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DATA USERS HANDBOOK

National Aeronautics and Space Administration
Greenbelt, Maryland

15 September 1971

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DATA USERS HANDBOOK

NASA EARTH RESOURCES • TECHNOLOGY SATELLITE •

COLOR ILLUSTRATIONS REPRODUCED IN BLACK AND WHITE

GODDARD SPACE NASA FLIGHT CENTER

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SECTION 1
INTRODUC' ION

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 will launch two experimental satellites into orbit: ERTS A in 1972; ERTS B, during the following year. Each will acquire multispectral images of the earth's surface and transmit this raw data through ground stations to a data processing center, at the NASA Goddard Space Flight Center, for conversion into black-and-white or color 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 investigators' experience with ERTS A/B data.

This handbook has been designed to satisfy investigators' 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 investigators is included in this section.

Section 3 Output Data Products
Provides a detailed description of each type of data that is available to investigators, 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 investigator 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 investigators. These topics are:

A. Payload — Describes equipment, characteristics, and operating modes of RBV (Return Beam Vidicon), MSS (Multi Spectral Sensor), 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) and MSFN (Manned Space Flight Network) stations supporting the mission and the transfer of data between those stations and the GDHS (Ground Data Handling System) at Goddard Space Flight Center.
D. Operations Control Center — Describes the function performed by this facility in planning and conduct-

ing the flight operations and its role in the collection of payload data.

E. NASA Data Processing Facility — Describes the conversion and correction of raw video tapes into useful photographic and digital tape products. The different types of processing within the NDPF 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 from the NDPF.

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, the systematic coverage which results, and the time at which images are collected.

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. List of NASA Principal Investigators — Provides the names of the principal investigators selected by NASA and their planned field of investigation.

N. Sample Products — Provides samples of imagery and calibration data available prior to launch of the spacecraft.

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 System is proceeding concurrently with preparation of this handbook. Consequently, the document is bound in loose-leaf 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 investigators' 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, produced during system integration and testing, are provided in Appendix N of the handbook. In many cases, this data will actually be products of calibration tests; hence, they will serve a dual purpose of providing ERTS product samples, as well as calibration data relative to ERTS products.

Distribution of this handbook and subsequent update material will be made in accordance with a controlled list established by NASA. 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:

ERTS PROJECT OFFICE
National Aeronautics and Space
Administration
Goddard Space Flight Center
Greenbelt, Maryland, 20771
Attention: Thomas M. Ragland, Code 430

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 A and B) will point the way toward development of fully operational and more effective systems for earth resources management.

Figure 2-1 is a photographic reproduction to match the ERTS 1:1,000,000 scale to give the user an appreciation of the scale and image quality that can be expected.

The photograph was made from an Apollo SO-65 color photograph with three contact printing stages and two enlargements. It is estimated that its resolution, as reproduced here, is similar to an ERTS Precision color photograph. Because the picture was made from a single original negative, there is no registration error.

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 A 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 A (Five Channels for ERTS B), and a three camera Return Beam Vidicon (RBV) system. In addition, the ERTS Observatory will be utilized as a relay system to gather data from remote, widely distributed, earth-based sensor platforms equipped by 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.

Figure 2-1. Color Composite of Precision Processed Image (of Salton Sea)

NOT REPRODUCIBLE

The overall ERTS A/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 and at two MSFN sites: Goldstone, California and the GSFC Network Test and Training Facility (NTTF) at Greenbelt, Maryland.

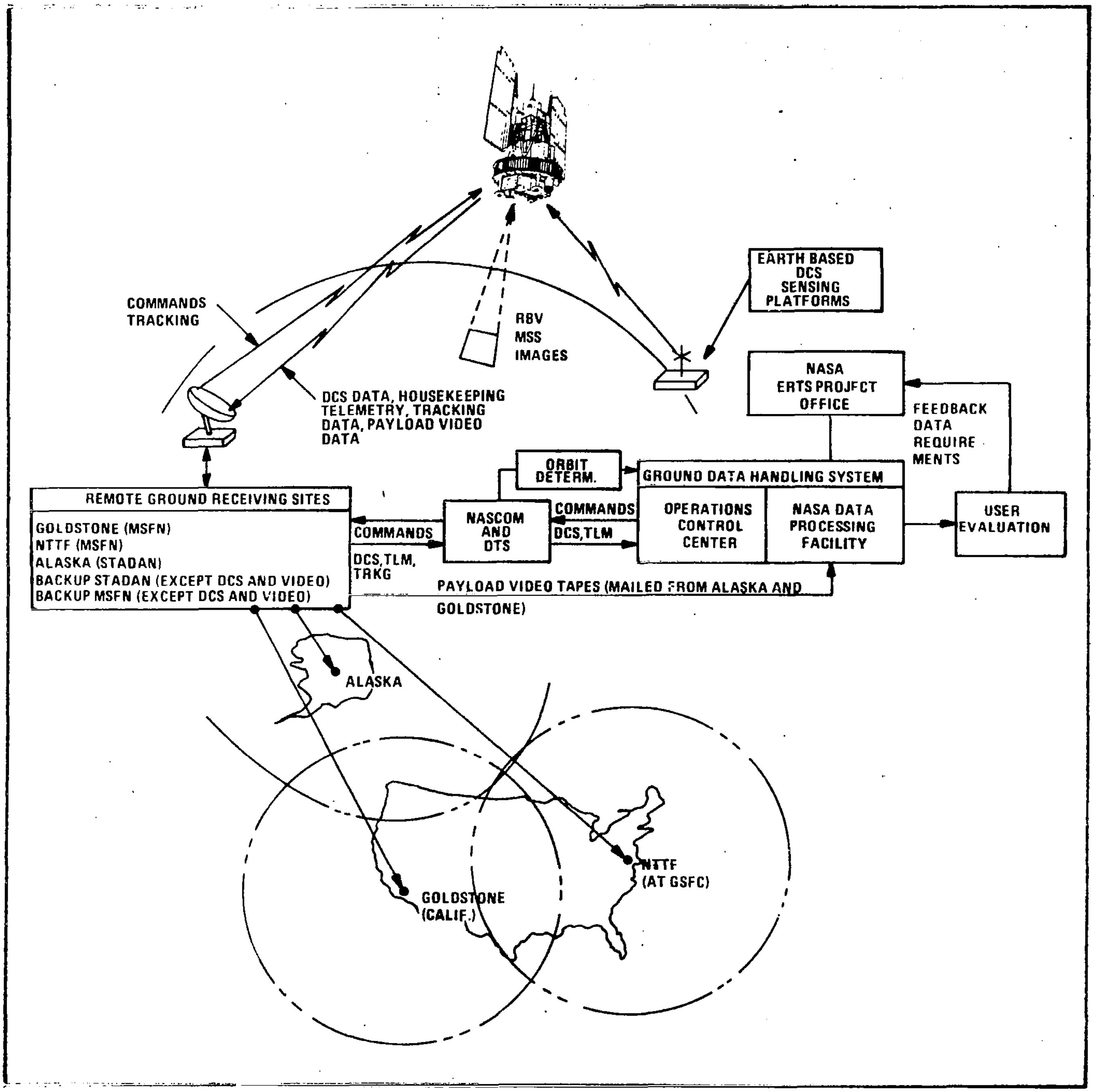

Figure 2-2. Overall ERTS System

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 the OCC and remote ground sites is accomplished by NASA Communications (NASCOM). The NASA Data Processing Facility (NDPF) accepts payload video data in the form of magnetic tapes received in real time at the NTTF Station via the OCC or by mail from Alaska and Goldstone. The NDPF then performs the video-to-film conversion and correction, producing black and white images from individual spectral bands and color composites from several spectral bands. The NDPF includes a storage and retrieval system for all data and provides for delivery of data products and services to the investigators and other data users. Together the OCC and NDPF comprise the ERTS Ground Data Handling System (GDHS).

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 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 Measuring Subsystem (AMS), operating over a narrow range of about 2 degrees, provides

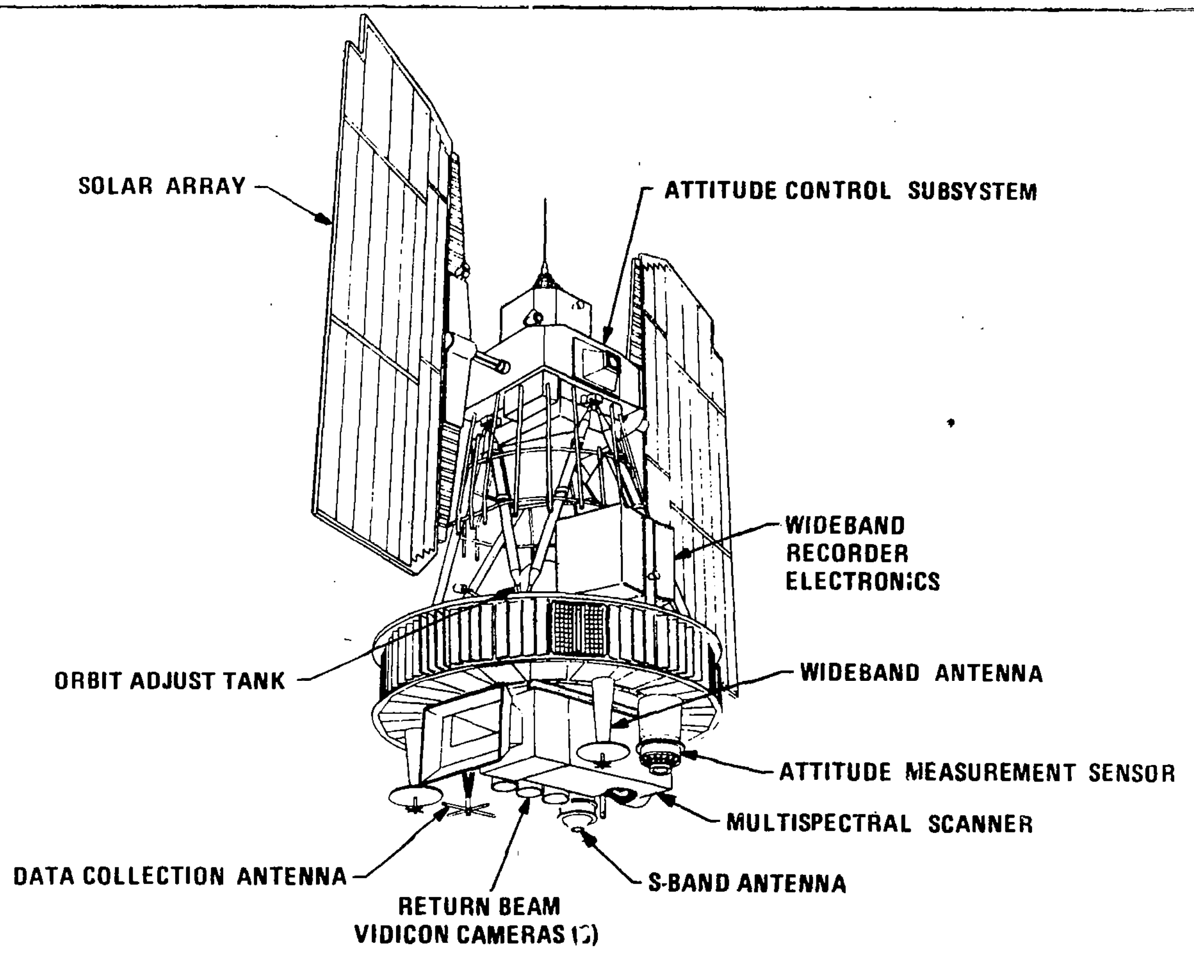

Figure 2-3. Observatory Configuration

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.

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 3.5 MHz. Orientation of the three camera heads is shown in Figure 2-4.

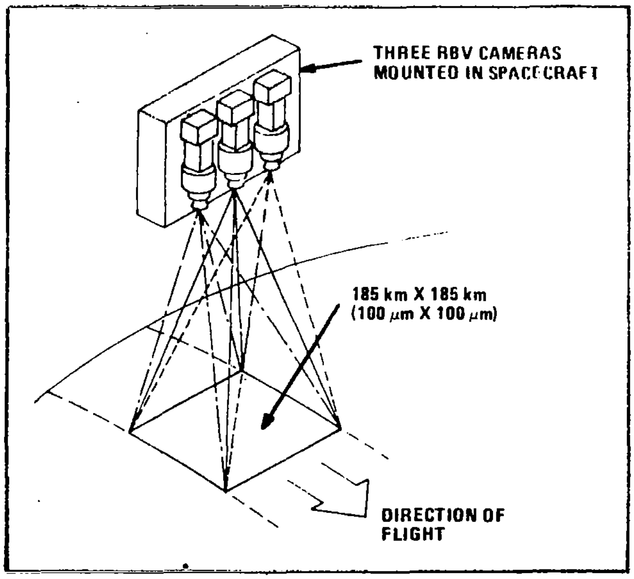

Figure 2-4. RBV Camera Head Orientation

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 band 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.

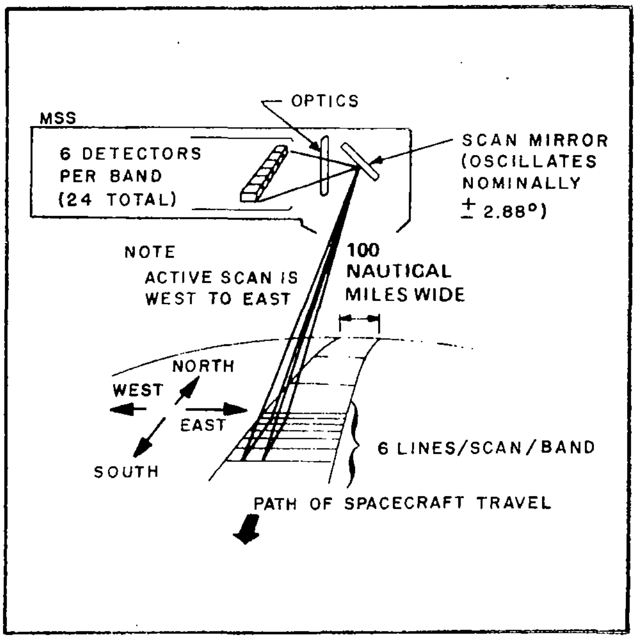

Figure 2-5. MSS Ground Scan Pattern

2.3.3 Wideband Video Tape Recorders

The use 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.

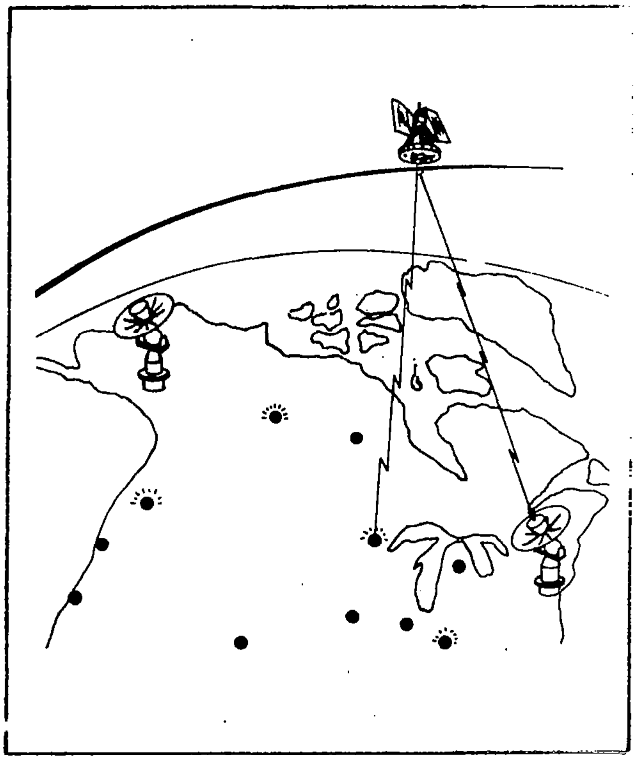

Figure 2-6. Data Collection System

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 Operation 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-hour 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.

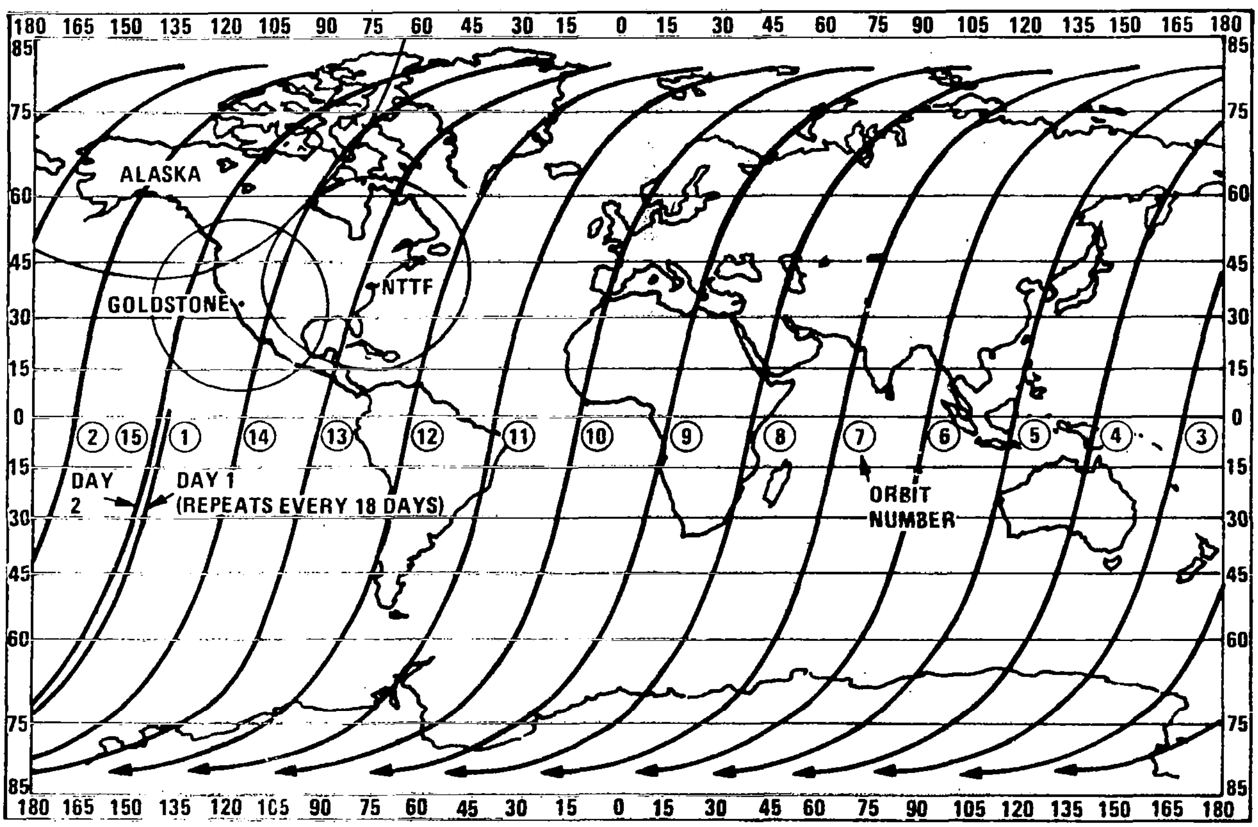

Figure 2-7. Typical ERTS Daily Ground Trace (Daylight Passes Only)

The Operations Control Center system is shown in Figure 2-8. The OCC computer performs spacecraft and sensor "house-keeping", 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.

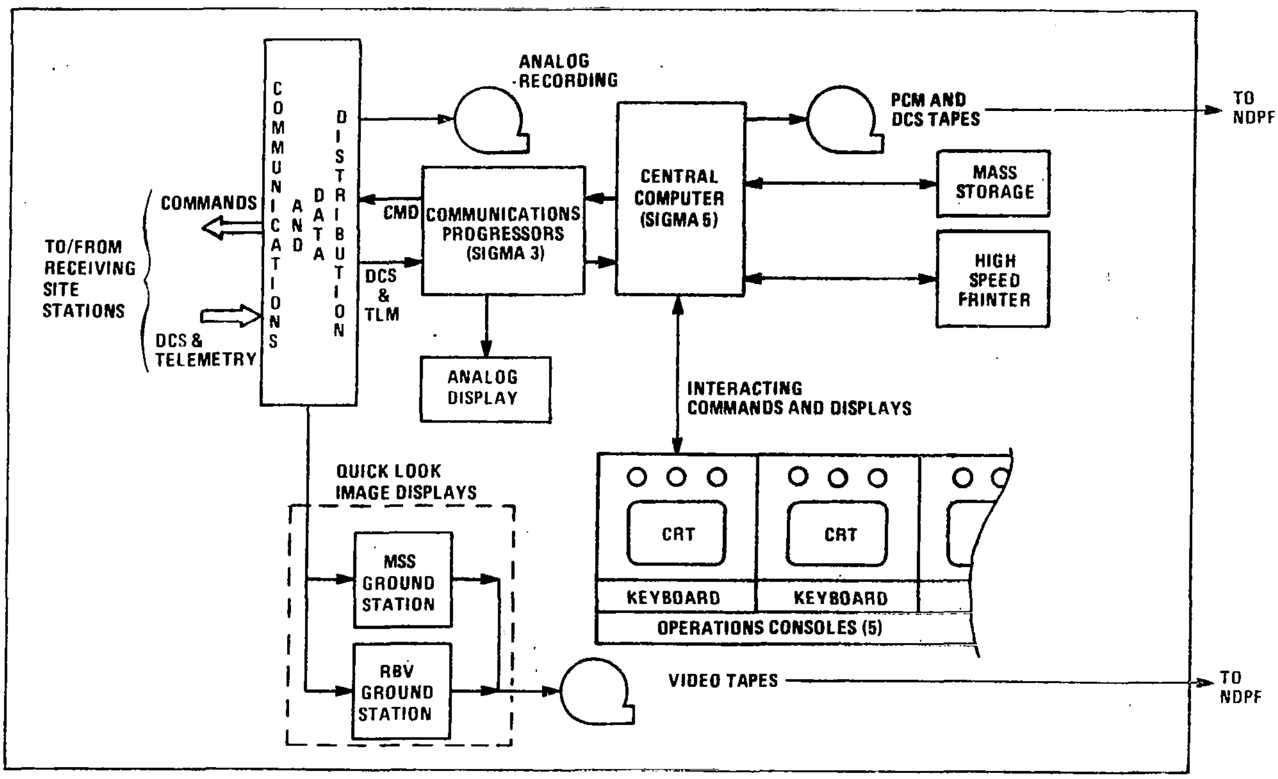

Figure 2-8. OCC System

2.6 NASA DATA PROCESSING FACILITY

The NASA Data Processing Facility is a job-oriented facility which 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 NDPF from the Operation Control Center. This data, along with telemetry data containing spacecraft attitude and sensor operation information, is used to produce an Image Annotation Tape for identification, location and annotation of all imagery during image processing. There are three types of image processing performed in the NDPF: Bulk, Precision and Special. All data is Bulk processed while only selected data is Precision or Special processed.

2.6.1 Bulk Processing

Payload video data tapes are the principal input to Bulk Processing. Here an electron beam recorder (EBR) produces corrected 55 mm images on 70 mm film of data from all video tapes. During video-to-film conversion, alphanumeric annotation data, image location, and a gray scale for calibration is recorded. Initial radiometric and geometric corrections are also made to the image. The 70 mm film images produced by Bulk Processing are developed in the Photographic Processing subsystem and inspected for quality and cloud cover. The images which are requested by investigators are enlarged (if required), printed, inspected, logged, and distributed.

2.6.2 Precision Processing

Precision Processing is performed on selected image data when requested by investigators. The 70 mm film images produced by Bulk Processing are re-processed by a hybrid system which produces corrected film images on a 9-1/2 inch format. This process removes additional geometric errors not corrected in Bulk Processing and performs precision location and orthographic projection of the corrected image relative to Universal Transverse Mercator (UTM) and geographic map coordinates.

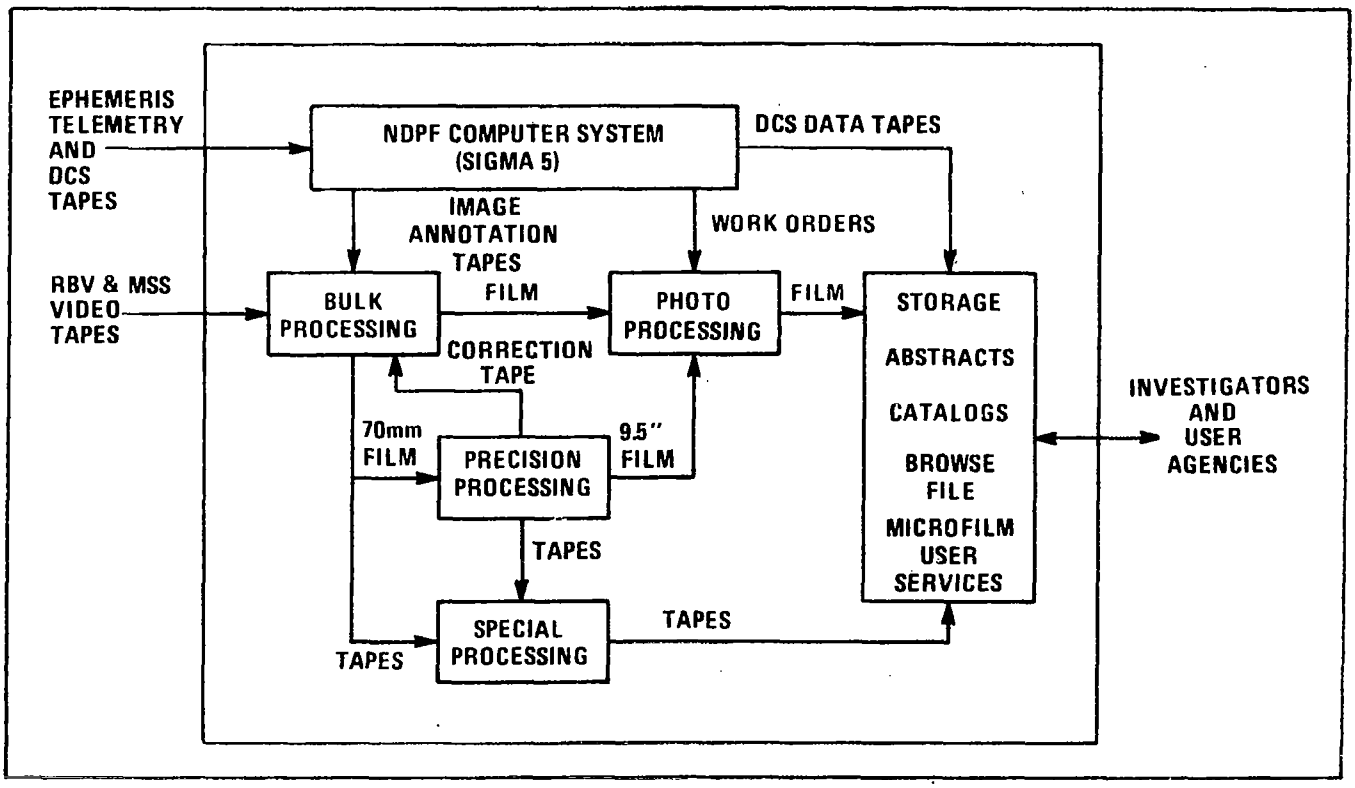

Figure 2-9. NASA Data Processing Facility

2.6.3 Special Processing

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

2.6.4 DCS Data Processing

Data Collection System data is processed, formatted and distributed to investigators on magnetic tape, computer listing or punched cards within 24 hours from the time data collection platform sensor measurements are relayed by the spacecraft to ground receiving sites.

2.6.5 Support and User Services

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

It is anticipated that close to one-half million master images will be processed and stored at the NDPF 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 NDPF data through several files to provide efficiency in searching areas of interest. These aids include:

- Browse Files — Complete microfilm file of all available images arranged by date and location, with a data base query and search system and image viewing equipment.

- Coverage Catalogs — Listing in two separate catalogs of all U.S. and non-U.S. images that are returned over each 18-day coverage cycle. These catalogs are updated and distributed on a regular schedule.

- DCS Catalog — Listing of information available from the remote, instrumented data collection platforms.

Imagery requested by investigators is processed in either black and white or color from archival images stored in the master file. Samples of Bulk and Precision imagery and color composites are available to permit the investigator to select the material most useful for his purposes. Other (such as DCS tapes and listings, digital image tapes, catalogs, and calibration data) are provided to investigators either to fill a standing order or specific data requests.

SECTION 3
OUTPUT DATA PRODUCTS

Investigators may choose the product or products most useful to their specific area of investigation. It is expected, for example, that investigators performing digital analyses based on scene radiance will choose computer compatible tapes of Bulk Processed Multispectral Scanner images. Those requiring the best resolution will select 70mm products; for precise location of topographical features Precision products will be used. It is not implied that a single product necessarily serves the total needs of an individual investigator, but only that the best possible quality in terms of such individual parameters as geometric accuracy, resolution or radiometric accuracy will be found in different data product. No single data product is best in terms of all quality parameters. Figure 3-1 summarizes all output data products of the NASA Data Processing Facility (NDPF) that are available to investigators. Photographic products are discussed in Section 3.1, digital products are presented in Section 3.2, and the Data Collection System (DCS) products in Section 3.3.

3.1 PHOTOGRAPHIC PRODUCTS

The following terms and definitions are used in this section when discussing all ERTS photographic products.

Bulk refers to all imagery that contains the radiometric and initial spatial corrections introduced during the process of video tape to film conversion but not those corrections provided by the Precision Processing subsystem. Bulk photographic products are discussed in Section 3.1.1.

PRODUCT TYPE	BLACK & WHITE	COLOR	DIGITAL
BULK RBV & MSS	70 MM NEGATIVE 70 MM POSITIVE 9.5 INCH* POSITIVE 9.5 INCH* PAPER PRINT	9.5 INCH* POSITVE 9.5 INCH* PAPER PRINT	COMPUTER COMPATIBLE TAPES
PRECISION RBV & MSS	9.5 INCH* NEGATIVE 9.5 INCH* POSITIVE 9.5 INCH* PAPER PRINT	9.5 INCH* POSITIVE 9.5 INCH* PAPER PRINT	COMPUTER COMPATIBLE TAPES
DATA COLLECTION SYSTEM			DIGITAL TAPES PUNCH CARDS COMPUTER LISTINGS

*240 MM NOMINAL

Figure 3-1. ERTS Output Products Available to Investigators

Precision refers to all imagery that has received the radiometric and spatial corrections, including transformation into UTM coordinates which are provided by the Precision Processing subsystem. Precision photographic products are discussed in Section 3.1.2.

Generation number assigned to photographic product is referenced to the bulk, archival output from the Electron Beam Recorder which is designated as the first generation. Each successive photographic product generated adds one generation. Thus, the bulk enlargement from a 70mm archival image is a second generation product.

Sensor Spectral Band

The relationship between the sensor, the spectral band numbers, wavelengths, and the NDPF Band Code numbers are shown in Table 3-1.

Table 3-1. Sensor Spectral Band Relationships

Sensor	Spectral Band No.	Wavelengths (Micrometers)	NDPF Band Code
	1	.475 - .575	1
RBV	2	.580 - .680	2
	3	.690 - .830	3
	1	.5 - .6	4
MSS	2	.6 - .7	5
	3	.7 - .8	6
	4	.8 - 1.1	7
	5 (ERTS B only)	10.4 -12.6	8

Size and Scale of Photographs

Photographic products are available in two basic film sizes - 70mm and 9.5 inch (240 mm nominal). The 70 mm size is only used for bulk products. The 9.5 inch size include bulk enlarged images and precision images. Bulk processing uses the spacecraft altitude at "image center time" to scale each 70mm image to 1:3,369,000. When the image on 70mm film is enlarged by a factor of 3.369 and printed on 9.5 inch film, the scale is 1:1,000,000. The NDPF precision processed image on 9.5 inch film is also generated to a scale of 1:1,000,000.

3.1.1 Bulk Photographic Products

3.1.1.1 Image Production

The production flow for each of the bulk photographic products available to investigators is shown in Figures 3-2 through 3-4.

3.1.1.2 Image Format and Annotation

A sample of the RBV and MSS bulk image format, including registration marks, tick marks, gray scale and alphanumeric annotation, is shown in Figure 3-5. The MSS image format is identical, except the data does not

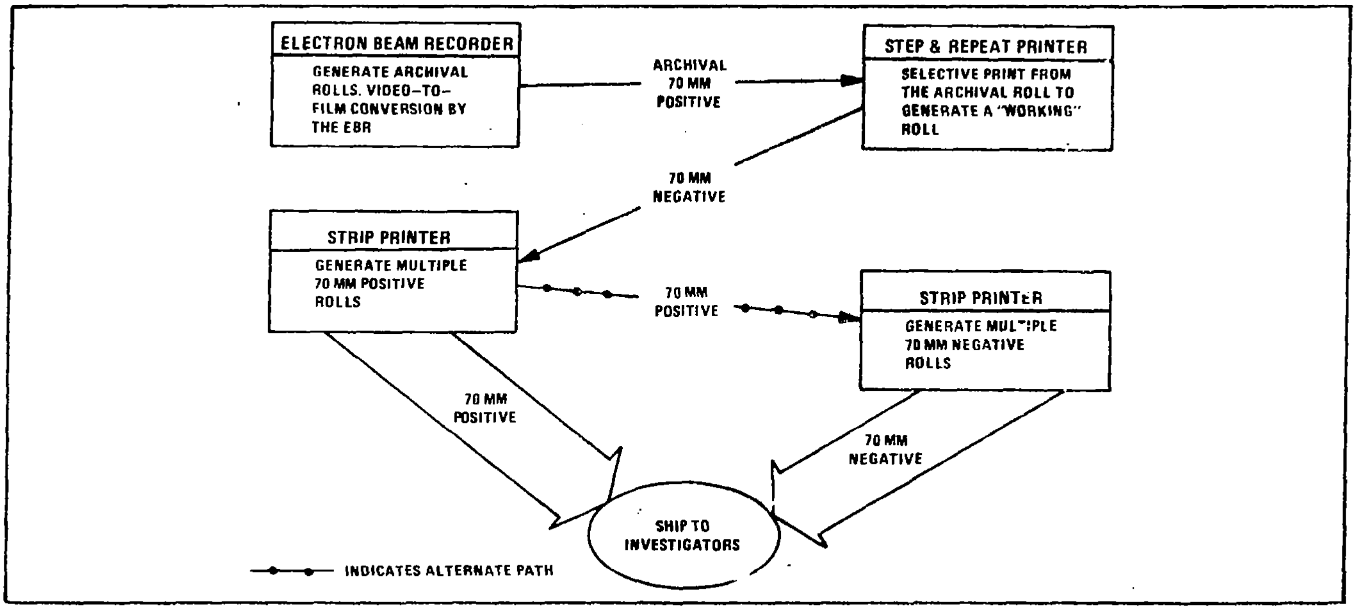

Figure 3-2. Production Flow of a 70mm Positive and Negative Product (Black and White Only)

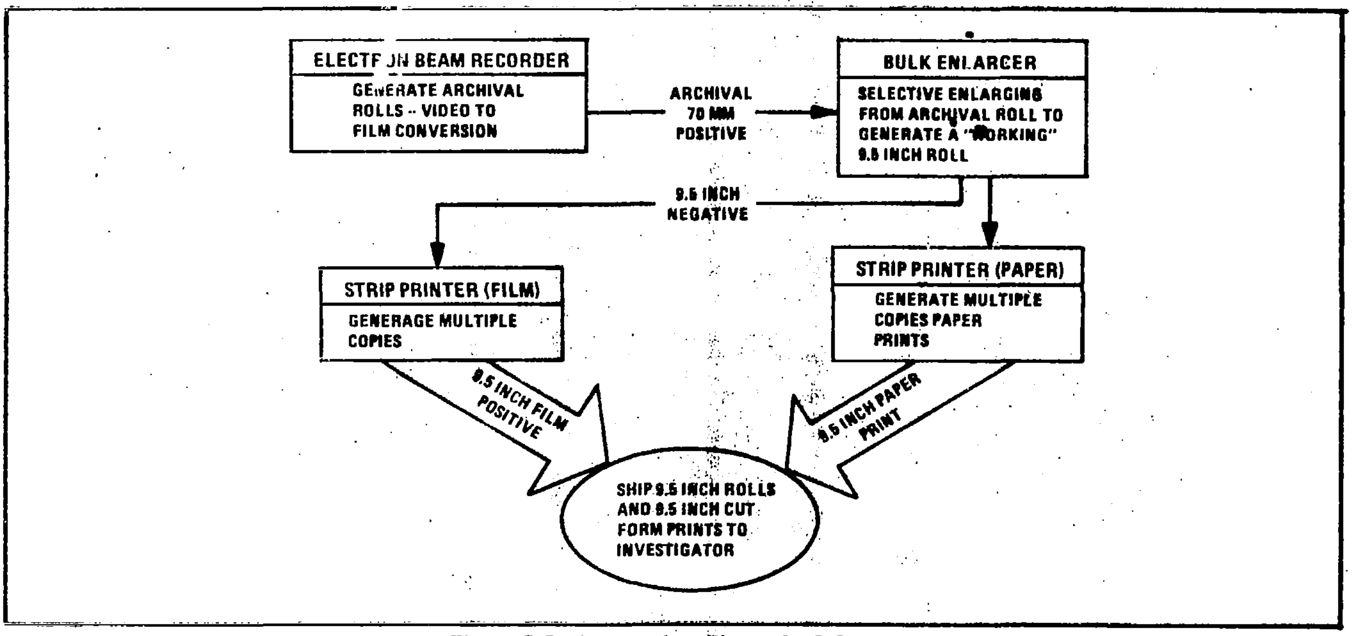

Figure 3-3. Production Flow of a 9.5-inch Bulk Black and White Films or Paper Product

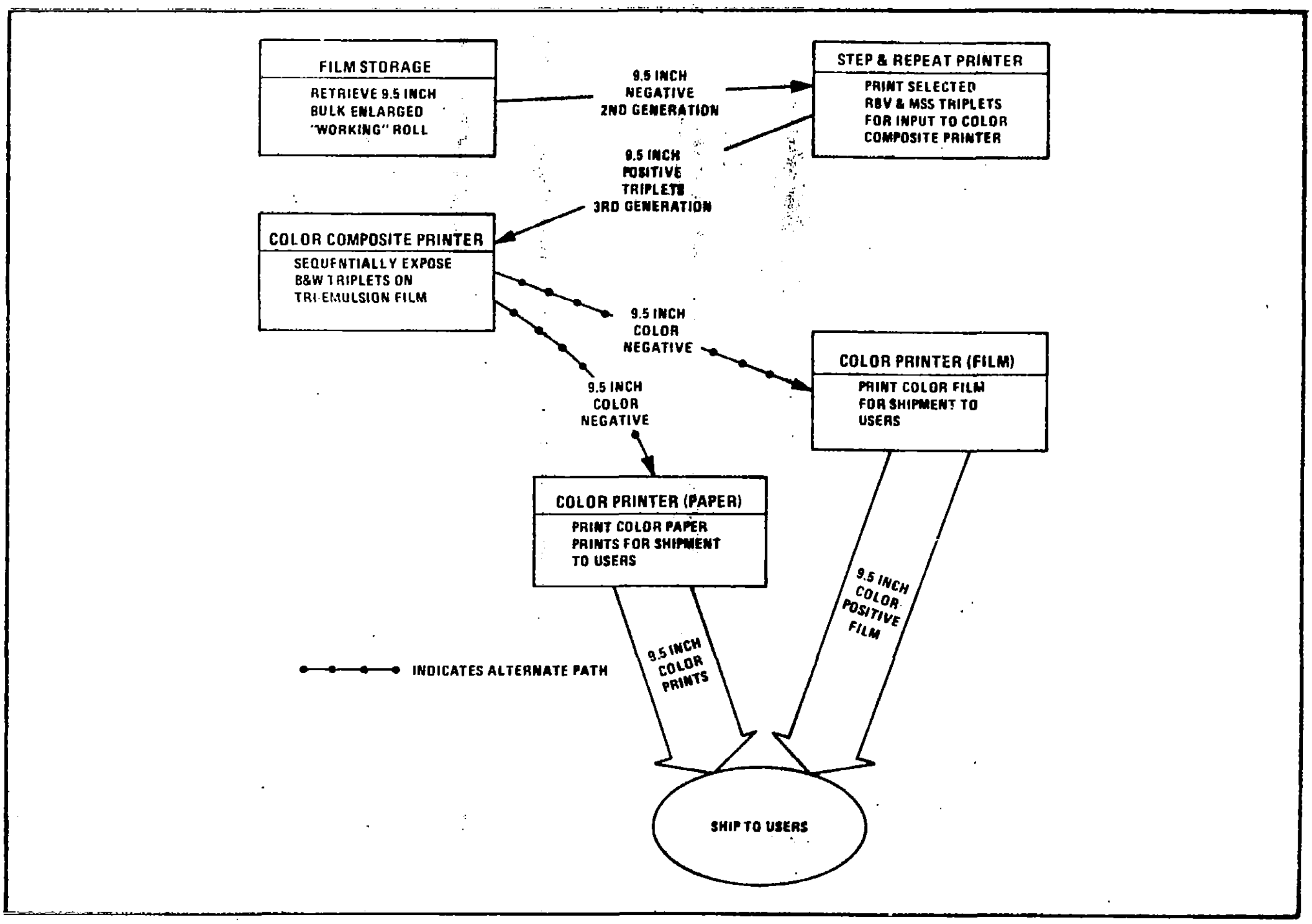

Figure 3-4. Production Flow for Bulk Color Film and Prints

Figure 3-5. Bulk RBV Image Format - 9.5 Inch Film

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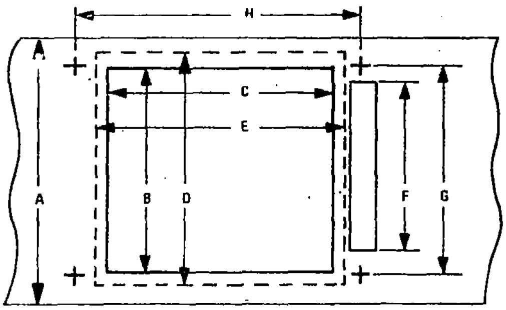
contain the fiducial refer :nces (reseau and anchor marks). The spacecraft heading is always toward the annotation block.



Dimension Code	Description	70 mm		Enlarged ① 9.5 inch	
		RBV	MSS	RBV	MSS
A	Film Width	70	70	240	240
B	Nominal Image Size (cross track)	55②	55②	185.3	185.3
C	Nominal Image Size (in track)	55②	53③	185.3	178.5
D	Writing Area (cross track)	60	60	202.2	202.2
E	Writing Area (in track)	60	55.5	202.2	190.4
F	Annotation Block Length	52	52	175.3	175.3
G	Registration Mark Separation (cross track)	58.6	58.6	197.5	197.5
H	Registration Mark Separation (in track)	64	59.5	215.7	200.5

NOTES:

① Bulk Processing uses spacecraft altitude at "image center time" to scale each 70 mm image to a ratio of 1:3,369,000. The Bulk enlarging factor is 3.369 which provides a scale of 1:1,000,000 the Bulk enlarged image.

② Equivalent to 100 nautical miles.

③ Equivalent to 98.3 nautical miles.

Figure 3-6. Bulk Product Dimensions

The dimensions for the 70 mm and 9.5 inch RBV and MSS film products are given in Figure 3-6.

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 dimensional details of these registration marks are shown in Figure 3-7.

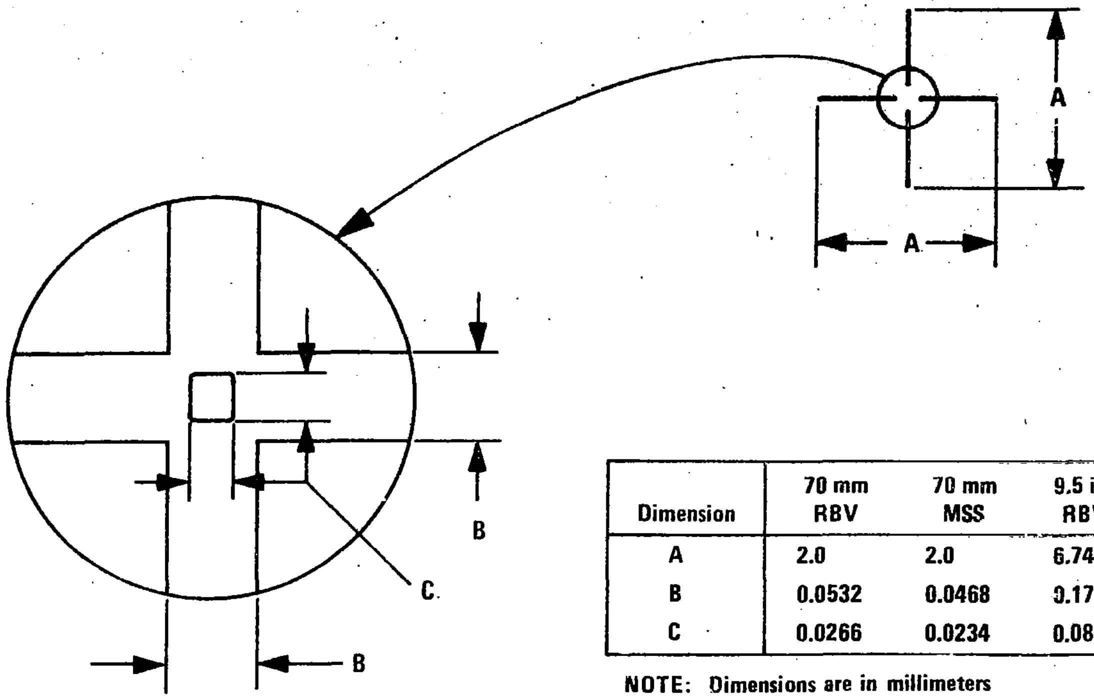
The intersection of diagonals drawn through the four registration marks is the Format Center of the image. The Format Center of a scene imaged at the same time by both the RBV and MSS will be identical. Annotation not otherwise specified refers to properties at the Format Center.

Tick Marks

Latitude and Longitude tick marks are placed outside the edge of the image writing area 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 or south, tick marks are spaced at one-degree intervals to prevent crowding.

Gray Scale

A 15-step gray scale tablet is exposed on every frame of imagery as it is produced on the Electron Beam Recorder (EBR). This scale is subject to the same copying and processing as the image to which it is attached. The gray scale gives the relationship between a level of gray 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. This incident energy is shown in Table 3-2 for the MSS and in Table 3-3 for the RBV.



Dimension	70 mm RBV	70 mm MSS	9.5 in. RBV	9.5 in. MSS
A	2.0	2.0	6.74	6.74
B	0.0532	0.0468	0.1793	0.1578
C	0.0266	0.0234	0.0896	0.0788

NOTE: Dimensions are in millimeters

Figure 3-7. Bulk Products Registration Mark Details

Table 3-2. Irradiance at MSS Versus Image Gray Scale

Gray Scale Step	Band 1 Normal	Band 1 Hi Gain	Band 2 Normal	Band 2 Hi Gain	Band 3 Normal	Band 4 Normal	Band 5 Normal	Band 5 Hi Gain
1 White								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15 Black								

DATA TO BE SUPPLIED IN REVISION

Alphanumeric Annotation

Figure 3-9 details the alphanumeric annotation shown at the bottom of Figure 3-5. Paragraphs a through i explain the data contained in this annotation.

```
   a          b                c           d        e          f        g       h           i          <=(1)
                                                                                        1        1
         1         2         3         4         5         6         7         8         9         0         1
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456 <=(2)

07JUN72 C N33-05/W115-18 N N33-04/W115-20 RBV 1  DXA SUN EL30 AZ015 194-1234-  N-P-1H NASA  E-1042 16032-1  <= EXAMPLE
                                                                                      ERTS
                                          RBV  2
                                          RBV  3
                                          MSS  4
                                          MSS  5
                                          MSS  6
                                          MSS  7
                                          MSS  8

NOTES: (1) THE LETTERS "a" THROUGH "i" REFER TO PARAGRAPHS IN THIS DOCUMENT THAT EXPLAIN THE ANNOTATION BLOCK.
       (2) CHARACTER "POSITION" IN THE ANNOTATION BLOCK.
```

a. Character Positions 01-08. 07JUN72
Day, month and year of picture exposure

b. Character Positions 09-25. CN33-05/W115-18
Format Center Latitude and longitude at the center of the RBV and MSS image format is indicated in degrees and minutes. The MSS Format Center is identical to the RBV Format Center. Format Center is defined as the geometric extension of the spacecraft yaw axis to the earth's surface.

c. Character Positions 26-42. CN33-04/W115-20
Latitude and longitude of the nadir (the intersection with the earth's surface of a perpendicular line from the spacecraft to the earth ellipsoid) is indicated in degrees and minutes. The NASA Ellipsoid is the Earth model.

d. Character Positions 43-54. RBV 1 DXA
The characters in this group are sensor and spectral band specific:
For RBV Images:

43-49 Sensor and NDPF, spectral band identification code. Note that the spectral identification code numbers are purposely staggered (see Figure 3-9) to permit identification of the spectral images used to make a color composite transparency.

50 "D" indicates direct transmission (real time); "R" indicates stored data playeo back from the satellite wideband video tape recorder.

51-52 "XA" means the shutter this image was set for 16 milliseconds.

RBV duration of exposure will be encoded by alphabetic letters as follows:

Alphabetic Code	Duration of Exposure Time (msec)
A	16
B	12
C	8.8
D	8.0
E	7.2
F	6.4
G	5.6
H	4.8
I	4.0

For MSS images

43-51 The sensor and NDPF spectral band identification code.

53 Type of transmission, direct or recorded.

e. Character Position 55-68. SUN EL30 AZ015
Sun Angles - the sun elevation angle and sun azimuth angle measured clockwise from true North at the time of RBV exposure or midpoint of MSS frame is specified to the nearest degree.

f. Character Positions 69-79. 194-1234-A
Spacecraft heading, orbit revolution number, and type of ephemeris data.

The "194" is spacecraft heading to the nearest degree, measured clockwise from true North. It is the orbital path plus spacecraft yaw. Heading relative to an image is always toward the image annotation block.

The "1234" is a four digit orbit revolution. Rev "0001" starts with the first ascending node (south to north equator crossing) after launch.

NOTE: Compressed data will be decompressed during processing.

The "A" indicates the ground recording station. G=Goldstone, A=Alaska, N=NTTF.

g. Character positions 80-89 N-P-1H

The "N" means the image was processed using normal processing procedures. Abnormal processing will be indicated with "A".

The "P" means "predicted" orbit ephemeris data was used to compute image center; a "D" indicates "definitive" or best fit ephemeris was used. Normally the latter is used since it is more accurate.

The "1" indicates a linear mode, a "2" indicates a compressed mode of MSS signal processing prior to transmission from satellite to ground station.

(This applies to Bands 4, 5, and 6 only. See Appendix A.2)

"H" is high gain, "L" is low gain for Bands 4 and 5 only, which have a commandable gain option.

h. Character positions 90-98 NASA ERTS

Identifies the Agency and the Project.

i. Character positions 99-114 E-1042-16032-10

Frame Identification Number – each image or frame will have a unique identifier which will contain encoded information consisting primarily of time of exposure relative to launch. Its format is E-ADDD-HHMMS-B and is interpreted as follows:

- E – Encoded Project Identifier
- A – ERTS Mission: 1=ERTS A, 2=ERTS B
- DDD – Day number relative to launch at time of observation
- HH – Hour at time of observation
- MM – Minute at time of observation
- S – Tens of seconds at time of observation
- B – NDPF Identification Code (RBV: 1, 2, 3; MSS: 4, 5, 6, 7, 8)
- R – Blank for earth images, either 0, 3, or 8 for RBV radiometric calibration images, indicating 0%, 30%, or 80% exposure level

Figure 3-9. Details of Bulk Image Annotation Block

3.1.1.3 Performance Characteristics

A complete discussion of product characteristics is given in Appendix F. These characteristics include the effects of the corrections (geometric and radiometric) normally made during bulk processing.

3.1.1.4 Delivered Form

Most photographic products will be delivered in cut form. In special cases, when the order is for a large number of consecutive images, film products will be delivered in roll form. Prints will always be delivered in cut form.

Roll form products will appear as shown in Figure 3-10. Note that the MSS images are grouped by spectral band; that is, sequentially adjacent images on the roll are for sequential geographical areas. These images are followed by the same sequence of adjacent images in the next spectral band, etc.

3.1.2 Precision Photographic Products

3.1.2.1 Image Production

The functional production flow for the various Precision photographic products is shown in Figure 3-11. This flow includes the initial Bulk Processing prior to Precision Processing.

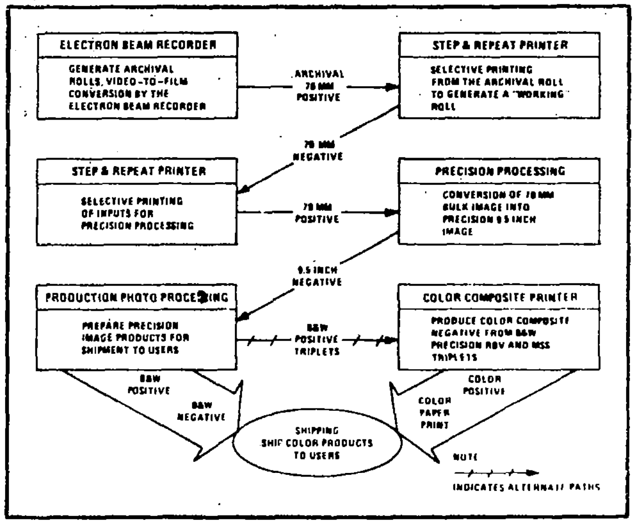
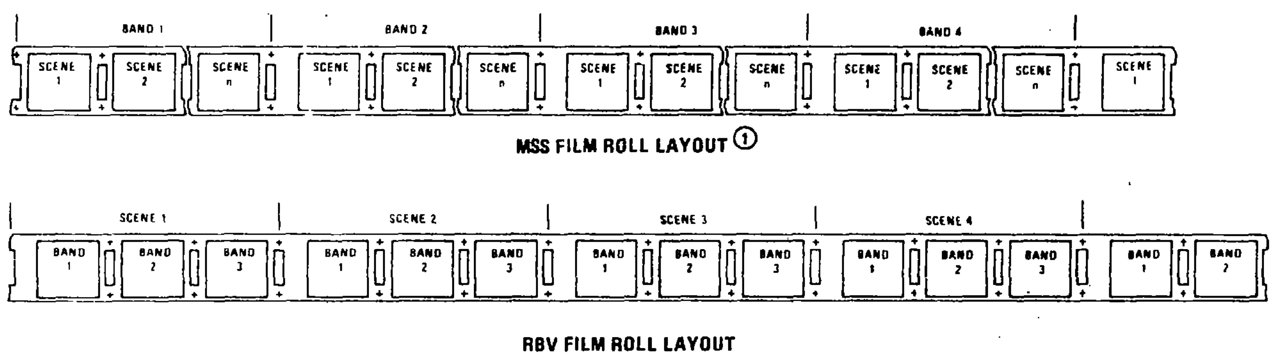


Figure 3-11. Production Flow for Precision, Black and White and Color Products



NOTE: ① THE MSS VIDEO TAPE-TO-FILM CONVERSION PERFORMED BY THE BULK PROCESSING ELECTRON BEAM RECORDER (EBR) "GROUPS" THE IMAGES ON THE ARCHIVAL FILM ROLL BY SPECTRAL BANDS AS ILLUSTRATED. THE NUMBER OF IMAGES, n, IN A SPECTRAL "GROUP" IS DETERMINED BY THE NUMBER OF SCENES ON THE MSS VIDEO TAPE. THIS NUMBER CAN VARY FROM SOME NOMINAL MINIMUM OF, SAY 12, TO A MAXIMUM OF 48. (A SCENE MEANS ONE 25-SECOND, 100 BY 100 NAUTICAL MILE OBSERVATION). THE INTEGRITY OF THIS SPECTRAL GROUPING WILL BE MAINTAINED IN THE ROLL-FORM PRODUCTS THAT ARE SENT TO THE USER. A GIVEN ROLL WILL CONTAIN ALL SPECTRAL IMAGES FOR EACH SCENE.

Figure 3-10. Bulk Roll Form Scene/Band Layout

3.1.2.2 Image Format and Annotation

A sample of the Precision image is shown in Figure 3-12. The alphanumeric and gray scale blocks at the left of the image area are copied directly from the Bulk image. The tick marks and alphanumeric annotation blocks in the lower left and lower right corners are unique to precision data and are explained in Table 3-4.

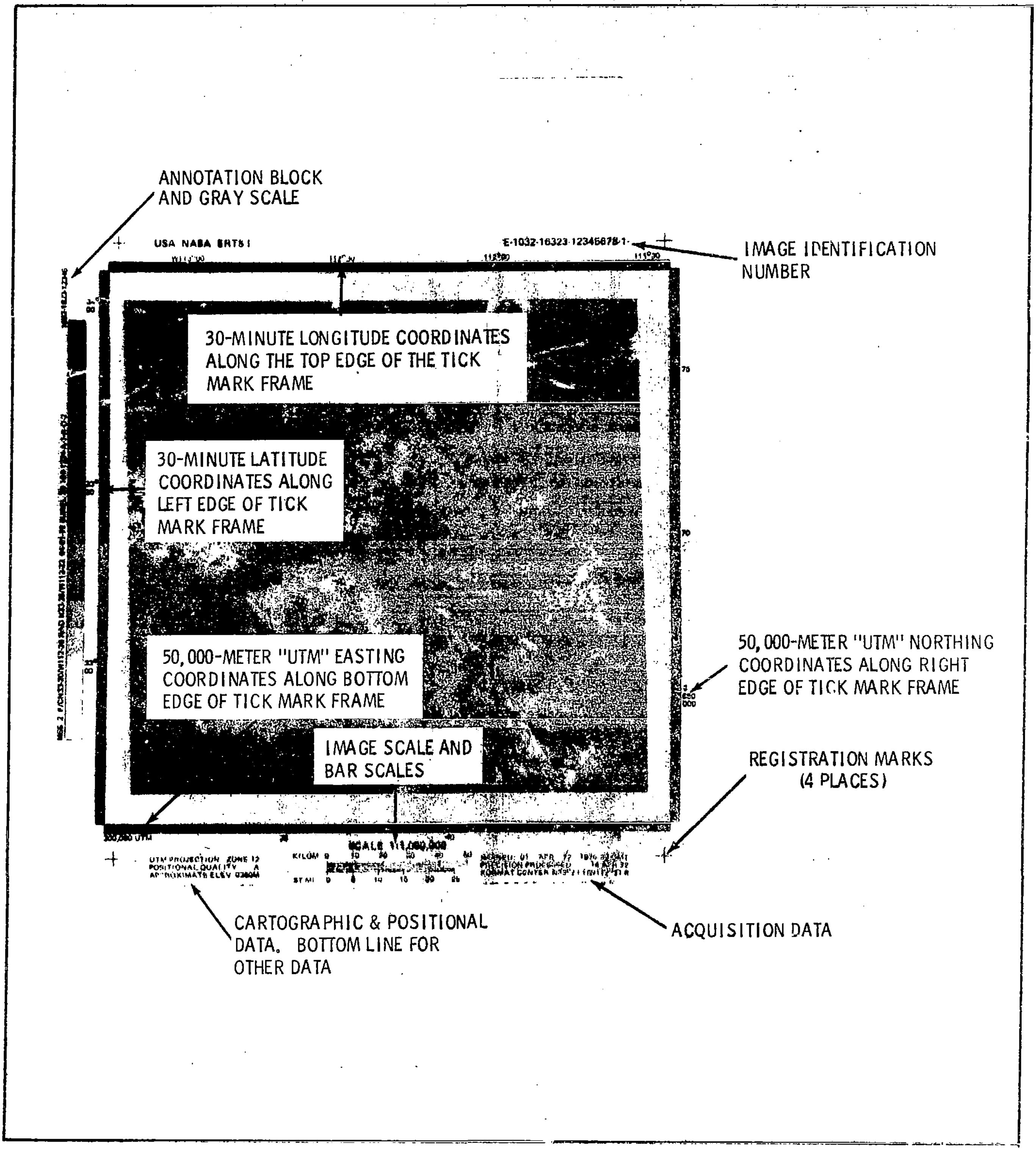


Figure 3-12. Precision Processed Image Format

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Table 3-4. Format and Annotation

A. **TICK MARK ANNOTATION**

The tick marks are individually printed in an unexposed band 3, millimeters wide, framing the outer four edges of the image writing area and are slanted in the direction of the coordinate they designate.

The origin and length of the tick marks in the tick mark frame depend on the designated coordinate:

1. Latitude-longitude tick marks extend inward from the outside edges of the bands; even-degree ticks extend 2.3 mm inward, 30-minute ticks extend 1.0 mm inward. Degrees-minutes labeling is along the left and top margins.

2. Universal Transverse Mercator (UTM) tick marks extend outward from the inside edges of the bands; integral 100,000 meter ticks extend 2.3 mm outward; 50,000 meter ticks extend 1.0 mm outward. Labeling is along the right (Northing) and bottom (Easting) margins.

Each tick mark will be approximately 0.1 mm thick and oriented (inclined) to within ± one degree of the corresponding (N-S or E-W) direction.

B. **INTERNAL TICK MARK CROSSES**

When requested, small (2 mm) crosses designating the intersection of the map tick marks bordering the image writing area are printed upon the image. These tick mark lines are typically 0.5 mm wide. The crosses locate either geographic or UTM coordinates as follows:

In geographic coordinates, the crosses define the intersection of each 30 arc minute latitude with each

(a) 30 minute longitude for format-center latitudes between 0 and 60 degrees;
(b) one-degree longitude, for format-center latitudes between 60 to 75 degrees;
(c) even numbered degree longitude, (e.g., 0, 2, 4, . . . 356, 358 degrees), for format-center latitudes above 75 degrees.

In UTM coordinates, the internal crosses are located at

(d) the intersection of each 50,000 meter Northing and Easting coordinate.

The crosses are printed with a video intensity sufficient to produce a contrast of about 0.5 density units above the local image density.

C. **CARTOGRAPHIC AND POSITIONAL DATA (lower left data block)**

The first line indicates UTM zone number in which the image is projected. (Some images will include two UTM zones, but the projection will be in only one zone.)

The second line indicates the positional quality as determined by computation of the Ground Control Point (GCP) residual errors. Letters A through D are used as follows:

Letter	Residual Error
A	This information will be
B	supplied in a supplement
C	to be published later.
D	

The third line is the approximate elevation in meters. It is a four digit number representing the elevation of the Ground Control Point (GCP) closest to the image center.

The fourth row of characters is reserved for special data. A "P" indicates Precison Processing was done with predicted ephemeris; a blank (the normal case) indicates best fit ephemeris was used. Other special data is TBD.

D. **ACQUISITION DATA (lower right data block)**

The first line is the date and time of image acquisition in Greenwich Meridian Time (GMT).

The second line denotes the date at which the Precision image was printed.

The third line denotes the format center to the nearest tenth-minute in geographic coordinates.

The fourth row is reserved for up to 32 characters of standard or special annotation data. These characters are TBD.

3.1.2.3 Performance Characteristics

A complete discussion of the Precision product parameters is contained in Appendix F.

3.1.2.4 Delivered Form

All Precision photographic products are delivered as individually cut images.

3.2 COMPUTER COMPATIBLE TAPES

Digital data is available upon request in the form of Computer Compatible Tapes (CCT). These tapes are standard half-inch wide magnetic tapes and may be requested in either a

9-track or 7-track format. Coding on the 9-track is EBDIC for alphanumeric data and binary for video data. All data on the 7-track tape is binary.

Four CCT's are required for the digital data corresponding to one scene observation by either the RBV (three spectral images) or the MSS (four or five spectral images).

One of three different CCT formats are used depending upon whether the CCT's are Bulk MSS data, Bulk RBV data or Precision data (either RBV or MSS). Data content and format of these tapes is described in Sections 3.2.1 through 3.2.3. Detailed information on CCT's necessary to write software to process these tapes is contained in a separate document "Digital Image Tape Format" which is available through the ERTS User Services section of NDPF.

3.2.1 Bulk MSS Computer Compatible Tapes

The full frame 100 by 96.3 nautical mile image is segmented into four 25 by 96.3 nautical mile strips for conversion into CCT format.

The MSS data is spectrally interleaved as illustrated in Figure 3-13. The interleaving is done in groups of 8 bytes, 2 bytes from each spectral band. The staggering of the spectral samples in each interleaved 8-byte group corrects for a 2-byte spatial misregistration that is introduced by the arrangement and sampling sequence of the detectors on the spacecraft. As a result of the correction, the two bytes for each band in the group represent the same ground data. Dummy bytes, indicated by "0", are used to fill in at the beginning or end of a line.

Radiometric calibration data for each spectral band is also inserted as a 56-byte calibration group following each block of 435 8-byte groups of interleaved video data.

Figures 3-13 through 3-16 illustrate the Bulk MSS CCT format and data content; symbols used in these illustrations are defined in Table 3-5.

Table 3-5. Explanation of Symbols Used (MSS)

Item/Symbol	Description
S_{bkj}	Sample within a scan line corresponding to a specified Bulk MSS video picture element location where: b=spectral band number ($1 \leq b \leq 5$) k=sequential scan line index j=sample number within line length adjusted scan line S_{bkj} comprising 7 bits of video right justified in a 8-bit byte
R_{ik}	Record corresponding to a specific set of S_{bkj} comprising a segmented interleaved Bulk MSS scan line where: i=image segment and Computer Compatible tape number k=sequential scan line index
B_{ik}	Fifth spectral band record where: i=image segment and CC tape number k=sequential band 5 scan line index
$L_{i,p}$	Line set number assigned to a set of three 4-band records (plus one 5th band record for ERTS-B) where: i=image segment and CC tape number p=sequential line set number. For ERTS-A each L_{ip} contains three 4-band records. For ERTS B each L_{ip} contains three 4-band records plus one fifth band record.
$CAL_{b,k}$	Calibration data and line length information for scan line k of band b. Each $CAL_{b,k}$ is a 14-byte string.
$G_{k,m}$	Group of 8 spectrally interleaved spatially registered samples, 2 bytes from each of 4 bands where: m=sequential group within an interleaved scan line k-sequential full frame scan line index $G_{k,m}$ contains Bulk MSS video samples S_{bkj} in the order: $S_{1\,k\,2m-1},\ S_{1\,k\,2m},\ S_{2\,k\,2m-1},\ S_{2\,k\,2m},\ S_{3\,k\,2m-1},\ S_{3\,k\,2m},\ S_{4\,k\,2m-1},\ S_{4\,k\,2m}$ An interleaved entire scan line may contain a maximum of 1740 $G_{k,m}$ groups.
IDA	Two data records consisting of scene and annotation data for each image strip recorded on CCT.
EOF	End of file

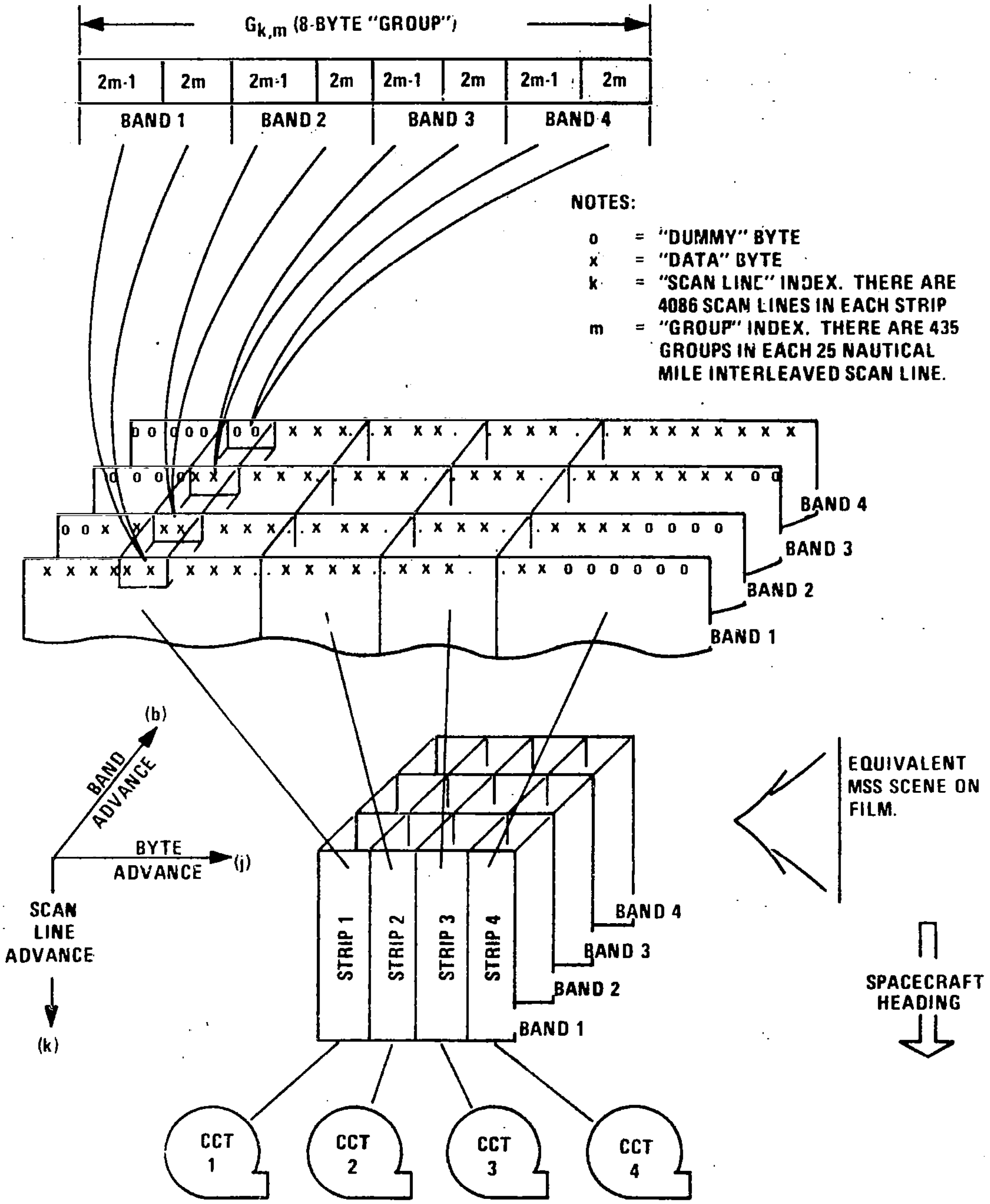


Figure 3-13. Bulk MSS 4-Band Scene to Interleaved CCT Conversion

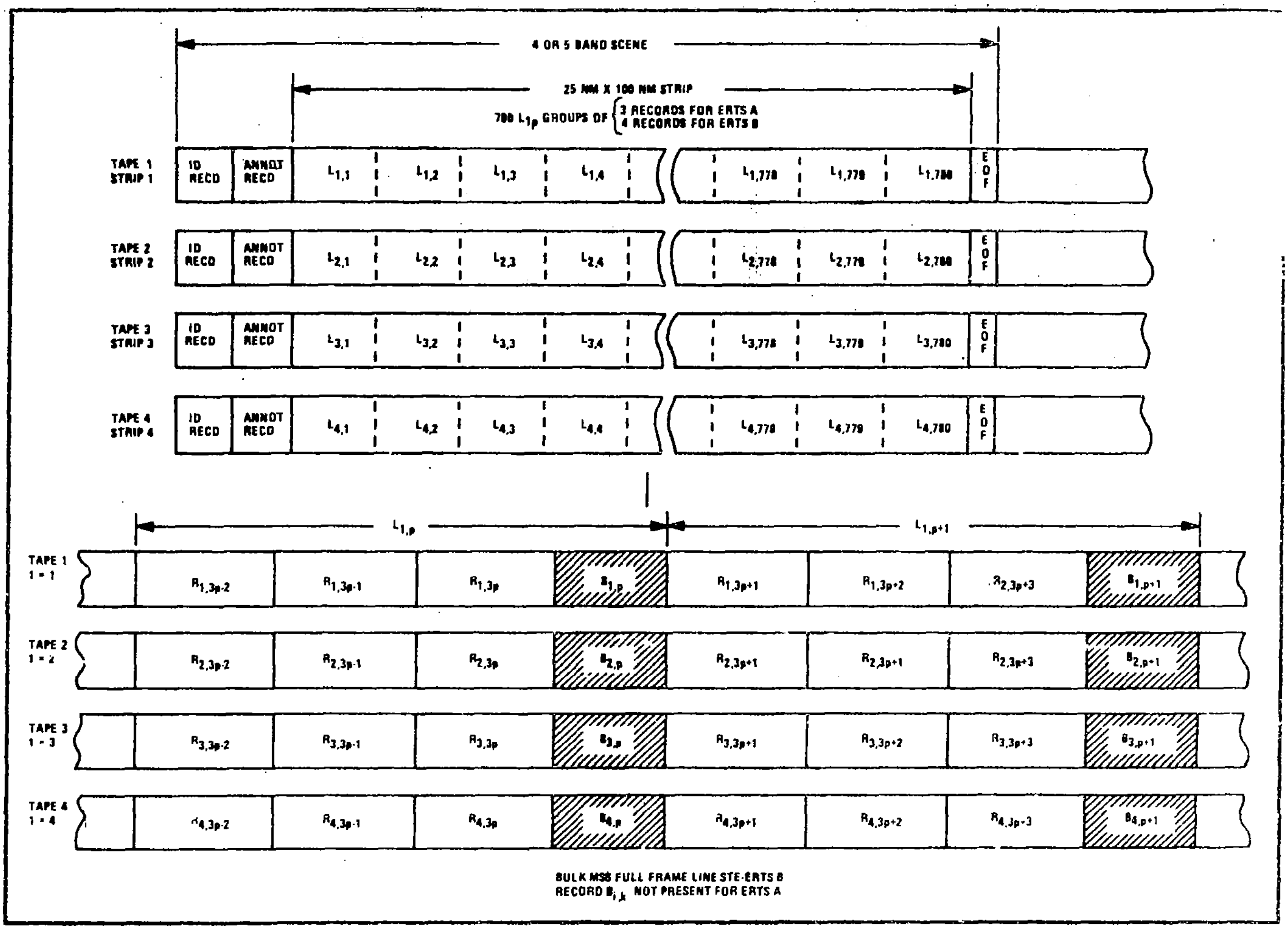


Figure 3-14. Bulk MSS Full Scene. Four CCT Format

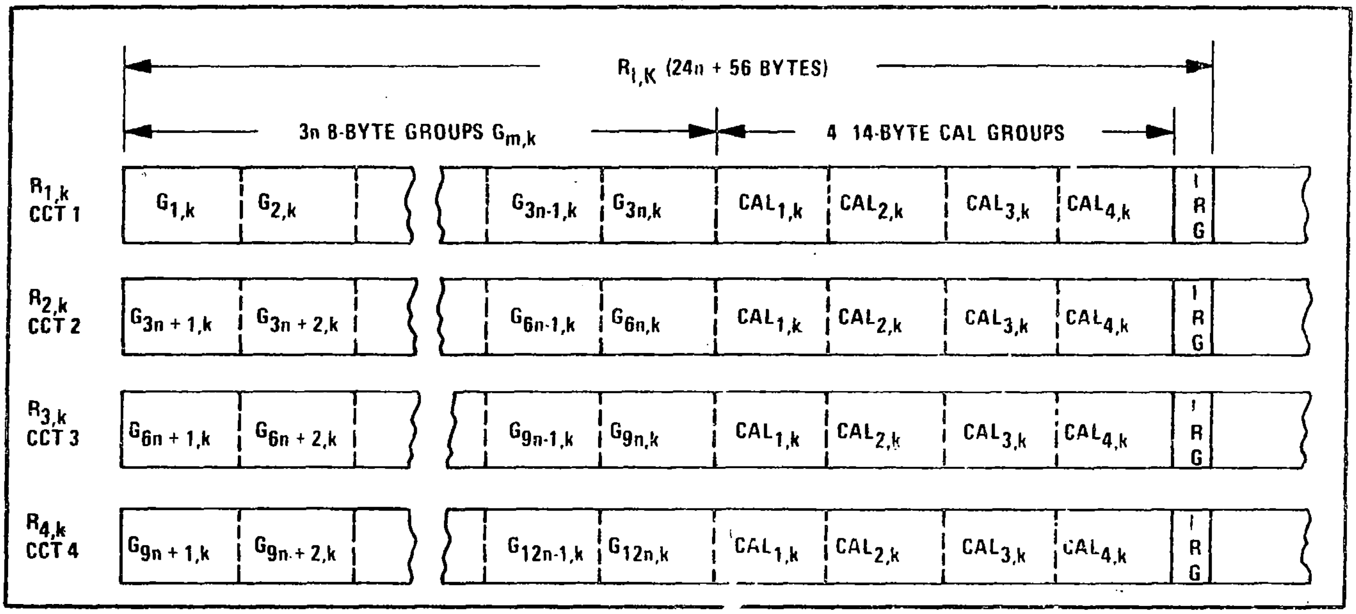


Figure 3-15. Bulk MSS Full Scene Interleaved Record Format

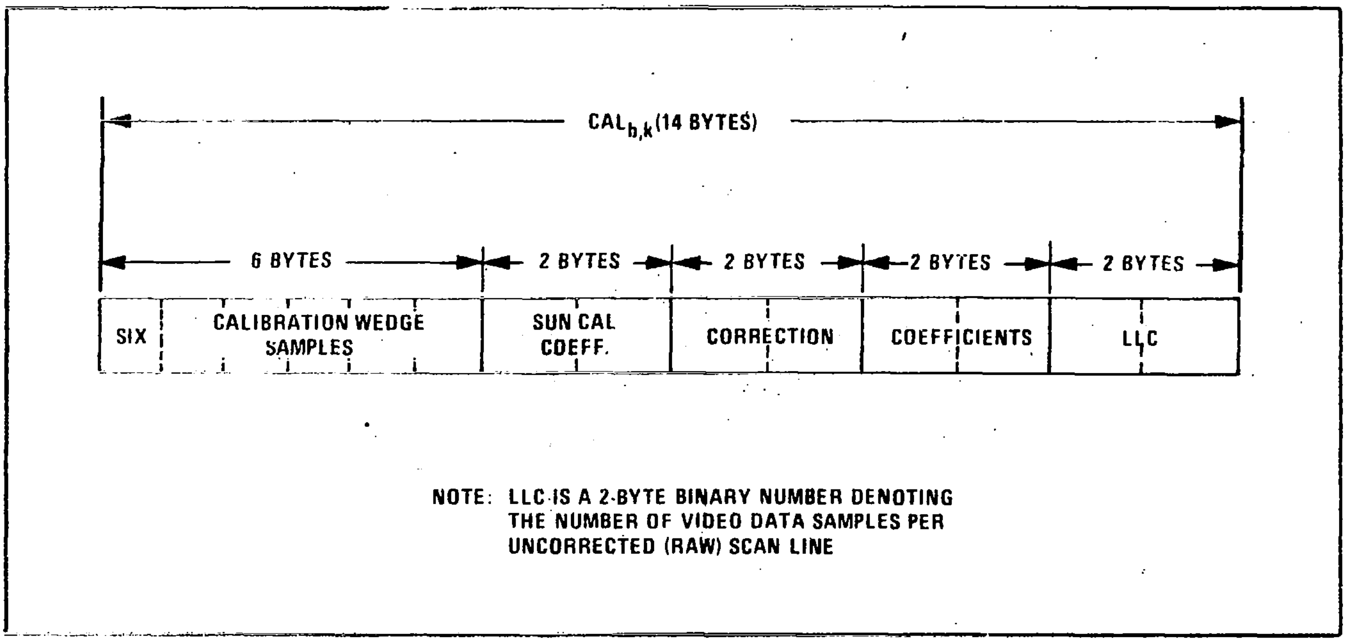


Figure 3-16. Bulk MSS Calibration Group Detail

3.2.2 Bulk RBV Computer Compatible Tapes

A significant difference between the formats of the Bulk RBV and MSS Computer Compatible Tapes (CCT) is that the MSS format has the four spectral bands interleaved, while the RBV format has each band separate and sequential on the CCT — Band 3, Band 2 and Band 1. See Figure 3-17. Another difference is that there are no "calibration bytes" associated with each scan line of RBV data as is the case with MSS. No geometric or radiometric corrections are performed on Bulk RBV CCT data.

Figure 3-18 illustrates the Bulk RBV CCT format; symbols are defined in Table 3-6.

3.2.3 Precision MSS and RBV Computer Compatible Tapes

The format for RBV and MSS data on a Precision Computer Compatible Tape (CCT) is the same. A basic difference between the Bulk and Precision format is that the Precision CCT in effect segments the fullframe image into 8 strips. Each strip is further segmented into 8 blocks that contain 512 scan lines per block. Figure 3-19 illustrates the correlation between a 100 by 100 nautical mile image and the four CCT's. Each of the four CCT's contains approximately 1500 feet of data for a full RBV scene or 2000 feet of data for a full MSS scene.

Table 3-6. Explanation of Symbols (RBV)

Item/Symbol	Description	
S_{ijk}	Sample number within a data record corresponding to a specified RBV video picture element location along a segmented scan line where i=image strip index and Computer Compatible Tape number. j=segmented sample index k=segmented scan line index Each S_{ijk} contains 6 bits of video data, right justified in an 8-bit byte.	Video Data Storage
L_{ik}	A specific set of S_{ijk} compromising a segmented RBV scan line where: i=image strip index and CC tape number and k=segmented scan line index.	Format Notation
IDA	Two data records consisting of identification and annotation data for each segmented image strip recorded on CCT.	ID Data Storage

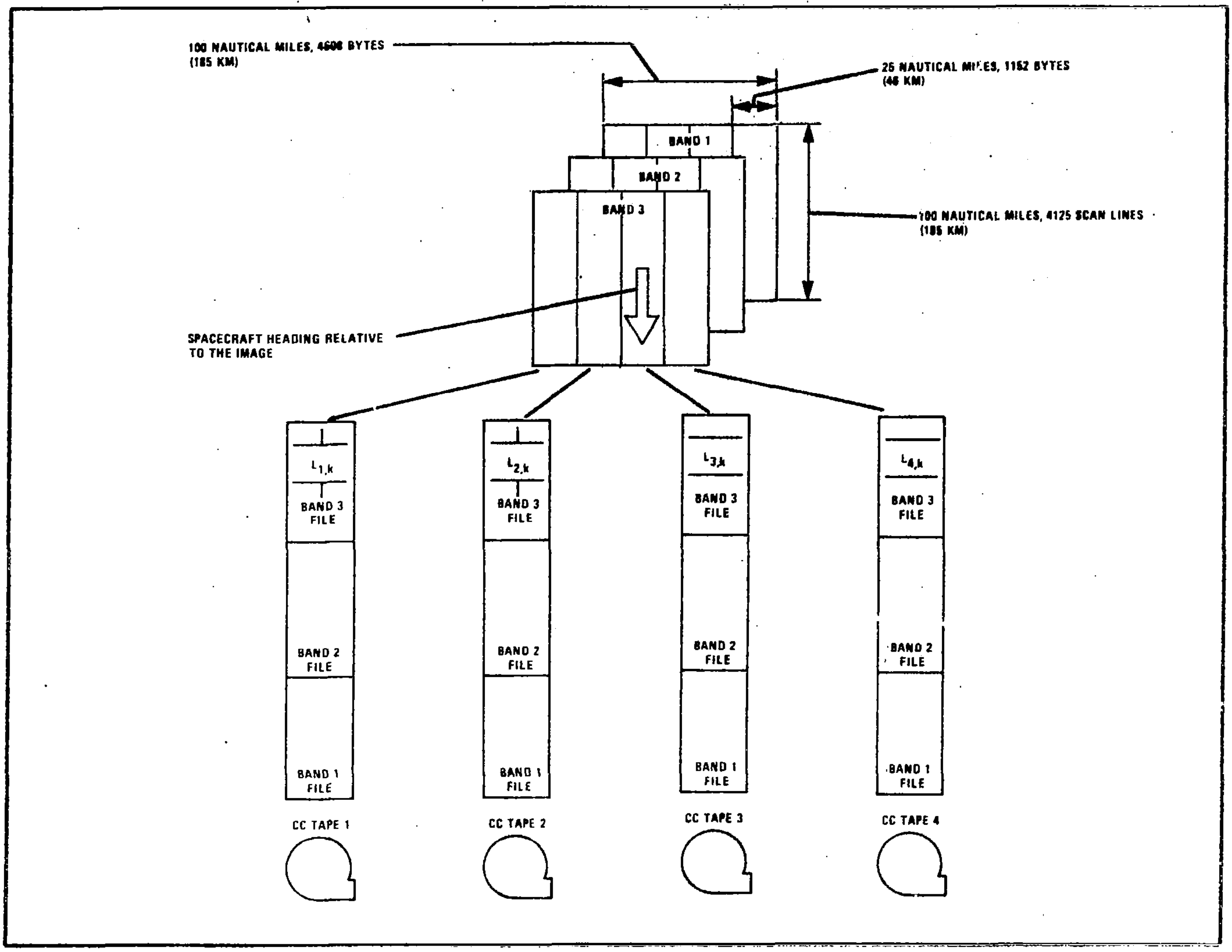


Figure 3-17. Bulk RBV Conversion from Scene to 4-Computer Compatible Tape Format

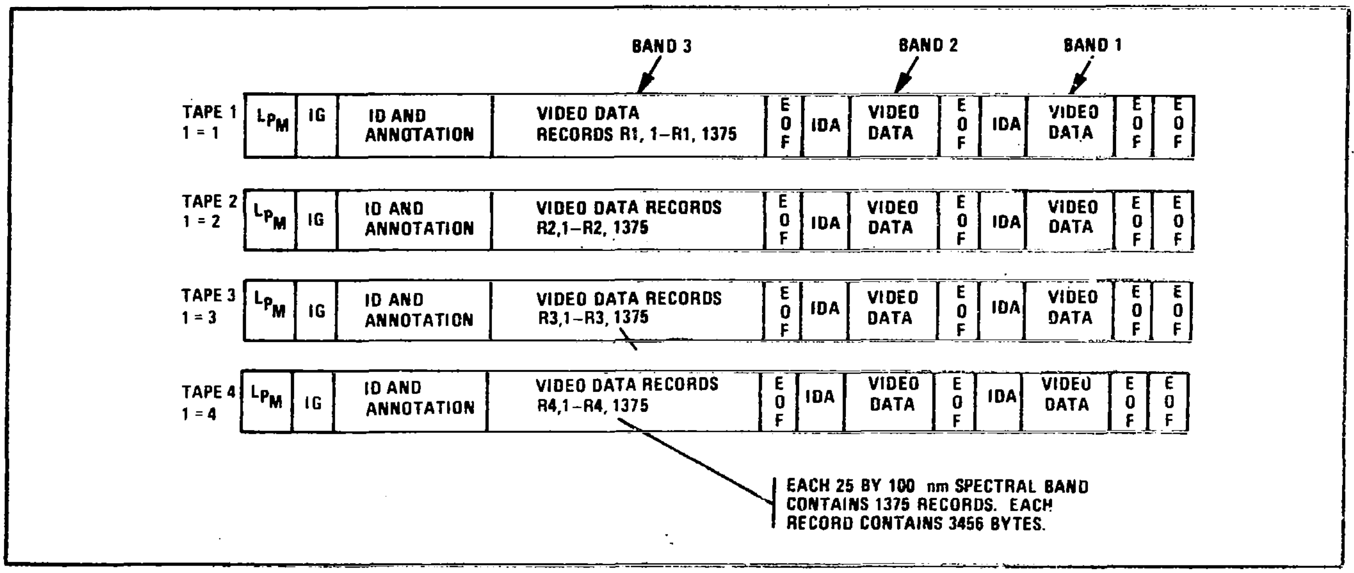


Figure 3-18. RBV Bulk Scene, 4-Computer Compatible Tape Format

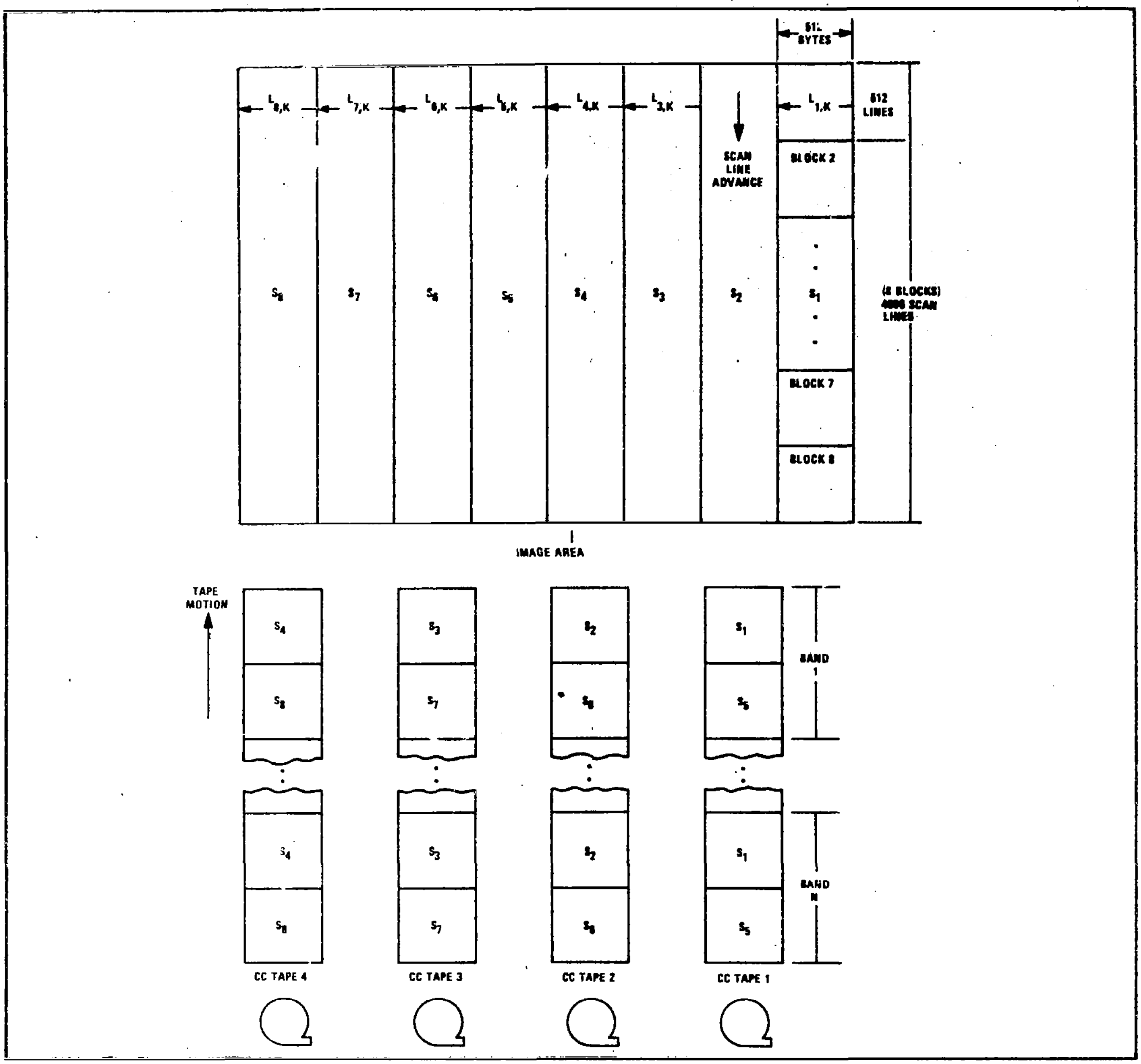


Figure 3-19. Conversion of Precision Image to Computer Compatible Tape

The radiometric and geometric corrections applied to the Precision film images also applied to the digital output from Precision Processing.

Figure 3-20 illustrates the Precision CCT format; symbols are defined in Table 3-7.

3.3 Data Collection System Products

The NDPF produces three types of Data Collection System (DCS) data products, punch cards, computer listings and magnetic tapes. These products along with their contents and formats are described in Figures 3-21 through 3-23. DCS data transmission format is listed in Table 3-8.

In addition, a DCS catalog summarizing the platform transmission activity, is prepared and distributed to subscribers on a routine basis. The catalog is described in Section 4.2.3.

Table 3-7. Item/Symbol Definition

Item/Symbol	Description
S_{ikj}	Sample element within a data record corresponding to a specified precision video picture element location along a scan line k where: i=image strip index j=sequential sample index within scan line k=sequential scan line within image strip Each S_{ikj} contains 7 bits of video data, right justified
$L_{i,k}$	Scan line within an image strip where: i=image strip index k=sequential scan line index There are $512S_{ikj}$ within each $L_{i,k}$
R_{in}	Record corresponding to a collection of eight sequential scan lines $L_{i,k}$ of an image strip where: i=image strip index n=image strip record index Each R_{in} contains 4096 bytes of precision video corresponding to scan lines L_{jk} where $8n-7 \leq k \leq 8n$
IDA	Two data records consisting of scene, spectral band and annotation data for each image strip recorded on CCT
EOF	End of file

Table 3-8. DCS Data Transmission Format

Word	Bit	Item	Mode	Format
1	0-15	Platform ID	Binary	XXXX
	16-23	Satellite ID	EBCDIC	½
	24-31	Station ID	EBCDIC	A/G/N
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	13PP
	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	

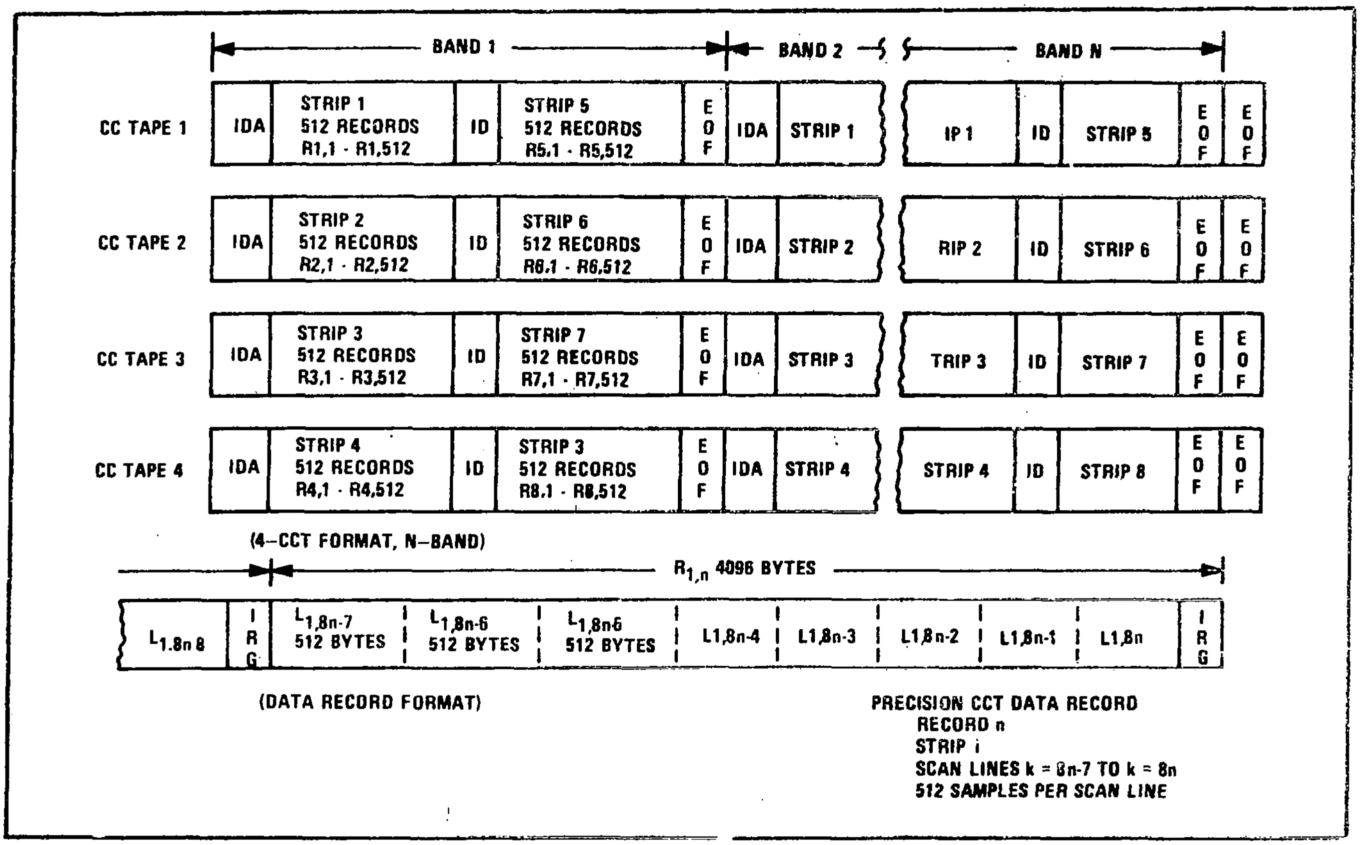
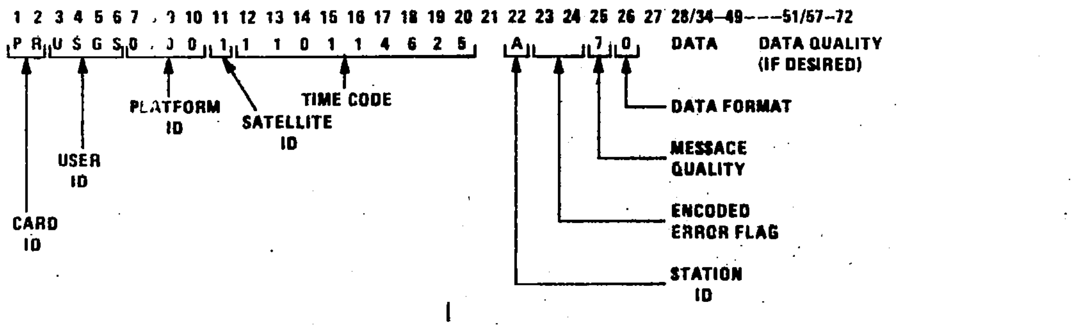


Figure 3-20. Precision, N-Band 4-Computer Compatible Tape and Data Record Format



CARD COLUMN	CONTENT
1-2	CARD ID-SC TO INDICATE PRODUCT REQUEST,
3-6	USER ID-CONSISTING OF 4 ALPHABETIC CHARACTERS
7-10	PLATFORM ID-CONSITING OF DECIMAL DIGITS RANGING FROM 1-1000
11	SATELLITE ID, 1 FOR ERTS A, 2 FOR ERTS B
16	TIME CODE-REPRESENTING THE TIME WHEN THE PLATFORM TRANSMITTED THE DATE. THE FORMAT IS DDDHHMMSS WHERE: DDD = DAY SINCE LAUNCH HH = HOUR OF DAY MM = MINUTES SS = SECONDS
22	RECEIVING STATION ID WHERE: A = FAIRBANKS, ALASKA G = GOLDSTONE, CALIFORNIA N = GREENBELT, MARYLAND (NTTF)
23-24	ENCODED ERROR FLAG WHERE: 32 = INVALID RECEIVING STATION ID 16 = INVALID PLATFORM ID 8 = POOR PLATFORM QUALITY 4 = INVALID TIME CODE 2 = DUPLICATE MESSAGE 1 = REDUNDANT MESSAGE A SUMMED VALUE TO INDICATE ANY COMBINATION OF THE ABOVE 63 = ALL OF THE ABOVE CONDITIONS EXIST
25	MESSAGE QUALITY WHERE: 0 = LONG OR SHORT MESSAGE DEPENDING UPON SYNCHRONIZATION 1-7 = TO INDICATE LOWEST TO HIGHEST QUALITY
26	DATA FORMAT FLAG WHERE: O = OCTAL DIGITS (22 COLUMNS) H = HEXIDECIMAL DIGITS (16 COLUMNS)
28	FOR OCTAL DIGITS, DATA STARTS HERE
34	FOR HEXIDECIMAL DIGITS, DATA STARTS HERE
51	QUALITY DIGITS (IF DESIRED) FOR OCTAL START HERE
57	QUALITY DIGITS (IF DESIRED) FOR HEXIDECIMAL START HERE

Figure 3-21. DCS Data Card Format

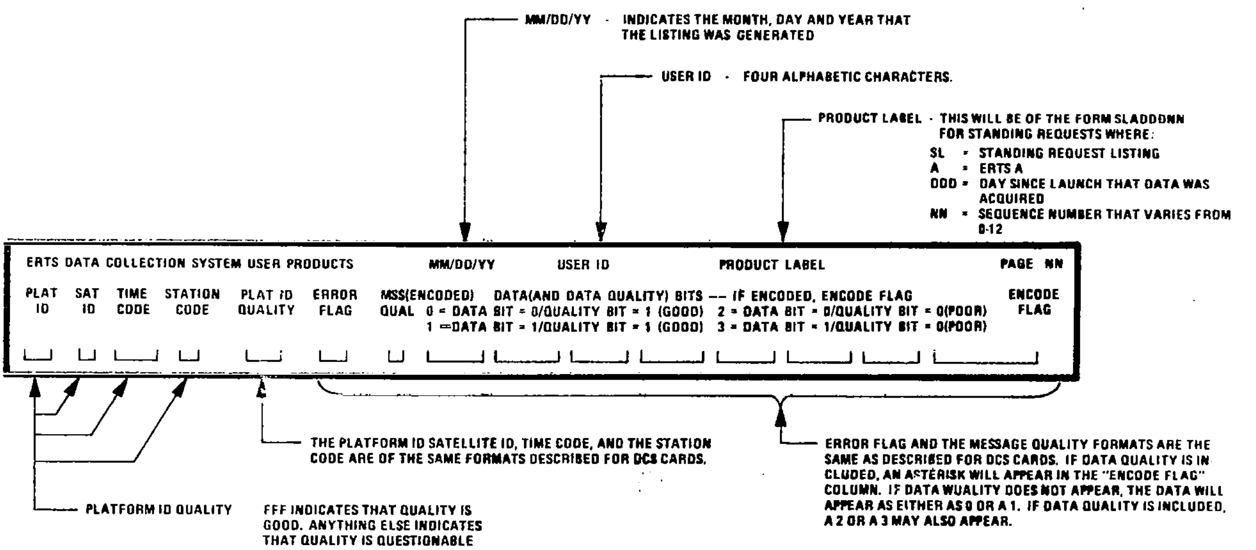
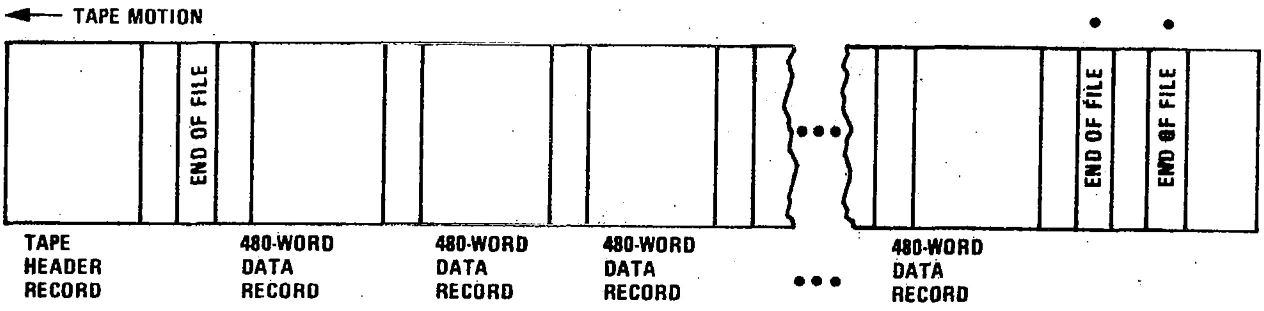


Figure 3-22. DCS Computer Listings Format



HEADER RECORD FORMAT: SEE BELOW
RECORDS CONSISTS OF 60 DATA BLOCKS (480 WORDS).
EACH DATA BLOCK CONSISTS OF ONE DATA TRANSMISSION (8 WORDS).
EACH DATA TRANSMISSION IS IN THE FORMAT OF AN ADF ENTRY.

HEADER RECORD FORMAT:

STANDING REQUEST TAPE: STaDDDnnUUUUYY/MM/DD
VARIABLE REQUEST TAPE: VTaDDDnnUUUUYY/MM/DD

THE 1ST 8 EBCDIC CHARACTERS ARE THE STANDARD NDPF TAPE LEBEL –
a = SATELLITE NUMBER (1 OR 2), DDD = DAYS SINCE LAUNCH (OF TAPE GENERATION)
nn = SEQUENCE NUMBER (BINARY), UUUU = USER ID, YY/MM/DD = DATE OF PROCESSING (STANDING) OR DATE OF REQUEST (VARIABLE)

Figure 3-23. DCS Magnetic Tape Format

ORIGINAL

SECTION 4
USER SERVICES

The User Services Section of the NASA Data Processing Facility functions as the single source of contact for all investigators and user agencies on all matters relating to ERTS data products.

Users of ERTS data will be able to place orders for any data product described in Section 3, and seek information and advice regarding these data, data availability and ordering procedures through this section. Contact may be by phone, mail or personal visit to the following address:

ERTS USER SERVICES
Code 563
Building 23, Room E203
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771
Phone (301) 982-4018

Users are defined to be either individual investigators or agencies which have been approved by the NASA/ERTS Project Office for receipt of ERTS data. All other data users should apply to the User Services Section which will forward their requests to the NASA/ERTS Project Office for approval.

The flow of information between User Services and the user/investigator community is shown in Figure 4-1. Table 4-1 summarizes the user services activities and can be used as an index to the remainder of this section.

4.1 ORDERING PROCEDURES

Investigators may request data products either by direct mail to the NDPF or by placing a telephone order with a representative in the User Services Section. These representatives are trained to assist investigators in formatting their requests.

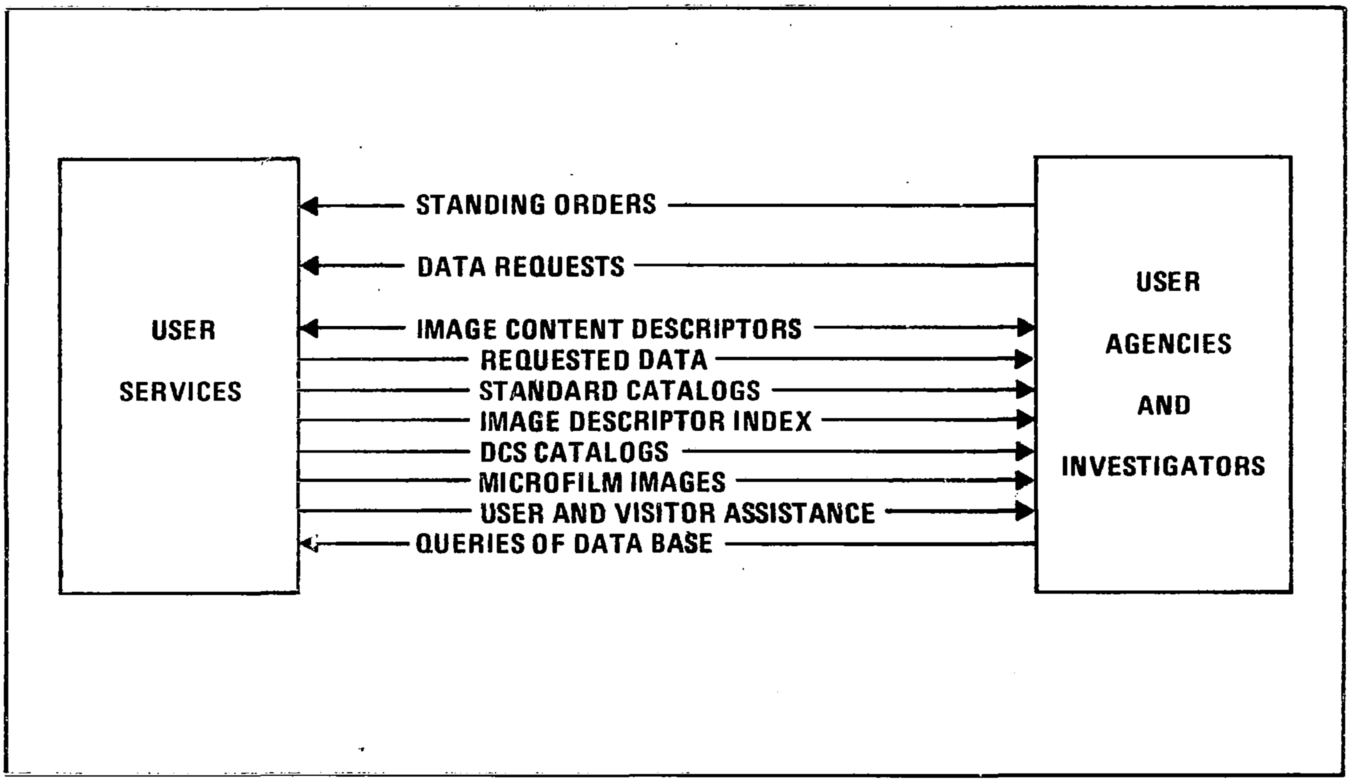


Figure 4-1. User Services Information Flow

Photographic images may be ordered in one of two ways:

- Standing Orders for image data which is yet to be acquired by the Observatory
- Data Requests for image data that already exists in the NDPF

Digital products are available in the form of computer compatible tapes containing digitized imagery that is produced by Bulk or Precision processing. They can be ordered only by using Data Requests (see Paragraph 4.1.2).

NOTE: In the discussion that follows, the forms used by User Services are identified. The use of these forms, however, is primarily an internal function; requestors do not necessarily need to submit their requests on the form but need only provide sufficient information to support the completion of the forms illustrated. This information may be provided by letter, telephone or personal visit.

4.1.1 STANDING ORDERS FOR IMAGES

The Standing Order is designed to help investigators obtain those specific photographic products he will need throughout his investigation. It permits the ordering of image products which may not yet have been acquired by the Observatory. Once generated, the Standing Order applies unless cancelled or changed by the investigator. It is expected that many Standing Orders will be submitted prior to launch, although new ones may be submitted or old ones altered at any time.

A Standing Order can specify several elements describing an image, a location, or quality attributes of the imagery desired. For example investigators may request all images taken of an area bounded by specific latitude and longitude points (up to a maximum of six points) with one of three levels of image quality, with one of eleven levels of acceptable cloud cover and a specific time period; (Example: "points of latitude and longitude for Greenbelt, Maryland, 'good' quality, with cloud cover less than 20 percent, between June 1 and October 13, 1972.") These delimiters are placed in the NDPF computer system as a Standing Order. As observations are made and images are processed, a comparison is made to the Standing Orders. When a match occurs, a Work Order to reproduce the images and a Shipping Order to ship them to the investigator are automatically produced by the NDPF computer system. In this way, all data matching the investigator's request is automatically generated for distribution to him. All data which satisfies a Standing Order will be reproduced and distributed to the requestor. No prior notification of intent to distribute data will be mailed out, thus it is imperative that the requestor keep his Standing Orders up to date and consistent with his requirements. Figure 4-2 shows the form used in placing Standing Orders for all imagery and/or catalogs. The figure includes explanations of each entry plus an illustrative example of a complete form.

4.1.2 DATA REQUEST FOR IMAGES

The second type of order, called a Data Request, is used to order data that already exists in the NDPF. The requestor specifies the observation identification, the sensor and band identification code, the product format and product type desired. This request, like the Standing Order, is entered into the NDPF system. Since the master images already exist, a Work Order to produce the products and the Shipping Order to ship them are generated immediately.

Figure 4-3 shows the Data Request form. The figure includes explanations of each entry plus an illustrative example of a completed form. Again it is emphasized that the User Services staff will provide assistance in completing the forms. The discussion here is intended mainly to illustrate the kind of information required.

Item	Summary Description	Reference Section
Standing Orders	Users may place a Standing Order for imagery which may not yet have been acquired by the Observatory. All data produced will be matched against Standing Orders. Whenever an image is generated which satisfies a Standing Order, an internal NDPF request will be generated to automatically reproduce and send the image to the requestor. In this way the user may request data which does not yet exist. Nominal delivery time is two weeks from the date of spacecraft observation to the date of shipment.	4.1.1
Data Requests	Users may place a Data Request for the reproduction of data already on file at the NDPF. The user must accurately specify the data required. The nominal delivery time is one week if the product exists and two weeks if a new product must be created.	4.1.2
Standard Catalogs	Standard catalogs announcing the images available are produced and sent to users. Separate catalogs for both U.S. and non-U.S. coverage are generated and contain data describing the images collected from a complete 18 day coverage cycle.	4.2.1
Image Descriptor Index	A cumulative catalog of image descriptors is produced every 30 days and distributed to the users. This catalog is generated from a standard list of image descriptors supplied by individual investigators based on their analysis of imagery.	4.2.2
DCS Catalog	A catalog summarizing all DCS transmissions is published on a 30-day cycle and distributed to the users. Since the data content of the DCS messages are a function of the individual platforms which are owned by the investigators, the catalog only summarizes the number of messages by platform and not the message content.	4.2.3
Microfilm Images	The Microfilm Images provide users with data which they can screen to select useful images. They grossly display what imagery is available and are not for data analysis. Each set of microfilmed images is in exact correspondence with the Standard Catalog and is produced on an 18-day cycle.	4.3
Browse Facility	The Browse Facility in Building 23 at GSFC is available to assist visitors in their examination and selection of imagery data. Trained personnel are available to instruct and assist visitors to the facility.	4.4
Queries of the Data Base	User Services maintains an interactive information system which can query and search the computerized data base to identify images of interest to an investigator. Access to this system is available to visitors and via telephone and mail requests.	4.5

Table 4-1. User Services Summary

ERTS 1 STANDING ORDER FORM

DATE ____________

PRINCIPAL INVESTIGATOR ____________

TELEPHONE NO. ____________

SHIP TO: ____________
(NAME)

____
(AGENCY)

____
(STREET)

____
(CITY) (STATE) (ZIP)

NDPF USE

D ____________
N ____________
ID ____________
AA ____________
REP ____________

CATALOGS DESIRED

STANDARD ☐ U.S. ☐ NON–U.S.
DCS ☐
MICROFILM ☐ U.S. ☐ NON–U.S.

CHECK IF ADDRESS IS NEW ☐

GEOGRAPHIC POINTS		CLOUD COVER %	QUALITY	COVERAGE PERIOD		PROD		TM-IA CR KK	QUALITY	RBV BANDS ⑨			MSS BANDS ⑨				DELETE
LATITUDE	LONGITUDE			START MMDDYY	STOP MMDDYY	TYPE	FORMAT			1	2	3	1	2	3	4	
1a	1b	2	3	4	4	5	6	7	8								10
EXAMPLE																	
4500N	12022W	3	G	041572	103172	C	T	U	3								
0015N	12022W																
3820N	10330W																
4535N	04500W																

FOUR CORNER POINTS OF AREA OVER NORTH AMERICA

UP TO 30% CLOUD COVER

GOOD IMAGES ONLY

COVERAGE FROM 4 15 72 TO 10 31 72

PRECISION COLOR IMAGE

TRANSPARENCY

UTM TICK MARKS

3 COPIES

Figure 4-2. Standing Order Form

(1) Geographic Points

a. Latitude (Format DDMMd) where:

DD = Degrees (0° - 90°)
MM = Minutes (0' - 59')
d = Hemisphere (N or S)

b. Longitude (format DDDMMd) where:

DDD = Degrees (0° - 180°)
MM = Minutes (0' - 59')
d = Direction (E or W)

The requestor specifies either (1) one point or (2) three to six points as defined by a latitude and a longitude. The defined polygon must be convex. That is, the line joining any two points within the polygon must be wholly within the polygon as illustrated below. All of the continental U.S., Alaska or Hawaii may be ordered simply by inserting "U.S.", "Alaska" or "Hawaii". All other areas must be ordered by geographic points.

(2) Cloud Cover, where:

0 = No cloud cover acceptable
1 = 0-10% cloud cover acceptable
2 = 0-20% cloud cover acceptable
3 = 0-30% cloud cover acceptable
4 = 0-40% cloud cover acceptable
5 = 0-50% cloud cover acceptable
6 = 0-60% cloud cover acceptable
7 = 0-70% cloud cover acceptable
8 = 0-80% cloud cover acceptable
9 = 0-100% cloud cover acceptable

This is the percent of the image obscured by clouds above which the image is of no value to the investigator.

(3) Quality specifies the minimum acceptable quality as defined below. (These quality parameters refer to processing quality and are not related to image content)

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 significantly noisy.

The requestor should specify the acceptable degradation, if any, he will accept by using one of the above codes. For example "F" would order all good images plus images which are fair.

(4) Coverage Time where:

MM = Month (start, stop)
DD = Day of month (start, stop)
YY = Year of month (start, stop)

This is the coverage time period over which the requestor desires imagery

(5) Product Type where:

Blank = Bulk Photographic Image (9½ inches)
A = Precision Photographic Image
B = Bulk Color Photographic Image
C = Precision Color Photographic Image
G = Bulk 70 mm

(6) Product Format where:

N = Negative
T = Transparency
P = Print

NOTE: The permissable combination of product types and product formats are summarized in the table at the bottom of this page.

(7) Tick Mark where (Precision image only):

Blank = No internal tick marks in image area
U = Universal Transverse Mercator (UTM) tick marks (See reference "gridding")
L = Geographic tick marks

(8) Number of Copies, where NN designates the actual number of products desired (numerical). Maximum number of copies is 63.

(9) Return Beam Vidicon Images (1 through 3 spectral bands)
Multispectral Scanner Images (1 through 4 spectral bands for ERTS A)

(10) Delete = Delete Standing Order, where entry is
YES = Delete Standing Order for Products Described
BLANK, or NO = Do not delete Standing Order

When the NDPF system processes the users' Standing Orders, an area number will be assigned by the system. The requestor will be informed by mail of the area number when his Standing Order is confirmed by User Services. If the user wishes to delete the area from his set of Standing Orders he may enter that number in place of latitude and the word "YES" in the delete column rather than supplying information for the entire form.

SUMMARY OF PRODUCT TYPE AND PRODUCT FORMAT

P = Prod Type	Processing Method	F = Format: N = Negative	T = Transparency	P = Print
Blank	Bulk	Black and White 70 MM Negative	Black and White 9.5" x 9.5" Positive Transparency	Black and White 9.5" x 9.5" Positive Print
A	Precision	Black and White 9.5" x 9.5" Negative	Black and White 9.5" x 9.5" Positive Transparency	Black and White 9.5" x 9.5" Positive Print
B	Bulk Color	N/A	Color 10" x 10" Positive Transparency	Color 10" x 10" Positive Print
C	Precision Color	N/A	Color 10" x 10" Positive Transparency	Color 10" x 10" Positive Print
G	Bulk	Black and White 70 MM Negative	Black and White 70 MM Positive Transparency	N/A

N/A - Not Applicable

DATA REQUEST FORM

DATE ______________

1. USER ID ______________
2. NEW ☐ CHANGED ADDRESS ☐
3. NAME ______________
4. AGENCY ABBR. ______________
5. NDPF REPRESENTATIVE ______________
6. USER ADDRESS ______________
7. CATALOGS DESIRED
   - STANDARD ☐ U.S. ☐ NON-U.S.
   - DCS ☐
   - MICROFILM ☐ U.S ☐ NON-U.S.
8. TELEPHONE NO. ______________
9. DATA REQUESTED

ADDDHHMMS = OBSERVATION IDENTIFIER	B = SENSOR BAND	P = PROD. TYPE	F = PROD. FORMAT	T = TICK MARKS	NN NUMBER COPIES	COMMENTS
①	②	③	④	⑤	⑥	⑦
EXAMPLES						
113210223	3	C	T	U	5	

ERTS A
132 Days Since Launch
10 Hours of the Day
22 Minutes of the Hour
30 Seconds

RBV

PRECISION COLOR IMAGE

POSITIVE TRANSPARENCY

UTM TICK MARKS

5 COPIES

NO COMMENTS

Figure 4-3. Data Request Form

ORIGINAL

(1) Observat ·n Identifier (Format ADDDHHMMS)

- A = Satellite Number (1 = ERTS A; 2 = ERTS B)
- DDD = Days since launch
- HH = Hour of day (GMT)
- MM = Minutes of hour (GMT)
- S = Tens of seconds of minutes (GMT)

(2) Identification Code
Sensor band or bands used to produce the product. The values that B may assume are:

B&W (if blank, A or G in column 3	Color* (if B or C in column 3
1 = RBV 1	
2 = RBV 2	
3 = RBV 3	3 = RBV 1, 2 & 3
4 = MSS 1	
5 = MSS 2	
6 = MSS 3	6 = MSS 1, 2 & 3
7 = MSS 4	7 = MSS 1, 2 & 4
8 = MSS 5 (ERTS B)	
R = All RBV Bands	
M = All MSS Bands	
X = All Bands	

*Color products are made by using one of three standard composite combinations, either RBV 1, 2 and 3, MSS 1, 2 and 3 or MSS 1, 2 and 4. The infrared band used in each combination is unique: RBV 3, MSS 3 (low infrared) and MSS 4 (high infrared). Therefore, the infrared band is used to denote each composite.

(3) Product type where:

- b = Bulk Photographic Image
- A = Precision Photographic Image
- B = Bulk Color Photographic Image
- C = Precision Color Photographic Image
- D = Bulk Digital
- E = Precision Digital

(4) Format of the product where:

N = Negative	M = 70 mm negative
T = Positive Transparency	S = 70 mm transparency
P = Print	7 = 7-track tape (556 BPI)
	9 = 9-track tape (800 BPI)

(5) Type of tick marks on precision processed products where:

- U = Universal Transverse Mercator (UTM) tick marks
- L = Geographic tick marks
- B = no tick marks

(6) NN = Desired number of copies of a product. 1 ≤ NN ≤ 63. Any other character will assume a default value of 1.

(7) Comments or Image Descriptors may be placed in this area. Text is limited to 40 characters.

4.1.3 Delivery Schedule

All data produced as a result of Standing Orders are normally shipped within two weeks after the date of sensor observation. Depending upon the data requested and the data processed, the imagery sent to the investigator may consist of only the data requested or it may also include unrequested data which was processed at the same time. In general, an attempt will be made to produce only the requested materials; the economics of production may, however, result in the distribution of additional products.

Data Requests which require only reproduction of existing master imagery will normally be shipped within one week. Requests involving the generation of new products from in-hand raw data require two weeks. To hasten delivery of requested data, the NDPF will prepare partial shipments when a delay of five or more days is required to complete the order.

4.1.4 Requests for DCS Data

Requests for Data Collection Systems data are processed separately from the image requests. Data may be requested on a Standing Order basis or on a Data Request basis. All orders must specify product type and platform number. A fuller discussion of the DCS products and their distribution is contained in Section 4.2.3. Because the NDPF anticipates a relatively stable DCS user community, no request forms have been prepared. All requests will be processed on an individual basis by User Services.

4.2 DATA CATALOGS

One of the most important functions of User Services is the prompt announcement of the image and DCS data acquired by the observatory. Because the user community has many and varied requirements, the catalogs are designed to provide a maximum degree of announcement flexibility. Thus, for example, Standard Catalogs are divided into discrete U.S. and non-U.S. volumes. The user may choose to subscribe to either or both catalogs.

In addition to producing Standard Catalogs, the NDPF generates 16 mm microfilm data sets which correspond to each of the Standard Catalogs. These catalogs and microfilm sets are published every 18 days. A cumulative index of image descriptors and a catalog of DCS transmissions are generated for distribution every 30 days. The contents and format of each catalog are treated in the following paragraphs.

4.2.1 Standard Catalogs

Every 18 days a U.S. Standard Catalog, covering the continental U.S. plus Alaska and Hawaii, is produced by the NDPF and issued approximately three weeks after the start of the 18-day orbital coverage cycle (see Appendix I). Each Standard Catalog contains image data for an 18-day period and consists of an outline map graphically displaying coverage, and a computer listing tabulating by observation number the imagery obtained in sequential order. Catalogs for non-U.S. data are identical in format and are produced nine days out-of-phase with the U.S. catalog.

4.2.1.1 Standard Catalog Outline Map

Each of the two Standard Catalogs contains an outline map. The U.S. Standard Catalog has outline maps of the United States including, Alaska and Hawaii (see Figure 4-4), and the non-U.S. Standard Catalog contains an outline map of the world (see Figure 4-5). Each of these maps indicates which areas have been imaged during the 18-day period covered by the catalog. In addition, the U.S. outline map shows an estimate of the cloud cover contained in the imagery by a four shade spectrum along the subsatellite path for each north to south pass. No shading indicates that no imagery was collected.

4.2.1.2 Standard Catalog Page Listing

A large part of the Standard Catalog consists of computer listings produced from the information systems data base. All listings are in sequence by observation identifier. The NDPF has established three nested levels of ERTS imagery identification: an Observation ID,

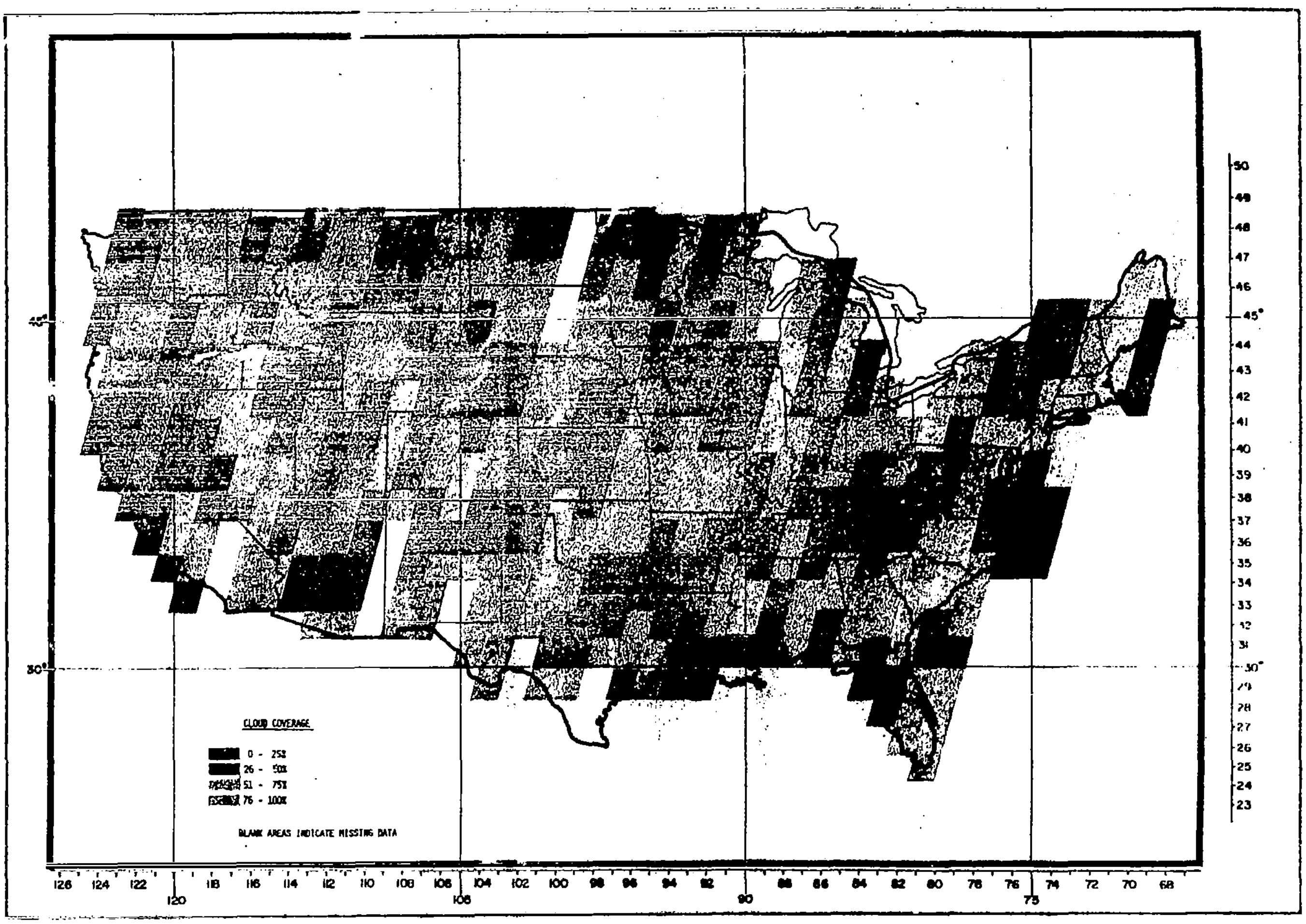


Figure 4-4. Sample Continental U.S. Outline Map

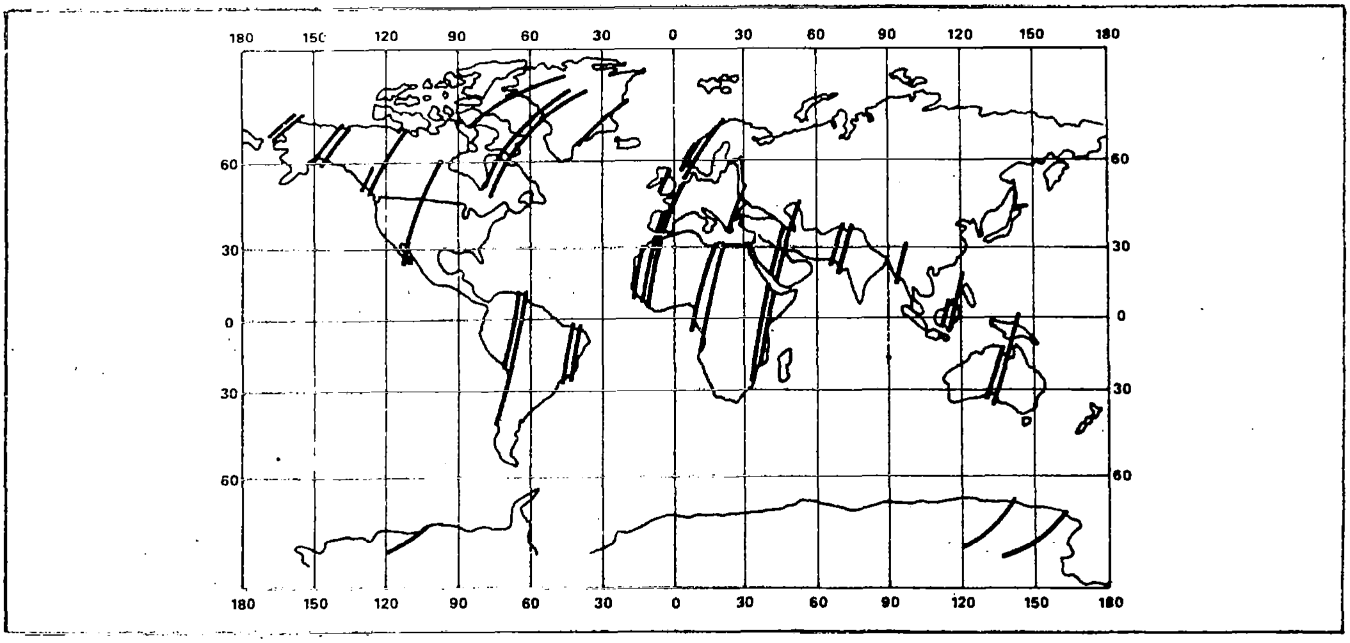
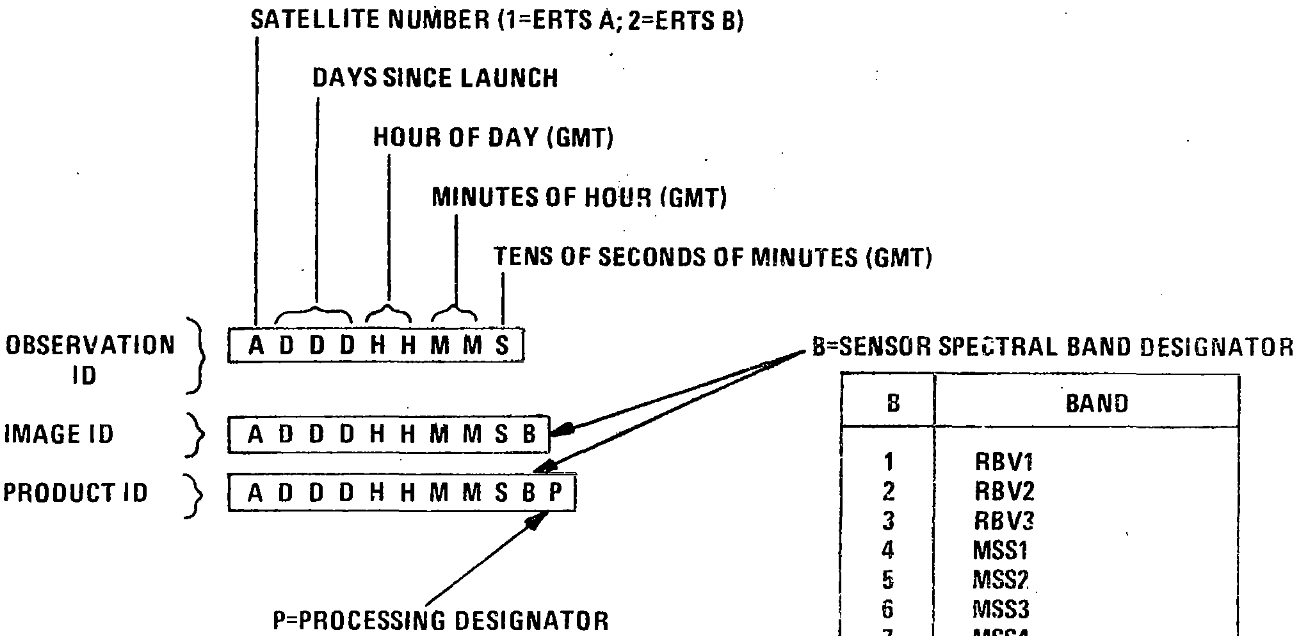


Figure 4-5. Sample World Map

an Image ID and a Product ID. Figure 4-6 explains the format and content of each type of identification. All orders, announcements, queries and image annotations utilize one of these identifiers.

A sample catalog page with an explanation of its contents is shown in Figure 4-7. RBV and MSS Band 2 images are also available in continuous tone microfilm format as described in Section 4.3. For every 18 day observation cycle, the microfilm roll number is listed, followed by entries for the individual observations which are on the specified microfilm roll.



B	BAND
1	RBV1
2	RBV2
3	RBV3
4	MSS1
5	MSS2
6	MSS3
7	MSS4
8	MSS5 (ERTS B ONLY)
R	ALL RBV BANDS
M	ALL MSS BANDS
X	ALL BANDS

P	PROCESSING TYPE
BLANK	BULK
A	PRECISION
B	BULK COLOR
C	PRECISION COLOR
D	BULK DIGITAL
E	PRECISION DIGITAL
X	NON-STANDARD PROCESSING

Figure 4-6. Observation, Image and Product Identification Number Formats

4.2.2 Image Descriptor Index

4.2.2.1 Index

The NDPF does not perform any content analysis of the images, nor is any examination conducted of the data to determine terrain features or other phenomena. The NDPF Information System, however, accepts and records image descriptors supplied by investigators. An image descriptor is a term which assists in defining the content of an image. For example, an image may show a rain forest with mud flats surrounding a pasture. A user inspecting this image may choose to describe the image with the terms Rain Forest, Mud Flats, and Pasture. All image descriptors returned to the NDPF by investigators will be compiled and entered into the ERTS data bank for subsequent user query servicing.

Every 30 days a cumulative Image Descriptor Index is published, containing each image descriptor that is stored in the Image Descriptor Data Bank file. This index allows investigators to tabulate various findings pertaining to each image, and to index these findings via image descriptors in a catalog available to all investigators.

2 04/29/72 — STANDARD CATALOG — 1 04/10/72 TO 04/27/72 — PAGE 1

KEY TO IMAGE CLARITY

3 G : GOOD
F : FAIR
P · POOR

4 THE IMAGES INDICATED BELOW ARE ON MICROFILM ROLL NUMBER: 001

OBSERV. ID	MICR. RBV	PAS.# MSS	DATE	CLOUD COVER	PRINCIPAL POINT OF IMAGES	SUN ELEV.	SUN AZIM.	RBV 1 2 3 MSS 1 2 3 4	BULK RBV	BULK MSS	BULK COLOR RBV	BULK COLOR MSS	PREC. RBV	PREC. MSS	PREC. COLOR RBV	PREC. COLOR MSS	DIGITAL RBV	DIGITAL MSS	DCS DATA
A00112250	0001	0002	07/01/72	45	44.290N 83.290W	31.2	31.2	G G G P P P F	X	X	X	X	X	X	X	X	X	X	X
A00112255	0003	0004	07/01/72	60	42.500N 83.500W	30.4	30.4	G G G G G G G	X	X	X	X	X	X	X	X	X	X	
A00112258	0005	0006	07/01/72	40	40.400N 84.280W	30.0	30.4	F F F G G F F	X	X	X	X	X	X	X	X	X	X	
A00112263	0007	0008	07/01/72	30	40.100N 80.480W	28.5	30.4	P F G F F G P	X	X	X	X	X	X	X	X	X	X	
A00112265	0009	0010	07/01/72	35	38.580N 85.260W	28.0	30.5	G G G G F F F	X	X	X	X	X	X	X	X	X	X	
A00212250	0011	0012	07/02/72	20	37.190N 85.500W	28.0	30.2	P P P P P G G	X	X	X	X				X	X	X	
A00212255	0013	0014	07/02/72	30	35.190N 86.190W	27.9	29.9	F F F G G P F	X	X	X	X	X				X		
A00212258	0015	0016	07/02/72	10	34.340N 86.590W	27.9	29.8	G G G G G G G	X	X	X			X	X		X	X	
A00212263	0017	0018	07/02/72	15	35.290N 87.100W	27.8	29.7	F F F G G G F	X		X	X	X	X				X	
A00212265	0019	0020	07/02/72	45	31.490N 87.490W	27.8	29.7	G G F F F F G	X	X	X	X	X		X		X		X

STOP 0

5 6 7 8 9 10 11 12 13

Definitions

1. Date of Image Coverage
2. Date of Catalog Listing
3. Image Quality Key (RBV Band 1,2,3; MSS Band 1,2,3,4 (5 ERTS-B)
4. Microfilm Roll Number
5. Observation, ID (See Figure 4-6)
6. RBV and MSS Image Position on Microfilm Roll
7. Date of Observation
8. Estimated Percent of Cloud Cover (U.S. Images)
9. Latitude and Longitude at Image Center
10. Sun Elevation and Azimuth at Image Center
11. Image Quality Selected from 3 (RBV Band 1,2,3; MSS Band 1,2, 3,4)
12. Image/Data Product Availability; (Bulk, Bulk Color, Precision, Precision Color, Digital).
13. Existence of a DCS platform within the observation range. This does not necessarily mean a valid platform recording is associated with the image

Code	Meaning	Definition
Blank	Band not present (no image available in this band)	N/A
G	Good Image	Complete image with good tone, resolution and granularity. Little or no noise
F	Fair Image	Lighter or darker than "good" imagery or noticeable noise
P	Poor Image	Very light or dark image, partial image or significant noise

Figure 4-7. Annotated Sample of Standard Catalog

Figure 4-8 shows a representative page from the Image Descriptor Index. The index is organized alphabetically by image descriptors and each descriptor has the product ID's for the images which have been assigned this descriptor listed below it. Each image descriptor is presented along the left side of the printed page followed by up to 10 columns of product ID's. It should be noted that in some cases the reference is to an observation; i.e., all spectral images in that scene contain that feature, whereas in other cases the reference is to a single spectral image or product type. In the latter case the descriptor applies only to the specific product and not to other images in the observation. By way of example, note the first column listed under flood plain. The first entry indicates that only the image of MSS Band 4 (spectral band code - 7) contains useful data related to a flood plain. The second entry indicates that all bands of both sensors contain data showing flood plain.

The format of the Image Descriptor Index is a series of pages, as illustrated, preceded by a concordance, which lists all image descriptors and the number of times each was used. A sample concordance list is shown in Figure 4-9.

February 23, 1972

CONCORDANCE LISTING

NO.	DESCRIPTORS
1	CANYONS
3	HYDROLOGY
2	VOLCANO
1	CITIES
5	FOREST
5	ZOLOGY
1	GEOLOGY
1	OCEANOGRAPHY
4	MILITARY
5	DESERT

Figure 4-9. Sample Page, Concordance Listing of Image Descriptor Index

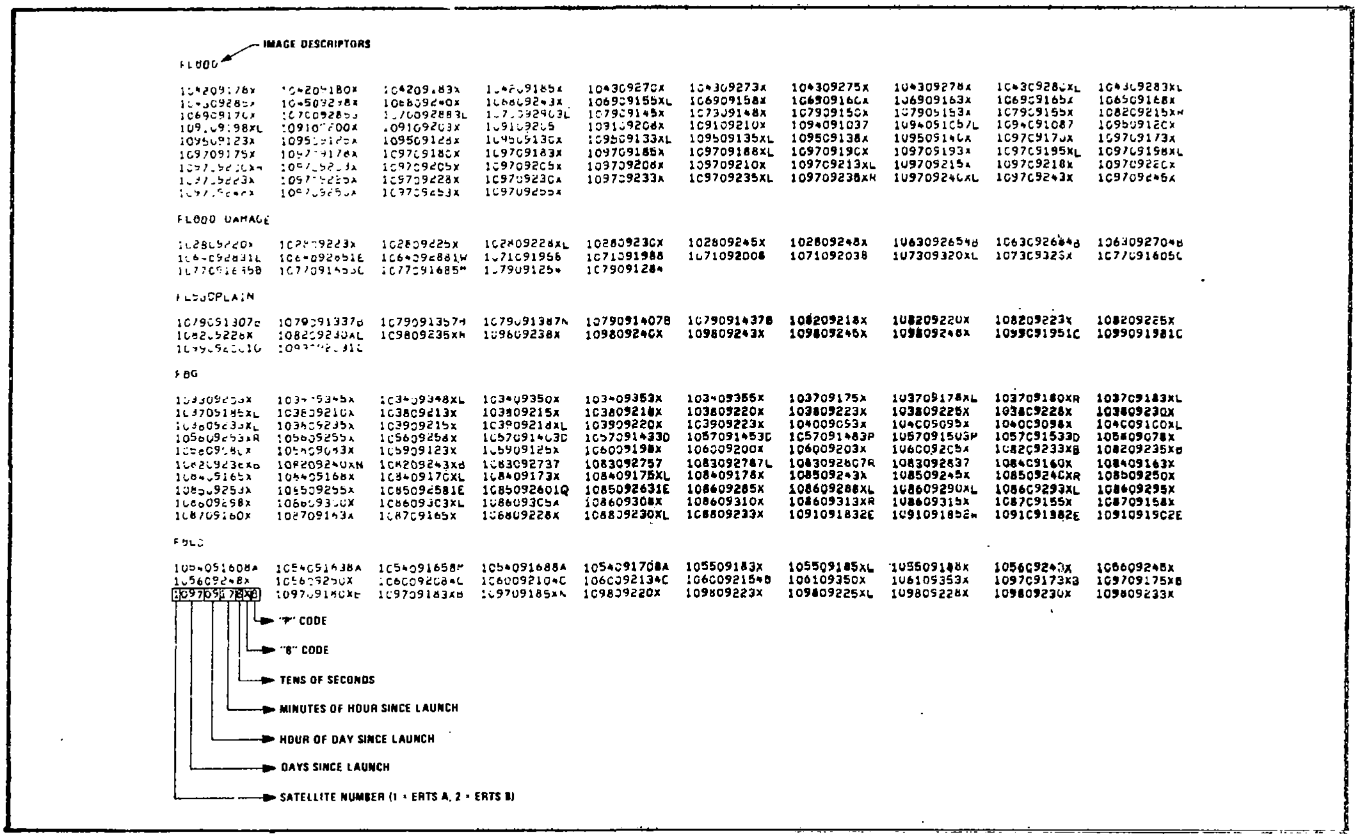


Figure 4-8. Sample Page of Image Descriptor Index

4.2.2.2 Forms

When images are shipped to investigators, a form is included for listing the appropriate image descriptors and identifiers. Figure 4-10 illustrates a sample Imag Descriptor Form. Investigators are requested to mail this form back to the NDPF after they have analyzed the images and noted the descriptors they feel pertain to each image.

After the Investigator's Name, Date, Investigator's ID and Agency fields are completed, the investigator should decide if there are any descriptors he believes will be used considerably more frequently than others. If there are such descriptors, the investigator writes them in the first row of blank columns under the header, FREQUENTLY USED DESCRIPTORS. Each image ID to which the investigator assigns descriptors is written in the PRODUCT ID column. The identification includes band and product type codes.

If an image is to be described by a descriptor in the FREQUENTLY USED DESCRIPTORS column, a check (✓) mark is all that is required. Other descriptors which are not frequently used are written separately in the DESCRIPTORS column.

ERTS IMAGE DESCRIPTOR FORM

USER NAME ______________________ DATE __________

USER ID ______________________

AGENCY ______________________

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS				DESCRIPTORS
	FOG*	*	*	*	
1017182656A	✓				DUNE

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E203
NASA GSFC
GREENBELT, MD. 20771

Figure 4-10. Image Descriptor Form

4.2.2.3 Vocabulary

The possibilities of cooperative exchange of information through the use of image descriptors are numerous. The ease of exchange, however, can be greatly increased by establishing a common vocabulary. The NDPF computer system has been implemented to handle two types of image descriptors; the first type is from a suggested vocabulary supplied to each user and the second type is one which an investigator creates and is not contained in the suggested vocabulary. The two types of descriptors together comprise what is known as an open vocabulary. No restrictions are placed on investigators who wish to supply their own descriptors.

The suggested vocabulary has several advantages over the open vocabulary:

1. It maintains a consistent use of descriptors from one image to another
2. It simplifies the exchange of information among different user groups.

As a step toward the development of a suggested vocabulary, a list of approximately 400 terms has been compiled that pertain to remote sensing of earth resources; the vocabulary is presented in Table 4-2. The terms were chosen for their diagnostic potential in evaluating ERTS imagery.

The suggested vocabulary is provided as the basis for which individual investigators may describe image contents which fall within their field of interest. As might be expected from such an abbreviated grouping, all earth resource disciplines may not yet be evenly represented in the suggested vocabulary.

Information searches of the data base may be made using descriptors from the open vocabulary. The difficulty here is that the descriptors from the user-created vocabulary are only known to the person or group entering them into the system, which tends to reduce the overall value of the analysis and decreases the exchange of information between groups of users.

4.2.3 DCS Catalog

The Data Collection System (DCS) relays messages from platforms to the NDPF for distribution to users. The nature of the messages is a function of the platform and its instrumentation sensors. Since each platform is different and separately owned by specific investigators, the NDPF limits its processing to validations, sorting, and formatting. As a result, the DCS Catalog is restricted to a summary announcement of the data collected during a 30-day reporting period.

The Catalog is printed and delivered every 30 days and contains the following for each platform:

1. Platform identification
2. Primary user's identification
3. Platform geographic location (latitude and longitude)
4. Time of first transmission in the reporting period.
5. Time of the last transmission in the reporting period
6. Total number of messages within this time range
7. Total number of messages sent by the platform since its inception

The format of this DCS Catalog listing is shown in Figure 4-11. Additional information concerning the platform sensor package, the sensor units and calibrations, and the message formats are normally available from the primary user. The User Services Section maintains an up-to-date list of all primary users and platform owners and will provide assistance in obtaining information for other investigators.

Table 4-2. Earth Resources Vocabulary

A
Acclinal Valley
Active Glacier
Active Volcano
Actiniform Clouds
Adobe Flat
Advancing Glacier
Advancing Shoreline
Aerial Imagery Used
Agriculture
Airfield
Alfalfa
Algal Bloom
Alkali Flat (use Salt Flat)
Alluvial Cone
Alluvial Fan
Alluvial Flat
Alluvial Plain
Alluvial Terrace
Altocumulus
Altostratus
Anaclinal Stream
Anaclinal Valley
Annular Drainage Pattern
Anticlinal Mountain
Anticlinal Valley
Anticline
Anticlinorium
Anvils
Aquifer
Arroyo
Ash Cone (use Cinder Cone)
Atoll
Atoll Reef
Avalanche
Avalanche Scar
Axial Stream

B
Back Bay
Backshore
Badland
Bajada
Barbed Tributary
Barchan
Barley
Barrens
Barrier Bar
Barrier Beach
Barrier Flat
Barrier Island
Barrier Lagoon
Barrier Lake
Barrier Reef
Basin
Basin and Range
Batholith
Bay
Bay-Head Bar
Bay-Head Beach
Bay-Head Delta
Bay Ice
Baymouth Bar
Bayou
Bed
Bedrock
Belt
Belted Plain

B *(cont'd)*
Billow
Billow Cloud
Bioluminescence
Bird-Foot Delta
Blight (use Diseased)
Bog (use Marsh)
Braided Stream
Breakwater (use Jetty)
Bridge
Broken Clouds
Brush
Butte

C
Caldera
Canal
Canyon (use Valley)
Cape
Cartography
Catchment Area
Cay
Chaotic Cloud Pattern
Chaperral
Cinder Cone
Cirque
Cirrocumulus
Cirrostratus
Cirrus
Cirrus Shield
Citrus
City
Clearing
Closed Basin
Closed Fault
Closed Fold
Cloud Streets
Coast
Coastal Current
Coastal Dune
Coastal Marsh
Coastal Plain
Coast Line
Col (use Gap)
Cold Front
Cone
Conifer
Consequent Lake
Consequent Stream
Consequent Valley
Contact
Continental Shelf
Copses
Coral Head
Coral Reef
Corn
Cotton
Coulee
Crater
Cropland
Cross-Bedding
Cross-Fault
Cuesta
Cumulonimbus
Cumulus
Current
Cusp
Cyclone

D
Dam
Deciduous
Delta
Deltaic Coastal Plain
Dendritic Drainage
Depression
Desert
Desertline
Dike
Diseased Vegetation
Divide
Dome
Dormant Vegetation
Drought Conditions
Drumlin
Dune

E
Earthquake Damage
Echelon Fault
Eddy
EEO (Excellent Example of) Keyword
End Moraine
Entrenched Stream
Erosion
Esker
Estuary

F
Fall Line
Fallow Field
Fan
Fault
Finger Lake
Fiord
Fire
Firebreak
Fire Damage
Flood
Flood Damage
Floodplain
Fog
Fold
Forest
Forest Fire
Forest Fire Damage
Frost Damage
Frontal Wave
Frozen Lake
Frozen Soil

G
Gap
Geofracture
Geography
Geology
Geosyncline
Glacier
Gorge (use Valley)
Graben
Grass
Grassland
Gravel Deposit
Grazing Land (use Pasture)
Ground Truth Used
Gulf

H
Harbor
Hardwood Forest
Hay
Haze
Highway
Hogback
Horst
Hourglass Valley
Hurricane
Hurricane Damage
Hydrology

I
Ice
Iceberg
Ice Floe
Ice Jam
Ice Pack
Ice Shelf
IRI (Image Referenced in) Journal
Industrial Area
Inlet
Inlier
Insect Damage
Inshore Zone
Insequent Stream
Interlacing Drainage
Intermontane Floor
Intrusion
Irrigation
Island
Island Arc
Isthmus

J
Jet Stream Indicated
Jetty

K
Kame
Karst
Kelp
Kettle
Key (use Cay)
Klippe

L
Lagoon
Lake
Lake Bed
Landslide
Laterite
Lattice Drainage Pattern
Lava
Lee Wave
Lineament
Littoral Current
Littoral Drift
Littoral Transport
Locust Swarm
Locust Damage
Longshore Bar
Longshore Current
Lumbering Area

Table 4-2. Earth Resources Vocabulary

M
Maar
Marsh
Massif
Mature Stream
Mature Vegetation
Meadowland
Meander
Mesa (use Butte)
Meteor Crater
Meteorology
Metropolitan Area
Microwave Data Used
Millet
Mine
Monoclinal Valley
Morainal Delta
Morainal Lake
Moraine
Mountain
Mud
Mud Flat
Muskeg

N
Nappe
Nunatak

O
Oasis
Oats
Occluded Front
Oceanography
Oil Field
Oil Slick
Open Pit Mine
Orchard
Orographic Cloud
Outlet
Outlier
Outwash Plain

P
Parallel Drainage
Park
Pass (use Gap)
Pasture

P *(cont'd)*
Pediment
Pediplain
Peneplain
Peninsula
Permafrost
Piedmont
Piedmont Plain
Peidmont Scarp
Pier (use Jetty)
Pinnacle
Plain
Plankton Bloom
Plateau
Playa
Playa Lake
Plowed Field
Pond (use Lake)
Potatoes
Prairie
Pressure Ridge
Protozoans

Q
Quarry

R
Radial Drainage Pattern
Railroad
Rain Forest
Raised Reef
Rangeland
Rapids
Ravine (use Valley)
Rectangular Drainage
Red Tide
Reef
Reservoir (use Lake)
Residential Area
Retrogressive Shoreline
Rice
Ridge
Rift
Rift Valley
River
Road (use Highway)
Runoff
Rural Area
Rust

S
Saline Dome
Saline Soil
Salt
Salt Flat
Salt Marsh
Sand Dune (use Dune)
Savannah
Scar
Scattered Clouds
Scrub
Sea
Sea Grass
Sea Wall
Secondary Front
Sediment
Shallow Water
Shield
Shipyard
Shoal
Silt
Sink
Slash
Slick
Smog
Smoke
Snow
Snow Pack
Soil
Soybean
Split
Spring
Squall Line
Stationary Front
Step Fault
Steppe
Stoss-and-Lee Topography
Strait
Strath
Stream
Suburban Area
Sugar Beet
Sugar Cane
Swamp (use Marsh)
Synclinal Valley
Syncline
Synclinorium

T
Terrace
Tidal Flat
Tidal Wave
Tidal Wave Damage
Thrust Fault
Timberline
Tobacco
Tombolo
Tornado
Tornado Damage
Towering Cumuli
Transverse Fault
Transverse Valley
Trellised Drainage
Trench
Tributary
Tsunami
Tsunami Damage
Tundra
Typhoon
Typhoon Damage

U
Upwelling
Urban Area

V
Valley
Vegetation
Vineyard
Volcano

W
Wadi (use Arroyo)
Warm Front
Wave
Wharf (use Jetty)

X Y Z

DATA COLLECTION SYSTEM CATALOG MM/DD/YY PAGE NN

CATALOG CYCLE: FROM MM/DD/YY TO MM/DD/YY

PLAT. ID	USER ID	LATITUDE	LONGITUDE	TIME PERIOD FROM	TIME PERIOD TO	NO. OF MESSAGES	TOTAL NO. OF MESSAGES
____	____	N S__ DEG__ MIN	E W___DEG___MIN	____	__	______	______

Figure 4-11. Format of DCS Catalog Listing

4.3 MICROFILM IMAGES

Every 18 days the NDPF Microfilm Facility produces high quality 16-mm microfilm of representative imagery covering one 18 day observation cycle. These images are solely to indicate to the investigators what imagery is available and are not intended for data analysis.

As in the case of the Standard Catalog, the microfilm data is divided into U.S. and non-U.S. segments. Each set of microfilm images is in exact correspondence to a Standard Catalog and can be used in conjunction with the catalog for selecting desired images. The catalog contains roll and position numbers and data which, along with the microfilm image, provides the investigator with enough information to decide whether or not the observation (scene) is useful to him.

Because the microfilm images are intended to provide only a summary of the data available, the images are limited to one band each for the RBV and MSS. Thus, although a single observation will produce seven (eight for ERTS B) images, in the production of microfilm only the RBV Spectral Band 2 images and the MSS Spectral Band 2 images are reproduced on microfilm. Each image is a photograph of a bulk processed image and contains the image identifier and full annotation block as described in Section 3. A typical roll of microfilm contains the following:

- 1 Leader Frame of Microfilm Identification
- 1 Leader Frame of Map Coverage (Outline Map as contained in the Standard Catalog)
- Up to 1000 Frames of RBV Images
- Up to 1000 Frames of MSS Images

The microfilm is on open reels suitable for mounting by the user in a cartridge of his choice. Two rapid search capabilities are incorporated on the microfilm. The first allows counting images for precise location of them and requires the counting capability on the viewer being used. The second is a moving bar indicator which permits gross locating of images to within about 200 images. Details of these two schemes are described in the Standard Catalog.

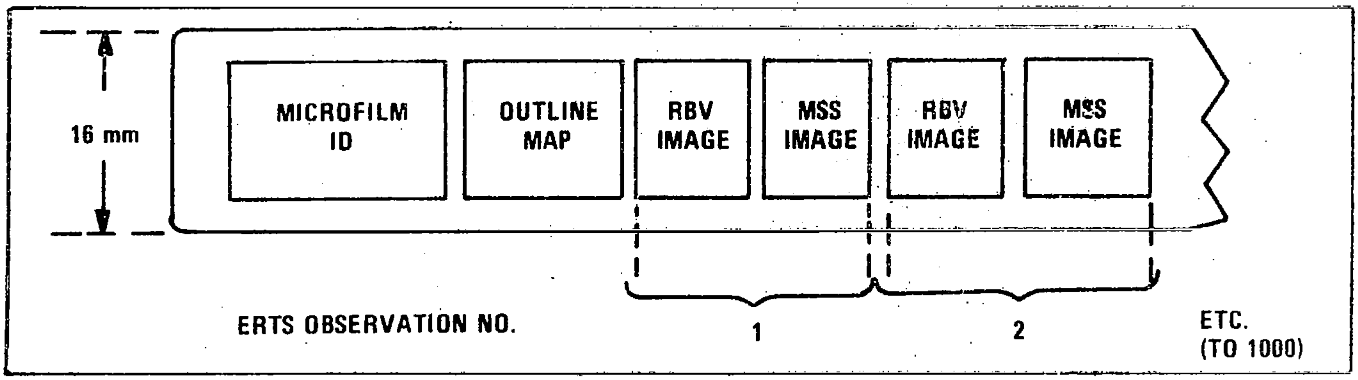


Figure 4-12. Sample Format of Microfilm Roll

The RBV and MSS image frames will be alternating per observation on the roll of microfilm as shown in Figure 4-12. The total number of rolls of microfilm produced in an 18-day cycle is:

Coverage	No. of Rolls	Approx Total No. of Images	Breakdown
U.S.	1	2000	1000 RBV images 1000 MSS images
Non-U.S.	3	5000	2500 RBV images 2500 MSS images

A complete set of microfilm data is maintained in the NDPF Browse Facility for visitor's perusal. High volume production of the microfilm data has been provided and data sets are available for routine distribution to users.

4.4 USER AND VISITOR ASSISTANCE

Assistance is provided to users and NDPF visitors by specialists in the Browse Facility where a means of examining and selecting products in a convenient and well-equipped facility is provided. Visitors to the Browse Facility may place orders for images here and receive technical aid through associated publications contained in the Browse Facility library.

The Browse Facility, located in Room 204, Building 23, at Goddard Space Flight Center, Greenbelt, Maryland, contains the products and references listed in Table 4-2.

Table 4-2. Browse Facility Contents

1. Selected data samples of 9-1/2 x 9-1/2 inch positive transparancies and prints consisting of:
   a. Bulk processed RBV and MSS images
   b. Precision processed RBV and MSS images
   c. Color composite images
2. 16-mm rolls of microfilm (black and white images) - quantity equal to the number of 18-day coverage cycles completed.
   a. U.S. data coverage (1 roll per 18 days)
   b. Non-U.S. data coverage (3 rolls per 18 days)
3. Data Collection System data
4. Image annotation data

References and Facilities

1. Atlases (U.S. and World)
2. Data Catalogs
   a. Standard Catalog
   b. Image Descriptor Index
3. Light tables for image inspection
4. Microfilm viewers (manual and index search)
5. Remote CRT Computer Terminal (for a NDPF Information Systems data base search and query.
6. Table workspace
7. Trained ERTS personnel for user assistance

A full-time Browse Facility assistant is available to instruct and assist visitors in the capabilities and operational aspects for the NDPF Browse Facility. The assistant will place orders for imagery, catalogs, or microfilm for investigators desiring retention copies and will instruct and aid investigators in the use of the query system.

The Browse Facility assistant is available to demonstrate the use of catalogs, atlases and user guides. A log of all reference material is maintained in the Browse Facility and is available to visitors. The assistant will provide instruction for operation of light tables, microfilm viewing equipment, and the CRT terminal.

4.5 COMPUTER QUERY AND SEARCH CAPABILITY

Information about every image processed is maintained in a data base in the NDPF computer. This information consists of two basic types:

1. Imagery parameter information always available from the normal NDPF activities such as in Table 4-3.
2. Information resulting from investigator analysis of images and subsequent submission to the NDPF in the form of user supplied image descriptors.

In order to permit investigators to conveniently search this data base in a flexible manner, a special computer program known as Query Processing is available. It can be used either in a batch mode or in an interactive mode directly from a remote Cathode Ray Tube (CRT) terminal in the Browse Facility. In addition, investigators may phone a User Service representative and research the data base with the User Service representative operating Query Processing from his remote computer terminal.

A complete manual describing the Query Processing program is available at the NDPF or can be obtained from the NDPF for those investigators expecting to make frequent use of this service.

Table 4-3. Imagery Parameter Information Stored in NDPF Computer

Observation ID	**Sun Elevation**
Orbit No.	**Sun Azimuth**
Station ID	**Quality (Good, Fair, Poor)**
Ephemeris Type (Best fit or predicted)	**Cloud Cover (percent)**
Transmission Mode (Direct or Recorded)	**Geographic Area**
Altitude	**Time**
Heading	**Sensor**
Track	**Image Product (Type & Spectral Band)**

The program is such that a search can be made for given time periods, given geographical areas, any one of the items listed in Table 4-3 or by any descriptor in the Image Descriptor Catalog supplied to users. Moreover, the program is sufficiently flexible to allow almost any logical combination of search criteria to be specified.

The normal output of a search is the number of images found which meet the specified search criteria. Additional outputs can be specified as follows:

1. A Listing of all image identification numbers for those images satisfying the search.
2. A Catalog as shown in Figure 4-13 containing one-line descriptions of each image which satisfy the search criteria. The information for each image is essentially the same as detailed in the Standard Catalog.
3. An Image Output which is a printout of all data in the data base for each image which satisfy the search criteria. See Figure 4-14.

04/29/72 STANDARD CATALOG 04/10/72 TO 04/27/72 PAGE 1

KEY TO IMAGE CLARITY

G = GOOD

F = FAIR

P = POOR

THE IMAGES INDICATED BELOW ARE ON MICROFILM ROLL NUMBER: 001

OBSERV. IC	MICR. RBV	PAS. # MSS	DATE	CLOUD COVER	PRINCIPAL POINT OF IMAGES		SUN ELEV.	SUN AZIM.	IMAGE QUALITY RBV 1	RBV 2	RBV 3	MSS 1	MSS 2	MSS 3	MSS 4	AVAILABLE PRODUCTS BULK RBV	BULK MSS	BULK COLOR RBV	BULK COLOR MSS	PREC. RBV	PREC. MSS	PREC. COLOR RBV	PREC. COLOR MSS	DIGITAL RBV	DIGITAL MSS	DCS DATA
A00112250	0001	0002	07/01/72	45	44.290N	83.290W	31.2	31.2	G	G	G	P	P	P	F	X	X	X	X	X	X	X	X	X	X	X
A00112255	0003	0004	07/01/72	60	42.500N	83.500W	30.4	30.4	G	G	G	G	G	G	G	X	X	X	X	X	X	X	X	X	X	
A00112258	0005	0006	07/01/72	40	40.400N	84.280W	30.0	30.4	F	F	F	G	G	F	F	X	X	X	X	X	X	X	X	X	X	
A00112263	0007	0008	07/01/72	30	40.100N	80.480W	28.5	30.4	P	F	G	F	F	G	P	X	X	X	X	X	X	X	X	X	X	
A00112265	0009	0010	07/01/72	35	38.580N	85.260W	28.0	30.5	G	G	G	G	F	F	F	X	X	X	X	X	X	X	X	X	X	
A00212250	0011	0012	07/02/72	20	37.190N	85.500W	28.0	30.2	P	P	P	P	P	G	G	X	X	X	X				X	X	X	
A00212255	0013	0014	07/02/72	30	35.190N	86.190W	27.9	29.9	F	F	F	G	G	P	F	X	X	X	X	X				X		
A00212258	0015	0016	07/02/72	10	34.340N	86.590W	27.9	29.8	G	G	G	G	G	G	G	X	X	X			X	X		X	X	
A00212263	0017	0018	07/02/72	15	35.290N	87.100W	27.8	29.7	F	F	F	G	G	G	F	X		X	Y	X	X				X	
A00212265	0019	0020	07/02/72	45	31.490N	87.490W	27.8	29.7	G	G	[illegible]	[illegible]	F	F	G	X	X	X	X	X		X		X		X

STOP 0

Figure 4-13. Browse Processing — Display Catalog Output

OBSERVATION ID: 143100361 DATE: 06/04/73

ORBIT NUMBER:	2345	PICT CENTER (LONG):	7.300	DEG
TOTAL CLOUD COVER:	93	PICT CENTER (LAT):	35.710	DEG
STATION:	GOLDSTONE	ALTITUDE:	23.2	DEG
EPHEMERIS TYPE:	REFINED	HEADING:	741.7	NM
TRANSMISSION MODE:	DIRECT	TRACK:	321.2	DEG
SUBLAT POINT (LONG):	256.791 DEG	SUN ELEVATION:	0.1	DEG
SUBLAT POINT (LAT):	-73.428 DEG	SUN AZIMUTH:	-1.9	DEG
BLOCK:	CONT. U.S.	DCS DATA:	YES	

NUMBER OF PRODUCT ENTRIES PRESENT: 43

INDIVIDUAL CLOUD COVER TABLE

2 7 0 3

5 9 6 7

6 1 8 4

1 5 6 3

SENSOR	STATUS	QUALITY
RBV 1	ON	GOOD
RBV 2	OFF	GOOD
RBV 3	ON	POOR
MSS 1	ON	GOOD
MSS 2	OFF	POOR
MSS 3	OFF	FAIR
MSS 4	ON	GOOD

ABSTRACT DESCRIPTORS: *RIVERS * LAKES * DESERT

PRODUCT ENTRY PRODUCT CODE 175-L-19-U

BAND	PRESENT	BAND	PRESENT		
RBV1	YES	MSS1	NO	TYPE:	BULK
RBV2	NO	MSS2	YES	SIZE:	50x50
RBV3	YES	MSS3	YES	GRID NUMBER:	19
		MSS4	YES	TICK MARKS:	UNIVERSAL

DATE PRODUCED:	01/01/72
DATE OF LAST REQUEST:	03/15/73
ORIGINAL REQUEST NUMBER.	471
NUMBER OF REQUESTS:	31762

Figure 4-14. Browse Processing — Display Image Output

In addition to any or all of the above outputs, a request can be made for copies of those images satisfying the search criteria.

An example of the use of Query Processing via telephone is as follows:

- The User Services representative receives a telephone request. The investigator says that he wants all pictures for April 1972 for which users have identified cornfields (keyword: Corn).

- The representative dials the computer and, through the Query Processing Program, receives a count of such images. If the count is excessively large, he might ask the investigator to delimit his request.

- The investigator decides he really wants only those pictures with cloud cover less than 20 percent.

- The representative asks the computer to select from the first results those meeting this new criterion. Again, a count is returned.

- This delimitation can continue as long as necessary. At the end the investigator can order those images that satisfy his final search.

For investigators using Query Processing at the Browse Facility, the option exists to have special header labeling printed on the various outputs of the program. This option facilitates the investigator's preparation of reports based on his searches of the NDPF computer data base.

APPENDIX A
PAYLOAD

The Earth Resources Technology Satellite payload includes: a Return Beam Vidicon (RBV) camera subsystem, a Multispectral Scanner (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 complete description of the performance characteristics of each of these payloads.

A.1 RETURN BEAM VIDICON CAMERA

The Return Beam Vidicon (RBV) camera subsystem contains three cameras that operate in the following spectral bands:

Camera No.	*Spectral Band (micrometer)*
1	**.475 – .575**
2	**.580 – .680**
3	**.698 – .830**

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 Specifications

Item	Camera 1 .475 – .575 μm	Camera 2 .580 – 680 μm	Camera 3 .690 – .830 μm
Crosstrack Resolution (with high contrast target)	90 lp/mm	90 lp/mm	90 lp/mm
Edge Resolution (% of center)	80	80	80
Signal-to-Noise Ratio (at 100% highlight)	33 dB	33 dB	25 dB
Gray Scale (2 transmission steps)	10	10	8
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*
Video Bandwidth (MHz) without aperture correction	3.2 (–20dB)	3.2 (-20dB)	3.2 (–20dB)
Time Between Picture Sets (second)	25	25	25
Exposure Set Time		(milliseconds)	
(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
Focal Length of Lens f Number	126 mm	126 mm	126 mm

*Readout time includes 3.3 seconds ground scene 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.1-1. When the cameras are shuttered, the images are stored on the RBV photosensitive surfaces, then scanned to produce video outputs. The shutter provides uniform exposure over the photoconductor within a maximum variation of ±5 percent. As shown in the RBV timing relationships illustrated in Figure A.1-2, 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.

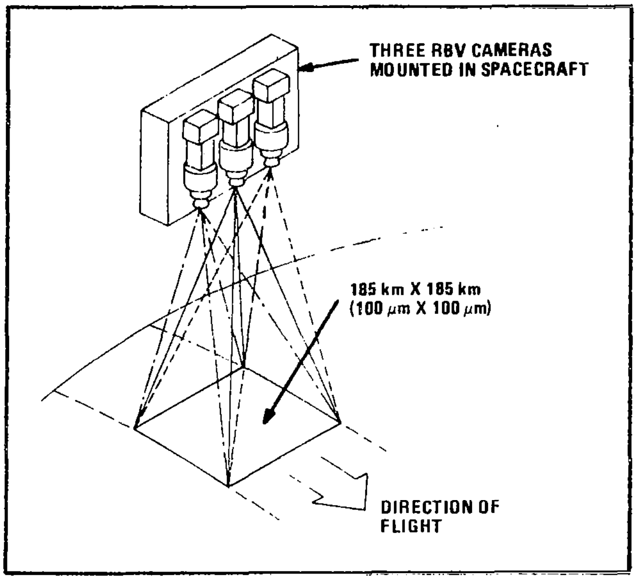


Figure A.1-1. RBV Scanning Pattern

The video data interval for each camera lasts for 3.3 seconds, lines 251 through 4375 of the composite video output. The format of the video data is presented in Figure A.1-3. The 720 microseconds of active video in each of the lines will be 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.

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.

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.

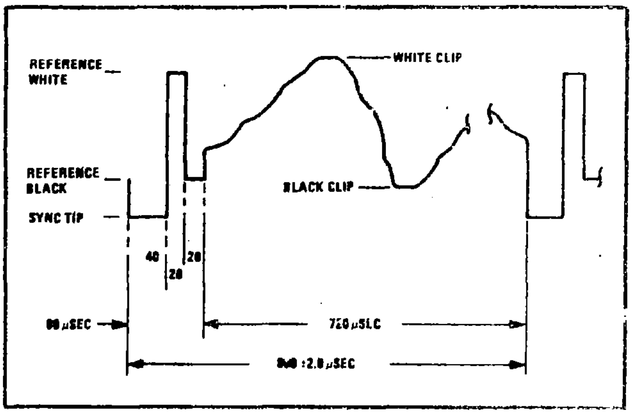


Figure A.1-3. Video Data Format for One Horizontal Line

In addition a calibration mode is provided and is exercised by command. In this mode the erase lamps provide three different exposures to each camera which are nominally 0, 30 and 80 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.1-4. 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 level for each of the three cameras.

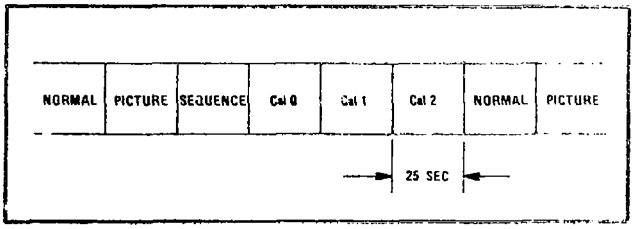


Figure A.1-4. Calibrate Mode Operation

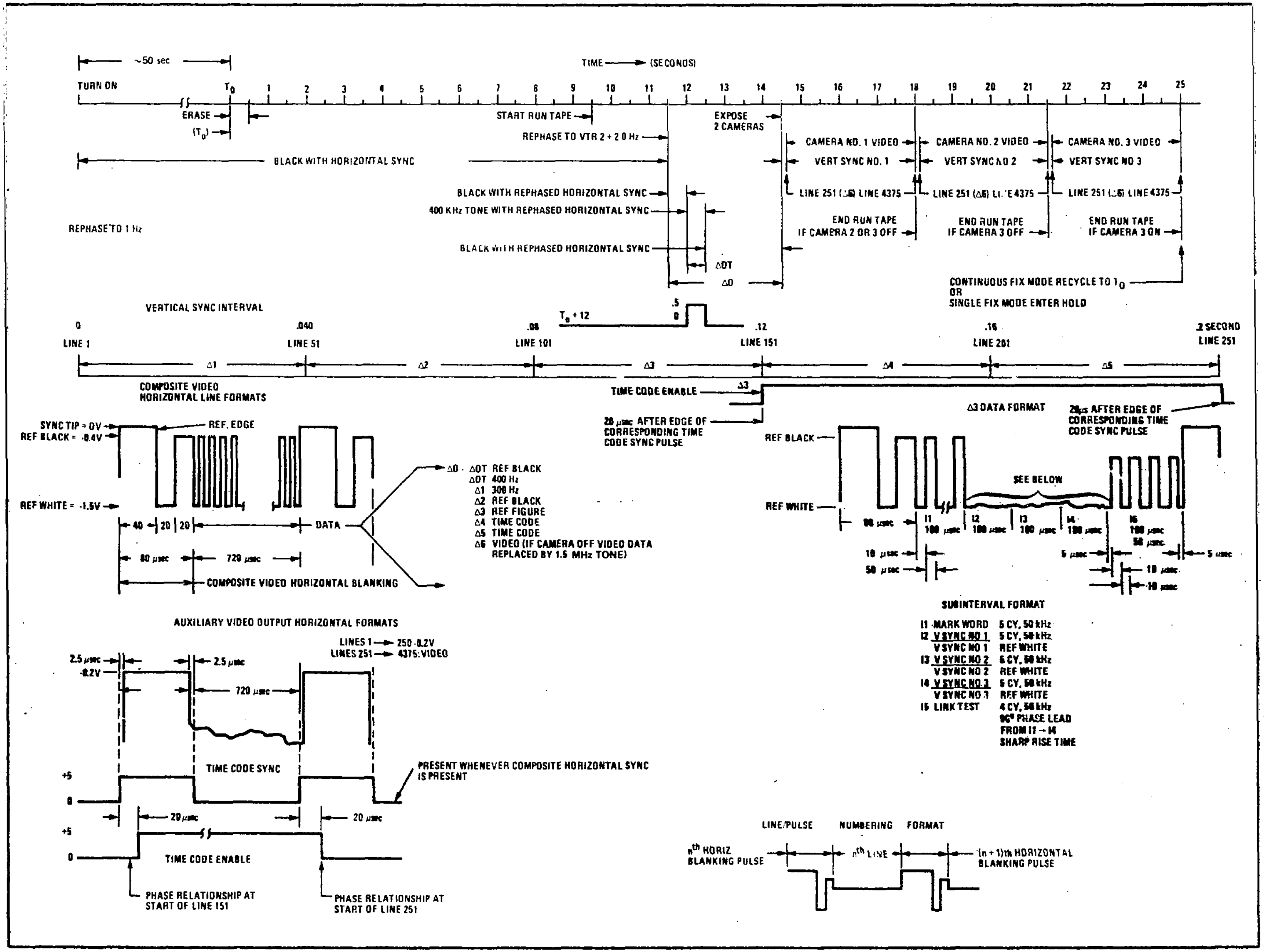


Figure A.1-2. RBV Camera Subsystem Timing Relationship

A.1.1.1 Reseau Marks and Scan Orientation

A reseau pattern is inscribed on the photoconductive surface of the RBV tube. Figure A.1-5 shows the reseau pattern as it projects into the scene being viewed by the camera. The orientation of the pattern is indicated by using two unique anchor marks in the pattern. These marks are defined in Figure A.1-6, along with the other pattern elements. The arrows in Figure A.1-5 marked "H" and "V" (lower right 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.

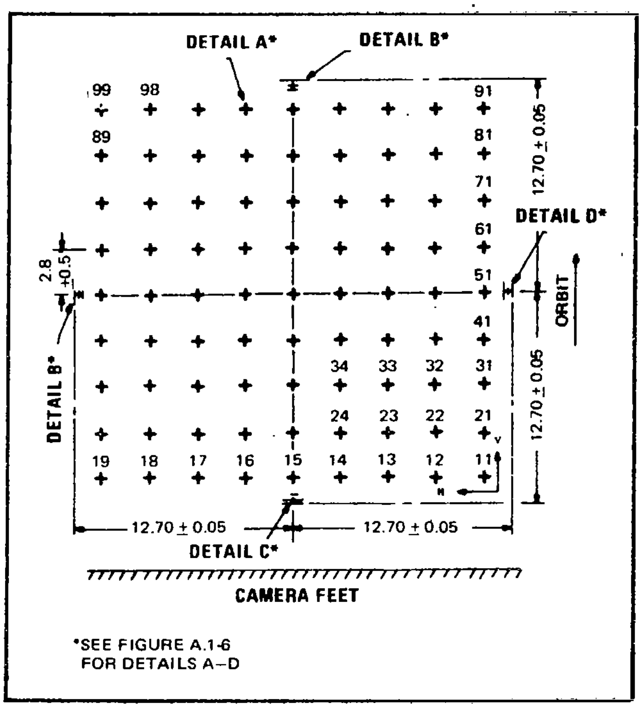


Figure A.1-5. Reseau Marks on Scene

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.1-5. 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 (shown in Figure A.1-7). The orbit track direction and shutter motion direction are also shown. The shutter mechanism in each RBV camera consists of two adjacent

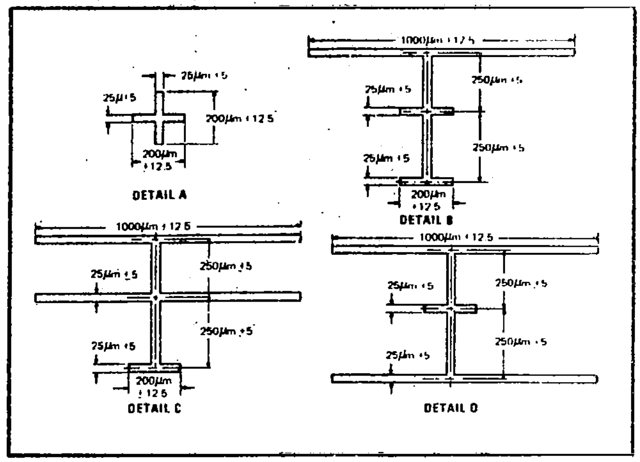


Figure A.1-6. Reseau Pattern Orientation

blades with offset cutouts which sweep across the vidicon aperture to provide the precommanded exposure time to each portion of the photoconductor.

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 reseaus will be mapped on the vidicon faceplate with approximately 3 micrometer accuracy.

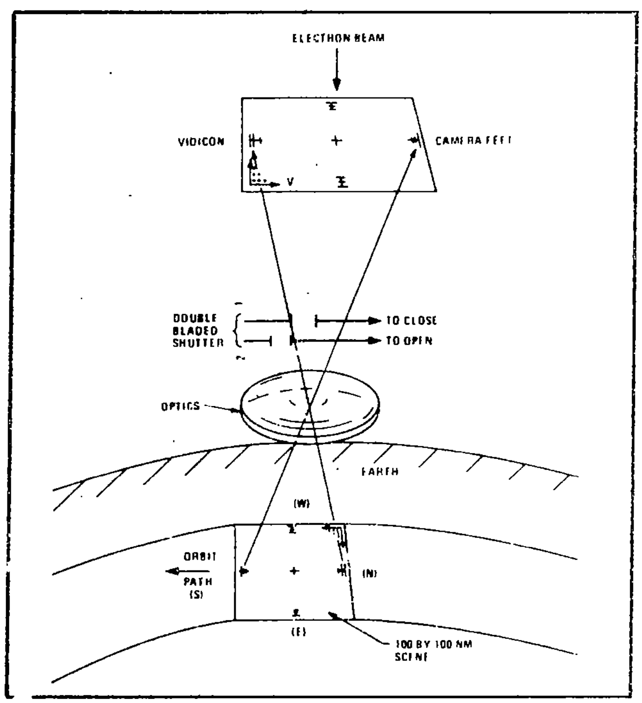


Figure A.1-7. Camera-Scene Orientation

A.1.2. Performance

A.1.2.1 Resolution

Typical modulation transfer functions (MTF) for the RBV (lens, vidicon and amplifier) are shown in Figure A.1-8. An improvement in the basic MTF, 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 in MTF will apply 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 "in" or "out."

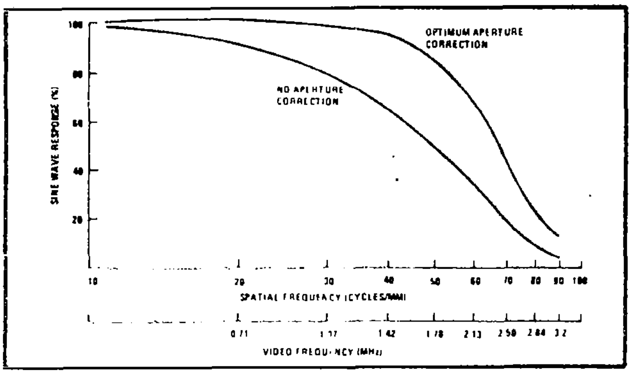


Figure A-1-8. Typical Sine Wave Response – RBV Camera (at center of image, with high contract target)

The limiting resolution at the center of each camera at the video bandwidth of 3.2 MHz is 90 l/mm, which is equivalent to a bar width of approximately 45 meters on the ground. Edge resolution will be no less than 80 percent of center resolution. A more detailed presentation of resolution with other than high 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 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	RBV DESIGN SPECIFICATION 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		±1% MAXIMUM EACH AXIS	1310
5	NONLINEARITY		±1% MAXIMUM EACH AXIS	518
6	SKEW		3.5% MAXIMUM	377
7	RASTER ROTATION		1 DEGREE	754

A.1.2.3 Radiometric Fidelity

Based upon the definitions of shading given in Figure A.1-9 and test results, it is expected that for cameras 1 and 2 at points 10 percent down, the center, and 10 percent up on the image, the shading characteristics will be approximately 60 percent signal shading at the corners and 30 percent black shading in a one inch radius quality circle. For camera 3 (red) the shading goes up considerably; approximately 40 percent in the circle of quality and greater than 100 percent at the corners. These conditions are summarized in Table A.1-3.

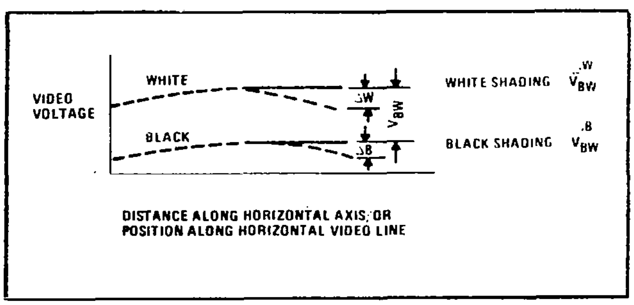


Figure A.1-9. Shading Definitions

Table A.1-3. RBV Shading

	RBV CAMERA		
	1	2	3
SIGNAL SHADING (%)	60	60	100
BLACK SHADING IN 1 INCH RADIUS QUALITY CIRCLE (%)	30	30	40

As described in Appendix F and Appendix G, shading is compensated utilizing RBV radiance maps in the NDPF correction processes.

Figure A.1-10 illustrates the RBV camera subsystem and graphically shows the effects of radiometric errors as an input is processed through the camera subsystems.

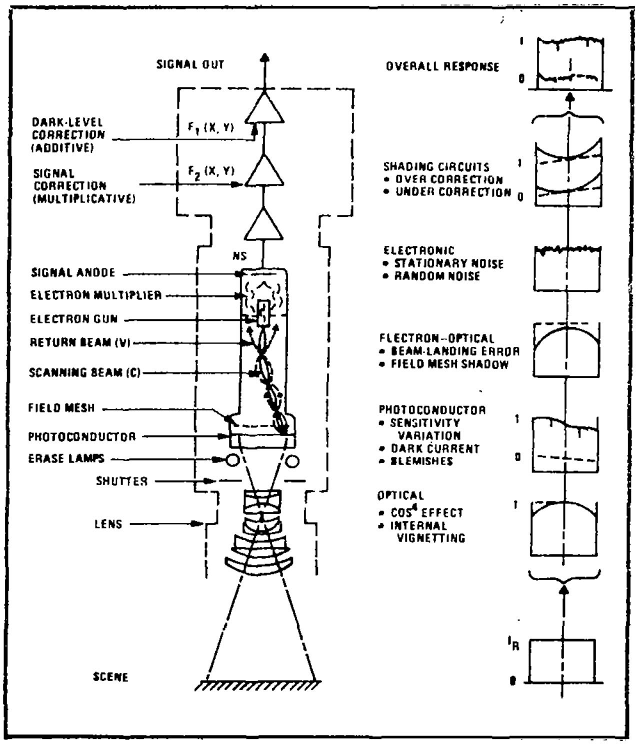


Figure A.1-10. RBV Camera Subsystem and Radiometric Error Sources

A.1.2.4 RBV Exposure Capabilities

The capability of the RBV cameras to recognize specific scene radiance without saturating is a function of the light transfer characteristics (LTC) and time of exposure of each camera. The LTC relates voltage output to exposure for mean levels or levels in large areas (near zero spatial frequencies). Figure A.1-11 presents a typical LTC for Bands 1 and 2. An estimate for Band 3 is also shown. This information will be updated in a supplement to the Handbook.

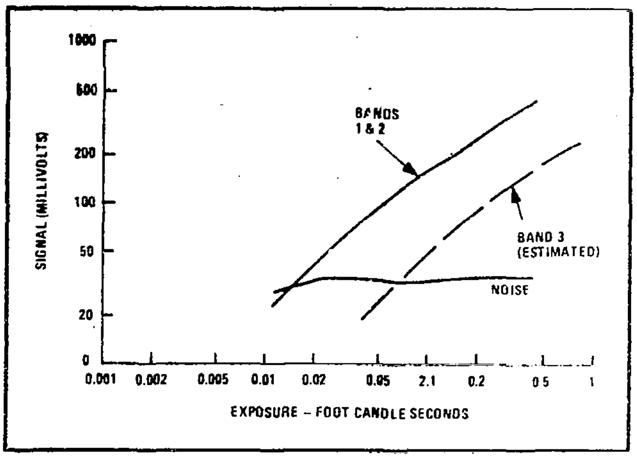


Figure A.1-11. Light Transfer Characteristics at 3000°K for RBV Bands 1 & 2

The saturation level for Bands 1 and 2 is 0.78 μ joules/cm^2 and 1.2 μ joules/cm^2 for Band 3. The maximum mean radiance of a scene at the vidicon faceplate is related to the saturation levels and exposure time by:

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

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.1-4 delineates the exposure time settings along with the value of scene radiance at saturation of the vidicon.

Table A.1-4. Scene Radiance at Saturation for Various Exposure Times

Exposure Set	Band 1		Band 2		Band 3	
	t_s (ms)	N_{SAT} (mw/cm^2-sr)	t_s (ms)	N_{SAT} (mw/cm^2-sr)	t_s (ms)	N_{SAT} (mw/cm^2-sr)
1	16	0.63	16	.63	16	1.02
2	12	0.85	12	.85	12	1.36
3	8	1.27	8.8	1.16	8.8	1.85
4	5.6	1.82	6.4	1.54	7.2	2.26
5	4	2.54	4.8	2.12	6.4	2.55

Table A.1-5 shows calculated values of scene radiance at sensor input for various solar zenith angles and typical ERTS scenery. 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 be interpreted as precision values.

A.2 MULTISPECTRAL SCANNER SUBSYSTEM

The Multispectral Scanner (MSS) subsystem 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 wave length. 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 approximately +2.89 degrees about its nominal position as shown in Figure A.2-1.

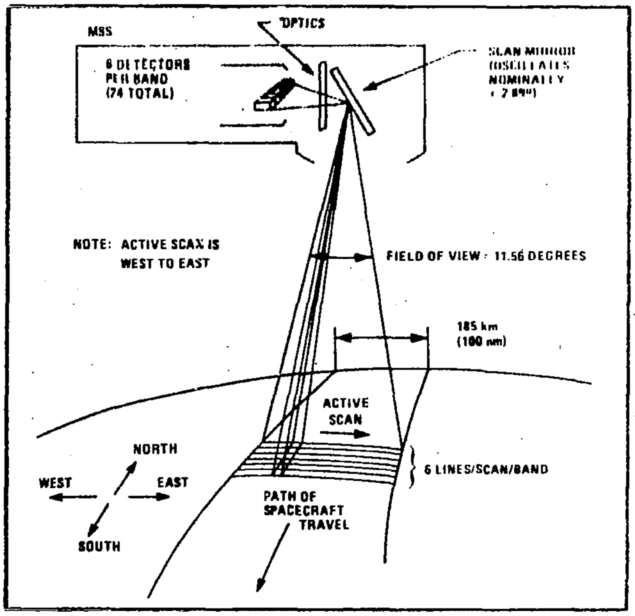


Figure A.2-1. MSS Scanning Arrangement

The instantaneous field of view of each detector subtends an earth-area square of 79 meters on a side form 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

Table A.1-5. 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
$+1\sigma$ 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.

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.

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 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.

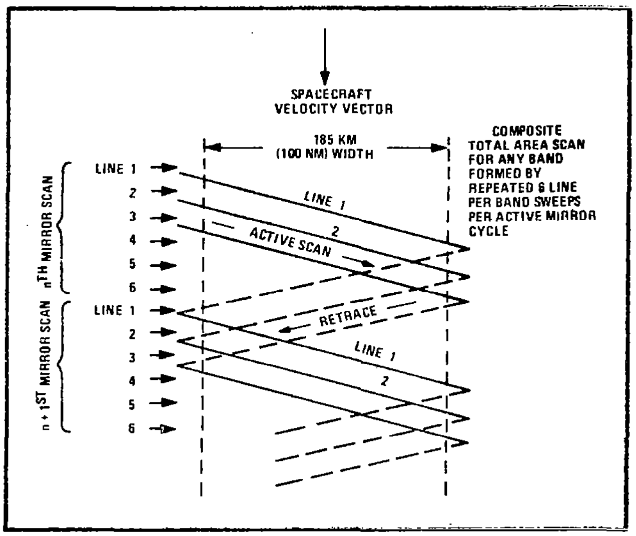


Figure A.2-2. Ground Scan Pattern for a Single MSS Detector

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) spectral 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. Resolution dimensions are three times greater than for Bands 1 through 4. Energy is accepted through a slit near the fiber matrix and conducted by relay optics onto the detectors which form the field stops. The 5-band MSS has 26 video channels.

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 swath. Sampling of the detectors is initiated at the mirror position corresponding to the westward edge of the swath. Sampling is preempted by an end-of-line code as the mirror reaches the position corresponding to the eastward edge of the swath. By this method the scan line may be corrected by NDPF processing to exactly 185 kilometers in length.

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 characteristics of the calibration or gray wedge are as shown in Figure A.2-3.

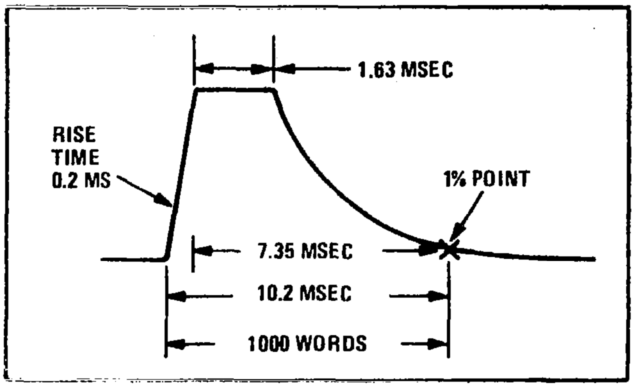


Figure A.2-3. Nominal Calibration Wedge Output

Knowledge of the lamp spectrum makes it possible to obtain a check of the relative radiometric levels and also to equalize gain changes which may have occurred in the six lines for one 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.

The shutter is actually designed to rotate once for every two scans so that the calibration signals are available during alternate retrace intervals. Band 5 is calibrated at the two ends of the sensitivity scale by means of absorbing (black body) and reflecting (sensor self temperature) targets located on the shutter wheel.

Once in each orbit, shortly after spacecraft sunrise, a small four-faceted mirror, located below the scan mirror, deflects a sample of sun light through a neutral density filter and on to the scan mirror. The level of the data output during this time provides an absolute calibration point by which the calibration lamps may be checked.

The video outputs from each detector in the scanner are sampled and commutated once in 9.96 microseconds and multiplexed into a pulse amplitide modulated (PAM) stream. The commutated samples of video then can be transmitted directly to the analog-to-digital (A/D) converter for encoding, or bands 1 through 3 can be directed to a logarithmic signal compression amplifier and, then, to the encoder. This selection is made by ground command. 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.

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 (SNR) ratio
2. Spatial resolution which is nominally defined by a modulation transfer function (MTF) analysis
3. Band-to-band registration
4. Geometric fidelity
5. Relative radiometric accuracy

The amplitude resolution and MTF are inherent characteristics of the sensor system and cannot be improved by ground processing. The last three characteristics are representative of properties which are amenable to ground processing correction if errors are systematic or slowly time varient. These five characteristics are treated in Paragraphs, A.2.2.1 through A.2.2.5.

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.2-1. Estimates of SNR performance for two-scene conditions are shown in Table A.2-2.

Table A.2-2. Scanner Sensitivity

	Spectral Bands (ERTS A)			
	1	2	3	4
Voltage SNR for bright scene	80	62	40	89
Radiance at scanner (10^{-3} watts cm^{-2} $ster^{-1}$)	2.48	2.00	1.76	4.60
Voltage SNR for dim scene	25	20	12	8.9
Radiance at scanner (10^{-3} watts cm^{-2} $ster^{-1}$)	0.25	0.20	0.18	0.46
		ERTS B (Band 5)		
Noise equivalent incremental temperature (NE Δ T)		1.08° nominal		
Scene temperature (°K)		300		

Table A.2-1. MSS Parameters Affecting Signal-To-Noise Ratio

Parameter (Units)	Band	Nominal
Instantaneous Field-of-View (mr)	1-4 5	0.086 0.258
Mean photocathode sensitivity over spectral band 9 ma watt-1)	1 2 3	34.5 25.0 12.0
PMT sensitivity enhancement factor	1-3	2.40
Electrical Bandwidth (kHz)	1-4 5	42.3 14.1
Optical efficiency, including obscuration	1-4 5	0.26 0.34
Electron multiplier noise factor	1-3	1.40
Preamplifier noise factor	4 5	1.35 1.30
Noise equivalent power (10^{-14} watts $Hz^{-1/2}$)	4	11.0
Noise equivalent power (10^{-10} watts $Hz^{-1/2}$)	5	1.0
Radiance into sensor to produce full scale output (milliwatts cm^{-2} $ster^{-1}$)	1 2 3 4	2.48 2.00 1.76 4.60
Spatial frequency response (MTF for sine wave)	1-5	1
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 changer per unit temperature change (10^{-} watts cm^{-2} $°K^{-1}$ $ster^{-1}$ μm^{-1})	5	0.131

The minimum system voltage SNR output, in both the compression and linear modes of operation, versus input radiance levels are shown in Figure A.2-4.

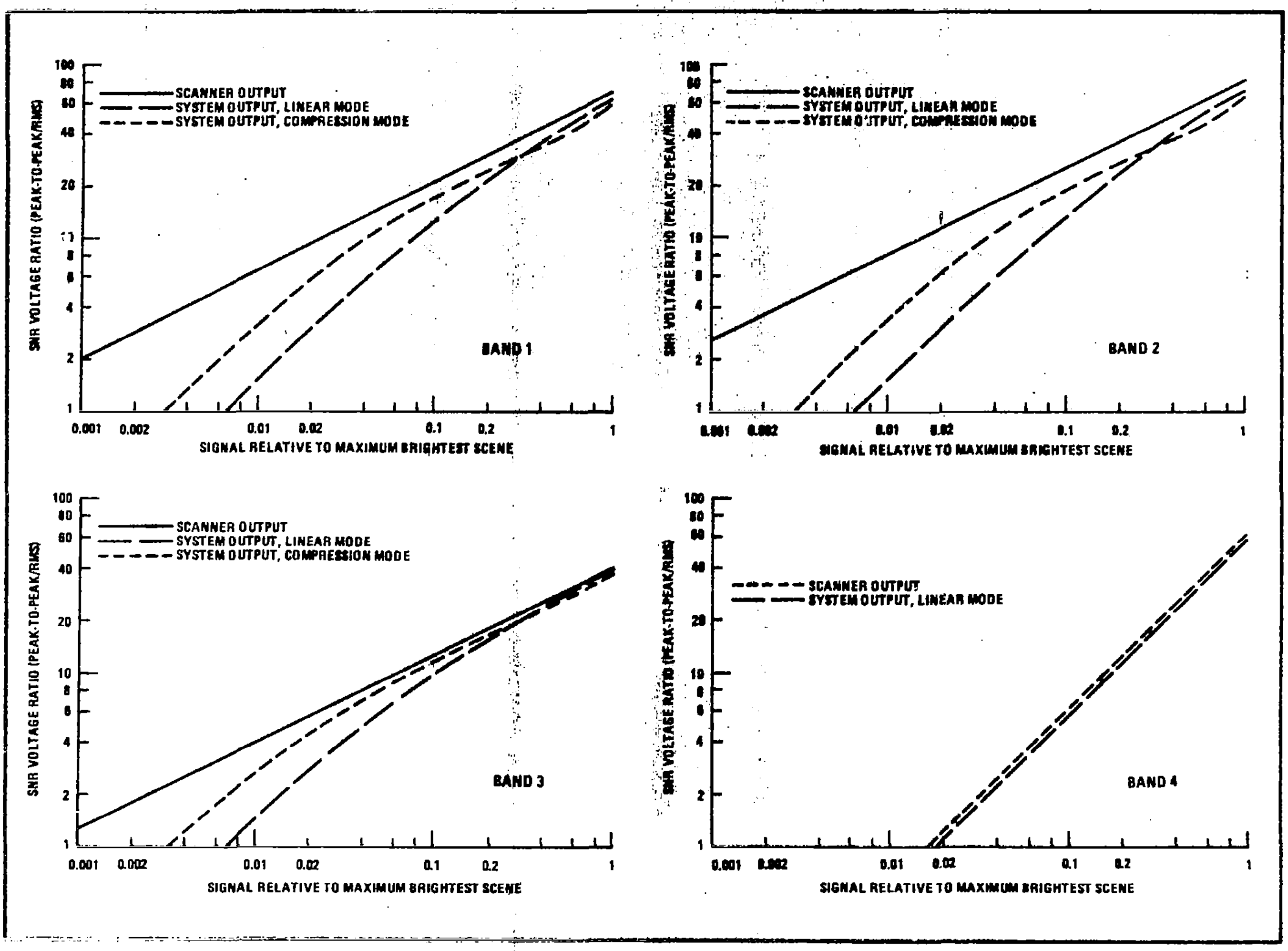


Figure A.2-4. Signal Relative to Maximum Brightest Scene

A.2.2.2 Modulation Transfer Function (MTF)

The modulation transfer function for the MSS is shown in Figure A.2-5 along with the components which are the principal contributors to the total MTF. Not included are MTF's for the 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 and the primary source of error lies in the accuracy with which the optical fibers can be aligned and the variation in scan rate across the swath. Effects of these tolerances of the optical fibers are listed in Table A.2-3.

Table A.2-3. Systematic Registration Errors Among Spectral Bands Due to Fiber Pattern

Direction	Magnitude
Across Track	±10 meters
Along Track	±20 meters

ORIGINAL
SEPTEMBER 15, 1971

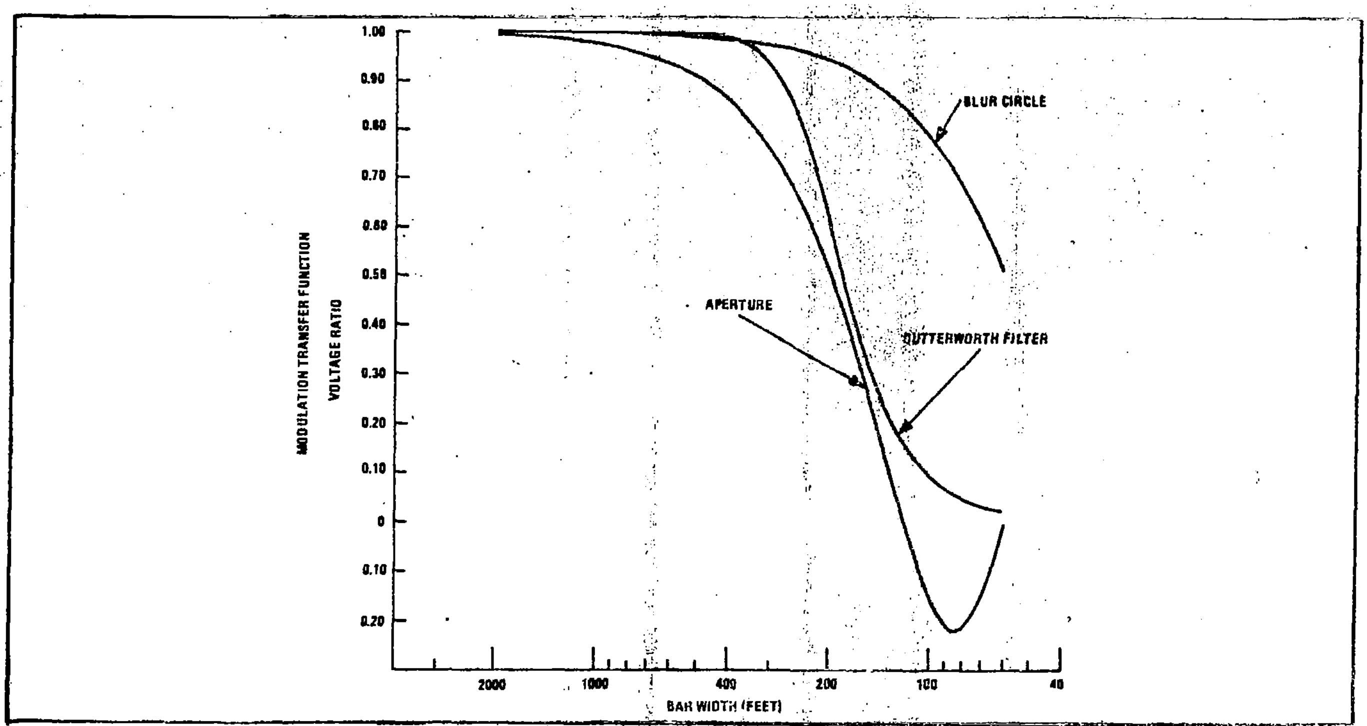


Figure A.2-5. Modulation Transfer Function

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 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).

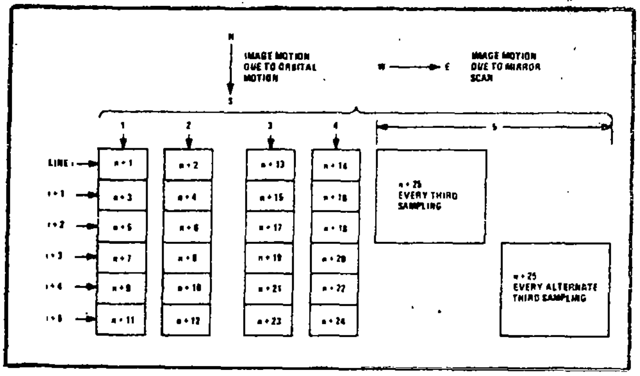
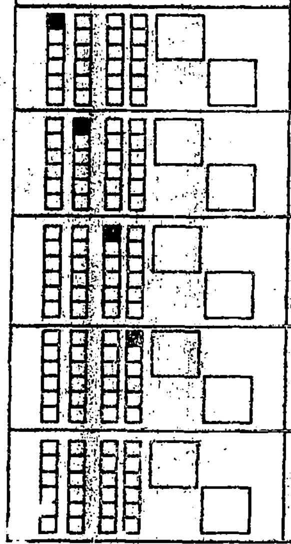


Figure A.2-6. Detector Spatial Layout and Sampling Sequence

Figure A.2-6 shows the detector layout and sampling sequence while Figure A.2-7 shows the band to band registration delays required to yield the same sample on the ground under the assumption of a constant scan velocity.



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
	44.676	4 COMPLETE SCAN SEQUENCES PLUS 12 SEQUENTIAL SAMPLES
	64.074	6 COMPLETE SCAN SEQUENCES PLUS 13 SEQUENTIAL SAMPLES
	—	COMPLETE SCAN SEQUENCES PLUS SEQUENTIAL SAMPLES

NOTES: 0.393 μSEC PER SEQUENTIAL SAMPLE
9.85 μSEC PER COMPLETE SAMPLING SEQUENCE (28 SAMPLES)

Figure A.2-7. Band-to-Band Registration Delay

For a nonlinear mirror sweep rate there will be misregistration at the ends of the scan. The expected error is small as shown below:

Band (Band 1 is Reference)	Misregistration at Scan Extreme
2	5 meters
3	10 meters
4	15 meters

Unprocessed errors due to the inaccuracies in the fiber matrix and variations in scan rate for the MSS prototype model are given below.

- Horizontal Registration Errors: worst case:

Between → ↓	Bands 1	2	3
	Meters on Ground		
4	15.25	7.92	7.83
3	7.92	3.35	-
2	7.32	-	-

- Vertical Registration Errors: worst case 2.74 meters

This type of tabulation, with a microscope photograph of the fiber matrix, will be supplied with each flight subsystem.

A.2.2.4 Geometric Fidelity

A tabular summary of scanner errors which introduce positional errors in the imagery is shown in Table A.2-4.

The scan nonlinearity arises from the nonlinear torque due to the mirror support pivots.

Cross scan jitter is defined in terms of deviations from a straight line active sweep. It can be considered as being made up of systematic and random components. For a systematic cross-axis input from scan to scan, the consecutive scans would be distorted but

Table A.2-4. MSS Geometric Errors

Scan Linearity	+1.4 to -3.9% (1σ) within a band
Random Cross Scan Jitter	9 μ rad rms 17 μ rad peak
Scan-to-Scan Repeatability	4 μ rad rms 8 μ rad peak
Scan Start Variation	1 μ sec
Detector Alignment	¼ resolution element
Sample Time	120 ns sample and hold
Scan End Variation	(Data will be supplied in a later supplement)
Sampling Uncertainty	10^{-4} crystal error

not blurred as the full area would be covered. The random or scan to scan variation results in a blurring effect which can be described by an equivalent MTF (measurements indicate a 0.99 MTF).

Scan to scan repeatability errors of the mirror contribute to the amount by which one set of six lines is misaligned along the scan direction with respect to the adjacent six lines after the line lengths have been normalized. These errors are dependent on mirror repeatability, line length adjustment electronics, and the setting of the time delay before data sampling begins.

The other characteristics noted in Table A.2-4 include: scan start variation, detector or fiber optics alignment, sample time, scan end variations, and sampling uncertainties.

A.2.2.5 On-Board 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 an incandescent light source is projected on the fibers by way of a prism. A continuously variable neutral density filter is swept across the light path so that each video channel carries a triangular pulse of about 10 milliseconds duration, which begins with an abrupt transistion from black to white and descends monotonically back to black where the intensity ratio from beginning to end is about 100 to 1. Knowledge of the lamp spectrum makes it possible to obtain a check of the relative radiometric levels and also to equalize gain changes which may have occurred in the six lines for one 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 to within two percent so that striping will be avoided.

Illumination is provided by a tungsten lamp operated at a derated temperature of 1900°K. The illuminated surface of a lens is imaged near the lamp in order to optimize the uniformity over the 0.015 by 0.015 inch fiber array. The 0.040-inch diameter beam illuminates the fibers with a variation less than ± 5 percent and with sufficient energy to simulate a bright scene in Band 1 (0.5 to 0.6 micrometer).

To achieve a relative spectral distribution similar to that of the sun, a combination of 1 mm Schott BG-14 and 2 mm Schott KG-1 color glass filters are used in the source assembly.

The shutter rotates once for every two scans so that the calibration signals are available during alternate retrace intervals. Once in each orbit, a small four-faceted mirror located below the scan mirror, deflects a sample of direct sun light across the optical fibers. The output appears as a one to two millisecond pulse in the data and may be regarded as the primary calibration source by which the spectral output of the calibration lamps may be monitored.

For the ERTS B mission, a black body reference patch is mounted on the same shutter wheel so that IR calibration signals for Band 5 are also available during the scan mirror retrace time.

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.

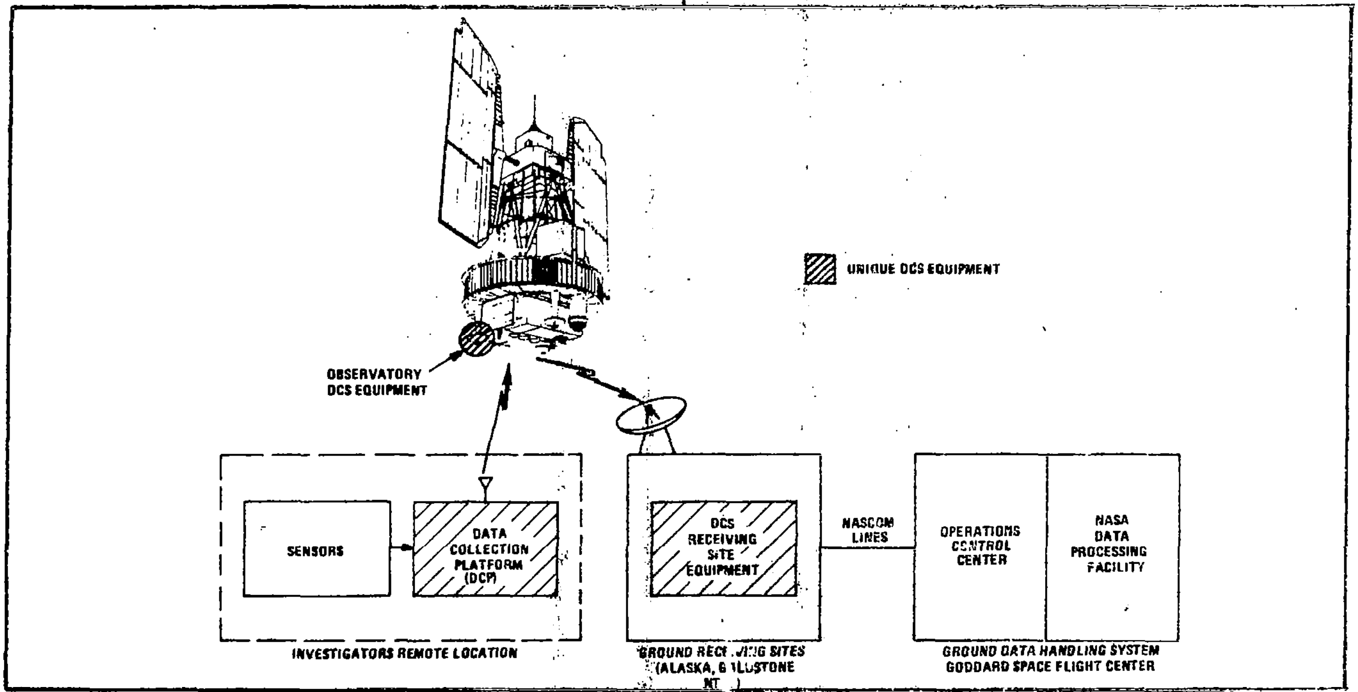


Figure A.3-1. Data Collection System Block Diagram

The DCP is connected to individual analog sensors which are selected and provided by the investigator or user agency to satisfy his own particular needs. Up to eight individual analog sensors may be connected to a single DCP. The DCP transmits the sensor data which is relayed 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 passed to the NASA Data Processing Facility (NDPF) for further processing 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 492 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 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.

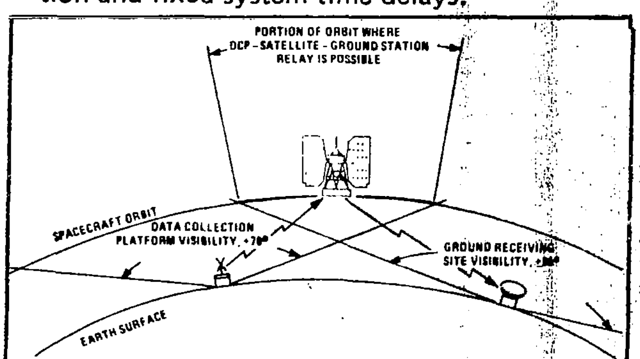


Figure A.3-2. DCS Data Relay Geometry

The orbit parameters of 492 nautical mile altitude and 103 minute period 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, provide 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 a ground receiving site 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

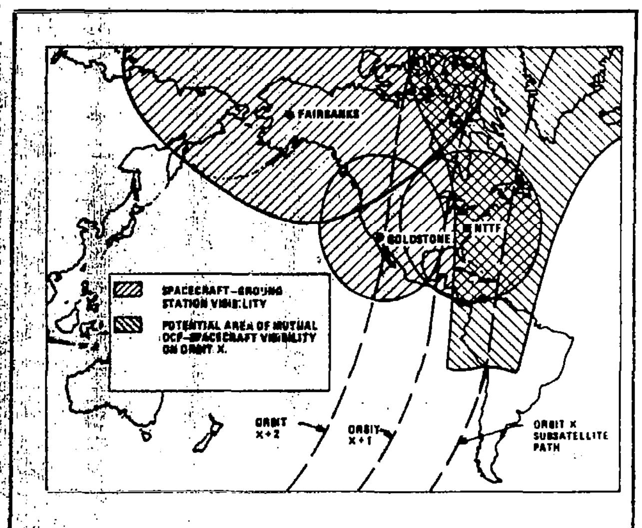


Figure A.3-3. Mutual DCP-Receiving Site Visibility identify messages containing errors and to identify incomplete messages. The probability of erroneously indicating that a given message is valid (i.e., stating that a message which contains an error does not) is less than 0.01.

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 hardware subsystems—the Data Collection Platforms, the receiving and transmitting equipment in the satellite, and special receiving 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.

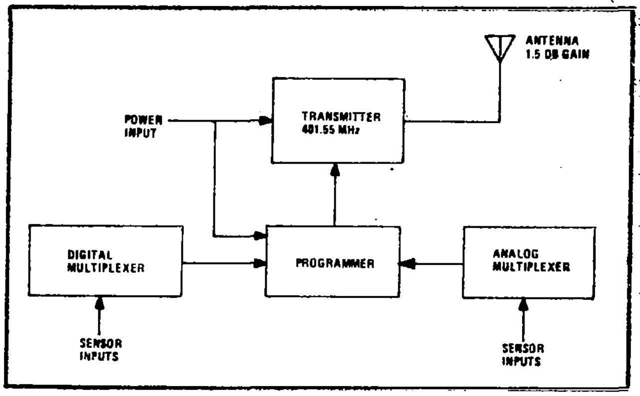


Figure A.3-4. Data Collection Platform Block Diagram

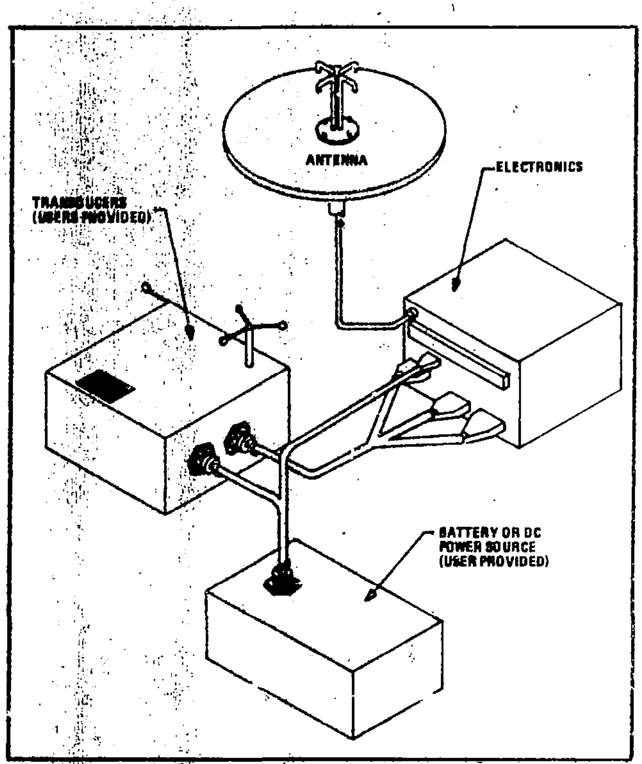


Figure A.3-5. Data Collection Platform

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.

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 sequence 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 on-board recording, processing or decoding of the data is performed. A DCS unique UHF antenna and receiver is provided. Unified S-Band (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 data 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 representation recovered from the DCP transmission is in the form of a four-bit byte; one bit, indicating the presence or lack of signal, 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. This data is outputted to a site modem in real time as messages are received. The data is buffered and formatted into a 1200-bit NASCOM block and transmitted to the OCC by hardline. 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.

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, 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 messages except for receiving site (station ID). An active data file is generated which maintains a record of the most recent

24 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
	24-31	Station ID	EBCDIC	A/G/N
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	'3FF'
	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	

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 format is given in Figure 3-21.

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	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	0-7
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 same format as the data bits. Columns 51/57-72 are optional, depending on the use of data quality bits.

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 DCS catalog is available to users and is explained in Section 4.2.3.

APPENDIX F
OBSERVATO ?Y

The ERTS observatory (F:gure B-1) is an earth-pointing stabilized spa-ecraft consisting of integrated subsystems that provide the power, control, environment, orbit maintenance, attitude control, and information flow required to support the payloads for a period of one year in orbit. It weighs 1,800 pounds (818 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).

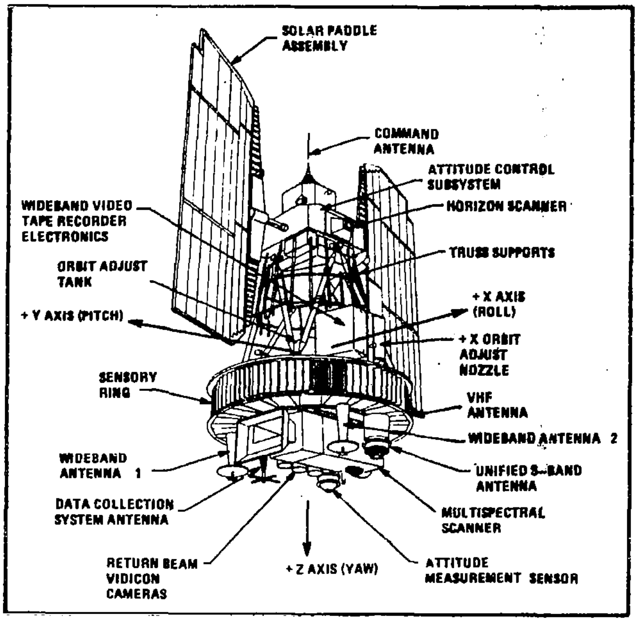


Figure B-1. ERTS Observatory

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 degrees 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 3.5-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 21 minutes of payload (both RBV and MSS) "ON — time" per orbit initially and 13.5 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.

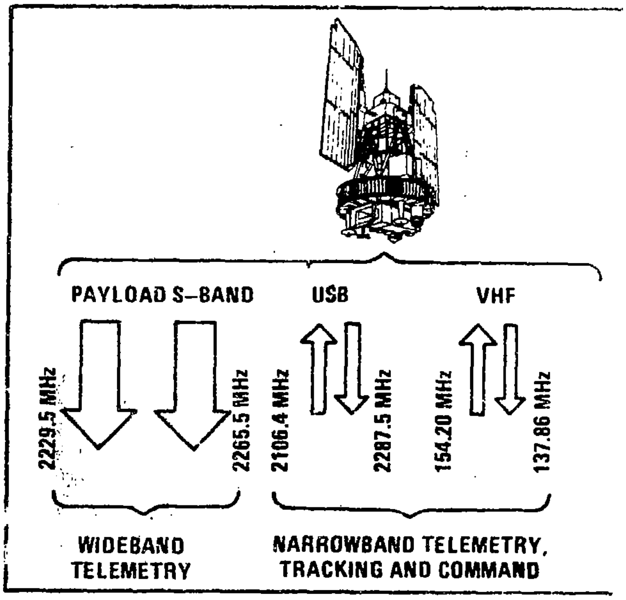


Figure B-2. ERTS Communication Links

B.5.1 WIDEBAND TELEMETRY SUBSYSTEM

The Wideband Telemetry Subsystem accepts and processes data from the RBV, the MSS 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 twice 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 of 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 (i.e. 19.53 mv.)

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.

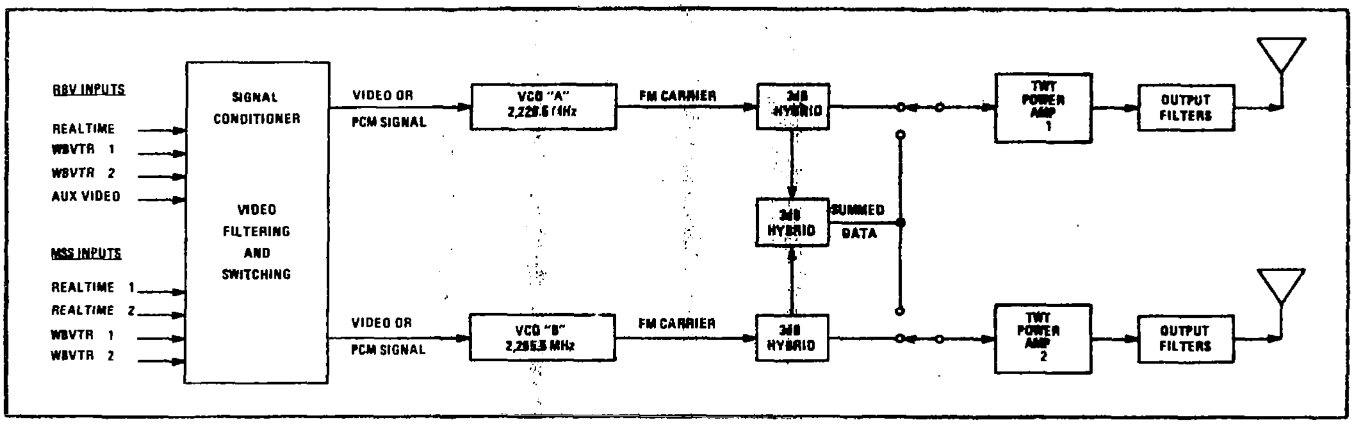


Figure B-3. Wideband Telemetry Subsystem Functional Block Diagram

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 either the Manned Space Flight Network (MSFN) or Satellite Tracking and Data Acquisition Network (STADAN), 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 34 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 part of either NASA's Manned Space Flight Network (MSFN) or Space Tracking and Data Acquisition Network (STADAN). The NASA Communications (NASCOM) System 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).

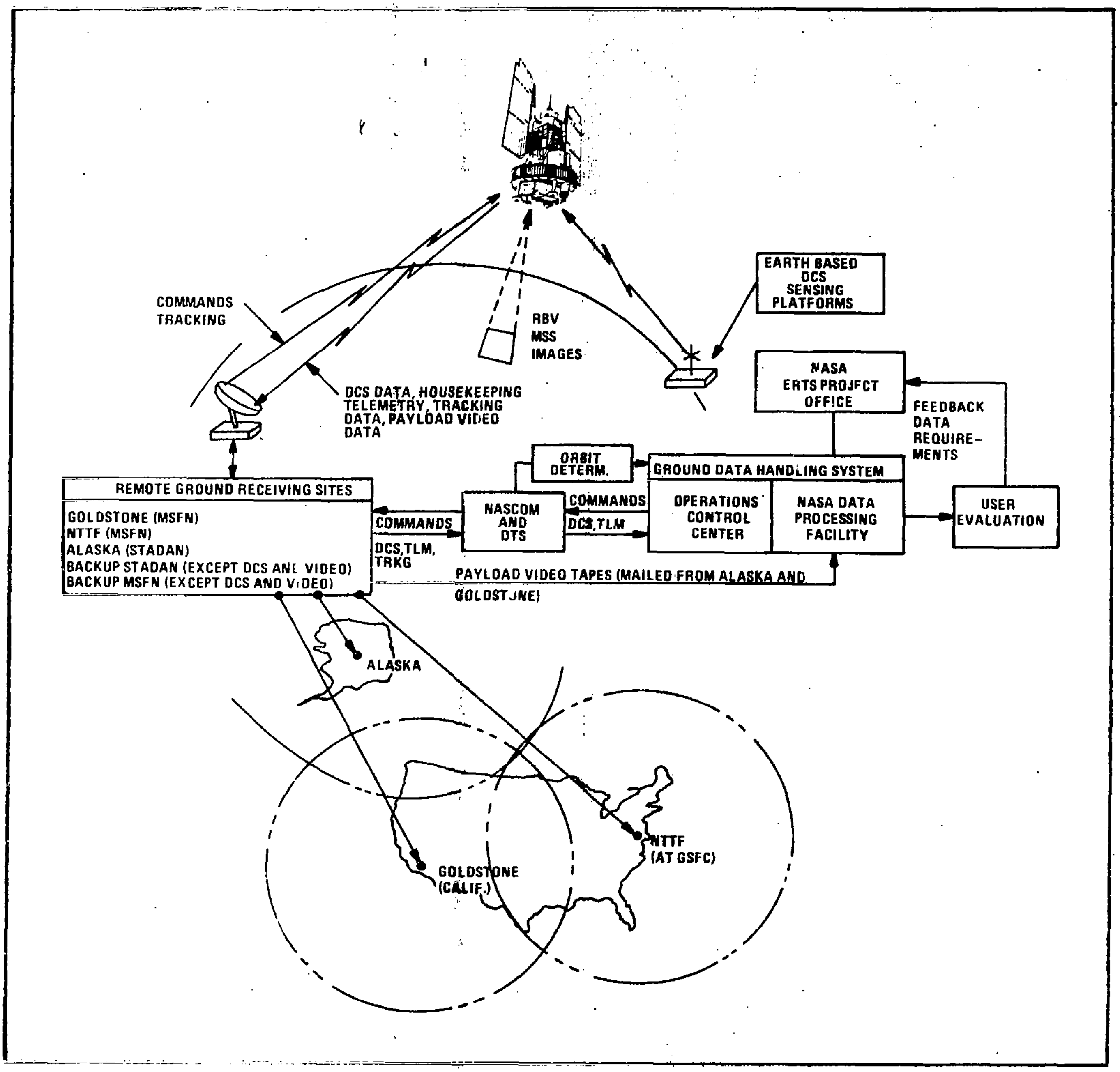


Figure C-1. Communications and Data Flow Configuration

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

STATION		NETWORK
Goldstone (Calif.)	—	MSFN
NASA Test and Training Facility (NTTF)	—	MSFN
Alaska	—	STADAN

These are the only sites equipped to receive the Multispectral Scanner (MSS), Return Beam Vidicon, and Data Collection System (DCS) data, and perform all narrowband telemetry, tracking and command functions. Other MSFN and STADAN 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	STATION				
	Goldstone	Alaska	NTTF	Backup MSFN	Backup STADAN
Payload Data					
Receive RBV/MSS Video	X	X	X		
Receive DCS Data (USB)	X	X	X		
Transfer RBV/MSS Video To OCC			X		
Mail RBV/MSS Video Tapes to NDPF	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	
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

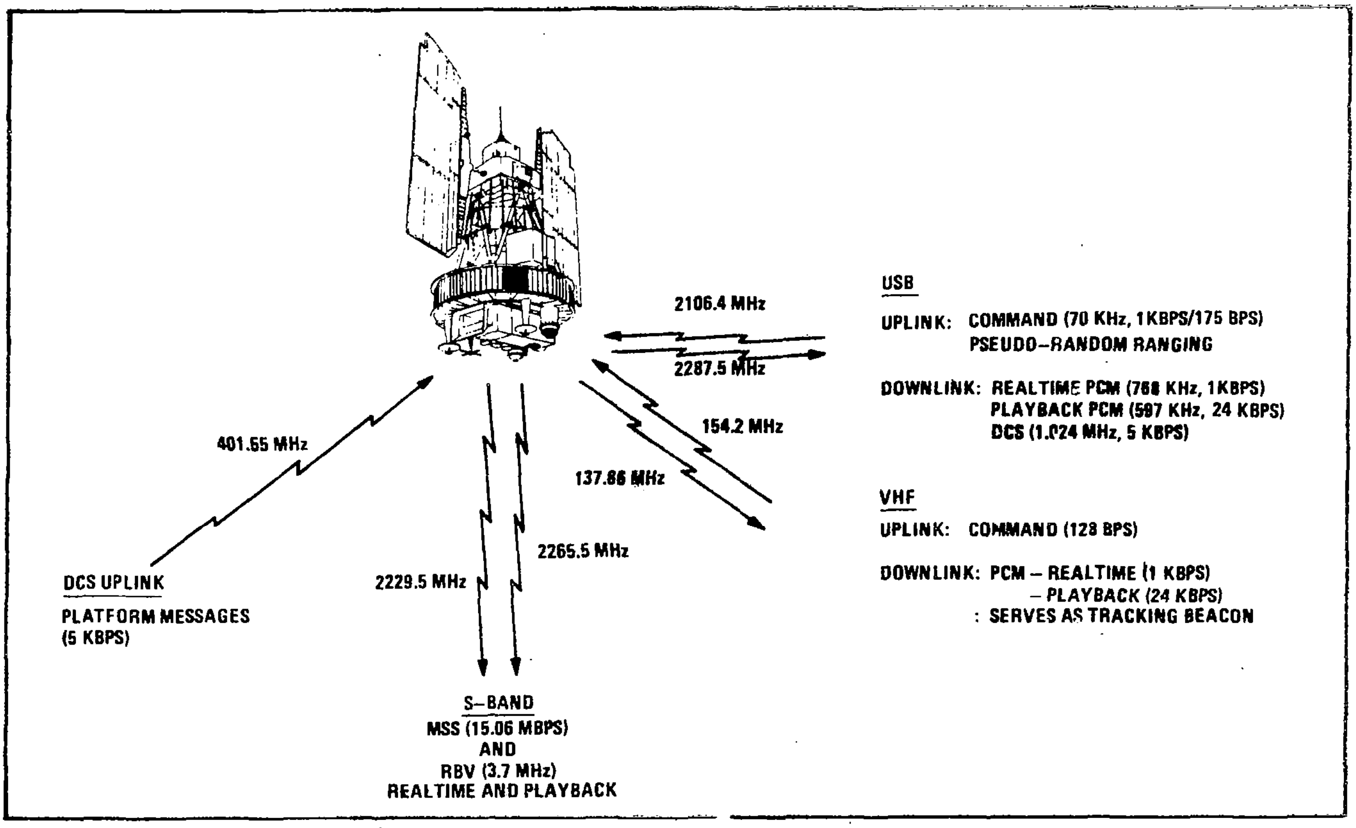


Figure C-2. Spacecraft/Ground Communication Links

C.2 PAYLOAD WIDEBAND COMMUNICATIONS

C.2.1 Spacecraft to Ground Communication

RBV and MSS wideband d. .a are normally telemetered simultaneously to one of the three prime ground stations over two S-Band links operating at center frequencies of 2229.5 MHz and 2265.5 MHz. The RBV camera has a video bandwidth of 3.5 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 and Goldstone stations the data is received and demodulated and then hardwired into special Receiving 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.

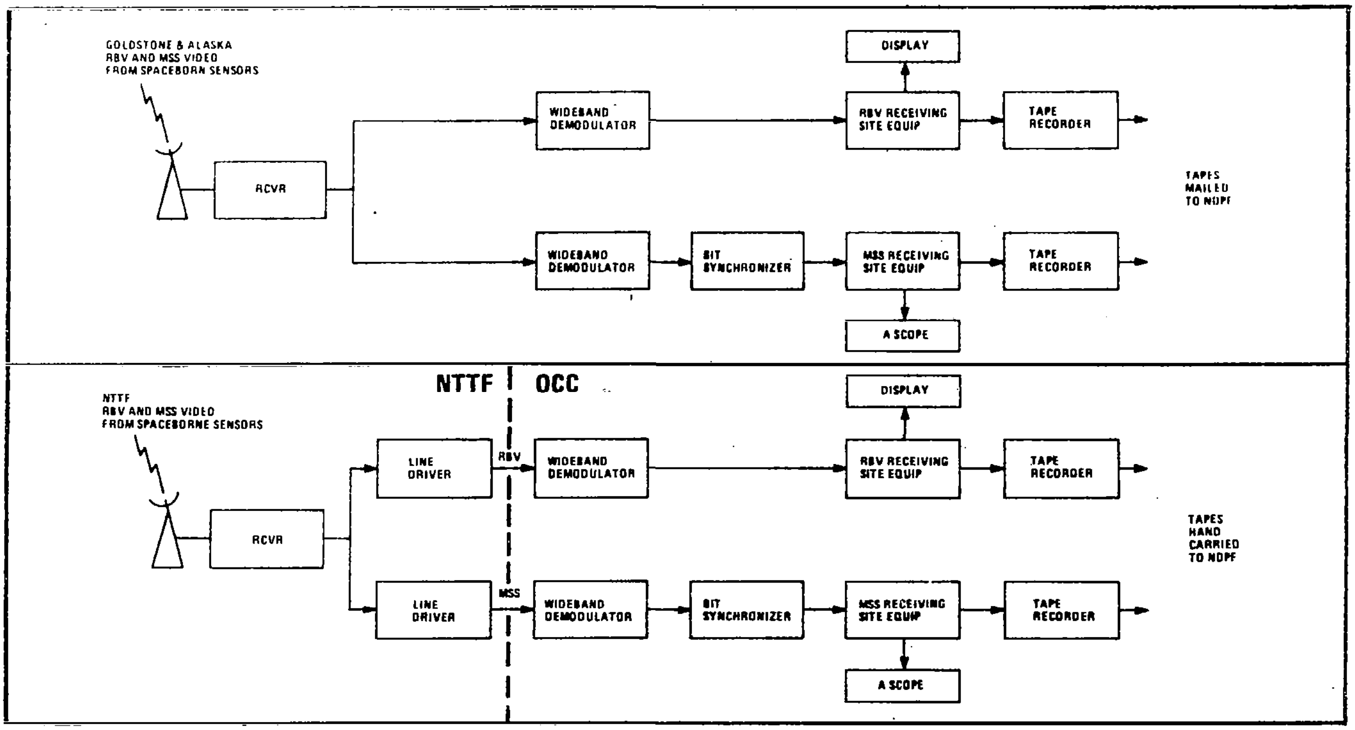


Figure C-3. Wideband Video Data Flow

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 MSFN or STADAN type stations. S-band equipment is provided for the former and VHF equipment for the latter. The stations and the NASA ground communication facilities provide the link for the near real-time 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 STADAN stations or a subcarrier of the unified S-band (USB) downlink to MSFN 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-lagged commands that are stored for execution at a prescribed later time. In emergency situations commands may be sent from other stations. Commands from MSFN stations are transmitted on a subcarrier of the USB link and from STADAN 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 at STADAN 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 NASA Communication Network (NASCOM) 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 pass at the OCC but are processed 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.

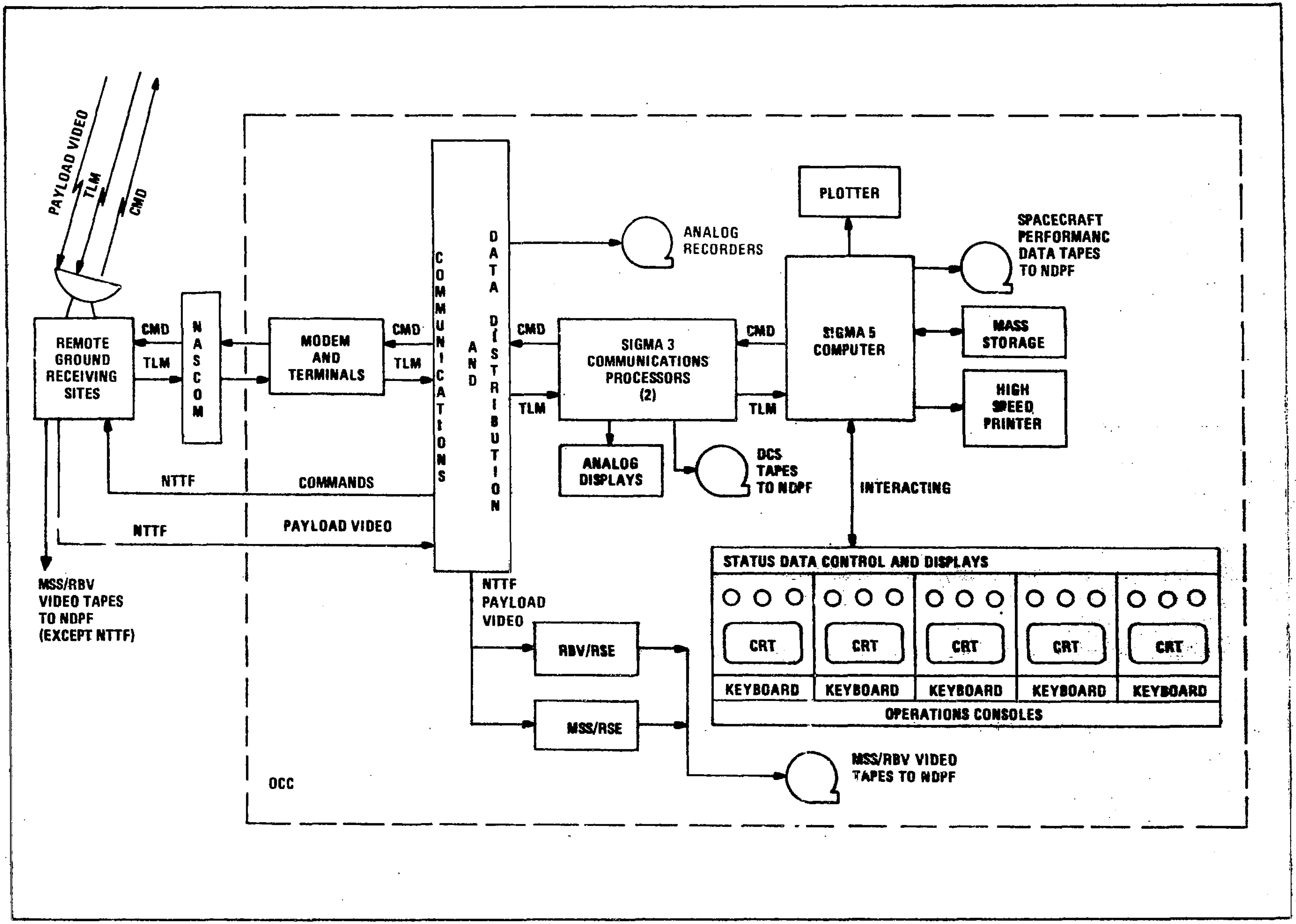


Figure D-1. Major Elements of Operations Control Center

APPENDIX E
NASA DATA PROCESSING FACILITY

The NASA Data Processing Facility (NDPF) processes and stores all sensor data and disseminates large quantities of his data to users in the form of film imagery, computer compatible tape, and Data Collection System (DCS) tapes, cards, and listings. To accomplish these functions, the NDPF utilizes the following subsystems:

- Bulk Processing Subsystem (BPS)
- Precision Processing Subsystem (PPS)
- Special Processing Subsystem (SPS)
- Photographic Processing Facility (PPF)
- Quality Control Subsystem
- Computing Services Subsystem
- User and Support Services

Figure E-1 illustrates the flow of data through the NDPF and its relationship to the various subsystems.

The Bulk Processing Subsystem processes all imagery data received at the NDPF. Data is accepted in the form of video tapes and transferred to film imagery using an electron beam recorder. Image annotation tapes produced by image annotation processing provide descriptive and positional data to Bulk Processing. User and Support Services determine and control the process flow through the system by means of work orders.

Latent film from Bulk Processing is developed and transferred to the Photographic Processing Facility where multiple copies are made for distribution to investigators. Based on investigator requests, selected film images are inputted to the Precision Processor, where their data contents are corrected both spatially and radiometrically. The corrected images are written out onto film which is also processed by the Photographic Processing Facility.

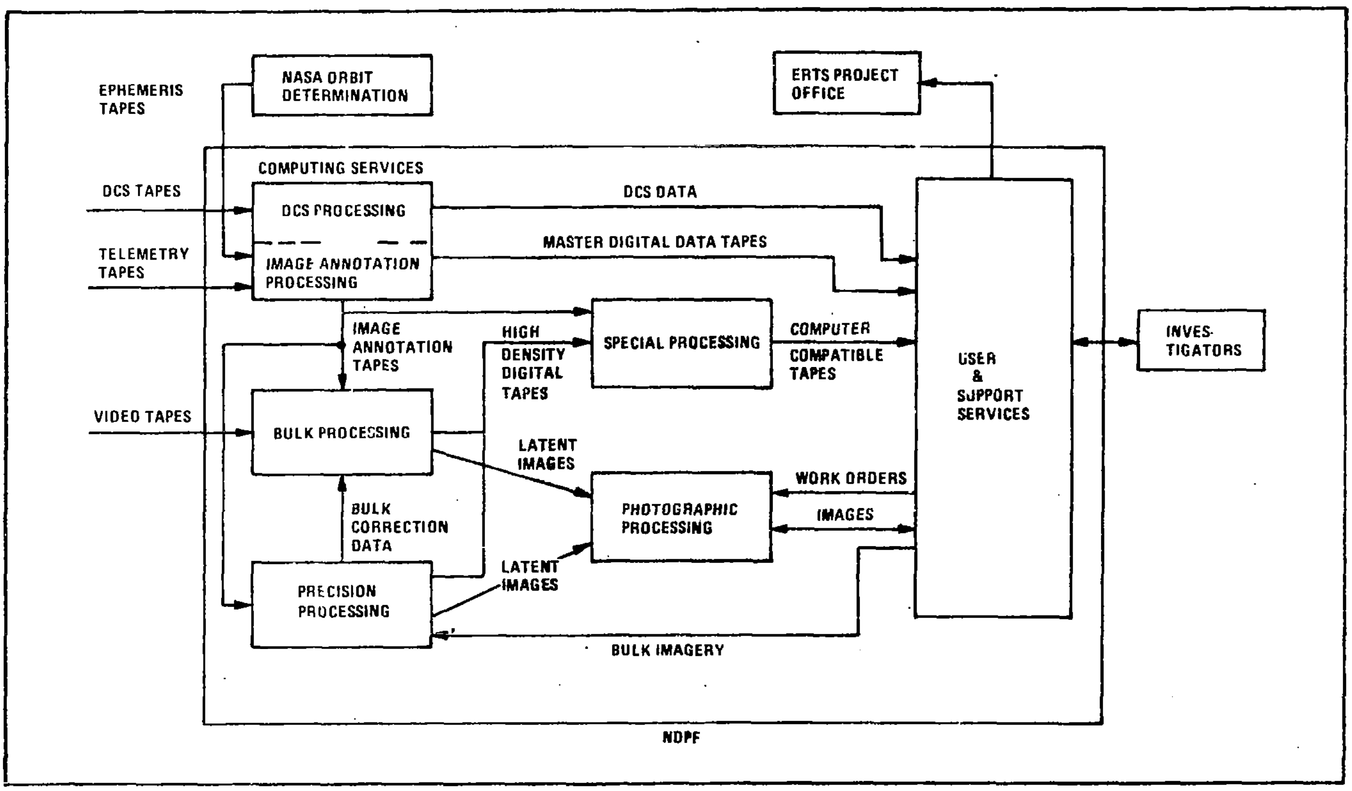


Figure E-1. NDPF Functions

Both the Bulk Processing and Precision Processing Subsystems are capable of writing image data on High Density Digital Tape (HDDT). These tapes are used in the Special Processing Subsystem to produce digital image data on computer compatible tapes (CCT). The CCT's are then duplicated by support services and distributed to the investigators.

Processing of DCS information in the NDPF consists of editing, storing the data received on magnetic tape, and reformatting it into products suitable for distribution to investigators. This process is completely independent of image acquisition and processing.

E.1 BULK PROCESSING SUBSYSTEM

The Bulk Processing Subsystem, shown in Figure E-2, produces latent images on 70 mm film from the data received for each spectral band of the RBV and MSS sensors. The data is also digitized, reformatted, and placed on high density digital tape.

Certain corrections and annotation are applied to the data during the Bulk Processing operation and include:

- Geometric correction for spacecraft platform instabilities
- Reduction of systematic errors caused by RBV camera distortion and image generation
- Radiometric correction for each RBV and MSS spectral band
- Framing of MSS data to be spatially coincident with RBV data

The Bulk Processing Subsystem equipment includes video tape recorders for handling input data, a computer digital tape recorder for input of annotation data, an annotation generator, high resolution film recorder, and a high density digital tape unit and associated control units. Operation of all of this equipment is controlled by the process control

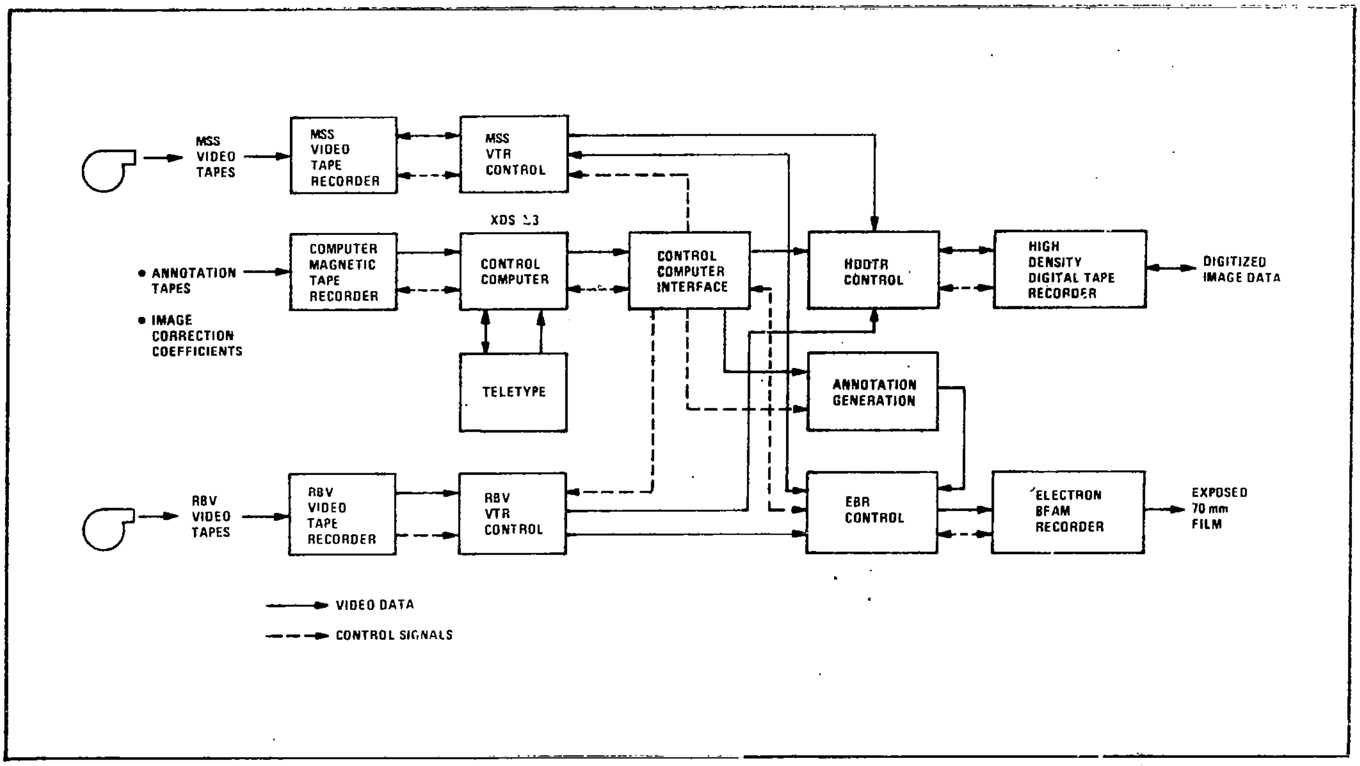


Figure E-2. Bulk Processing Subsystems Equipment Configuration computer which is a small scale, dedicated computer providing control and timing of all hardware in BPS, formatting of annotation data, and computation of geometric corrections to be applied to imagery.

The high resolution film recorder is an Electron Beam Recorder (EBR), and all images are generated through this device. The recorder has a continuous film transport to minimize degradations at the corners of the image and to allow dynamic framing of the MSS data. Its functional parameters and performance data are given in Tables E-1 and E-2.

Control Unit accepts the analog RBV data, performs necessary signal conditioning and error signal generation, and outputs the data to the EBR control unit.

E.1.1 RBV Video Processing

RBV data is entered into BPS via the RBV Video Tape Recorder (VTR). The RBV VTR Control Unit accepts the analog RBV data, performs necessary signal conditioning and error signal generation and outputs the data to the EBR control unit.

During RBV data processing, geometric and radiometric corrections are applied to the video data. These corrections are derived from measurements of actual RBV imagery and pre-flight calibration data by the Precision Processing Subsystem. They remove systematic RBV camera non-linearities, alignment errors, and shading errors, as well as EBR internal errors. The correction coefficients are transferred to the BPS from the PPS on computer-readable tape, stored in the control computer, and used to control writing beam position and intensity during image generation.

The Video Tape Recorder control unit also digitizes the RBV video data and outputs it to high density digital tape. This data is essentially raw video, with no calibration or corrections applied.

E.1.2 MSS Video Processing

MSS data is inputted to the BPS Bulk Processing Subsystem via the MSS Video Tape Recorder (MSS VTR). The MSS VTR control unit decommutates image and calibration data, time, line length, and frame ID codes and performs calibration and digital-to-analog conversion of the MSS data. The BPS then outputs the video data in analog form to the EBR control unit.

The MSS VTR control unit also outputs reformatted digital data to the high density digital tape recorder control unit. However, the MSS data on the HDDT is not corrected or calibrated by Bulk Processing. All calibration and correction of the MSS digital data is later done by the Special Processing Subsystem.

E.1.3 Framing

The RBV and MSS sensor systems are normally operated in time coincidence, i.e., both sensors are taking imagery data at the same time. Since framing of the RBV images is inherent in the simultaneous shuttering action of the three cameras, the centers of the RBV images are nominally identical. There are, however, slight offsets between the image centers due to misalignments between the cameras. During Bulk Processing, the EBRIC

Table E-1. Electron Beam Recorder Functional Parameters

Mode	Lines Per Frame	Line Rate (lines/sec)	Cells Per Line	Active Line Time (μsec)	X Sweep Speed (μsec/mm)	Band Width (MHz)	Active Writing Time Per Frame (sec)	Framing Time (sec)	Film Speed (mm/sec)	Image Writing Speed (mm/sec)	Y Sweep Speed (mm/sec)	Aperture Scanned (mm)	Spot Wobble (μm)
RBV-VFC	4125	1250	4003	720	13.09	3.20	3.3	3.5	18.286	16.667	1.619	5.344 10.344 MAX	13.3
MSS-VFC	4312	163.44	3300 ± 300 ± 30	2160	39.27	.768	27.8	25	2.320	1.918	.466	12.86 15.36 MAX	11.7

VFC = Video Data To Film Conversion

Table E-2. Electron Beam Recorder Performance Data

Parameter	Performance
Video Bandwidth	0 to 8MHz at -3dB
Video Filter	RBV: passband 0 to 3.5MHz at -1dB MSS: passband 0 to 1.0MHz at -1dB
Line Scan Rate	RBV: 1250 lines/sec MSS: 326 lines/sec
Dynamic Writing Area	63 x 16 mm
Horizontal center: Frequency edge Response	8000 TV lines at 50% response 7200 TVL at 50% response
Vertical Lines per frame	RBV: 4125 (55 mm frame) MSS: 4512 (53 mm frame; after line doubling
Density Range	0.1 to 2.1
Transmission Range	100:1
Field Flatness	Max. density variation $< 1\%$ of D_{max}
Scan Jitter	peak-to-peak variation $< 0.01\%$ of 63 mm
Film Transport Jitter	rms variations line-to-line (non-cumulative) $< 20\%$ raster pitch
Repeatability	Peak error < 0.03 mm

correction data from Precision Processing is used to adjust for these alignment differences and to position each image within the writing area so that the latitude and longitude called out in the annotation block represents the format center. Format center is the intersection of the diagonals between the four registration marks.

During the sensor ON periods, RBV shutter action occurs every 25 seconds. In this interval, the satellite ground track and sensor "coverage area" advance 86.04 nautical miles. This results in 14 miles of overlapping data at the top and bottom of an RBV image as illustrated in Figure E-3A.

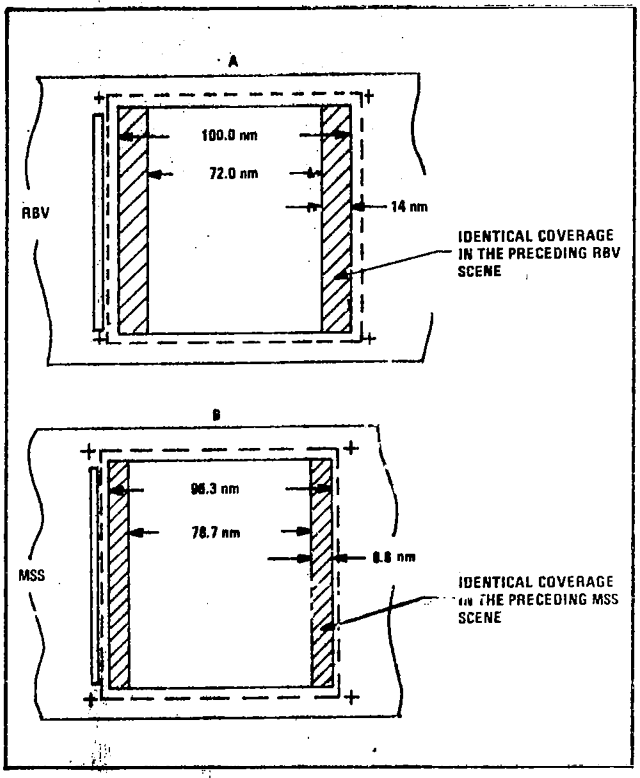


Figure E-3. RBV and MSS Overlap Area Between Consecutive Scenes

The MSS, on the other hand, is a continuous scanning device, and were it not for the dynamic framing technique used in the NDPF, would produce continuous strips of film imagery. In the framing technique, the GMT exposure for the RBV shutters is used as the reference time to compute the MSS frame center. Using this time and "counting back" the number of scan lines equivalent to one half a frame, then MSS imagery can be framed to correspond to RBV imagery. Framing is coincident to within 10 milliseconds.

Overlap of imagery between MSS frames is also provided as shown in Figure E-3B. The overlap corresponds to approximately 8.8 nautical miles on the ground and is made possible by writing MSS scan lines twice — once on each of two adjacent frames as illustrated in Figure E-4. The MSS overlap is limited by the beam deflection aperture of the EBR.

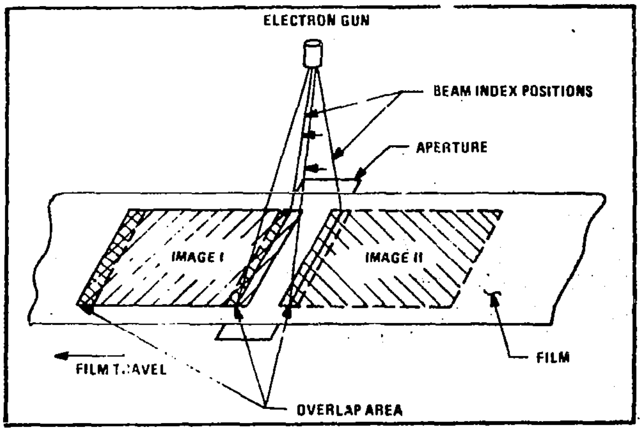


Figure E-4. MSS Dynamic Framing Technique

E.2 PRECISION PROCESSING SUBSYSTEM

The Precision Processing Subsystem (PPS) accepts selected bulk-processed 70 mm imagery and, through a hybrid analog-to-digital processing system, produces geometrically and radiometrically corrected images on a 9-1/2 inch format. Automated reseau measurements and ground control point correlation techniques are used to remove geometric distortions, and perform precision location and scaling of the corrected data relative to map coordinates.

A key feature of PPS is the use of ground control points to measure and correct positional errors in the MSS and RBV images. The ground control points used for precision location of imagery are objects having a known position on the earth's surface and which can be identified in an image. Data obtained from measurements of these control points are used to perform geometric corrections in PPS and provide data to BPS for systematic error removal.

The PPS also has the capability to digitize the corrected data, and record it on high density tape for conversion to a computer compatible tape by the Special Processing Subsystem.

The PPS consists of a viewer/scanner assembly which receives the 70 mm film input from BPS, a scanner/printer assembly to produce the 9-1/2 inch precision-processed film image, a high density digital tape recorder and a process control computer. Figure E-5 shows the major hardware components of the PPS.

The image measurement functions are performed using the viewer/scanner. This instrument is basically a precision, two-stage image comparator with automatic and manual image-matching and coordinate-measuring

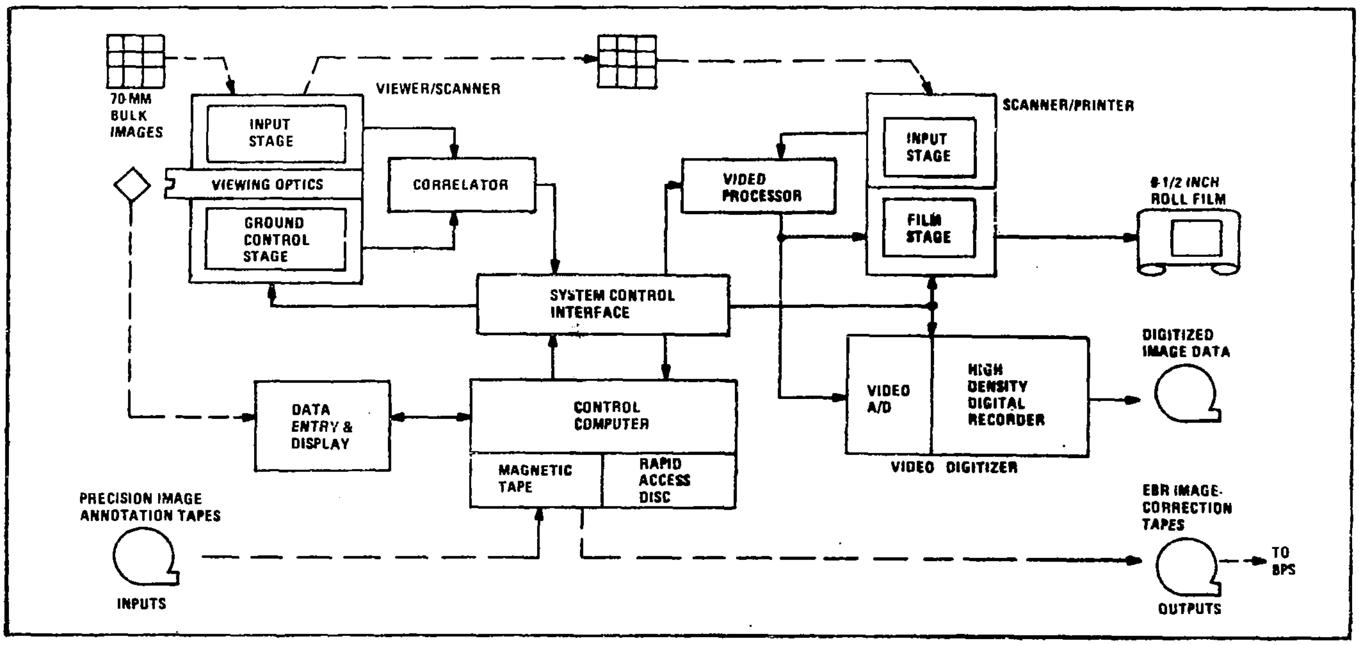


Figure E-5. Precision Processing Subsystem Equipment Configuration capability. The operator station includes a data entry device, binocular viewing optics, X-Y handwheels, and a video monitor.

The image conversion and annotation functions are performed by the scanner/printer. This is a precision, two-stage instrument—one stage equipped with a CRT scanner, the other with a CRT printer. The operator station contains a teletype, X-Y handwheels, and a video monitor. The digitized image output equipment includes an analog-to-digital converter to encode the video signals, a Newell high-density digital tape recorder, and associated control electronics.

The computer operates as a real-time control computer for the image measurement, conversion and annotation, and video digitization functions. It is connected through a direct input/output channel with the viewer, printer, and video digitizer electronics. The computer, with associated magnetic tape unit and rapid-access disc memory, also functions as a data processor for other system operations. It reads and checks the annotation tape during initial screening, maintains control point and scene files, and performs the geometric and radiometric transform computations.

Figure E-6 shows the major internal functions of the Precision Processing Subsystems and their relation to the system inputs and outputs. The normal throughput path is from bulk-processed image inputs to precision latent-image film and digital-image tape outputs. The major functions are separated into three groups, performed sequentially for a given set of scene images, but otherwise independent in time.

E.2.1 Input Screening and Ground Control Selection

The input images are received as 70 mm cut-film positives, accompanied by a daily work order and a precision image annotation tape. The work order provides precision processing instructions and the annotation tape defines satellite position, attitude, and attitude-rate

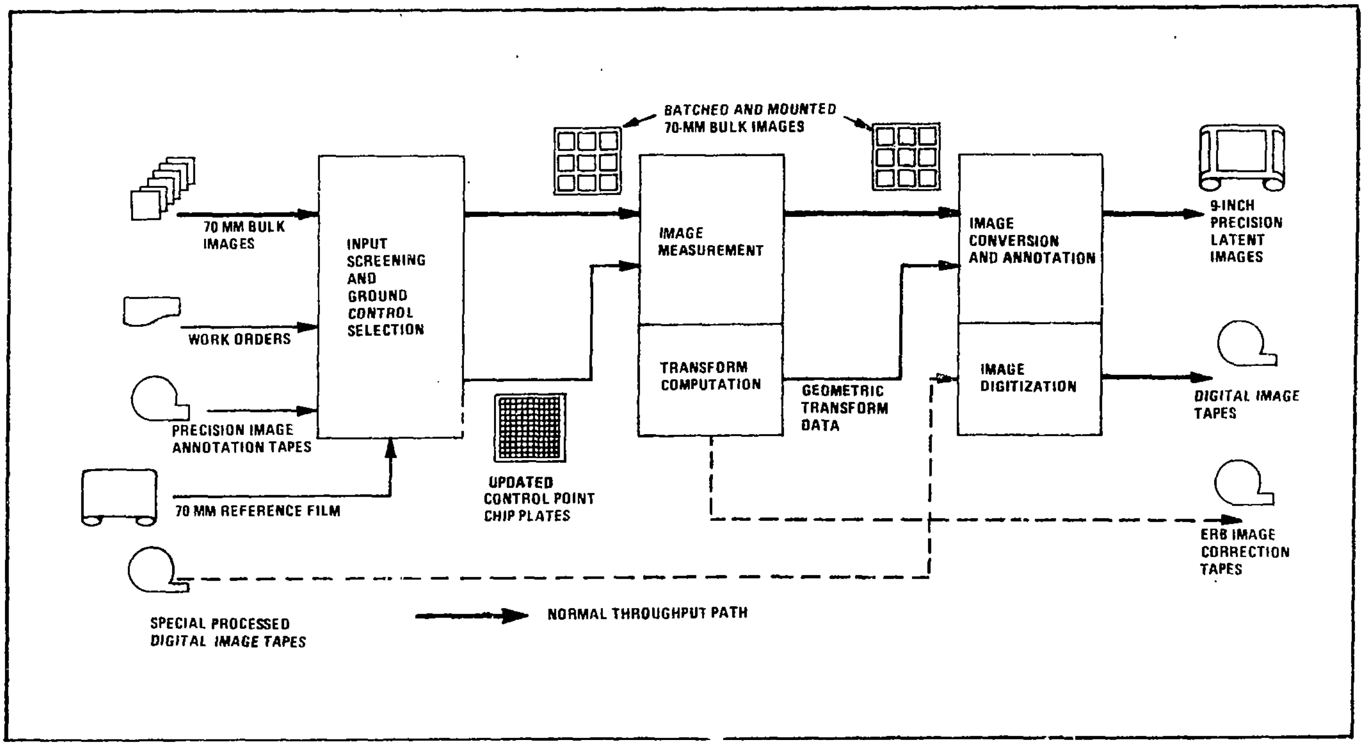


Figure E-6. Precision Processing Operation data for each image. Each scene is evaluated by the system and additional control points are selected if required. In preparation for subsequent functions, the images are batched and mounted on transfer frames.

E.2.2 Image Measurement, Transform Computation

The mounted images are placed in the viewer/scanner and measurements are made of the coordinates of all (81) reseaus in each RBV image, and the coordinates of each control point (typically 9) in one RBV and one MSS image per scene. These measurements are made by automatic scanning and correlation equipment and referenced to an image coordinate system established by the image-corner registration marks provided in the bulk images.

In the geometric transform computation, separate spatial resection computations are performed for the RBV and MSS scenes to determine the position, attitude, and attitude-rate for each sensor which provides the best least-squares fit to the control points. RBV and MSS image coordinates are then computed to be used in each of 64 output print blocks.

When radiometric calibration images are included with the input RBV images, they are batched separately for transmission measurements. The RBV radiometric transform is not computed until after gray scale measurements are made on the scene images during the image conversion process.

E.2.3 Image Conversion and Annotation, Image Digitization

The mounted images are transferred to the scanner/printer. After gray scale measurements are made, the scene information in each input image is converted to a video signal, processed to make the required radiometric transformation, and printed on the output film in UTM projection at a scale of 1:1,000,000. The geometric transformation is implemented by linear interpolation between

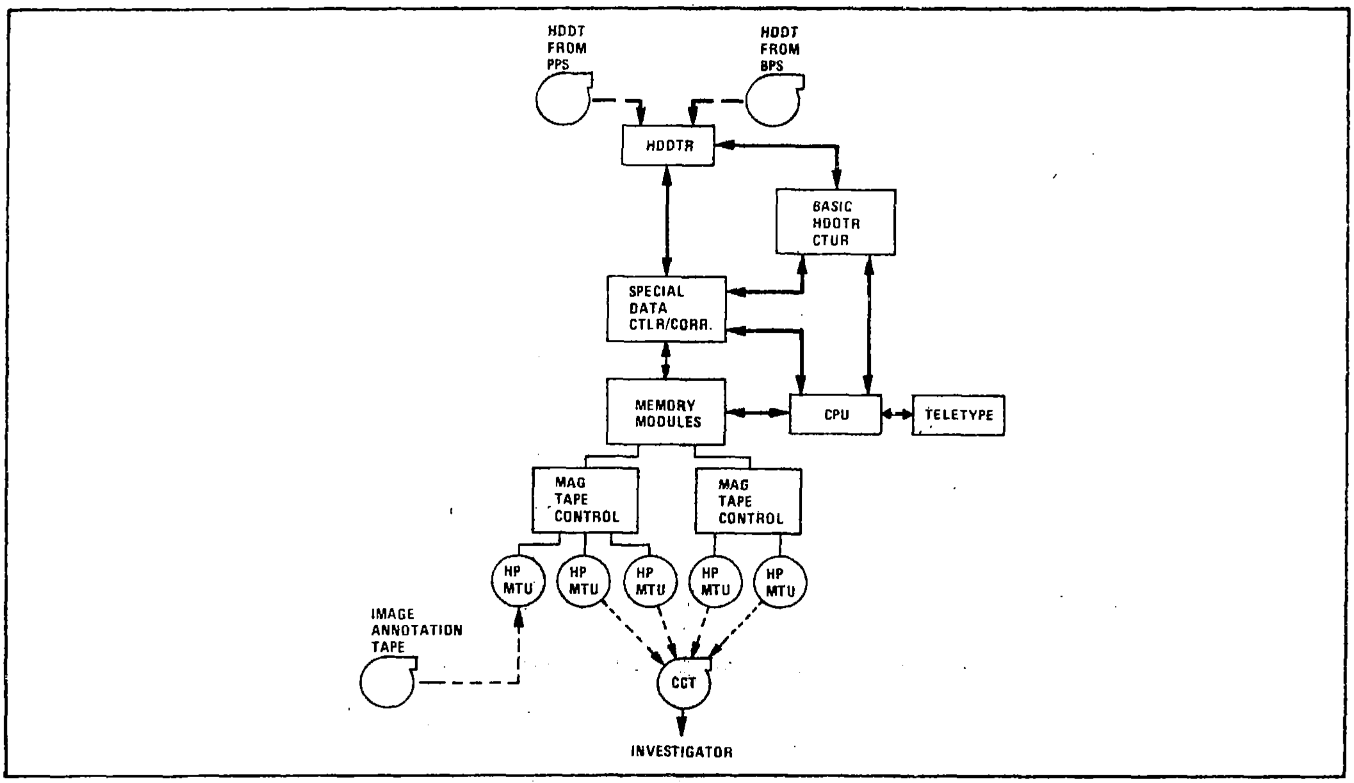


Figure E-7. Special Processing Subsystem Equipment Configuration the computed input-image coordinates for the corners of each of the 64 print blocks in an 8 by 8 array. Image annotation information tick marks and alphanumerics are printed around the image periphery. When requested, the corrected video signals are also digitized and recorded on high density digital tape during image conversion.

Figure E-6 also indicates two occasional, low-throughput operations by dotted input and output lines. One retrieves digital image data from Special Processing and produces 9-1/2 inch latent images. The other generates EBR Image Correction (EBRIC) tapes for use in the Bulk Processing Subsystem.

E.3 SPECIAL PROCESSING SUBSYSTEM

The Special Processing Subsystem (SPS) provides transformation of selected Bulk or Precision digitized data to a computer compatible tape (CCT) format. The SPS equipment consists of a process control computer, five magnetic tape units, a data controller/corrector, and a high density digital tape recorder (HDDTR). These items and the SPS relationship to the Bulk and Precision Processing Subsystems are shown in Figure E-7.

The high density digital tape (HDDT) and associated HDDTR are essential to the efficient flow of data within the NDPF. The HDDTR provides high bit packing density and transfer rates during Bulk and Precision Processing, along with playback at lower speeds to retain compatibility with the average recording rate on the SPS computer compatible tapes.

The control computer is used in a process control mode whereby the digital image data is transferred to the memory modules and the main frame computer performs the data correction computation. As shown in Figure E-8 the subsystem reads data into the control computer memory, accepts manual instruction inputs, operates on the stored data to correct, edit, reformat, and annotate it, and records the processed data on CCT.

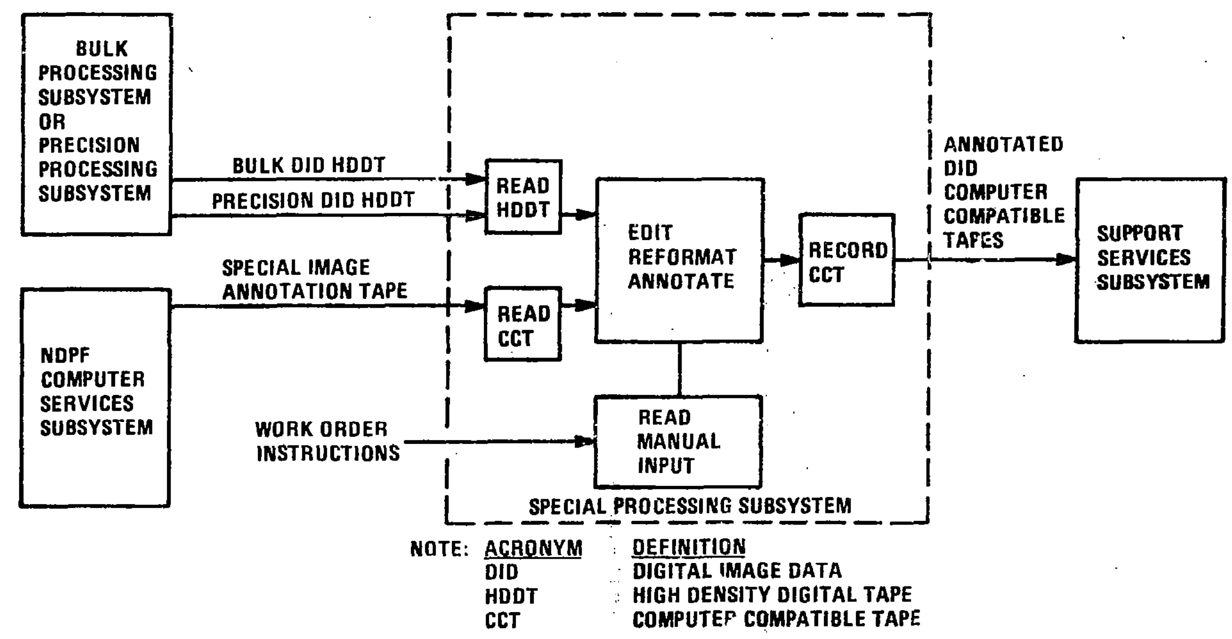


Figure E-8. Special Processing Operation

For MSS data, selected corrections are performed by the Special Data Controller/ Corrector consisting of line length adjust, radiometric calibration, and decompression.

E.4 PHOTOGRAPHIC PROCESSING FACILITY

The Photographic Processing Facility (PPF) accepts the Bulk and Precision processed film images and produces large volumes of imagery. The facility is capable of producing 70 mm and 9-1/2 inch black and white imagery, 9-1/2 inch color imagery, and 16 mm microfilm. Equipment used to accomplish this includes continuous tone automatic black-and-white processors, automatic color film and paper processors, high speed strip printers, and step-and-repeat contact printers. Specialized equipment includes a photographic enlarger modified to a fixed focus enlargement of 3.37, a color composite printer, and microfilm copying, processing, and duplicating equipment.

The PPF also includes a centralized chemical mixing and storage facility incorporating a pollution abatement system consisting of electrolytic silver recovery units, black-and-white, fixer recirculation, and color bleach regeneration and recirculation.

Inputs to the PPF are latent film from Bulk and Precision Processing, stored imagery from Support Services, and computer generated work orders. The orders specify images to be reproduced and type and quantity of products required.

Black-and-white processing includes the following activities as illustrated in Figure E-9:

- Processing of 70 mm latent film from BPS and 9-1/2 inch latent film from PPS
- Enlargement and processing of 9-1/2 inch master bulk imagery negatives

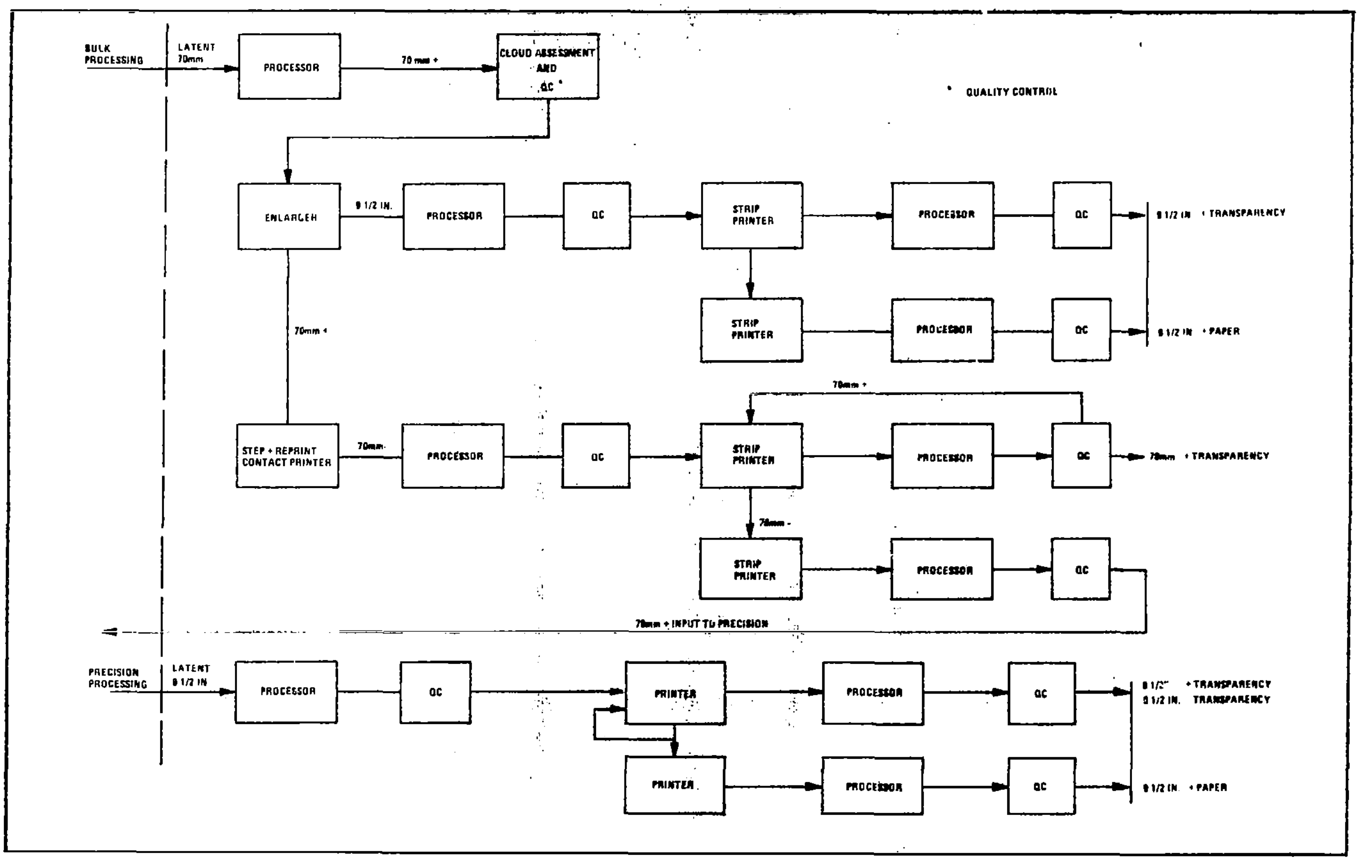


Figure E-9. Black and White Processing

- Printing and processing of all 70 mm and 9-1/2 inch internegatives and interpositives
- Printing and processing of the 70 mm input for Precision Processing
- Printing and processing of 9-1/2 inch triplet sets used for generation of composite negatives
- Duplicating and processing 70 mm negatives and 9-1/2 inch positive transparencies and paper prints for dissemination to users

Color processing as shown in Figure E-10 includes the following activities:

- Punching of registration points in black-and-white triplet sets
- Generation of color composite negatives from Bulk and Precision black-and-white triplet sets
- Printing and processing 9-1/2 inch color transparencies and color paper prints for users

Figure E-11 shows the flow of microfilm preparation and processing. Each print is filmed to produce an archival negative. Inventory is updated by denoting the identifiers contained on the roll, and the roll number. The archival negative is processed, analyzed for quality, and spot-checked to assure the images are in proper order. Negative masters are converted to positive copies which are then shipped to the investigators.

E.5 QUALITY CONTROL

Process control testing and process independent testing are performed in the NDPF photographic facility. The basic tool used to monitor process activities is a quality control strip containing four 21-step wedges, each with a different orientation. The strip measures "within frame" variability as well as gamma, film speed, and base plus fog. The wedge is used every half hour, or after each 500 square feet of film is processed. When a processor is in control, a go-no go sample of three steps in each wedge is used to assess quality. Quality control is also exercised through incoming material and mixed chemistry tests, archival evaluation, and printing master evaluation.

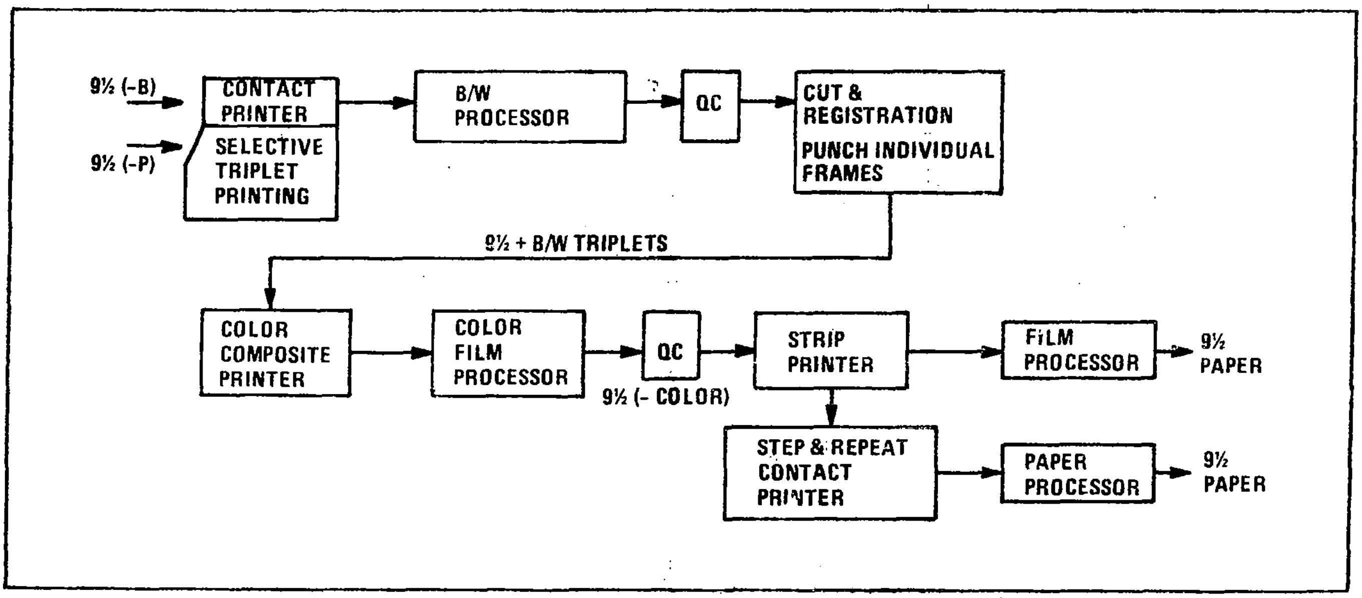


Figure E-10. Color Processing

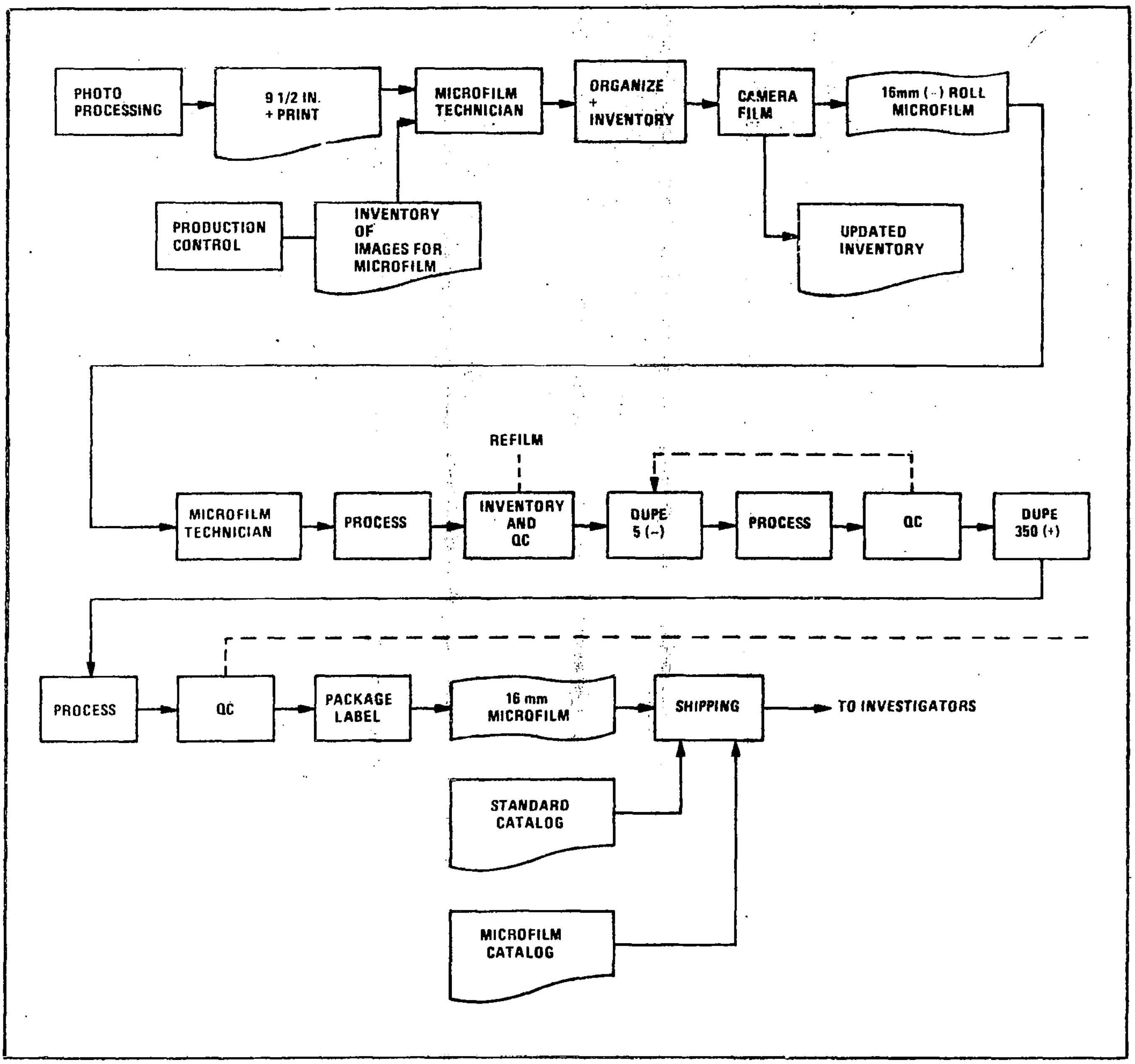


Figure E-11. Microfilm Processing

The quality control procedures for printers consist of observations, tests, and preparation of control charts once per day for:

- Light source intensity and exposure duration
- Evenness of illumination
- Printer operating speed
- Resolving power
- Physical characteristics

The successful image development of archival film, printing of masters and user products is predicated on rigid control of the processing equipment and it is necessary to frequently monitor variables encountered in the processing equipment operation. Those factors requiring continual monitoring and the frequency of monitoring are:

- Processor operating speed — once per hour
- Processor solution temperature — once per hour
- Solution replenishment flow rate — once per day
- Sensitometric response — once per shift
- Physical characteristics — once per shift

Processing chemistry is prepared from standard commercial package mixes. To maintain quality control standards, a fraction of each incoming lot of chemicals is evaluated to determine that its action is within limits prescribed by previous testing of individual developers.

E.6 COMPUTING SERVICES SUBSYSTEM

A central computer system, utilizing a comprehensive data base and information storage and retrieval capability, provides control of NDPF operations. The NDPF Information System utilizes a dedicated Xerox Sigma-5 computer and provides the capability for production control, management reporting, data storage and retrieval, service to users, and preparation of digital products.

The Information System, illustrated in Figure E-12, is built around a central data base providing support for computation and production control functions. It provides accurate accounting and storage of all data pertaining to observations, production schedules, and management control. All phases of operation are entered into the data base, including data received at the NDPF, conditions under which the observations were made, results of image quality assessment, results of cloud assessment, status of production, and status of shipment. All data is readily available for general searches, in addition to being available to satisfy the more specific requirements of production control.

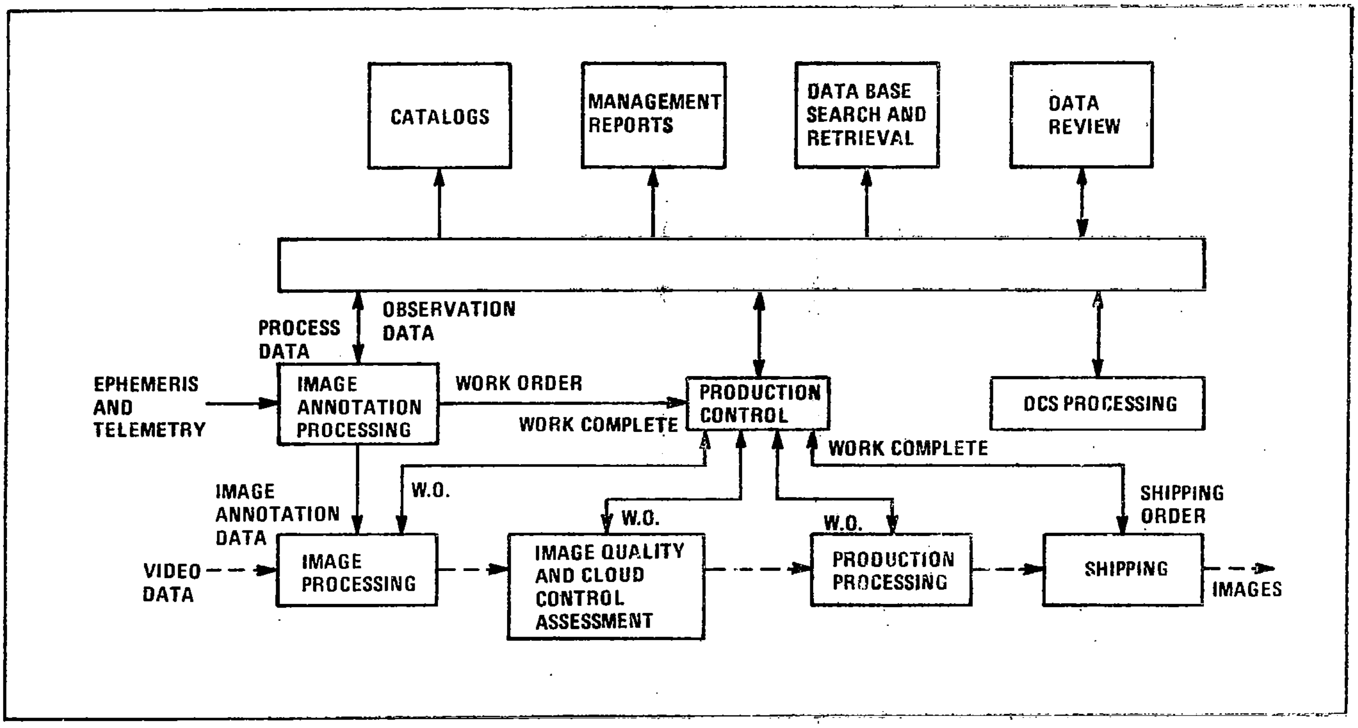


Figure E-12. NDPF Information Systems

The various reports and catalogs generated in the NDPF are prepared by this system. In addition two specific types of processing are performed which are associated directly with the payload data; they are DCS processing and image annotation processing.

E.6.1 DCS Processing

DCS data transmissions are relayed by land lines from receiving stations to the Operations Control Center where the data is decoded and recorded on the Data Collection System Magnetic Tape (DCST). The DCST is forwarded to the NDPF where the data is edited, reformatted, and stored on disc for up to 48 hours. At the end of each 24-hour period, the preceding 24 hours of collected data is placed on a permanent archive tape. This transfer allows for retrieval of data at any time in the future, while permitting quick access to current (the most recent 24-48 hours) data.

DCS processing also prepares the platform data products for the DCS investigators. Capability is provided to produce, on request, digital tapes, listings, and punched cards containing a selected sub-set of available, uncalibrated platform data. Means are also provided to accumulate and print summary data suitable for the DCS catalog.

E.6.2 Image Annotation Processing

Image annotation processing accepts ephemeris and spacecraft performance data and generates the correlative data required for annotation and geometric correction of the imagery. The annotation and computational data are passed to the image processing subsystems in the form of an Image Annotation Tape (IAT). This tape also contains processing instructions and supplements the work orders generated by Production Control. IAT's are generated for each of the three subsystems: Bulk Processing, Precision Processing, and Special Processing.

E.7 USER AND SUPPORT SERVICES

The NDPF information system provides computer support for the User Services section of the NDPF. This section services investigators in a timely and selective manner by providing a full range of activities including: catalogs, a comprehensive data retrieval system, microfilm services, dissemination of all imagery and DCS data, image descriptor maintenance, and the data ordering system. A detailed discussion of these services is contained in Section 4.

APPENDIX F
SYSTEM PERFORMANCE

F.1 GEOMETRIC ACCURACY

Performance of the system is considered in this appendix from the point of view of geometric fidelity, Section F.1; radiometric fidelity, Section F.2; and image resolution, Section F.3.

F.1.1 Measures of Geometric Accuracy

The geometric accuracy of imagery can be measured in several ways including:

- Positional accuracy (sometimes called mapping accuracy) refers to the ability to locate a point in an image. Positional location is usually referenced, in an absolute sense, to geocentric latitude and longitude. Thus, positional accuracy is a measure of the ability to locate a point in an image in terms of its latitude and longitude.

- Registration accuracy refers to the ability to superimpose the same point in two different images.

- Spatial registration accuracy is used when referring to two different spectral images of the same ground scene taken at the same time.

- Temporal registration accuracy refers to comparisons between two images of the same ground scene taken at different times. When the term "registration accuracy" is used unqualified, spatial registration is implied.

It is convenient to relate all measures of geometric accuracy to expected error in terms of meters on the ground. Expected error is taken as 68 percential (rms). This estimate is not meant to imply that all errors are random errors normally distributed about zero. The use of the rms error is intended only to present typical error figures, since the maximum errors often are misleading. (For example, the positional effects of some errors are proportional to radial distance from the image center, and a maximum error in the extreme corner gives an incorrect picture of overall error distribution.)

F.1.2 Error Sources and Their Magnitude

The ability to positionally locate or register ERTS imagery is based upon the ability to define all error sources, to quantify these errors, and to compensate for or remove them in the process of generating the images. Individual error sources may affect either or both positional and registration accuracy. It is convenient to group these individual error sources into three categories:

- External Sensor Errors—those errors external to the RBV or MSS, principally related to the spacecraft attitude, ephemeris, etc.

- Internal Sensor Errors—those errors originating within the sensor, such as nonlinearities, offsets, etc.

- Processing Errors—those errors associated with creating, transforming, and copying images, including errors or residuals resulting from applying corrections

The nature and expected magnitude of each of these categories of error sources are discussed in the following paragraphs. Consideration of the extent to which they may be corrected and how this correction is implemented is discussed in Section F.1.3.

F.1.2.1 External Error Sources

A summary of the external error sources is shown in Table F.1-1. Brief discussions of significant items are presented in the following paragraphs.

Item 1: Knowledge of Sensor to Spacecraft Alignment

Uncertainty in the knowledge of the alignment of imaging sensors to the spacecraft's

Table F.1-1. Positional Effects of External Sources

Item No.	Name of Error	rms Positional Effect (meters) RBV	MSS
1	Sensor Alignment	656	656
2	Ephemeris Position	128	128
3	Exposure Time	22	22
4	Attitude	858	814
	Resultant	1090	1052

attitude control reference system manifests itself as a positional mapping accuracy. The resultant error indicated in Table F.1-1 reflects the uncertainty in alignment which may exist after the spacecraft is injected into orbit.

Item 2: Spacecraft Ephemeris

Table F.1-1 indicates image positional errors which result from the estimated orbit determination inaccuracies for the Manned Space Flight Network (MSFN) range-rate tracking system using the prime ERTS stations when tracking all spacecraft passes.

Item 3: Exposure Time

The "moment of exposure" for the RBV cameras is taken as the mid-point of their actual exposure. The uncertainty in determining the initiation of the exposure cycle results in a positional mapping error. Similar uncertainties exist for the MSS sensor.

Item 4: Attitude

Table F.1-1 indicates the positional mapping uncertainty resulting from uncertainties introduced in determining the attitude of the spacecraft. Examples of sources contributing to such uncertainty are:

- Attitude sensor measurement uncertainty
- Attitude sensor measurement noise
- Attitude telemetry quantization

These spacecraft induced attitude uncertainties result in different image mapping uncertainties for the RBV and MSS sensors as a result of their different imaging processes.

F.1.2.2 Internal Sensor Errors

The characteristics of the internal sensor errors are unique to the particular sensor; therefore, RBV and MSS internal errors are discussed separately.

F.1.2.2.1 RBV Internal Errors

Table F.1-2 shows the raw internal RBV errors. The optical distortion accounts for errors introduced by the optical imaging portion of the sensor from the lens to the RBV faceplate. This error is static (and thus can be calibrated) except for small variations caused primarily by temperature variation in the spacecraft and small residual calibration uncertainties. Except for optical distortion, all other error sources are effects associated with

Table F.1-2. RBV Internal Errors

ITEM NO.	NAME OF ERROR	AMOUNT OF ERROR (MAX)
1	RASTER CENTERING	±2%
2	RASTER SIZE	
3	RASTER SKEW	0.5°
4	ROTATION	1°
5	OPTICAL DISTORTION	30 μm
6	MAGNETIC DISTORTION	1%
7	FIELD INTERACTION	46μ
8	RASTER NONLINEARITY	1%

the electromagnetic characteristics of the vidicon camera. The values for these errors are maximum estimates based on current RBV specifications.

These RBV internal distortions result in an uncompensated rms positional mapping uncertainty of 1530 meters. This uncertainty, combined with the external uncertainties for RBV imagery (Table F.1-1), result in an RBV positional mapping uncertainty of 1880 meters as input to the NDPF.

F.1.2.2.2 MSS Internal Errors

Table F.1-3 indicates the most significant of the internal MSS error sources which contribute to MSS imagery positional mapping inaccuracy. These internal MSS uncertainties combine to contribute an rms positional mapping uncertainty of 25 meters.

MSS internal error sources, when combined with the external uncertainties affecting MSS imagery (Table F.1-1), result in an MSS positional mapping uncertainty of 1053 meters as input to the NDPF.

Table F.1-3. Positional Effects of MSS Internal Sensor Errors

Item No.	Name of Error
1	Mirror Jitter
2	Scan Start Time
3	Detector Alignment
4	Sample Time
5	Scan End Time
6	Scan Repeatability
7	Uncertainty in Calibration of Mirror Scan Profile and Drift

F.1.3 Output Product Geometric Fidelity

The following paragraphs summarize the effects of the NDPF on geometric fidelity of the output products.

F.1.3.1 Bulk Image Products

The geometric fidelity of NDPF output products is a complex function of numerous sources of degradation and correction. These sources can be classified into three major groupings:

1. Input error sources which the NDPF does not operate on nor attempt to remove

2. Sources of degradation within the NDPF system itself

3. Input error sources or imaging conditions which the NDPF attempts to remove or model in order to improve geometric fidelity

The geographic location of bulk images is derived from spacecraft data relating time(s) of exposure, estimated spacecraft ephemeris, and the spacecraft's attitude profile. Errors in these data fall into the first classification for bulk image products, and these input sources of error contribute directly to bulk output image positional mapping error.

During the conversion of raw image data to bulk image products, the NDPF itself slightly degrades the geometric fidelity of the imagery. Such degradations are introduced by the system hardware, by the software, and by image modeling approximations. Examples of such sources of error which are common to both RBV and MSS images are listed in Table F.1-4.

The NDPF also improves the geometric fidelity of bulk image products. This is accomplished by determining image corrections for significant systematic mapping errors and image distortions existing in the input imagery. These corrections are determined for 81

Table F.1-4. Examples of Geometric Degradation Contributed by the NDPF to Both RBV and MSS Bulk Images

Hardware

- **Electron Beam Recorder Printing Accuracy**
- **Film (Paper) Distortion and Scale Change**
- **Enlarger Distortion and Enlargement Variations**
- **Alignment During Spectral Registration**

Software

- **Computational Precision**
- **Data Base Errors**

Modeling

- **Flat Earth Assumption**
- **Non-compensation for Keystoneing and Obliquity Resulting from Non-nadir Pointing**

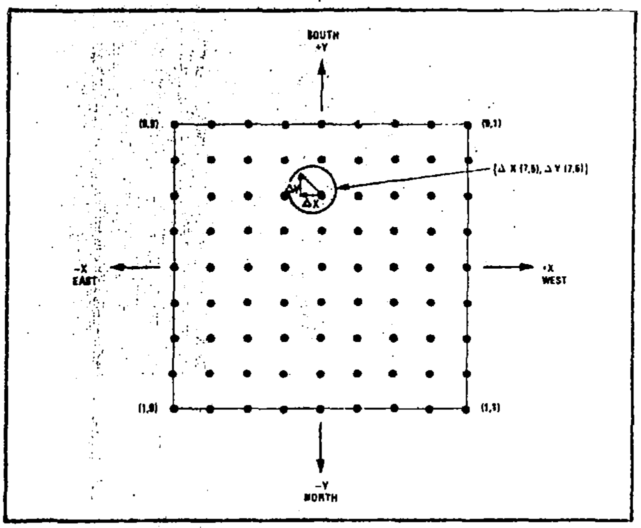


Figure F.1-1. RBV Breakpoint Error Correction Technique

breakpoints in a matrix evenly distributed over the image as shown in Figure F.1-1. Bilinear interpolation is utilized for corrections between the breakpoints. Such corrections reduce but cannot entirely remove all errors and, thus, a residual error remains in bulk image products. Brief discussions of corrections applied to the RBV and MSS bulk images are provided in the following paragraphs.

F.1.3.1.1 RBV Error Removal

The Bulk Processing RBV image correction data flow is shown in Figure F.1-2. Scale corrections are made to RBV bulk imagery to

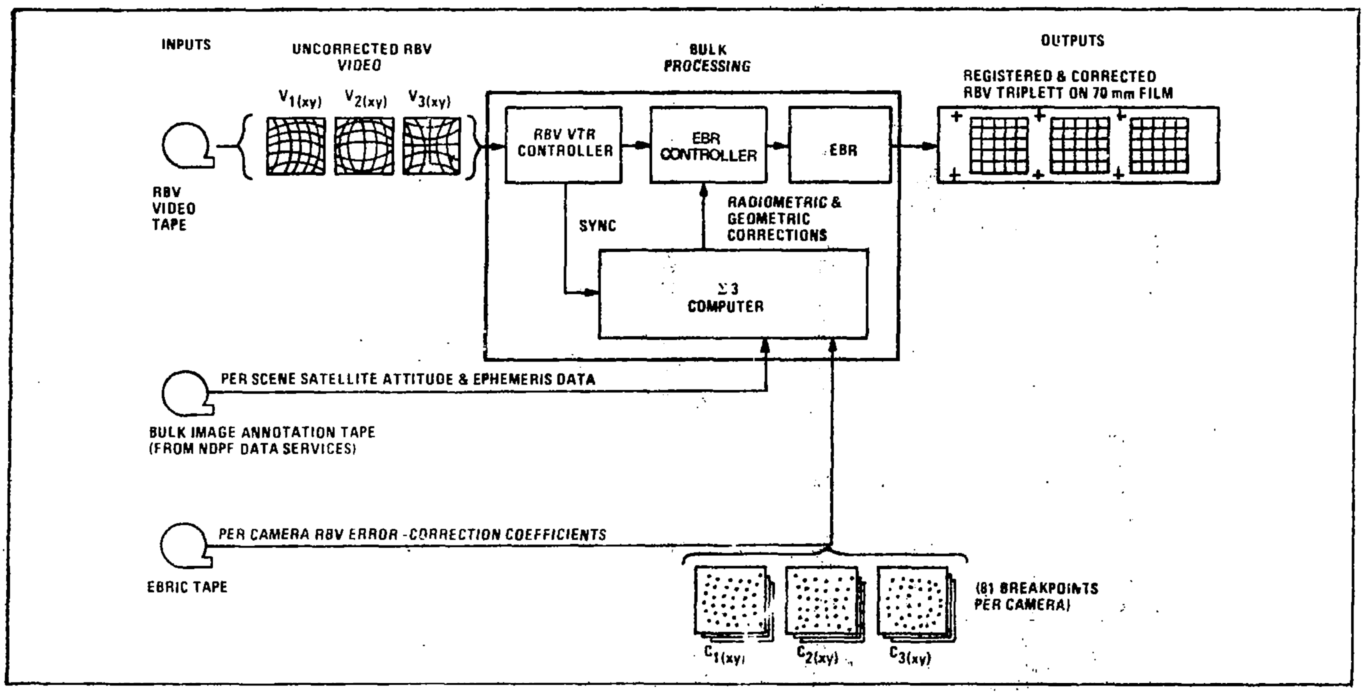


Figure F.1-2. Bulk Processing RBV Image Correction account for frame to frame variations in altitude. In addition, calibrations of the systematic and stable portions of the RBV internal errors and distortions are performed on a regular basis. Corrections for calibrated distortions and errors are determined and applied to all RBV bulk images. Residual distortion errors in the RBV bulk imagery are present as a result of calibration errors, RBV drift from calibration, and RBV random errors.

Table F.1-5 shows the total, rms, geometric errors in RBV Bulk Output Products resulting from all of the contributing error sources.

Table F.1-5. RBV Bulk Output Product Residual Errors (rms)

Positional Mapping Accuracy	
Film Products	**1120 meters**
Paper Products	**1130 meters**
Registration Accuracy	
All Products	**340 meters**

F.1.3.1.2 MSS Error Removal

MSS imagery is obtained under dynamic conditions, and conversions of MSS image data to output products without accounting for these dynamic imaging conditions would introduce sizeable image mapping errors and distortions. To reduce these dynamic errors the NDPF models the significant MSS imaging dynamics (nominal and systematic variations from nominal) and corrects the MSS output images accordingly.

The Bulk Processing MSS image correction data flow is shown in Figure F.1-3. Examples of corrections which are applied include:

- Altitude variation from frame to frame and within a frame
- Attitude variations within a frame
- Variations in velocity from nominal orbital velocity
- Image skew caused by earth rotation and finite scan times

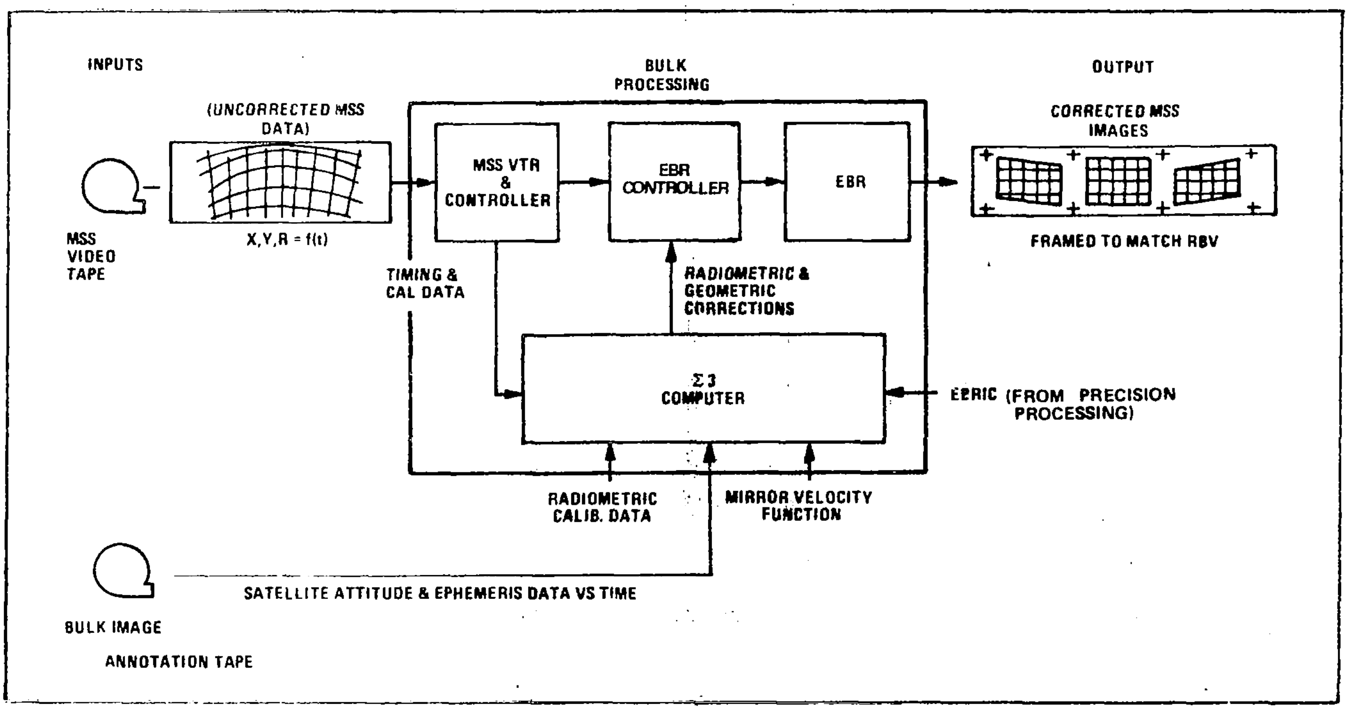


Figure F.1-3. Bulk Processing MSS Image Correction

- Systematic band-to-band off-sets resulting from finite detector sampling sequences
- Non-linear mirror scan profile
- Electron Beam Recorder and MSS mirror scan differentials

Residual error in this correction process results from dynamic modeling assumptions and limitations. Table F.1-6 shows the total, rms, geometric errors in MSS Bulk Output products resulting from all of the contributing error sources.

Table F.1-6. MSS Bulk Output Product Residual Errors (rms)

Positional Mapping Accuracy	
Film Products	**1075 meters**
Paper Products	**1085 meters**
Registration Accuracy	
All Products	**155 meters**

F.1.3.2 Precision Image Products

Conceptually, Precision Processing is an extension of the correction process discussed in Section F.1.3.1. However, the correction mechanism for Precision Processing is totally different than that for Bulk Processing. Errors are determined by measurements of the input imagery and comparison with known quantities. Once image distortion corrections are determined, the input image is scanned by a CRT scanner in sub-areas of approximately 1/64 the area of the input image. Inverse corrections are applied to the scanning CRT. The scanning CRT is hardwired to a printing CRT which prints exact 1/64 image sub-areas, thus correcting the image distortions. In the same process, the image is enlarged to a scale of 1:1,000,000. In addition, corrections for image location are determined and corrected image location tick marks applied to the printed image. Precision Processing image correction flow is shown in Figure F.1-4.

Bulk 70 mm film products are the source of input imagery for conversion to Precision Output products. Thus, the output geometric

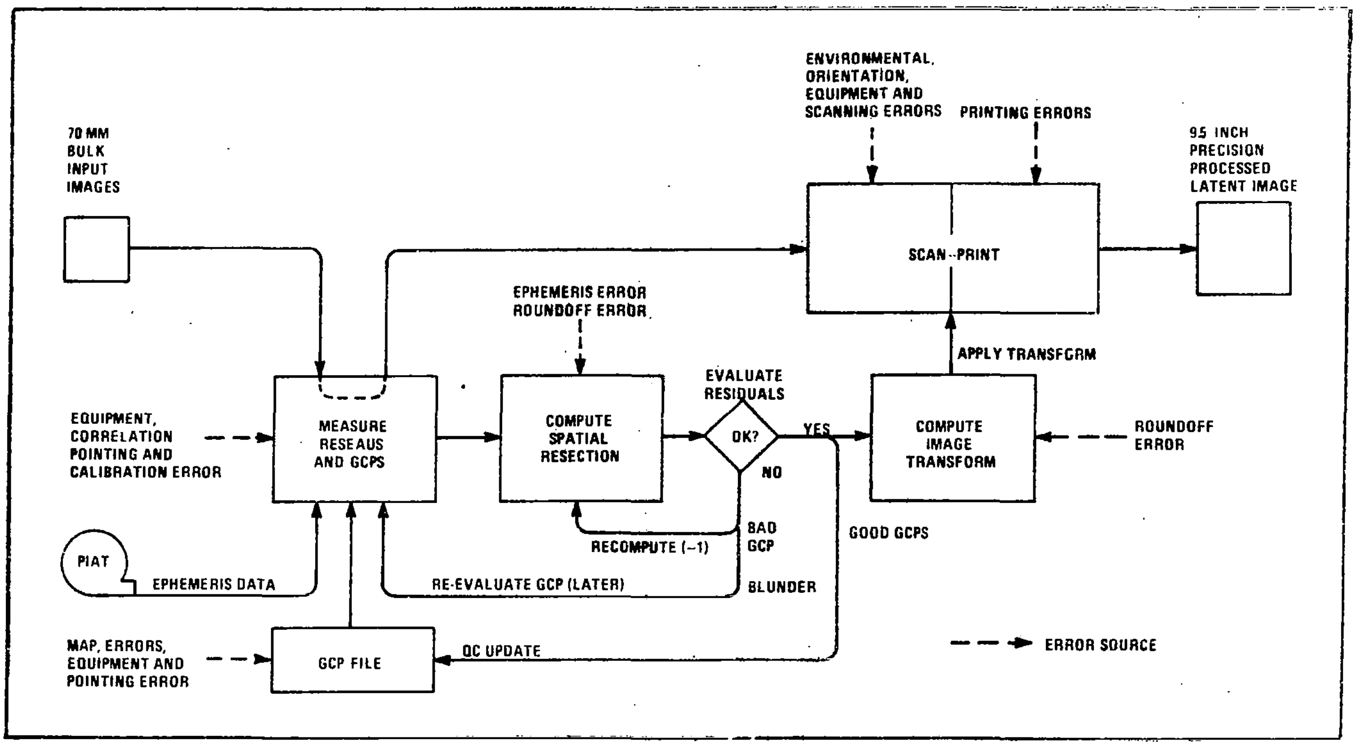


Figure F.1-4. Precision Processing Data Flow and Error Sources fidelity discussed in Section F.1.3.1 is the input fidelity for Precision Processing.

An initial step in Precision Processing is the measurement of distortion in the input image. For RBV input images, these residual distortions result from:

- Those introduced by the RBV camera since the last calibration and not compensated in Bulk Processing (see Section F.1.3.1)

- Those introduced by Bulk Processing

- Those for which no compensation was attempted in Bulk Processing

- Those where compensation was not exact.

Similar residual distortions exist in the input MSS imagery. Image corrections are determined for a matrix of 81 points with bilinear interpolation between points and corrections are applied during the scanning/printing operation.

In addition to the measurement of image distortions, identifiable control points in the input image are measured relative to known stored locations of the control points. By utilizing photogrammetric spatial resection techniques, the position and attitude of the spacecraft can be estimated. Utilization of redundant (i.e., more than necessary) control points within an image increases the accuracy of such estimates to better than those which are obtainable from spacecraft telemetry and the ephemeris derived from tracking. The resulting increased accuracy in spacecraft position and attitude increases the positional location accuracy of the image. Based on these estimates, corrected geographic tick marks are then computed and applied.

Tables F.1-7 and F.1-8 show the total, rms, geometric fidelity for RBV and MSS Precision Output Products.

Table F.1-7. RBV Precision Output Product Residual Errors (rms)

Positional Mapping Accuracy	
Film Products	**95 meters**
Paper Products	**135 meters**
Registration Accuracy	
All Products	**115 meters**

Table F.1-8. MSS Precision Output Product Residual Errors (rms)

Positional Mapping Accuracy	
Film Products	**235 meters**
Paper Products	**250 meters**
Registration Accuracy	
All Products	**150 meters**

F.2 RADIOMETRY

The radiometric fidelity of the ERTS system described in this appendix considers the macro-scale or low spatial frequency effects primarily caused by non-repetitive variations, such as short term drifts of dc-reference levels, bursts of low-frequency noise smudging due to developer and developing process local variations—effects that are systematic in nature and removable by proper calibration methods. These effects include referencing to the electronically introduced gray scale located on the sides of the electron beam recorder film images. The relatively high frequency noise components are excluded. These are noise phenomena at spatial frequencies equal to the size of a resolution element, where the SNR ratios are low, i.e., about 5/1 or less.

At high spatial frequencies (i.e., very small sampling apertures) the effects of film granularity are large. Selwyn's Law, shown graphically in Figure F.2-1, holds only for small apertures and density ratios approaching

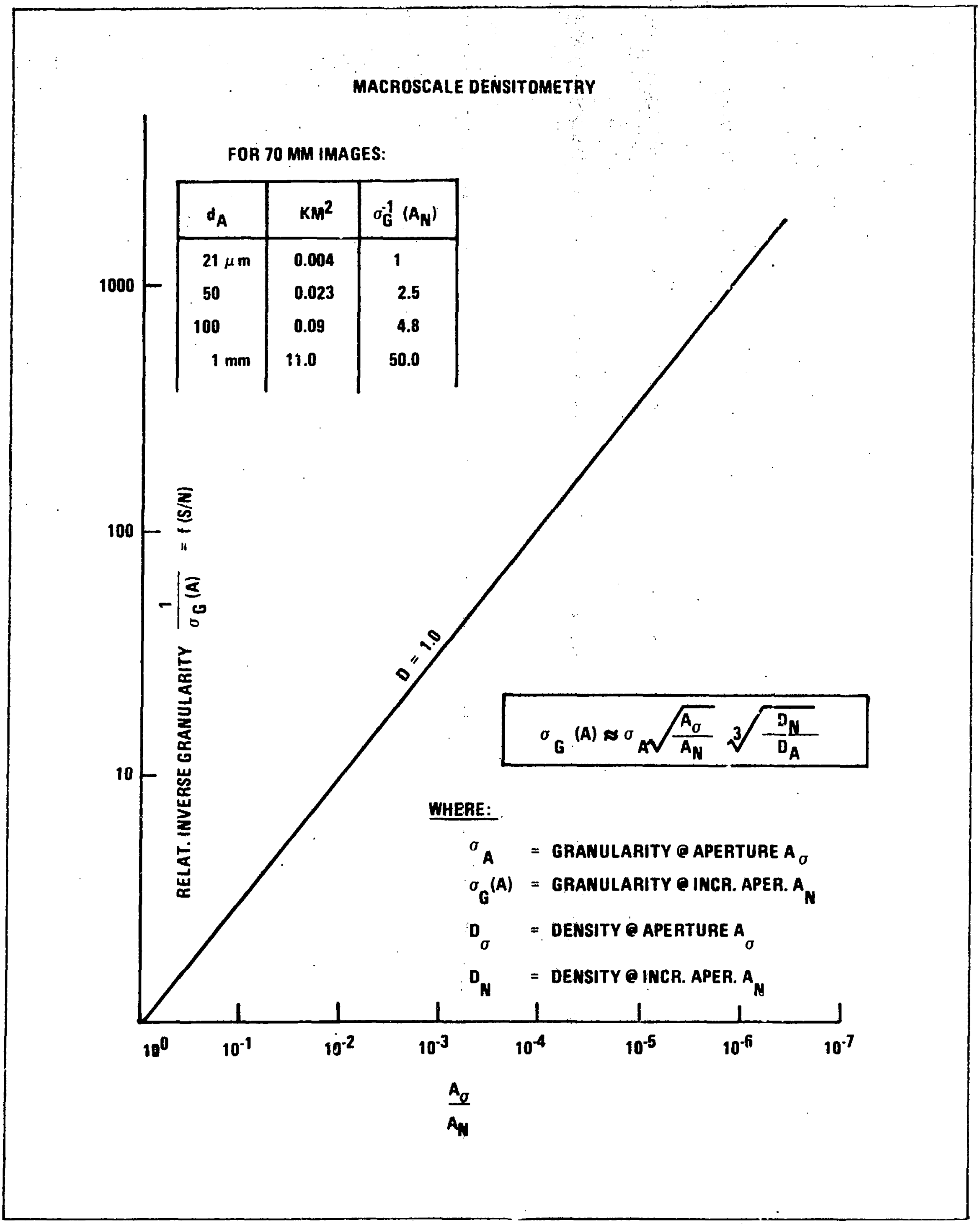


Figure F.2-1. Macro Scale Densitometry unity, but for illustrative purposes it can be used to show the reason behind macro-scale radiometric analysis and why noise effects at that level are negligible.

Sampling with small apertures, like 50 μm, produces relative inverse granularity in the order of 2, thus precluding radiometric evaluation with any degree of certainty. In order to increase the certainty of radiometric evaluation, the sampling aperture must be increased (equivalent to increasing the actual area covered on the ground) to a point where the relative inverse granularity becomes high, about 50/1 or more. As can be seen from Figure F.2-1, to obtain such a ratio at a density level of 1.0, the aperture should be at least 1 mm in diameter, or, in terms of an equivalent covered area on the ground, it becomes a minimum of 11 square kilometers.

In practice the University of Purdue uses a minimum SNR criterion of 30, or about 30 dB in their analyses of digital data. Since the precise relationship between relative inverse granularity and SNR has not been defined, using a ratio of 50/1 or a sampling area of 1 mm diameter is conservative, and analysis based on it entirely justifiable.

In order to make the results more coherent, all video signals have been normalized to the equivalent dynamic density range ΔD of 2.0, where 2.0 represents 100 percent. Further, since most film and process data are published for a density of 1.0, this value was used throughout the calculations. Also, a particular film/chemistry combination has no impact on the results since experimentation has indicated a similar and uniform behavior between combinations.

The difference between relative and absolute radiometry should be noted here. The radiance seen by the payload sensor is a relative measure of the true spectral signature of the target. The atmospheric path contributes a significant amount of spectral radiance through Rayleigh, Mie, and selective scattering processes. This path radiance is directly additive to scene radiance and since it will not be sensed separately on ERTS A or B, measurement of the true or absolute radiometric spectral signatures of scenes will not be possible.

F.2.1 Return Beam Vidicon Camera Radiometry

The major error contributors to RBV radiometry are:

1. RBV camera subsystem
2. Communications elements
3. Restabilization of the signal
4. Image recording processes

The overall flow of RBV data from a radiometric viewpoint is shown in Figure F.2-2.

F.2.1.1 RBV Subsystem

The most important error sources in the RBV are residual image effects and shading. Residual image effects, illustrated in Figure F.2-3, are known to exist in all slow scan vidicons. Careful "clean sweep" (i.e., photoconductor preparation) will minimize it, but values much lower than 5 percent of the peak signal output amplitude are difficult to obtain.

Shading found in some images produced by the RBV has been densitometrically traced with the results shown in Figure F.2-4. Shading within the camera can be as large as 30 to 60 percent of the total signal (black and white amplitude) over the full picture frame. Preflight calibration data taken at fixed points over a 9 by 9 matrix in the camera image will provide shading correction information. This data will be applied during Bulk Processing and will reduce the shading error to less than 5 percent of ΔD. The resulting 5 percent is illustrated by the lower trace in Figure F.2-4. The corrections will be made by linearly interpolating between the calibration data points of the 9 by 9 matrix.

RBV SYSTEM FLOW

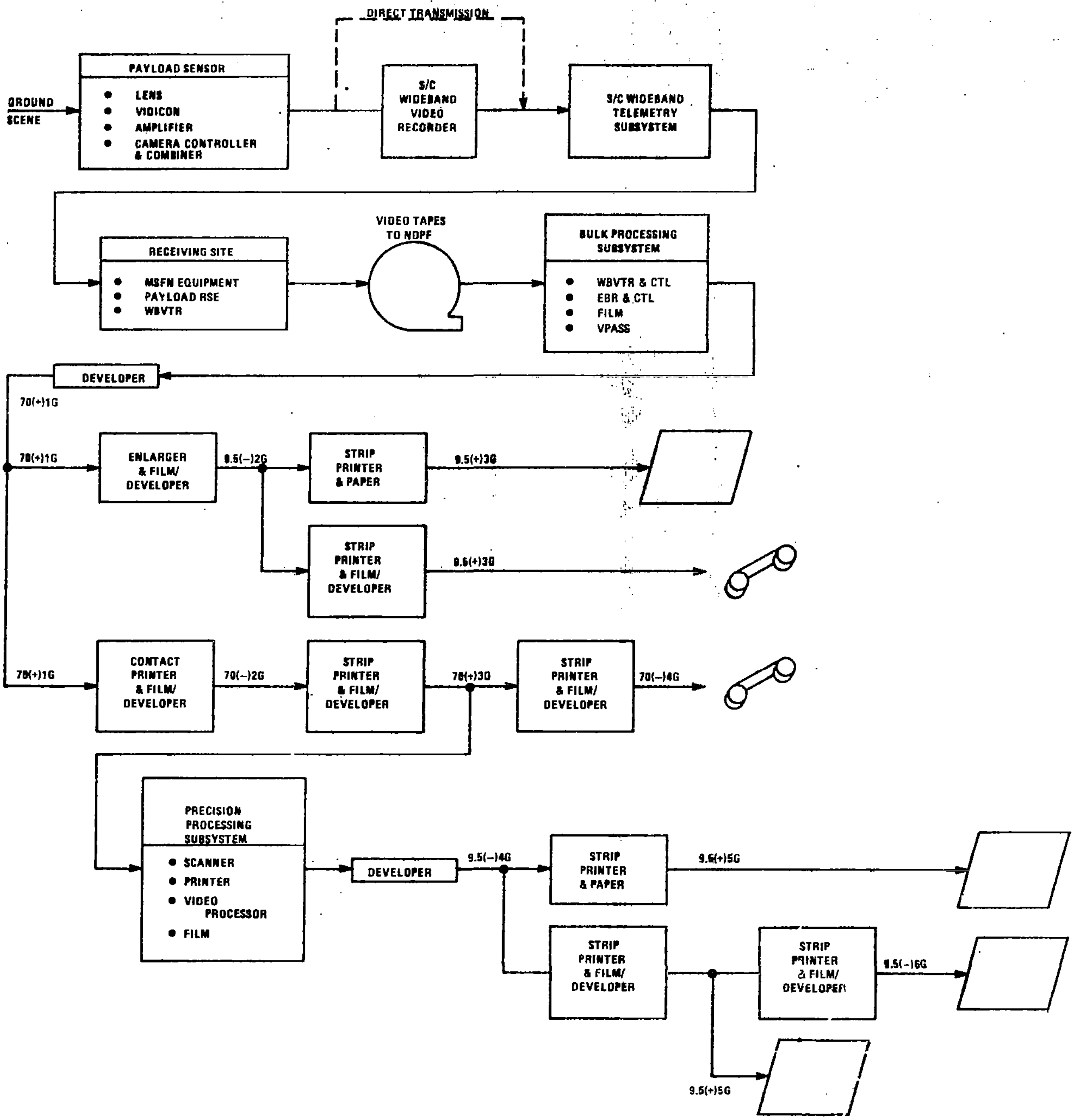


Figure F.2-2. RBV System Flow

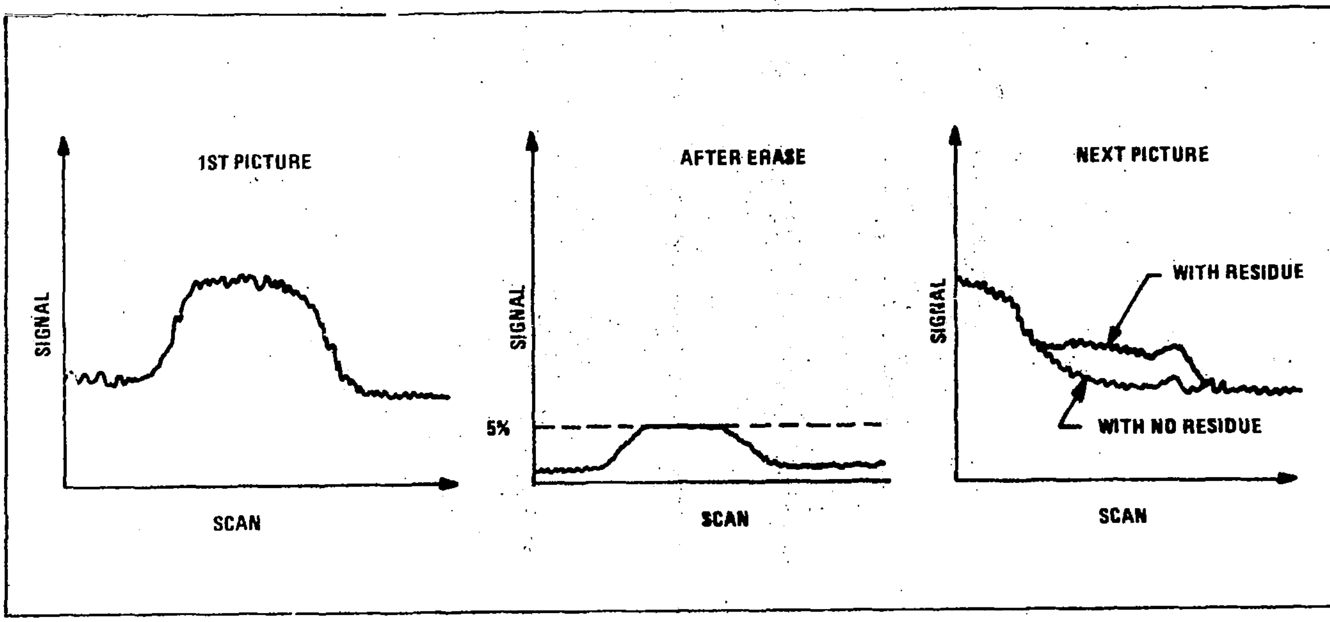


Figure F.2-3. RBV Residual Image Effect

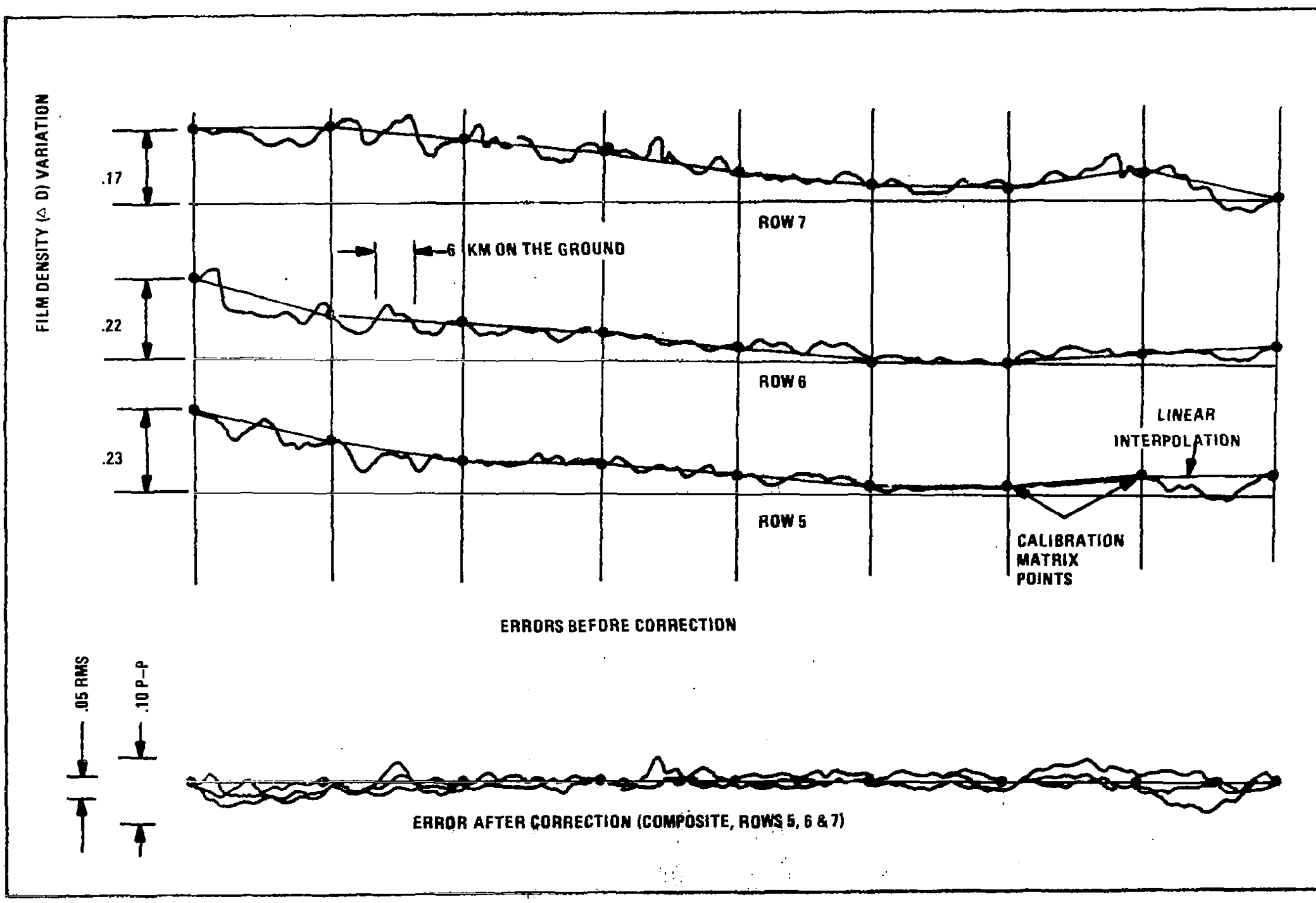


Figure F.2-4. RBV Shading Effects and Calibration

In addition to the preflight calibration, in-orbit calibration will be made using lamps within the RBV. These corrections will also be applied during Bulk Processing at the same time as the preflight calibration corrections are made. A comprehensive description of the calibration methods is given in Appendix G.

F.2.1.2 Communication Equipment

The components contributing to radiometric degradation in the communication path are also shown in Figure F.2-2 starting with the on-board wideband video tape recorder (WBVTR) and proceeding through the ground tape recorder playback stage in the NDPF. Considered here are such effects as doppler shift, RF polarization, second detector drift, level adjustment inaccuracy, and AGC effects in the receiver. Best estimates of the degradations due to this portion of the system are 3 to 5 percent of ΔD. Most of this degradation is removable on the ground.

F.2.1.3 Restabilization of Signal

Due to various effects, such as dc level shifts in the camera electronics and low frequency noise pick-up from spacecraft ground loops which tend to modulate dc signals, the RBV signal suffers from amplitude variations on a line-to-line basis. These variations consist of both dc level drift and zero to full scale amplitude changes. To eliminate these variations, the RBV signal is reclamped in the NDPF Video Processor and Sync Separator (VPASS). This process effectively establishes a new dc reference (black) level and nullifies nearly all preceding dc level variations including the 3 to 5 percent link errors illustrated in Figure F.2-5. Resulting radiometric error will be less than one percent of ΔD.

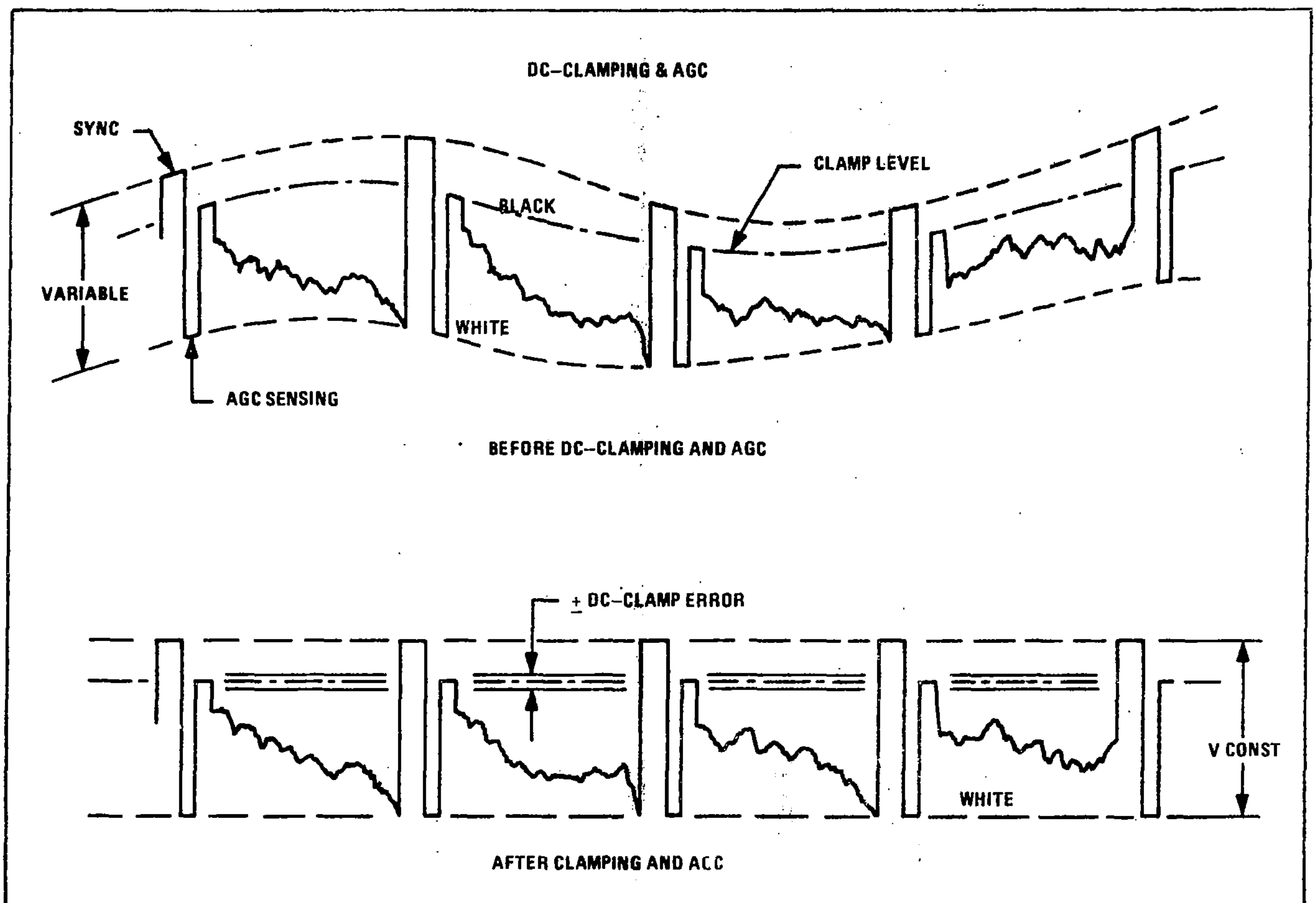


Figure F.2-5. DC Clamping and AGC

Automatic Gain Control (AGC) in the electron beam recorder (EBR) control unit, by sensing the sync tip to peak white amplitude, tends to keep the absolute peak-to-peak value of the signal constant.

F.2.1.4 RBV Bulk Processed Data

Additional errors are introduced by photo reproduction. Initial photo processing involves developing the SO-219 film emerging from the electron beam recorder. The output is the first generation, 70 mm imagery for the RBV as shown in Figure F.2-2. The error contributors are primarily due to the film variations and developing process and contribute less than 2 percent of ΔD.

The contributors to radiometric performance degradation during photo processing are:

Film and developing processes	± 1.0%
Strip printer	± 0.50%
Contact printer	± 0.50%
Enlarger	± .5%

The RSS total of these contributors is also less than 2 percent.

F.2.1.5 RBV Precision Processed Data

The overall radiometric linearity and dc level stability in the Precision Processing subsystem is determined by:

1. Characteristics of the leveler and video photomultiplier tubes of the framing stage in the viewer/printer
2. Video processing electronics stability and linearity
3. Residual optical effects in the optical portion of precision processing. Automatic correlation is performed in the viewer/scanner, but since the characteristics of the correlator operation are primarily geometric, they do not affect the system's radiometric performance.

The radiometric effects are:

1. Optical Effects—$\cos^4$ losses and vignetting. However, due to a cancelling effect in the leveler loops, a residual of only ± 0.7 percent remains.
2. Photo Multipliers—PM's are regarded as the most critical components affecting radiometric performance. The most important parameters are quantum efficiency, stability/degradation, gain linearity and repeatability. PM's are calibrated every four minutes, or every half minute if required by out-of-spec temperature variations in the operating environment. The calibration is determined by its stability and is better than 0.1 percent.
3. Video Processor—The main parameters are dc—level and gain stability with respect to temperature. Due to individual precision temperature compensation the corresponding ΔD effect is less than one percent.

F.2.1.5.1 EBRIC

The generation of the radiometric corrections to be used in Bulk Processing is one of the functions of the Precision Processing subsystem. This process consists of the following:

1. Taking as input uncorrected bulk calibration reference images generated in the Bulk Processing subsystem,
2. Measurement of calibration images to derive the relationship between the actual signal from, (1) above, and the corrected, proper value,
3. Generation of Electron Beam Recorder Image Correction (EBRIC) data utilizing calibration reference data

The corrections are subsequently transferred to the electron beam recorder control and the original images are corrected by gain adjustment of the electron beam recorder signal during Bulk Processing.

The corrections remain valid as long as new inflight calibrations do not indicate any change in RBV radiometric calibration. Should this occur, however, the new corrections will be derived by forming difference signals between the old and new calibration (in-flight) information. The "revised" information is subsequently applied to the EBRIC.

F.2.1.6 RBV Special Processing

F.2.1.6.1 Bulk

The RBV recorded video data must be converted from analog to digital form before reformatting and conversion to computer compatible tapes (CCT). There is essentially no degradation to the data during this process and the RBV data recorded on bulk CCT's represents the raw data received on tape in the NDPF. It should be noted that no calibration is performed on this data at all and it still contains up to 30 to 60 percent radiometric errors due to shading alone. The user desiring to interpret this data must be prepared to apply his own corrections; see Figure F.2.6.

F.2.1.6.2 Precision

Precision processed CCT's are derived from the precision processor and since the data has already been bulk processed, the data is corrected prior to digitizing. The contributed error during this digitization process is negligible; see Figure F.2-7.

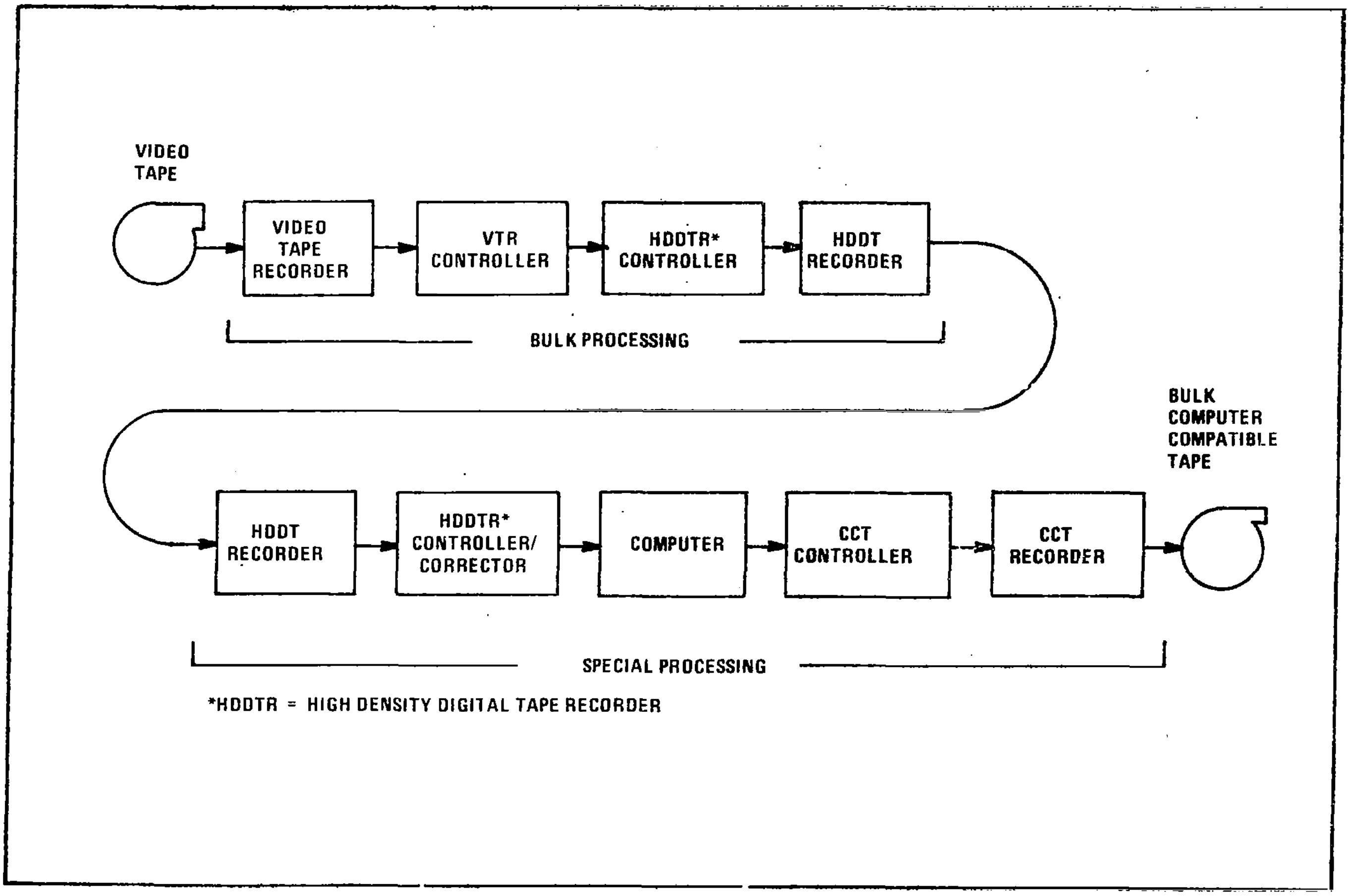


Figure F.2-6. RBV and MSS Bulk Computer Compatible Tape Generation

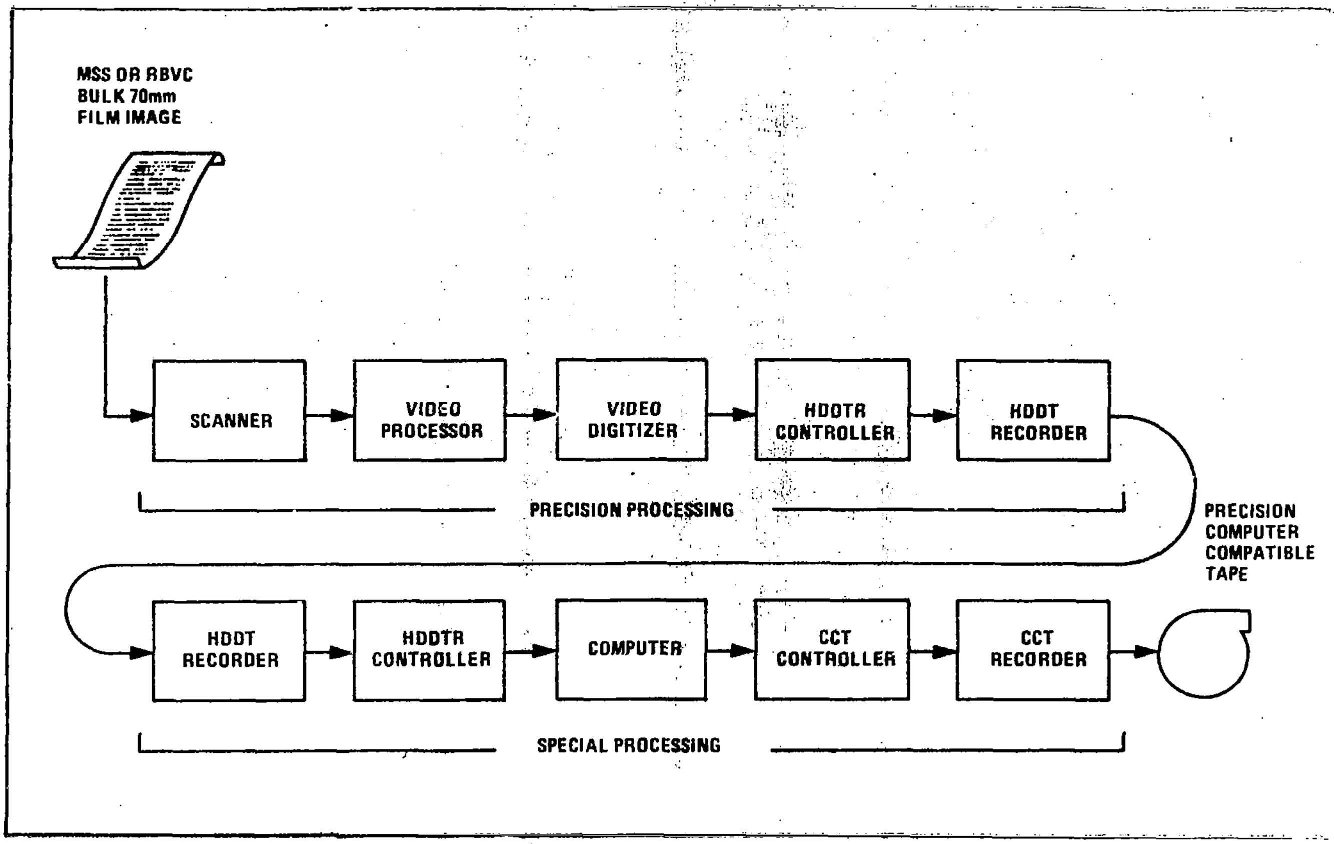


Figure F.2-7. Precision Digital Image Data

F.2.1.7 RBV Summary

The net effect of all radiometric errors for the RBV is given in Table F.2-1. The table shows the radiometric accuracy for all output products. All error sources in the flow are root-sum-squared with the exception of the residual RBV shading after EBR-CTL which is added directly to the RSS total. The VPASS removes the 3 to 5 percent link errors, and EBR-CTL reduces original shading error.

Table F.2-1. Summary of RBV Radiometric Errors

Output Product	Type	RBV Data (% Density Range)
Bulk Processed:		
Archival Film	70 (+) 1G	±6.8
70 MM Positive	70 (+) 3G	±7.5
9.5 In. Positive	9.5 (+) 3G	±7.5
70 MM Negative	70 (–) 4G	±7.7
Precision Processed:		
9.5 In. Positive	9.5 (+) 5G	±8.1
9.6 In. Negative	9.5 (–) 6G	±8.3
CCT Bulk Tapes	Digital Magnetic Tape	Uncorrected Raw Digital Video
CCT Precision Process Tapes	Digital Magnetic Tape	±7.8

NOTE: 70 (+) 3G = 70 MM, positive transparency, 3rd generation.

F.2.2 Multispectral Scanner Radiometry

F.2.2.1 Spacecraft and Link Errors Sources

The initial stages of the MSS sensor are analog in nature. Bands 1, 2, and 3 use dc coupling while Band 4 utilizes ac coupling with dc reclamping. The bulk (1.5 percent) of the MSS-contributed radiometric error is due to dc voltage instabilities in the baseband amplifier. The analog signals are applied to an analog-to-digital converter and finally to a multiplexer. Temperature variations will cause quantization errors of 0.8 percent. Total radiometric error out of the MSS sensor amounts to 1.7 percent of ΔD.

The signal emerges from the MSS in digital form and is transmitted and handled in this form up to the digital-to-analog converter in the NDPF as shown in Figure F.3-1. The error sources down through the D/A converter can be attributed to within-the-line amplitude jitter, clamping inaccuracies, and spurious A/D and D/A conversions lasting over many resolution cells, but values of these contributing errors are negligible.

F.2.2.2 MSS Bulk Processed Data

The image recording and reproduction procedures and functions are essentially the same for both RBV and MSS data. The error sources and contributed degradations are identical; they are described in Section F.2.1.4. The combined effect of all radiometric errors for the MSS as seen in the photo output products is given in Table F.2-2.

Table F.2-2. Summary of MSS Radiometric Errors

Output Product	Type	MSS Data (% Density Range) (Typical)
Bulk Processed:		
Archival Film	70 (+) 1G	±2.4
70 MM Positive	70 (+) 3G	±2.8
9.5 In. Positive	9.5 (+) 3G	±2.9
70 MM Negative	70 (–) 4G	±3.1
Precision Processed:		
9.5 In. Positive	9.5 (+) 5G	±3.5
9.5 In. Negative	9.5 (–) 6G	±3.6
CCT Bulk Tapes	Digital Magnetic Tape	±1.7
CCT Precision Process Tapes	Digital Magnetic Tape	±3.1

Note: *70 (+) 3G = 70 MM, positive transparency, 3rd generation.*

F.2.2.3 MSS Precision Processed Data

The precision processing function is also common to the RBV and MSS data. The errors sources and contributed degradations are identical and are described in Section F.2.1.5.

F.2.2.4 MSS Special Processing

F.2.2.4.1 Bulk

The MSS signal on the video tape received in the NDPF is already in digital form. The recording process to generate bulk CCT's involves merely a reformatting and contributes essentially no degradation in terms of radiometry; see Figure F.2-6.

F.2.2.4.2 Precision

Precision CCT's are derived from the precision processor which in itself contributes less than 0.1 percent degradation; see Figure F.2-6. The total radiometric degradation in the MSS output CCT's is given in Table F.2-2.

F.3 RESOLUTION

F.3.1 MSS Resolution

The MSS sensor instantaneous field of view (IFOV) is 0.086 milliradians corresponding to 79 meters as measured on the ground. Due to the integrating effects of the fiber optics in the MSS, resolution is limited to the IFOV dimension. Resolution, as used in this handbook, refers to the ability of an observer to recognize adjacent fields of a certain width (e.g., 80 meters). It is possible that the existence of boundaries between radiance fields as small as 1/2 IFOV can be sensed in certain scenes, however, this is not the same as recognizing the actual field dimension.

Scene radiance, as measured from nominal ERTS altitude, serves as the input to the MSS sensor. Since the radiance is measured through the atmosphere, it is a relative measure of the actual radiance on the ground. Table F.3-1 lists some apparent radiance levels for various observables as viewed by the sensor. This data is representative of the radiance levels to be sensed by the various bands of the MSS.

The scene radiance is sensed in the MSS, transformed to a video signal and immediately converted to a digital bit stream. It remains in digital form throughout transmission to the ground and until it reaches the digital to analog (D/A) converter in the Bulk Processing subsystem. Figure F.3-1 outlines the flow of MSS data from ground scene input, through the spacecraft sensor, wideband telemetry,

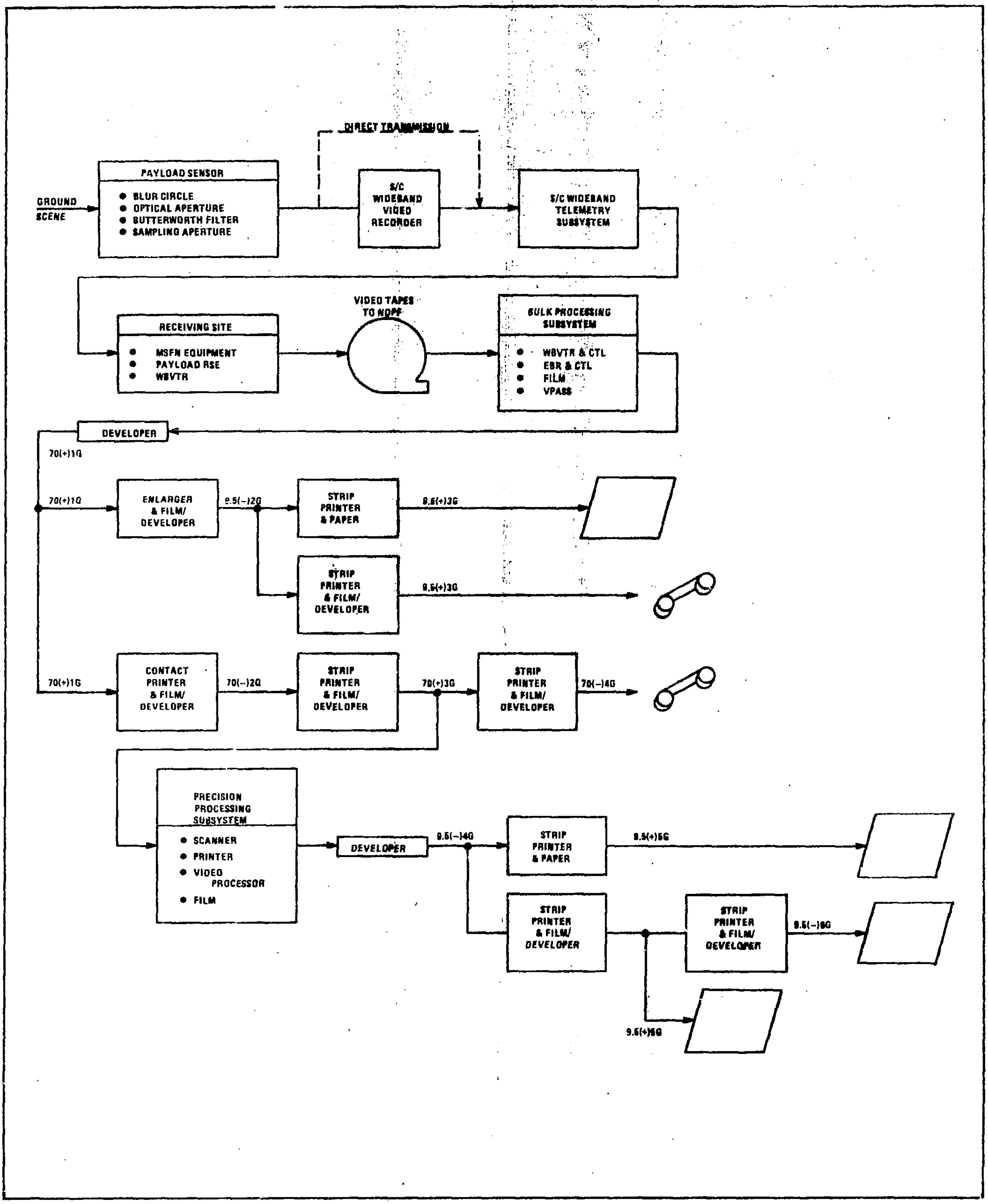


Figure F.3-1. MSS System Flow

Table F.3-1. Apparent Radiance Levels of Some Observables for 60° Zenith Angle at Sensor Input

Observable	Band			
	1	2	3	4
Wheat	.322	.225	.320	.810
Barley, Mildewed	.385	.355	450	1.011
Oats	.280	.192	.285	.825
Pine	.345	.292	.490	1.410
Sycamore	.355	.400	.690	1.590
Dry Loam	.584	.592	.532	1.221
Gneiss	.612	.570	.468	.933
Water	.327	.195	.105	.165
Snow	1.590	1.312	1.110	.780

Note: All Radiances are in milliwatts/cm^2 - sr

Bulk Processing, Precision Processing, Photographic Production Processing to image outputs to the investigators.

Once the data is digitized in the sensor, there will be no degradation to resolution until it reaches the D/A converter where it is reconverted to an analog video signal. From this point on, the various equipments in the Bulk, Precision and photo processes all contribute some degradation to the resolution quality of the MSS data. The significant contributors in the Bulk Processing subsystem are the D/A converter, EBR beam, control electronics, and the film. In the Photo Processing subsystem, the film, developer, printers and enlargers are the major contributors.

Every piece of equipment or process can be represented by its modulation transfer function (MTF). Each Bulk Processed output image will have been operated on by the MSS, Bulk Processing, and Photo Processing subsystems and can be represented by the combined transfer functions for MSS, BPS, and Photographic subsystems. A comparison of the MSS MTF (at output of the sensor) with the MTF up to the 9.5 inch, positive, third generation transparency is shown in Figure F.3-2.

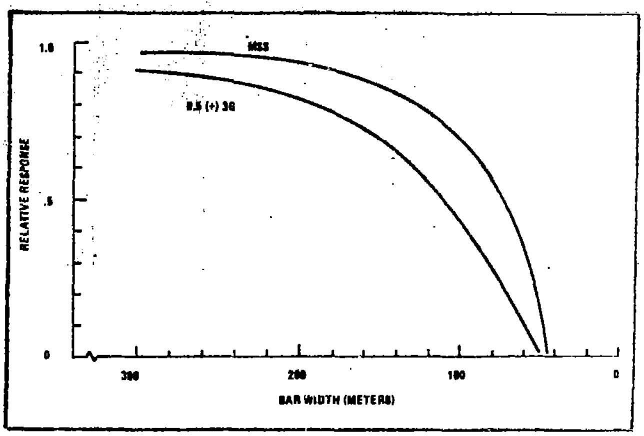


Figure F.3.-2. Modulation Transfer Functions – Sensor and Bulk Output, Third Generation

In the Precision Processing subsystem, the scanning and printing CRT's, their optics, the video processor, and the film each contribute some additional degradation to the resolution of the video data. The various photo processing steps also contribute degradation. Figure F.3-3 shows the original MSS output MTF with the MTF for the 9.5 (+P) 5th Generation output of the system. This figure is representative of the "worst" degradation through the system.

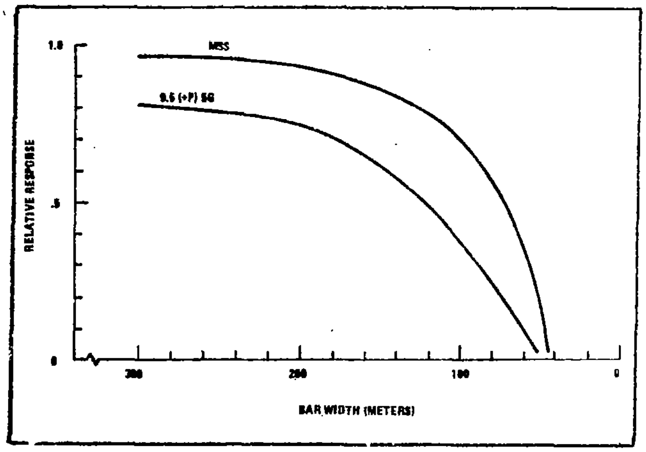


Figure F.3-3. Modulation Transfer Functions – Sensor and Bulk Output, Fifth Generation

Resolution is defined by that value of signal-to-noise ratio which just permits recognition of a tri-bar pattern by a human observer. This criterion was developed by Otto Schade through experiments which yielded 4.0:1 as the SNR threshold. The functional relationships for determining SNR output of the MSS detectors are as follows:

PMT (Bands 1-3)

$$SNR = \frac{N_2' - N_1'}{(N_2')^{1/2}} \times MTF \times K_n$$

Photodiode (Band 4)

$$SNR = (N_2' - N_1') \times MTF \times K_n$$

Where

N' = apparent radiance in optical passband of bars in test pattern as seen from space, $mw/cm^2 - sr$

MTF = system modulation transfer function

K_n = unique constant for each spectral band, n

Note that the SNR is directly dependent on the input radiance, hence the resolution is directly dependent on the scene itself.

The resolution characteristics for the four spectral bands of the MSS have been plotted in Figures F.3-4 through F.3-7. The curves show performance at two different points in the system:

1. MSS output—representing the resolution performance of the sensor itself, or, the performance of the system were there no degradations due to ground processing. Resolution cannot be better than this

2. 9.5 (+P) 5G—represents the most degraded output that is sent to investigators. All other imagery will have better resolution.

To interpret the results for any two observables, the scene radiances are selected from Table F.3-1 corresponding to the observables in question. The smaller of the two radiances is subtracted from the larger and the resulting value entered on the ordinate of the graph. The larger of the two radiances is plotted on the abscissa. The boundary line directly below the resulting point represents the recognizable bar width for those scene characteristics.

For example, in Band 1, wheat versus mildewed barley will have $N_1' = 0.322$ (wheat), $N_2' = 0.385$ (mildewed barley) and $(N_2' - N_1') = 0.063$. Plotting 0.063 on the ordinate and 0.385 on the abscissa of Figure F.3-4 yields a resolution limit for this scene of:

1. 100 meters at the MSS output

2. slightly less than 300 meters on a 9.5 (+P) 5G image

This means that a human observer, hypothetically placed at the MSS output, could recognize adjacent fields of wheat and mildewed barley if they each exceeded 100 meters in width. If he were viewing a 9.5 (+5) 5G image, he could recognize the same fields if they exceeded 300 meters in width.

The investigator can use the curves of Figures F.3-4 through F.3-7 to determine the MSS system resolution for any pair of observables using Table F.3-1 or his own input values.

The Special Processing subsystem takes digitized MSS video data from the NDPF WBVTR and converts it to computer compatible tapes for distribution to investigators. Since this is strictly a reformatting process and does not involve any digital-to-analog conversion, no degradation to resolution results, and the resolution will be essentially the same as at the MSS output. Any photographic reproduction which is subsequently done by the investigator will have an effect on resolution commensurate with the MTF's of the equipment used.

Computer compatible tapes (CCT) generated by the Precision Processing subsystem will

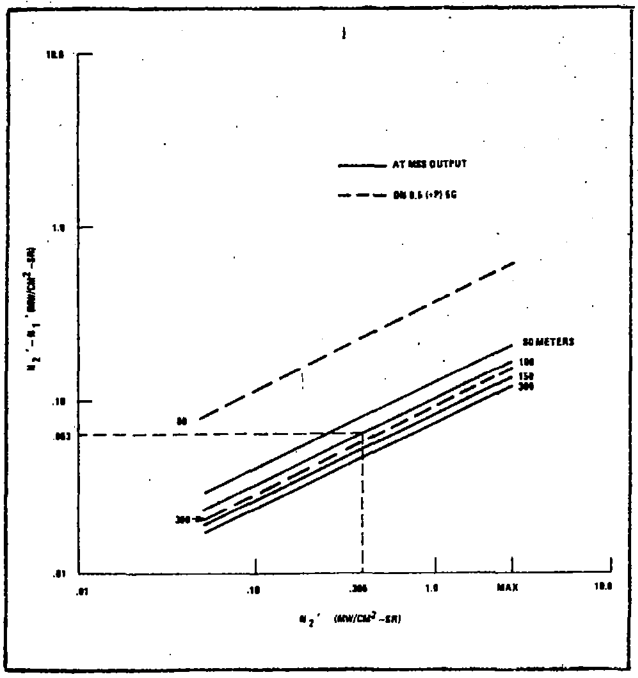


Figure F.3-4 MSS System Resolution – Band 1

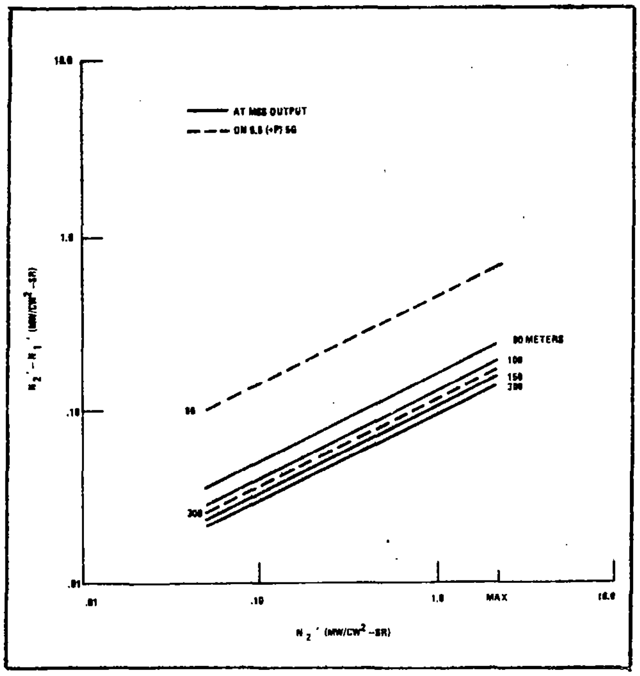


Figure F.3-5. MSS System Resolution – Band 2

have a resolution only slightly better than that of the Precision Processing imagery outputs. This is because the data on the precision CCT's has already passed through the Bulk photo and part of the Precision Processing equipment and has been degraded by these equipments.

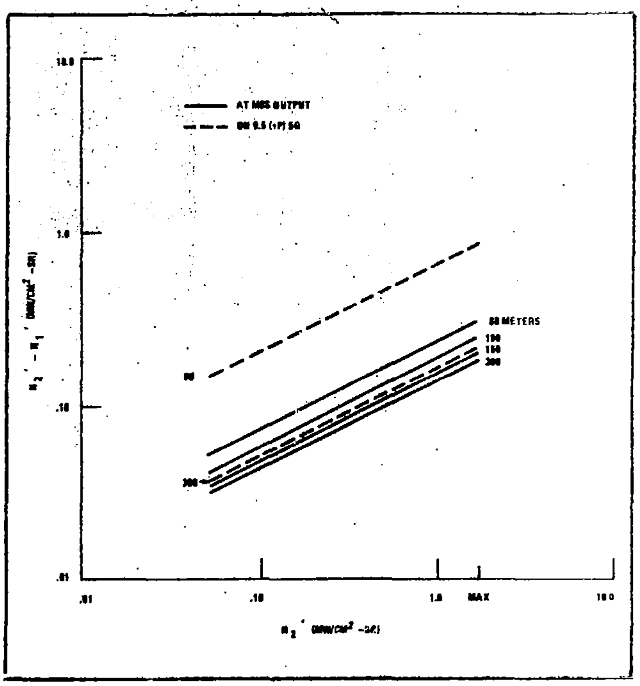


Figure F.3-6. MSS System Resolution – Band 3

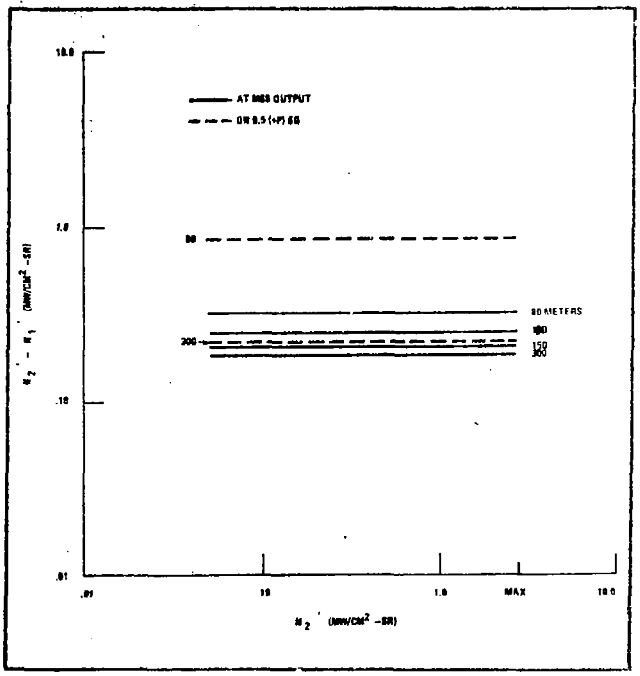


Figure F.3-7. MSS System Resolution – Band 4

F.3.2 RBV Resolution

Scene radiance and contrast, as measured from the nominal ERTS altitude, serve as input to the RBV sensor. Since these parameters are measured through the atmosphere, they are a relative measure of the actual parameters on the ground. Table F.3-2 lists some apparent contrast and radiance levels for various combinations of observables as viewed by the sensor. This data is representative of the scene characteristics to be viewed by the RBV.

Table F.3-2. Resolution Analysis Typical Scene Characteristics

BAND	1	2	3
Wavelength Interval (μM)	.475 – .575	.580 – .680	.690 – .830
Average Plant vs. Dry Loam			
Ground Contrast	2.18:1	3.72:1	1.50:1
Space Contrast	1.5 :1	2.0 :1	1.3 :1
Mean Radiance mw/cm^2–sr	.485	.434	.625
Average Plant vs. Water			
Ground Contrast	1.32:1	1.79:1	19.9:1
Space Contrast	1.1 :1	1.2 :1	3.4:1
Mean Radiance	.366	.255	.354
Average Plant vs. Wet Loam			
Ground Contrast	1.16:1	1.79:1	1.68:1
Space Contrast	1.0 :1	1.3 :1	1.4 :1
Mean Radiance	.382	.314	.476
+ σ Plant vs. Average Plant			
Ground Contrast	1.47:1	1.57:1	1.4 :1
Space Contract	1.2 :1	1.2 :1	1.4 :1
Mean Radiance	.425	.306	.653
Average Plant vs. – σ Plant			
Ground Contrast	1.90:1	2.29:1	1.57:1
Space Contrast	1.2 :1	1.4 :1	1.5 :1
Mean Radiance	.357	.238	.448

The scene characteristics are sensed by the RBV cameras, and converted to an analog video signal (Figure F.3-8). The video, in analog form, passes through the camera controller and combiner, spacecraft WBVTR, wideband telemetry system, receiving site electronics, and is recorded on a receiving site video tape recorder (VTR). The tapes are then transported to the NDPF for processing.

At the NDPF, the data is played back on a VTR, fed through the electron beam recorder (EBR) control unit and written on 70 mm film by the EBR. The latent image is developed, printed and possibly enlarged depending on the path taken through the Photographic subsystem.

Each component in the video path contributes some degradation to the signal-to-noise ratio of the video and hence the resolution of the RBV imagery. The degradation is a function of the modulation transfer functions (MTF) of the individual components. The only exception is the video processor and sync separator (VPASS), a major piece of equipment both at the receiving site and at the NDPF. It has a very wide frequency response, –1dB at 8 MHz, and contributes essentially no degradation to the signal.

The output signal-to-noise ratio of the RBV is determined using the following equation:

$$R_\Delta(f) = SNR_{FS} \sqrt{\frac{f_N\, F_A(\infty)}{f\, F_A(f)}}\ \sqrt{5}\ \left(\frac{E_X}{E_{XFS}}\right)^{\gamma} \left[2\gamma m_o \bar{\tau}_R\ (f)\right]$$

The full scale signal-to-noise ratio of the RBV (SNR_{FS}) is read from Figure F.3-9 given the full scale exposure value (E_{XFS}) for each channel. For a given exposure time (t_s) and using the effective f-number of the lens (T) then the following equation is used with mean radiance (N′) of the scene in each channel to determine the mean exposure of the scene at the vidicon faceplate:

$$E_X = \frac{\pi N' t_s}{4T^2} \quad \text{microjoules/cm}^2.$$

The slope (γ) of the light transfer characteristic for the camera is 0.9.

The input scene modulation is calculated from the space contrast ratio (C_o) of the scene at the vidicon faceplate using:

$$m_o = \frac{C_o - 1}{C_o + 1}$$

where

$$C_o = \frac{N_2'}{N_1'}$$

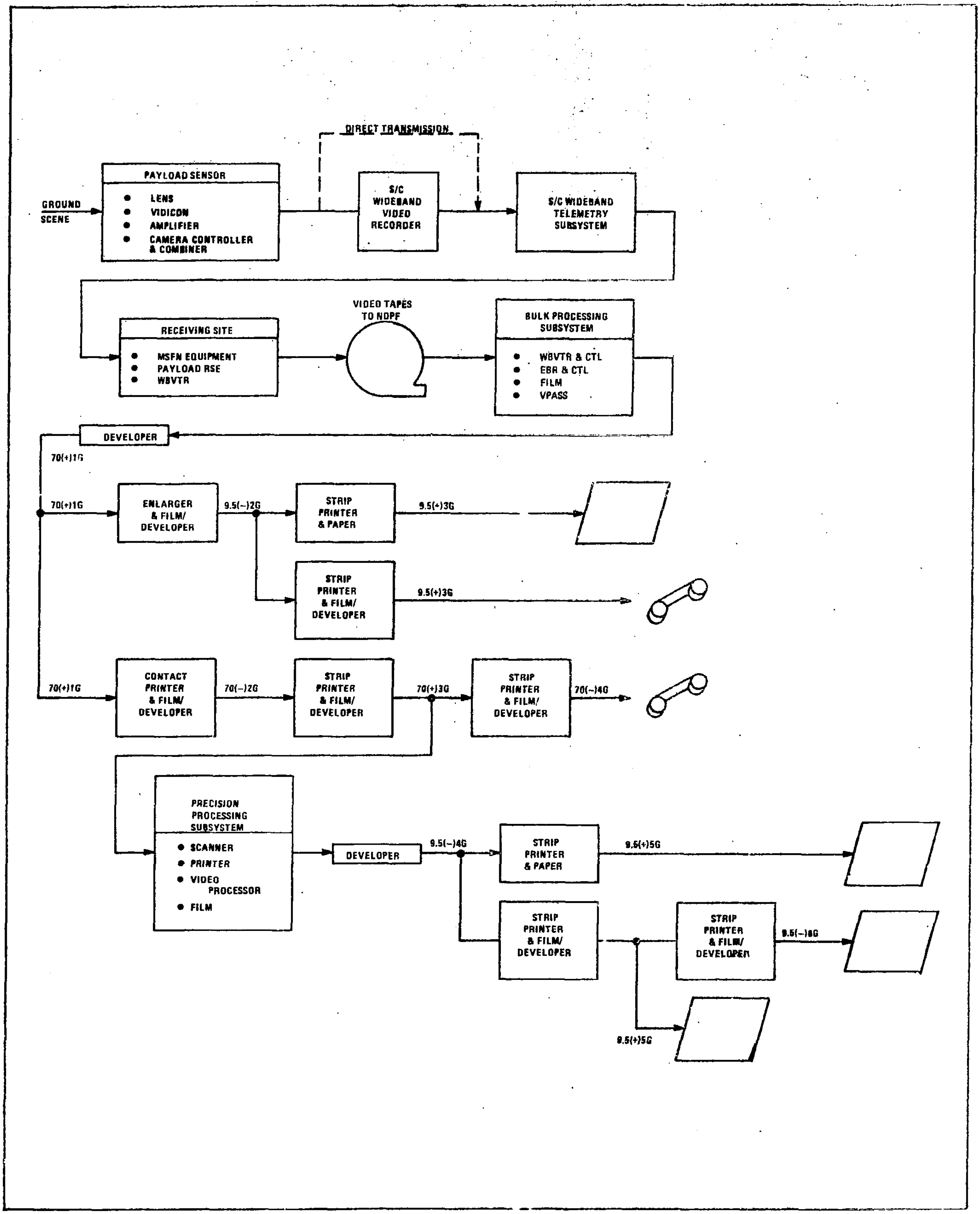


Figure F.3-8. RBV System Flow

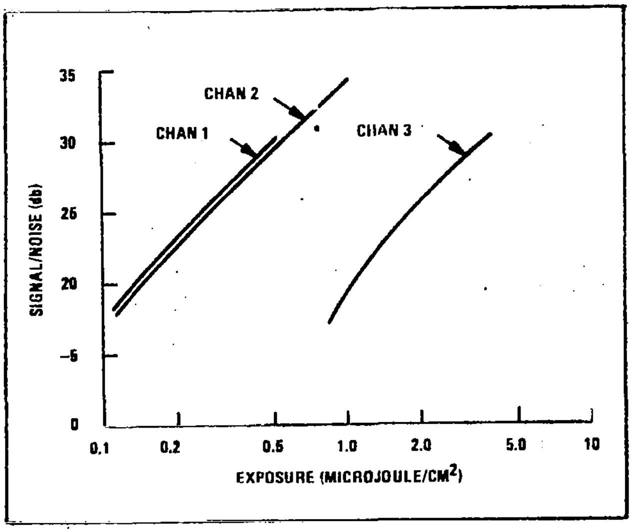


Figure F.3-9. Spectral Signal-to-Noise Characteristic (Typical)

The video amplifier is assumed to be ideal with a 3.3 MHz bandwidth so that $F_A(f) = f$ and $F_A(\infty) = 2440$. f_n is the Nyquist frequency of the raster in cycles/line. The units for spatial frequency (f) will be cycles/line as defined below:

cycles/line = (cycles/millimeter) x (width of scanned format in millimeters)
= (video frequency (MHz) x (active scan time (microseconds)).

The conversion of resolved spatial frequency to meters on the ground is accomplished through:

$$R_G = \frac{W}{2f} \times \frac{h}{F},$$

where W is the width of the scanned format, h is the spacecraft altitude and F is the focal length of the RBV lens.

The average square wave response r_R of the RBV is determined from the modulation transfer function (MTF) of the lens, vidicon and amplifier by:

$$\bar{r}_R(f) = \frac{8}{\pi^2}\left[\tilde{r}_R(f) + \frac{\tilde{r}(3f)}{9} + \frac{\tilde{r}_R(5f)}{25}\right],$$

where

$$\tilde{r}_R(f) = \tilde{r}_{RBV}(f)\,\tilde{r}_{LENS}(f)\,\tilde{r}_{AMP}(f).$$

Figures F.3-10 and F.3-11 show the resolution expected if a human observer were placed at the RBV output. This is a hypothetical point representing no additional degradations due to rest of the system, i.e., resolution can be no better than this. The curves were generated by applying Schade's criterion, which is that threshold value (4:1) on SNR which just permits target recognition. Figures F.3-12 and F.3-13 show the resolution at the most degraded output-a 9.5 (+) 5G paper print after Precision Processing. Calculations were performed using a 12 millisecond exposure time. The effect of using another exposure time, t_s, would be to modify the ordinates (mean radiance) of Figures F.3-10 through F.3-13 by a factor of $12/t_s$.

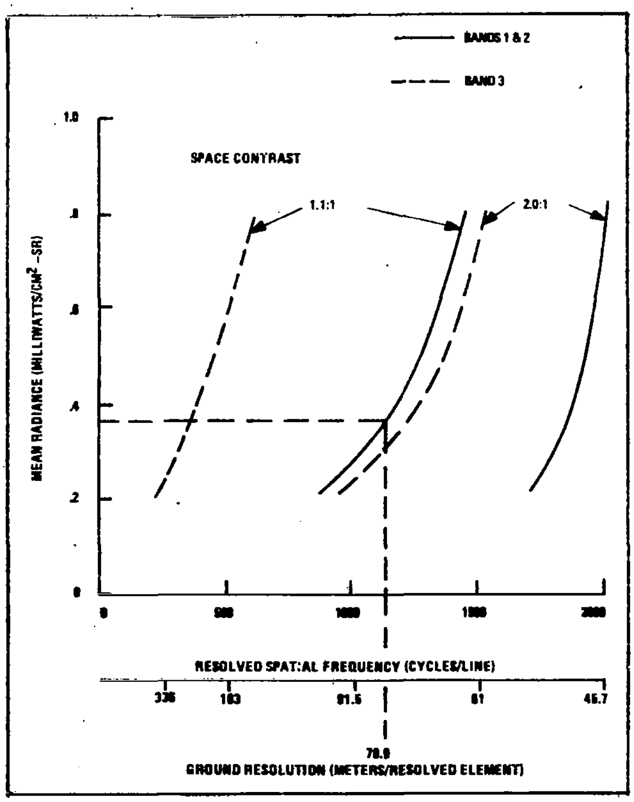


Figure F.3-10. RBV System Resolving Power – RBV Output Cross-track

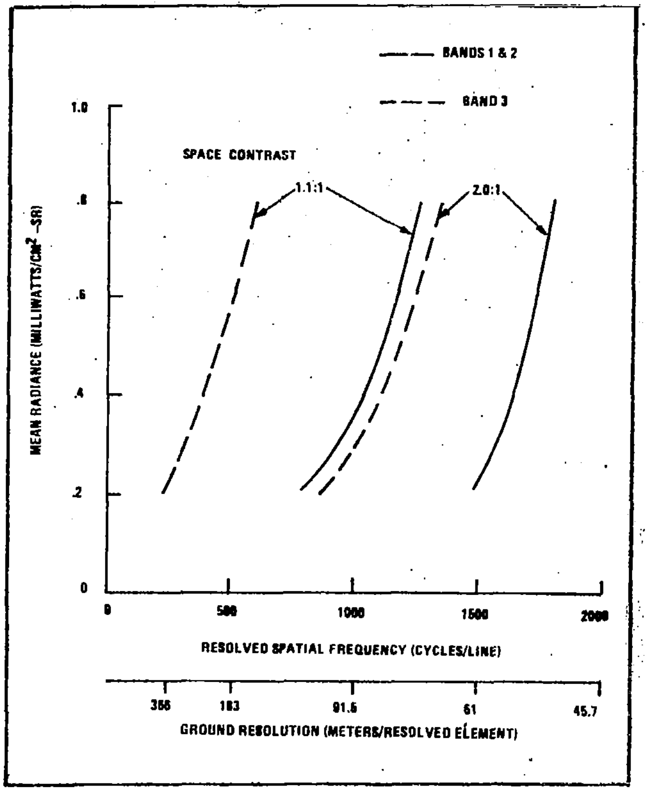


Figure F.3-11. RBV System Resolving Power — RBV Output Along-Track

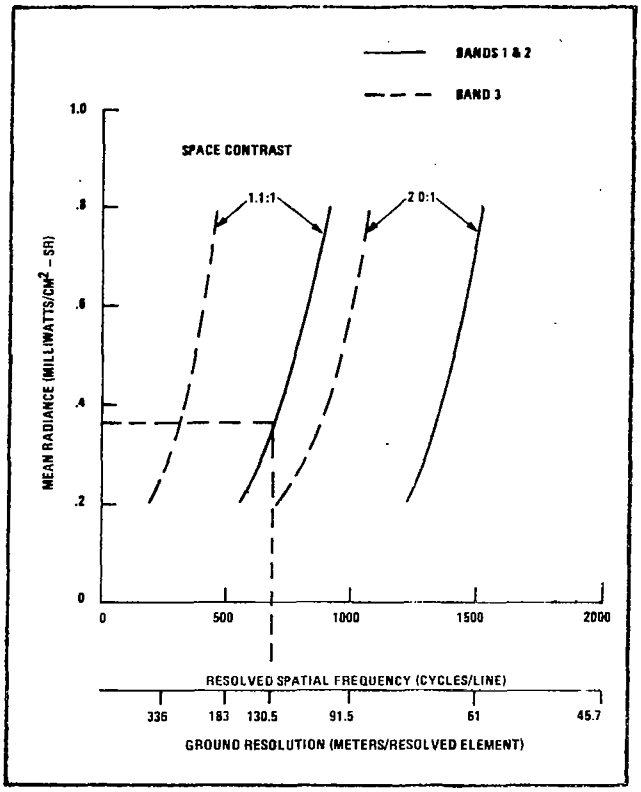


Figure F.3-12. RBV System Resolving Power — 9.5 (+P) 5G Precision Cross-track

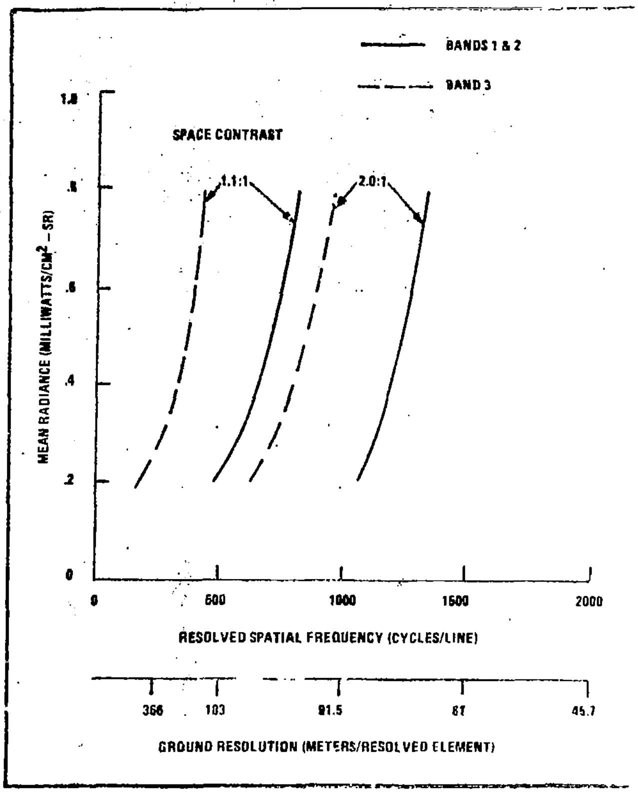


Figure F.3-13. RBV System Resolving Power — 9.5 (+P) 5G Precision Along-Track

In order to effectively use the curves, they must be related to a particular ground scene. Table F.3-2 presents characteristics for a number of typical ERTS scenes. The values of radiance are predicated upon a sun angle (refer to Appendix J) of 30 degrees, which represents the worst case for the continental United States. Lower sun angles result in some resolution degradation due to poorer illumination conditions.

As an example, the average plant vs. water has a mean radiance of 0.366 mW/cm^2 —sr and a space contrast of 1.1:1, as shown in Table F.3-2. On Figure F.3.2-10, the cross-track resolution at the RBV output can be read as 78.9 meters/resolved element. By comparison, the resolution of a 9.5 (+P) 5G image will be 130.5 meters for the same scene, as shown in Figure F.3-12. Note that using a fifth generation image is an extreme example. However, by showing curves at RBV output (best possible resolution) and on 9.5 (+P) 5G (worst expected resolution) the performance of the system has been effectively bounded.

Along-track resolution can be determined using Figures F.3-11 and F.3-13, which were also calculated with an exposure time of 12 milliseconds. Comparison with Figures F.3-10 and F.3-12 indicates slightly worse resolution, which is due to smear. The effect of smaller exposure times, by reducing smear, is to cause along-track resolution to approach the cross-track values. Larger exposure times, however, increase smear and further degrades along-track resolution. As an example, for a 16 millisecond exposure time (maximum for ERTS A), cross-track resolution at the RBV output is 71.4 meters while along-track is 93.3 meters.

The Special Processing subsystem takes digitized video data from the Bulk Processing subsystem and converts it to computer compatible tapes for distribution to investigators. Perfect image generation by the investigator results in resolution slightly worse than at the RBV output. With Precision Processed video data, the resolution of images generated from these computer compatible tapes (CCT) would be that of the Precision Processed subsystem output, i.e., slightly better than the resolution on 9.5 (+P) 5G.

APPENDIX G
CALIBRATION

The ERTS Image Processing Subsystems generate and apply radiometric and geometric corrections to the sensor data during the initial process of converting received video tapes into film images. These operations require appropriate radiometric calibration data for the RBV cameras and the MSS.

Two types of calibration data are employed for the RBV: (1) radiance maps obtained via a uniform calibrated source, such as a Hovis sphere, and (2) internal calibration (erase) lamp radiance maps. From the uniform calibrated source radiance maps, the light transfer characteristics (LTC) and radiance correction maps for each camera are derived. The LTC defines the calibrated relationship between the RBV signal voltage and input (scene) irradiance.

The radiance correction maps provide the two-dimensional functions to linearize the spatially-variable signal and black-level characteristics of a given camera to its LTC. The calibration-lamp maps for each camera provide the two-dimensional calibration functions to relate the in-flight calibration images of a given camera to its LTC.

In addition geometric calibration determines the two-dimensional projective geometry of each camera, the axial alignment of the three cameras to each other, and the alignment of the camera system to the axes of the spacecraft.

For the MSS, three types of calibration data are employed: (1) calibration of the scanner via the Hovis integrating sphere, (2) calibration of the scanner via a calibrated collimator, and (3) the calibration wedge of the collimator itself. From the integrating sphere the response characteristics of the individual detectors are obtained. Each detector is adjusted so that maximum radiance corresponds to full voltage. Utilizing the scanner as the transfer function, the collimator is calibrated to the integrating sphere. The calibration wedge radiance versus voltage and radiance versus word-count response are then derived by correlating the calibrated collimator response at various radiance levels to the calibration wedge output. The calibration wedge supplies the calibration function to provide conversion between input radiance and output voltage.

G.1 RETURN BEAM VIDICON (RBV)

G.1.1 Calibration Methods

G.1.1.1 Radiometric Calibration

Radiometric calibration is based on measuring and recording RBV output signal versus position in the two-dimensional RBV image format for a number of known input radiance levels which span (1) the spectral band, and (2) the range of scene radiance for which each camera is designed.

Two types of RBV radiometric calibration data are utilized for the purpose of calibration:

1. Initial calibration data, describing the complete (spatial, spectral, voltage level) response of each camera to known, through-the-lens exposures, which is obtained prior to flight. This consists of uniform calibrated source radiance mapping, calibration-lamp radiance mapping, and test data.

2. Inflight calibration images, indicating the response of each camera to fixed and precalibrated on-board exposure sources, which are obtainable upon ground command.

Initial calibration consists of a radiance mapping utilizing: (1) a uniform calibrated source and (2) the calibration (erase) lamps of the RBV's. Through the calibrated source mapping, radiance corrections are derived for the scene and are applied to "correct" the calibration-lamp maps. The corrected calibration-lamp maps are then used as the standard to which all future LTC and spatially variant corrections are based. RBV radiometric calibration is illustrated in Figure G.1-1.

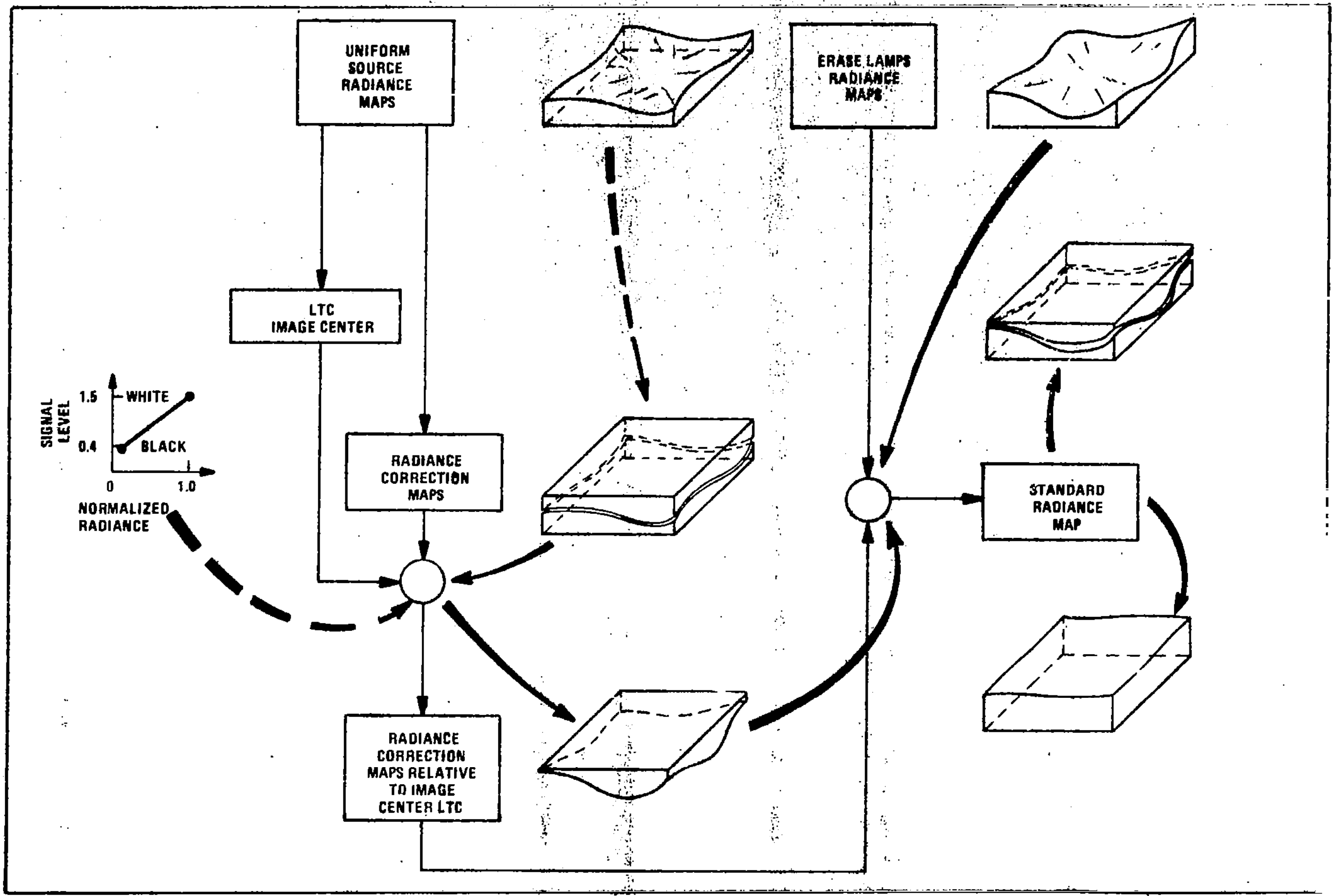


Figure G.1-1. Return Beam Vidicon Calibration

G.1.1.2 Uniform Calibrated Source Radiance Mapping

This mapping is performed utilizing a Spectra-Prilchard Photometer "light-box" with a 0.25-degree field of view which has been calibrated against a Hovis sphere. The useful diameter of the photometer is 5 inches and is uniform about an average intensity of 2147 foot-Lamberts, to within limits of +2.9 percent and -3.1 percent. The mapping is performed at two radiance levels for each camera:

> Camera 1 — full black and 0.85 mW/cm^2-sr at 12 ms exposure
>
> Camera 2 — full black and 0.85 mW/cm^2-sr at 12 ms exposure
>
> Camera 3 — full black and 1.36 mW/cm^2-sr at 12 ms exposure

utilizing the appropriate neutral density filters with the calibrated source.

For each of the two radiance levels, the mapping is obtained by utilizing a radiance calibration computer program which provides a map of the video output on an 18 x 18 matrix (324 points) based on the reseau spacing. To smooth out the noise and eliminate spurious readings, each value presented is the average of data taken on 64 sequential lines. The individual samples are integrated for 10 seconds along the horizontal direction; thus the program collects 18 x 18 x 64 = 20,736 individual samples.

The sample points are uniformly spaced over the active raster according to the scheme presented in Table G.1-1. Size and centering corrections are made to correct for raster distortion by comparing the known positions of the reseau, as measured through the lens by the United States Geological Survey, with the position of the reseau determined by the same configurational test equipment used for the mapping. This correction provides a linear stretch in the vertical or horizontal directions and a shift of the entire set of sample points.

In addition, gain and offset values are applied to the measured values for the radiance mapping, in order to correct the raw data input for minor variations to the alignment and calibration of the circuitry in the test set-up.

Once the data is obtained on the 18 x 18 matrix it is transformed to a 9 x 9 matrix which is based on 1/8 subdivision of the nominal image format dimensions. Figure G.1-2 shows the relationship of the 18 x 18 points presented in Table G.1-1 to the 9 x 9 matrix of points.

The 9 x 9 correction-breakpoint matrix does not coincide with the radiance mapping data matrix. Therefore, radiance data values corresponding to the breakpoints located within the 18 x 18 radiance data array are computed by interpolation within the four nearest data points; radiance data values corresponding to each breakpoint located at the edges of the image format are computed by extrapolation from the four nearest breakpoints.

The equations for the reformatting transformation are presented below and are referenced to Figures G.1-3 through G.1-6 inclusive.

Interpolation

$$a = (x-x_i) / (x_{i+1} - x_i)$$

$$b = (y-y_j) / (y_{j+1} - y_j)$$

$$V_{xy} = (1-b)\left[(1-a)V_{i,j} + a\, V_{i+1,j}\right]$$

$$-b \left[(1-a)\, V_{i,j+1} + aV_{i+1,j+1}\right]$$

Corner-Point Extrapolation

$$V_{x,y(c)} = (1+b)\left[(1+a)\, V_{9,9} - a\, V_{8,9}\right]$$

$$-b \left[(1+a)\, V_{9,8} - a\, V_{8,8}\right]$$

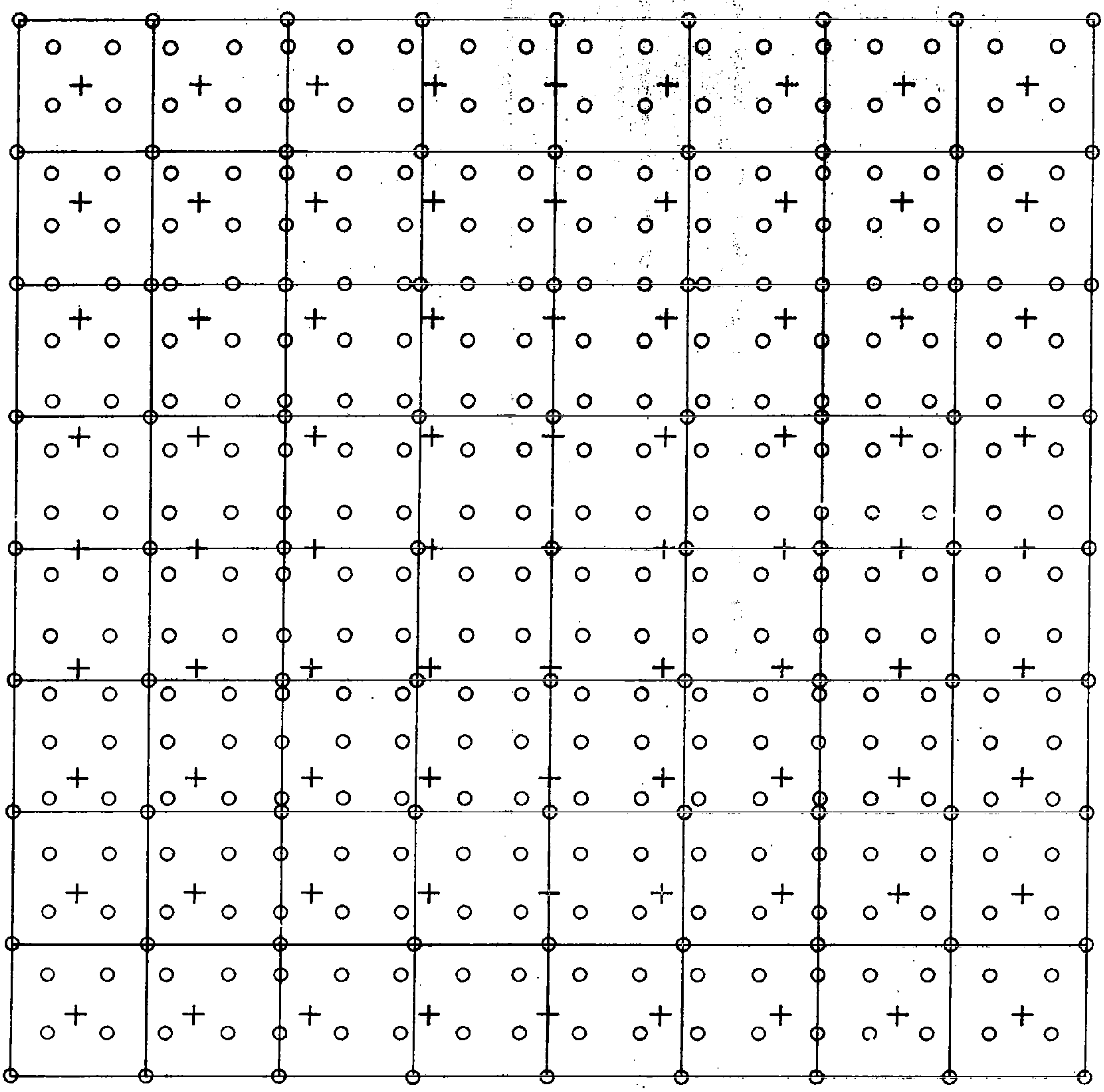
Edge-Point Extrapolation

$$V_{xy}(R,L) = (1-b)\left[(1+a)\, V_{9,j} + aV_{8,j}\right]$$

$$+b \left[(1+a)V_{9,j+1} + aV_{8,j+1}\right]$$

Table G.1-1. Sample Points for Tests (18 x 18 Matrix)

Vertical: Line Number at Start of Sample	Sample Number	Horizontal: Line Time at Start of Sample	Horizontal: Element Number at Start of Sample
92	1	17.7 μs	110
320	2	57.4	358
548	3	97.1	606
776	4	136.8	854
1004	5	176.5	1102
1232	6	216.2	1350
1460	7	255.9	1598
1688	8	295.6	1846
1916	9	335.3	2094
2144	10	375.0	2342
2372	11	414.7	2590
2600	12	454.4	2838
2828	13	494.1	3086
3086	14	533.8	3334
3284	15	573.5	3582
3512	16	613.2	3830
3740	17	652.9	4078
3968	18	692.6	4326



⊕ BREAKPOINT LOCATIONS FOR 9 X 9
BULK–PROCESSING IMAGE CORRECTIONS
55 mm RBV IMAGE

○ 18 X 18 MEASUREMENT POINTS (RCA)

+ RESEAUS

Figure G.1-2. Relationship of 18 x 18 Matrix to 9 x 9 Matrix

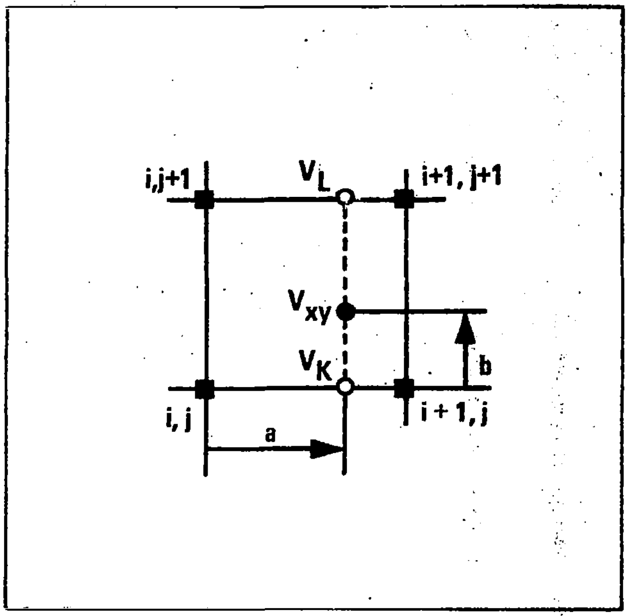


Figure G.1-3. Interpolation

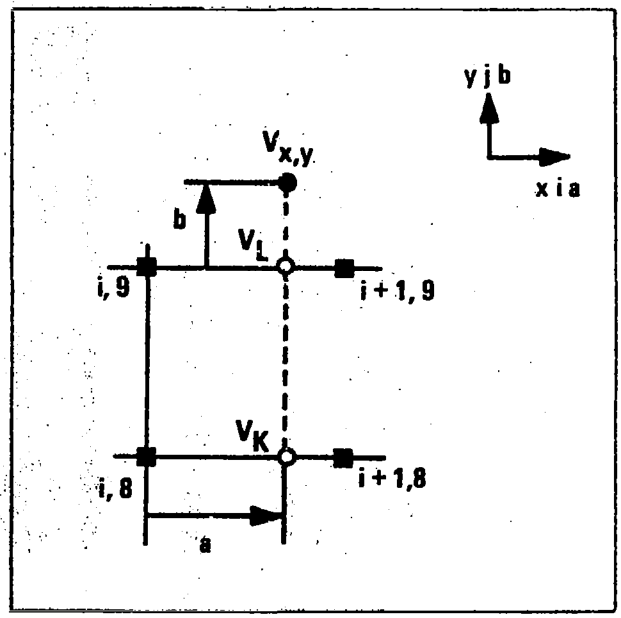


Figure G.1-5. Top-Bottom Extrapolation

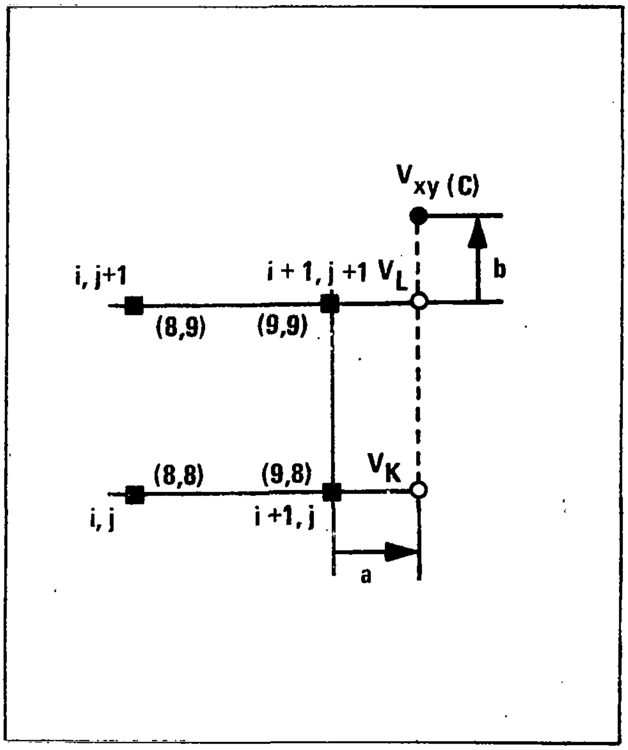


Figure G.1-4. Corner Extrapolation

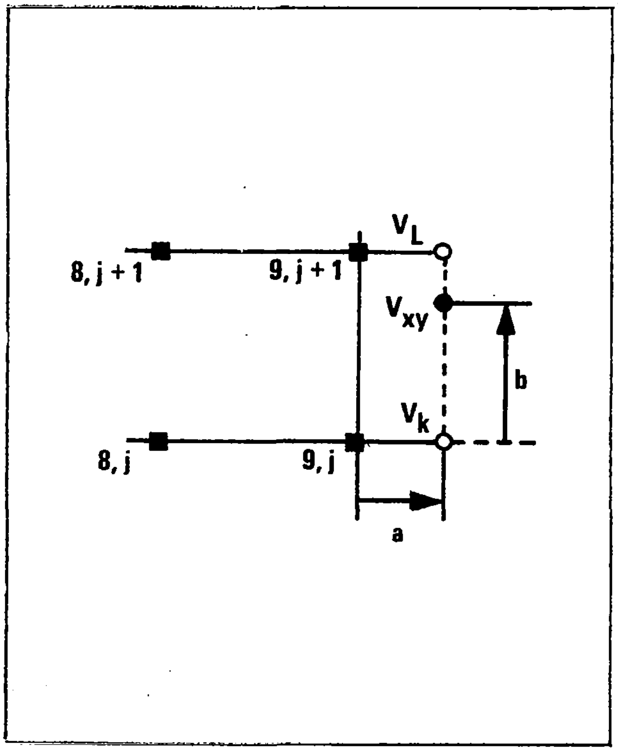


Figure G.1-6. Right-Left Extrapolation

From this reformatted data, the radiometric transfer characteristics of each camera can be "mapped" as a two-dimensional function of image position.

The two-dimensional exposure-response characteristics of a typical RBV camera is shown in Figure G.1-7. The upper figure represents a uniform 100 percent input radiance level which (for a given shutter time) produces a full-scale RBV output signal, indicated by the lower figure. The map of the RBV voltage signal corresponding to the 100 percent input exposure level is indicated by the upper surface; the lower surface is a map of the RBV voltage signal V_0, corresponding to zero input exposure.

The variation in voltage response over the photoconductor is called "shading". Such shading effects are inherent in RBV operation. They are associated (mainly) with spatial differences in the sensitivity of the photoconductor, and off-axis variation in the efficiency of photoconductor charge preparation as well as other effects much more complicated in their nature. The shading effects of a given vidicon tube tend to be stationary, i.e., they are a fixed characteristic of that tube and its configuration, and thus are ameanable to correction by post-acquisition processing of the RBV signal. The radiance mapping data is therefore used to derive the correction functions that are applied to remove the shading effects.

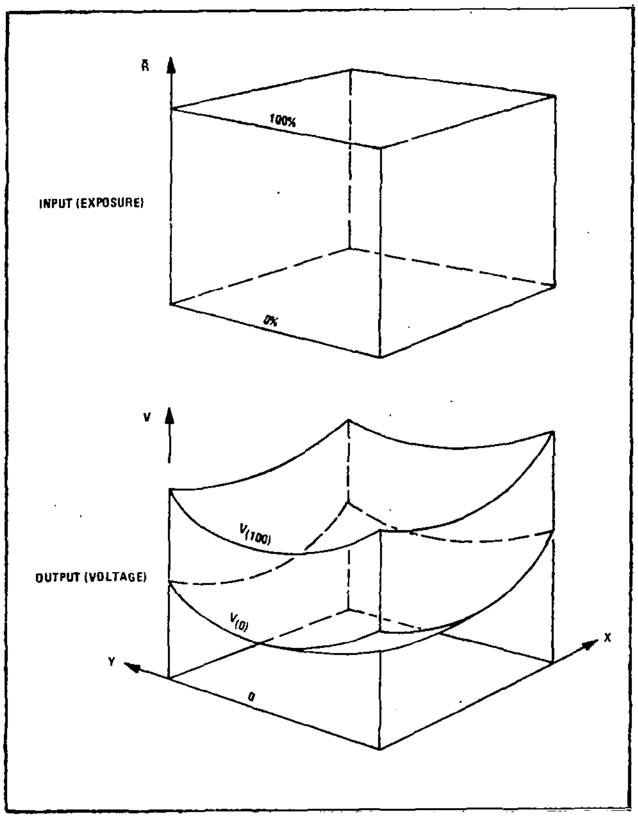


Figure G.1-7. RBV Exposure-Response Characteristics

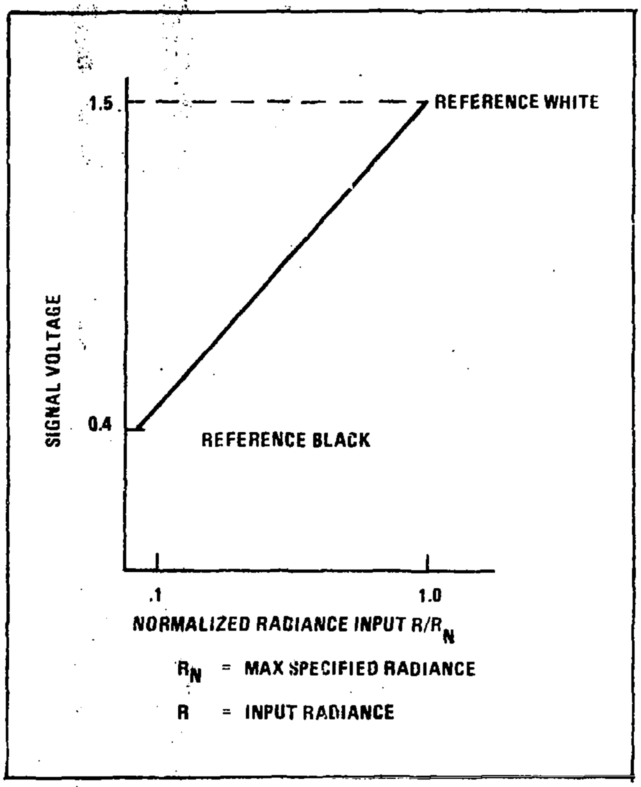


Figure G.1-8. Calibrated Light Transfer Characteristics – Image Center

A calibrated LTC, as shown in Figure G.1-8, is then defined as the relationship of the output signal at the image center to the known range of input radiance. The radiance map is used to define the ratio of camera response at all other points relative to the image center calibrated LTC as shown in Figure G.1-9.

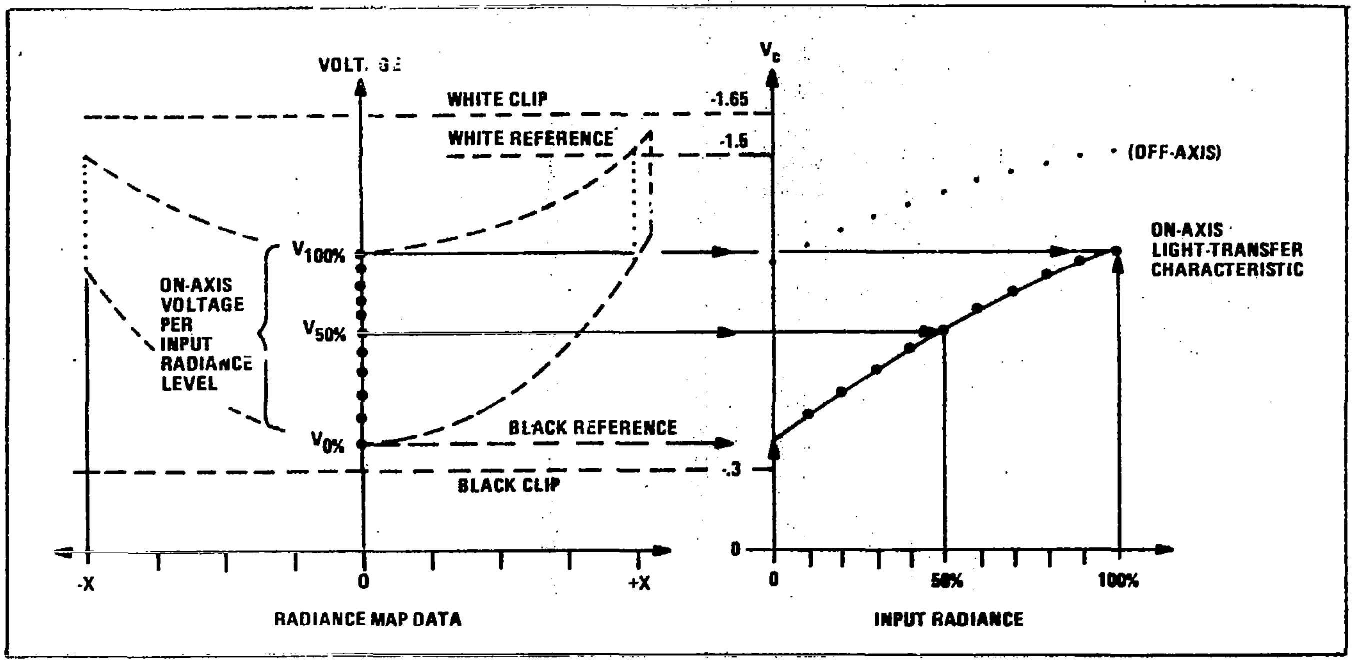


Figure G.1-9. Derivation of Light Transfer Characteristics

G.1.1.3 Calibration Lamp Radiance Mapping

This mapping, using the RBV calibration lamps, is performed before and after the calibrated source radiance mapping. Three fixed radiance levels are utilized; 0%, 30% and 80% of the following levels for each camera:

Camera 1 — 0.85 mW/cm^2-sr at 12 ms exposure

Camera 2 — 0.85 mW/cm^2-sr at 12 ms exposure

Camera 3 — 1.36 mW/cm^2-sr at 12 ms exposure

The mapping is performed utilizing the previously mentioned radiance calibration program over the 18 x 18 matrix of points and then transformed to the 9 x 9 matrix of points.

Radiance corrections for the scene, derived via the calibrated source mapping, are applied to this data. The "corrected" calibration-lamp maps serve as the standard against which the relative degradation will be measured.

G.1.1.4 Test Data

Radiometric mapping is performed during testing of the RBV, and consists of a mapping using the calibration lamps. The radiance calibration program and procedures previously described are utilized.

The calibration lamp maps are compared with those previously obtained during initial calibration, i.e., compared with the baseline/standard. This provides the relative degradation (if any) for each camera. The correction coefficients obtained from the final test data are used as the initial corrections for flight data.

G.1.1.5 In-Flight Calibration

In-flight calibrations are performed periodically throughout the mission. In-flight calibration consists of again using the calibration (erase) lamps as described in Appendix A. The calibration imagery for each of the three radiance levels (0, 30, and 80%) is analyzed in the Precision Subsystem of the NASA Data Processing Facility.

During the orbital operation, the in-flight radiometric images are read out and transmitted in the same manner as normal-scene RBV images. Owing to the stability of the erase lamp exposures, differences between in-flight radiometric images and the initial calibration data are indicative of electronic changes occurring in the camera, which would be applicable to scene images produced by that camera as well.

Typical characteristics of the erase-lamp calibration exposures are shown in Figure G.1-10. The upper figure shows the "actual" irradiance distribution of the erase lamps on the photoconductor. The resulting exposures are not spatially uniform (due to the location of the four erase lamps). But the levels and distribution of exposure are spatially and temporally invariant. The lower figure indicates the resulting two-dimensional voltage response to the erase-lamp exposure. The zero-level in-flight calibration images are thus used to detect changes in the black-level voltage response and/or (less likely) changes in the black-level shading function of each camera. The two finite-level response functions indicate the response of the camera to the in-flight calibration exposures, modified by the camera signal shading characteristics. The high-level exposure is used to determine the response to a radiant input near the maximum design limit of the camera. Because of the radial increase in erase-lamp radiance, the high-level exposure signal will be saturated at the outer edges of the image, so it is not used for shading evaluation. The intermediate-level erase-lamp exposure signal however will not be saturated, and will be used for evaluating the spatial stability of the shading. Subsequent finite-level in-flight exposures can thus be compared with the black-level exposure and initial calibrated response to detect changes in the gain of the video system, and/or discriminate between gain and black-level changes, and/or to detect any change in spatial shading characteristics.

G.1.2 NDPF Calibration Processing

RBV radiometric calibration data is used in the NASA Data Processing Facility (NDPF) for two purposes:

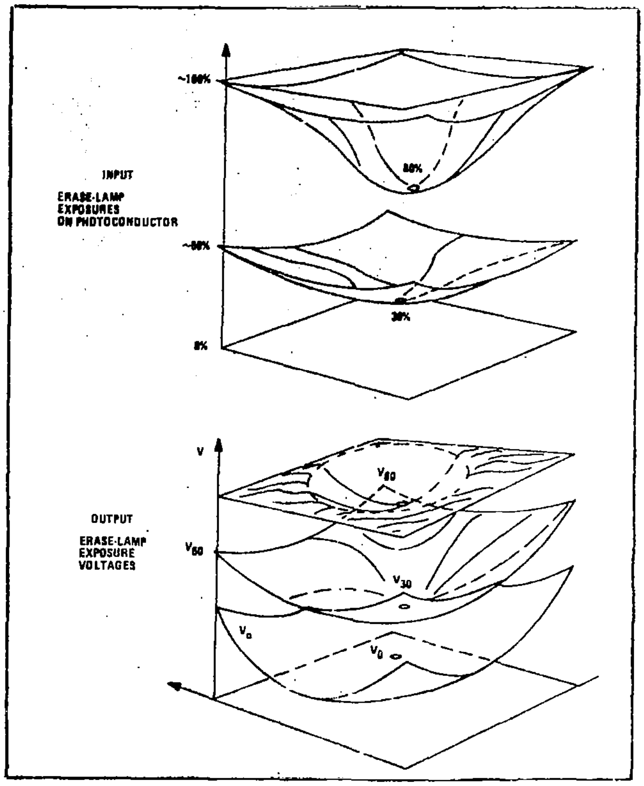


Figure G.1-10. RBV Erase-Lamp Exposures and Response Characteristics

1. To derive correction functions for removing stationary RBV shading errors from all RBV images during bulk image processing (initial corrections).

2. To update bulk-processing correction functions as required to compensate for major changes or long-term variations in sensor response, and to compensate for short-term sensor response variations, if required, in precision RBV image processing (updating corrections).

The flow of RBV calibration and correction data to implement these operations is diagrammed in Figure G.1-11.

Basic to the use of the RBV radiance-mapping data, originating in the lower block of Figure G.1-11, is a reformatting operation. As previously described this operation reduces and

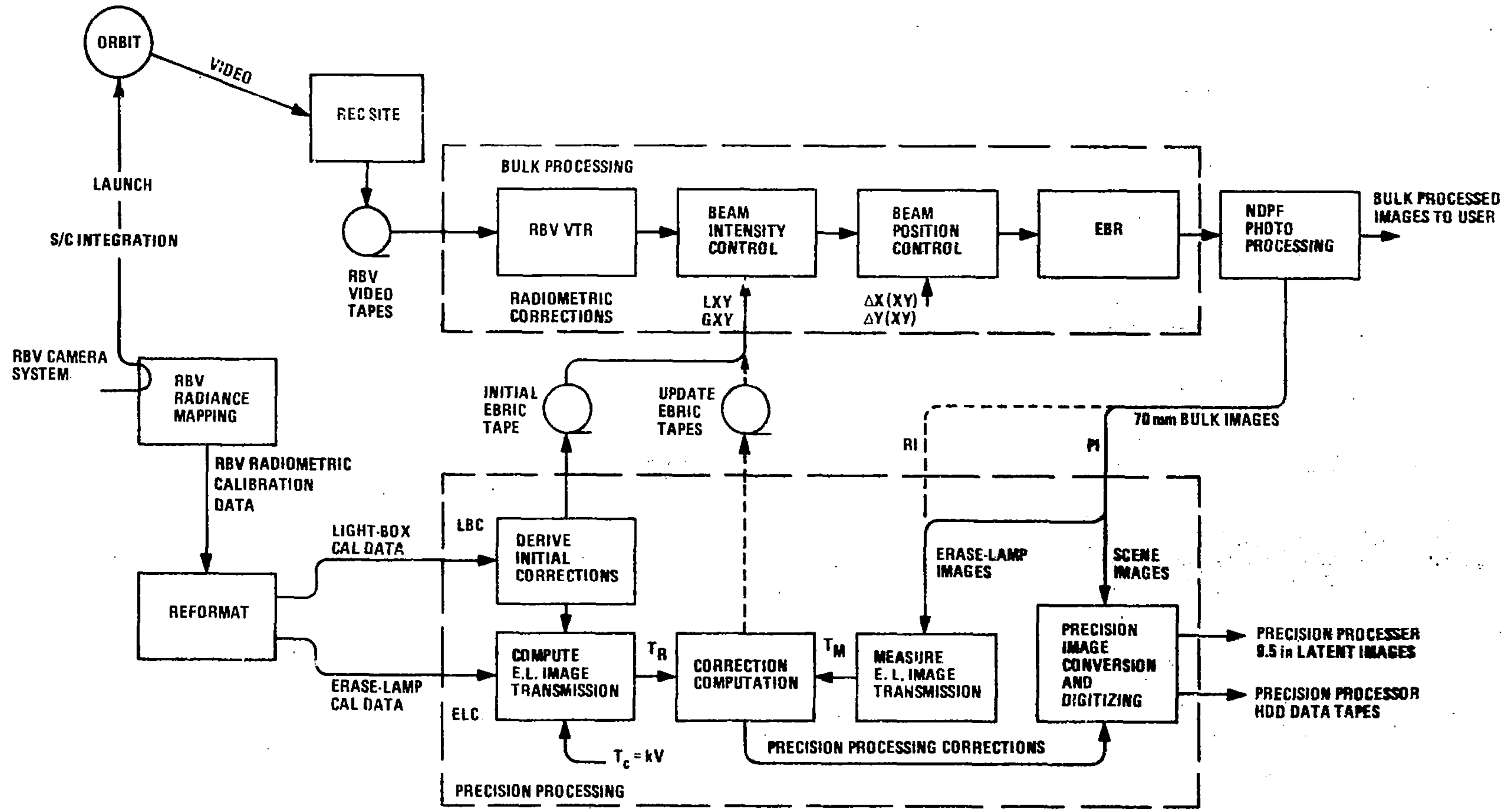


Figure G.1-11. Flow and Utilization of RBV Radiometric Calibration and Corrections transforms the arrays of RBV radiance calibration-data into a spatial format compatible with the methods by which the processing corrections are applied.

From the light-box calibration data input, the bulk shading corrections required for each RBV camera are derived prior to spacecraft launch. These corrections comprise arrays of digital coefficients, which are output to the Bulk Processing Subsystem via the Electron Beam Recorder Image Correction (EBRIC) tape, as shown. The initial set of corrections are also premanently stored for reference in Precision Processing.

To the erase-lamp calibration data input, the Precision Processing subsystem applies the initial EBRIC radiance correction functions, and a gray-scale calibration (i.e., the input signal-voltage-to-film-transmission characteristics) of the Bulk Processing Electron Beam Recorder. The results of this computation are arrays of data signifying the film-transmission distribution of the in-flight radiometric calibration images. Since this data is derived (a) from the erase-lamp calibration data, (b) from shading correction functions derived from the RBV input-radiance calibration data, and (c) from the calibrated EBR transfer characteristics, the computed obtained data is presumed to present the reference calibration of the bulk-processed radiometric images produced from the three known erase-lamp exposures. These data are stored in the Precision Processor memory, for comparison against subsequent measurements of in-flight RBV erase-lamp images obtained periodically during the ERTS orbital operation.

The basic processes involved for the removal of stationary RBV shading errors are described in the following paragraphs.

G.1.2.1 Shading Correction

Due to the presence of shading effects, the voltage response to the same range of input radiance at some point off-axis in the RBV may be different from the on-axis response. The shading characteristics of a given camera are defined quantitatively from the voltage difference labelled A, B_M, and C on Figure G.1-12.

From calibration measurements of the black-level shading effect, a level-correction voltage (L_{xy}), equal to the two-dimensional variation of the black-level voltage $V_{B(0,0)} - V_{B(xy)}$

$$L_{xy} = V_{B(0,0)} - V_{B(xy)},$$

is derived and stored for each camera.

To correct for the off-axis variation of the video signal range (A_{xy}), a two-dimensional gain correct function G_{xy} is also derived and stored for each camera, where the magnitude of the gain correction is inversely proportional to the signal shading characteristic:

$$G_{xy} = \frac{A_o}{A_o - A_{(xy)}}$$

During signal recording, the level correction voltage is added to the unconnected input signal V' thus resulting in the level-corrected

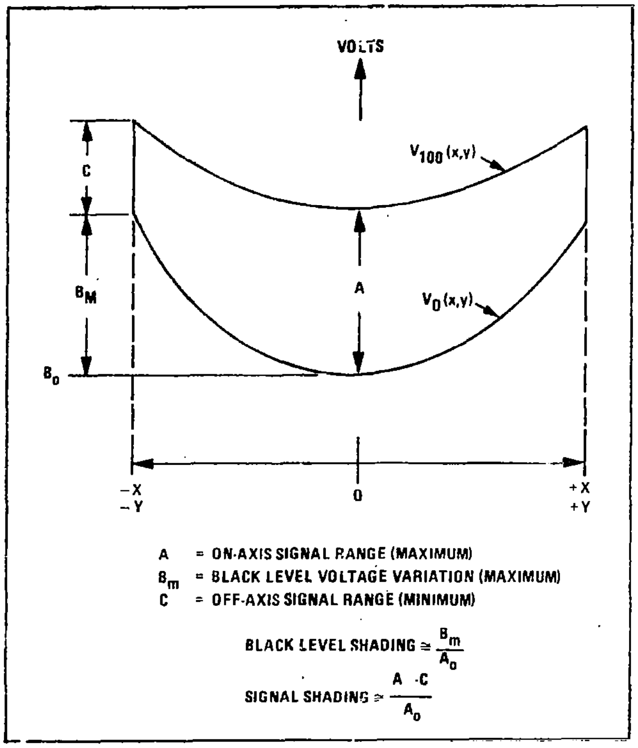


Figure G.1-12. RBV Shading Parameters

signal which is then multiplied by the gain correction to form the radiometrically-corrected output signal V''.

$$V'' = (V' + L_{xy})\, C_{xy} \,.$$

This is the basic equation describing the shading-correction operation performed by the EBRIC circuitry. In the actual case, the on-axis black reference voltage may be non-zero so a simultaneous solution is performed for the two correction terms.

Also due to shading, the on-axis 100 percent video level will tend to be at some signal value less than the white reference level. Therefore the G_{xy} term may include a constant component to expand the on-axis video range to the white reference level and occupy the full dynamic range of the film.

G.1.2.2 Derivation of Shading Corrections

The RBV radiometric correction functions are derived from the light-box response data and internal processing relationships.

G.1.2.2.1 Input Data

Light-box radiance mapping data per camera for R = 0%, 30%, and 80% input exposure:

$$V_{1,0,i,j} \quad V_{1,30,i,j} \quad V_{1,80,i,j}$$

$$V_{2,0,i,j} \quad V_{2,30,i,j} \quad V_{2,80,i,j}$$

$$V_{3,0,i,j} \quad V_{3,30,i,j} \quad V_{3,80,i,j}$$

G.1.2.2.2 Reformatting

The above radiance-map data is reformatted from the i,j data point array to the x,y breakpoint array. Letting the subscript n = camera number (n = 1,2,3),

$$V_{0,nij} \Rightarrow V_{0,nxy} \qquad n = 1,2,3$$

$$V_{30,nij} \Rightarrow V_{30,nxy} \qquad n = 1,2,3$$

$$V_{80,nij} \Rightarrow V_{80,nxy} \qquad n = 1,2,3$$

G.1.2.2.3 Voltage Scaling

During reformatting, the camera voltages (V), i.e., the recorded camera-controller output voltages, are also transformed to the EBRIC input voltage scale V'.

$$V_{0,nxy} \Rightarrow V'_{0,nxy}$$

$$V_{30,nxy} \Rightarrow V'_{30,nxy}$$

$$V_{80,nxy} \Rightarrow V'_{80,nxy}$$

This transformation involves scaling, offset, and sign reversal:

$$V' = K_1 V \pm K_2.$$

The constants K_1, K_2 are derived from respective white clip (WC) and black clip (BC) voltage levels. Assuming K_2 is positive,

$$V'_{WC} = K_1\, V_{WC} + K_2$$

$$V'_{BC} = K_1\, V_{BC} + K_2$$

Hence

$$K_1 = \frac{V'_{WC} - V'_{BC}}{V_{WC} - V_{BC}}$$

$$K_2 = V'_{BC}\, V_{WC} - V'_{WC}\, V_{BC}$$

Since (at this time),

$$V_{BC} = -0.3 \text{ volts}$$

$$V_{WC} = -1.65 \text{ volts}$$

$$V'_{BC} = 0. \text{ volts}$$

$$V'_{WC} = 2.048 \text{ volts (or 2.000 volts)}$$

Thus

$$K_1 = \frac{2.048}{-1.35} = -1.52 \quad \left(\text{or } \frac{2.000}{-1.35} = -1.485\right)$$

$$K_2 = (2.048)\,(0.3) = 0.6144 \text{ (or 0.6000)}$$

Hence,

$$V' = -1.52\, V + 0.6144 \text{ volts}$$

or

$$V' = -1.485\, V + 0.6000 \text{ volts}$$

G.1.2.2.4 Establish Calibration-Reference Voltages

The calibrated camera response is defined as the on-axis response value. Reference voltages corresponding to the "0" (zero exposure) and "H" (high exposure) calibration (C) levels are derived from the on-axis (x,y = 5,5) 0% and 80% radiance-map data values:

$$V'_{OC,n} \triangleq \text{Zero-level Calibration voltage}$$

$$V'_{OC,n} \equiv V'_{0,n,5,5}$$

$$V'_{HC,n} \triangleq \text{High-level Calibration voltage}$$

$$V'_{HC,n} \equiv V'_{80,n,5,5}$$

G.1.2.2.5 Derive Spatial-Correction Coefficients

The basic equation for the spatial correction function is

$$V''_{nxy} = (V'_{nxy} + L_{nxy})\, G_{nxy}.$$

Referring to Figure G.1-13, the gain term G_{nxy} at an off-axis point x,y must correct the video amplitude response at that point $(V'_{Hxy} - V'_{0xy})$ to the calibrated on-axis amplitude $(V'_{HC} - V'_{OC})$

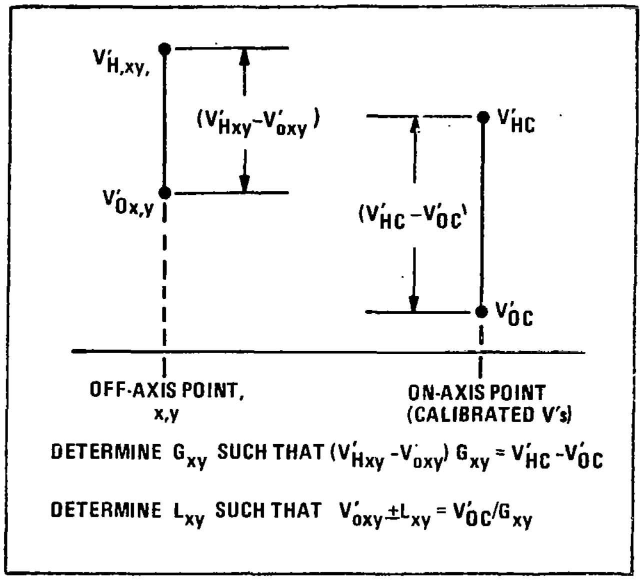


Figure G.1-13. Determination of Spatial-Correction Coefficients

Therefore G_{nxy} terms are derived from the data as

$$G_{nxy} = \frac{V'_{HC,n} - V'_{OC,n}}{V'_{H,nxy} - V'_{0,nxy}}$$

Since gain is applied after the video level correction, the magnitude of the level L_{xy} required to bring the off-axis zero level voltage $V'_{n,0,x,y}$ into coincidence with the calibrated zero level voltage, $V'_{n,0C}$ must include the applied gain.

From

$$V'_{OC,n} = (V'_{0,nxy} + L_{nxy})\, G_{nxy}$$

then

$$L_{nxy} = \frac{V'_{OC,n}}{G_{nxy}} - V'_{0,nxy};$$

substituting G_{nxy} gives the expression for the level shading corrections:

$$L_{nxy} = \frac{(V'_{OC,n}\, V'_{H,nxy}) - (V'_{HC,n}\, V'_{0,nxy})}{V'_{HC,n} - V'_{OC,n}}$$

G.1.2.3 Dynamic Range Compensation

The 81 x,y level coefficients and 81 x,y gain coefficients derived above define the break-points of two spatially bivariant linear functions. These functions correct the RBV video signal over the entire image to the calibrated black-level and calibrated video range of the signal at the image center.

However, the tendency of black-level shading to exceed signal-shading essentially reduces the dynamic range of the on-axis video signal. The on-axis peak-to-peak video signal (0 to 100% exposure) may be typically 30% (TBV) lower than the zero-to-white-reference voltage range, ostensibly available through the communication channel and film recorder. As a result, the radiometrically corrected signal may not cover the full dynamic range available on film.

Therefore, for image-processing purposes, the "calibrated" video signal range is altered by redefining the high-level on-axis calibration voltage $(V'_{HC,n})$ as 0.8 x V' reference white and replacing $V'_{HC,n}$ in the previous equations by this value.

G.1.2.4 Bulk-Processed Film Trnnsfer Characteristics

The bulk-processing film transfer characteristic is designed to produce a first-generation (master positive) image whose transmission is linearily proportional to the corrected signal and defined by

$$T_{xy} = T_o + KV''_{xy}$$

where T_o is the transmission bias level corresponding to a zero-voltage signal. This relationship will be calibrated as follows.

A set of fifteen accurate reference voltages

$$V_n = V_o + (n-1)\,\Delta V \qquad n=1,2...15$$

will be recorded by the electron beam recorder as a 15-level gray scale across the bottom of each image.

Each voltage increment ΔV is one-fourteenth of the maximum input signal voltage:

$$\Delta V = \frac{V_{max}}{14}$$

where

$$V_{max} = 2048.000 \times 10^{-3} \text{ volts } (\pm \text{ TBD*});$$

hence

$$\Delta V = 146.285 \times 10^{-3} \text{ volts } (\pm \text{ TBD*})$$

*To be determined later and included in revised page.

The base voltage V_O will be a stable bias applied to the writing electron beam (corresponding to zero input signal volts). The base voltage will be blanked during the video blanking interval.

Transmission characteristics of the shading-corrected RBV signal superimposed on the film will tend to appear as shown in Figure G.1-14. The figure shown is derived from the typical on-axis LTC response curves.

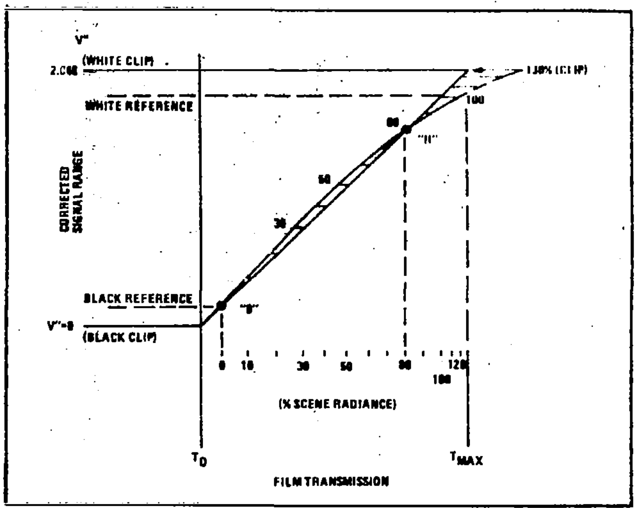


Figure G.1-14. Transmission Characteristics of RBV Corrected Signals

G.1.2.5 Updating Corrections

Basic to refining the corrections for the RBV imagery are certain image inputs to Precision Processing.

One routine input of such imagery to Precision Processing is indicated by the dotted path labelled RI in Figure G.1-11, which stands for Reference Images. These images have two purposes: (a) for selection of ground control points, for which the internal flow path is not shown, and (b) for periodic measurement of imagery for EBRIC update, as shown. These manipulations include a routine or periodic (e.g., weekly) measurement of in-flight RBV erase-lamp images to check the radiometric and geometric stability of the RBV system. If and when significant changes occur, new sets of (updated) bulk-correction coefficients are computed, and an updated EBRIC tape is generated and sent to Bulk Processing.

The other image input path to Precision Processing is labelled PI, Precision Images, which are the user-selected images to be precision processed. This interface is organized so that in-flight RBV calibration images, obtained during the orbit in which the scene images were obtained, are included as inputs along with the scene images to be processed.

The inflight calibration images bracketing (or closest in time to) each scene image are automatically measured. From these measurements, radiometric corrections, e.g., as required to compensate for minor or short-term variations in RBV response, are applied to the appropriate scene images during the precision processing operation.

The routine (periodic) radiometric measurement/correction-update function is provided to maintain a semi-continuous evaluation of the RBV signal stability, and to ensure some amount of flexibility in the determination and correction of temporal or temperature-dependant variations in sensor response in both bulk and precision image processing.

G.1.2.6 Sensor Stability Considerations

Stability is one of the most important sensor performance characteristics to be initially evaluated.

The precision processing operation performs a detailed evaluation of the radiometric (and geometric) stability of the RBV System once a week, after some initial period of more frequent evaluation, specifically for purposes of updating bulk-processing corrections.

G.1.2.7 Reference Calibration of In-Flight Erase-Lamp Images

Fundamental to detecting changes in gain, level, or shading characteristics of the RBV system is the derivation of reference data defining its as-calibrated condition.

The reference erase-lamp calibration for each camera is computed from the following data:

1. The 0%, 30% and 80% Erase-Lamp Radiance Mapping Data, spatially reformatted as per Section G.1.1.5.

2. The Bulk-Processing EBRIC coefficients, from the light-box calibration data.

3. The Bulk-Processing Film Transfer Characteristics, defined in Section G.1.2.4.

Erase-lamp images are recorded just as though they are scene images. That is, during bulk recording, the spatial shading and gain corrections for a given camera are applied to the in-flight erase-lamp signals from that camera, as they are recorded on film. The erase-lamp images are sent to Precision Processing, where their transmission and transmission distribution are measured and compared with the reference erase-lamp data.

Therefore the reference data are computed as sets of reference transmission values (T_R) for the 0%, 30% and 80%(H) exposure-level erase lamp images:

$$T_{RO,nxy} \qquad T_{R\ 30,\ nxy} \qquad T_{RH,\ nxy}$$

where the subscripts n (camera number), 0, 30, 80 (cxposure level) and x, y (breakpoint locations) are as before.

Each reference transmission value is computed as

$$T_{RO,nxy} = \left[(V'_{EO,\ nxy} + L_{nxy})\ G_{nxy}\right] K_f + T_o$$

$$T_{R30,\ nxy} = \left[(V'_{E30,\ nxy} + L_{nxy})\ G_{nxy}\right] K_f + T_o$$

$$T_{RH,\ nxy} = \left[(V'_{E80,\ nxy} + L_{nxy})\ G_{nxy}\right] K_f + T_o$$

where $V'_{E()nxy}$ are the reformatted erase-lamp radiance-map data points $V_{CE()ij}$, scaled to the EBRIC voltage range.

G.1.2.8 Measurement of In-Flight Erase-Lamp Images

Film transmission is measured in the Precision Processing equipment by scanning cathode ray tubes and photomultipliers that are maintained in continual calibration against stabilized radiance sources. The transmissions of the in-flight erase-lamp images are recorded as photomultiplier currents (I):

$$I_{MO,nxy} \qquad I_{M30,nxy} \qquad I_{MH,nxy}$$

The film may contain slight transmission errors due to normal tolerance on photoprocessing uniformity. These errors are compensated routinely (for every image) as follows: The calibrated gray scale of each erase-lamp image is measured and stored as photomultiplier currents:

$$I_{MG,g,o,n} \qquad I_{MG,g,30,n} \qquad I_{MG,g,H,n}$$

where the subscript rotation refers to "Measured gray-scale current of the gth gray-scale step of the (0, 30, H) exposure-level image of camera (n)."

For each gray level g, g + 1. . .there are theoretical transmission values $T_{G,g}$, $T_{G,g+1}$ corresponding to the calibrated voltages which exposed them, with a uniform interval between levels:

$$T_{G,g} - T_{G,g+1} = \Delta T_G$$

Thus "measured" transmission values T_M are computed from the measured photomultiplier currents corrected for film errors by

$$T_{MO,\,nxy} = T_{G,\,g} + \left[\frac{I_{MO,\,nxy} - I_{MGg0,\,n}}{I_{MGg0,\,n} - I_{MO,\,nxy}}\right] (T_{G,\,g+1} - T_{G,\,g})$$

$$T_{M30,\,nxy} = T_{G,\,g} + \left[\frac{I_{M30,\,nxy} - I_{MGg30,\,n}}{I_{MGg30,\,n} - I_{M30,\,nxy}}\right] (T_{G,\,g+1} - T_{G,\,g})$$

$$T_{MH,\,nxy} = T_{G,\,g} + \left[\frac{I_{MH,\,nxy} - I_{MGgH,\,n}}{I_{MGgH,\,n} - I_{MH,\,nxy}}\right] (T_{G,\,g+1} - T_{G,\,g})$$

G.1.2.9 Derivation of Updated Correction Coefficients

The following derivation assumes a spatial error has occurred, requiring the use of the 0 and 30% exposure-level measurements.

The measured transmission of the in-flight calibration image relates to the extant gain correction terms G_{xy} L_{xy} by

$$T_{M,O,x,y,n} = (V_{EO,x,y,n} + L_{nxy}) G_{nxy} K_f + T_o$$

$$T_{M30,x,y,n} = (V_{E30x,y,n} + L_{nxy}) G_{nxy} K_f + T_o$$

The measured transmission values are then compared to the reference transmission values. If

$$(T_R - \epsilon_T)_{nxy} \leq T_{M,nxy} \leq (T_R + \epsilon_T)_{nxy}$$

(where ϵ_T is some allowable error value, to be determined later) the existing correction coefficients are acceptable.

If however

$$(T_R - \epsilon_T)_{nxy} \geq T_{M,\,nxy} \geq (T_R + \epsilon_T)_{nxy}$$

the present correction coefficients are no longer valid. A new set, denoted by primes,

$$G'_{nxy} \qquad L'_{nxy}$$

must be generated.

One, several, or perhaps entirely new sets of G'_{nxy} L'_{nxy} coefficients may be required (owing to spatial and/or temporal changes in either or both of the received signal voltages $V_{EO,\,nxy}$, $V_{E30,\,nxy}$) to provide the signal processing corrections required to regain the calibrated Reference Transmission values. Thus the new coefficients relate to the required transmission distribution as

$$T_{RO,\,nxy} = (V_{EO,nxy} + L'_{nxy}) G'_{nxy} K_f + T_o$$

$$T_{R30,\,nxy} = (V_{E30,\,nxy} + L'_{nxy}) G'_{nxy} K_f + T_o$$

Manipulation of these equations yields the new level coefficients

$$L'_{nxy} = L_{nxy} + \frac{(T_{R30,\,nxy} - T_o)(T_{M30,\,nxy} - T_{MO,\,nxy})}{K_f G_{nxy} (T_{R30,nxy} - T_{RO,nxy})} - \frac{(T_{M30,\,nxy} - T_o)}{K_f G_{nxy}}$$

The bulk image processing corrections are updated by generating a new EBRIC tape, forwarded to Bulk Processing, and the new set of corrections is stored in Precision Processing.

G.1.3 Geometric Calibration

The primary sources of geometric calibration of the RBV system come from initial calibration measurements. The initial data include calibrated measurements of the position of the reseaus in the image plane of each camera and the projection of the reseaus in object space; the alignment of the axes of the three camera relative to one another; and the alignment of the camera system to the attitude measurement axes of the spacecraft. These measurements are described in this section.

Geometric calibration data are also derived after the spacecraft is launched, from measurements of ground points obtained in the image. These measurements are made throughout system operation.

G.1.3.1 Reseau Calibration

Two types of reseau calibration measurements are performed: Reseau Measurement determines the positions of the reseau marks on the tube faceplate; Reseau Mapping determines the projection of the reseau field through the lens, and the location of the imaging axis of the lens on the image plane.

G.1.3.1.1 Reseau Measurement

The location of the reseaus on the RBV face plates is measured by the United States Geological Survey. The measurements are made with a precision-calibrated, two-axis optical monocomparator having a stage resolution of one micrometer. The comparator is equipped with digital coordinate readout and a card punch.

The reseau field of each camera is measured four times by three operators. The calibrated reseau locations are then determined by averaging the operator bias. The mean position of the reseau marks x_i, y_i, and the four anchor marks, are defined in millimeters relative to a coordinate system originating at the central reseau. (The standard deviation of the error from the mean values is expected to be 0.85 (TBV) μm) These calibration data will be published for all flight-model RBV tubes.

G.1.3.1.2 Reseau Mapping

Reseau mapping is the measurement operation to determine the angular projection of each of the reseau marks into space. The reseaus will be mapped with a catadioptric theodolite, mounted on precision orthogonal ways capable of being moving in a plane perpendicular to the lens axis as shown in Figure G.1-15.

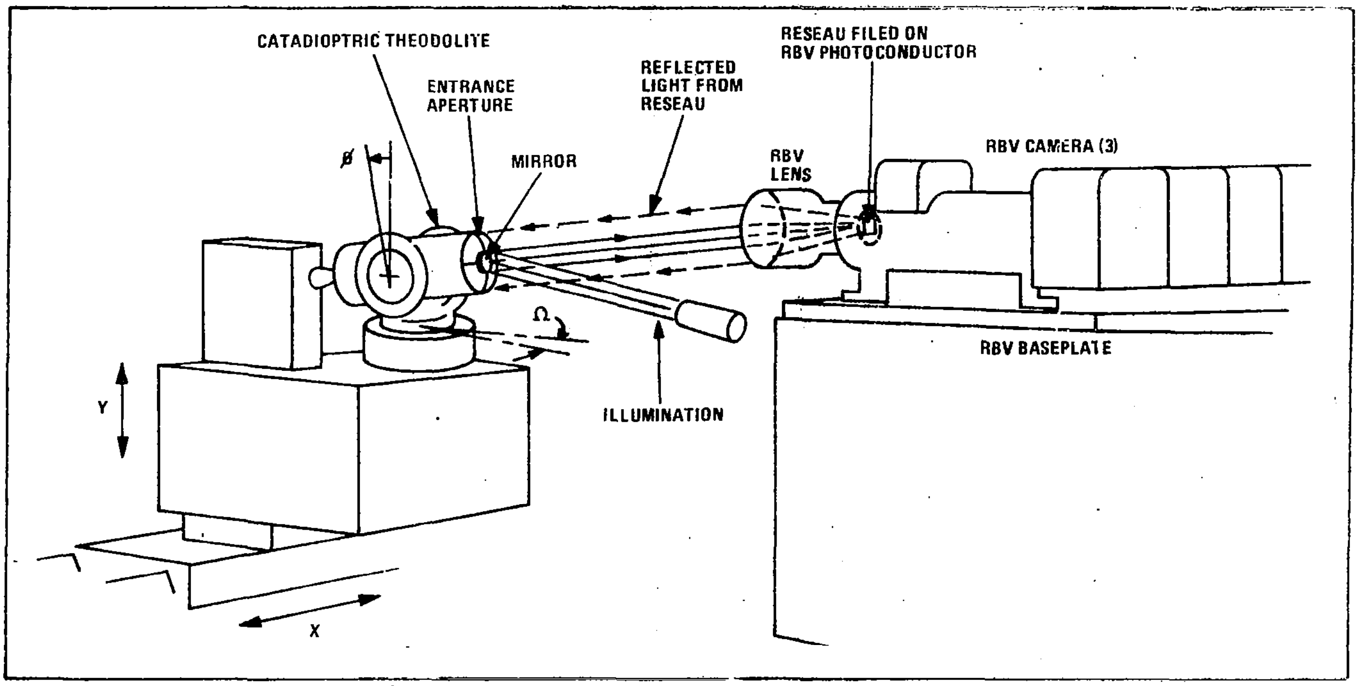


Figure G.1-15. RBV Reseau Mapping (Conceptual, per U.S. Geological Survey)

The reseau marks on the tube face are observed (in crosshairs in the eyepiece of the theodolite) through the lens of the camera system. The marks are illuminated by a beam projected into the lens from a mirror mounted concentric with the theodolite axis.

Angular measurements are made of those reseau marks appearing within the theodolite field of view. The theodolite is then translated (orthogonally to the camera axis), the angles of next group of reseau marks are measured and so on, until all the marks in the field, and the four anchor marks, are mapped. The angular and orthogonal-translation measurements are then processed to calibrate the following parameters of each camera:

1. Lens focal length
2. Lens principal point
3. Radial lens distortion.

It is anticipated that the focal length of each lens will be determined to an accuracy of about 20μm. It is desirable to determine the principal point and the lens distortion to a higher accuracy. The principal point is that point in the image plane which is pierced by the optical axis, or it can be defined as that point in the image about which the (radial) component of lens distortion is symmetrical. The location of the principal points and calibrations of the lens distortion is expected to be determined to an accuracy of about 5μm.

G.1.3.2 Camera-to-Camera Alignment

The angular alignment of the three cameras relative to one another (relative boresight alignment) is calibrated with the three cameras installed on the RBV baseplate. The measurements are performed during, and with the same equipment used for, reseau mapping. The relative alignment between the three cameras is referred to the reflecting axis of a mirror mounted on the baseplate of the assembled camera system for subsequent alignment of the camera system with the spacecraft.

The specified tolerance of the relative camera misalignment between any two of the three cameras is (TBD) minutes of arc (TBD degrees). The accuracy to which the relative camera alignment will be calibrated is anticipated to be about 3 arc seconds (TBV).

G.1.3.3 Camera system to Spacecraft Alignment

The RBV system is aligned to each spacecraft axis to 0.1 degree and known to 14 arc seconds.

G.2 MULTISPECTRAL SCANNER (MSS)

G.2.1 Initial Calibration Methods

Initial calibration consists of (1) adjusting the gain and calibrating each detector using the Hovis integrating sphere, (2) calibration of the MSS collimator and (3) determining the response of the calibration wedge for each detector. The response of the calibration wedge, voltage versus word count, and radiance versus word count, is used to provide the standard function from which all future conversions between output voltage and input radiance are derived.

G.2.1.1 Gain Setting and Calibration of Detectors

The output of each detector is adjusted using the Hovis integrating sphere such that four volts output represents the maximum specified radiance for that given band as specified below.

Band	Max. Specified Radiance ($mW/cm^2 - sr$)
1	2.48
2	2.00
3	1.76
4	4.60

In bands 1 and 2 these specified radiance values cannot be obtained utilizing the Hovis sphere, since it is physically limited in these bands. The values obtainable using the Hovis sphere for each band are given below. Thus, each detector is adjusted to a voltage other than four volts such that the 4 volts will correspond to the radiance values shown above. These voltages are given below.

Band	Hovis Sphere Output ($mW/cm^2 - sr$)	Detector Voltage for which Gain is Adjusted
1	2.28	3.68
2	1.98	3.96
3	1.78	4.05
4	4.61	4.01

G.2.1.2 MSS Collimator Calibration

Once the gain is adjusted and each detector calibrated, the collimator is calibrated using the MSS as the transfer function; i.e., the collimator is calibrated through the scanner.

The output of the collimator lamp is constant and seven neutral density (nd) filters are used for various radiance levels. The radiance output of the collimator for a particular nd filter and MSS detector is determined by relating the MSS detector output voltage to a given radiance value as previously obtained with the Hovis sphere. This radiance level is now the calibrated level for the MSS detector and collimator setting/nd filter. The appropriate radiance levels for the nd filters are:

1. max. (open)
2. 50% max.
3. 25% max.
4. 10% max.
5. 5% max.
6. 2.5% max.
7. opaque

Table G.2-1 is a sample of the calibrated collimator radiance output for the seven levels for each detector. It is apparent from the table that each detector within a band does not have the identical calibrated radiance for a given nd filter. This is due to the particular spectral characteristics of each detector. Also, note that the maximum radiance for a detector is not exactly the maximum specified reference level. This is because the transmission factors of both the filters and detectors are not contained in these stated reference levels. Thus, for example, the 50 percent transmission nd filter is slightly less, but is acceptable since the numerical values for these levels are only for reference.

Once the collimator is calibrated with the MSS it becomes an integral portion of the test equipment for the particular MSS unit.

G.2.1.3 Calibration Wedge Response

The calibrated collimator determines the calibration wedge response for each detector at the different gains and modes of the MSS. This is accomplished by correlating the calibration wedge response to the response using the collimator. The response utilizing the collimator provides, for each detector, the curves relating voltage to radiance. This provides a radiance value for each voltage on the calibration wedge. Thus, tables are prepared relating voltage, radiance and word count for the calibration wedge. This response is used to provide the standard/reference base to which conversions between output voltage and input radiance are derived.

G.2.1.4 Test Data

During spacecraft testing the calibration wedge is checked and compared with the standard obtained in initial calibration. In addition, the radiometer response of the MSS is again ascertained using the collimator/nd filters.

These two tests will determine the degradation, if any, of the detectors. The calibration wedge will provide the initial check on degradation. The seven radiance levels utilizing the collimator will provide a correlation of calibration wedge results.

G.2.1.5 In-Flight Calibration

In-flight calibration consists of utilization of the calibration wedge on alternate scans, as described in Appendix A, and a sun calibration. The sun calibration, also described in Appendix A, serves as a standard against which the calibration wedge will itself be calibrated.

Table G.2-1. Sample of Calibrated Collimator Radiance Output

Radiance (mW/cm^2-sr)

1A	1B	1C	1D	1E	1F
2.45452	2.44298	2.48455	2.43867	2.56689	2.36073
1.16393	1.18325	1.19054	1.18390	1.19664	1.17485
0.65536	0.65194	0.65424	0.65857	0.65732	0.65651
0.24941	0.24258	0.23984	0.24921	0.24718	0.24781
0.13444	0.12788	0.12472	0.13276	0.13117	0.13104
0.05495	0.06130	0.05769	0.06301	0.06156	0.06227
0.01201	0.01713	0.01503	0.01756	0.01640	0.01686
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2A	**2B**	**2C**	**2D**	**2E**	**2F**
1.82591	2.97511	2.81786	2.72858	2.87797	2.89951
1.45667	1.49127	1.44130	1.40539	1.46517	1.46484
0.76634	0.77498	0.75339	0.72888	0.76499	0.76223
0.29270	0.29424	0.28853	0.27496	0.29113	0.28880
0.16345	0.16346	0.16011	0.15203	0.16076	0.15948
0.07982	0.07950	0.07760	0.07274	0.07726	0.07543
0.02432	0.02377	0.02343	0.02182	0.02380	0.02298
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
3A	**3B**	**3C**	**3D**	**3E**	**3F**
2.54976	2.71020	2.71157	2.60236	2.63401	2.74429
1.36503	1.41395	1.39537	1.37351	1.38888	1.42527
0.69234	0.70673	0.68870	0.69102	0.70399	0.70998
0.27423	0.27481	0.26226	0.26796	0.27605	0.27240
0.15984	0.15950	0.14910	0.15461	0.16047	0.15503
0.08099	0.07879	0.07236	0.07541	0.07928	0.07534
0.02745	0.02642	0.02379	0.02561	0.02722	0.02463
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4A	**4B**	**4C**	**4D**	**4E**	**4F**
7.47004	7.59612	7.22850	6.72398	7.98225	8.01650
4.05189	4.16707	4.10776	4.36008	4.39057	4.46220
1.91425	1.95591	1.95626	1.99802	2.06782	2.10426
0.76029	0.78295	0.77400	0.78059	0.80003	0.72790
0.46001	0.47574	0.47010	0.48752	0.48423	0.47830
0.23566	0.25353	0.24798	0.26726	0.24509	0.63670
0.09930	0.09204	0.09553	0.12625	0.09519	0.05567
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

G.2.2 NDPF Radiometric Calibration Processing (MSS)

G.2.2.1 Sensor Calibration

Each of the four spectral bands of the MSS on ERTS A contains six sensor channels that effectively sweep across the ground scene. The gain and offset of each channel may differ slightly, resulting in stripes appearing on the reproduced photographic image. To prevent this and to provide a constant conversion gain between input radiance and output voltage for each mode of operation, the received voltage from each channel must be adjusted.

A calibration signal wedge is supplied on alternate mirror sweeps for each channel. The Bulk Processing Subsystem samples this wedge and decommutates six points whose radiance levels and locations in the calibration wedge are determined from initial calibration tables. Using linear regression (6 points), the channel gains and offsets are calculated. Since these values will vary due to noise on the calibration wedge, they must be filtered. These filtered values are then used to calculate the calibration coefficients which in turn are used to adjust the received signal voltage. The calibration procedures for the Bulk Processing Subsystem and Special Processing Subsystem are the same with Bulk Processing supplying the six calibration wedge voltage levels to Special Processing. Functionally, the complete calibration procedure is as shown in Figure G.2-1.

G.2.2.2 Calibration Algorithms

G.2.2.2.1 Linear Regression

The initial calibration tables, radiance versus word count and voltage versus word count for each detector calibration wedge, supply the information needed for decommutating the calibration wedge and for supplying the relative radiance levels to the regression analysis software program. The radiance values in the initial calibration tables are normalized to the maximum specified radiance presented in Section G.2.1.1. Figures G.2-2 and G.2-3 show in graphical form how these tables are used to obtain the standard for word count, expected voltage levels, and relative radiance level.

Ideally, without detector degradation, each voltage on the calibration wedge, V_i, correlates directly with the radiance value at that work count as determined in initial calibration, some error is expected such that

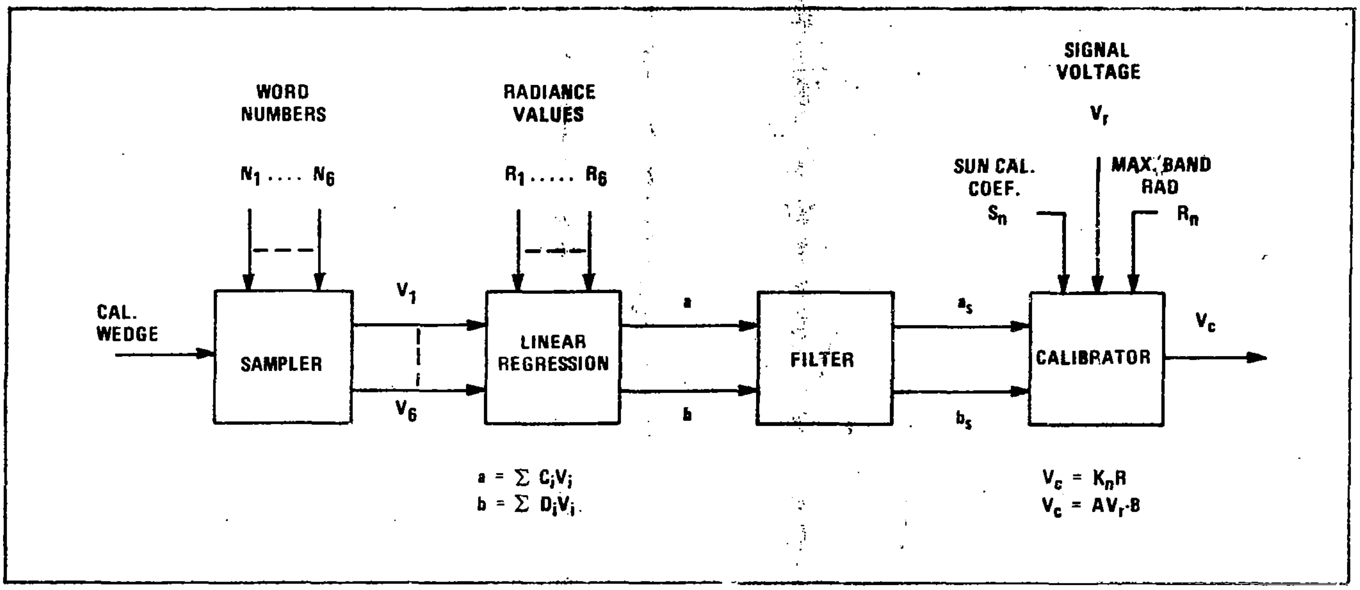


Figure G.2-1. MSS Sensor Calibration Functional Flow

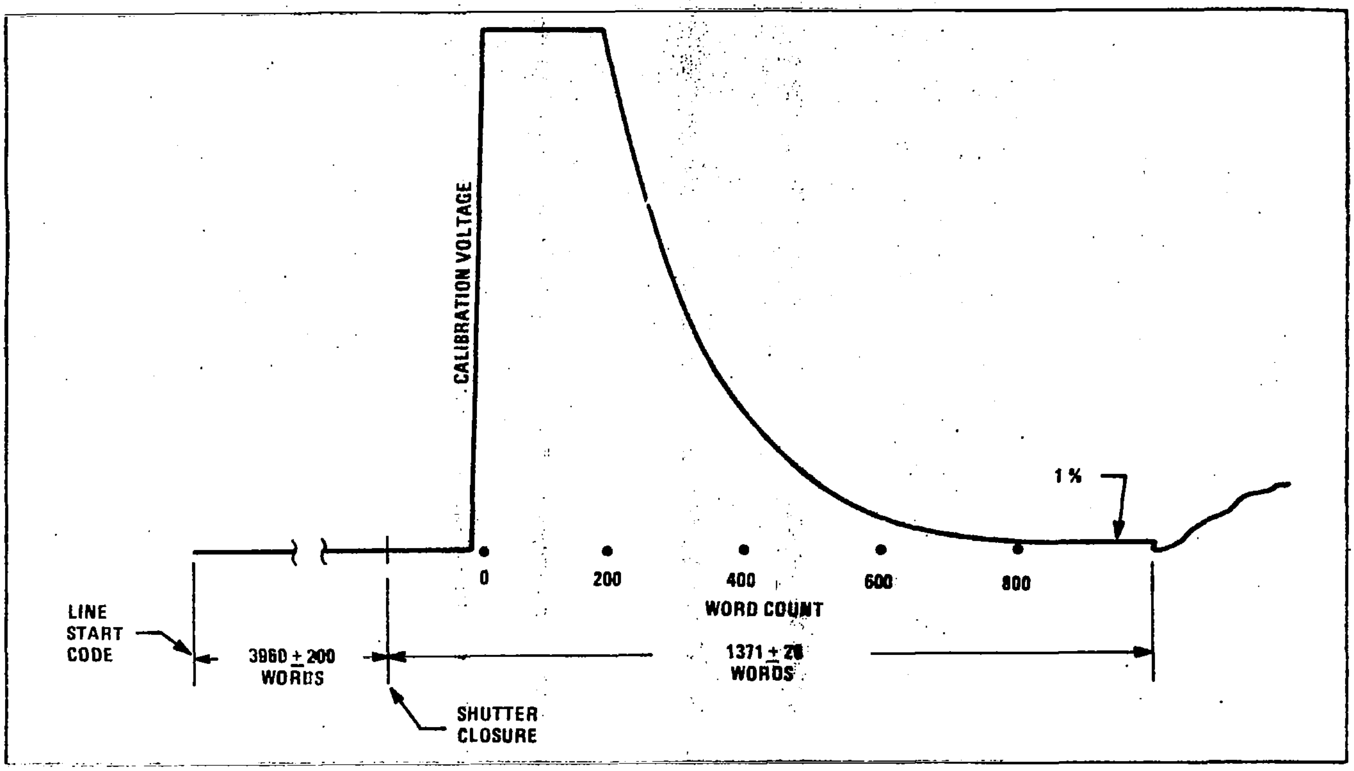


Figure G.2-2. MSS Typical Calibration Wedge

$V_i = a + b\,X_i + e_i$

where:

V_i = voltage output

X_i = ratio of calibration signal radiance (R) to maximum specified radiance value (R_n)

e_i = error associated with the actual calibration wedge reading

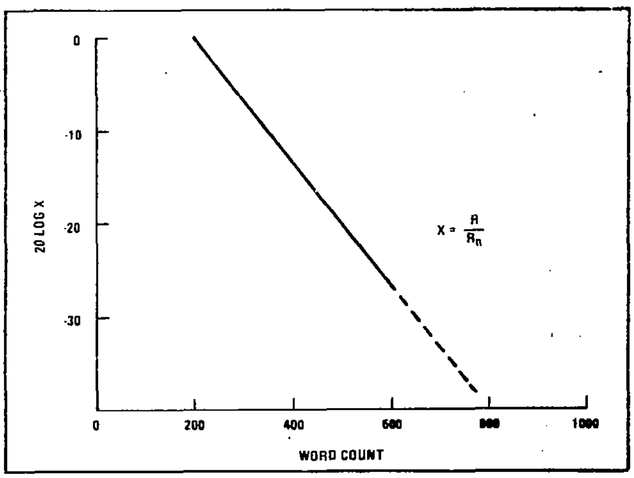


Figure G.2-3. Example of MSS Radiometric Level vs Word Count

Solving for the root-sum-square error, differentiating and setting to zero, the gain b and offset a for an ideal linear radiance vs voltage is obtained. Figure G.2-4 shows how the 6 sampled voltages, when combined with the chosen 6 relative radiance levels, can be used to determine the best straight line fit using linear regression.

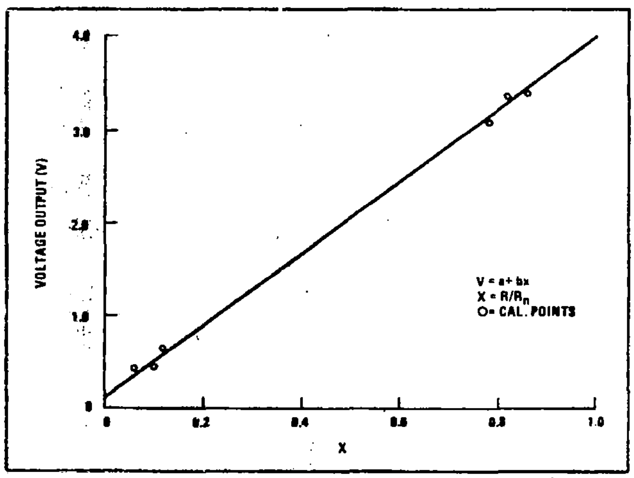


Figure G.2-4. Example of MSS Voltage vs Radiometric Level

The equations used to calculate a and b, given k relative radiance levels (X_i) and the corresponding k voltage measurements (V_i), are:*

$$a = \Sigma C_i V_i$$

$$b = \Sigma D_i V_i$$

$$C_i = \frac{(\Sigma X_i^2) - (\Sigma X_i) X_i}{k(\Sigma X_i^2) - (\Sigma X_i)^2}$$

$$D_i = \frac{K X_i - (\Sigma X_i)}{k(\Sigma X_i^2) - (\Sigma X_i)^2}$$

*All summations are from $i = 1$ to k. The values of a and b will be calculated for all 24 channels for high and low gains.

The desired straight line can then be represented by,

$$V_i = a + bX_i$$

The values of X_i may be different for each mode of operation and channel, but are constant otherwise. They will be provided from initial calibration so that all values of the constants C_i and D_i may be calculated.

G.2.2.2.2 Data Smoothing

Since the calibration wedge contains noise, the calculated values of a and b must be smoothed. A Kalman type filter is used and implemented with an optimum variable weighting factor for the first 16-64 calibration data samples and then held constant for the run's duration. When the MSS data is interrupted, the filter is initialized again. Data interruption is defined as the changing of video tape or when the recorded data has a time discontinuity. This type of filter was chosen because the optimum variable weighting factor reduces signal variance due to noise very rapidly and allows reasonable initial transient response time. The constant weighting factor keeps the signal variance low and allows low-frequency signal variations to be followed.

The filter noise reduction properties are shown in Figure G.2-5 and are such that the error variance is reduced by the factor (n+1) as compared to each individual parameter measurement variance when using the optimum variable weighting factor, and will be K/2 for the constant value.

The filter equations for the smoothed channel gain b and offset a coefficients are:

$$a_s(n) = a_s(n-1) + w(n)\,(a(n) - a_s(n-1))$$
$$b_s(n) = b_s(n-1) + w(n)\,(b(n) - b_s(n-1))$$

where

n = sample number

subscript s means smoothed value

$$w(n) = \frac{1}{n+1} \text{ for } n \le 16 \text{ (or 64)}$$
$$= K \text{ for } n > 16 \text{ (or 64)}$$

$$K = \frac{1}{64}$$

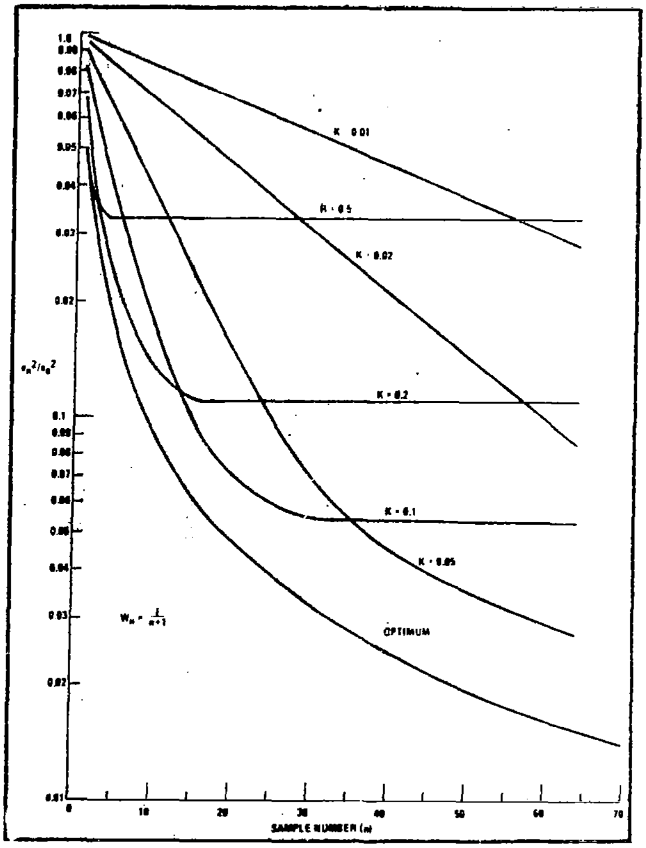


Figure G.2-5. Noise Reduction Properties of Kalman Filter

Initial values of a_s and b_s are supplied from the initial calibration tables.

G.2.2.2.3 Calibrator

The calibrator section of the calibration procedure is the memory look-up table where the conversion from received signal voltage V_r to calibrated voltage V_c can be obtained from the relationship

$$V_c = AV_r - B$$

where

$$A = \frac{K_n R_n}{b_s}$$

$$B = \frac{K_n R_n A_s}{b_s}$$

$$K_n = \frac{\text{full scale voltage}}{\text{full scale band radiance}} = \frac{4.0}{R_n}$$

G.2.2.2.4 Summary of Equations

A summary of all the equations used for sensor calibration follows:

1. General Equations

V_i = Calibration wedge voltage sample No. i

X_i = Ratio of calibration signal radiance (R) to maximum value (R_n)

i = Sample No. (i = 1, 2, ... , 6)

$$C_i = \frac{(\Sigma X_i^2) - (\Sigma X_i)\, X_i}{k(\Sigma X_i^2) - (\Sigma X_i)^2}$$

$$D_i = \frac{kX_i - (\Sigma X_i)}{k(\Sigma X_i^2) - (\Sigma X_i)^2}$$

Σ = summation of i = 1 to k

k = no. of samples actually used (either 4 or 6)

2. Channel Offset (a)

$$a = \sum_{i=1}^{k} C_i V_i$$

3. Channel Gain (b)

$$a = \sum_{i=1}^{k} D_i V_i$$

4. Filtered Values of a and b

$$a_s(n) = a_s(n-1) + w(n)\,(a(n) - a_s(n-1))$$

$$b_s(n) = b_s(n-1) + w(n)\,(b(n) - b_s(n-1))$$

$$w(n) = \frac{1}{n+1} \text{ for } n \leq 16 \text{ (or 64)}$$

$$= K \text{ for } n > 16 \text{ (or 64)}$$

$$K = 1/64$$

5. Calibration Coefficients

$$V_c = K_n R$$

$$V_c = AV_r - B$$

where

R = signal input radiance

K_n = conversion gain $\approx \dfrac{\text{full scale voltage}}{R_n}$

V_r = received signal voltage

V_c = calibrated signal voltage

$$A = \frac{K_n R_n}{b_s}$$

$$B = \frac{K_n R_n a_s}{b_s}$$

R_n = full scale band radiance (maximum specified radiance for band)

G.2.2.2.5 Sun Calibration

Sun calibration data is received and stored on Computer Compatible Tape (CCT) and, at a later time, the data is processed in order to obtain updated calibration coefficients. The acquisition of sun calibration data occurs at a maximum of once per orbit. Data is obtained in the MSS data format during the sensor data time interval and the Bulk Processing Subsystem (BPS) makes a normal framed image. This continues until the data ends, which is normally less than the equivalent of 100 nm on the ground (see Figure G.2-6). The sun appears in the image as a smeared disk with a flat central portion that covers about 0.05 degrees.

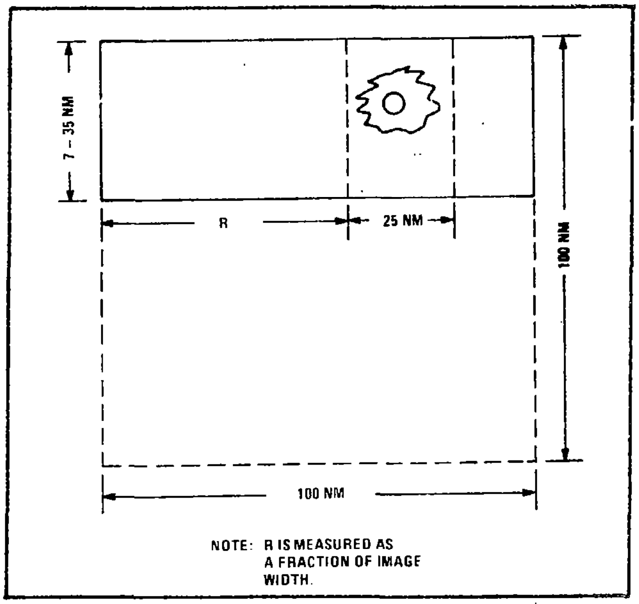


Figure G.2-6. MSS Sun Calibration

When the BPS is in the image generation mode and the Image Annotation Tape indicates the time that sun calibration data was received, the BPS makes a framed image. When this sun image frame is developed, an interpreter locates the sun within a 25-nm strip. The start of this strip must be measured with respect to the left edge (West) of the frame. The interpreter then has a work order made so that the BPS can make High Density Data Tape of the desired image. The Special Processing Subsystem (SPS) then receives this tape and makes one CCT which contains the desired sun disk in all four spectral bands.

At a later time when the sun data is processed, the CCT is inputted to the SPS. This data is continuously calibrated for channel gain and offset variations. Next, the sun image is located by requiring the data level to exceed a set threshold. When the sun image is located, all of the data exceeding the threshold level is outputted to the line printer so that a special plot of sun voltage levels may be obtained. The data is also entered into memory and a histogram made of the number of times a given data voltage level has been received. From this histogram, a larger threshold value more representative of the sun disk location is determine; and the CCT run again. The sun disk plateau is then averaged. This average value for each spectral band is used to calculate the sun calibration coefficients. The actual calibration procedure is shown in Figure G.2-7.

G.2.2.2.6 Sensor Calibration

The calibration of each channel is performed as described in Section G.2.2. Since approximately 20 sweeps are required for the channel calibration data averaging filter to settle down if the input channel gain and offset initial estimates are not correct, it is necessary that the sun disk be 20 or more sweeps down from the top of the image to obtain accurate sensor calibration. This will normally occur since the MSS sensor is turned on prior to the actual viewing of the sun.

G.2.2.2.7 Image Locator

The Sun Image Locator Program receives the sun data one record at a time and calibrates each byte as it is read out of memory. Each calibrated byte of a record is compared with a set threshold. When N_1 consecutive bytes exceed this threshold for N_2 consecutive records, the sun image is assumed to be located. All of the following data that exceeds the threshold is then put into the Central Disk Averager memory. This continues until N_2 consecutive records have not output data. Once the sun image has been completely scanned, the CCT is back-spaced to the beginning of the sun image. The program is repeated for each spectral band.

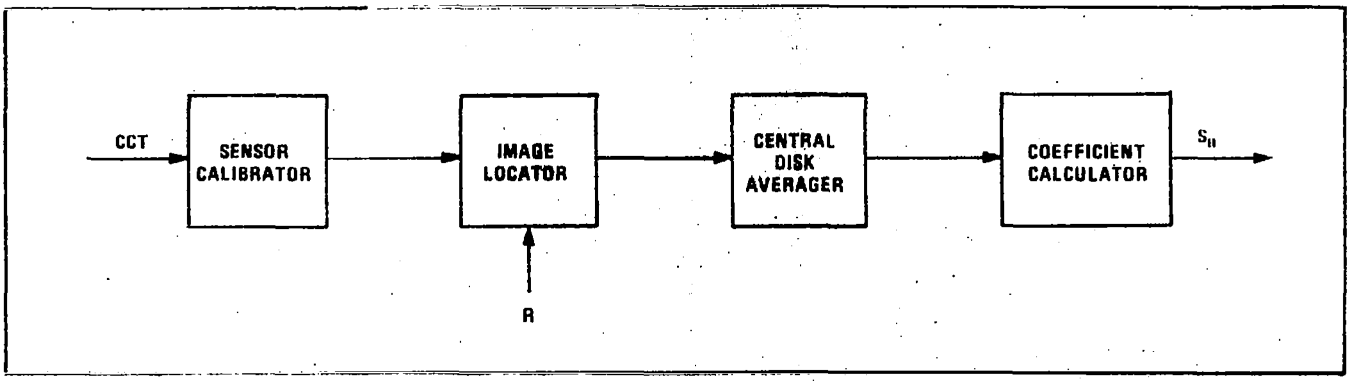


Figure G.2-7. MSS Sun Calibration Procedure

G.2.2.2.8 Central Disk Averager

All data obtained from the Image Locator Program is put into memory in such a way that a histogram is created. From this histogram, a new larger data threshold is determined by finding the largest memory address containing a count of N_3 or more. This memory address is then used as a new threshold and the CCT is started again. The actual sun disk is now bounded by this new threshold and all values within this bound are averaged together to form the average sun voltage value. This program is repeated for each spectral band and the numbers are supplied to the coefficient calculator program. The actual value of N_3 depends upon the amplitude statistics of the central disk of the sun which normally contains a plateau of about 100-200 data bytes of constant amplitude. The plateau contains the maximum data values. Using this model of sun disk plateau, N_3 would be smaller and would be determined analytically from the printout of the sun image. The data averaging technique depends critically upon this model being correct and that the plateau contains the maximum data values. Should the sun disk plateau be surrounded by a ring of peak values, for example, the averaging technique software program would have to be modified to average only those data values of interest.

G.2.2.2.9 Coefficient Calculator

The calibrated voltages are denoted as V_c and their relationship to input radiance is:

$$V_c = K_n R$$

where K_n = system conversion gain for the given band and mode of operation. Since the sun radiance value for each spectral band remains constant, the only way that the received calibration sun voltage values (V_c^s) could change would be for K_n to change. Collecting values of V_c^s each time sun calibration is performed and calculating the average value as a function of time, the change in K_n with time is determined. The change in K_n is then:

$$S_n = \left[V_c^s \text{ (ave)}_1 - V_c^s \text{ (ave)}_2 \right] \frac{K_n \text{ (old)}}{V_c^s \text{ (ave)}_1}$$

where

V_c^s (ave)$_1$ = average value determined during initial sun calibration runs.

V_c^s (ave)$_2$ = average value determined during subsequent sun calibration runs.

The gain constant K_n can then be adjusted by,

$$K_n \text{ (new)} = K_n \text{ (old)} + S_n.$$

APPENDIX H
FILM AND DEVELOPER CHARACTERISTICS

Table H-1 indicates the film/developer combinations used in the photographic subsystem. All black and white products are processed in Kodak Model 11-C Versamats. Color negatives and transparencies are processed in Kodak Model 1811 Versamats.

All films selected are "standard" materials that are commonly used for military aerial reconnaissance duplication tasks as well as other applications. The single exception to this is the Kodak SO-219 film specifically designed and used for electron beam recording. This film differs from ordinary film in that it has a special layer between the emulsion and base that is electrically conductive. The layer effectively normalizes any electrical charges between exposed and unexposed portions of a frame while the Electron Beam Recorder (EBR) is writing the image. If this layer were not present, it would be possible, in theory, for geometric distortions to occur in the images because of electrical charge differentials between exposed and unexposed portions of the image.

H.1 PHOTOGRAPHIC IMAGE QUALITY

Photographic image quality is mainly dependent upon the choice of film, although the developer is sometimes significant. Generally, films of high light sensitivity have relatively inferior image quality while films of low light sensitivity have relatively high image quality. Aerial duplicating films used in the ERTS photographic facility are all of low light sensitivity and consequently have good image quality characteristics.

Image quality is broadly defined by three parameters

1. Tone reproduction

2. Modulation Transfer Function (MTF) or resolution

3. Granularity or graininess

These parameters were originally used as criteria to select the films used in the photo processing subsystem and are described in the following paragraphs.

Table H-1. Film/Developer Combinations

ITEM NO.	ITEM	FILM TYPE	DEVELOPER
BULK BLACK & WHITE			
1*	70 mm archival positive	SO-219	MX-641
2*	9.5 in. master negative	TBD**	TBD**
3*	70 mm intermediate negative	TBD	TBD
4	9.5 in. transparency for user	TBD	TBD
5	9.5 in. print for user	1717RC	MX-641
6	70 mm positive transparency for user	TBD	TBD
7*	9.5 in. positive input for color	TBD	TBD
8	70 mm negative for user	TBD	TBD
PRECISION BLACK & WHITE			
1*	9.5 in. archival negative	2490	MX-641
2	9.5 in. transparency for user	TBD	TBD
3	9.5 in. print for user	1717RC	TBD
4*	9.5 in. input for color	TBD	TBD
5	9.5 in. negative for user	TBD	TBD
BULK COLOR			
1*	9.5 in. archival negative	2445	C-22/EA5
2	9.5 in. transparency for user	SO-193	C-22/EA5
3	9.5 in. print for user	RC-30	EKTAPRINT-3
PRECISION COLOR			
1*	9.5 in. archival positive	2445	C-22/EA5
2	9.5 in. transparency for user	SO-193	C-22/EA5
3	9.5 in. print for user	RC-30	EKTAPRINT-3
MICROFILM			
1*	16 mm original negative	SO-281	MX-641
2*	16 mm intermediate negative	7470	MX-641
3	16 mm positive for user	7464	MX-641

* Product is used internally within NDPF and is not available to investigators

** All TBD's refer to one film/developer combination that has not yet been selected

H.1.1 Tone Reproductior.

Tone reproduction can be illustrated by a plot of resultant film density (D) against the log of exposure. The nominal D 'og E curve for the ERTS duplication film/chemistry combination is shown in Figure H-1. This figure was determined by exposing the duplication film in a Hernfeld Sensitometer filtered to simulate the blue light exposures used in the printers. The exposure time was 1/5 sec. The curve is nominal; however, the deviations from the average are small and consistent because of the extensive quality control and inspection procedures used. Because of these procedures the tonal range of user generation products is not compressed and simulates the original SO-219 photos accurately.

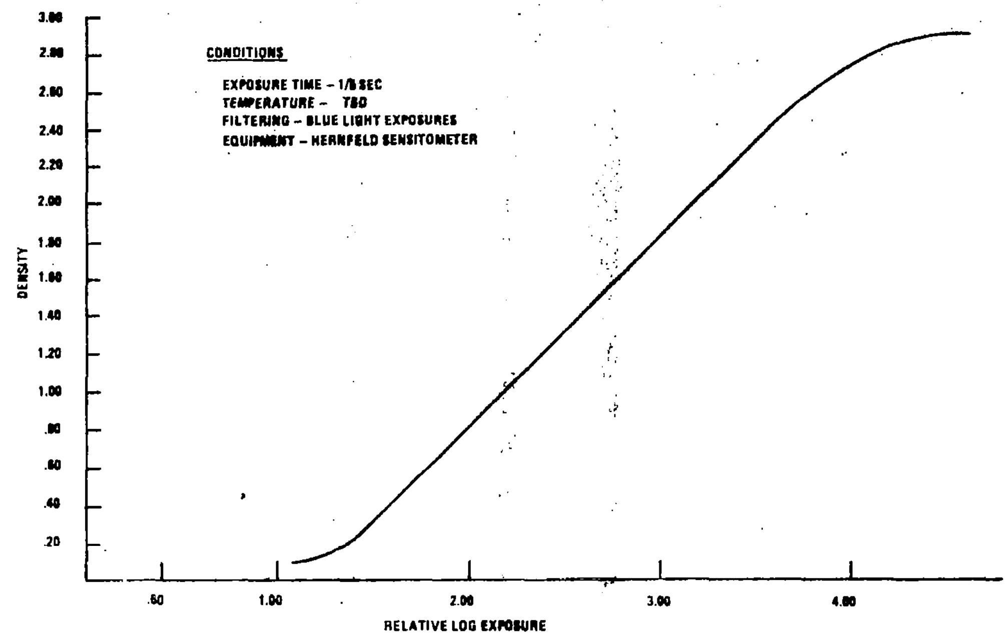


Figure H-1. Tone Reproduction Characteristics of (TBD) Film and (TBD) Developer

Figure H-2 represents the effect of the second and third generation copying processes on the tone reproduction. The SO-219 density when illuminated by light becomes the exposure for the second generation and the illuminated second generation becomes the exposure for the third generation. The intensity of the light is chosen to position the D-log E curve optimally relative to the curve for the preceding generation. The SO-219 density scale is translated clockwise through Figure H-2 and becomes the ordinate for quadrant IV. The SO-219 exposure is brought down to become the abscissa of quadrant IV. This is indicated by the construction lines.

The fidelity of the reproduction process is obtained by comparing quadrant IV to the SO-219 D-Log E curve. Because the second and third generation processes have a gamma of 1.0 and because the correct printing exposure has been chosen, a gray scale recorded on SO-219 is reproduced exactly in the third generation.

Paper prints, both black and white and color, are processed to a gamma higher than 1.0 so that a more pleasing subjective impression will result. Necessarily, these photos are not linear over a very wide exposure range because of their higher gamma characteristics and, consequently, will be of limited use for gathering quantitative density data.

The color negative and transparencies also have a limited linear range. Their exact tone reproduction is to be determined.

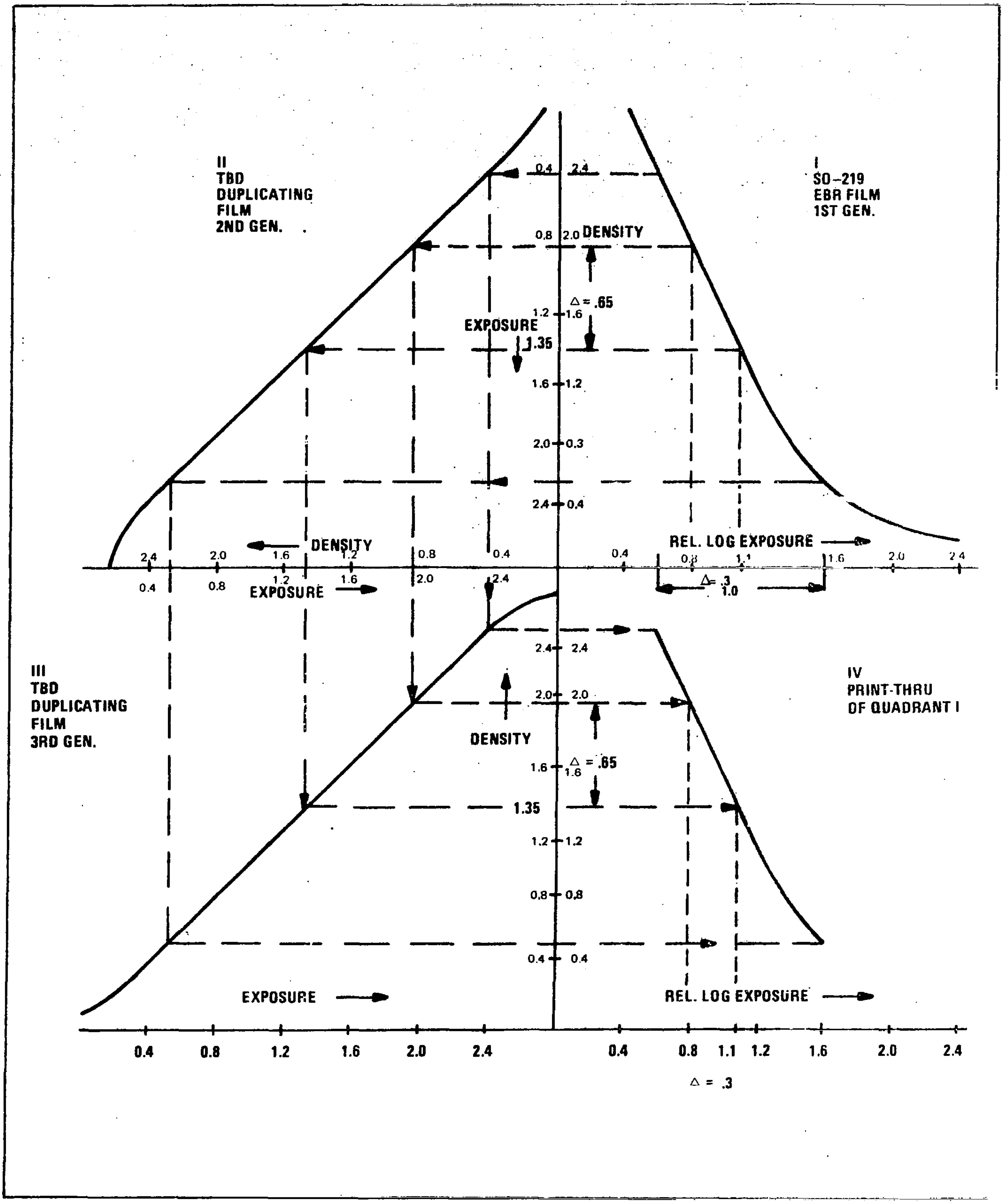


Figure H-2. Tone Reproduction Characteristics of Photo Processing Subsystem

H.1.2 MTF and Resolution

A typical MTF response for the duplication films is shown in Figure H-3. These duplication films have very good MTF characteristics relative to the electronic sensor systems. They are capable of resolving about 250 1p/mm using a 1000:1 contrast targets and high resolution contact printers.

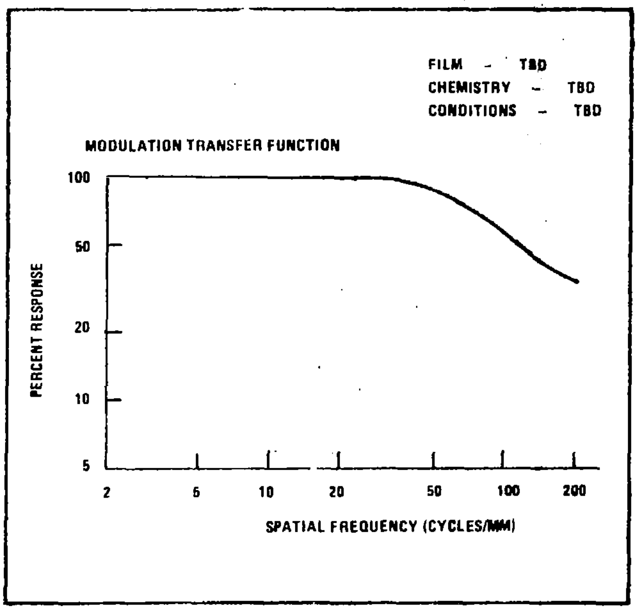


Figure H-3. Typical MTF Response

Because of the high resolving power capability of the duplication films being used, resolution of the original EBR photographic image is not seriously reduced. Using the limiting resolving power capability of the sensor and recording systems of 38 1p/mm (70mm format), the limiting resolution at the various generations of photography are as shown in Table H-2.

Table H-2. Estimated Limiting Resolution

Reproduction Stage (Gen.)	Resolution (1p/mm)
0 (input)	38
1st Gen. (SO-219) positive	34
2nd Gen. Negative	30
3rd Gen. Positive	26

H.1.3 Granularity

Granularity of the products at various stages of reproduction has been estimated from approximately 5000 independent density samples and is defined as 1000 times the standard deviation of the density of an evenly exposed portion of a photograph when scanned with a microdensitometer (f/2.0) using a 48μm aperture in the white light mode. Granularity vs density curves of the various products are useful for placing confidence limits on microdensity areas. Figure H-4 is an estimated granularity vs density curve for SO-219. Figure H-5 estimates the granularity vs density of each stage.

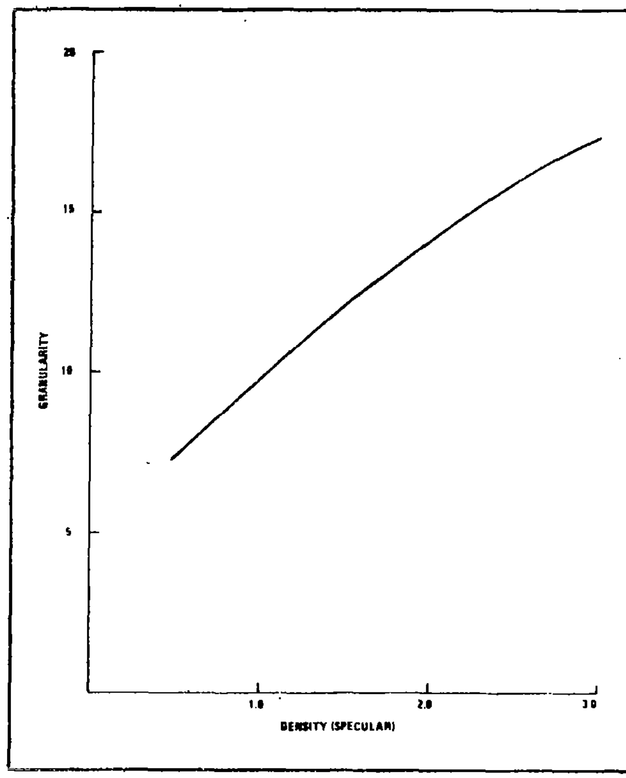


Figure H-4. Estimate of SO-219 Granularity

H.1.4 Photographic Micro-Image Quality

For investigators wishing to scan photographs with a microdensitometer, aperture size will be critical. Because of MTF, granularity and sensor and recording systems considerations, scans using apertures smaller than approximately 20 μm diameter will be essentially meaningless. Even scans with aperture sizes of approximately 40 μm will probably not correlate well with macro-density readings, even when assuming that the investigator has made necessary corrections from specular to diffuse density. This problem originates from the fact that system MTF and therefore contrast is affected differently at higher spatial frequencies than at the lower frequencies. If absolute density comparisons are needed at these frequencies, it will be necessary to consider micro-image effects.

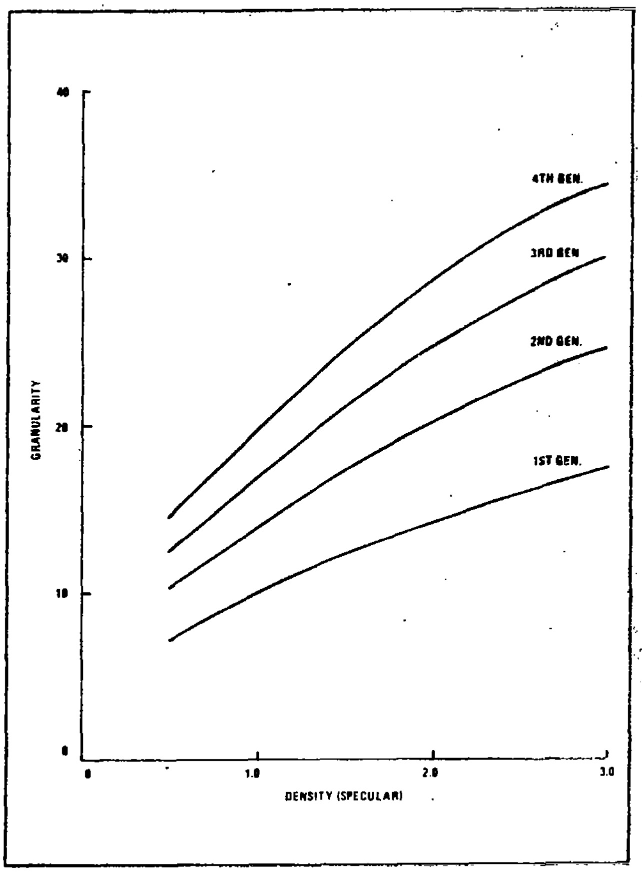


Figure H-5. Estimate of Granularity at Each Generation

Figure H-6 gives an estimate of the difference that can be expected between macro and micro characteristic curves. The micro-curve has a higher slope mainly because of photographic chemical adjacency effects. Quantitative data on the micro-density characteristics of the various products will be made available at a later date in an addendum to this document.

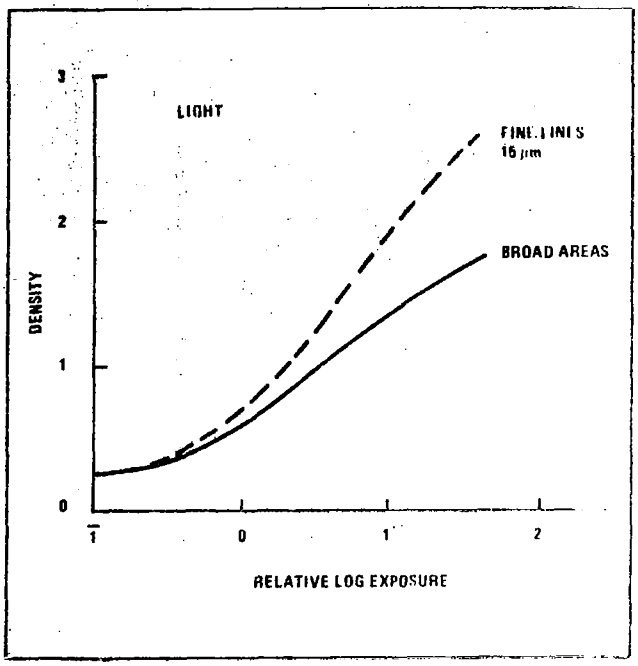


Figure H-6. Difference Between Macro and Micro Characteristic Curves

H.2 DIMENSIONAL STABILITY

All films used in the NASA Data Processing Facility use either Estar or Cronar polyester film bases which are relatively insensitive to dimensional changes. However, polyester bases do exhibit minor size changes due to three independent factors:

1. Thermal changes
2. Humidity changes
3. Processing

Environmental operational parameters within the photographic laboratory are:

Temperature	$70^{\circ} \pm 5^{\circ}$
Humidity	50% ± 10%

Thus, maximum changes could be as high as 10 degrees for temperature and 20 percent for relative humidity. Using data supplied from Eastman Kodak these changes are equal to 0.028 percent maximum size change for Estar based material. Processing dimensional change and aging shrinkage adds another 0.04 percent so that the total maximum change would be approximately 0.0680 percent per image generation. A third generation photo would have a maximum dimensional error of approximately 0.204 percent. These values are maximum dimensional error; the actual value should be much less because the environment within the laboratory is not expected to be at its maximum limits. Also, because there will be shrinkage as well as expansion, the net change will be less than that given above.

Random dimensional changes of 5 μm have been reported in the literature. Using an RSS summation, this change is 8.7 μm over three generations. For comparison with the above figures, this is equivalent to 0.01 percent.

It should be noted that all data used in making color composites are generated in a given batch. Because of this, dimensional differences should be less than 0.01 percent. Moveover, all images have tick marks for good relative accuracy.

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 A and B. A circular sun-synchronous orbit with a 9:30 a.m. descending node (equatorial crossing) has been selected. The nominal orbital parameters for ERTS A 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. Nominal Orbit Parameters

Orbit Parameter	Nominal Orbit
Semi-major axis	7294.00 km
Inclination	99.092 deg
Period	103.267 min
Eccentricity	0
Time at descending node (equatorial crossing)	9:30 a.m.
Coverage cycle duration	18 days (251 revs)
Distance between adjacent ground tracks	159.38 km

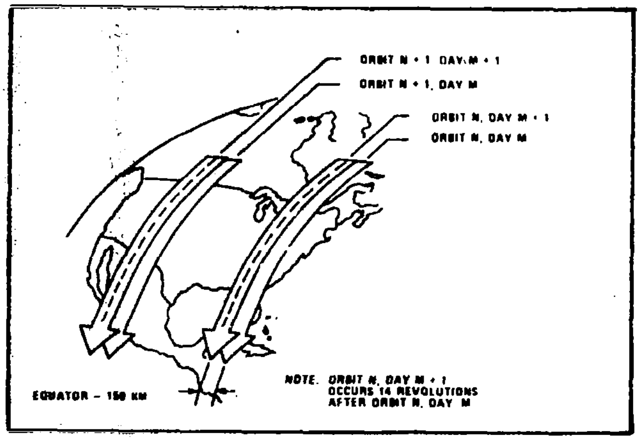


Figure I-1. Ground Coverage Pattern

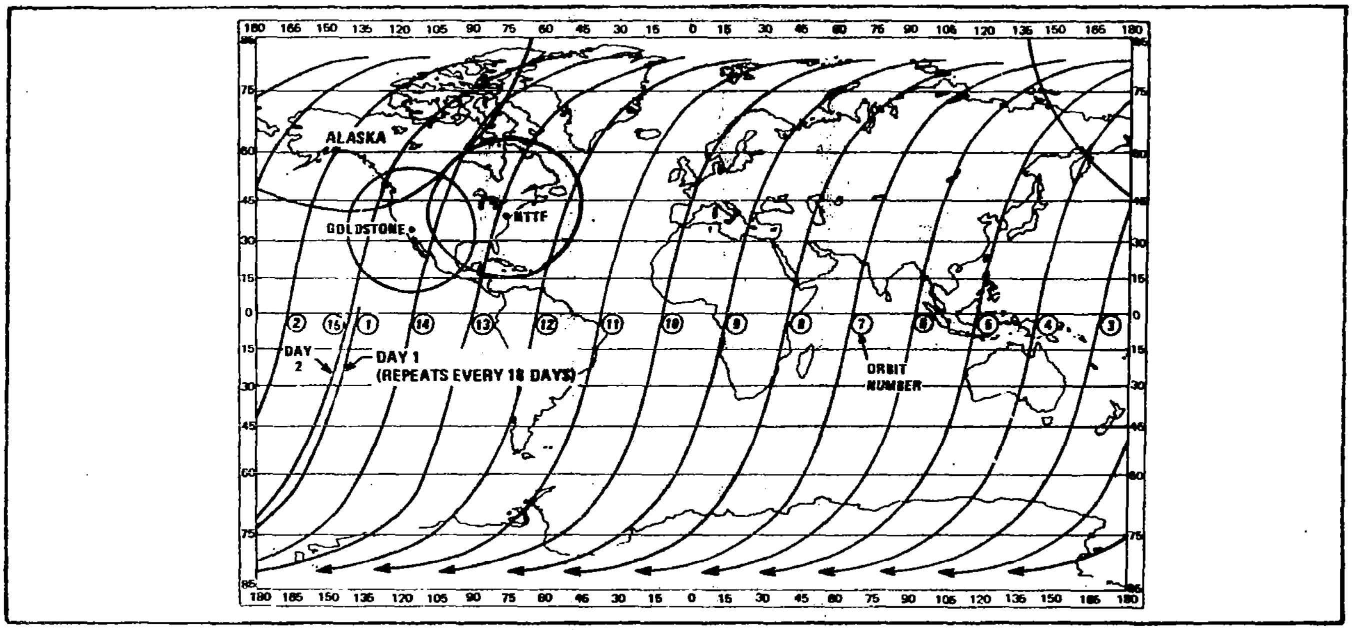


Figure I-2. Typical ERTS Ground Trace for One Day (Only Southbound Passes Shown)

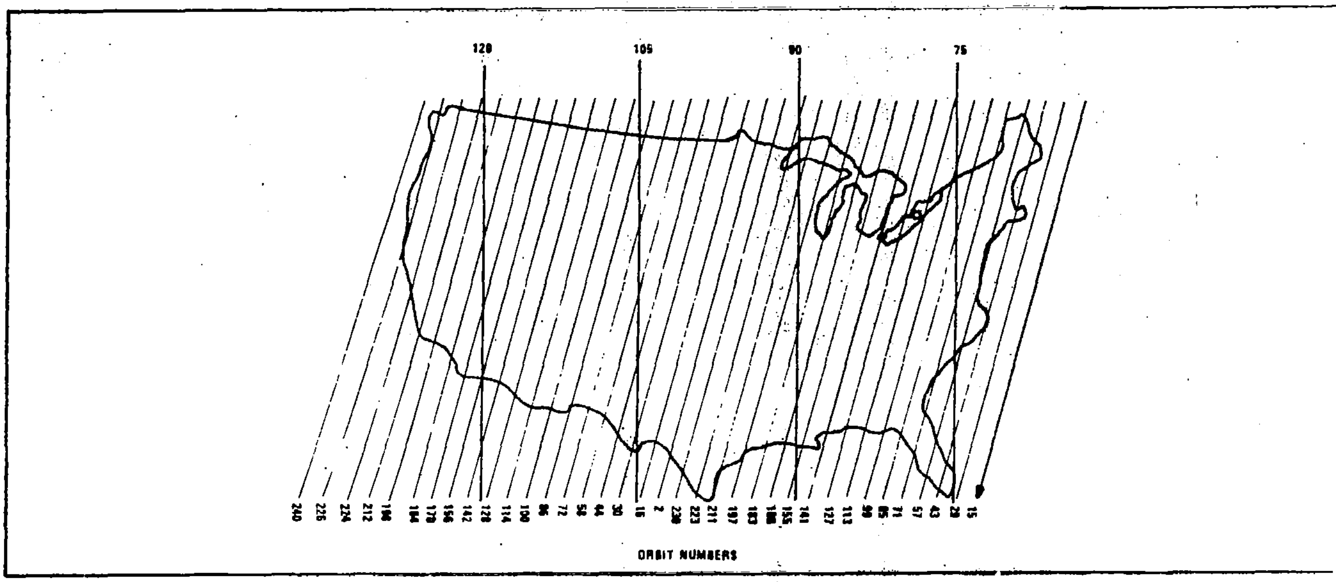


Figure I-3. ERTS Coverage of Continental United States

Coverage over the United States 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, U.S. coverage is completed after orbit 251, and is repeated beginning with Orbit Number 1. With the three ground stations used for ERTS, data covering the United States (including Alaska but excluding Hawaii) is obtained in approximately 18 minutes of operation per day.

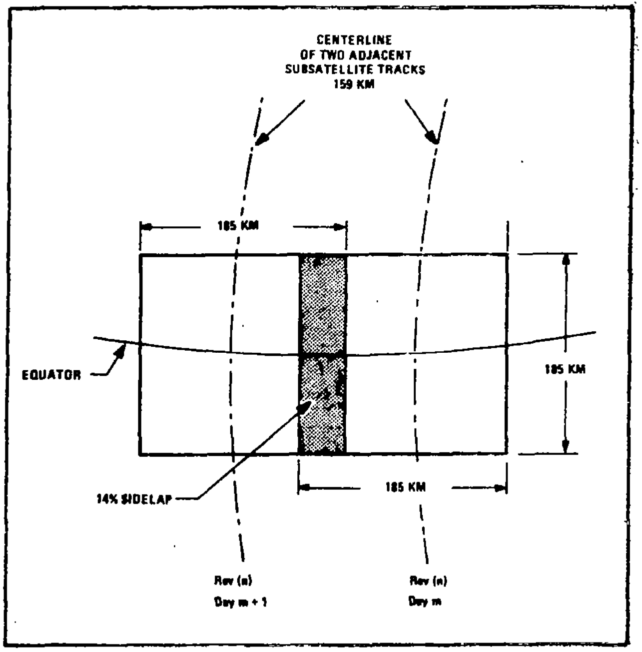


Figure I-4. Imagery Sidelap at the Equator

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

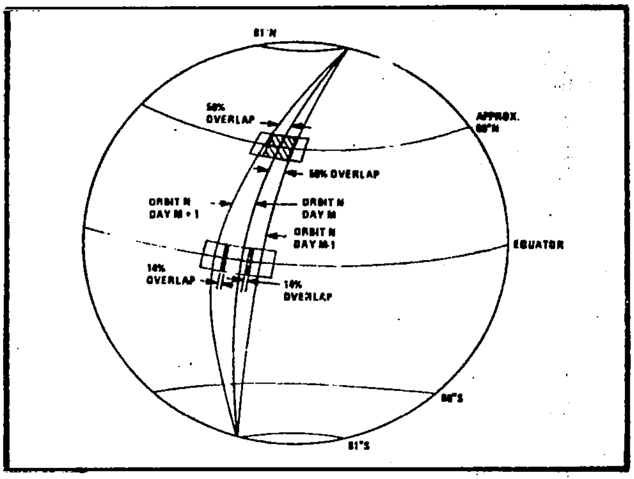


Figure I-5. ERTS Overlapping Coverage

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 pictures 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 earth, sun and moon. The combined effects of

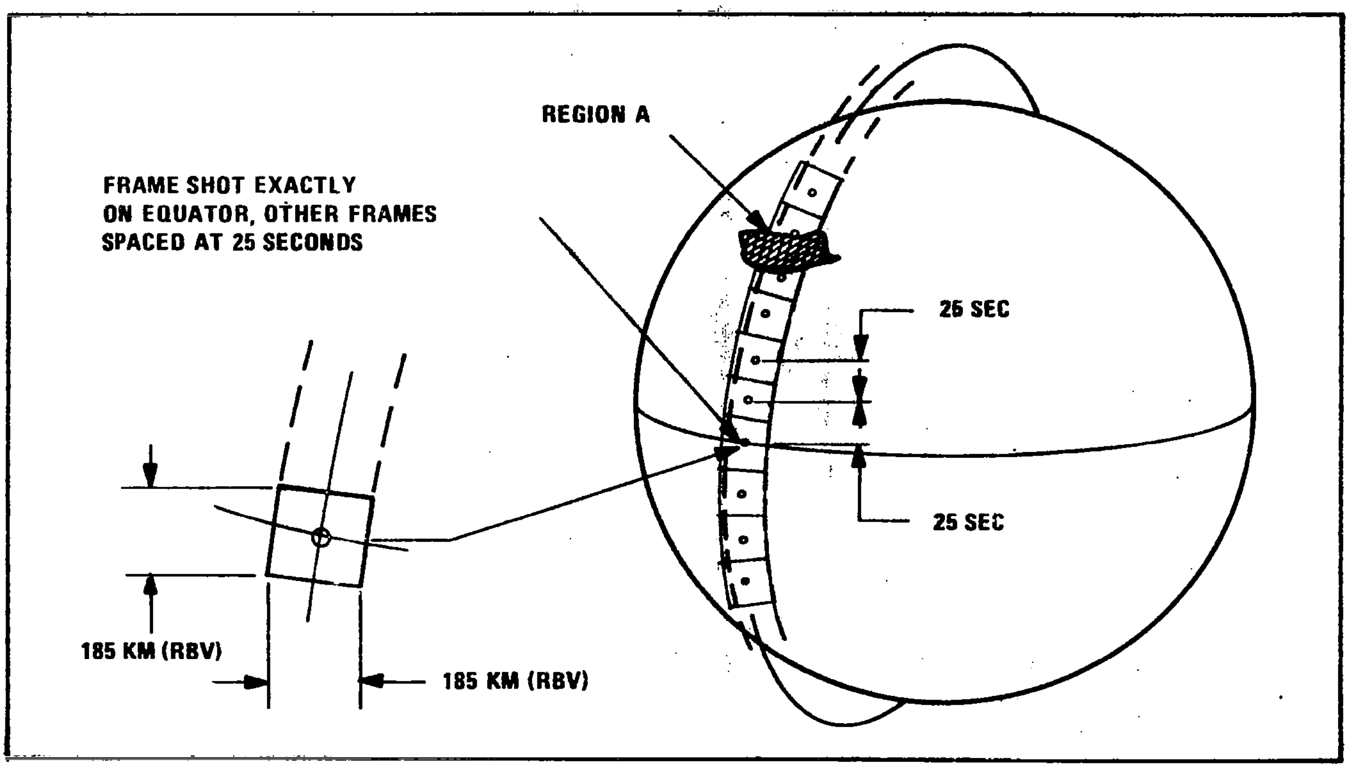


Figure I-6. In-Track Picture Scheduling oblateness and perturbing forces will cause the altitude of the satellite to vary periodically within the range of 900 to 950 km throughout the mission life.

I.5 DETERMINATION OF LOCAL OBSERVATION TIME

The ERTS orbit is sun-synchronous, as shown in Figure I-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. This estimate 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. For orbit n the equator crossing is taken as 9:30 in time zone a. One hour and 45 minutes later (one orbital period) on orbit n+1, the equator crossing occurs in time zone c. The local time of the crossing is 11:13 in time zone a and 9:13 in time zone c.

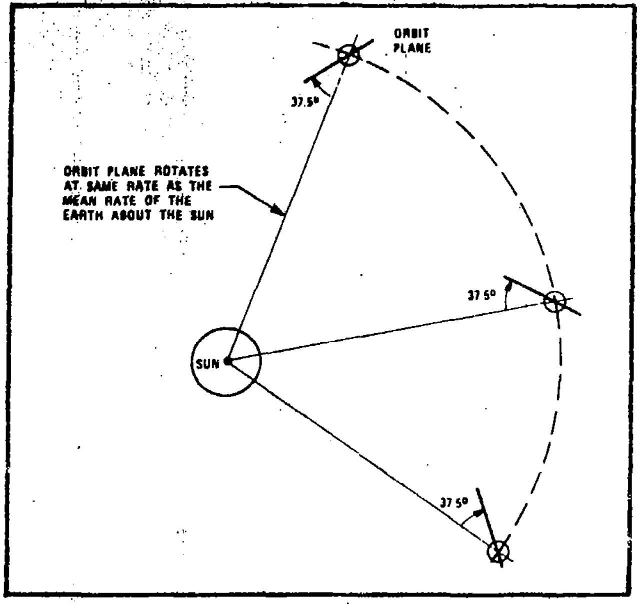


Figure I-7. Motion of Orbit Plane in Sun-Synchronous Orbit

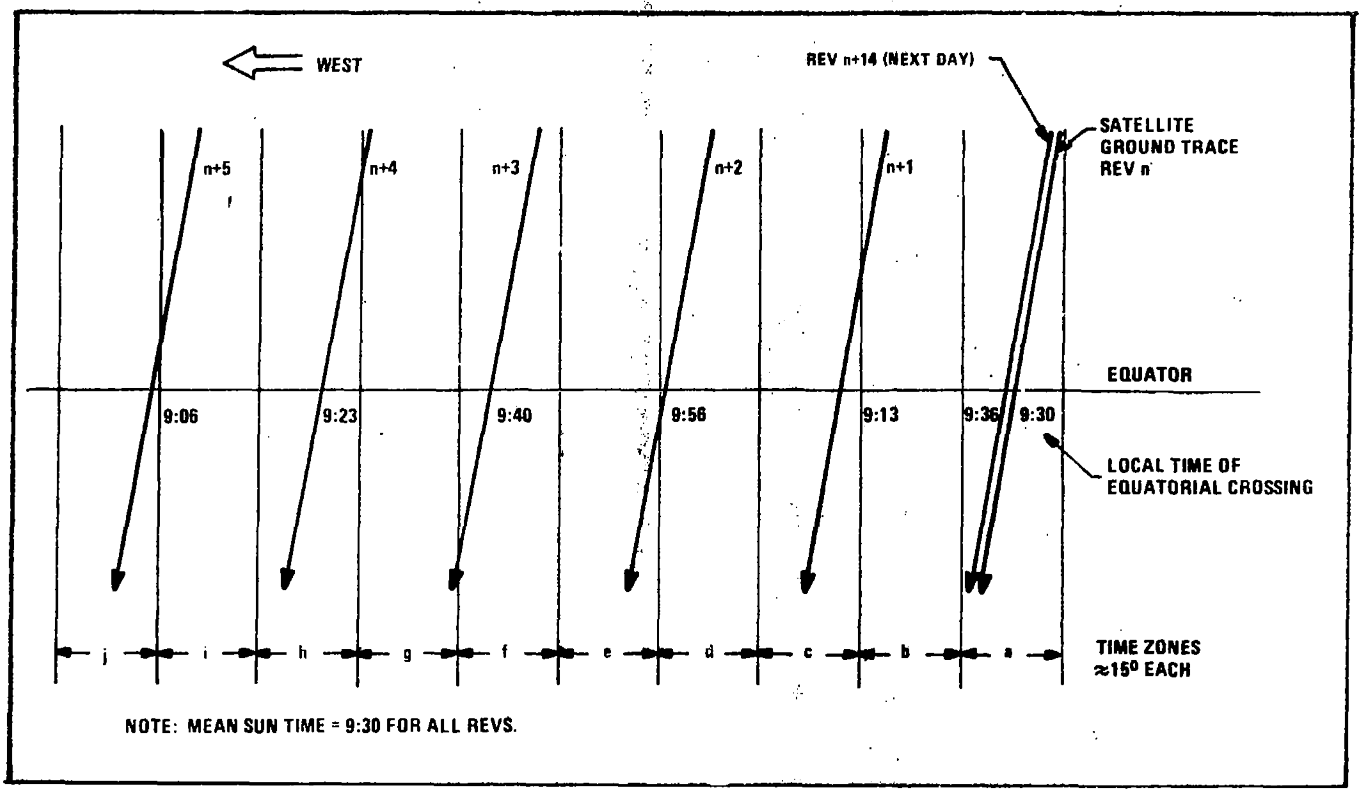


Figure I-8. Variation in Local Time of Equatorial Crossing

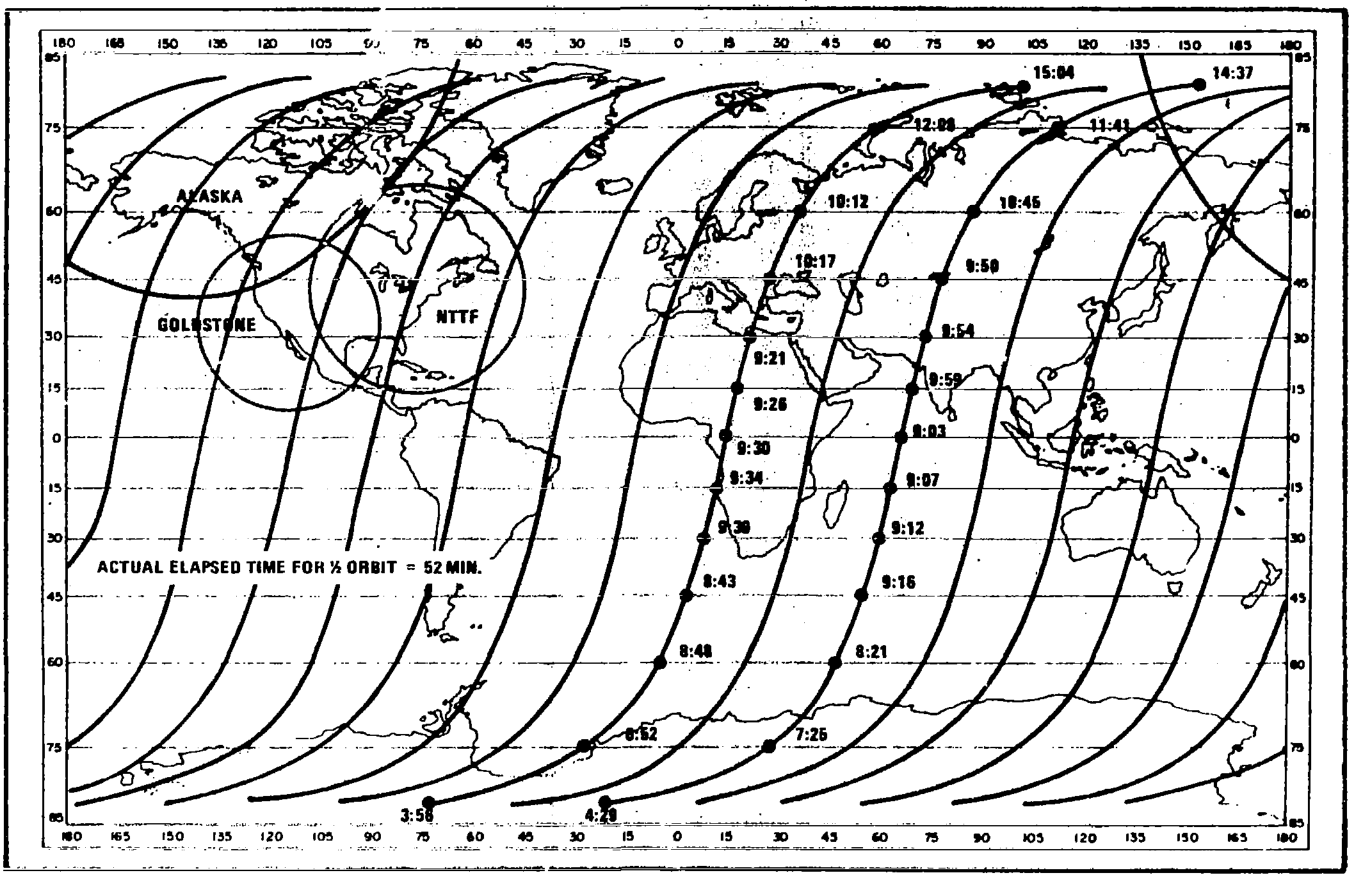


Figure I-9. Local Time – Variations Within an Orbit

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.

2. Define the approximate descending node as follows:

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

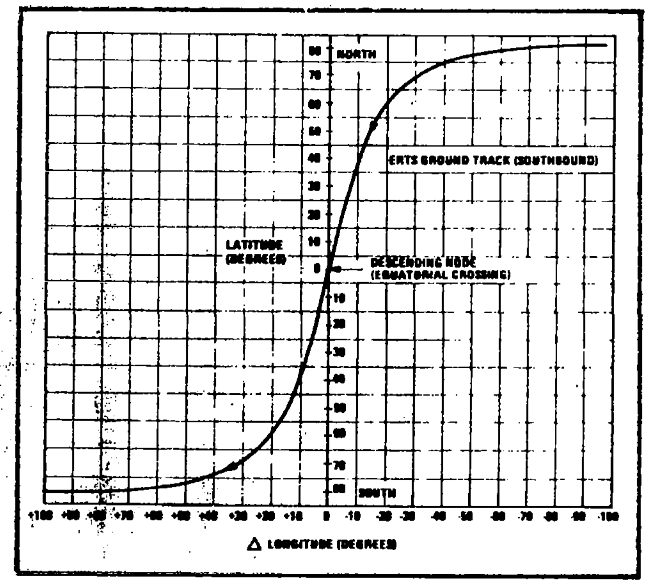


Figure I-10. Satellite Longitude Corrections (Measured from Descending Node)

b. Read the value of Δ longitude from the curve.

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-3, 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 1-3. Descending Node Parameters**

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Day M	Orbit Number N	Greenwich Mean Time of Descending Node
− .94	3	38	09:11
− 2.37	4	52	09:17
− 3.81	5	66	09:22
− 5.24	6	80	09:28
− 6.67	7	94	09:34
− 8.11	8	108	09:40
− 9.54	9	122	09:45
− 10.97	10	136	09:51
− 12.41	11	150	09:57
− 13.84	12	164	10:03
− 15.28	13	178	10:08
− 16.71	14	192	10:14
− 18.14	15	206	10:20
− 19.58	16	220	10:25
− 21:01	17	234	10:31
− 22.44	18	248	10:37
− 23.89	1	111	10:43

Table I-3. Descending Node Parameters (Continued)*

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Day M	Orbit Number N	Greenwich Mean Time of Descending Node
− 25.32	2	25	10:48
− 26.75	3	39	10:54
− 28.19	4	53	11:00
− 29.62	5	67	11:06
− 31.06	6	81	11:11
− 32.49	7	95	11:17
− 33.92	8	109	11:23
− 35.36	9	123	11:29
− 36.79	10	137	11:34
− 38.23	11	151	11:40
− 39.66	12	165	11:46
− 41.09	13	179	11:52
− 42.53	14	193	11:57
− 43.96	15	207	12:03
− 45.39	16	221	12:09
− 46.83	17	235	12:14
− 48.26	18	249	12:20
− 49.70	1	12	12:26
− 51.14	2	26	12:32
− 52.57	3	40	12:37
− 54.01	4	54	12:43
− 55.44	5	68	12:49
− 56.87	6	82	12:55
− 58.31	7	96	13:00
− 59.74	8	110	13:06
− 61.17	9	124	13:12
− 62.61	10	138	13:18
− 64:04	11	152	13:23
− 65.48	12	166	13:29
− 66.91	13	180	13:35
− 68.34	14	194	13:41
− 69.78	15	208	13:46
− 71.21	16	222	13:52
− 72.64	17	236	13:58
− 74.08	18	250	14:03
− 75.52	1	13	14:09
− 76.95	2	27	14:15
− 78.39	3	41	14:21
− 79.82	4	55	14:26
− 81.26	5	69	14:32
− 82.69	6	83	14:38
− 84.12	7	97	14:44
− 85.56	8	111	14:49
− 86.99	9	125	14:55

Table I-3. Descending Node Parameters (Continued)*

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Day M	Orbit Number N	Greenwich Mean Time of Descending Node
− 88.42	10	139	15:01
− 89.86	11	153	15:07
− 91.29	12	167	15:12
− 92.73	13	181	15:18
− 94.16	14	195	15:24
− 95.59	15	209	15:30
− 97.03	16	223	15:35
− 98.46	17	237	15:41
− 99.90	18	251	15:47
−101.34	1	14	15:52
−102.77	2	28	15:58
−104.20	3	42	16:04
−105.64	4	56	16:10
−107.07	5	70	16:15
−108.51	6	84	16:21
−109.94	7	98	16:27
−111.37	8	112	16:33
−112.81	9	126	16:38
−114.24	10	140	16:44
−115.68	11	154	16:50
−117.11	12	168	16:56
−118.54	13	182	17:01
−119.98	14	196	17:07
−121.41	15	210	17:13
−122.84	16	224	17:19
−124.28	17	238	17:24
−125.72	18	252	17:30
	(1)	(1)	
−127.15	2	15	17:36
−128.59	3	29	17:41
−130.02	4	43	17:48
−131.46	5	57	17:53
−132.89	6	71	17:59
−134.32	7	85	18:04
−135.76	8	99	18:10
−137.19	9	113	18:16
−138.62	10	127	18:22
−140.06	11	141	18:27
−141.49	12	155	18:33
−142.93	13	169	18:39
−144.36	14	183	18:45
−145.79	15	197	18:50
−147.23	16	211	18:56
−148.66	17	225	19:02
−150.09	18	239	19:08

Table I-3. Descending Node Parameters (Continued)*

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Day M	Orbit Number N	Greenwich Mean Time of Descending Node
−151.54	1	2	19:13
−152.97	2	16	19:19
−154.40	3	30	19:25
−155.84	4	44	19:31
−157.27	5	58	19:36
−158.71	6	72	19:42
−160.14	7	86	19:48
−161.57	8	100	19:53
−163.01	9	114	19:59
−164.44	10	128	20:05
−165.87	11	142	20:11
−167.31	12	156	20:16
−168.74	13	170	20:22
−170.18	14	184	20:28
−171.61	15	198	20:34
−173.04	16	212	20:39
−174.48	17	226	20:45
−175:91	18	240	20:51
−177.35	1	3	20:57
−178.79	2	17	21:02
+179.78	3	31	21:08
+178.35	4	45	21:14
+176.91	5	59	21:19
+175.48	6	73	21:25
+174.04	7	87	21:31
+172.61	8	101	21:37
+171.18	9	115	21:42
+169.74	10	129	21:48
+168.31	11	143	21:54
+166.87	12	157	22:00
+165.44	13	171	22:05
+164.01	14	185	22:11
+162.57	15	199	22:17
+161.14	16	213	22:23
+159.71	17	227	22:28
+158.27	18	241	22:34
+156.83	1	4	22:40
+155.40	2	18	22:45
+153.96	3	32	22:51
+152.53	4	46	22:57
+151.09	5	60	23:03
+149.66	6	74	23:08
+148.23	7	88	23:14
+146.79	8	102	23:20
+145.36	9	116	23:26

Table 1-3. Descending Node Parameters (Continued)*

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Day M	Orbit Number N	Greenwich Mean Time of Descending Node
+143.93	10	130	23:31
+142.49	11	144	23:37
+141.06	12	158	23:43
+139.62	13	172	23:49
+138.19	14	186	23:54
+136.76	15	200	00:00
+135.32	16	214	00:06
+133.89	17	228	00:12
+132.46	18	242	00:17
+131.01	1	5	00:23
+129.58	2	19	00:29
+128.15	3	33	00:35
+126.71	4	47	00:40
+125.28	5	61	00:46
+123.84	6	75	00:52
+122.41	7	89	00:57
+120.98	8	103	01:03
+119.54	9	117	01:09
+118.11	10	131	01:15
+116.68	11	145	01:20
+115.24	12	159	01:26
+113.81	13	173	01:32
+112.37	14	187	01:38
+110.94	15	201	01:43
+109.51	16	215	01:49
+108.07	17	229	01:55
+106.64	18	243	02:01
+105.20	1	6	02:06
+103.76	2	20	02:12
+102.33	3	34	02:18
+100.90	4	48	02:24
+ 99.46	5	62	02:29
+ 98.03	6	76	02:35
+ 96.59	7	90	02:41
+ 95.16	8	104	02:47
+ 93.73	9	118	02:52
+ 92.29	10	132	02:58
+ 90.86	11	146	03:04
+ 89.42	12	160	03:09
+ 87.99	13	174	03:15
+ 86.56	14	188	03:21
+ 85.12	15	202	03:27
+ 83.69	16	216	03:32
+ 82.26	17	230	03:38
+ 80.82	18	244	03:44

Table 1-3. Descending Node Parameters (Continued)*

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Day M	Orbit Number N	Greenwich Mea Time of Descending Node
+ 79.38	1	7	03:50
+ 77.96	2	21	03:55
+ 76.51	3	35	04:01
+ 75.08	4	49	04:07
+ 73.64	5	63	04:13
+ 72.21	6	77	04:18
+ 70.78	7	91	04:24
+ 69.34	8	105	04:30
+ 67.91	9	119	04:36
+ 66.48	10	133	04:41
+ 65.04	11	147	04:47
+ 63.61	12	161	04:53
+ 62.17	13	175	04:58
+ 60.74	14	189	05:04
+ 59.31	15	203	05:10
+ 57.87	16	217	05:16
+ 56.44	17	231	05:21
+ 55.01	18	245	05:27
+ 53.56	1	8	05:33
+ 52.13	2	22	05:39
+ 50.70	3	36	05:44
+ 49.26	4	50	05:50
+ 47.83	5	64	05:56
+ 46:39	6	78	06:02
+ 44.96	7	92	06:07
+ 43.53	8	106	06:13
+ 42.09	9	120	06:19
+ 40.66	10	134	06:25
+ 39.23	11	148	06:30
+ 37.79	12	162	06:36
+ 36.36	13	176	06:42
+ 34.92	14	190	06:47
+ 33.49	15	204	06:53
+ 32.06	16	218	06:59
+ 30.62	17	232	07:05
+ 29.19	18	246	07:10
+ 27.75	1	9	07:16
+ 26.31	2	23	07:22
+ 24:88	3	37	07:28
+ 23.45	4	51	07:33
+ 22.01	5	65	07:39
+ 20:58	6	79	07:45
+ 19.14	7	93	07:51
+ 17.71	8	107	07:56
+ 16.28	9	121	08'02

Table 1-3. Descending Node Parameters (Continued)*

Longitude (deg) of Descending Node (Equatorial Crossing)	Orbit Day M	Orbit Number N	Greenwich Mean Time of Descending Node
+ 14.84	10	135	08:08
+ 13.41	11	149	08:14
+ 11.97	12	163	08:19
+ 10.54	13	177	08:25
+ 9.11	14	191	08:31
+ 7.67	15	205	08:36
+ 6.24	16	219	08.42
+ 4.81	17	233	08:48
+ 3.37	18	247	08:54
+ 1.93	1	10	08:59
+ .50	2	24	09:05

***This table contains parameters for a typical orbit. The table will be republished after launch with parameters corresponding to the exact orbit.**

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-11.

   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

   a. Determine the number of hours between the local time zone and the Greenwich time zone from Figure I-12.

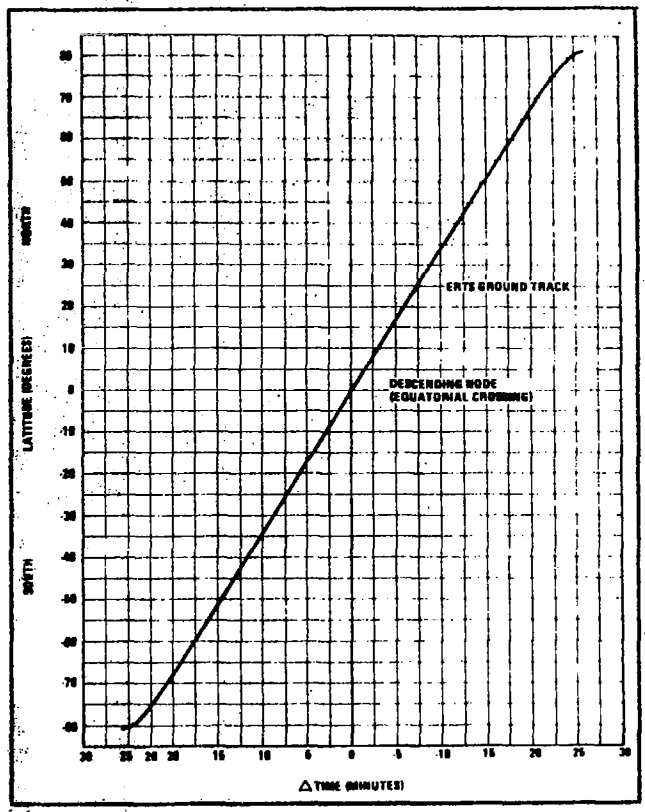


Figure I-11. Time Difference Measured from Descending Node

   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

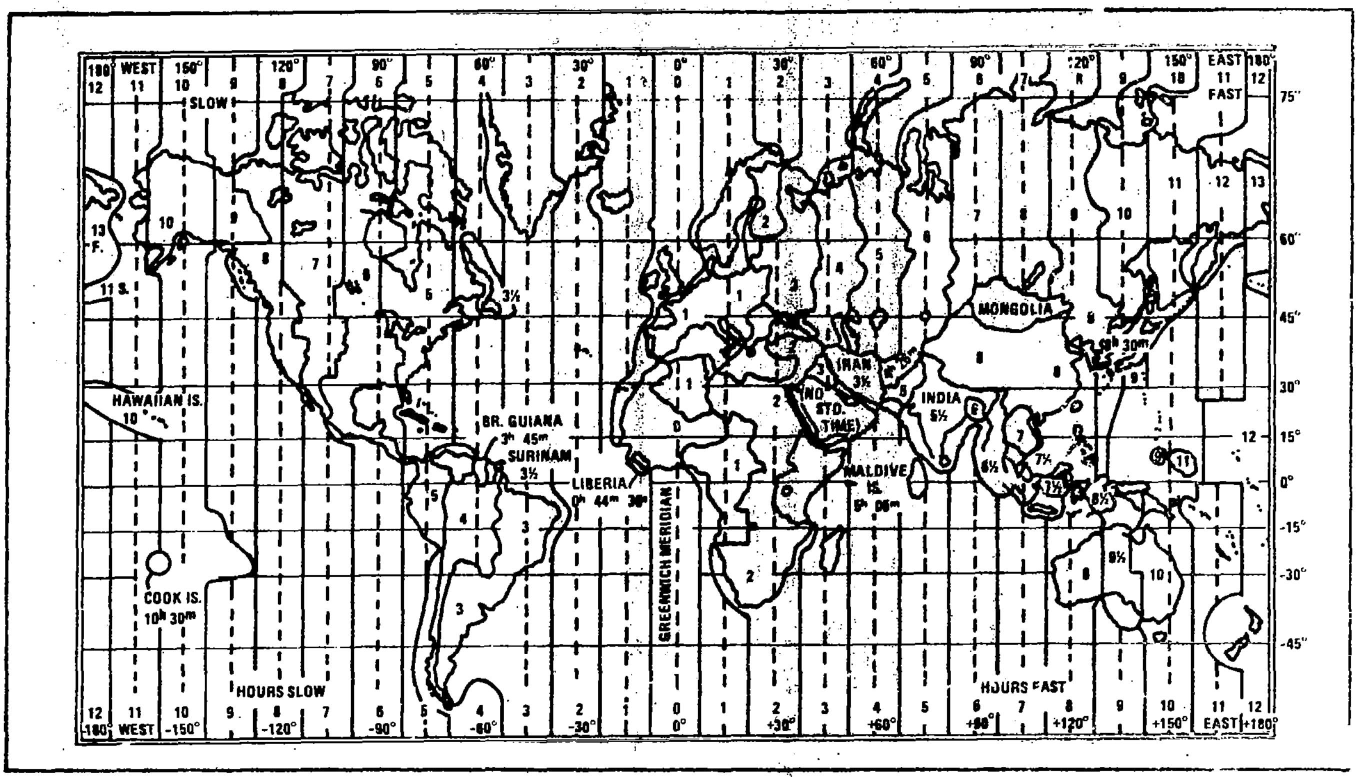


Figure I-12. Time-Zone Map of the World

Step 2

From Figure I-10, 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-3 is −132.89°. Hence, imagery will be taken of the desired point on day 6 in revolution 71. The GMT at the descending node will be 17:59.

Step 4

From Figure I-11 the Δ time for 45° North latitude is −13 minutes. Hence, the GMT when imaging of the desired point will occur is (17:59) + (−:13) or 17:46.

Step 5

From Figure I-12 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 17:46 or 9:46. This is the Standard Mean (local) Time of imaging the desired location.

Note that Table I-3 is for a typical orbit, that is, the exact longitudinal placement of the ground traces cannot be determined before launch. Actual placement of ground traces will be determined post launch and a table for the exact orbit ground traces will then be provided as a replacement for Table I-3.

APPENDIX J
ORBIT CONTROL

Several significant characteristics of the ERTS orbit are discussed in this appendix which have been selected to enhance the utility of the returned imagery. In general, these characteristics 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.

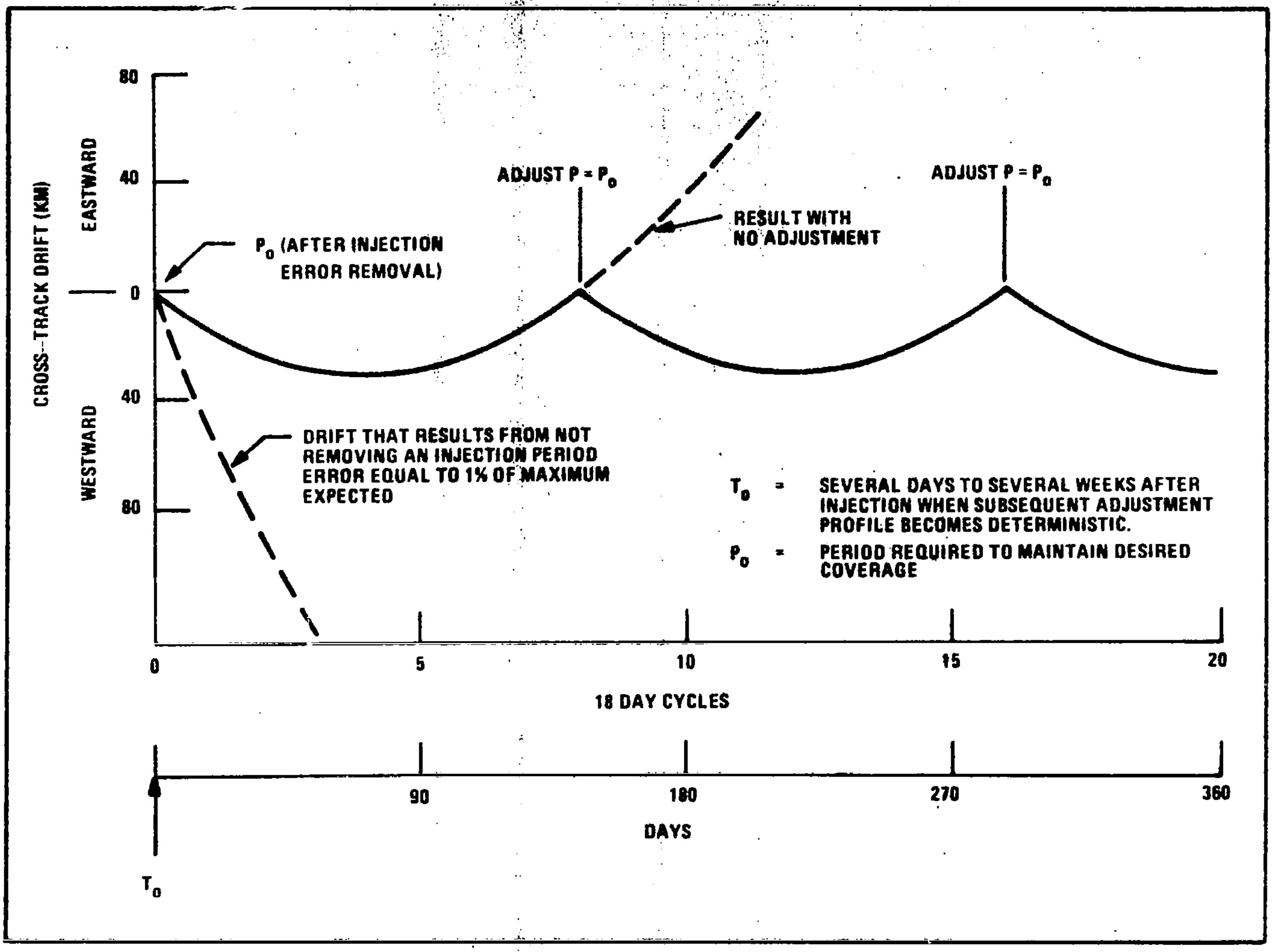


Figure J-1. Typical Cross-Talk Drift of Ground Trace and Period Adjustment Profile

APPENDIX K
MISSION PLANNING

The spacecraft has access to all global area between 81 degrees North and 81 degrees South Latitude every 18 days, as shown in Figure I-2 in Appendix I. However, due to constraining factors both within and 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

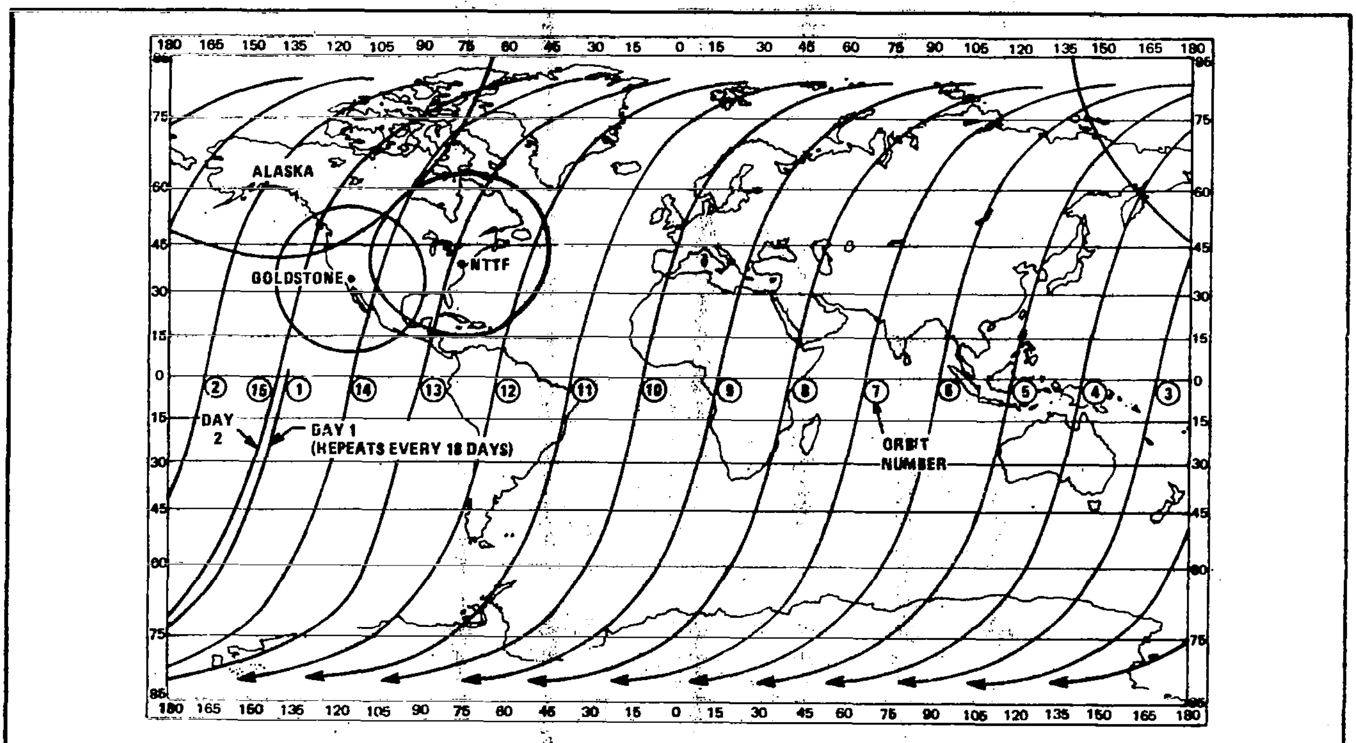


Figure K-1. Typical ERTS Coverage – One Day ground station that can receive ERTS data. The three primary ERTS stations shown in Figure K-1 (NTTF, Goldstone, and Alaska) provide coverage of most of North America and real-time imagery transmission is normally scheduled during this time. Data recovery over 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.

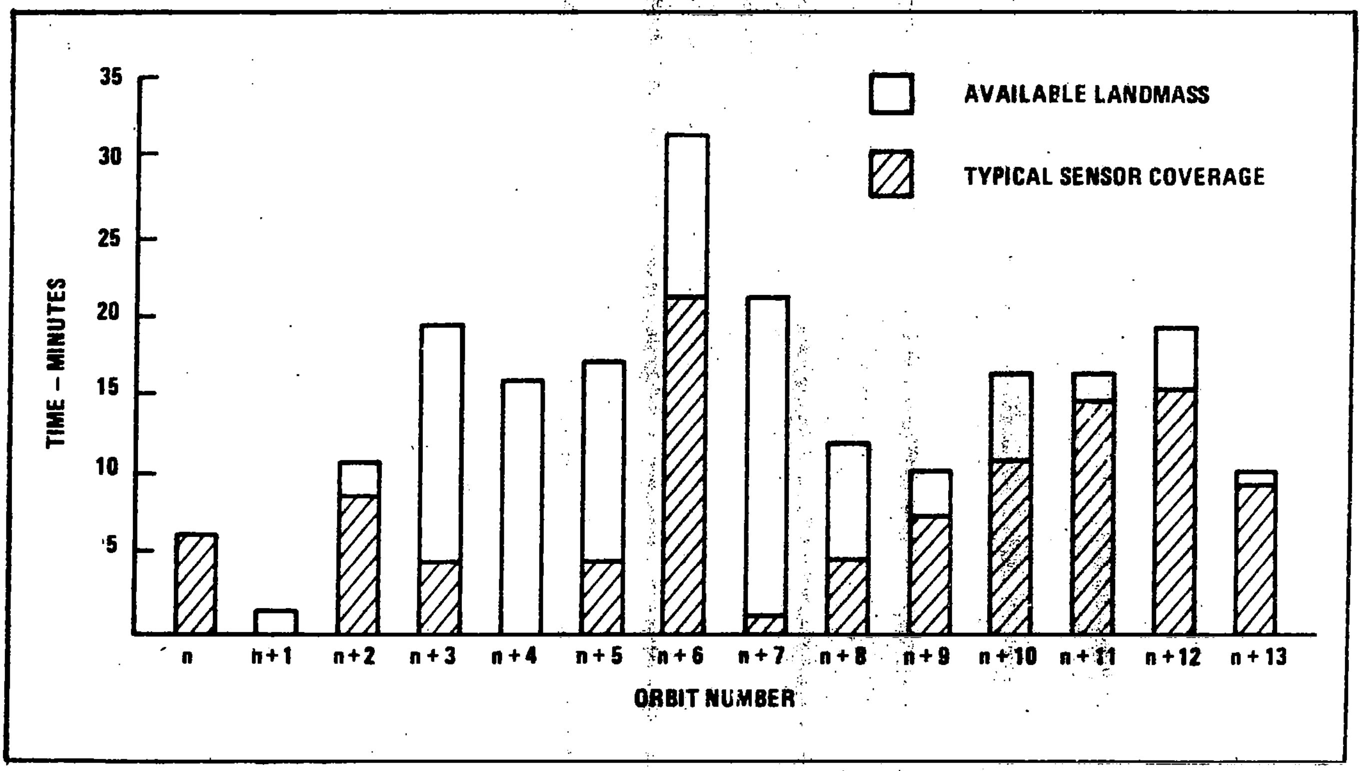


Figure K-2. Available Landmass and Typical Daily Coverage

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 1.2), 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.

The actual effect of changing solar elevation angle on a given scene is very dependent on

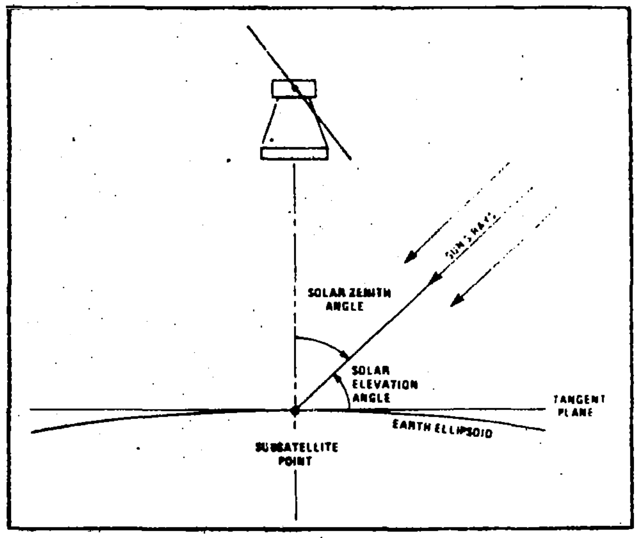


Figure L-1. Solar Elevation Angle

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

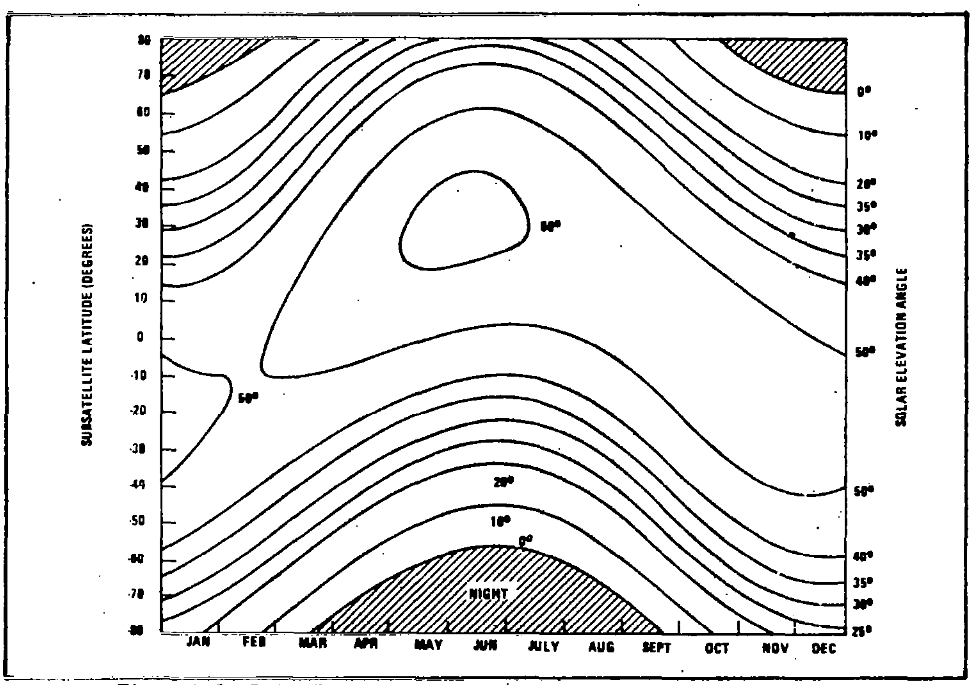


Figure L-2. Solar Elevation Angle History as a Function of Subsatellite Latitude — Descending Node at 9:30 a.m.

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.

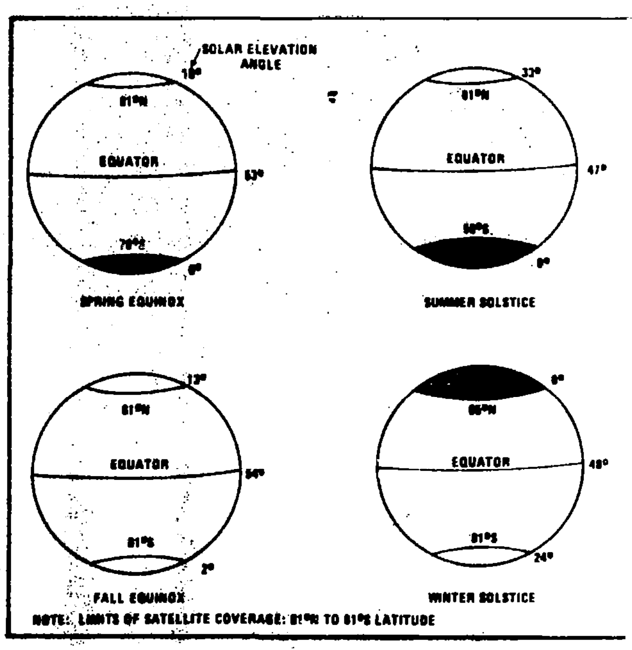


Figure L-3. Seasonal Variations in Solar Elevation Angle – 9:30 a.m. Descending Node

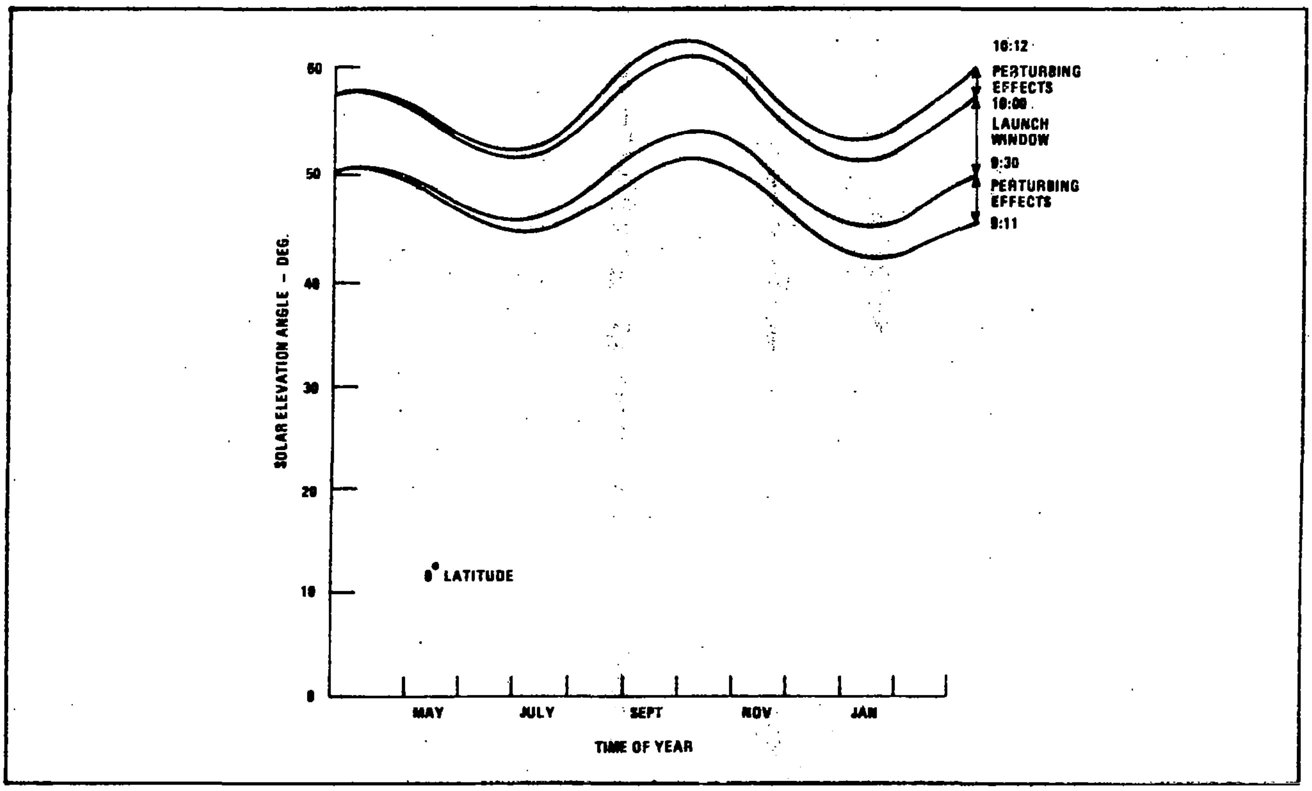


Figure L-4. Launch Window and Orbit Perturbing Effects on Solar Elevation Angle at 0 Degrees Latitude

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.

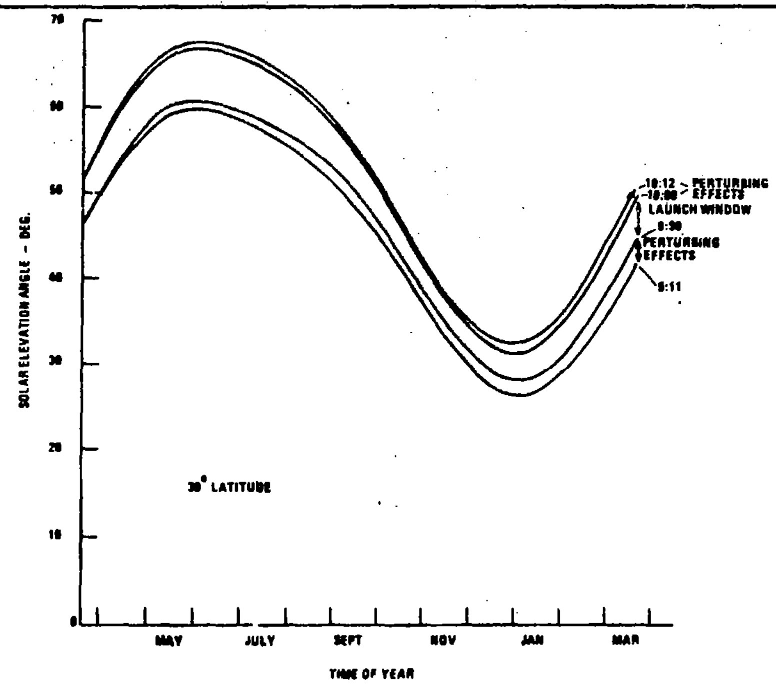


Figure L-5. Launch Window and Orbit Perturbing Effects on Solar Elevation Angle at 30 Degrees North Latitude

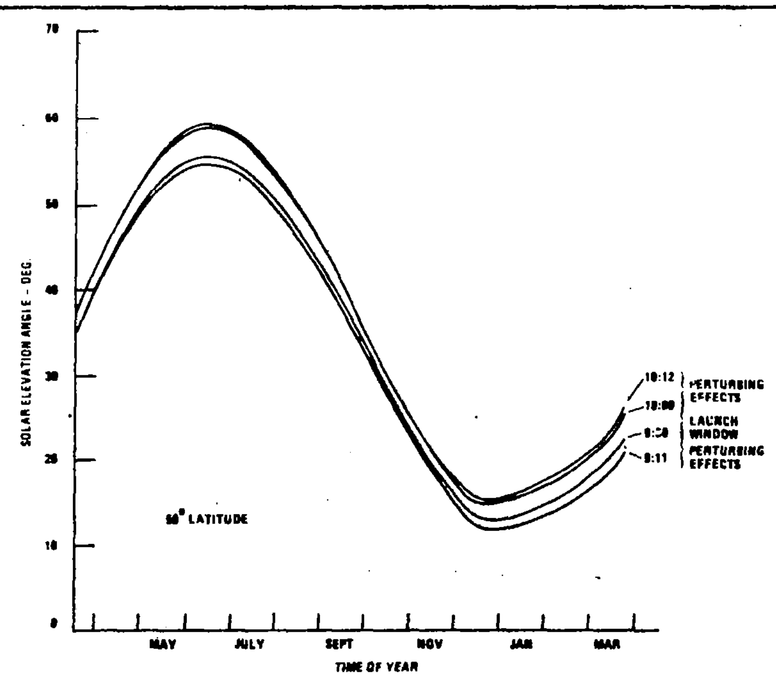


Figure L-6. Launch Window and Orbit Perturbing Effects on Solar Elevation Angle at 50 Degrees North Latitude

APPENDIX M
LIST OF NASA PRINCIPAL INVESTIGATORS

At the time this document went to press, identification of the principal investigators of ERTS data was not complete. A comprehensive list will be published as a supplement to this document at a later date.

APPENDIX N
SAMPLE PRODUCTS

A pocket is provided on the inside of the back cover of this document for the storage of sample products. These products will be supplied later as an addendum to this handbook.

LIST OF ACRONYMS

A/D	Analog to Digital
AGC	Automatic Gain Control
AMS	Attitude Measuring Subsystem
BIT	Bench Integration Test
bps	Bits per second
BPS	Bulk Processing Subsystem
BTE	Bench Test Equipment
C&DH	Communications and Data Handling
CCC	Camera Controller Combiner
CCT	Computer Compatible Tape
CIU	Command Integrator Unit
CP	Communications Processor
D/A	Digital to Analog
DCP	Data Collection Platform
DCS	Data Collection System
DCS/RSE	DCS Receiving Site Equipment
DCST	Data Collection System Tape
DEMUX	Demultiplexer
DID	Digital Image Data
DTR	Digital Tape Recorder/Reader
DTU	Data Transfer Unit
EBDIC	Extended Binary Decimal Interchange Code
EBR	Electron Beam Recorder
EBRIC	Electron Beam Recorder Image Correction
ELC	End of Line Code
EMI	Electromagnetic Interference
ERTS	Earth Resources Technology Satellite
EU	Electronics Unit
FFS	Full Field Source
FFSPS	Full Field Source Power Supply
FOV	Field of View
FSK	Frequency Shift Keying
GCE	Ground Checkout Equipment
GCP	Ground Control Point
GDHS	Ground Data Handling System
GMT	Greenwich Meridian Time
GPE	Ground Processing Equipment
GSFC	Goddard Space Flight Center
HDDT	High Density Digital Tape
HSD	High-Speed Data
IAT	Image Annotation Tape
ID	Identification
IFOV	Instantaneous Field of View
kbps	Kilobits per second
LNS	Link Noise Simulator
LSB	Least Significant Bit
LTC	Light Transfer Characteristics
MOI	Moments of Inertia
MSFN	Manned Space Flight Network
MSS	Multispectral Scanner
MTF	Modulation Transfer Function
MUX	Multiplexer
NASCOM	NASA Communication Network
NBTR	Narrowband Tape Recorder
nd	Neutral Density
NDPF	NASA Data Processing Facility
NRZ	Non-Return to Zero
NRZ-L	Non-Return to Zero Logic
NTTF	Network Test and Training Facility
OAS	Orbit Adjust Subsystem
OCC	Operations Control Center
ODG	Orbit Determination Group
OGO	Orbiting Geophysical Observatory
PAM	Pulse Amplitude Modulated
PCM	Pulse Code Modulation
PDU	Power Distribution Unit
PM	Photo Multiplier
PPF	Photographic Processing Facility
PPS	Precision Processing Subsystem
PRN	Pseudo-Random Noise
PSK	Phase Shift Keying
RBV	Return Beam Vidicon
REA	Rocket Engine Assembly
RSE	Remote Site Equipment
S/C	Spacecraft
SIAT	Special Image Annotation Tape
SMDE	Scan Mirror Drive Electronics

SME	Scan Mirror Electronics
SNR	Signal-to-Noise Ratio
SPDT	Spacecraft Performance Data Tape
SPS	Special Processing Subsystem
S/S	Subsystem
STADAN	Satellite Tracking and Data Acquisition Network
STC	Scanner Temperature Controller
STE	Special Test Equipment
STS	Scanner Test Set
TBD	To Be Determined
TBV	To Be Verified
T/C	Time Code
TCS	Thermal Control Subsystem
TPG	Test Pattern Generator
TT&C	Telemetry Tracking and Command
TU	Transport Unit
UHF	Ultra-High Frequency
USB	Unified S-Band
UTM	Universal Transverse Mercator (map coordinates)
VIP	Versatile Information Processor
VPASS	Video Processor and Sync Separator
VPIR	Video Processor and Image Recorder
WBT	Wideband Transmitter
WBVTR	Wideband Video Tape Recorder
WTS	Wideband Telemetry Subsystem

The enclosed supplement to the ERTS Data Users Handbook has been prepared by personnel in the U.S. Geological Survey to describe the EROS Program Data Center at Sioux Falls, South Dakota. Please incorporate this material in the ERTS Data Users Handbook which you recently received in the mail.

SUPPLEMENT
to the
ERTS DATA USERS HANDBOOK
Prepared by
EROS Program, U.S. Geological Survey

A Data Center in Sioux Falls, South Dakota, is operated by the EROS Program of the Department of the Interior to provide access to ERTS imagery for the general public, industry, educational institutions, and foreign and domestic government agencies at all levels. The Center serves all persons and groups not qualified, as ERTS Principal Investigators, to receive the imagery directly from NASA.

In addition to the reproducible ERTS imagery, the Center also holds NASA aircraft imagery, current USGS aerial photography, and computer compatible tapes of ERTS and NASA aircraft data. Facilities are available for imagery storage, retrieval, reproduction, and dissemination, and for user assistance and training.

The EROS Data Center is presently located at:

10th & Dakota Avenue
Sioux Falls, South Dakota 57101

This is a temporary location until the permanent center is completed at a site north of Sioux Falls. The same services and products that are available at the interim facility will be available at the permanent Data Center.

PRODUCTS

All products of the EROS Data Center are for sale. Price lists are available on request.

ERTS Imagery

ERTS imagery, originally processed at the Goddard Space Flight Center, NASA Data Processing Facility (NDPF), is a significant part of the Data Center imagery file. Each scene, covering 10,000 square nautical miles, is imaged seven times from ERTS-A and eight times from ERTS-B: three images from the Return Beam Vidicon (RBV) and four or five images from the Multispectral Scanner (MSS). The raw data are either bulk-processed and provided to the Data Center in the form of 70mm film, or precision-processed and provided on film at a scale of 1:1,000,000. The Data Center has a catalog of the ERTS imagery and a browse file including only one RBV image and one MSS image per scene for evaluation of coverage and cloud cover. The image formats are the same as those available from the NDPF.

Copies of bulk-processed individual images and color composites, derived by processing the three RBV and four MSS images together, may be purchased as:

contract paper prints contact film positives contact film negatives	roughly 2½ x 2½ inches

or

1:1,000,000 (3.38X enlargement) paper prints 1:1,000,000 film positives 1:1,000,000 film negatives	roughly 9 x 9 inches including marginal data

Copies of precision-processed images may be obtained only at scales of 1:1,000,000 or larger. These images have been rectified to truly orthographic photographs and have been overprinted with the UTM grid. Both individual images and color composites at 1:1,000,000 are available in various forms:

paper prints film positives film negatives	roughly 9 x 9 inches, including marginal data

Only about 5 percent of the images available in the Data Center are precision-processed.

Orders for all the above items will ordinarily be filled within a week of receipt of the request.

Paper prints of individual bulk- or precision-processed images enlarged to a scale of 1:250,000, or a paper print color composite at the same scale may be ordered. However, it will take at least two weeks to fill such a request.

Orders for other forms of the ERTS imagery will be honored whenever possible, but delivery time and costs will be determined on an individual basis. Film negative and film positives of 1:250,000-scale enlargements of ERTS imagery are in this category.

NASA Aircraft Imagery

Imagery obtained by NASA, as part of its Aircraft Program in support of the development of Earth Resources Surveys by aircraft and spacecraft, is processed at the Manned Spacecraft Center. This imagery was acquired for specific purposes and to varied specifications as to time, areal coverage, and sensors, and is primarily of test sites within the continental United States. A catalog of this imagery, and a browse file, is also at the Data Center.

Copies of these images may be purchased at contact scales and enlargements, in color or black-and-white, on film or on paper. Each image is reproduced with marginal information that provides, among other things: frame number, date, geographic coordinates, and order number in an understandable code. A request for reproductions is normally processed within 1 week.

USGS Aerial Photography

Aerial photographs, made by the U.S. Geological Survey primarily for purposes of topographic and geologic mapping, are available from the Data Center. The vast majority are black-and-white, vertical photographs at a scale of approximately 1:24,000, and contact prints are 9 x 9 inches. Because of the need to see the ground surface, these photograph were usually made in the late fall or earl spring. Coverage is of discontinuous are throughout the conterminous U.S., Alask Hawaii, and the Territories. The remainder a either low oblique, taken with cameras tilt approximately 20° from the vertical, or hig altitude photographs. Both are black-an white, and in a 9 x 9 inch format. Catalogs the USGS photographs and a browse file f evaluation of coverage are available at tl Data Center.

All photographs are available at contact scal and enlargements, on film or on paper. Ea scene is reproduced with marginal inform tion that provides, among other things: fran number, date, geographic coordinates, ar order number in an understandable cod Photographs obtained prior to 1941 are he by the National Archives and Record Servic Material is available on request but not with the normal 1-week reproduction time.

Magnetic Tapes

Computer-compatible magnetic tapes of bo ERTS data and NASA Aircraft Program da are available for reproduction through tl Data Center. Of the total ERTS data, about percent of the raw RBV data, about 5 percer of the raw MSS data, and 100 percent of tl precision-processed data are available in th form. Tapes of data from Aircraft Progra investigations, as with NASA Aircra imagery, cover a variety of sites and situ tions, but all that have been produced a available.

Browse Files

The catalogs of ERTS imagery, Aircraft Pr gram imagery, and USGS imagery produce on 16mm film are available for purchase. Th browse files have two indexes to identif scenes at high speeds: Kodamatic Indexe Code Lines and Image Control. Each film i also designed so that it can be cut an mounted by the user for microfiche presenta tion. Browse files for the ERTS data ar updated every 18 days and are available on subscription basis. Updating of the other browse files is irregular and films must be purchased individually.

Thematic or Special Subject Maps

Thematic maps produced systematically or mechanically from ERTS imagery are available at the Data Center. The special subjects covered are: extent of standing water, infrared-reflective vegetation, massed works of man, and snow cover. Maps are prepared for the entire United States or parts thereof if the subject, as for example snow cover, is not applicable to the entire country. The maps are produced as single-color transparent overlays to a base map series, both with UTM grid to expedite registration.

The subject data are extracted periodically for comparative purposes, in order to detect changes in these dynamic phenomena. The data for the overlays are also available on magnetic tape.

SERVICES

Search and Retrieval

The EROS DATA Center staff is prepared to assist in locating imagery to suit individual needs. They respond to inquiries by telephone, letter, and personal visits.

The computerized imagery storage and retrieval system is based on a geographical system, including the UTM grid, supplemented by such information as date and scale. The staff will convert inquiries into searches of the computer-based system. They will also assist in ordering reproductions. Visitors to the Center may consult the browse file to evaluate the frames of particular interest before placing a purchase order.

Assistance In Interpretation Techniques

Users who visit the Data Center will find special equipment available for the manipulation of the imagery, such as densitometers, additive color viewers, and stereo viewers. The scientific staff is available for consultation on the use of this equipment and on interpretative problems.

Training

Periodically, the scientific staff at the Data Center offers courses in various aspects of remote sensing. The instructions offered are a cartography course, an interpretation course, and a scientific research course, all of which involve field and laboratory exercises.

The cartography course is designed to train cartographers and engineers to apply ERTS data to mapping techniques. Topics covered include: ERTS instrumentation and orbital characteristics, space data characteristics, ground control requirements, information extraction techniques, and cartographic processes.

The interpretation course is designed to train resource scientists and managers to apply simple interpretation tools and techniques to ERTS data. Topics covered include: the electromagnetic spectrum, ERTS instrumentation and orbital characteristics, space data characteristics, multidiscipline approach to remote sensing interpretation, interpretation instrument requirements, and ERTS imagery search procedures.

The scientific research course is designed to give remote sensing scientists an opportunity to study various research techniques in the field of remote sensing. Topics covered are: computer manipulation of digital data, density slicing, and analysis of the color additive process.

Details on course coverage, duration, schedules, and costs may be obtained by writing to:

EROS Data Center
Training Officer
10th & Dakota Avenue
Sioux Falls, South Dakota 57101

ERRATA SHEET
ERTS DATA USERS HANDBOOK
GE DOCUMENT NO. 71SD4249

APPENDIX A

Page A-2, Figure A.1-1

In center of figure, change:

(100 μm X 100 μm) to (100 nm X 100 nm)

Page A-9, Figure A.2-3

Change:	1.63 MSEC	to	1.43 MSEC
	7.35 MSEC	to	8.8 MSEC
	10.2 MSEC	to	9.0 MSEC
	1000 WORDS	to	903 WORDS

Corrected figures are reproduced below. These may be cut out and pasted over the original drawings.

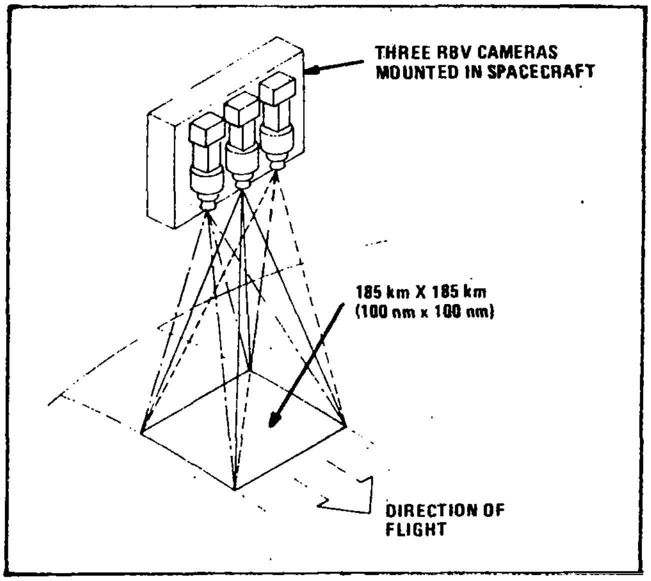


Figure A.1-1

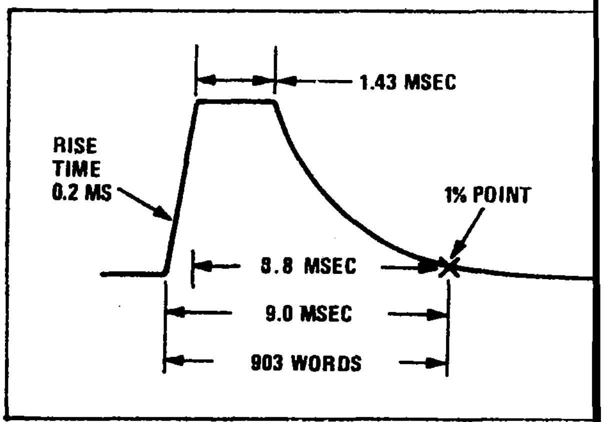


Figure A.2-3

APPENDIX I

For ease in reading data from the charts, full-page enlargements of Figures I-10 (page I-5) and I-11 (page I-11) are attached.

ORI

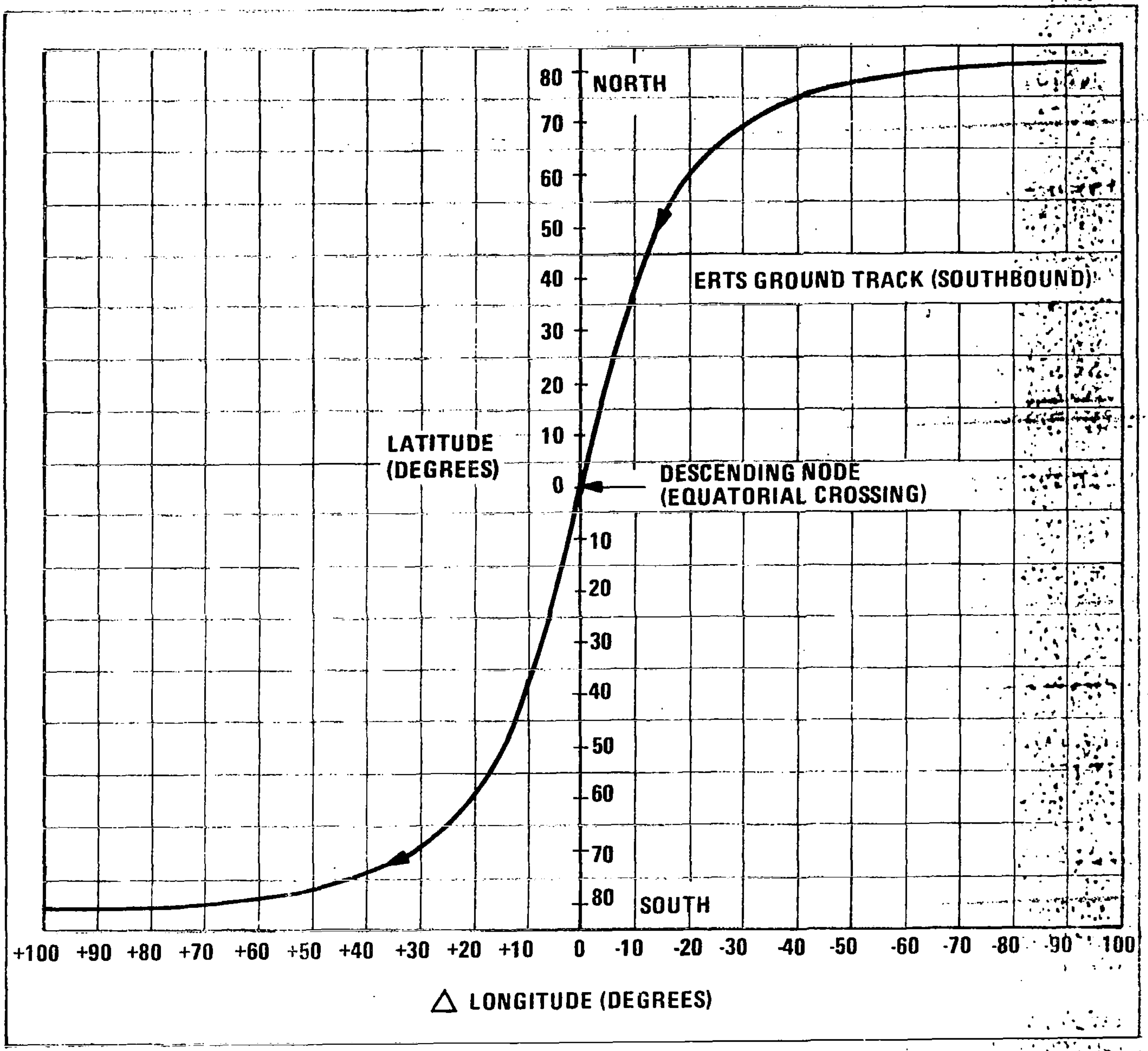


Figure I-10. Satellite Longitude Corrections (Measured from Descending Node)

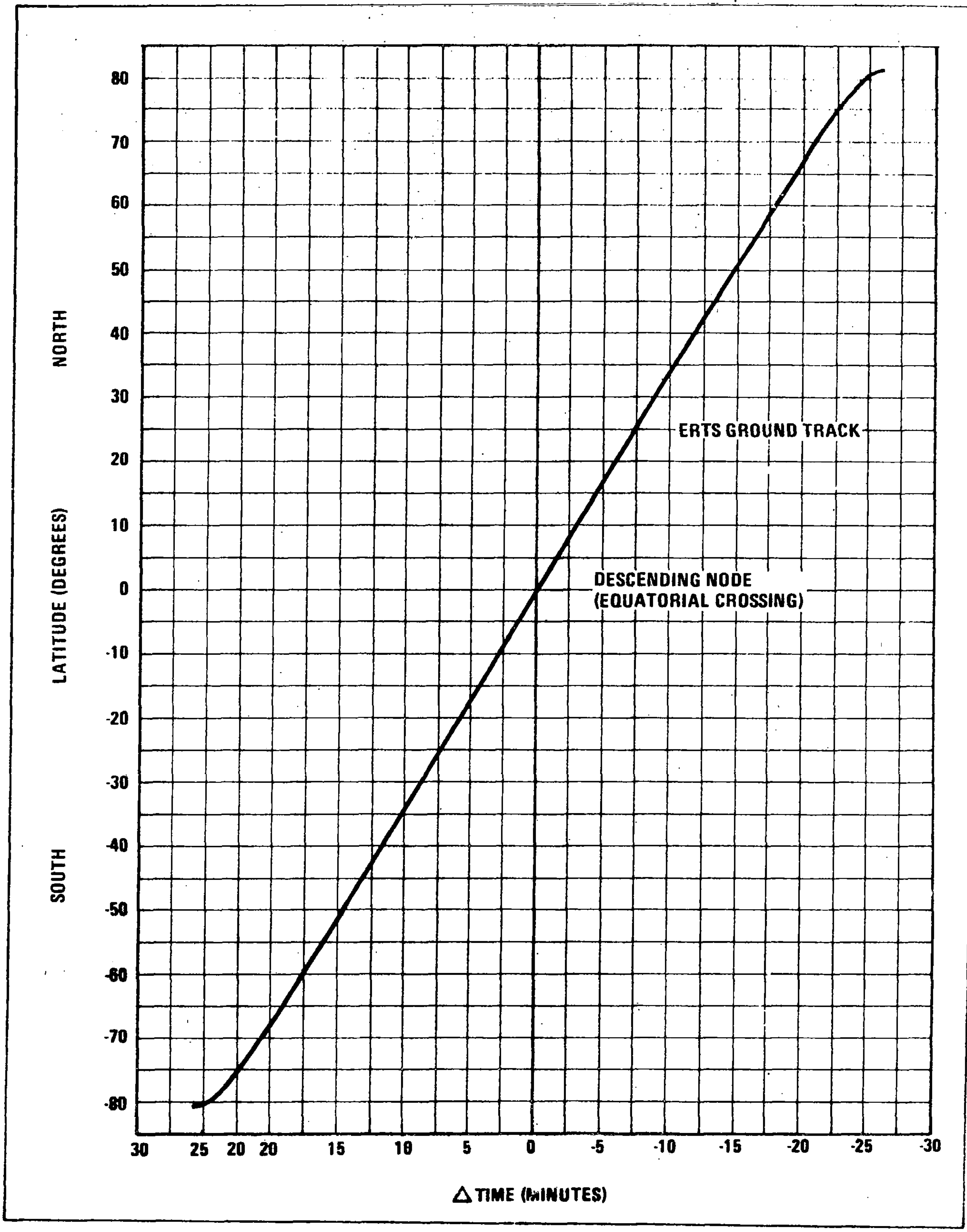


Figure I-11. Time Difference Measured from Descending Node

GLOSSARY

Across-track — across the direction of spacecraft ground track; sometimes called horizontal when referring to output product coordinates.

Along-track — in the direction of the spacecraft ground track; sometimes called vertical when referring to output product coordinates.

Altitude — the distance from the nadir ground point to the spacecraft.

Bulk Processing Subsystem — converts all video data from RBV and MSS sensors to 55 by 55 (or 53) mm annotated and corrected images, on 70 mm film.

Channel — there are 6 channels per MSS spectral Bands 1, 2, 3, and 4, and 1 channel for MSS spectral Band 5; hence, the MSS is a 25-channel scanner.

Contrast — the ratio of two adjacent scene radiances expressed as a number equal to or greater than one.

Earth Ellipsoid — the NASA Ellipsoid which is used to model the earth.

Format Center — the center of the RBV and MSS total image writing area in Bulk Processing. MSS Format Center is identical to RBV Format Center; the intersection of the film registration mark diagonals, defined as the geometric extension of the spacecraft axis to the earth's surface.

Geometric Accuracy

- Geographic (latitude-longitude) — based on the standard earth-fixed coordinate reference system, which employs latitude and longitude.
- Positional — the ability to locate a point in an image with respect to a map.
- Scene Registration — the ability to superimpose the same point in two images of a scene taken at the same time (different spectral bands)
- Temporal Registration — the ability to superimpose a point in two images of the same scene taken at different times (same or different spectral bands).
- Tick Marks — positional marks placed on imagery to enable a locational grid coordinate system to be constructed.

Ground Control Point — any point that has a known location on the earth's surface which can be identified in ERTS imagery.

Ground Track/Trace — the stream of earth surface points which pass directly under the vehicle as it revolves in orbit.

Image/Frame — that data from one spectral band of one sensor for a nominal framing area of the earth's surface.

Image Processing Subsystems — receives video data, image annotation, and correction data to produce both film imagery and digital image data.

Master Image — the 70 mm film output from video data as originally processed in Bulk Processing; this image is held in archive.

Modulation Transfer Function — the sine wave amplitude response of a component versus its spatial frequency.

Nadir — the intersection with the earth's surface of a line from the spacecraft perpendicular to the nearest plane tangent to the earth ellipsoid.

Nominal — desired conditions within requirements.

Observation/Scene — the collection of the image data of one nominal framing area of the earth's surface; this includes all data from each spectral band of each sensor.

Orthophotograph — a photograph of the earth taken or rectified such that the optical axis of the taking camera is perpendicular to the plane tangent to the earth's surface at the nadir point; this photograph can then be used as a map with appropriate annotation.

Platform — a Data Collection System sensor package on the earth's surface.

Playback — the later transmission of data which was recorded locally at the time of occurrence.

Precision Processing Subsystem (PPS) — the PPS receives user-selected, Bulk-Processed imagery and produces precision-located and corrected imagery on 9-1/2 inch (241.3 mm) film.

Principal Point — the intersection with the earth's surface of a line which is an extension of the optical axis of an RBV camera. This point differs from the format center by the boresight angle error from nominal alignment.

Radiometric — concerned with the combined electronic and optical transmission of data.

Real Time — generally associated with data transmission; transmission at the time of occurrence, i.e., no delay.

Registration Marks — locations on the film plane outside the image writing area of Bulk Processing; there are four marks, one outside each corner of the writing area, fixed in position such that their diagonals intersect at the format center, or center of the tick mark coordinate center.

Reseau — the rectangular grid pattern inscribed on the RBV faceplate.

Saturation — the point at which additional input energy to the sensor results in no increase in sensor output.

S/C Heading — the direction of the spacecraft velocity vector plus yaw in the plane formed by the roll and pitch axes.

Sensor/Band Identification — the RBV spectral bands are identified as Bands 1, 2, and 3; the MSS as Bands 1, 2, 3, 4, and 5.

Shading — varying output across the RBV photoconductive surface when a uniform input energy exposes it.

Skew — image distortion caused by scanning the scene in a direction non-parallel to the plane formed by the spacecraft and the instantaneous ground track velocity vector.

Special Processing Subsystem (SPS) — the SPS receives digitized image data from Bulk and Precision Processing and produces digital image data in a computer-compatible format.

Spatial — that which exists in the physical world and can be located and described by linear dimensions.

Subsatellite Point — the intersection with the earth's surface of a line from the spacecraft to the center of the earth.

Swath — the dimension on the ground seen as transverse to spacecraft velocity, within the sensor field of view (FOV).

Temporal — that which exists in the physical world and is not spatial, such as telemetry information.

Universal Transverse Mercator (UTM) — the standard ERTS imagery grid projection system.

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"ERTS Return Beam Vidicon Camera Flight Equipment Subsystem — Interface Agreement Document"; Document No. 70SD4258; prepared by General Electric Company for Goddard Space Flight Center, — Latest Revision.

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"Final Report for Multispectral Point Scanner Study and Multispectral Scanning Point Scanner Camera System"; V. Norwood and J. Lansing, HAS/SBRC, 30 January 1970.

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Digital Image Tape Format

"Computer Compatible Tape Format", ICD No. (later).

User Services Query Program

"Users Manual for NDPF Data Base Query Program", Document No. (later).

Photography

"An Evaluation of Photographic Image Quality and Resolving Power", Otto Schade Journal of SMPTE, February 1964.

REFERENCE LIBRARIES

There are several reference libraries which collect the current materials related to remote sensing of earth resources and associated technologies. These libraries are noted for possible further reference.

EROS Program Library
Room 1109 801-19th Street, N.W.
Washington, D.C. 20242
Telephone (202) 343-7500

Maintains copies of reports generated by EROS Program activities and general references on remote sensing of earth resources. Materials may be borrowed or used there.

Technology Application Center
University of New Mexico
Albuquerque, New Mexico 87106
Telephone (505) 277-3118, 3111

A NASA Regional Dissemination Center providing bibliographic service. Has access to all reports produced and collected by NASA, except raw data collected by NASA's Earth Resource Aircraft Program. Provides complete bibliography on remote sensing in three volumes ($125) from 1962 to present and updated annually. Provides microfiche or hard copy of included reports at cost and also provides bibliographic services including searches. Sells Gemini and Apollo photos. Price lists available on request.

Earth Resources Research
Data Facility
NASA, Manned Spacecraft Center
Houston, Texas 77058
Telephone (713) 483-7681

Maintains reports, photos, and magnetic tapes of raw data and reports produced from NASA Earth Resource Aircraft Program. Material available for use at facility only. Special arrangements can be made for reproduction of materials.

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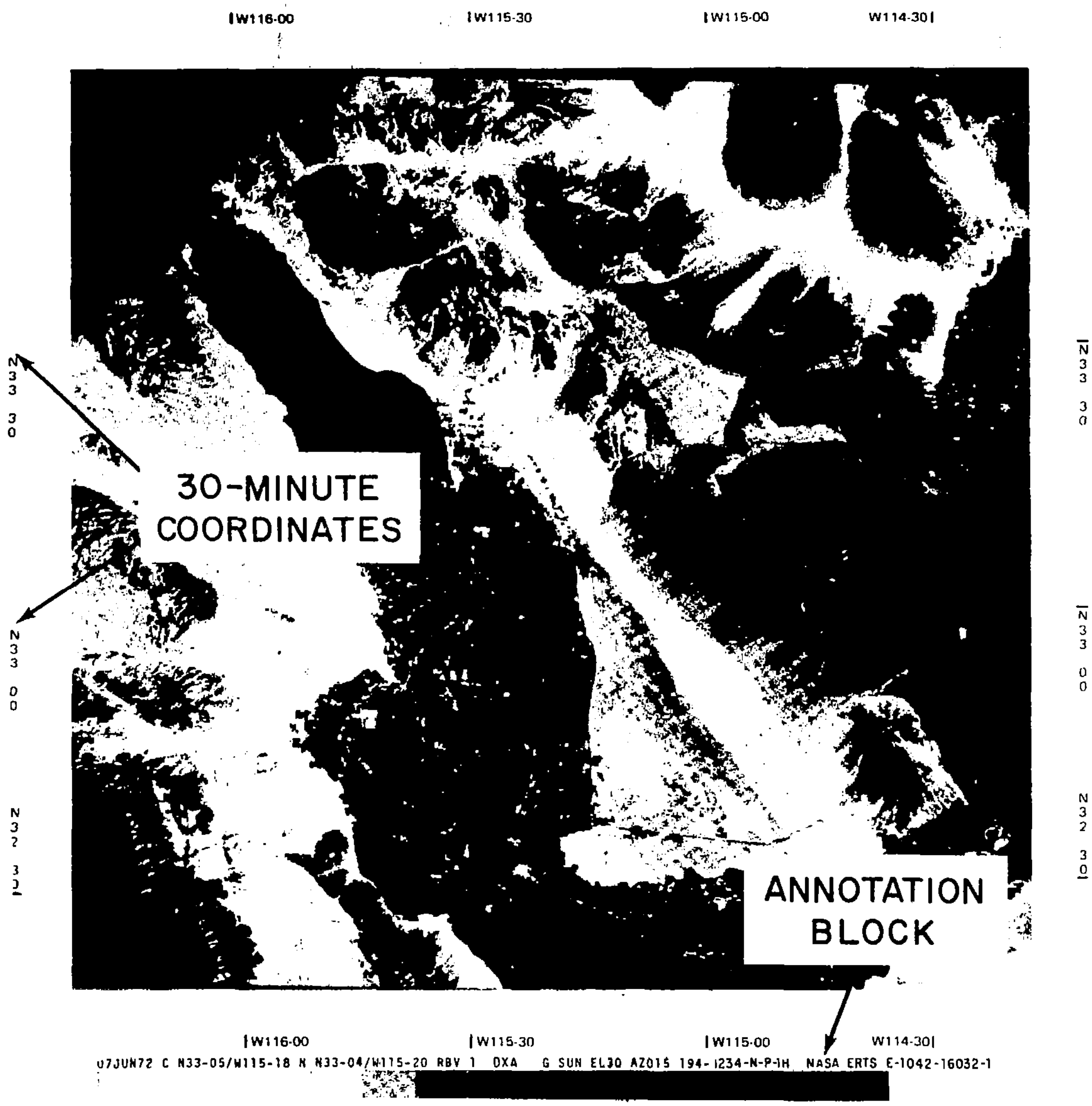

Figure 3-5. Bulk RBV Image Format - 9.5 Inch Film

.2 Image Format and Annotation

mple of the Precision image is shown in ·e 3-12. The alphanumeric and gray scale ‹s at the left of the image area are copied directly from the Bulk image. The tick marks and alphanumeric annotation blocks in the lower left and lower right corners are unique to precision data and are explained in Table 3-4.

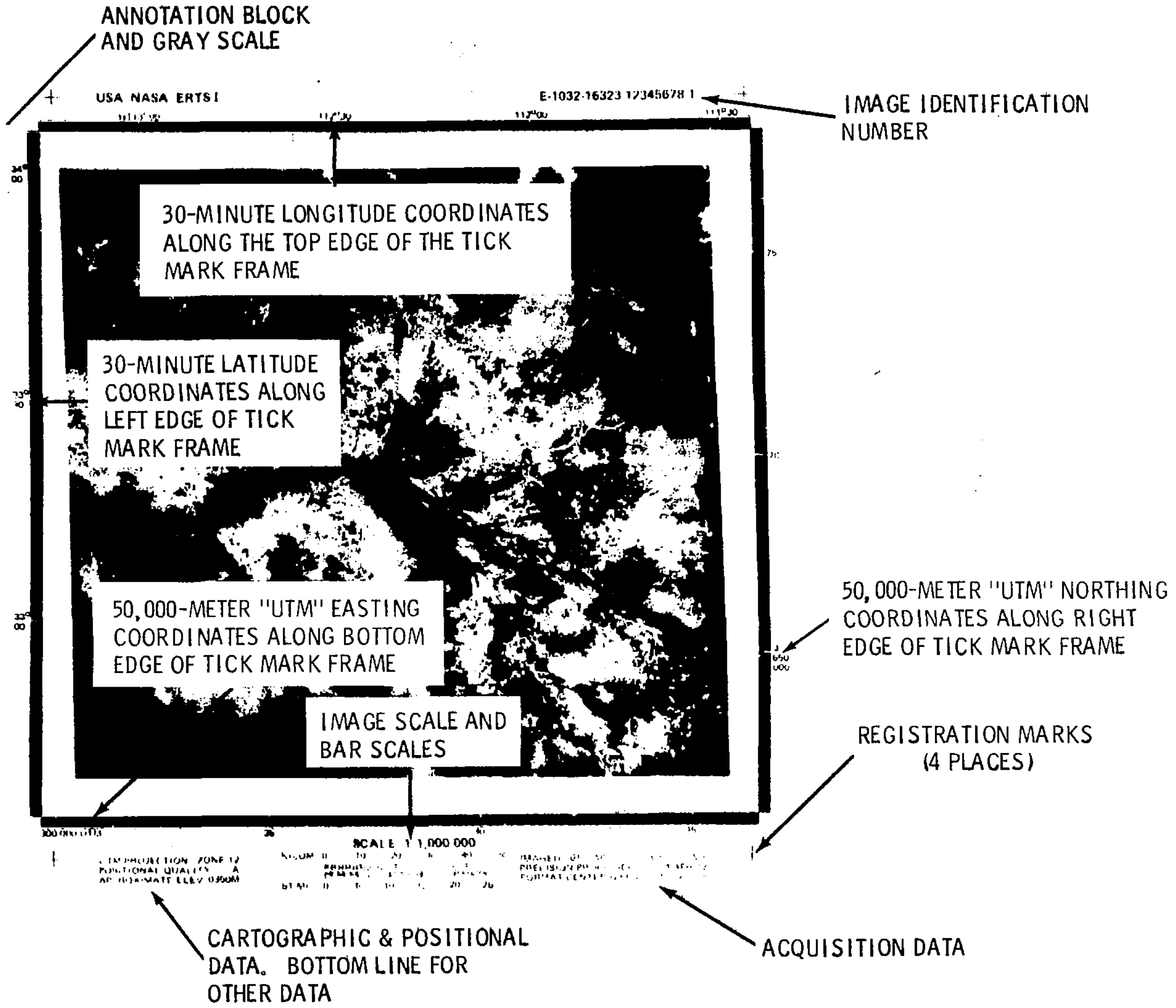

Figure 3-12. Precision Processed Image Format

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