EARTH SENSING WITH LARGE APERTURE RADIOMETERS

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ABSTRACT

Three microwave radiometer instruments built by JPL for NASA for remote sensing of the Earth's atmosphere and surface are described. The three instruments are the Microwave Sounder Unit, the Scanning Multichannel Microwave Radiometer and the Microwave Limb Sounder.

I. Introduction

Earth Remote sensing from space using microwave radiometer techniques has been done for over 20 years. The advantage of using space instruments is their ability to provide global and synoptic coverage in a relatively short time. Microwave radiometers also have the ability to provide surface information through clouds, day and night, and to measure temperature and abundance of molecules in the Earth's atmosphere.

The first NASA Earth remote sensing microwave radiometers were the Electrically Scanned Microwave Radiometer (ESMR) and the Nimbus-E Microwave Spectrometer (NEMS) launched in 1972 on the Nimbus-E satellite. Improved versions of these instruments were launched on Nimbus-F in 1975. These instruments made measurements of rain rate, temperature profiles, water vapor and liquid water content in the atmosphere and sea ice concentration, ice classification and snow cover on the surface. In 1978, a follow-on to NEMS, the Microwave Sounder Unit (MSU), was launched on the TIROS-N satellite to measure the atmospheric temperature profile. Eight MSU instruments of the TIROS series have been flown, providing continuous information since 1978.

In 1978 the Scanning Multichannel Microwave Radiometer (SMMR) instrument was launched on the Nimbus-G and SeaSat A spacecraft. The SMMR on SeaSat A operated successfully for 95 days until the satellite failed. The SMMR on Nimbus-G operated successfully for nine years. The SMMR made measurements of the water vapor content, liquid water content and rain rate in the atmosphere and the sea state, sea surface temperature, sea ice concentration, ice classification snow cover and soil moisture on the surface. In 1992, the refurbished SMMR flight spare will be launched on the TOPEX satellite to measure the water vapor content in the atmosphere.

The Microwave Limb Sounder (MLS) instrument will be launched in 1991 on the Upper Atmospheric Research Satellite (UARS). This instrument will measure $C\ell O$, H_2O, and O_3 molecules in the atmosphere which are related to the O_3 destruction in the atmosphere.

In the following sections, the MSU, SMMR and MLS, which were built by JPL for NASA, will be discussed.

II. The Microwave Sounder Unit

The Microwave Sounder Unit (MSU) is a four-frequency passive radiometer operating in the 50 to 60 GHz range. It is used to measure the vertical and horizontal global temperature distribution of the Earth's atmosphere (1). 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 depends on 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 the antenna beam across the satellite ground track.

Figure 1 shows the MSU instrument with 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 important system characteristics, and Figure 2 shows the MSU block diagram.

The antennas consist of two scanning reflectors and two fixed corrugated feed horns. The antennas have a main-beam efficiency >95%. 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 a 2300 km swath. 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 47° scan angle. Instrument calibration is provided by one scan position toward space (2.7 K) and another toward an ambient temperature blackbody target (≈290 K). A complete scan, including calibration, takes 25.6 seconds.

Table 1. MSU Characteristics

Channel Frequencies (GHz)	50.3, 53.7, 54.5, 57.9
IF Bandwidth (MHz)	10-110
Integration Time (sec)	1.82
ΔT RMS (K)	<0.3
Absolute Temperature Accuracy (K)	≤1
Antenna Beamwidth (Deg)	7.5
Antenna Beam Efficiency (%)	>95
Mass (kg)	<29
Power (Watts)	<30

Table 2. SMMR Characteristics

Channel Frequencies (GHz)	6.6, 10.7, 18, 21, 37
IF Bandwidth (MHz)	10-110
Integration Time (msec)	126 to 30
ΔT RMS (K)	0.9 to 1.5
Absolute Temperature Accuracy (K)	2 (1 σ)
Antenna Beamwidth (Deg)	4.5 to 0.8
Antenna Beam Efficiency (%)	80 to 90
Mass (kg)	55
Power (Watts)	65

The microwave energy received by each antenna is separated into vertical and horizontal polarization components by an orthomode transducer, as shown in Figure 2. Each of these signals is then sent into one of the four Dicke switched radiometers. Each incoming signal is square-wave modulated by a ferrite switch so that a constant comparison is made between an ambient temperature reference and the incoming signal. The modulated signal passes through an isolator and is mixed in a low-noise balanced mixer with a local oscillator signal from a Gunn diode 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 to the spacecraft data system for transmission to Earth.

One of the best features of the MSU was the high absolute accuracy due to thermal load calibrations through the antenna system. The next generation of atmospheric sounders will be the Advanced Microwave Sounding Unit (AMSU). AMSU is being developed by NASA and NOAA and is scheduled for launch in 1993.

III. Scanning Multichannel Microwave Radiometer

The spaceborne Scanning Multichannel Microwave Radiometer (SMMR) measured passive radiation from the Earth's surface and the atmosphere (2). The radiation was measured at five frequencies and with both horizontal and vertical polarizations while the antenna had a conical scan with a 1200 km swath over the Earth's surface. Figure 3 shows the SMMR instrument and the SMMR characteristics are listed in Table 2. The microwave thermal emission from the Earth's surface and atmosphere was collected by an offset parabolic reflector antenna which focused this radiation into a multi-frequency antenna feed system. One of the major developments of SMMR was the multi-frequency corrugated feed horn shown in Figure 4. It has ten waveguide output ports corresponding to orthogonal polarizations at five frequencies from 6-37 GHz. Over this frequency range the feed loss was <1 dB, and the beam efficiencies ranged from 80-90%. The feed system was connected to the radiometer inputs through orthomode transducers for separating the polarizations and then through polarization, calibration, and ferrite switches. Figure 5 shows the block diagram of a typical Dicke switched radiometer channel.

The offset parabolic antenna had an 80-cm diameter aperture projected normal to the direction of observation and was scanned 25° to either side of the direction of satellite motion. The angle of the beam, with respect to nadir was maintained at 42° to provide a constant Earth-incidence angle of 50°. The beamwidth for 37 GHz was 0.8° and gives a surface resolution element for that channel of 17 × 26 km. Resolutions for other channels are larger in proportion to their respective wavelengths.

The major problem with SMMR data was the error due to the radiometer calibration and polarization rotation as the antenna scanned. The instrument was built with long waveguide runs and lossy components between the antenna, the calibration sky horns and the radiometers. This configuration required accurate knowledge of losses and temperature distributions along these paths. The lack of precision in the ground calibration of the instrument limited the accuracy of the data to 2 K.

The TOPEX Microwave Radiometer (TMR) is a non-scanned 3 frequency SMMR (18, 21 and 37 GHz). It will be launched on the TOPEX spacecraft in 1992. Special care has been taken to measure and model the losses and expected temperature distributions. It is expected that TMR will have an absolute accuracy of <1 K.

IV. The Microwave Limb Sounder (MLS)

The Microwave Limb Sounder (MLS) will measure thermal emission from selected molecular species in the atmosphere at millimeter wavelengths (3). The molecular emission of interest are chlorine monoxide (CℓO) at 204 GHz, ozone (O_3) at 206 GHz, and water vapor (H_2O) at 183 GHz. The altitude of the measurements is determined by measuring the atmospheric pressure in the oxygen (O_2) emission band at 63 GHz. Measurements are performed continuously, day and night. The instrument integrates measurements over 2-second intervals. Vertical resolution for all molecular measurements is $\approx$3 km.

Figure 6 shows the MLS instrument mounted on the vibration test facility. The elliptical offset parabolic antenna is 1.6 × 0.8 m. The three main assemblies are the radiometers, spectrometers and power supplies. The MLS block diagram is shown in Figure 7, and the instrument characteristics are summarized in Table 3.

Table 3. MLS Characteristics

Channel Frequencies (GHz)	63, 183, 205
IF Bandwidth (MHz)	500
Spectrometer Bandwidths (MHz)	2 to 128
Integration Time (sec)	1.8
ΔT RMS (K) (205 GHz)	1.2 to 0.2
Absolute Temperature Accuracy (K)	<1
Antenna Beamwidth (Deg)	0.2 to 0.07
Antenna Beam Efficiency (%)	>90
Mass (kg)	280
Power (Watts)	163

A switching mirror inside the radiometer box selects either the atmospheric signal from the antenna system, or a calibration from an internal target or a space view. Because of the high stability of the solid state radiometers, these radiometers will be operated in the total power mode. It is expected that gain calibrations will only be required every minute.

The signals from the switching mirror are separated into various spectral bands by a quasi-optic multiplexer. Ambient-temperature Schottky-diode mixers down-convert these bands to the intermediate frequencies. These signals are amplified by low noise amplifiers and then frequency-converted to a common center frequency and transmitted to the spectrometer assembly.

The spectrometer consists of a set of six identical 15-channel filter banks. The resolution of individual channels varies from 128 MHz on the edge to 2 MHz near the center of the spectral line being measured. This resolution is matched to the characteristic shape of the atmospheric emission lines over the altitude range covered. A detector following each filter channel produces a voltage proportional to the power received by that channel. This voltage is then integrated, digitized to 16 bits, and read by the command and data handling system where it will be transmitted to Earth.

In 1989, the MLS instrument was delivered for integration onto UARS. Launch of UARS is scheduled from the space shuttle in October 1991.

ACKNOWLEDGEMENTS

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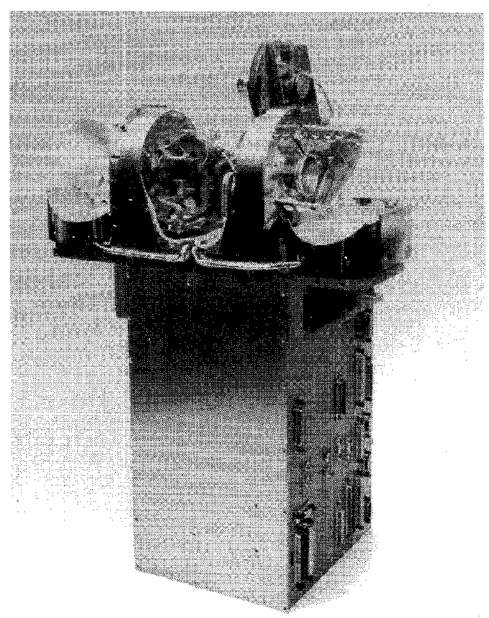

Figure 1. Microwave Sounder Unit (MSU)

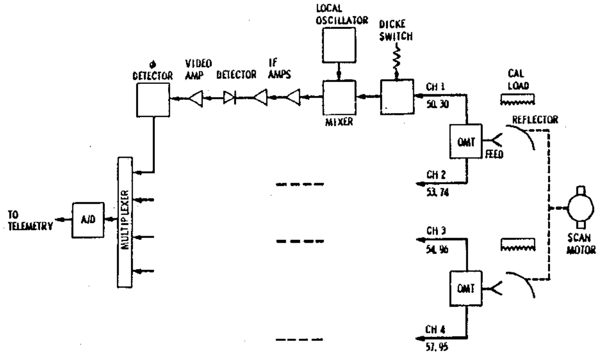

Figure 2. MSU Block Diagram

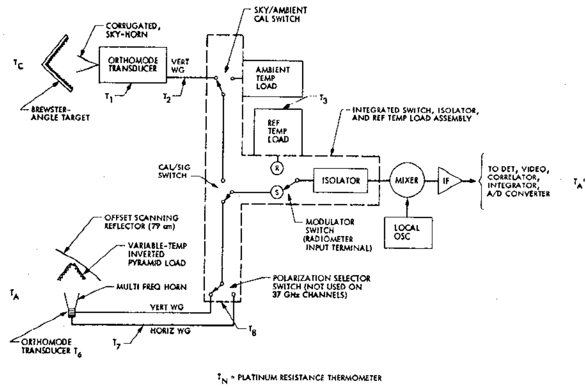

Figure 5. SMMR Typical Channel Block Diagram

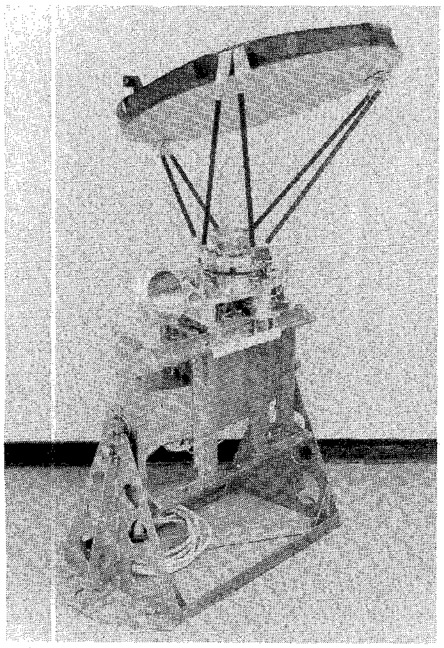

Figure 3. Scanning Multichannel Microwave Radiometer (SMMR)

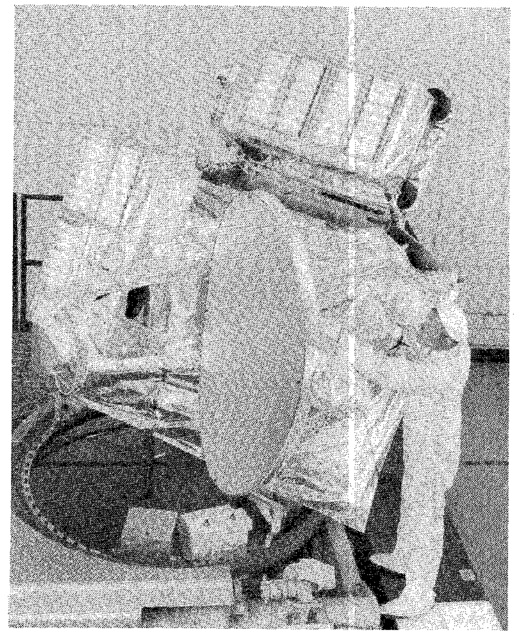

Figure 6. Microwave Limb Sounder (MLS)

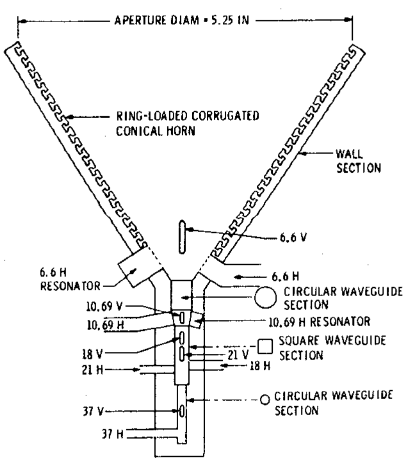

Figure 4. SMMR Multi-Frequency Feed Horn

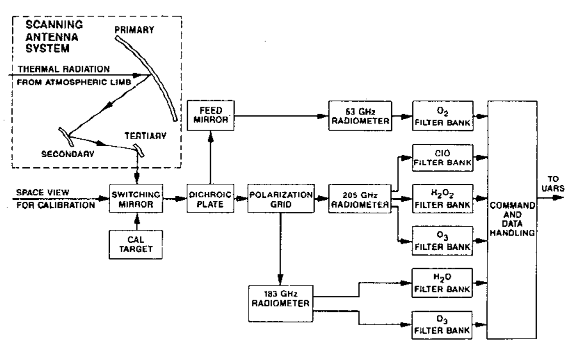

Figure 7. MLS Block Diagram