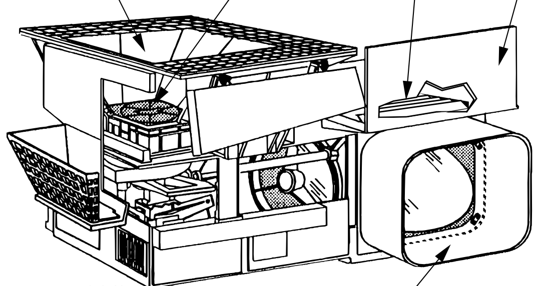
Sounder

The Sounder is a 19-channel discrete-filter radiometer that senses specific data parameters for atmospheric vertical temperature and moisture profiles, surface and cloud top temperature, and ozone distribution. As in the Imager, the Sounder is capable of providing full earth imagery, sector imagery (including earth's disk), and scans of local regions. The nineteen spectral bands (seven longwave (LW), five midwave (MW), six shortwave (SW), and one visible) produce the prime sounding products.

Sounder Instrument Characteristics



Channels	Detector Type	Nominal Circular IGFOV (μrad)
1 to 7 (LW IR)	HgCdTe	242
8 to 12 (MW IR)	HgCdTe	242
13 to 18 (SW IR)	InSb	242
19 (visible)	Silicon	242
Star sense	Silicon	28*

*square detectors

Parameter	Performance
FOV defining element	Field stop
Telescope aperture	31.1-cm (12.2-in) diameter
Channel definition	Interference filters
Radiometric calibration	Space and 300 K IR blackbody
Field sampling	Four areas N/S on 280 μrad centers
Scan step angle	280 μrad (10-km nadir) EW
Step and dwell time	0.1, 0.2, 0.4 s adjustable
Scan capability	Full earth and space
Sounding areas	10 km by 40 km to 60° N/S and 60° E/W
Signal quantizing	13 bits, all channels
Output data rate	40 kb/s
Channel-to-channel allignment	22 μrad

Sounder Detectors Channel Allocation

Detector	Channel Number	Wavelength (µm)	Wave No. (cm^{-1})	Meteorlogical Objective and Max. Temp. Range
Longwave	1	14.71	680	Temperature (space – 280 K)
	2	14.37	696	Sounding (space – 280 K)
	3	14.06	711	Sounding (space – 290 K)
	4	13.64	733	Sounding (space – 310 K)
	5	13.37	748	Sounding (space – 320 K)
	6	12.66	790	Sounding (space – 330 K)
	7	12.02	832	Surface temperature (space – 340 K)
Midwave	8	11.03	907	Surface temperature (space – 345 K)
	9	9.71	1030	Total ozone (space – 330 K)
	10	7.43	1345	Water vapor (space – 310 K)
	11	7.02	1425	Sounding (space – 295 K)
	12	6.51	1535	Sounding (space – 290 K)
Shortwave	13	4.57	2188	Temperature (space – 320 K)
	14	4.52	2210	Sounding (space – 310 K)
	15	4.45	2248	Sounding (space – 295 K)
	16	4.13	2420	Sounding (space – 340 K)
	17	3.98	2513	Surface temperature (space – 345 K)
	18	3.74	2671	Temperature (space – 345 K)
Visible	19	0.70	14367	Cloud

Sounder Performance Summary

Parameter	Performance		
System absolute accuracy	Infared channel ≤ 1 K Visible channel ± 5% of max. scene radiance		
System relative accuracy	Line to line	≤ 0.25 K	
	Detector to detector	≤ 0.40 K	
	Channel to channel	≤ 0.29 K	
	Blackbody calibration to calibration	≤ 0.60 K	
Star sense area	21° N / S by 23° E / W		
Sounding rate	3000 by 3000 km ≤42 min		
Time delay	≤3 min		
Visible channel data quantization	≤0.1% albedo		
Infrared channel data quantization	1 / 3 specified noise equivalent radiance difference (NEΔN)		
Data timeliness			
Spacecraft processing	≤30 s		
Sounding periods		*Noon ±8 Hours*	*Midnight ±4 Hours*
Image navigation accuracy at nadir		10 km	10 km
Registration within 120 minute sounding	120 min	84 µrad	112 µrad
Registration between repeated soundings	24 h	280 µrad	280 µrad
Channel-to-channel registration		28 µrad	28 µrad

The Subsystem

The Sounder consists of sensor, electronics, and power supply modules. The sensor module contains the telescope, scan assembly, and detectors, all mounted on a baseplate external to the spacecraft with shields and louvers for radiation and heat control. The electronics module provides redundant circuitry and performs command, control, and signal processing functions and also serves as a structure for mounting and interconnecting the electronic boards for proper heat dissipation. The power supply module contains the dc / dc converters, fuses, and power control for converting and distributing spacecraft bus power to the Sounder circuits. The electronics and power supply modules are mounted on the equipment panel of the spacecraft (internal north panel).

The Sounder's multi-detector array simultaneously samples four locations of the atmosphere in 0.1-second intervals (0.2- and 0.4-second dwells at the same FOV are also commandable). Each field of view (FOV) provides output from 19 spectral channels in each sample period. Infrared (IR) spectral definition is provided by a rotating wheel that inserts selected filters into the optical path of the detector assembly; the filters are arranged in three spectral bands on the wheel. Wheel rotation is synchronized with stepping motion of the scan mirror.

A user may request by command a set of soundings that start at a selected latitude and longitude and end at another latitude and longitude. The Sounder responds to scan locations that correspond to those command inputs. The sounding frame may include the whole or any portion of the earth and the frame may begin at any time. The Sounder scan control is not limited in scan size or time; thus an entire viewing angle of 21˚ north-to-south by 23˚ east-to-west is available for star location. Sounding limits are 19˚ north / south (N / S) by 19.2˚ east / west (E / W), limited by the scan aperture and end-of-scan-line conditions. Requests for up to 16 repeats of a given location can be made by ground command. Capability is provided for interrupting a frame sequence for "priority" scans. The system will scan a priority frame set or star sense, then automatically return to the original set.

Radiometric quality is maintained by frequent (every 2 minutes) views of space for reference. Less frequent views (20 minutes) of the full aperture internal blackbody establish a high temperature baseline for instrument calibration in orbit. Further, the amplifiers and data stream are checked for stability by an electronic staircase signal during each blackbody reference cycle.

Other aspects of the Sounder are the same as for the Imager.

Operation

The Sounder is controlled by a defined set of command inputs. The instrument is capable of full earth sounding (19° N/S by 19.2° E/W) and sector sounding, including various sounding area sizes totally enclosed within the earth scene. Area scan size can be as small as one sounding location. The sounding dwell at each step is selectable to be 0.2 or 0.4 second in place of 0.1 second. An optional capability is provided for skipping scan lines to increase the rate of area sounding at a dwell time of 0.2 second per sounding.

The Sounder's flexible operation includes a star sensing capability. Once the time and location of a star is predicted, the Sounder is pointed to that location within its 21˚ N/S by 23˚ E/W field of view and the scan stopped. A separate linear array of eight silicon detectors with a 240-µrad N/S coverage, similar to the Imager, is used. As the star image passes through the detectors, the signal is sampled, then encoded and included in each Sounder data block for extraction and use at the ground station. The star sense detectors are sampled at 40 times per second.

Duplication of the four-element array in each of the three bands (longwave, 12 µm to 14.7 µm; midwave, 6.5 µm to 11 µm; and shortwave, 3.7 µm to 4.6 µm) yields the spectral separation of the infrared bands; the filters are arranged on the wheel for efficient use of sample time and optimal channel coregistration. Each detector converts the atmospheric radiance into an electrical signal that is amplified, filtered, and digitized; the resulting digital signal is routed to a sensor data transmitter, then to an output multiplexer for downlinking to a ground station.

By synchronizing filter wheel rotation with the scan mirror's stepping motion, all sampling is accomplished with the mirror in a stopped condition. Upon ground command, the scan system can generate frames of any size or location using west-to-east stepping and east-to-west stepping of 280 µrad, with a north-to-south step of 1120 µrad, continuing the pattern until the desired frame is completed. The visible channel (0.7 µm), not part of the filter wheel, is a separate set of uncooled detectors with the same field size and spacing. These detectors are sampled at the same time as the infrared channels (3, 11, and 18), providing registration of all sounding data.

By virtue of its digitally controlled scanner, the Sounder provides operational sounding from full earth scan to mesoscale area scans. Accuracy of location is provided by the absolute position control system in which position error is noncumulative. Within the instrument, each position is defined precisely and any chosen location can be reached and held to a high accuracy. This registration accuracy is maintained along a scan line, throughout an image and over time. Total system accuracies relating to spacecraft motion and attitude determination also include this allocated error.

Motion of the Imager and Sounder scan mirrors causes a small but well-defined disturbance of spacecraft attitude, which is gradually reduced by spacecraft control but at a rate too slow to be totally compensated. Because all physical factors of the scanners and spacecraft are known and scan positions are continuously provided by the Imager and Sounder, the disturbances caused by each scan motion on the spacecraft are easily calculated by the attitude and orbit control subsystem (AOCS). A compensating signal is developed and applied in the scan servo-control loop to bias scanning and offset the disturbance. This simple signal and control interface provides corrections that minimize any combination of effects. With this technique, the Imager and Sounder are totally independent, maintaining image location accuracy regardless of the other unit's operational status. If needed, this mirror motion compensation scheme can be disabled by command.

The AOCS also provides compensation signals that counteract spacecraft attitude, orbital effects, and predictable structural-thermal effects within the spacecraft-instrument combination. These disturbances are detected from star sensing and land features. Ground-developed corrective algorithms are fed to the instruments via the AOCS as a total image motion compensation signal that includes the mirror motion compensation described above.

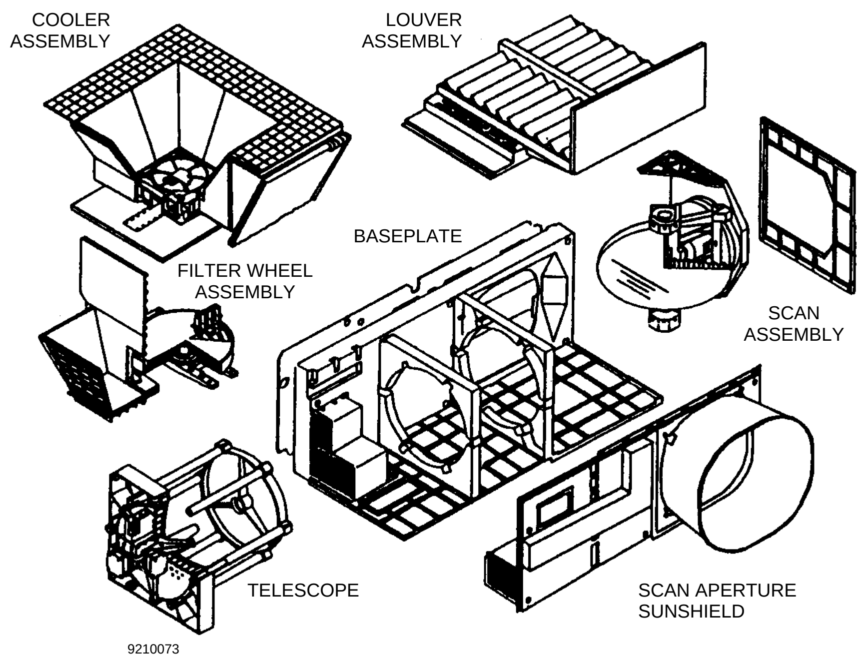
Sensor Module

The sensor module consists of a louver assembly, baseplate, scan assembly, scan aperture sun shield, preamplifiers, telescope, aft optics, filter wheel, and cooler assembly. The baseplate becomes the optical bench to which the scan assembly and telescope are mounted. A passive louver assembly and electrical heaters on the base aid thermal stability of the telescope and major components. A passive radiant cooler with a thermostatically controlled heater maintains the infrared detectors at 94 K during the winter solstice season and 101 K for the remaining portion of the year (with 104 K as backup). The visible and star sense detectors are at instrument temperature of 13 to 30 ˚C. Preamplifiers in the sensor module convert the low-level signals to higher level, low impedance outputs for transmission by cable to the electronics module.

Sounder Optics

The Sounder telescope is similar to that of the Imager. Dichroic beamsplitters separate the scene radiance into the spectral bands of interest. The IR energy is deflected toward the detectors located on the coldest stage of the radiative cooler, while the visible energy passes through a dichroic beamsplitter and is focused on the visible (sounding and star) detector elements. The SW and MW bands are reflected by another dichroic beamsplitter and the LW is transmitted through it. Optical separation of the 18 IR channels takes place at the filter wheel assembly.

Expanded View of Sensor Module

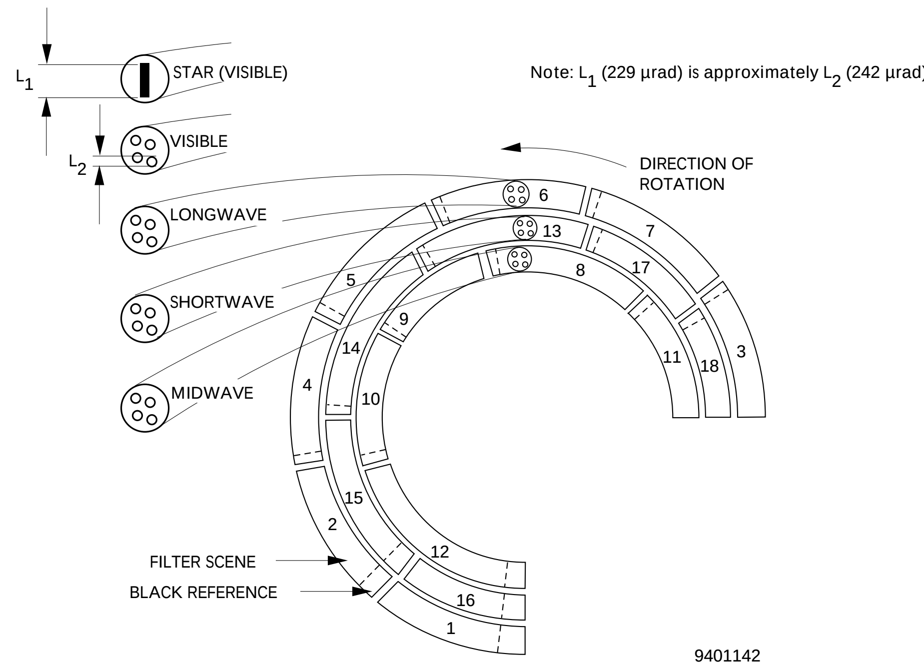


Filter Wheel

The filter wheel is a 28.2-centimeter (11.1-inch) diameter disk containing 18 filter windows divided into three concentric rings, one ring for each IR detector group. The outer ring contains seven LW channels, the middle ring contains six SW channels, and the inner ring contains five MW channels. Filter angular lengths are selected to provide nearly equal performance margin in each channel. The wheel has approximately one-fourth of its area clear of filters. By synchronizing the stepping of the scan mirror to occur in this “dead zone,” the wheel can continue rotating while the mirror steps to the next location and is stopped while the 18 channels are sampled. Stopping the mirror ensures that all channels sample the same column of the atmosphere; holding and sampling in 0.075 second provides virtually simultaneous sampling of the channels.

The first channels to be sampled are high altitude sensors that have little spatial definition and are less affected by the settling characteristics of the scan mirror. The earth surface viewing channels are grouped near the end of the sounding

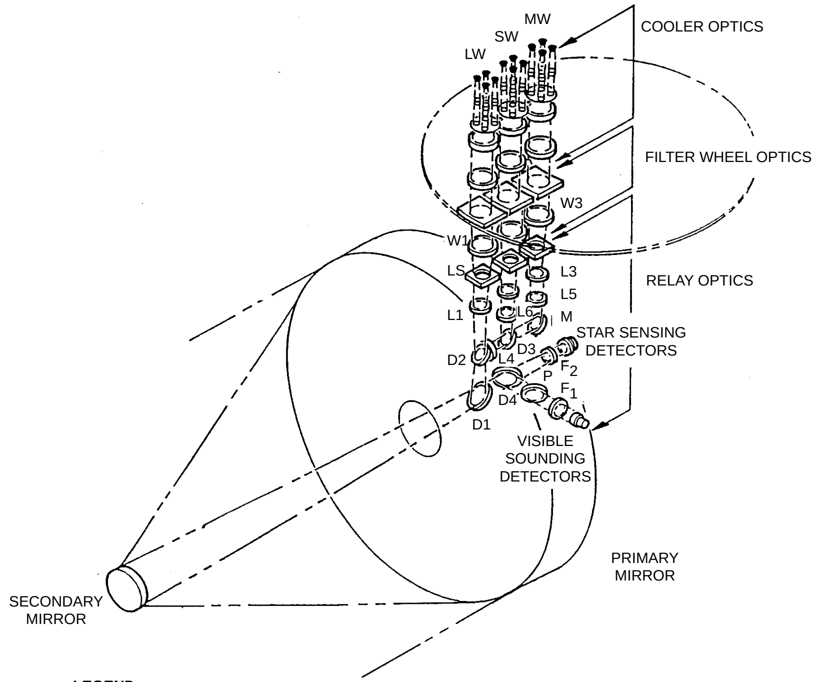
Filter Wheel and Channel Separation



period for maximum stability and coregistration. Though not viewed through the filter wheel, the visible detectors are gated so that they sample the same atmospheric column at the same time as the IR channels.

The filter wheel acts as the spectral defining element in the optics, though it also has a major effect on radiometric stability and signal quality. Each filter has a very narrow spectral bandpass, restricting the radiant input from the scene and contributions from optical parts in the path to the filter wheel. From filter wheel to detectors, there is no spectral limit other than a broadband limiting filter in the cooler. Any small deviation of radiance in this area may cause unwanted noise in the signal. To reduce emitted energy that might cause random noise and to provide very low background radiance input to the detectors, the filter wheel is cooled to 235 K. The temperature of the filter wheel housing is brought to about 238 K by thermal connection to a radiating surface. Heaters and a precision temperature control circuit maintains the housing within 1 ˚C of the set temperature.

Sounder Optical Elements



LEGEND

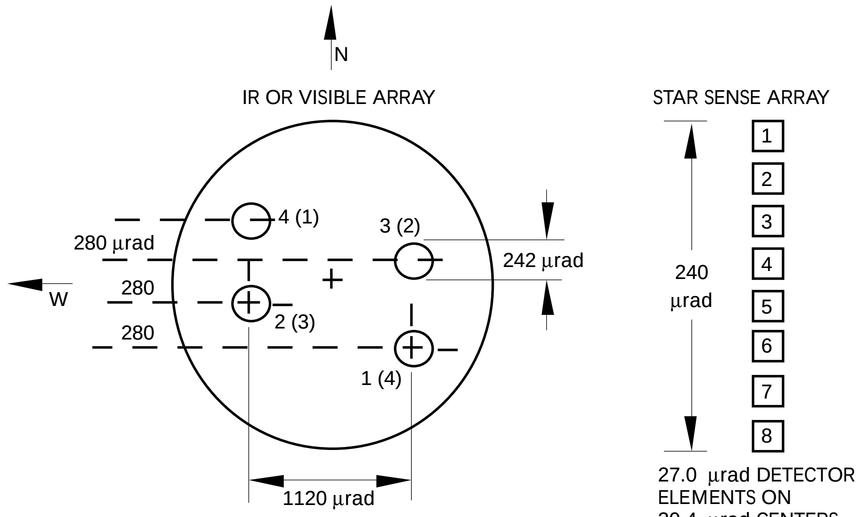
D1	Dichroic Beamsplitter, Visual/IR
D2	Dichroic Beamsplitter, LW/(SW+MW)
D3	Dichroic Beamsplitter, SW/MW
L1-L6	Intermediate Lenses
M	Folding Mirror (MW)
D4	STAR/Visual Trichroic Beamsplitter
W1	Filter Wheel, Window
W2	Filter Wheel, Window
W3	Filter Wheel, Window
F_1	Visible Filter
F_2	Star Sensing Filter
P	Depolarizing Window
LS	Lyot Stop

9608135

Detectors

The Sounder acquires radiometric data for 19 distinct wavelengths or channels through the use of four separate detector assemblies and a rotating filter wheel. This generates an 1120-μrad N/S swath that is moved latitudinally in 280-μrad (10-kilometer) steps. A fifth detector array provides the Sounder with star sense capabilities. Each of the radiometric channels is characterized by a central wavelength denoting primary spectral sensitivity. The 19 channels are broadly split into two classes: visible (channel 19) and infrared (channels 1-18).

IR, Visible, and Star Sense Detector Arrays



DETECTOR NUMBERS: ITT NO. (GVAR NO.)
NOTE: ITT LABELS THE NW DETECTOR AS NO. 4;
IN GOES VARIABLE DATA FORMAT (GVAR) IT IS
LABELED NO. 1 OR A.

Visible Channel

The visible silicon detector array (channel 19) contains four detectors having an instantaneous geometric field of view (IGFOV) of 242 µrad in diameter set by the detectors, corresponding to an 8.7-kilometer (5.4-statute mile) diameter nominal pixel size at the spacecraft suborbital point. A star sensing array, consisting of a separate set of eight silicon detectors, is on the same mount and aligned to the center of the visible sounding detectors. It is identical to the Imager visible detector array but has 0.97-kilometer (0.60-statute mile) resolution and 8.5-kilometer (5.3-statute mile) array coverage.

Infrared Channels

The IR channels (1 through 18) are contained in three detector sets: LW, MW, and SW, each set consisting of four detectors. The fields of view are set by the field stops in a pattern the same as the visible channel.

Configuration

Each of the field stop or detector patterns is arranged in the same asymmetric fashion, with a nominal focal plane configuration. The star sensing array and visible radiometric array have a clear optical path in the instrument. The three arrays dedicated to IR wavelengths (LW, MW, and SW) are optically located behind the filter wheel assembly, each handling a different region of the infrared spectrum. Although physically separated in the instrument, the four radiometric arrays are coregistered optically, resulting in automatic coalignment of the pixels for all 19 channels.

Scan Control

As in the Imager, the Sounder scans the selected image area in alternate lines (that is, west-to-east followed by east-to-west or vice versa) and is capable of scanning both north-to-south and south-to-north. However, the OGE can only ingest north to south scans, which is an operational constraint. The Sounder's scanning mirror position is controlled by two servo motors, one for the N/S angle and one for the E/W scanning angle. The position of the scanning mirror, and hence the coordinate system employed for the instrument, is measured in terms of the inductosyn outputs. Scan control for both axes is generated by establishing a desired angular position for the mirror. The desired angle is input to an angular position sensor (one inductosyn for each axis), which produces a displacement error signal. This signal is fed to a direct drive torque motor (one for each axis) that moves the mirror and sensor to the null location.

For E/W deflection, the direct-drive torque motor is mounted to one side of the scan mirror and the position-sensing device (inductosyn position encoder) is mounted on the opposite side. All rotating parts are on a single shaft with a common set of bearings. Using components of intrinsically high resolution and reliability, coupling of the drive, motion, and sensing is therefore very tight and precise. North/South motion is provided by rotating the gimbal (holding the above components) about the optical axis of the telescope. This rotating shaft has the rotary parts of another torque motor and inductosyn mounted to it, again providing the tight control necessary.

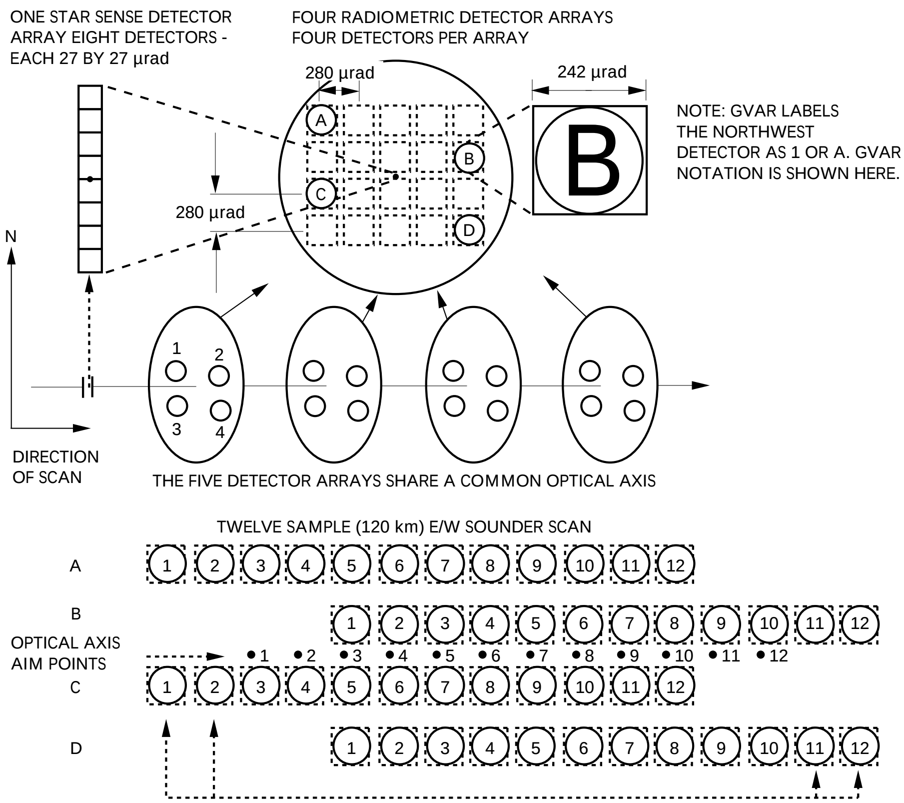
The servo system is not absolutely accurate because of noise, drag, bearing imperfections, misalignment, and imperfections in the inductosyn. Such inherent position-related errors cause pointing errors that preclude achieving the highest possible system accuracy. Slight variations of individual pole pairs cause a systematic pattern that is repeatable and measurable and can therefore be stored and subtracted to counteract the inductosyn's inherent error. This fixed error pattern and other systematic factors are measured, encoded, and stored in read-only memory. By injecting this stored error signal into the main control loop, the effect of inductosyn electromechanical errors and other systematic effects are reduced to less than one-fourth of their noncorrected values.

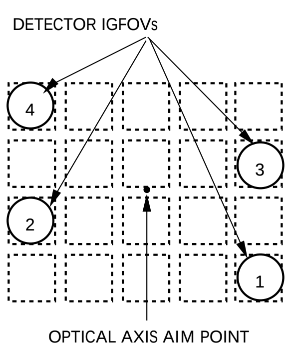
Drive and error sensing components used for the two drive axes are essentially identical. Control components are optimized for their frequency and control characteristics, and logic is developed for the precise control of position in response to a system-level control processor.

Scan Operation

Scan control is initiated by input commands that set start and end locations of a sounding frame. A location is identified by an inductosyn cycle and increment number within that cycle, the increment number determining the value of sine and cosine for that location. Each E/W increment corresponds to 17.5 µrad of E/W mechanical rotation or 35 µrad of E/W optical rotation. Each N/S increment corresponds to 17.5 µrad of N/S mechanical and optical rotation. The distance

Detector Separation and Scan Pattern





- Four Detectors Per Channel
- Each Detector Has 8.7 km (242.6 µrad) IGFOV (Maximum)
- Neighboring Detectors On 10 km (280 µrad) Centers In N/S Direction
- Neighboring Detectors On 10 km (280 µrad) Centers In E/W Direction
- Channels Aim Point For a Sample Is:
  - 20 km (560 µrad) East of 4 and 2 Detectors
  - 20 km (560 µrad) West of 3 and 1 Detectors
  - 15 km (420 µrad) South of 4 Detector
  - 5 km (140 µrad) South of 3 Detector
  - 5 km (140 µrad) North of 2 Detector
  - 15 km (420 µrad) North of 1 Detector
  - Detector Numbers As Identified In ITT Notation

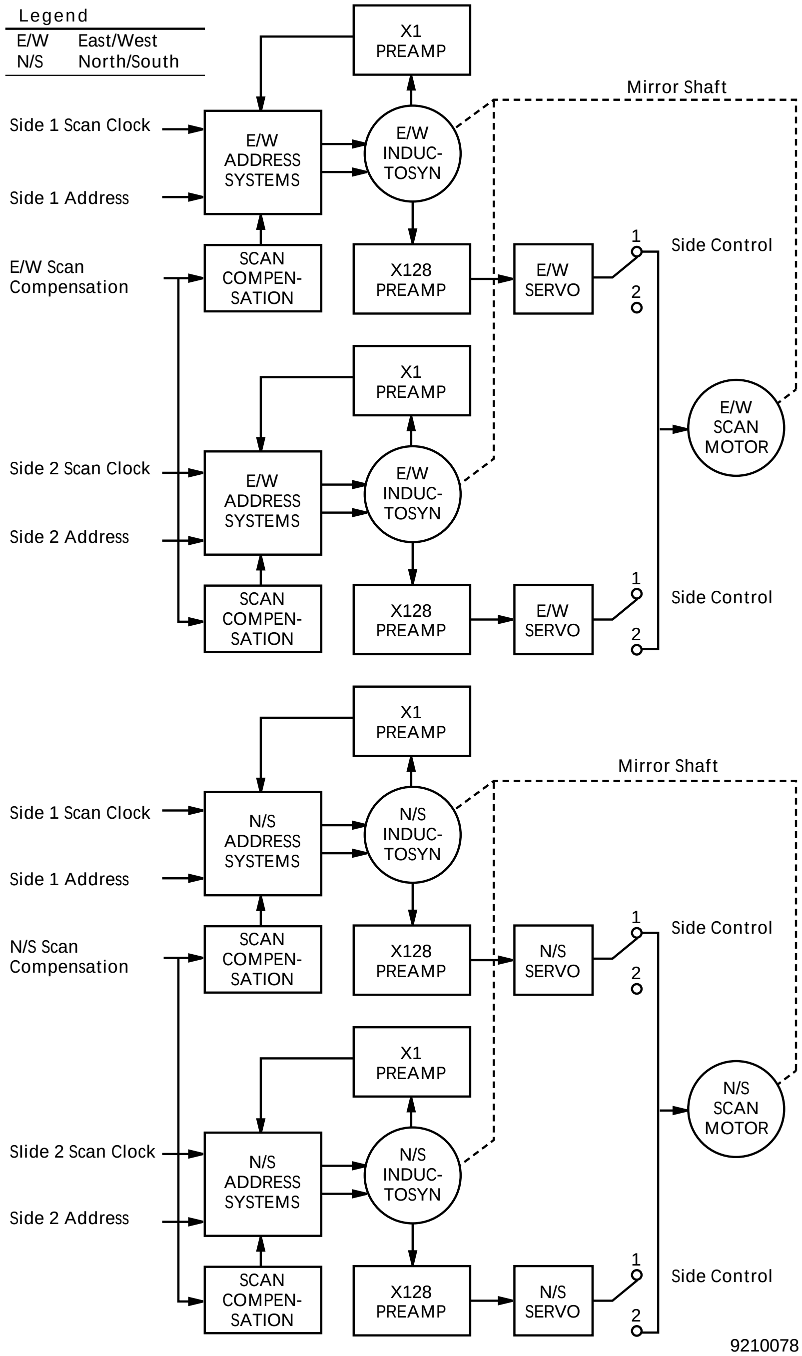
Legend

E/W	East/West
GVAR	Goes Variable Data Format
IGFOV	Instantaneous Geometric Field of View
N/S	North/South

NOTE: ITT LABELS THE NORTHWEST DETECTOR AS 4.
ITT NOTATION IS SHOWN HERE.

9401143

Scan Control Schematic



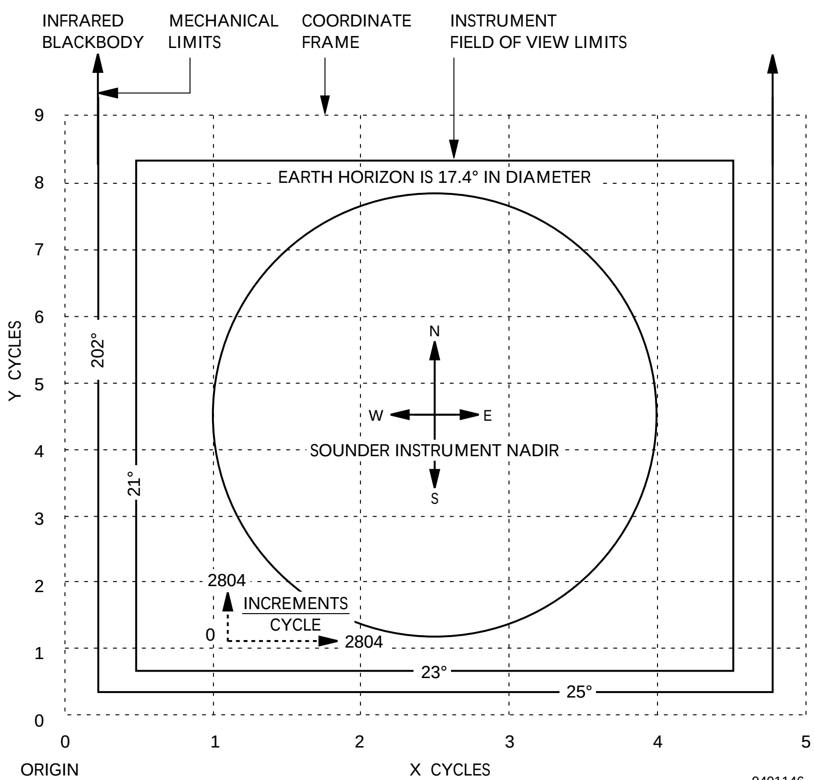
between a present and start location is recognized, causing incremental steps (17.5 μrad) at a high rate (10°/s) to reach that location. To minimize peak power demand the scan slews latitudinally, then longitudinally to a requested location.

Scan to space for space clamp or to star sensing, or to the IR blackbody uses the slew function. Command inputs (for star sensing or priority scan) or internal subprograms (for space clamp and IR calibration) take place at the proper time during a frame.

Sounding Generation

The E/W scan of the Sounder is acquired via a repeating sample-step-settle sequence that constitutes a 100 ms (single dwell), 200 ms (double dwell), or 400 ms (quadruple dwell) intervals. This is controlled by the filter wheel rotation. This step-settle sequence repeats until the end of the scan line is reached. At this point, a 100-ms interval is executed in which the mirror will be stepped 1120 μrad (40 kilometers at the spacecraft suborbital point) in the N/S direction, which is four times larger than the E/W scan step. At the conclusion of this interval, acquisition of the next scan line will be initiated in the opposite E/W direction

Sounder Coordinate Frame



using the sample-step-settle sequence. In the double (quadruple) dwell mode, two (four) detector samples are acquired at each step.

The mapping between cycles and increments and the instrument field of view are referenced to a coordinate frame whose origin is zero cycles and zero increments (southwest corner of the frame). In geostationary orbit, the earth will be centered within the frame, at instrument nadir, which corresponds closely to the spacecraft suborbital point, also centered in the frame. The GVAR coordinate system for both the Imager and Sounder is in line / pixel space and has its origin in the NW corner.

Electronics

The Sounder electronics module is similar to the Imager's, but with additional circuitry required for the filter wheel motor drive, synchronization, and channel registration. There is no coherent error integrator for the Sounder in the E / W direction, though an average error integrator (AEI) is active in the N / S and E / W directions to improve position accuracy. The AEI is a simple error correction circuit that acts upon the servo error signal to reduce that error to zero. The scan control electronics are contained in the electronics module. The servo preamplifiers are located at the scanner in the sensor module.

Signal Processing

Preamplification of the low-level IR and visible channel signals occurs within the sensor module. These analog signals are sent to the electronics module, which amplifies, filters, and converts the signals to digital code. All channels in the visible and IR bands are digitized to one part in 8192 (13 bits), the visible for high-quality visible sounding and to aid the star sensing capability, and the IR for radiometric measurement. Data from all channels move in continuous streams throughout the system; thus each channel's output must enter a short-term memory for proper formatting in the data stream. Each channel is composed of a detector, preamplifier, filter, postamplifier, analog-to-digital converter, and signal buffer. All signal chains are totally independent and isolated. Redundant chains of signal processing circuitry are provided with each circuit ending in a line driver designed to interface with the spacecraft sensor data transmitter.

Electronic Calibration

Electronic calibration signals are injected into the preamplifier of all channels while the Sounder is looking at space. Sixteen precise signal levels derived from a stepped digital-to-analog (D / A) converter are inserted during the 0.2-second spacelook. The electronic calibration signal is derived from a 10-bit converter having 0.5-bit accuracy, providing the accuracy and linearity for precise calibration. This is inserted into all preamplifiers of all channels, both visible and IR.

Visible Channels

The visible channel and star sensing detector arrays have a separate amplifier / processor for each detector element. These preamplifiers are current sensing types that convert the photon-generated current in the high impedance silicon detector into an output voltage, with a gain of about 10^8 V / A. The preamplifiers are followed by postamplifiers that contain electrical filtering and space clamping circuits. The digitization of the data signals is also part of the space clamp circuitry. The visible information is converted to 13-bit digital form, providing a range from near 0.1% to over 100% albedo for the visible channel. Differences of approximately 0.1% are discernible, and the linear digitization provides for system linearity errors of 0.5 bit in the conversion process.

Infrared Channels

The IR channels have a separate amplifier / processor for each detector element. Individual amplifiers, mounted on the cooled patch, are provided in the sensor module.

The IR information is converted to 13-bit digital form, providing a range from near 0.1% to over 100% of the response range. Each channel has a gain established for space-to-scene temperatures of 320 to 340 K. The 13-bit digital form allows the lowest calculated noise level to be differentiated. The digital system is inherently linear with analog-to-digital (A / D) converter linearity and accuracy to 0.5 bit. The binary coded video is strobed onto the common data bus for data formatting by the system timing and control circuitry.

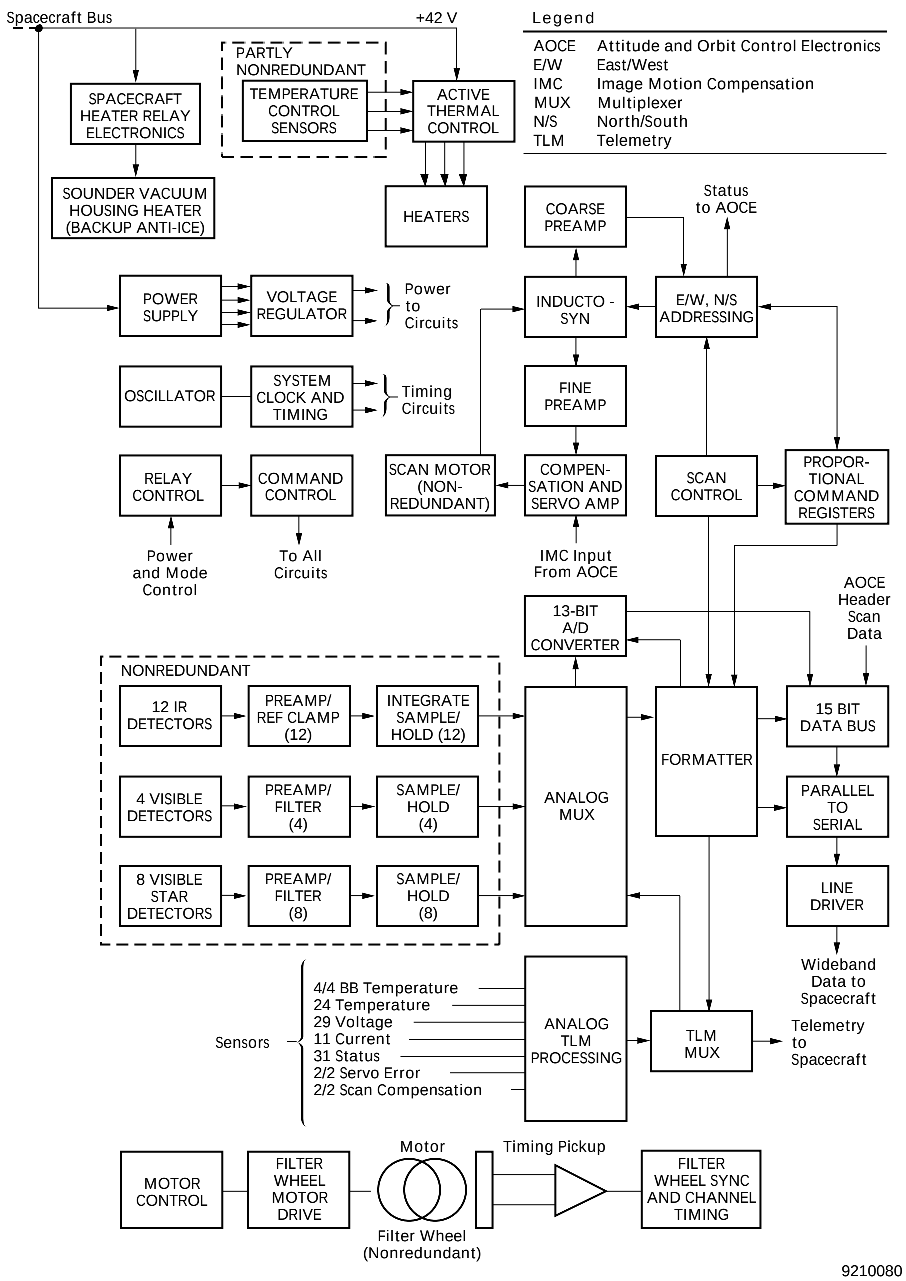
Formatting

Digital signal processing starts where data streams from the IR and visible detectors and telemetry merge via multiplexing (a parallel-to-serial conversion and data multiplexing take place to bring sensor data together). Other information, such as synchronization pulses, scan location, and telemetry data, are assembled in the data select circuitry. The data are then passed through a line driver where pulse amplitude and impedance levels are set for the transmitter interface.

A Sounder data block is transmitted during the time it takes for the filter wheel to complete one revolution (0.1 second). Unlike the Imager, there is no concept of multiple data block types that are formatted differently as a function of their data content. All of the data is contained in one Sounder data block stream, where each Sounder data block contains 250 16-bit words transmitted at a data rate of 40 kb / s or 10 blocks per second. A Sounder data block contains:

- Sounding data
- Star sense data
- Telemetry
- Header data
- Synchronization
- Attitude and orbit control electronics (AOCE) data
- Scan position
- Scan control data

Sounder Block Diagram



Power Supply

The Sounder power supply is very similar to that of the Imager. The Sounder power supply provides the additional power, control and regulation required by the filter wheel.