QC
879.5
.U4
no.7
c.2

U.S. National Environmental Satellite Center,
Washington,D.C.
Technical memorandum NESCTM 7. The improved Tiros
operational satellite, by E.G. Albert.

147 046

M(
U5
C2

NATIONAL ENVIRONMENTAL SATELLITE CENTER
Washington, D.C.

August 1968

The Improved TIROS Operational Satellite

ATMOSPHERIC SCIENCES
LIBRARY

NOV 12 1968

E. S. S. A.
U. S. Dept. of Commerce

Technical Memorandum NESCTM 7

U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

147 046

National Environmental Satellite Technical Memoranda

The National Environmental Satellite Center is responsible for the establishment and operation of the National Operational Meteorological Satellite System and the environmental satellite systems of the Environmental Science Services Administration. The three principal offices of NESC are Operations, System Engineering, and Research. The NESC Technical Memorandum series is used by these offices to facilitate early distribution of general information of interest to other ESSA organizations. Publication of such information in this series will not preclude later publication in a modified form in scientific journals, etc. References to a paper in this series should identify it as an NESC Technical Memorandum.

The NESC Technical Memoranda are available through the Clearinghouse for Federal Scientific and Technical Information, U.S. Department of Commerce, Sills Building, Port Royal Road, Springfield, Virginia, 22151. Cost per item is uniform: $3.00 for hard copy, $.65 for microfiche.

NESCTM
1. Publications by Staff Members, National Environmental Satellite Center and Final Reports on Contracts and Grants Sponsored by the National Environmental Satellite Center 1958-1966. March 1967.

NESCTM
2. Publications by Staff Members, National Environmental Satellite Center and Final Reports on Contracts and Grants Sponsored by the National Environmental Satellite Center 1967. January 1968.

NESCTM
3. Computer Processing of Satellite Cloud Pictures. C. L. Bristor. April 1968.

NESCTM
4. Modification of the APT Ground Station Recorder for Increasing the Size of DRIR Data. A. S. Vossler. June 1968.

NESCTM
5. Reserved

NESCTM
6. Reserved

UDC 551.507.362.2

U. S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
National Environmental Satellite Center

U. S. National Environmental Satellite Center, Washington, D.C.
Technical Memorandum NESCTM 7

THE IMPROVED TIROS OPERATIONAL SATELLITE

Edward G. Albert

QC
879.5
.U4
no. 7
c. 2

WASHINGTON, D. C.
August 1968

National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

ERRATA NOTICE

One or more conditions of the original document may affect the quality of the image, such as:

Discolored pages
Faded or light ink
Binding intrudes into the text

This has been a co-operative project between the NOAA Central Library and the Climate Database Modernization Program, National Climate Data Center (NCDC). To view the original document contact the NOAA Central Library in Silver Spring, MD at (301) 713-2607 x124 or Library.Reference@noaa.gov.

HOV Services
Imaging Contractor
12200 Kiln Court
Beltsville, MD 20704-1387
January 26, 2009

PREFACE

For the benefit of potential data users, this technical memorandum briefly describes the Improved TIROS Operational Spacecraft. Emphasis is placed on those aspects of the spacecraft which directly influence its data acquisition capabilities. The sensors of this spacecraft will provide both full photographic coverage of the illuminated portions of the earth - as is currently provided by the TOS (TIROS Operational Satellite) system - and global radiating surface temperature measurements by means of infrared radiometry.

In the interest of brevity, most detailed specifications of subsystem performance and signal formats have been omitted. The only material in print dealing with these details are the actual specifications for the spacecraft and its subsystems, and a design study report published by the Astro-Electronics Division, Radio Corporation of America, as part of its contractual obligation to the Goddard Space Flight Center, National Aeronautics and Space Administration, which is managing the development effort. Readers having a genuine interest in such detail are invited to correspond with the author.* (A brief table of general specifications is included in the appended "ITOS Fact Sheet.")

It is not unusual for spacecraft designs to change significantly during development. At the time of this writing, August 1968, the design phase is complete. However, the pressures and problems of integrating and testing these spacecraft will undoubtedly force design changes before the first one is launched.

*Mr. E. G. Albert
National Environmental Satellite Center
Environmental Science Services Administration
Washington, D. C. 20233

Blank page retained for pagination

TABLE OF CONTENTS

		Page
Preface		i
I.	GENERAL	1
II.	LAUNCH AND ORBIT	2
III.	STABILIZATION	2
IV.	PRIMARY ENVIRONMENTAL DATA	3
V.	SECONDARY ENVIRONMENTAL DATA	6
APPENDIX -	ITOS FACT SHEET	A-1

LIST OF FIGURES

		Page
Figure 1.	The ITOS in operational mode showing sensor fields of view.	8
Figure 2.	The ITOS with sensors and other major external features shown.	9
Figure 3.	Relationship of earth observational coverage by ITOS APT pictures and interspersed SR scans.	10
Figure 4.	Digitally rectified ESSA 3 AVCS picture data received on December 13, 1967.	11
Figure 5.	Cutaway view of the Scanning Radiometer.	12
Figure 6.	A model of the Flat Plate Radiometer.	13
Figure 7.	A flight model Solar Proton Monitor.	14

THE IMPROVED TIROS OPERATIONAL SATELLITE

I. GENERAL

The Improved TIROS Operational Satellite (ITOS)* is a three-axis earth-stabilized platform for environmental sensors. Its primary sensors combine in a single spacecraft the daylight television picture functions of the existing AVCS TOS and APT TOS** and add the capability of two-channel scanning radiometers. In one channel the radiometers provide an alternative source of daytime cloud pictures. The second channel provides day and night measurements of "radiating surface temperatures" using infrared energy detected in the 11-micron water vapor window.

The ITOS secondary sensors are a Flat Plate Radiometer having hemispheric field of view detectors to provide data on the earth's gross heat balance and a Solar Proton Monitor to count energetic particles encountered in orbit.

Figure 1 is a drawing of the ITOS in orbit around the earth. The relationships among the fields of view of the sensors are shown.

The spacecraft's structure is box-like. Its dimensions are 40 inches by 49 inches on the earth-facing side by 40 inches "up." The three 65-inch by 36-inch panels erected at one end of the ITOS hold solar cells in the plane of the orbit so that they face the sun. The panels are slightly curved to fit inside the shroud when folded down on three sides of the ITOS during launch.

A thin black ring, 40 inches in diameter by 5 inches high, and a similar, smaller diameter ring are mounted concentrically on the reflective surface of the sun-facing end of the ITOS. These surfaces comprise a passive thermal control system. As the sun's incidence angle changes, the absorption of radiant energy by these rings changes. This counteracts the thermal effect of the related changes in electrical energy produced by the solar cells. An active thermal control system utilizes louvers activated by fluid expansion to vary the area of uninsulated radiating surfaces. The two systems will combine to significantly reduce temperature variations in the sensor systems.

---

* TIROS M is the NASA prototype of this operational spacecraft. Its launch is planned for mid-1969. Data from TIROS M will be used operationally.

** See IV. A. and B.

A ring 5 inches high on the opposite (anti-sun) end of the spacecraft is used to attach the ITOS to its launch vehicle. The ring surrounds the stabilization system flywheel described in Section III. Figure 2 shows the earth-facing and anti-sun faces of an ITOS model.

II. LAUNCH AND ORBIT

The ITOS will be launched into a sun-synchronous 790 n. mi. circular orbit on a two-stage Delta launch vehicle. The first stage is a Thor modified with lengthened tankage and strapped-on Castor solid rockets. The Delta second stage is the improved large-diameter tank version, modified for controlled shut down and restart of its engines.

The launch sequence will begin with a southwest trajectory from the Western Test Range launch site in California. The solid, strapped-on rockets and the first stage are separated and dropped into the Pacific Ocean along the Western Test Range as they are exhausted. Second stage burn is shut down under ground control when guidance calculations indicate that the trajectory is proper for the intended transfer elipse. An approximately one-hour coast phase is conducted using internal attitude control. When the apogee of the transfer elipse is reached, the Delta programmer and inertial guidance properly orient the vehicle. A controlled second burn of the second stage engine then injects it into orbit. Finally, the vehicle is rotated 90° to place the thrust axis along the orbit normal, the ITOS flywheel is spun up* about that axis and separation occurs.

III. STABILIZATION

The momentum stored in the flywheel of the gyromagnetic control system is the basis of ITOS stabilization. Nominally, when the flywheel rotates at 150 rpm, the ITOS rotates once per orbit and is therefore earth-stabilized.

The horizon detectors, flywheel speed and position detectors, and pitch control electronics of the attitude control system form a

---

* Several alternative means of providing the angular momentum required for stabilization are under study. The momentum wheel might be set spinning prior to launch, or the whole ITOS might be spun at separation.

feedback loop for a servomechanism which actively controls the pitch position of the ITOS through fine control of flywheel speed. Pitch attitude control is expected to hold the earth sensor axes within about one degree of the local vertical if the orbit is as planned. For other orbits, the sensor axes should be held within about one degree of pointing directions which may not coincide with the local vertical but which will be predictable many days in advance.

Roll and yaw attitude control is based on proven TOS techniques. Controlled currents in coils in the ITOS will create controlled spacecraft magnetic fields to interact with the earth's field. Properly timed operation of those coils will allow maintenance of the ITOS spin axis within about one degree of the orbit normal.

A special feature of the ITOS magnetic attitude control system will work continuously to hold roll and yaw position firmly against the significant disturbing force of solar pressure.

IV. PRIMARY ENVIRONMENTAL DATA

Three primary sensors provide remotely sensed measurements of the earth and its atmosphere. Two of each of these primary sensors are included in each ITOS to increase the probability of a long operational life.

A. Automatic Picture Transmission (APT) System

APT cameras of the type used so successfully in TOS operations and on one TIROS and two Nimbus spacecraft will be used on ITOS. In this system, video data are broadcast immediately so that properly equipped receiving stations within sight of the satellite may receive pictures of meteorological conditions in the surrounding area.

The APT camera will point straight down at the earth and take a picture through a lens which allows a 90° side-to-side angular field of view. Pictures are about 1800 n. mi. wide when taken from the 790 n. mi. ITOS altitude. TV line resolution is the same as for TOS, about 2 miles* over most of the picture and about 4 miles at the corners. Ten grey shade performance is provided.

---

* Modulation at this resolution is about 15%. Resolution is about 4 miles for 50% modulation.

Although operation of existing APT station ground equipment will continue essentially unchanged, a number of changes are being made in the camera operation. The vertical height of the picture format has been reduced from 800 lines to 600 lines. The same, 4 per second, line rate is used, but the time between pictures has been reduced to 260 seconds. This means that the ITOS APT signal at a local readout station will consist of a 3-second 300 Hz start tone and a 5-second 4 Hz phasing signal (no change) followed by 600 video lines in 150 seconds (50 seconds less total time) followed by 102 seconds of no signal or 94 seconds of a signal from the scanning radiometer described below and 8 seconds of no signal.

Since the pictures are taken more frequently (260 seconds versus 352 seconds) than was the case for the TOS series, about the same 30% overlap will be present for successive frames (See Figure 3). Average picture quality will be improved since it is the lower quality first 100 lines and last 100 lines that are deleted. Gridding procedures will not change.

B. Advanced Vidicon Camera System (AVCS)

The AVCS has provided successful operational service in the TOS system and performed briefly on Nimbus 1 and 2. The camera's picture geometry is nearly identical to APT (1800 n. mi. wide, 2 to 4 n. mi. TV resolution). AVCS video data are recorded on magnetic tape and later transmitted to command and data acquisition (CDA) stations for relay to global weather analysis centers. Figure 4 shows a global cloud mosaic, rectified by digital computer and displayed to scale on standard map projections. This operational product was produced at the National Environmental Satellite Center from one day's ESSA 5 pictures. Similar analyses enhanced with infrared data from the scanning radiometer described below will be produced using ITOS AVCS pictures.

A modified version of the AVCS used on TOS and Nimbus will be used. Signals from the new AVCS will be identical to those from TOS AVCS. An 833-line video format will again reproduce the image from a 90° side-to-side lens system. About 10 grey shades will be available. (In a non-operational test mode which bypasses the tape recorder, 12 grey shades performance will be possible.) Eleven pictures will be taken at 260-second intervals to cover the sunlit portion of the earth (sun elevation greater than 15 degrees). Frame to

frame overlap along the track will again be 50% since the full frame height is about twice the separation between picture centers.

C. Scanning Radiometer (SR)

The SR is a new system based on the technology of previously proven instruments. In this device, a mirror, rotating at 48 rpm, provides an optical scan perpendicular to the direction of spacecraft motion. Energy from the single spot which is the elemental field of view at any instant passes through a beam splitter and spectral filters to provide both a 10.5- to 12.5-micron infrared channel and a .52- to .73-micron visible channel (See Figure 5).

System optics are designed to provide a 5.3-milliradian field of view for the IR detector. It will therefore "see" a 4 n. mi. spot at the nadir. As the scan mirror rotates and the "spot" moves toward the horizon, its size increases. In equatorial regions contiguous data from successive orbits will occur at points about 900 n. mi. from the subsatellite point where the data zenith angle is 60° and the spot covers about 8 n. mi. by 12 n. mi.

If data from this IR channel are interpreted in terms of the temperature of an equivalent black body radiator, the noise equivalent temperature difference (NEΔT) is expected to range from 1°C for a 300°K scene to 4°C for a 185°K scene. Instrument stability, combined with prelaunch calibration and post-launch in-flight calibration and analysis, is expected to provide absolute temperature measurement accuracy (for an equivalent black body) equal to about twice the NEΔT.

The visible channel optics are designed for a 2.7-milliradian field of view or a 2-mile "spot" at the nadir. Since the scan advances about 4 miles per mirror rotation, visible scan lines are separated at the nadir. However, they expand to fill the scene at the sides where orbit to orbit contiguity occurs. This sensor geometry allows higher effective resolution to be obtained than would otherwise be possible. Due to its more favorable modulation transfer function and dynamic range, SR visible data are expected to be of better quality than APT or AVCS pictures.

The scanning radiometer IR channel provides the only ITOS primary sensor data that will be usable at night. It is equally usable for daytime observations as is the visible channel. This instrument versatility is combined in the ITOS with a flexible data programming

system so that the SR becomes a nearly universal sensory subsystem. Since the SR will be capable of providing completely usable data over the daylight side of the earth, it will function as an operational replacement for both camera systems in the event of their total failure.

For direct readout to local "APT" stations, IR data may be broadcast continuously during the approximately 70-minute nighttime period and either IR or visible channel data may be broadcast continuously in place of APT video during the 45-minute day portion of the orbit. For global observations (data recorded on magnetic tape and replayed through CDA stations to global weather analysis centers), IR data may be recorded during the day or night portions of each orbit. Daytime visible channel data may also be recorded. TIROS M and early ITOS recorder capacity limitations will prevent full day and night recorded data recovery when CDA contacts are missed, but AVCS cloud picture coverage requirements can be fully met.

A special feature of the ITOS SR will be its broadcast for 94 seconds of the 102 seconds between APT transmissions. In this way about 75 lines of IR data can be provided with each APT frame. The area covered by IR is near the center of the next APT picture (See Figure 3).

V. SECONDARY ENVIRONMENTAL DATA

The Flat Plate Radiometer and the Solar Proton Monitor are considered to be secondary sensors. Only one of each is carried on the ITOS. Although their data are to be used operationally, their failure will not be deemed a mission failure.

A. Flat Plate Radiometer (FPR)

The FPR measures energy in broad spectral bands with hemispheric angular acceptance. The sum of energy emitted by the earth and solar energy reflected by the earth is measured by black sensors sensitive between 0.3 and 30 microns. White sensors measure earth-emitted energy between 7 and 30 microns only. These measurements are used to determine the heat balance of the earth.

Two pairs of sensors (See Figure 6) will be used on the ITOS FPR. One black/white pair will operate as radiative equilibrium detectors just as the heat balance radiometers used on TOS did. Data

from this pair are expected to be closely comparable to data observed on the TOS flights. The two sets of data are expected to be sufficiently similar in calibration that they may be considered together for climatological purposes.

The second black/white sensor pair is of a new thermal feedback design. The energy required to maintain a constant temperature will be measured. Except for calibrated losses to the mounts, energy, not its fourth root, temperature, is measured directly. As an added feature, this thermal feedback sensor pair will rotate to view its housing for in-flight calibration of IR response.

The sensor measurements and auxiliary calibration data are recorded on a digital tape recorder for relay through CDA stations to the National Environmental Satellite Center for processing and study.

B. Solar Proton Monitor (SPM)

The SPM measures the flux of energetic particles (protons, electrons, etc.) in several energy ranges. The primary function of the SPM is to detect the arrival of energetic solar protons in the vicinity of the earth. The SPM measures the energetic particles flux in several ranges: protons in the 10, 30, and 60 Mev range and electrons in the 100 to 750 Kev range. The flux toward the earth along the local vertical is measured with one set of detectors. A second set measures the flux along the orbit normal, from the side of the spacecraft away from the sun (See Figure 7).

The data, in digital form, are tape recorded and are also used to modulate the ITOS beacon transmitter when higher priority data* are not present.

The tape recorded data are quickly processed at NESC after relay via a CDA station, and a greatly reduced volume of calibrated data is passed to the Space Disturbances Laboratory of the ESSA Research Laboratories at Boulder, Colorado, for solar storm warning purposes. Later all the processed data are sent to ESSA Research Laboratories for study.

---

* Attitude scanner signals, "housekeeping" telemetry, etc.

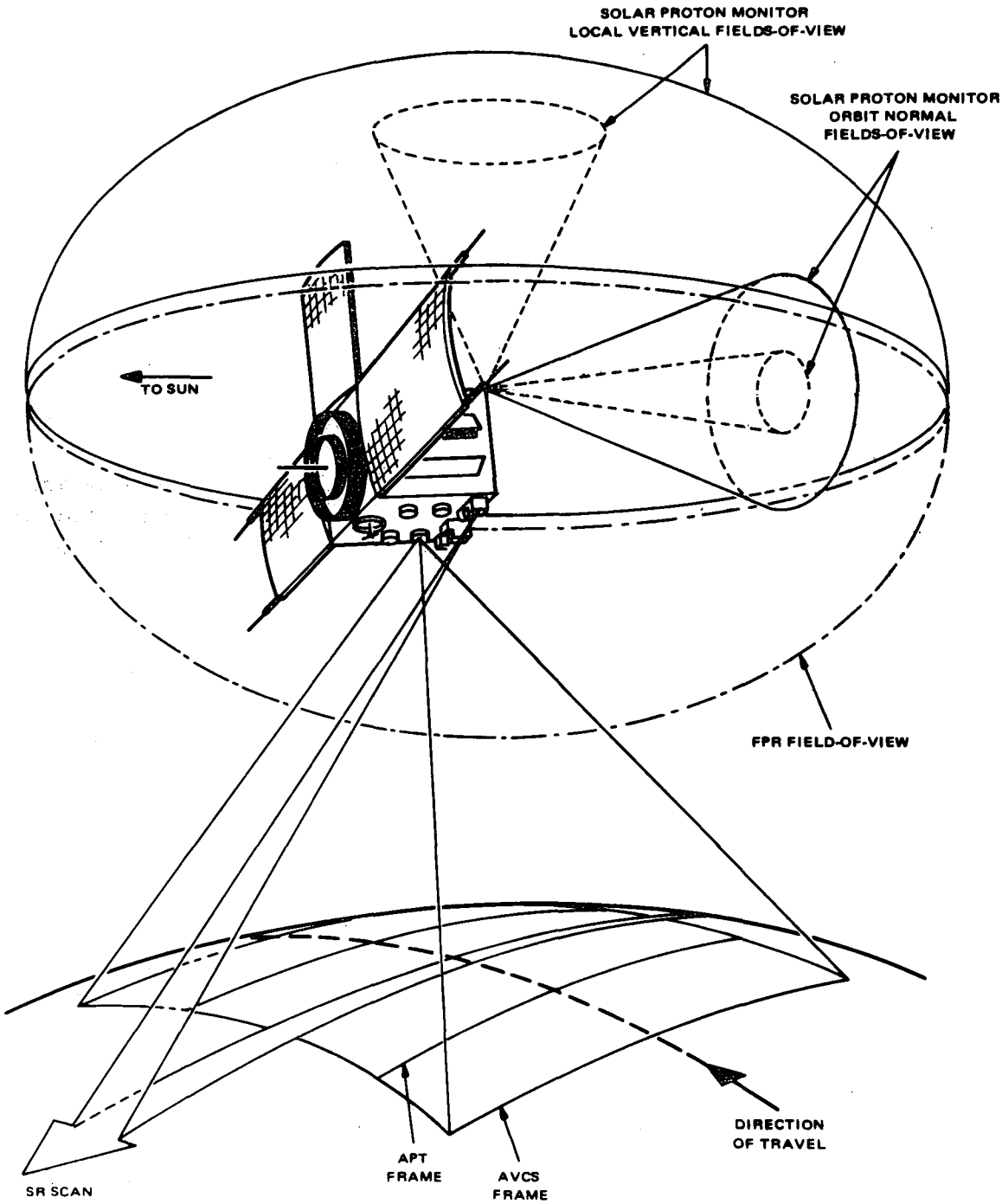

Figure 1. The ITOS in operational mode showing sensor fields of view. (Courtesy, Astro-Electronics Division, Radio Corporation of America).

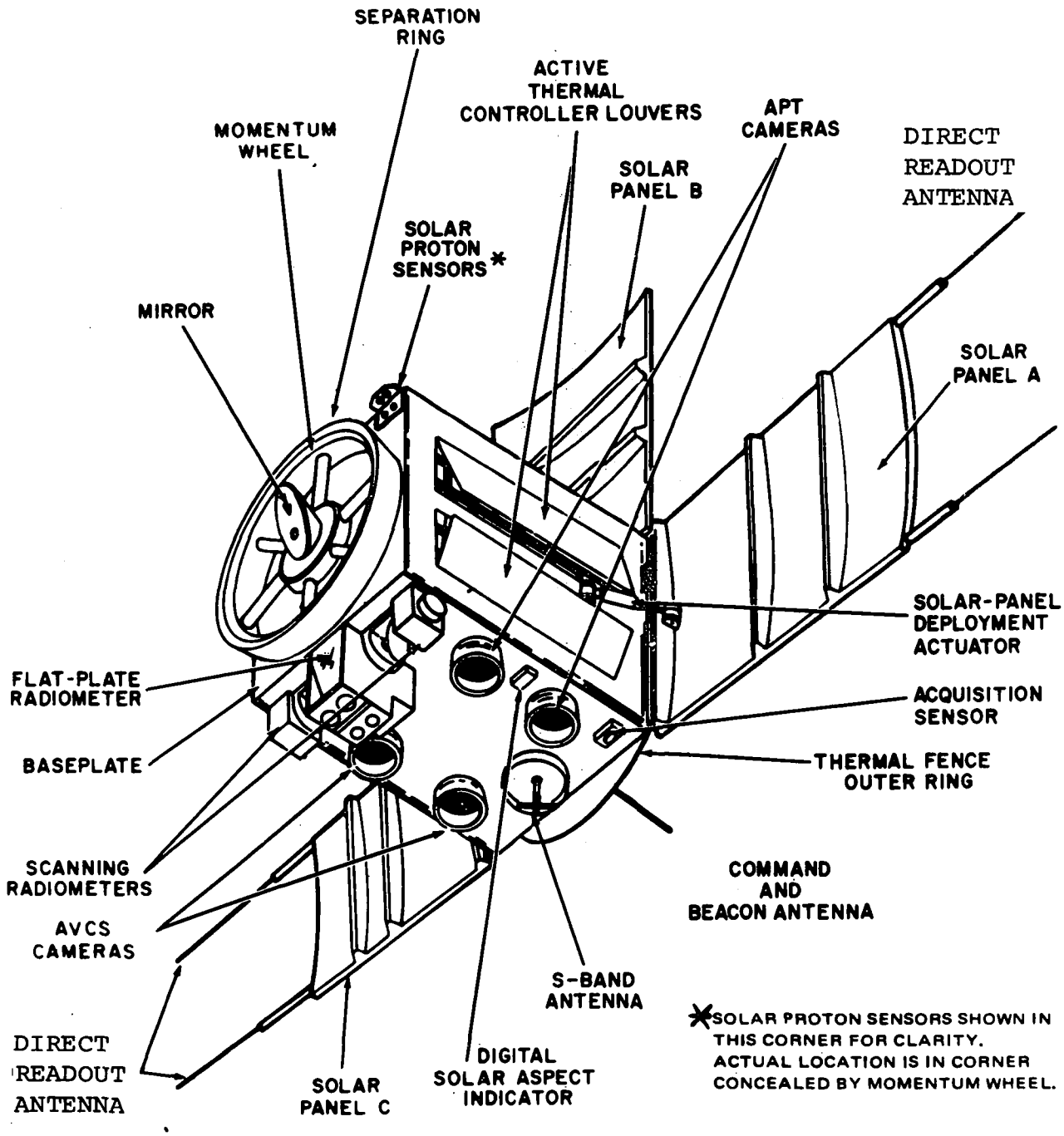

Figure 2. The ITOS with sensors and other major external features shown. (Courtesy, Astro-Electronics Division, Radio Corporation of America).

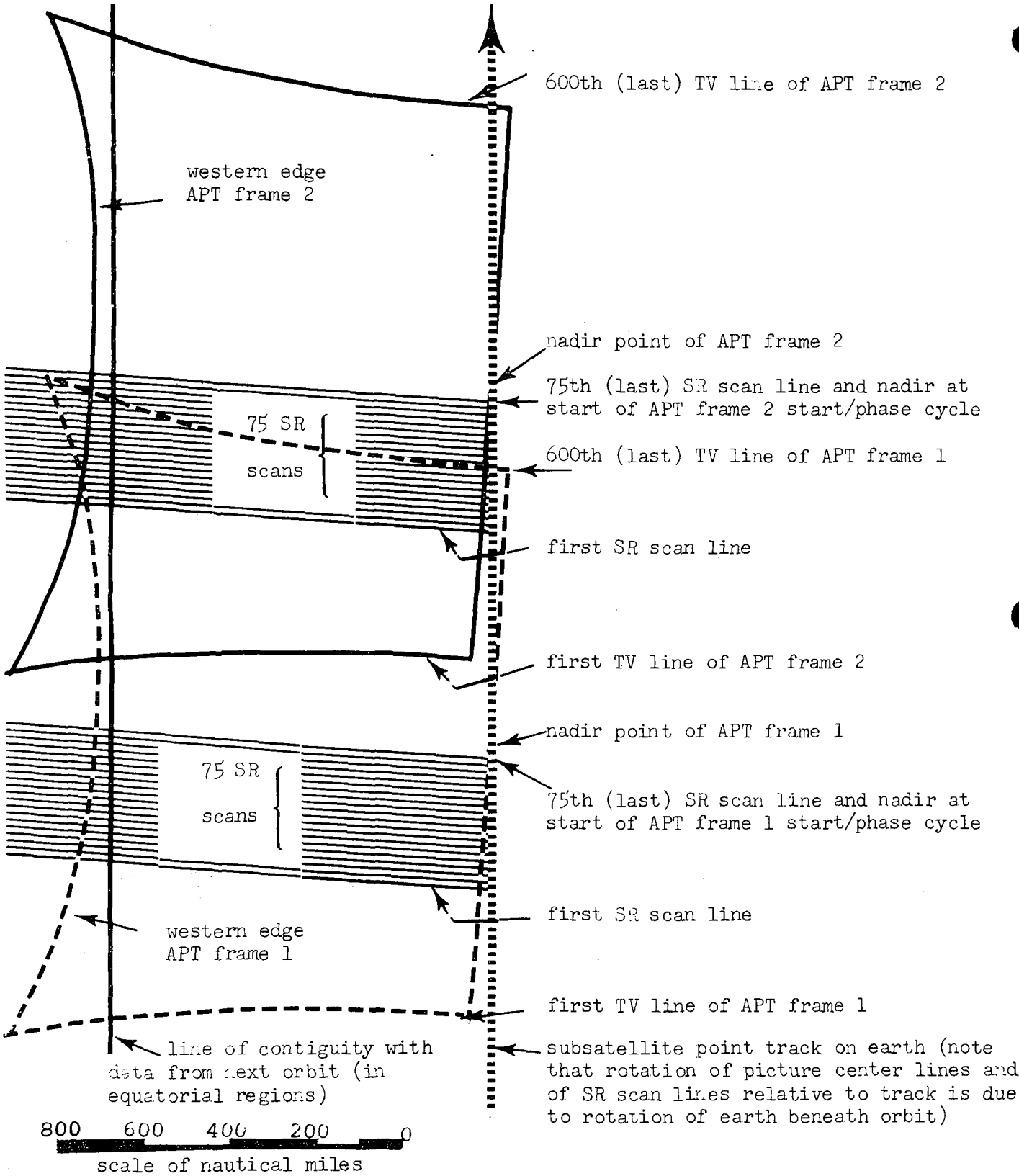

Figure 3. Relationship of earth observational coverage by ITOS APT pictures and interspersed SR scans. Only the western halves of the areas are shown.

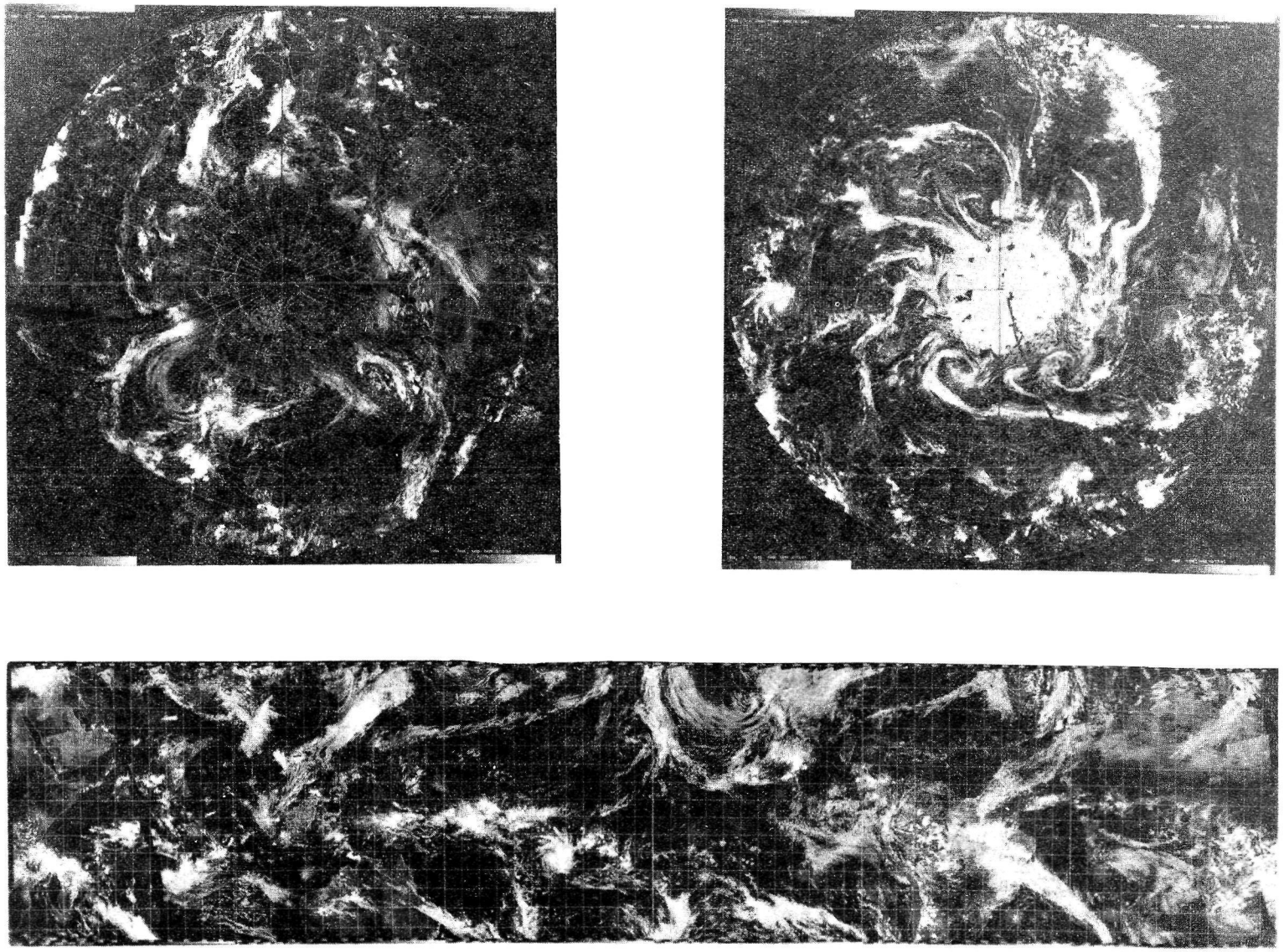

Figure 4. Digitally rectified ESSA 3 AVCS picture data received on December 13, 1967.

147 046

ERRATA: NESCTM-7

Page 12, 13. Figures 5 and 6 are printed upside down. The top of each figure as printed should be facing the bottom of the page.

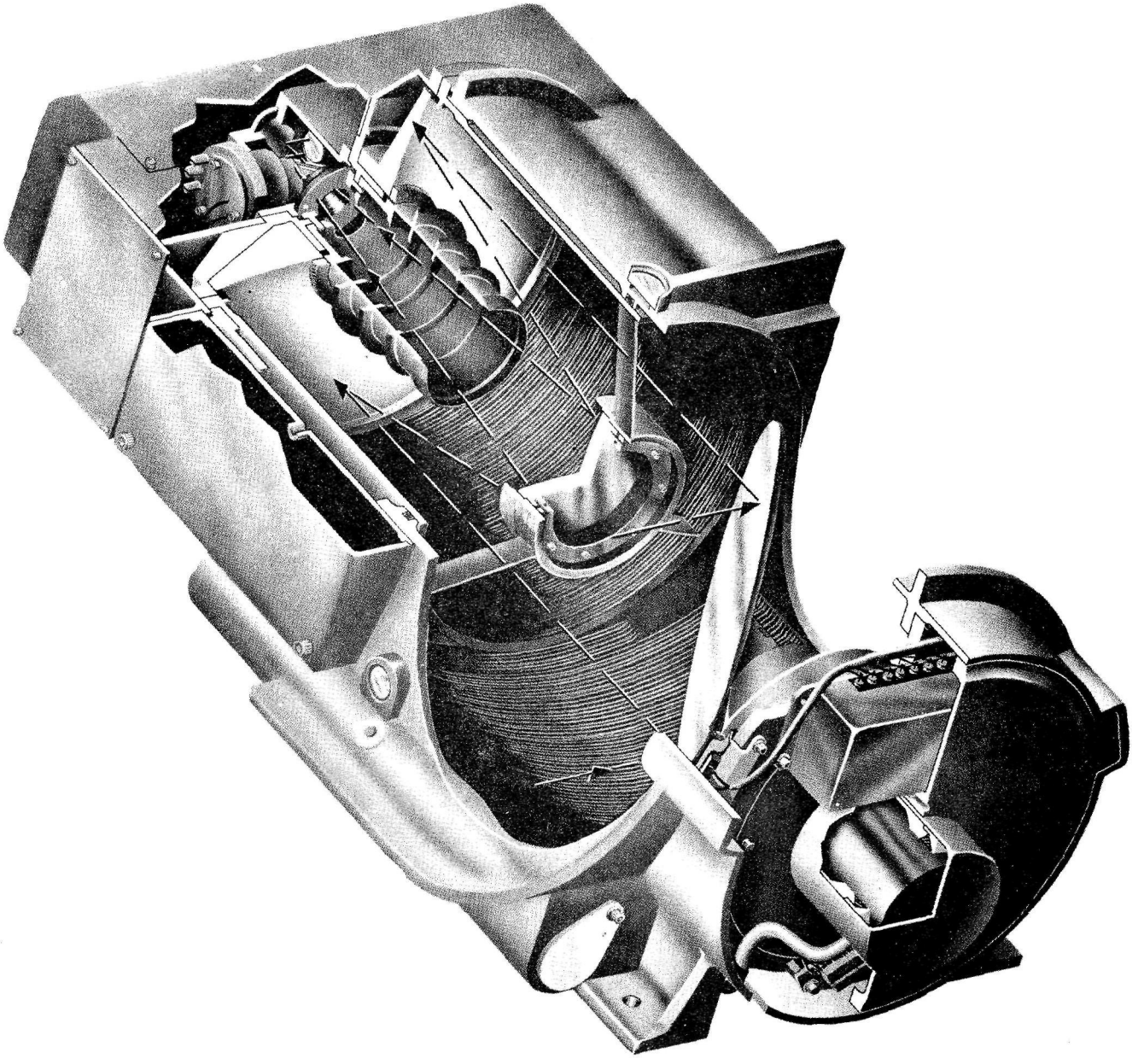

Figure 5. Cutaway view of the Scanning Radiometer (SR) showing path of incoming energy through telescope to beam splitter/detector optical assembly at far right. The SR is mounted on the earth-facing side of the ITOS as shown in Figure 2. (Courtesy, Santa Barbara Research Center)

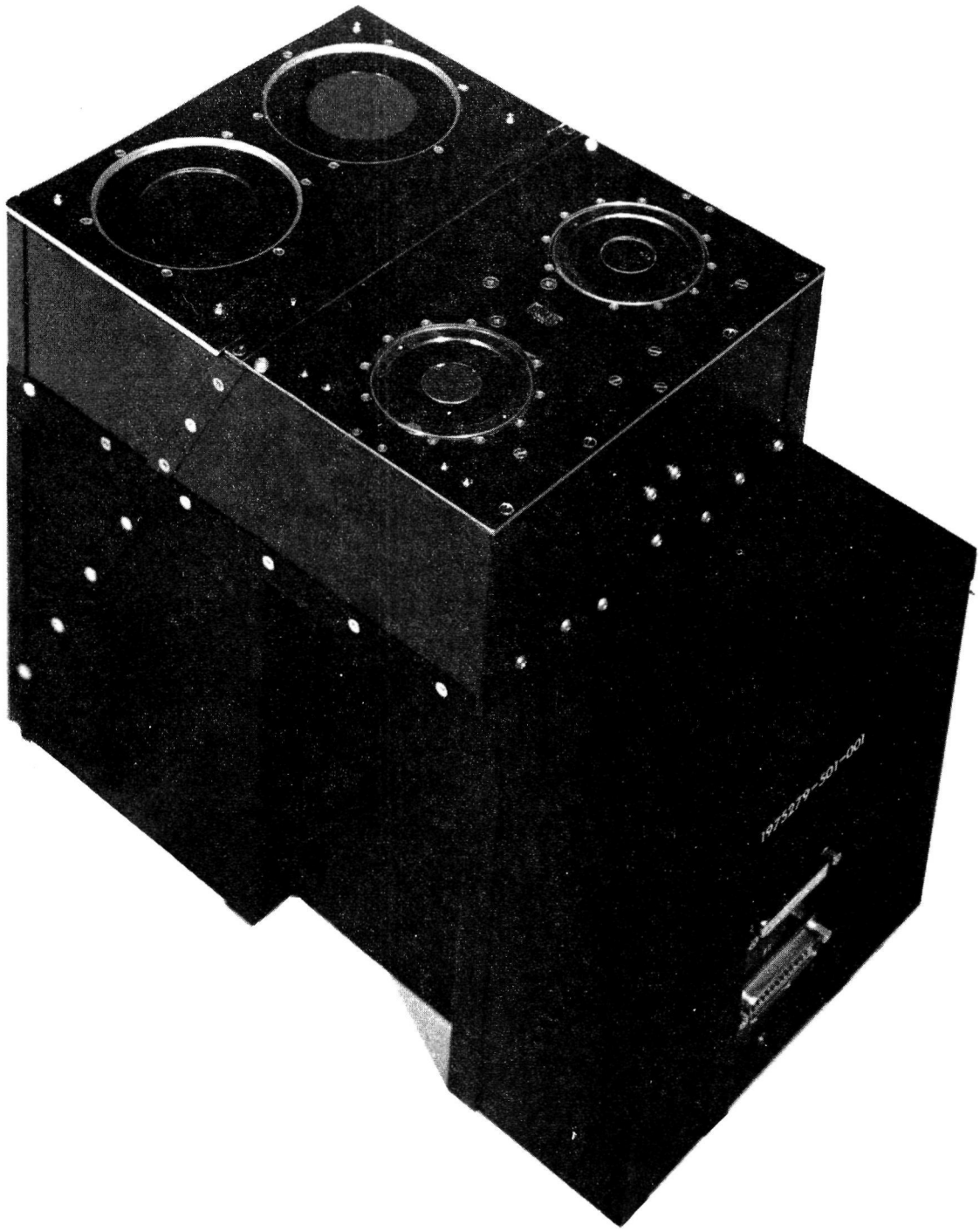

Figure 6. A model of the Flat Plate Radiometer (FPR). The detectors are shown on the earth-facing side of the FPR at the bottom of the figure. The FPR is mounted on the earth-facing side of the ITOS as shown in Figure 2. (Courtesy, Space Science and Engineering Center, University of Wisconsin)

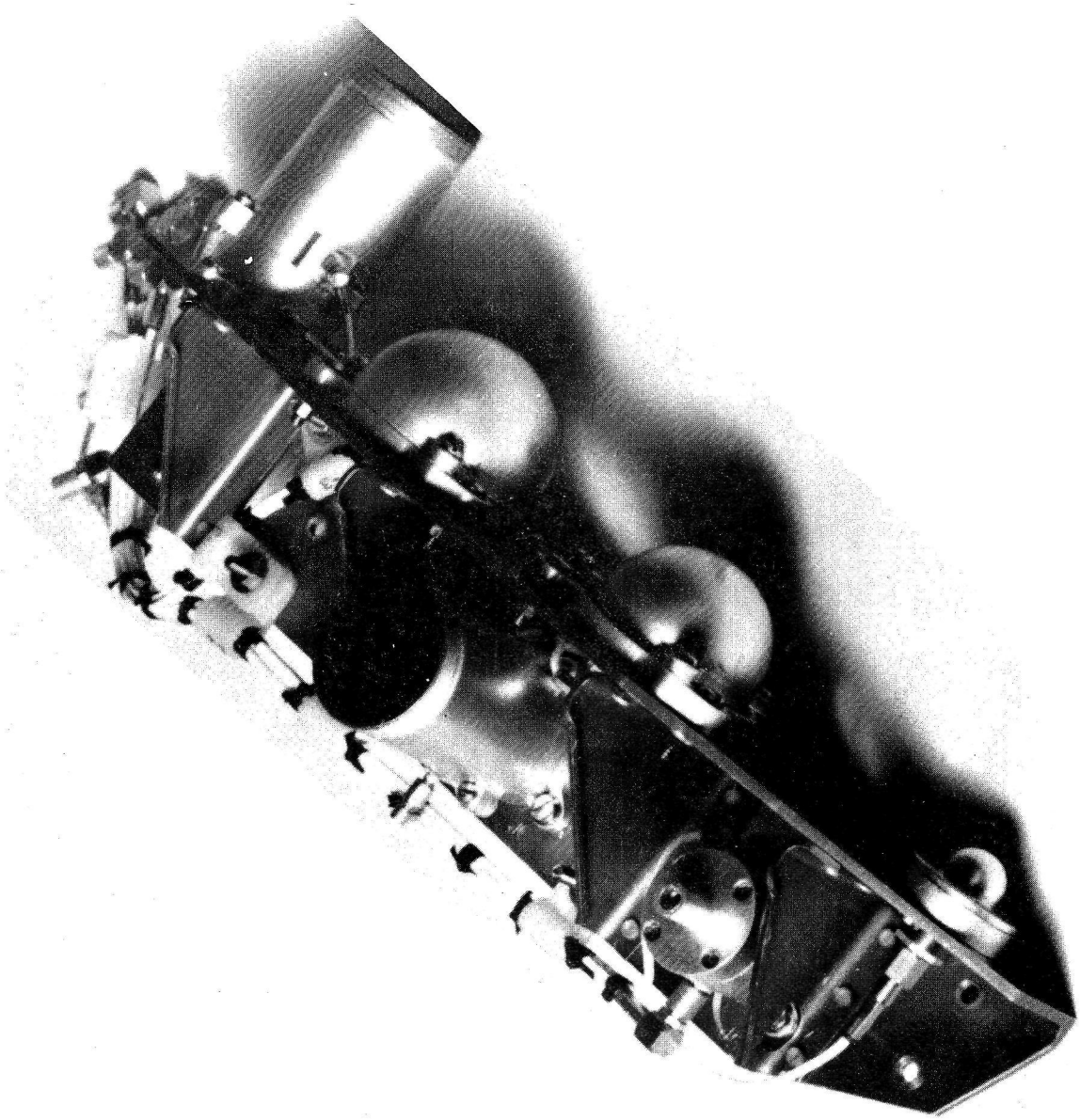

Figure 7. A flight model Solar Proton Monitor. A 40° field-of-view detector, sensitive between 1 and 10 Mev, and three hemispheric field-of-view detectors having threshold sensitivities of 60 Mev, 30 Mev, and 10 Mev are mounted on the anti-earth side shown at the upper right. Another 40° field-of-view detector and a 13° field-of-view detector intended primarily for electron detection are mounted on the anti-sun side shown facing out at the lower left. (Courtesy, Applied Physics Laboratory, Johns Hopkins University)

APPENDIX

ITOS FACT SHEET

Total Spacecraft Weight: 675 pounds

Weight of Sensors: 220 pounds (includes tape recorders and data switching functions)

Spacecraft Body Size: 40 inches by 40 inches by 49 inches

Solar Panel Size: 65 inches by 36 inches (3 panels per spacecraft)

Maximum Power Produced by Solar Array: 400 watts

Power Used by Equipment in Full Operation: 60 watts

Lifetime: 6 months minimum, 1 year goal for engineering design

Primary Sensor Parameters:

	AVCS	APT	SR IR	SR Visible
focal length (inches)	0.22	0.22	16.9	16.9
effective f/number	8	5.6	0.28	3.38
shutter open (milli-sec)	16.7	25	----	----
spectral range (microns)	.5-.7	0.5-0.7	10.5-12.5	0.52-0.73
lines per sec.	133	4	0.8	0.8
information bandwidth (kHz)	60	1.680	0.455	0.9
resolution (see text)				

Possible Modes of Operation:

DAY

Day Direct Readout	Day Global Storage
APT only	AVCS only
APT with strips of SR IR	SR only (both visible and IR)*
APT with strips of SR visible	AVCS plus both SR channels
SR IR only	none
SR visible only	
none	

NIGHT

Night Direct Readout	Night Global Storage
SR IR	SR IR
none	none*

*There is a free choice of mode within any one of the four categories (day/night, direct/global) with one exception. If SR is to be recorded for global storage during day it must also be recorded at night.

APPENDIX

Space to Ground Communications:

1. From S Band Antenna to CDA Stations: A right-hand circularly polarized 1695 MHz carrier is frequency modulated by multiplexed signals (nominal effective radiated power ((ERP)) 34 dbm, worst case ERP 30.2 dbm).

Data (from Tape Recorders)	Multiplexer Frequency Band (kHz)
AVCS flutter and wow	12.5 ± 1.5
AVCS video	25 to 150
SR-A* flutter and wow	200 ± 1.5
SR-A* video	230 to 280
Pilot (crystal controlled)	300 ± 0.1
SR-B* video	320 to 370
SR-B* flutter and wow	400 ± 1.5
FPR and telemetry digital data	444 ± 4
Digital bit reference signal	460 ± 4
SPM digital data	476 ± 4

*Two SR data channels are recoverable at one time. If a single tape recorder is played back, both visible and IR channel data are transmitted and only one flutter and wow signal is present. If both tape recorders are played back simultaneously, only the IR channel data from each and the flutter and wow signal from each are present.

2. From Direct Readout Antenna to APT Stations: A linearly polarized wave with center frequency of 137.5 MHz is frequency modulated to 9 kHz peak deviation by a 2.4 kHz subcarrier which is amplitude modulated by video (worst case ERP 31.7 dbm).

Video Amplitude	APT and SR Visible Data	SR IR Data
2.8 v	White	Hot (330°K)
0.1 v	Black	Cold (185°K)

3. From Beacon Antenna to CDA Stations and Other Tracking Stations: A linearly polarized wave with center frequency of 136.77 MHz is phase modulated by 2.3 kHz and 3.9 kHz subcarriers simultaneously (worst case operational mode ERP 10 dbm).

A variety of data is transmitted to CDA stations via this link. Away from CDA stations the transmitter is normally on and SPM digital data in return-to-bias form modulates the 2.3 kHz subcarrier while "differentiated" analog signals from a 150 rpm (nominal) horizon detector modulate the 3.9 kHz subcarrier.