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AN INTRODUCTION TO THE GOES I-M IMAGER AND SOUNDER INSTRUMENTS AND THE GVAR RETRANSMISSION FORMAT

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PREFACE

This document is an update of NOAA Technical Report NESDIS 33, published in October, 1987. It is addressed to experienced direct readout users of the GOES Mode AAA processed instrument data. Readers wanting a greater familiarity with Mode AAA are referred to the following documents:

GOES GH Data Book, Hughes Aircraft Company, March 1986

Operational VAS Mode AAA Format, Specification, NOAA/NESDIS Office of Systems Development, February 1987, SFP002

The purpose of this document is to acquaint these users with the characteristics of the processed instrument data that are available from the new series of GOES satellites, GOES I-M. This document includes a comparison of the GOES D-H VAS instrument with the instruments on the GOES I-M series of satellites and a definition of the processed instrument data format for GOES I-M. It is the intent of this document to provide direct readout (Mode AAA) users with sufficient background information for them to phaseover to GOES I-M.

The topic of this report is the GVAR processed data as it will be retransmitted to direct readout users. Information on the spacecraft, the imaging and sounding instruments, and the ground system is presented only to provide sufficient background and context for an understanding of the GVAR format. GVAR contains Imager and Sounder data. The other on-board instruments and their data and the special purpose transponders are not addressed in this report.

GOES I was launched April 13, 1994; redesignated GOES-8 upon attaining geostationary orbit, it is undergoing checkout through October, 1994. The remaining spacecraft in the GOES I-M series are in various stages of assembly. GOES-J is scheduled for launch in 1995; its instruments are in test at this time.

The defining document for the GVAR format is Section 3 of Space Systems/Loral Operations Ground Equipment (OGE) Interface Specification DRL 504-02-1, Contract NAS5-29500. The most recent version available at the time of publication is Revision C dated 01/28/94. Much of the material contained herein is compiled directly from documents delivered to the Government under contract by Ford Aerospace and Communications Corporation, Space Systems/Loral, and their subcontractors.

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1.0 INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) operates a Geostationary Operational Environmental Satellite (GOES) system with multiple satellites to provide continuous monitoring of the earth's environment. The National Aeronautics and Space Administration (NASA) is responsible for procuring and launching new satellites for NOAA and the other civilian agencies. The NASA Goddard Space Flight Center (GSFC) and NOAA have been given responsibility for procuring the necessary space-segment hardware and support services to meet the mission requirements. In 1985, NASA contracted with the Ford Aerospace and Communications Corporation (FACC), Western Development Laboratories, Palo Alto, California, for five GOES spacecraft (I, J, K, L, and M), collectively known as GOES I-M. The GOES Variable (GVAR) format is the retransmission format for processed instrument data from these spacecraft.

The primary mission of the GOES program is the continuous and reliable collection of environmental data in support of weather forecasting and related services. Spacecraft and ground based systems work together to accomplish this mission.

1.1 GOES Program

Since 1974, geostationary satellites have been used to collect and disseminate environmental data. GOES sensors provide two-dimensional cloud and temperature imagery in both visible and infrared spectra, radiometric data providing the capability to determine the three-dimensional structure of atmospheric temperature and water vapor distribution, and solar and near space environmental data. In addition to broadcasting GVAR, transponders on the GOES spacecraft also support the Data Collection System (DCS), Search and Rescue, and Weather Facsimile (WEFAX); the DCS relays data from thousands of environmental sensing platforms distributed throughout the western hemisphere. Specific applications of the meteorological data include severe storm detection, monitoring, and tracking; wind measurements from cloud motion; sea surface thermal features; precipitation estimates; frost monitoring; rescue operations; and research.

1.2 GOES I-M Spacecraft System

The GOES spacecraft configuration is based on FACC's Indian Satellite (INSAT) design. Its six-sided main body carries the Imager, the Sounder, and Space Environment Monitor (SEM) instruments. A continuous-drive solar array is attached to the south panel through a yoke assembly, and a solar sail is mounted off the north panel to offset solar pressure torque. See Figure 1-1.

There are significant differences between the GOES I-M series of spacecraft and the predecessor GOES D-H series that impact the requirements for the ground system. The GOES D-H satellites were built by the Hughes Aircraft Company using a passive spin-stabilized attitude control system. The GOES I-M satellites use a three-axis attitude control system, implying thatthe three axes of the satellite will remain stationary relative to their pointing axis. These satellites use internal momentum wheels to provide attitude control. The satellites require corrective action from the ground to compensate for the effects of thermal gradients, solar winds, and radiance gradients. The mirror in each instrument moves in two dimensions. Unlike the GOES D-H series, GOES I-M series satellites have separate Imager and Sounder instruments that operate independently and simultaneously.

These differences necessitate major changes in the product processing systems. The navigation accuracy (the ability to point to a specific latitude and longitude on the earth's surface) and registration accuracy (the ability to point to the same point on earth on successive images) are fundamental to the value of GOES I-M meteorological data. Table 1-1 compares the major characteristics of the present series GOES D-H satellites with the GOES I-M series.

1.3 GOES I-M Ground System

As with the predecessor GOES System, the GOES I-M Ground System is physically divided between two locations, the Satellite Operations Control Center (SOCC) at Suitland, Maryland, and the Command and Data Acquisition (CDA) station at Wallops, Virginia (see Figure 1-2). The SOCC is responsible for continuous monitoring and supervision of the spacecraft and instruments. The SOCC plans and schedules spacecraft and ground system activities to satisfy the mission requirements. The CDA station is the principal terrestrial interface with the GOES satellites. It provides communication with the GOES spacecraft. In general, those components closely associated with real time production of the GVAR data stream derived from the raw instrument data, and with retransmitting this stream through the spacecraft, are located at the CDA. The remaining components primarily those associated with scheduling and planning and off-line engineering and analysis functions, are located at the SOCC for normal operation, but are backed up by redundant copies at the CDA for continued operation during communication outages or catastrophic failures of the SOCC.

Command schedule generation is performed at the SOCC with commands being relayed to the CDA station by way of the telemetry and command system. Commands are uplinked to the spacecraft by the transmit/receive systems at the CDA, which also receives and processes spacecraft telemetry data.

The GOES I-M Imager and Sounder data communications system function similarly to its counterpart in the GOES D-H system. The raw output data stream from the spacecraft is received at the CDA station, where it is demodulated, processed, and output in the GVAR format by the Sensor Processing System (SPS) component of the OGE. After processing by the SPS, the calibrated, earth-located, GVAR formatted data stream is transmitted from the CDA to the spacecraft which, in turn, retransmits it to Direct Readout earth stations.

The Orbit and Attitude Tracking System (OATS) component of the OGE assists in navigation

(Orbit and Attitude Determination) of the GOES I-M Spacecraft. The Product Monitors (PMs) assist the OATS by extracting landmark information from the Imager and Sounder data in addition to providing image quality control and coefficients for SPS normalization and coregistration functions.

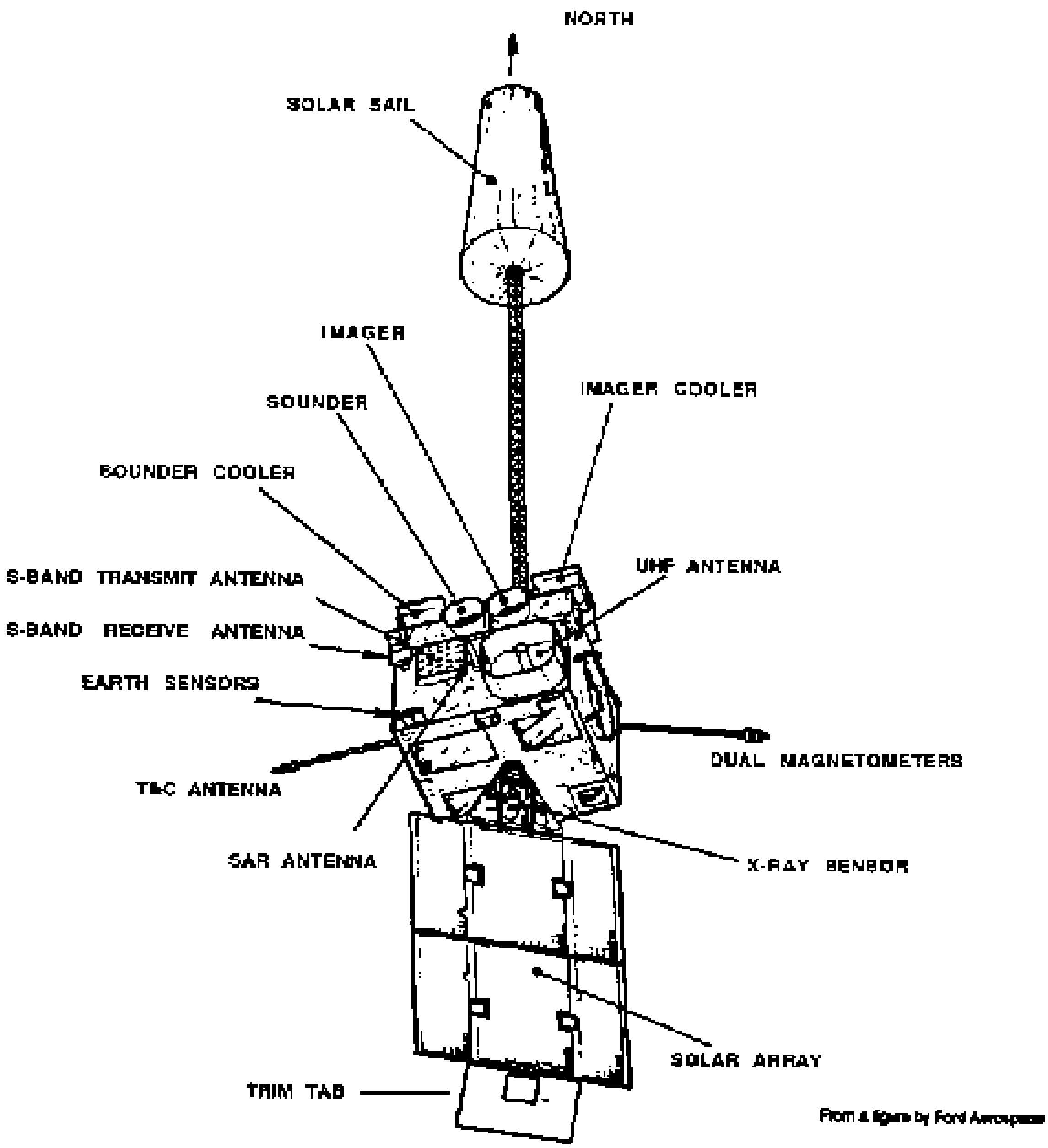

Figure 1.1
GOES I-M Spacecraft

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Table 1-1

GOES Comparison

CHARACTERISTIC	GOES D-H (4-7)	GOES I-M (8-12)
SPACECRAFT		
Stabilization	Spin stabilized	3-axis body stabilized
Instrument Configuration	Combined imager and sounder (VAS) -- single telescope and scan mirror	Independent Imager and Sounder, each with its own telescope and scan mirror
INSTRUMENT SCANNING		
Scan Mechanism	Spin scan	2-axis gimballed scan
Areas Scanned	Full or partial disk scans -- fixed width	Full disk, sector, or area scans
Frame Limits	Selectable NS within 20 EW by 20 NS	Selectable NS and EW within 19.2 EW by 19 NS
Scan Direction	West-to-east only	Alternating west-to-east and east-to-west, ground corrected to appear as all west-to-east
IMAGING		
Scan Characteristics		
Priority scanning	N/A	Priority scan available
NS stepping	192 μr steps	224 μr step for an 8-line visible swath
EW scan width	Fixed	Variable from image to image, constant for the image being scanned
Radiometrics		
Vis Detectors	PMT	Solid state
Visible resolution	0.89 km at nadir (25μr x 21μr)	1 km at nadir (28μr x 16μr)
Vis signal quantization	6 bits	10 bits
IR Detectors	Dual-element IR detectors, offset in NS plane (192μr and 384μr squares)	Multi-element IR detectors, no offset in NS plane (112μr and 224μr squares)
IR Spectrum	12 bands, filter wheel selectable	4 bands, fixed
Images per frame	Up to 4, selectable (interleaved)	4 non-selectable (not interleaved)
IR resolution	Selectable, 7 km or 13 km	Band-fixed. 4km and 8km
IR signal quantization	10 bits	10 bits
Calibration		
Spacelook (SL)	Every spin (scan)	Every other scan for wide frames; on 36.6 second or 9.2 second interval timer for narrow frames; data timed at 2 minute interval
Blackbody (BBCAL)	BBCAL on each spin (scan)	Timed or commanded -- operationally commanded every 30 minutes
Electronic (ECAL)	Before every frame	With each BBCAL

CHARACTERISTIC	GOES D-H (4-7)	GOES I-M (8-12)
Earth Location	By ground system	By ground system
Earth Pointing	Not actively controlled	By instrument; Star sensing through instrument visible array -- operationally commanded every 30 minutes; ranging; landmarking
SOUNDING		
Scan Characteristics		
Mechanism	Multiple-spin line sampling	Step and settle column sampling
Dwell	Up to 255 spins per band	Selectable 0.1, 0.2, or 0.4 seconds at each step -- all bands sampled
Line skipping	Every line with alternating band options	True line skipping; available at 0.2 sec dwell on GOES-8, at 0.1 sec dwell on GOES-9
NS Stepping	192 μr/line -- line commandable	1120 μr with skip line capability
EW Stepping	3822 samples -- Full width, no ground control	280 μr sample, 1, 2, or 4 samples
Radiometrics		
IR Detectors	Dual-element IR detectors, offset in NS plane	Four element IR detectors, short, medium, and long wave, offset in NS and EW planes
Spectrum	4 of 12 bands, filter wheel selectable	18 IR bands, 1 visible band, non-selectable
IR Resolution	13 km at nadir	8 km at nadir
IR Signal Quantization	10 bits	13 bits
Calibration		
Spacelook (S/L)	Before every scan	By timer, every 2 minutes
Blackbody (BBCAL)	Before every frame	Timed or commanded -- operationally commanded approximately every 20 minutes
Electronic (ECAL)	Before every scan	With each spacelook
Earth Location	By ground system	By ground system
Earth Pointing	Stability not actively controlled	By instrument; Star sensing through instrument visible array -- operationally commanded every 30 minutes; ranging; landmarking

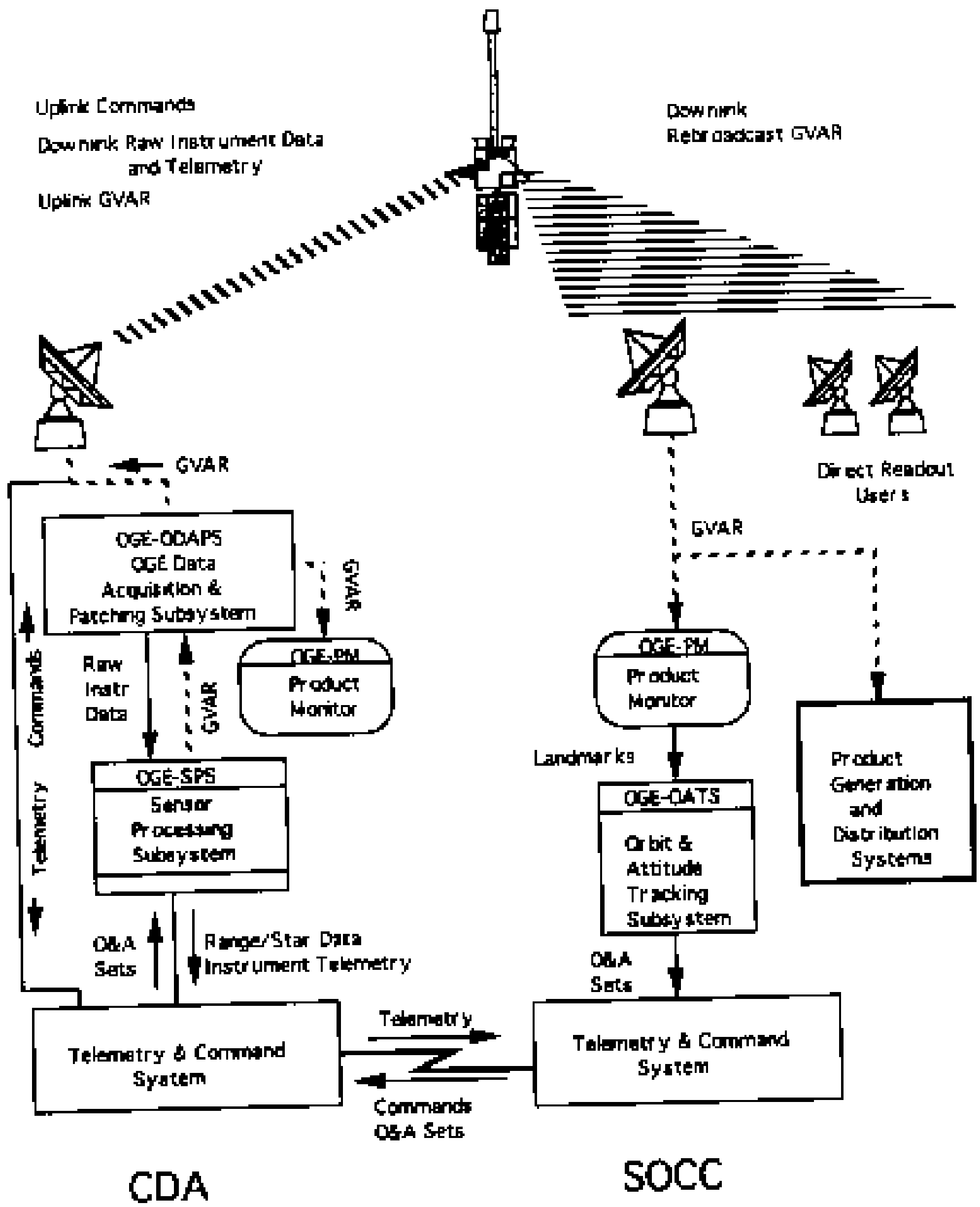

Figure 1-2

GOES I-M Ground System

2.0 THE IMAGER AND THE SOUNDER

The GOES I-M Imager and Sounder have increased capabilities compared with the instruments onboard the GOES D-H satellites. The GOES I-M instruments have more spectral channels, higher resolution IR and Sounder, increased sensitivity, more rapid area coverage, and much improved location accuracy over previous GOES systems. They have flexibility of scan parameters and complete independence of the two instruments.

A body-stabilized satellite with one surface continually oriented toward the earth provides the platform for the instruments. The full-time operation of the Imager and Sounder permits maximum sensitivity and flexibility of control, enhancing synoptic, aperiodic, and mesoscale observations.

The GOES I-M satellites carry a five-channel (four infrared and one visible) Imager and a 19-channel (18 infrared and one visible) Sounder. This system provides capabilities not available in the predecessor GOES in that the GOES I-M Imager has: a) simultaneous imaging from all infrared and visible channels and b) higher IR resolution (4km) in the surface and cloud detection channels. GOES I-M Sounder quality is improved by having: a) total isolation and independence from imaging, b) more and narrower spectral channels, c) spatial resolution reduced to 8km and d) sufficient sensitivity for full quality soundings to be derived from each atmospheric column.

2.1 Instrument Description

The GOES Imaging and Sounding Subsystem shown in Figure 2-1 is made up of two instruments, each having very similar functional capability. Scan control and data collection for the instruments are independent of each other and of most other activity on the spacecraft. An on-board computer provides a method of automatic motion compensation unique to this

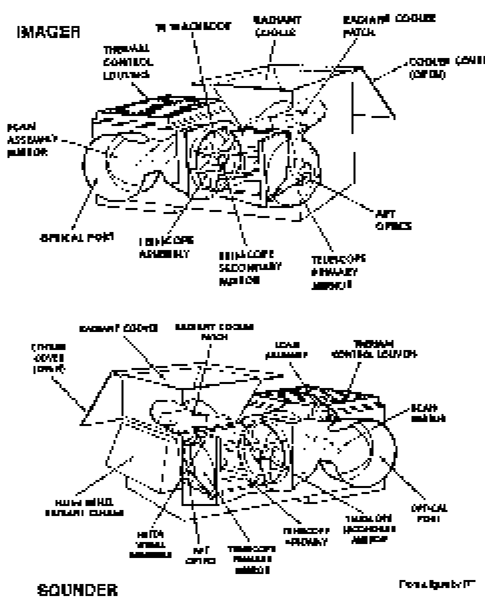

Figure 2-1
GOES I-M Instrument Assemblies

Each instrument is under operator control to command the start time, location, and size of earth areas to be imaged or sounded. Radiance from the earth is sampled by identical two-axis scan systems and nearly identical telescopes in each unit. Spectral separation in the two instruments differs to meet their separate requirements. Separation in the Imager is by fixed dichroic beam splitters, permitting simultaneous sampling of all five spectral channels. In the Sounder, the visible spectrum and three IR bands are separated by dichroic beam splitters; the three IR bands then pass through three concentric rings of a filter wheel (see Figure 2-2) where channel filters provide sequential sampling of the seven longwave, five midwave, and six shortwave channels. The infrared detectors operate at three patch temperatures: 94oK for seven or eight months that include the winter season, 101oK for the four or five months that include the summer season, and 104oK for radiative cooler contingencies.

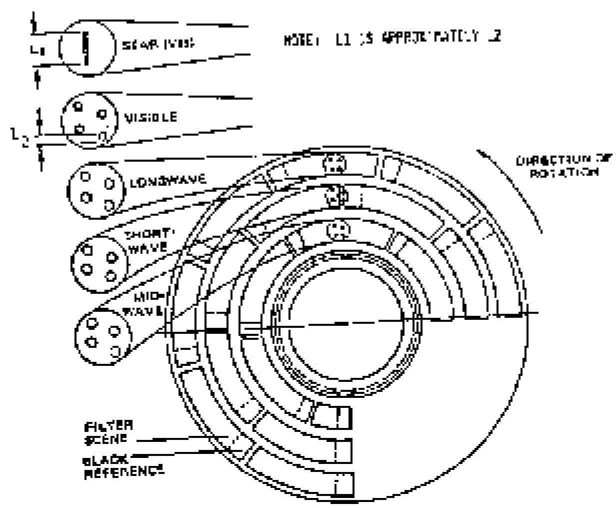

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Figure 2-2

Each linear scan of the Imager samples an 8-km NS swath (at nadir). The Sounder has four detector's in each band. Each detector's Field of View (FOV) is 8-km at nadir and a scan swath is 40-km wide (NS) at nadir. The Imager has a highly linear scan in the West-East or East-West direction at a rate of 20.021o per second. It then drops 224 μr (8 km at nadir) to scan in the opposite direction to continue a frame. The Sounder steps at a fixed pattern rate of 0.1 seconds for each 280 µr (10 km at nadir) in the West-East or East-West direction, then steps down (or up) 1120 µr (40 km) to the next contiguous scan to continue a frame. See Figure 2-3.

Interactive operation of the instruments and spacecraft permits independent operation of the individual scan systems, yet maintains the pointing accuracy of each optical system. This is accomplished by a Mirror Motion Compensation (MMC) algorithm on the spacecraft which recognizes

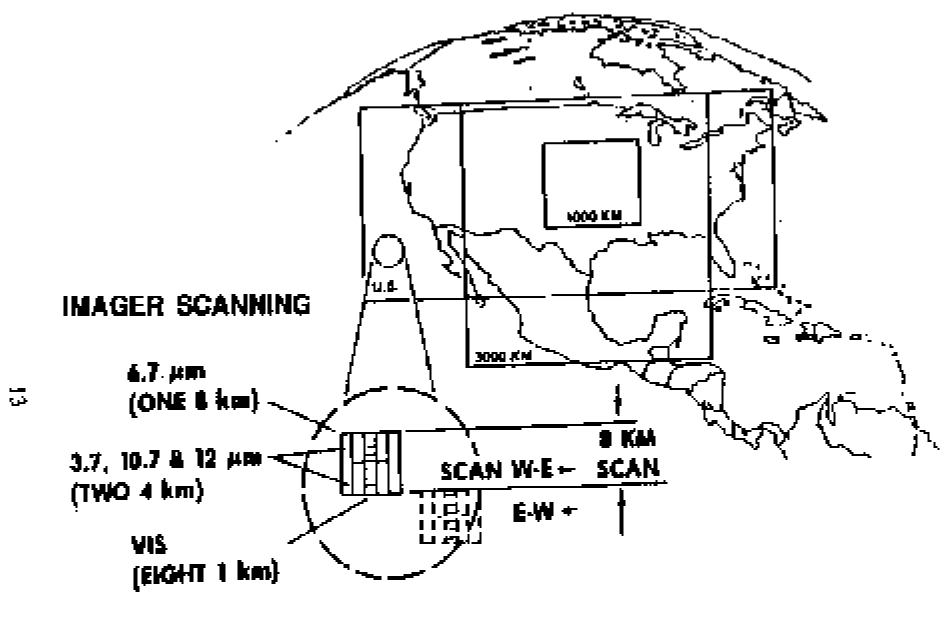

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Figure 2-3
Scan Operation

the scan mirror motions and their physical effect on the spacecraft. A counteracting signal is developed and fed to both instruments to apply the appropriate corrections that maintain the scan mirror angle accuracy with respect to the earth.

Star reference data collection is performed by each instrument. This permits regular determination of optical references. These features that reduce pointing errors permit the total system to achieve high accuracies with respect to ground coordinates.

Each instrument's optical assembly measures approximately 18" x 18" x 42". A 9" long sun shield extends from the scan cavity and a 24" square by 12" extension shields the radiative cooler. The separate electronics module for each instrument, containing nearly all the control and signal processing circuitry, is located across from the optical assembly.

Raw Imager data is transmitted at 2.6208 Mbps. The Sounder has a much lower rate at 0.040 Mbps.

2.2 Key Features

General characteristics of the two units are summarized and their performance is given in Tables 2-1, 2-2, 2-3, and 2-4. Figures 2-4 and 2-5 show the coordinate frames and scan limits for the instruments. Prime features of these instruments are as follows:

+ Scan control

  - Commandable frame size and location.

  - Imager and Sounder mechanically independent and fully stable against other instrument's motion (MMC).

  - Capability to interrupt long duration frames to permit priority (storm watch) observations -- not expected to be used operationally.

  - Repeat-frame option, similar to Rapid Interval Scan Operations (RISOPS) -- not expected to be used operationally due to lack of control of frame start time.

+ Position Location and Frame Overlay Accuracies

  - Imager pixel locations accurate to 4 km at nadir, at noon ± 8 hours; registration between repeated images from 53 μr and 210 μr depending upon time of day and time between frames.

  - Sounder sample locations accurate to 10 km at nadir, at all times; registration between repeated soundings of 280 μr.

+ Long Term Stability and Calibration

- Space reference used for short term radiance reference.

- Full aperture blackbody reference used for regular slope (radiance per output count) calibration approximately every half hour to offset diurnal variation.

+ Application to Weather and Climate. Typical imaging scenarios, based on some approximations of time required for image generations, are

  - A full earth image requires 30 minutes, including overhead functions.

  - An area scan of 3000 km by 3000 km requires 3 minutes.

  - A 1000 km by 1000 km area requires 45 seconds.

Combinations of these frames may be pre-programmed and repeated. It is possible, though not operationally planned, to interrupt one frame with another (priority), such as for continuous storm watch through a period of scheduled synoptic images. Small area (mesoscale) images may be positioned precisely and repeated as required for the planned purpose.

Imager Features

Channels	Detector	Number of Detectors	IGFOV (Nominal km sq.)
Visible	Silicon	8	1
Shortwave	InSb	2	4
Moisture	HgCdTe	1	8
Longwave 1	HgCdTe	2	4
Longwave 2	HgCdTe	2	4
Defining Element Channel Separation Channel-to-channel Alignment		Detector Beamsplitter (Simultaneous Output, all Channels) 14 μr (0.5 km) ground corrected	
Radiometric Calibration		Space and 290°K IR Blackbody (Varies with housing temperature)	
Space look		Every 9.2 sec, 36.6 sec, or every other scan depending on frame size	
Blackbody Calibration		Every 10 minutes, 40 sec duration, but operationally inhibited within a frame and commanded every 30 minutes between frames	
Detector Temperature Signal Quantizing		94°/101°/104°K, IR Channels 10 bits, all channels	
Downlink Data Rate		2.6208 Megabits per second (Mbps)	
Scan Speed (EW) Scan Capability System Power Average		20.021°/sec optical + 0.2 sec turnaround per scan Full Earth, Sector, Area 74 watts	
System Weight Sensor Assembly Electronics Module Total		 118 lb (53.6 kg) 33 lb (15.0 kg) 151 lb (68.6 kg)	

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Table 2-2
Sounder Features

Channels	Detector	Number	IGFOV (μr) Specified Maximums	IGFOV (μr) Nominal
Longwave IR	HgCdTe	4	224	215 diagonal
Midwave IR	HgCdTe	4	224	215 diagonal
Shortwave IR	InSb	4	224	215 diagonal
Visible	Silicon	4	224	215 diagonal
Star	Silicon	8	No spec	22.8 square
FOV Defining Element			Field stop	
Telescope Aperture			31.1 cm (12.25 in) diameter	
Channel Separation, LW-SW-MW			Dichroic	
Channel Definition			Interference filters	
Radiometric Calibration			Space and 290°K-IR blackbody	
Space Look			Every 2 minutes, 10 sec duration approx.	
Blackbody Calibration			Every 20 minutes, 55 sec duration approx.	
IR Detector Operating Temperatures			94°/101°/104°K	
Field Sampling			4 areas N-S on 10 km centers	
EW Scan Step Angle			280 μr (10 km nadir); 560 μr optional	
Step and Dwell Time			0.1 seconds; 0.2s and 0.4s optional + 0.1 sec turnaround per scan	
Scan Capability			Full earth and sector areas	
Signal Quantizing			13 bits all channels	
Downlink Data Rate			40,000 bits per second	
System Power Average			74 watts	
System Weight				
Sensor Assembly			126 lb (57.5 kg)	
Electronics Module			31 lb (14.0 kg)	
Total			157 lb (71.5 kg)	

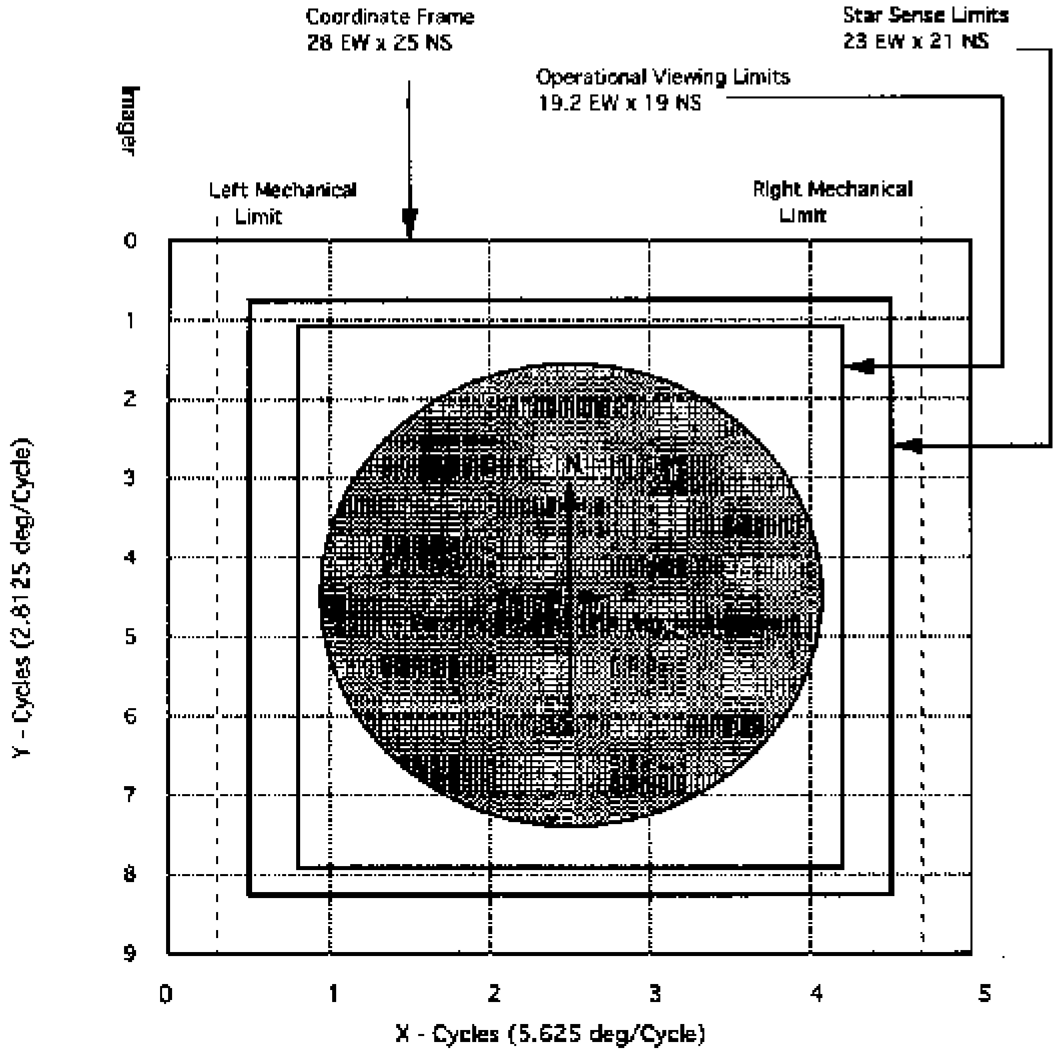
Table 2-3
Imager Performance

Sensitivity					
Channel	Spectrum (μm)	IGFOV (μr)	NEΔT or S/N Spec	Actual	At Scene Temperature
1	0.55 to 0.75	28	150:1	248:1 min.	100% ALBEDO
2	3.80 to 4.00	112	1.4 °K	0.2 °K	300 °K
3	6.50 to 7.00	224	1.0 °K	0.2 °K	230 °K
4	10.20 to 11.20	112	0.35 °K	0.14 °K	300 °K
5	11.50 to 12.50	112	0.35 °K	0.30 °K	300 °K

Optical Capability				
Channel	IGFOV (μr) NS	EW	Channel-to-channel Co-registration (μr)	MTF @ x cycles/radian
1	26.8 to 27.3	27.4 to 27.9	39 max. vis-to-IR; ground corrected to 14μr vis to IR	0.49 @18,000
2	A 86.9 B 86.2	103.2 103.0	20 max. IR-to-IR	0.35 @4490
3	214	200	14	0.41 @4490
4	A 127 B 126	105 106	14	0.29 @4490
5	A 101 B 103	110 106	14	0.28 @4490

Table 2-4
Sounder Spectral and Sensitivity Performance

Channel	Central Wavenumber (cm^{-1})	Half PWR BW (cm^{-1})	MAX BR Temp. (°K)	NEΔN ($mWm^{-2}sr^{-1}cm$) Specified	NEΔN ($mWm^{-2}sr^{-1}cm$) Actual[1]
Long Wave					
1	680	13	260	0.66	1.99
2	696	13	260	0.58	1.27
3	711	13	270	0.54	1.09
4	733	16	290	0.45	0.89
5	748	16	300	0.44	0.79
6	790	30	315	0.25	0.38
7	832	50	330	0.16	0.23
Medium Wave					
8	907	50	335	0.16	0.16
9	1030	25	310	0.33	0.19
10	1345	55	300	0.16	0.10
11	1425	80	285	0.12	0.09
12	1535	60	265	0.15	0.13
Short Wave					
13	2188	23	310	0.013	0.018
14	2210	23	295	0.013	0.014
15	2245	23	275	0.013	0.015
16	2420	40	330	0.0080	0.006
17	2513	40	335	0.0082	0.007
18	2671	100	335	0.0036	0.003
VIS 19	14,367	1000	N/A	0.10%A	0.099%A



Note: Arrangement shown assumes instrument is earth centered.

Figure 2-4

Imager Scan Frame

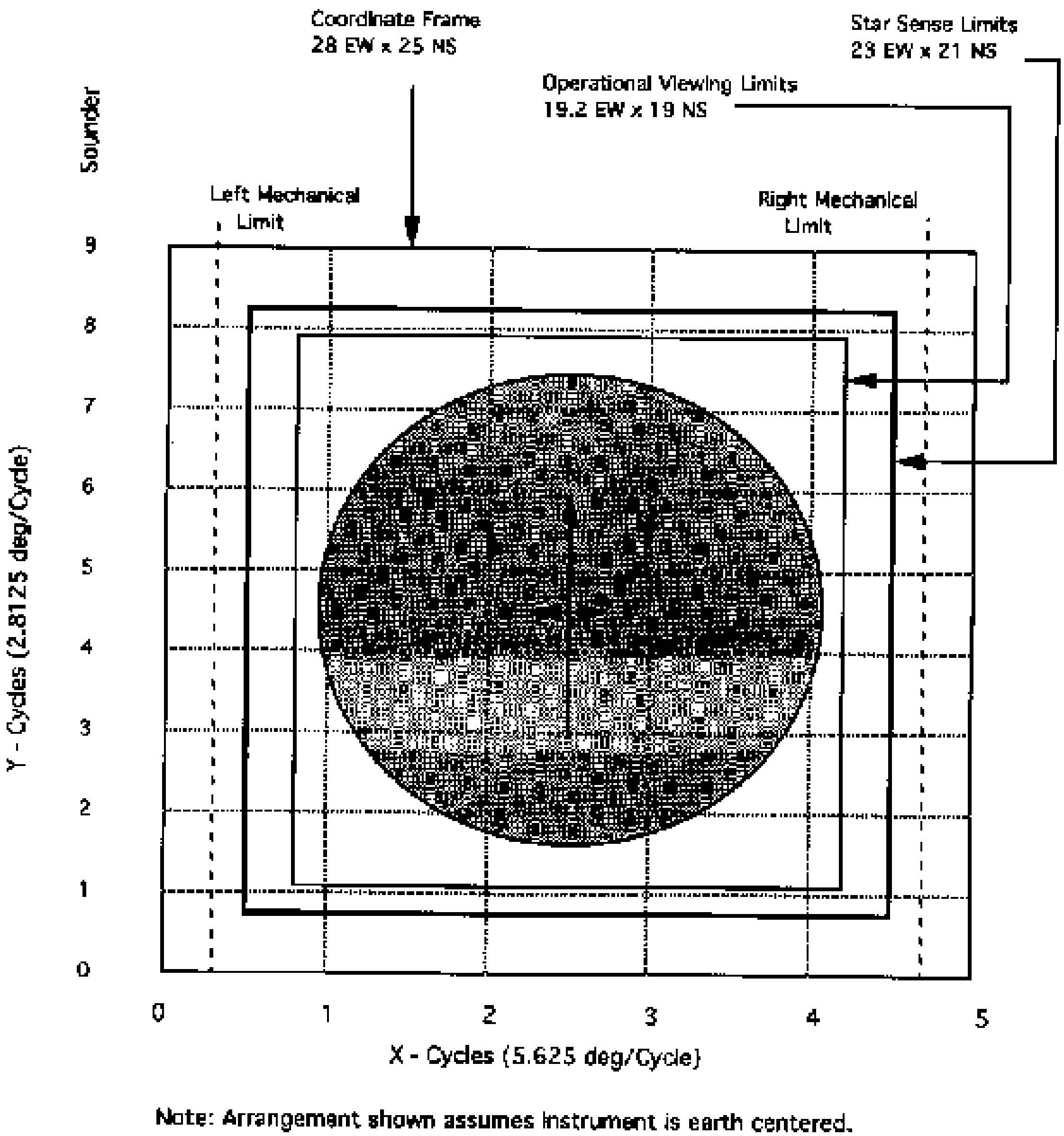


Figure 2-5

Sounder Scan Frame

2.3 Instrument Operational Modes

At any given time, each instrument is in one of six modes:

+ Normal Scan Frame -- The instrument is scanning some portion of the earth/space within commanded rectangular scan limits.

+ Priority Scan Frame -- Scanning in this mode is identical to scanning in a normal scan frame. However, a priority scan frame may be started when the instrument is in idle mode or when it is in normal scan frame mode. That is, a priority scan frame may interrupt a normal scan frame. If a priority frame interrupts a normal frame, then when the priority scan frame is completed the normal scan frame resumes from the point of interruption. In the Imager, upon returning to a normal frame from a completed priority frame, scanning is resumed at the beginning of the scan line that was interrupted. There are two levels of priority. See Section 4 for the operational uses of this mode.

+ Star Sense/Sequence -- The instrument slews to just beyond the location of a star, and holds that position for a commanded period of time as the star drifts across the field of view.

+ Space Look -- Based on the expiration of a timer, the ongoing operation, e.g., frame scan, is interrupted while the instrument slews to space, collects data for a fixed period of time, and resumes the interrupted operation.

+ Blackbody Calibration -- Based on the expiration of a timer (10 minutes for the Imager and then only out of frame; 20 minutes for the Sounder, either in or out of frame), the instrument performs a space look followed by a view of the internal blackbody. Operationally the timer is disabled and blackbody calibrations are commanded approximately every 30 minutes for the Imager between scan frames, and every 15 minutes for the Sounder.

+ Idle -- The instrument remains in idle mode whenever no other operation is being performed.

Any of the above modes can be terminated by a scan reset command. In response to a scan reset, the instrument slews to nadir, performs a blackbody calibration, returns to nadir, and enters idle mode, and performs system reinitialization.

3.0 GVAR

This section defines the structure and content of the GVAR (GOES I-M Variable) processed instrument data transmission format. This format is primarily used to transmit meteorological data measured by the Imager and Sounder instruments. Additionally, parameters associated with the measuring instrumentation are transmitted in the format, as are auxiliary products.

The GVAR format has its origins in the Operational VAS Mode AAA (Triple A) format. The AAA format featured a fixed length format composed of twelve equal size blocks. These blocks are transmitted synchronous with the spin of the earlier GOES, i.e., one complete 12-block sequence occurs for each rotation of the satellite.

With the advent of the three-axis stabilized GOES employing a two-degree of freedom imaging scan mirror and a separate independent sounding instrument, the range and flexibility of satellite operations are increased. The use of a fixed length transmission format would have required that operational limitations be placed on the satellite's capabilities. The GVAR format was developed to permit full use of the new capabilities while maintaining as much commonality with AAA reception equipment as possible.

GVAR is generated by the Sensor Processing System (SPS), a portion of the Operations Ground Equipment (OGE). Each SPS, one per spacecraft, generates a separate GVAR data stream. The SPS calibrates and normalizes Imager and Sounder data and generates gridding and earth location data for Imager data.

GVAR data words are in Gould floating point format.

3.1 Scan Format

The GVAR transmission sequence is depicted in Figure 3-1. It consists of twelve distinct blocks numbered 0 through 11. Blocks 0 through 10 are transmitted as a contiguous set for each Imager scan swath (eight lines). Block 10 will be followed by a variable number of Block 11s according to what data is available for transmission. Each GVAR Block is transmitted with a 10,032-bit synchronization code, a 720-bit header (3 copies of a 240-bit sequence), the variable length information field containing 1-4 records and a 16-bit Cyclic Redundancy Check (CRC) trailer. Blocks 0 and 11 are fixed, equal length blocks of 64,320 bits each in the information field. The information fields in Blocks 1 through 10 vary in length directly in accordance with the width of the Imager scan line. The formula for computing the total number of bits downlinked in GVAR Blocks 0-10, including synchronization fields, headers and trailers, in a single scan is 185,168 + 390 x N, where N is the number of mirror 4-pixel groups (4 x 16 μr pixels) in the scan line. The formula for computing the number of words in the Information Fields only in GVAR Blocks 0-10 for a single scan is 8,280 + 39 x N, yielding a range of 8,280 to 212,484 words. Table 3-1 provides further details about the structure of the GVAR format information field.

The Block 1-10 formats are shown with a maximum of 5236 4- pixel groups, corresponding to a 19.2o field of view (FOV), an operational limit imposed to avoid vignetting from the shield around the optical port. This accommodates scans wider than a full disc (earth edge to earth edge at the equator is 17.4o). Operationally, the instruments are limited to a NS scan of 19o for earth viewing, 21o for star viewing. These scan limits would normally be earth centered, but not necessarily centered within the 23ox25o instrument aperture (see Figure 2-4). A NS scan of 19o equates to 1480 swaths (11,840 visible lines) for the Imager and 296 swaths (1184
lines) for the Sounder.

Table 3-1
GVAR Format--Information Field

Block Number	Contents	Number of Records	Record Structure	Record Length Formulation	Record Length Range	Block Length Range
0	Documentation	1	8,040 8-bit words	64,320 bits	64,320 bits	64,320 bits
1	IR Detectors P1-P4	4	Doc[1] + Data-I[2]	16 + N[4] wrds[5]	17 - 5,252 wrds	68-21,008 wrds
2	IR Detectors P5-P7	3	Doc + Data-I	16 + N wrds	17 - 5,252 wrds	51-15,756 wrds
3	Visible Detector V5	1	Doc + Data-V[3]	16 + 4 N wrds	20 - 20,960 wrds	20-20,960 wrds
4	Visible Detector V6	1	Doc + Data-V	16 + 4 N wrds	20 - 20,960 wrds	20-20,960 wrds
5	Visible Detector V7	1	Doc + Data-V	16 + 4 N wrds	20 - 20,960 wrds	20-20,960 wrds
6	Visible Detector V8	1	Doc + Data-V	16 + 4 N wrds	20 - 20,960 wrds	20-20,960 wrds
7	Visible Detector V1	1	Doc + Data-V	16 + 4 N wrds	20 - 20,960 wrds	20-20,960 wrds
8	Visible Detector V2	1	Doc + Data-V	16 + 4 N wrds	20 - 20,960 wrds	20-20,960 wrds
9	Visible Detector V3	1	Doc + Data-V	16 + 4 N wrds	20 - 20,960 wrds	20-20,960 wrds
10	Visible Detector V4	1	Doc + Data-V	16 + 4 N wrds	20 - 20,960 wrds	20-20,960 wrds
11	Sounder and Auxiliary Data	1	10,720 6-bit words or 8,040 8-bit words or 6,432 10-bit words	64,320 bits	64,320 bits	64,320 bits

Notes:

1. Each Imager Record begins with 16 10-bit words of line documentation.

2. In a scan line, i.e., in a Block 1-2 set, each Data-I contains the same number of pixels and therefore each IR record is the same length, namely one word-per-pixel times one pixel-per-group = one word-per-group.

3. In a scan line, i.e., in a Block 3-10 set, each Data-V contains the same number of pixels and therefore each Vis record (identical with the Vis block) is the same length, namely one word-per-pixel times four pixels-per-group = 4 words-per-group.

4. Imager operational scanning range is 1 to 5,236 4-pixel groups (64 µr pixels) in a scan line.

5. Blocks 1-10 contain 10-bit words.

3.2 Imager Data--Blocks 0-10

The layout of the Imager instrument detectors is provided in Figure 3-2. There are a total of 22 detectors split into three groups:

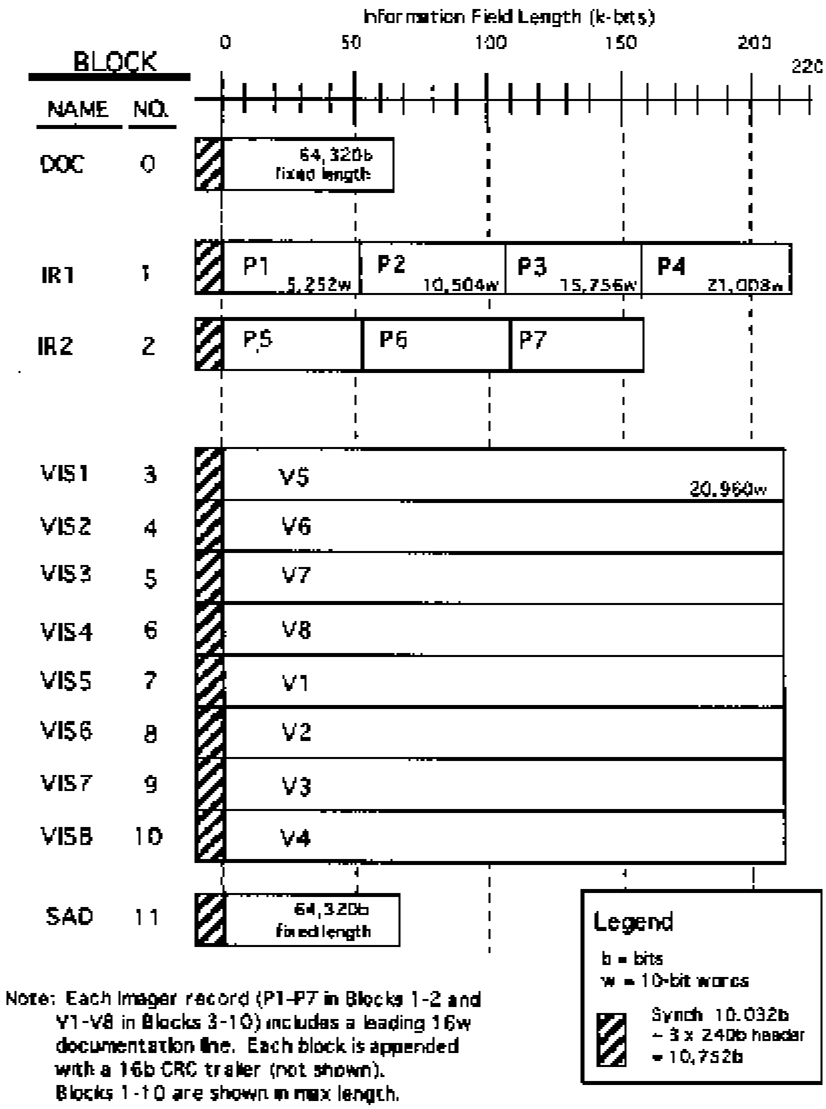


Figure 3-1

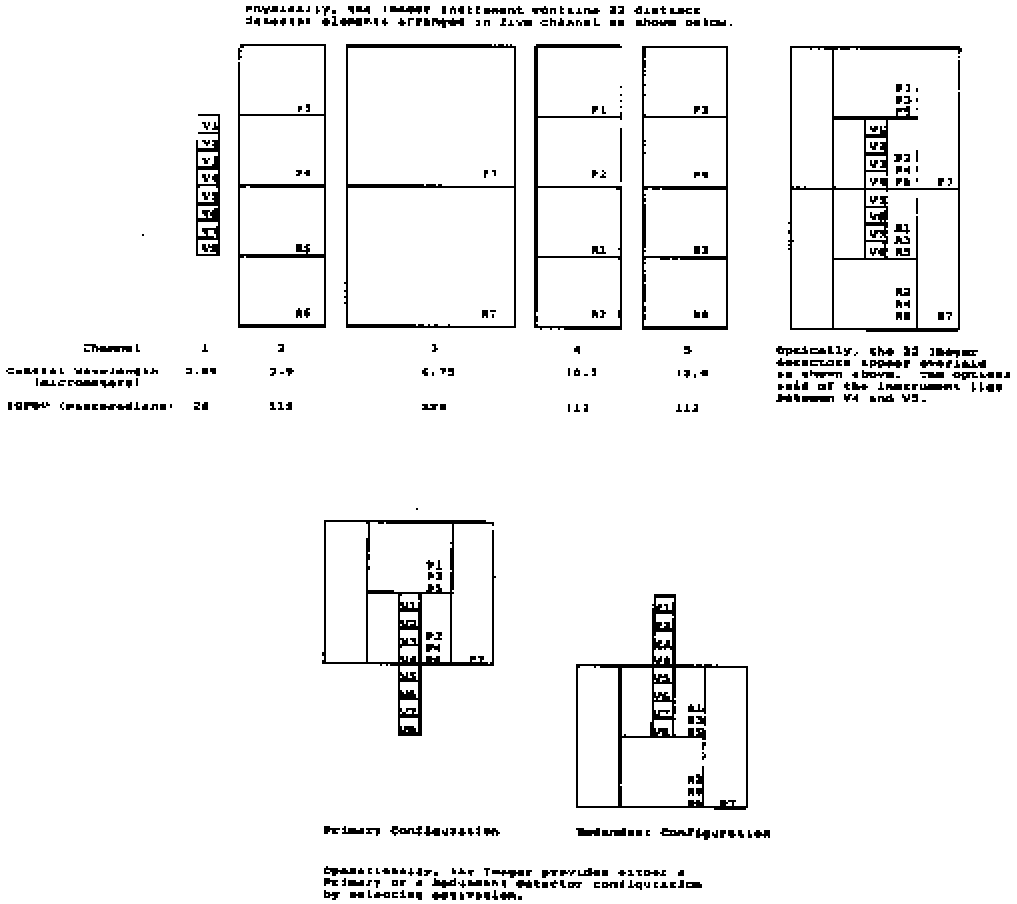
GVAR Format

1. Eight visible detectors, V1 through V8
2. Seven primary infrared detectors, P1 through P7
3. Seven redundant infrared detectors, R1 through R7

During any frame the detectors will be active in either a primary or a redundant (corresponding to Side 1 and Side 2 of the instrument electronics) configuration as illustrated in Figure 3-2. In both configurations the visible detector group (V1-V8) and one of the two infrared groups are active. The resultant swath on the earth's surface generated by either of these two configurations is misaligned in the infrared and visible bands as indicated in Figure 3-3. This misalignment is removed in the GVAR format by lagging data from appropriate detectors. The lagged data is combined with detector data from a subsequent scan, forming earth scan swaths in which the visible and infrared detector data are coincident.

In the primary detector configuration, data from visible detectors V5 through V8 is lagged. This lagged data will be combined with infrared (P1 through P7) and visible (V1 through V4) detector data gathered during the next scan to create a GVAR block sequence. For the redundant detector configuration, data from visible detectors V5 through V8 and infrared detectors R1 through R7 is lagged. The lagged data is combined with data from visible detectors V1 through V4 gathered during the next scan to create a GVAR block sequence. In the cases of scan-type calibration sequences of space look and blackbody, no data lagging is performed.

Coregistration of the VIS and IR detectors is performed on the ground by the SPS. Coregistration of the VIS and IR detectors is necessary because of thermal distortion of IR FOV relative to VIS FOV. Additional leading/lagging of data is possible depending on the coregistration requirements, e.g., ±8 visible pixels NS, ±64 visible pixels EW.

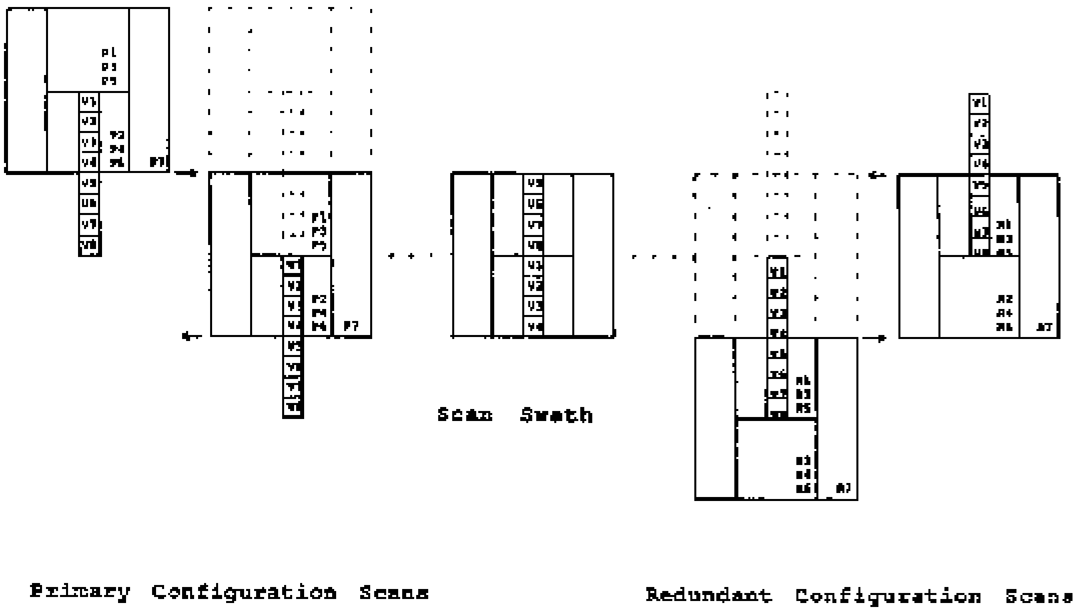


From a figure by ISI

Figure 3-2

Imager Detector Configuration

--



From a figure by ISI

A single scan contributes to two successive scan swaths. Two successive scans are required to construct a complete scan swath. A scan swath collection of detector data is transmitted in a GVAR Block 0-10 set.

Figure 3-3

Imager Scan Lines

3.3 Non-Imager Data--Block 11

A scan by the Imager instrument will result in the generation of GVAR Blocks 0-10. The transmission of Blocks 0-10 will be followed by the transmission of a variable number of Block 11s (0 to n) according to the nature of the data available for transmittal. The priority followed in determining what data to transmit next is shown in Table 3-2.

When the Imager is actively scanning, there is not always sufficient time to transmit all of the generated Block 11s between consecutive Block 0-10 sets. There is always sufficient time for all Sounder data Block 11s generated during simultaneous operation of both instruments. The number of Block 11s that appear contiguously is the number there is time for, i.e., until the next Block 0-10 set is ready for output.

Note in Table 3-2 that the total effective rate of generation of non- fill Block 11s is about 80 per minute (1.3 per second) when both instruments are actively scanning. A full width Imager scan takes 1.16 seconds including turnaround. So, while Block 11s are being generated at about the same rate as Block 0-10 sets, and while it is true that the SPS will generate fill Block 11s in otherwise idle time between Block 0-10 sets, it is NOT true that a Block 11 will necessarily appear every few Block 0-10 sets. Rather, because the SPS buffers many scan lines of Imager data before assembling and outputting GVAR Block 0-10 sets, the GVAR data stream can contain many consecutive Block 0-10 sets without any intervening Block 11s.

3.4 Bandwidth Considerations and Sector Scanning Limits

The output bandwidth available for GVAR is 2,111,360 bps. All GVAR blocks must fit within this channel without significant delays or else a data overflow, i.e., data loss, will occur within the SPS. The bandwidth requirements can be calculated a priori for each of the instrument block types. For scan related data, the required bandwidth is a function of instrument scanning width. For non-scan instrument related data (calibrations, statistics, NLUTs, star senses) the required bandwidths can be treated as a constant time-dependent overhead.

A lower limit has been established for the size of any GVAR block. The lower limit is 32,208 bits, which includes the block synchronization code (10,032 bits), the block header (720 bits), the block CRC (16 bits), and information field (21,440 bits). The lower limit is established to insure that a minimum processing time of 15.25 milliseconds is available at the GVAR receiver for each GVAR block. This limit prevents overrunning the receivers with too many blocks per second and permits a maximum of 65.5 GVAR blocks per second. The minimum information field length of 21,440 bits equates to a 1.9o scan for the Imager blocks. Imager scan widths of less than 1.9o will require that Blocks 1-10 be zero filled. The effect of the minimum block length is to raise the bandwidth overhead associated with smaller Imager scans.

Since all of the Sounder data is transported through Block 11s, there is no direct effect on Imager

Table 3-2
Block Sequencing Priority

Priority	Block Contents	Block # and type	Frequency of Occurrence	Average Rate (per minute)
1.	Next Imager Scan Line	Blocks 1-10	1 set every scan line	50 sets
2.	Imager Compensation and Servo Errors	Block 11 x07		14.06
3.	Sounder Compensation and Servo Errors	Block 11 x0E	1 every 6.4 sec	9.375
4.	Imager Telemetry Statistics	Block 11 x15	1 every 2 min	.5
5.	Imager Spacelook Statistics and Data	Block 11 x16	6 every 2 min	3
6.	Imager Calibration Coefficients and Limits	Block 11 x19	1 every 2 min +	.5
			1 every 20 min	.05
7.	Imager Electronic Calibration (ECAL) Statistics and Data	Block 11 x1A	2 every 20 min	.1
8.	Imager Blackbody Statistics and Data	Block 11 x1C	1 every 20 min	.05
9.	Imager Visible Normalization Look-up Tables (NLUTS)	Block 11 x1F	2 every 20 min	.1
10.	Imager Star Sense Data	Block 11 x3B	9 every 30 min	.3
11.	Sounder Documentation Data	Block 11 x20	1 every scan line	.5
	Sounder Scan Data	Block 11 x23	100 every scan line	50
12.	Sounder Telemetry Statistics	Block 11 x25	1 every 3 min	.333
13.	Sounder Spacelook Statistics and Data	Block 11 x26	5 every 3 min	1.667
14.	Sounder Calibration Coefficients and Limits	Block 11 x29	2 every 3 min +	.667
			2 every 30 min	.067
15.	Sounder ECAL Statistics and Data	Block 11 x2A	3 every 30 min	.1
16.	Sounder Blackbody Statistics and Data	Block 11 x2C	5 every 30 min	1.667
17.	Sounder Visible NLUTS	Block 11 x2F	9 every 30 min	.3
18.	Sounder Star Sense Data	Block 11 x3D	3 every 30 min	.3
19.	T & C Text Messages	Block 11 x32	as required	
20.	SPS Text Messages	Block 11 x34	as required	
21.	Auxiliary Data	Block 11 x31	as required	
22.	Fill	Block 11 x01	as required	

block length. However, Blocks 11s may contain only small amounts of meaningful data when transporting non-Sounder data, e.g., text messages.

The Imager and Sounder each has a bandwidth requirement component that is dependent on the scan width of the instrument and a component that is nearly independent of the scan width. Spare bandwidth available for any combination of Imager and Sounder scan widths is measured in units of spare Block 11s (75,088 bits) available per second. There are conditions under which the available bandwidth of 2,111,360 bps will be exceeded by the requirements of the two instruments. These conditions arise from three primary sources of GVAR overhead:

1. The 10,032-bit block synchronization code (13.4% of each Block 11).

2. The 21,440-bit minimum data length requirement imposed for small GVAR blocks (1-10).

3. The Sounder Documentation Block 11 prefixing each Sounder scan line output.

For each of these three sources, the most negative effects are found at small scan width where the overheads outweigh the instrument data being transported. For the Imager, the synchronization code and the minimum data length represent over 90% of the visible data bandwidth requirement for a 0.2o scan width. A similar scan width for the Sounder yields 57% of bandwidth requirement being allocated for non-instrument data. As the scan widths for each instrument are increased, the percentage of the GVAR output bandwidth allocated to overheads declines, approaching 5% for the Imager visible data, and 13.4% for Sounder scan data.

In addition to the instrument data, the GVAR stream must also provide transport for auxiliary data and text messages (from the SPS operator and the telemetry & command system). The text messages are low-rate in the sense that the ingest channels available for their reception at the SPS are narrow, 9600 bps. Additionally, their expected frequency of occurrence is very small. The auxiliary data, on the other hand, has a relatively wide ingest channel (57,344 bps) and its expected usage rate is to be determined. To provide room for each of these three sources within the GVAR stream, time for one spare Block 11 per second has been allocated. Adequate bandwidth exists to support all functions for both instruments as well as the text and auxiliary data if the following scan width constraints are observed:

Imager: No constraints if Sounder is inactive (not scanning). If Sounder is active, then Imager scan width should be greater than 0.3o.

Sounder: No constraints if Imager is inactive. If Imager scan width is less than 14.4o, then the Sounder scan width should be greater than 0.3o. If the Imager scan width is greater than 14.4o, then the Sounder scan width should be greater than 0.6o.

These constraints can be violated without the loss of any instrument data. The only penalty incurred by doing so is to increase the time required to complete the transmission of any text and auxiliary data that may be ready for GVAR output.

3.5 Transmission Delays and Preprocessing Delays of GVAR Blocks

The GVAR data stream is transmitted from the spacecraft at a carrier rate of 2,111,360 bps. The GVAR formatted data is received by a user after some variable amount of time delay from the point at which the data was actually measured by the satellite instrumentation.

Block delays have four components:

1. Satellite-to-Sensor Processing System (SPS): raw data (raw downlink)

2. SPS processing time (two to 40 seconds)

3. SPS-to-Satellite: GVAR transmission (processed uplink)

4. Satellite-to-user: GVAR transmission (processed downlink)

The block transmission time for each of items 1,3, and 4 above, is approximately 0.5 seconds. SPS processing time, however, can be up to 40 seconds in duration. SPS processing transforms the raw data into GVAR formatted data. The raw Imager data arrives in alternate west-to- east and east-to-west scans; reordering the east-to-west scans to appear in west-to-east order in GVAR necessitates a minimum delay of one scan, which can be a full second for a large frame. The buffering process is used to perform west-to-east ordering and to lag visible detector data to enable creation of visually overlaid (coregistered) infrared scan lines. Additionally, data for four of the visible detectors will be delayed (lagged) one more instrument scan time to overlay the next set of infrared data. However, calibration is performed on recently received data after a spacelook occurs; i.e., the first group of scan lines in a frame are buffered until a spacelook occurs and all subsequent scan lines are buffered between spacelooks; the time between spacelooks, and therefore the buffer accumulation time prior to the first Block 0-10 set, is 36.6 (or 9.2) seconds for frames narrower than full disk. Instead of requiring actual spaceclamps to obtain calibration data, full disk frames are calibrated by overscanning the image to include 400 IR samples beyond earth edge on one side -- this effectively provides spacelook data for calibration at an interval of approximately every two seconds. At this point, transmission of Blocks 0-10 is enabled. Regardless of the calibration mechanism, 9.2 second spaceclamp, 36.6 second spaceclamp, or alternate scan scanclamp, calibration samples are included in GVAR as a set of four Block 11s queued up for transmission every two minutes -- the four Block 11s contain the most recent spacelook samples from the two-minute interval.

A similar buffering process is performed on the Sounder data by the SPS, primarily to permit west-to-east ordering. Calibration of the Sounder data is performed after all of the raw data for a scan line swath has been received. The calibration procedure generates 76 arrays (one array for each of 19 Sounder channels by four detectors) of calibrated pixel information plus sounder visible information. These arrays, along with the original raw downlinked Sounder Data blocks, are then sectioned and packaged into the Block 11 format for Sounder sensor data. A full-width (19.2o) Sounder scan will require 101 Block 11s for complete transmission. It takes the Sounder 120 seconds to scan 19.2o at its fastest rate of 0.16o/sec (two and four times as long at its slower rates). Consequently, the buffering process for the Sounder data takes that long. The subsequent calibration and Block 11 sectioning will take between 10 and 15 seconds to perform. Calibrated Sounder blocks are then queued for output along with other Block 11 products. Finally, transmission of the 101 Block 11s could take anywhere from 3.1 (no concurrent imaging) to 38 seconds (concurrent full-width imaging).

3.6 Encoding

Prior to biphase modulation, the data to be retransmitted undergoes three stages of encoding. The encoding scheme is identical to that used with Mode AAA:

1. All even number eight-bit bytes (regardless of word length) are complemented; the first byte following initial synchronization is byte number one.

2. The second stage involves PN coding. The PN sequence is generated by a shift register whose input is the output of an exclusive-OR gate. Bits 8 and 15 (MSB) of the shift register are the inputs to this gate. The output of the gate is combined with a data line using a second exclusive-OR gate.

3. The PN coded data stream described above is passed through an NRZ-S differential encoding process. This process produces a transition for each logic zero input and none otherwise.

3.7 Receiver Considerations

Direct read-out stations configured for the GOES-7 Mode AAA processed data stream require some modifications to receive GOES-8 imagery in the GVAR format.

+ If the front end demodulator is tunable, it must be retuned to the new 65.7 MHz IF--assuming the Local Oscillator (L.O.) frequency is 1620 MHz., since GVAR is 1685.7 MHz. vs. 1687.1 MHz. for Mode AAA.

+ If the demodulator is not tunable, it must be replaced it with one tuned to 65.7 MHz.

This can sometimes be done by replacing crystal oscillator and matched filter components without replacing the whole demodulator unit. Users are advised to check with the manufacturer. This assumes the Local Oscillator (L.O.) frequency is 1620 MHz. since GVAR is 1685.7 MHz. vs. 1687.1 MHz. for Mode AAA.

+ The bit synchronizer should handle GVAR with no changes.

+ If the frame synchronizer reads the Mode AAA header (with particular regard to word and block sizes) and responds accordingly, and if it ignores block type and block ordering, then it will probably operate correctly with GVAR. Users should contact the frame synchronizer manufacturer regarding this.

When processing GVAR, a user device should not use the data valid flag in the header to turn itself on or off. This flag merely indicates the validity of the data in the block, and not the frame status. There are separate flags for frame status in the Imager documentation block (Block 0) and the Sounder documentation block (one of the Block 11 types).

3.8 Earth Location

GVAR does not contain an earth location array for the Imager due to bandwidth limitations. An earth location array is provided with GVAR Sounder data that maps each pixel into a specific lat/lon point. An algorithm to convert Imager scan line and pixel coordinates to earth Lat/Lon is available in software programmed in Fortran 77. The software, and its accompanying documentation, known as the Earth Location User's Guide (ELUG), was produced by Integral Systems, Inc. (ISI - Lanham, Maryland).

3.9 Calibration

In orbit, the infrared channels of both the Imager and Sounder are calibrated with data taken as they view space and their on-board blackbodies. The SPS at Wallops, VA applies calibration to the scene data in real time. The SPS also normalizes the visible-channel data to minimize east-west striping in the images. The visible channels are not calibrated in orbit because the GOES I-M instruments do not have on- board calibration targets in the visible.

The calibration coefficients (three per channel/detector) and the scaling coefficients (two per channel) are also contained in GVAR. Users can derive the radiances from counts in the retransmitted data stream by inverting the scaling operation. They can retrieve the raw data from the radiances by inverting the calibration. For the Sounder, GVAR will contain both raw and calibrated data. For the Imager, it will only contain the calibrated data, because the GVAR data stream has insufficient bandwidth to contain both. GVAR also contains statistical data and telemetry information for monitoring the calibration and instrument performance.

When an instrument receives radiation emitted and/or reflected from a scene, it puts out a signal related to the intensity of the received radiation. Calibration is the process quantifying that relationship. Since the relationship is nearly linear (see reference 8), it can be determined by measuring the instrument's responses (in digital counts) to radiation from two targets at known, but different, temperatures. The imager and sounder make these measurements by observing space (whose temperature is effectively zero in the infrared) and internal blackbodies, whose temperatures are constantly monitored. In orbit, an instrument's calibration relationship is almost always varying, because it depends on the temperatures of the instrument's components, transmissivities of the mirrors and other optics components, etc., and these properties may vary diurnally, seasonally, and with instrument age. Therefore, the instruments need to be calibrated frequently.

Blackbody calibration is based on the expiration of a timer, 10 minutes for the Imager and 20 minutes for the Sounder. Imager calibration occurs only out of frame, i.e., not while a frame scan is in progress; if the timer expires while a scan is in progress, the blackbody calibration occurs upon completion of the frame. Sounder blackbody calibration occurs either in or out of frame, upon expiration of the timer, but after any dwell that might be in progress. The instrument performs a space look followed by a view of the internal blackbody. Operationally the timer is disabled and blackbody calibrations are commanded approximately every 30 minutes for the Imager between scan frames, and every 15 minutes for the Sounder.

The Imager can perform spacelooks in two ways. The scan can be interrupted and the mirror pointed to space to take a reading; this is called a spaceclamp. Or the scan frame can be made such that either the east side or the west side extends beyond earth edge, beyond earth shine, into space, making the instrument scan space; this is called a scanclamp.

Spaceclamps are performed upon the execution of a timer. The timer is selectable at 9.2 seconds or 36.6 seconds; the timer restarts upon expiration so that spacelooks are at fixed intervals. Upon timer expiration, the Imager completes the line it is scanning, slews horizontally to the preselected side to a point 10.4E from nadir to perform the spacelook, performs a turnaround sequence, and resumes scanning the frame. Therefore, the time between two spacelooks may vary by up to two seconds (plus or minus) from the timer interval. The turnaround sequence includes retracing the last line three times, so the duration of the interruption is proportional to the width of the frame. And, of course, the total amount of time the scan is interrupted is proportional to the number of spacelooks performed, and therefore, to the total size of the frame. A set of six Block 11s containing spacelook data will be generated every two minutes, or once at the end of the frame for shorter duration frames.

In scanclamp mode the frame scan is never interrupted, but the frame actually scanned extends out into space, beyond the area of meteorological interest. The frame edge extends beyond earth edge, beyond earth shine (a 0.5E wide ring around the earth), and out into space far enough to acquire a preset number of samples. Initially, the number of samples obtained by the GOES-8 Imager will be 400 IR samples, 64 r on center, for a displacement of 1.47E beyond earth shine. Scanclamp mode will typically be used for full disk frames, making the frame boundary lie 1.97E beyond earth edge at the equator, or 10.67E from nadir. In a full disk frame scanned thusly, with the overscan into space applied only to one side of the earth, i.e., every other scan line, space calibration data is obtained every 2.2 seconds. The full width of an Imager frame scanned in this mode typically will not be seen in the GVAR data. Instead, in GVAR the frame will contain only the portion of meteorological interest, the width of the frame typically truncated at earth edge. As in spaceclamp mode, a set of six Block 11s containing spacelook data will be generated every two minutes.

The Sounder operates only in spaceclamp mode with a 2 minute timer, asynchronous to the frame start. The spaceclamp occurs upon expiration of the timer and after completion of any 0.1 second sounding.

4.0 OPERATIONAL SCHEDULES

Sector scanning, as opposed to full disk scanning, is the standard mode of operation for the GOES I-M series with the scanning of almost any local sector area technically possible. There are three defined modes of operation -- Routine, Rapid Scan, and Full Disk. The Imager and the Sounder each has its own schedule. Due to spacecraft housekeeping requirements every six hours, each daily schedule consists of four repetitions of a basic six-hour schedule. This has the effect of synchronizing Imager and Sounder operation every six hours. Each six- hour schedule is composed of six one-hour schedules, which also repeat, but with major exceptions, first to accommodate the spacecraft housekeeping, and, secondly if necessary, to accommodate a sector that is not scanned every hour. The hourly schedule for each instrument is a result of National Weather Service requirements for products.

+ The Routine mode is the normal mode of operation. In this mode the Imager will scan a full disk every three hours, with a Northern Hemisphere, CONUS, and Southern Hemisphere sector scanned in each half-hour not occupied by a full disk scan or spacecraft housekeeping. The Sounder's Routine Mode will scan a Full Region Northern Hemisphere sector each hour for the first four hours of each six-hour cycle; the fifth hour contains seasonally dependent sectors, and the sixth hour contains a Limited Regional sector. See figure 4-1.

+ The Rapid Scan mode will be enacted when the onset of severe weather is suspected. The Imager, in the half-hour periods not devoted to Full Disk sectors, will scan a Northern hemisphere sector, three repetitions of the CONUS sector, and a Small Souther Hemisphere sector. This effectively rescans the CONUS four times each half- hour except during full disk scans and spacecraft housekeeping. The Sounder will scan a Limited Regional sector for a 45-minute period each three hours; otherwise it will repeatedly scan a half-hour Mesoscale sector. See figure 4-2.

+ Full Disk mode is reserved for non-routine operations. In this mode the Imager will repeatedly scan the Full Disk every half-hour except for spacecraft housekeeping. the Sounder's Full Disk Mode schedule is the same as its Routine schedule. See figure 4-3.

Sectors are described in Table 4-1. These sectors and schedules support the operational requirements of the National Centers and other, non-NWS users of GOES imagery (e.g., international WEFAX). These products and schedules are subject to change due to changing spacecraft operational requirements or changing requirements of the National Weather Service.

Table 4-1
Day-1 Sectors (GOES-8 at 90W)

FRAME / BOUNDARIES	North	South	West	East
IMAGER SECTORS				
Full Disk	Earth edge	Earth edge	Earth edge	Earth edge
Northern Hemisphere	65N	0N	120W	40W
Extended Northern Hemisphere	65N	20S (17S)	120W	35W
South Southern Hemisphere	20S	57S	122.5W	26.5W
CONUS	60N	14N	115W	68W
Small Southern Hemisphere	0N	15S	110W	80W
SOUNDER SECTORS				
Full Regional Northern Hemisphere	51.5N	23.3N	121W	68W
Full Regional Southern Hemisphere	20S	50S	125.5W	78W
Limited Regional - NH	50N (47.7N)	26N	120W	70.5W
Mesoscale CONUS 1	49N	25N	87W	73W
Mesoscale CONUS 2	50N	27N	96W	80W
Mesoscale CONUS 3	50N	27N	106W	90W
Mesoscale CONUS 4	50N	30N	120W	103W
Mesoscale Tropics 1	46N	24N	60W	50W
Mesoscale Tropics 2	23N	11N	70W	46W
Mesoscale Tropics 3	23N	11N	92W	72W
Mesoscale Tropics 4	23N	11N	112W	92W
Mesoscale Tropics 5	23N	10N	135W	114W

Estimates of the GVAR data volumes associated with these sectors were calculated by the GIMCALC software program and are given in Table 4-2. For the Imager, the number of blocks shown in the table is that generated directly by frame scanning and does not include Block 11s generated by Imager star looks or blackbody calibrations (BBCALs) that may occur immediately before or after the scanning of a particular frame. Imager star looks and BBCALs are scheduled activities; their placement in schedules may be rearranged from time to time to best support instrument performance and operational requirements. Sounder star looks and BBCALs are timer triggered, interrupting an active scan; Sounder starlook and BBCAL Block 11s are included in the block counts in the table. Actual block counts may be slightly different if sector boundaries are adjusted or if the spacecraft is situated at a different longitude. Storage requirements in megabytes are based on two bytes per GVAR data word.

Table 4-2

GVAR Data Volume for Day-1 Sectors

(Block Counts and Total Megabytes Storage)

IMAGER SECTORS	Block 0	Block 1-2	Block 3-10	Block 11	MBytes
Full Disk	1356	2712	10848	372	556
Northern Hemisphere	649	1298	5192	139	182
Extended Northern Hemisphere	918	1836	7344	201	266
South Southern Hemisphere	367	734	2936	81	106
CONUS	440	880	3520	67	80
Small Southern Hemisphere	205	410	1640	25	26
SOUNDER SECTORS	**Data**	**Doc'mtn**	**Other**	**Total B11s**	**MBytes**
Full Regional Northern Hemisphere	2576	56	867	3499	56
Full Regional Southern Hemisphere	2604	62	868	3524	56
Limited Regional - NH	1924	47	689	2710	44
Mesoscale	658	47	194	899	14

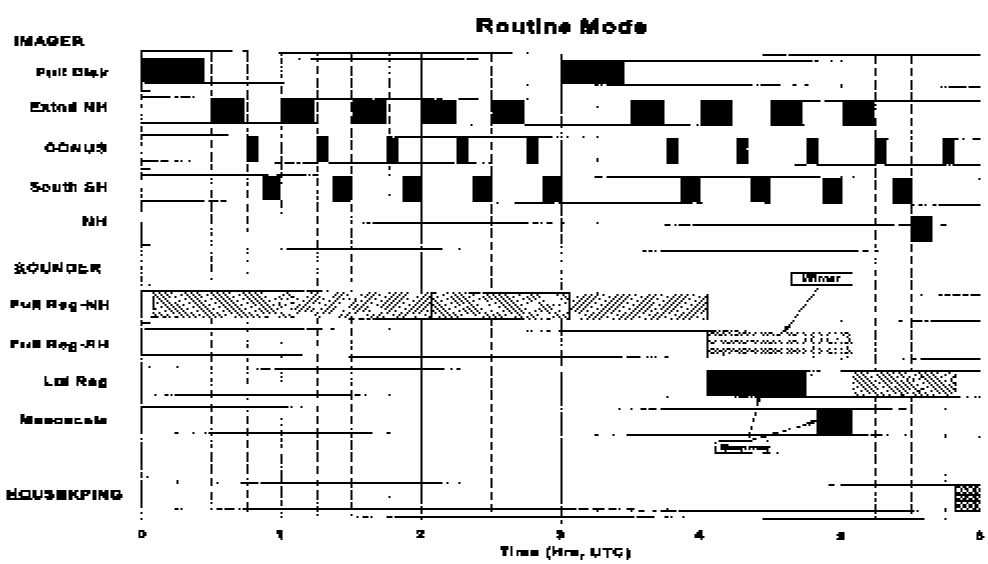


Figure 4-1

Routine Mode Schedule

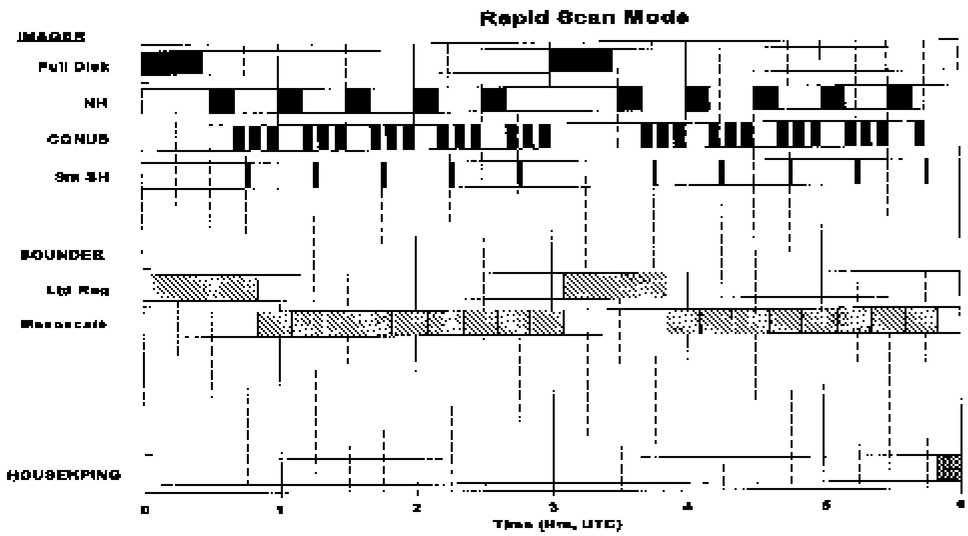


Figure 4-2

Rapid Scan Mode Schedule

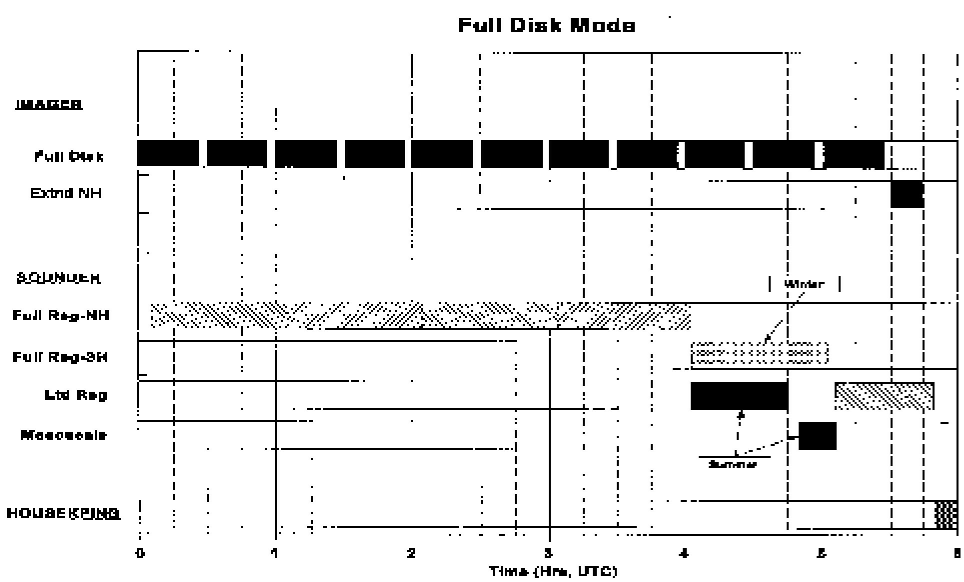


Figure 4-3

Full Disk Mode Schedule

Each instrument maintains four command registers, corresponding to command levels numbered 0 through 3. Level numbers indicate command priority, with 3 being the highest. Level 0 is used for normal frame commands, levels 1 and 2 are priority frame commands, and level 3 is star sense/sequence. Operationally, only one frame command will be sent at a time, so only one priority level will be in use at any time.

While NESDIS is not presently planning to interrupt GOES-8 Imager frame scans with "nested" (interrupting) priority frames, the various priority levels will appear in the GVAR Block-0 ISCAN flag. These priority levels are associated with frame execution registers in the instrument; the various spacelook modes are constrained to certain registers; so each frame will have the "priority" associated with its spacelook mode. Full disk frames, which will be scanned in scanclamp spacelook mode, will be of priority 2; all other frames will be of priority 1. Register 0 is currently reserved for special operations -- appearance of a "normal frame" (ISCAN flags 4 & 5 set to 00) may indicate an exceptional situation and the frame may not be useable for production applications or operational purposes. Tables 2-5 and 2-6 summarize the use of the registers/priorities for the Imager and the Sounder, respectively. NESDIS may change this practice on GOES-8 or following satellites and implement priority frame interrupts (nested frames) as a part of the operational scenario.

Table 4-4
Sounder Priority Scan Flags

Sounder Register	SSCAN Bits 4 & 5 - Instrument Operational Mode	Frame
0	00 - Normal	Full Regional - Northern Hemisphere
1	01 - Priority 2	Limited Regional
2	10 - Priority 1	Mesoscale or Full Regional - Southern Hemisphere

Table 4-3
Imager Priority Frame Flags

Imager Register	ISCAN Bits 4 & 5 - Instrument Operational Mode	Full Disk Schedule Mode	Routine Schedule Mode	Rapid Scan Schedule Mode	Spacelook Modes[9] Available
0	00 - Normal Scan Frame	Special use frame[10]	Special use frame[10]	Special use frame[10]	Scan Clamp to Space Clamp at 9.2 second interval
1	01 - Priority 2 Scan Frame	Full Disk Frame	Full Disk Frame	Full Disk Frame	Scan Clamp
2	10 - Priority 1 Scan Frame	Extd N H. Frame	All Other Predefined Frames	All Other Predefined Frames	Space Clamp at 36.6 second interval

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9 The 9.2 second interval Spaceclamp can be used with any Imager execution register. Present plans are that the 9.2 second interval Spaceclamp will not be used operationally

10 Nothing precludes the future use of this register in a normal operating scenario.

The Sounder Scan Data Block (Block 11 priority 11 in Table 3-2) contains fields that indicate whether the current stream of Sounder data (Block 11s) are parts of a normal or a priority Sounder frame and whether the Block 11 is the first, last, or an intermediate Block in the frame.

Star Sense, Space Look, and BBCAL for the Imager and for the Sounder are later indicated by the occurrence of the corresponding Block 11, see Table 3-2. When both instruments are in Idle mode and no other Block 11s are incoming, GVAR consists of a stream of Fill Block 11s (priority 22 in Table 3-2).

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GLOSSARY

Acronyms

AAA	Mode Triple-A (Processed instrument data format for current GOES)
BB	Blackbody
BBCAL	Blackbody calibration
bps	bits per second
CDA	Command and Data Acquisition Station (NOAA)
CONUS	The contiguous 48 of the United States
CRC	Cyclic Redundancy Check
ECAL	Electronic calibration
EW	East-West
FACC	Ford Aerospace and Communications Corporation
FOV	Field of View (given in either angular or earth surface spatial units)
GSFC	Goddard Space Flight Center (NASA)
GOES	Geostationary Operational Environmental Satellite
GVAR	GOES Variable (processed instrument data format for GOES I-M)
IFOV	Instantaneous Field of View
IGFOV	Instantaneous Geometric Field of View
IMC	Image Motion Compensation
IR	Infrared
K	Kilo (thousand) or Kelvin degrees (temperature)
Kbps	Kilobits per second (thousand bits per second)
μr	microradians
mr	milliradians
μm	micro-meters
MMC	Mirror Motion Compensation
Mbps	Megabits per second (million bits per second)
n/a	not applicable
NLUTS	Normalization Look-up Tables
NS	North-South

OATS	Orbit and Attitude Tracking System (of OGE)
OGE	Operations Ground Equipment (i.e., SPS , OATS, PM, and ODAPS)
PID	Processed Instrument Data (e.g., AAA or GVAR)
RID	Raw Instrument Data
RISOPS	Rapid Interval Scan Operations
SAR	Search and Rescue (GOES transponder)
SEM	Space Environment Monitor (GOES instruments)
SOCC	Satellite Operations Control Center (NOAA)
SPS	Sensor Processing System (of OGE)
T&C	Telemetry and Command
TCS	Telemetry and Command System
WEFAX	Weather Facsimile

APPENDIX A

OPERATIONAL IN-ORBIT CALIBRATION

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OPERATIONAL IN-ORBIT CALIBRATION OF GOES-I IMAGER AND SOUNDER

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1. INTRODUCTION

Radiometric calibration of the GOES I-M imagers and sounders is a multi-stage process beginning before the launch of each satellite and extending throughout its life. Before launch, the instruments' performance is characterized under controlled conditions by their manufacturer (ITT, Ft. Wayne, IN) and by the GOES I-M prime contractor (Space Systems/Loral Palo Alto, CA). In orbit, the infrared channels will be calibrated with data taken as they view space and their on-board blackbodies. The calibration will be applied to the scene data in real time in the ground system at NOAA's Command and Data Acquisition Station at Wallops, VA. At the same time, the visible-channel data will be normalized to minimize east-west striping in the images. The visible channels will not be calibrated in orbit, because the GOES I-M instruments do not have on-board calibration targets in the visible.

2. CALIBRATION OF INFRARED CHANNELS

In orbit, each instrument views space and its on- board warm blackbody to provide data to calibrate its infrared channels. Each instrument's blackbody is in front of its optical chain and fills its optical aperture, providing a full-system calibration. The calibration equation (one for each infrared channel), which relates sensor output x (in digital counts) to scene radiance R (mW/[m2-sr-cm-1]) is

R = qx2 + mx + b.

The coefficients m and b, termed the slope and intercept, respectively, are determined by the in-orbit calibration. The value of q, the coefficient of the quadratic term, is known a priori, having been determined from measurements made before launch. The quadratic term allows for possible non-linearities in sensor response. Since the GOES-I satellite will be three-axis stabilized, temperatures in the instruments will vary diurnally by tens of degrees Kelvin. The instruments must be calibrated often to preserve the precision of the measurements. In addition, since the imager clamps its electronic zero on space, it must view space frequently to avoid excessive 1/f noise. (The sounder clamps on its filter wheel, not space.) Space-look intervals are programmed into the scan pattern, whereas blackbody measurements occur on command. The intervals between calibration measurements are listed in Table 1. These values represent compromises between considerations of radiometric integrity and operational scheduling. For the imager, current plans are to use the 2.2-sec space-look interval when imaging the full Earth and the 36.6-sec interval for imaging smaller sectors. Studies of image quality with thermal-vacuum test data suggest that image quality is approximately the same for the 9.2- and 36.6-sec intervals.

TABLE 1

Interval between Calibration Measurements

	Sounder	Imager
Space	2.2, 9.2, or 36.6 sec	2 min
Blackbody	30 min	20 min

2.1 Slopes and Intercepts

For the sounder, the slopes m will be determined from each blackbody measurement and the space measurement that precedes it. The intercepts b will normally be computed once every two minutes from each space measurement. To account for rapid changes in intercepts driven by severe variations in on-board temperatures near midnight, we have the option to update the intercepts once every 1.1 sec, utilizing their observed correlations with those temperatures.

For the imager, the processing includes devices to reduce potential effects of 1/f noise--most notably low frequency "drifts" in the signal. Since the blackbody and space measurements are not simultaneous, drift may render them incompatible and corrupt the computation of the calibration slope. To ameliorate this problem, we estimate the signal from space at the time of the blackbody measurement by interpolating the signal linearly between the preceding and following space looks.

If there is drift between two successive space looks, the calibration intercepts may become invalid during the interval between them. We remove the effect of the linear component of the drift by interpolating the intercept values to the time of each scene pixel. This means that the intercepts are updated pixel by pixel.

The use of detector arrays may make some subtle effects of noise in the calibration more apparent. The imager and sounder use north-south arrays of detectors in most spectral channels--all, in fact, except channel 3 of the imager. With each scan of the earth, adjacent detectors sweep out adjacent east-west lines. Because the noise is uncorrelated among the detectors of an array, noise-induced errors in slope computations may cause line-to-line radiance biases. In images, this could cause east-west stripes. The pattern of the stripes would change after each blackbody measurement. Although pre-launch test results suggest that this effect should be relatively weak, we plan to incorporate algorithms in the ground system shortly after launch to minimize it.

2.2 Quadratic Term

The coefficient q of the quadratic term was determined in pre-launch thermal-vacuum tests as a function of two parameters--the temperature of the instrument's detector patch and the temperature of its baseplate. A table of q vs these two temperatures is stored in the ground system. When GOES-I is in orbit, we measure those temperatures and estimate the appropriate value of q by interpolating in the table.

In the thermal vacuum tests, for each setting of baseplate temperature and patch temperature, the values of q were determined as follows: The instrument was illuminated by an external blackbody equipped with temperature sensors whose calibration is traceable to the National Institute of Standards and Technology. The output of the instrument (in digital counts) was recorded as the temperature of the blackbody was stepped between 200K and 320K in seven approximately equal-radiance increments. Radiances in each channel were computed from the temperatures of the blackbody. The value of q was then determined from a least square fit of a quadratic to the radiance-vs-count data. As an example of this process, Figure 1 shows the residuals of linear and quadratic fits to the data in channel 3 (6.7 um) of the GOES-I imager.

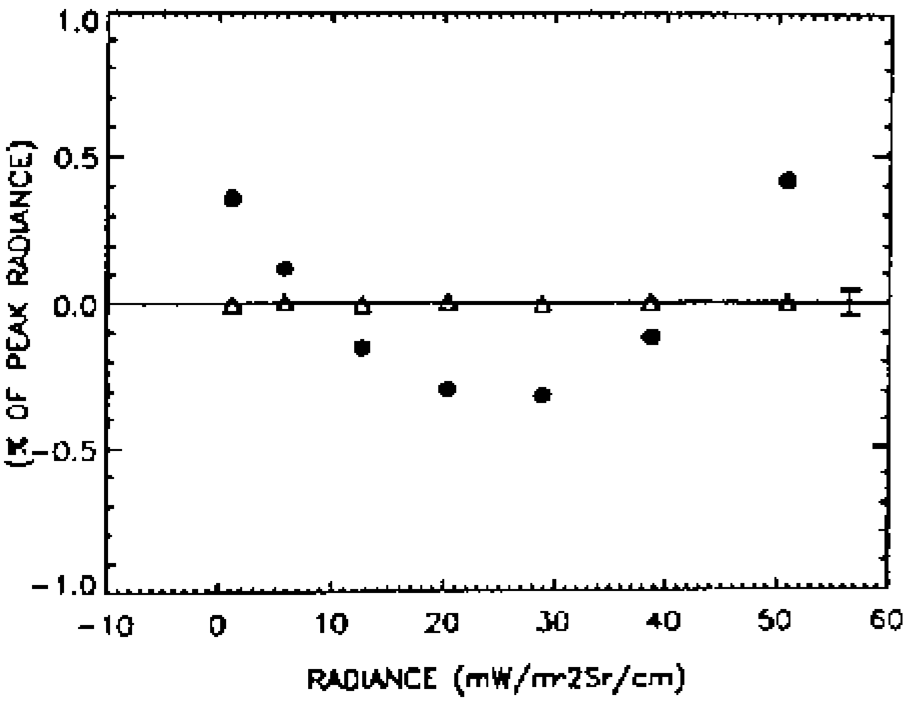

Figure 1. Residuals from linear fit (filled circles) and quadratic fit (triangles) to calibration data in channel 3 of GOES-I imager (from Cousins et al., 1993).

(The residuals are in units of percent of the peak radiance, which corresponds to approximately 320K, and are plotted against radiance. The error bar at the right side of the plot is an estimate of the single sample noise.) The residuals of the linear fit exhibit a distinct curvature, indicating the need for a higher-order fit. The quadratic is sufficient, since its residuals and any pattern they may exhibit are insignificant in comparison to measurement noise.

2.3 Data Flow

When the GOES-I is in orbit, raw imager and sounder data will be transmitted to the Command and Data Acquisition Station (CDA) continuously in real time. Raw imager data will be in 10-bit words, raw sounder data in 13-bit words. Calibration processing for the infrared channels, culminating in the retransmission of the data to users, will take place at the CDA in real time. In the processing, the calibration coefficients will be computed as previously discussed, and they will be applied to the raw data, converting them to radiances. The radiances will then be scaled linearly so that they utilize the full 10-bit (imager) or 16-bit (sounder) word length of the retransmitted data stream. The calibration coefficients (three per channel/detector) and the scaling coefficients (two per channel) will also be in the retransmitted data stream. Users can derive the radiances from counts in the retransmitted data stream by inverting the scaling operation. They can retrieve the raw data from the radiances by inverting the calibration. (For the sounder, the retransmitted data stream will contain both raw and "calibrated" data. For the imager, it will only contain the "calibrated" data, because the retransmitted data stream has insufficient bandwidth to contain both.) The data stream will also contain statistical data and telemetry information for monitoring the calibration and instrument performance.

3. NORMALIZATION OF VISIBLE-CHANNEL DATA

The imager uses a north-south array of eight silicon diode detectors to image the earth, and the sounder uses an array of four similar detectors, primarily for cloud detection. With each rotation of the scan mirror, the imager thus produces eight adjacent east-west lines and the sounder, four. The visible detector-channels are not calibrated in orbit, but the retransmitted data stream will contain coefficients determined before launch that convert instrument output (in counts) to radiance (W/[m2-sr-u]) and reflectance factor or albedo (on a scale of 0-1). Since detector responsivities can vary unpredictably, the pre-launch calibration may not be valid after launch.

Without in-orbit calibration, the images will be susceptible to striping. Striping will be reduced by the normalization of each detector's output to the output of a stable reference detector (see below). The normalization will be applied in real time at the CDA at Wallops, VA through application of normalization look-up tables (NLUTs) to the raw scene data.

Image quality will be monitored daily off line at NESDIS in Suitland, MD. If striping becomes significant, new NLUTs will be generated at NESDIS and transmitted electronically to Wallops. Because detector responsivities are expected to vary slowly, at least in the short term, it is expected that a given NLUT will remain valid for periods of the order of a month or longer.

The technique for generating NLUTs involves matching the empirical distribution functions (EDFs) of the raw data from each detector to the EDF of the raw data from the reference detector (Weinreb et al., 1989). The reference detector will be chosen after launch as the one with the best combination of such characteristics as long-term stability and maximum use of the count range of the data system without clipping at the upper and lower limits.

When the GOES-I is in orbit, the data flow for the visible-channel data will be similar to that for the infrared. The raw data from the imager and sounder will be transmitted to the CDA as 10-bit and 13-bit words, respectively. In the CDA, the raw data will be normalized, but no calibration will be applied. The retransmitted data stream will contain the normalized data in 10-bit words (imager) and 16-bit words (sounder). The retransmitted data stream will also carry the normalization look-up tables, the identity of the reference detector, and the date the normalization look-up tables were created. In addition, it will contain the pre-launch calibration coefficients (three per detector, but with the quadratic coefficients identically zero) and the factor that converts radiance to reflectance factor. If users wanted to apply the pre-launch calibration to the normalized data, they should apply the calibration coefficients for the reference detector to the data from all detectors.

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