NOAA Technical Memorandum NESS 35

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite Service

Modified Version of the Improved TIROS Operational Satellite (ITOS D-G)

A. SCHWALB

WASHINGTON, D.C.
April 1972

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National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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MODIFIED VERSION OF THE IMPROVED TIROS OPERATIONAL SATELLITE (ITOS D-G)

Arthur Schwalb
National Environmental Satellite Service

ABSTRACT. The modified ITOS Spacecraft system will become operational in mid-1972, with the launch of ITOS-D. The spacecraft, though similar in outward appearance to previous ones in this series, will contain new sensors. Cameras are no longer a part of the sensor complement; a Very High Resolution Radiometer and Vertical Temperature Profile Radiometer will be flown for the first time. General information about the spacecraft, its orbit and its sensor complement is presented. Specific details on the real time data links are included for those planning to receive these data from the spacecraft.

The direct transmission of sensor data for local acquisition worldwide will continue. A letter sent to the World Meteorological Organization defines our plans for these transmissions.

INTRODUCTION

The Improved TIROS Operational Satellites (ITOS D, E, F, & G), the first of which is planned for launch in mid-1972, are an outgrowth of the TIROS M and ITOS development described in NESCTM 7 (1968).[1] These modified spacecraft are similar in outward appearance to TIROS M. The modifications include the addition of new sensors and attitude control systems and the removal of all vidicon camera systems and the flatplate radiometer; the Scanning Radiometer and the Solar Proton Monitor will be retained.

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[1]Albert, Edward G., "The Improved TIROS Operational Satellite" ESSA Technical Memorandum NESCTM-7, National Environmental Satellite Service, Suitland, Md., Dec. 1971, 6 pp.

The primary environmental sensors for these spacecraft are:

- A two channel Scanning Radiometer (SR) essentially the same as that on earlier ITOS spacecraft. One channel is sensitive to energy in the visible spectrum, the other to energy in the atmospheric infrared "window." This sensor will meet mission requirements for stored and real time global data, and will be used to continue the Automatic Picture Transmission (APT) service.[2]

- A Vertical Temperature Profile Radiometer (VTPR) designed to obtain measurements of the vertical temperature structure of the atmosphere. Energy will be measured at 6 discreet, narrow intervals in the 15 micrometer (μm) CO_2 region, at an interval in the 11μm window and at an interval in the 18μm water vapor region. Measurements from the 8 channels of the VTPR will be used to compute temperature profiles from the earth's surface to 100,000 feet (30,480 m).

- A Very High Resolution Radiometer (VHRR) similar to the scanning radiometer with 0.5-n.mi. (0.93-km) resolution. Sensing will be in the visible part of the spectrum and in the Infrared (IR) window region. Data from this sensor will be transmitted in real time to relatively complex "S-Band" receiving stations. Receiving stations can be located wherever desired; the U.S. will have a VHRR receiver located at each Command and Data Acquisition (CDA) station and at other locations. A limited quantity of VHRR data from each orbit will be stored in a spacecraft recorder. Stored data will be transmitted only to U.S. CDA stations for retransmission to a central location for processing.

Each spacecraft will carry a Solar Proton Monitor similar to that flown on previous ITOS. This sensor is designed to detect and count the proton and electron fluxes encountered during orbit.

LAUNCH AND ORBIT

Each of the ITOS D-G spacecraft will be launched into a sun-synchronous, 790 n.mi. (1464 km) orbit by a two-stage Delta launch vehicle. Nominal orbital elements are shown in table 1. The choice of orbit time (either 1500 local solar time northbound

[2]See appendix.

or 0900 local solar time southbound - figure 1) will be made to provide for receipt of data at the time of day that best meets operational requirements.

Table 1.--Nominal orbit parameters

Parameters	Values
Altitude (above earth surface)	790 n.mi. (1464 km)
Apogee and Perigee	790 ±25 n.mi. (1464 ±46 km)
Inclination	101.7°
Nodal Period	115.14 min
Spacecraft Sun Angle	Varies with month of launch. Should be kept between 30° and 60° during the active lifetime of the spacecraft.
Precession of Nodes	0.9857° per day (for complete sun synchronism)
Equator crossing time (northbound)	1500 or 2100 local solar time

The first stage of the launch vehicle is a modified Thor rocket, with lengthened tankage and strapped-on Castor solid rockets. The Delta second stage is the large-diameter tank version modified for programmed shut down and restart of its engines. The launch sequence is shown in table 2.

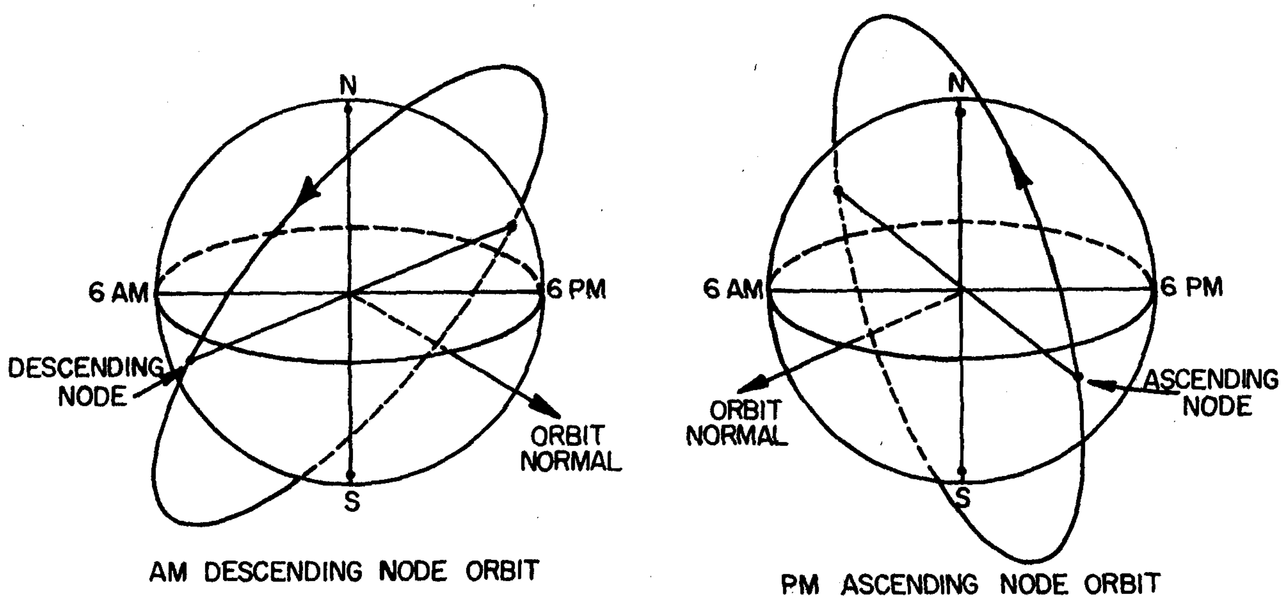

Figure 1.--ITOS Orbits

THE SPACECRAFT

The modified ITOS spacecraft (figure 2 and table 3), is a rectilinear solid, 40 in. by 40 in. by 57 in. (102 cm by 102 cm by 145 cm); a three-panel solar cell array is attached to one end. The central equipment module, or main body of the spacecraft, houses the data gathering subsystems. The baseplate and two side panels are used as mounting surfaces for the subsystems. To facilitate spacecraft integration, the side panels, used as mounting surfaces, are hinged so they can be laid flat during assembly and initial checkout. After these panels are closed during final assembly of the spacecraft, minor repairs or adjustments to the equipment can be made through access ports.

Constraints imposed by sensor field-of-view, thermal constraints, and electrical harness requirements were major factors in determining equipment location. For example, the cooler for the Very High Resolution Radiometer (VHRR) must have an unobstructed view of space, so it was placed on the side of the spacecraft that will always face away from the sun.

Table 2.--ITOS launch phases

Step	Event
1	First stage ignition and lift off. Three solid strap-on rockets ignite at lift off, the remaining 3 solids ignite about 30 seconds later.
2	The solid rockets are jettisoned.
3	First stage engine cuts off.
4	Separation of first and second stages, ignition of second stage motor.
5	Fairing separates from the second stage.
6	Second stage motor cut-off, begin coast phase of approximately one hour.
7	End coast, re-start second stage motor.
8	Second stage motor cut-off.
9	Roll jets spin-up second stage and spacecraft to add momentum to the system.
10	Spacecraft separation; second stage fires retro rockets to change its orbit to preclude interference with the spacecraft.

Stabilization

ITOS spacecraft are stabilized by a gyromagnetic control system; basic stabilization is maintained by momentum stored in the flywheel of this system. Nominally, the spacecraft rotates about its pitch axis once per orbit so the appropriate sensors always face the earth, i.e., the spacecraft is earth stabilized. Momentum transferred between the flywheel and the body of the spacecraft maintains the proper pointing accuracy. During normal mission operations, the gyroscopic stability of the wheel keeps the yaw axis aligned with the local vertical and the roll axis aligned with the orbital plane (see figure 3). An increase in flywheel speed transfers momentum from the spacecraft and causes the spacecraft body to rotate counterclockwise about the positive pitch axis; conversely, a decrease in speed will cause the spacecraft to move in a clockwise direction about the pitch axis. The exchange of momentum between wheel and body is controlled by a closed loop servo-mechanism which responds to error signals from either of the two horizon sensors. Spacecraft pitch attitude is maintained within ±½ degree. Roll and yaw-axis orientation change slowly because of the torque effects caused by the earth's magnetic field. Electrical coils in the spacecraft work to counteract this force and maintain the proper orientation. A stable earth-oriented platform is provided for the sensors by this three-axis orientation control system.

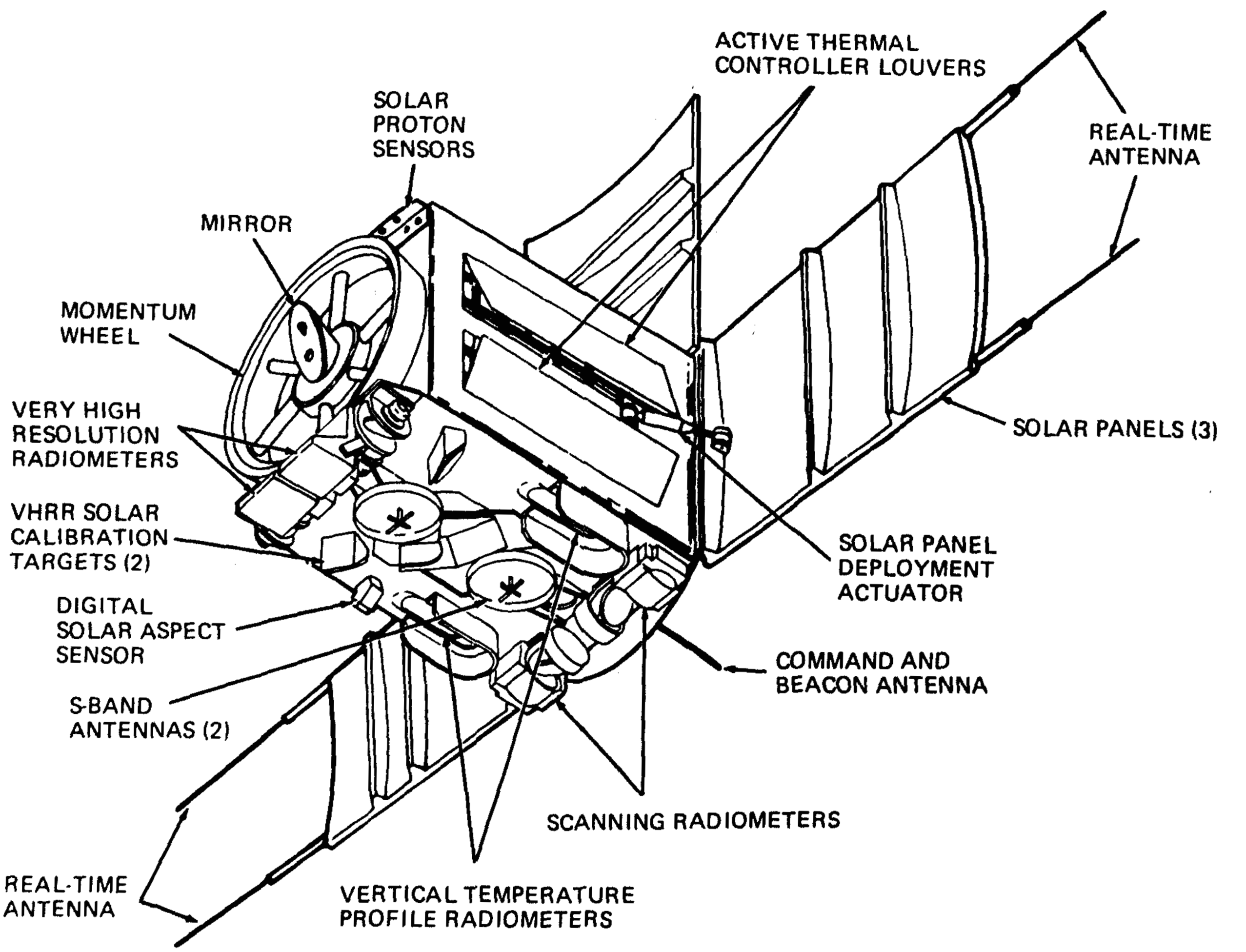

Figure 2.--External features of modified ITOS spacecraft (courtesy of RCA Corp.)

Table 3.--ITOS D-G summary sheet

Spacecraft - total weight	741 lb (336 kg)
Sensors - weight including tape recorders	220 lb (100 kg)
Primary sensors	
2 scanning radiometers	Fully redundant system
2 vertical temperature profile radiometers	Fully redundant system
2 very high resolution radiometers	Fully Redundant system
Secondary sensor	
1 Solar proton monitor	
Spacecraft body size	40" x 40" x 49" (102 cm x 102 cm x 125 cm)
Solar panel size	65" x 36" (165 cm x 91 cm) 3 panels/ spacecraft
Power requirement-full operation	Approximately 150W
Lifetime	
Design	6 months
Goal	1 year

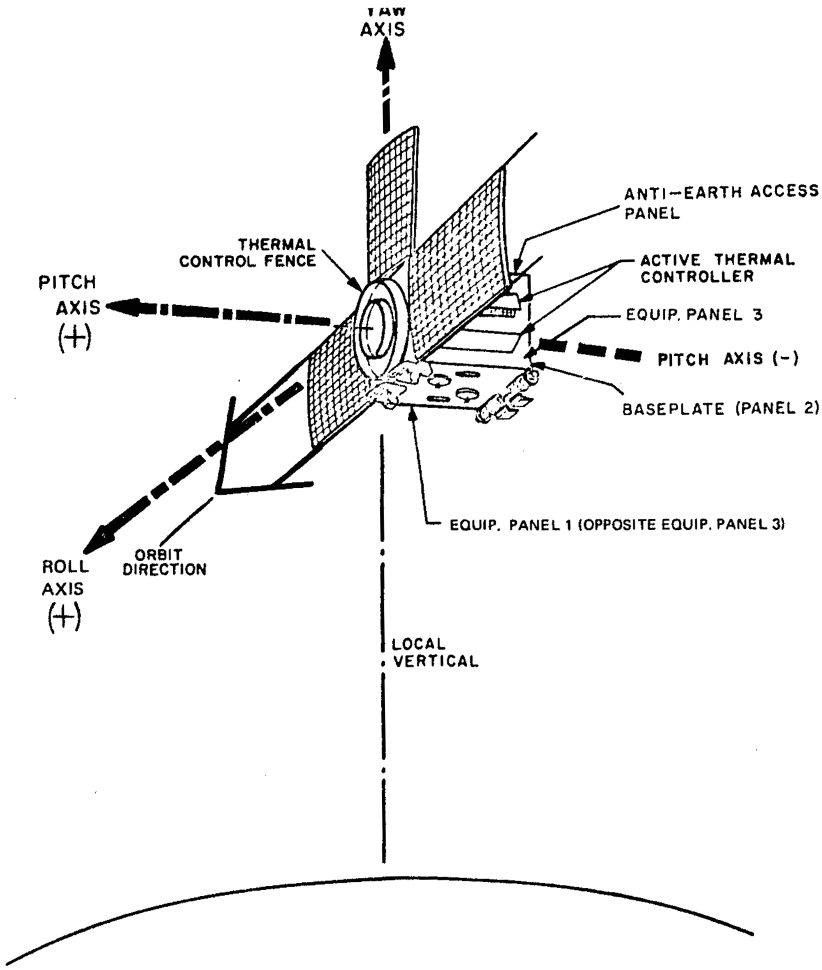

Figure 3.--ITOS spacecraft orientation

Thermal Control

Thermal control is provided by both active and passive elements. The passive element, a thermal control fence, consists of flat mirrors mounted on the sun-facing end of the spacecraft. Two flat metallic strips formed into cylindrical rings are mounted concentrically on these mirrors (see figure 3). These rings are painted black to absorb heat. As the solar incidence angle decreases (high gamma angles), the spacecraft would normally cool; however, in this attitude the black surface is well illuminated, so it absorbs and conducts heat to the spacecraft structure. At solar angles where the spacecraft is normally warm, the mirrors reflect excess heat.

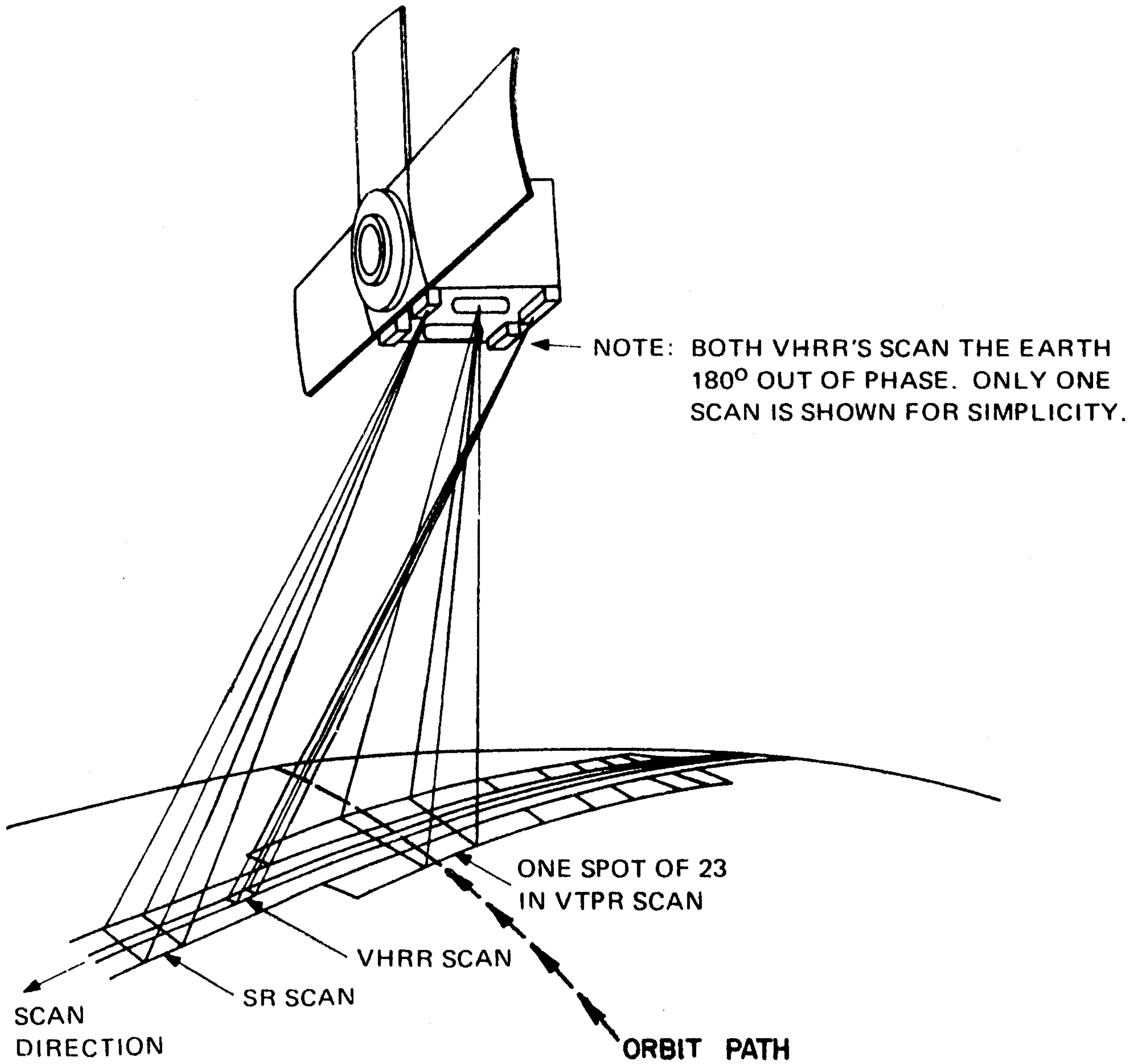

Figure 4.--Modified ITOS spacecraft in operational mode showing sensor field of view

The active elements, mounted on the equipment panels, consist of two sets of louvers, each driven by a thermal actuator sensor. The louvers open and close in response to changes in the spacecraft temperature, thus varying the effective area of uninsulated radiating surface. These elements maintain the temperature of the equipment panels within acceptable limits.

Power

The ITOS D-G solar array, essentially the same as the ones used for ITOS 1 and NOAA 1, consists of three panels, each 36½ in. (92.71 cm) wide and 65¼ in. (166.14 cm) long. In space, these panels lie in the orbital plane with the solar cells facing the sun. Each panel is covered with approximately 10,000 $2cm^2$ boron-doped N-on-P solar cells that convert sunlight into electrical energy. This power is used to operate the subsystems and to re-charge the nickel cadmium batteries; battery power is used to support short term heavy power loads and nighttime operation.

SCANNING RADIOMETER

The Scanning Radiometer (SR) is a two-channel scanning instrument sensitive to energy in the visible spectrum[3] 0.5 to 0.7 μm and in the infrared (IR) window region 10.5 to 12.5 μm. The instrument was designed to operate on a sun-synchronous spacecraft in a 790 n.mi. (1464 km) orbit. Energy is gathered by a 5-inch (12.7 cm) eliptical scan mirror with a plane surface area of 100.4 cm^2 (15.6 $in.^2$). The scan mirror is set at an angle of 45^o to the scan axis and rotates at 48 rpm; a Cassegrainian type optical system (figure 5) focuses the energy. After being transmitted through the dichroic beam splitter and relay lens the infrared window radiation is collected into a thermistor bolometer, the size of which (5.3 milliradians) defines the Instantaneous Field of View (IFOV).

The dichroic beam splitter reflects the visible energy which is focused on and detected by a silicon photo voltaic detector. The size of the detector, together with a field stop, limits the IFOV to approximately 2.8 milliradians (mr).

A sun shield keeps direct and reflected solar radiation from entering the field of view of the instrument.

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[3]On later spacecraft it is planned to change this range to 0.4 to 1.1 μm to provide a better delineation of land-water boundaries.

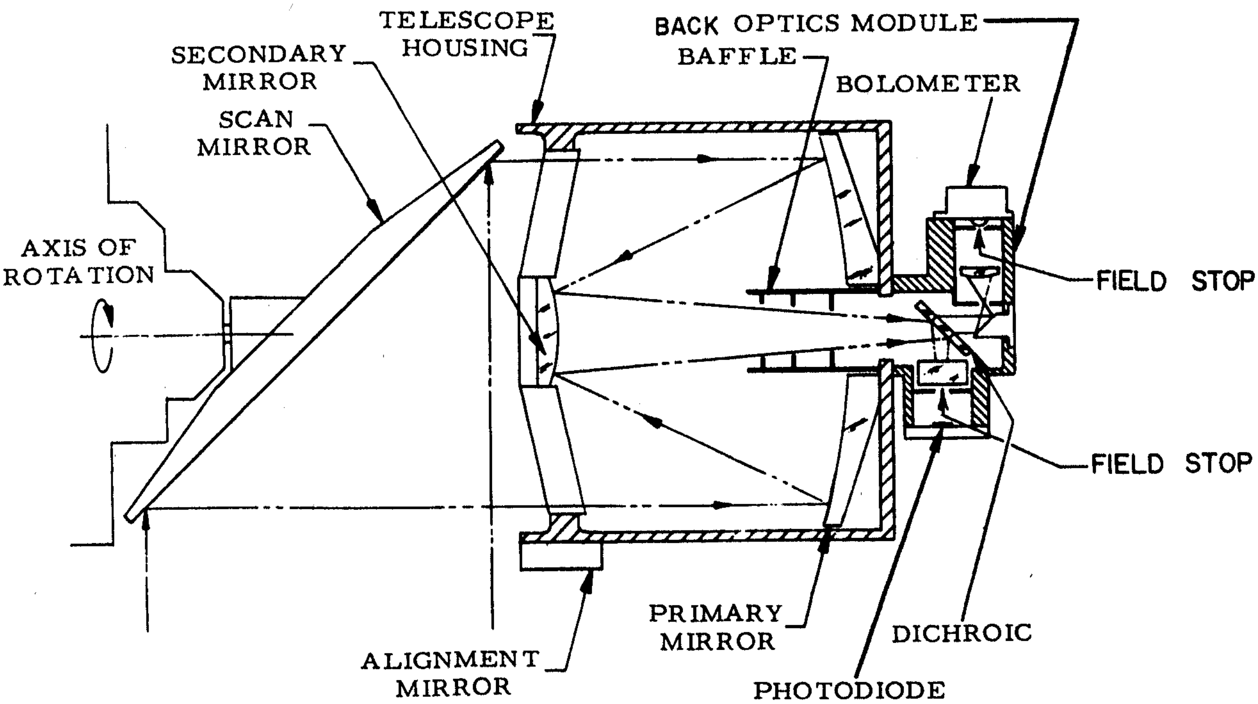


Figure 5.--Optical schematic, ITOS scanning radiometer (courtesy of Santa Barbara Research Center)

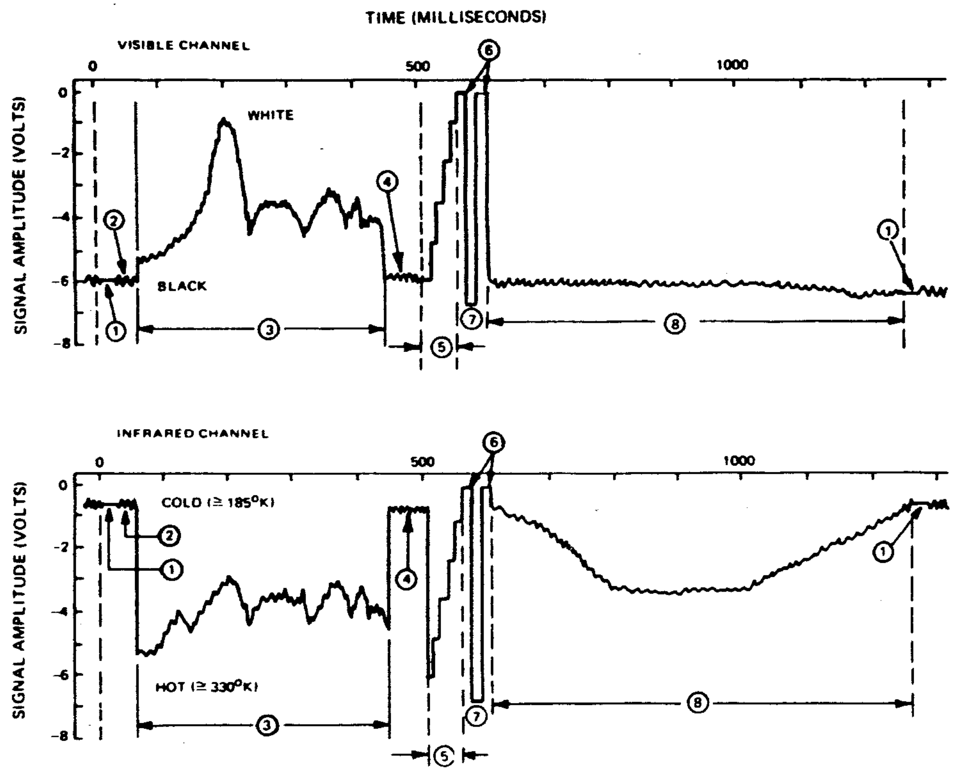
Coverage And Resolution

The SR is a line scan device; global coverage is achieved from continuous horizon-to-horizon cross-track scanning by the mirror combined with the forward motion of the spacecraft. Since the mirror rotates at a constant angular rate, the geometric resolution on the ground changes as the distance from the subsatellite point increases; a picture produced from these signals will appear foreshortened in the area of the horizons. The 5.3 mr IFOV of the infrared channel provides a ground resolution of approximately 4 n.mi (7.5 km) at the subpoint. Successive lines are contiguous at the subpoint and overlap as the distance from the subpoint increases. In equatorial regions, contiguous data from successive orbits will occur at a point about 900 n.mi. (1668 km) from the subsatellite point; at this point the data zenith angle is 60° and the IFOV spot covers about 8 n.mi. by 12 n.mi. (15 km by 22 km). The visible channel, with a 2.8 mr IFOV produces a 2 n.mi (4 km) spot at the subpoint; this spot size increases to approximately 4 n.mi. by 8 n.mi. (7.5 km by 15 km) at the equatorial contiguity point. It should be noted that there will be a 2 n.mi. (4 km) "gap" between visible channel data lines at the subpoint. The gap will not be apparent in the display and will disappear entirely at distances more than about 750 n.mi. (1385 km) from the subpoint.

Data Format

The radiometer views the earth during approximately 1/3 of the period required for one full mirror rotation. During the remaining 2/3 of each rotation the mirror views space and instrument housing; during this time telemetry and synchronization data are inserted in the data stream. The discriminated data output for the infrared and visible channels of the ITOS D through G radiometers is shown schematically in figure 6.

Once each scan, while the instrument is viewing space, the baseline of detected signals is restored to a pre-set zero level. The output of the radiometer during the remainder of the scan (earth viewing) then is equal to the difference in detected energy between the zero-point and the radiating (reflecting) surface. In operation, the anti-sun side horizon, where restoration of signal baseline occurs, is well defined and provides a zero radiance level for calibration purposes. The sun side horizon is evident in the data but the output level is indeterminate since the warm sun shield gradually enters the



1	AMPLIFIER RESTORING PERIOD	20 MILLISECONDS
2	OUTER SPACE SCAN	41 MILLISECONDS
3	EARTH SCAN	378 MILLISECONDS
4	SPACE SCAN	61 MILLISECONDS
5	VOLTAGE CALIB. SIGNAL	50 MILLISECONDS
6	FRONT & BACK PORCH (A)	10 MILLISECONDS (EACH)
7	SYNC PULSE	30 MILLISECONDS
8	BACK SCAN	650 MILLISECONDS

(A) FOR SYNC PULSE

Figure 6.--SR sensor-radiometer output signal characteristics. These signals are inverted before transmission so that cold clouds will appear white when displayed at the local station.

field of view of the instrument and changes the output level. This signal level restoration technique, using cold space as a reference, effectively removes the effect of self-emission of the optics.

Radiometer Performance

The IR channel data of the SR may be used to determine the equivalent black body temperature of the radiating surface. The ability to determine this temperature accurately is characterized by the instrument noise equivalent differential temperature (NE Δ T). For practical purposes, NEΔT may be considered as the temperature differential that can be discerned by the instrument when scanning from one uniform black body to another. In actuality, it is the blackbody energy differential of the target which, when sensed by the instrument, is equal to the root mean square (rms) noise level. When measuring warm targets, the NEΔT's will be significantly lower (better) than when measuring cold targets since the instrument response is linear with input energy and system noise is not affected by target temperature. System noise, and therefore NEΔT, is affected by the temperature of the radiometer itself so that no single number can be used to fully define the system NEΔT. For this reason, published NEΔT's are usually general and represent conditions at a nominal or worst case instrument operating temperature. When the bolometer temperature is 25°C (77.0°F) and the scene temperature is 300°K (80.6°F) (27°C), the NEΔT is approximately 0.3°C (0.5°F); with the scene at 185°K, (-126.4°F) (-88°C), the NEΔT degrades to approximately 1.4°C (2.5°F) (both values determined at the instrument output). Unfortunately, the spacecraft data link (tape recorders in particular) and ground handling of data further reduce the NEΔT. A realistic estimate of NEΔT for the 300° K target with bolometer at 25°C is 2 to 3 C° (3.6 to 5.4 F°), for the 185° K target, 8 to 10 C° (14.4 to 18.0 F°). The link analysis for a VHF receiving station is shown in table 7. Statistical processing of temperature data from a relatively uniform radiating surface (such as the sea surface) can reduce these uncertainties somewhat.

Automatic Picture Transmission (APT) Service

For recording on the spacecraft recorder and for transmission to the local APT stations, the two channels of data, together with appropriate synchronization and telemetry from a single instrument, are combined into a single data stream. One channel of data will be transmitted during the time the scanner mirror rotates through 180 degrees (0.625 seconds). The alternate channel is transmitted during the remaining 0.625 seconds of the 360 degree mirror rotation. In practice this will be accomplished by transmitting the infrared window data directly from the radiometer; the visible channel data from the same scanner will be tape recorded and played back one-half spin period (0.625 seconds) later. Table 4 contains the data timing information for the Scanning Radiometer APT transmission. This same information is shown schematically in fig. 7. Transmission link characteristics are summarized in tables 6, 7, 8, and 9.

It should be noted that:

1. Seven pre-earth synchronization pulses (300-Hz rate) precede each set of data (IR and visible).

2. The post-earth synchronization porches (zero-level signals before and after the synchronization pulse) are 10 milliseconds in duration; the synchronization pulse itself is 30 milliseconds (this is one-half the duration of previous systems).

3. The telemetry window (time period allotted for transmission of calibration data) for the IR channel (see E, figure 7) will consist entirely of voltage calibration steps (five steps, six levels, each of ten millisecond duration); the visible channel telemetry window (see E', figure 7) will consist of 25 lines, 11 of which will contain telemetry data for calibrating the IR output. The remaining 14 lines will be voltage calibration steps. The SR telemetry window assignments are shown in table 5.

Table 4.--ITOS D-G data timing for real-time direct readout SR APT transmission

	Sequence	Time after start of 7 sync pulses (milliseconds)	Duration (milliseconds)	Characteristics
1.	Start sequence (IR) 7 sync pulses	0.0	23.31	7 pulses, 300 Hz square wave, 100% amplitude
2.	Space scan (pre-earth)	23.31	24.47*	96% amplitude
3.	Earth scan (IR data)	47.78*	377.78*	At 900 n.mi. the period would be 364 milliseconds At 600 n.mi. (1112 km) the period would be 406 milliseconds Range 4% to 96% amplitude
4.	Space scan (post-earth)	425.56*	61.11*	Near 90% amplitude increasing as the sun shield enters the field of view
5.	Telemetry window	486.67±3.0	50±3.0	Voltage calibration steps
6.	Back porch	536.67±6.0	10±1	Amplitude 100%
7.	Playback synchronization pulse	546.67±7.0	30±2	Minimum amplitude (2 to 4%) used primarily for central processing of global data
8.	Front porch	576.67±9.0	10±1	Amplitude 100%
9.	Back scan and overlap allowance	586.67	23.23	
10.	Sync delay	609.90	15.10	Spaceview used for instrument restore (VSBL)
11.	Start sequence (VSBL) 7 sync pulses	625.00	23.31	Same as IR
12.	Space scan (pre-earth)	648.31	24.47*	4% amplitude
13.	Earth scan (Visible data)	672.78*	377.78*	Same period as IR scan. Range 4% to 100%
14.	Space scan (post-earth)	1050.56	61.11	4% amplitude. Scan will gradually include the sun shield which will also be a 4% amplitude
15.	Telemetry window	1111.67±3.0	50±3	See separate listing table
16.	Back porch	1161.67±6.0	10±1	Amplitude 100%
17.	Playback synchronization pulse	1171.67±7.0	30±2	Minimum amplitude (2 to 4%) used primarily for central processing of global data
18.	Front porch	1201.67±9.0	10±1	Amplitude 100% level
19.	Back scan and overlap allowance	1211.67	23.23	
20.	Sync delay	1234.90	15.10	Spaceview used for instrument restore (IR)
21.	Start IR 7 sync pulses	1250.0(0.0)		End of one full (360°) mirror rotation

*Assumes: S/C altitude 790 n.mi. Roll angle = zero. Full (100%) amplitude is equivalent to that of the porch levels. ± tolerances are within the radiometer but are fixed for a particular instrument.

Table 5.--SR telemetry window data

Scan line* number	No. 1 Window - IR portion	No. 2 Window - Visible portion
1	Voltage calibration steps[e]	Spacecraft time code[a] (16 most significant bits)
2	"	600 Hz Marker[b]
3	"	4% signal level calibration[c]
4	"	82% signal level calibration[c]
5	"	Housing back scan sampled[d]
6	"	Spare
7	"	Voltage calibration steps[e]
8 through 20	"	Both windows
21	"	Scanner electronics temperature[g]
22	"	Electronics module temperature[g]
23	"	SR housing ref. D. temperature[f]
24	"	SR housing ref. C. temperature[f]
25	"	Spare

*See E and E' in figure 7. Data lines are numbered sequentially from 1-25 for convenience.

a These data will not be useful to the real-time stations. The time encoded here will be a spacecraft reference only and will indicate the elapsed time since the clock was last updated.

b Used to delineate between IR and visible channels for global analysis programs.

c Electronically generated data levels which should be constant throughout the life time of the system. Actual data level (voltage) will depend upon the system in use at the local station. Percentage values are only approximate.

d IR channel radiometer output while viewing the instrument housing whose actual temperature is indicated by thermocouples (lines 23 and 24). These data can be used to calibrate the instrument in flight. Curves will be provided to those users requiring this information.

e Five steps (6 levels of data).

f Thermocouple output voltage can be converted to housing temperature. The output of the IR channel of the radiometer when viewing this area is transmitted in Telemetry Window no. 5 (Visible Channel).

g Used for engineering evaluation of the instrument.

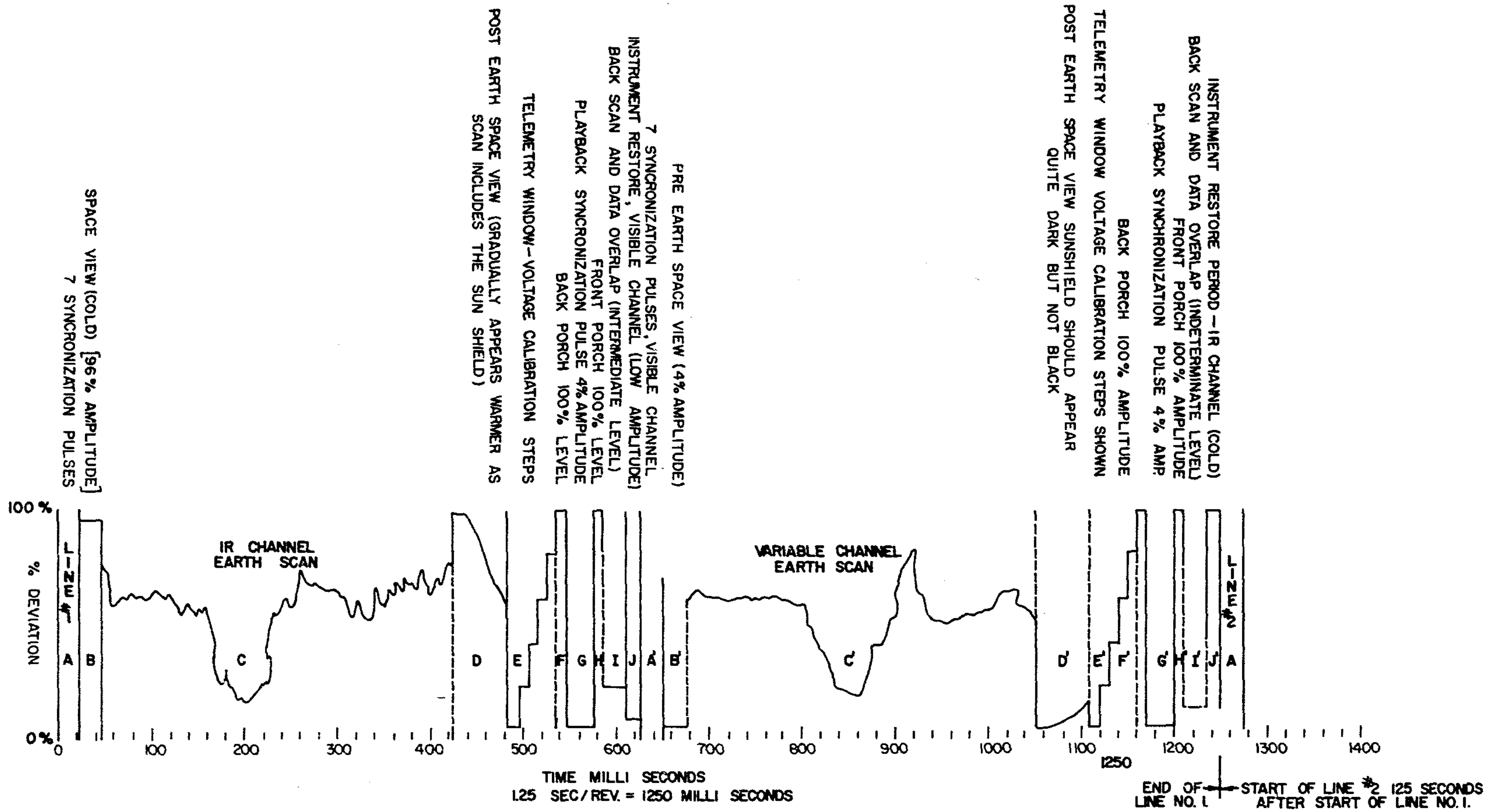


Figure 7.--SR sensor-APT signal characteristics

Table 6.--Characteristics of VHF APT transmission

Element	Description
Frequency	137.50 or 137.62 MHz ±0.005% -- 2 possible transmission frequencies are assigned to eliminate possible interference when 2 spacecraft are near the same areas at the same time. Only 1 frequency will be used at one time. Notification of the assigned frequency will be given in the "APT Predict" message
Transmitter power output	5 watts minimum
Antenna polarization	Linear
Carrier modulation	FM
Peak carrier deviation	9 ±1 KHz
RF spectrum bandwidth	27.2 KHz
Subcarrier center frequency	2400 ±0.014 Hz
Subcarrier modulation	AM
Peak subcarrier modulation	90%
Baseband video bandwidth (design)	IR data 450 Hz Visible data 900 Hz

Table 7.--VHF APT real-time link performance summary
Estimated overall system S/N* op real-time SR
data at local station (P-P video† RMS noise)

Contributing Element	5% Elev IR data‡	5% Elev Visible Data§	Nominal (20° Elev) IR data‡	Nominal (20° Elev) Visible Data§
SR sensor	45 dB	44 dB	49 dB	66 dB
SR processor	47 dB	47 dB	52 dB	52 dB
SR recorder (delayed VIS)	N/A	36 dB	N/A	40 dB
VHF RT transmitter	47 dB	47 dB	52 dB	52 dB
RF link	37.5 dB	34.4 dB	45.6 dB	42.4 dB
Ground receiver (est.)	47 dB	47 dB	52 dB	52 dB
Demod (est.)	47 dB	47 dB	52 dB	52 dB
Overall system S/N				
Normal mode (IR + VIS)	35 dB	31 dB	42 dB	37 dB
Backup mode (IR or VIS)	35 dB	33 dB	42 dB	41 dB
Equivalent NEΔT				
@ 185°K	9.3°K	N/A	4.2°K	N/A
@ 300°K	1.9°K	N/A	0.8°K	N/A

*S/N - Signal to Noise ratio

†Peak to Peak-video dynamic range (increase S/N numbers by +2.0 dB if referenced to sync pulse amplitude)

‡450 Hz baseband bandwidth

§900 Hz baseband bandwidth

Table 8.-- VHF (APT) real-time link

Parameter	Worst Case	Nominal
Transmitter power	+37.0 dBm (5W)	+38.0 dBm (6.3W)
Transmitting circuit losses	-1.8 dB	-1.3 dB
Transmitter antenna gain	-3.5 dB	-1.0 dB
Polarization loss	-3.0 dB	-3.0 dB
Path loss	-147.4 dB (5° elev)	-144.4 dB (20° elev)
Receiver antenna gain	+12.5 dB	+12.5 dB
Receiver circuit losses	-1.0 dB	-1.0 dB
Received power	-107.2 dBm	-100.2 dBm
Effective noise temperature = 1692°K		
Predetector noise bandwidth = 50 kHz		
Equivalent noise input	-119.3 dBm	-119.3 dBm
C/N ratio	+12.1 dB	+19.1 dB
Threshold	+12.0 dB	+12.0 dB
RF carrier margin	+0.1 dB	+7.1 dB

Table 9.--Subcarrier and baseband parameters, APT VHF real-time link

Parameters	Worst Case	Nominal
AM subcarrier signal-to-noise ratio	+29.7 dB	+37.6 dB
Subcarrier threshold	+10.0 dB	+10.0 dB
Subcarrier margin	+19.7 dB	+27.6 dB
Video Peak-to-Peak*/rms noise		
1.2 kHz video bandwidth	+33.9 dB	+41.0 dB
900 Hz video bandwidth	+34.4 dB	+42.4 dB
450 Hz video bandwidth	+37.5 dB	+45.6 dB

*Video dynamic range (increase numbers +2.0 dB IF referenced to sync amplitude)

Information Bandwidth and Ground Station Filtering

The original Scanning Radiometer was designed with a baseband, video bandwidth of 900 Hz for the visible channel (Modulation Transfer Function (MTF)) equal to or better than 0.15 at 175 cycles/radian) and 450 Hz for the infrared channel (MTF equal to or better than 0.22 at 90 cycles/radian). However, to optimize the electronic processing of the signal, the electrical bandwidth of the signal for the ITOS D through G instruments was increased to 1200 and 600 Hz respectively. There has been no basic change in response of the detectors: the effect of the change was simply to permit the limited response, higher frequency data (and its associated noise) already present in this range to be maintained through the data handling system.

The individual users have several alternatives available in the choice of a filter[4] for use with the ground station receiver.[5] These alternatives are:

1. Keep the 1600-Hz filter already present and used for APT data. The total signal bandwidth will be maintained: high-frequency noise, not part of the SR signal, will also be retained. For those users interested only in receiving a picture for synoptic analysis, this technique should be adequate.

2. Install a 1200-Hz filter. High-frequency noise not a part of the original signal will be removed. Full high-frequency response will be maintained, though noise above the "normal" information bandwidth (900 Hz and 450 Hz) will also be present.

3. Install a 900-Hz filter. Normal visible channel data will be displayed at its full planned resolution; high-frequency noise will be eliminated. It should be noted, however, that noise outside the normal information bandwidth (450 and 900 Hz) of the infrared channel will be maintained, but full high-frequency response also will be present.

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[4]A 4-pole Gaussian filter is recommended.

[5]This discussion considers only a single filter for both channels of data since these data are intermingled when received on the ground.

4. Install a 600-Hz filter. High-frequency noise not a part of the original infrared channel data will be eliminated. Full high-frequency response for the infrared channel data will be maintained though noise above the normal (450 Hz) information bandwidth will also be present. The high-frequency response of the visible channel will be lost. Signal-to-noise ratio will be enhanced but effective geometric resolution will be reduced.

5. Install a 450-Hz filter. Normal infrared channel data will be displayed at its full planned resolution; high-frequency noise will be eliminated. Those users planning to make quantitative measurements from the signal will find this method of filtering probably will provide an optimized signal insofar as ground resolution and effective signal-to-noise ratio of the received signal are concerned. It must be considered that the visible channel response above 450 Hz will be eliminated by this filter; the effective resolution will be reduced from two miles to four miles.

6. Install a filter with bandwidth less than 450 Hz. The effective geometric resolution of both channels will be reduced but effective signal-to-noise ratio for both channels will be improved by elimination of noise. In each case, the filter itself should be of the 4-pole gausian type to provide an optimum output to the user.

VERY HIGH RESOLUTION RADIOMETER

The Very High Resolution Radiometer (VHRR) is a two-channel scanning instrument sensitive to energy in the visible spectrum[6] 0.6 to 0.7 μm and the infrared (IR) window 10.5 to 12.5 μm. As in the Scanning Radiometer (SR), energy is gathered by a 12.7-cm (5-inch) eliptical scan mirror with a plane surface area of 100.4 cm^2 (15.6 $in.^2$) and a telescope. The scan mirror is set at an angle of 45° to the scan axis and rotates at 400 rpm. A Dall-Kirkham optical system focuses the incoming radiation at a point behind the primary mirror; the visible energy is detected by a silicon photo diode detector located at this focal point.

[6] This range may be expanded for later instruments.

A dichroic beam splitter reflects the IR radiation which comes to a focus in the plane of a field stop which, together with the detector size defines the channel field-of-view. Relay optics are used to re-image the IR radiation on a mercury-cadmium-telluride (H_gCdTe) detector. Bandpass filters in both channels define the spectral characteristics of each. The instantaneous field of view is designed to be 0.6 milliradians for both channels; this provides a spatial resolution of approximately 0.5 n.mi. (0.9 km) at the subpoint.

The infrared detector is cooled to its operating range (near 105°K) (-270°F) (-168°C) by a radiant cooler. A relatively large cooling patch provides the cooling capacity to bring the detector below the temperature 105°K (-270°F) (-168°C) which provides desired signal-to-noise ratio. Thermostatically controlled heaters then warm the detector and maintain the desired temperature. A special labyrinth baffle protects the detector from ice (which has been known to form from outgassing moisture at these low operating temperatures). The cooling patch itself is suspended on Kapton belts to minimize heat conduction between it and the remainder of the radiometer.

In a manner similar to that used for the Scanning Radiometer, the zero point for detected energy is restored to a pre-set zero level once each scan, while viewing space. The output of the radiometer during the remainder of the scan is equal to the difference in detected energy between space and the radiating surface (earth). As with the SR, the anti-sun side horizon will be well defined, providing a zero radiance level for calibration purposes. The sun-side horizon will probably be of indeterminate level as the radiometer scans across the solar illuminated target to be used for visible channel calibration. These targets (one for each radiometer) will be illuminated once per orbit as the spacecraft reaches the polar regions. The radiometer actually views the earth during approximately 1/3 of the period required for one full mirror rotation. The remainder of the period is given over to viewing space and instrument housing while telemetry and appropriate synchronization data are inserted in the data stream. The formatted (discriminated) data output for both channels of the ITOS-D radiometer are shown schematically in figure 8. Table 10 lists detailed timing information for these data when combined in a time-sharing multiplex mode for transmission to the ground.

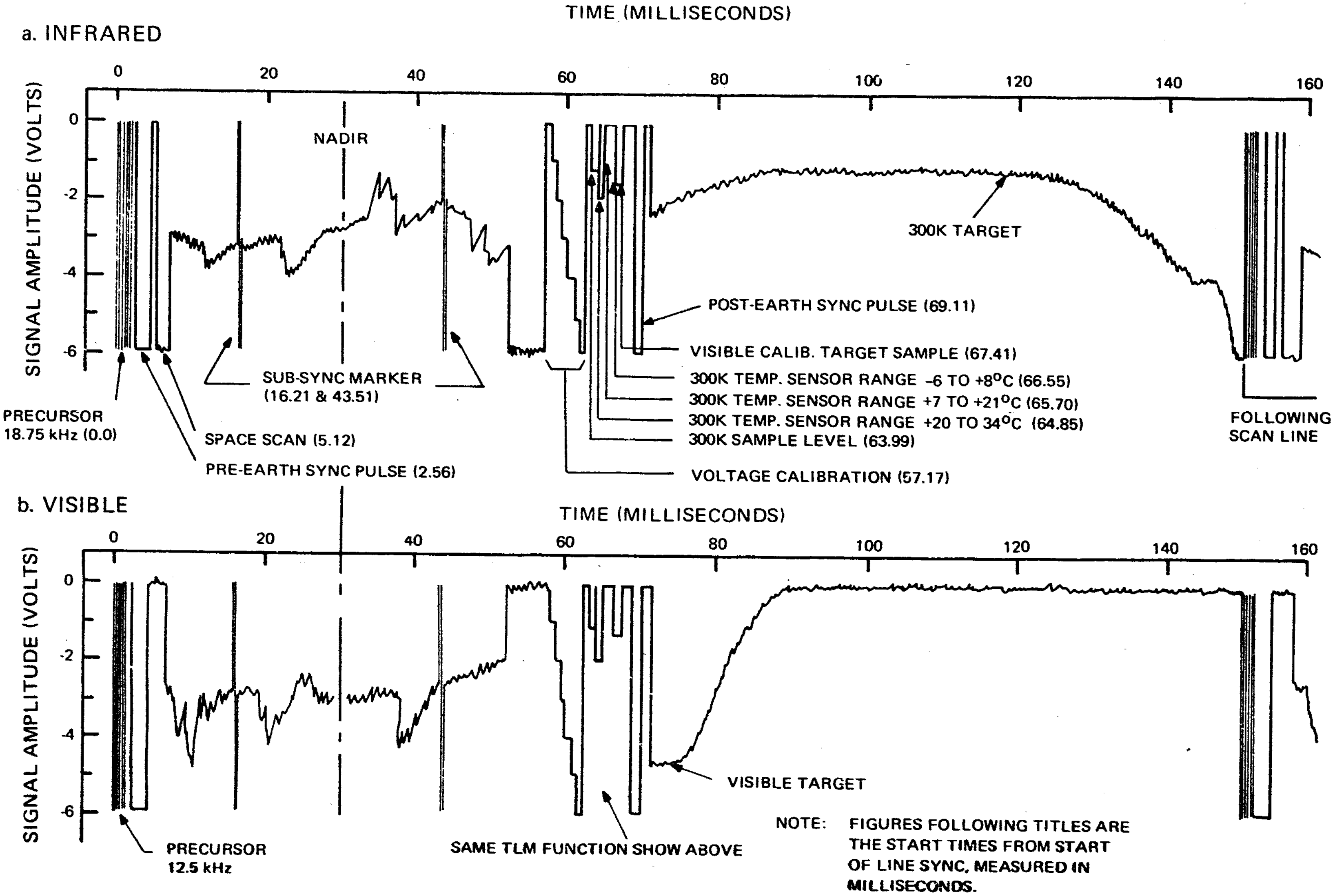

Figure 8.--VHRR sensor-IR and visible signal characteristics

Table 10.--VHRR HRPT data timing (continued on pp. 28 and 29)

Function	After Start of IR Precursor Counts*	After Start of IR Precursor Time (msec)	Duration Counts	Duration Time (msec)	Signal Characteristics
Precursor IR	0	0	5.2	1.71	18.75 kHz square wave. 0 to 100% amplitude starts 72 ± 1° before nadir
Pre-earth Synchronization signal					
Front Porch	521	1.71	256	0.85	Amplitude 0%
Sync Pulse	768	2.56	512	1.71	Amplitude 100%. Starts 65.8 ±1° before the nadir
Back Porch	1280	4.27	256	0.85	Amplitude 0%
Space scan	1536	5.12	Not clock controlled	2.08†	Amplitude 100% period varies with spacecraft altitude & attitude
Earth scan		7.20†	Not clock controlled	45.32†	Amplitude varies over range 0% to 100% (0% Hot, 100% Cold). Period varies from 43.68 msec @900 n.mi. to 48.64 msec @600 n.mi.
1st Sub-Sync marker	4864	16.21	16	0.05	Two level signal starting at 0% amplitude for ½ the period when switching to 100% for the remainder of the period
2nd Sub-Sync marker	13056	43.51	16	0.05	Same as 1st Sub-Sync marker
Space scan (post earth)	Not clock controlled	52.52	--	4.64†	Amplitude is undefined as signal may be influenced by the visible channel calibration target
Voltage Calibration	17152	57.17	1792	5.97	Seven levels increasing in amplitude from 0 to 100%. Zero level following 7th step.
Visible calibration	18944	63.14	256	0.85	Normal range when target is illuminated by sun is about 20% amplitude
Radiance calibration 300K target	19200	63.99	256	0.85	Amplitude about 20%. Varies with target's actual temperature

Table 10.-- Continued

Function	After Start of IR Precursor Counts*	After Start of IR Precursor Time (msec)	Duration Counts	Duration Time (msec)	Signal Characteristics
Temperature Sensor 300K target (expanded range +20 to +34°C)	19456	64.85	256	0.85	For normal temperature range amplitude will be between 0 and 80%. (If the temperature is out of this range, the signal will either be 0 or between 85% and 100%)
Temperature Sensor (expanded) range +7 to +21°C)	19712	65.70	256	0.85	Same as above
Temperature Sensor (expanded range -6 to +8°C)	19968	66.55	256	0.85	Same as above
Post-earth Synchronization					
Front Porch	20224	67.41	1024	3.41	Amplitude 0%
Sync Pulse	21248	70.82	256	0.85	Amplitude 100%
Back Porch	21504	71.67	256	0.85	Amplitude 0%
End of IR scan	21760	72.53			
Precursor Vis	22523‡	75.00±1.00	512	1.71	12.50kHz square wave. 0 to 100% amplitude. Starts 72±10 before nadir
Pre-earth Synchronization Signal					
Front Porch	23035	76.78	256	0.85	Same as IR signal
Sync Pulse	23291	77.63	512	1.71	Same as IR signal
Back Porch	23803	79.34	256	0.85	Same as IR signal
Space scan (pre-earth)	24059	80.19	Not clock controlled	2.08†	Amplitude 0%. Period varies identically with IR signal

Table 10.-- Concluded

Function	After Start of IR Precursor Counts*	Time (msec)	Duration Counts	Time (msec)	Signal Characteristics
Earth scan	Not clock controlled	82.27‡	Not clock controlled	45.32†	Amplitude varies over range of 0% to 100%. (0% Black, 100% White). Period varies identically with IR channel.
1st Sub-Sync marker	27387	91.28	16	0.05	Same as IR signal
2nd Sub-Sync marker	35579	118.58	16	0.05	Same as IR signal
Space scan (post earth)	Not clock controlled	127.59	Not clock controlled	4.64†	Same as IR signal
Voltage calibration	39675	132.24	1792	5.97	Same as IR signal
Visible calib. target	41467	138.22	256	0.85	Same as IR signal
Radiance calibration 300°K target	41723	139.00	256	0.85	Same as IR signal
Temperature sensor (+20 to 34°C)	41979	139.93	256	0.85	Same as IR signal
Temperature sensor (+7 to +21°C)	42235	140.78	256	0.85	Same as IR signal
Temperature sensor (-6 to +8°C)	42491	141.64	256	0.85	Same as IR signal
Post-earth Synchronization Signal					
Front Porch	42747	142.49	1024	3.41	Same as IR signal
Sync Pulse	43771	145.90	256	0.85	Same as IR signal
Back Porch	44027	146.76	256	0.85	Same as IR signal
Multiplex tolerance safety zone	44283	147.61	--	~2.39	
End of Scan		150.00			

*A count is one cycle of 300-kHz square wave.
†Spacecraft at 790 n.mi., 0° roll error, and nominal position for start of precursor
‡Nominal value for switchover from IR to Visible Scan. All following times assume that this switchover is nominal.

For recording on the spacecraft tape recorder (capacity is only 8½ minutes of data) and for real-time (High Resolution Picture Transmission (HRPT)) to the ground (S-band at 1697.5 MHz) the output of the two radiometers will generally be combined in a "time-sharing" mode. Bandwidth limitations and the desire to maintain signal-to-noise ratios preclude using the simultaneous output of a single radiometer except for backup purposes when degraded data would be acceptable (see figure 9). Since only limited recording capacity is practical because of the high data rates and volume, it is not possible to format the data for direct transmission by playing back one channel from the recorder as is done with the Scanning Radiometer. In the primary mode of operation the two VHRR instruments are slaved together but are exactly 180 degrees out of phase. While radiometer no. 1 is viewing the earth, no. 2 will be looking upward at its housing. By proper electronic switching, it is possible to transmit first the infrared channel data from one radiometer, and then, one-half mirror rotation period later, the visible data from the second. It should be noted that the data from the two channels will not be coincident; some offset (about 5 n.mi. (8 km) on the earth at the contiguity point) will exist. Prelaunch alignment measurements will provide an indication of the degree of non-coincidence; these figures can be used to correct for offset when gridding the pictures after receipt. These corrections can reduce the coincidence uncertainty to less than 2 n.mi. (4 km). Total location inaccuracy, when considering spacecraft attitude as well, should be less than 1/3 degree of latitude, or 20 n.mi. (37 km).

In the event of the failure of a single VHRR instrument, two backup data transmission techniques will be available. The simplest selection will be to transmit data from one channel only. Data format, transmission, and signal-to-noise ratio would then be unchanged. In place of data from the other channel, backscan information would be transmitted to complete the time for a full mirror rotation. The second alternative involves a loss in effective signal-to-noise ratio. In this alternate method, data from both channels of the single operating instrument are frequency multiplexed and transmitted. Should a

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[7] The output from one channel of radiometer #1 will immediately precede the output of the alternate channel from radiometer #2. Each output is present during one-half the period necessary for one mirror rotation.

single instrument fail, a choice of backup mode will be made after a thorough analysis of user needs and requirements.

VHRR Performance

VHRR data can be used in the same way the SR data are used. The infrared channel output can be used to determine the equivalent black-body temperature of the radiating surface. The noise equivalent differential temperature (NEΔT) as measured at the instrument output is estimated to be 0.5^{o}C (0.9^{o}F) for a 300^{o}K (80.6^{o}F) (27^{o}C) scene and 2.0^{o}C (3.6^{o}F) for a 185^{o}K scene. These values will be degraded by the transmission, receiving, and data processing equipment. In the normal time-sharing mode of operation at a local station the NEΔT for a 300^{o}K scene is expected to be approximately 1½^{o} to 2^{o}C, for a 185^{o}K scene, 6^{o} to 8^{o}C. In the backup mode of operation, in which data from both channels are frequency multiplexed, the NEΔT will be degraded to 4^{o} to 5^{o}C for a 300^{o}K scene and 20^{o} to 25^{o}C for a 185^{o}K scene. When tape recorded and analyzed centrally, the NEΔT is expected to be degraded somewhat over that received directly without recording. For a 300^{o}K scene NEΔT is estimated to be 2^{o} to 3^{o}C; for a 185^{o}K scene, 12^{o} to 15^{o}C. Here again, statistical processing of temperature data from a relatively uniform radiating surface should reduce the uncertainties to some extent (perhaps by a factor of 2).

VHRR - High Resolution Picture Transmission (HRPT) System

In the primary mode of operation (time-shared transmission of IR data from one VHRR and visible channel data from the second) the composite signal frequency modulates a 99 kHz subcarrier (figure 9). In the backup mode of operation, where the two channels of data from a single radiometer are frequency multiplexed, the output from one of the channels will modulate the 99 kHz subcarrier while the output from the other modulates a separate 249 kHz subcarrier (table 11).

In either mode of operation, the modulated subcarriers will, in turn, frequency modulate one of the two redundant 1697.5 MHz S-band transmitters to produce a RF carrier bandwidth of 1.0 MHz. In the primary mode, a deviation ratio of about 2 will be employed, while in the backup mode, deviation ratios of 1/3 to 1/2, will be used, respectively, for the 99 kHz and 249 kHz subcarriers. The output of each transmitter will be permanently connected to its own antenna. The radiated wave from either will be right-hand circularly polarized. Sample link calcula-

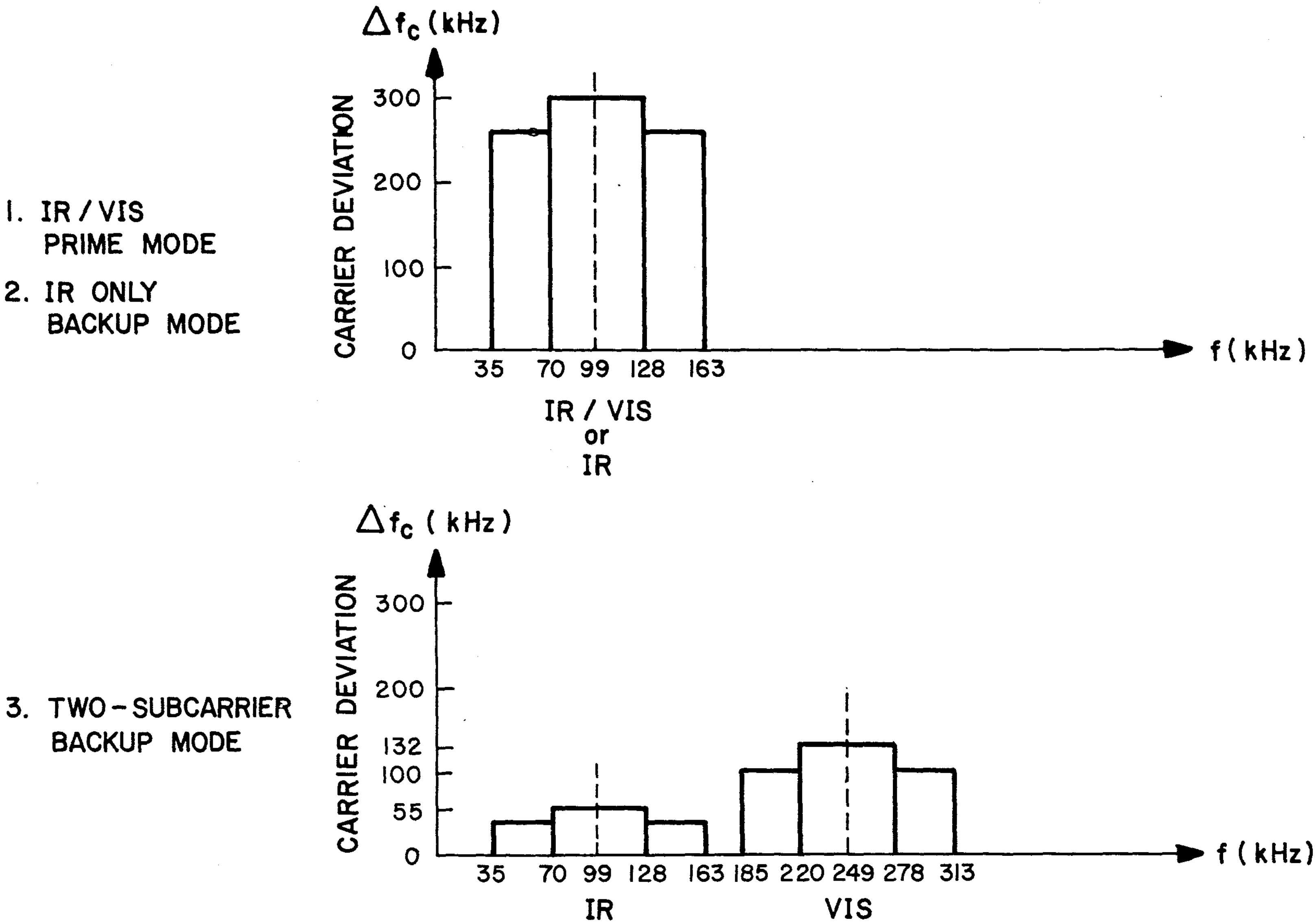

Figure 9.--S-band real-time HRPT modulation spectra

tions are given in Tables 12, 13 and 14.

HRPT Receiving Stations

At the local HRPT stations, the S-band signal will be received by an appropriate antenna and demodulated by the FM receiver as described in the next section. The subcarriers will then be individually demodulated by FM discriminators to recover their video basebands for recording on an appropriate display device.

Antenna-Receiving System[8]

It is desired that the antenna-receiver system provide a carrier-to-noise ratio of at least 13.5 dB, and preferably more, to ensure a good operating margin. In designing the ground station an analysis should be made of the system to show that the desired carrier-to-noise and signal-to-noise ratios will be met. The analysis should consider:

- (a) Antenna gain and efficiency,
- (b) antenna noise temperature; this could be assumed at 70°K (-203°C) (-333.4°F),
- (c) polarization loss,
- (d) feed assembly loss,
- (e) preselector filter loss,
- (f) preamplifier gain and noise temperature,
- (g) frequency converter and noise temperature,
- (h) cable loss, and
- (i) receiver noise temperature.

The antenna should have an autotrack capability and be designed to receive right-hand circularly polarized signals from the spacecraft. The system should be designed for continuous tracking of orbital passes from any azimuth direction with elevation angles down to 5 degrees above the local horizon. It may be desirable to provide for remote control of the antenna up to 1500 ft (457 m) depending upon the particular installation). The remote control unit should include azimuth and elevation indicators, autotrack/manual selector, velocity and position controllers and manual hand cranks and braking mechanisms on both axes. It is recommended that a parametric amplifier be used as the preamplifier and that it and the frequency converter

[8]Compiled by D. Holmes and A. Vossler, NESS, Ground Systems Group.

be mounted on the antenna structure close to the antenna feed. Sufficient gain should be provided by the frequency converter to overcome cable losses between the antenna and the receiver.

The receiver should be of high quality, having a noise figure of no more than 10 dB. A highly stable, switchable Automatic Frequency Control (AFC) circuit should be incorporated. Selectable Intermediate Frequency bandwidths of 50, 100, and 1000 kHz and perhaps others should be considered. The filters could be in plug-in module form. The filters should provide for interchannel separation in the backup mode of at least 20 dB, assuming the signal power to be 10 dB down at the 163-kHz and 185-kHz pass-band limits and signal power roll-offs of 40 dB per decade above and below these frequency limits. Consideration should be given to providing auxiliary outputs at the analog video and first FM demodulator for tape recording purposes. The ground station equipment is listed in table 15; the block diagram for the ground station is shown in figure 10.

Table 11.--VHRR HRPT real-time mode characteristics

Frequency	1697.5 MHz ±0.005%
Transmitting power output	5 watts min.
Transmitting circuit losses	0.7 dB maximum
Antenna directivity	+1.9 dB minimum at 5° elevation
Antenna polarization	Right hand circular
Carrier modulation	FM
Peak carrier deviation	
normal submode	300 ±47 kHz
backup submode (IR only- 1 subcarrier)	300 ±47 kHz
backup submode (IR & visible 2 subcarriers)	187 ±30 kHz
RF Spectrum bandwidth	
normal submode	0.9 MHz
backup submode (IR only- 1 subcarrier)	0.9 MHz
backup submode (IR & visible 2 subcarriers)	1.0 MHz
Subcarrier center frequencies	
normal mode	99 ±1.4 kHz
backup submode (IR only- 1 subcarrier)	99 ±1.4 kHz
backup submode (IR & visible 2 subcarriers)	99 ±1.4 kHz 249 ±1.2 kHz
Subcarrier modulation	FM
Peak subcarrier deviation	±29 ±2.4 kHz
Baseband video bandwidth	35 kHz

Table 12.--VHRR-HRPT real-time S-band link analysis (general)

Contribution element	Gain
Spacecraft transmitter power (5 watts)	37.0 dBm
Spacecraft transmitter circuit loss (estimated)	-0.70 dB
Spacecraft antenna gain	1.90 dB
Pointing loss	0.0 dB
Path loss (range 2180 miles; elevation 5°)	-169.2 dB
Polarization loss	-0.6 dB
Receiving circuit loss	-1.00 dB
Off beam loss (receiving pointing loss)	-0.50 dB

Table 13.--VHRR-HRPT real-time (S-band) link analysis (detailed)

Parameter	Paraboloidal Reflector	
	15 foot	10 foot
Receiving antenna gain	35.7 dB	32.0 dB
Total received power	-97.4 dBm	-101.1 dBm
Received noise spectral density (System temperature 269K)	-174.3 dB/Hz (-147.3 dBm/Hz)	-174.3 dB/Hz (-147.3 dBm/Hz)
Received power noise spectral density	76.94 dB/Hz	73.3 dB/Hz
Received noise power	-60.0 dB	-60.0 dB
IF bandwidth: 1MHz	(-114.3 dBm)	(-114.3 dBm)
Carrier to noise ratio	16.94 dB	13.3 dB
Baseband signal to noise ratios		
(Peak to peak/rms)		
Normal mode (99 kHz)	49.3 dB	42.2 dB
Backup mode (frequency multiplex)		
(99 kHz)	33.7 dB	27.5 dB
(249 kHz)	34.5 dB	27.4 dB

Table 14.-- Signal-to-noise ratio for VHRR HRPT real-time S-band link, worst case analysis

Contributing element	15' Antenna	10' Antenna
VHRR sensor	43.7 dB	43.7 dB
VHRR processor	48 dB	48 dB
S-band transmitter	48 dB	48 dB
RF link		
Normal mode	49.3 dB	40.0 dB
Backup mode (frequency multiplex)	34 dB	24.9 dB
Ground receiver (estimated)	48 dB	48 dB
Demodulator (estimated)	50 dB	50 dB
Overall system		
Normal mode	40 dB	37 dB
Backup mode	30 dB	25 dB

Table 15.--VHRR-HRPT real-time ground station equipment

Item	Characteristics
Antenna	Type: Parabola - tracking Size: 10 to 15 feet (diameter) Polarization: Right-hand circular Pre-selector loss: 1.0 dB maximum
Preamplifier	Type: Uncooled paramp* Noise figure: 1.3 dB maximum (101°K) Gain: 17 dB minimum
Receiver	Type: FM with mean-of-peaks AFC IF bandwidth: 1.0 MHz Noise figure: 10 dB maximum
Demodulator	Type: 2 FM subcarriers Bandwidth: 140 kHz (each subcarrier) Baseband output bandwidth: 35 kHz

*A cooled parametric amplifier is suggested for use with the 10-foot antenna to maintain a reasonable margin.

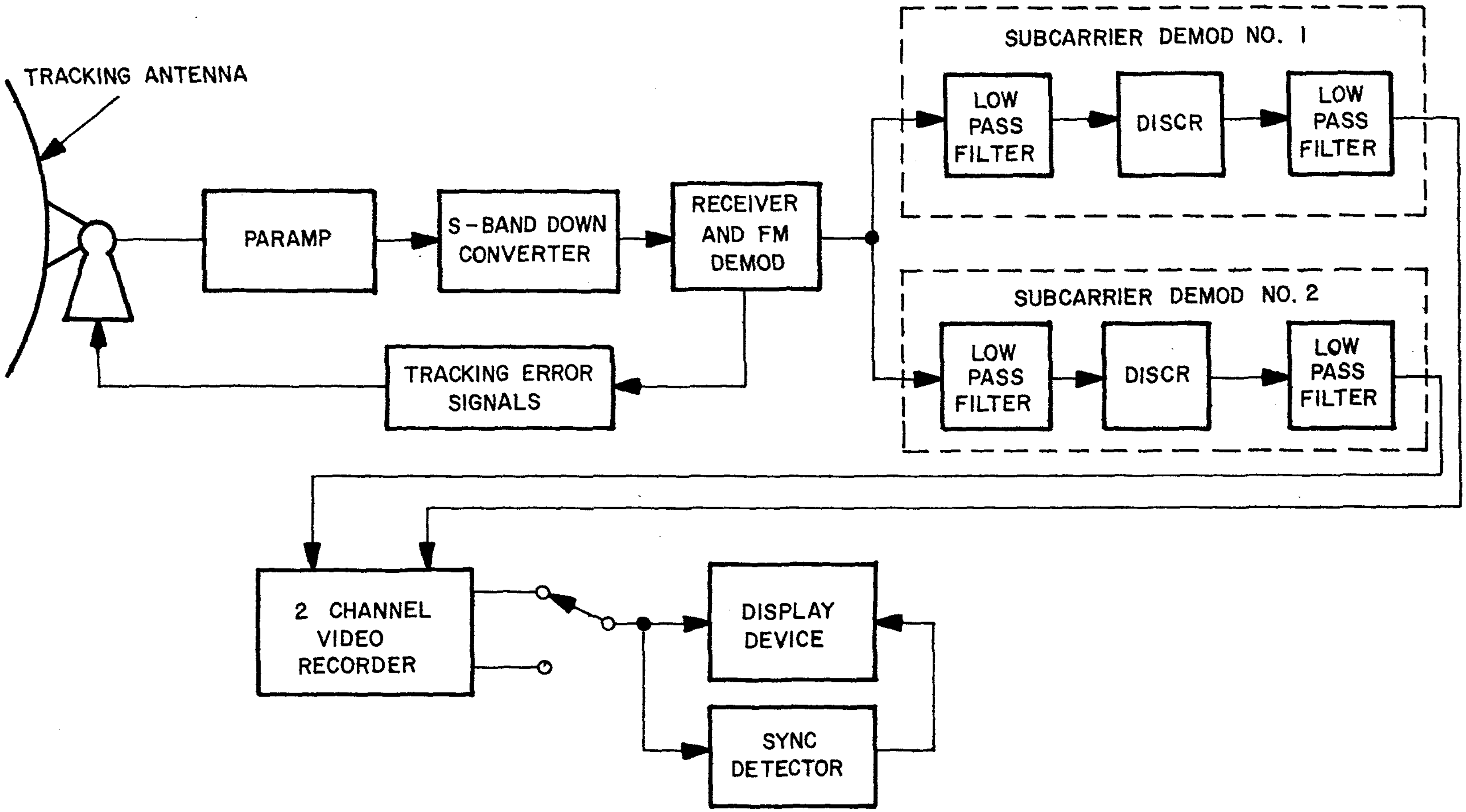

Figure 10.--Typical local-user ground station equipment for acquiring VHRR-HRPT real-time transmissions

Operational Limitation

The 1697.5 MHz transmitter used for global VHRR data transmission must also accommodate all transmission of recorded data to the CDA stations (Wallops Island, Virginia or Gilmore Creek, Alaska).

During tape recorder playback to the CDA stations, the VHRR data, though remaining in the same frequency domain, are frequency multiplexed and are broadcast with insufficient power density (carrier deviation reduced to 55 kHz) to provide usable data to VHRR stations within range of the spacecraft. Usable data will be acquired only by the 85-ft. antenna at the CDA station.

VERTICAL TEMPERATURE PROFILE RADIOMETER

The Vertical Temperature Profile Radiometer (VTPR) is an instrument designed to measure infrared radiance in eight narrow-band spectral regions between 11 and 19 micrometers. These data can be used to deduce the atmospheric temperature profile of the radiating column. Sensors (channels) in each of the six spectral intervals of the carbon dioxide absorption band (table 16) will measure energy from a different range of altitudes in the atmosphere; the atmospheric temperature profile will be deduced from these measurements. Channel #1 (668.5 cm^{-1}), the Q branch, is a maximum absorption region. All energy in this wave number that reaches this layer from below will be absorbed and re-radiated upward. The CO_2 acts as a black body at the temperature of the layer. Thus, data from this channel can be used to determine the temperature near the top of the atmosphere. Other channels receive their energy from lower levels because the layers of the atmosphere above the radiating layers are reasonably transparent to this energy. Data from the water vapor channel (535 cm^{-1}) are used to correct readings in other channels; data from the window channel (835 cm^{-1}) are used to determine surface temperature in clear areas and to indicate cloudy areas. In cloudy areas, temperature profiles can be computed upward only from the cloud top level.

The VTPR instrument (figure 11) is equipped with a single optical system and a pyroelectric detector. A wheel with the eight filters that define the channels is located in the optical path in front of the detector. This wheel rotates at 120 rpm, bringing each of the eight filters into the field of view every 62.5 milliseconds. By this method, the data from which a

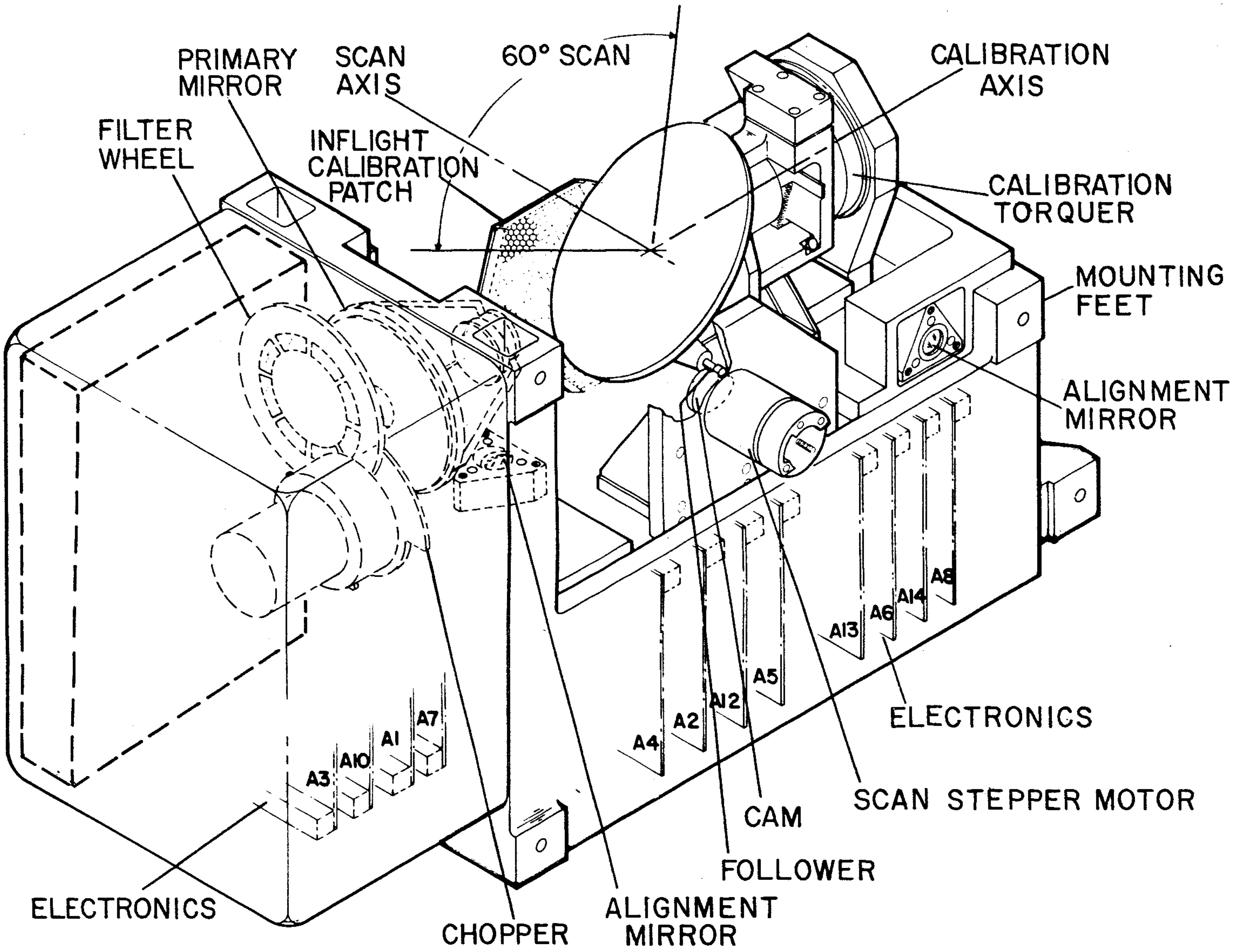

Figure 11.--Isometric view of VTPR instrument
(courtesy of Barnes Engineering Company)

temperature profile may be deduced is obtained every 0.5 seconds. The instrument scans across and 31.45 degrees to either side of the orbit path in 23 equal steps; coverage along the satellite track results from the movement of the satellite. The scan and satellite motion combined provides essentially global coverage except in the equatorial region where there are gaps in coverage between successive orbits of the satellite. The instrument field of view (2.235^{o} by 2.235^{o}) provides a ground resolution of approximately 32 n.mi. by 32 n.mi. (59 km by 59 km) at the subpoint (figure 4). Thus, one complete scan of 23 steps sweeps across an area approximately 32 n.mi. (59 km) wide by 736 n.mi. (1364 km) long. The time to complete one scan is 12.5 seconds, one second of which is used for the scan mirror retrace prior to starting a new line of data.

The VTPR is designed to have an absolute accuracy better than 0.5 percent and a relative accuracy between channels of 0.125 percent (0.25 percent for the Q branch). To achieve this level of accuracy, it is necessary to calibrate the instrument at frequent intervals. Calibration is used to check the absolute radiance calibration and linearity of the instrument. For calibration, the instrument first looks at space (4^{o}K) for 16 seconds and then at an internal black body source approximately 285^{o}K (12^{o}C) (53.6^{o}F), for 15 seconds. Telemetry data necessary for data interpretation is inserted in the data stream during the "flyback" (fast scan retrace) period and during calibration periods.

To maintain the signal-to-noise ratio of the instrument through the data processing and transmission link, the instrument analog output is digitized (to 10 bits) before storage on the spacecraft recorder. The signal from the detector is fed to an integrator which optimizes the system signal-to-noise by accurately measuring the data level of the input. From the integrator the signal goes to a Buffer Amplifier which brings all the signals to a common baseline and raises the level of the Q branch data by a factor of four to make the best use of the digital range. This step is necessary because of the limited response in this narrow-bandwidth channel. Though radiometric accuracy is not improved by raising the signal level, the quantization error ($\pm$0.5 bit) is limited to the same percentage as that present in data from other channels. Finally, the data are digitized and formatted with appropriate telemetry for storage on the spacecraft recorder.

Table 16.--VTPR spectral filter characteristics

Channel	Wave Number	Bandwidth	Region
1 (Q branch)	668.5 cm^{-1}	7.0 $\pm$0.5 cm^{-1}	CO_2
2	695	10.0 $\pm$2.5	CO_2
3	725	10.0 +1.0 -2.0	CO_2
4	535	10.0 +1.0 -2.0	Water vapor
5	835	8.0 +1.0 -2.0	IR window
6	747	10.0 $\pm$2.5	CO_2
7	708	10.0 $\pm$2.5	CO_2
8	677	10.0 $\pm$2.5	CO_2

Data from this instrument are not available for direct transmission to local stations and can be acquired only at the CDA's, which retransmit them for central processing and analysis.

SOLAR PROTON MONITOR

The Solar Proton Monitor (SPM) measures the flux of energetic particles (protons, electrons, etc.) in several energy ranges. The SPM is used to detect the arrival of energetic solar protons in the vicinity of the earth. The SPM measures the energetic particle flux in several ranges: protons in the 10-, 30- and 60-Mev range, and electrons in the 100- to 750-Kev range. The flux toward the earth along the local vertical is measured with one set of detectors. A second set of detectors measures the flux along the orbit normal from the side of the spacecraft away from the sun.

The data are tape recorded in digital form and are transmitted to the ground, when higher priority[9] data are not present, by modulation of the ITOS beacon transmitter signal.

The tape-recorded data are quickly processed at NESS after relay from a CDA station. A greatly reduced volume of processed data is sent to the NOAA Space Environment Laboratory at Boulder, Colorado, for solar storm warning purposes. Later all the processed data are sent to Boulder for study and archiving.

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[9]Attitude scanner signals, spacecraft telemetry, etc.

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Rockville, Md. 20852

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APPENDIX

The Secretary-General
World Meteorological Organization
41, Avenue Giuseppe Motta
Geneva, Switzerland

December 28, 1971

Dear Mr. Secretary-General:

Your letter of 14 October 1971 (25.747/OSM) solicited clarification of plans for automatic picture transmissions from U.S. operational meteorological satellites. We regret that uncertainties apparently continue to prevail. The following is a summary of the main points regarding our plans for the direct broadcast of images.

1. The Automatic Picture Transmission (APT) service, defined as the direct broadcast of images in the very high frequency (VHF) band (137.62 or 137.5 MHz), and having a resolution on the order of three km, will be continued indefinitely. However, the sensors used to obtain the images may be changed or modified from time to time. We expect that such changes will require only minor modification to existing APT receivers.

2. As was announced several years ago, a most important modification of the APT service will be the introduction during 1972 of satellites (ITOS-D and later satellites) carrying only scanning radiometers for direct broadcast. The use of scanning radiometers, (similar to those used on ITOS-1 and NOAA 1) will be continued in the future so that APT service will be available at night as well as in the daytime.

3. APT broadcasts of signals generated by vidicon cameras will continue (depending upon user requirements) as long as old satellites equipped with such cameras continue in working condition, and should provide a period of transition to complete reliance on scanning radiometers for APT. Therefore, an optimum configuration for APT recorders during this period would be that which retains the option to display data generated by either the vidicon camera or scanning radiometer. Ultimately, only scanning radiometers will be used to generate images for the APT service.

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4. When only scanning radiometers are used to generate images for the APT service (as will be the case with the ITOS-D and subsequent spacecraft in polar orbit), both visible and infrared channels will be broadcast simultaneously during the daylight portion of each orbit. Depending on the design of present APT receivers, they will need little or no modification to receive and display both channels. To our knowledge, all existing APT receivers can be used to display, at a minimum, one or the other of the two channels without any modification.

5. The Very High Resolution Radiometer (VHRR), to be flown on the U.S. operational meteorological satellites in polar orbit (ITOS-D et. seq.) beginning before the end of 1972, is entirely unrelated to the present and planned APT service. The VHRR will be used in a new broadcast service, to be called the "High Resolution Picture Transmission" (HRPT) service, and will be operated separately from, but simultaneously with, the APT service.

In summary, there will be two independent cloud imaging direct broadcast services which will be operated simultaneously. The first will be the continuation of the APT service on VHF which will require a slight modification to those APT displays not already modified for scanning radiometer compatibility. The second service to be introduced in 1972 is the HRPT service which will broadcast on an S-band frequency (1697.5 MHz) and have a resolution on all channels of about one km. Initially we will use the VHRR as an imaging sensor, with both visible and infrared channels being broadcast, in the HRPT service. This second system will require an entirely new ground station because of the high resolution and associated bandwidth. This ground station, of course, is much more sophisticated (and expensive) than that required to receive APT data.

We understand that there is considerable concern among some members having APT ground stations regarding the proper display of APT signals originating from the new scanning radiometer sensor. We shall be happy to assist members and the suppliers of their display equipment in finding solutions to this problem. Anyone wishing to obtain such assistance, or more detailed information on the ground equipment for the HRPT service, may communicate with the Director, National Environmental Satellite Service, National Oceanic and Atmospheric Administration, FOB-4, Washington, D. C. 20233, USA. Requests for assistance on APT problems should include specific information concerning the display device the user has in service or contemplates using. Some more detailed information concerning APT and HRPT ground station requirements will be forwarded soon in a supplement to this letter.

You may wish to circulate this letter for the information of members.

Sincerely,

/s/
Robert M. White
Permanent Representative
of the US to the WMO

Enclosures

☆ U.S. GOVERNMENT PRINTING OFFICE : 1972—481-332/209

(Continued from inside front cover)

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NESCTM 24 Operational Brightness Normalization of ATS-1 Cloud Pictures. V. Ray Taylor, August 1970. (PB-194 638)

NESCTM 25 Aircraft Microwave Measurements of the Arctic Ice Pack. Alan E. Strong and Michael H. Fleming, August 1970. (PB-194 588)

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NESS 26 Potential of Satellite Microwave Sensing for Hydrology and Oceanography Measurements. John C. Alishouse, Donald R. Baker, E. Paul McClain, and Harold W. Yates, March 1971. (COM-71-00544)

NESS 27 A Review of Passive Microwave Remote Sensing. James J. Whalen, March 1971.

NESS 28 Calculation of Clear-Column Radiances Using Airborne Infrared Temperature Profile Radiometer Measurements Over Partly Cloudy Areas. William L. Smith, March 1971. (COM-71-00556)

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NESS 30 Limits on the Accuracy of Infrared Radiation Measurements of Sea-Surface Temperature From a Satellite. Charles Braun, December 1971.

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NESS 32 On Reference Levels for Determining Height Profiles From Satellite-Measured Temperature Profiles. Christopher M. Hayden, December 1971.

NESS 33 Use of Satellite Data in East Coast Snowstorm Forecasting. Frances C. Parmenter, February 1972.

NESS 34 Chromium Dioxide Recording--Its Characteristics and Potential for Telemetry. Florence Nesh, March 1972.