A MULTICHANNEL PASSIVE MICROWAVE ATMOSPHERIC TEMPERATURE SOUNDING SYSTEM

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ABSTRACT

The development of a small, lightweight, low-power, seven-channel passive microwave radiometer system for use on the Defense Meteorological Satellite Program (DMSP) is described. This 50-60 GHz sensor system operates in the region of an intense atmospheric oxygen absorption band to provide atmospheric temperature profiles to 30 kilometer altitudes on a global basis.

1. INTRODUCTION

Knowledge of the temperature distribution of the atmosphere on a global scale is a key factor in the prediction of various weather parameters by meteorologists. Although some such profile information is currently available from radiosonde, rocketsonde and infrared atmospheric sounding systems, each of these systems has its obvious limitations. This paper describes a multichannel passive microwave radiometric sensor system that has been developed (Ref. 1) for use on the Defense Meteorological Satellite Program (DMSP) to gather such temperature distribution information on a global basis. Atmospheric temperatures for pressure levels of 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20 and 10 mb; 14 thicknesses between these levels; and the temperature and pressure of the tropopause will ultimately be provided.

The radiometric characteristics of the atmosphere are determined primarily by the absorption and emission characteristics of the oxygen molecule in the 50-60 GHz band of the frequency spectrum. Since the mixing ratio of oxygen is constant in the atmosphere, the contribution of a particular layer of the atmosphere to the total radiation detected by a spaceborne radiometer operating in this frequency range is primarily controlled by the air temperature and the product of two competing factors — namely, the emission per unit volume, which decreases monotonically with height due to the decreasing air density, and the transmission factor of the atmosphere above the layer under consideration, which increases with height. The product results in a function (the weighting function) which typically peaks at some height and decreases with distance away from the peaking altitude. By choosing frequencies with different absorption coefficients, weighting functions emphasizing radiances from preselected atmospheric layers may be obtained. The problem of profiling the temperature of the atmosphere then reduces to finding the most probable profile which, when weighted by the appropriate weighting functions, produces the measured brightness temperature values of the selected frequencies.

Since the underlying earth surface also contributes to the detected radiation at those frequencies responding to the lowest portion of the atmosphere, the software used in the extraction of atmospheric information from the microwave data must be designed to eliminate the effects of the surface. A unique, highly efficient algorithm that accounts for varying surface emissivities, lower tropospheric effects, and terrain height variability has been developed to do this (Ref. 2).

Specification of the altitudes at which the weighting functions are to peak and the full width half maximum of the weighting functions establishes the center frequency and bandwidth of the individual sensor channels. At the higher peaking altitudes where the pressure broadening is reduced and the line widths are extremely narrow, both frequency and bandwidth selections must reflect a consideration of both software and hardware roles. Consequently, narrow bandwidths and a high degree of frequency stability are required at these altitudes.

Profiling of the atmosphere from sea level to an altitude of 30 kilometers has resulted in the selection of seven channels ranging in frequency from 50. 5 GHz to 59. 4 GHz as shown in Table I. A requirement for a maximum calibration uncertainty of 1 K and maximum NETD for the various channels of 0. 4 to 0. 6 K has established the electrical performance requirements of the sensor system. Stringent weight, power and size limitations of 11. 5 kg, 18 watts and 0. 20 x 0. 36 x 0. 41 meters respectively, have also restricted the physical characteristics of the sensor.

This paper describes the design and performance of a lightweight, low-power, seven-channel radiometer sensor system that satisfies these requirements.

2. SYSTEM CONFIGURATION

The Multichannel Passive Microwave Temperature Sounder System, shown in Figure 1 and in simplified block diagram form in Figure 2, consists of a mechanically scanned reflector antenna, a stepper motor/gear antenna drive, a seven-channel superheterodyne receiver, and signal processing/timing circuitry. Precise total system inflight calibration is achieved by viewing known radiometric temperatures through the antenna system. An accurately known ambient load (300 K nominal) and the cosmic background (2. 7 K) are used for this purpose. These absolute calibration points make it possible to determine the sensed antenna temperatures in an absolute manner.

The mechanically scanned reflector antenna system shown in Figure 3 consists of a lens-corrected, corrugated feed horn, a shrouded reflector and an orthogonal mode transducer (OMT). It provides a planar scan by a rotation of the reflector surface; this allows the antenna feed system to remain fixed. A metallic hood shrouds the reflector to eliminate back radiation and provides a guided interface to the calibration system. A thermal shroud is also incorporated into the design to shade the inflight calibration source apertures during scan and reduce thermal gradients at the calibration apertures.

As seen in Figure 4, the antenna beam is step-scanned through seven discrete earth-looking positions at a fixed, programmed rate, then is rapidly rotated, first to the warm calibration reference, then to the cold calibration reference, before the scanning sequence is repeated. Key scan parameters are detailed in Table II. Because the calibration paths are characterized by low reflective and dissipative losses, the equivalent antenna input temperature during calibration can be accurately determined.

The antenna input brightness temperature (T_i) is determined from the relationship

$$T_i = T_H - \frac{T_H - T_C}{V_C - V_H} (V_i - V_H)$$

where T_H = warm calibration input temperature, T_C cold calibration input temperature, V_H = output voltage during warm calibration, V_C = output voltage during cold calibration, V_i = output voltage corresponding to T_i . (The modulator temperature is not required in the above expression for T_i because of the thermal characteristics of the instrument and the periodicity of calibration.)

Signals in the 50 to 60 GHz frequency range are received by the antenna system and subsequently split into two orthogonal polarizations by an orthogonal mode transducer (OMT). The use of an OMT allows both orthogonal polarizations to be utilized, thereby establishing the initial level of frequency channelization. One polarization is used for the lower altitudes, Channels 1-4; the other polarization is used for the upper altitudes, Channels 5-7.

From the OMT the received signals are applied to a unique broadband, low-loss dual resistive vane modulator. This device serves to chop the input signal and does not, as mentioned previously, influence the determination of T_i . With an attenuation that exceeds

50 dB and an insertion loss of less than 0.3 dB over the entire frequency band this modulator approximates an ideal switch and thus avoids the switching errors associated with ferrite type modulators.

After modulation, one of the signals is applied to an RF diplexer, the other to an RF bandpass filter. The RF diplexer splits the signal into two bands containing Channels 1, and 2, 3, and 4 frequencies, respectively. Specifics of the channel peaking altitude, frequency, bandwidth and NETD were shown previously in Table I. The Channel 1 band is down-converted, amplified, filtered, and subsequently detected. Down-conversion is accomplished in a broadband balanced mixer in which GaAs Schottky-barrier diodes are used. Similarly the Channel 2, 3, and 4 band is down-converted and amplified in a common mixer-IF amplifier and then applied to an IF triplexer which splits the signal into three discrete channels of information, which are then detected by square-law detectors.

The signal from the other half of the dual-vane modulator, i.e., the signal applied to the RF bandpass filter, contains Channels 5, 6, and 7. The filter serves to remove the corresponding image frequencies. After filtering, these channels are treated in a manner identical to that used for Channels 2, 3 and 4. The overall receiver bandwidth and channelization characteristics are shown in Figure 5.

A single frequency stabilized Gunn oscillator is used as the local oscillator to conserve power and weight. The frequency of the oscillator was chosen such that potentially detrimental EMI signals would fall outside the filtered IF passbands. Stability specifications for the oscillator are based on the profiling accuracy required over a two-year life of the instrument. The fundamental Gunn oscillator is matched and locked to a high-Q Invar cavity to achieve the required long-term frequency stability. Since the stabilization network is totally passive, long-term reliability is assured.

After detection, the seven channels of information are processed by individually programmable stepped automatic gain control (SAGC) attenuators. The SAGC maintains the system gain such that the analog-to-digital converter resolution capability is optimized for any possible variation in the predetection gain. After gain conditioning, the signals are processed by individual synchronous demodulator integrate-and-dump circuits. These integrated signals are then multiplexed into a common 12-bit analog-to-digital (A/D) converter and subsequently demultiplexed into data storage and readout circuits. Critical points throughout the system are thermally monitored by temperature sensor readout channels which are multiplexed into the A/D converter for subsequent readout.

The system operates in both a synchronized mode and an independent or automatic mode. In the synchronized mode, an external synchronization signal causes the sensor to initiate scanning in a step-synchronized fashion with an onboard IR sensor. When the system is operated in the automatic mode, antenna scanning is completely independent of the external synchronization signal.

3. CALIBRATION

As described previously, the inflight calibration system, shown schematically in Figure 6, consists of two noise sources. A cold path views the cosmic background (2.7 K) for one calibration point and a built-in "warm" load ($\approx$300 K) is observed for the other calibration point. The radiometer (including the antenna) is calibrated once during each 32-second scan cycle.

The inflight calibration system is a well-matched, closed-path configuration with very low dissipative wall losses. A shroud on the reflector allows direct coupling to both the cold path and warm load. The cold path is an oversize circular transmission line that is used to restrict the radiometer field of view so that extraneous input signals due to both the surrounding spacecraft and the earth's atmosphere are minimized. Due to the location of the sensor on the spacecraft it is not possible for the sensor antenna to view the sky directly. Therefore, it is necessary to utilize a reflecting miter bend in the cold path to direct the antenna pattern in the proper direction. The warm load is an extended microwave radiator made up of a large number of tapered absorbing sections and is designed to provide a stable blackbody temperature source at approximately 300 K. An accurate measurement of the surface temperature of the load is provided as a result of the warm load thermal design. A shroud allows direct coupling to the antenna and a sun shield located on the antenna reflector prevents the warm load from viewing the sun, thereby enhancing the thermal stability of this load.

Precision primary temperature standards are used for laboratory calibration of the instrument. In these standards the surface temperature of the microwave load is measured very precisely and the reflection characteristics are extremely low. Two primary standards stabilized at approximately 78 K and 300 K are used to calibrate the radiometer in the laboratory under stable thermal-vacuum conditions. A remotely controlled, semiautomatic primary standard transport mechanism, Figure 7, is used in conjunction with the radiometer to accomplish the calibration process. Once the radiometer has been calibrated with at least two primary standards, the calibration and linearity of the instrument is verified by viewing additional standards at temperatures between the calibration extremes.

4. PACKAGING DESCRIPTION

To achieve the high packaging density required by system weight and size limitations, a compartmentized design has been used. As shown in Figure 8, the RF components of the receiver and the antenna feed horn are mounted to a honeycomb shelf. Use of a shelf allows the antenna reflector to be mounted high in the instrument, thereby avoiding radiation pattern interference from the instrument walls. Use of the shelf also allows the feed horn, orthogonal mode transducer and the modulator to be mounted close together on the same surface, reducing RF losses. A higher than usual packaging density for RF components is achieved by packaging the three mixers and IF amplifiers in three parallel routes on each side of the modulator. The IF filter and triplexers, as well as the seven detector/preamplifiers are located in the forward part of the lower compartment. All post detection circuitry is mounted on printed circuit cards located in the rear portion of this lower compartment.

5. SYSTEM PERFORMANCE

The overall measured performance of the sensor system is summarized in Table III. The final size, weight and power consumption of the sensor system are 0.2 x 0.28 x 0.41 meters, 11.2 kilograms, and 14.2 watts respectively. An antenna beam efficiency in excess of 95.8 percent and a beamwidth of 14.4 degrees or less were achieved at all seven frequencies and all seven beam positions.

6. REFERENCES

1. United States Air Force, Space and Missile Systems Organization, Contract F04701-75-C-0090.

2. Rigone, J. L. and A. P. Stogryn, "Data Processing for the DMSP Microwave Radiometer System," Eleventh International Symposium on Remote Sensing of Environment, April 1977, Poster Session P-123.

TABLE I. CHANNEL PARAMETER REQUIREMENTS

Channel	Peaking Height (km)	Frequency (GHz)	Bandwidth (MHz)	NETD
1	0 (window)	50.5	400	0.6
2	2	53.2	400	0.4
3	6	54.35	400	0.4
4	10	54.9	400	0.4
5	30	58.4	115	0.5
6	16	58.825	400	0.4
7	22	59.4	250	0.4

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TABLE II. KEY SCAN PARAMETERS

Scan Type	Cross-Track Nadir
Cross-Track Positions	7
Calibration Positions	2-Cosmic Background and ≈300 K
Total Cross-Track Scan	±36°
Total Scan Period	32 Seconds
Dwell Time (Cross-Track and Calibration Positions)	2.7 Seconds

TABLE III. MEASURED PERFORMANCE

Channel No.	Center Freq GHz	Bandwidth MHz	NETD K	Calib Uncertainty K
1	50.5	400	0.32	0.25
2	53.2	400	0.24	0.21
3	54.35	400	0.36	0.24
4	54.9	400	0.22	0.13
5	58.4	115	0.39	0.06
6	58.825	400	0.29	0.24
7	59.4	250	0.31	0.13

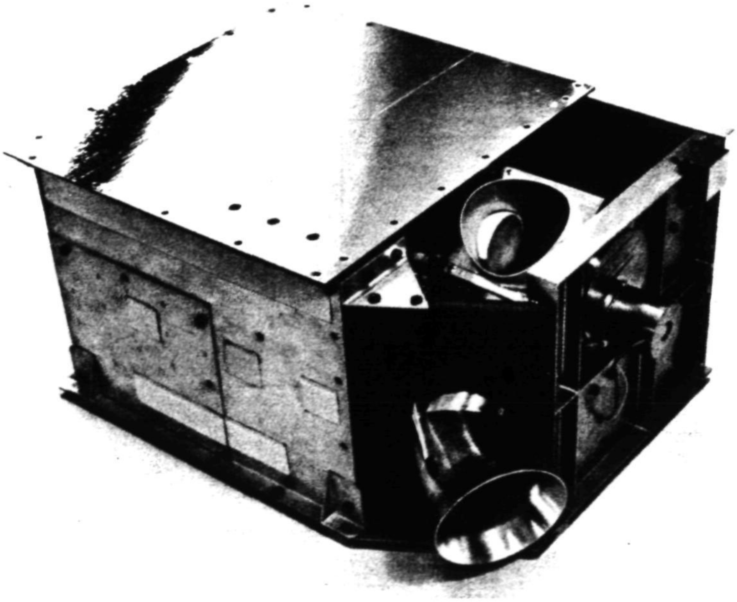

Figure 1. Multichannel Passive Microwave Temperature Sounder System

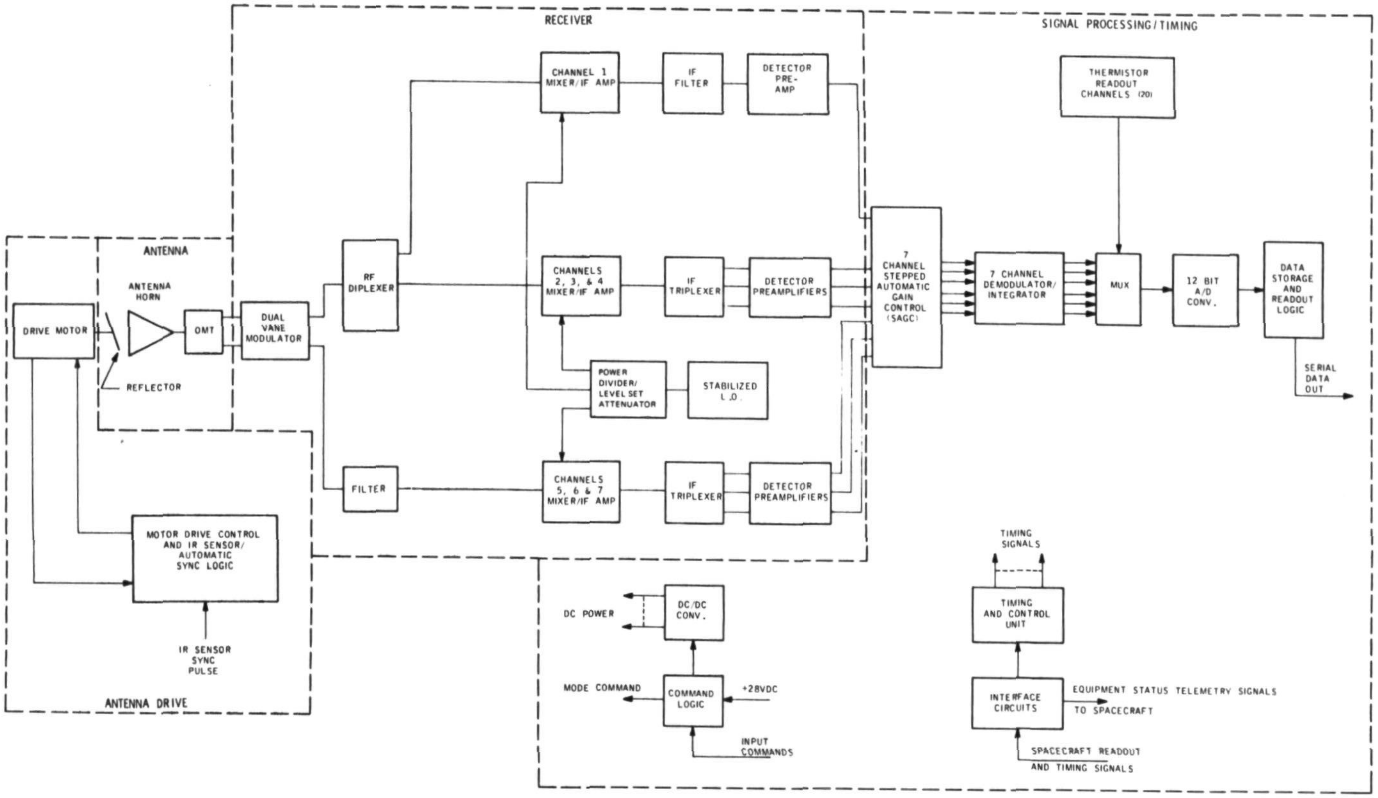

Figure 2. Simplified System Block Diagram

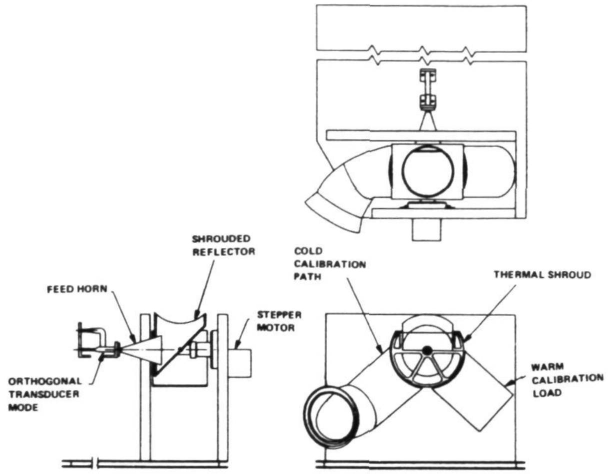

Figure 3. Antenna Subsystem

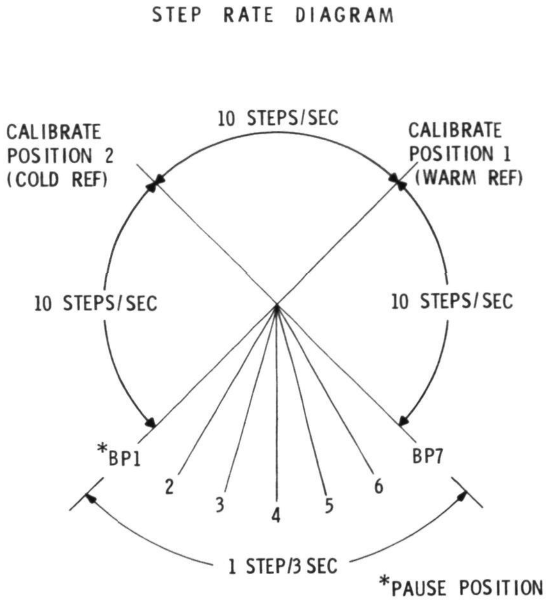

Figure 4. Calibration and Scanning Geometry

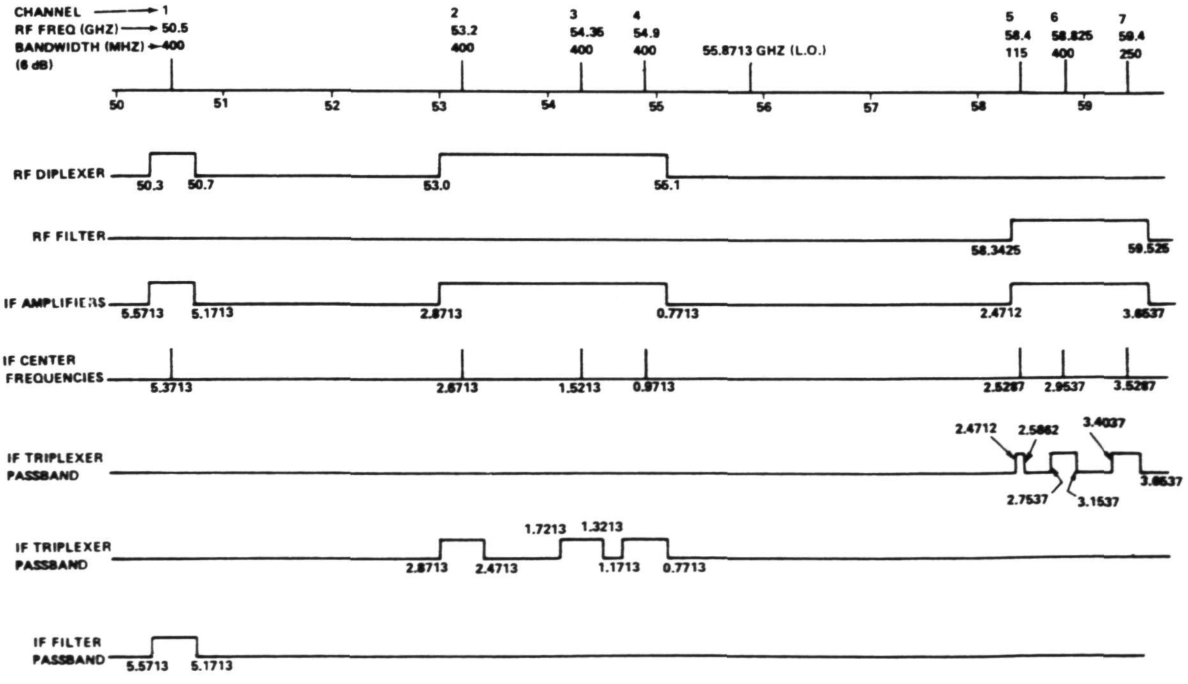

Figure 5. Receiver Bandwidth and Channelization

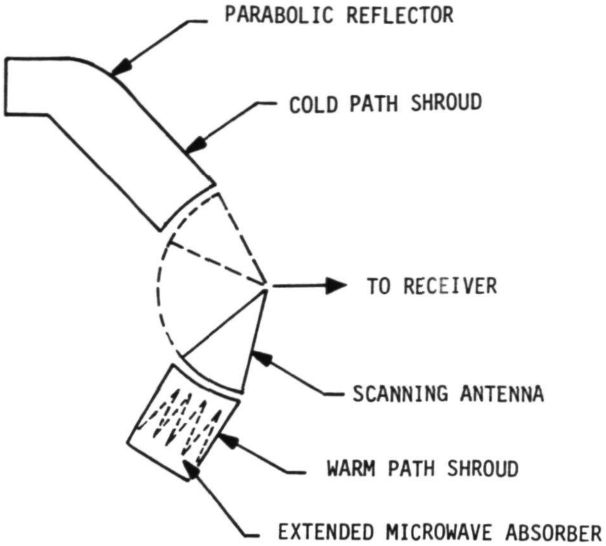

Figure 6. Calibration Subsystem

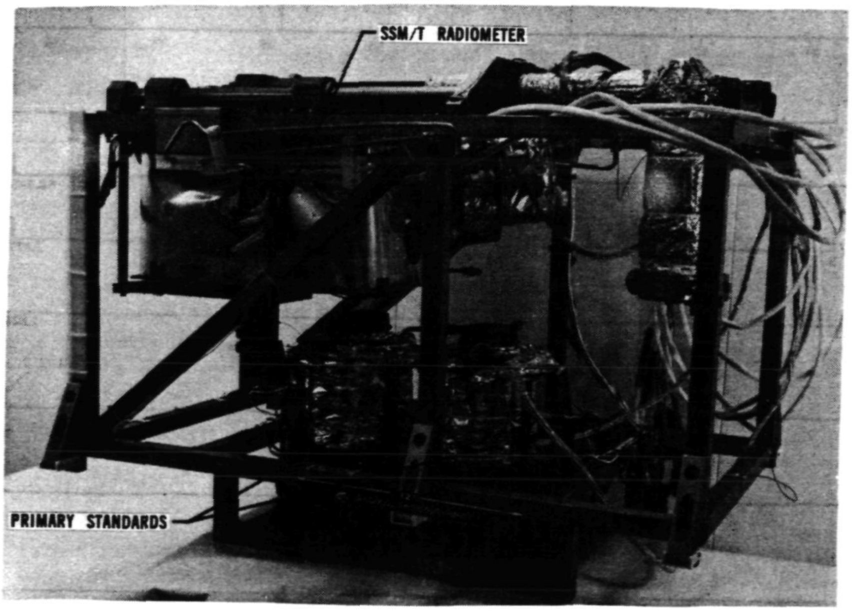

Figure 7. Primary Standard Transport Unit

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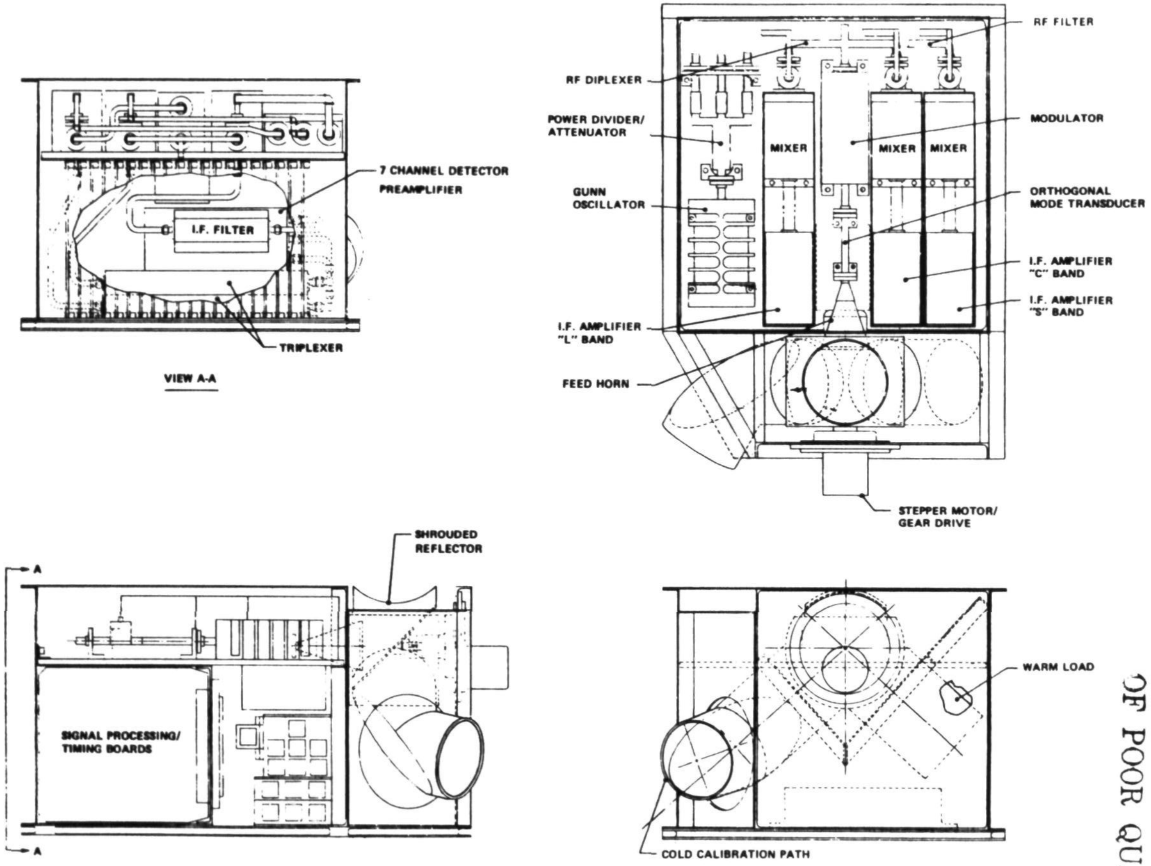

Figure 8. Radiometer Packaging