THE TIROS-N MICROWAVE SOUNDER UNIT

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SUMMARY

The TIROS-N Microwave Sounder Unit (MSU) is described. The MSU uses passive radiometry in the 50 to 60 GHz region to remotely measure the three-dimensional temperature distribution of the Earth's atmosphere.

INTRODUCTION

The TIROS-N Microwave Sounder Unit (MSU) is a four-frequency passive radiometer operating in the 50 to 60 GHz range and is used to measure the vertical and horizontal global temperature distribution of the Earth's atmosphere. A series of satellites beginning with TIROS-N, launched on 13 October 1978 and ending with NOAA-G, will carry the MSU instruments into space. The TIROS-N/NOAA satellite series is described in detail elsewhere.[1]

Temperature sounding techniques and the MSU are descended directly from the Scanning Microwave Spectrometer (SCAMS) flown aboard NIMBUS-6 in 1975.[2] The basic method of atmospheric temperature sounding from space involves observing at several frequencies on the wings of the 60 GHz oxygen line. The height above the surface at which the observed radiation originates will depend upon the particular frequency band. For example, at 59 GHz the maximum radiation originates at an altitude of 17 Km while at 55 GHz it originates at 10 Km. Horizontal resolution is provided by scanning a narrow beam across the satellite ground track. Figure 1 shows the four MSU vertical weighting functions with altitude given in millibars.

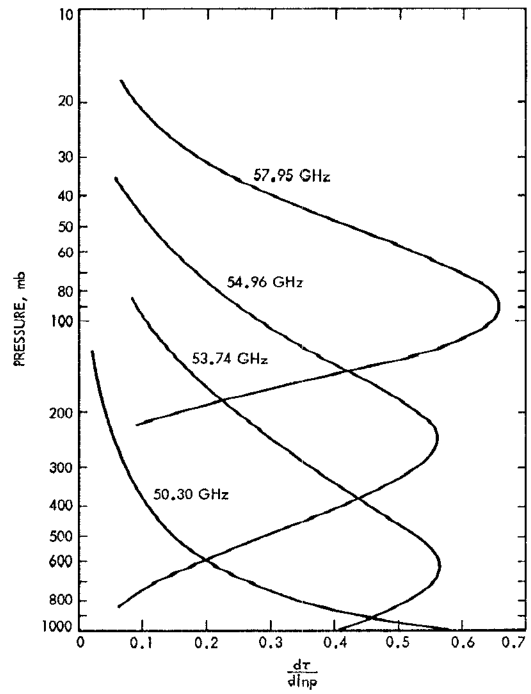

Figure 1. MSU Oxygen Line Weighting Functions

INSTRUMENT DESCRIPTION

Figure 2 is a photograph of the instrument showing the scan mechanism and the two antennas on the top and the RF, IF and data chassis on the bottom. In orbit the scan mechanism faces the Earth. Table 1 lists the most important system parameters.

Figure 3 is a block diagram of the complete MSU. The antennas consist of two scanning reflectors and two fixed, corregated feed horns. The antennas have very high, main-beam efficiency and low sidelobes. The antenna beams step scan in a plane normal to the spacecraft orbital velocity vector. The Earth views are provided by 11 scan positions covering an angle of 47.4 degrees on each side of the nadir position. The 7.5 degree beams form a ground footprint varying from a 109 Km circle at nadir to a 177 × 323 Km ellipse at the maximum scan angle. Instument calibration is provided by one scan position toward space (3K) and another toward an ambient temperature black-body target ($\simeq$290K). A complete scan, including calibration, takes 25.6 seconds.

The microwave energy received by each antenna is separated into vertical and horizontal polarization components by an orthomode transducer. Each of these is then fed into one of the four radiometers. Each incoming signal is square-wave modulated by a Dicke switch so that a constant comparison is made between an ambient temperature reference and the incoming signal. The modulated signal passes through a ferrite isolator and is mixed in a low-noise balanced mixer with a signal from a Gunn local oscillator. The resulting IF is amplified, detected and then square-wave demodulated by a phase detector.

The dc output voltage, proportional to the antenna temperature, is digitized along with the antenna scan position, instrument temperatures and power supply voltage.

For each scan position, eight 16-bit words are sent in a bit stream to the spacecraft data system for transmittal to Earth.

Thermal control for the instrument is provided by two thermal radiator plates covered by movable louvers. The louvers are controlled by a bimetallic spring which senses temperature changes in the instrument. Instrument temperature in orbit varies less than five degrees. The power supply module is mounted remotely from the rest of the instrument and contains a separate power supply for each radiometer channel.

CALIBRATION

The radiometers are calibrated externally to the antenna by means of a black-body target for one calibra-

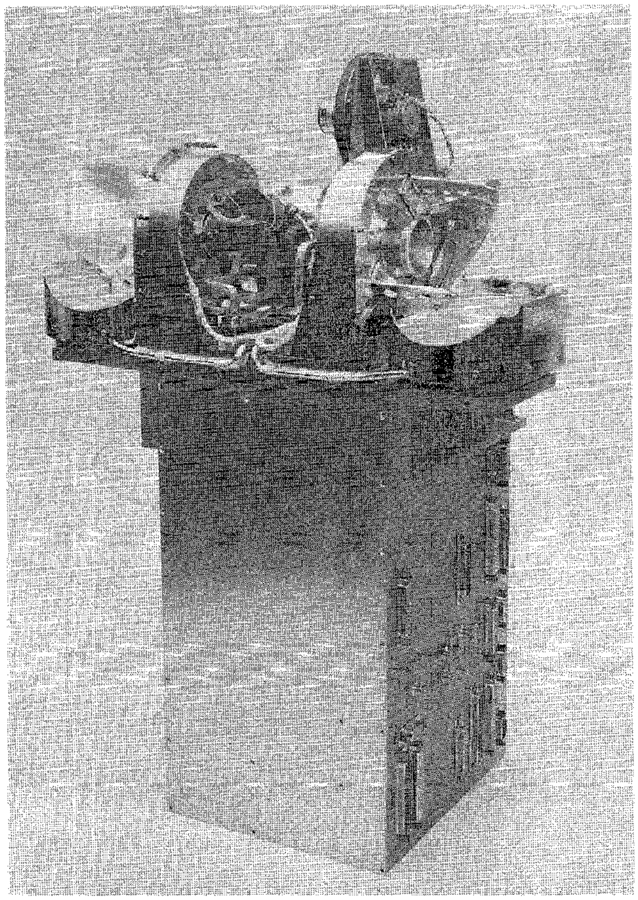

Figure 2. MSU Instrument

tion point and the 3K cosmic background as the other. A calibration is performed during each scan of the antennas every 25.6 seconds.

Before delivery of the instrument it undergoes extensive environmental testing. One of these tests is the thermal vacuum test where the instrument operates in a vacuum at temperatures which can be varied to simulate space conditions. Brewster angle black-body targets made from iron-filled epoxy are placed in front of the antennas to simulate cold space and the Earth. The Earth target is controllable in temperatures from 100K to 350K while the space target is held near 100K.

The thermal vacuum tests last approximately 10 days during which the instrument temperature is varied from 280K to 315K and the Earth target is varied over its entire range of 250 degrees in steps of approximately 25 degrees. This extensive and carefully controlled testing allows the calibration equation to be verified and measures the linearity of the system to better than one percent. The antenna temperature is related to the measured instrument outputs by the following calibration equation.

$$T_{ANT} = T_T + (C_E - C_T) \left[\frac{T_T - T_S}{C_T - C_S}\right] + A_o + A_1 (C_E - C_T) + A_2 (C_E - C_T)^2 \qquad (1)$$

where T_T = Temperature of the ambient calibration target.

T_S = Temperature of the space calibration, (3K in orbit; 100K in thermal vacuum)

C_E = Voltage output in arbitrary digital counts when viewing the Earth or Earth target.

C_T = Voltage output in the same digital counts when viewing the ambient calibration target.

C_S = Voltage output in digital counts when viewing space or the space target during thermal vacuum tests.

and A_o, A_1, A_2 are coefficients determined from thermal vacuum testing that correct the nonlinearity of the instrument over the range of antenna temperatures 100K to 350K and provide an arbitrary dc offset.

Typical values of these coefficients are:

$$A_o = 0.1$$
$$A_1 = 2 \times 10^{-3}$$
$$A_2 = 2 \times 10^{-6}$$

When equation (1) is applied to the complete thermal vacuum data set the rms difference between the calculated T_{ANT} from (1) and the measured temperature of the Earth target is approximately 0.5K averaged over all channels.

FLIGHT RESULTS

TIROS-N was launched on 13 October 1978 and NOAA-A on 27 June 1979. The MSU on TIROS-N has been operating for well over a year without incident. Smith[3] et al have made a preliminary analysis of the TIROS-N orbital data and have compared the MSU-derived vertical temperature profiles with the High Resolution Infrared Sounder (HIRS), radiosonde data and the National Meteorological Center (NMC) grid. Deviations from the HIRS temperature profiles are less than 0.5 degrees but vary as much as three degrees from the radiosonde data. However, in the 300 to 700 millibar region, the error approaches the 1.5 degree accuracy of the radiosond data. Comparisons of continental-scale MSU temperature maps with the NMC-generated grid show excellent agreement. Work is presently being carried out to incorporate the MSU data directly into the NMC grid.

REFERENCES

1. The TIROS-N/NOAA A-G Satellite Series; NOAA Technical Memorandum NESS 95; March 1978.

2. Microwave Spectroscopy Imagery of the Earth; Staelin, D. M., et al; Science, 2 Sept. 1977.

3. The TIROS-N operational Vertical Sounder; Smith, W. L.; Woolf, H. M.; Wark, D. Q.; McMilliam, L. M., Paper presented at NOAA-A Scientific Colloquim, Wash., D. C., May 3, 1979 and Geneva, Switzerland, May 5, 1979

ACKNOWLEDGEMENTS

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Table 1. MSU Parameters (Unit #4)

	Channel			
	1	2	3	4
Frequency (GHz)	50.30	53.74	54.96	57.95
RF bandwidth (MHz)	220	220	220	220
Integration time (sec)	1.82	1.82	1.82	1.82
ΔT rms (K) for 1.8 sec integration time	0.21	0.22	0.18	0.21
Dynamic range (k) (min)	0-400	0-400	0-400	0-400
Instrument absolute accuracy (K rms) (long term)	$\lesssim$ 1	$\lesssim$ 1	$\lesssim$ 1	$\lesssim$ 1
IF frequency range (MHz)	10-110	10-110	10-110	10-110
Antenna beamwidth (deg)	7.8 × 7.1	7.3 × 7.0	7.6 × 7.3	7.3 × 7.0
Antenna main beam efficiency (%)	95.3	95.5	95.2	97.4
Mass	29 kg			
Power	30 w			

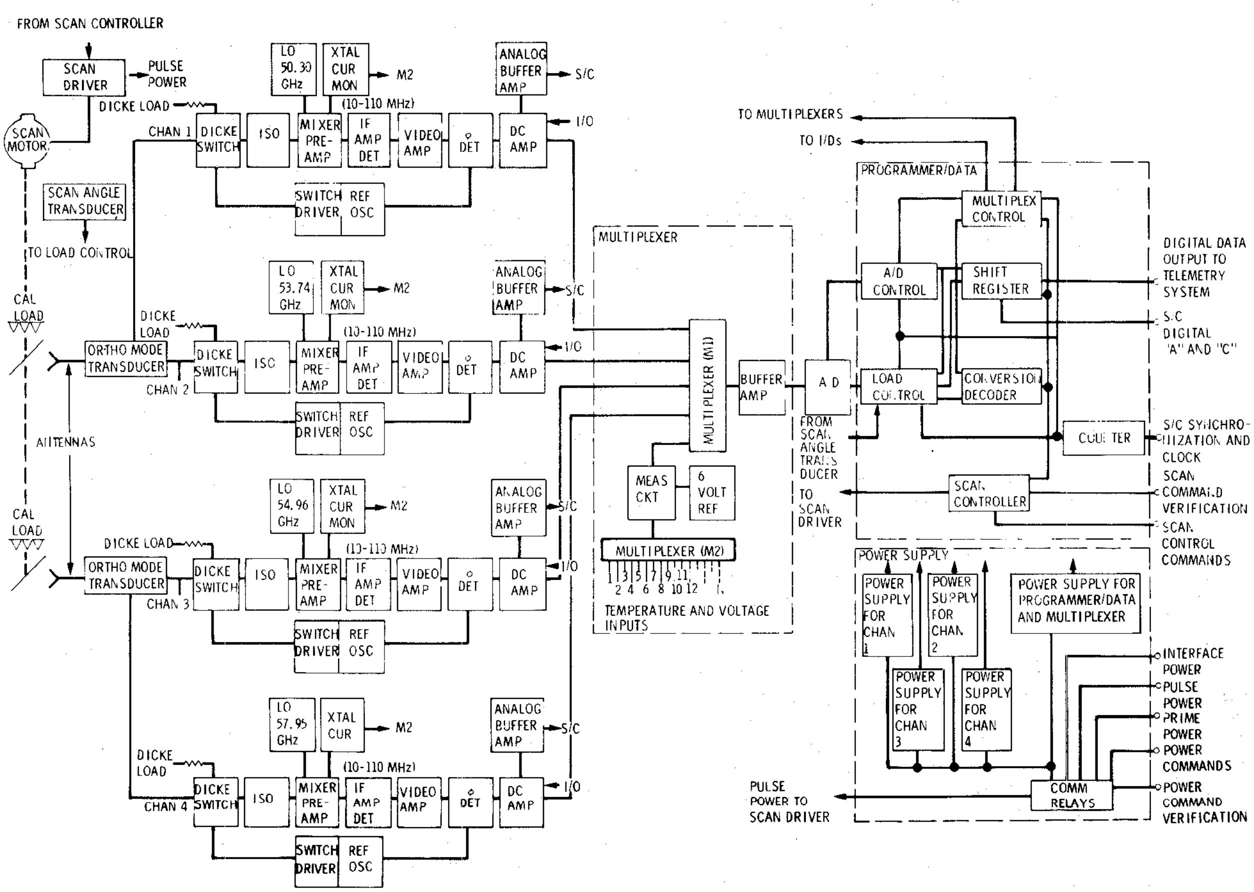

Figure 3. MSU Block Diagram