DMSP PRIMARY SENSOR DATA ACQUISITION

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ABSTRACT

A Data acquisition system which provides global pictorial cloud cover data for operational military meteorological purposes is described with emphasis on significant design features. These features include near constant geometric resolution through use of an oscillating scanner and variable instantaneous field of view (IFOV), thermal infrared channel output linear with temperature, visible wavelength sensitivity continuous from sub-solar to sub-lunar, along scan gain control permitting albedo images through the terminator, glare suppression enabling sensing of nighttime scenes in the presence of solar illumination on the spacecraft, wow/flutter correction of video data sampling to that of a reference scan motion, and dual geometric resolution capability from a single detector by synthesis of low resolution data.

INTRODUCTION

The Operational Linescan System (OLS) is a complete self-contained data collection system, built by the Aerospace Division of Westinghouse Electric Corporation, which serves as the primary sensor for the Defense Meteorological Satellite Program (DMSP). DMSP is a joint service program providing operational military meteorological data in a timely manner to both strategic and tactical users. Since 1976, the 5D-1 OLS has provided global cloud cover imagery in the visible and thermal infrared spectral bands. This paper describes the data acquisition of the new 5D-2 OLS which provides data nearly identical to 5D-1 with higher reliability through added redundancy.

CHARACTERISTICS OF OLS IMAGERY

Earth scene data is sensed by the OLS in two complementary spectral bands -- the visible light (L-channel) and the thermal infrared (T-channel). In each channel the scene resolution across scan is made nearly constant by use of variable IFOV in conjunction with near constant surface velocity of sensed area achieved by selection of scan motion. For global coverage the nominal smoothed mode resolution in each channel is 2.78 km; for selected regional coverage of higher resolution a nominal 0.56 km fine mode is provided in each channel.

The L-channel senses scene radiance in the 0.4 to 1.1 um spectral band for scene illuminations from sub-solar to sub-lunar at quarter moon -- a range of over ten million to one. Throughout this range, continuous adjustment of channel gain compensates for the changing scene incident illumination. By this means, useful imagery is obtained even in the terminator region where the illumination changes a factor of ten every two geocentric degrees. The L-channel output data may be made either linear or two-decade logarithmic compressed with scene radiance.

The T-channel senses scene radiance in the 10 to 13 um spectral band over the scene temperature range from 190 K to 310 K. The output data is made linear with temperature over the dynamic range.

OPTICAL SYSTEM OF THE OLS

Wideband scene radiant energy is collected by a scanning telescope selectively processed in two spectral paths by a relay optics subsystem and focused on one T-channel detector and two L-channel detectors located at three different focal planes of the optical system (see Figure 1). The L-channel detectors are a silicon high resolution diode (HRD) for daytime scenes and a photomultiplier tube (PMT) for nighttime scenes.

Scan Motion - The OLS employs a scanning telescope to scan the earth scene in the cross track direction while the forward motion of the satellite in its 833 kin circular, sun synchronous, polar orbit provides the along track incremental motion. The telescope scans in a precisely controlled sinusoidal scan motion of ±57.85° amplitude to cause the surface velocity to be nearly constant throughout the earth scan of ±1482 km cross track necessary for contiguous equatorial coverage at 833 km altitude. This scan motion has the added advantage of yielding a relatively high (0.85) ratio of active scan time to total scan time. The 101 minute orbit period and the nominal 0.56 km resolution along track constrain the frequency of scan motion to be 5.94 Hz.

Scan Drive - The scan drive, with minimal power expenditure, produces a sinusoidal scan motion with time whose amplitude and frequency are 57.85°and 5.94 Hz respectively. A high Q spring/mass torsional pendulum system provides the sinusodal scan motion. Four flat, spirally wound springs provide torque; one end of each spring is attached to the fixed structure and the other end is attached to the oscillating shaft. Matching the spring constant and the angular inertia of the oscillating assembly provides the proper scan frequency.

Since the system is mechanically resonant, frequency stability is inherent and the scan drive must only supply energy to overcome the low damping losses to maintain amplitude stability. The energy is provided by pulsing a dc torque motor twice each cycle of the scanner with a pulse whose width is controlled in a feedback loop based on scan amplitude.

Image Motion Compensation (IMC) - Because of the sinusoidal scanning motion of the OLS, received data without IMC would be distorted such that regions near the end of scan would be alternately compressed and expanded along track. Compensation has been mechanically incorporated into the scanner optics by oscillating mirror M3 ±0.4 mr in the along track direction at twice the telescope scan frequency.

Telescope - The telescope, a five reflective surface Cassegrain assembly, receives the scene radiant energy through an effective aperture of 239 cm^2. Figure 1 shows the basic optical configuration of the telescope and illustrates the size of the light bundles along the optical paths. The primary mirror (M1) is 20.3 cm, f/1.0 parabolic. The secondary mirror (M2) is hyperbolic with a focal length of -6.35 cm. The resulting telescope focal length is 122 cm. Energy reflected from M2 is intercepted by a flat mirror (M3) on the rotational center line. M3 redirects the energy at an angle of about 30° away from the rotational center line in the plane determined by the telescope axis and rotational axis. M3 also provides the IMC that converts the scan motion to rectilinear.

An elliptical mirror (M4) approximately 0.5 cm in front of the telescope image plane has a dual function: it redirects the line of sight radially inboard toward the rotational axis where the line of sight is intercepted by a flat mirror (M5) and it serves as a field stop. M5 reflects the line of sight away from the telescope assembly both coparallel to and concentric with the rotational axis. As the telescope scans, the mirror M4 traverses an arc in space. Near the end of scan in either direction, the line of sight is interrupted by calibration mirrors M4' and M4", which are near M4. These calibration mirrors direct the view from the detectors into cone shaped near-blackbody sources of known temperature for T-channel calibration. The L-channel also uses the -Z (anti-sun) calibration source as a dark reference.

Relay Optics - The configuration of the relay optics, the stationary portion of the OLS optics, is also shown in Figure 1. The wideband radiant energy received from the telescope is first split spectrally by a dichroic beamsplitter which reflects the 10 to 13 um thermal infrared energy for the T-channel while transmitting the 0.4 to 1.1 um visual and near infrared energy for the L-channel.

The T-channel energy reflected from the beamsplitter is refracted into a slightly coverging beam by a germanium lens (L1) before being directed by two flat mirrors (MT1 and MT2) along the optical axis of the T detector optics. The final T-channel optical transformation is performed by an f/1.0 germanium meniscus lens. This lens uses spherical first and second surfaces to focus the T-channel energy on the T detector through a germanium flat for correction of spherical aberration.

The L-channel energy transmitted by the beamsplitter is directed by a folded optical system utilizing two mirror surfaces to the field splitter focal point. The central core of the field of view is reflected by the field splitter into a series of lenses that focus the energy on the HRD detector focal plane. The rest of the field of view is transmitted through the field splitter into a series of lenses and redirecting flat mirrors that focus the energy on the PMT detector focal plane.

Glare Suppression - Loss of data due to on-axis scattering of incident sunlight is minimized by incorporating antiglare features into the optical/mechanical design of the telescope and by providing sunshades. Glare is suppressed in the telescope in four ways. First, the geometric configuration of the telescope limits the maximum input acceptance angle to 14°. Second, the low scatter finishes on M1 and M2 reduce the amount of energy scattered into the field of view from sources off the optical axis. Third, a field stop at M4 limits the maximum field half angle to 2.5 mr. Fourth, an aperture stop mask between M5 and the relay optics blocks glint from the edges of the hat-shaped part of the telescope, the outer edge of M1, and the support spiders for M2. M4 is an elliptical mirror that provides a soft focus of these glare sources at the mask position.

For glare suppression in orbits having sun angles between 75° and 95°, planar first surface specular mirror sunshades are mounted immediately adjacent to the aperture area of the telescope. These highly specular mirrors prevent direct impingment and minimize primary scatter of sunlight on any part of the telescope or surrounding diffuse scattering surfaces.

For glare suppression in orbits having sun angles between 0° and ±45°, the spacecraft provides an additional sunshade comprised of a large stationary opaque glare obstructor (GLOB) at the +Z (Sunward) end of the spacecraft. It projects in the +X (Earthward) direction and prevents sunlight from impinging directly on any part of the telescope or surrounding diffuse surfaces.

DETECTORS

The T detector is a two-segment Mercury-Cadmium-Telluride (HgCdTe) photoconductive detector cooled to a temperature near 108 K and maintained within ±0.1 K of the chosen set point by an active temperature, control loop using a small heater on the inner stage of a two-stage passive cryogenic cooler. The detector consists of two orthogonal elements, designated T-left and T-right.

The HRD detector is a three segment silicon photoconductive PIN diode with the N side (cathodes) common for all three elements. The dc dark leakage currents are so small below +10° C, that no cooling is required for the HRD.

The PMT detector is a cesiated GaAs (gallium arsenide) opaque photocathode, image dissector type, multiple dynode photomultiplier tube that serves as the low resolution detector for the nighttime visible wavelength energy. With the proper focusing fields in the front end (determined by the photocathode, focus, cone, and plate voltages), only photoelectrons emitted from the effective photocathode area will pass through the defining aperture hole, undergo secondary emission multiplication in the dynode chain and subsequently be collected by the anode. To vary the field of view (FOV), the image dissector magnetically deflects the defining electron aperture image referred to the photocathode. This effect, in conjunction with the physically limited (masked) photocathode area, allows IFOV control by varying the size of the overlap region between the limited photocathode area and the defining electron aperture image. The magnetic deflection is accomplished by controlling the currents in two orthogonal coils on the PMT yoke. Figure 2 shows the PMT detector aperture configuration.

Each of the detectors make use of the rotation, as a function of scan angle, of the detector image on the scene to improve the IFOV in the along scan direction. The along scan projection of the detector on the earth enlarges as the scan angle increases, due to decrease of the incident angle of the line of sight and increase in slant range, so that at the ±1482 km ends of scan the projection is six times that at nadir. At the side quarters of scan (between ±766 km and ±1482 km surface distance) only the detector segment which has a favorable along scan projection is selected to cause spatial resolution to be more nearly constant throughout the scan. The central half of the scan uses the total available detector area to improve the signal-to-noise performance in this region where projection enlargement is not a problem. Figure 3 shows segment switching for the HRD and T detectors. PMT segment switching is similar to that shown for the HRD.

ANALOG SIGNAL PROCESSING

The channel analog electronics convert the three primary detector low level electrical signals into full scale analog signals using amplification, dark level dc restoration, switching, summing, commanded gain changes, and low-pass video filtering. The analog portion of smoothed resolution data processing is simply low pass filtering to an 8 KHz instead of the 40 KHz fine mode bandwidth. Four OLS data outputs result from analog processing: L-fine (LF), L-smoothed (LS), T-fine (TF) and T-smoothed (TS). Significant amounts of commendable redundant analog hardware blocks and fallback modes are provided in the 5D-2 OLS.

L-Channel Analog Signal Processing

The L-channel block diagram is shown in Figure 4 from the detector input through the channel output to the A/D converters. After amplification, the detector signal is dc restored to the dark reference that is viewed during the -Z overscan period by the postamplifier. Selection of detector, detector segment, postamplifier and VDGA gain value are provided under processor control. Amplification may be made linear or two-decade logarithmic compressed and switching transients are suppressed before presample five pole active filters limit the LF signal to 40 KHz and the LS signal to 8 KHz bandwidth. Redundancy is provided in both normal and fallback modes.

Gain Control - The ability of the L-channel to follow the rapid decrease in scene illumination through the terminator by varying the gain of the channel in a compensating manner is called along scan gain control (ASGC). ASGC is controlled by a digital processor which determines the gain required using knowledge of scan angle, solar position data provided by the spacecraft and a stored table of gain value versus scene solar elevation (GVVSSE) which can be modified by ground command. The voltage gain is calculated over a 140 dB range in 1/8 dB steps and is dynamically composed of 30 dB in the PMT postamplifier, 46 DB in PMT/HRD sensitivity ratio, and 64 dB in the variable digital gain amplifier (VDGA) which can be varied in 1/8 dB steps. The ASGC mode is capable of following the desired gain well within 1 dB in most scenes with peak deviations of less than 4 dB under worst case conditions. The ASGC mode is backed up with an along track gain control (ATGC) mode and a preset gain control (PGC) mode. ATGC uses the gain calculated at mid scan throughout the scan and PGC relies on stored commands to establish gain.

Transient Blanking - As large blocks of gain are switched within the channel for ASGC or segment switching, some undesirable transients result. These transients are blocked out by a switching transient blanker which holds the prior video value during the transient.

Normal Operation Redundancy - In the analog hardware all circuits after the postamplifier outputs are duplicated. The redundant source selection gates, VDGA, lin/log amplifier, switching transient blanker, and LF and LS low pass filters are all identical to the primary hardware. They are continuously active and the choice of which hardware source of data outputs (LF and LS primary or LF and LS redundant) to use is made by ground command selection.

Fallback Mode Redundancy - An HRD Segment C fallback postamplifier is provided which can be selected by ground command for use across the entire scan in the event that the HRD postamplifier were to malfunction. In addition, ground command can select either

HRD left or HRD right for use across the entire scan line to bypass a failure in one detector segment, pre-, amplifier or postanplifier.

T-Channel Analog Signal Processing

The T-channel block diagram is shown in Figure 5 from the detectors through the output to the A/D converters. After amplification, the detector signal is dc restored to the known reference temperature of the clamp source that is viewed during the -Z overscan period by a gated clamp in the postamplifier. The T video from the postamplifier is shaped by a six line segment shaper function which linearizes output signal to equivalent blackbody temperature. The T left/mid/right switching for TF data is located after the shaper function so that continuous T video is available for TS data. Switching is at a high signal level so transient suppression is excellent. The T left and T right video signals from the shaper are summed into the TS five pole, 8 kHz active low-pass filter. The T right, T mid and T left switching for TF video are followed by the TF five pole, 40 kHz active low-pass filter. Again redundancy is provided in both normal and fallback modes.

Normal Operation Redundancy - In the analog hardware all circuits after the postamplifier are duplicated. The redundant buffer amplifiers, shaper networks, segment switching gates and TF and TS low pass filters are all identical to the primary hardware. They are continuously active and the choice of which hardware source of data outputs to use (TF and TS primary or TF and TS redundant) is made by ground command selection.

Fallback Mode Redundancy - If a failure occurs in one detector element, preamplifier, commandable gain amplifier or post amplifier, the opposite detector segment signal can be used across the entire scan to provide TF and TS data by ground command selection.

SCAN MOTION SIGNAL PROCESSING

Scan angle information is needed in the OLS for control of scanner amplitude, synchronization of control functions, and to enable accurate video data sampling under non-ideal scanner motion conditions.

Optical Encoder - The indication of scan angle is provided by an optical encoder that produces a series of 2049 clock pulses spaced at equal 0.98551 mr increments throughout the scan. The nominal scan is ±1024.5 clock pulses or 57.85° peak scan angle. Control pulses at the middle of scan (nadir), 146 clock pulses on the +Z side of nadir to differentiate -Z from +Z, and at ±1018 clock pulses (near the ends of scan) are used as reference positions within the scan.

The optical encoder consists of a polygon, encoder optics and an auxiliary encoder. A multifaceted polygon ring having fifteen mirror surfaces is mounted to the oscillating assembly and is “viewed” by the encoder optics which contains light sources, slits and detectors to produce clock and control pulses. A backup mode for providing control pulses is supplied by a separate light source/detector combination in the encoder optics. Since the optical generation of the encoder clock pulses can not readily be made redundant, a digital encoder simulator has been incorporated which synthesizes clock pulses from scanner control pulses. A synthetic clock track is generated by reading delay values from a read only memory. Frequency and position are corrected by the processor in order to make this synthetic clock track closely match the actual scanner motion.

Video Data Sampling Correction - A wow/flutter clock generator processes the encoder pulses and generates a clock whose frequency varies from a nominal 512 kHz as a direct function of the amount the actual scanner motion deviates from the reference scanner motion. The reference scanner motion is defined to be a sine wave of amplitude 57.85°, frequency 5.94 Hz, and zero offset. This wow/flutter clock is then divided down to frequencies appropriate for video data sampling and for wow/flutter data for ground use. The wow/flutter clock generator mechanization is that of an oscillator whose frequency is corrected in a feedback control loop which periodically compares the oscillator output count since beginning of scan to that required by the reference scanner motion at that point in scan.

SYNTHESIS OF SMOOTHED DATA

The OLS uses along scan and along track smoothing of fine data to produce a lower bandwidth video (smoothed data) without requiring a second detector. The along scan smoothing is accomplished using an analog filter which reduces the 40 kHz fine data to 8 kHz along scan smoothed data. The along track smoothing digitally integrates along-scan-smoothed data samples in five-successive-scan-line groups to produce 1.6 kHz smoothed data. The along track integration algorithm consists of a prescaler, an 8 bit A/D converter (which is shared by L and T video), a digital adder and memory and a postscaler. The prescaler is required to allow the full scale analog input to produce the full scale digital output and to allow individual data samples to exceed full scale. The digital adder works in conjunction with ping-pong memories for both L and T video. Each of the L video memories 1465 words by 8 bits in size while each of the T video memories is 1465 words by 10 bits in size. After each group of five lines is integrated, the ping-pong memories switch functions so that the one which stored partial-integration sums becomes the source for output readout and vice-versa. The digital adder for the L video has the further memory hardware saving feature of using only 8 bit memory word length. This is accomplished by truncating the 8 bit adder output to 6 bits prior to loading into the memory and by setting to 10 the two least significant bits of the 8 bit memory input to the adder for the last four lines. This method provides an L video algorithm transfer function which does not skip any output states for dc no noise inputs. Upon readout from a memory the postscaler truncates the word length by two bits to provide the required 8 bit T data from the 10 bit T memory output and 6 bit L data from the 8 bit L memory output.

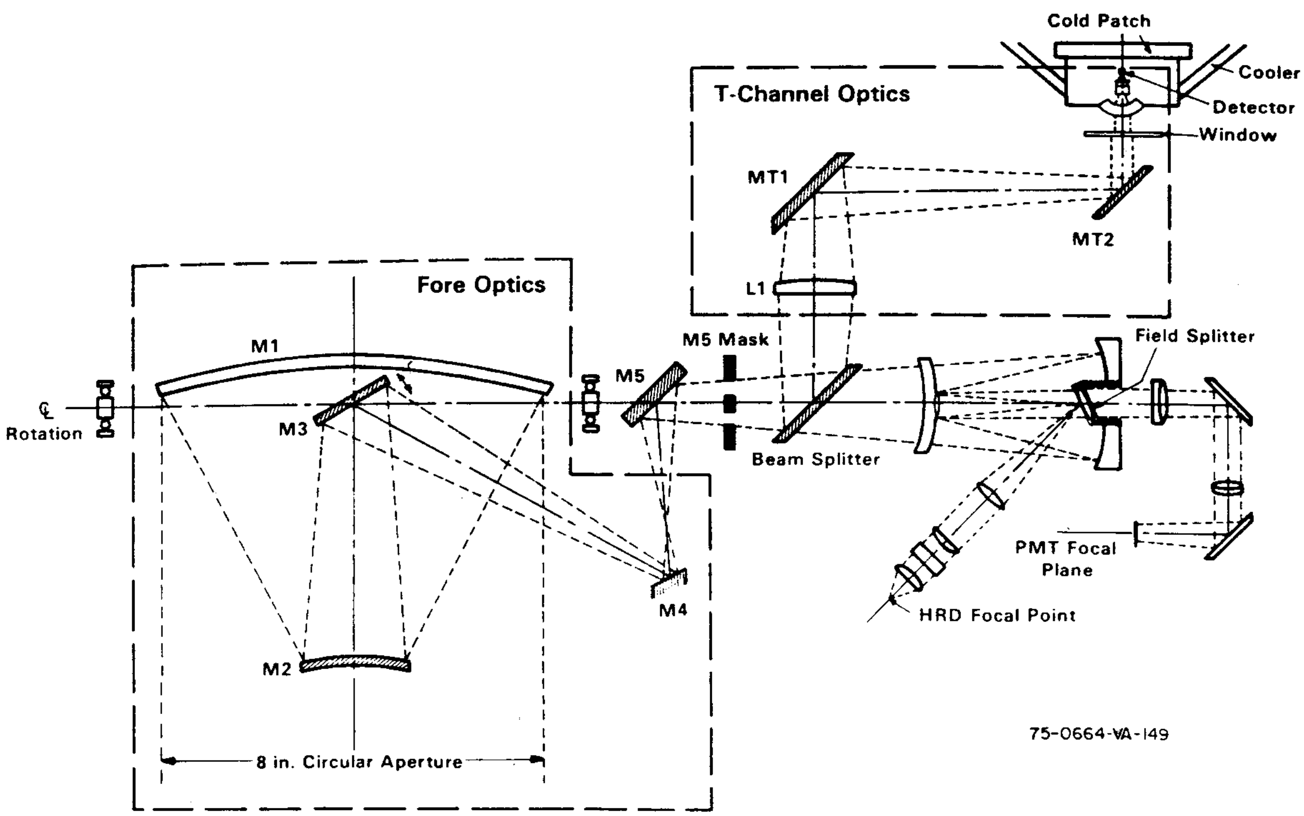

Figure 1. OLS Optics

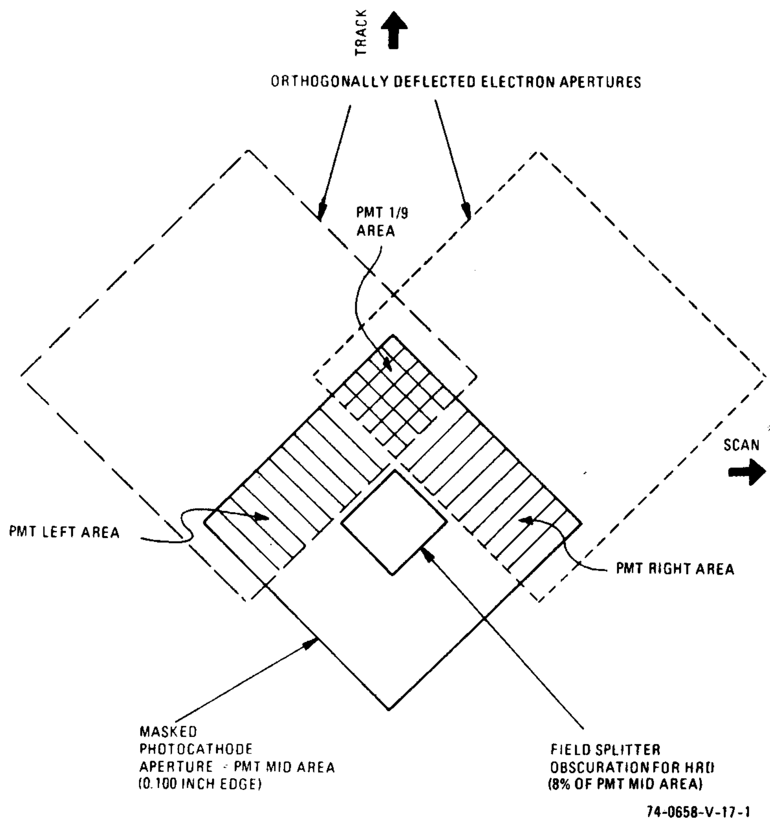

Figure 2. PMT Detector Aperture

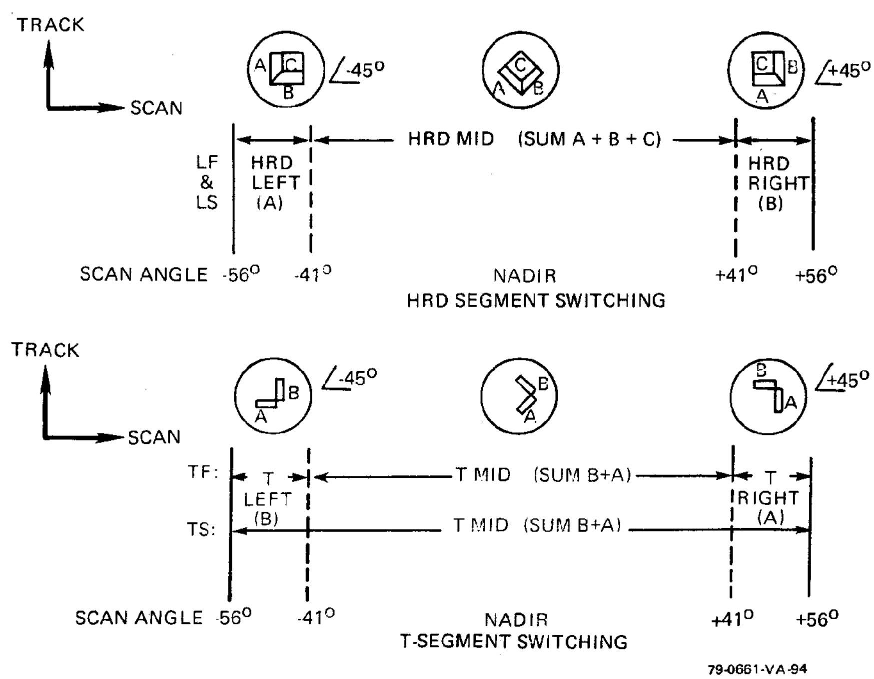

Figure 3. HRD & T Detector Segment Switching

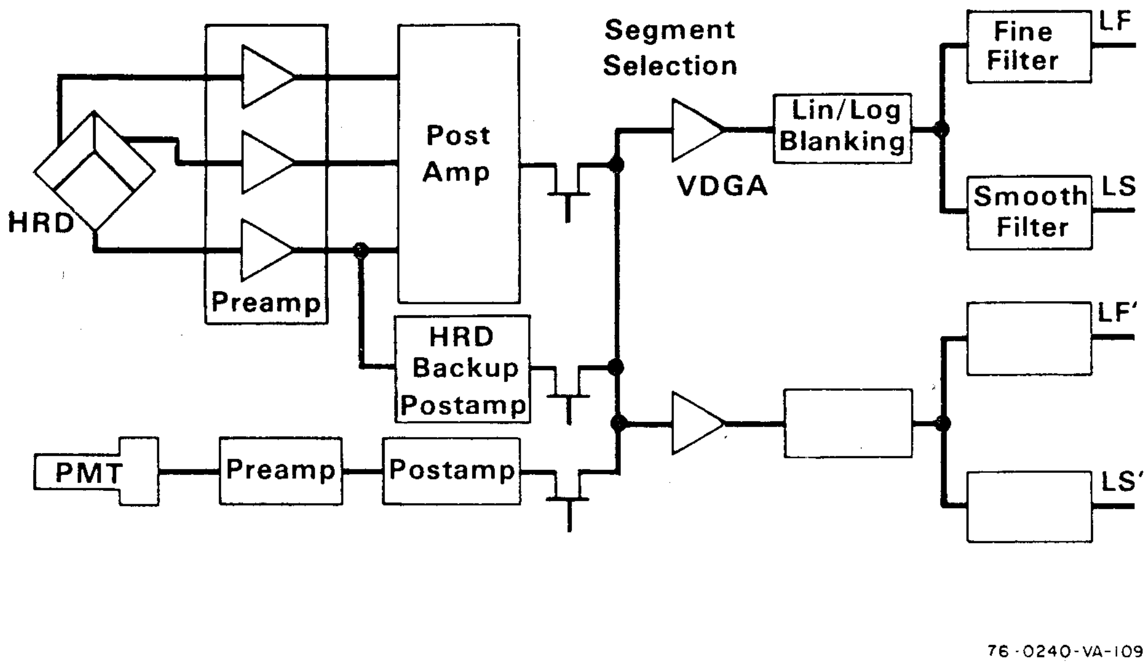

Figure 4. L-Channel Analog Processing

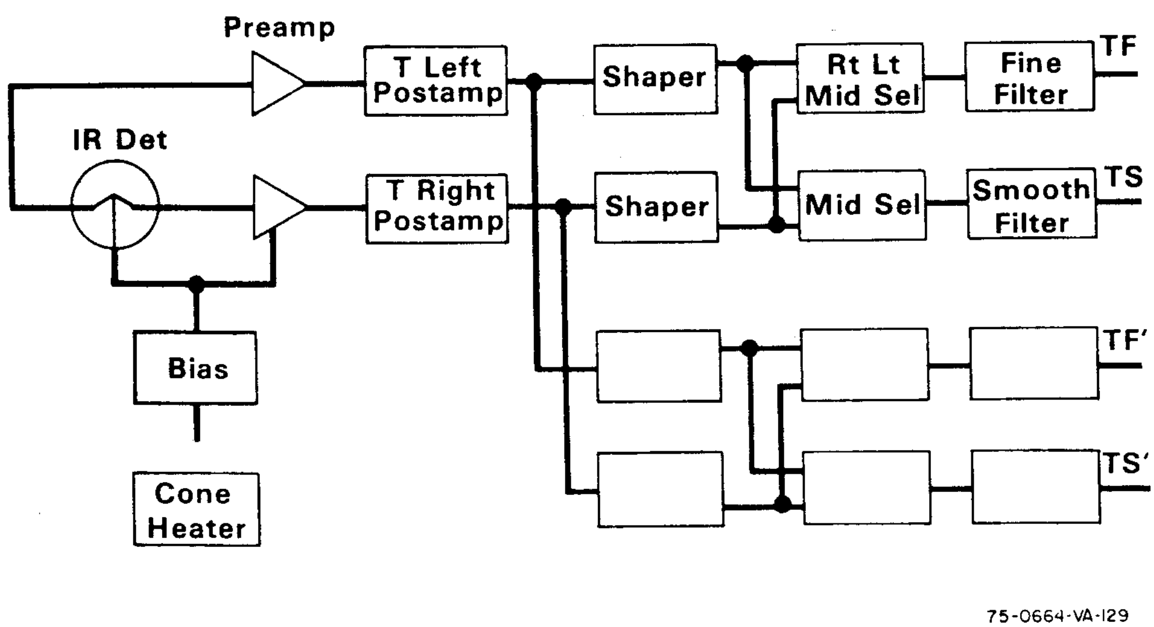

Figure 5. T-Channel Analog Processing