NOAA Technical Memorandum NESS 107

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

DATA EXTRACTION AND CALIBRATION OF TIROS-N/NOAA RADIOMETERS

Washington, D.C.
November 1979

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Environmental Satellite Service

NOAA TECHNICAL MEMORANDUMS

National Environmental Satellite Service Series

The National Environmental Satellite Service (NESS) is responsible for the establishment and operation of NOAA's environmental satellite systems.

NOAA Technical Memorandums facilitate rapid distribution of material that may be preliminary in nature and so may be published formally elsewhere at a later date. Publications 1 to 20 and 22 to 25 are in the earlier ESSA National Environmental Satellite Center Technical Memorandum (NESCTM) series. The current NOAA Technical Memorandum NESS series includes 21, 26, and subsequent issuances.

Publications listed below are available (also in microfiche form) from the National Technical Information Service, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, VA 22161. Prices on request. Order by accession number (given in parentheses). Information on memorandums not listed below can be obtained from Environmental Data and Information Service (D822), 6009 Executive Boulevard, Rockville, MD 20852.

NESS 66 A Summary of the Radiometric Technology Model of the Ocean Surface in the Microwave Region. John C. Alishouse, March 1975, 24 pp. (COM-75-10849/AS)

NESS 67 Data Collection System Geostationary Operational Environmental Satellite: Preliminary Report. Merle L. Nelson, March 1975, 48 pp. (COM-75-10679/AS)

NESS 68 Atlantic Tropical Cyclone Classifications for 1974. Donald C. Gaby, Donald R. Cochran, James B. Lushine, Samuel C. Pearce, Arthur C. Pike, and Kenneth O. Poteat, April 1975, 6 pp. (COM-75-10676/AS)

NESS 69 Publications and Final Reports on Contracts and Grants, NESS-1974. April 1975, 7 pp. (COM-75-10850/AS)

NESS 70 Dependence of VTPR Transmittance Profiles and Observed Radiances on Spectral Line Shape Parameters. Charles Braun, July 1975, 17 pp. (COM-75-11234/AS)

NESS 71 Nimbus-5 Sounder Data Processing System, Part II: Results. W. L. Smith, H. M. Woolf, C. M. Hayden, and W. C. Shen, July 1975, 102 pp. (COM-75-11334/AS)

NESS 72 Radiation Budget Data From the Meteorological Satellites, ITOS 1 and NOAA 1. Donald H. Flanders and William L. Smith, August 1975, 20 pp. (PB-246-877/AS)

NESS 73 Operational Processing of Solar Proton Monitor Data (Revision of NOAA TM NESS 49). Stanley R. Brown, September 1975, 15 pp. (COM-73-11647)

NESS 74 Monthly Winter Snowline Variation in the Northern Hemisphere From Satellite Records, 1966-75. Donald R. Wiesnet and Michael Matson, November 1975, 21 pp. (PB-248-437/6ST)

NESS 75 Atlantic Tropical and Subtropical Cyclone Classifications for 1975. D. C. Gaby, J. B. Lushine, B. M. Mayfield, S. C. Pearce, and K.O. Poteat, March 1976, 14 pp. (PB-253-968/AS)

NESS 76 The Use of the Radiosonde in Deriving Temperature Soundings From the Nimbus and NOAA Satellite Data. Christopher M. Hayden, April 1976, 19 pp. (PB-256-755/AS)

NESS 77 Algorithm for Correcting the VHRR Imagery for Geometric Distortions Due to the Earth Curvature, Earth Rotation, and Spacecraft Roll Attitude Errors. Richard Legeckis and John Pritchard, April 1976, 31 pp. (PB-258-027/AS)

NESS 78 Satellite Derived Sea-Surface Temperatures From NOAA Spacecraft. Robert L. Brower, Hilda S. Gohrband, William G. Pichel, T. L. Signore, and Charles C. Walton, June 1976, 74 pp. (PB-258-026/AS)

NESS 79 Publications and Final Reports on Contracts and Grants, NESS-1975. National Environmental Satellite Service, June 1976, 10 pp. (PB-258-450/AS)

NESS 80 Satellite Images of Lake Erie Ice: January-March 1975. Michael C. McMillan and David Forsyth, June 1976, 15 pp. (PB-258-458/AS)

NESS 81 Estimation of Daily Precipitation Over China and the USSR Using Satellite Imagery. Walton A. Follansbee, September 1976, 30 pp. (PB-261-970/AS)

NESS 82 The GOES Data Collection System Platform Address Code. Wilfred E. Mazur, Jr., October 1976, 26 pp. (PB-261-968/AS)

(Continued on inside back cover)

NOAA Technical Memorandum NESS 107

DATA EXTRACTION AND CALIBRATION OF TIROS-N/NOAA RADIOMETERS

Levin Lauritson
Gary J. Nelson
Frank W. Porto

Washington, D.C.
November 1979

UNITED STATES
DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator

National Environmental
Satellite Service
David S. Johnson, Director

CONTENTS

TABLES

FIGURES

GLOSSARY

ADC	-	analog-to-digital converter
AM	-	amplitude modulated
APT	-	Automatic picture transmission
ARGOS	-	French abbreviation for their data collection and location system (Service ARGOS)
AVHRR	-	Advanced very high resolution radiometer
bps	-	bits per second
CAL	-	calibration
CDA	-	command and data acquisition
ch	-	channel
cm	-	centimeter
Cmd.	-	command
CNES	-	Centre National D'Etudes Spatiales
CPU	-	central processing unit
CV	-	command verification
DAC	-	digital-to-analog converter
dB	-	decibel
dBm	-	decibels above (or below) one milliwatt
DCS/DCLS	-	Data collection and location system
DIG	-	digital
DSB	-	Direct sounder broadcast
EIRP	-	effective isotropic radiated power
FM	-	frequency modulation
fps	-	frames per second
GHz	-	gigahertz
GMT	-	Greenwich mean time
GOES	-	Geostationary Operational Environmental Satellite
HEPAD	-	High energy proton and alpha detector
HIRS/2	-	High resolution infrared radiation sounder, mod. 2
HRPT	-	High resolution picture transmission
Hz	-	hertz
ICT	-	Internal cold target/internal calibration target
ID	-	identification
IFOV	-	Instantaneous field of view
IR	-	infrared
ITOS	-	Improved TIROS operational system
IWT	-	Internal warm target
K	-	Kelvin temperature
kbps	-	kilobits per second
kHz	-	kilohertz
km	-	kilometer
LSB	-	Least significant bit
m	-	meter
MAX	-	maximum
mbar	-	millibar
Mbps	-	megabits per second
MHz	-	megahertz
MEPED	-	Medium energy proton and electron detector
MI	-	modulation index

GLOSSARY (CONTINUED)

MIN	- minimum
μm	- micrometer
MIRP	- Manipulated information rate processor
MSB	- Most significant bit
msec	- millisecond
MSU	- Microwave sounding unit
mV	- millivolt
mW	- milliwatt
NESS	- National Environmental Satellite Service
NEΔN	- Noise equivalent radiance difference
NEΔT	- Noise equivalent temperature difference
No.	- number
NOAA	- National Oceanic and Atmospheric Administration
PMC	- Pressure modulated cell
pps	- pulses per second
PRT	- Platinum resistance thermometer
PT	- point
REF	- Reference
S/C	- spacecraft
SEC,sec	- second
SEM	- Space environment monitor
S/N	- Signal-to-noise ratio
SOCC	- Spacecraft Operations Control Center
SPM	- Solar proton monitor
sr	- steradian
SSU	- Stratospheric sounding unit
SUBCOM	- subcommutation
SYNC	- synchronous
TED	- Total energy detector
TEMP.	- temperature
Tgt.	- target
THERM.	- thermal
TIP	- TIROS information processor
TIROS	- Television Infrared Observational Satellite
TLM	- telemetry
TOVS	- TIROS operational vertical sounder
Vdc	- volts, direct current
VHF	- very high frequency
XSU	- cross-strap unit

DATA EXTRACTION AND CALIBRATION OF TIROS-N/NOAA RADIOMETERS

Levin Lauritson, Gary J. Nelson
and Frank W. Porto

National Environmental Satellite Service,
NOAA
Washington, D. C.

ABSTRACT. The TIROS-N/NOAA series is the third generation of environmental satellites providing real-time data to direct readout users. This publication has been prepared for the direct readout user of the Automatic Picture Transmission (APT) service, the High Resolution Picture Transmission (HRPT) service and the Direct Sounder Broadcast (DSB) service transmitted from these satellites. Information is presented that will enable users to extract from the telemetry streams data that are unique to a given sensor, to calibrate these data, and to develop an understanding of the accuracy and precision that can be expected of the calibrated data.

1. INTRODUCTION

This publication has been prepared for the user of the direct readout of the Automatic Picture Transmission (APT) service of the High Resolution Picture Transmission (HRPT) service, or of the Direct Sounder Broadcast (DSB) service from the TIROS-N/NOAA series spacecraft. It is intended to provide the information necessary to extract data from the telemetry streams that are unique to a given sensor, to calibrate these data, and to develop an understanding of the accuracy and precision that can be expected of the calibrated data.

Information is provided that will enable users with varying degrees of hardware capability and interest to realize the maximum utility from their particular systems. For example, an APT user may be interested in only the service that provides low resolution image products. On the other hand, a station that is equipped to read out, decommutate, and process HRPT data may wish to develop and produce quantitative products. In either case, the information will enable the user to realize the maximum capability from his system.

Much of the material contained in this document describing the TIROS-N/NOAA instruments, data frame formats, downlink characteristics, etc., has been published before. Schwalb (1978) describes the TIROS-N/NOAA A-G satellite series in detail in NOAA Technical Memorandum, NESS-95. Schneider (1976) describes TIROS-N ground receiving stations. This publication is an attempt to bring together, under one cover, the informational content of much of that material.

2. INSTRUMENTS

2.1 Advanced Very High Resolution Radiometer (AVHRR)

The AVHRR provides data for transmission to both APT and HRPT users. HRPT data are transmitted at full resolution (1.1 km); the APT resolution is reduced to maintain allowable bandwidth. The AVHRR for TIROS-N is a scanning radiometer, sensitive in four spectral regions; a fifth channel will be added on later satellites in this series. Deployment of four- and five-channel instruments is as follows: four-channel instruments are planned for TIROS-N, NOAA-A, NOAA-B, NOAA-C and NOAA-E; five-channel instruments for NOAA-D, NOAA-F, and NOAA-G.

The APT system transmits data from any two of the AVHRR channels selected by command from the National Environmental Satellite Service (NESS) Spacecraft Operations Control Center (SOCC). The HRPT system transmits data from all AVHRR channels. To avoid future changes on the spacecraft and in the ground receiving equipment, the TIROS-N/NOAA series HRPT data format has been designed to handle five AVHRR channels from the outset.

When operating with a four-channel instrument, the data from the 11-micrometer (μm) channel are inserted in the data stream twice so that the basic HRPT data format is the same for both the four- and five-channel versions.

Table 2-1 lists the spectral characteristics of the four- and five-channel instruments and designates the spacecraft on which they are planned to be deployed.

Table 2-2 is a listing of the basic AVHRR parameters.

2.2. TIROS Operational Vertical Sounder (TOVS)

The TOVS provides data for transmission to both HRPT and DSB receiving stations. The data are transmitted in digital format at full instrument resolution and accuracy.

The TOVS consists of three independent instrument subsystems from which data may be combined for computation of vertical atmospheric temperature and humidity profiles. These are:

a. High resolution infrared radiation sounder mod. 2

b. Stratospheric sounding unit

c. Microwave sounding unit

Table 2-1. Spectral characteristics of the TIROS-N/NOAA AVHRR instruments

Ch 1	Ch 2	Ch 3	Ch 4	Ch 5
Four-channel AVHRR, TIROS-N				
Ch 1 0.55-0.9 µm	Ch 2 0.725-1.1 µm	Ch 3 3.55-3.93 µm	Ch 4 10.5-11.5 µm	Ch 5 Data from Ch 4 repeated
Four-channel AVHRR - NOAA-A, -B, -C, and -E				
Ch 1 0.58-0.68 µm	Ch 2 0.725-1.1 µm	Ch 3 3.55-3.93 µm	Ch 4 10.5-11.5 µm	Ch 5 Data from Ch 4 repeated
Five-channel AVHRR, NOAA-D, -F, and -G				
Ch 1 0.58-0.68 µm	Ch 2 0.725-1.1 µm	Ch 3 3.55-3.93 µm	Ch 4 10.3-11.3 µm	Ch 5 11.5-12.5 µm

Note: Changes to the above deployment scheme may occur as a result of instrument availability or changing requirements.

Table 2-2. AVHRR instrument parameters

Parameter	Value
Calibration	Stable blackbody and space for IR channels. No inflight visible channel calibration other than space.
Cross track scan	±55.4° from nadir
Line rate	360 lines per minute
Optical field of view	1.3 milliradians
Ground resolution (IFOV)(1	1.1 km @ nadir
Infrared channel NEΔT(2	<0.12 K at 300 K
Visible channel S/N(3	3:1 @ 0.5% albedo

1) Instantaneous field of view
2) NEΔT - Noise equivalent differential temperature
3) Signal-to-noise ratio

2.2.1 High Resolution Infrared Radiation Sounder (HIRS/2)

The HIRS/2 is an adaptation of the HIRS/1 instrument flown on the Nimbus-6 satellite. The instrument, built by the Aerospace/ Optical Division of the International Telephone and Telegraph Corporation, Fort Wayne, Indiana, measures incident radiation in 19 regions of the IR spectrum and one region of the visible spectrum.

Table 2-3 is a listing of the HIRS/2 parameters.

Table 2-3. HIRS/2 instrument parameters

Parameter	Value
Calibration	Stable blackbodies (2) and space background
Cross-track scan	±49.5° (±1125 km) @ nadir
Scan time	6.4 seconds per line
Number of steps	56
Optical field of view	1.25°
Step angle	1.8°
Step time	100 milliseconds
Ground resolution (IFOV)* (nadir)	17.4 km diameter
Ground resolution (IFOV) (end of scan)	58.5 km cross-track by 29.9 km along track
Distance between IFOV's	42 km along-track @ nadir
Data rate	2880 bits/second

*Instantaneous field of view.

Table 2-4 is a listing of the HIRS/2 spectral characteristics and noise equivalent differential radiance (NEΔN's). Note: There will be some variation in the achieved parameters from one HIRS/2 instrument to another, particularly in the NEΔN's.

2.2.2 The Stratospheric Sounding Unit (SSU)

The SSU, which has been provided by the United Kingdom, employs a selective absorption technique to make measurements in three channels. The spectral characteristics of each channel are determined by the pressure in a carbon dioxide gas cell in the optical path. The pressure of carbon dioxide in the cells determines the height of the weighting function peaks in the atmosphere. SSU characteristics are shown in tables 2-5 and 2-6.

Table 2-4. HIRS/2 spectral characteristics

Channel	Channel frequency (cm^{-1})	μm	Half power bandwidth (cm^{-1})	Maximum scene temperature (K)	Specified NEΔN FM 3-7
1	669	14.95	3	280	3.00
2	680	14.71	10	265	0.67
3	690	14.49	12	240	0.50
4	703	14.22	16	250	0.31
5	716	13.97	16	265	0.21
6	733	13.64	16	280	0.24
7	749	13.35	16	290	0.20
8	900	11.11	35	330	0.10
9	1,030	9.71	25	270	0.15
10	1,225	8.16	60	290	0.16
11	1,365	7.33	40	275	0.20
12	1,488	6.72	80	260	0.19
13	2,190	4.57	23	300	0.006
14	2,210	4.52	23	290	0.003
15	2,240	4.46	23	280	0.004
16	2,270	4.40	23	260	0.002
17	2,360	4.24	23	280	0.002
18	2,515	4.00	35	340	0.002
19	2,660	3.76	100	340	0.001
20	14,500	0.69	1000	100% A	0.10% A

NEΔN in mW/(sr m^2 cm^{-1})

Table 2-5. SSU channel characteristics

Channel number	Central wave no. (cm^{-1})	Cell pressure (mb)	Pressure of weighting function peak (mbar)	NEΔT mW/(sr m^2 cm^{-1})
1	668	100	15	0.35
2	668	35	5	0.70
3	668	10	1.5	1.75

Table 2-6. SSU instrument parameters

Parameter	Value
Calibration	Stable blackbody and space background
Cross-track scan	±40° (±737 km)
Scan time	32 seconds
Number of steps	8
Step angle	10°
Step time	4 seconds
Ground resolution (IFOV) (at nadir)	147 km diameter
Ground resolution (IFOV) (at scan end)	244 km cross-track by 186 along-track
Distance between IFOV's	210 km along-track @ nadir
Data rate	480 bps

2.2.3 The Microwave Sounding Unit (MSU)

The MSU is a four-channel Dicke radiometer making passive measurements in the 5.5-μm oxygen band with characteristics as shown in tables 2-7 and 2-8.

Table 2-7. MSU channel characteristics

Parameter	Value
Channel frequencies	50.3, 53.74, 54.96, 57.95 GHz
Channel bandwidths	200 MHz
NEΔT	0.3 K

Table 2-8. MSU instrument parameters

Parameter	Value
Calibration	Stable blackbody and space background each scan cycle
Cross-track scan angle	±47.35°
Scan time	25.6 seconds
Number of steps	11
Step angle	9.47°
Step time	1.84 seconds
Angular resolution	7.5° (3 dB)
Data rate	320 bps

2.3 Data Collection and Location System (DCLS)

The Data Collection and Location System (DCLS) for the TIROS-N/NOSS series was 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 locating the position of fixed or moving platforms and for obtaining environmental data from them (e.g., temperature, pressure, altitude, etc.). Location information may be computed by differential Doppler techniques using data obtained from the measurement of platform carrier frequency 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. A technical discussion of the DCLS and the processing of its data is not included in this publication. Detailed information concerning the DCLS, 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

2.4 Space Environment Monitor (SEM)

The SEM instrument consists of three independent components designed and built by the Ford Aerospace and Communication Corporation. The instrument measures solar proton, alpha particle, electron flux density, energy spectrum, and the total particulate energy disposition at the altitude of the satellite.

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 augments the measurements being made by NOAA's Geostationary Operational Environmental Satellite (GOES).

A technical discussion of the SEM and the processing of its data is not included in this publication. Information can be obtained by contacting:

U. S. Department of Commerce
National Oceanic & Atmospheric Administration
Environmental Research Laboratory
Space Environmental Laboratory
Boulder, Colorado 80303

3. REAL-TIME DATA TRANSMISSION SERVICE

As mentioned previously, three separate real-time data services are available from the TIROS-N/NOAA series satellites. The data flow for these services, on board the spacecraft, is shown in figure 3-1; their characteristics are described in table 3-1.

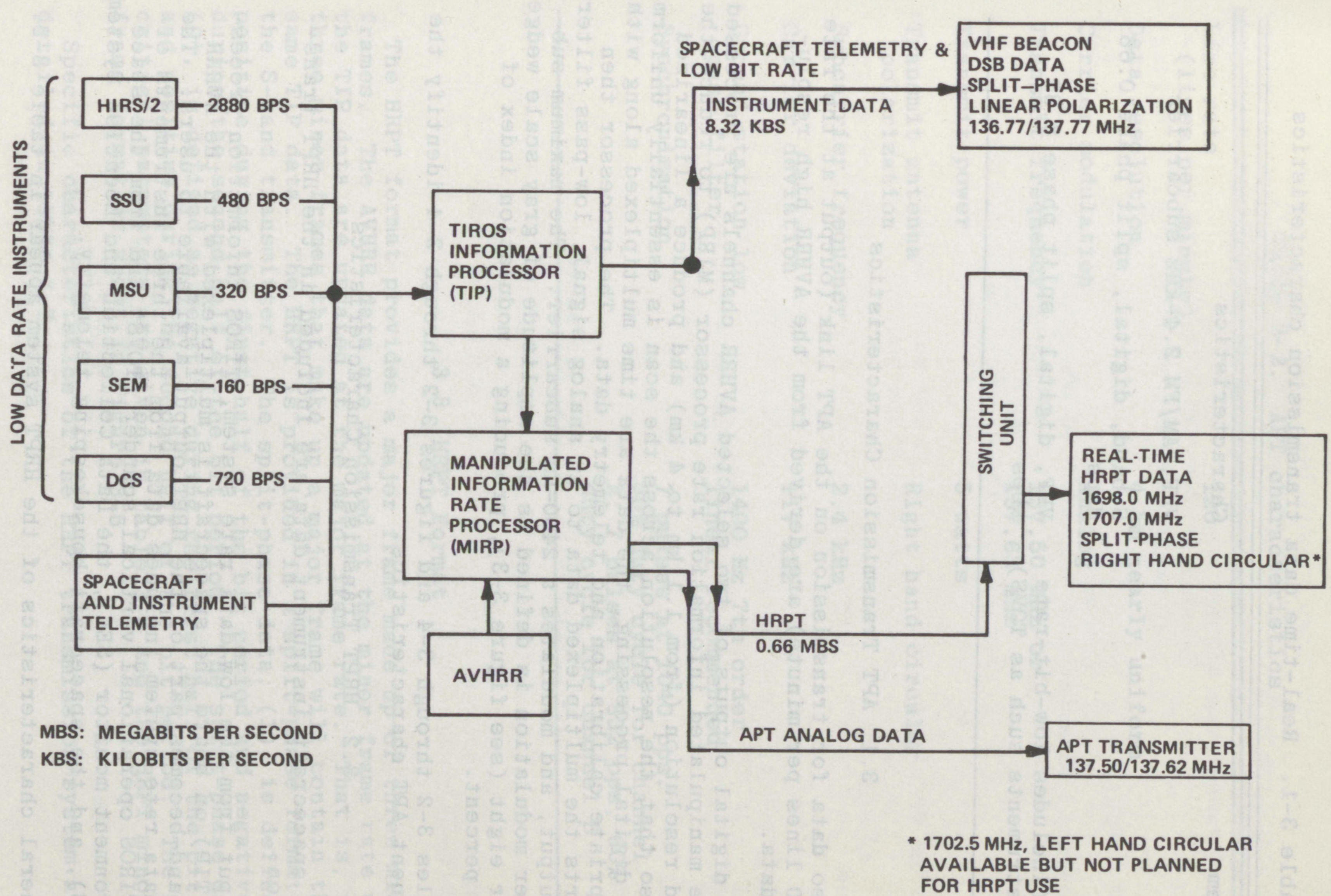


Figure 3-1. TIROS-N/NOAA real-time systems data flow

Table 3-1. Real-time data transmission characteristics

System	Characteristics
APT	VHF, AM/FM 2.4-kHz subcarrier
HRPT	S-band, digital, split phase 0.66 Mbps
DSB (includes low-bit-rate instruments such as TOVS)	VHF, digital, split phase 8.32 kbps

3.1 APT Transmission Characteristics

Video data for transmission on the APT link (output at the rate of 120 lines per minute) are derived from the AVHRR high resolution data.

The digital outputs of two selected AVHRR channels are processed in the manipulated information rate processor (MIRP) to reduce the ground resolution (from 1.1 km to 4 km) and produce a linearized scan so that the resolution across the scan is essentially uniform. After digital processing, the data are time multiplexed along with appropriate calibration and telemetry data. The processor then converts the multiplexed data to an analog signal, low-pass filters the output, and modulates a 2400-Hz subcarrier. The maximum subcarrier modulation is defined as the amplitude of gray scale wedge number eight (see figure 3-3), producing a modulation index of 87 ± 5 percent.

Tables 3-2 through 3-4 and figures 3-2 through 3-4 identify the pertinent APT characteristics.

3.2 HRPT Transmission Characteristics

All spacecraft instrument data are included in the HRPT transmission.

Output from the low data rate system, TIROS information processor (TIP) on board the spacecraft is multiplexed with the AVHRR data and becomes part of the HRPT output available to users. The low data rate system includes data from the three instruments of the TIROS operational vertical sounder (TOVS) and from the space environment monitor (SEM), the Data Collection and Location System (DCLS), and the spacecraft housekeeping telemetry.

General characteristics of the HRPT system appear in table 3-5.

Table 3-2. APT characteristics

Line rate (lines per minute)	120
Data resolution	4 km nearly uniform
Carrier modulation	Analog
Transmit frequency	137.50 MHz or 137.63 MHz
Transmit power	5 watts
Transmit antenna polarization	Right hand circular
Subcarrier frequency	2.4 kHz
Carrier deviation	±17 kHz
Ground station low pass filter	1400 Hz 7th order linear recommended
Synchronization	7 pulses at 1040 pps. 50% duty cycle for channel A; 7 pulses at 832 pps, 60% duty cycle for channel B

3.3 HRPT Format

The HRPT format provides a major frame made up of three minor frames. The AVHRR data are updated at the minor frame rate while the TIP data are updated at the major frame rate. That is, the three minor frames that 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 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 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 3-6 and the HRPT minor frame format is shown in figure 3-5.

Specific characteristics of the HRPT transmission system are detailed in table 3-7.

Table 3-3. 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	33.5 dBm worst case 37.2 dBm nominal
Antenna	
Gain at 63° from nadir	-0.5 dBi, right circular polarization
Ellipticity	4.0 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	$+2 \times 10^{-5}$
Subcarrier modulator	
Subcarrier frequency	2400 ±0.3 Hz
Subcarrier modulation index	87 ±5%
Post modulator filter, type 3-dB bandwidth	3-pole Butterworth 6 kHz, minimum
Premodulator filter, type 3-dB bandwidth	3-pole Butterworth-Thompson 2.4 kHz, minimum

Table 3-4. APT format parameters

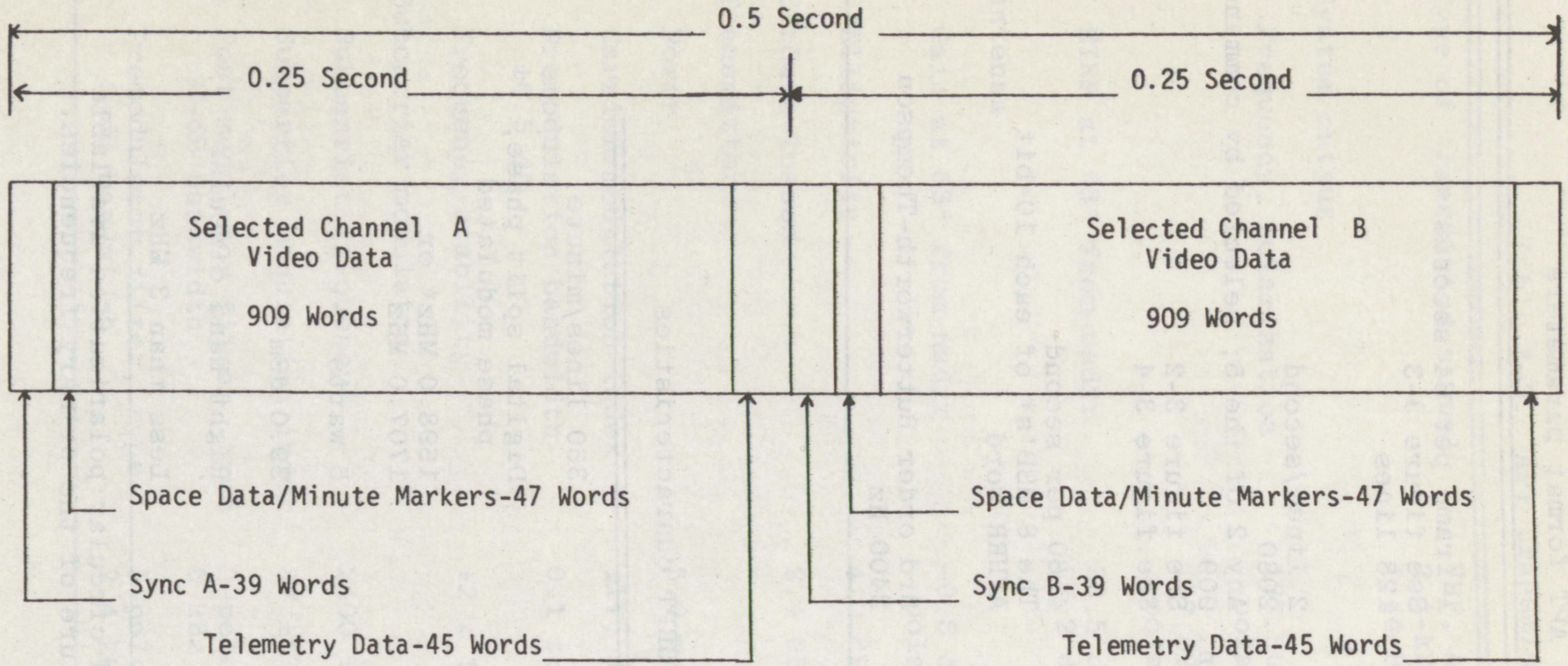
Frame	
Rate	1 frame per 64 seconds
Format	See figure 3-3
Length	128 lines
Line	
Rate	2 lines/second
Number of words	2080
Number of sensor channels	Any 2 of the 5; selected by command
Number of words/sensor chan.	909
Format	See figure 3-2
Line sync format	See figure 3-4
Word	
Rate	4160 per second
Analog-to-digital Conversion accuracy	The 8 MSB's* of each 10-bit AVHRR word
Low-Pass Filter	
Type	3rd order Butterworth-Thompson
3 dB bandwidth	2400 Hz

*Most significant bits (MSB)

Table 3-5. HRPT characteristics

Line rate	360 lines/minute
Carrier modulation	Digital split phase, phase modulated
Transmit frequency	1698.0 MHz* or 1707.0 MHz
Transmit power	5 watts
EIRP (approximate)	39.0 dBm
Polarization	Right hand circular
Spectrum bandwidth	Less than 3 MHz

*1702.5-MHz left hand circular polarization available in the event of failure of the primary frequencies.



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 3-2. APT video line format (prior to D/A converter)

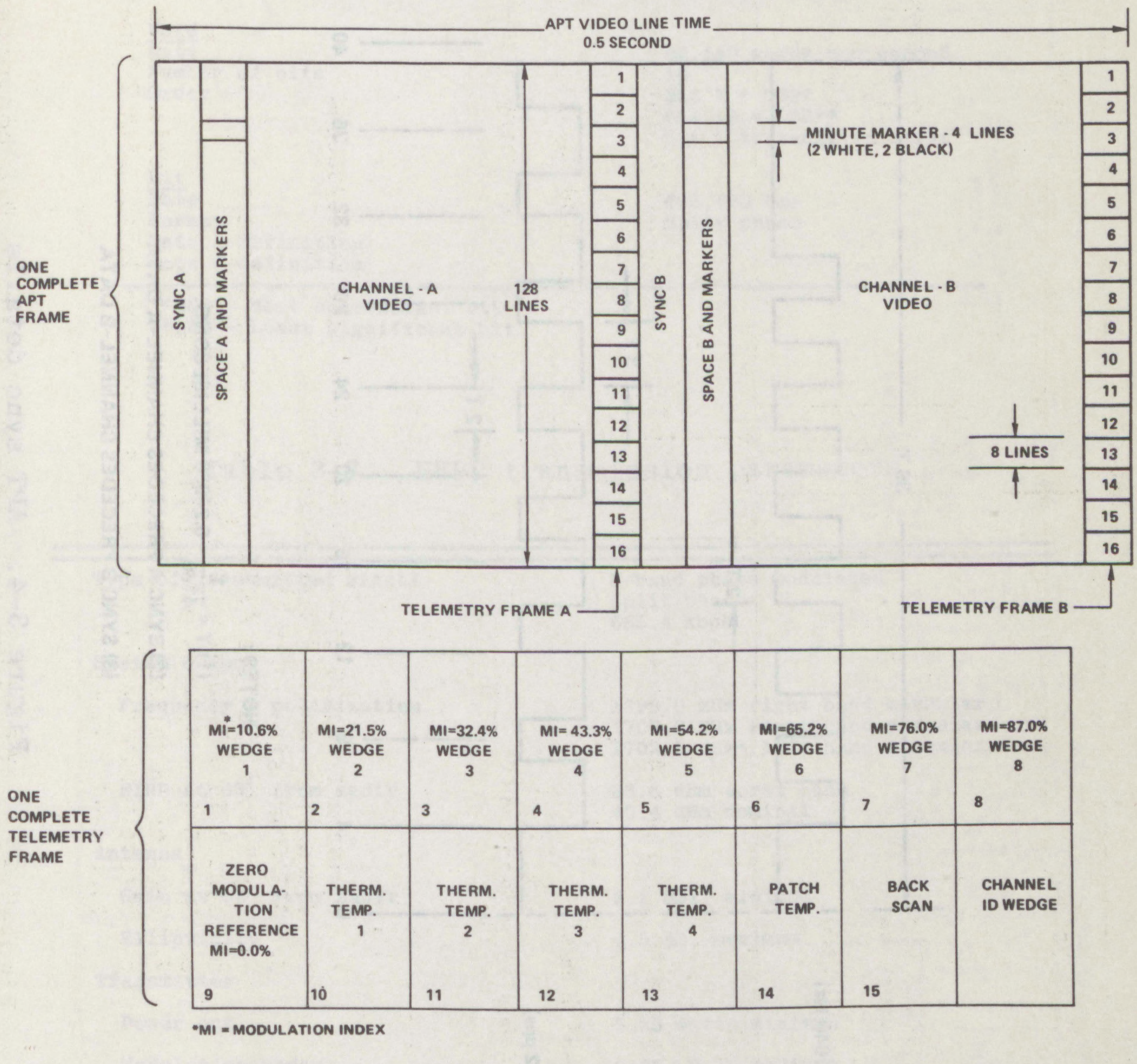
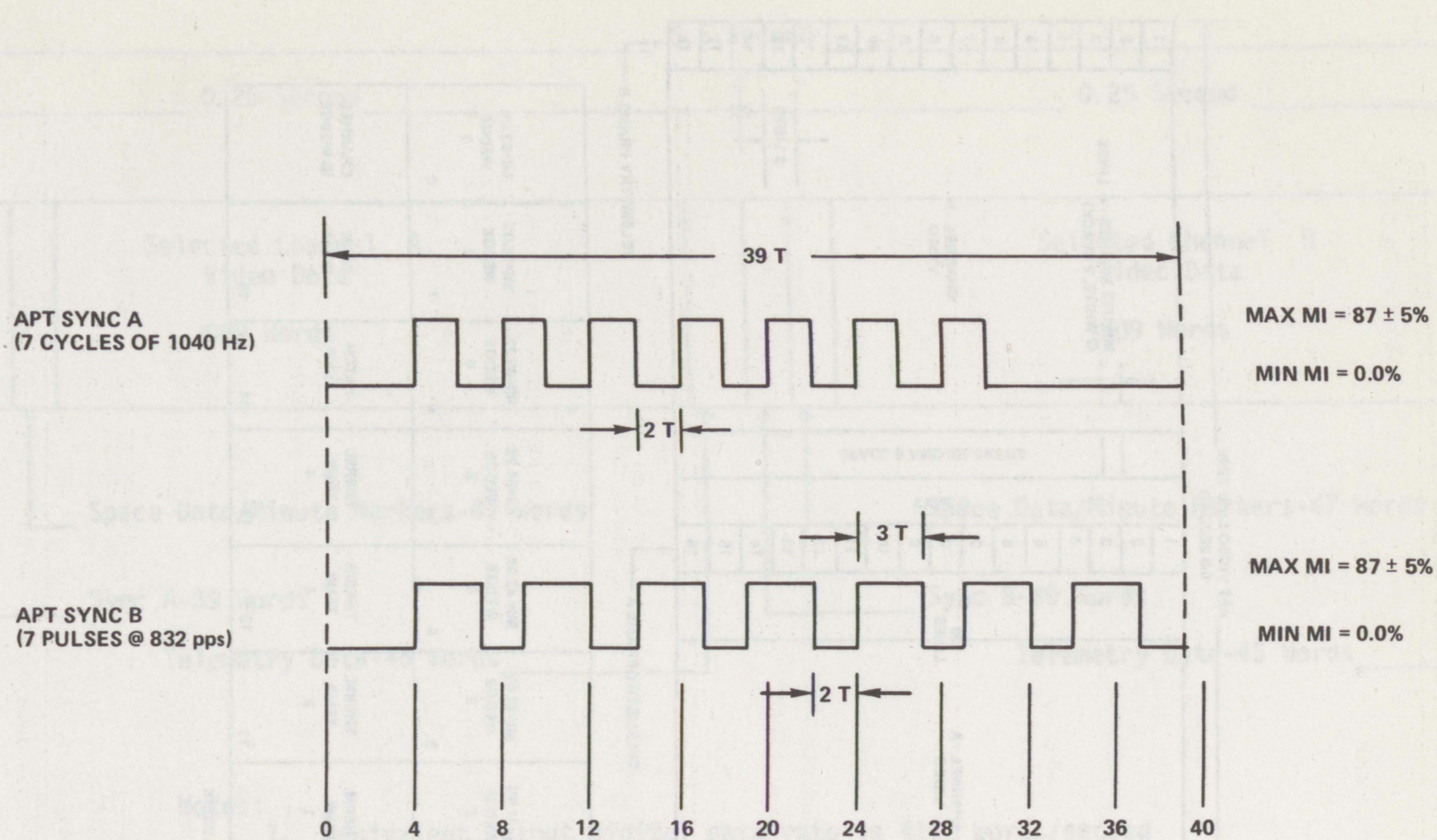


Figure 3-3. APT frame format



NOTES :

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

(2) SYNC A PRECEDES CHANNEL-A DATA

(3) SYNC B PRECEDES CHANNEL-B DATA

Figure 3-4. APT sync details

Table 3-6. HRPT parameters

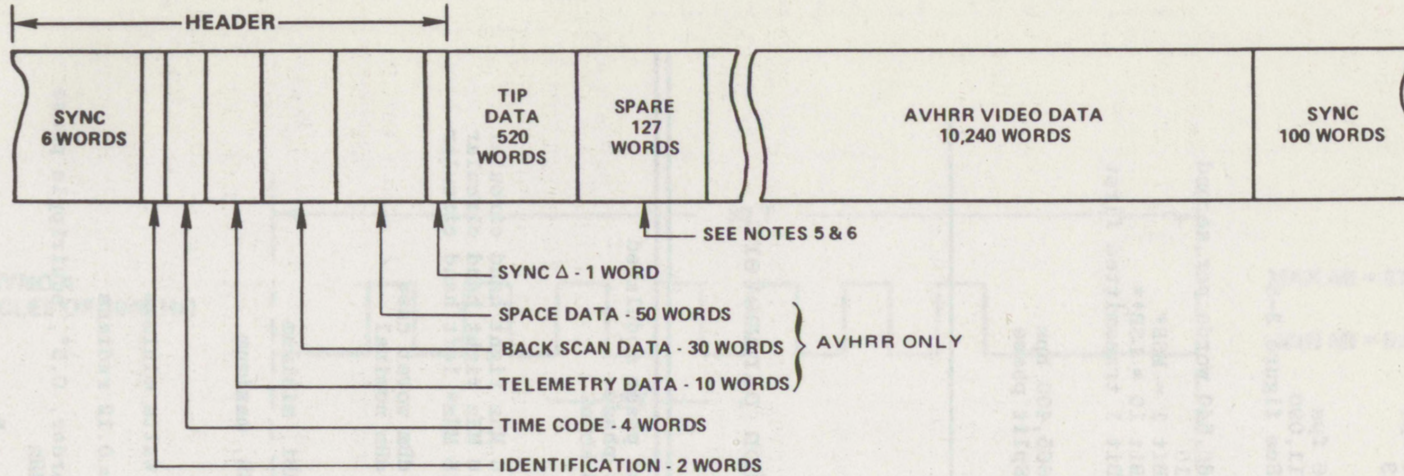
Major Frame	
Rate	2 fps
Number of minor frames	3
Minor Frame	
Rate	6 fps
Number of words	11,090
Format	See figure 3-5
Word	
Rate	66,540 words per second
Number of bits	10
Order	Bit 1 = MSB* Bit 10 = LSB** Bit 1 transmitted first
Bit	
Rate	665,400 bps
Format	Split phase
Data 1 definition	
Data 0 definition	

*MSB - Most significant bit
**LSB - Least significant bit

Table 3-7. HRPT transmission parameters

Type of transmitted signal	S-band phase modulated Split phase 665.4 kbps
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	4.5 dB, maximum
Transmitter	
Power out	5.25 watts minimum
Modulation index	2.35 ± 0.12 radians
Premodulation filter, type 3 dB bandwidth	5th order, 0.5°, 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) ALL SPARES ARE 10TH DEGREE P-N CODE (BAR).

TLM WORD ALLOCATIONS		ID WORD BIT ALLOCATIONS		
		1ST ID WORD		2ND ID WORD
1-5	RAMP CALIBRATION			(SPARE)
6	CHANNEL-3 TARGET TEMP (5 PT SUBCOM)	1	SYNC ID	
		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	10	DATA 1	

Figure 3-5. TIROS-N/NOAA HRPT minor frame format

3.3.1 Detailed Description of HRPT Minor Frame Format

While figure 3-5 shows the identification and relative location of each segment of the HRPT minor frame, a detailed description of each of these segments appears in table 3-8. Bit 1 is defined as the most significant bit (MSB) and bit 10 is defined as the least significant bit (LSB).

3.4 DSB Transmission Characteristics

The TIROS-N/NOAA DSB contains the TIP output. 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 3-9.

The TIP output on the DSB contains a multiplex of analog housekeeping data, digital housekeeping data and low bit rate instrument data. The key parameters of the data format are contained in table 3-10. A detailed description of the TIP frame format is given in section 3.4.

3.5 TIP Data Format

The format of a TIP minor frame is shown in figure 3-6. This figure identifies the relative location of the instrument data within each TIP minor frame. A detailed description of a TIP minor frame is given in table 3-11.

Each TIP minor frame is composed of 104 eight-bit words. Bit 1 is defined as the most significant bit (MSB) and bit 8 is defined as the least significant bit (LSB). This format is retained for the DSB. When the TIP data are multiplexed into the HRPT data stream, two bits are added to each TIP word. This is described under Function, TIP data in table 3-8.

These bits are the two LSB's of each 10-bit word and, once removed, produce a TIP frame identical to that of the DSB TIP.

Each HRPT minor frame contains five unique TIP minor frames. HRPT minor frames 2 and 3 contain TIP data identical to that contained in the first HRPT minor frame. HRPT minor frames 1, 2, and 3 can be identified by examining bits 2 and 3 of data word 7 of the 103 word header, as previously defined in table 3-8. All further discussion of the TIP minor frame format will assume that the TIP data have been eliminated from 2 of the 3 HRPT minor frames and that the 2 extra bits have been removed from each 10-bit word of the remaining TIP data.

Table 3-8. 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	First 60 bits from a 63-bit PN(1) generator started in the all 1's state. The generator polynomial 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 (AVHRR)	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 of msec count
			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 of msec count
	Telemetry (AVHRR)	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 3-8 (continued)

	Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10 Plus Word Code & Meaning
HEADER	Telemetry (cont.) (AVHRR)	10	17	Ramp calibration AVHRR ch 5
			18	AVHRR internal target(2) temperature data: Each of these words is a 5-ch subcom, 4 words of IR data plus a subcom referance value
			19	temperature
			20	data
			21	AVHRR patch temperature
			22	0 0 0 0 0 0 0 0 0 1 spare
	(AVHRR) Internal target data	30	23 → 52	10 words of internal target data from each AVHRR ch 3, 4, and 5. These data are time multiplexed as ch 3 (word 1), ch 4 (word 1), ch 5 (word 1), ch 3 (word 2), ch 4 (word 2), ch 5 (word 2), etc.
	Space data (AVHRR)	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 ch 1 (word 1), ch 2 (word 1), ch 3 (word 1), ch 4 (word 1), ch 5 (word 1), ch 1 (word 2), ch 2 (word 2), ch 3 (word 2), ch 4 (word 2), ch 5 (word 2), etc.
	Sync Δ (AVHRR)	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 3-8 (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 3-8 (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 (AVHRR)	10,240	751	Ch 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	Ch 2 - Sample 1	
		753	Ch 3 - Sample 1	
		754	Ch 4 - Sample 1	
		755	Ch 5 - Sample 1	
		756	Ch 1 - Sample 2	
		↓	↓	
		10,985	Ch 5 - Sample 2047	
		10,986	Ch 1 - Sample 2048	
		10,987	Ch 2 - Sample 2048	
		10,988	Ch 3 - Sample 2048	
		10,989	Ch 4 - Sample 2048	
		10,990	Ch 5 - Sample 2048	
Auxiliary sync	100	10,991	1 1 1 1 1 0 0 0 1 0	Derived from the noninverted 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	

Table 3-9. DSB 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 dBm nominal
Antenna	
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	±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	$+2 \times 10^{-5}$

[1]Observed by an optimum polarization diversity receiver.

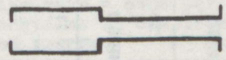
Each TIP minor frame contains information identifying the major and minor frame count. The major frame counter is located in bits 4, 5, and 6 of TIP word 3 and cycles from 0 to 7. The minor frame counter is composed of 9 bits. MSB is bit 8 of word 4, and the LSB is bit 8 of word 5. The minor frame count will cycle between 0 and 319 for each major frame count.

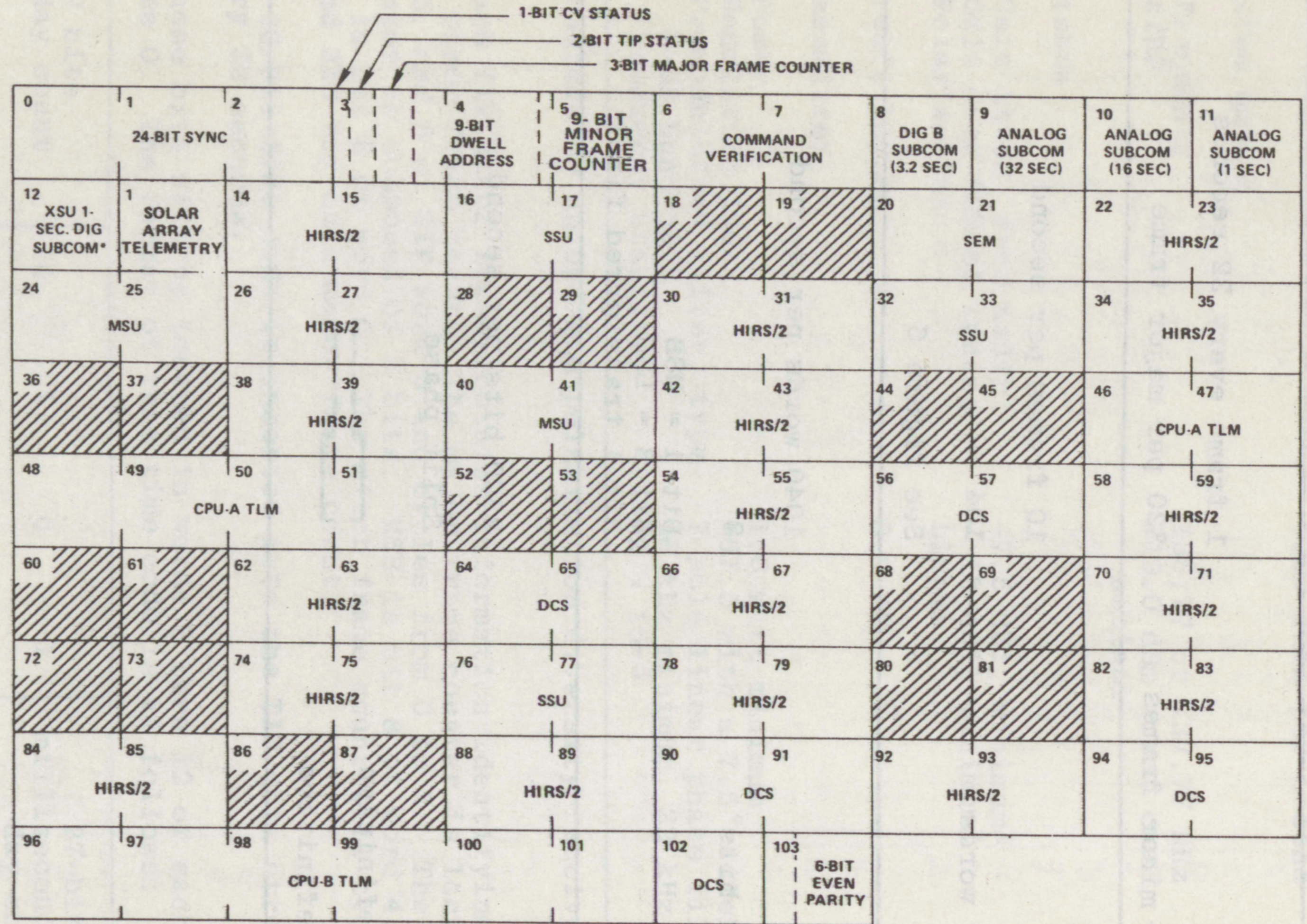
A 40-bit time code is inserted into the TIP data stream once every 32 seconds.

These bits will be located in words 8 thru 12 of each minor frame 0. The format of this time code is as follows:

9 bits day count	0 1 0 1 4 spare bits	27-bit milliseconds of day count

Table 3-10. DSB TIP parameters

Major Frame	
Rate	1 frame every 32 seconds
Number of minor frames	320 per major frame
Minor frame	
Rate	10 frames per second
Number of words	104
Format	See figure 6
Word	
Rate	1040 words per second
Number of bits	8
Order	Bit 1 = MSB Bit 8 = LSB Bit 1 transferred first
Bit	
Rate	8320 bits per second
Format	Split phase
Data 1 definition	
Data 0 definition	



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 3-6. TIP minor frame format

Table 3-11. Detailed description of TIP minor frame

Function (no. of words)	Word position	Word format and function
Frame sync & S/C ID (3)	0 1 2	1 1 1 0 1 1 0 1 The last 4 bits of 1 1 1 0 0 0 1 0 word 2 are used for 0 0 0 0 A A A A spacecraft ID
Status (1-)	3	Bit 1: Cmd. verification (CV status; 1=CV update word present in frame; 0=no CV update in frame. Bits 2 & 3: TIP status; 00=orbital mode 10=CPU memory Dump mode 01=dwell mode 11 boost mode. Bits 4 - 6: Major frame count: MSB first; Counter incremented every 320 minor frames. 000=major frame 0 111=major frame 7
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. MSB is first 0 0 0 0 0 0 0 0 0 = Analog ch 0 1 0 1 1 1 0 1 0 1 = Analog ch 383
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.
Time code (5)	8,9 9 9,10,11,12	9 bits of binary day count, MSB first bits 2-5: 0 1 0 1, spare bits 27 bits of binary msec 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.
3.2 - Sec. 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*
16-sec analog (1)	10	These two subcoms are under Programmed. Read Only Memory control. A maximum of 128 analog points can be placed in the 169 slots; super
1-sec analog subcom (1)	11	commutation of some selected analog channels is done 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.

*mv: millivolts

Table 3-11 (continued)

Function (no. of words)	Word position	Word format and function
XSU 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...
Satellite data subcom (1)	13	Solar array telemetry
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 HIRS/2 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.
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 (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
Parity (1-)	103	Bit 3: Even parity check on words 2 through 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

The day-counter has the capability of updating through day 511 before being automatically reset. In practice, however, NESS manually resets the day counter to 1 on Jan. 1 at 0000 GMT.

4. CREATION OF INSTRUMENT DATA BASES

The information necessary for the location of specific instrument data, its extraction from the DSB or HRPT, its arrangement according to instrument scanning geometry, and the identification of calibration and Earth view data is provided in this section for the TOVS and AVHRR only.

4.1 HIRS/2

Each TIP minor frame contains 288 bits of HIRS/2 radiometric and telemetry data (36 TIP words). This information is contained in TIP words 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, and 93 (see figure 3-6).

The HIRS data contained in each TIP minor frame are defined as an element. The identification and location of the data for each element is shown in table 4-1. A HIRS line is composed of 64 (0-63) successive elements and the extraction of HIRS data for the creation of a line should begin on minor frames 1, 65, 129, 193, or 257 of each major frame.

Bits 27-286 of elements 0-62 contain 20 thirteen-bit data words. Each word is composed of 12 bits of data and 1 sign bit. The sign bit is the MSB and when set to 0 indicates that the value of the 12 bits of data is negative.

Twenty words of data from elements 0-55 contain the digitized radiometric signal outputs of all 20 channels, for a single scan mirror dwell position (one IFOV). The radiometric channel number, with respect to word location, is shown in table 4-2. The 20 words of data in elements 56-62 contain housekeeping and ancillary instrument data. Elements 58 and 59 contain thermistor data necessary for determining internal cold and warm target temperatures (ICT, IWT).

During normal operation, the HIRS/2 instrument repeats a calibration cycle automatically, once every 40 lines (256 sec). A calibration cycle is one line of space-view radiometric data, one line of ICT radiometric data, and one line of IWT radiometric data. This is followed by 37 lines of Earth scanned data.

The lines containing space and internal target data can be identified by examining the line count provided in element 63, bits 27-39, or by the value of the encoder position, element 0-55, bits 1-8, (table 4-1). A line count of 0 indicates space view, 1 indicates ICT, and 2 indicates IWT. Line count value of 3-39 indicates the following 37 Earth view scan lines.

Table 4-1. HIRS/2 digital A data output

Element 0-55	
Bit 1-8	Encoder position (1-56=Earth view, 68=space, 105=ICT, 156=IWT)
Bit 9-13	Electronic cal level (0-31)
Bit 14-19	Channel 1 period monitor
Bit 20-25	Element number (1 less than encoder value for Earth views)
Bit 26	Filter sync designator
Bit 27-286	Radiant signal output (20 ch x 13 bits)
Bit 287	Valid data bit
Bit 288	Minor word parity check (odd parity)
Element 56-63	
Bit 1-26	Same as above
Bit 287, 288	Same as above
Element 56	
Bit 27-286	Positive electronic cal. (cal level advances one of 32 equal levels on succeeding scans)
Element 57	
Bit 27-286	Negative electronic cal.
Element 58	
Bit 27-91	Internal warm target #1, 5 times
Bit 92-156	Internal warm target #2, 5 times
Bit 157-221	Internal warm target #3, 5 times
Bit 222-286	Internal warm target #4, 5 times
Element 59	
Bit 27-91	Internal cold target #1, 5 times
Bit 92-156	Internal cold target #2, 5 times
Bit 157-221	Internal cold target #3, 5 times
Bit 222-286	Internal cold target #4, 5 times
Element 60	
Bit 27-91	Filter housing temp. #1, 5 times
Bit 92-156	Filter housing temp. #2, 5 times
Bit 157-221	Filter housing temp. #3, 5 times
Bit 222-286	Filter housing temp. #4, 5 times
Element 61	
Bit 27-91	Patch temp. expanded, 5 times
Bit 92-156	First-stage temp., 5 times
Bit 157-221	Filter housing control power /temp., 5 times)
Bit 222-286	Electronic cal DAC, 5 times (counts)
Element 62	
Bit 27-39	Scan mirror temp.
Bit 40-52	Primary telescope temp.
Bit 53-65	Secondary telescope temp.
Bit 66-78	Baseplate temp.
Bit 79-91	Electronics temp.
Bit 92-104	Patch temp. - full range
Bit 105-117	Scan motor temp.
Bit 118-130	Filter motor temp.
Bit 131-143	Cooler housing temp.
Bit 144-156	Patch control power

Table 4-1. HIRS/2 digital A data output (continued)

Element 62 (continued)

Bit 157-169	Scan motor current	
Bit 170-182	Filter motor current	
Bit 183-195	+15 Vdc	
Bit 196-208	-15 Vdc	
Bit 209-221	+7.5 Vdc	
Bit 222-234	-7.5 Vdc	
Bit 235-247	+10 Vdc	
Bit 248-260	+5 Vdc	
Bit 261-273	Analog ground	
Bit 274-286	Analog ground	

Element 63

Bit 27-39	Line count	
Bit 40-41	Fill zeros	
Bit 42-44	Instrument serial number	
*Bit 45-52	Command status	
Bit 53-57	Fill zeroes	
*Bit 58-65	Command status	
Bit 66-78	Binary code (1,1,1,1,1,0,0,1,0,0,0,1,1)	+3875 (base 10)
Bit 79-91		+1443
Bit 92-104		-1522
Bit 105-117		-1882
Bit 118-130		-1631
Bit 131-143		-1141
Bit 144-156		+1125
Bit 157-169		+3655
Bit 170-182		-2886
Bit 183-195		-3044
Bit 196-208		-3764
Bit 209-221		-3262
Bit 222-234		-2283
Bit 235-247		-2251
Bit 248-260		+3214
Bit 261-273		+1676
Bit 274-286		+1992
*Bit 45	Instrument ON/OFF	ON = 1
*Bit 46	Scan motor ON/OFF	ON = 0
*Bit 47	Filter wheel ON/OFF	ON = 0
*Bit 48	Electronics ON/OFF	ON = 1
*Bit 49	Cooler heat ON/OFF	ON = 0
*Bit 50	Internal warm tgt. position	True = 0
*Bit 51	Internal cold tgt. position	True = 0
*Bit 52	Space position	True = 0
*Bit 58	Nadir position	True = 0
*Bit 59	Calibration enable/disable	Enabled = 0
*Bit 60	Cover release enable/disable	Enabled = 0
*Bit 61	Cooler cover open	Yes = 1
*Bit 62	Cooler cover closed	Yes = 1
*Bit 63	Filter housing heat ON/OFF	ON = 0
*Bit 64	Patch temp. control ON/OFF	ON = 0
*Bit 65	Filter motor power HIGH	Normal = 1

*Command status bits

NOTE:

Each data sample is a 13-bit word with the MSB being the sign bit. The sign convention is such that 1 is positive and 0 is negative. The exceptions are the line number and command status words of element 63.

Table 4-2. HIRS/2 channel word location

Word location	Nominal central wave number (ν_c)	Radiometric channel number
1	668.4	1
2	2360.6	17
3	679.23	2
4	691.12	3
5	2190.4	13
6	703.56	4
7	2511.9	18
8	1363.7	11
9	2671.2	19
10	748.27	7
11	897.71	8
12	14367.0	20
13	1217.1	10
14	2212.7	14
15	721.28	6
16	716.05	5
17	2240.1	15
18	1484.4	12
19	2276.3	16
20	1027.9	9

A secondary mode of operation of the HIRS/2 is possible where the automatic calibration cycle is overridden by ground command. During this mode, the calibration data normally found for line count 0, 1, and 2 will be replaced with Earth view scan data. Under these conditions, channel gains and intercepts can be derived as a function of the housekeeping parameter data contained in elements 60-62. Should this mode ever be exercised, NESS will supply the necessary coefficients as a supplement to this document.

4.2 MSU

Each TIP minor frame contains four 8-bit words of MSU data. These data are located in TIP word positions 24, 25, 40 and 41 (figure 3-6). Each two words (e.g., 24 and 25), when taken as one 16-bit word, represent one data sample of either telemetry or radiometric output data. All future reference to MSU data words will assume a word size of 16 bits.

One scan line of MSU data will contain 512 data words; however, only 112 of these words contain "real" MSU instrument output data. The remaining 400 words are zero filled. The real data are identified by examination of the MSB of each word. If the value of this bit is equal to 1, the word is real and should be included in the 112 words of valid MSU data.

The identification and relative position of the 112 words of MSU data are shown in table 4-3, and the formats of the data words are shown in table 4-4. Within the 512 words, real data will be grouped in eight consecutive words. These eight words contain the data accumulated during one dwell position (one IFOV). Each IFOV contains four words of radiometric data (one word per channel), and four words of ancillary data. The first eleven IFOV's contain radiometric Earth view data respectively, and IFOV 14 contains no usable radiometric data. Associated with each dwell position is a scan angle value that is encoded in word eight of each IFOV. (See E bits in table 4-4.)

Because of slight variations in scan positioning from line-to-line, it is necessary to define several acceptable scan angle values for each scan dwell position (IFOV). The acceptable values are shown in table 4-5. These position variations are negligible for all practical purposes.

Table 4-3. MSU scan line format

IFOV		WORD 1: INSTRUMENT VOLTAGES	WORD 2: INSTRUMENT TEMP (SYSTEM A)	WORD 3: INSTRUMENT TEMP (SYSTEM B)	WORD 4: CHANNEL 1 DATA (RADIOMETRIC DATA)	WORD 5: CHANNEL 2 DATA (RADIOMETRIC DATA)	WORD 6: CHANNEL 3 DATA (RADIOMETRIC DATA)	WORD 7: CHANNEL 4 DATA (RADIOMETRIC DATA)	WORD 8: SCAN POSITION LINE COUNT (2)
1		0 INST SCR LO	1 T_A CAL LO	2 T_B CAL LO	3 CH 1 DATA	4 CH 2 DATA	5 CH 3 DATA	6 CH 4 DATA	7 SCAN POS 0 SCAN COUNT
2		8 E CAL LO	T_A CAL HI	T_B CAL HI	↓	↓	↓	↓	15 SCAN POS 1 SCAN COUNT
3		16 E CAL HI	OTH 1 TEMP	OTH 2 TEMP					23 ↓
4		24 XTAL 1+	L.O. 1 TEMP	L.O. 2 TEMP					31
5		32 XTAL 1–	L.O. 3 TEMP	L.O. 4 TEMP					39
6		40 XTAL 2+	DICKE LOAD 1 TEMP	DICKE LOAD 2 TEMP					47
7		48 XTAL 2–	DICKE LOAD 3 TEMP	DICKE LOAD 4 TEMP					55
8		56 XTAL 3+	PRT 1A	PRT 1B					63
9		64 XTAL 3–	PRT 2A	PRT 2B					71
10		72 XTAL 4+	ANT. 1 BEARING TEMP	ANT. 2 BEARING TEMP					79
11		80 XTAL 4–	MOTOR TEMP	MOTOR TEMP					87
12	(SPACE)	88 -15 VOLTS	RF CHASSIS	RF CHASSIS					95
13	(INTERNAL TARGET)	96 5 VOLTS	PROG TEMP	PROG TEMP					103 SCAN POS 12 SCAN CNT
14	(SCAN TO IFOV 1)	104 E ZERO	105 PROG TEMP	106 PROG TEMP	107 CH 1 REF	108 CH 2 REF	109 CH 3 REF	110 CH 4 REF	111 SCAN POS X SCAN CNT

NOTES: 1. ALL 12–BIT WORDS; 112 WORDS = 1 SCAN LINE = 25.6 SEC
2. COUNTS TO 5 AND RESETS EVERY 128 SEC

Table 4-4. MSU bit formats for each IFOV

Typical format for all words except word 8

MSB (bit 16)															LSB bit 1
1	1	Ø	Z	D	D	D	D	D	D	D	D	D	D	D	D

D = Data
Z = 1 when in zero reference disable mode; 0 at all other times
Ø = 0 for the first seven words
1 = indicates it is the first word in a scan; 0 for all other words
1 = indicates that the word is a real word; 0 occurs only for an all-zero word

Scan position - line count, word 8

MSB bit 16															LSB bit 1
1	0	1	Z	S	R	R	R	E	E	E	E	E	E	E	E

E = Scan angle (position) data
R = Scan line count (reset by 128-sec sync)
S = 1 when in scan disabled mode; 0 at all other times
Z = 1 when in zero reference disable mode
1 = indicates that this is the 8th word in the scan position
0 = indicates that this is not the first word in a scan
1 = indicates that the word is a real word

Table 4-5. Acceptable scan angles

IFOV	Scan Angles
1 and 14	83, 91, 90
2	94, 95, 31
3	24, 26, 27
4	20, 21, 17
5	1, 4, 5
6	8, 10, 11
7	46, 47, 15
8	35, 42, 43
9	38, 39, 36
10	48, 49, 53
11	60, 57, 56
Space (12)	163, 162, 171
Internal target (13)	200, 201, 202

Formation of the 112 words of MSU data must start when bit 15 has a value of 1 indicating that this is the first word of a scan line. The timing of the output of MSU data, relative to the TIP minor frames, varies slightly. Consequently, an MSU scan line will start at one of the TIP major/minor frame counters listed below, or within two minor frames thereafter.

TIP major frame	Minor frame
0	19
0	257
1	211
2	147
3	83
4	19
4	257
5	211
6	147
7	83

4.3 SSU

Each TIP minor frame contains six 8-bit words of SSU data located in word positions 16, 17, 32, 33, 76, and 77. Each two words (e.g., 16 and 17), when taken together as one 16-bit word, represent one data sample of either telemetry or radiometric data. Thus, each TIP minor frame contains three SSU data words. The SSU data word contains 12 bits of information, *left justified*, within each 16-bit word. The lower order four bits are data value 0. Before processing, the 12 bits of data should be right shifted 4 bits. This can be accomplished by dividing each 16-bit data word by 16. Further discussions of SSU data will assume a 12-bit word.

An SSU scan is 32 seconds in duration (1 TIP major frame or 320 TIP minor frames) beginning at each minor frame 0. The SSU provides a complete sampling of data every second. Recalling that each TIP minor frame is 0.1 second in duration, and that each minor frame contains three SSU data words, this provides 960 data words per scan, at a rate of 30 words per second. Each second of data (30 words) contains two radiometric data samples for each channel. The radiometric data samples for channel 1 are located in words 16 and 28, for channel 2 in words 17 and 29, and for channel 3 in words 18 and 30. The identification of the 30 SSU words is shown in table 4-6.

Digital words 1, 2, and 3 in table 4-6 are described as follows. In digital work 1, bit 1 (LSB) identifies the mirror synchronous recovery status, and is normally 0. Bits 2-12 comprise an 11-bit second counter that is reset to 0 at the beginning of the space view.

Table 4-6. 30-word SSU data sampling
(repeated 32 times per SSU scan)

SSU Data	Words
Digital word 1	1
Digital word 2	2
Digital word 3	3
Space port temperature	4
Earth port temperature	5
PMC bulkhead temperature	6
Detector temperature	7
Black body thermistor	8
Black body thermistor	9
Cell temperature ch 1	10
Cell temperature ch 2	11
Cell temperature ch 3	12
Base plate temperature	13
Middle bulkhead temperature	14
Optics baseplate temperature	15
Radiometric sample ch 1	16
Radiometric sample ch 2	17
Radiometric sample ch 3	18
Thermistor reference	19
Mirror fine position	20
Black body PRT	21
PMC Amplitude ch 1	22
PMC Amplitude ch 2	23
PMC Amplitude ch 3	24
ADC calibration 5% of full scale	25
ADC calibration 50% of full scale	26
ADC calibration 90% of full scale	27
Radiometric sample ch 1	28
Radiometric sample ch 2	29
Radiometric sample ch 3	30

Digital word 2 contains instrument configuration information as defined below:

Bit 12 (MSB)	Power on/off ('1' = on)
11	Mirror inhibit on/off ('1' = on)
10	Calibration mode auto/manual ('1' = manual)
9	Calibration verification (normally '0')
8	Mirror in position space view ('0' if in position)
7	Mirror in position blackbody ('0' if in position)
6	Mirror in position Earth view 1 ('0' if in position)
5	Mirror in position Earth view 5 ('0' if in position)
4	Mirror in position Earth view 8 ('0' if in position)
3	Mirror position correct (fine position sensor) yes/no ('0' = yes)
2-1	Channel identification for frequency reading 00 = channel 3 (1.4 mb) 01 = channel 1 (14 mb) 10 = channel 2 (4 mb)

Digital word 3 contains information necessary for evaluating the pressure modulated cell (PMC) channel frequencies. A data value will be inserted into this position once every 32 seconds. This will occur at minor frame 0 of each major frame. Word 2, bits 1 and 2, must be used with word 3 for proper identification of the PMC being sampled.

An SSU scan line consists of eight, 4-second Earth/calibration dwell periods. During each dwell period, eight radiometric data samples are taken for each channel (2 per second).

These eight radiometric data samples require additional processing to derive a final radiometric data value for a given dwell period.

During normal operations, the SSU instrument repeats a calibration cycle once every eight lines (256 seconds). A calibration cycle consists of one line of data, beginning at TIP major frame 0, minor frame 0. This line contains radiometric data samples taken while the instrument views space and the internal calibration target. The remaining seven scan lines contain radiometric Earth view data samples.

4.4 AVHRR

The AVHRR data are located in two sections of the HRPT minor frame. The radiometric calibration data and telemetry information are contained in the 103-word header. The radiometric Earth view data are located in that portion of the minor frame labeled AVHRR VIDEO (figure 3-5, section 3.2). Each minor frame contains a complete scan line of AVHRR data from all five channels. The AVHRR video data are located starting at HRPT word 751 and contains 10,240 words (2048 ten-bit words per channel). These data words are multiplexed sequentially into the video portions of the minor frame according to table 3-8. Every five words represent one simultaneous radiometric sample from each of the channels.

Space data and internal target data, required for calibration of the IR channels, are located in the header portions of the HRPT minor frame (figure 3-5). The order in which these data are multiplexed is shown in table 3-8, section 3.3.

4.5 Scan Timing and Geometry

The purpose of this section is to provide the user with the information necessary to establish the timing and scan geometry relationships between the TOVS instruments. The timing relationships are shown in table 4-7.

The start time of each instrument scan line can be derived by using the TIP 32-second time code that was described in section 3.4. Table 4-8 identifies the start of each instrument scan line relative to that time code.

This table also identifies the major and minor frame numbers that correspond to the start of each scan line. Noted that the minor frame counters corresponding to the start of each scan are not the same for each instrument. For example, at the time corresponding to major frame 0, minor frame 0 (TC(0/0) in table 4-8), all instruments begin their scan sequence. However, the data that corresponds to the start of the HIRS/2 scan line appears in major/minor frame 0/1, for SSU in 0/0, and for MSU in 0/19.

Since the TIP major frame count value cycles from 0 to 7, table 4-8 can be expanded by replacing major frame values 0, 1, 2, and 3 with major frame values 4, 5, 6, and 7 respectively.

Table 4-7. Instrument scan timing parameters

Instrument	Time between start of each scan line	Step and dwell time	No. of Earth view steps per line	*ΔTime
HIRS/2	6.4 sec	0.1 sec	56	0.5 sec
MSU	25.6 sec	1.81 sec	11	0.9 sec
SSU	32 sec	4.0 sec	8	2 sec

*ΔTime - the difference between the start of each scan and the center of the first dwell period (see figures 7 and 8).

Table 4-8. Scan line timing of the TOVS instruments

Scan start time (seconds)	TIP major minor frame HIRS/2	SSU	MSU
*TC (0/0)			
+6.4	0/1	0/0	0/19
+12.8	0/65		
+19.2	0/129		
+25.6	0/193		
	0/257		
*TC (1/0)	1/1	1/0	0/275
+6.4	1/65		
+12.8	1/129		
+19.2	1/193		1/211
+25.6	1/257		
*TC (2/0)	2/1	2/0	
+6.4	2/65		
+12.8	2/129		2/147
+19.2	2/193		
+25.6	2/257		
*TC (3/0)	3/1	3/0	
+6.4	3/65		3/83
+12.8	3/129		
+19.2	3/193		
+25.6	3/257		

*TC (n/0) is the time calculated from TIP major frame n and minor frame 0, where n=0, 1, 2, and 3.

Note: This timing table for major frames 0-3 repeats for major frames 4-7.

Figures 4-1 and 4-2 show the relationship between the scan patterns of each of the TOVS instruments.

All TOVS instruments scan in the same direction, Sun to anti-Sun. It should be noted that the scan direction of the AVHRR instrument is opposite that of the TOVS instruments.

5. CALIBRATION

Williamson (1977) presents an excellent description of the methodology of calibration for satellite-borne radiometers. In general, the calibration processes involve exposing a radiometer to an extended source that has been calibrated against a primary or secondary standard of one of the national laboratories and establishing a relation between the output of the radiometer and the quantity of radiation (radiance) measured by the radiometer.

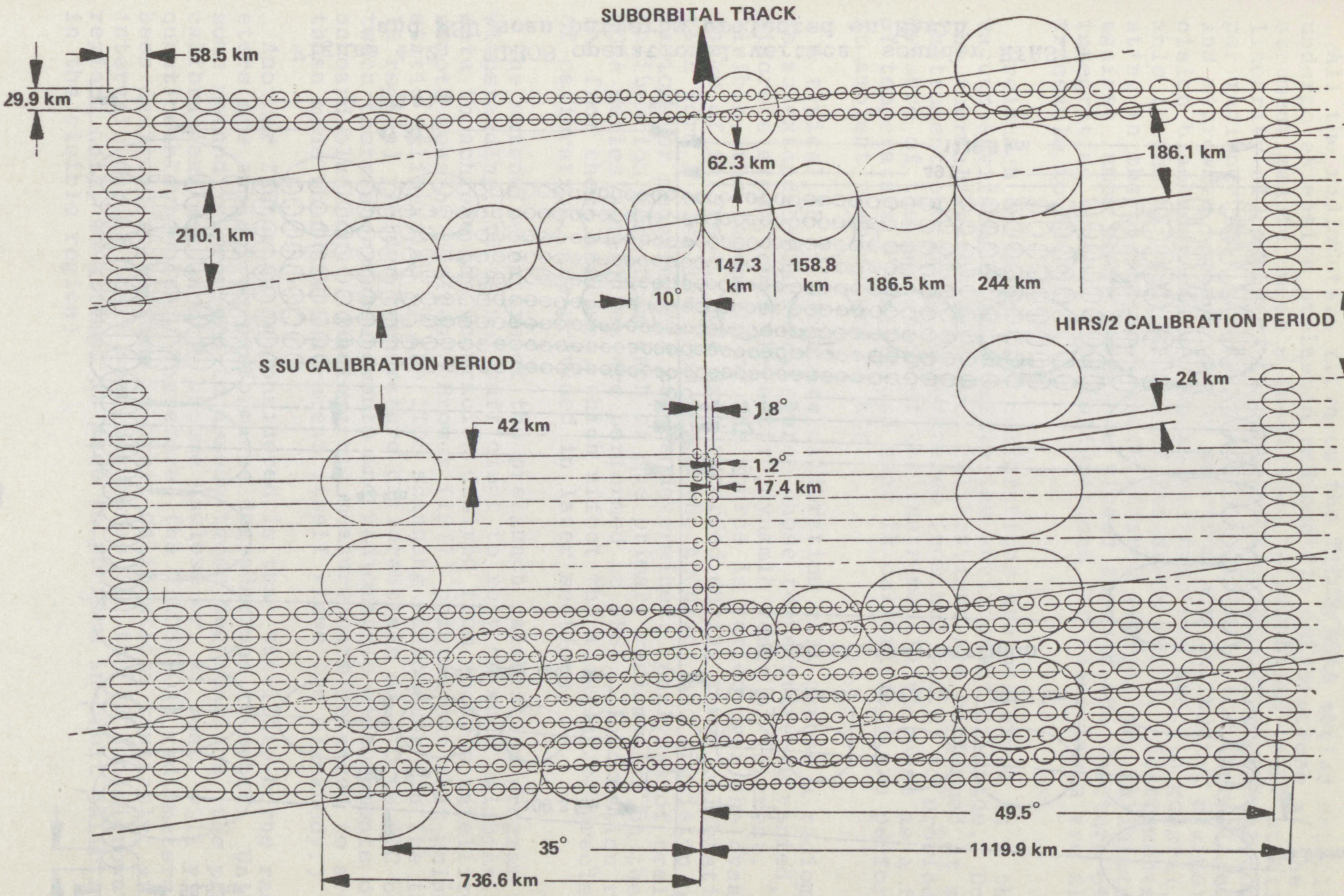


Figure 4-1. TIROS operational vertical sounder HIRS/2 and SSU scan patterns projected on Earth

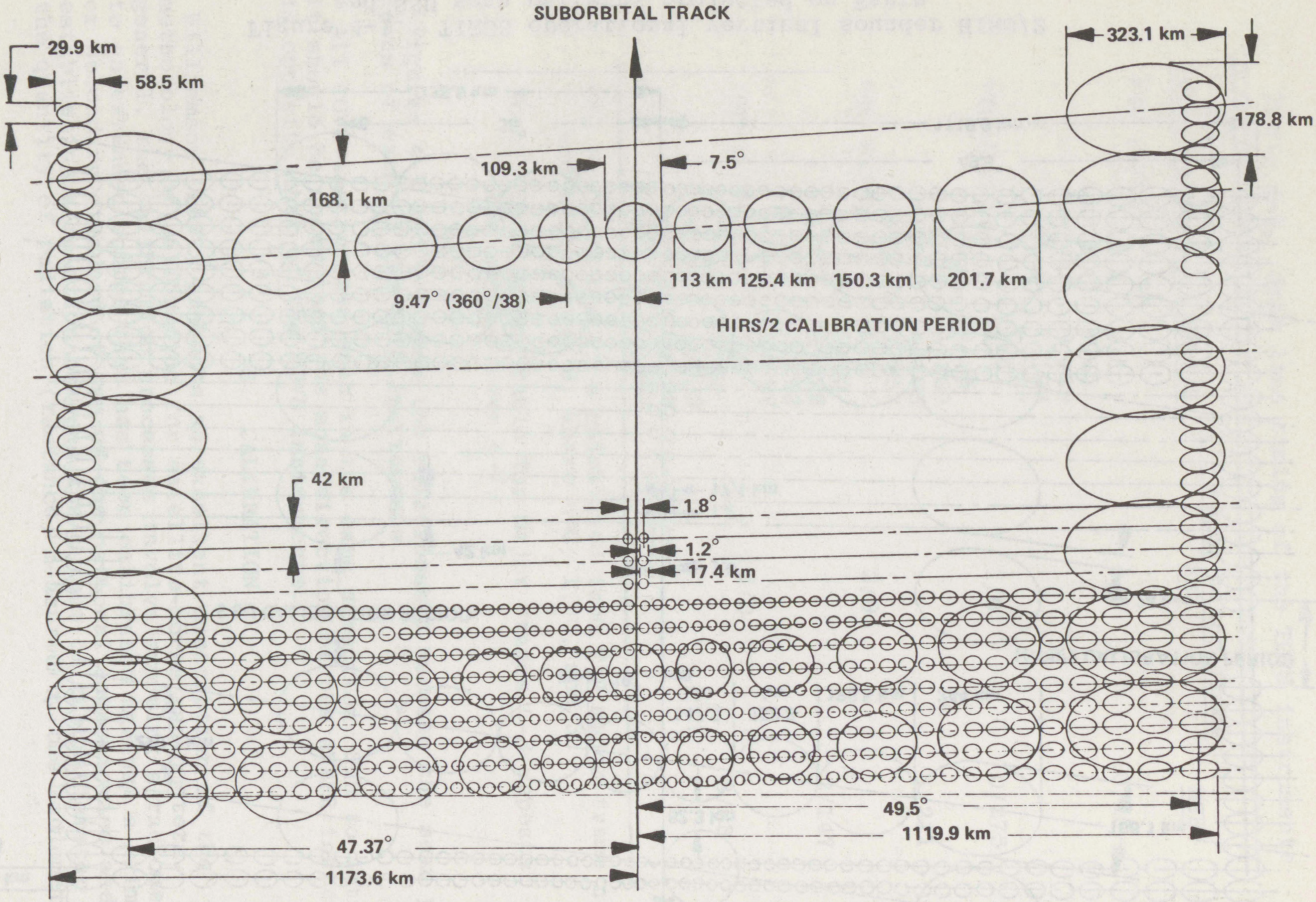


Figure 4-2. TIROS operational vertical sounder HIRS/2 and MSU scan patterns projected on Earth

All the radiometers flown on the TIROS/NOAA series satellites undergo extensive prelaunch radiometric calibrations at the instrument manufacturer's facilities to establish their stability, linearity of response, and sensitivity in output digital counts per radiance unit. Instruments operating in the thermal infrared and microwave regions of the spectrum are calibrated against precision blackbody sources whose calibrations are, in general, traceable to the National Bureau of Standards (NBS). Instruments operating in the visible and near-infrared regions are calibrated against lamps whose output is viewed through the aperture of an integrating sphere. The calibrations for these lamps are also traceable to NBS.

Prelaunch infrared (IR) calibrations are performed in a thermal/vacuum environment to simulate the environment of space. During the thermal/vacuum exposure, calibrations are performed at several instrument operating temperatures (nominal ±10°C) to provide a measure of the deviation of the instrument's response as a function of temperature. Visible and near IR calibrations are performed at ambient temperature in air.

A typical IR or microwave calibration will expose a radiometer to an extended blackbody source whose temperature is varied, in discrete steps, over the entire dynamic range of interest. In the visible, the intensity of the source is varied over the dynamic range of interest. The data recorded during these calibrations then form a baseline from which the accuracy and precision of the radiometer measurements can be determined. Analyses of prelaunch calibration data from each of the primary radiometers on the TIROS/NOAA series satellites are performed at NESS. Information resulting from these analyses, which affect the accuracy or precision of calibration, are provided in later sections.

The extensive nature of the prelaunch calibration program notwithstanding, it is not sufficient to rely on such calibration data to achieve the accuracies desired from today's satellite-borne remote sensing devices. Brower (1977) pointed out that using such static calibration of the ITOS scanning radiometer (in the thermal IR region) yielded temperature differentials of 2°C to 4°C between thermistor measurements and radiometric measurements of an onboard blackbody. (Radiometric measurements referred to are those made when the instrument itself views the blackbody.)

Another factor to be considered is that satellite-borne radiometers are subject to performance degradations in orbit. Unless some method is provided to assess those degradations, the prelaunch calibrations may shortly become useless or, at best, will yield questionable results. Therefore, the TIROS/NOAA radiometers, have been designed to perform in-orbit calibrations routinely, at intervals during their scan sequences (in the IR and microwave regions only; no attempt is made to perform in-orbit calibrations in the visible region).

In-orbit calibration is accomplished by programming a given radiometer's scan mirror to view: space (near-zero radiance), and part of its housing, which is a designed blackbody. This onboard blackbody is maintained at approximately the operating temperature of the radiometer (15°C or 288 K). Also, it is instrumented with temperature sensors whose outputs are multiplexed into the radiometer's telemetry. Thus, the zero radiance from the space look and the radiance from the 15°C onboard blackbody provide a two-point, in-flight calibration.

Calibration of the onboard blackbody is generally performed during the prelaunch calibration program. One method of doing this (and the method preferred by NESS) is to use the instrument itself as a transfer standard. Once the output of the radiometer in counts per radiance unit, has been established (using a precision calibration blackbody), the onboard blackbody temperature sensor outputs are merely correlated with the output of the radiometer when it views the onboard blackbody. Since the radiometer is calibrated at several different temperatures, calibration curves representing radiometrically derived temperatures can be generated for each of the temperature sensors in the onboard blackbody.

In the following sections, the calibration procedures employed by NESS are treated in detail for each of the TIROS/NOAA primary radiometers.

5.1 AVHRR

The information required for producing AVHRR IR channel calibration coefficients is located in the 103-word HRPT header. (See figure 3-5 and table 3-8.)

Header words 18, 19, and 20 each contain a five-point subcommutation of the outputs of four platinum resistance thermometers (PRT) that monitor the temperature of the internal calibration target (ICT). Each of these words contain redundant information. Any one of these words, when extracted from five consecutive HRPT minor frames, produces a reference (REF) value and one sample of each of the four PRT's. The pattern is as follows:

HRPT minor frame	Parameter sampled
.	.
.	.
n	REF
n+1	PRT1
n+2	PRT2
n+3	PRT3
n+4	PRT4
n+5	REF
.	.
.	.
.	.

The reference value can be easily identified since it will be the only output having a count value of less than 10. NESS averages 10 samples from each PRT to produce a mean PRT count value for conversion to temperature units.

The 30 words of internal target data (header words 23-52) provide 10 samples each for IR channels 3, 4, and 5. The 50 words of space view data (header words 53-102) provide 10 samples each for all five AVHRR channels. These data are multiplexed as described in table 3-8.

NESS averages 50 samples of space and internal target radiometric data per channel to produce mean count values.

To calculate the internal target radiance, it is first necessary to compute the target temperature.

The conversion of PRT mean counts to temperature is accomplished by:

$$T_i(K) = \sum_{j=0}^{4} a_{ij}\bar{X}_i^j$$

where $\bar{X}_i$ is the mean count for PRT_i where $i = 0,1,2,3,4$ a_{ij} are the coefficients of the conversion algorithm and T_i is the temperature of the internal target calculated from PRT_i. For example, the conversion of PRT_1 count value ($\bar{X}_1$) into temperature (K) is

$$T_1(K) = a_{1,0}+a_{1,1}\bar{X}_i+a_{1,2}\bar{X}_1^2+a_{1,3}\bar{X}_1^3+a_{1,4}\bar{X}_1^4$$

The coefficients a_{ij} are supplied in appendix B.

The average temperature of the internal target is computed by

$$\bar{T} = \sum_{i=1}^{4} b_i T_i$$

where $\bar{T}$ is the average of the internal target temperatures (K) and b_i is the weighting factor of each PRT (supplied in appendix B). The conversion of temperature, $\bar{T}$ to radiance units (N) is described in appendix A.

Let us assume, for the time being, that the output of each channel (in counts) is linear as a function of sensed radiance. Then:

$$N = G X + I$$

describes the relationship between counts and radiances where: N is the radiance of the target at count value X, G is the channel gain, and I is the channel intercept.

The gain of each channel is calculated by:

$$G = \frac{N_{sp} - N_{\overline{T}}}{\overline{X}_{sp} - \overline{X}_{\overline{T}}}$$

where G is the channel gain (radiance unit per count), N_{sp} is the radiance of space, $N_{\overline{T}}$ is the radiance of the internal target and $\overline{X}_{sp}$ and $\overline{X}_{\overline{T}}$ are the mean output count values when the instrument views space and the internal target respectively. The intercept of each channel is calculated by:

$$I_i = N_{sp} - GX_{sp}$$

In reality, the response of the channels in the 11 μm -μ12 m region (channels 4 and 5) are slightly nonlinear. This nonlinearity is a function of the physical properties of the detectors employed in these channels.

Since only a two-point calibration is possible in flight, a correction must be made to both the gain and intercept algorithms. This is accomplished by adding a correction factor to the N_{sp} parameter. This correction factor is calculated from subsystem test data to provide the smallest temperature error in the range of 225 K to 310 K. A table of errors and corrected values for N_{sp} are presented in appendix B. The 3.5-μm region channel (channel 3) uses a different type of detector and does not require corrections.

Calibration of the visible AVHRR channels (1 and 2) is not performed in flight. Subsystem data are evaluated, however, to produce coefficients for the calibration algorithm.

$$A = GX + I$$

where G and I are the gain and intercept of each visible channel, X is the count value output of the radiometer for each channel, and A is the percent albedo of the target.

Coefficients G and I are supplied for channels 1 and 2 in appendix B. Also included in appendix B are spectral response curves for channels 1 and 2.

5.2 MSU

The parameters necessary for calibrating the MSU are provided with each scan line. Since each scan line contains only one sample for each parameter, an average of these data from several scan lines is used for the calculation of calibration coefficients.

The location of the space and internal target radiometric data is defined in section 4.2 MSU. The calibration coefficients for a specific scan line are computed from an average of the data contained in 25 lines (12 lines prior to and 12 lines subsequent to that line for which coefficients are being computed).

The relationship between input radiance and instrument output counts is not linear in the MSU channels. Since only a linear relation between radiance and instrument output counts can be derived from the in-flight data, a nonlinearity correction algorithm must be applied to each channel. The coefficients for this algorithm are produced by NESS for each instrument, using preflight subsystem calibration information and are supplied in appendix B.

The algorithm is:

$$C' = \sum_{i=0}^{2} d_i C$$

where C is the radiometric count output, d_i is the nonlinearity correction coefficient and C' is the modified count value to be used in the linear algorithm.

Each of the two inflight calibration targets has two PRT's that are used to determine the temperature of these targets. In-flight target (#1) is viewed by channels 1 and 2. The temperature of this target is derived from PRT 1A and PRT 1B. In-flight target #2 is viewed by channels 3 and 4. The temperature of this target is derived from PRT's 2A and 2B. The output count values from PRT's 1A, 1B, 2A and 2B are located in words 2 and 3 of IFOV's 8 and 9 (see table 4-3).

The conversion of each PRT count output to temperature (K) requires the use of two algorithms, the first to convert counts to resistance (R) and the second to convert resistance to temperature (K). The first algorithm is:

$$R_A = K_0 + K_1 \frac{C_A - T_A \text{ CAL LO}}{T_A \text{ CAL HI} - T_A \text{ CAL LO}} \quad \text{for PRT 1A \& 2A}$$

or

$$R_B = K_0 + K_1 \frac{C_B - T_B \text{ CAL LO}}{T_B \text{ CAL HI} - T_B \text{ CAL LO}} \quad \text{for PRT 1B \& 2B}$$

where:

R_A is the resistance of PRT 1A or 2A; R_B is the resistance of PRT 1B or 2B; C_A is the count value of PRT 1A or 2A; C_B is the count value of PRT 1B or 2B; K_0 and K_1 are the resistance conversion coefficients supplied in appendix B.

T_A CAL HI and T_A CAL LO and T_B CAL HI and T_B CAL LO are the high and low calibration reference points for electronic systems A and B respectively.

T_A CAL LO, T_B CAL LO, T_A CAL HI and T_B CAL HI are located in words 2 and 3 of IFOV's 1 and 2 as defined in table 4-3.

The second algorithm, converting R to temperature is:

$$T = \sum_{i=0}^{2} e_i R^i$$

where T is the temperature (K) of the internal target as derived from the resistance ($R = R_A$ or R_B) and e_i are the temperature conversion coefficients for each PRT.

The coefficients e_i are supplied in appendix B.

The temperature of target #1 is the average of the temperature derived from PRT's 1A and 1B. The temperature for target #2 is the average of the temperature derived from the PRT's 2A and 2B.

The target temperature used for the calculation of calibration coefficients is averaged over 25 scan lines.

The conversion of these average temperatures to radiance units (N_T) is described in appendix A.

Channel gains are calculated by:

$$G = \frac{N_{SP} - N_T}{\bar{C}'_{SP} - \bar{C}'_T}$$

where G is the gain of each channel, N_{SP} and N_T are the radiance of space and the internal target respectively, and $\bar{C}'_{SP}$ and $\bar{C}'_T$ are the corrected count values of the space and internal target views averaged over 25 scan lines. The values of N_{SP} are supplied in appendix B.

Channel intercepts are calculated by:

$$I = N_{SP} - G\,\bar{C}'_{SP}$$

5.3 SSU

During normal operation, calibration of the SSU instrument is performed once every 256 seconds. The scan sequence format for the SSU provides 32 seconds (1 line) of radiometric space and internal target view data followed by 7 scan lines of Earth view data.

The SSU calibration line contains four dwell periods of space data followed by four dwell periods of internal target data. These data can be identified by examining bits 7 and 8 of digital word 2, defined in section 4.3, SSU. Each dwell period contains 8 radiometric data samples per channel spaced according to the following timing chart.

Sample (s)	Time (t)
1	4 sec
2	1.0 sec
3	1.4 sec
4	2.0 sec
5	2.4 sec
6	3.0 sec
7	3.4 sec
8	4.0 sec

The accumulation of these samples over a four-second dwell period produces a linear relationship between output samples (counts) and time (seconds). The slope of this line is defined as a RAMP (counts per sec). This RAMP is computed using the lease squares equation:

$$\text{RAMP} = \frac{8\,\Sigma\,ts - \Sigma\,t\,\Sigma\,s}{8\,\Sigma\,t^2 - (\Sigma t)^2}$$

where all the summations over the eight samples and s is the count output value from a data sample at time t.

An average of the four RAMP values from the space view and an average of the four RAMP values from the internal target view are used in the calculations of calibration coefficients.

The temperature of the internal target can be calculated from the blackbody PRT data samples (word 21, table 4-6) during the last 12 seconds of the calibration line and during the entire 32 seconds of the other seven scan lines.

The PRT provides the most precise measure of the internal target temperature. However, should the blackbody PRT fail, the data samples from the two blackbody thermistors (words 8 and 9, table 4-6) may be used to derive the internal target temperature.

The temperature of the internal target calculated from the blackbody PRT data samples is:

$$T(K) = \sum_{i=0}^{2} a_i \bar{X}^i$$

where a_i are the conversion coefficients contained in appendix 2, and $\bar{X}$ is the averaged PRT data value (in counts). It is sufficient to average only the last 12 seconds of each line to produce $\bar{X}$.

The temperature of the internal target calculated from the blackbody thermistor data samples is:

$$T(K) = \frac{\sum_{i=0}^{3} b_i \bar{X}^i + \sum_{i=0}^{3} c_i \bar{Y}^i}{2}$$

where b_i and c_i are temperature conversion coefficients for each thermistor contained in appendix B and $\bar{X}$ is the average of the blackbody thermistor (word 8 divided by the thermistor reference [word 19]). $\bar{Y}$ is the average of the blackbody thermistor (word 9 divided by the thermistor reference [word 19]). Again, it is sufficient to average only the last 12 seconds of each line to produce $\bar{X}$ and $\bar{Y}$.

The internal target temperature is converted to radiance (N) as described in appendix A. Channel gains are calculated by:

$$G = \frac{N_{SP} - N_T}{\overline{RAMP}_{SP} - \overline{RAMP}_T}$$

where G is the gain of channel, N_{SP} and N_T are the radiance of space and the internal target respectively, and $\overline{RAMP}_{SP}$ and $\overline{RAMP}_T$ are the average ramp value for the space and the internal target views.

Channel intercepts are calculated by:

$$I = N_{SP} - G\ \overline{RAMP}_{SP}$$

5.4 Calibration of HIRS/2

During normal operation, calibration of the HIRS/2 instrument is performed once every 256 seconds (40 lines). Calibration is provided by viewing two internal targets and space. The temperature of both internal targets, a warm target (IWT) (290 K) and a cold target (ICT) (260 K to 270 K), are determined from four thermistors embedded in each target. Because of large temperature gradients induced by solar effects throughout the orbit, the temperature of the ICT cannot be reliably determined with sufficient accuracy to improve the calibration. Therefore, only the IWT and space-view data are used for calculating calibration coefficients.

Element 58 of each HIRS/2 line contains five samples of each of the four thermistors used to determine the temperature of the IWT (see table 4-1). The output of each thermistor is converted to temperature K by:

$$T = \sum_{j=0}^{4} a_j \bar{X}^j$$

where T is the temperature indicated by the thermistor, $\bar{X}$ is the average of 200 samples for that thermistor (40 lines x 5 samples per line), and a_j are the conversion coefficients supplied in appendix B.

The temperature of the IWT (T_{IWT}) is determined by averaging the temperatures derived from the four thermistors. The T_{IWT} is converted into radiance (N) as shown in appendix A. The computation of calibration coefficients requires that for each channel an average value of the space and internal warm target view data be computed. For that line containing space-view data, there are 56 samples per channel. Samples 1 through 8 contain data while the scan mirror is moving to the space target and are, therefore, not usable. For that line containing IWT view data, all 56 samples per channel are usable.

The channel gains are computed by:

$$G = \frac{N_{SP} - N_{IWT}}{\bar{X}_{SP} - \bar{X}_{IWT}}$$

where G is the gain for each channel, N_{SP} and N_{IWT} are the radiance of space and the internal warm target, $\bar{X}_{SP}$ is the mean space value (in counts) of the 48 usable space data samples, and $\bar{X}_{IWT}$ is the mean IWT value (in counts) of the 56 usable IWT data samples.

The channel intercepts are completed by:

$$I = N_{SP} - G\bar{X}_{SP}$$

5.5 Application of Calibration Coefficients to Earth View Data

The gains and intercepts as computed for each instrument (sections 5.1 to 5.4) are used to convert Earth view radiometric samples (X_E in counts) to calibrated radiance values (N_E). The algorithm is

$$N_E = G\,X_E + I$$

For the MSU, X_E is defined as the count value modified for instrument nonlinearity (C) (section 5.2).

The calibrated radiance values N_E do not include corrections for atmospheric attenuation, slant path corrections, or other atmospheric phenomena.

5.6 APT

The APT frame format is shown in figure 3-3. Space data for the selected channel (instrument output while viewing space) appear in each APT video line immediately following the synchronization pulses. All of the other data necessary to perform the calibration appear in the telemetry frame.

The outputs of the four sensors, which monitor the housing blackbody target temperature, appear in telemetry points 10, 11, 12, and 13 (thermal temperature number 1 through 4, respectively). Each thermal temperature is repeated on eight successive APT video lines. Thermal temperature #1, for example, begins on line 73 and is repeated through line 80; thermal temperature #2 begins on line 81; #3 on line 89; and #4 on line 97.

The output of the instrument when viewing the housing blackbody target appears in telemetry point 15 (back scan) that begins on APT video line 113.

It must be emphasized that APT is processed AVHRR data. Two selected channels from AVHRR are time division multiplexed into an output data stream that has been processed to achieve both bandwidth reduction and geometric correction. This processing is accomplished in the digital domain before being converted to an analog signal for output on the APT transmitter.

To effect calibration of the selected IR channel, the AVHRR calibration data must be related to the APT video signal. This is accomplished by determining the relative signal level using the eight wedge levels as a scale. A minimum signal level would be equivalent to telemetry point 9; a maximum signal would be equivalent to point 8. Calibration curves showing the relationships of the four housing blackbody temperature sensors to the eight-level wedge scale are presented in figures 5-1 and 5-2.

The calibration procedure is as follows:

a. Determine the temperature of the housing blackbody by normalizing (scaling) the output of thermal temperatures 1 through 4 to the wedge levels. Plot the values found on the appropriate graph (figures 9 and 10). There will be slight differences between the sensors in indicated temperatures because of thermal gradients induced in the blackbody by solar input energy and Earth albedo; therefore, an average of the four indicated temperatures will be a good representation of the effective blackbody temperature.

b. Determine the IR channel output while viewing the blackbody by scaling the data appearing in telemetry point 15 (back scan) to the eight-level wedge.

c. Determine the IR channel output while viewing space by normalizing the data immediately following the synchronization pulses to the eight-level wedge.

d. On figure 5-3 (3.7-μm channel) or figure 5-4 (11-μm channel) plot the normalized value determined in step 2 against the blackbody temperature found in step 1.

e. On figure 5-3 or 5-4, plot the normalized value determined in step 3 against the minimum temperature shown on the graph (240 K for the 3.7-μm channel and 150 K for the 11-μm channel.)

The slope of a line connecting the two points plotted in steps 4 and 5 above is a measure of the response of the selected channel.

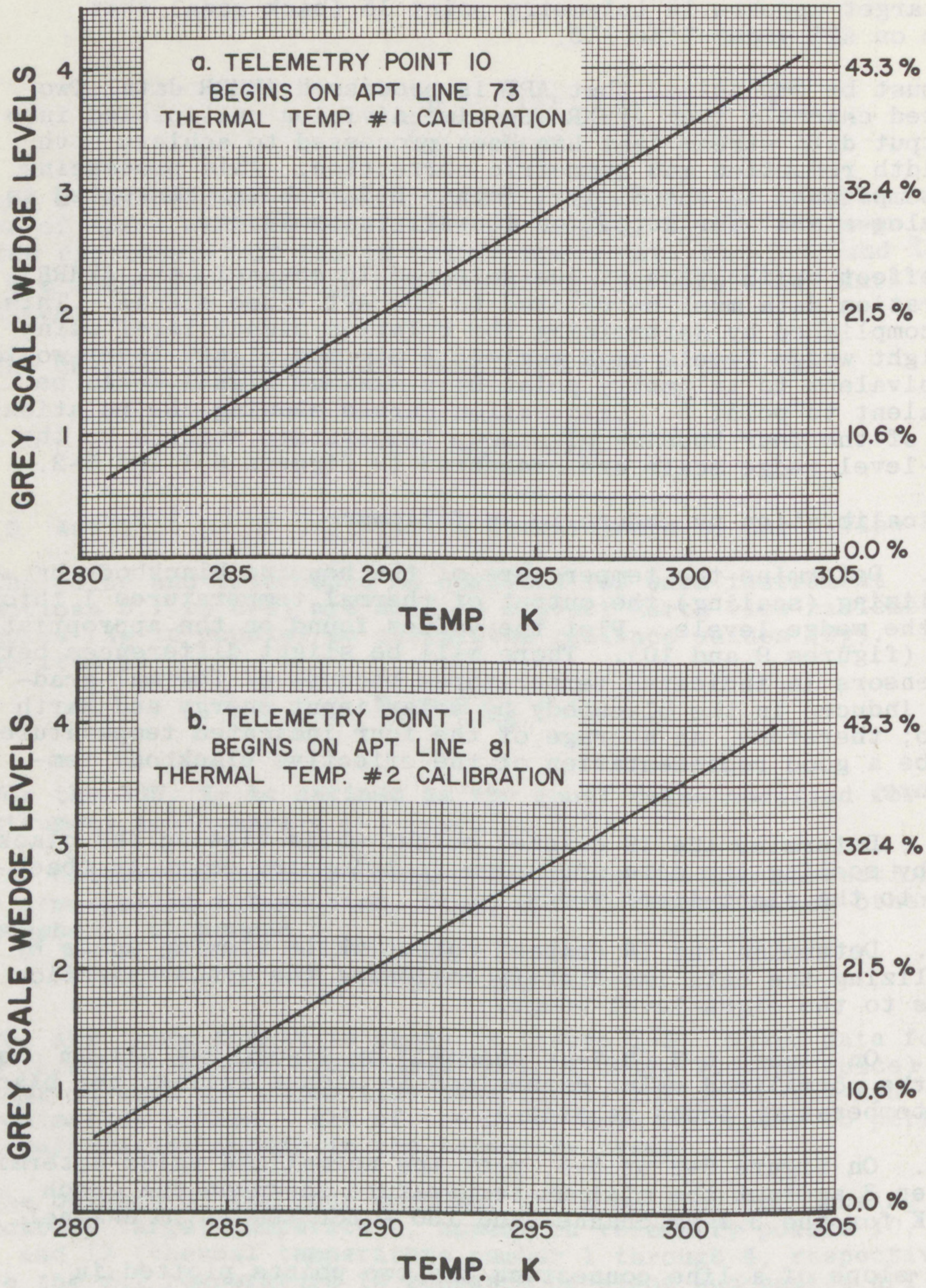
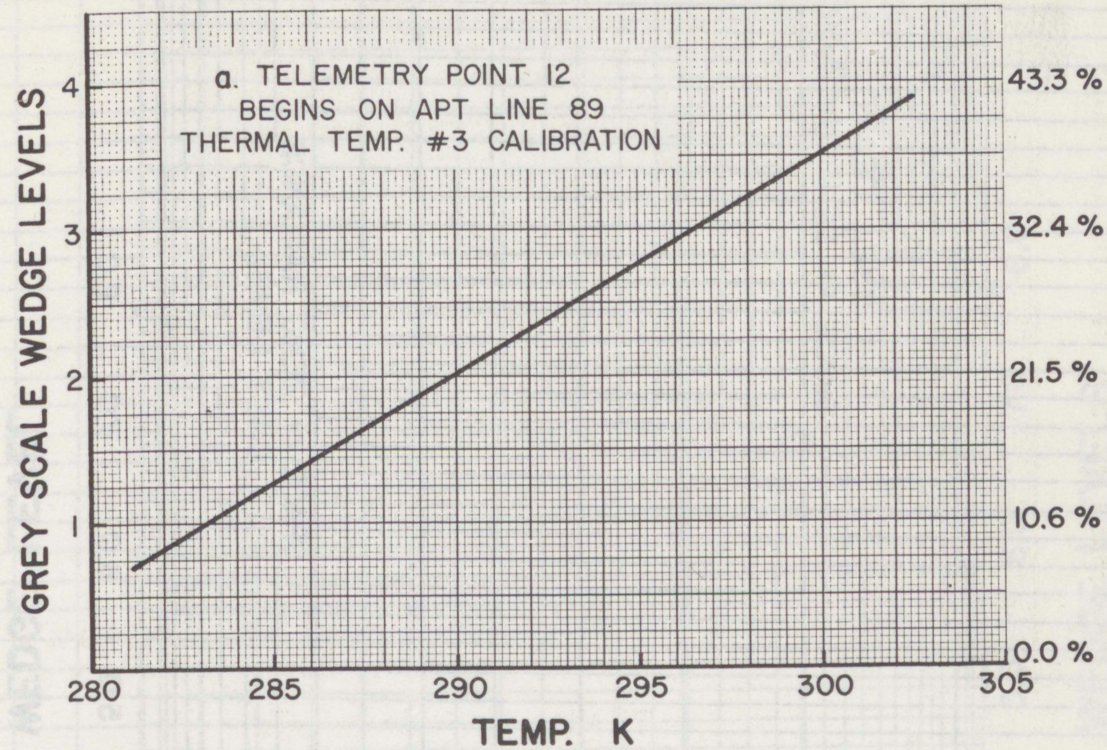


Figure 5-1. Thermal temperatures 1 and 2



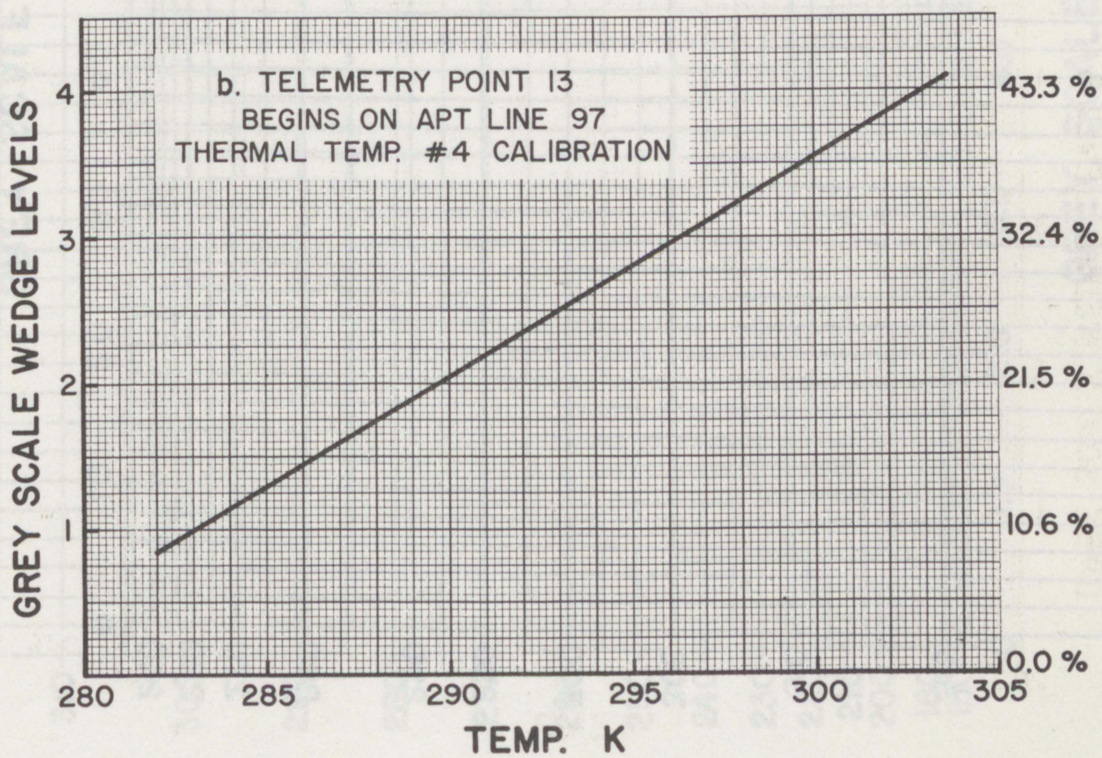


Figure 5-2. Thermal temperatures 3 and 4

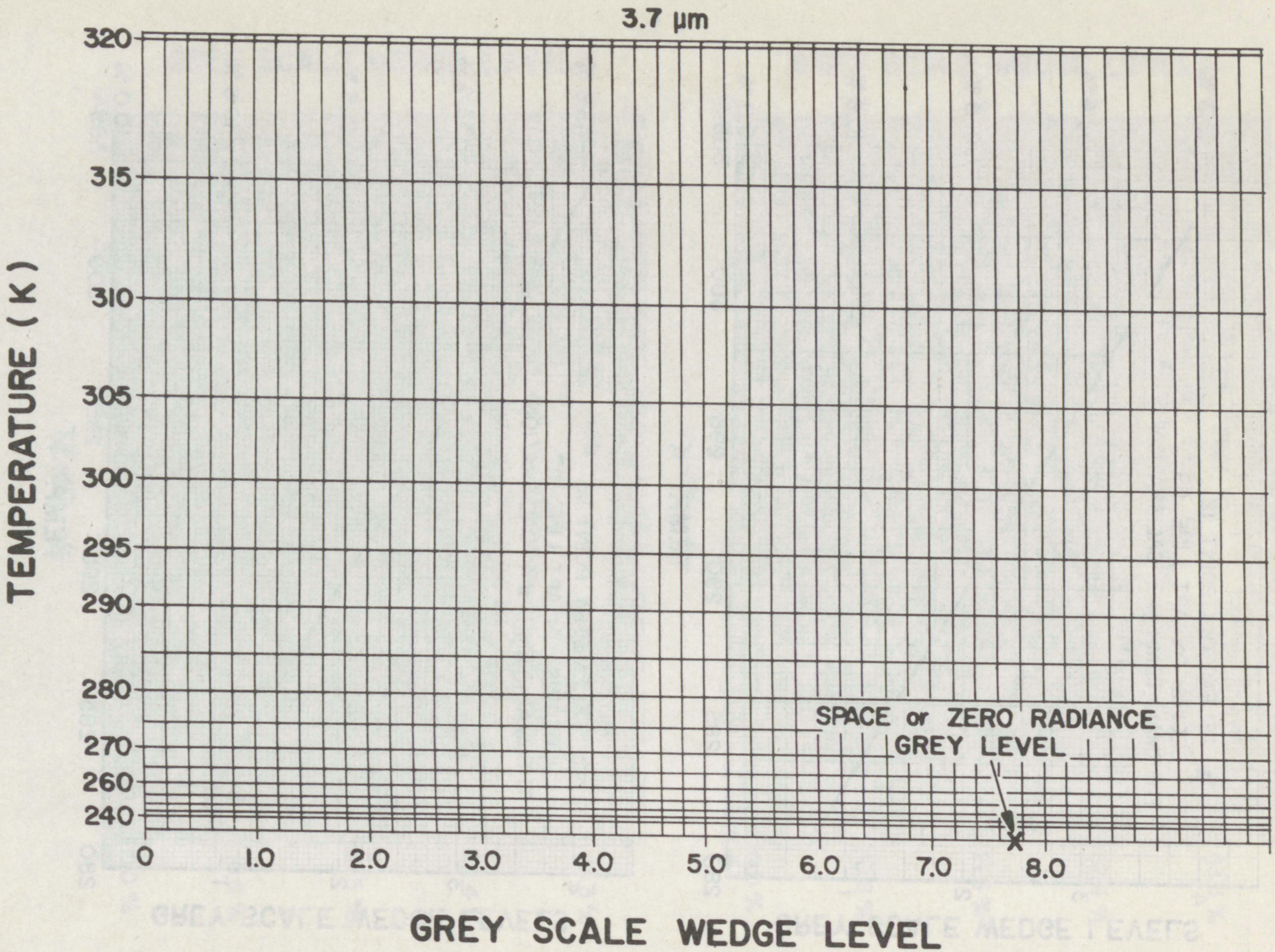


Figure 5-3. Grey level equivalent blackbody temperature, 3.7 μm

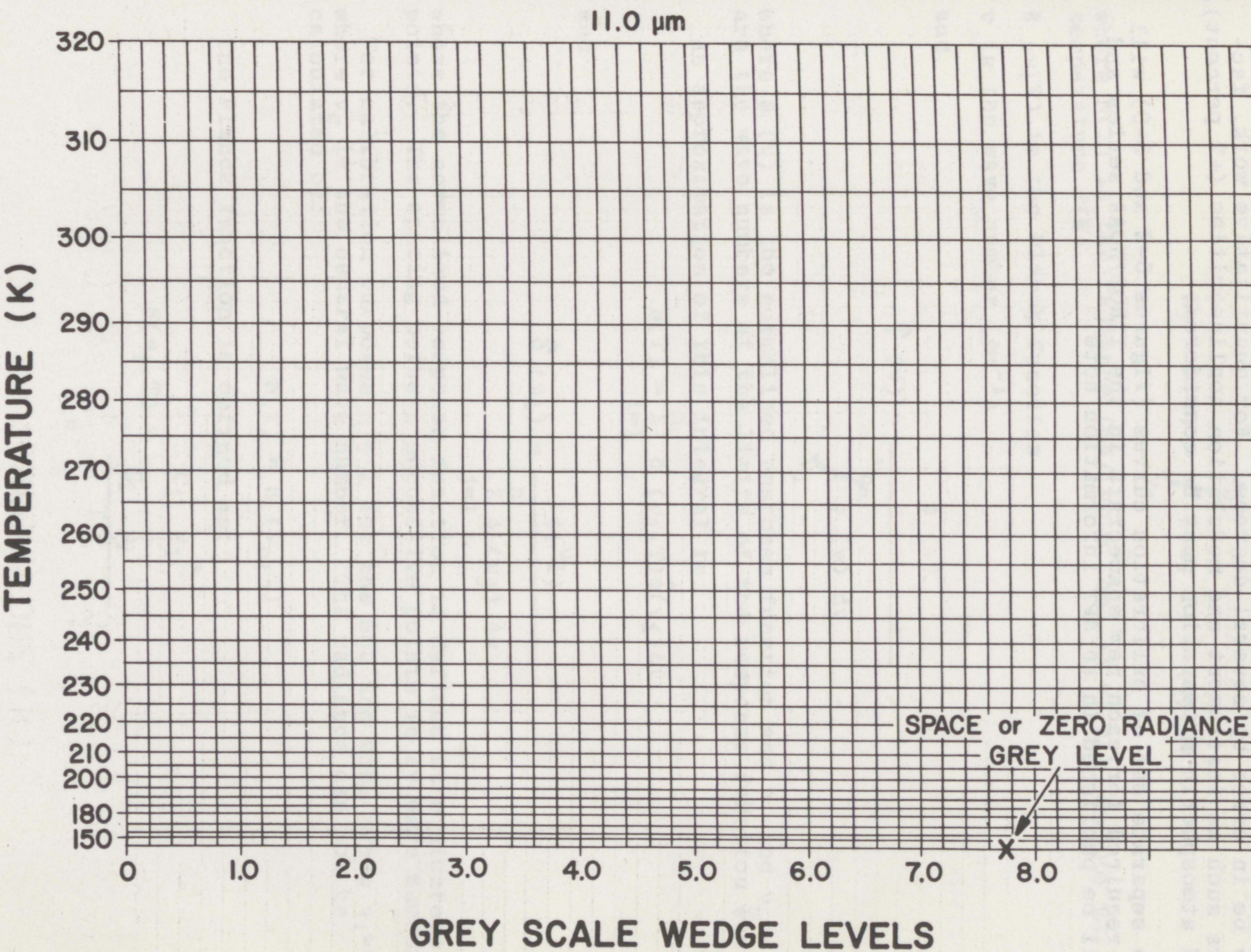


Figure 5-4. Grey level equivalent blackbody temperature, 11.0 μm

Note that scene temperature retrieved using this response curve may be in error by several degrees. For quantitative work, factors such as instrument and modulation nonlinearities (±2 percent), and atmospheric attenuation must be considered.

A separate set of calibration curves (figures 5-2 and 5-3) will be required for each new spacecraft in the TIROS/NOAA series and will be published in an APT information note.

APPENDIX A. Temperature-to-Radiance Conversion

$$N_T = N(T) = \int_{\nu_i}^{\nu_n} \beta(\nu, T)\, \hat{\phi}(\nu)\, d\nu$$

where N(T) is the radiance (mW/(sr m^2 cm^{-1})) of a blackbody at temperature T(K).

$\beta(\nu_1 T)$ is the Planck function

ν is the wave number (cm^{-1})

and

$$\hat{\phi}(\nu) = \frac{\phi(\nu)}{\int_{\nu_1}^{\nu_n} \phi(\nu)\, d\nu}$$

where $\hat{\phi}(\nu)$ is the normalized response function and ν_1 and ν_n are the wave numbers at the limits of the response function $\hat{\phi}(\nu)$.

An approximation of this integral is:

$$N(T) = \sum_{i=1}^{n} \beta(\nu_i, T)\hat{\phi}(\nu_i)\Delta\nu$$

and

$$\hat{\phi}(\nu_i) = \frac{\phi(\nu_i)}{\sum_{j=1}^{n} \phi(\nu_j)\, \Delta\nu}$$

where the normalized response function is defined at n discrete points. The spacing between successive points in $\Delta\nu$ wave numbers.

For calibration purposes n = 1 for the SSU and MSU. Then $\nu_1 = \nu_n = \nu_c$ where ν_c is the central wave number. The radiance can now be calculated by:

$$N(T) = \beta(\nu_c, T)$$

The Planck function is defined as:

$$\beta(\nu_i, T) = \frac{C_1 \nu_1^3}{e^{\frac{C_2 \nu_i}{T}} - 1}$$

where the universal constants are:

$$C_1 = 1.1910659 \quad 10^{-5} \quad \frac{\text{mW}}{\text{m}^2 \text{ sterad. cm}^{-4}}$$

$$C_2 = 1.438833 \text{ cm K}$$

The values of ν_1, $\Delta\nu$ and $\hat{\phi}(\nu_i)$ where i=1 to n are supplied for each channel for each instrument.

For the HIRS/2 an alternate method for converting temperature into radiance is to apply a band-correction algorithm to T. This algorithm is:

$$T^* = b + cT$$

where T* is the apparent temperature and b and c are the band-correction coefficients for each channel (supplied in appendix B).

The radiance can be computed by:

$$N(T) = \beta(\nu_c, T^*)$$

where ν_c is supplied in appendix B (band-correction coefficients).

Appendix B

TIROS-N

I. AVHRR (Section 5.1)

a_{ij} - coefficients to convert PRT counts to temperature (K)

PRT	a_o	a_1	a_2	a_3	a_4
i=1	277.73	0.047752	8.29×10^{-6}	0.0	0.0
2	277.41	0.046637	11.01×10^{-6}	0.0	0.0
3	277.14	0.045188	14.77×10^{-6}	0.0	0.0
4	277.42	0.046387	10.59×10^{-6}	0.0	0.0

b_i - PRT weighting factors

b_i	b_2	b_3	b_4
0.25	0.25	0.25	0.25

Normalized response function (See appendix A)

Channel 3

$\nu 1$ 2496.1357 cm^{-1}
$\Delta\nu$ 6.36541 cm^{-1}
n 60

$\phi(\upsilon_1)$	0.0	0.92952E-03	0.19064E-02	0.28019E-02
	0.34776E-02	0.38782E-02	0.40496E-02	0.40441E-02
	0.39138E-02	0.37108E-02	0.34871E-02	0.32947E-02
	0.32635E-02	0.30885E-02	0.30618E-02	0.30753E-02
	0.31211E-02	0.31912E-02	0.32775E-02	0.33720E-02
	0.34668E-20	0.35539E-02	0.36257E-02	0.36805E-02
	0.37193E-02	0.37434E-02	0.37539E-02	0.37520E-02
	0.37389E-02	0.37158E-02	0.36838E-02	0.36442E-02
	0.35982E-02	0.35468E-02	0.34887E-02	0.34209E-02
	0.33399E-02	0.32459E-02	0.31493E-02	0.30626E-02
	0.29984E-02	0.29687E-02	0.29596E-02	0.29200E-02
	0.27958E-02	0.25408E-02	0.21780E-02	0.17654E-02
	0.13610E-02	0.10103E-02	0.71843E-03	0.48297E-03
	0.30148E-03	0.17153E-03	0.88544E-04	0.41631E-04
	0.18720E-04	0.77809E-05	0.28887E-09	0.0 $\phi(\nu_{60})$

Channel 4

	$\nu 1$	840.0337	
	$\Delta\nu$	2.41389	
	n	60	

$\phi(\upsilon^1)$	0.0	0.37701E-04	0.73654E-04	0.10611E-03
	0.14390E-03	0.24906E-03	0.50024E-03	0.95828E-03
	0.15939E-02	0.23496E-02	0.31779E-02	0.40893E-02
	0.51155E-02	0.62748E-03	0.74753E-02	0.85702E-02
	0.94211E-02	0.10012E-01	0.10418E-01	0.10718E-01
	0.10961E-01	0.11164E-01	0.11335E-01	0.11489E-01
	0.11635E-01	0.11786E-01	0.11954E-01	0.12147E-01
	0.12374E-01	0.12644E-01	0.12877E-01	0.12887E-01
	0.12539E-01	0.12331E-01	0.12071E-01	0.11931E-01
	0.11982E-01	0.12175E-01	0.12387E-01	0.12766E-01
	0.13462E-01	0.14131E-01	0.14239E-01	0.13355E-01
	0.11367E-01	0.87492E-02	0.60630E-02	0.38563E-02
	0.23495E-02	0.13991E-02	0.84093E-01	0.51723E-03
	0.33615E-03	0.24878E-03	0.20690E-03	0.16664E-03
	0.11659E-03	0.59942E-04	0.61584E-08	0.0 $\phi(\nu_{60})$

Channel 5--Repeat of channel 4 data.

N_{sp}- Radiance of space including nonlinearity correction

Channel	N_{SP} (mW/sr M^2 cm^{-1})
3	0.0
4	-1.151
5	-1.151

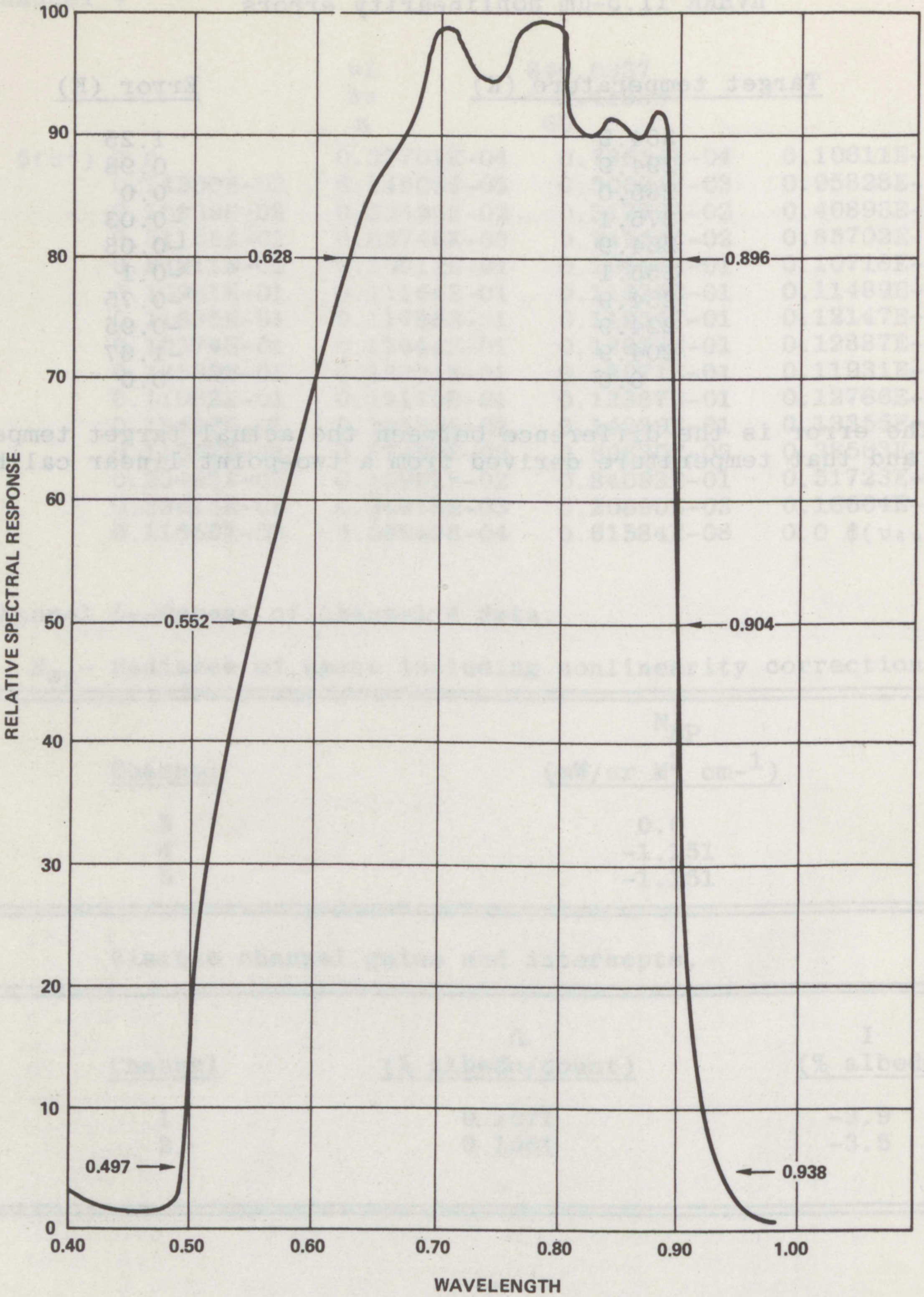
Visible channel gains and intercepts.

Channel	G (% albedo/count)	I (% albedo)
1	0.1071	-3.9
2	0.1051	-3.5

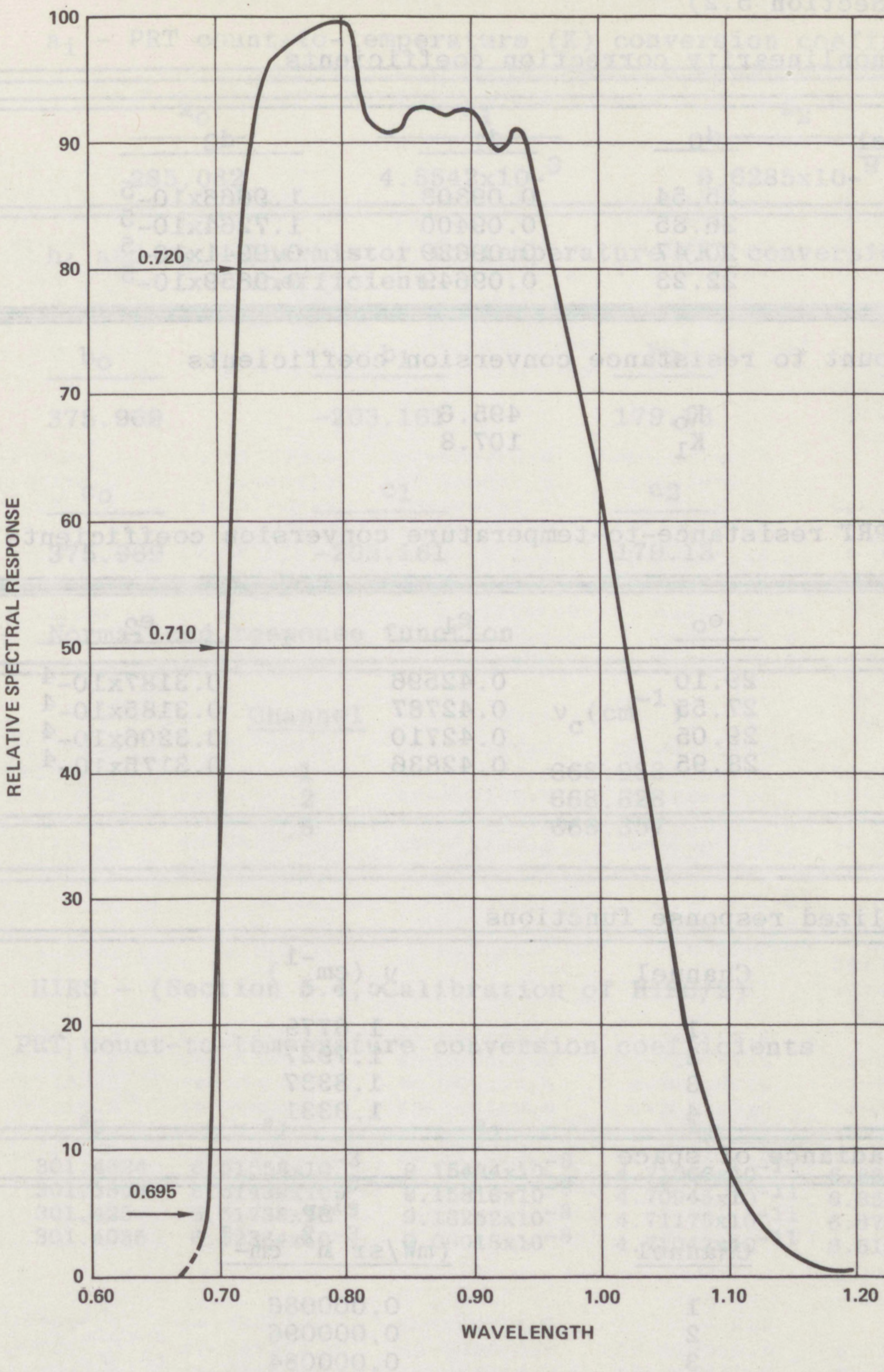
AVHRR 11.5-μm nonlinearity errors

Target temperature (K)	Error (K)
304.9	1.25
294.9	0.98
285.0	0.0
275.1	-0.03
264.9	-0.08
255.1	-0.1
234.9	-0.75
224.9	-0.95
204.9	-1.67
0.0	0.0

The error is the difference between the actual target temperature and that temperature derived from a two-point linear calibration.



Channel #1. AVHRR Spectral Response



Channel #2. AVHRR Spectral Response

II. MSU (Section 5.2)

d_i - nonlinearity correction coefficients

Channel	d_0	d_1	d_2
1	35.54	0.09303	1.9666×10^{-5}
2	26.85	0.09400	1.7264×10^{-5}
3	20.47	0.09639	0.9941×10^{-5}
4	22.23	0.09649	0.9659×10^{-5}

PRT count to resistance conversion coefficients

K_o	495.6
K_1	107.8

e_i - PRT resistance-to-temperature conversion coefficients

PRT	e_o	e_1	e_2
1A	29.10	0.42596	0.3187×10^{-4}
2A	27.55	0.42787	0.3185×10^{-4}
1B	29.05	0.42710	0.3206×10^{-4}
2B	28.95	0.42836	0.3175×10^{-4}

Normalized response functions

Channel	ν_c (cm^{-1})
1	1.6779
2	1.7927
3	1.8337
4	1.9331

N_{sp}-Radiance of space

Channel	N_{SP} (mW/sr M^2 cm^{-1})
1	0.000086
2	0.000096
3	0.000084
4	0.000092

III. SSU (Section 5.3)

a_i - PRT count-to-temperature (K) conversion coefficient

a_o	a_1	a_2
285.082	4.5542×10^{-3}	9.6285×10^{-9}

h_i and c_i - Thermistor to temperature (K) conversion coefficient

b_o	b_1	b_2	b_3
375.969	-203.161	179.13	-85.16
c_o	c_1	c_2	c_3
375.969	-203.161	179.13	-85.16

Normalized response function

Channel	$\nu_c(cm^{-1})$
1	668.988
2	668.628
3	668.357

IV. HIRS - (Section 5.4, Calibration of HIRS/2)

IWT PRT count-to-temperature conversion coefficients

PRT	a_0	a_1	a_2	a_3	a_4
1	301.4624	6.51558×10^{-3}	9.15434×10^{-8}	4.71066×10^{-11}	6.83373×10^{-16}
2	301.3504	6.51439×10^{-3}	9.15816×10^{-8}	4.70945×10^{-11}	6.85893×10^{-16}
3	301.425	6.51738×10^{-3}	9.16252×10^{-8}	4.71175×10^{-11}	6.87601×10^{-16}
4	301.4035	6.52364×10^{-3}	9.00018×10^{-8}	4.71042×10^{-11}	6.61634×10^{-16}

HIRS/2 Normalized response functions

CHANNEL 1

νI 0.64478E+03

Δν 0.15569E+01

n 30

φ(ν1)

0.0	0.0	0.0	0.0	0.0
0.59535E-03	0.13780E-02	0.19544E-02	0.22813E-02	0.37781E-02
0.67337E-02	0.65331E-02	0.10956E-01	0.37600E-01	0.10773E+00
0.24056E+00	0.13744E+00	0.42285E-01	0.16070E-01	0.96671E-02
0.70848E-02	0.45358E-02	0.30782E-02	0.19029E-02	0.14659E-03
0.0	0.0	0.0	0.0	0.0 φ(ν30)

CHANNEL 2

0.64963E+03

0.17348E+01

30

0.0	0.38536E-04	0.61955E-04	0.55126E-04	0.48187E-05
0.0	0.18996E-04	0.24868E-03	0.54076E-03	0.98188E-03
0.19493E-02	0.53736E-02	0.15249E-01	0.35984E-01	0.56572E-01
0.66207E-01	0.71556E-01	0.73453E-01	0.70851E-01	0.67441E-01
0.57290E-01	0.32595E-01	0.12600E-01	0.37951E-02	0.17191E-02
0.11304E-02	0.57940E-03	0.20094E-03	0.0	0.0

CHANNEL 3

0.66239E+03

0.18372E+01

30

0.0	0.12939E-03	0.25370E-03	0.49574E-03	0.74091E-03
0.68609E-03	0.15904E-02	0.29565E-02	0.54024E-02	0.10279E-01
0.16939E-01	0.25465E-01	0.35152E-01	0.46499E-01	0.58506E-01
0.65313E-01	0.65012E-01	0.60953E-01	0.54585E-01	0.43027E-01
0.25858E-01	0.12643E-01	0.56397E-02	0.23568E-02	0.11728E-02
0.99069E-03	0.77027E-03	0.56020E-03	0.34185E-03	0.49624E-07

CHANNEL 4

0.67213E+03

0.20952E+01

30

0.0	0.19732E-03	0.26173E-03	0.31839E-03	0.43452E-03
0.59934E-03	0.74702E-03	0.93328E-03	0.30657E-02	0.71495E-02
0.15859E-01	0.29669E-01	0.43223E-01	0.51285E-01	0.55779E-01
0.56275E-01	0.54627E-01	0.51420E-01	0.45299E-01	0.30597E-01
0.15455E-01	0.69094E-02	0.28103E-02	0.12985E-02	0.95467E-03
0.81771E-03	0.66252E-03	0.45631E-03	0.23091E-03	0.27196E-07

CHANNEL 5

0.69215E+03

0.16462E+01

30

0.0	0.0	0.17603E-03	0.42121E-03	0.73494E-03
0.17055E-02	0.31094E-02	0.68216E-02	0.13675E-01	0.25076E-01
0.37010E-01	0.46951E-01	0.53012E-01	0.56768E-01	0.58225E-01
0.58345E-01	0.56076E-01	0.52079E-01	0.45086E-01	0.35510E-01
0.24314E-01	0.14677E-01	0.79779E-02	0.42149E-02	0.22060E-02

0.15887E-02	0.10903E-02	0.51661E-03	0.17387E-03	0.21101E-07

CHANNEL 6
0.70292E+03
0.20697E+01
30

0.0	0.10683E-03	0.35175E-03	0.54755E-03	0.71655E-03
0.10437E-02	0.24346E-02	0.43927E-02	0.93891E-02	0.17538E-01
0.29015E-01	0.39233E-01	0.48418E-01	0.55492E-01	0.56534E-01
0.53720E-01	0.49329E-01	0.43743E-01	0.33313E-01	0.19285E-01
0.88276E-02	0.39846E-02	0.18884E-02	0.10136E-02	0.67522E-03
0.77611E-03	0.71517E-03	0.48018E-03	0.22767E-03	0.26550E-07

CHANNEL 7
0.71868E+03
0.21469E+01
30

0.0	0.12999E-03	0.25128E-03	0.41487E-03	0.47051E-03
0.60941E-03	0.13171E-02	0.24532E-02	0.64535E-02	0.16744E-01
0.34688E-01	0.48257E-01	0.49030E-01	0.47343E-01	0.48389E-01
0.49120E-01	0.47376E-01	0.42798E-01	0.32389E-01	0.18733E-01
0.89446E-02	0.42907E-02	0.20624E-02	0.10671E-02	0.79916E-03
0.59123E-03	0.41487E-03	0.36511E-03	0.32464E-03	0.52829E-07

CHANNEL 8
0.85874E+03
0.29503E+01
30

0.0	0.20970E-04	0.11557E-03	0.26923E-03	0.42594E-03
0.71324E-03	0.20680E-02	0.63747E-02	0.16130E-01	0.27272E-01
0.31854E-01	0.28090E-01	0.23958E-01	0.23597E-01	0.26615E-01
0.30642E-01	0.29340E-01	0.23980E-01	0.18849E-01	0.15587E-01
0.12560E-01	0.93453E-02	0.57336E-02	0.29580E-02	0.13134E-02
0.54309E-03	0.30317E-03	0.20612E-03	0.98819E-04	0.79949E-08

CHANNEL 9
0.97327E+03
0.35114E+01
30

0.0	0.0	0.32686E-04	0.15474E-03	0.23178E-03
0.34605E-03	0.44637E-03	0.58700E-03	0.11863E-02	0.26227E-02
0.58356E-02	0.13746E-01	0.24057E-01	0.30806E-01	0.31946E-01
0.30989E-01	0.30931E-01	0.33060E-01	0.34309E-01	0.24791E-01
0.10504E-01	0.41005E-02	0.16395E-02	0.90045E-03	0.48867E-03
0.43136E-03	0.33065E-03	0.21892E-03	0.10863E-03	0.75578E-08

CHANNEL 10
0.11664E+04
0.43724E+01
30

0.0	0.72668E-04	0.20591E-03	0.39377E-03	0.15113E-02

0.63529E-02	0.16438E-01	0.15287E-01	0.13630E-01	0.14088E-01
0.15338E-01	0.16610E-01	0.16912E-01	0.16326E-01	0.15880E-01
0.15695E-01	0.15131E-01	0.13897E-01	0.11770E-01	0.93964E-02
0.72436E-02	0.43396E-02	0.13362E-02	0.38562E-03	0.12278E-03
0.14573E-03	0.12214E-03	0.62856E-04	0.21571E-04	0.10519E-08

CHANNEL 11
0.13002E+04
0.44690E+01
30

0.0	0.13828E-03	0.21610E-03	0.31746E-03	0.42389E-03
0.45338E-03	0.73419E-03	0.14339E-02	0.33733E-02	0.76183E-02
0.14344E-01	0.19363E-01	0.22858E-01	0.25275E-01	0.25850E-01
0.25140E-01	0.23369E-01	0.20228E-01	0.14814E-01	0.89935E-02
0.46482E-02	0.21809E-02	0.82877E-03	0.40805E-03	0.30361E-03
0.20551E-03	0.14941E-03	0.98024E-04	0.10751E-04	0.0

CHANNEL 12
0.13850E+04
0.65379E+01
30

0.0	0.16205E-04	0.48341E-04	0.91743E-04	0.11248E-03
0.13542E-03	0.17451E-03	0.63797E-03	0.28377E-02	0.91147E-02
0.12855E-01	0.12997E-01	0.12396E-01	0.11942E-01	0.12265E-01
0.12240E-01	0.11054E-01	0.92167E-02	0.79691E-02	0.80158E-02
0.82459E-02	0.78370E-02	0.77852E-02	0.40281E-02	0.67062E-03
0.15221E-03	0.80740E-04	0.37131E-04	0.21406E-06	0.0

CHANNEL 13
0.21574E+04
0.26276E+01
30

0.0	0.30060E-04	0.22036E-03	0.38340E-03	0.60588E-03
0.93276E-03	0.21316E-02	0.53916E-02	0.12933E-01	0.24509E-01
0.34065E-01	0.39017E-01	0.45438E-01	0.49207E-01	0.47191E-01
0.39833E-01	0.30792E-01	0.21572E-01	0.12694E-01	0.64428E-02
0.33730E-02	0.15011E-02	0.96914E-03	0.72675E-03	0.45805E-03
0.18337E-03	0.0	0.0	0.0	0.0

CHANNEL 14
0.21713E+04
0.26414E+01
30

0.0	0.0	0.24504E-04	0.13143E-03	0.25461E-03
0.37555E-03	0.50986E-03	0.87127E-03	0.18636E-02	0.38958E-02
0.91194E-02	0.18925E-01	0.30354E-01	0.39493E-01	0.43922E-01
0.43988E-01	0.41861E-01	0.40717E-01	0.39441E-01	0.32244E-01
0.17690E-01	0.70879E-02	0.26174E-02	0.12528E-02	0.71984E-03
0.54343E-03	0.41303E-03	0.23317E-03	0.46055E-04	0.83335E-09

CHANNEL 15

0.22007E+04
0.22966E+01
30

0.0	0.79733E-04	0.21621E-03	0.37126E-03	0.57019E-03
0.72901E-03	0.95111E-03	0.17292E-02	0.33760E-02	0.67461E-02
0.12594E-01	0.19282E-01	0.26297E-01	0.31995E-01	0.36159E-01
0.37675E-01	0.37255E-01	0.35665E-01	0.35300E-01	0.36850E-01
0.37685E-01	0.33881E-01	0.22589E-01	0.10155E-01	0.40117E-02
0.16927E-02	0.90866E-03	0.54144E-03	0.16167E-03	0.81766E-08

CHANNEL 16

0.22042E+04
0.45552E+01
30

0.0	0.14519E-04	0.90289E-04	0.19591E-03	0.27279E-03
0.29177E-03	0.38869E-03	0.73598E-03	0.13389E-02	0.28889E-02
0.60880E-02	0.11783E-01	0.18138E-01	0.22411E-01	0.23877E-01
0.24405E-01	0.25845E-01	0.28875E-01	0.27099E-01	0.14968E-01
0.54040E-02	0.20352E-02	0.90562E-03	0.51643E-03	0.37920E-03
0.32251E-03	0.20182E-03	0.60547E-04	0.0	0.42874E-12

CHANNEL 17

0.23206E+04
0.26448E+01
30

0.0	0.79604E-06	0.13127E-03	0.29242E-03	0.41079E-03
0.68353E-03	0.12220E-02	0.27048E-02	0.59437E-02	0.11609E-01
0.20172E-01	0.28871E-01	0.34953E-01	0.37382E-01	0.37032E-01
0.35416E-01	0.35438E-01	0.38234E-01	0.38378E-01	0.26748E-01
0.13460E-01	0.45415E-02	0.19994E-02	0.10384E-02	0.53769E-03
0.43853E-03	0.30908E-03	0.13971E-03	0.18749E-04	0.0

CHANNEL 18

0.24413E+04
0.44793E+01
30

0.0	0.56051E-04	0.16357E-03	0.31492E-03	0.43911E-03
0.62260E-03	0.10040E-02	0.19815E-02	0.31389E-02	0.48298E-02
0.66208E-02	0.89415E-02	0.11866E-01	0.16394E-01	0.22548E-01
0.27661E-01	0.28402E-01	0.25735E-01	0.22139E-01	0.17642E-01
0.11452E-01	0.57890E-02	0.27498E-02	0.12093E-02	0.51102E-03
0.50647E-03	0.36630E-03	0.15953E-03	0.89575E-05	0.0

CHANNEL 19

0.24870E+04
0.10672E+02
30

0.0	0.82141E-05	0.32770E-04	0.63039E-04	0.94635E-04
0.13096E-03	0.17462E-03	0.24440E-03	0.36272E-03	0.77008E-03
0.16924E-02	0.36865E-02	0.64839E-02	0.83669E-02	0.91290E-02
0.92284E-02	0.89148E-02	0.84298E-02	0.82562E-02	0.89863E-02
0.92917E-02	0.58195E-02	0.21922E-02	0.72760E-03	0.33192E-03
0.12578E-03	0.83615E-04	0.54912E-04	0.17244E-04	0.0

Band-correction coefficients

Channel	ν_c	b	C
1	668.00	.99986	.047
2	679.23	.99979	.067
3	691.12	.99962	.131
4	703.56	.99991	.015
5	716.05	.99993	.010
6	732.38	.99974	.092
7	748.27	1.00015	-.101
8	897.71	1.00013	-.252
9	1027.87	.99978	.118
10	1217.10	.99903	-.132
11	1363.69	.99982	.136
12	1484.35	.99948	.424
13	2190.43	.99969	-.015
14	2212.65	1.00011	.041
15	2240.15	1.00032	.074
16	2276.27	1.00057	.143
17	2360.63	1.00025	.060
18	2511.95	1.00020	.110
19	2671.18	1.00175	.650

REFERENCES

Brower, Robert L., "DRIR Calibration," National Environmental Satellite Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Suitland, Maryland, 1977.

Schneider, John R., "Guide for Designing RF Ground Receiving Stations for TIROS-N," NOAA Technical Report, NESS 75, December 1976.

Schwalb, Arthur, "The TIROS-N/NOAA A-G Satellite Series," NOAA Technical Memorandum, NESS 95, March 1978.

Williamson, L. Edwin, "Calibration Technology for Meteorological Satellites," Atmospheric Science Laboratory Monograph Series, U.S. Army Electronics Command, White Sands Missile Range, New Mexico, June 1977.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1979 311-046/312

(Continued from inside front cover)

NESS 83 River Basin Snow Mapping at the National Environmental Satellite Service. Stanley R. Schneider, Donald R. Wiesnet, and Michael C. McMillan, November, 1976, 19 pp. (PB-263-816/AS)

NESS 84 Winter Snow-Cover Maps of North America and Eurasia From Satellite Records, 1966-1976. Michael Matson, March 1977, 28 pp. (PB-267-393/AS)

NESS 85 A Relationship Between Weakening of Tropical Cyclone Cloud Patterns and Lessening of Wind Speed. James B. Lushine, March 1977, 12 pp. (PB-267-392/AS)

NESS 86 A Scheme for Estimating Convective Rainfall From Satelliue Imagery. Roderick A. Scofield and Vincent J. Oliver, April 1977, 47 pp. (PB-270-762/AS)

NESS 87 Atlantic Tropical and Subtropical Cyclone Classifications for 1976. D. C. Gaby, J. B. Lushine, B. M. Mayfield, S. C. Pearce, K.O. Poteat, and F. E. Torres, April 1977, 13 pp. (PB-269-674/AS)

NESS 88 National Environmental Satellite Service Catalog of Products. Dennis C. Dismachek (Editor), June 1977, 102 pp. (PB-271-315/AS)

NESS 89 A Laser Method of Observing Surface Pressure and Pressure-Altitude and Temperature Profiles of the Troposphere From Satellites. William L. Smith and C. M. R. Platt, July 1977, 38 pp. (PB-272-660/AS)

NESS 90 Lake Erie Ice: Winter 1975-76. Jenifer H. Wartha, August 1977, 68 pp. (PB-276-386/AS)

NESS 91 In-Orbit Storage of NOAA-NESS Standby Satellites. Brtce Sharts and Chris Dunker, September 1977, 3 pp. (PB-283-078/AS)

NESS 92 Publications and Final Reports on Contracts and Grants, 1976. Catherine M. Frain (Compiler), August 1977, 11 pp. (PB-273-169/AS)

NESS 93 Computations of Solar Insolation at Boulder, Colorado. Joseph H. Pope, September 1977, 13 pp. (PB-273-679/AS)

NESS 94 A Report on the Chesapeake Bay Region Nowcasting Experiment. Roderick A. Scofield and Carl E. Weiss, December 1977, 52 pp. (PB-277-102/AS)

NESS 95 The TIROS-N/NOAA A-G Satellite Series. Arthur Schwalb, March 1978, 75 pp. (PB-283-859/AS)

NESS 96 Satellite Data Set for Solar Incoming Radiation Studies. J. Dan Tarpley, Stanley R. Schneider, J. Emmett Bragg, and Marshall P. Waters, III, May 1978, 36 pp. (PB-284-740/AS)

NESS 97 Publications and Final Reports on Contracts and Grants, 1977. Catherine M. Frain (Compiler), August 1978, 13 pp. (PB-287-855/AS)

NESS 98 Quantitative Measurements of Sea Surface Temperature at Several Locations Using the NOAA-3 Very High Resolution Radiometer. Laurence Breaker, Jack Klein, and Michael Pitts, September 1978, 28 pp. (PB-288-488/AS)

NESS 99 An Empirical Model for Atmospheric Transmittance Functions and Its Application to the NIMBUS-6 HIRS Experiment. P.G. Abel and W.L. Smith, NESS, and A. Arking, NASA, September 1978, 29 pp. (PB-288-487/AS)

NESS 100 Characteristics and Environmental Properties of Satellite-Observed Cloud Rows. Samuel K. Beckman (in consultation).

NESS 101 A Comparison of Satellite Observed Middle Cloud Motion With GATE Rawinsonde Data. Leroy D. Herman, January 1979, 13 pp. (PB-292-341/AS)

NESS 102 Computer Tracking of Temperature-Selected Cloud Patterns. Lester F. Hubert, January 1979, 15 pp. (PB-292-159/AS)

NESS 103 Objective Use of Satellite Data To Forecast Changes in Intensity of Tropical Disturbances. Carl O. Erickson, April 1979, 44 pp. (PB-298-915)

NESS 104 Publications and Final Reports on Contracts and Grants. Catherine M. Frain, (Compiler), September 1979.

NESS 105 Optical Measurements of Crude Oil Samples Under Simulated Conditions. Warren A. Hovis and John S. Knoll, October 1979, 20 pp.

NESS 106 An Improved Model for the Calculation of Longwave Flux at 11 m. P. G. Abel and A. Gruber, October 1979, 24 pp.

NOAA--S/T 79-315