NASA Technical Memorandum 100680

Performance Characteristics of Omnidirectional Antennas for Spacecraft Using NASA Networks

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Microwave Instrument and
RF Technology Branch

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All measurement values are expressed in the International System of Units (SI) in accordance with NASA Policy Directive 2220.4, paragraph 4.

PREFACE

This document describes the performance capabilities and critical elements of the shaped omni antenna developed for NASA for space users of NASA networks. The shaped omni is designed to be operated in tandem for virtually omnidirectional coverage and uniform gain free of spacecraft interference. These antennas are ideal for low gain data requirements and emergency backup, deployment, and retrieval of higher gain RF systems. Other omnidirectional antennas that have flown in space are described in the final section of this document. A performance summary for the shaped omni is in the Appendix.

CONTENTS

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PERFORMANCE CHARACTERISTICS OF OMNIDIRECTIONAL

ANTENNAS FOR SPACECRAFT USING NASA NETWORKS

HISTORICAL BACKGROUND OF SPACE DATA SYSTEMS

The success of all space missions has been based on the ability to gather data in space and return that data to earth-based investigators. The National Aeronautics and Space Administration (NASA) tracking and data acquisition stations, located on various parts of the Earth, underwent three distinct evolutions, which were the following:

a. *Space Tracking and Data Acquisition Network (STADAN)*—STADAN, completed in 1958, was used for tracking unmanned spacecraft in Earth orbits from ground facilities that used sensitive receivers and powerful transmitters.

b. *Manned Space Flight Network (MSFN)*—During the Mercury, Gemini, and Apollo programs of the early 1960s, MSFN provided astronauts with two-way contact between the ground, the sea, and space.

c. *Deep Space Network (DSN)*—Implemented in the early 1960s to support NASA's lunar and planetary missions, DSN used parabolic dish antennas in three stations each separated by approximately 120° of longitude. DSN is still operational and continues to support planetary missions under the Jet Propulsion Laboratory (JPL) management.

The Spaceflight Tracking and Data Network (STDN), operational from May 1971 to the era of the Tracking and Data Relay Satellite (TDRS) System (TDRSS) Network, is a combination of the STADAN and the MSFN.

TDRSS NETWORK

It was recognized that the Ground Spaceflight Tracking and Data Network's (GSTDN) limitations could be removed through a new network that used geostationary satellites rather than ground stations for tracking and communicating with user spacecraft. This network could provide coverage for almost the entire orbital period of a user spacecraft, support a number of spacecraft simultaneously, and have a high assurance of availability. Several NASA studies showed that this network was feasible by using state-of-the-art technology developed in the middle to late 1970s and by using the ATS-6 and the Nimbus-6 spacecraft as demonstration models. This research led to the development of the TDRSS network, which demands higher performance on the TDRSS user spacecraft.

Antennas with higher gain, receivers with more sensitivity, transmitters with higher power, and high performance diplexers have all been developed to meet the requirements for increased effective isotropic radiated power (EIRP) in user spacecraft on their primary data links. TDRSS users also require a group of antennas that provide omnidirectional coverage for deployment, retrieval, and emergency backup communications. A cadre of antennas has been developed to perform this function for TDRSS users.

DESIGN CONSIDERATIONS—OMNIDIRECTIONAL ANTENNAS

Omnidirectional antennas require a simple electronic and mechanical interface and clear field of view (FOV) to qualify as an emergency backup component. They are used to acquire the data link when spacecraft orientation may be unknown or uncontrollable. Because they are required to emit nearly isotropic radiation and

have a simple configuration, the omnidirectional antenna is best realized by using a single feed. The FOV of a single element antenna will be limited unless the antenna can be positioned well away from the spacecraft. (See Figure 1.)

ANTENNAS PAST THIS LINE
ARE TOO FAR AWAY FROM
THE SPACECRAFT TO WORK
PROPERLY

FOV ≈ 300°

FOV ≈ 270°

FOV ≈ 350°

SPACECRAFT

ANTENNA POSITIONS 1A AND 1B
180° + 180°
+ INTERFEROMETRY
FOV ≈ 350°
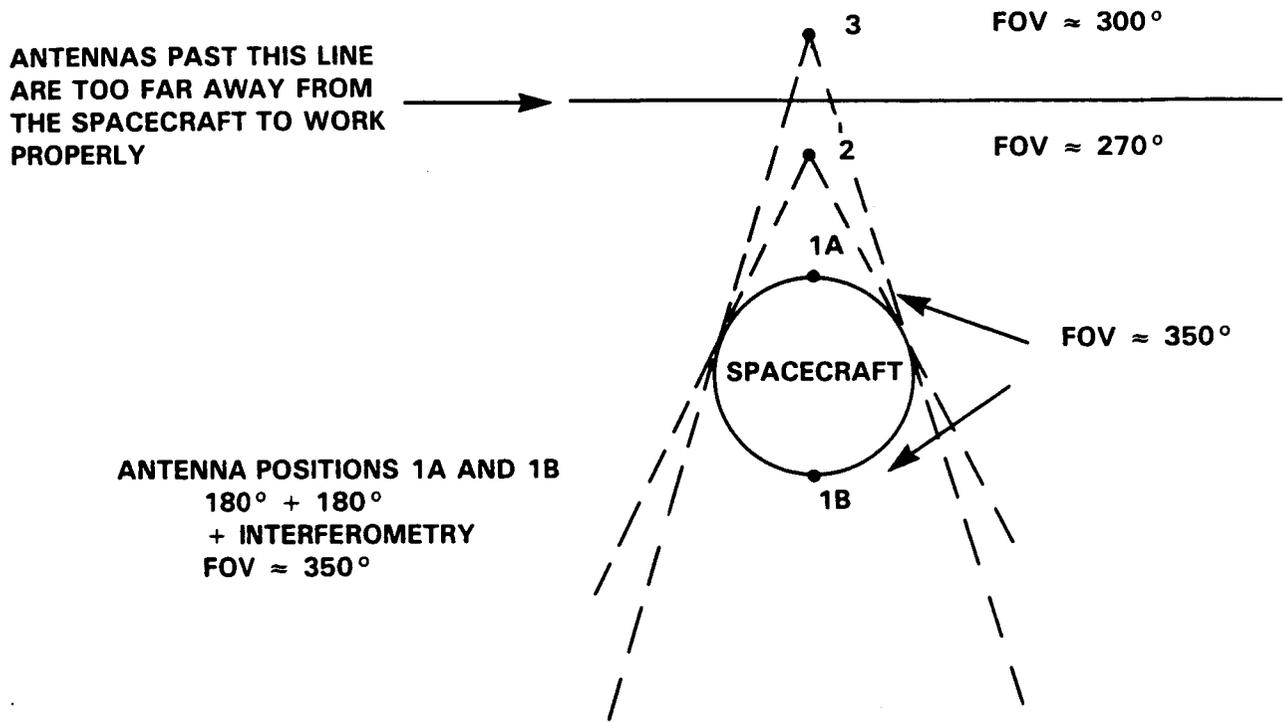
Figure 1. Fields of View (FOVs) for
Various Omnidirectional Antenna Positions

Position 3 is eliminated from consideration because of the adverse effects it would have on the attitude control system, deployment operations, and the additional transmission line losses that it would introduce. Therefore, the backup omnidirectional antenna systems developed by NASA employ a single feed positioned a short distance away from the spacecraft (position 2) or two identical antennas with their signals combined, with a hybrid combiner or switching network, working in tandem and directed 180° apart (positions 1A and 1B).

In the single antenna configuration, there is a zone of spacecraft interference that is unacceptable unless the spacecraft has the ability to keep the TDRS within its FOV. In the tandem configuration, the radiation patterns of the two identical antennas interfere with each other along the plane of the spacecraft mounting surface because of the phase differences between signals caused by the physical separation of the antennas.

DEVELOPMENT PROGRAM—SHAPED OMNI

It was recognized that with evolving materials and complex space missions that an improved omni antenna with hemispherical coverage that would satisfy most missions would be desirable.

A development program was initiated with Research and Technology Objectives and Plans (RTOP) funding to pursue the following design improvements on the spacecraft mounted (tandem) version of the omnidirectional antenna, known as the shaped omni. The shaped omni program set out to do the following:

2

a. Refine the beamwidth on a single antenna of the set to a level approaching exactly 180° (±90° off boresight)

b. Maintain uniform gain over the front hemisphere

c. Minimize the radiation in the back hemisphere (toward the spacecraft)

There was a provision included as an option to build an engineering model antenna with the following design considerations and to meet the subsequent performance specifications.

Environmental Objectives

The Shaped Omni Antenna:

Materials	— Nonmagnetic space flight materials with negligible outgassing
Temperature	— Survives temperature extremes of −100° to 100 °C and operates under conditions of −65° to 75 °C
Vacuum	— Operates under a pressure range of $10-8$ torr to one atmosphere
Noise and Vibration	— Survives acoustic and vibration levels required for spacecraft components

Spacecraft Interface Objectives

Size and Weight	— Provides user spacecraft compatibility by minimizing the size and weight. (Limits for the original engineering model were set as a 36-in.-diameter sphere, weighing less than 5 lb)
Connectors	— Uses a single SMA RF connection
Mounting	— Can be mast-mounted or spacecraft-mounted

Performance Objectives

Polarization	— Uses left-hand circularly polarized signals for transmission and reception
Gain	— Provides gain greater than −1 dB throughout the front hemisphere

QUADRIFILAR HELIX

The radiating element chosen for the shaped omni antenna is the quadrifilar helix (Figure 2). It is comprised of identical radiators wound around a tube of teflon and fiberglass and fed in phase quadrature to create an omnidirectional radiator.
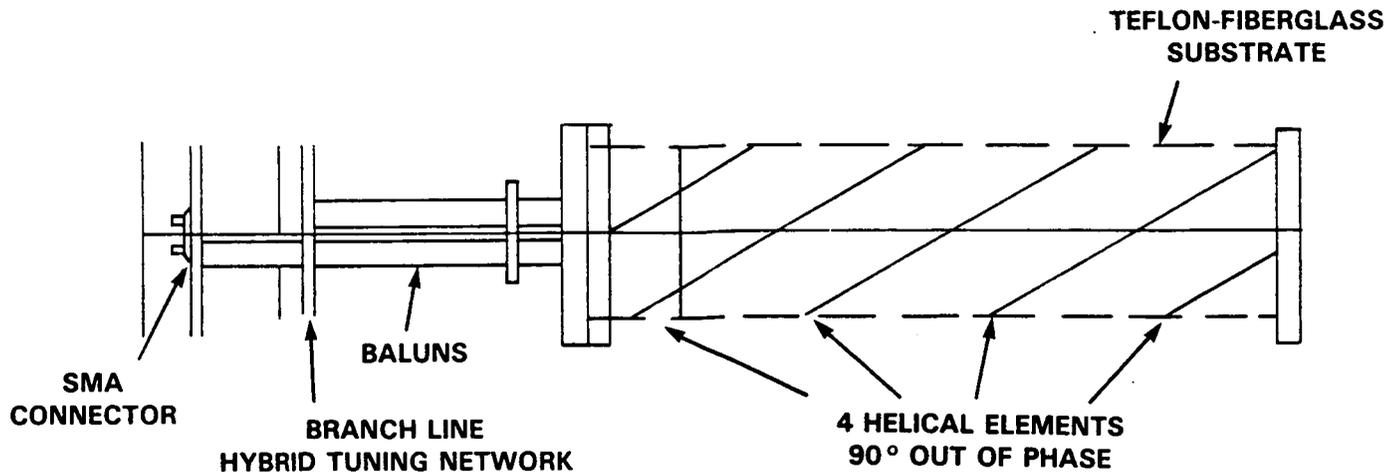
Figure 2. Quadrifilar Helix Radiating Element

The element assembly will be used to transmit and receive. Therefore, to achieve the required bandwidth, a double-tuned matching network with 90° hybrid couplers and baluns is a necessary component as part of the feed. The matching network uses tuning stubs and impedance transformer sections on a microstrip board. Theoretically, the element assembly is matched exactly at 2,106 and 2,287 MHz, as shown in Figure 3.

An interface connector feeds the hybrids, which provide two 90° signals for the tuning network. The tuning network feeds four balanced signals to the elements through baluns. The hybrid and tuning networks are microstrip boards bonded back to back. The baluns are 1:1, 180° coaxial devices connected to the base of the element quad. The elements are wire supported on a cylinder of thin teflon/fiberglass substrate. The quadrifilar element alone creates a cardioid pattern like the one shown in Figure 4.

BAFFLED GROUND PLANE

The ground plane of the shaped omni antenna causes the sharp cutoff of the pattern to occur in the hemisphere behind the ground plane. Figure 5 shows the latest model of the shaped omni. It weighs 3 lb and uses a 12-in.-diameter low-profile cone incorporating four concentric circular baffles. In the Appendix, Figure X-2 shows the original 36-in.-diameter shaped omni, that weighed 20 lb and had more than 30 baffles. Using flight materials we project that weight can be reduced to less than 2 lb.

The cone angle is 78°, a 12° slope above the plane normal to the radiating element. The height of the baffles, their separation, the slope of the ground plane, and fringing all affect the angle of cutoff. They were chosen to effect coverage down to 5° above the horizontal for an 8 to 10 percent bandwidth (2,100 to 2,300 MHz). At a single frequency, very sharp cutoff can occur, but the spacing of the baffles was continuously varied to achieve slightly slower cutoff over a wide bandwidth. The chokes are arranged so that the higher frequencies are attenuated by baffles closer to the element and the lower frequencies are attenuated by baffles closer to the perimeter. The engineering model performed better at the higher of the two frequencies (Figure 6).

The baffles act as chokes in place of the normal conductive surface and suppress the vertical component of the signal. GSFC's tests of the shaped omni used conductive materials to short circuit many of the perimeter baffles. The results of these tests suggested that the center baffles had a greater effect on the attenuation of unwanted radiation.
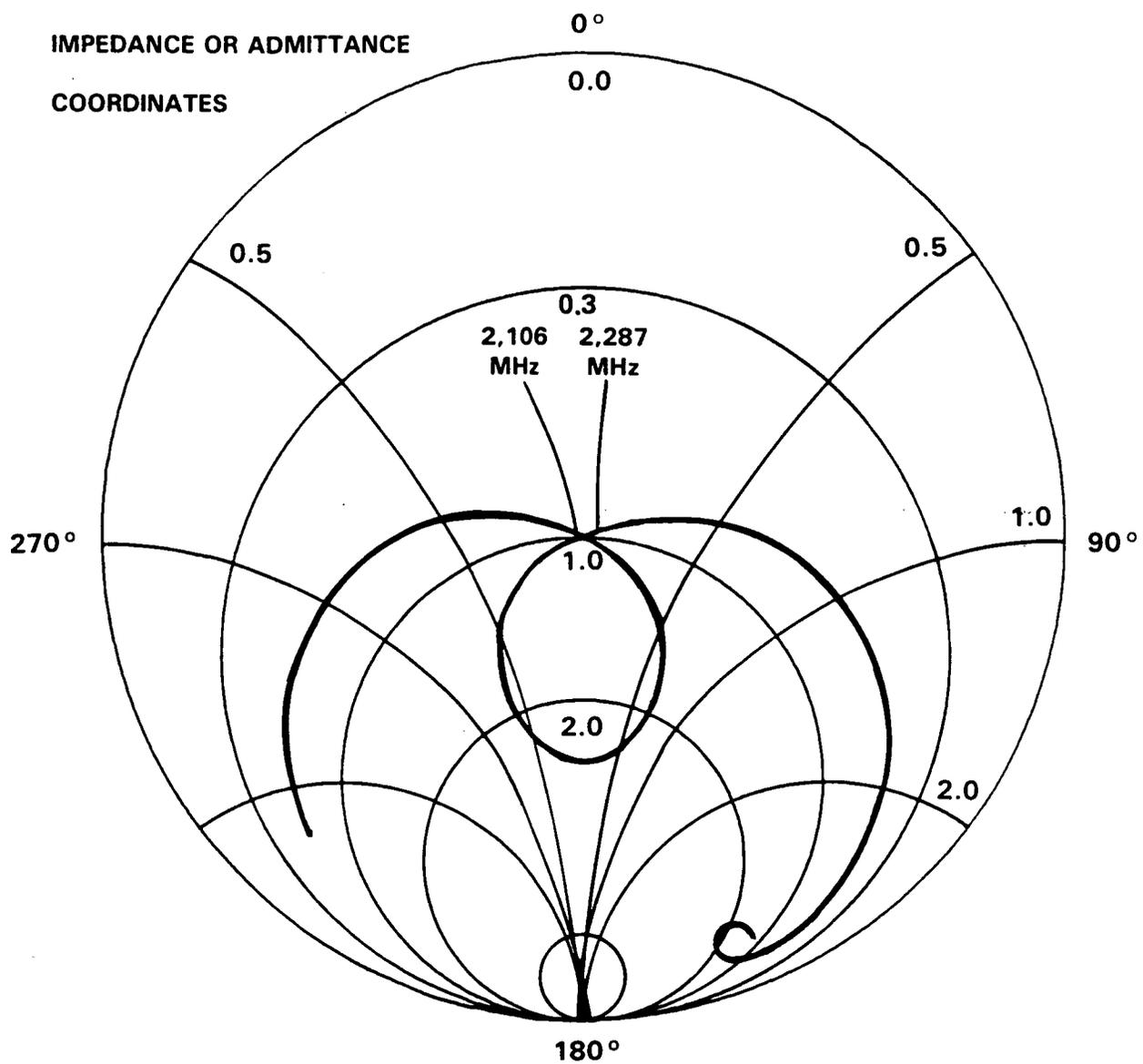
Figure 3. Quadrifilar Helix Input Impedance With the Double Tuning Network
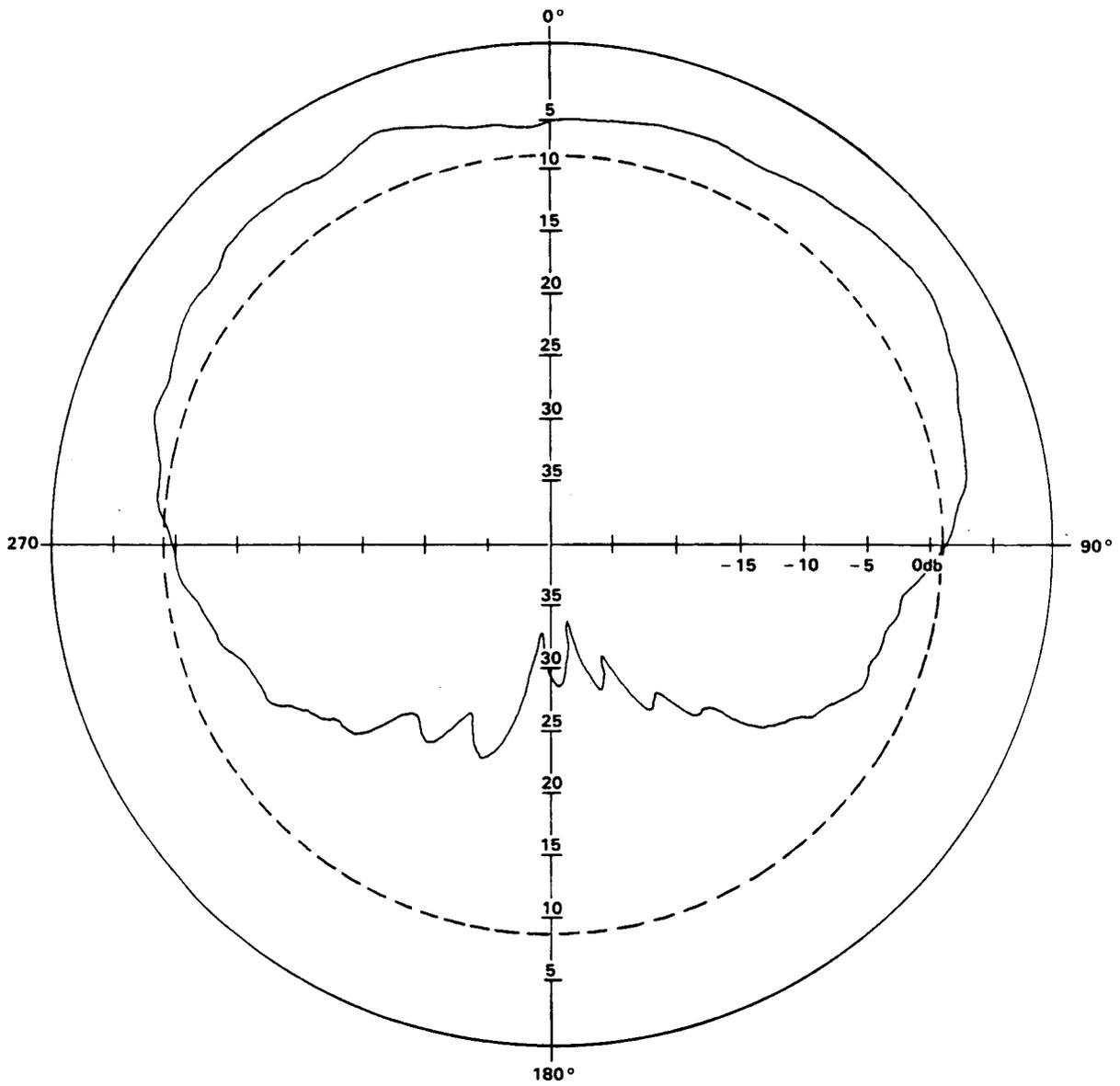
Figure 4. Cardioid Pattern Created by Quadrifilar Alone
(2,287 MHz Without Ground Plane)
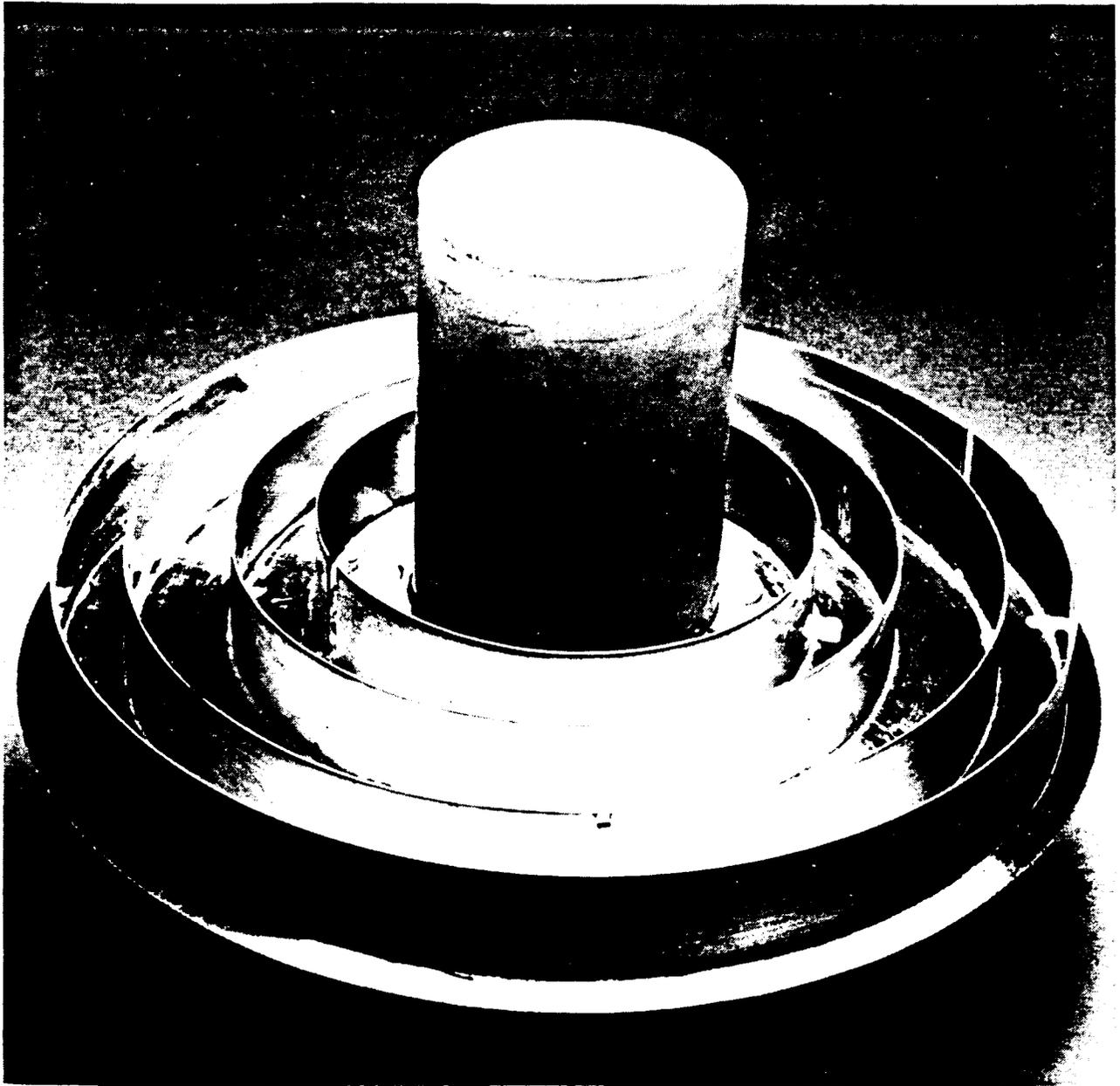
Figure 5. Shaped Omni Antenna
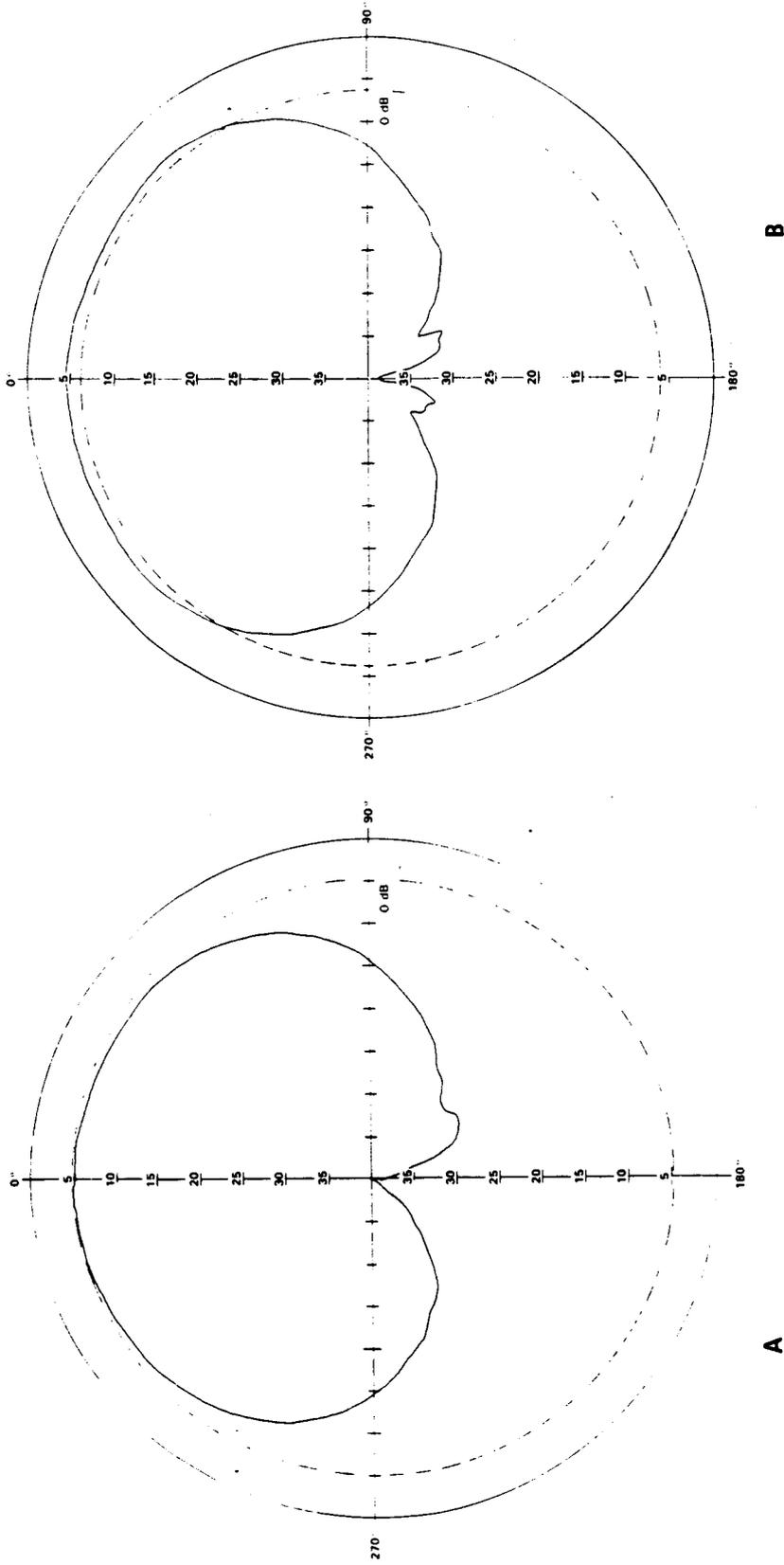
Figure 6. Patterns Created by Antennas at 2,106 MHz (a) and 2,287 MHz (b)

8

Because the large ground plane on the first engineering model pushed the limits of spacecraft mounting constraints, a second shaped omni was fabricated that uses a 12-in. ground plane. An analysis of the tradeoff between a larger ground plane and enhanced antenna performance will be included with the final report on the 12-in. engineering model. (See Appendix.)

The 12-in. shaped omni uses only four baffles and provides hemispherical coverage at the correct frequencies. The patterns show a predictable degradation in the horizon cutoff characteristics. This effect is a direct result of reducing the size of the ground plane. It was determined that the center baffles on the 36-in. shaped omni were effectively shorting out the element, and the engineering model responded best at a higher frequency—2,425 MHz. The advantage of removing these interior baffles on the 12-in. design was twofold: first, there is a better response for the frequency range of interest; and, second, it creates a ground plane of lower complexity for easier manufacture. It was also determined that the wideband frequency response of the baffles was better achieved by putting the widely spaced, low-frequency baffles in the center and the baffles responding to high frequency on the edge of the ground plane. A change in materials was made on the 12-in. ground plane. The base material was copper, which added weight but allowed the baffles to be soldered into place without plating. This allowed the baffles to be optimally placed and the solution to be easily arrived at by an empirical method. Extra rigidity was added to the quadrifilar element for ease in handling. There is no requirement to keep the material copper. The biggest factor in maintaining a good pattern is the symmetry of the baffles and the helix.

TESTING RESULTS

The shaped omni antenna has been tested as a single antenna to investigate its ability to meet the performance objectives of the development program. Besides the low-angle cutoff exhibited in Figure 6, the shaped omni also met the performance criteria shown in Table 1 over the 200-MHz frequency range.

Table 1
Performance Specifications for the Shaped Omni Antenns

Parameter	Band 1	Band 2
Frequency (MHz)	2,106 ±20	2,287 ±20
Gain (dBi): $-85 \leqslant \emptyset \leqslant 85$ $\emptyset \leqslant -100, \emptyset \leqslant 100$	0 -35	0 -35
VSWR (ref 50 Ω)	2:1	1.8:1
Phase Variation (electrical deg per mechanical deg)	<5	<5
Power Handling (W)	10	10

SYSTEM CONFIGURATIONS

Two omnidirectional antenna set systems configurations are readily assembled with two shaped omni antennas. The coupled configuration is shown on the left side of Figure 7. A composite pattern was calculated for a pair of antennas directed 180° apart and fed from points approximately 30 wavelengths apart, to simulate the width of a hypothetical spacecraft. In the areas that the individual antenna's beams overlap, an interferometry pattern is observed due to the difference in signal phase.

Another configuration of shaped omni antennas would have two antennas *switched* into the transponder. On the right side of Figure 7, the switched configuration adds some complexity and RF losses but further improves the radiation patterns so that the zone of interferometry is reduced to image effects. A more detailed link margin analysis is shown in the "Data Link Calculations" in the Appendix.

Additional patterns were taken of the shaped omni antenna to study the effect of a large reflective mounting surface. Antennas mounted in positions 1A and 1B of Figure 1 will exhibit a pattern like those shown in Figure 8. A 4- by 8-ft piece of aluminum was used to simulate a spacecraft mounting surface. Because the shaped omni ground plane was originally designed for a diameter of 36 in., the engineering model was not flush mounted to the 4- by 8-ft surface, but a gap of approximately 3 in. was left. By eliminating this gap, the user will eliminate the gain fluctuations in the front hemisphere and attain the steep angle cutoff characteristics available with spacecraft mounting. This effect has been studied extensively in microstrip omni antennas. (See the "Other Omnidirectional Antennas" Section.)

OTHER OMNIDIRECTIONAL ANTENNAS

There are several other antennas that have been developed to serve the purpose of providing omnidirectional coverage for space satellites.

Spacecraft Mounted

Another way of getting omnidirectional coverage from a low-profile antenna is to use a microstrip belt array antenna. The Canadian Communications Technology Satellite (CTS) antenna and the Air Force P78-1 satellite used microstrip belt antenna arrays around their perimeter (Figure 9).

Goddard has used microstrip patches around a deployable boom for the International Sun-Earth Explorer (ISEE) Spacecraft. The ISEE antennas pictured in Figure 10 provide simultaneous right- and left-hand circular polarization with 15 dB minimum isolation between ports. The 32-element antenna provides 10 dBi gain and a minimum 7 dBi gain at ±10° from the equator with six different beam combinations.

Microstrip Radiators

These cylindrical antennas use rectangular microstrip patches. Circular patches may also be used. Aluminum radiators mounted on a teflon/fiberglass printed circuit board use conductive cladding on the lower side as the microstrip ground plane. For the rectangular patches, slots are formed perpendicular to the feed line between the edge of their radiating element and the ground plane parallel to it. The fields of both edges reinforce each other in the front hemisphere if they are located approximately ½ wavelength apart. A ½ wavelength square element can be fed by two lines excited in phase quadrature to provide circular polarization. Another
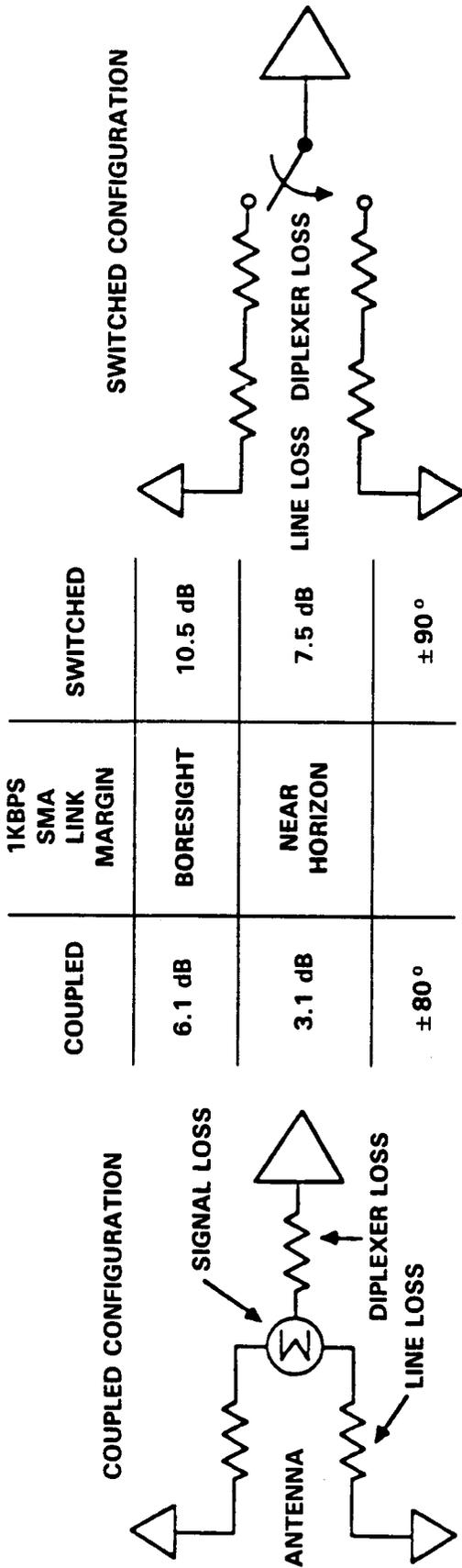
SWITCHED CONFIGURATION

DIPLEXER LOSS

LINE LOSS

1KBPS SMA LINK MARGIN		COUPLED	SWITCHED
	BORESIGHT	6.1 dB	10.5 dB
	NEAR HORIZON	3.1 dB	7.5 dB
		±80°	±90°

COUPLED CONFIGURATION

SIGNAL LOSS

DIPLEXER LOSS

LINE LOSS

ANTENNA

ZONE OF INTERFEROMETRY
~ 0 DEGREES

ZONE OF INTERFEROMETRY
± 10 DEGREES
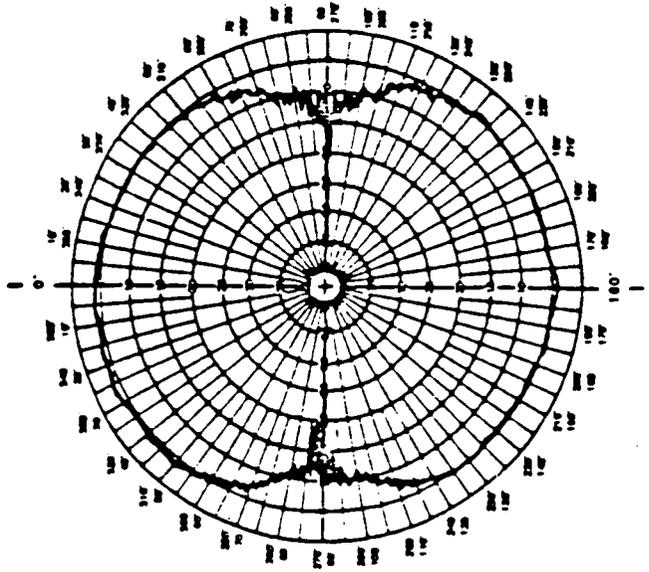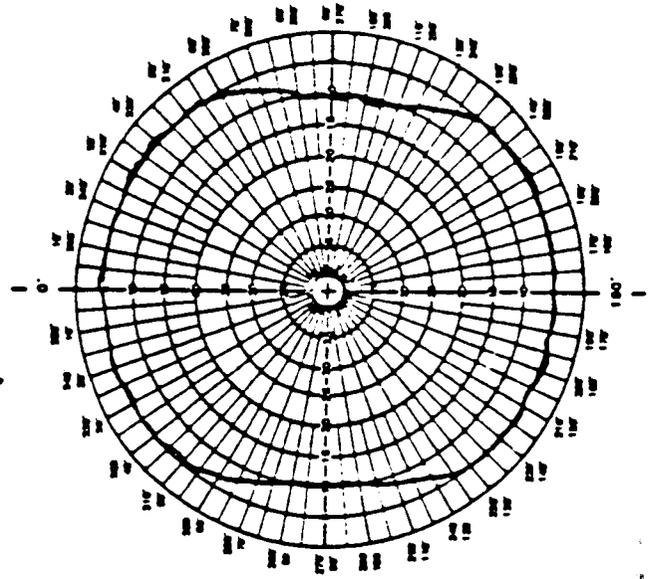
Figure 7. Shaped Omni Antennas (2,106 MHz Forward Link)

0 dB
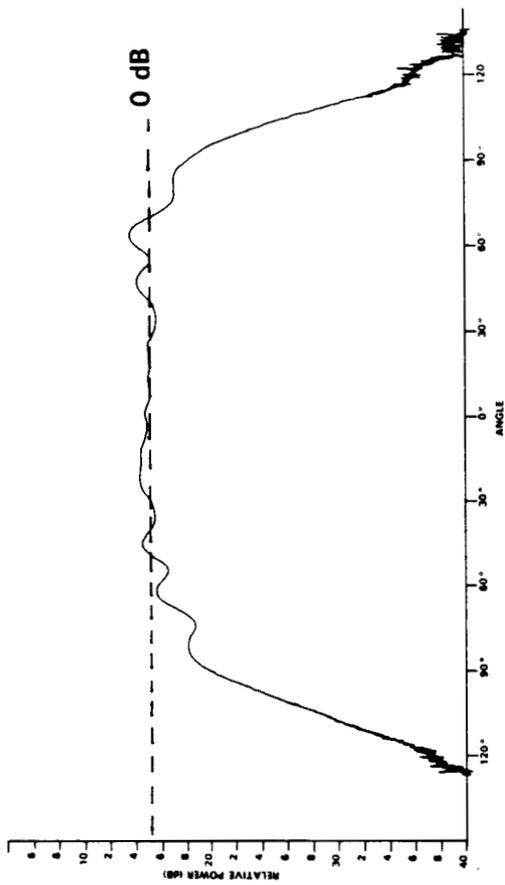
f RECEIVE =
2,106.4 MHz

0 dB
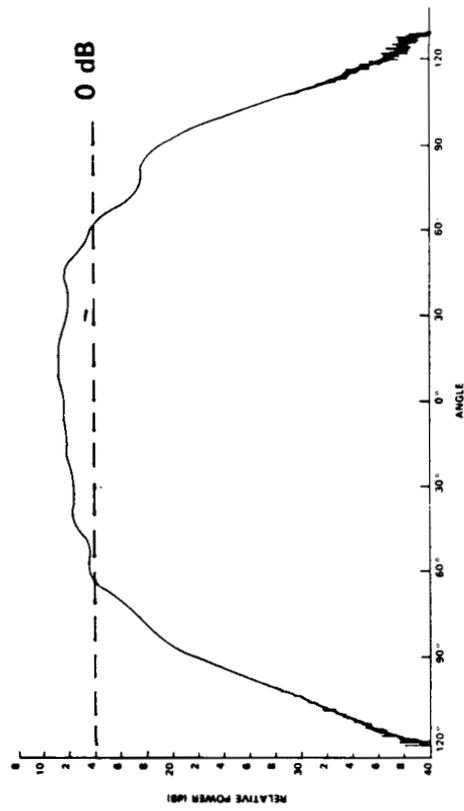
f TRANSMIT =
2,287.5 MHz

8 FT

1 FT

4 FT

3 IN
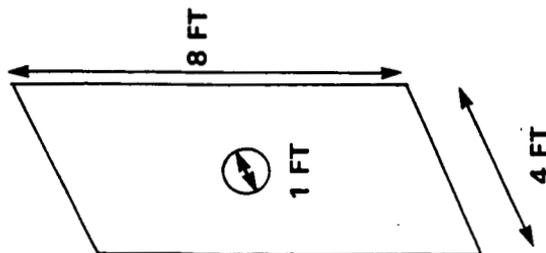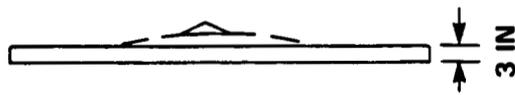
Figure 8. Shaped Omni Antenna Radiation Patterns — Affixed to Reflective Surface
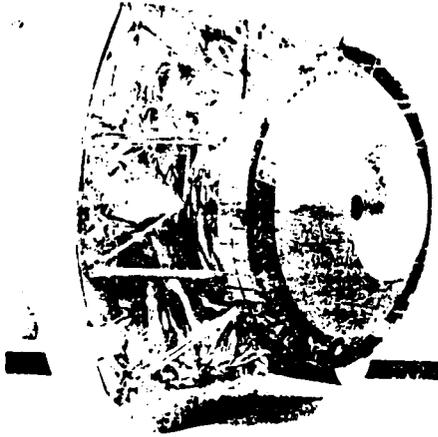
ANTENNA ON P78-1 SATELLITE

SPACECRAFT OMNI: MICROSTRIP BELT ARRAY ANTENNAS
• OMNIDIRECTIONAL, CIRCULARLY POLARIZED COVERAGE NORMAL TO SPACECRAFT SPIN AXIS   • CONFORMAL, LIGHTWEIGHT, LOW PROFILE, AND LOW COST • SINGLE ANTENNA ASSEMBLY COVERS TELEMETRY AND COMMAND FREQUENCIES

Figure 9. Microstrip Belt Array Antennas
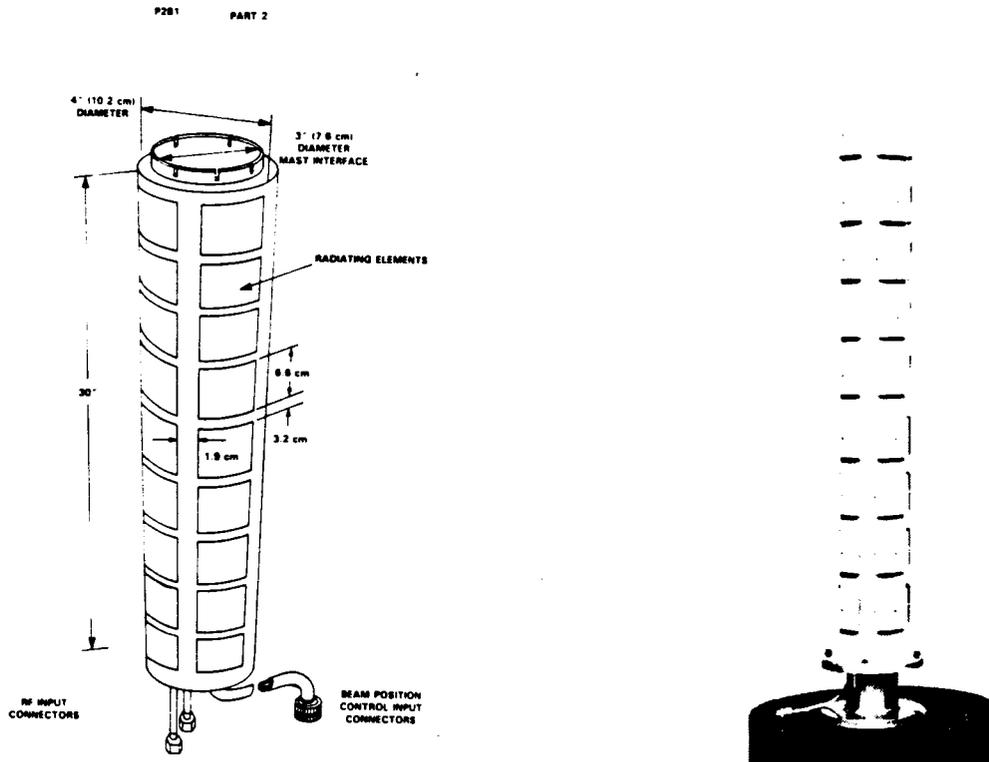
Figure 10. ISEE-C Antenna Radiator External Configuration

approach is to use a ½ wavelength diameter disk fed at points 90° apart. The ERBS omnidirectional antenna radiator was such a disk-shaped microstrip patch fed at a single point. An appropriately sized notch or tab added at the edge of the disk introduces a nonsymmetry and the disk radiates with circular polarization. (See Figures 11a and 11b.)
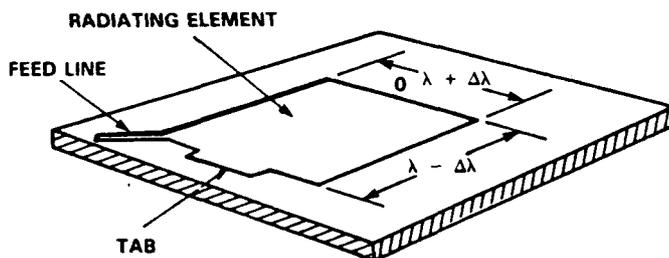
Figure 11a. Circularly Polarized Microstrip
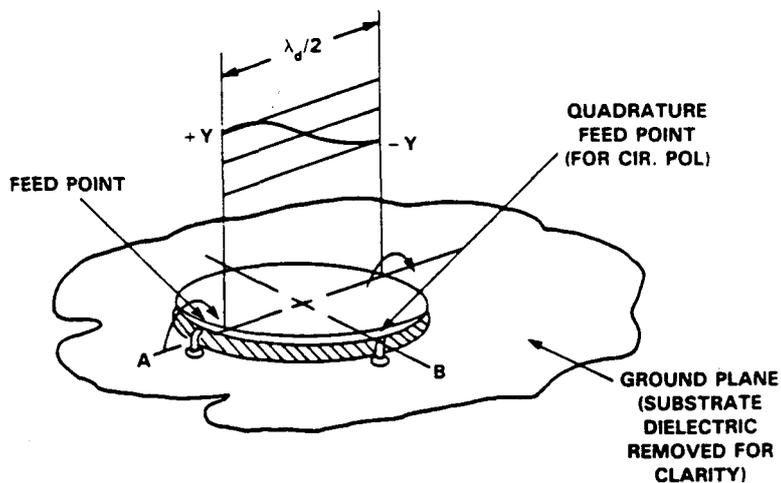
Figure 11b. Disk Shaped Circular Polarized Microstrip Radiator

Performance

Nearly uniform gain for all angles out to 77° from boresight can be obtained by shaping the beam pattern normally obtained from a microstrip patch. Raising the microstrip element a fraction of a wavelength above the structural ground plane depresses the beam on boresight and enhances its energy directed toward broader

14

look angles. Varying the size of the ground plane changes the performance of the antenna markedly. Varying the height above the ground plane also affects the resultant radiation pattern (Figure 12).

The ISEE-3 32 element antenna used four additional radiating elements which were raised off the ground plane for extra beamwidth. A 4-element omni mounted just above the 32-element antenna and suspended further from the substrate provided −4.5 dBi coverage over a ±45° beamwidth.

Other specifications such as VSWR and bandwidth are illustrated over different temperature ranges in Table 2.
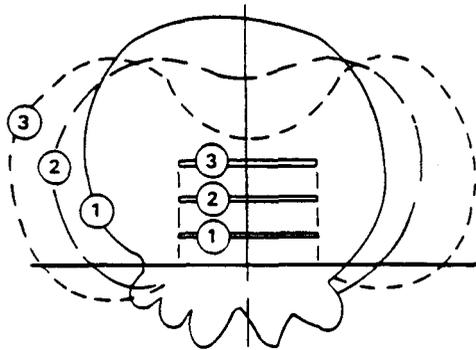
Figure 12. Qualitative Effect of Radiative Height on Patterns

Table 2
Medium Gain Microstrip Antennas

SPECIFICATIONS

TYPICAL CHARACTERISTICS
(TECHNOLOGY AVAILABLE FOR OTHER APPLICATIONS)

ELECTRICAL PERFORMANCE REQUIREMENTS

	ISEE-A	ISEE-C
OPERATING FREQUENCY AND POLARIZATION	2,215.5 MHz-RHC	2,217.5 MHz-RHC
	− 2,264.8 MHz-LHC	2,270.4 MHz-LHC
COVERAGE SECTOR RELATIVE TO SPACECRAFT EQUATOR (ELEV.)	±30°	±6°
GAIN—MINIMUM RELATIVE TO ISOTROPIC CIRCULAR POLARIZED SOURCE	+3 dB	+7 dB
AZIMUTH COVERAGE SECTOR	OMNIDIRECTIONAL	OMNIDIRECTIONAL
PHASE JITTER MAXIMUM	±20°	±20°
POWER HANDLING CAPABILITY	20 WATTS CW	20 WATTS CW
INPUT IMPEDANCE—VSWR W.R.T. 50 ohms	2.0:1	2.0:1
ISOLATION BETWEEN INPUT PARTS	− 15 dB	− 15 dB
NO. ELEVATION BEAM POSITIONS (MAXIMUM)	6	3
AMPLITUDE VARIATION (ROLL PLANE)	±1.0 dB	±1.0 dB

PHYSICAL CHARACTERISTICS

	ISEE-A	ISEE-C
RADIATOR ASSEMBLY		
LENGTH (MAX)	35.6 cm (14")	88 cm (34")
INSIDE DIAMETER	2.5 cm (1")	6.35 cm (2.5")
OUTSIDE DIAMETER	11.0 cm (4.3")	11.0 cm (4.3")
WEIGHT	1,400 GRAMS	5,500 GRAMS
CONTROL UNIT		
SIZE (MAX)	15.24 × 14 × 5.1 cm	15.24 × 14 × 5.1 cm
WEIGHT	950 GRAMS	950 GRAMS
MOUNTING TYPE	SURFACE FLANGE	
CONTROL CABLE		
LENGTH	2.44 METERS	2.44 METERS
	1 SHIELD	1 SHIELD
CONNECTORS	AMP HD-22 15 PIN	AMP HD-22 15 PIN
WEIGHT	350 GRAMS	350 GRAMS
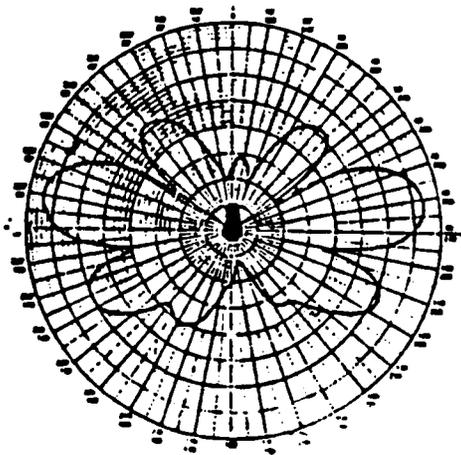
TYPICAL ASPECT PATTERN
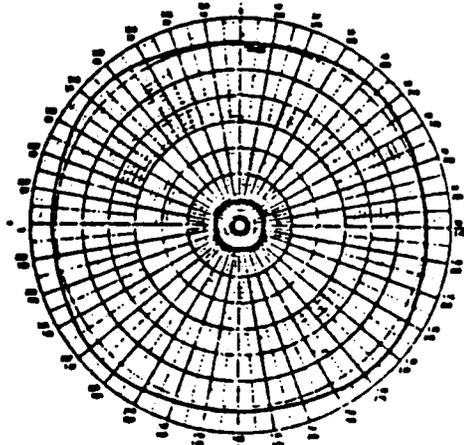
TYPICAL ROLL PATTERN

APPENDIX

SHAPED OMNI ANTENNAS

FOR SPACE USERS OF NASA NETWORKS

APPENDIX: SHAPED OMNI ANTENNAS

SPECIFICATIONS

TYPICAL CHARACTERISTICS
(TECHNOLOGY AVAILABLE FOR OTHER APPLICATIONS)

ELECTRICAL PERFORMANCE REQUIREMENTS

OPERATING FREQUENCY AND POLARIZATION	RCV / XMIT	2,106.4 ± 20 MHz-LHC
		2,287.5 ± 20 MHz-LHC
COVERAGE SECTOR RELATIVE TO SPACECRAFT EQUATOR (ELEV.)		±80°
GAIN—MINIMUM RELATIVE TO ISOTROPIC CIRCULAR POLARIZED SOURCE		0 dBi
AZIMUTH COVERAGE SECTOR		±80°
PHASE JITTER MAXIMUM		±5°
POWER HANDLING CAPABILITY		10 WATTS
INPUT IMPEDANCE—VSWR W.R.T. 50 ohms		2.0:1
ISOLATION BETWEEN XMIT/RCV FREQUENCIES		SINGLE PORT CIRCULATOR REQUIRED
AMPLITUDE VARIATION FRONT HEMISPHERE		±1 dB MAX

PHYSICAL CHARACTERISTICS

RADIATOR ASSEMBLY	
HEIGHT OF RADOME/ELEMENT ASSEMBLY	5″
DIAMETER OF RADOME	3″
DIAMETER OF GROUND PLANE	12″
WEIGHT	2 lb (W/COPPER GROUND PLANE)
CONTROL UNIT HOUSING	BROADBAND NETWORK
SIZE (MAX)	2″ DIAMETER × 1½
WEIGHT	1 lb
CONTROL CABLE	SEMI-RIGID
LENGTH	COAXIAL 1 METER
CONNECTORS	SMA
WEIGHT	350 GRAMS
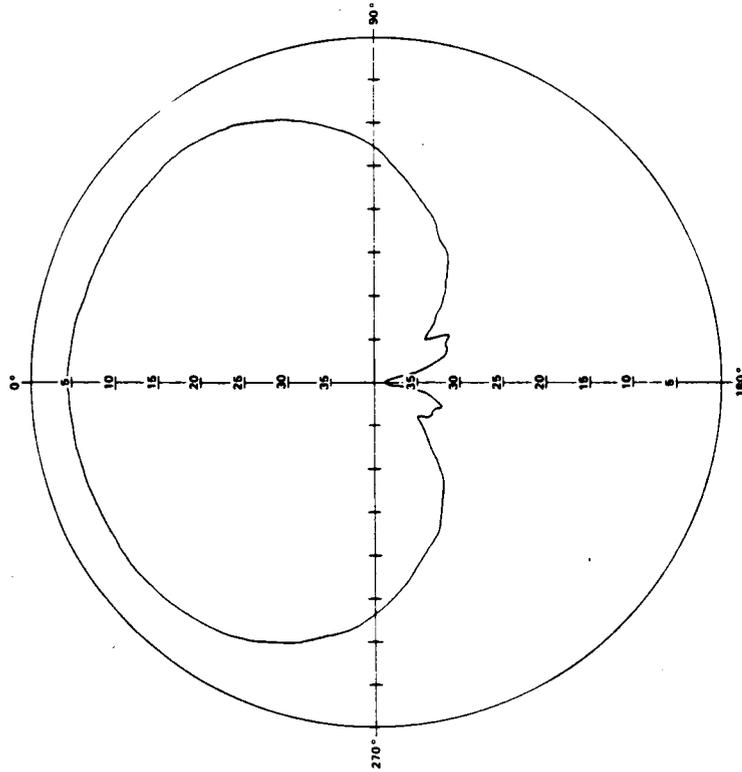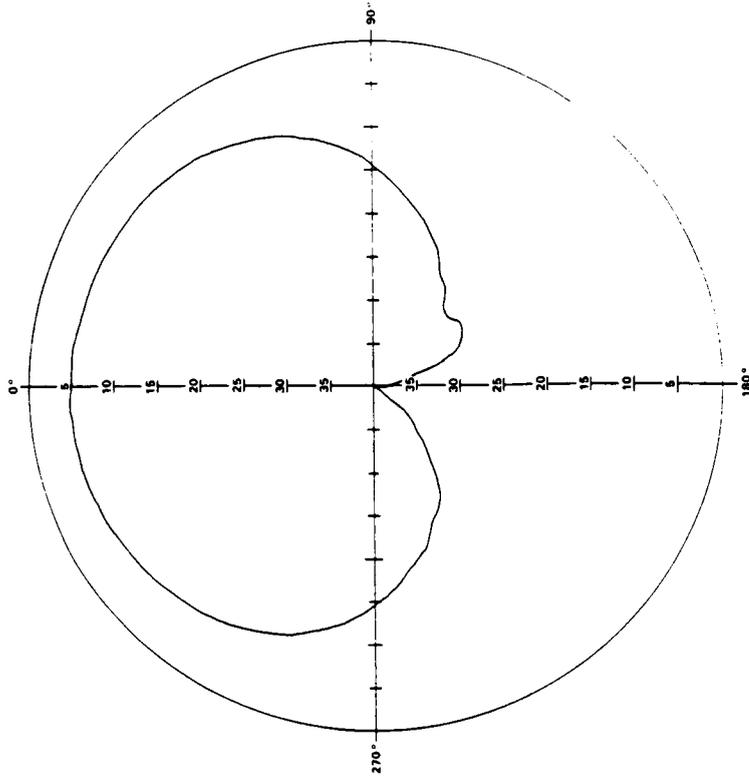
Figure X-1. Typically Shaped Omni Pattern at 2,106.4 MHz (left) and at 2,287.5 MHz (right)
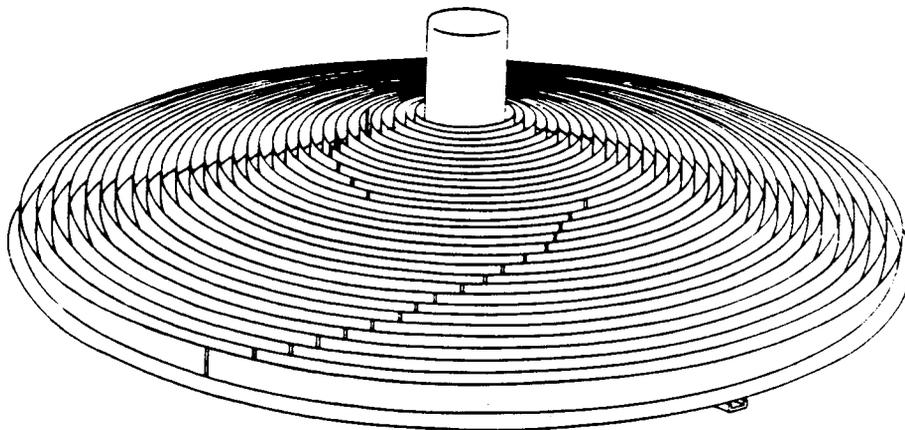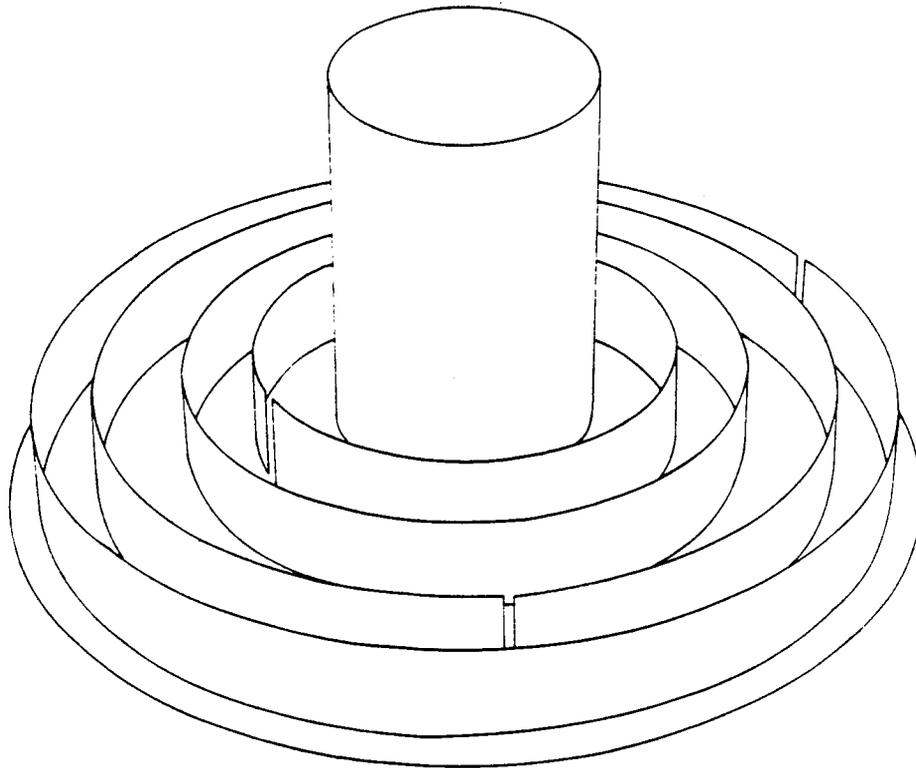
Figure X-2. Shaped Omni Antenna (36 in. Shaped Omni below)

If space permits, the baffled ground plane cone can be extended again for applications that require increased coverage on the horizon. The original 36 in. shaped omni exhibited outstanding cutoff characteristics $\pm 85°$ off axis. Reducing the size of the 12 in. ground plane would eliminate the broadbanding capabilities, and quickly degrade the rapid cutoff characteristics of the antenna assembly. The 12 in. design nearly optimizes the mechanical electronic tradeoff, as Figure X-3 shows.
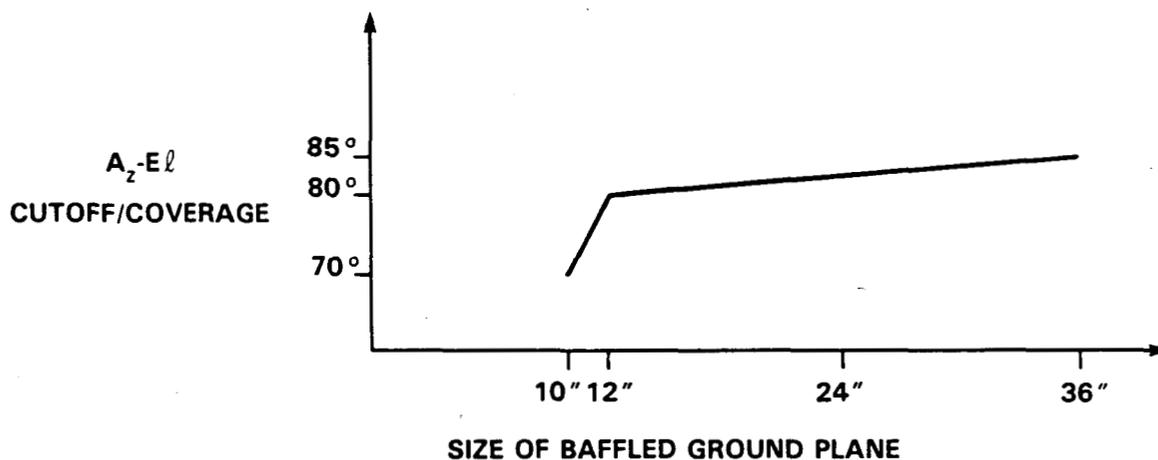
Figure X-3. Effects of Ground Plane Size on Pattern Cutoff

DATA LINK CALCULATIONS

f = 2,106.4 MHz
RECEIVE ———————— COUPLED CONFIGURATION
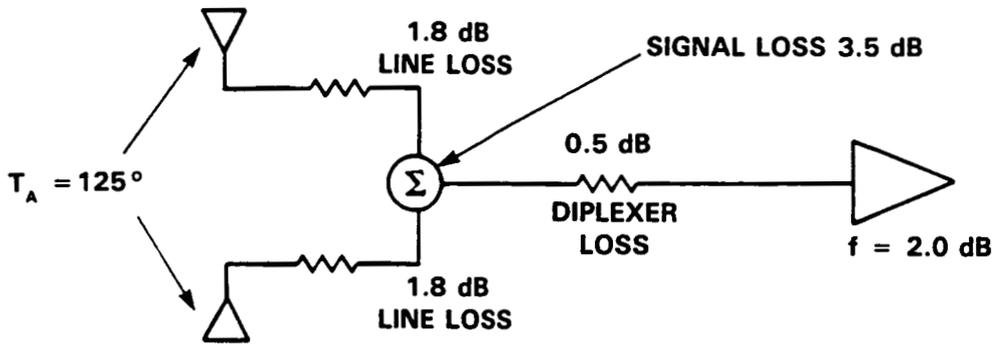
dBs CONVERTED   L = LOSSES
TO MULTIPLES   F = NOISE FIGURE

$$T_s = \frac{2\,T_a}{L} + 290 \left(\frac{L-1}{L}\right) + 290 \quad (f-1)$$

$$= \frac{250}{3.8019} + 290 \left(\frac{.9055}{1.9055}\right) + 290\,(0.5848) = 373.2$$

$$N_o = 228.6 - 25.7 = \boxed{202.9 \text{ dBW/Hz}}$$

A-5

	S-BAND SINGLE ACCESS (SSA)	S-BAND MULTIPLE ACCESS (SMA)
FORWARD LINK COUPLED		
TDRS EIRP	43.6 dBW	34.0 dBW
PATH LOSS	– 191.5 dB	– 191.5 dB
RECEIVE ANTENNA GAIN	0.0 dB	0.0 dB
POLARIZATION LOSS	– 3.0 dB	– 3.0 dB
UQPSK LOSS	– 0.5 dB	– 0.5 dB
HYBRID/LINE/DIPLEXER LOSSES	– 5.8 dB	– 5.8 dB
EQUIPMENT IMPLEMENTATION LOSS	– 3.0 dB	– 3.0 dB
RECEIVED SIGNAL	– 160.2 dBW	– 169.8 dBW
LESS TRANSPONDER NO REDUCTION	202.9 dB bps/W	202.9 dB bps/W
	42.7 dB bps	33.1 dB bps
DATA RATE/REQUIRED S/N_o	8 KBPS/ – 39.0 dB bps	1 KBPS/ – 30.0 dB bps
	3.7 dB	3.1 dB

LINK MARGINS IN AREA
OF UNIFORM GAIN (± 80° OFF BORESIGHT)

RETURN LINK		
TRANSMIT POWER 5 W	7 dBW	7 dBW
COAXIAL LINE/DIPLEXER/HYBRID	5.8 dB	5.8 dB
ANTENNA GAIN	+ 1.0 dB	+ 1.0 dB
POLARIZATION LOSS	3.0 dB	3.0 dB
EFFECTIVE EIRP	– 0.8 dBW	– 0.8 dBW
TDRSS USERS GUIDE CONSTANT (DG-1)	34.0 dB	23.6 dB
ACHIEVABLE DATA RATE	33.2 dB bps	22.8 dB bps
DATA RATE/LESS REQUIRED S/N_o	1 KBPS/ – 30.0 dB bps	125 bps/ – 21.0 dB bps
	3.2 dB	1.8 dB

LINK MARGINS IN AREA
OF UNIFORM GAIN (± 80° OFF BORESIGHT)

f = 2,106.4 MHz

RECEIVE ———————— **SWITCHED CONFIGURATION**

125 K

SWITCH LOSS = 0.2 dB

f = 2 dB

1.8 dB
LINE LOSS

0.5 dB
DIPLEXER LOSS
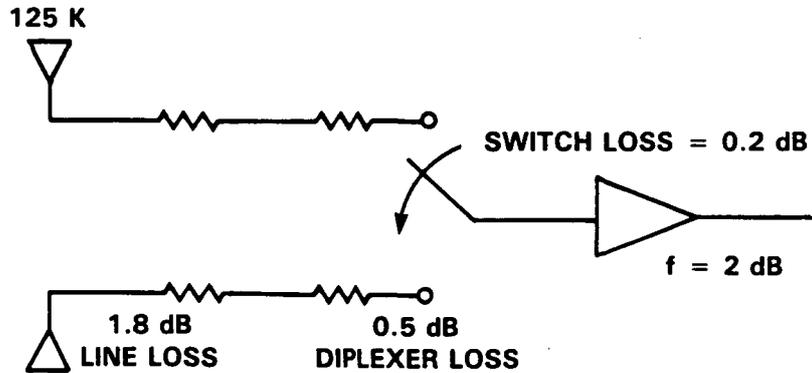
dBs CONVERTED   L = LOSSES
TO MULTIPLES   F = NOISE FIGURE

$$T_s = \frac{125}{L} + 290 \left(\frac{L - 1}{L}\right) + 290 \quad (f - 1)$$

$$= \frac{125}{1.6982} + 290 \left(\frac{0.6982}{1.6982}\right) + 290 \ (0.5848) \ = 362.46 \ (25.6 \ dB)$$

$$N_0 = 228.6 - 25.6 = \boxed{+204 \ dBW/Hz}$$

RETURN LINK SWITCHED	S-BAND SINGLE ACCESS (SSA)	S-BAND MULTIPLE ACCESS (SMA)
TDRS EIRP	43.6 dBW	34.0 dBW
PATH LOSS	− 191.5 dB	− 191.5 dB
RECEIVE ANTENNA GAIN	0.0 dB	0.0 dB
POLARIZATION LOSS	− 3.0 dB	− 3.0 dB
UQPSK LOSS	− 0.5 dB	− 0.5 dB
SWITCH/LINE/DIPLEXER LOSSES	− 2.5 dB	− 2.5 dB
EQUIPMENT IMPLEMENTATION LOSSES	− 3.0 dB	− 3.0 dB
RECEIVED SIGNAL	− 156.9 dBW	− 166.5 dBW
LESS TRANSPONDER NO REDUCTION	204.0 dB bps/W	204.0 dB bps/W
	47.1 dB bps	37.5 dB bps
DATA RATE/REQUIRED S/N_0	10 KBPS/ − 40.0 dB bps	1 KBPS/ − 30.0 dB bps
	7.1 dB	7.5 dB

LINK MARGINS IN AREA
OF UNIFORM GAIN (± 90° OFF BORESIGHT)

RETURN LINK		
TRANSMIT POWER	7 dBW	7 dBW
COAXIAL LINE/DIPLEXER/SWITCH	2.5 dB	2.5 dB
ANTENNA GAIN	+ 1.0 dB	+ 1.0 dB
POLARIZATION LOSS	3.0 dB	3.0 dB
EFFECTIVE EIRP	2.5 dBW	2.5 dBW
TDRSS USERS GUIDE CONSTANT (DG-1)	34.0 dB bps/W	23.6 dB bps/W
ACHIEVABLE DATA RATE	36.5 dB bps	26.1 dB bps
DATA RATE/LESS REQUIRED S/N_0	1 KBPS/ − 30.0 dB bps	125 bps/ − 21.0 dB bps
	6.5 dB	5.1 dB

LINK MARGINS IN AREA
OF UNIFORM GAIN (± 90° OFF BORESIGHT)

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15. Supplementary Notes·

16. Abstract

This document describes the performance capabilities and critical elements of the shaped omni antenna developed for NASA for space users of NASA networks. The shaped omni is designed to be operated in tandem for virtually omnidirectional coverage and uniform gain free of spacecraft interference. These antennas are ideal for low gain data requirements and emergency backup, deployment, and retrieval of higher gain RF systems. Other omnidirectional antennas that have flown in space are described in the final section of this document. A performance summary for the shaped omni is in the Appendix.

This document introduces organizations and projects to the shaped omni applications for NASA's space use. Coverage, gain, weight, power, and implementation and other performance information for satisfying a wide range of data requirements are included.

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