DESIGN OF A GEOSTATIONARY MICROWAVE PRECIPITATION RADIOMETER

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ABSTRACT

The Geostationary Microwave Precipitation Radiometer will be a passive microwave radiometer system to be flown on the NASA Geostationary Earth Observatory. This instrument will provide microwave images for meteorology. It will measure radiation from the Earth and its atmosphere in seven frequency bands from 37 to 220 GHz. The instrument will have a 4.4×4.0 m offset parabolic antenna which will be mechanically scanned to provide images of the Earth in ≈ 2 hours. The radiometer system uses a low-loss quasi-optical frequency multiplexer. This multiplexer divides the input signal into four separate focal planes for the different radiometers. Conventional low-noise heterodyne mixer systems were used for most of the radiometers. However, because of the narrow bandwidths required in the 54 and 118 GHz radiometers, new low noise mm-wave amplifiers were used in the first stage of these radiometers. Also in the 54 and 118 GHz radiometers, multi-channel filterbanks were used to provide the required spectral information for atmospheric sounding.

SYSTEM OVERVIEW

The Geostationary Earth Observatory is one component of NASA's Mission to Planet Earth initiative. A geostationary platform is uniquely suited for monitoring rapidly evolving earth processes, such as storms. The current launch vehicle is the Titan IV/Centaur. The present time frame for this mission is technology readiness by 1993, followed by a new start in 1994.

The Geostationary Microwave Precipitation Radiometer (GMPR) will provide microwave images for meteorology. It will detect and map quickly evolving precipitation events as well as measure the surface brightness in the 37, 101, 150 and 220 GHz atmospheric window channels. It will also do atmospheric temperature sounding using the 50-58 GHz and 118 GHz oxygen absorption lines and water vapor sounding with the 183 GHz water vapor absorption line.

A preliminary design of the GMPR instrument has been completed (1). This design was based on scientific functional requirements developed in coordination with members of the Geostationary Earth Observatory science steering committee. Figure 1 shows a drawing of the design, and Table 1 lists the key instrument characteristics. The system block diagram is shown in Figure 2.

The required footprint size and the antenna beam efficiency of >90% dictated the use of an offset parabolic antenna with major and minor axes of 4.4 and 4.0 m, respectively. The f/D ratio is 0.5 and the projected aperture size is a 4.0 m diameter circle. The on-orbit requirement for RMS surface tolerance over the full reflector is $<25\mu$ ($<0.001''$) to maintain >90% beam efficiency at 183 GHz. The reflecting surface material is a metalized graphite/epoxy composite with an areal mass density of ≈4 kg/m^2. The backup truss structure is made up of graphite epoxy struts connected by aluminum joints. A thin teflon radome and multi-layer insulation will be used to minimize the thermal gradients due to the Sun angle variations.

The antenna will be mechanically scanned ±10.4° in each direction to image the Earth and maintain >90% beam efficiency. To minimize the momentum transferred to the spacecraft, the antenna's scan system was designed to scan just the 4 × 4.4 m diameter offset reflector in the Earth's latitude direction. During this part of the scan, the subreflector, radiometer and electronics boxes and the supporting structure will remain stationary. At the end of each scan line (≈18 sec), the entire structure will be stepped in Earth's longitude by 2.7 arc min. Momentum compensation units will be used to reduce the torque transferred to the platform to <0.1 N-m with frequency components <1 Hz. Based on the mechanical design, it was possible to set the scan rate to 1°/sec, and the antenna turnaround time to seven seconds and satisfy these constraints. With these parameters, the Earth's scan time is ≈2 hours.

ANTENNA DESIGN

Figure 1 shows a drawing of the GMPR antenna system. The design of the GMPR antenna system was driven by four major performance requirements:

1) A 4-meter projected antenna aperture is required to get a 15 km Earth footprint at 220 GHz. An antenna surface with RMS errors $\leq 25\mu$ (0.001″) is

KK

required to achieve ≥90% beam efficiency at 183 GHz.

2) An offset fed antenna geometry is required to achieve ≥90% beam efficiency. A symmetric Cassegrain configuration was initially considered; however, beam spoilage due to aperture blockage by the subreflector and its supports was unacceptable.

3) Mechanical scanning for Earth coverage at geosynchronous orbit is required. Electrical beam scanning could not be accomplished at the end of the scanning pattern (±8.7°) without unacceptable beam distortion.

4) Reaction torques transmitted to the platform must be minimized. The GMPR is the largest instrument proposed for the GEO platform. Mechanical scanning of this instrument could impart unacceptable reaction torques to the platform, interfering with the pointing of other instruments and requiring compensation from the platform's attitude control system. As an initial guideline, a maximum allowable torque transfer of 0.1 N-m to the platform in each axis from mechanical scanning of the GMPR was assumed.

The state-of-the-art in precision reflector technology in the 4-meter GMPR size range is now represented by the Precision Segmented Reflector (PSR) and the Advanced Communications Technology Satellite (ACTS) 3.3 meter reflector. The PSR is a joint development by NASA Langley Research Center and Jet Propulsion Laboratory. It includes a 3.8 meter center fed, parabolic reflector constructed of 0.9 meter hexagonal graphite/epoxy and aluminum honeycomb core sandwich panel segments supported by a precision truss structure. The goal of this technology development activity is a 5μ RMS reflector surface. Individual panel segments with better than 2μ RMS surfaces have been fabricated and tested (2). The 3.3 meter ACTS reflector was developed by Composite Optics, Inc. It is constructed of a single, thin graphite/epoxy and Nomex honeycomb core sandwich surface with integral sandwich rib stiffeners on its back surface. The "as-fabricated" precision of this reflector is approximately $60 \pm 15\mu$ RMS (3). Because of high confidence that PSR could meet the GMPR surface precision requirements in 5 years, a design similar to the PSR was initially used for the GMPR primary reflector. However, an extension of the ACTS reflector technology might also be capable of meeting the GMPR requirement.

RADIOMETER SYSTEM

Overall Design

The radiometer system block diagram is shown in Figure 2. A calibration switching mirror switches the input signal between the antenna, a cold space view or two calibration targets (≈295K and ≈250K). A large range of signal frequencies, from 37 to 220 GHz, is required, and thus a low-loss quasi-optic frequency multiplexer separates the different frequency bands to the individual radiometers. Multiple feed horns receive all the frequency bands simultaneously. All feed horns are close to the center boresight positions so very little degradation in the beam efficiency will occur.

Table 2 summarizes the radiometer system characteristics. The receiver noise temperatures, T_{rec}, represent 1990 state-of-the-art performance for the receiver type. Two exceptions are the 54 and 118 GHz amplifiers, which haven't been developed yet. However, with the current advances in low noise mm-wave HEMT's, it is expected that these amplifiers will be available in a few years.

All the radiometers operate in the total power mode with gain calibrations after each scan line, approximately every 18 seconds. With an expected background temperature of 275K over the land or from the atmosphere, the total system noise, T_{sys}, was calculated for each radiometer and shown in Table 2. Using the IF bandwidth for each radiometer with the antenna scan rate of 1°/sec, the RMS noise, ΔT, was calculated for each footprint and is also shown in Table 2. The system was designed for the fastest antenna scan rate to achieve $\Delta T \leq 0.5K$ with a minimum number of radiometers.

As seen from Table 2, the 118, 183 and 220 GHz radiometers are the critical ones with respect to the RMS noise requirement. With the current number of radiometers, the antenna scan rate is limited to ≤ 1.3°/sec to meet the ΔT requirement of ≤0.5K. The scan rate is also limited by the maximum torque which can be transferred to the platform. The choice of a scan rate of 1°/sec with a seven-second turnaround time is consistent with the maximum torque transfer requirement and the $\Delta T \leq 0.5K$.

Quasi-Optical Multiplexer

The single large offset parabolic main reflector and hyperbolic subreflector are shared by all the GMPR frequency channels through a low loss quasi-optic multiplexing subsystem. Figure 3 shows the physical layout of a candidate design. This layout is presented to estimate the size and weight requirements of the subsystem and to provide a baseline for computing the SNR performance of the radiometers. The optics separate the single antenna beam from the antenna into four beams, one for each focal plane array of feed horns. This section discusses details of this separation.

The signal from the antenna first enters the radiometer enclosure and reflects at 90° off a calibration plate positioned by the switching motor. This and all later mirrors, grids, and plates are sized to intercept the -30 dB Gaussian beam waist of the signal. (The beam waist shown in Figure 3 represents the 1/e power level.) The calibration plate has four positions that point the radiometers to: 1) the antenna; 2) a cold space calibration view; or 3) and 4) two temperature controlled calibration targets, nominally at 295K and 250K.

After the calibration plate, the signal is divided by a frequency selective dichroic plate (D1). The high frequency channels, 183 and 220 GHz, pass through and the lower frequency channels reflect off this dichroic filter. Its frequency response will be tuned to optimize performance at 183 GHz at the expense of slightly higher insertion loss at 150 GHz.

After the dichroic plate, D1, all channels are refocused with elliptical mirrors to reduce the size of later elements. After refocusing, the higher frequency, 183 and 220 GHz, channels are separated by a polarization grid into orthogonal components, nominally designated V- and H-pol, for the redundant radiometers. Only one of these polarizations will be used at a time. The lower frequency channels, 37-150 GHz, are split by a second dichroic plate (D2) after their refocusing mirror. Performance at 54 GHz is optimized over that at 101 GHz since the atmospheric line channel has a narrower IF bandwidth than the atmospheric window channel.

SCANNING and MOMENTUM COMPENSATION

The GMPR will generate images of the Earth by mechanically scanning its antenna in a raster fashion. The motion consists of two independent, perpendicular components designed to minimize the torque transferred to the GEO platform. A latitudinal scan is generated by rotating just the main reflector about an axis aligned with the boresight of the feed at a 1°/sec scan rate. A longitudinal scan is generated by rotating the entire antenna reflector and feed assembly about an axis perpendicular to the first axis 2.7 arc-min every 18 sec. In both cases, the rotation is over a range of ±10.4° about the local s/c nadir. The nominal scan mode will provide full Earth disc coverage in 134 minutes.

In the latitudinal scan mode, the axis of rotation is colinear with the boresight of the feed's antenna pattern after it reflects off of the hyperbolic subreflector. The main reflector rotates about this axis while the subreflector, feed cluster, and radiometer electronics remain stationary. This approach significantly reduces the torque required to scan the antenna beam (compared to moving the entire antenna) by reducing the rotating moment of inertia in two ways: the moving mass has been reduced, and the axis of rotation can be more nearly aligned with the system center of mass.

For latitudinal raster scanning, the reflector dish and its supporting truss structure are mechanically rotated about an axis between the centroid of the reflector and the centroid of the subreflector. In addition, for longitude steps, the entire instrument is rotated about a second axis parallel to the system and passing through the system center of mass.

Acknowledgements This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA under contract to the National Aeronautics and Space Administration.

REFERENCES

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(2) R. Freeland, *et al*, "PSR Panel Development Review," Internal presentation to JPL Division 35 Review Board, Aug. 1990.

(3) J. Rule and S. Kulick, *personal conversations*, Composite Optics, Inc., San Diego, CA, Jan. 1990.

Table 1. Instrument Characteristics

Item	Design
Antenna Diameter	4 m
Antenna Main Beam Efficiency	> 90%
Frequency channels (GHz)	37 54 101 118 150 183 220
Footprint size (km)	91 62 33 28 29 18 15
RMS Noise per Earth Footprint (K)	0.1 0.2 0.2 0.4 0.2 0.4 0 4
Absolute Calibration Accuracy	0 5%
Time to scan Earth disk	134 min
Area scanned in 0.5 hr	3900 x 3900 km
Mass	509 kg (329 kg goal)
Power (nominal)	292 Watts
Data Rate	60 Kbps
Design lifetime	8 years with redundancy

Table 2. Radiometer Characteristics

Freq (GHz)	θ_b (arc-min)	F* (km)	L_{rec} (dB)	T_{rec}# (K)	BW (MHz)	T_{int} (ms)	T_{sys}** (K)	ΔT (K)	Receiver Type
37	8.7	91	0.4	800	2000	145	1180	0.07	Mixer
54	6.0	62	0.5	300	200	99	647	0.15	Amplifier
101	3.2	33	0.8	1000	2000	53	1536	0.15	Mixer
118	2.7	28	0.8	500	100	45	935	0.44	Amplifier
150	2.7	28	1.0	1400	2000	45	2113	0.22	Sub-Harm Mixer
183+	1.8	18	0.8	1500	1000	29	2137	0.39	Sub-Harm Mixer
220+	1.5	15	1.0	2000	2000	24	2868	0.41	Sub-Harm Mixer

+ 2 radiometers separated in longitude by θ_b
* 4-m diameter antenna footprint at 0° latitude
# Double sideband for mixers
** Includes T(background) = 275 K

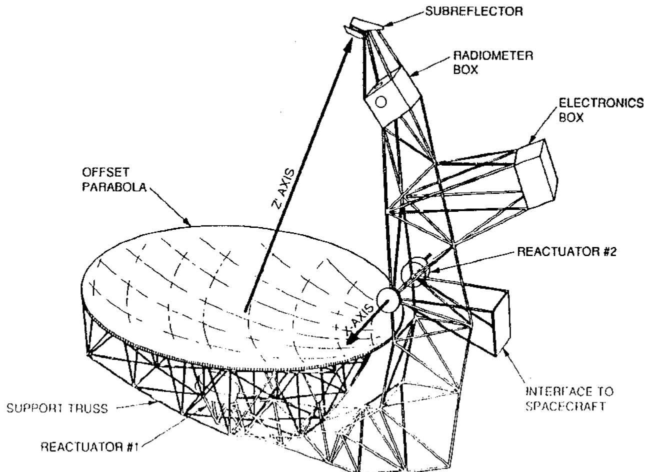

Figure 1. The Geostationary Microwave Precipitation Radiometer

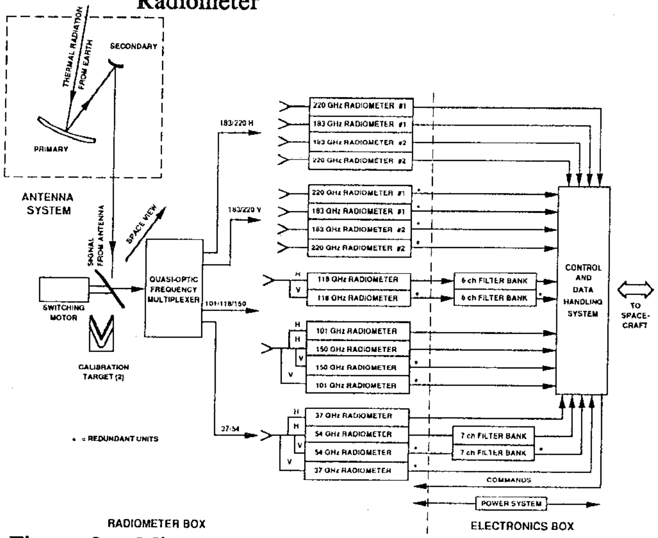

Figure 2. Microwave Instrument System Block Diagram

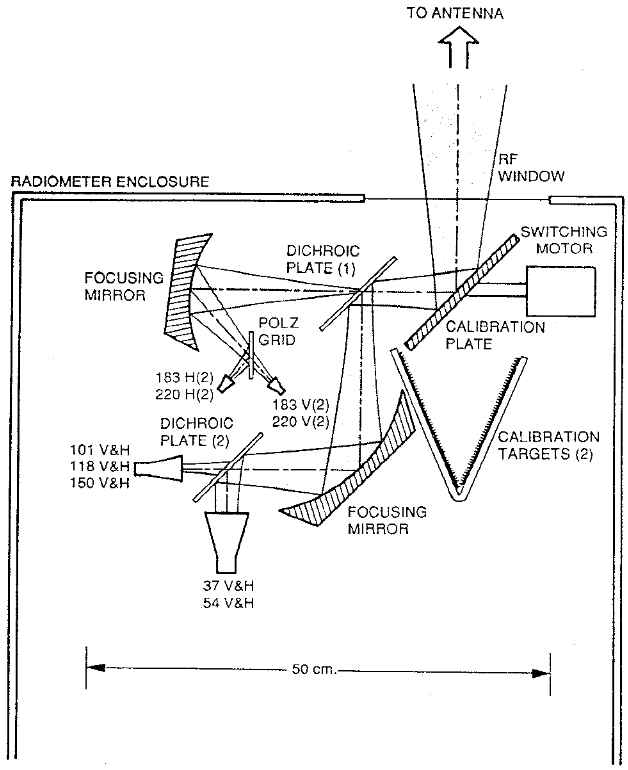

Figure 3. Quasi-Optical Multiplexer