TDRSS ANTENNAS
GROUND STATION AND SPACEBORNE

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ABSTRACT

Three sixty foot diameter K_u-Band Antennas have been completed as part of the Tracking and Data Relay Satellite System (TDRSS) at the NASA Johnson Space Center, White Sands Test Facility. These very high efficiency satellite communication antennas provide in excess of 68dBi directivity. Further characteristics include autotrack accuracy of 0.01°, frequency reuse, and surface accuracy within less than .02" rms of the desired shaped surface.

Two TDRSS antennas weighing less than 52 pounds are ready for launch aboard each satellite. These 16 foot deployable antennas provide frequency reuse performance in two frequency bands - K_u and S. As with the sixty foot antenna, shaping of the subreflector and main reflector is utilized to achieve high aperture efficiency.

This paper describes some of the design, analysis and measurement techniques used in the development of these antennas.

INTRODUCTION

The ground station for NASA , s Tracking and Data Relay Satellite System (TDRSS) located at the White Sands Test Facility (WSTF), New Mexico, is nearing completion. TDRSS, when operational in 1981, will represent a significant development in satellite communications and tracking. This system, consisting of three satellites and one ground station, will functionally replace NASA’s worldwide tracking network. Two of the satellites will perform the primary mission of tracking and data relay; the third satellite will serve as an in-orbit spare. The two primary satellites will be placed in synchronous orbit separated by approximately 130 degrees. This separation allows both satellites to be covered by the White Sands ground station. The spare satellite will be located in a synchronous orbit at a longitude between the two on-line primary satellites. In these orbits, the TDRSS satellites will act as “bent pipe” relays for the data from user satellites to the ground station. User satellites can communicate through one of three types of service channels:

- K-Band Single Access - KSA
- S-Band Single Access - SSA
- Multiple Access (S-Band) - MA

The WSTF ground station pictured in Figure 1 consists of three 60 foot K-Band antennas for communication with the three TDRSS satellites. The smaller antennas shown allow the ground system to simulate a user spacecraft so that total loop testing of the system can be performed. Figure 2 shows one of the satellite systems. The larger two reflectors (16') provide communication to the user spacecraft. The reflectors are separately gimballed and are deployed after the satellite is placed in geosynchronous orbit.

GROUND STATION ANTENNA REQUIREMENTS

The primary functions of the 60 foot antennas are to:

- Provide for reception of the K-Band signal from a TDRS.
- Provide the capability of transmitting K-Band signals to a TDRS.
- Provide capability to automatically track the satellite.
- Provide the capability to position and configure the antenna via computer control.
- Provide the means to connect three sets of receive equipment to the three antennas in any combination.
- Provide redundancy in the receive and transmit waveguide paths.
- Provide a hot-standby-spare low noise amplifier to serve as backup to either the polarization-1 or polarization-2 low noise amplifiers.

The antennas were required to provide the following performance requirements:

- Transmit
  - Frequency - 14.6 GHz to 15.2 Ghz
  - Aperture Gain - >66 dBi
  - Polarization - Rotatable Linear

- Receive
  - Frequency - 13.4 GHz to 14.0 Ghz
  - Polarization - Dual-Rotatable Linear
  - Polarization Isolation - 30 dB
  - G/Ts - >40.3dB/°K

- Positioning Accuracy
    - S Autotrack Accuracy - 0.01 degree (3σ)
    - S Program Track Accuracy - 0.03 degree (3σ)

In order to achieve the required aperture gain, the antenna surface was designed to achieve an rms surface tolerance of better than 0.020 inch rms. To meet the receive G/T requirement, the following specifications were allocated to the receive components:

Aperture Gain (KSA1)	66.7 dBi
Feed Loss	0.5 dB
Pointing Loss	0.2 dB
Net Gain	66.0 dBi
System Noise Temperature	220°K
Allocated G/Ts	=42.6 dB/°K

Note that the allocated requirements allowed for a design and test margin over the required 40.3 dB/°K specification.

SPACEBORNE ANTENNA REQUIREMENTS

The Tracking and Data Relay Satellite (TDRSS) utilizes two 4.8 meter deployable antennas for accessing and communicating with high data rate user satellites. These single access antennas operate at the dual frequencies of S- and Ku- band, with full tracking capability at Ku-Band. The stringent gain and tracking requirements at Ku-Band require state-of-art designs in the deployable reflector and the dual frequency feed system. To meet these requirements special, surface shaping techniques and thermally stable materials were developed for the deployable reflector. A unique dual frequency cassegrain feed system utilizing sidelobe crossover for tracking was developed to meet the tracking requirements. The feed system tracking performance is essentially insensitive to reflector distortions.

The primary functions of the spacecraft antenna systems are to:

- Simultaneous transmission/reception of S-Band and K-Band signals to and from a single user spacecraft.
- Process and provide two-axis, monopulse, autotrack error signals from the received K-Band signals.

- Provide peak gains for right hand circular polarization (RHCP) and left hand circular polarization (LHCP):

36 dB	2.025-2.120 Ghz
36.8 dB	2.200-2.300 GHz
49.69 dB	11.7-12.2 GHz
52.29 dB	13.75-13.8 GHz
52.49 dB	14.0-14.5 GHz
53.29 dB	14.896-15.121 GHz

- Axial ratio requirements between 3 dB points are:

S-Band	1.5 dB
Ku-Band	1.0 dB - 13.75-15.12 GHz
	1.5 dB - 11.7-12.2 GHz

- Minimum autotrack scale factor of

  .35 volts/volts/degree over all environmental conditions

- Autotrack scale factor variation of less than ±3.5 dB over the pull-in range.

GROUND ANTENNA DESIGN AND TEST RESULTS

A simplified block diagram for the TDRSS Ground Antenna subsystem is shown in Figure 3.

The elevation azimuth antenna structure as shown in Figure 4 utilizes a Harris wheel and plate pedestal. The system is constructed on site by welding 20-inch hollow tubes into a very stiff, lightweight pedestal. In order to achieve the exacting reflector surface accuracy requirements, care was taken in the design, fabrication and mounting of the reflector panels to the backup structure. The panel skins were fabricated using a stretch form process that was adopted from the automotive industry. These panel skins were then bonded to kerfed channel frames to achieve a high degree of stiffness. The net result of this process was that the individual panel accuracy was within 0.006 inch rms deviation from the desired shape.

As shown in Figure 5, three rings of 32 panels form the reflector surface. The panels are mounted and aligned on the backup structure while the structure is on the ground. The entire reflector (40,000 pounds) was then lifted approximately 40 feet onto the pedestal. The final reflector alignment was performed at night to preclude detrimental thermal effects on the alignment process. The final measured surface tolerances for each of the three antennas was found to be better than 0.011 inch rms. The panel’s surfaces are mounted in such a manner that no metal-to-metal contact can occur, thus inhibiting generation of intermodulation products.

Predictions of RF beam deflections and pattern shape deviations which are caused by wind, thermal, and gravity loading were made using structural geometric optic computer modeling.

The total structure as analyzed using a finite element structural analysis program. This program coupled with an RF antenna pattern analysis program and modeling on an interactive graphics terminal allowed for optimization of the antenna performance in the presence of wind and gravitation disturbances. Using these programs, the stiffness of the feed cone, reflector, and pedestal mounting was designed to allow the antenna to closely approximate a homogeneous unit. For example, the feed cone stiffness was designed such that the gravity droop of the feed compensated for the reflector gravity deformation.

The antenna utilizes a Cassegrain reflector/subreflector that are both shaped to optimize the aperture gain. The reflector and subreflector were shaped to provide for uniform aperture illumination except for a sharp roll off near the reflector’s edge. The measured antenna gain indicates that the efficiency exceeds 70 percent. This feed is supported by a monopod feed cone. The subreflector is supported by a dielectric cone made of quartz cloth and low density polystyrene foam. The monopod mounting allows accurate feed to subreflector alignment at the factory. Furthermore, elimination of the more conventional subreflector support spars minimizes aperture blockage and simplifies the reflector design since the feed/subreflector is supported only at the reflector hub.

The antenna feed pictured in Figure 6 consists of a central corrugated horn surrounded by four open-ended circular waveguide horns. The central horn carries the receive and transmit channels while the four peripheral horns provide autotracking information. Each of the feed horns is connected to a rotating 180 degree phase shifter as shown in the feed block diagram, Figure 7. This polarization rotation is computer-controlled to align the polarization with the incoming signal from the spacecraft. E-stub filters provide greater than 100 dB of band reject isolation, while having in-band loss of approximately 0.25 dB.

Three Low Noise Amplifiers (two on-line and one backup) are mounted in the feed cone. The three LNA’s are configured and controlled in such a way that should one of the two on-line units fail, the third LNA is automatically switched on-line. The LNA’s provided the following performance:

Noise Temperature	100°K
Absolute Gain	50 dB

Gain Flatness	±0.5 dB
Third Order Intercept Point	+10 dBM

The antenna utilizes dual, torque-biased DC drive motors in velocity and 0.5°/sec velocity and 0.5°/sec acceleration in each axis. Automatic spacial acquisition of the satellite and fault detection is provided by microprocessor control of the antenna position system.

Each of the antennas has five waveguide runs from the antenna feed to the pedestal base to allow passage of two on-line receive channels, one on-line transmit channel, one spare receive channel, and one spare transmit channel. After passing through the five elevation and five azimuth rotary joints, the waveguide enters an underground trench. The receive waveguide remains WR 75 for the run to the waveguide switches located in the main TDRSS equipment building. The transmit waveguide transitions into TE01 waveguide for the run into the building. The TE01 mode in WC166 guide significantly lowers the loss to about 0.005 dB/ft for the long (up to 260 feet) run between the transmitters and the antennas. Waveguide interconnects the three antennas to the downconverters and transmitter located in the equipment building. Computer-controlled waveguide switches allow for interconnection of the three antennas to any of three downconverters or transmitters for any service.

A far field range was established utilizing a K-Band signal source located on a TV tower located 27 miles from the site. The antenna gain was measured to be within ±0.5 dB of the predicted value as shown in Figure 8. Polarization isolation was tested and exceeded the 30 dB requirement and, over most of the frequency band, exceeds 40 dB. The measured antenna patterns shown in Figure 9 closely agreed with the predicted patterns. Antenna autotrack accuracy was measured to be <0.003° (3σ).

SPACEBORNE ANTENNA (REFLECTOR & FEED) DESIGN AND TEST RESULTS

Figure 10 shows a functional diagram of the spaceborne feed system. This primary feed system illuminates a subreflector (shaped for uniform) which in turn illuminates the 16 foot shaped reflector.

Figure 11 shows the deployable reflector in the radome test facility. The reflector utilizes eighteen graphite fiber reinforced plastic (GFRP) ribs to shape and support the reflective mesh surface. The number of ribs is based on a trade-off considering surface tolerance and weight. As the number of ribs increases, the surface error decreases, while weight increases. The minimum number of ribs consistent with the surface tolerance requirements is, therefore usually selected. The ribs are circular in cross-section tapering from 1.5 inches diameter at the root to 0.75 inches at the tip. The rib is constructed of 4 plies of HMS graphite oriented in a 90°, 0°, ±45° configuration. The resulting wall thickness is 0.016-inch. The reflective mesh surface is attached to the ribs by adjustable standoffs and therefore the tolerance on rib shape is not critical parameter. The ribs are typically fabricated to a constant radius of curvature rather than a parabolic shape.

The reflective mesh consists of 1.2 mil diameter, gold-plated, molybdenum wire which is knitted into a soft (low spring rate), elastic mesh. The mesh opening size can be varied to ensure adequate RF reflectivity for a given requirement. The mesh opening size for the TDRS reflector is 0.1 inches. Figure 12 shows a sample of the reflector mesh material in a reflectivity measurement system. Mesh loss at 15 GHZ is approximately 0.46 dB. The required reflector surface tolerance is achieved with minimum weight through the use of a secondary drawing surface technique. A series of circumferential quartz cords is attached to the back of the ribs by adjustable standoffs. A second series of quartz cords is attached to the front mesh surface. These “front” cords run parallel to the “back cords”. The front and back cords are connected by a series of beta glass tie wires. By properly adjusting the rib standoff heights, the back cord geometry, and these individual tie wires, a very accurate surface contour is achieved (18 mils for TDRSS). The reflector contour is measured in the face-up and the face-down positions. The measured face-up and face-down positions are then averaged to determine the “zero-gravity” surface contour. This contour is then compared on a point-by-point basis with the desired parabolic contour and surface adjustments made as necessary to achieve the desired manufacturing contribution to the total surface tolerance budget. The setting process is iterative, with each setting iteration requiring approximately one week.

The primary feed is shown in Figures 13 and 14. The Ku-Band Tracking System consists of a scalar sum horn and four tracking error horns. Five-Horn Cassegrain feeds are very desirable for communications antennas for which the tracking requirements are usually not very stringent. The simplicity of the sum channel makes possible greater bandwidth and higher efficiency. The historical problem has been the trade-off between a sufficiently large sum horn for good illumination efficiency and sufficiently small error horn spacing for adequate error channel secondary pattern crossover. The error horns crossover on the first sidelobe. Generally, crossover on the first sidelobe or beyond has been avoided because of the sensitivity of the low-level sidelobes to various factors, including reflector distortion, frequency change and blockage. The sensitivity of tracking performance to reflector distortion is especially important for spaceborne antennas.

The Five-Horn Cassegrain feed has been developed for the TDRSS 4.8 meter deployable antenna, which uses the up-taper of the dual shaped reflectors in conjunction with a special error horn design to produce a stable tracking crossover on high-level sidelobes. This permits use of a larger sum horn with greater spillover efficiency.

The error horns are rectangular with the narrow dimension in the plane of the associated tracking crossover. Because the error horns have a much broader illumination in this plane than the sum horn, the up-taper which produces uniform reflector illumination (maximum gain) for the sum channel results in a highly inversed distribution for the error horns, and hence the desired high sidelobes.

The output of the Ku-Band sum horn inputs to an OMT/Polarizer is shown in Figure 15. The polarizer is a “Simons” type with 19 vanes. Axial ratio of the polarizer is better than 0.25 dB for the 13.75-14.121 GHZ frequency range and 0.8 dB for the 11.7-12.2 GHZ frequency range.

The S-Band feed design consists of 4 sleeve cross-dipoles in individual cavities, which are concentric to the Ku-Band tracking and sum horns. The outputs of the dipole elements input to a combing network which form the RHCP and LHCP polarizations.

Range testing of the mesh reflector system was performed on an elevated range. Gain and axial ratio measurements at S and Ku-Band were obtained to within an accuracy of 0.4 dB. A 10 feet reflector calibrated by the National Bureau of Standards (NBS) was used as the gain standard. The 10 feet standard was mounted to a vertical probe system which enabled the multipath errors to be minimized by averaging the received power over the probe travel distance.

In addition to the mesh reflector antenna tests, each feed system, including subreflector was tested in a 16 feet solid reflector representation of the mesh reflector contour. This solid reflector “test bed” enabled each feed to be accurately characterized without regard to gravity effects. Figure 16 shows the solid reflector and 10 feet reference antenna probe system.

CONCLUSION

The ground station and spaceborne systems for TDRSS represent state-of-the-art advances in Ku-Band communications systems. Each system exceeded requirements. The spaceborne system is planned for launch by the shuttle in 1982 and will be the major communication link for NASA and other spacecraft users.

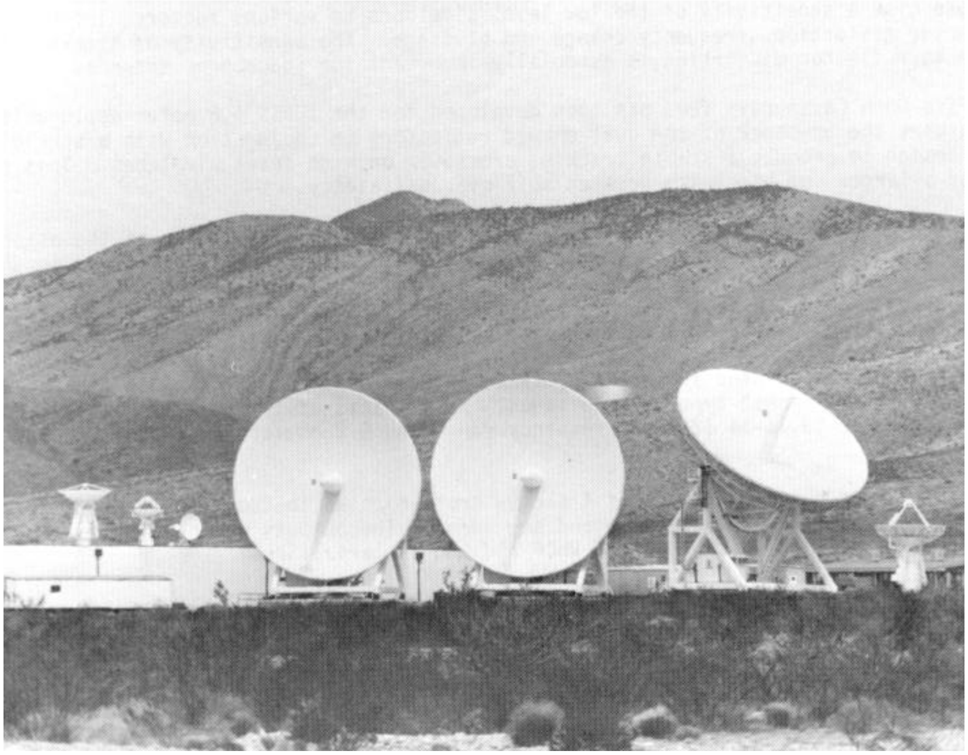

Fig. 1

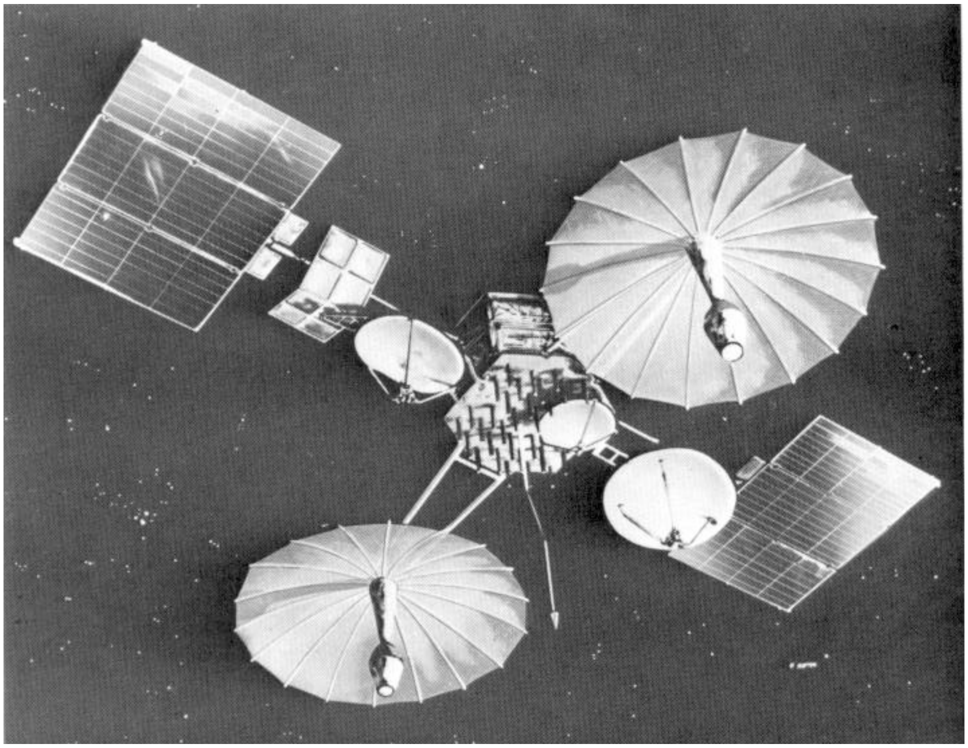

Fig. 2

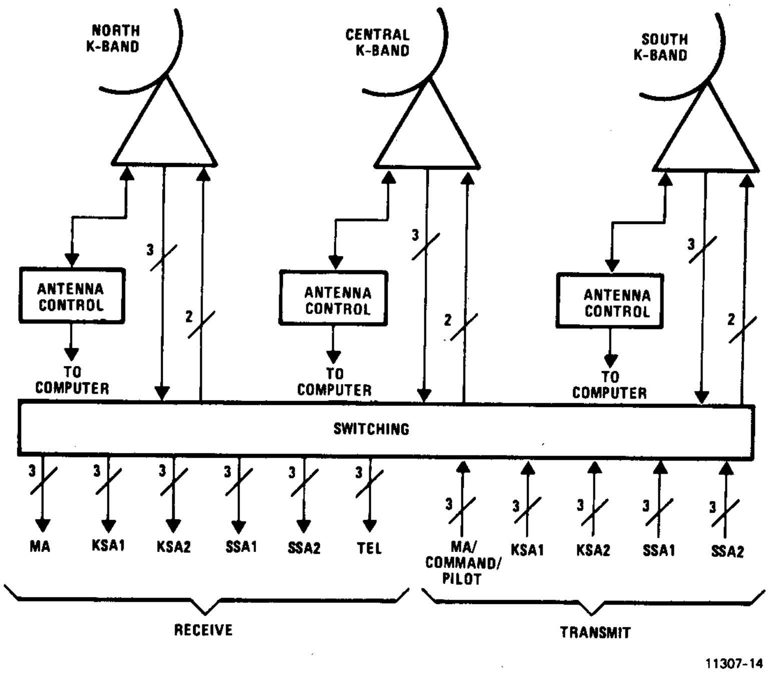

FIGURE 3. GROUND ANTENNA SUBSYSTEM BLOCK DIAGRAM

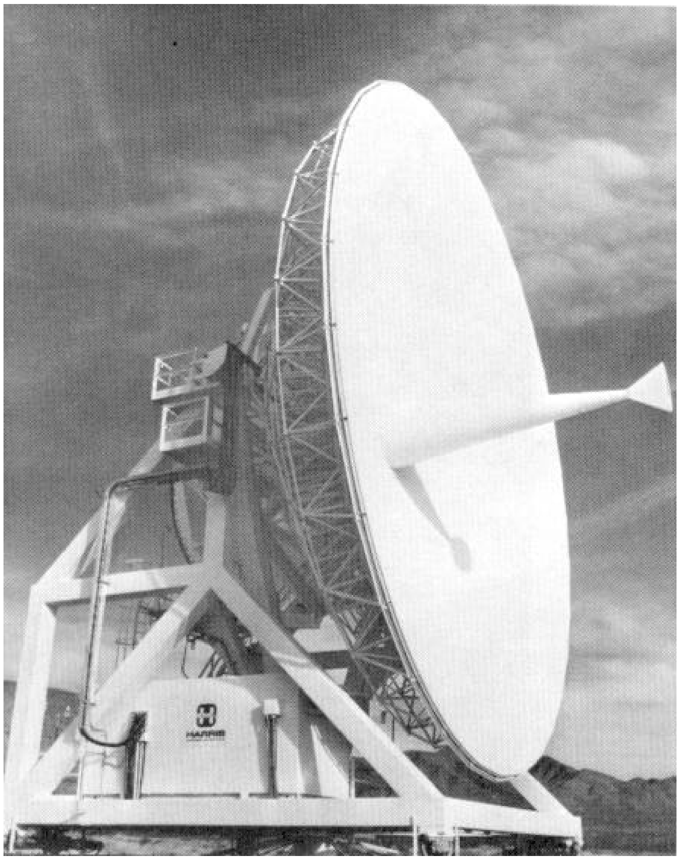

Fig. 4

Fig. 5

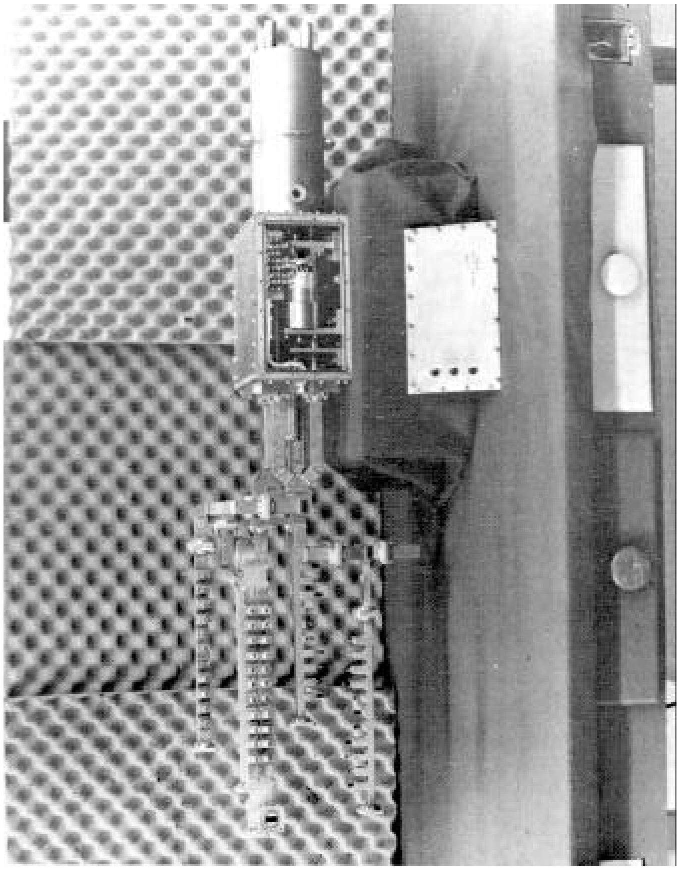

Fig. 6

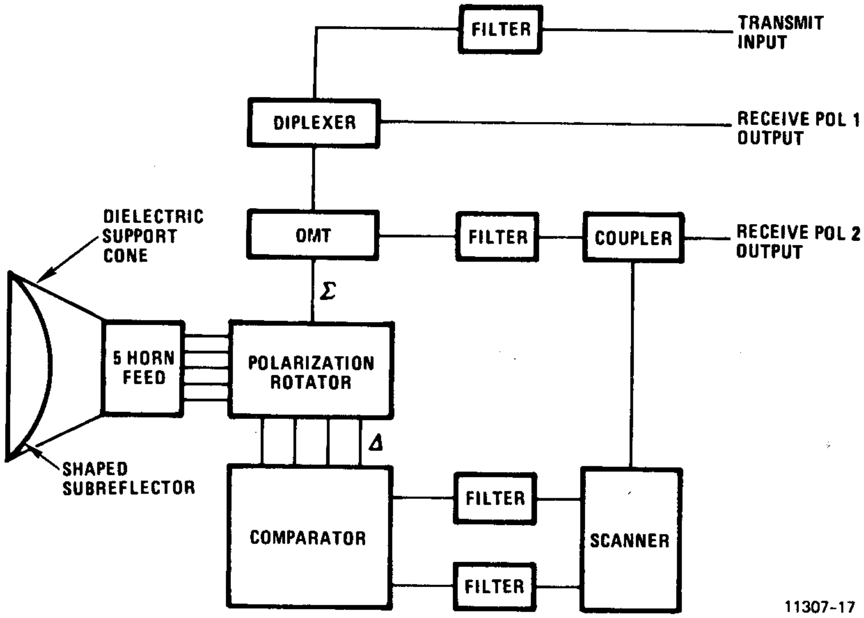

FIGURE 7. GROUND ANTENNA FEED MICROWAVE COMPONENTS BLOCK DIAGRAM

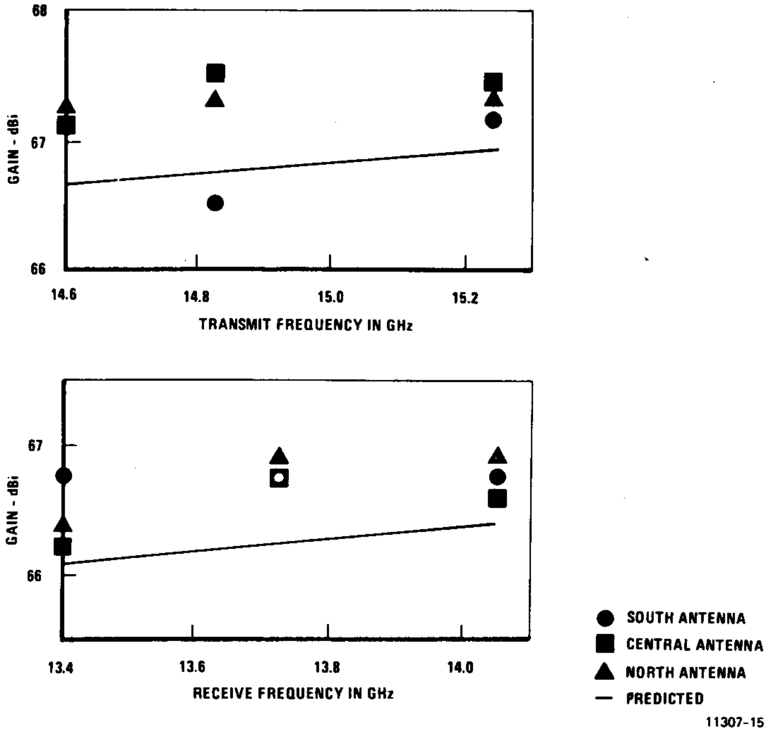

FIGURE 8. MEASURED ANTENNA GAIN FOR GROUND ANTENNA

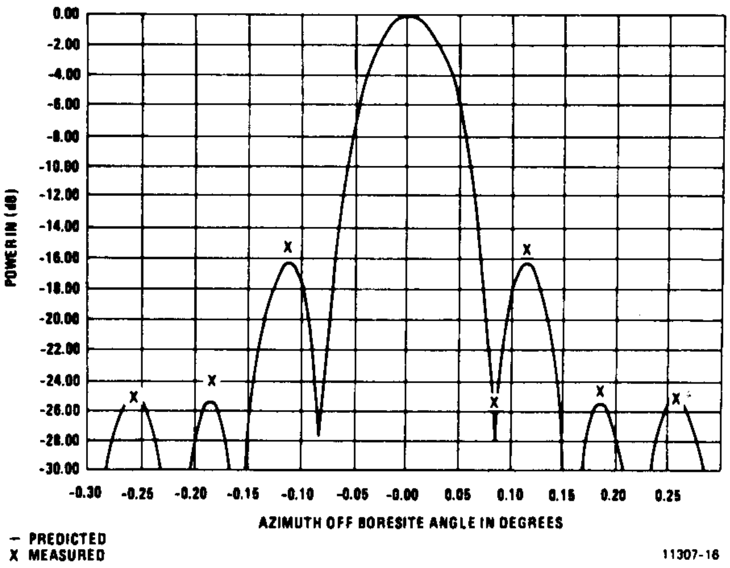

FIGURE 9. FAR FIELD ANTENNA PATTERN - AZIMUTH CUT FOR GROUND ANTENNA

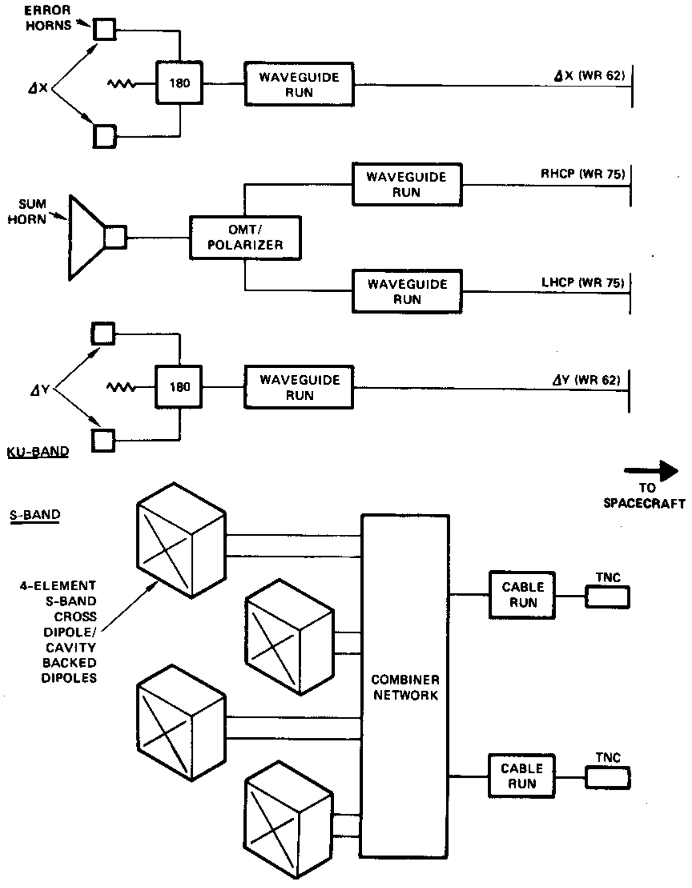

FIGURE 10. SPACEBORNE ANTENNA PRIMARY FEED FUNCTIONAL DIAGRAM

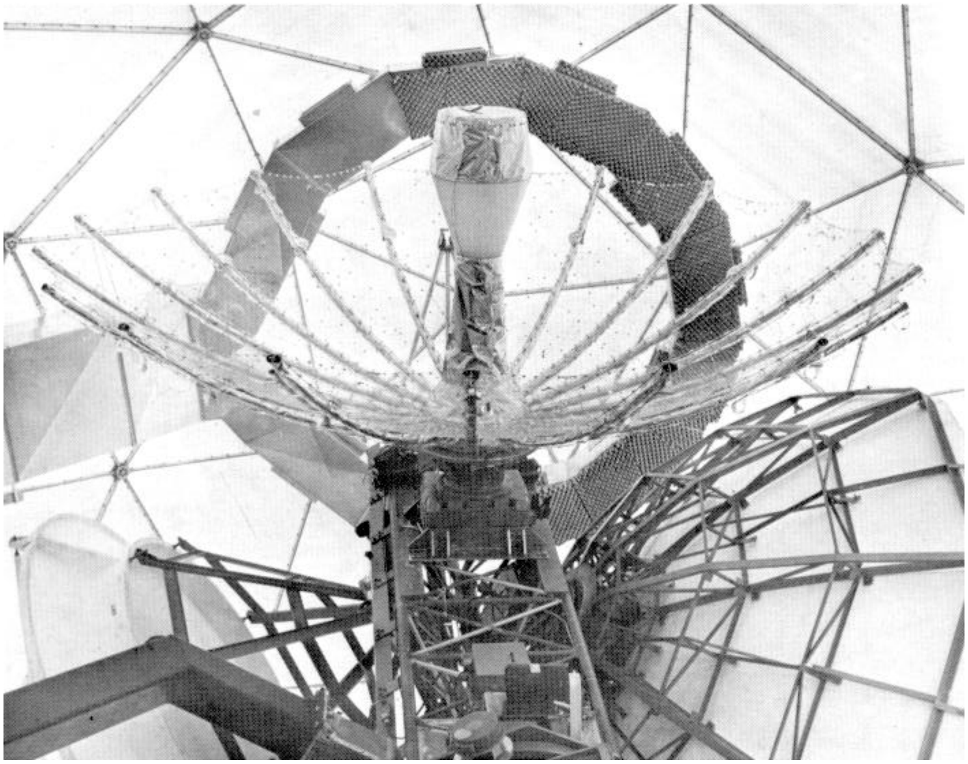

Fig. 11

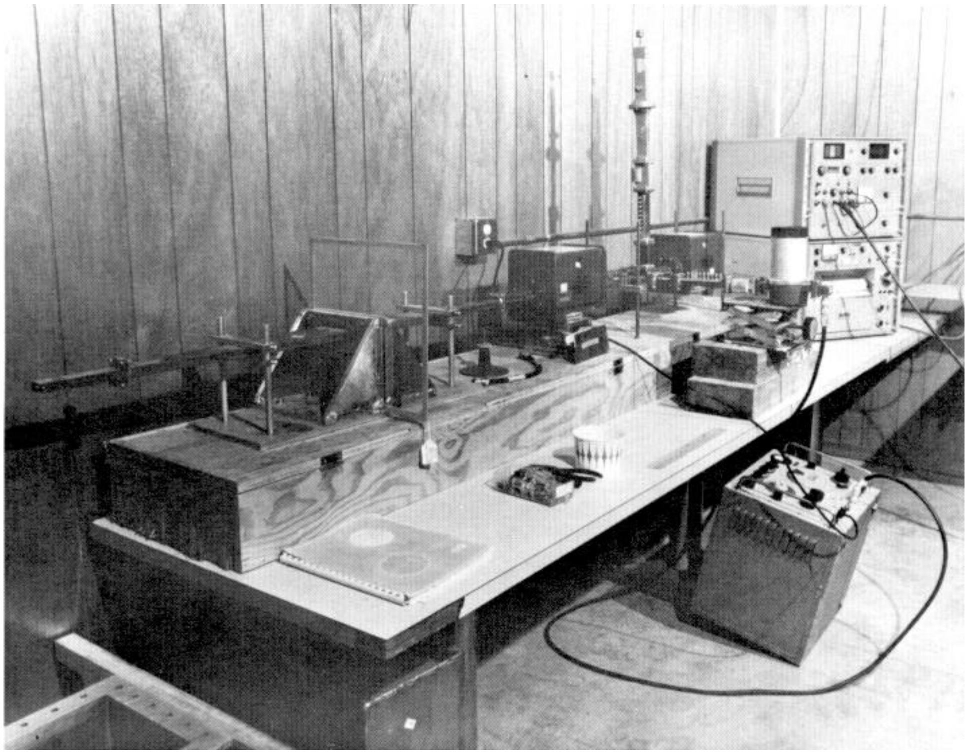

Fig. 12

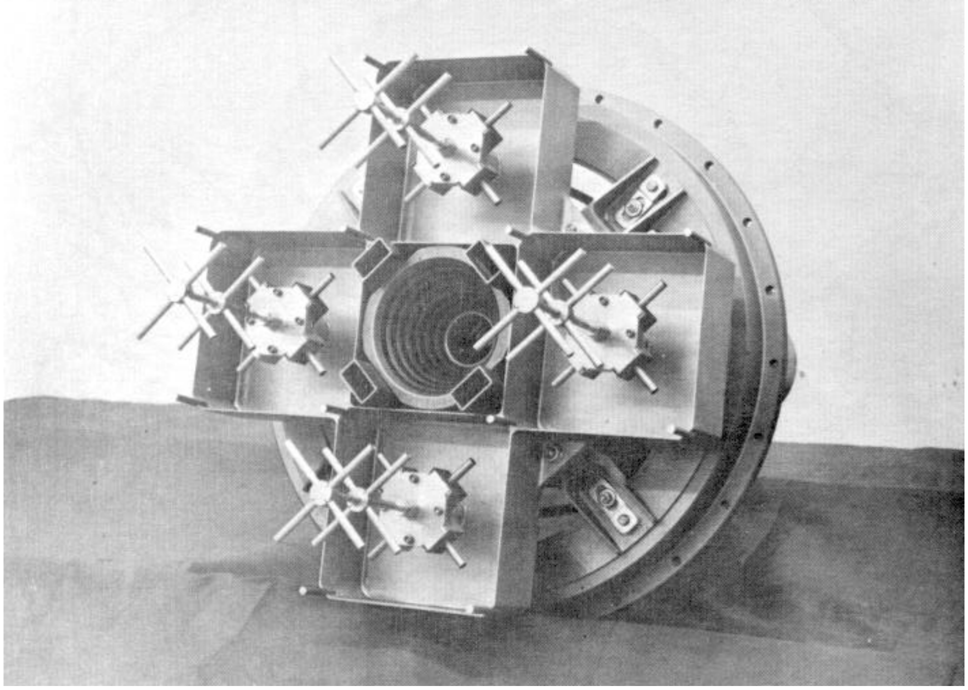

Fig. 13

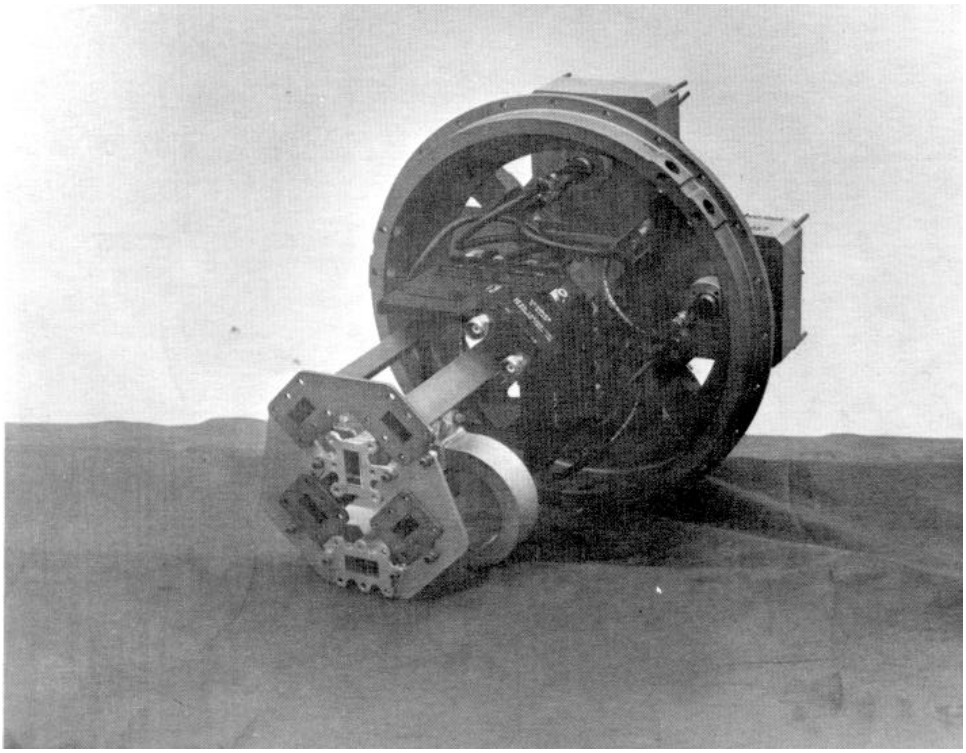

Fig. 14

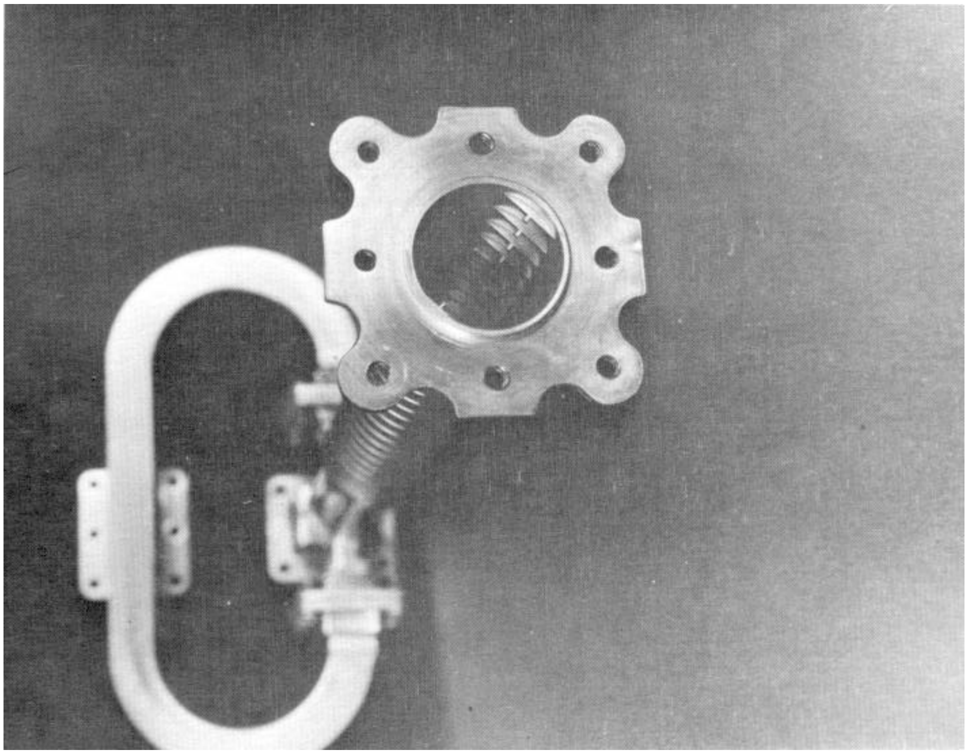

Fig. 15

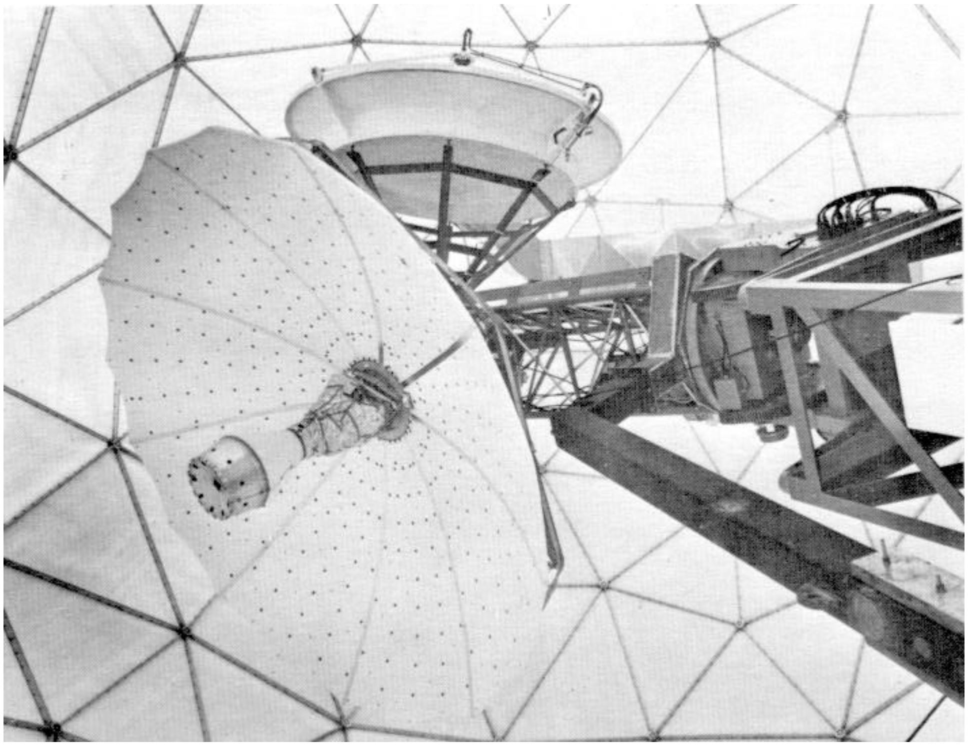

Fig. 16