
(Measured from Descending Node)

FOR NORTH LATITUDES ONLY – SEE NOTE 1				
LATITUDE DEGREES	**Δ LONGITUDE DEGREES**		**LATITUDE DEGREES**	**Δ LONGITUDE DEGREES**
1	– 0.23		41	–10.94
2	– 0.47		42	–11.31
3	– 0.70		43	–11.71
4	– 0.94		44	–12.12
5	– 1.17		45	–12.49
6	– 1.40		46	–12.92
7	– 1.64		47	–13.37
8	– 1.87		48	–13.83
9	– 1.11		49	–14.29
10	– 2.34		50	–14.67
11	– 2.58		51	–15.16
12	– 2.82		52	–16.66
13	– 3.06		53	–16.18
14	– 3.30		54	–16.70
15	– 3.54		55	–17.23
16	– 3.78		56	–17.78
17	– 4.03		57	–18.40
18	– 4.28		58	–19.04
19	– 4.53		59	–19.72
20	– 4.78		60	–20.48
21	– 5.03		61	–21.21
22	– 5.29		62	–22.02
23	– 5.55		63	–22.86
24	– 5.81		64	–23.81
25	– 6.08		65	–24.82
26	– 6.35		66	–25.90
27	– 6.62		67	–27.02
28	– 6.89		68	–28.25
29	– 7.17		69	–29.61
30	– 7.45	SEE NOTE 2	70	–31.06
31	– 7.74		71	–32.75
32	– 8.04		72	–34.70
33	– 8.34		73	–36.89
34	– 8.65		74	–39.82
35	– 8.96		75	–42.39
36	– 9.28		76	–45.60
37	– 9.60		77	–49.50
38	– 9.92		78	–54.48
39	–10.25		79	–60.62
40	–10.59		80	–70.95

NOTES:

1. **For south latitudes, the algebraic sign of the Δ longitudes is positive.**
2. **Above 70 degrees, the variation in Δ longitude is very sensitive to latitude. Under certain conditions of data point interpolation in this table, errors may result in determining the exact day of satellite coverage. For latitudes above 70 degrees, consult ERTS User Services for assistance.**

Table I-4. Descending Node Parameters

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Date* (August 1972)	Orbit Number*	Greenwich Mean Time of Descending Node
– .94	12	274	09:45
– 2.37	13	288	09:51
– 3.81	14	302	09:57
– 5.24	15	316	10:03
– 6.67	16	330	10:08
– 8.11	17	344	10:14
– 9.54	18	358	10:20
–10.97	1	121	10:25
–12.41	2	135	10:31
–13.84	3	149	10:37
–15.28	4	163	10:43
–16.71	5	177	10:48
–18.14	6	191	10:54
–19.58	7	205	11:00
–21.01	8	219	11:06
–22.44	9	233	11:11
–23.89	10	247	11:17
–25.32	11	261	11:23
–26.75	12	275	11:29
–28.19	13	289	11:34
–29.62	14	303	11:40
–31.06	15	317	11:46
–32.49	16	331	11:52
–33.92	17	345	11:57
–35.36	18	359	12:03
–36.79	1	122	12:09
–38.23	2	136	12:14
–39.66	3	150	12:20
–41.09	4	164	12:26
–42.53	5	178	12:32
–43.96	6	192	12:37
–45.39	7	206	12:43
–46.83	8	220	12:49
–48.26	9	234	12:55
–49.70	10	248	13:00
–51.14	11	262	13:06
–52.57	12	276	13:12
–54.01	13	290	13:18
–55.44	14	304	13:23
–56.87	15	318	13:29
–58.31	16	332	13:35
–59.74	17	346	13:41
–61.17	18	360	13:46
–62.61	1	123	13:52
–64.04	2	137	13:58
–65.48	3	151	14:03
–66.91	4	165	14:09
–68.34	5	179	14:15
–69.78	6	193	14:21
–71.21	7	207	14:26
–72.64	8	221	14:32
–74.08	9	235	14:38
–75.52	10	249	14:44
–76.95	11	263	14:49
–78.39	12	277	14:55
–79.82	13	291	15:01
–81.26	14	305	15:07
–82.69	15	319	15:12
–84.12	16	333	15:18
–85.56	17	347	15:24
–86.99	18	361	15:30
–88.42	1	124	15:35
–89.86	2	138	15:41

Table I-4. Descending Node Parameters (Continued)

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Date* (August 1972)	Orbit Number*	Greenwich Mean Time of Descending Node
– 91.29	3	152	15:47
– 92.73	4	166	15:52
– 94.16	5	180	15:58
– 95.59	6	194	16:04
– 97.03	7	208	16:10
– 98.46	8	222	16:15
– 99.90	9	236	16:21
–101.34	10	250	16:27
–102.77	11	264	16:33
–104.20	12	278	16:38
–105.64	13	292	16:44
–107.07	14	306	16:50
–108.51	15	320	16:56
–109.94	16	334	17:01
–111.37	17	348	17:07
–112.81	18	362	17:13
–114.24	1	125	17:19
–115.68	2	139	17:24
–117.11	3	153	17:30
–118.54	4	167	17:36
–119.98	5	181	17:41
–121.41	6	195	17:48
–122.84	7	209	17:53
–124.28	8	223	17:59
–125.72	9	237	18:04
–127.15	10	251	18:10
–128.59	11	265	18:16
–130.02	12	279	18:22
–131.46	13	293	18:27
–132.89	14	307	18:33
–134.32	15	321	18:39
–135.76	16	335	18:45
–137.19	17	349	18:50
–138.62	18	363	18:56
–140.06	1	126	19:02
–141.49	2	140	19:08
–142.93	3	154	19:13
–144.36	4	168	19:19
–145.79	5	182	19:25
–147.23	6	196	19:31
–148.66	7	210	19:36
–150.09	8	224	19:42
–151.54	9	238	19:48
–152.97	10	252	19:53
–154.40	11	266	19:59
–155.84	12	280	20:05
–157.27	13	294	20:11
–158.71	14	308	20:16
–160.14	15	322	20:22
–161.57	16	336	20:28
–163.01	17	350	20:34
–164.44	18	364	20:39
–165.87	1	127	20:45
–167.31	2	141	20:51
–168.74	3	155	20:57
–170.18	4	169	21:02
–171.61	5	183	21:08
–173.04	6	197	21:14
–174.48	7	211	21:19
–175.91	8	225	21:25
–177.35	9	239	21:31
–178.79	10	253	21:37
–179.78	11	267	21:42

*NOTE: "Orbit Date" and "Orbit Number" are given for the period August 1 through August 18, 1972. To determine the orbit date and orbit number for any other day, use the conversion provided in Table I-5.

Table I-4. Descending Node Parameters (Continued)

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Date* (August 1972)	Orbit Number*	Greenwich Mean Time of Descending Node
+178.35	12	281	21:48
+176.91	13	295	21:54
+175.48	14	309	22:00
+174.04	15	323	22:05
+172.61	16	337	22:11
+171.18	17	351	22:17
+169.74	18	365	22:23
+168.31	1	128	22:28
+166.87	2	142	22:34
+165.44	3	156	22:40
+164.01	4	170	22:45
+162.57	5	184	22:51
+161.14	6	198	22:57
+159.71	7	212	23:03
+158.27	8	226	23:08
+156.83	9	240	23:14
+155.40	10	254	23:20
+153.96	11	268	23:26
+152.53	12	282	23:31
+151.09	13	296	23:37
+149.66	14	310	23:43
+148.23	15	324	23:49
+146.79	16	338	23:54
+145.36	18	352	00:00
+143.93	1	366	00:06
+142.49	2	129	00:12
+141.06	3	143	00:17
+139.62	4	157	00:23
+138.19	5	171	00:29
+136.76	6	185	00:35
+135.32	7	199	00:40
+133.89	8	213	00:46
+132.46	9	227	00:52
+131.01	10	241	00:57
+129.58	11	255	01:03
+128.15	12	269	01:09
+126.71	13	283	01:15
+125.28	14	297	01:20
+123.84	15	311	01:26
+122.41	16	325	01:32
+120.98	17	339	01:38
+119.54	18	353	01:43
+118.11	(19) 1	(367) 116	01:49
+116.68	2	130	01:55
+115.24	3	144	02:01
+113.81	4	158	02:06
+112.37	5	172	02:12
+110.94	6	186	02:18
+109.51	7	200	02:24
+108.07	8	214	02:29
+106.64	9	228	02:35
+105.20	10	242	02:41
+103.76	11	256	02:47
+102.33	12	270	02:52
+100.90	13	284	02:58
+ 99.46	14	298	03:04
+ 98.03	15	312	03:09
+ 96.59	16	326	03:15
+ 95.16	17	340	03:21
+ 93.73	18	354	03:27
+ 92.29	1	117	03:32
+ 90.86	2	131	03:38
+ 89.42	3	145	03:44

Table I-4. Descending Node Parameters (Continued)

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Date* (August 1972)	Orbit Number*	Greenwich Mean Time of Descending Node
+ 87.99	4	159	03:50
+ 86.56	5	173	03:55
+ 85.12	6	187	04:01
+ 83.69	7	201	04:07
+ 82.26	8	215	04:13
+ 80.82	9	229	04:18
+ 79.38	10	243	04:24
+ 77.95	11	257	04:30
+ 76.51	12	271	04:36
+ 75.08	13	285	04:41
+ 73.64	14	299	04:47
+ 72.21	15	313	04:53
+ 70.78	16	327	04:58
+ 69.34	17	341	05:04
+ 67.91	18	355	05:10
+ 66.48	1	118	05:16
+ 65.04	2	132	05:21
+ 63.61	3	146	05:27
+ 62.17	4	160	05:33
+ 60.74	5	174	05:39
+ 59.31	6	188	05:44
+ 57.87	7	202	05:50
+ 56.44	8	216	05:56
+ 55.01	9	230	06:02
+ 53.56	10	244	06:07
+ 52.13	11	258	06:13
+ 50.70	12	272	06:19
+ 49.26	13	286	06:25
+ 47.83	14	300	06:30
+ 46.39	15	314	06:36
+ 44.96	16	328	06:42
+ 43.53	17	342	06:47
+ 42.09	18	356	06:53
+ 40.66	1	119	06:59
+ 39.23	2	133	07:05
+ 37.79	3	147	07:10
+ 36.36	4	161	07:16
+ 34.92	5	175	07:22
+ 33.49	6	189	07:28
+ 32.06	7	203	07:33
+ 30.62	8	217	07:39
+ 29.19	9	231	07:45
+ 27.75	10	245	07:51
+ 26.31	11	259	07:56
+ 24.88	12	273	08:02
+ 23.45	13	287	08:08
+ 22.01	14	301	08:14
+ 20.58	15	315	08:19
+ 19.14	16	329	08:25
+ 17.71	17	343	08:31
+ 16.28	18	357	08:36
+ 14.84	1	120	08:42
+ 13.41	2	134	08:48
+ 11.97	3	148	08:54
+ 10.54	4	162	08:59
+ 9.11	5	176	09:05
+ 7.67	6	190	09:11
+ 6.24	7	204	09:17
+ 4.81	8	218	09:22
+ 3.37	9	232	09:28
+ 1.93	10	246	09:34
+ .50	11	260	09:40

*NOTE: "Orbit Date" and "Orbit Number" are given for the period August 1 through August 18, 1972. To determine the orbit date and orbit number for any other day, use the conversion provided in Table I-5.

Table I-5. Orbit Date and Orbit Number Conversion

Orbit Date Conversion		1972	1972	1972	1972	1972	1972	1972	1972/73	1973	1973
Aug 1, 1972	Corresponds to →	Aug 19	Sept 6	Sept 24	Oct 12	Oct 30	Nov 17	Dec 5	Dec 23	Jan 10	Jan 28
2		20	7	25	13	31	18	6	24	11	29
3		21	8	26	14	Nov 1	19	7	25	12	30
4		22	9	27	15	2	20	8	26	13	31
5		23	10	28	16	3	21	9	27	14	Feb 1
6		24	11	29	17	4	22	10	28	15	2
7		25	12	30	18	5	23	11	29	16	3
8		26	13	Oct 1	19	6	24	12	30	17	4
9		27	14	2	20	7	25	13	31	18	5
10		28	15	3	21	8	26	14	Jan 1	19	6
11		29	16	4	22	9	27	15	2	20	7
12		30	17	5	23	10	28	16	3	21	8
13		31	18	6	24	11	29	17	4	22	9
14		Sept 1	19	7	25	12	30	18	5	23	10
15		2	20	8	26	13	Dec 1	19	6	24	11
16		3	21	9	27	14	2	20	7	25	12
17		4	22	10	28	15	3	21	8	26	13
18		5	23	11	29	16	4	22	9	27	14

Orbit Number Conversion										
Take the Orbit Number in Table I-4 and Add	251	502	753	1004	1255	1506	1757	2008	2259	2510

Orbit Date Conversion		1973	1973	1973	1973	1973	1973	1973	1973	1973	1973
Aug 1, 1972	Corresponds to →	Feb 15	Mar 5	Mar 23	Apr 11	Apr 29	May 17	Jun 4	Jun 22	Jul 10	Jul 28
2		16	6	24	12	30	18	5	23	11	29
3		17	7	25	13	May 1	19	6	24	12	30
4		18	8	26	14	2	20	7	25	13	31
5		19	9	27	15	3	21	8	26	14	
6		20	10	28	16	4	22	9	27	15	
7		21	11	29	17	5	23	10	28	16	
8		22	12	30	18	6	24	11	29	17	
9		23	13	Apr 1	19	7	25	12	30	18	
10		24	14	2	20	8	26	13	Jul 1	19	
11		25	15	3	21	9	27	14	2	20	
12		26	16	4	22	10	28	15	3	21	
13		27	17	5	23	11	29	16	4	22	
14		28	18	6	24	12	30	17	5	23	
15		Mar 1	19	7	25	13	31	18	6	24	
16		2	20	8	26	14	June 1	19	7	25	
17		3	21	9	27	15	2	20	8	26	
18		4	22	10	28	16	3	21	9	27	

Orbit Number Conversion										
Take the Orbit Number in Table I-4 and Add	2761	3012	3263	3514	3765	4016	4267	4518	4769	5020

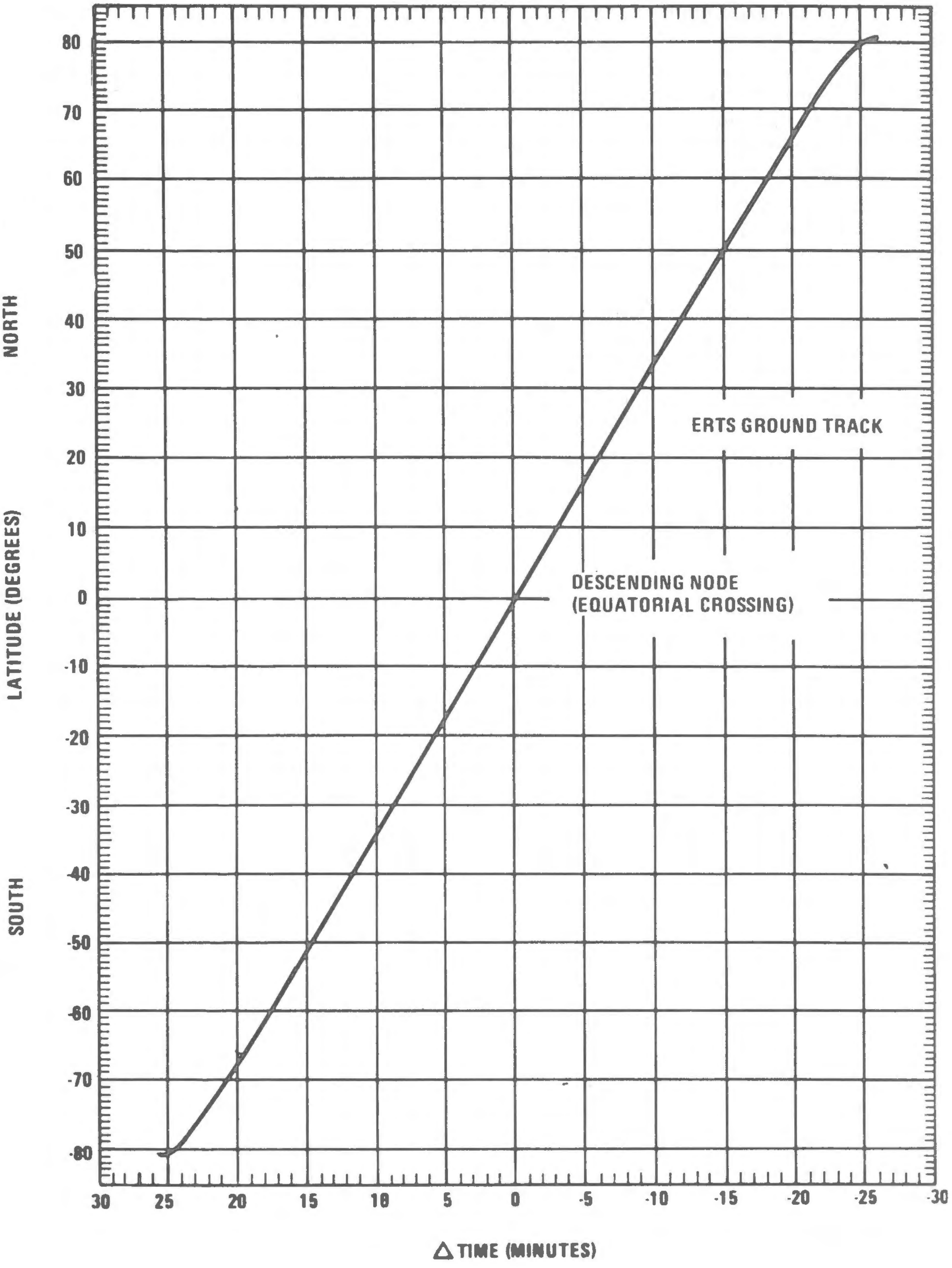


Figure I-10. Time Difference Measured from Descending Node

b. The orbit day, orbit number, and the Greenwich Mean Time (GMT) of the descending node can be read from the table.

4. Determine the GMT at the position of interest as follows:

   a. Locate the latitude of the position of interest on the ordinate of the graph of Figure I-10.

   b. Read the Δ time from the curve.

   c. Add the Δ time to the GMT of the descending node determined in step 3-b, carefully noting algebraic signs.

5. Determine the Standard Mean (Local) Time of satellite passage over the position of interest as follows:

   a. Determine the number of hours between the local time zone and the Greenwich time zone from Figure I-11.

   b. If the longitude of the position of interest is west of the Greenwich meridian, subtract the number of hours from the GMT determined in step 4-c.

   or

   if the longitude of the position of interest is east of the Greenwich meridian, add the number of hours to the GMT determined in step 4-c.

The following example illustrates the procedure:

Step 1

Point of Interest: Latitude = 45° North
Longitude = −120° West

Step 2

From Table I-3, the Δ longitude for 45° north latitude is −12.5°. The approximate descending node longitude is then (−120°) + (−12.5°) or −132.5°. Since this does not fall outside the limits of −180° to 180° there are no adjustments required.

Step 3

The closest descending node from Table I-4 is −132.89°. Hence, imagery will be taken of the desired point on August 14 in rev 307. The GMT at the descending node will be 18:33.

From Table I-5, the same point will be observed by the satellite again on September 1 (orbit 307 + 251 = 558), on September 19 (orbit 307 + 502 = 809), etc.

Step 4

From Figure I-10 the Δ time for 45° North latitude is −13 minutes. Hence, the GMT when imaging of the desired point will occur is (18:33) + (−:13) or 18:20.

Step 5

From Figure I-11 the number of hours from Greenwich at the desired location is 8. Since the desired location is West of the Greenwich meridian, subtract 8 hours from 18:20 or 10:20. This is the Standard Mean (local) Time of imaging the desired location.

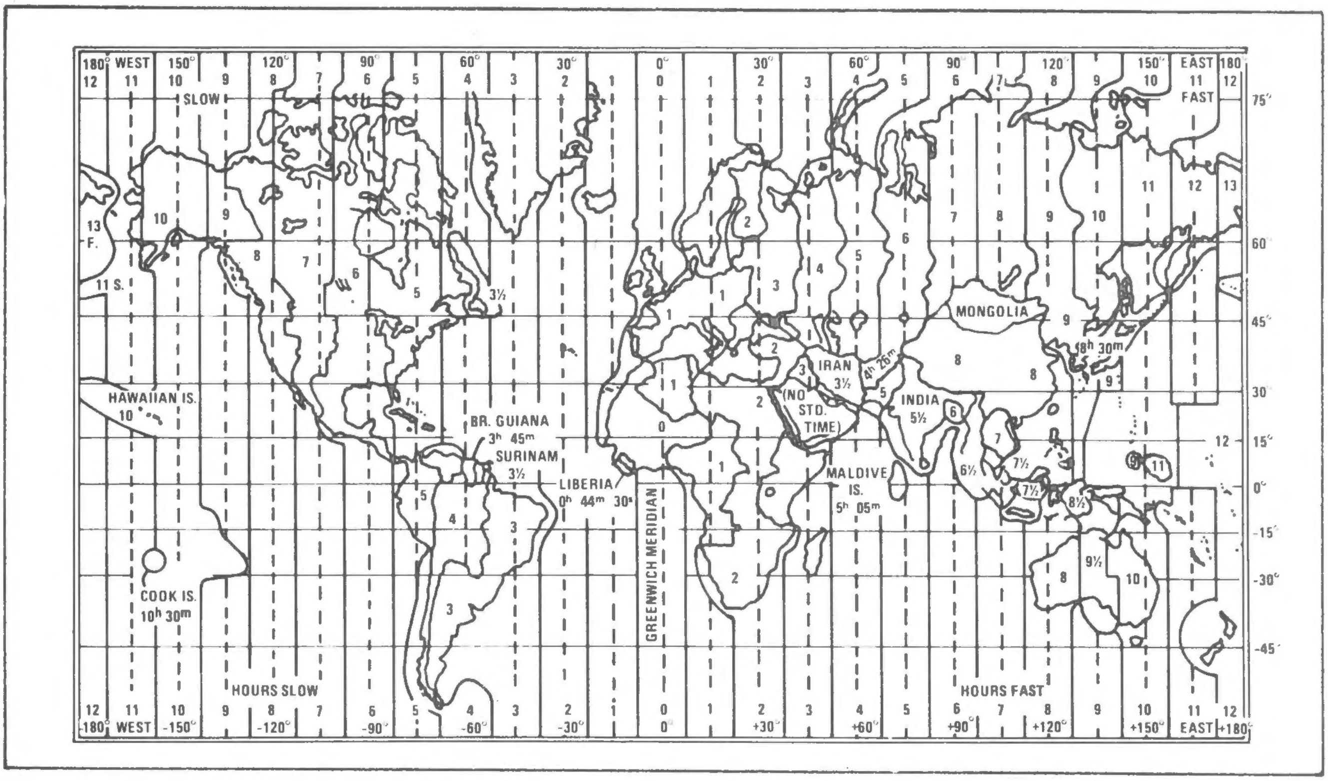


Figure I-11. Time-Zone Map of the World

APPENDIX J
ORBIT CONTROL

Several significant characteristics of the ERTS orbit have been selected to minimize variations in observation conditions and provide a systematic process of imagery collection. Precise control of the orbital parameters is required for the attainment and maintenance of the desired characteristics. Hence, the ERTS spacecraft includes an orbit adjust capacity which is used to attain the orbit initially and maintain this orbit throughout the life of the mission.

The orbit adjust subsystem is a monopropellant system consisting of three rocket engines fed by a common propellant/pressurant tank. The three thrusters are aligned to provide impulse along or opposed to the spacecraft velocity vector and also perpendicular to the orbital plane. Each thruster imparts a thrust of approximately one pound force.

J.1 ATTAINMENT OF REQUIRED ORBIT

The Delta launch vehicle injects the spacecraft into its final orbit to within the limits of the errors inherent in the launch vehicle system. Launch vehicle errors at injection are random and can be of magnitudes which impact the desired observation characteristics. When required, the spacecraft orbit adjust capabilities are utilized after spacecraft separation to remove any residual launch vehicle injection errors.

The orbital parameters most critical to providing the desired imagery characteristics are the semi-major axis (or equivalently the period of the orbit), the inclination, and the eccentricity. For ERTS, a unique combination of orbital period and inclination are required to establish the desired coverage pattern and sun synchronism. Errors in eccentricity will also affect these characteristics. However, for the expected range of injection errors, the eccentricity errors have a negligible effect compared to the effect of inclination and period errors.

J.1.1 Period Errors

The maximum expected injection error in the orbital period exceeds by a wide margin the accuracy required for satisfactory systematic coverage and cross-track repeatability. For example, an injection period error of only one percent of the maximum (3σ) error will result in a 35 kilometer sidelap error in the second 18-day cycle relative to imagery from the corresponding revolutions in the first 18-day cycle. This error, as illustrated in the lower left portion of Figure J-1, will continue to expand with time resulting in a relative error of approximately 750 kilometers after one year.

J.1.2 Inclination Errors

Injection inclination errors cause a drift in the time of the descending node and also imagery sidelap errors. Without an orbit adjustment capability, an injection inclination error equal to the maximum (3σ) error will result in a relative sidelap error of 417 kilometers after one year. These inclination effects can be compensated by adjusting the orbital period.

J.1.3 Error Correction

Thus, injection period errors have to be removed and compensation provided for the inclination error. Period adjustments are accomplished by utilizing one of the two thrusters which impart impulse along the velocity vector. Because of the one pound force of these thrusters, the weight of the spacecraft, the magnitude of the period adjustment, and other scheduling criteria, the period adjustment process can take up to 6 days from injection to completion. A typical adjustment sequence consists of:

1. Several days to ascertain spacecraft health, to track, and to determine maneuver requirements
2. Several consecutive orbits with approximately 20-minute rocket firings on each orbit

3. Several orbits to track and ascertain that adjustments were executed as planned

4. Continued interspersing of several orbits of adjustments with several orbits of tracking until the correct orbit has been attained

The launch vehicle can inject the spacecraft into an orbit with an eccentricity of acceptable accuracy. However, an orbit with circular characteristics is most preferable to minimize the variations in observation altitude. It is sometimes possible when adjusting the period of the orbit to schedule the adjustments to more nearly circularize the orbit. Therefore, when period adjustments are required and when they can be scheduled to circularize the orbit, the injection eccentricity errors will be reduced. Otherwise, no orbit adjustments are planned to specifically remove injection eccentricity errors.

J.2 MAINTENANCE OF REQUIRED ORBIT

Several forces (such as: atmospheric drag, the gravitational attraction of the sun and moon, and the spacecraft's own attitude control mass expulsion subsystem) act upon the spacecraft after the desired orbit has been attained. These forces cause changes to the orbit which compromise the desired coverage and repeatability characteristics. The orbit to which the injection error removal process will be targeted has been selected to minimize the effects of these subsequent forces on the desired coverage characteristics. Nonetheless, orbit adjustment will occasionally be required during the mission to compensate for these forces.

During the first several weeks of the mission, several small although significant perturbing factors (e.g., the force due to the attitude control system mass expulsion subsystem) will be determined. Once these factors are determined, they will be included in orbit planning operations to minimize the number of subsequent adjustments. Several small adjustments may be necessary during this period to optimize the desired coverage characteristics. These adjustments are minor and will be scheduled so not to interfere with imaging operations.

Subsequent to the first several weeks of the mission, the requirements for adjustments will become minimal, systematic, and predictable. The requirements for these adjustments result from the perturbing forces on the spacecraft which, over long periods of time, cause predictable perturbations to the orbit. The significant impact of these perturbations is a systematic cross-track drift of imagery from revolutions of one 18-day, Earth coverage cycle relative to imagery from corresponding revolutions of other 18-day cycles during the mission. Orbit adjustments will be scheduled to limit this cross-track imagery drift to 37 kilometers during the entire mission. Figure J-1 shows a typical drift and adjustment profile. Acceptable coverage can be maintained over a one-year mission by several small orbital period adjustments. These adjustments are only of several seconds duration and are scheduled over primary ERTS ground stations during night time portions of the orbit, so not to interfere with imaging operations.

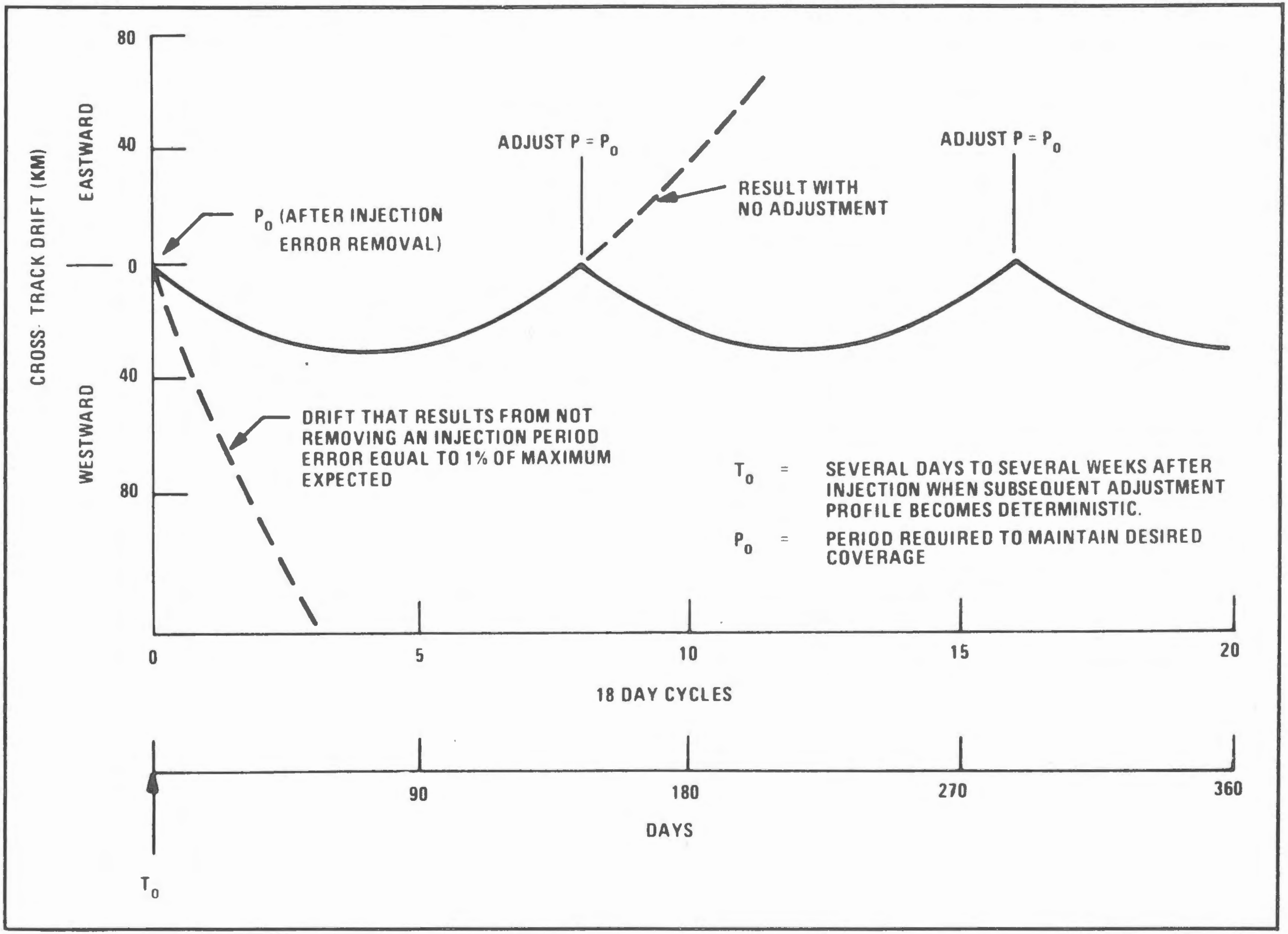


Figure J-1. Typical Cross-Track Drift of Ground Trace and Period Adjustment Profile

APPENDIX K
MISSION PLANNING

The spacecraft has access to all global area between 81 degrees North and 81 degrees South Latitude every 18 days. However, due to constraining factors both within the external to the ERTS system, not all of this area can be imaged all the time. The constraints include:

1. On-board tape recorder capacity of 30 minutes maximum
2. On-board command memory capability for switching sensors on and off
3. Ground station availability and contact time duration
4. Global landmass distribution
5. Ground scene illumination conditions
6. Cloud cover

The purpose of the mission planning function is to define the sequence of spacecraft and ground-station operations to maximize the imagery yield while operating within these constraints. The output is a time-ordered sequence of events which define all sensor, wideband tape recorder, and assorted routine spacecraft functions. This sequence of events is then used to define the specific commands for operating the spacecraft. In addition, the mission planning function defines the events which are to occur during every spacecraft/ground-station contact.

The bulk of the mission planning operation is done once a day and results in activity plans for that day's operation. These plans are updated on an orbit-by-orbit basis as required to include the latest cloud cover information and to account for any last-minute anomolous occurrences such as ground station outages.

Figure K-1 illustrates the coverage for a typical day's operation. The spacecraft will normally be scheduled to send real-time (direct) data whenever it is concurrently over an area of interest and is within view of a

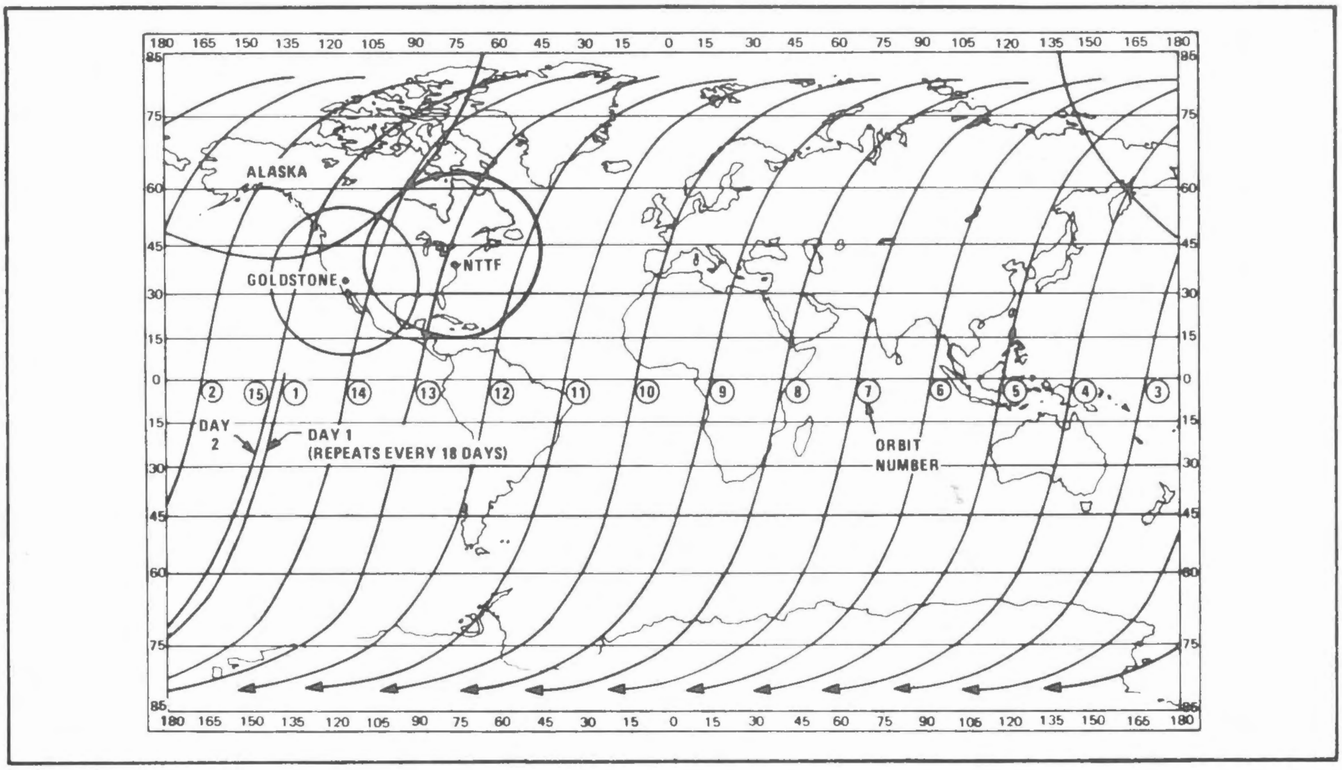


Figure K-1. Typical ERTS Coverage – One Day ground station that can receive ERTS data. The four primary ERTS stations (PASS, NTTF, Goldstone and Alaska) provide coverage of most of North America and real-time imagery transmission is normally scheduled during this time. Data recovery over the rest of the globe is performed by recording the data on the on-board wideband video tape recorders and playing back during subsequent ground station contacts.

The bar chart of Figure K-2 shows the total time during daylight when the spacecraft is over any land area for one day's operation, and the amount of land area that can typically be imaged by the spacecraft. Figure K-2 corresponds to the typical day of Figure K-1. During remote operations the spacecraft has access to much more coverage area than can be accommodated by the wideband tape recorders. Therefore, a selection process is required to determine which areas are to be recorded during any given remote operation. To assist in this selection process, a system of priorities is used for all coverage areas of the world. By scheduling payload operations based on these priorities, coverage of the areas of greatest investigator interest is assured.

In order to establish the priorities several factors must be considered. These include:

1. Scientific importance of the area -- is there investigator interest in a given area and how often need it be imaged?
2. Season of the year -- when is imagery of that area most/least desirable?
3. Lighting conditions — image quality varies with scene contrast and brightness which in turn varies with local sun angle; what lighting conditions are required for the given scene?
4. Time since the area was last imaged — how recent is the imagery for that area; was it obscured by clouds?

The priorities in the system are quite dynamic, in that, they must be periodically updated to reflect changes in the desirability of imaging the various areas. The investigator's requests for data provide information to the ERTS Project to assist in defining the various areas of interest and priorities.

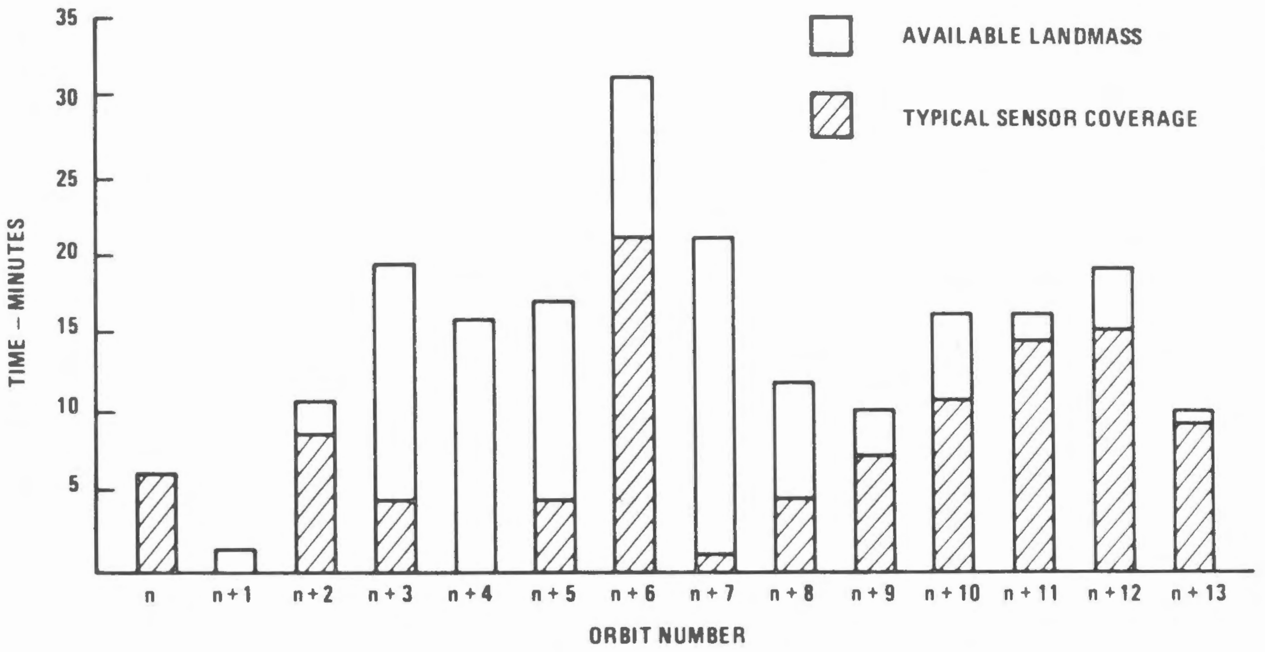


Figure K-2. Available Landmass and Typical Daily Coverage

Predicted cloud cover data is used in mission planning to minimize the number of obscured images. Prediction data is received from National Oceanographic & Atmospheric Administration (NOAA) on a periodic basis and the spacecraft schedule is updated as near as possible to the upcoming data pass to include the most recent cloud information. Due to spacecraft command constraints, the sensors and recorders can be switched on and off only a limited number of times; hence, some imagery of fully cloud-covered areas may be taken.

The decision not to schedule sensor operation over a given area depends both on the percentage cloud cover expected and the degree of investigator interest in that particular area. Areas of very high investigator interest are normally scheduled even though a fairly high percentage of cloud cover is predicted. Areas of low, or no investigator interest tend not to be scheduled even for a lesser percentage of cloud cover. The objective is to maximize the number of cloud-free images while at the same time making every attempt to image the areas of greatest interest.

The possibility of cloud obscured scenes has one major implication to investigators who require periodic repeating coverage. Since the satellite has access to a given scene only once every 18 days (except for higher latitudes—see Section I.2), cloud cover could result in the repeating coverage being interrupted for periods of 36, 54, or more days for any particular scene.

APPENDIX L
SUN ELEVATION EFFECTS

The choice of orbit for ERTS causes the spacecraft to pass over the same point on the earth at essentially the same local time every 18 days. However, even though the local time remains essentially the same, changes in solar elevation angle, as defined in Figure L-1, cause variations in the lighting conditions under which imagery is obtained. These changes are due primarily to the north/south seasonal motion of the sun.

Changes in solar elevation angle cause changes in the average scene irradiance as seen by the sensor from space. The change in irradiance is influenced both by the change in intrinsic reflectance of the ground scene and by the change in atmospheric backscatter. Exposure time of the RBV will be varied by ground commands to accommodate the changing illumination levels. At certain times of the year imagery will not be obtained in the high and low latitude regions of the earth due to inadequate scene illumination.

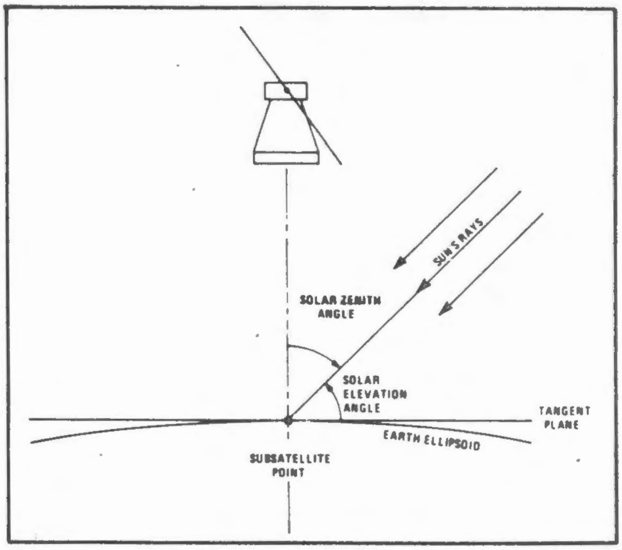


Figure L-1. Solar Elevation Angle

The actual effect of changing solar elevation angle on a given scene is very dependent on the scene itself. For example, the intrinsic reflectance of sand is significantly more sensitive to changing solar elevation angle than are most types of vegetation. Due to this scene dependence, each type of scene must be evaluated individually to determine the range of solar elevation angles over which useful imagery will be obtained.

Figure L-2 shows the solar elevation angle as a function of time of year and latitude. This family of curves is for a 9:30 a.m. descending

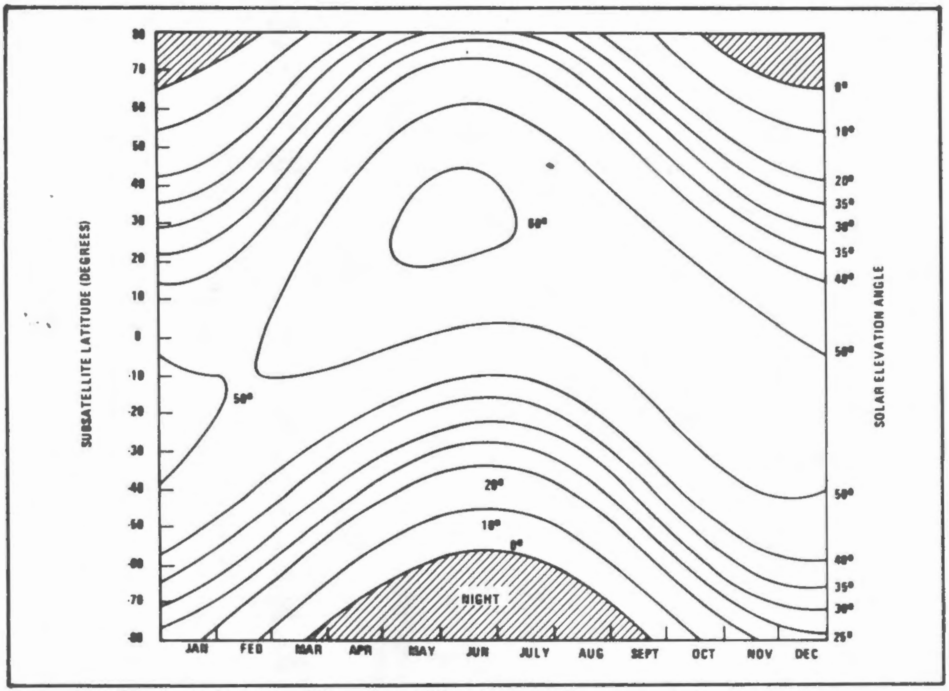


Figure L-2. Solar Elevation Angle History as a Function of Subsatellite Latitude – Descending Node at 9:30 a.m.

node time which is the nominal expected time of equatorial crossing for the satellite. By drawing a horizontal line for a given latitude, the solar elevation angle can be determined for any time of year. Portions of this data have been transferred to the global maps in Figure L-3. These maps show the range of possible sensor operation (i.e., daylight) for the various seasons. Depending on the scene, it may or may not be possible to obtain useful imagery at the lower solar elevation angles. At solar elevation angles greater than 30 degrees, it is expected that all scenes can be satisfactorily imaged.

Two other parameters may affect the local solar elevation angle. These are the ERTS launch window and perturbations to the orbit. The launch window (allowable launch time variation) is plus 30 and minus zero minutes, which results in a possible descending node time anywhere in the range of 9:30 to 10:00 a.m. The effects of launch time variations on solar elevation angle are shown in Figures L-4 through L-6 for various latitudes.

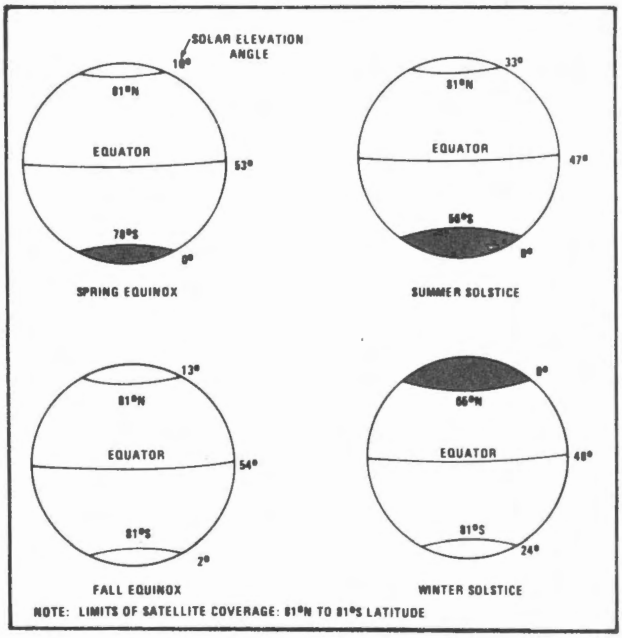


Figure L-3. Seasonal Variations in Solar Elevation Angle – 9:30 a.m. Descending Node

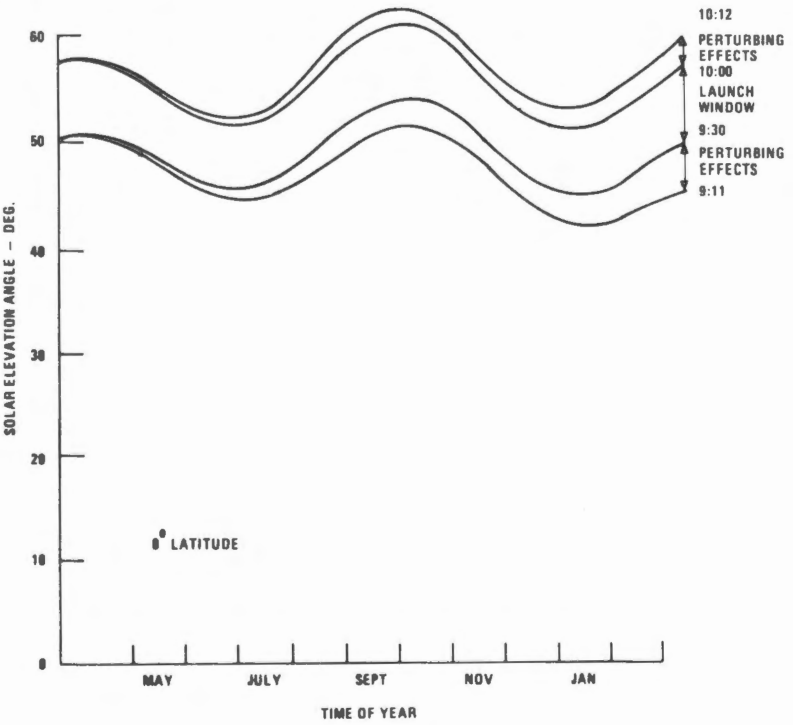


Figure L-4. Launch Window and Orbit Perturbing Effects on Solar Elevation Angle at 0 Degrees Latitude

Whatever time the spacecraft is launched, the local times would then remain fixed throughout the mission were it not for perturbing forces to the orbit. These forces, such as atmospheric drag and the sun's gravity, will shift the time of descending node throughout the year, resulting in changes to the nominal solar elevation angle. The changes due to these perturbing effects are also shown in Figures L-4 through L-6. Under worst case conditions, the solar elevation angle changes due to perturbing forces will amount to no more than 4 degrees throughout the year.

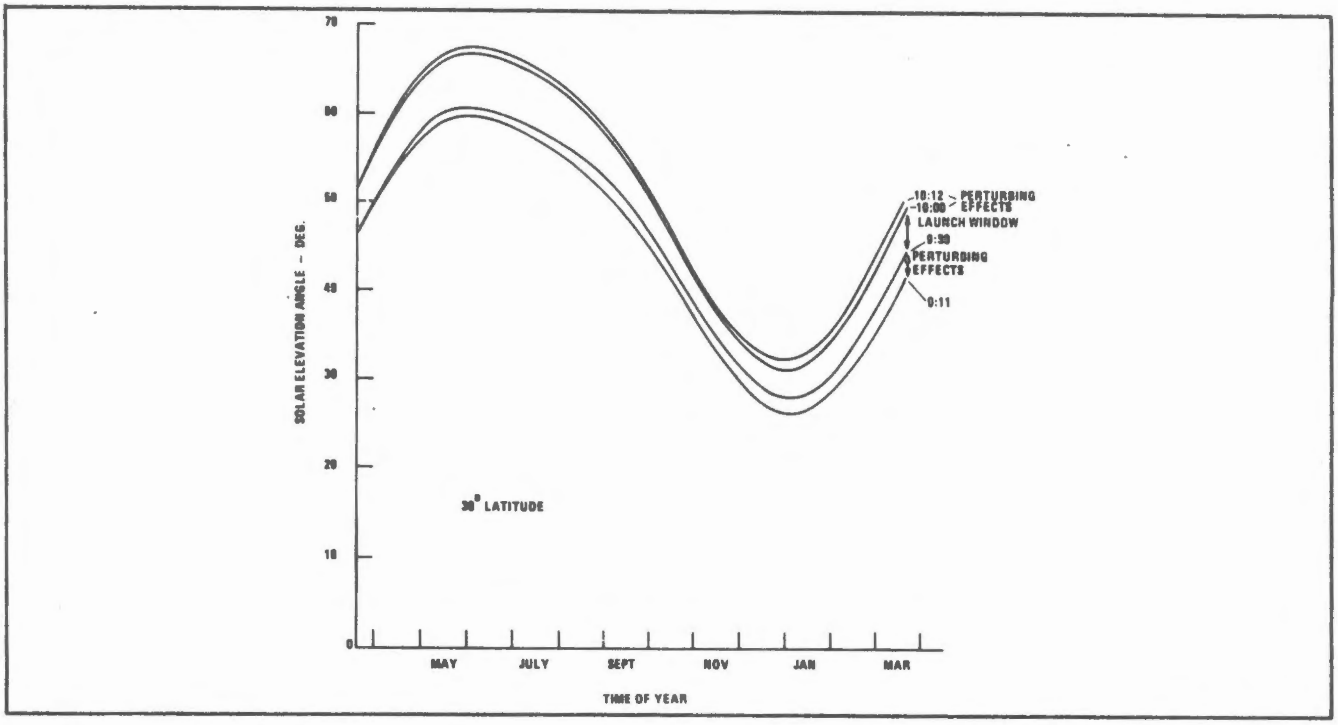


Figure L-5. Launch Window and Orbit Perturbing Effects on Solar Elevation Angle at 30 Degrees North Latitude

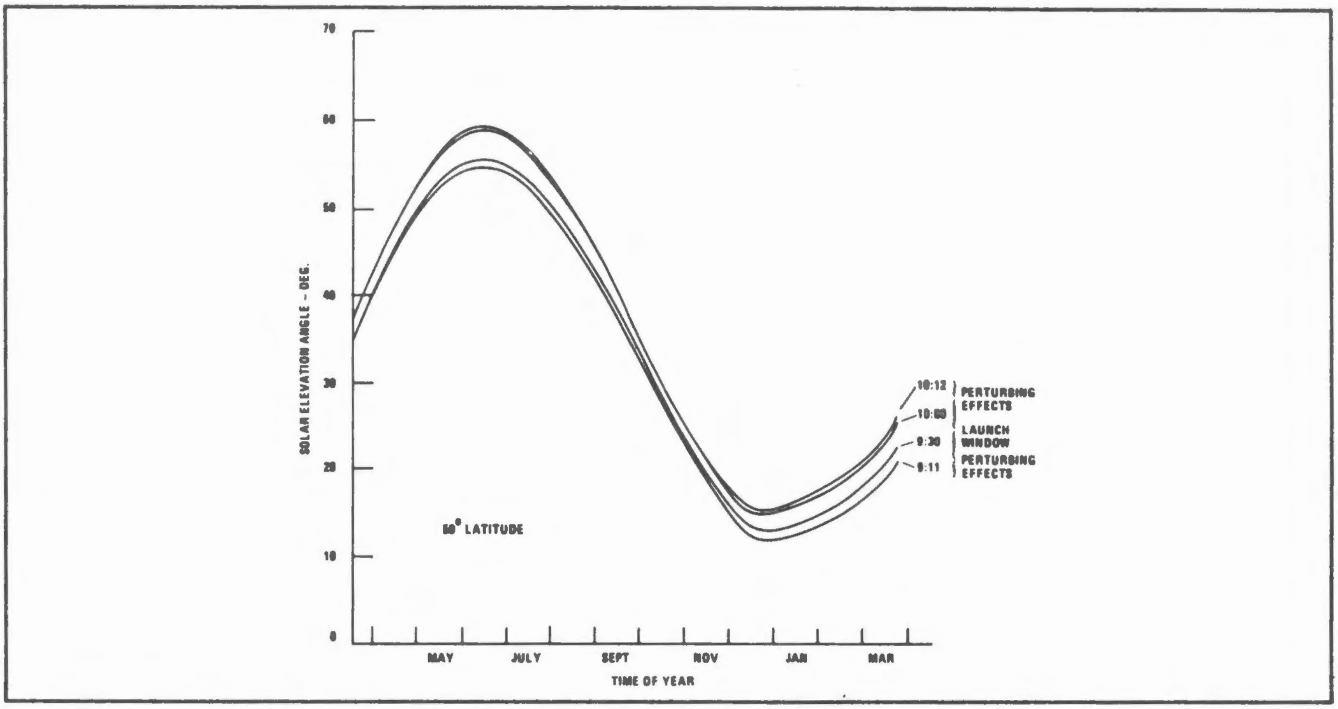


Figure L-6. Launch Window and Orbit Perturbing Effects on Solar Elevation Angle at 50 Degrees North Latitude

APPENDIX M

CCRS INTERPRETATION AIDS

(This Appendix is in preparation)

ACRONYMS

(This Appendix is in preparation)

GLOSSARY

(This Appendix is in preparation)

REFERENCES

(This Appendix is in preparation)