A Technical Memorandum NESS 95

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

THE TIROS-N/NOAA A-G SATELLITE SERIES

Washington, D.C.
March 1978

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Environmental Satellite Service

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Arthur Schwalb

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UNITED STATES
DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
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National Environmental
Satellite Service
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TIROS-N/NOAA A-G Summary Sheet

Spacecraft	:	Total weight (includes expendables)	1421 Kg (3127 lbs)
Payload	:	Weight including tape recorders	194 Kg (427 lbs)
	:	Reserved for growth	36.4 Kg (80 lbs)

Instrument Complement:

Advanced Very High Resolution Radiometer (AVHRR)
High Resolution Infrared Radiation Sounder (HIRS/2)
Stratospheric Sounder Unit (SSU)
Microwave Sounder Unit (MSU)
Data Collection System-ARGOS (DCS)
Space Environment Monitor (SEM)

Spacecraft Size: 3.71 meters in length (146 inches)
1.88 meters in diameter (74 inches)

Solar Array : 2.37 m X 4.91 m : 11.6 square meters
(7.8 ft X 16.1 ft : 125 sq ft)

420 watts, end of life, at worst solar angle

Power Requirement: Full operation-330 watts
Reserved for growth-90 watts

Attitude Control System: 0.2° all axes
0.14° determination

Communications

Command Link : 148.56 MHz

Beacon : 136.77; 137.77 MHz

S-Band : 1698; 1702.5; 1707 MHz

APT : 137.50; 137.62 MHz

DCS (uplink) : 401.65 MHz

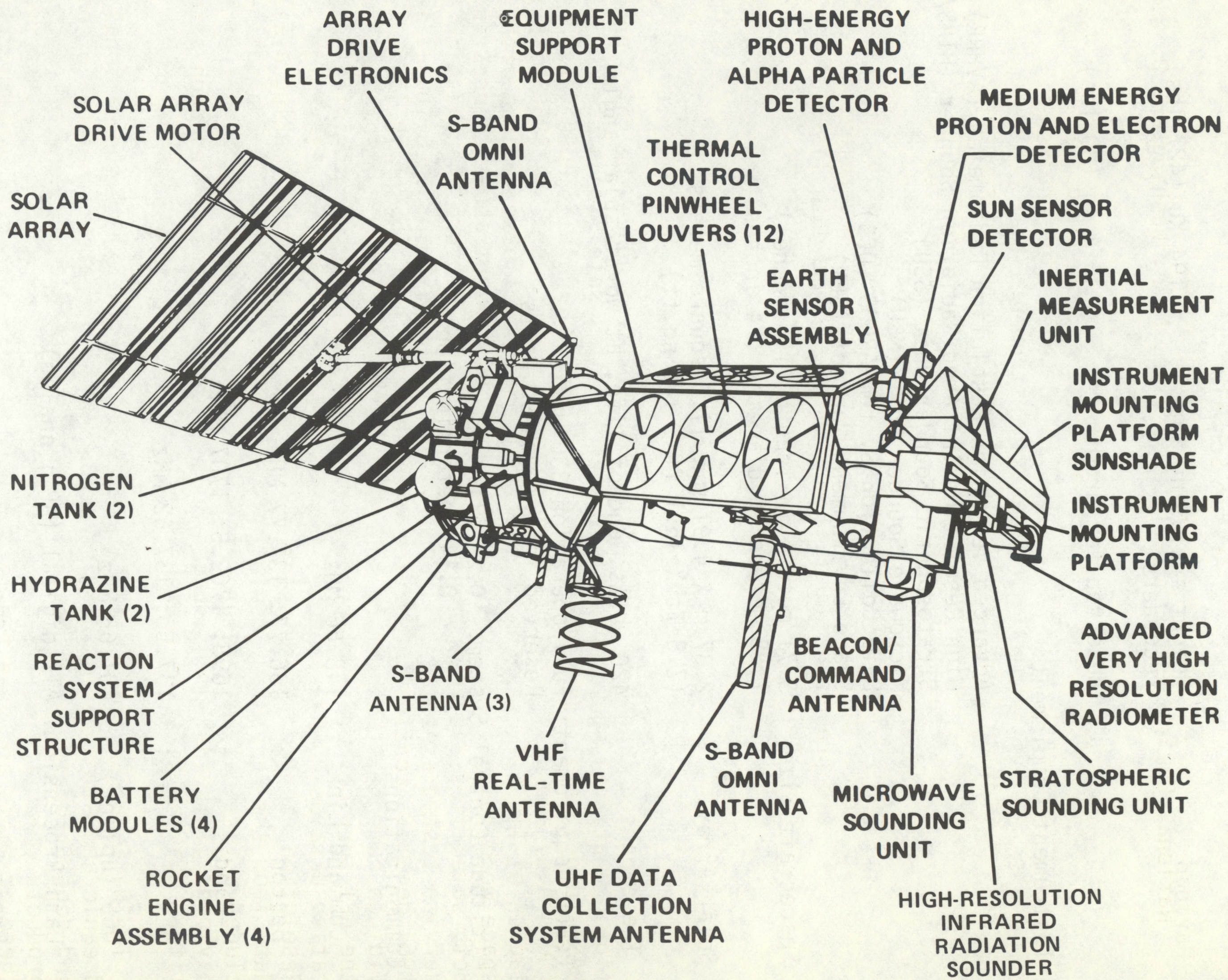
Data Processing: All digital (APT; analog)

Orbit : 833; 870 km nominal

Launch Vehicle: Atlas E/F

Lifetime : 2 years planned

TIROS-N Spacecraft



THE TIROS-N/NOAA A-G SATELLITE SERIES

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ABSTRACT. The TIROS-N satellite is scheduled for launch in mid-1978. This third generation environmental satellite will carry instruments that can provide data to meet stated requirements in support of both day-to-day environmental monitoring and global research programs. The satellite system is a cooperative effort of the United States, the United Kingdom, and France. General information about the spacecraft, its orbit, and its instruments are presented. Details on the real-time data links are included for those planning to receive these data from the spacecraft.

1. INTRODUCTION

The expected launch of TIROS-N in 1978 will introduce the third generation operational, polar orbiting, environmental satellite system. This NASA-funded satellite is to be followed by the launch of NOAA versions (NOAA A-G) and will continue the program begun on April 1, 1960 with the launch of TIROS-I. As the potential advantages of observations from space were recognized, evolving requirements brought about changes in both satellites and instruments. The Automatic Picture Transmission (APT) service tested experimentally on TIROS-VIII in 1963 and on Nimbus-I in 1964 became a continuing service with the launch of ESSA-2 in 1966. Vidicon cameras, the primary source of data for central processing, and the APT service were replaced by radiometers capable of providing quantitative data on NOAA-2 launched in 1972. At the same time, the High Resolution Picture Transmission (HRPT) service was begun, making available data from the Very High Resolution Radiometer (VHRR). NOAA-2 also included a Vertical Temperature Profile Radiometer (VTPR) as a part of the payload. This instrument, based on technology tested on research satellites, was the first operational vertical sounder to be flown.

The National Environmental Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA) operates a network of polar and geostationary satellites which provide data used to generate output products which are utilized in meeting some of the NOAA responsibilities. These products are used for meteorological prediction and warning, oceanographic and hydrologic services, and space environment monitoring and prediction. The two satellite systems (polar and geostationary) are complementary, each having been designed to meet mission requirements for which it is uniquely qualified. For example, continuous monitoring of storm areas in the temperate and tropical latitudes near the United States is primarily a geostationary satellite mission. Measurement of data from which the vertical temperature profile of the atmosphere can be deduced is today a polar orbiter objective.

The NOAA satellite program is based on the philosophy of meeting operational requirements for products with instruments whose potential has been proven in space. The payload chosen for the TIROS-N series was selected to meet NOAA requirements. Predecessor instruments have flown experimentally on Nimbus satellites (sounders), ITOS and AE (Space Environment Monitor), and EOLE (Data Collection System). These instruments were redesigned to meet both scientific and technical (orbit constraints, spacecraft bus, etc.) requirements of the mission. The goal of the redesign has been to improve the reliability of the instrument and the quality of the data without changing the previously proven concepts.

The TIROS-N series of satellites is a cooperative effort of the United States (NOAA and NASA), the United Kingdom, and France. As has been true in the past, NASA will fund the development and launch of the first flight satellite (TIROS-N); subsequent satellites will be procured and launched by NASA using NOAA funds. The operational ground facilities including the Command and Data Acquisition (CDA) stations, the Satellite Control Center, and the data processing facilities (with the exception of the Data Collection System [DCS] processing facility) will be procured, funded and operated by NOAA. The United Kingdom, through its Meteorological Office (Met O), Ministry of Defense, will provide a Stratospheric Sounding Unit (SSU), one of three sounding instruments for each satellite. The Centre National d'Etudes Spatiales (CNES) of France will provide the DCS instrument for each satellite and will provide the facilities necessary to process and make available to users the data obtained from this system. The Centre d'Etudes de la Meteorologie Spatiale (CEMES) of France will provide ground facilities for receipt of sounder data during the blind orbit periods.

The primary environmental sensors for these satellites are:

o A TIROS Operational Vertical Sounder (TOVS). The TOVS is a three instrument system consisting of:

a. The High Resolution Infrared Radiation Sounder (HIRS/2) - a 20 channel instrument making measurements primarily in the infrared region of the spectrum. The instrument is designed to provide data that will permit calculation of 1) temperature profile from the surface to 10 mb; 2) water vapor content in three layers in the atmosphere; and 3) total ozone content. The design is based on the HIRS instrument flow on the Nimbus satellite.

b. The Stratospheric Sounding Unit (SSU) - employing a selective absorption technique to make measurements in three channels. The spectral characteristics of each channel is determined by the pressure in a carbon dioxide gas cell in the optical path. The amount of carbon dioxide in the cells determines the height of the weighting function peaks in the atmosphere.

c. The Microwave Sounding Unit (MSU) - a 4-channel Dicke radiometer, making passive measurements in the 5.5-mm oxygen band. This instrument, unlike those making measurements in the infrared region, is little affected by clouds.

Data from the TOVS will be available locally as a part of the HRPT transmission and on the spacecraft beacon transmission.

o The Advanced Very High Resolution Radiometer (AVHRR) - a 4-channel (5 channels on later satellites of this series) scanning radiometer sensitive in the visible, near infrared and infrared window regions. This instrument will provide data for central processing, APT, and HRPT outputs. HRPT data (all spectral regions) will be transmitted at full resolution (1.1 km); APT (two selectable spectral regions) will have reduced resolution (4 km).

o The Space Environment Monitor (SEM) data will also be included in the HRPT and beacon transmissions. The SEM consists of three separate instruments and a data processing unit. The components are:

a. The Total Energy Detector (TED): measures a broad range of energetic particles from 0.3 Kev to 20 Kev in 11 bands.

b. The Medium Energy Proton and Electron Detector (MEPED): senses protons, electrons, and ions with energies from 30 Kev to several tens of Mev.

c. The High Energy Proton and Alpha Detector (HEPAD): senses protons and alphas from a few hundred Mev up through relativistic particles above 840 Mev.

o The Data Collection System (DCS): a random access system to acquire data from fixed and free-floating terrestrial and atmospheric platforms. Platform location will be possible by ground processing of the Doppler measurements of carrier frequencies. Data collected from each platform will include identification, as well as environmental measurements. These data are also included in the HRPT and beacon transmissions.

2. THE SPACECRAFT

In keeping with the general philosophy of making maximum use of previously developed space components, it was decided to use applicable parts of the Defense Meteorological Satellite Program (DMSP) Block 5D spacecraft for the flight of the payload specified by NOAA. The TIROS-N spacecraft will be an adaptation of the spacecraft built by the RCA Corporation and first launched in 1976. RCA is also building the TIROS-N/NOAA A-G spacecraft bus and testing the fully integrated (including instruments) satellite. Ground rules used during the design were:

1. Meet the NOAA mission requirements.

2. Make maximum use of existing Block 5D designs where applicable (ex: attitude control system).

3. Change 5D only where necessary or where cost advantages can be shown for the change.

The TIROS-N satellite is an integrated system designed to provide for and control injection into a nominal 833- or 870-Km (450 or 470 n.mi.) circular, Sun-synchronous orbit after separation from the Atlas-E/F launch vehicle.

2.1. Structure

The spacecraft structure consists of four components: 1) the Reaction System Support Structure (RSS); 2) the Equipment Support Module (ESM); 3) the Instrument Mounting Platform (IMP); and 4) the Solar Array (SA). Instruments are located on both the IMP and the ESM. With the exception of the SEM, all instruments face the Earth when the satellite is in mission orientation.

The satellite, including the injection motor assembly, is approximately 3.71 meters (12 ft. 2 in.) in length and 1.88 meters (6 ft. 2 in.) in diameter. Exclusive of expendables consumed during the launch phase, the satellite is expected to weigh 737 Kg (1620 lb). Of this weight, approximately 230 Kg (507 lb) will be used for the payload or kept in reserve for future growth instruments.

2.2. Power System

Spacecraft power is provided by a direct energy transfer system whose primary source is a single axis oriented solar array; the secondary source is a pair of nickel cadmium batteries. The solar array is made up of eight panels of solar cells each 61.4 cm X 237.5 cm (24.2 X 93.5 in.). There are 93 cells (2 x 4 cm) in series in each of the 136 parallel strings that comprise the array. The array, which must be deployed from its launch stowed position, will be canted at 36° to the orbit normal. A solar array drive system will cause the array to rotate once per orbit so that the array will continuously face twoard the sun. Current supplied to the satellite through slip rings during daylight portions of the orbit is used to operate the satellite and to charge the two 26.5-ampere-hour batteries. These batteries supply spacecraft power during dark portions of the orbit and augment the array during daylight peak load conditions. Total orbit average load capacity for the system is expected to be 420 watts at the end of 2 years in orbit at a worst case sun angle.

2.3. Reaction Control Equipment (RCE)

The TIROS-N satellite includes an integrated system for guidance and control of orbital injection following separation from the Atlas vehicle. The Reaction Control Equipment (RCE) provides ascent phase, attitude control (3 axis), and orbital velocity trim for final injection. The RCE is operational from Atlas separation to handover to the orbital control system.

2.4. Attitude Determination and Control

The on-orbit Attitude Determination and Control Subsystem (ADACS) provides three axis pointing control for the satellite. The ADACS maintains system pointing by controlling torque in three mutually orthogonal wheels (a fourth skewed wheel is available in the event of failure of one of these three). The torque is determined by analysis of spacecraft orientation in space. Input to these computations are acquired from the Earth Sensor Assembly (ESA) for pitch and roll, and an intertial reference with sun sensor updates for yaw.

The ADACS is required to control spacecraft attitude so that orientation of the three axes is maintained to within $\pm 0.2°$ (3σ) of the local geographic reference. Information to permit computation of yaw, pitch, and roll to within 0.1° by computer processing on the ground, after the fact, is also available. Analysis has shown that except for short duration perturbations of up to 0.2 °, the attitude should generally be maintained to within approximately 0.12°.

The ADACS is a nominally zero momentum control system consisting of the following:

- o One Earth Sensor Assembly (ESA)
- o One Sun Sensor Assembly (SSA)
- o Four Reaction Wheel Assemblies (RWA's)
- o Two Roll/Yaw Coils (RYC's)
- o Two Pitch Torquing Coils (PTC's)
- o Four Gyros
- o Computer Software for Data Processing

The Earth Sensor Assembly (ESA) is a static infrared (15 μm region) sensor designed to operate over the range 740 to 926 km (400-500 n.mi.). Nominally, the Earth is centered between four independent detectors which view a segment of the horizon in each of four quadrants. If perfectly centered, the spacecraft roll and pitch error would be zero. In practice, pitch and roll are determined from these readings and the control system tries to keep the error as close to zero as possible.

The Sun Sensor Assembly (SSA) is a single axis digital Sun sensor whose output can be used to compute the satellite yaw attitude error. Needed for this computation are spacecraft pitch and roll angles, gyro data, and spacecraft and solar ephemeris. The calculated yaw error is used to re-initialize (update) the spacecraft yaw attitude once per orbit. Attitude changes between this update and the following update are derived from the combined yaw, roll, and pitch gyro outputs.

The Reaction Wheel Assembly (RWA) provides active attitude control by generating reaction torques about the three orthogonal spacecraft axes. Three of the RWAs are mounted orthogonally to produce torques about each of the three primary spacecraft axes; the fourth RWA is canted at an angle of approximately 54.7° with respect to each of the three axes, so that a portion of its torque resolves into all three of the axes. The fourth RWA is normally idle unless one of the orthogonal RWAs fails.

The coils pitch and roll/yaw magnetic torquing provide a capability for unloading accumulated satellite momentum. Current flowing in these coils generates an electric field that interacts with the Earth's magnetic field to remove momentum.

The ADACS also contains four gas-bearing, rate-integrating gyros. Like the RWAs, three gyros are orthogonal, while the fourth is canted to the spacecraft control axes. The gyros measure the attitude rates around each of the three axes for control loop damping and for deriving yaw attitude between periodic Sun sensor determinations.

2.5. Thermal System

The thermal design of the satellite involves accurate temperature control of both the spacecraft structure and the instrument payload. Both active and passive elements are used for this purpose. Passive control is effected by the appropriate use of multilayer insulation blankets, aluminized teflon thermal shielding, special finishes, and thermal conduction control materials. The two major elements of the thermal control system are heaters and louver-controlled cooling radiators. There are two types of louvers, vane and pin-wheel. Control of both types is maintained thermostatically by the Thermal Control Electronics Unit (TCE).

2.6. Data Handling System

The TIROS-N data handling subsystem consists of four primary components:

- The TIROS Information Processor (TIP) - a low data rate processor
- The Manipulated Information Rate Processor (MIRP) - a high data rate processor
- Digital Tape Recorders (DTR)
- A Cross Strap Unit (XSU)

All data available for transmission to the ground through the lifetime of the mission are processed by some or all of these components, as is shown in Figure 1.

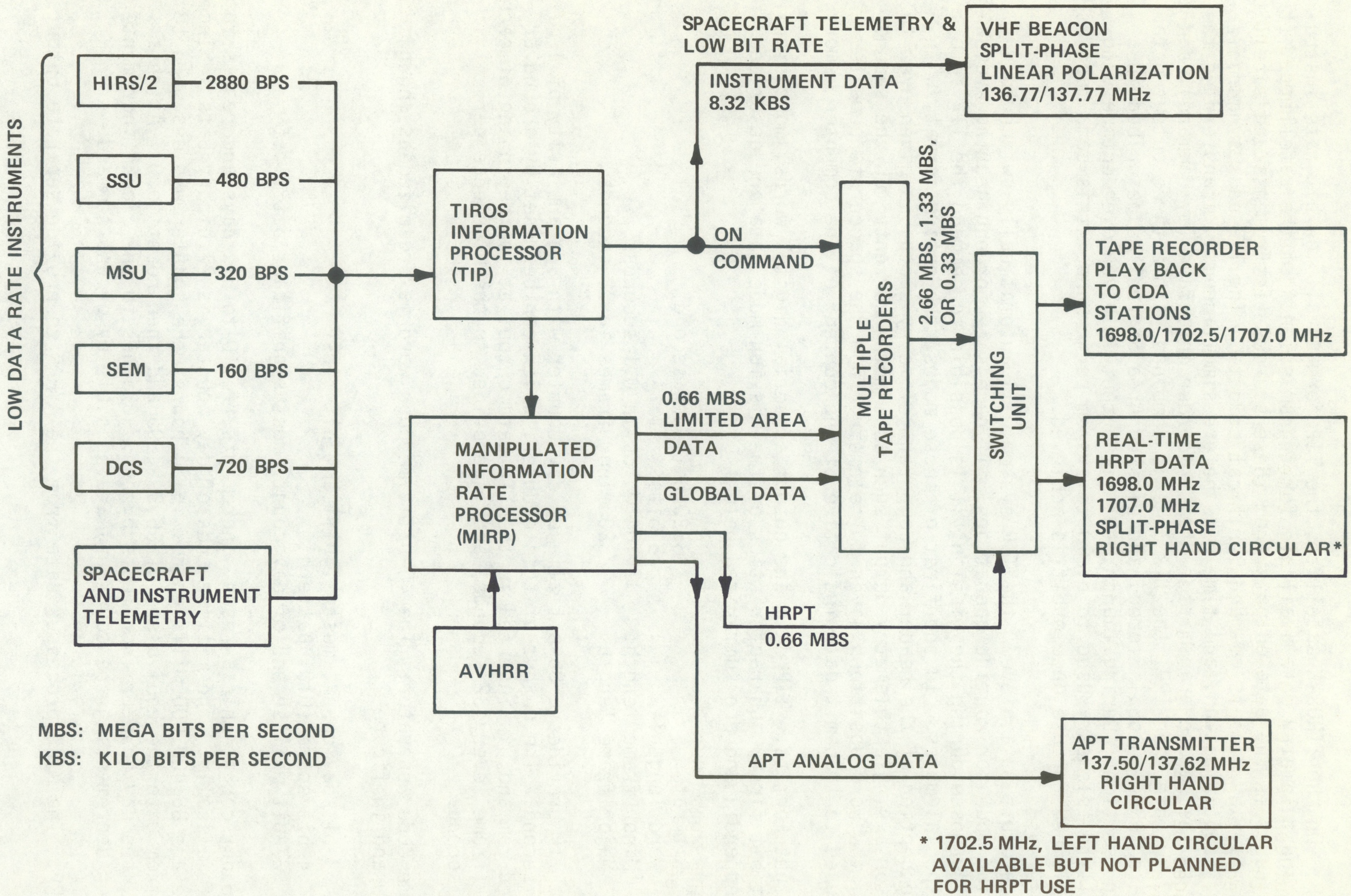


Figure 1.--TIROS-N data flow diagram

TIP: On the TIROS-N satellite, the TIP formats all low bit rate instrument and telemetry data available for transmission from the satellite. It also controls the data outputs from these sources (instruments and satellite systems), and accepts command verification data. The TIP adds synchronization, identification, and time code before simultaneously transferring the data to the beacon transmitter, tape recorder interface (by command), and MIRP. Within the MIRP, the TIP data is combined within three output data formats (HRPT, Global Stored, and Limited Area Stored) as described in a later section. During launch, the TIP output is given over entirely to satellite telemetry used to evaluate system performance; this data mode is not planned for use once orbit is achieved.

Once orbit is achieved, the TIP system will automatically switch to mission mode for routine operations. If necessary for engineering evaluation purposes during the mission, it is possible to command the TIP into two special modes. In the first of these modes, the entire format, with the exception of the header and computer telemetry slots, is given over to monitor a single telemetry output such as a motor current. In the second mode, the word positions given to telemetry from the spacecraft computer are used to transmit data indicative of the content of the computer memory.

Output Formats: TIP data are output as serial digital words, most significant bit first. Characteristics of the mission mode data are described in the Appendix and are summarized below:

Bit rate:	8320 bits per second
Word length:	8 bits
Minor frame length:	104 words in 0.1 seconds
Major frame length:	320 minor frames in 32 seconds

The TIP provides a 36-bit time of day counter with a granularity of 1 millisecond. The output of this counter, which can be reset by ground or stored command, is inserted in the TIP data output at the beginning of each major frame (every 32 seconds) and is provided to the MIRP once per millisecond.

Time Code Generator: The 40-bit time code word is organized as shown below and in figure 2.

9-bit day count, most significant bit first
4-bit spare (0101 pattern)
27-bit millisecond of day count, most significant bit first

The day count, unless reset, increments from 0 to 511 days and resets to 0 automatically. The milliseconds of day counter is 27 binary bits. Since there are 86,400,000 milliseconds in 24 hours, the counter was designed to run from 0 to the equivalent of 86,399,999 and then reset to 0. At this time, the day counter increments by one. Changes to the clock (incrementing or decrementing the counters) are possible by ground command.

MIRP: The MIRP processes data from the AVHRR to provide separate outputs

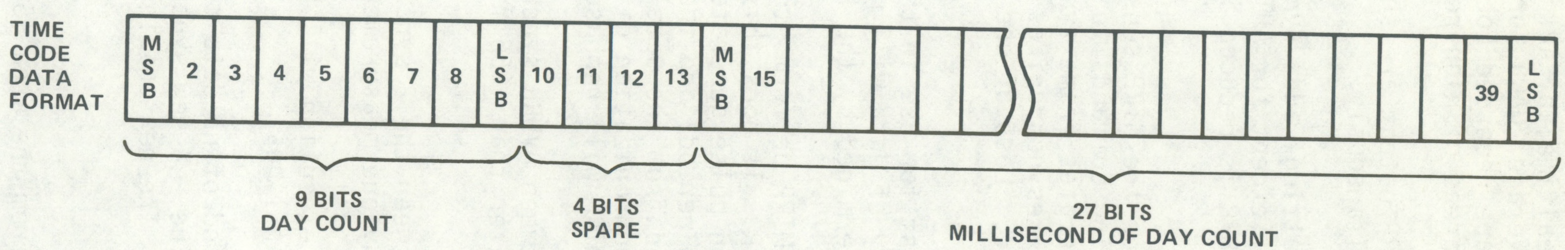


Figure 2.--40-bit time code format

for: a) HRPT transmission in realtime, b) APT transmission in realtime, c) tape recorded Global Area Coverage (GAC) for central processing of reduced resolution data, and d) tape recorded Local Area Coverage (LAC) for central processing of selected areas of high-resolution data.

The characteristics of the MIRP output are shown in table 1. The four data formats can be output simultaneously.

The MIRP, in addition to formatting, adds synchronization, identification, telemetry, time code, and (except for APT) the TIP output to the AVHRR. The high resolution AVHRR is reduced in resolution by averaging for both APT and GAC uses.

In the normal mode of operation the MIRP senses the start of line pulse from the AVHRR and issues sampling commands to the AVHRR in synchronization with this pulse.[1] The MIRP generates frame synchronization from an internal clock and, if necessary, resynchronizes automatically if phase displacement exceeds a preset value. Loss of one line of data is expected if this event occurs.

Backup modes of operation exist for use in the event of prime system failure. In this event, utility of data will most likely be reduced; the extent of this loss will be determined by the failure mechanism.

Data Scan Line Rephase: The MIRP performs the function of measuring line-to-line jitter of the AVHRR. It does this by measuring the elapsed time between the synchronization pulse generated by the AVHRR (directly related to scan mirror rotation period) and the digitally derived internal synchronization period developed from the satellite clock reference; this is assumed to be stable. A synchronization difference of up to 511 microseconds can be measured. The MIRP will rephase its output if either:

1. The time difference between AVHRR synchronization and MIRP synchronization is greater than ±256 microseconds for 2 consecutive lines, or

2. The time difference between the 2 synchronization pulses exceeds 511 microseconds for any one measurement.

If a rephase is necessary, the execution will be delayed until the end of the HRPT major frame (three scan lines).

Rephase will result in a period of no data transmission for a time equivalent to less than one scan line. A new synchronized frame will begin at the new phase reference point. The new phasing is then maintained until

---

[1] Earth scan data are retained from the area ±55.4° (nominal) from the nadir. High view angle data are ignored.

Table 1.--Characteristics of MIRP output

	HRPT & LAC*	GAC**	APT
Form of data	Serial Digital Bit Stream 10-bit words, most significant bit first		Analog A-M on 2.4 KHz Subcarrier
Line rate	6/sec	2/sec	2/sec
Word rate	66.54K words/sec	6654 words/sec	4160 words/sec prior to D-to-A Conversion
Number of AVHRR Channels Included	5	5	2
Words of Earth scan per line per channel	2048	409	909, prior to D-to-A Conversion
Processing of AVHRR data	Formatting only	Resolution reduction & formatting	Resolution reduction, correction for geometric distortion and formatting
Other data than AVHRR	TIP; time of day	TIP; time of day	Minute marks; calibration wedge

*Local Area Coverage (recorded high resolution data, analogous to the HRPT.
**Global Area Coverage (reduced resolution data for central processing.

the limits are again exceeded. APT users with mechanical facsimile machines will find it necessary to reset the line synchronization for their machine in the event this MIRP resynchronization is required.

Time Code Processing: The MIRP receives time code data from the TIP and includes it in all digital output formats. The code has a precision of 1 millisecond and consists of 40 bits, as shown in figure 2. The time inserted into the HRPT data is the time of the leading edge of the AVHRR generated synchronization pulse. This pulse becomes the reference used for AVHRR data sampling. The nadir position is nominally 34.25 milliseconds after this time. Time code is also inserted in the TIP data; it appears in the first minor frame of each major frame (32 seconds). Each successive minor frame occurs 0.1 seconds after the preceding frame. The inserted time code is the time of the beginning of that frame accurate to ± 1 millisecond.

It is planned to keep the spacecraft time code the same as Greenwich Mean Time (GMT) on the ground by updating the clock as necessary. It should be remembered, however, that the clock output is actually a spacecraft reference and may differ from actual GMT.

AVHRR Data System Test Mode: Although not planned for operational use, it will be possible by command to inhibit the AVHRR data and insert a known test pattern into the HRPT/APT so that an accurate evaluation of the data link may be made. In place of the AVHRR data, the MIRP will process the output of a Psuedo-Noise (P-N) generator. Knowing the input pattern to the MIRP, it will be possible to evaluate both the MIRP processing algorithms and the satellite-to-ground link, should either analysis become necessary. Two versions of this test mode are possible. In one, the frame format is maintained and the test pattern is only inserted for the AVHRR data portion. In the second mode, the frame format is not retained and the test data replaces the entire output; the test pattern will be continuously cycled until commanded off.

AVHRR/HRPT Processing: The AVHRR scan mirror rotates at 360 rpm. Once during each revolution of the mirror, a synchronization pulse is generated as the mirror reaches a precise (pre-Earth) position. This pulse is used as the reference for all subsequent event timing, which is controlled by the MIRP. Upon receipt of the synchronization pulse from the AVHRR, the MIRP begins a data sampling process which takes the appropriate number of samples at specified times during the scan line. Data are stored in a memory bank and read out at the appropriate rate for the HRPT data format.

Table 2 shows the number of data samples acquired during each portion of the instrument scan period. Data are acquired simultaneously from each spectral channel of the instrument. Similar information is shown in figure 3.

Full resolution data from the AVHRR with TIP information added are output for the HRPT/LAC transmissions. As may be seen in figure 4, no data lines are deleted for the HRPT.

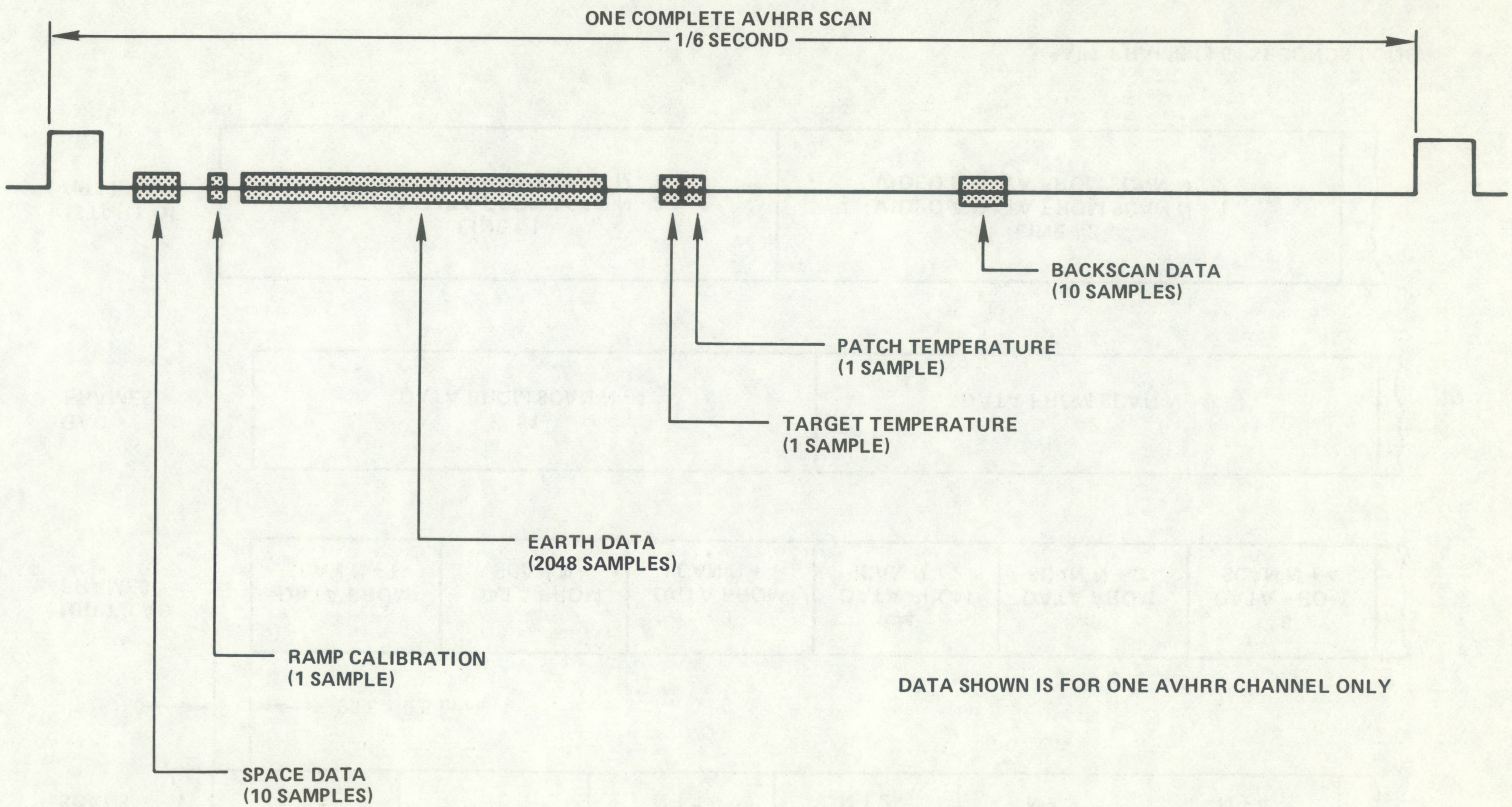


Figure 3.--AVHRR data sampling areas

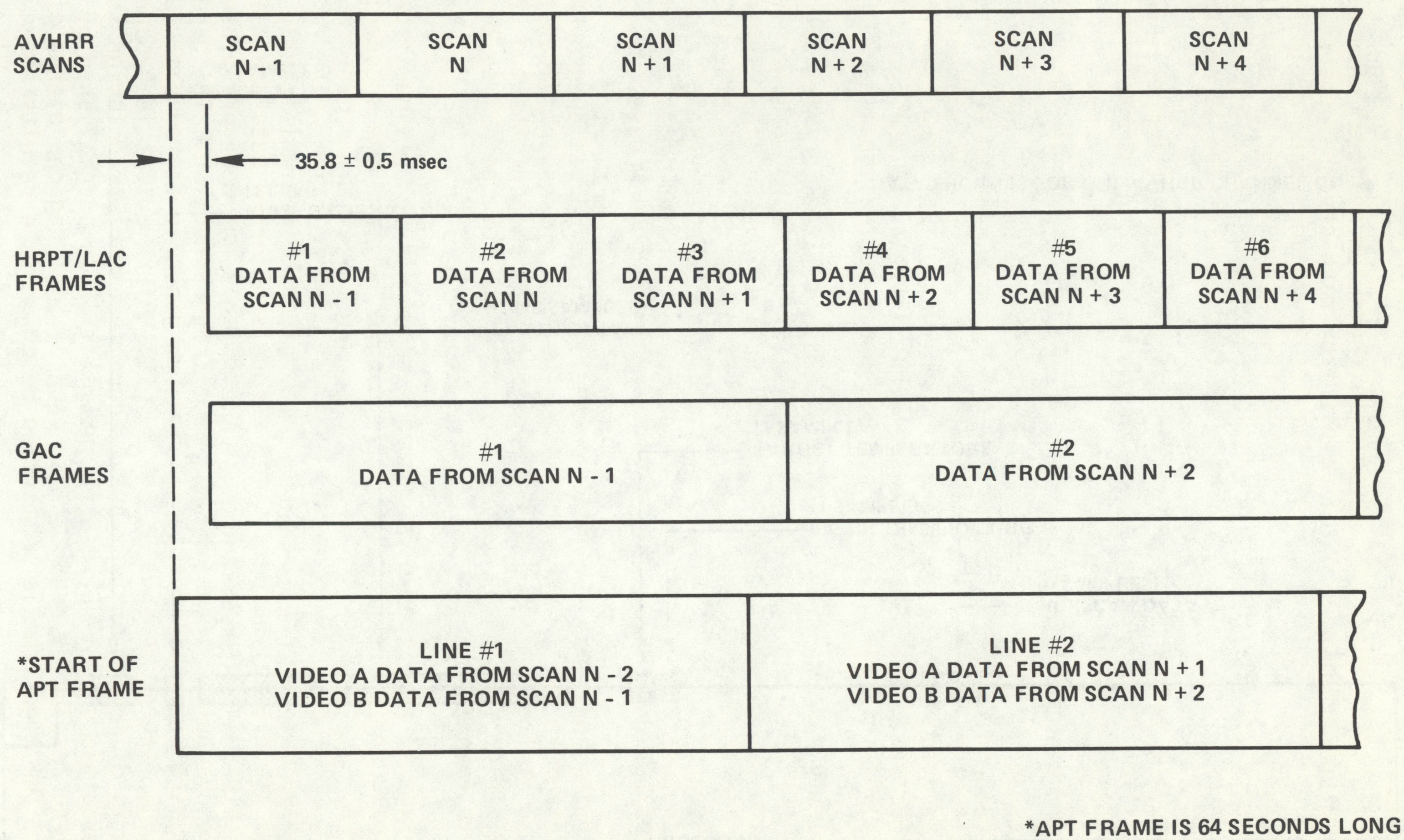


Figure 4.--Relative phasing of MIRP output frames

Table 2.--MIRP Data Sampling Intervals

Space Data[1]	10 samples from each spectral channel
Electronic ramp calibration	1 sample from each spectral channel
Earth data	2048 samples from each spectral channel
Target temperature[1]	1 sample from each of the IR channels
Cold patch temperature	1 sample from channel 4 of the instrument
Back scan[1]	10 samples from each of the IR channels

[1]Used to define the calibration of the IR channels. Target temperatures are the output from Platinum Resistance Thermometers (PRT) mounted in the instrument backscan region.

AVHRR/GAC Processing: MIRP uses one of three AVHRR lines for GAC data (figure 4). Data volume (and resolution) are further reduced by averaging four adjacent samples along the line; the following sample is skipped. This pattern is continued for the length of the scan line. The averaged values are inserted in the GAC format for eventual relay to the central processing facility. These data are not available to the local user.

TIP Data in HRPT (LAC) and GAC: The 520 words of TIP data which are contained in the HRPT/LAC and GAC formats consist of 5 contiguous minor frames (104 words each; 0.5 seconds total) of data supplied by the TIP. These data are supplied as 8-bit words which the MIRP converts to 10 bits by adding an even parity bit in the ninth position and the inverse of the first bit in the 10th position. Identical TIP data are repeated in each of three successive HRPT/LAC data lines before being replaced by new data.

AVHRR/APT Processing: Any two AVHRR channels can be chosen by ground command for output to the APT transmitter. The data processing algorithm was designed so that data from every third line from each of the two channels of the original high resolution output are formatted for the APT system; this is seen in figure 4.

It is important to note that APT channel A data will be obtained from line "N-2", while the B channel data will be obtained from the succeeding AVHRR scan line.

The APT data output, an amplitude modulated signal, is significantly different from the digital outputs. Two channels of AVHRR data are time-division multiplexed into an output data stream that has been pre-processed to achieve both bandwidth reduction and geometric correction. The bandwidth reduction algorithm is similar to that used for globally stored data (GAC) in that only one line of three from the original AVHRR output is processed. The algorithm is different in that nearly equal geometric resolution is maintained along the scan line. This linearization is accomplished by using a separate resolution reduction in each of five regions either side of the nadir. The algorithm is summarized below and the results shown in figure 5.

Region 1 (±16.9° from nadir): average four contiguous samples[1]

Region 2 (16.9° to 34.8° either side of nadir): average two samples; skip one and repeat

Region 3 (34.8° to 43.8° either side of nadir): average two samples

Region 4 (43.8° to 48.8° either side of nadir): average 1 1/2 samples $\left(\frac{A+B}{2} : \frac{B+C}{2}\right)$

Region 5 (48.5° to 55.4° either side of nadir): retain original resolution

All processing is accomplished in the digital domain before being converted to an analog signal for output on the APT transmitter. The resulting APT data format is shown in Appendix B. The averaging and geometric correction which produces 909 data samples per channel per line has an effective bandwdith of 2080 Hz. To minimize distortion in the data, the signal is low-pass filtered prior to amplitude modulation. The final output is AM modulated on a 2.4-KHz subcarrier and transferred directly to one of the two APT transmitters.

Digital Tape Recorders: Five digital recorders, each with a single electronic module and dual tape transport, will be provided to record data for subsequent transmission through the CDA to the central data processing facility. Each transport has an adequate tape capacity (168 m, 550 ft) to record approximately 4.5 X 10^8 bits of data. This is adequate to record either:

1. A full orbit (110 minutes) of GAC data.

2. Ten minutes of HRPT data (called LAC when recorded).

3. 250 minutes of TIP (low bit rate instrument) data only.

GAC and LAC are recorded on eight parallel tracks. Playback is split-phase for low data rates (1.33 Mbs[2] or 0.33 Mbs) and nonreturn to zero (NRZ) for the high data rate (2.66 Mbs). The recorder bit error rate is specified to be 5 in 10^7 at beginning of life and 1 in 10^6 at end of life. It has been designed for 25,000 passes on each transport unit.

2.7. Command and Control

The command and control group provides the functions of decoding ground commands, storing commands for later execution, and issuing control signals.

[1]AVHRR data is sampled at a rate of 2.8 samples per cycle so each original sample is equal to 0.71 of the original Instantaneous Field of View (IFOV).
[2]Mega bits per second.

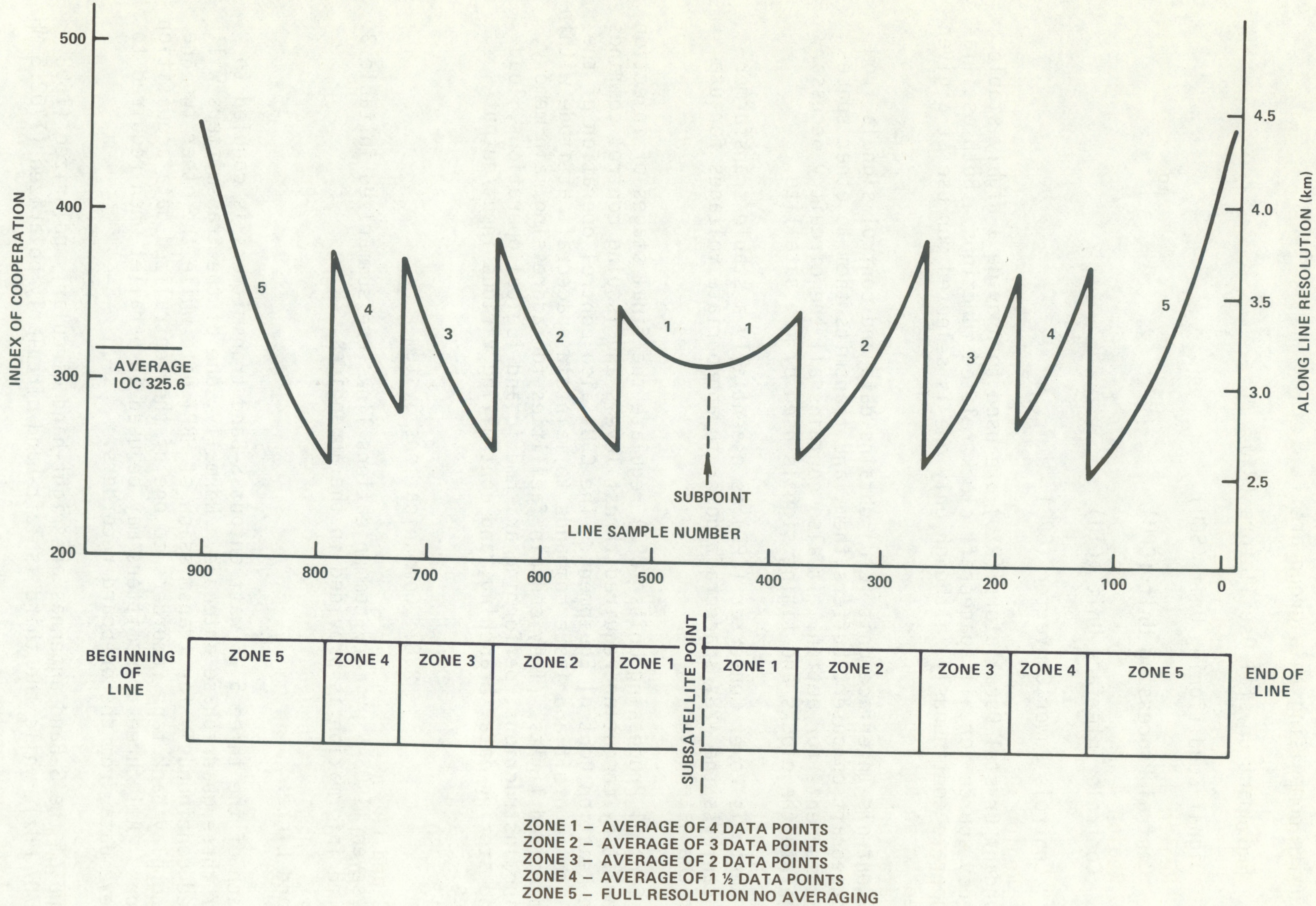


Figure 5.--APT linearization regions and resolution

Major units comprising this group are:

a. Redundant Crystal Oscillators (RXO)

b. Signal Conditioning Unit (SCU)

c. Central Processing Unit (CPU)

d. Controls Interface Unit (CIU)

e. Controls Power Converter (CPC)

Redundant Crystal Oscillators (RXO) are used to provide a highly stable frequency source for all spacecraft clock related functions. Both oscillators operate continuously, although only one is selected for use at a given time.

The Controls Interface Unit (CIU) obtains data and control signals from the spacecraft computer, buffers them, and transmits them to other spacecraft components for action. It also contains all the circuitry necessary to generate the clocks and timing signals used by the satellite.

The Controls Power Converter (CPC) is essentially a stable transformer which converts the +28V spacecraft power to appropriate voltages for use within the satellite.

The Central Processing Units (CPU) regulate the final stages of injection into orbit by computing required thrust levels and issuing control commands to the Reaction Control Equipment. The CPUs also control operation of the satellite in orbit and issue commands to maintain spacecraft attitude within predetermined limits. They contain facilities for addressing main memory, fetching instructions, performing arithmetic and logical operations, loading and storing data, branching, and controlling various input/output devices.

2.8. Communications System

The seven TIROS-N primary communications links are summarized in table 3. Detailed information is provided in the appendices.

S-Band Links:

Each of the three 5.25 watt output S-Band transmitters is coupled to one of three quadriphase antennas. Normally, one of the transmitters will be used continuously for transmission of HRPT data while the other two are used to play back tape recorders to one of the centralized data acquisition stations. All three transmitters may be used in parallel when required to retrieve data from the on-board recorders.

Two of the S-Band antennas are right-hand circularly polarized (1698 and 1707 MHz), while the third is left-hand circularly polarized (1702.5 MHz).

Table 3. Communication link summary

Link	Carrier Frequency	Information Signal	Baseband Bandwidth	Modulation	Subcarrier Frequency
Command*	148.56 MHz	Digital commands	1 kbps	Ternary FSK/AM	8,10,12 KHz
Beacon	137.77 MHz or 136.77 MHz	Low bit rate instrument data and spacecraft telemetry. All from TIP	8320 bps	Split-phase PSK	
VHF Real-time - APT	137.50 MHz or 137.62 MHz	Medium resolution video	2 KHz	AM/FM	2.4 KHz
S-Band Real-time - HRPT	1698 or 1707** MHz	High resolution video data, and TIP data from MIRP	665.4 kbps	Split-phase PSK	
S-Band playback to CDAs	1698, 1702.5 or 1707 MHz	High resolution video data from MIRP, medium resolution video data from MIRP	2.6616 Mbps	Randomized NRz-PSK	
Data collection*	401.65 MHz	Data from earth-based platforms and balloons	400 bps	Split-phase PSK	
S-Band TIP data playback	1698, 1702.5 or 1707 MHz	TIP data recovered from tape recorders	332.7 kbps	Split-phase PSK	

*Uplink to the satellite.
**1702.5 may be used for HRPT in the event of failure of primary transmitters.

During the ascent phase only, one of the S-Band transmitters is connected to a S-Band omnidirectional antenna to provide spacecraft telemetry.

VHF Links:

The VHF APT transmitter has a 5w output and operates at a preselected frequency of either 137.50 or 137.62 MHz. One of the transmitters is planned to operate continuously in the manner of previous APT transmissions. Choice of transmitting frequency will be made to preclude interference between signals emanating from two satellites in orbit at the same time. Either transmitter is coupled to the VHF realtime quadrifilar antenna via an RF switch. Modulation is AM on a 2.4-KHz subcarrier which in turn frequency-modulates the carrier. The antenna is a four element quadrifilar providing a shaped pattern; nominal directivity of the right-hand circularized antenna is +4.5 dBci at nadir and +0 dBci at the horizon.

3. LAUNCH AND ORBIT

3.1. Orbit and Constraints

The TIROS-N satellite series has been designed to operate in a Sun-synchronous orbit at 833 $\pm$90 km (450 $\pm$50 n.mi.). Two nominal altitudes have been chosen: 833 km (450 n.mi.) and 870 km (470 n.mi.). The choice between nominal altitudes will be made to keep the orbital periods of two operational satellites in similar orbits sufficiently different (1 minute) so that they do not both view the same point on the Earth at the same time each day.

Nominal orbital parameters are shown in table 4 below.

Table 4. TIROS-N series orbital parameters

Parameter	833 km orbit	870 km orbit
Inclination	98.739 degrees	98.899 degrees
Nodal period	101.58 minutes	102.37 minutes
Nodal Regression	25.40 degrees/orbit W	25.59 degrees/orbit W
Nodal Precession[1]	0.986 degrees/day E	0.986 degrees/day E
Orbits per day	14.18	14.07

[1]Figure 6b

A satellite pass directly over an antenna site will be within view of that antenna (horizon-to-horizon) for about 15.5 minutes when the satellite is at 833 km and 16 minutes when it is at 870 km. The user of APT or HRPT can therefore expect to receive data from a circular area 6200 km in diameter centered at the location of the antenna. If one assumes that the spacecraft must be 5° above the horizon for useful data to be acquired, the contact time and area is reduced to about 13.0 minutes (833 km satellite altitude), 13.7 minutes (870 km) and 5200 km.

Because the number of orbits per day is not an integer number, the sub-orbital tracks do not repeat from day-to-day although the local solar time for passing any latitude is essentially unchanged. For this reason, the orbital equator crossings will occur at varying longitudes during the lifetime of the satellite.

NOAA/NESS operates two Command and Data Acquisition (CDA) stations, one in Virginia and one in Alaska, to receive the environmental data from the satellite. However during three sequential orbits of the Earth (four, some days), the satellite remains out of contact with one of these sites. To eliminate delay in receipt of high priority temperature profile data during this period, a data receipt-only station is being established to receive data in Lannion, France by the Centre d'Etudes de la Meteorologie Spatiale (CEMES). This station will acquire stored TIP data and transmit it to the central processing facility in the United States. When this station is in use, the satellite will be out of contact with the ground for no more than one orbital period per day.

3.2. Drift from Sun-synchronous Conditions

Orbit parameter errors result from several causes associated with the booster operation. These errors may be characterized as either orbital plane (inclination) or altitude related. Orbital parameters for the TIROS-N series are expected to be within the following three sigma limits:

Altitude (average): ±18.5 km

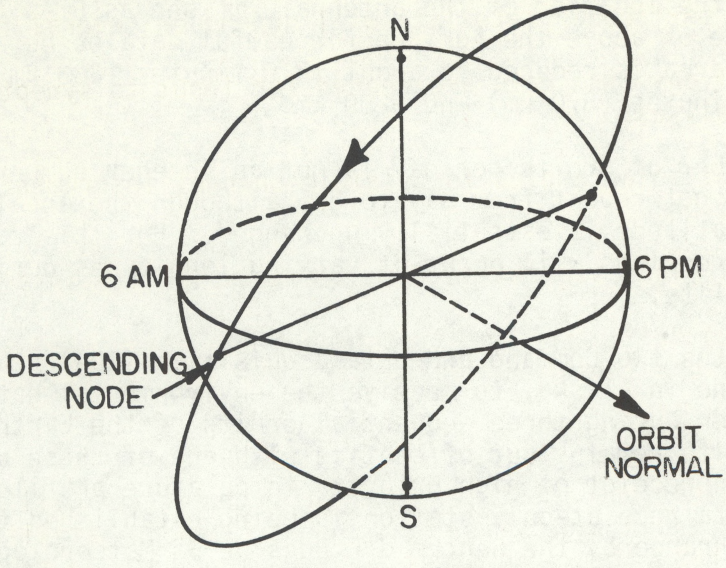
Inclination: ±0.15°

Apogee/perigee difference: less than 56 km

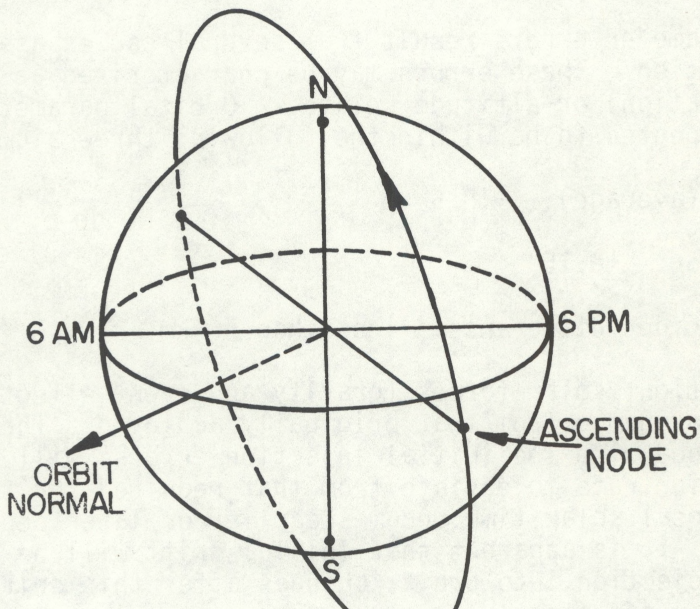
After injection, solar forces (gravity and event effects) will cause the inclination to change from that originally achieved. The effect of this change, combined with the initial injection errors, will probably cause the nodal precession rate to deviate from that required for true sun synchronism. Whether the local solar time becomes earlier or later depends upon the sign of the error. It is apparent that initial drift will be a factor of the accuracy of injection into orbit, changes after this drift is defined will be due to solar effects.

3.3. Equator Crossing Time

The TIROS-N satellite series has been designed to operate with a south-bound equator crossing between 0600 and 1000 Local Solar Time (LST), or a a northbound equator crossing between 1400 and 1800 LST (figure 6a). Power



AM DESCENDING NODE ORBIT



PM ASCENDING NODE ORBIT

Figure 6a.--TIROS-N/NOAA equator crossing times and thermal constraints preclude normal operation within 2 hours of noon (midnight) LST. The time of day actually chosen for the initial injection condition for a particular satellite will depend on several factors:

a. Time of day that data are needed for input to synoptic map analyses.

b. Subpoint solar angles for visible channel instruments (figure 6b).

c. Orbital plane separation from second satellite in orbit.

d. Expected drift from Sun-synchronous conditions and spacecraft time of day (solar angle) constraints.

e. Time of year launch will occur.

Preliminary indications are that the morning satellite will be launched into a 07:30 LST descending orbit, while the afternoon satellite is 15:00 LST ascending. These items represent a compromise between the selection criteria.

3.4. Orbit Injection

Satellites of the TIROS-N series will be launched into Sun-synchronous orbits. The first stage booster will be an Atlas E/F; second stage propulsion will be provided by a rocket motor integral with the satellite.

The guidance system of the Atlas vehicle is used to control the first stage of the satellite launch. The spacecraft system monitors launch parameters and controls the flight after separation from the Atlas vehicle. Body rates and accelerations are provided to the Central Processing Unit (CPU) by the Inertial Measurement Unit (IMU) which is made up of rate integrating gyros and accelerometers. The CPU uses a stored set of equations to determine the optimum flight profile which, after first stage separation, is maintained by the Reaction Control System (RCS). Hydrazine and nitrogen are used to provide spacecraft control during the solid motor burn, and to trim orbit velocity after insertion, and during the period when the solar array is deployed. Unused nitrogen gas will be retained on the satellite for use in the event of unexpected momentum buildup during the lifetime of the satellite. The RCE and the accelerometers are deactivated after the orbital insertion maneuvers are completed.

4. ACTIVATION AND EVALUATION PERIOD

The 4 to 6 week period following the launch of a satellite is reserved for engineering evaluation. Instruments will be tested during the period, but transmission of data will be sporadic at best. Neither the AVHRR or the HIRS/2 will be activated during the first 2 weeks following a launch. During this period, the radiant cooler covers will remain in place and the coolers will be heated to 40°C to assure that outgassing contaminants from

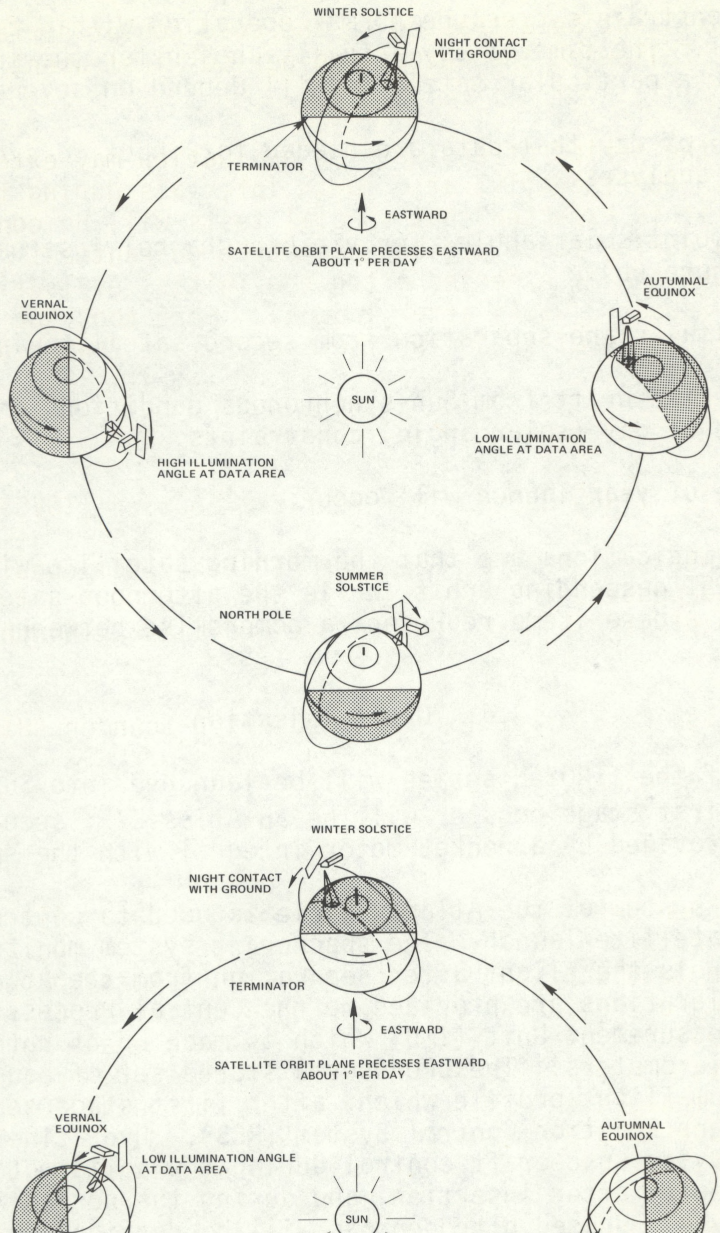


Figure 6b.--Satellite orbit precession with season

the satellite will not be attracted to the cold cooler surface and degrade its operation. Following the outgassing period, instrument evaluation will begin.

For TIROS-N, the period of engineering evaluation may extend through several months. Additionally, at 6 month intervals during the lifetime of this satellite it is expected that special tests will be conducted. Continuity of data during these periods cannot be guaranteed. Operational data from the NOAA A-G can be expected after the initial evaluation period has been completed (about 3 weeks after launch). Here too, the AVHRR and HIRS/2 instruments will be inactive during the approximate 2 week period following launch.

5. INSTRUMENTS

5.1. TIROS Operational Vertical Sounder (TOVS)

The TIROS Operational Vertical Sounder (TOVS) system consists of three separate and independent instruments, the data from which may be combined for computation of atmospheric temperature profiles. The three instruments are:

a. The High Resolution Infrared Radiation Sounder (HIRS)

b. The Stratospheric Sounding Unit (SSU)

c. The Microwave Sounding Unit (MSU)

The TOVS has been designed so that the acquired data will permit calculation of 1) temperature profiles from the surface to 10 mb, 2) water vapor content at three levels of the atmosphere, and 3) total ozone content. Improved accuracy of retrieval profiles and a better definition of the water vapor profile, even in the presence of clouds, are goals for this system. Previous NOAA systems provided atmospheric temperature profiles that varied from radiosonde measurements by about 2 1/2°C rms. The TOVS system is expected to reduce this difference to between 1 and 1.5°C. This improvement will be made possible by better computational models using data from many more (27 vs. 8 from NOAA-5) spectral regions and by the availability of data from the Microwave Sounding Unit (MSU) which is generally unaffected by non-precipitating clouds.

5.1.1 High Resolution Infrared Radiation Sounder (HIRS/2)

The High Resolution Infrared Radiation Sounder (HIRS/2) (figure 7) is an adaptation of the HIRS/1 instrument designed for and flown on the NIMBUS 6 satellite. The instrument, being build by the Aerospace/Optical Division of ITT, will measure incident radiation in 20 spectral regions of the IR spectrum, including both longwave (15 μm) and shortwave (4.3 μm) regions.

The HIRS/2 utilizes a 15 cm (6 in) diameter optical system to gather emitted energy from the Earth's atmosphere. The instantaneous field of

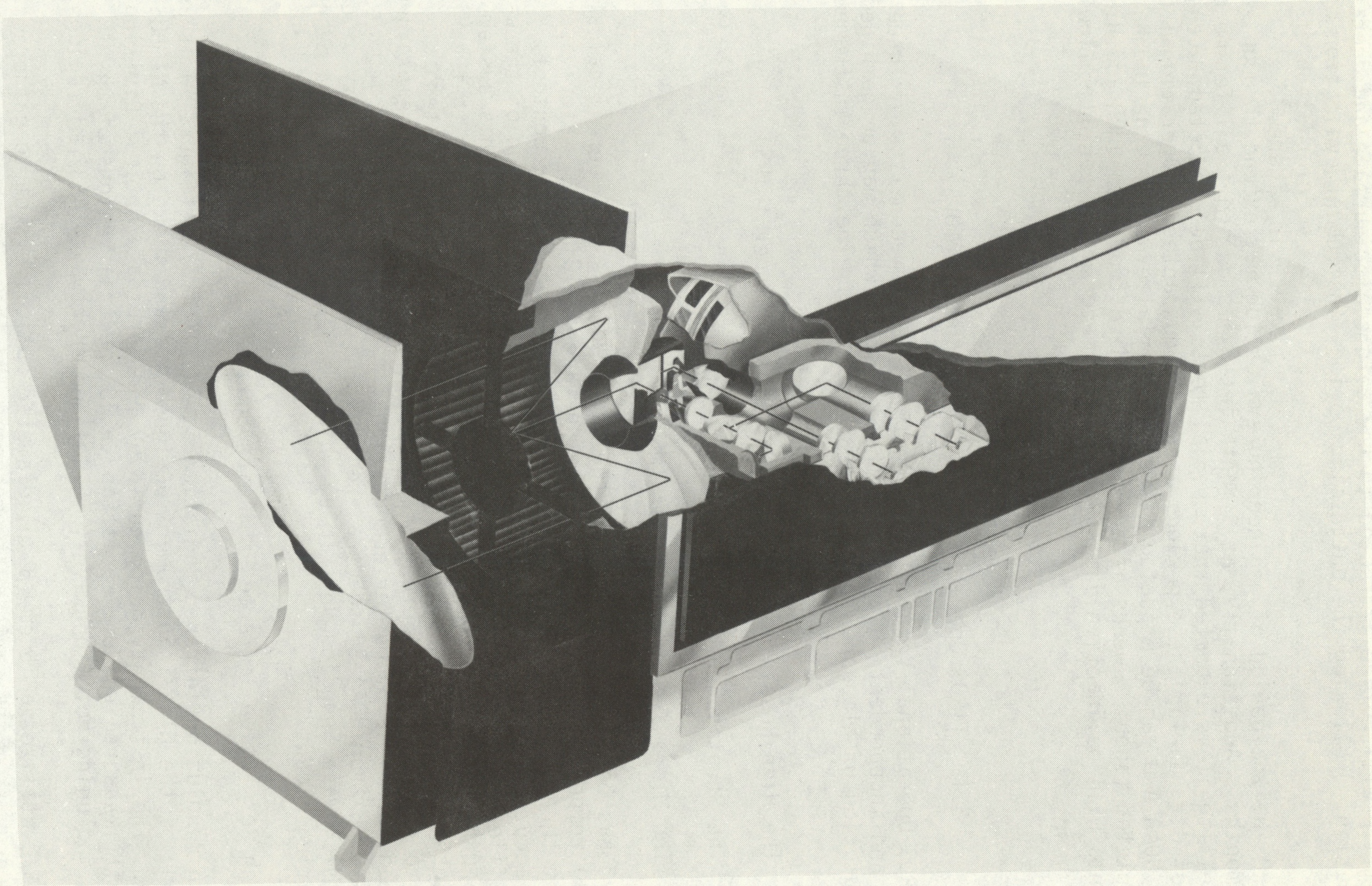


Figure 7.--TIROS-N High Resolution Infrared Radiation Sounder (HIRS/2)

(*Courtesy of ITT/Aerospace Optical Division*) view (IFOV) of all the channels will be stepped across the satellite track by use of a rotating mirror. This cross-track scan, combined with the satellite's motion in orbit, will provide coverage of a major portion of the Earth's surface. The coverage pattern may be seen in figure 8.

The energy received by the telescope is separated by a dichroic beam-splitter into longwave (above 6.4 μm) and shortwave (below 6.4 μm) energy, controlled by field stops and passed through bandpass filters and relay optics to the detectors. In the shortwave path, a second dichroic beam-splitter transmits the visible channel to its detector. Essential parameters of the instrument are shown in table 5. Primary system components shown in figure 7 include:

a. Scan system

b. Optics, including filter wheel

c. Radiant cooler and detectors

d. Electronics and data handling

e. Mechanics

Table 5.--HIRS/2 system parameters

Parameter	Value
Calibration	Stable blackbodies (2) and space background
Cross-track scan	±49.5° (±1120 km)
Scan time	6.4 seconds
Number of steps	56
Optical FOV	1.25°
Step angle	1.8°
Step time	100 milliseconds
Ground IFOV (nadir)	17.4 km diameter
Ground IFOV (end of scan)	58.5 km cross-track by 29.9 km along-track
Distance between IFOV's	42 km along-track
Data rate	2880 bits/second

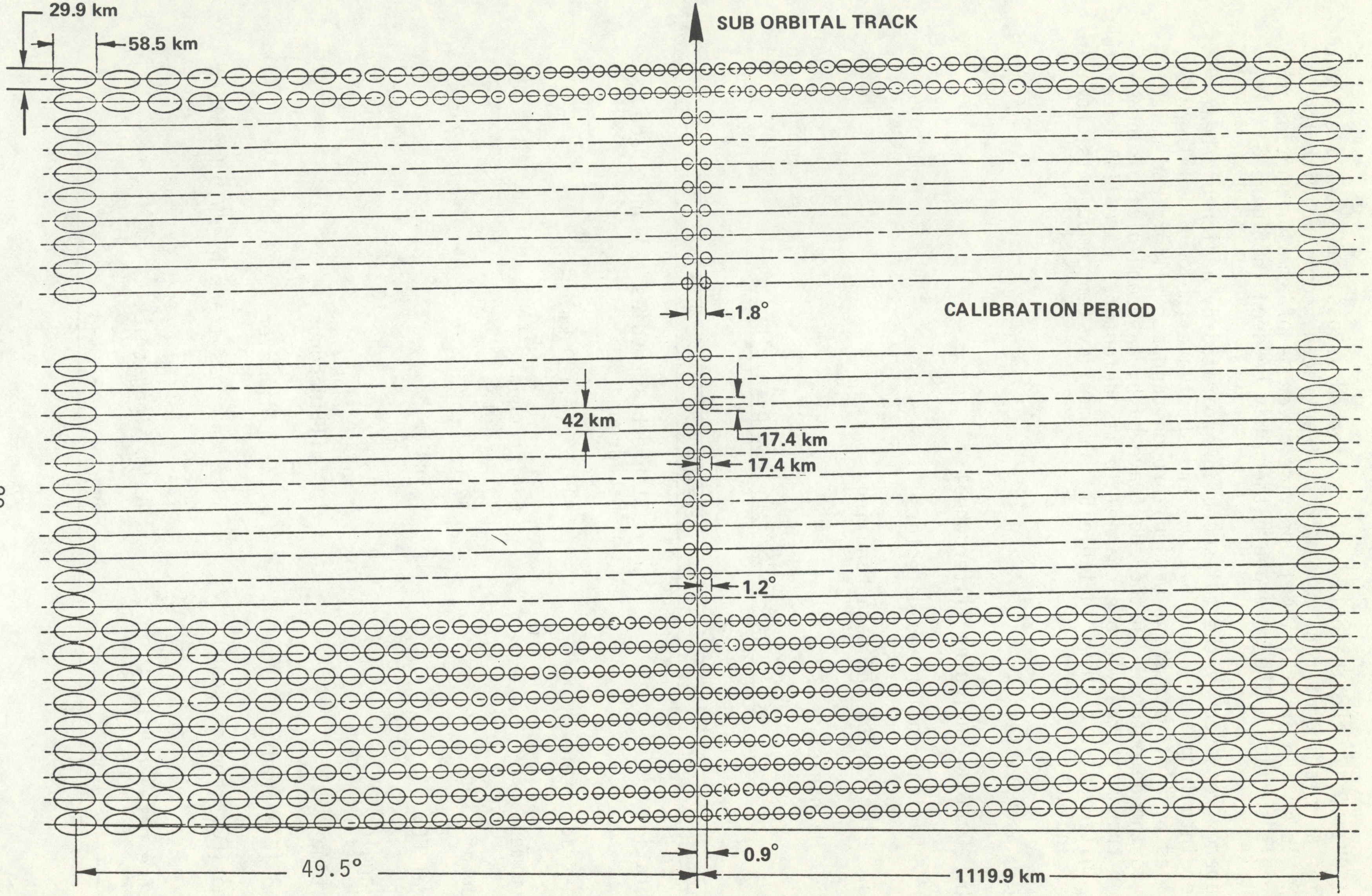


Figure 8.--TIROS Operational Vertical Sounder HIRS/2 Scan Pattern Projected on Earth

5.1.2 Instrument Operation/Scan System

In orbit, the instrument output is locked to the spacecraft clock. The scan mirror synchronizes its stepping to this clock, starting a new scan line in conjunction with the other TOVS components upon receipt of a major frame pulse from the spacecraft. The mirror steps from its initial or home position in 55, 1.8° steps (56 data points) over its 99° swath (measured from the spacecraft). At completion of data acquisition at the last position (#56), the mirror rapidly returns to the first (home) position and repeats the Earth scan pattern. Each scan line requires 6.4 seconds. Synchronization with both of the other instruments occurs every 128 seconds (every 20 scan lines).

The instrument can be commanded to automatically enter a calibration mode every 256 seconds. Upon receipt of the calibrate command, the instrument enters the calibrate mode. Starting from the beginning of a scan line, the mirror rapidly slews (equivalent to the time for 8 scan elements) to a space view where it stops for the length of time necessary to complete one line (equivalent to 48 scan elements). All channels of the instrument are sampled during this period. The mirror is next moved to a position where it views a cold calibration target. Data are taken for the equivalent of 56 scan steps at which time the scan mirror is stepped to view the internal warm target. After another 56 samples, the mirror continues its motion to the start of scan (home) position, where it begins normal Earth scan. The total calibration sequence is equivalent in time to three scan lines. No Earth data are obtained during this period.

5.1.3 Optical System

The HIRS/2 optical system has been based largely on the design used for the HIRS/1. Small changes to the longwave design have been instituted primarily to eliminate vignetting and to ensure that a minimum of energy from beyond the field-of-view reaches the detectors. The optical path (port) to the cooler has been kept as small as possible to reduce the heat loading effects. The effective field-of-view of the instrument has been defined by the field stops.

The first dichroic transmits the longwave and reflects the shortwave and visible channels. Therefore, two field stops define the field-of-view: one is for longwave channels, the other for short. Immediately behind the field stops, the bandpass defining filters are grouped on a wheel which rotates in such a manner that the energy reaching the detectors is defined by each filter in turn. The shortwave filters are located along the circumference of an outer radius, while the longwave defines an inner circumference. A chopper tooth is rigidly attached to the wheel and rotates with it; signal integration is confined to the time interval while viewing an optical filter. Length of the filter (and therefore the length of integration) has been chosen to provide an adequate signal-to-noise ratio.

The relay lens system is used to focus the received energy on the detectors. The goal of the design was to reduce vignetting and provide uniform illumination across the field.

Cooled detectors are used for all IR channels because of their high sensivity and short response time. The detectors will be maintained at their operating temperature (105°K) by a thermostatically controlled passive radiant cooler

5.1.4 Spectral Channel Characteristics

The HIRS/2 instrument will make measurements in 20 spectral regions, the specifications for which are given in table 6. The individual bandpass filters are positioned on the filter wheel in a manner consistent with the requirement to ensure registration with the long and shortwave window channels. Longwave to shortwave registration is achieved by adjusting the two detectors relative to each other. Response outside of bands is held to the minimum level consistent with state-of-the-art filter design.

5.1.5 Radiant Cooler and Detectors

The HIRS/2 instrument uses two solid state IR detectors which operate most efficiently near 105°K. As is the case for the AVHRR, the longwave detector is mercury-cadmium-teluride (HgCdTe), the shortwave is Indium Antimonide (InSb). A silicon detector operating at ambient temperatures is used for the visible channel.

The radiant cooler is functionally the same as that used for the AVHRR. Modifications to the cooler have been limited to those necessary to interface with the HIRS/2 optical system. Tests have shown that the cooler can reach an operating temperature of about 97K, if it were permitted to run uncontrolled. This provides an adequate reserve margin to ensure continuous operation at the 105°K control point.

To ensure that outgassing products do not condense on the cooler during the initial time in orbit, the cooler will be heated to 40°C for approximately 2 weeks following launch. The same heaters are also available to drive off contaminants in the event cooler performance degrades during the 2 year lifetime. No data will be obtained from the instrument IR channels during any period of decontamination.

5.1.6 Scan System

The mirror scan system for the HIRS/2 is only slightly changed from that of the original HIRS flown on the Nimbus satellite. A scan housing assembly, that can be detached from the baseplate, contains all electronic components of the scan system. The system has been designed so that during Earth scan stepping, the mirror steps 1.8° to each new position with minimum overshoot and settles to within 0.1° in 35 milliseconds. A mirror position encoder provides a positive indication of the scan position of the mirror.

5.1.7 Electronics and Data Handling

The instrument output consists of digitally converted data levels for each spectral interval at sufficient dynamic range and quantizing resolution to allow extraction of all radiometric information. The range of signal

Table 6.--HIRS/2 instrument specifications

Channel	Central Wave No. cm^{-1}	Half Power Bandwidth cm^{-1}	Wavelength µm	Specified NEΔN mw/m^2-sr cm^{-1}
1	688.5 ±1.3	$3.0^{+1}_{-0.5}$	14.96	0.80*
2	680.0 ±1.8	10.0^{+4}_{-1}	14.71	0.27
3	690.0 ±1.8	12.0^{+6}_{-0}	14.49	0.27
4	703.0 ±1.8	16.0^{+4}_{-2}	14.22	0.22
5	716.0 ±1.8	16.0^{+4}_{-2}	13.97	0.22
6	733.0 ±1.8	16.0^{+4}_{-2}	13.64	0.22
7	749.0 ±1.8	16.0^{+4}_{-2}	13.35	0.22
8	900.0 ±2.7	35.0±5	11.11	0.11
9	1030.0 ±4	25.0±3	9.71	0.16
10	1225.0 ±4	60.0^{+10}_{-3}	8.16	0.16
11	1365.0 ±5	40.0±5	7.32	0.22
12	1488.0 ±4.7	80.0^{+15}_{-4}	6.72	0.11
13	2190.0 ±4.4	23.0±3	4.56	0.002
14	2210.0 ±4.4	23.0±3	4.52	0.002
15	2240.0 ±4.4	23.0±3	4.46	0.002
16	2270.0 ±4.7	23.0±3	4.41	0.002
17	2360.0 ±4.7	23.0±3	4.24	0.002
18	2515.0 ±5	35.0±5	3.98	0.002
19	2660.0 ±9.5	100.0±15	3.76	0.001
20	14,500.0 ±20	1000.0 ±15	0.69	0.1% Albedo

*1.70 most likely achievable

from each channel is adjusted to conform with the range of input temperature expected in that spectral interval. Each channel signal will be offset to make full use of the 13-bit digital system.

In the TIP data stream, the HIRS data will be provided as a serial bit stream with no break or fill zero's to match the 16-bit TIP word pairs. All 20 channels of radiometric data will be accommodated in the 36 word (18 word pairs), 288 bit allocation in each TIP minor frame. All telemetry necessary to process the data is included in the instrument output data stream, while housekeeping telemetry is included within the spacecraft telemetry slots.

5.2. Stratospheric Sounding Unit (SSU)

The Stratospheric Sounding Unit (SSU) (figure 9) is being supplied by the United Kingdom Meteorological Office. It employs a selective absorption technique to make measurements in three channels. The principles of operation are based on the selective chopper radiometer flown on Nimbus 4 and 5, and the Pressure Modulator Radiometer (PMR) flown on the Nimbus 6. Basic characteristics are shown in table 8.

The SSU makes use of the pressure modulation technique to measure radiation emitted from carbon dioxide at the top of earth's atmosphere. A cell of CO_2 gas in the instrument's optical path has its pressure changed (at about a 40 Hz rate) in a cyclic manner. The spectral characteristics of the channel and, therefore, the height of the weighting function is then determined by the pressure in the cell during the period of integration. By using three cells filled at different pressures, weighting functions peaking at three different heights can be obtained. Primary objective of the instrument is to obtain data from which stratospheric (25-50 km) temperature profiles can be determined. This instrument will be used in conjunction with the HIRS/2 and MSU to determine temperature profiles from the surface to the 50 Km level.

5.2.1 Instrument Operation

The single primary telescope with its 10° IFOV is step scanned perpendicular to the subpoint track. Each scan line is composed of eight individual 4.0 second steps and requires a total of 32 seconds, including mirror retrace. As shown in figure 11, the 147 Km subsatellite point resolution produces an underlap between lines of approximately 62 Km at nadir.

The SSU uncooled pyroelectric detectors integrate the radiance in each channel for 3.6 seconds during each step. The integrated output signal level is sampled 8 times during this period. quantization is to 12 bit precision. Four zeros are added in the least significant bits to fill the TIP 16 bit word pair. Telemetry data is inserted into the TIP data stream together with the radiance data making the data output rate up to 30 TIP word-pairs per second.

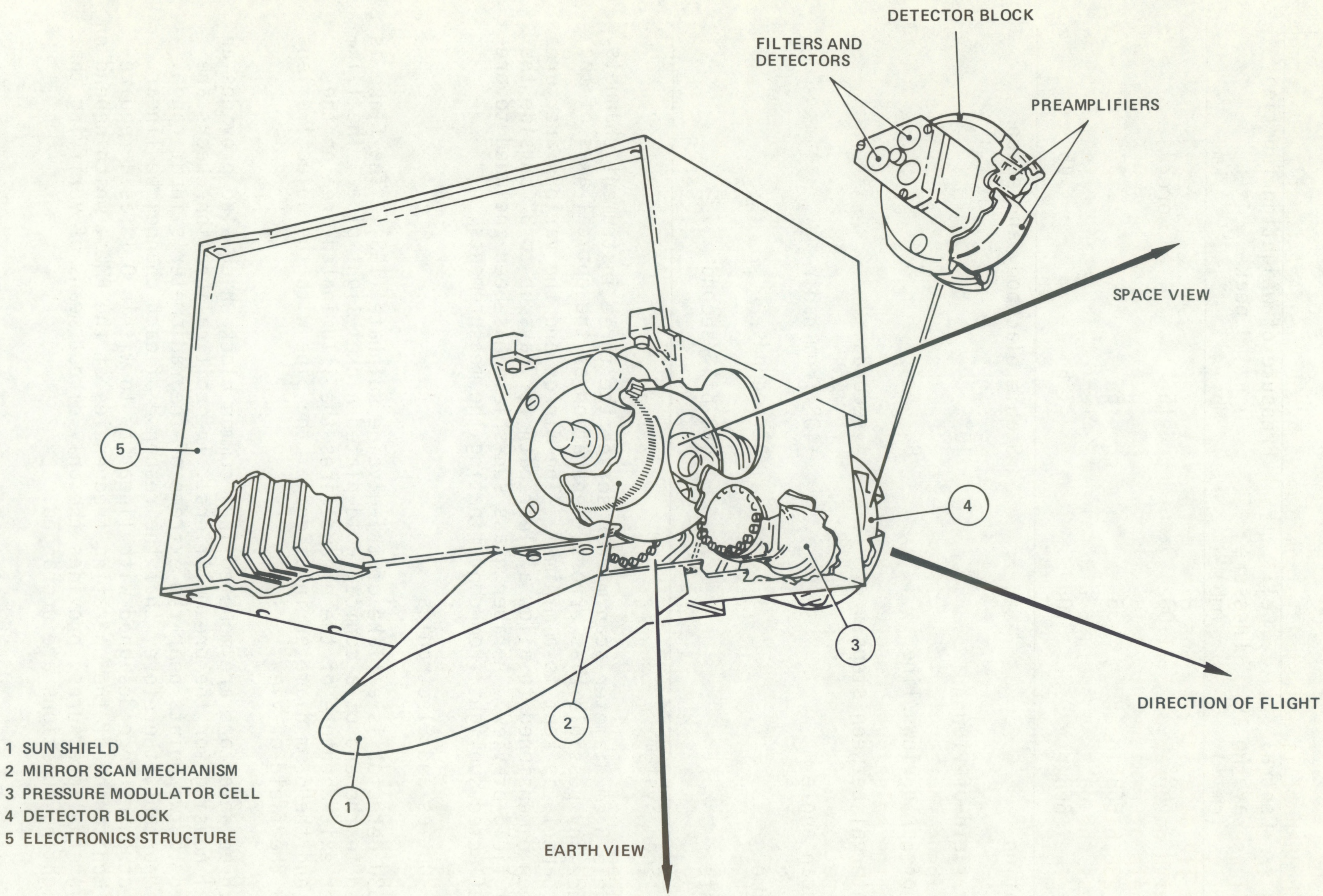


Figure 9.--The complete SSU, showing the views to earth and to space

Table 7.-- SSU characteristics

Channel Number	Central Wave No. (cm^{-1})	Cell Pressure (mb)	Pressure of weighting function peak Mb	Km
1	668	100	15	29
2	668	35	5	37
3	668	10	1.5	45

Calibration	Stable blackbody and space
Angular field-of-view	10°
Number of Earth views/line	8
Time interval between steps	4 seconds
Total scan angle	±40° from nadir
Scan time	32 seconds
Data rate	480 bits/second

5.2.2. Scan System

A single 8 cm diameter scan mirror serves the three instrument channels. To reduce any possible bias errors, separation of the optical axes of the three channels is kept to a minimum. The mirror and the various apertures have been dimensioned to allow a clear path for rays up to 3° outside the nominal field-of-view. A fiber glass sun-shield has been included to prevent reflected sunlight from contaminating the measurements.

5.2.3. Optics and Electronics

The SSU detector is a flake of tri-glycine sulphate (TGS). The flake is attached to the end of a conical gold-plated nickel light pipe. The 1.1-mm diameter exit aperture of the pipe defines the illuminated area on the flake, and the 6-mm diameter input end of the pipe with the objective lens defines the field-of-view.

The three detectors are mounted in a common block which also provides an integral housing for the preamplifiers. In-orbit calibration checks are confined to two points near the extreme of the radiometer's input range. It is important, therefore, that the response of each channel be linear. The electronics were designed with linearity to within 0.1% as a requirement. Monitoring of the operating frequencies of the PMCs, which depend on their internal pressures, provides the only direct means of verifying that the weighting functions are unchanged.

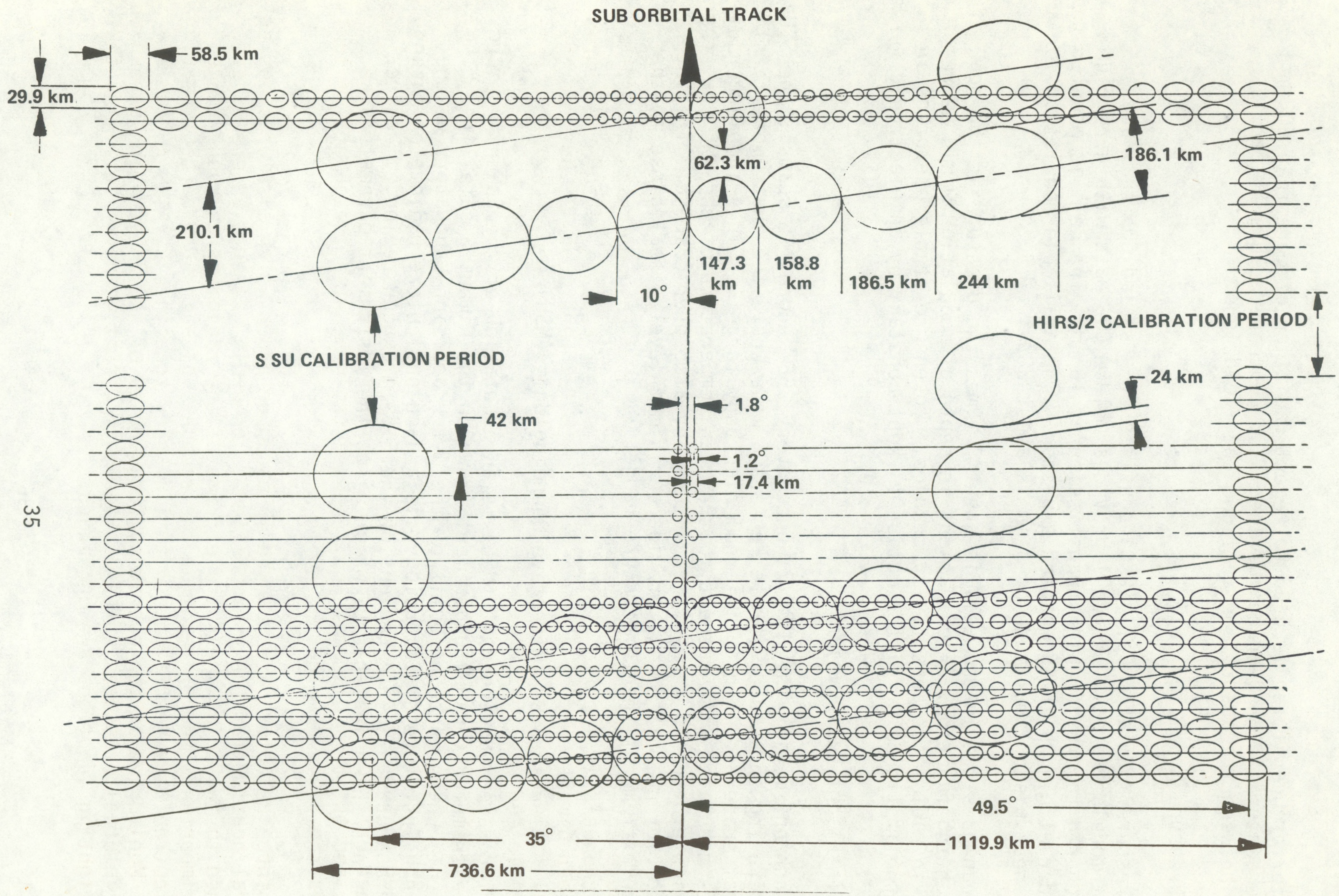


Figure 10.--TIROS Operational Vertical Sounder HIRS/2 and Stratospheric Sounding Unit scan patterns projected on earth

An interference filter is used to reject radiation at more than 50 cm^{-1} from the center of the Q-branch of the 15-μm CO_2 band. This filter is mounted between the absorption cell and the field lens.

5.2.4 Pressure Modulated Cell

The Pressure Modulated Cell (PMC) consists of a sealed CO_2 cell and a means of modulating it. The cell provides a 1-cm CO_2 path with germanium optics coated to provide high transmission at 15 μm. The cell is mounted to a cylinder within which is mounted a piston. The available modulation for a peak-to-peak piston amplitude of 3 mm is about 28%.

The mean pressure in the cell is about 7 times the pressure at the peak of the weighting function. Fluctuations in depth of modulation would be reflected in radiometer sensitivity changes. To ensure stable operation in orbit, the amplitude of piston motion is kept constant by an electronic servo system.

5.2.5 In-Flight Calibration

In synchronism with the HIRS/2, once every 256 seconds (8 scans), the SSU when operating in auto calibrate enters a mode where the instrument first looks at space and then an internal blackbody target. Since incoming radiation is modulated with respect to the mean temperature of the PMC CO_2, the space view provides a larger signal than any atmospheric scene. The internal blackbody near 15°C will provide a minimum level signal close to the opposite extreme of the temperature range.

5.3. Microwave Sounding Unit (MSU)

The Microwave Sounding Unit (MSU) is an adaptation of the Scanning Microwave Spectrometer (SCAMS) experiment flown on the Nimbus 6 satellite. The instrument, which is being built by the Jet Propulsion Laboratory of the California Institute of Technology, is a 4-channel Dicke radiometer making passive measurements in 4 regions of the 5.5-mm oxygen region. The frequencies are shown in table 8, which lists the instrument parameters.

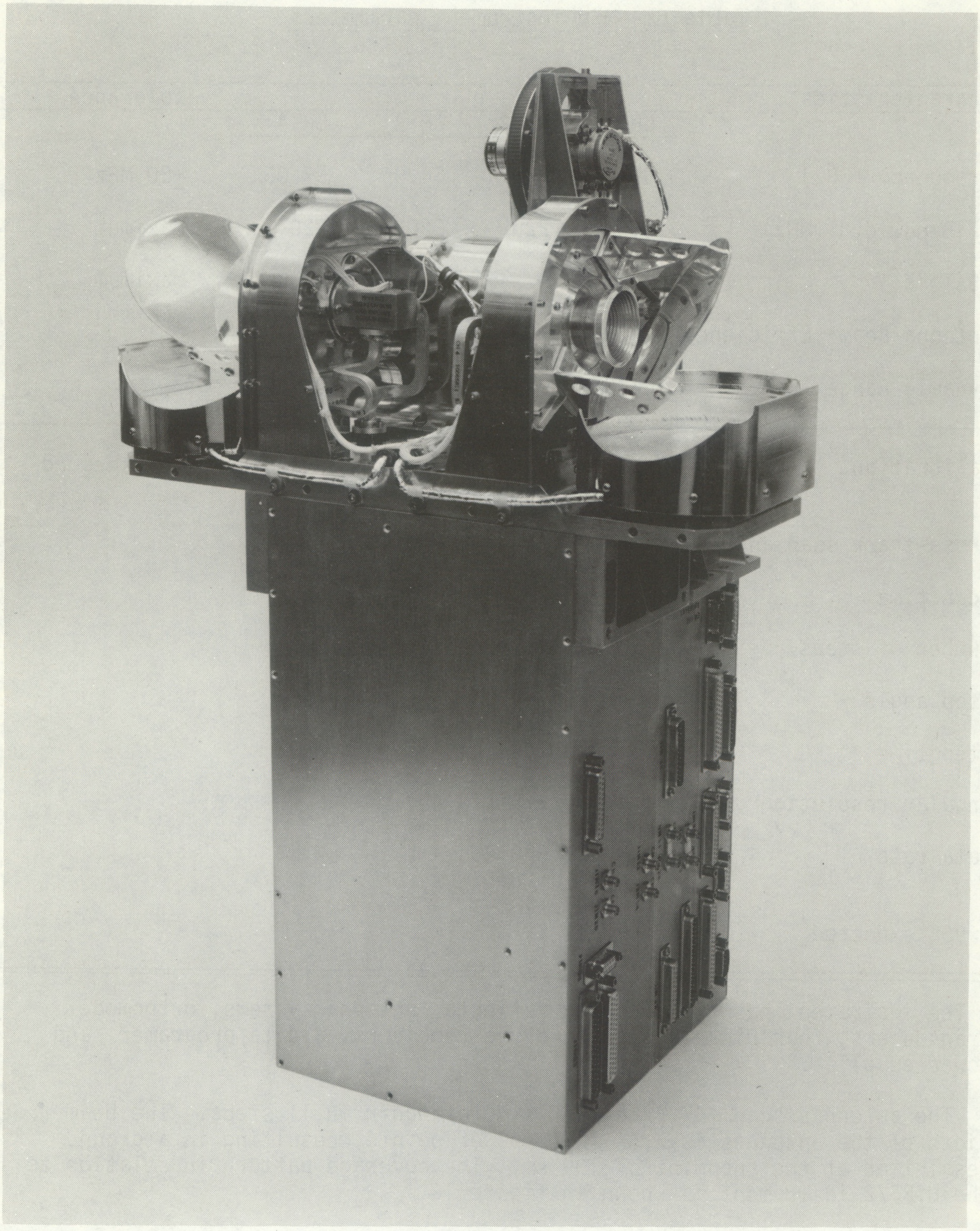


Figure 11.--Microwave Sounding Unit

(Courtesy of Jet Propulsion Laboratory)

Table 8.--MSU instrument parameters

Characteristics	Value CH 1	CH 2	CH 3	CH 4	Tolerance
Frequency (GHz)	50.3	53.74	54.96	57.05	±20 MHz
RF Bandwidth (MHz)	220	220	220	220	Maximum
NEΔT °K	0.3	0.3	0.3	0.3	Maximum
Antenna Beam* Efficiency	>90%	>90%	>90%	>90%	
Dynamic Range °K	0-350	0-350	0-350	0-350	

Calibration	Hot reference body and space background each scan cycle
Cross-track scan angle	±47.35°
Scan time	25.6 sec
Number of steps	11
Step angle	9.47°
Step time	1.84 sec
Angular resolution	7.5° (3 db)
Data rate	320 Bps

*>95% expected

The instrument has two scanning reflector antenna systems, orthomode transducers, four Dicke superheterodyne receivers, a data programer, and power supplies.

The antennas scan ±47.4° either side of nadir in 11 steps. The beam width of the antennas is 7.5° (half power point), resulting in a ground resolution at the subpoint of 109 km. The coverage pattern in relation to the HIRS/2 instrument is shown in figure 12.

Microwave energy received by each antenna is separated into vertical and horizontal polarization components by an orthomode transducer. Each of the four resulting signals is fed to one of the radiometer channels. The incoming noise temperature is modulated at a 1-KHz rate by a Dicke switch

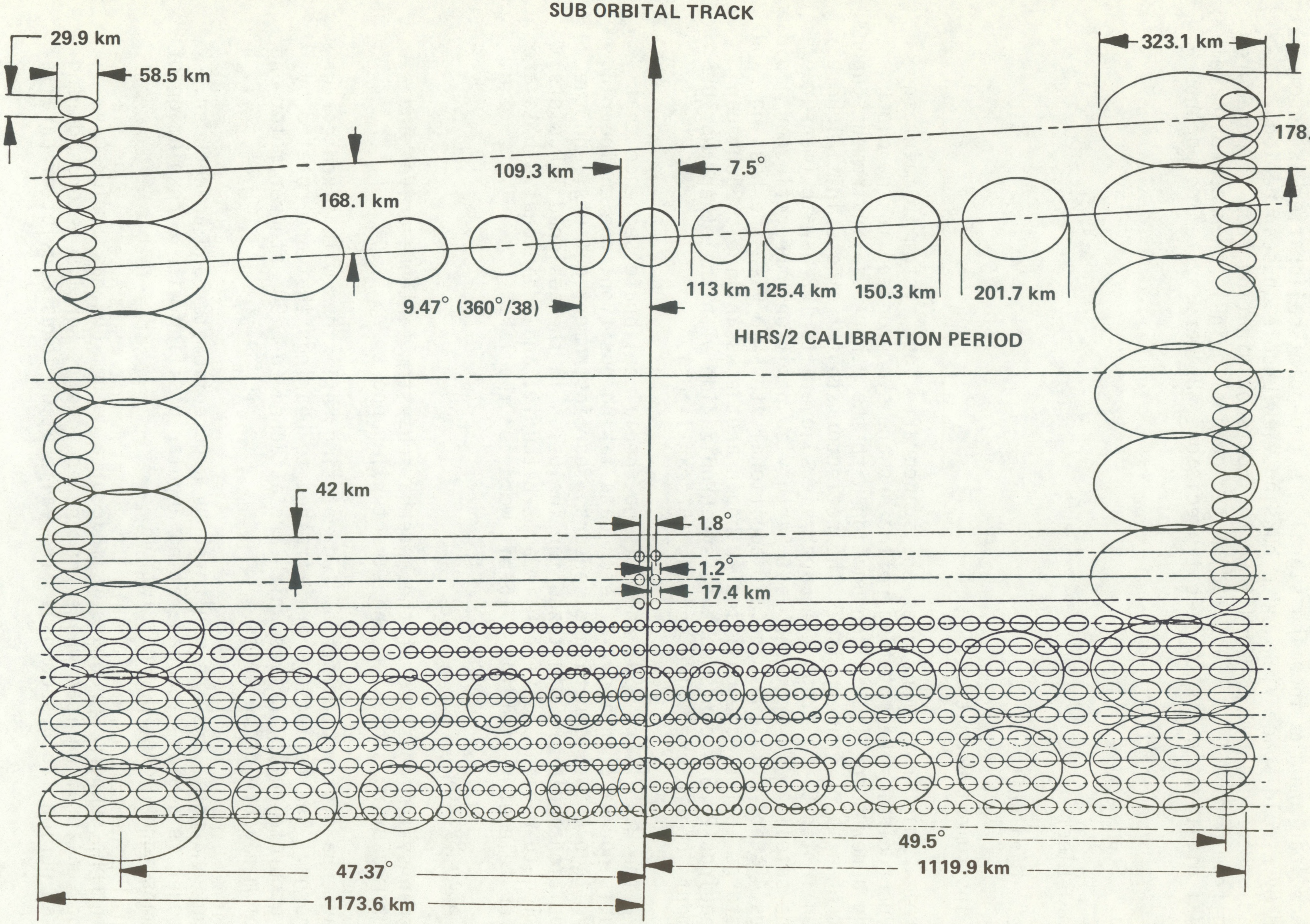


Figure 12.--TIROS Operational Vertical Sounder HIRS/2 and MSU scan patterns projected on earth

so that a constant comparison is made between the ambient temperature reference load and the incoming signal. A two-point calibration is accomplished by a cold space view and a housing view once each scan period. Each radiometer channel is sensitive to inputs originating from temperatures ranging from 0 to 350°K. Each radiometer channel gain is then approximately 35 mv/°K; digitization is to 12-bit precision. Primary system components include:

a. Scan system

b. Electronics

c. Data unit

5.3.1 Instrument Operation

In orbit, this instrument uses the spacecraft clock system to maintain scan synchronism. The rotating reflectors are synchronized to the clock starting a new scan line in conjunction with the other TOVS instruments upon receipt of a major frame pulse. The reflector steps from its initial home position in ten 9.45° steps (11 Earth views) over its 102° swath (measured from the satellite). From the last Earth view position, the reflector rapidly moves 4 steps to view space, 10 additional steps to view the housing, and then returns to the home position to begin another scan line. Each scan line requires 25.6 seconds so that synchronization with the other two TOVS instruments occurs every 128 seconds (5 scan lines).

Unlike the HIRS/2 and SSU, there is no special calibrate sequence that interrupts normal scanning. At each data taking position, one engineering word (voltage), two temperature sensors, four instrument outputs, and the scan position angle are digitized for inclusion in the assigned TIP slots. The analog-to-digital converter is a 12-bit unit, and additional 4 bits are added for telemetry yielding a 16-bit word for the TIP.

5.3.2 Scan System

The scan system consists of the antenna subsystem, antenna drive, and position measuring subsystem and structural support.

The antenna system consists of two rotating reflectors with fixed corrugated horns. The reflectors are attached to bearings that are rotated by highly accurate pulley drives which are attached to a 90° stepper motor and a set of miniature drive belts.

The antenna positions are monitored by a potentiometer and an encoder. The encoder is a disc-type generating angular position with a resolution of 256 counts (gray code) per revolution.

The antenna support structure is made of aluminum and has a microwave blackbody calibration load where the antenna dwells for 1.9 seconds during each scan period (25.6 seconds). The calibration loads consist of parallel rows of knife edge material made by casting an iron-filled epozy onto an aluminum backing plate. These essentially isothermal targets, with embedded temperature monitors, provide one of two calibration points for each antenna. The second calibration point is the cold space view.

5.3.3. Electronics System

The instrument electronics consists of three chassis -- the RF, IF/video, and data. These three components are mechanically connected by support brackets, radiator plates, and the antenna subsystem baseplate.

5.3.4 Data Unit

The data unit consists of a multiplexer and an analog-to-digital (A/D) converter. The A/D has 12-bit precision with a relative accuracy of ±0.05%. The multiplexer accepts the analog data, and monitors signals from the four channels and commutates them in sequence for the A/D converter. The sequencing and synchronizing signals for the multiplexer, the A/D converter, and the scan system are provided by a digital programer which in turn interfaces with the spacecraft clock and synchronization signals. The programer also provides formatting and buffering functions between the instrument and the spacecraft TIP.

5.4. Advanced Very High Resolution Radiometer (AVHRR)

The Advanced Very High Resolution Radiometer (AVHRR) for TIROS-N and four follow-on satellites will be four channel scanning radiometers, sensitive to visible/near IR and infrared (IR) radiation. The instrument channelization has been chosen to permit multispectral analyses which are expected to provide improved determination of hydrologic, oceanographic, and meteorological parameters. The visible (0.5 μm) and visible/near IR (0.9 μm) channels will be used to discern clouds, land-water boundaries, snow and ice extent, and when the data from the two channels are compared, an indication of ice/snow melt inception. The IR window channels will be used to measure cloud distribution and to determine temperature of the radiating surface (cloud or surface). Data from the two IR channels will be incorporated into the computation of sea surface temperature. By using these two data sets, it is possible to remove an ambiguity introduced by clouds filling a portion of the field-of-view. On later instruments in the series[1], a third IR channel will add the capability for removing radiant contributions from water vapor when determining surface temperatures. Prior to inclusion of this third channel, corrections for water vapor contributions will be based on statistical means using climatological estimates of water vapor content.

5.4.1. General Instrument Description

The AVHRR (figure 13) is comprised of five modules which are assembled

[1]to be called AVHRR/2

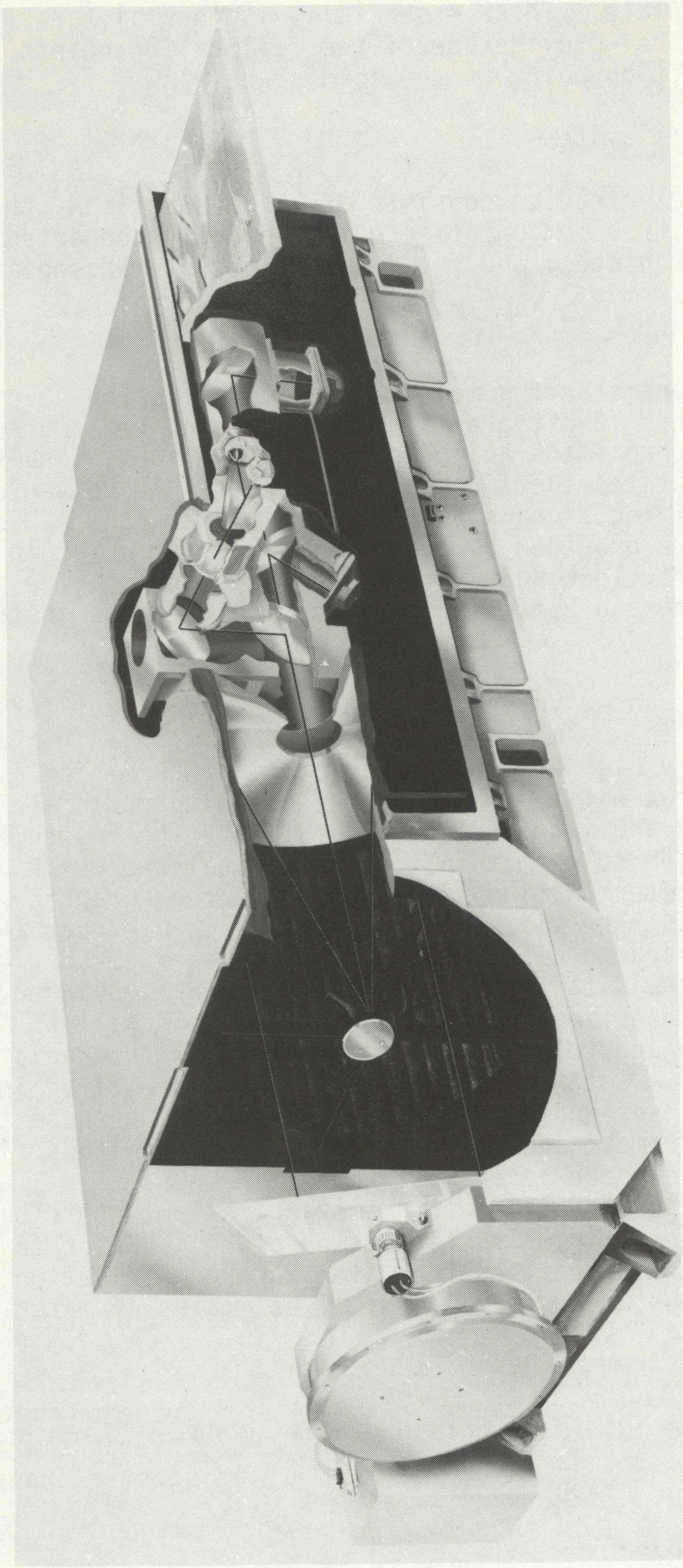


Figure 13.--TIROS-N Advanced Very High Resolution Radiometer
(Courtesy of ITT Aerospace/Optical Division)

together to form a single instrument. These modules are:

a. Scanner modules

b. Electronics modules

c. Radiant cooler

d. Optical system

e. Baseplate

5.4.1.1 Scanner Modules. This module includes the 80-pole hysteresis synchronous motor, the motor housing, and the scan mirror. The scan motor continuously rotates the mirror at 360 rpm to produce a cross-track scanning in orbit. The scan mirror size [20.96 cm (8.25 in) across minor axis; 29.46 cm (11.6 in) across the major axis] is adequate to fill the field-of-view of the 20.32 cm (8 in) telescope diameter. The instantaneous field was chosen so that the satellite motion along its orbit would cause successive scan lines to be contiguous at the subpoint.

5.4.1.2 Electronics Module. The electronics module is bolted to the instrument inboard side panel. Electronic functions including data processing, temperature control, telemetry generation, scan and motor logic are centered within this portion of the instrument.

5.4.1.3 Radiant Cooler. The radiant cooler consists of four separate components:

a. Cooler housing

b. First-stage radiator

c. Second-stage radiator (referred to as the "patch")

d. Cooler cover

The cooler cover shades most of the radiator surface from input radiation from the Earth. The first and second stage have unobstructed views of space and radiate sufficient energy to bring the patch to its desired operating temperature of 105°K. A proportional heater provides sufficient energy to the patch to keep its temperature from falling below this temperature. Should cooler performance unexpectedly degrade in orbit, it will be possible to restabilize the patch temperature at 107°K and continue normal operation.

5.4.1.4 Optical Subsystem. The optical system consists of an afocal 20.3 cm (8 in) aperture telescope combined with secondary optics which separates the radiant energy into discrete spectral bands which are then focused onto their respective field stops. The spectral bands are shown in table 9.

Table 9. AVHRR channelization

Protoflight instrument (1)	Four-channel flight instruments (4)
1.* 0.55 - 0.90 μm	1. 0.55 - 0.68 μm
2. 0.725 - 1.10 μm	2. 0.725 - 1.10 μm
3. 3.55 - 3.93 μm	3. 3.55 - 3.93 μm
4. 10.5 - 11.5 μm	4. 10.5 - 11.5 μm
5. Channel 4 data repeated	5. Channel 4 data repeated

AVHRR/2 - five channel instruments (3)
1. 0.58 - 0.68 μm
2. 0.725 - 1.10 μm
3. 3.55 - 3.93 μm
4. 10.3 - 11.3 μm
5. 11.5 - 12.5 μm

*In-orbit data obtained after completion of the protoflight instrument has shown the necessity of eliminating spectral overlap with channel 2 if snow cover areal extent is to be accurately measured.

The IFOV for all channels is specified to be 1.3 ±0.1 milliradians. Polarization effects were minimized to the extent practical by proper orientation of internal optical components. The instrument has been designed such that the IFOV of the four channels can be made coincident within ±0.1 mr (8%).

5.4.1.5 Baseplate. The baseplate is the instrument structure upon which all other modules are secured. A cover plate over the electronics modules and the cooler housing serve as a radiator for thermal control.

5.4.2 Operating Characteristics

Visible/near IR channels use silicon detectors to measure incident radiation. Both are square, 0.254 cm (0.100 in) on a side. The defining field stops are 0.06 cm (.0238 in) squares; analysis indicates that 99% of the rays passed through the field stop are collected by the detectors. Test results show that the instrument can easily meet the specified 3:1 signal-to-noise (at 0.5% albedo) requirements.

The IR channels use detectors cooled to 105°K. The detector chosen for the 3.8-μm channel is indium antimonide (InSb), while the 11-μm channel uses mercury cadmium teluride (HgCdTe). The InSb has a 0.0173 cm (0.0068 in) square active area and is mounted with the aplanat lens forming a hermetic seal. A noise equivalent temperature difference (NETD) better than 0.12°K (for a 300°K scene) is expected from this channel. The HgCdTe detector is optimized for best sensitivity between 10.5 and 11.4 μm. The detector is 0.0173 cm (0.0068 in) square and is also bonded to the aplanat. The NETD is expected to be better than the specified 0.12°K (for a 300°K scene).

The basic operation of this instrument is similar to its predecessor, the VHRR, which flew on the previous ITOS series of satellites. The zero point for detected energy is restored to a preset 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). Figure 11 is a simplified diagram showing the basic movement of the electronic signals from the detectors to the point where the outputs are sampled at a 40-KHz rate by the satellite data processor (MIRP).

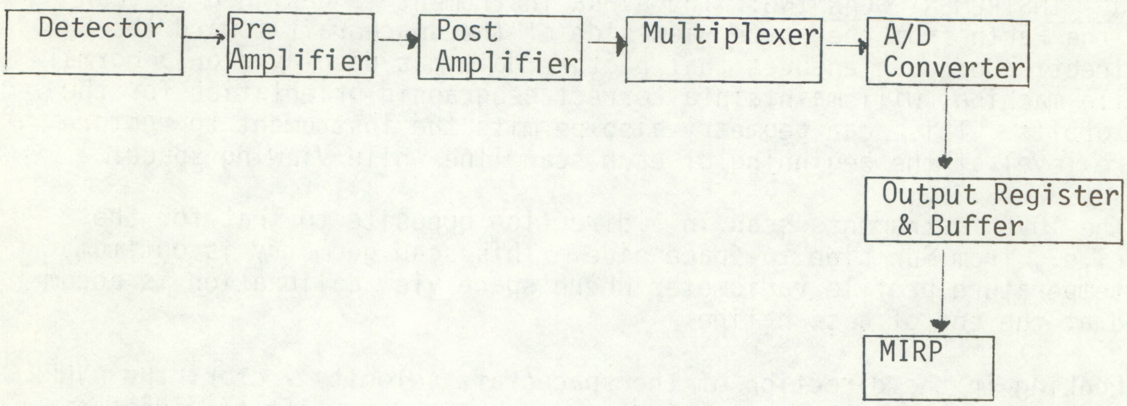


Figure 14.--AVHRR data flow

The instrument has an internally generated ramp to permit routine validation of the linearity of the instrument electronics. The ramp is produced by an on-board voltage divider which provides inputs to the A/D converter that will result in outputs from zero to 1023 counts. Input voltage intervals were designed to be slightly greater than the equivalent of one output step. It should be recognized that certain values will not occur and that several consecutive saturation (0 or 1023 counts) level values will occur so that a 1024 line cycle is maintained.

In-orbit calibration of the IR channels of the instrument is possible because the instrument output is linear with input energy. During every scan line, the instrument views cold space (0 radiance) and its housing (approximately 290°K). The housing portion of the instrument has been designed to be a blackbody target to be used in orbit for instrument calibration. Four Platimum Resistance Thermometers (PRTs) whose output values are included in the data stream are embedded in the housing and monitor the temperature of the target. By determining the instrument output while viewing the known warm target and cold space (also in the data format), it is possible to ascertain the instrument response curve.

5.4.3 Special Operating Mode

For special test purposes, it is possible to command the AVHRR into a special mode wherein the Earth scan data for three successive lines are deleted. In the place of these deleted data lines, constant voltage levels are output from the instrument. It is not planned to use this operating mode in orbit unless it is necessary to evaluate an instrument malfunction.

CAUTION - INSTRUMENT SCANNING: The AVHRR instrument is designed to scan across the Earth from the space view side of the spacecraft toward the Sun. This direction of scan ensures that picture data, as displayed on a normal facsimile machine, will maintain a correct geographic orientation for the chosen orbits. This scan geometry also permits the instrument to restore its zero level at the beginning of each scan line while viewing space.

The TOVS instruments scan in a direction opposite to that for the AVHRR; i.e., from Sun side to space side. This scan geometry is optimum for a temperature profile radiometer where space view calibration is accomplished at the end of a scan line.

Looking in the direction of the spacecraft velocity vector, the AVHRR will scan from right to left; the TOVS instruments from left to right. Since temperature profile radiometers are not generally used to produce picture displays, this scan geometry is expected to present no problems for the users.

5.5. Data Collection System (DCS)

The Data Collection and Location System (DCS) for TIROS-N is being designed, built, and furnished by the Centre National D'Etudes Spatiales (CNES) of France, who refer to it as the ARGOS Data Collection and Location

System. The ARGOS provides a means for obtaining environmental (e.g., temperature, pressure, altitude, etc.) data from, and Earth locating, fixed or moving platforms. Location information, where necessary, may be computed by differential doppler techniques using data obtained from the measurement of platform carrier frequency as received on the satellite. When several measurements are received during a given contact with a platform, location can be determined. The environmental data messages sent by the platform will vary in length depending on the type of platform and its purpose. The ARGOS (DCS) system consists of three major components:

a. Terrestrial platforms

b. On-board instrument

c. Processing center

5.5.1. Platforms

The terrestrial platforms may be developed by the user to meet his particular needs so long as it meets the interface criteria defined by CNES. Before being accepted for entry into the system, the platform design must be certified as meeting these criteria. By international agreement, entry into the system is limited to platforms requiring location service or for those situated in polar regions out of the range of the DCS on geostationary satellites. General platform criteria are shown in table 10.

5.5.2 On-board Instrument

The on-board instrument is designed to receive the incoming platform data, demodulate the incoming signal, and measure both the frequency and relative time of occurrence of each transmission. The on-board system consists of three modules: the power supply and command interface units, the signal processor, and the redundant receiver and search units. Figure 15 shows the basic relationship of the component modules.

Platform signals are received by the receiver, search unit at 401.65 MHz. Since it is possible to acquire more than one simultaneous transmission, four processing channels [called Data Recovery Units (DRU)] operate in parallel. Each DRU consists of a phase lock loop, a bit synchronizer, doppler counter, and a data formatter. After measurement of the doppler frequency, the sensor data are formatted with other internally generated data and the output transferred to a buffer interface with the spacecraft data processor (TIP). The DCS output data rate is controlled to 720 bits per second.

5.5.3 Processing Center

Data from the DCS are included with that from the low bit rate instruments within the TIP. After receipt of the stored data at the central processing facility, the DCS information is decommutated and sent to the CNES, ARGOS processing center in Toulouse, France. At the processing center, the DCS

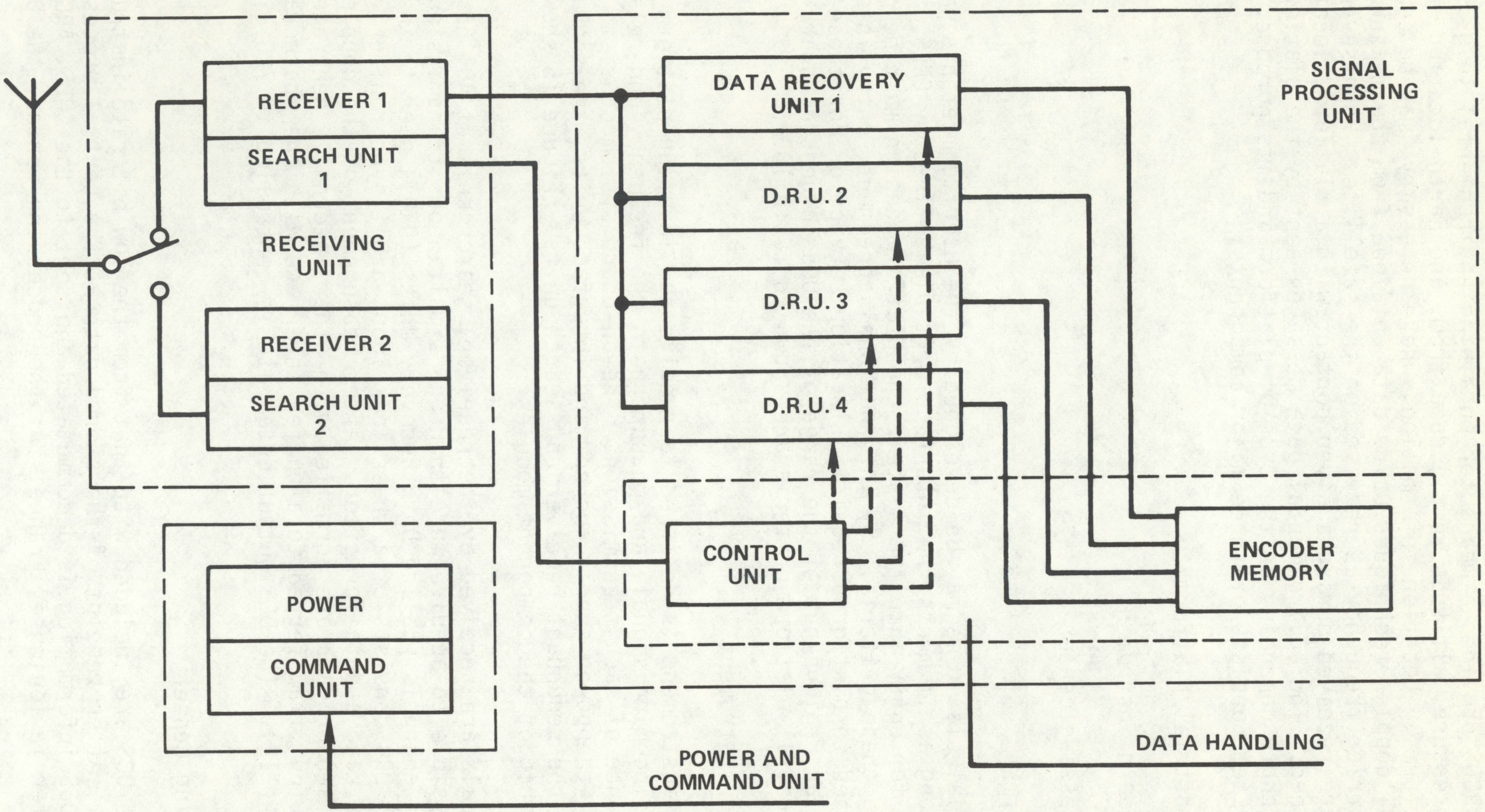


Figure 15.--Data collection system/ARGOS component modules

Table 10.--ARGOS platform characteristics

Carrier frequency	401.650 MHz
Aging (during life)	±2 KHz
Short term stability (100 ms)	1:10^9 (platform requiring location) 1:10^8 (platform not requiring location)
Medium term stability (20 min)	:0.2 Hz/min (requiring location)
Long term (2 hr)	:±400 Hz
Power out: 34.8 dBm (3w) nominal	
Range during transmission (stability)	:0.5 db
Antenna: Vertical linear polarization	
Message length: 360 ms to 920 ms	
Repetition period for message:	40-60 sec (requiring location) 60-200 sec (not requiring location)
Data sensors: 4-32 eight-bit sensors for environmental data	
Total number of platforms:	4,000 global 459 within view

data are received by and stored in a small computer and then transferred to a large computer where processing is completed. Resulting outputs are sent to system users and are retained on magnetic tape for archive purposes.

5.5.4. System Performance

Accuracy of platform location will depend upon the number of messages received from the platform. The system has been designed so that position determination is practical to within 3 to 5 km rms. Platform velocity determination is planned to be accurate to 0.5 to 1.5 mps, rms.

Detailed information concerning the DCS including technical requirements for platforms and criteria for use of the system can be obtained by writing to: Service ARGOS, Centre Spatial De Toulouse, 18, Avenue Edouard Belin, 31055 Toulouse Cedex, France.

5.6. Space Environment Monitor (SEM)

The Space Environment Monitor (SEM) instrument consists of three separate and independent components; it is being designed and built by the Ford Aerospace and Communication Corporation. The instrument will measure solar proton, alpha particle, and electron flux density, energy spectrum, and the total particulate energy disposition at satellite altitude.

The three components are:

a. Total Energy Detector (TED)

b. Medium Energy Proton and Electron Detector (MEPED)

c. High Energy Proton and Alpha Detector (HEPAD)

This instrument is a follow-on to the Solar Proton Monitor (SPM) flown on the ITOS series of NOAA satellites. The new instrument modifies the SPM capabilities and adds the monitoring of high energy protons and alpha flux. The package also includes a monitor of total energy deposition into the upper atmosphere. The instrument will augment the measurements already being made by NOAA's Geostationary Operational Environmental Satellite (GOES).

5.6.1 Total Energy Detector (TED)

The TED uses a curved plate analyzer and channeltron detector to determine the intensity of particles in the energy bands from 0.3 Kev to 20 Kev. Four curved plate analyzers (two measuring electrons, two protons) measure incoming particles reaching the instrument. Outputs from the analyzers are sent to the detectors and then to the Data Processing Unit for multiplexing into the final output data stream.

5.6.2 Medium Energy Proton and Electron Detector (MEPED)

The MEPED senses protons, electrons, and ions with energies from 30 Kev to greater than 60 Mev. This instrument is comprised of four directional, solid-state detector telescopes and one omni-directional sensor. All five components use solid-state nuclear detectors. Outputs from the detectors are connected to a signal analyzer which senses and logically selects those events which exceed specific threshold values. These data are fed to the DPU and are included with the instrument output.

5.6.3 High Energy Proton-Alpha Detector (HEPAD)

The HEPAD senses protons and alphas from about 370 Mev to greater than 850 Mev. The instrument is essentially a Cerenkov detector. The Cerenkov crystal is installed within a telescope in association with two solid-state detectors; the telescope is shielded to establish the instrument's field-of-view. In a manner similar to that for the MEPED and TED, the data output is processed by the DPU for eventual transfer to the TIP.

5.7. Growth

The TIROS-N satellite has been designed to retain adequate space, weight, and data handling capability so that additional instruments can be added later in the program without redesigning the satellite. Reserved capacity for payload growth is approximately 20% of the initial payload complement. Two possible candidate instruments have been considered for incorporation within this growth capability. One instrument, designed to measure ozone distribution, is based on the Solar Backscatter Ultraviolet (SBUV) instrument to be flown on NIMBUS. The second, designed to measure the Earth's heat balance, would be based on the Earth Radiation Budget (ERB) instrument, also flown experimentally on a NIMBUS satellite. Flight of these instruments is projected to be no earlier than NOAA-F.

APPENDIX A

Beacon Transmission Characteristics

The TIROS-N beacon will normally be directly modulated with the TIP output including data from the low bit rate instruments and spacecraft telemetry. These data are transmitted at 8.32 Kbps, split phase at either 136.77 or 137.77 MHz, linearly polarized. Transmission parameters are summarized in table 11 below.

Table 11.--VHF Beacon Transmission Parameters

Type of transmitted signal	VHF, phase modulated, split phase 8320 bits per second
System output	
Frequency	136.77 or 137.77 MHz
EIRP	+19.0 dbm worst case; +24.0 dbm nominal
Anntenna	
Gain at 63° from nadir	-7.5 dbi, minimum[1]
Gain over 90% of sphere	-18 dbi, minimum[1]
Polarization	Linear
Circuit Losses	3.7 db
Transmitter	
Power	1.0 watt minimum
Modulation index	$\pm$67.5° with a 7.5° tolerance
Premodulation filter, type	7 pole linear phase filter
3 db bandwidth	16 KHz minimum, 22 KHz maximum
Frequency stability	$\pm 2 \times 10^{-5}$

[1]As observed by an optimum polarization diversity receiver.

The TIP output on the beacon contains a multiplex of analog housekeeping data, digital housekeeping data and low rate instrument data. The format is based on a major frame (32 seconds - the time interval for one scan of the SSU and five scans of the HIRS/2) containing 320 minor frames (0.1 second). The major frame permits adequate sampling of low rate analog and digital housekeeping which is acquired in conjunction with the 550 words per second of instrument data. The key parameters of the data format are contained in the following tables (12 and 13) and figure 16.

Table 12.--Realtime TIP orbital mode parameters

Major Frame	
o rate	1 frame every 32 seconds
o number of minor frames	320 per major frame
Minor Frame	
o rate	10 frames per second
o number of words	104
o format	see table 13, figure 16
Word	
o rate	1040 words per second
o number of bits	8
o order	bit 1 = MSB bit 8 = LSB bit 1 transmitted first
Bit	
o rate	8320 bits per second
o format	split phase
o data 1 definition	
o data 0 definition	

Table 13.--TIP Minor Frame Format

Function	Number of Words	Word Position	Bit Number 1 2 3 4 5 6 7 8	Plus Word Code and Meaning
Frame Sync & S/C[1] ID[2]	3	0 1 2	1 1 1 0 1 1 0 1 1 1 1 0 0 0 1 0 0 0 0 0 A A A A	The last 4 bits of word 2 are used for spacecraft ID
Status	1-	3	Bit 1:	Cmd[3] Verification Status; 1=CV[4] update word present in frame; 0=no CV update in frame.
			Bits 2&3 :	TIP status; 00=orbital mode, 10=CPU[5] memory Dump Mode, 01=Dwell Mode; 11 Boost Mode.
			Bits 4-6 :	Major Frame Count: 000=Major Frame 0 111=Major Frame 7; MSB first; Counter incremented every 320 minor frames.
Dwell Mode Address	1+	3 4	Bits 7&8 Bits 1-7	9 bit dwell mode address of analog channel that is being monitored continuously 0 0 0 0 0 0 0 0 0 = Analog chan 0 1 0 1 1 1 0 1 0 1 = Analog chan 383 MSB[6] is first
Minor Frame Counter	1+	4 5	Bit 8 Bits 1-8	0 0 0 0 0 0 0 0 0 = Minor Frame 0 1 0 0 1 1 1 1 1 1 = Minor Frame 319 MSB is first
Command Verification	2	6 7		Bits 9 through 24 of each received command word are placed in the 16 bit slots of telemetry words 6 and 7 on a one-for-one basis

[1]S/C: Spacecraft
[2]ID : Identification
[3]Cmd: Command
[4]CV : Command Verification
[5]CPU: Central Processor Unit
[6]MSB: Most Significant Bit

Table 13.--TIP Minor Frame Format (Con't)

Function	Number of Words	Word Position	Bit Number 1 2 3 4 5 6 7 8 Plus Word Code and Meaning
Time Code	5	8, 9	9 bits of Binary Day Count, MSB first
		9	bits 2-5: 0 1 0 1, Spare bits
		9, 10,11,12	27 bits of Binary millisec of Day Count, MSB first.
			Time code is inserted in word location 8-12 only in minor frame 0 of every major frame. The data inserted is referenced to the beginning of the first bit of the minor frame sync word of minor frame 0.
Digital B Subcom	1	8	A subcommutation of Discrete Inputs collected to form 8 bit words. 256 Discrete inputs (32 words) can be accommodated. It takes 32 minor frames to sample all inputs once (sampling rate = once per 3.2 sec). A major frame contains 10 complete Digital B subcommuted frames.
32 Sec Analog Subcom	1	9	A subcommutation of up to 192 analog points sampled once every 32 seconds plus 64 analog points sampled twice every 32 seconds (once every 16 seconds). Bit 1 of each word represents 2560 mv while Bit 8 represents 20 mv[1].
16 Sec Analog Subcom	1	10	These two subcoms are under PROM[2] control. A maximum of 128 analog points can be placed in the 169 slots; super commutation of some selected analog channels will be done in order to fill the 169 time slots. The 170th slot is filled with data from the analog point selected by command. The slot is word number zero of the one second subcom. The analog point may be any of the 384 analog points available. Bit 1 of each word represents 2560 mv while bit 8 represents 20 mv.
1 Sec Analog Subcom	1	11	

[1]mv: milli volts [2]PROM: Programmed, Read Only Memory

Table 17.--TIP Minor Frame Format (Con't)

Function	Number of Words	Word Position	Bit Number 1 2 3 4 5 6 7 8 Plus Word Code and Meaning
XSU[1] Digital Subcom	1	12	The cross strap unit (XSU) generates an 8 word subcom which is read out at the rate of one word per minor frame. The XSU subcom is synchronized with its word 1 in minor frame 0, 8, 16....
Solar Array Telemetry	1	13	Subcom of Housekeeping telemetry associated w/solar array power system.
Spares	20	18, 19 28, 29, 36 37, 44, 45 52, 53, 60 61, 68, 69 72, 73, 80 81, 86, 87	0 1 0 1 0 1 0 1
HIRS/2	36	14, 15, 22 23, 26, 27 30, 31, 34 35, 38, 39 42, 43, 54 55, 58, 59 62, 63, 66 67, 70, 71 74, 75, 78 79, 82, 83 84, 85, 88 89, 92, 93	8 bit words are formed by the BSU experiment and are read out by the telemetry system at an average rate of 360 words per second.
SSU	6	16, 17, 32 33, 76, 77	8 bit words are formed by the SSU experiment and read out by the telemetry system at an average rate of 60 words per second.

[1]XSU: Cross Strap Unit

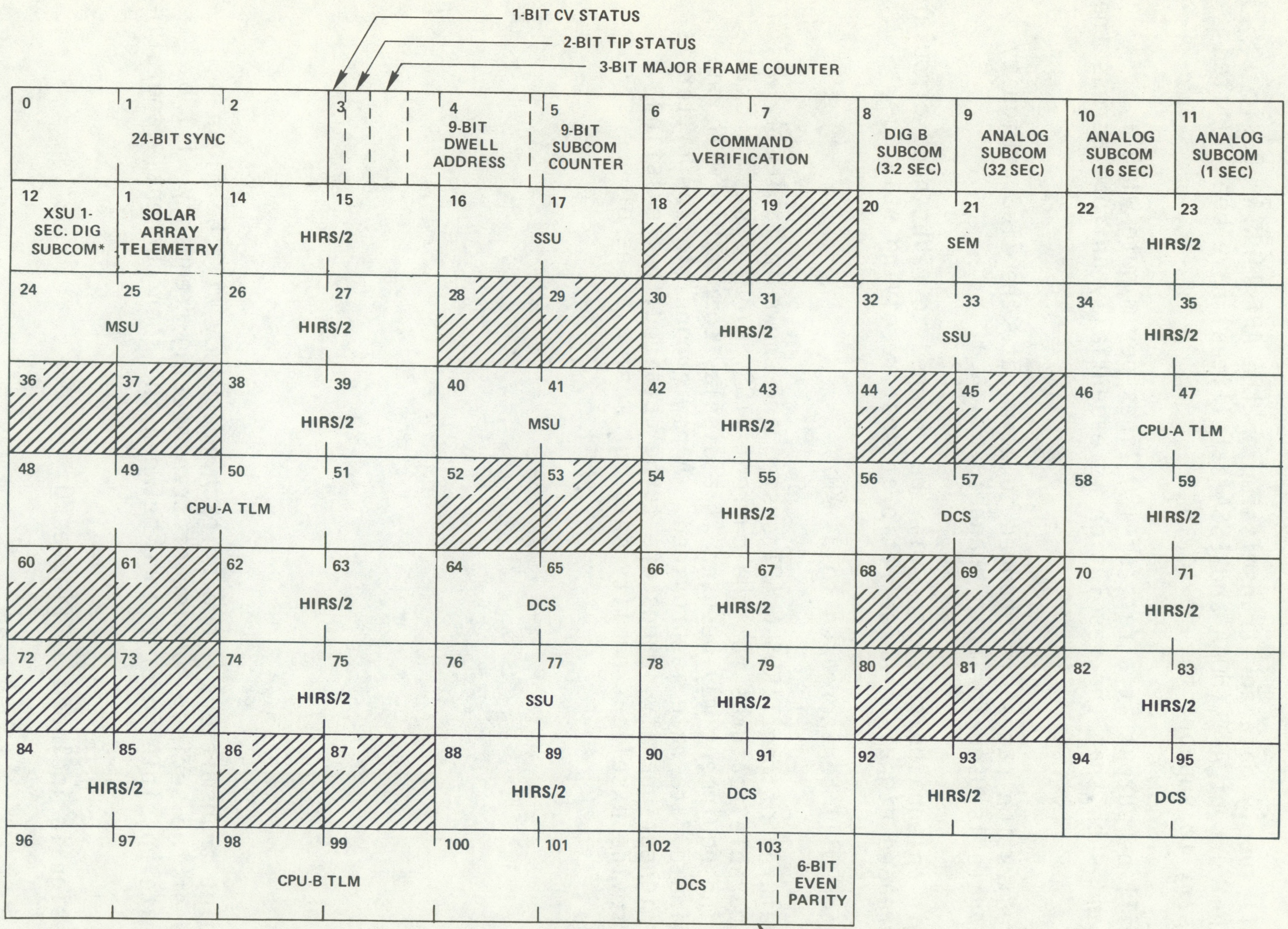
Table 13.--TIP Minor Frame Format (Con't)

Function	Number of Words	Word Position	Bit Number 1 2 3 4 5 6 7 8 Plus Word Code and Meaning
SEM	2	20, 21	8 bit words are formed by the SEM sensor and read out by the telemetry system at an average rate of 20 words per second.
MSU	4	24,25,40, 41	8 bit words are formed by the MSU experiment and read out by the telemetry system at an average rate of 40 words per second.
DCS	9	56,57,64 65,90,91 94,95,102	8 bit words are formed by the DCS experiment and read out by the telemetry system at an average rate of 90 words per second
CPU A TLM[1]	6	46,47,48 49,50,51	A block of three 16 bit CPU words is read out by the telemetry system every minor frame.
CPU B TLM	6	96,97,98, 99,100,101	A second block of three 16 bit CPU words is read out by the telemetry system every minor frame.
CPU Data Status	1⁻	103	Bits 1&2: 00 = All CPU data received 01 = All CPU-A data received; CPU-B incomplete 10 = All CPU-B data received; CPU-A incomplete 11 = Both CPU-A and CPU-B incomplete

[1]TLM: Telemetry

Table 13.--TIP Minor Frame Format (Con't)

Function	Number of Words	Word Position	Bit Number 1 2 3 4 5 6 7 8 Plus Word Code and Meaning
Parity	1-	103	Bit 3: Even parity check on words 2 through 18 Bit 4: Even parity check on words 19 through 35 Bit 5: Even parity check on words 36 through 52 Bit 6: Even parity check on words 53 through 69 Bit 7: Even parity check on words 70 through 86 Bit 8: Even parity check on words 87 through bit 7 of word 103.



NOTES: NUMBER IN UPPER LEFT HAND CORNER INDICATES MINOR FRAME WORD NUMBER.
TIME CODE DATA SHALL APPEAR DURING MINOR FRAME "0" WORD LOCATIONS 8 THROUGH 12.
////// WORD LOCATIONS ARE SPARE AND CONTAIN CODE 01010101.
* THE SUBCOMMUTATION FUNCTION IS ACCOMPLISHED IN THE EXTERNAL UNIT.

Figure 16.--TIP minor frame format

APPENDIX B

APT Transmission Characteristics

The AVHRR will supply data for transmission on the APT link.[1] Basic changes from the current APT (NOAA and ESSA satellites) have been limited to those necessary to support the following:

1. Data will be output at a rate of 120 lines per minute with a "linearized scan" such that the resolution is essentially uniform across the scan.

2. Synchronization rates are changed to eliminate the ITOS ambiguity where the same rate is used for both channels of data.

3. Transmit antenna polarization will be changed to right hand circular to provide increased signal-to-noise ratio at most receiving stations.

4. Deviation will be increased to 34 KHz.

The major features of the TIROS-N APT system are shown in table 14, which also shows comparable features for the current ITOS SR/APT system. Existing APT receiving equipment may be used if a display compatible with the 120-line-per-minute data rate is provided. A new ground station filter is desirable[2] if highest quality images are to be obtained, but existing filters will provide excellent quality data for most classes of users.

[1]Note: Redundant transmitters - one of each frequency will be flown on each satellite of the series. Choice of transmitting frequency will be made to eliminate possible interference between the then currently operating spacecraft.

[2]A proposed design is included as figure 20.

Table 14.--APT Characteristics

Characteristic	ESSA VIDICON/APT	ITOS/SR/APT	TIROS-N APT
Line rate (lines per minute)	240	48	120
Data resolution	4 km subpoint	IR 7.4 km subpoint Visible 3.7 km subpoint	4 km uniform
Carrier modulation	analog	analog	analog
Transmit frequency	137.50 MHz	137.50 MHz 137.62 MHz	137.50 MHz 137.62 MHz
Transmit power	5 watts	5 watts	5 watts
Transmit antenna polarization	linear	linear	right hand circular
Subcarrier frequency	2.4 KHz	2.4 KHz	2.4 KHz
Carrier deviation	±10 KHz	±9 KHz	±17 KHz
Ground station low pass filter	1600 Hz linear	Varies with station and use; 450-1600 Hz in use	1400 Hz 7th order linear recommended
Synchronization	n/a	7 pulses at 300 Hz for both channels	7 pulses at 1040 pps, 50% duty cycle for Channel A; 7 pulses at 832 pps, 60% duty cycle for Channel B

Specific characteristics of the APT transmission system are detailed in Table 15 below.

Table 15.--APT Transmission Parameters

Type of transmitted signal	VHF, AM/FM 2.4 KHz DSB-AM 1.44 Hz video
System output	
Frequency, polarization	137.50 MHz right circular polarization or 137.62 MHz right circular polarization
EIRP at 63° from nadir	32.8 dbm worst case 37.2 dbm nominal
Antenna	
Gain at 63° from nadir	-0.5 dbi, right circular polarization
Ellipticity	5.0 db, maximum
Circuit Losses	2.4 db
Transmitter	
Power	5.0 watts minimum
Carrier Modulation Index	±17, ±0.85 KHz
Premodulation bandwidth ±0.5 db	0.1 to 4.8 KHz
Frequency Stability	+2 X 10^{-5}
Subcarrier Modulator	
Subcarrier frequency	2400 ±0.3 Hz
Subcarrier Modulation Index	87 ±5%
Post Modulator Filter, type	3 pole Butterworth
3 db bandwidth	6 KHz, minimun
Pre-Modulator Filter, type	3 pole Butterworth-Thompson
3 db bandwidth	2.4 KHz, minimum

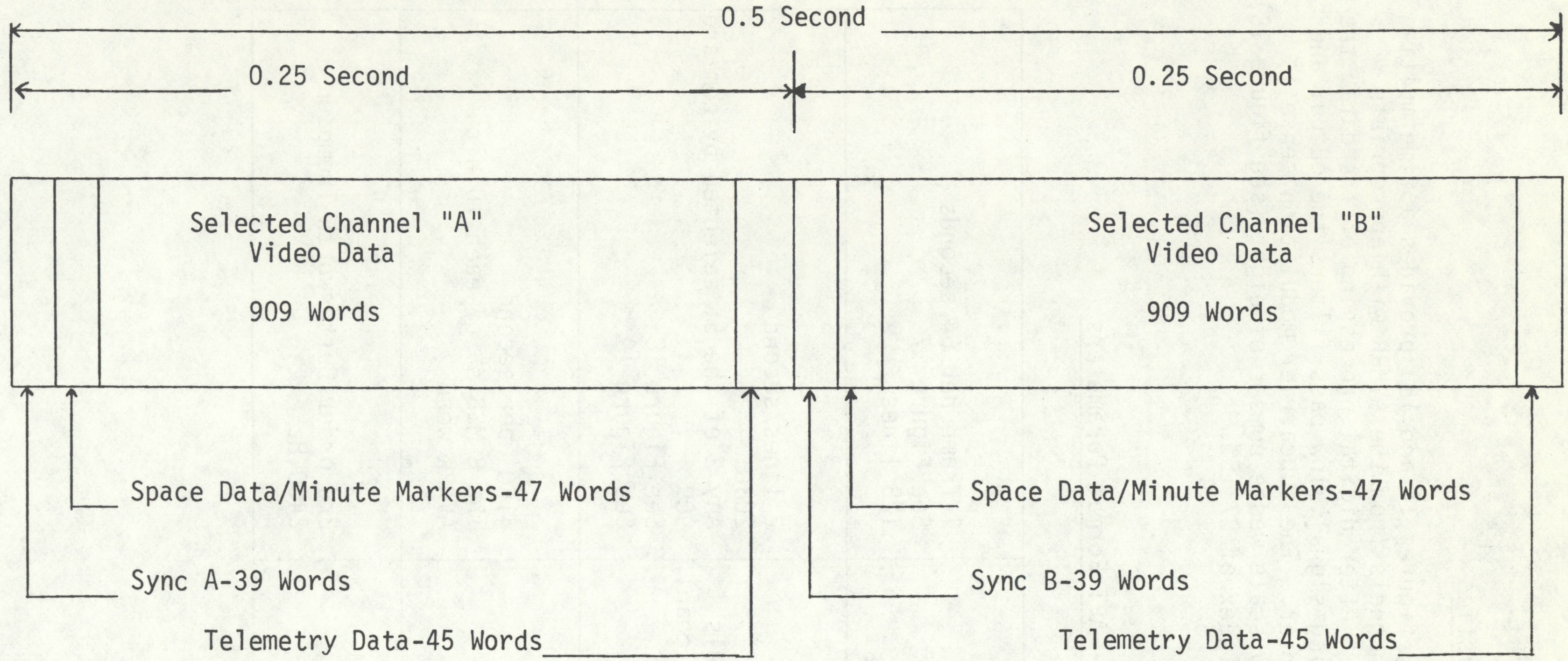
APT Data Transmission Characteristics

The APT data format (table 16, figures 14 and 15) provides a time multiplexed output of two selected channels from the AVHRR with appropriate calibrations and telemetry data. After digital processing of the data, the processor converts it to an analog signal, low pass filters the output and then modulates a 2400 Hz subcarrier. The subcarrier modulation sense is defined as the amplitude of gray scale wedge number of eight (see figure 18), producing a maximum modulation index of 87 ±5%.

Table 16.--APT Format Parameters

Frame	
o Rate	1 frame per 64 seconds
o Format	See Figure 17
o Length	128 lines
Line	
o Rate	2 lines/second
o Number of words	2080
o Number of sensor channels	Any 2 of the 5; selected by command
o Number of words/sensor chan.	909
o Format	See Figure 18
o Line sync format	See Figure 19
Word	
o Rate	4160 per second
o Analog-to-Digital Conversion Accuracy	The 8 MSB's* of each 10 bit AVHRR word
Low Pass Filter	
o Type	3rd order Butterworth-Thompson
o 3 db bandwidth	2400 Hz

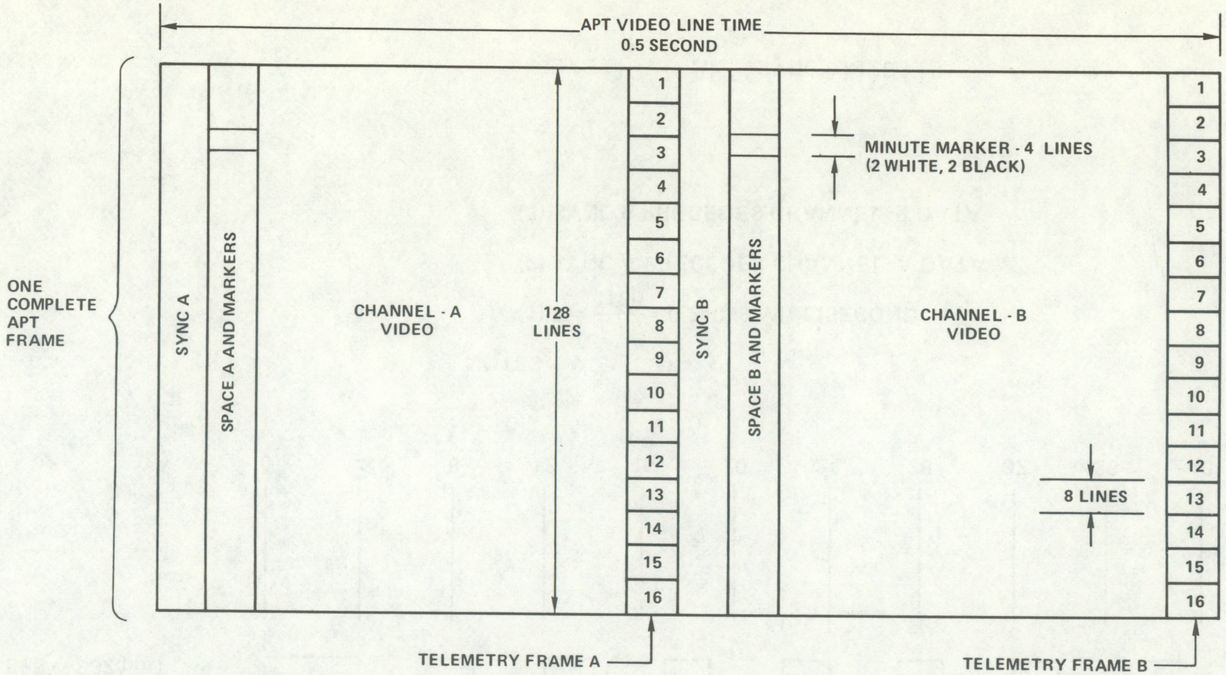
*Most Significant Bits (MSBs)



Notes:

1) Equivalent Output Digital Data Rate is 4160 Words/Second.
2) Video Line Rate - 2 Lines/Second.
3) APT Frame Size - 128 Lines.
4) Any two of the five AVHRR channels may be selected for use.
5) Sync A is a 1040 Hz square wave - 7 cycles.
6) Sync B is a 832 pps pulse train - 7 pulses.
7) Each of 16 telemetry points are repeated on 8 successive lines.
8) Minute markers are repeated on 4 successive lines, with 2 lines black and 2 lines white.

Figure 17.--APT video line format (prior to D/A converter)

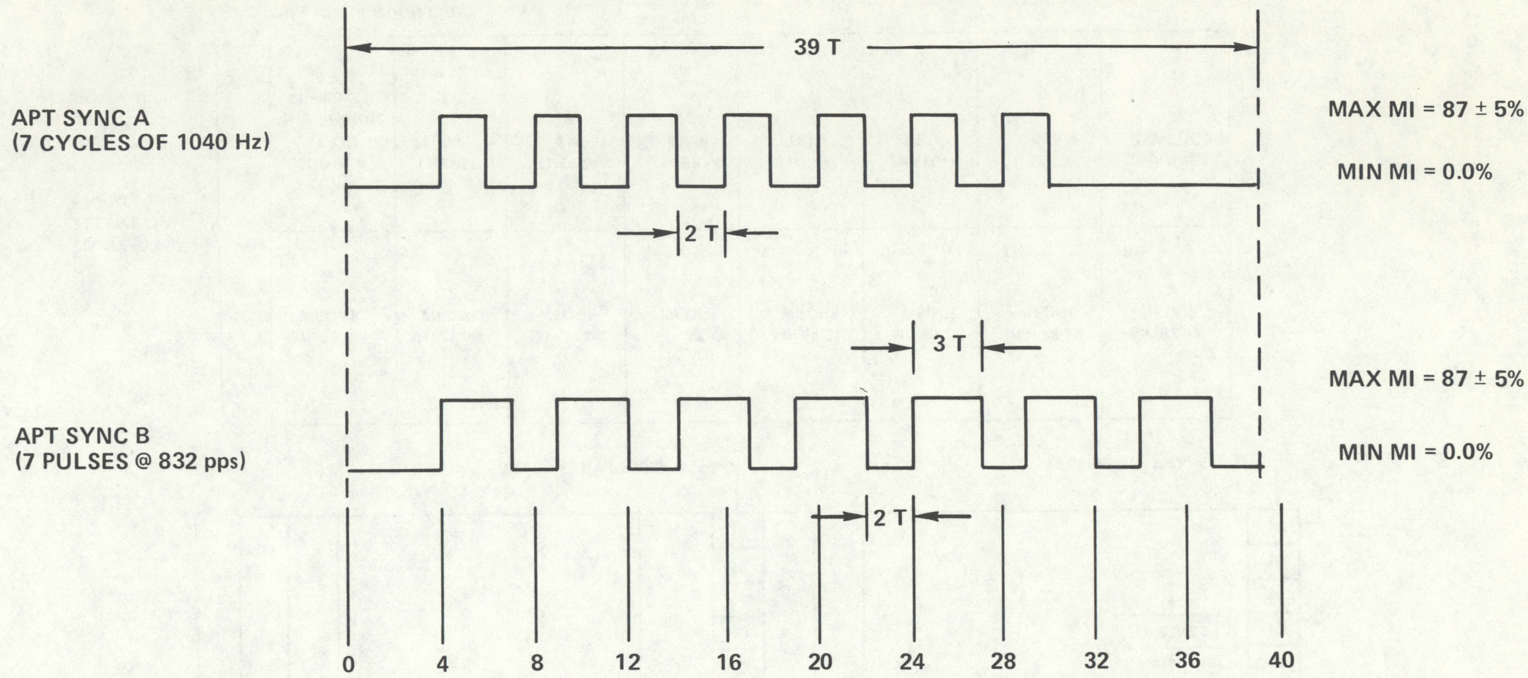


ONE COMPLETE TELEMETRY FRAME

MI=10.6%* WEDGE 1 (1)	MI=21.5% WEDGE 2 (2)	MI=32.4% WEDGE 3 (3)	MI= 43.3% WEDGE 4 (4)	MI=54.2% WEDGE 5 (5)	MI=65.2% WEDGE 6 (6)	MI=76.0% WEDGE 7 (7)	MI=87.0% WEDGE 8 (8)
ZERO MODULA-TION REFERENCE MI=0.0% (9)	THERM. TEMP. 1 (10)	THERM. TEMP. 2 (11)	THERM. TEMP. 3 (12)	THERM. TEMP. 4 (13)	PATCH TEMP. (14)	BACK SCAN (15)	CHANNEL ID WEDGE

*MI = MODULATION INDEX

Figure 18.--APT frame format



NOTES:

(1) $T = \frac{1}{4160} = 0.24038$ MILLISECOND

(2) SYNC A PRECEDES CHANNEL-A DATA

(3) SYNC B PRECEDES CHANNEL-B DATA

Figure 19.--APT sync details

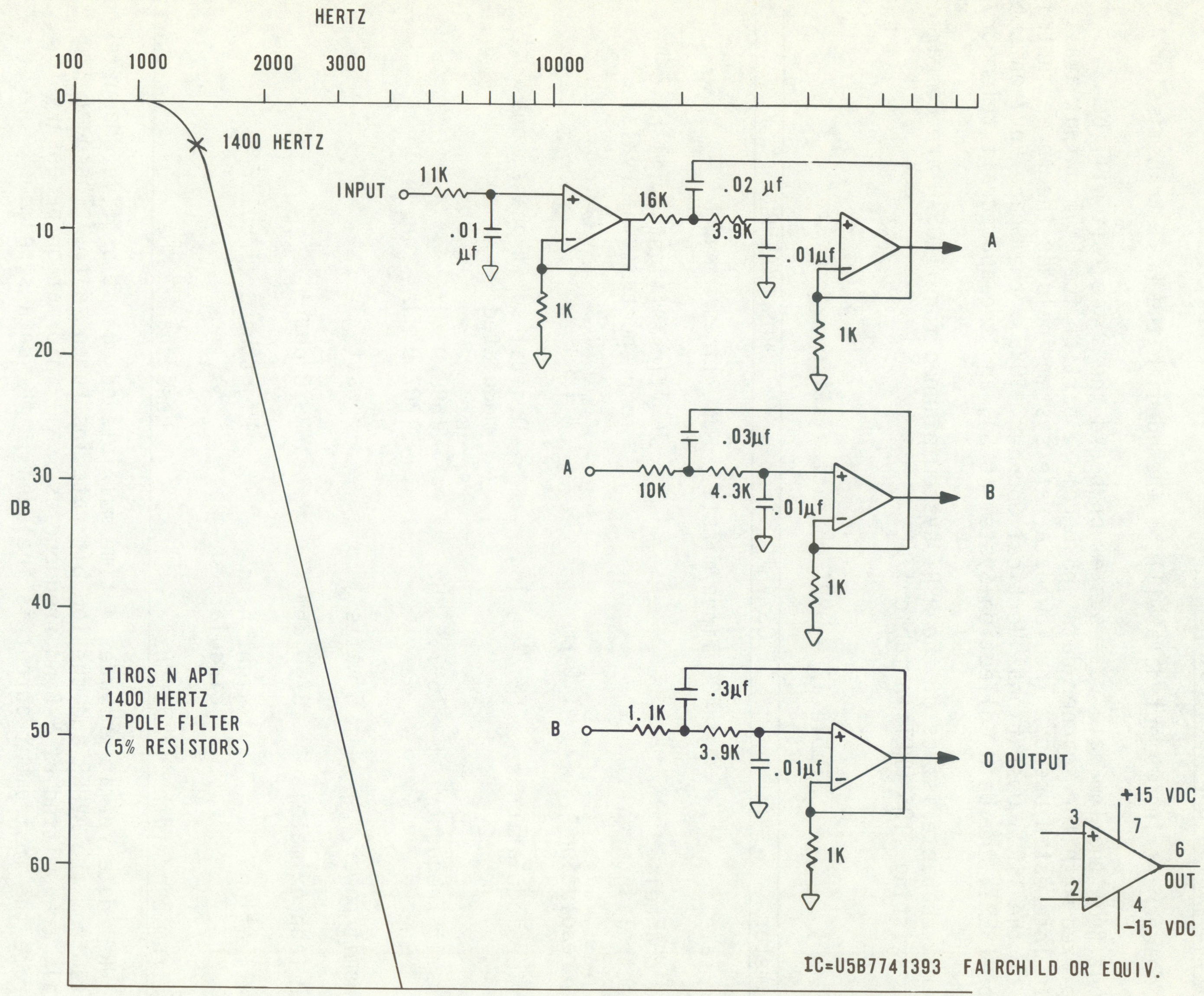


Figure 20.--Suggested TIROS-N ground station filter

APPENDIX C

HRPT Transmission Characteristics

All spacecraft instrument data will be included in the HRPT transmission.

Output from the low data rate system on board the spacecraft will be multiplexed with the scanner data and become a part of the HRPT output available to interested users. The low data rate system includes the three instruments of the TIROS Operational Vertical Sounder (TOVS), the Space Environment Monitor (SEM), the Data Collection System (DCS), and the spacecraft telemetry.

General characteristics of the HRPT system planned for TIROS-N are compared to the existing ITOS HRPT in table 17.

Table 17.--HRPT characteristics

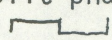
Parameter	ITOS/VHRR	TIROS-N/AVHRR
Line rate	400 lines/minute	360 lines/minute
Data channels (spectral intervals)	2	5 (first flights will have four spectral intervals)
Data resolution	1.0 km	1.1 km
Carrier modulation	FM: analog	Digital split phase, phase modulated
Transmit frequency	1697.5 MHz	1698.0 MHz 1707.0 MHz
Transmit power	5 watts	5 watts
EIRP (approximate)	37.0 dbm	39.0 dbm
Polarization	Right hand circular	Right hand circular
Spectrum bandwidth	1 MHz	Less than 3 MHz

The HRPT data format provides a time multiplexed output of five channels of data from the AVHRR and the low bit rate instrument data. The data are digital, transmitted at S-Band frequencies. All information necessary to calibrate the instrument output is included in the data stream.

HRPT Format

The HRPT format provides a major frame which is made up of three minor frames. The TIP data is the only information that is updated at the major frame rate. That is, the three minor frames which make up a major frame will contain the same TIP data. The HRPT is provided in a split phase format to the S-band transmitter. The split phase data 1 is defined as being positive during the first half of the bit period and negative during the second half of the bit period. The split phase data 0 is defined as being negative during the first half of the bit period and positive during the second half of the bit period. The HRPT critical parameters are given in table 18; the HRPT minor frame format is shown in figure 21 and table 20. The time code contained in each minor frame indicates the actual spacecraft time at the beginning of bit 1 of word 1.

Table 18.--HRPT Parameters

Major Frame	
o Rate	2 frames per second (fps)
o Number of Minor Frames	3
Minor Frame	
o Rate	6 fps
o Number of Words	11,090
o Format	See Table 20
Word	
o Rate	66,540 words per second
o Number of Bits***	10
o Order	bit 1 = MSB* bit 10 = LSB** bit 1 transmitted first
Bit	
o Rate	665,400 bps
o Format	split phase
o Data 1 definition	
o Date 0 definition	

*MSB - Most Significant Bit
**LSB - Least Significant Bit
***Note 8 bit TIP words in the data format are converted to 10 bit words for HRPT transmission. See page 15.

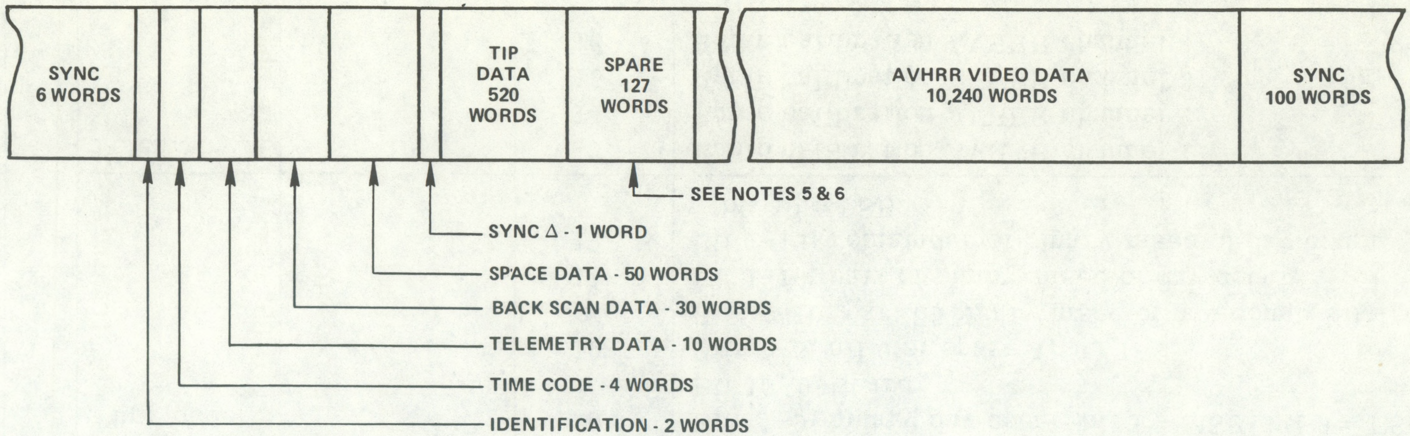
To minimize the effect of adding the fifth channel to the AVHRR for both on-board and ground systems, the spacecraft has been designed as though the instrument already had five channels. Output data from channel 4, the 11-micrometer IR window, will be included in the format twice. Users may find these data useful for noise analysis purposes since the instrument output is twice processed through the total instrument/satellite processing and transmission system. When developed and flown, the 11.5-12.5 micrometer channel data will be a direct replacement for the second transmission of the 10.5 to 11.5 micrometer data.

Specific characteristics of the HRPT transmission system are detailed in table 19 below.

Table 19.--HRPT Transmission Parameters

Type of transmitted signal	S-Band phase modulated Split phase 665.4 K bits per second
System Output	
Frequency & Polarization	1698.0 MHz right hand circular 1707.0 MHz right hand circular 1702.5 MHz* left hand circular
EIRP at 63° from nadir	36.8 dbm worst case 40.4 dbm nominal
Antenna	
Gain at 63° from nadir	2.1 dbi, minimum
Ellipticity	6.0 db, maximum
Transmitter	
Power out	5.25 watts minimum
Modulation Index	2.35 $\pm$0.12 radians
Premodulation filter, type 3 db bandwidth	5th order, 0.05°, equiripple phase 2.4 MHz
Frequency stability	$\pm 2 \times 10^{-5}$

*Not planned for HRPT use unless 1698 and 1707 MHz transmitters have failed.



NOTES:

(1) MINOR FRAME LENGTH - 11,090 WORDS
(2) THREE MINOR FRAMES PER MAJOR FRAME
(3) MINOR FRAME RATE - 6 FRAMES/SECOND
(4) WORD LENGTH - 10 BITS/WORD

(5) HRPT OUTPUT - ALL SPARES ARE 10TH DEGREE P-N CODE (BAR).
(6) IF A FOURTH SOUNDING INSTRUMENT IS ADDED, THESE SPARE WORD SLOTS WILL MOST LIKELY BE USED FOR DATA FROM THIS INSTRUMENT.

TLM WORD ALLOCATIONS		ID WORD BIT ALLOCATIONS			
		1ST ID WORD		2ND ID WORD	
				(SPARE)	
1-5	RAMP CALIBRATION				
6	CHANNEL-3 TARGET TEMP (5 PT SUBCOM)	1	SYNC ID	1-10	ALL DATA UNDEFINED
		2-3	FRAME ID		
7	CHANNEL-4 TARGET TEMP (5 PT SUBCOM)	4-7	SPACECRAFT ADDRESS		
8	CHANNEL-5 TARGET TEMP (5 PT SUBCOM)	8	RESYNC MARKER		
9	CHANNEL-3 PATCH TEMP	9	DATA 0		
10	SPARE (UNDEFINED)	10	DATA 1		

Figure 21.--TIROS-N HRPT frame format

Table 20.--HRPT minor frame format

	Function	No. of Words	Word Position	Bit No. 1	2	3	4	5	6	7	8	9	10	Plus word code & meaning
HEADER	Frame sync	6	1	1	0	1	0	0	0	0	1	0	0	1st 60 bits from a 63-bit PN[1] generator started in the all 1's state. The generator polynominal is $X^6 + X^5 + X^2 + X + 1$
			2	0	1	0	1	1	0	1	1	1	1	
			3	1	1	0	1	0	1	1	1	0	0	
			4	0	1	1	0	0	1	1	1	0	1	
			5	1	0	0	0	0	0	1	1	1	1	
			6	0	0	1	0	0	1	0	1	0	1	
	ID	2	7	Bit 1; 0 = internal sync; 1 = AVHRR sync Bits 2 & 3; 00 = not used; 01 = minor frame 1; 10 = minor frame 2, 11 = minor frame 3 Bits 4-7; spacecraft address; bit 4 = MSB, bit 7 = LSB Bit 8; 0 = frame stable; 1 = frame resync occurred Bits 9-10; spare; bit 9 = 0, bit 10 = 1										
			8	Spare word; bit symbols undefined										
	Time code	4	9	Bits 1-9; binary day count; bit 1 = MSB; bit 9 = LSB Bit 10; 0; spare										
			10	Bits 1-3; all 0's; spare 1, 0, 1 Bits 4-10; part of binary msec of day count; bit 4 = MSB										
			11	Bit 1-10; part of binary msec of day count;										
			12	Bit 1-10; remainder of binary msec of day count; bit 10 = LSB										
	Telemetry	10	13	Ramp calibration AVHRR channel 1										
			14	Ramp calibration AVHRR channel 2										
			15	Ramp calibration AVHRR channel 3										
			16	Ramp calibration AVHRR channel 4										

(1) PN = pseudo noise

Table 20.--HRPT minor frame format (continued)

Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10 Plus Word Code & Meaning
Telemetry (cont.)	10	17	Ramp calibration AVHRR channel 5
		18	AVHRR channel 3 target temp.[2] (Each of these words is a 5-channel subcom -4 words of IR data plus subcom sync (10 0's))
		19	AVHRR channel 4 target temp.
		20	AVHRR channel 5 target temp.
		21	Channel-3 patch temp.
		22	0 0 0 0 0 0 0 0 0 1 spare
Back scan	30	23 → 52	10 words of back scan data from each AVHRR channel 3, 4, and 5. These data are time multiplexed as Chan 3 (word 1), chan 4 (word 1), chan 5 (word 1), chan 3 (word 2), chan 4 (word 2), chan 5 (word 2), etc.
Space data	50	53 → 102	10 words of space-scan data from each AVHRR channel 1, 2, 3, 4, and 5. These data are time multiplexed as chan 1 (word 1), chan 2 (word 1), chan 3 (word 1), chan 4 (word 1), chan 5 (word 1), chan 1 (word 2), chan 2 (word 2), chan 3 (word 2), chan 4 (word 2), chan 5 (word 2), etc.
Sync Δ	1	103	Bit 1; 0 = AVHRR sync early; 1 = AVHRR sync late Bits 2-10; 9-bit binary count of 0.9984-MHz periods; bit 2 = MSB, bit 10 = LSB

(2) As measured by a platinum resistance thermometer embedded in the housing.

Table 20.--HRPT minor frame format (continued)

Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10	Plus Word Code & Meaning
Tip data	520	104 → 623		The 520 words contain five frames of TIP data (104 TIP data words/frame) Bits 1-8: exact format as generated by TIP Bit 9: even parity check over bits 1-8 Bit 10: - bit 1
Spare words	127	624	1 0 1 0 0 0 1 1 1 0	Derived by inverting the output of a 1023-bit PN sequence provided by a feedback shift register generating the polynominal: $X^{10} + X^5 + X^2 + X + 1$ The generator is started in the 1's state at the beginning of word 7 of each minor frame.
		625	1 1 1 0 0 0 1 0 1 1	
		626	0 0 0 0 1 0 1 1 1 1	
		627	1 0 1 1 0 0 0 1 1 1	
		628	1 1 0 1 0 1 0 0 1 0	
		↓	↓	
		748	1 0 0 1 0 1 1 0 1 0	
		749	1 1 0 0 1 0 0 0 1 0	
		750	1 0 0 0 0 0 0 0 0 0	

Table 20.--HRPT minor frame format (continued)

Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10	Plus Word Code & Meaning
Earth data	10,240	751	Chan 1 - Sample 1	Each minor frame contains the data obtained during one earth scan of the AVHRR sensor. The data from the five sensor channels of the AVHRR are time multiplexed as indicated
		752	Chan 2 - Sample 1	
		753	Chan 3 - Sample 1	
		754	Chan 4 - Sample 1	
		755	Chan 5 - Sample 1	
		756	Chan 1 - Sample 2	
		↓	↓	
		10,985	Chan 5 - Sample 2047	
		10,986	Chan 1 - Sample 2048	
		10,987	Chan 2 - Sample 2048	
		10,988	Chan 3 - Sample 2048	
		10,989	Chan 4 - Sample 2048	
		10,990	Chan 5 - Sample 2048	
Auxiliary sync	100	10,991	1 1 1 1 1 0 0 0 1 0	Derived from the non-inverted output of a 1023-bit PN sequence provided by a feedback shift register generating the polynominal: $X^{10} + X^5 + X^2 + X + 1$ The generator is started in the all 1's state at the beginning of word 10,991
		10,992	1 1 1 1 1 1 0 0 1 1	
		10,993	0 1 1 0 1 1 0 1 0 1	
		10,994	1 0 1 0 1 1 1 1 0 1	
		↓	↓	
		11,089	0 1 1 1 1 1 0 0 0 0	
		11,090	1 1 1 1 0 0 1 1 0 0	

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(Continued from inside front cover)

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