ISPM SPACECRAFT ANTENNAS*

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ABSTRACT

International Solar Polar Mission (ISPM) is a dual-spacecraft mission sponsored jointly by NASA and European Space Agency (ESA) to gather scientific information for further understanding of the sun and predicting its influence on the Earth's weather and climate. Jet Propulsion Laboratory of the California Institute of Technology has selected TRW to buiId U.S. spacecraft for the joint mission. The dual spacecraft will fly to Jupiter and use that planet's greater gravitational field to achieve a near 90 degree orbit change, placing the two spacecraft on separate trajectories to the North and South poles of the Sun from a high heliographic vantage point.

The antenna subsystem of the ISPM spacecraft consists of S-/X band high gain, S-band broad coverage, and X-Band medium gain antenna.

Command and ranging signals are received by the S-band high-gain and broad-coverage antennas. Scientific and engineering data are transmitted by these two antennas and the X-band high-gain antenna. Conscan acquisition is by the two S-band antennas. Emergency transmissions are by the S-band broad coverage and X-band medium-gain antennas.

The S-/X-band HGA is a 1.9 meter (78 inches) diameter dual reflector Cassegrain design with a dichroic subreflector. The Cassegrain mode is excited by an efficient dual mode conical horn whose dimensions have been optimized to provide high-gain performance for X-Band. The S-band feed, located directly behind the frequency selective subreflector, illuminates the parabolic reflector as a focal point feed, laterally displaced by 2.29 cm (0.9 inch) to provide conscan signals with a 1 dB crossover level. The selected configuration permits the use of a common antenna for both X- and S-band functions and utilizes previously developed TRW hardware. The selected design represents the largest non-deployable antenna that could be accommodated by shuttle/IUS and spacecraft physical interfaces. An x-ray XUV telescope (CXX) is located on the center of the spacecraf t which is despun about the spacecraft +Z axis. The ends of the coronograph

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cast shadows onto the edge of the reflector up to 9.72 cm (3.83 inches) inside the reflector. The shadowing effects from the coronograph have been analyzed and subsequently verified by antenna range testing. The performance of each antenna is substantiated by analyses and test data and pertinent design and analysis results are presented.

INTRODUCTION

The ISPM antennas are configured primarily to meet the overall mission objectives and link performance requirements of the telecommunication system. The spacecraft antennas selected for ISPM, to a great extent, are hardware developed and qualified configuration. The S-/X-band functions are performed with a common high-gain antenna. The S-band coverage antenna is the Pioneer 10 and 11 corrugated horn, used as is. The X-band medium gain horn is an existing design adapted from the DSCS II. These antennas employ existing TRW hardware and designs. Required gain and coverage characteristic are provided at low weight, volume, complexity, and risk. Test results are available indicating the selected antenna configuration provides the required link performance. All antennas mount rigidly to the spacecraft structure, are carefully aligned, and are located to the minimized pattern interference as shown in Figure 1. The S-band broad coverage antenna and the X-band medium-gain horn have unobstructed viewing angles of 90 and 60 degrees, respectively. The S-/X-band and high-gain antenna is offset to minimize the pattern perturbation from CXX instrument. Figure 2 presents the requirements versus capabilities of the antenna subsystem.

This paper discusses the design, analysis and performance characteristics details of the individual antennas.

S-BAND/X-RAND HIGH-GAIN ANTENNA

The dual-function primary antenna (Figure 3) is a Cassegrain design with a dichroic subreflector. The Cassegrain mode is excited by an X-Band dual mode conical horn. The S-band feed, located directly behind the frequency selective subreflector, illuminates the parabolic reflector as a focal point feed, laterally displaced by a 2.29 cm (0.9 inch) to provide conscan signals with a 1-dB crossover level. The selected configuration permits the use of a common antenna for both S- and X-band functions and utilizes previously developed TRW hardware.

The size of the main parabolic reflector, i.e., diameter (1.98 net) and focal length to diameter (f/D) ratio (.4), was dictated by mechanical envelope considerations. Electrical design efforts, are, therefore, restricted to the Cassegrain feed (primary feed horn and dichroic subreflector) geometry and feed components.

CASSEGRAIN FEED GEOMETRY

The geometry of the Cassegrain feed is shown in Figure 3C. Pertinent design characteristics are summarized in Figure 3B. A dual mode horn design was selected for the primary feed. It offers high illumination efficiency over the operating frequency together with design maturity. The Cassegrain geometry maximizes the performance of the antenna for S- and X-band. The selected design is similar to that used on LANDSAT-D.

The 31.90 cm (12.56 inch) diameter subreflector provides an optimum size from the standpoint of blockage and diffraction (main reflector spillover) losses. The extension of the subreflector beyond the angle subtended by the main reflector minimizes the diffraction losses caused by the electrically small subreflector.

X-BAND ANTENNA FEED

The antenna feed assembly (Figure 4A) is composed of three functional components:

- Primary feed horn - provides a circular symmetric right- hand circular polarized (RHCP) beam for efficient illumination of the subreflector.

- Circular polarizer - provides a 90 degree differential phase-shift to two linear orthogonally polarized signals.

- Mode transition - launches a TE_{11} circular waveguide mode from a dominant TE_{10} rectangular waveguide mode.

The dual mode conical horn operates over a relatively narrow frequency band, as compared to a corrugated horn. A step in the horn's throat causes a portion of the TE_{11} mode to be converted to the TM_{11} mode. By proper adjustment of relative power and phasing in each mode, a radiation pattern, with essentially no sidelobes and equal E and H planes beamwidths, are obtained at the operation frequency.

The dual mode conical horn geometry is shown in Figure 4A. The aperture is selected to provide a 10-dB taper excitation to the subreflector.

Right-hand circular polarization is obtained by a circular waveguide iris-type polarizer. The polarizer consists of nine symmetrical irises formed inside the waveguide. The irises are spaced a quarter of a guide wavelength apart and provide extremely small axial ratio over relatively wide bandwidths. Figures 4B through 4E show details of the polarizer and its performance in a feed.

Circular-to-rectangular guide taper transition provides the required interface between the polarizer and the WR112 guide.

S-BAND FEED

A cavity-backed crossed dipole antenna fed through a quadrature hybrid provides the radiation pattern for illuminating the parabolic reflector. By proper choice of cavity diameter and height, the optimum feed pattern is obtained for the particular f/D ratio of the reflector and secondary pattern desired. Figure 5A shows the S-band feed design details. A quadrature hybrid permits either right- or left-hand circular polarization. The right-hand circularly polarized port is terminated into a matched load for the ISPM design.

DICHROIC SUBREFLECTOR

The dichroic subreflector consists of a hyperbolic surface that reflects the X-band feed radiation but is transparent to the S-band radiation. The selectivity is obtained by etching metallic crossed dipoles on a dielectric sheet that are resonant at X-band but very small in terms of wavelength at S-Band. The angle of arrival of the X-band signal determines the bandwidth characteristics of the etched crossed dipoles. The dichroic subreflector dipole and support structure dimensions are shown in Figures 6A and 6B.

The dichroic subreflector is 31.90 cm (12.56 inches) in diameter, providing an efficient scatter or diffraction pattern with negligible blockage. Figure 6 presents details of this antenna. This unit (38.1 cm subreflector) consisted of Kevlar honeycomb facesheets of which one facesheet, on the hyperbolic surface, contained the printed circuit dipoles.

Figure 6C presents the measured radiation patterns of a 9-foot diameter reflector at 14.0 GHz. The worst case reflection loss is less than 0.1 dB, and the effect on the pattern beamwidth or sidelobes is negligible.

Similar tests were performed at S-band except that the radiation were recorded with and without the dichroic subreflector. Figure 6C presents the measured patterns at 2.1 and 2.3 GHz. The worst case transmission loss was less than 0.2 dB, and the effect on the pattern beamwidth and sidelobes was negligible.

S-/X-BAND HIGH-GAIN ANTENNA PERFORMANCE

Pattern performance and antenna gain of the high-gain antenna were determined using TRW proprietary computer programs. The computer programs account for all important antenna parameters, including feed pattern spillover and efficiency, subreflector diffraction pattern, reflector edge diffraction, subreflector/feed blockage, and thermal distortion of the feed, subreflector and reflector. Figure 7D presents the S-/X-band high-gain antenna gain/loss budgets for the transmit and receive bands and determined by the programs.

The computer-calculated transmit radiation pattern of the antenna at X-band (8415 MHz) is presented in Figure 7A. The calculated offset patterns for S-band, using the actual measured feed data from the existing cupped crossed dipole antenna, are shown in Figures 7B and 7C for the transmit and receive frquencies of 2295 and 2113.3 MHz The offset dimension of 2.29 cm (0.9 inch) provides the desired conscan beam with a 1-dB crossover level.

The S-band feed is composed of a cavity-backed crossed dipole. A matching balun excites the dipoles and a 90 degree hybrid permits either right- or left-hand circular polarization.

The X-band feed is composed of four components: a machined aluminum dual mode conical horn, an electroformed copper iris type circular polarizer, an electroformed copper circular-to-rectangular transition, and a machined aluminum mounting bracket. All components are attached via waveguide flanges. The assembled feed is attached to the main reflector via screws.

S-BAND BROAD COVERAGE ANTENNA

The proposed antenna is an unmodified design from Pioneer 10 and 11. It is a corrugated conical horn excited by unequal length crossed dipoles. The antenna is permanently aligned so that its electrical axis is an angle of approximately 8 degrees with respect to the spacecraft geometric axis (+z axis). This alignment provides a coarse conscan pattern as the spacecraft rotates about its spin axis. Its crossover level gain at the spin axis is nominally 1 dB down from the beam peak.

The antenna is right hand circular polarized, and its broad beam characteristics provide a conscan range of 10 degrees. The antenna has been qualified to handle 8.3 watts over a pressure range of 1 to 3 x 10^{-5} torr (a power handling test will be conducted to assure a 6 dB power handling margin for ISPM). The peak gain of the antenna is 16.2 dBi at the transmit frequency and 15.2 dBi at the receive frequency. Over the transmit and receive band, the coverage gain is greater than 10 dBi over a conical half angle of 18 degrees about the mechanical antenna axis. The antenna VSWR is less than 1.5:1. The axial ratio characteristics are 1.2 and 4.5 dB for the transmit and receive frequencies.

As shown in Figure 8A, the aperture outer diameter is 42.20 cm (16.613 inches). The antenna cone angle is 61.4 degrees. The corrugation depth is 4.80 cm (1.89 inches). The overall length of the antenna including the transition mount to offset the antenna beam is 35.56 cm (14.0 inches). The pattern performance is shown in Figures 9B and 8C.

The broad coverage antenna assembly is composed of three major components: the horn, the balun assembly, and the transition mount. The total assembly (less RF cables) weighs 1.668 kg (3-7 pounds).

The horn is a spot-welded assembly utilizing aluminum details. The interior of the horn has a series of aluminum conical vanes.

The balun assembly has a machined tublar aluminum outer conductor and a solid aluminum inner conductor. The four dipoles are also aluminum machinings and are attached to the top of the balun by threads.

The transition mount is an aluminum weldment. It is shaped like a truncated cone and flanged at both ends. The flanges provide for mounting the horn to the spacecraft structure. The flanges are reinforced with small triangular gussets. This unit provides the angular degree offset positioning required for the broad coverage antenna assembly.

X-BAND MEDIUM-GAIN ANTENNA

The X-band medium-gain antenna design is a corrugated conical horn excited by crossed dipoles (see Figure 9). This antenna provides a near optimum gain of 18 dBi with a low VSWR and low axial ratio. Design details of the antenna are shown in Figure 10A.

The aperture diameter is 3.4 wavelengths and the horn length is approximately 3.7 wavelengths, with five corrugations per wavelength. The flare angle of the horn is 49 degrees. The horn diameter and flare angle were selected to provide an axially symmetric beam of 20 degrees half power beamwidth. The grooves were designed to produce an antenna pattern of low sidelobes and backlobe.

The right-hand circular polarization is provided by the unequal length crossed dipole. When the dipole arms were adjusted to provide the necessary phase quadrature, a coverage axial ratio less than 1 dB over 3 percent operating frequency bandwidth was obtained.

The X-band medium-gain antenna is composed of three major components: the horn, the dipole assembly, and the waveguide mount assembly. The total assembly weighs 0.33 kg (.073 pound).

The horn is a machined aluminum configuration, the flanged base of which is the mounting base for the horn and attaches to waveguide mount assembly via screws. The dipole assembly is an unequal cross dipole configuration. The dipoles are machined copper parts attached to a 0.141 coaxial cable.

CORONAGRAPH EFFECTS ANALYSIS

The coronagraph is located outside of the high-gain antenna feed illumination fields. Its effects on the high-gain antenna can be assessed in terms of shadowing. The coronagraph is despun about the +Z axis. For coronagraph pointing angles θ between 37 to 60 degrees, the ends of the coronagraph cast shadows onto the edge of the reflector up to 9.72 cm (3.83 inches) inside the reflector. Only the difference in the two shadows provides a pseudo conscan signal. This difference area cuts through the edge of the reflector for a nominal angle θ = 59.1 degrees. This occurs when θ (pointing angle) = 60 degrees.

The pseudo conscan signal, which was computed for the maximum conscan pointing error of 0.5 degree, is 4.8 x 10^{-5} E_o. A comparison between this pseudo conscan signal and a signal corresponding to a conscan pointing resolution of 0.01 degree shows that the conscan error voltage is 0.27 E_o, which is 5600 times greater than the pseudo conscan signals. Based on these results, it is concluded that the shadowing effects from the coronagraph on the high-gain antenna will not adversely affect the conscan pointing accuracy.

The geometric relationship betwen the main reflector and conronagraph is shown in Figure 10, where the coronagraph is symmetrical about the pivot point. The coronagraph length is 101.60 cm (40 inches). the width is 15.24 cm (6 inches), and the height is 25.40 cm (10 inches).

An experimental test was conducted using a mockup of the LANDSAT high-gain antenna (HGA) (see Figure 11). The purpose of the test was to obtain quick look data to assess SW1 and CXX interference effects on the ISPM HGA. The existing LANDSAT test setup was used, and measurements were made at S- and Ku-band frequencies. Interference effects were determined by recording signal fluctuations as the mockup was moved past the antenna reflector, thus dynamically testing the protrusion condition of SW1 and CXX. While the mockup was in fixed positions, the pattern and contour measurements were also recorded. Contour and pattern data were evaluated for beam squint behavior caused by SW1 and CXX interference. A summary of the test results is as follows:

1) At S- and Ku-band frequencies, the SW1 peak gain change is less than 0.14 dB.

2) At S- and Ku-band frequencies, the CXX peak gain change is less than 0.05 dB.

3) Contour data at Ku-band revealed no SW1 or CXX beam-squint.

4) Pattern measurement data revealed no S-band beam-squint.

5) Altering the separation distance between the obstruction (mockup) and the reflector produced no noticeable effect on signal disturbance.

6) Reducing the degree of intrusion to the reflector, however, resulted in a pronounced reduction in signal variation.

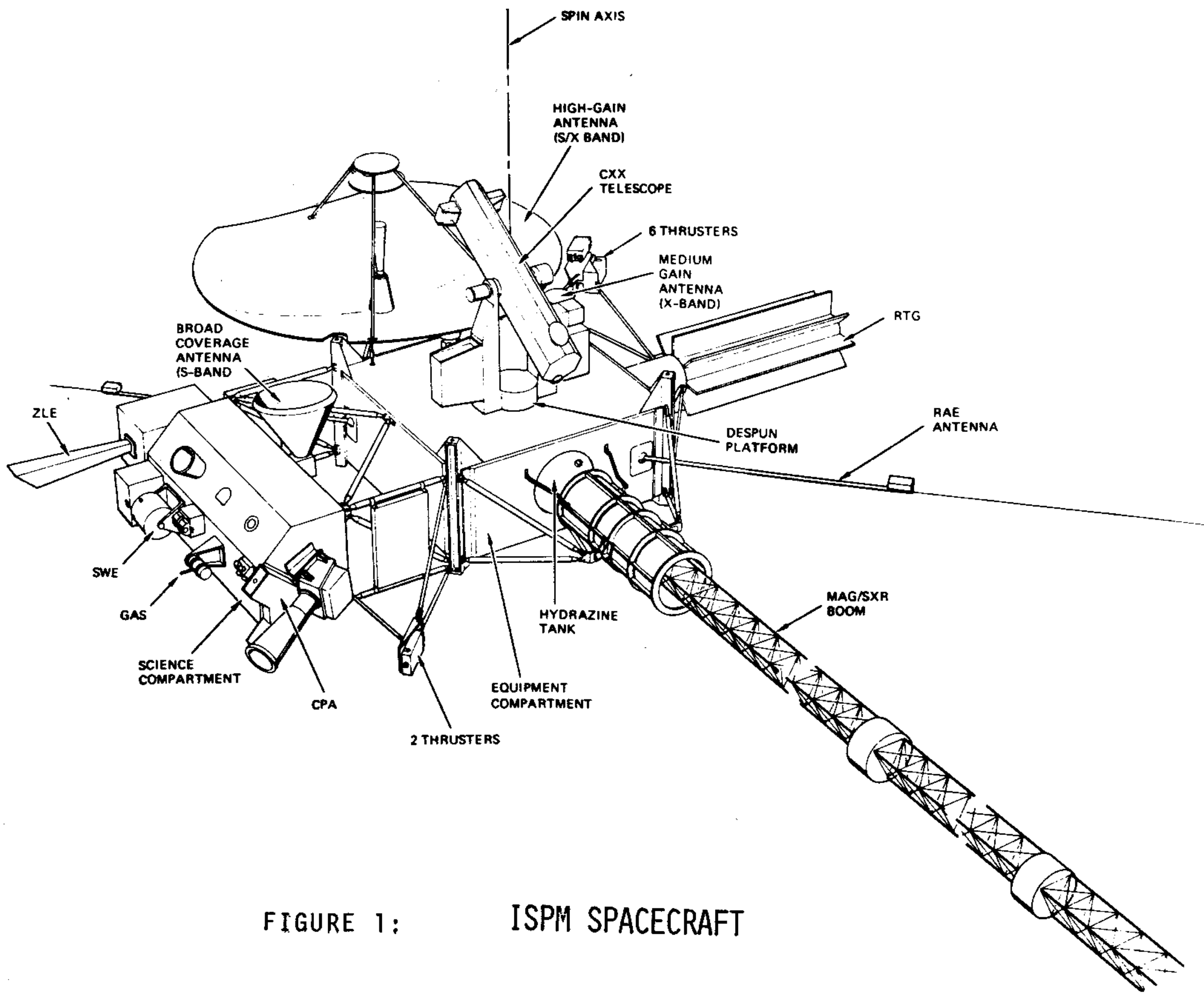


FIGURE 1:   ISPM SPACECRAFT

	S/X-Band HGA								
	S-Band Transmit			S-Band Receive			X-Band Transmit		
	Required	Capability	Design Margin	Required	Capability	Design Margin	Required	Capability	Design Margin
Frequency	2298 ± 5MHz	2295 ± 20 MHz	30MHz	2116 ± 5MHz	2115 ± 20MHz	30MHz	8426 ± 5MHz	8426 ± 100MHz	190MHz
Peak Gain	30.4dBi (Nominal) 30.0dBi (Adverse)	30.8dBi	.4dB	29.8dBi (Nominal) 29.4dBi (Adverse)	30.3dBi	.5dB	42.0dBi (Nominal) 41.6dBi (Adverse)	42.5dBi	.5dB
Beamwidth (3dB)	4.4 Deg. (Nominal)	>4.4 Deg.	-	4.80 Deg. (Nominal)	>4.80 Deg.	-	1.10 Deg. (Nominal)	>1.10 Deg.	-
Polarization	RHCP	RHCP	-	RHCP	RHCP	-	RHCP	RHCP	-
Axial Ratio	<2dB Over 2.0dB Beamwidth	<2dB	-	<2dB Over 2.0dB Beamwidth	<2dB	-	<2dB Over 3.0dB Beamwidth	<1.5dB	-
VSWR	<1.5:1	<1.3:1	-	<1.5:1	<1.3:1	-	<1.3:1	<1.2:1	-
Power Handling	4W*	16W	6dB	-	-	-	17W*	>68W	6dB

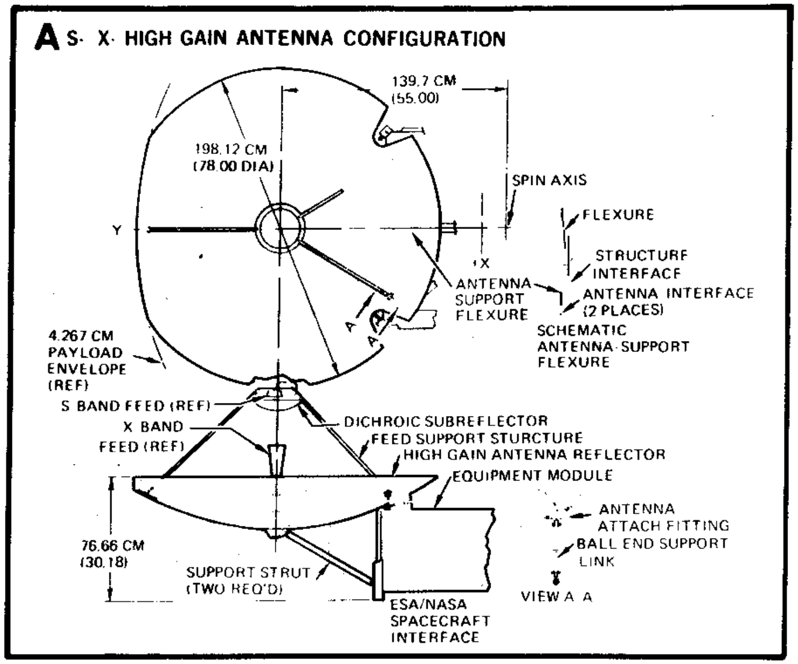
* Net power to antenna after transmission line losses.

FIGURE 2: REQUIREMENTS VERSUS CAPABILITIES

	S-Band Broad Coverage Antenna						X-Band Medium Gain Antenna		
	S-Band Transmit			S-Band Receive			Transmit		
	Required	Capability	Design Margin	Required	Capability	Design Margin	Required	Capability	Design Margin
Frequency	2298 ± 5MHz	2295 ± 5MHz	0	2116 ± 5MHz	2115 ± 5MHz	0	8426 ± 5MHz	8426 ± 100MHz	190MHz
Peak Gain	16.2dBi (Nominal) 15.8dBi (Adverse)	16.2dBi	0	15.2dBi (Nominal) 14.8dBi (Adverse)	15.2dBi	0	18.0dBi (Nominal) 17.8dBi (Adverse)	18.2dBi	2dBi
Coverage Gain	>10dBi (±18°)	10.7 ± .4dBi	.7 ± .4dB	>9.5dBi (±18°)	10.2 ± 4dBi	.7 ± .4dB	>15dBi (±9°)	15.5 ± .2dBi	.5 ± .2dB
Beamwidth (3dB)	28 Deg. (Nominal)	>28 Deg.	-	29 Deg. (Nominal)	>29 Deg.	-	20.0 Deg. (Nominal)	>20.0 Deg.	-
Polarization	RHCP	RHCP	-	RHCP	RHCP	-	RHCP	RHCP	-
Axial Ratio	<5dB Over ± 20 Deg. Beamwidth	≤4.5dB	-	<3dB Over ± 20 Deg. Beamwidth	≤1.2dB	-	<3dB Over ± 10 Deg. Beamwidth	≤2dB	-
VSWR	1.5:1	<1.35:1	-	1.5:1	<1.4:1	-	1.3:1	<1.3:1	-
Power Handling	3W*	>12W	6dB	-	-	-	15W*	60W	6dB

* Net power to antenna after transmission line losses.

FIGURE 2: REQUIREMENTS VERSUS CAPABILITIES (CONTINUED)



B PHYSICAL CHARACTERISTICS

MAIN REFLECTOR (PARABOLOID)		
MAXIMUM DIAMETER	D =	1.98 m (78 IN.)
FOCAL LENGTH	F =	81.28 cm (32 IN.)
HALF ANGLE	ψ =	62.7 DEGREES
f/D		0.41025
SURFACE	P =	0.020 cm (0.008") RMS
EDGE CUTOUTS (PROJECTED AREA)	ΔA	6%
DICHROIC SUBREFLECTOR (HYPERBOLOID)		
DIAMETER	d =	31.90 cm (12.56 IN.)
FOCAL LENGTH	f =	31.06 (12.23 IN.)
HALF ANGLE	α =	30.00 DEGREES
MAGNIFICATION	M	2.995
X-BAND FEED HORN		
APERTURE		8.20 cm (3.23 IN.) DIAMETER
S-BAND CUP DIPOLE FEED APERTURE		10.16 cm (4.00 IN.) DIAMETER
CASSEGRAIN SYSTEM		
FOCAL RATIO (μ)		f/F = 0.382
EFFECTIVE FOCAL LENGTH (M·F)		f_c = 2.434 m (95.84")

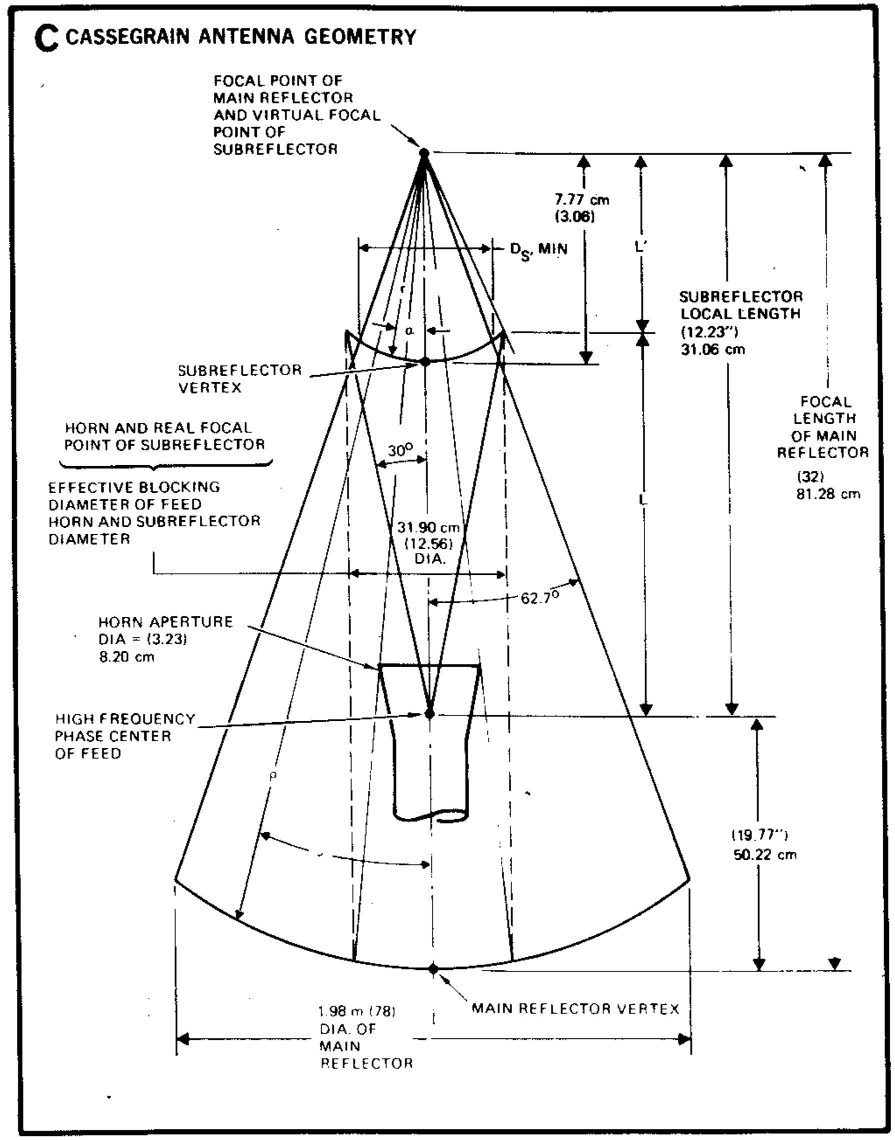


FIGURE 3: S-/X-BAND HIGH-GAIN ANTENNA EMPLOYS CASSEGRAIN DESIGN AND DICHROIC SUBREFLECTOR

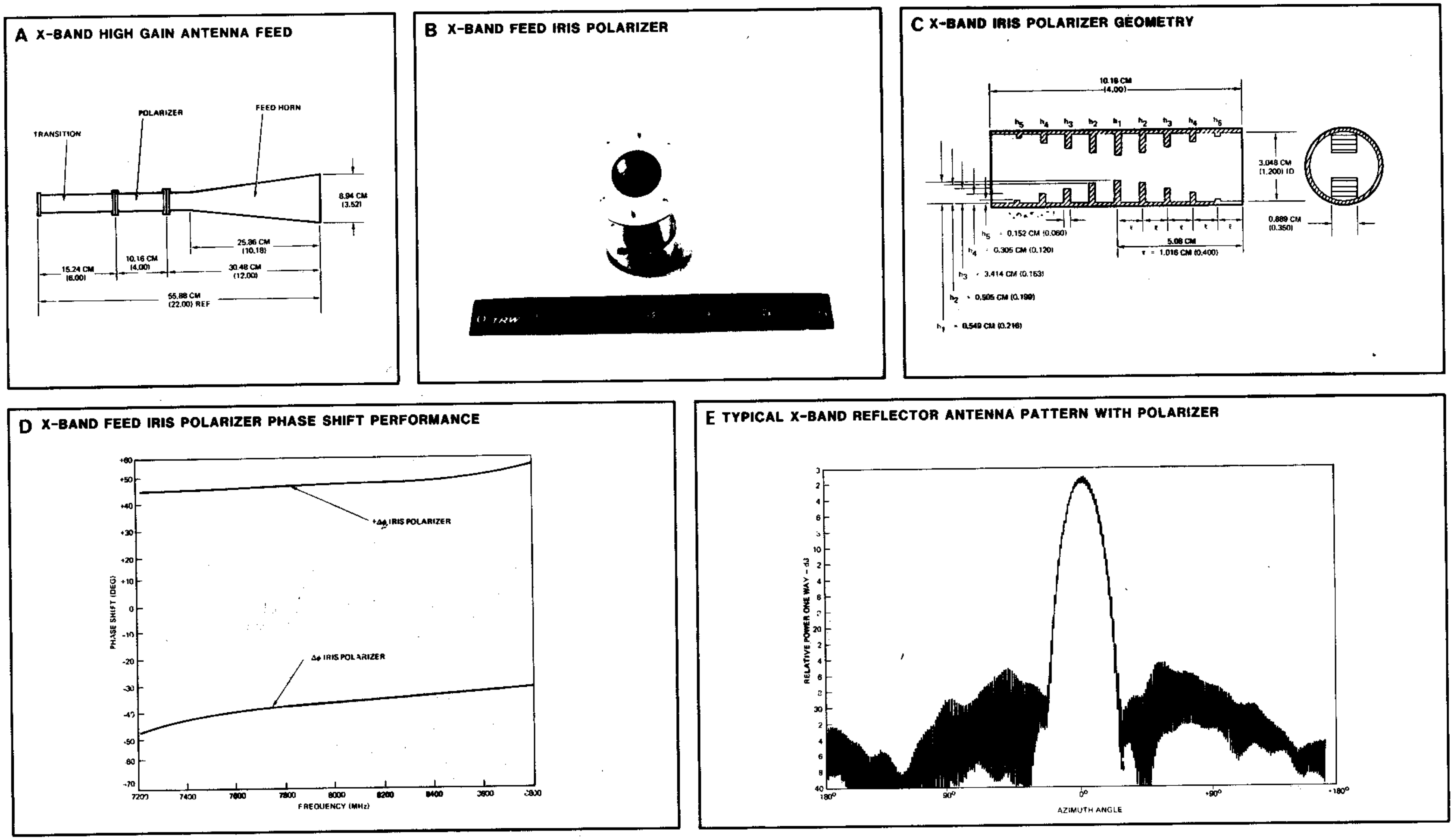


FIGURE 4: S-BAND HIGH-GAIN FEED USING A DUAL MODE HORN WITH IRIS POLARIZER

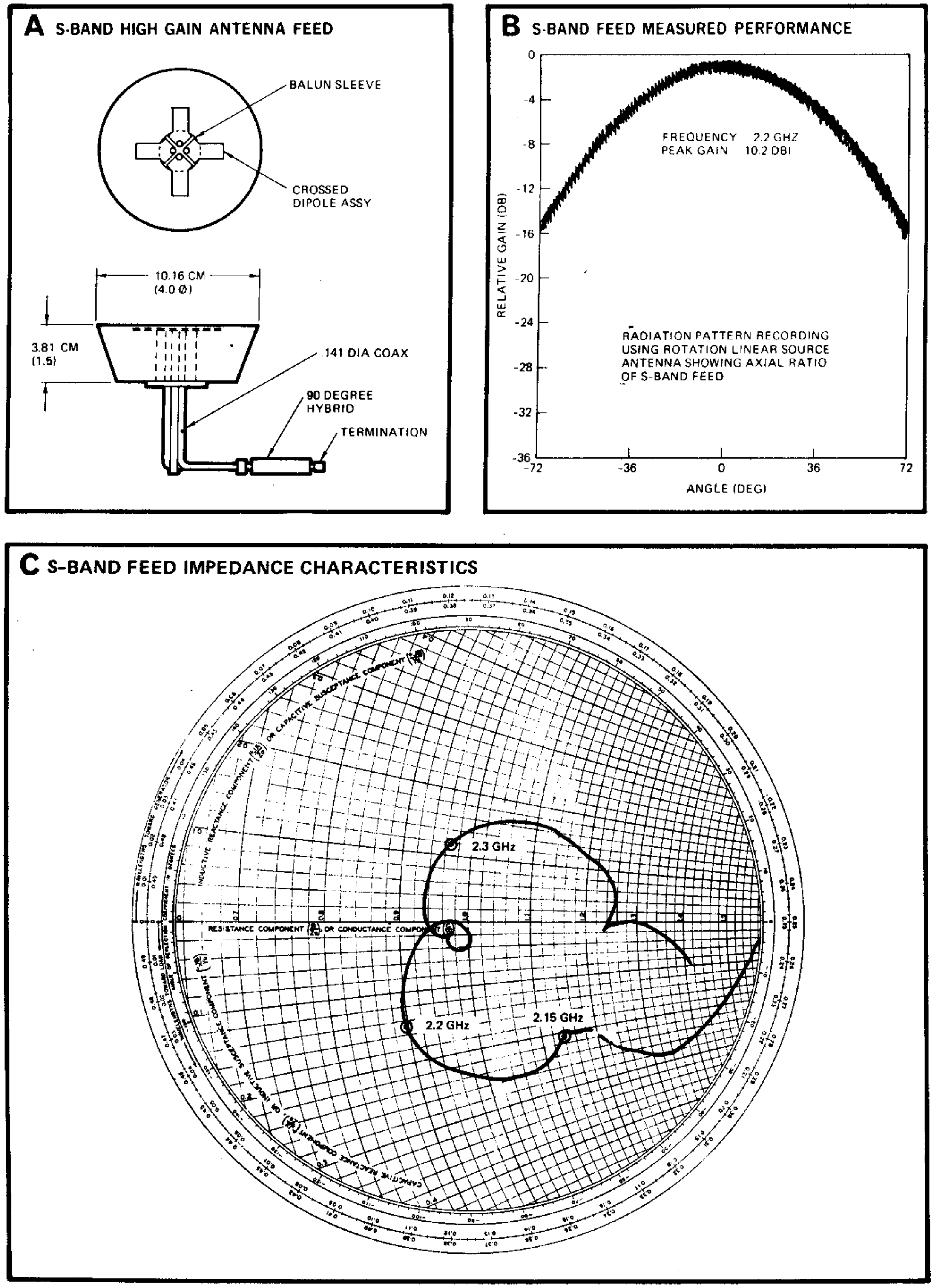


FIGURE 5: S-BAND HIGH-GAIN ANTENNA FEED AND TEST DATA

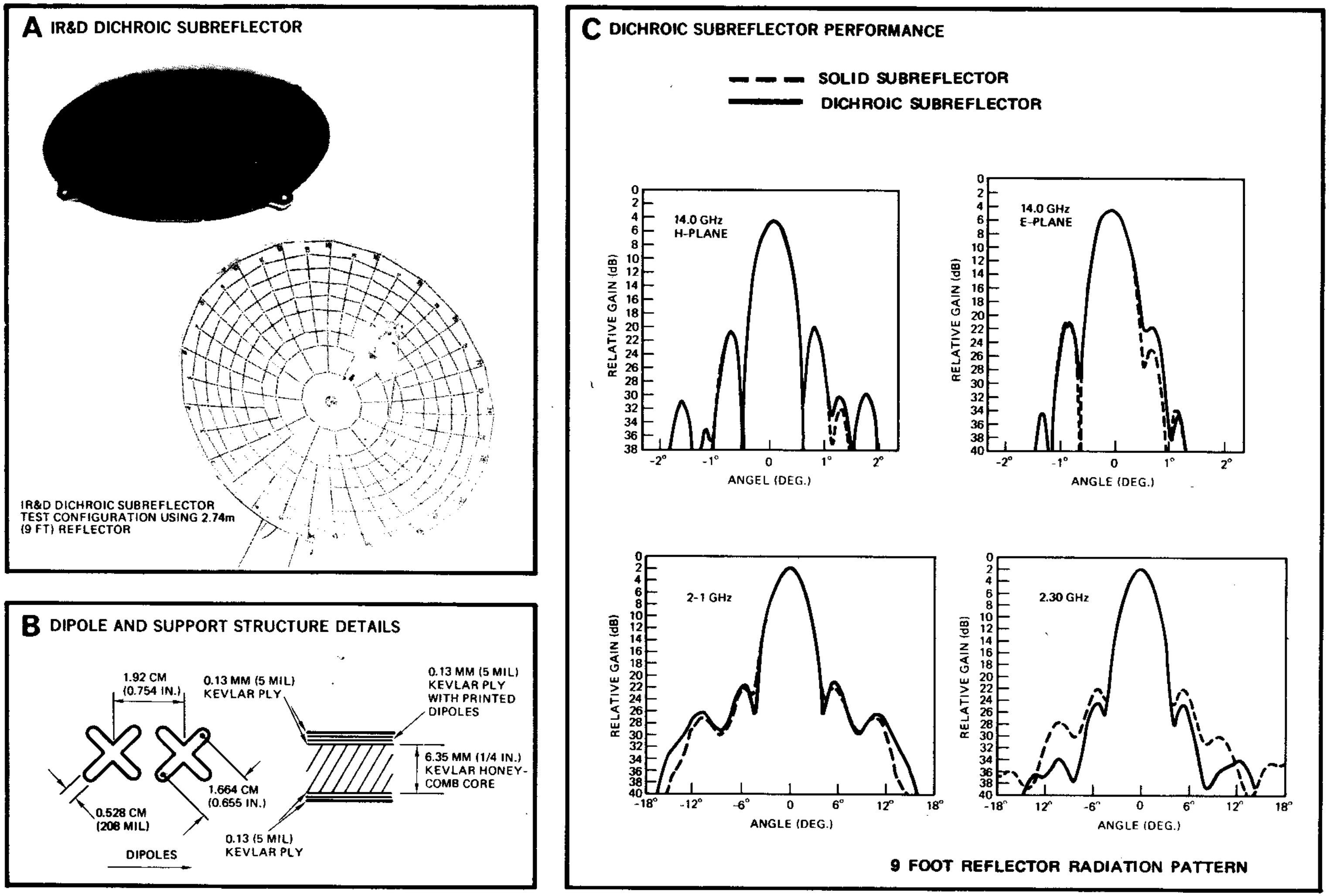
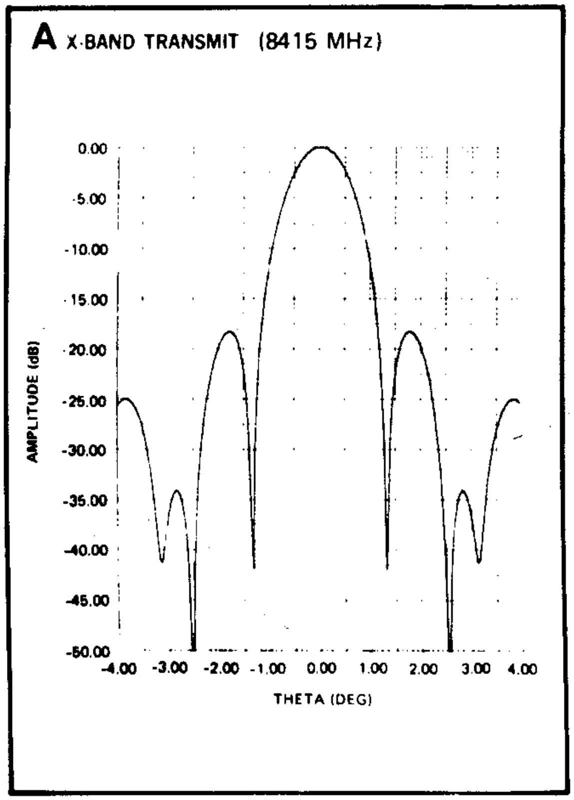
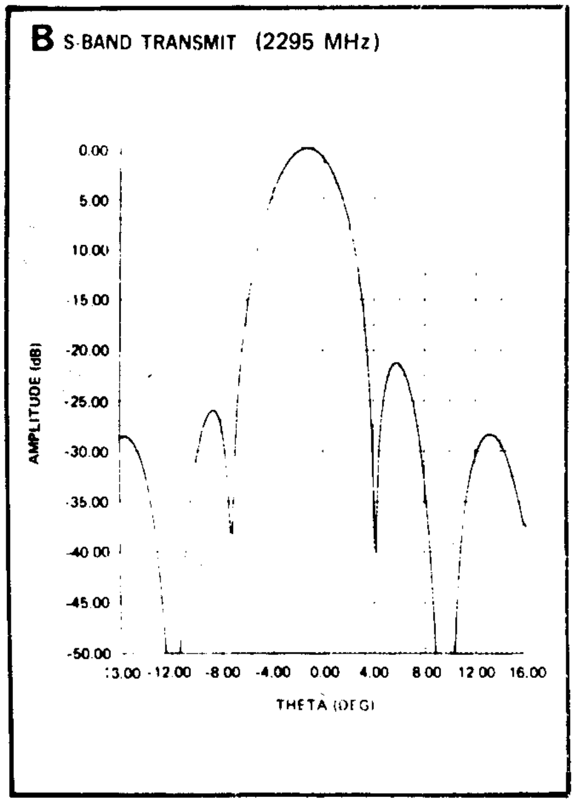
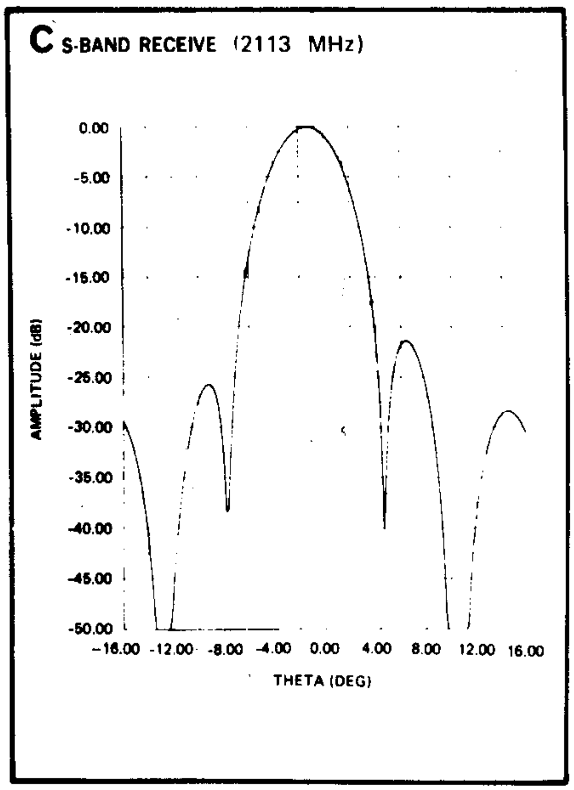


FIGURE 6: DICHROIC SUBREFLECTOR CONFIGURATION AND TEST DATA







D GAIN LOSS BUDGET FOR HIGH-GAIN ANTENNA

	X BAND	S-BAND	
PARAMETER	TRANSMIT 8415 (MHz)	TRANSMIT 2295 (MHz)	RECEIVE 2113.3 (MHz)
UNIFORM GAIN $(4\pi A/\lambda^2)$	44.85 dB	33.56 dB	32.84 dB
REFLECTOR EDGE TRIM			
LOSSES (dB)	0.04 dB	0.04 dB	0.04 dB
ILLUMINATION EFFICIENCY	0.17 dB	0.77 dB	0.77 dB
DIFFRACTION LOSS	0.53 dB		
SPILLOVER	0.39 dB	0.16 dB	0.16 dB
CROSS POLARIZATION	0.05 dB	0.07 dB	0.07 dB
BLOCKAGE	0.46 dB	0.15 dB	0.15 dB
DICHROIC SUBREFLECTOR	0.10 dB	0.20 dB	0.20 dB
SURFACE ERRORS (0.008 RMS)	0.10 dB	0.03 dB	0.03 dB
THERMAL DEFOCUSING	0.10 dB	0.05 dB	0.05 dB
FEED	0.15 dB	0.15 dB	0.15 dB
POLARIZER HYBRID	0.05 dB	0.15 dB	0.15 dB
WAVEGUIDE COAXIAL	0.05 dB	0.30 dB	0.30 dB
VSWR	0.06 dB	0.10 dB	0.10 dB
	2.25 dB	2.17 dB	2.17 dB
ANTENNA GAIN	42.60 dBi	31.39 dBi	30.67 dBi
EFFICIENCY (%)	59	60	60

FIGURE 7: S-/X,BAND HIGH-GAIN ANTENNA COMPUTER PERFORMANCE SUMMARY

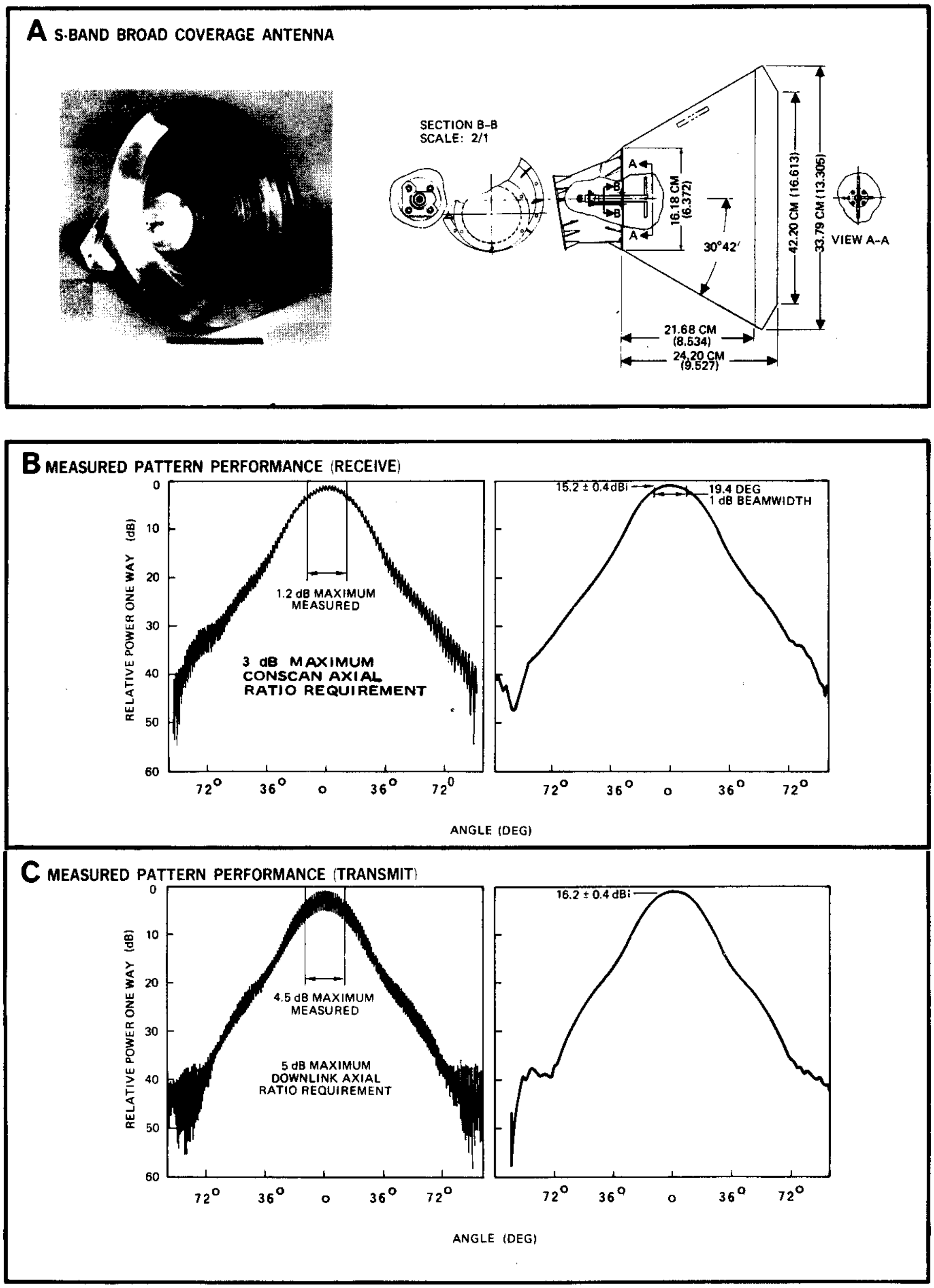
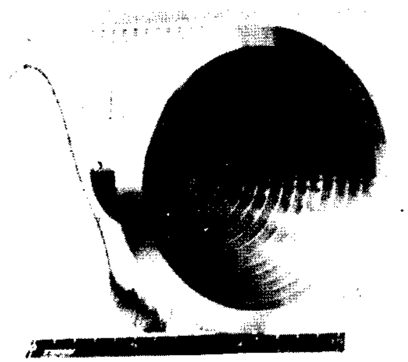
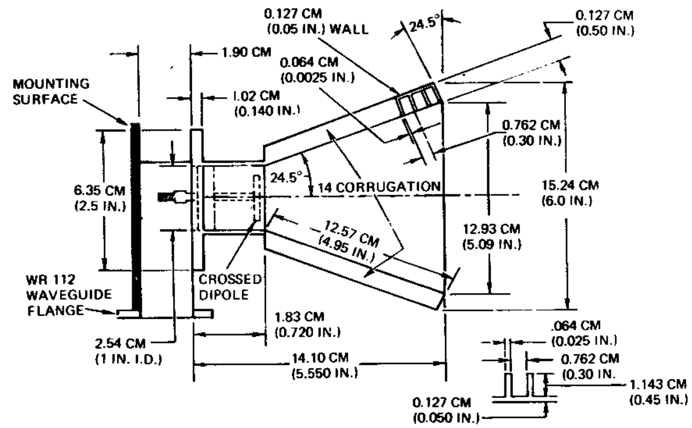


FIGURE 8: S-BAND BROAD COVERAGE ANTENNA IS THE PIONEER 10 AND 11 DESIGN USED AS-IS

A X-BAND MEDIUM GAIN ANTENNA





B X-BAND MEDIUM GAIN ANTENNA TEST RESULTS

GAIN AND AXIAL RATIO PERFORMANCE SUMMARY

ANTENNA NUMBER	FREQUENCY (GHz)	PEAK GAIN (dBi)	AR (dB)
1	7.9	18.3	0.8
	8.0	18.2	0.3
	8.1	18.1	0.9
2	7.9	18.0	1.2
	8.0	18.1	0.5
	8.1	18.2	1.2
3	7.9	18.3	0.8
	8.0	18.2	0.5
	8.1	18.3	1.1
4	7.9	18.3	0.8
	8.0	18.1	0.3
	8.1	18.3	1.0
5	7.9	17.8	1.0
	8.0	18.0	0.5
	8.1	18.3	1.0
6	7.9	18.0	1.0
	8.0	18.0	0.7
	8.1	18.2	1.0

VSWR PERFORMANCE

ANTENNA	FREQUENCY (GHz)	VSWR
1	7.9	1.20
	8.0	1.12
	8.1	1.08
2	7.9	1.16
	8.0	1.06
	8.1	1.05
3	7.9	1.14
	8.0	1.05
	8.1	1.06
4	7.9	1.20
	8.0	1.12
	8.1	1.08
5	7.9	1.20
	8.0	1.16
	8.1	1.14
6	7.9	1.18
	8.0	1.08
	8.1	1.02

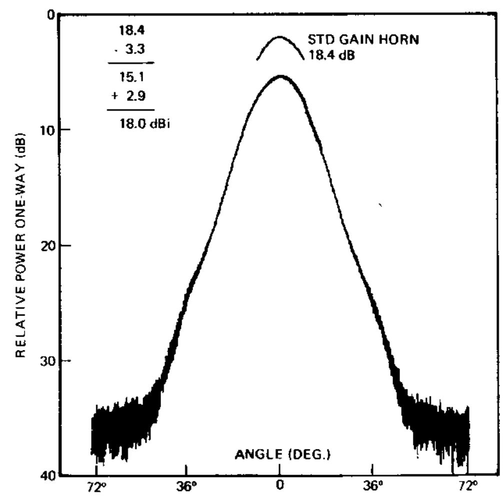


FIGURE 9: X-BAND MEDIUM-GAIN ANTENNA AND TEST RESULTS

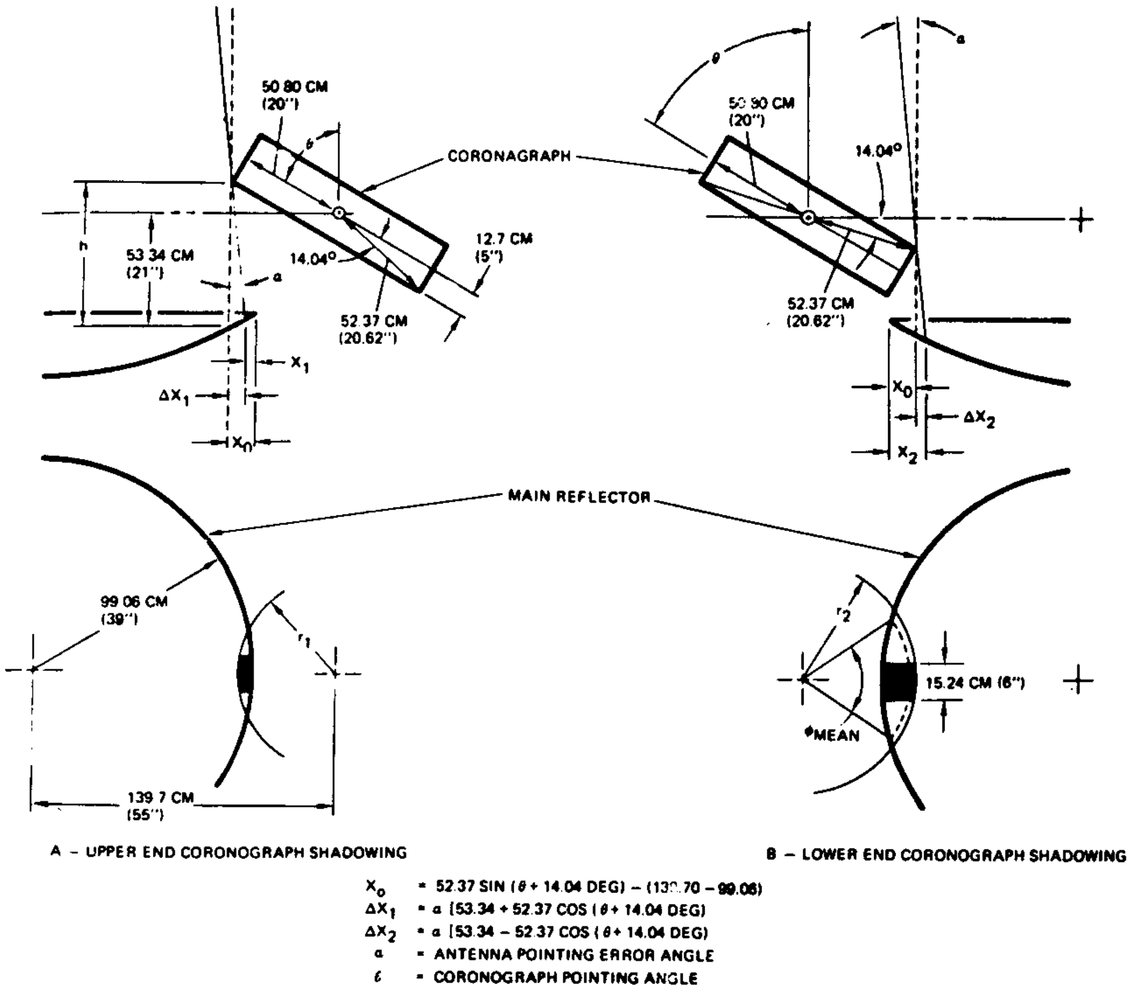
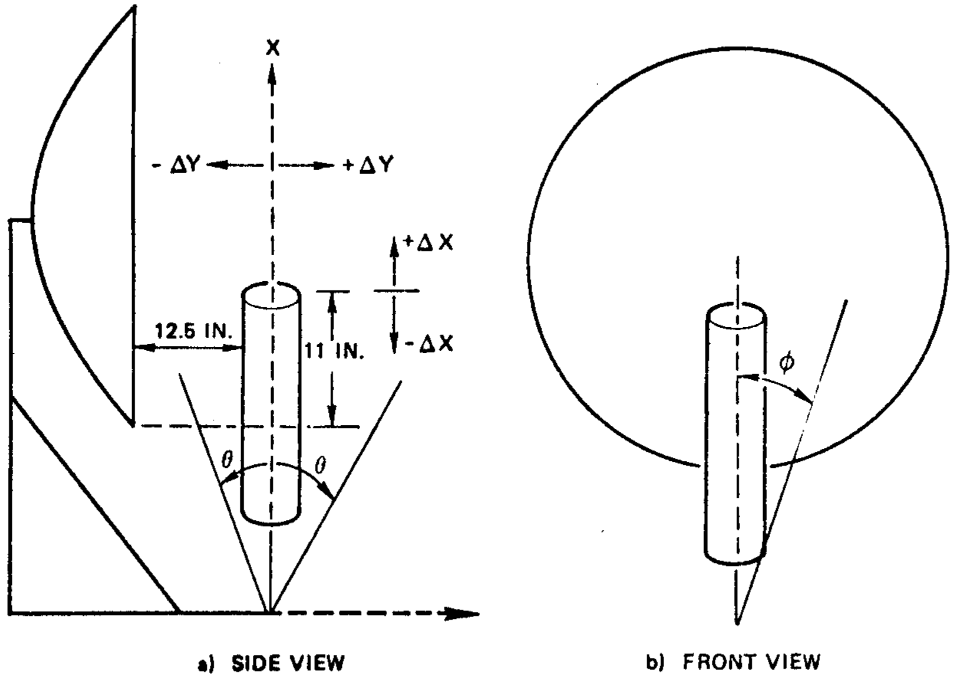


FIGURE 10: HGA AND CORONAGRAPH GEOMETRY

Where

X_1 = shadow due to upper end of coronagraph onto the reflector

X_2 = shadow due to lower end of coronagraph onto the reflector.



SW1 Test (Normal Position Defined by $\theta = 0°$, $\phi = 0°$, $X = Z = 0$)

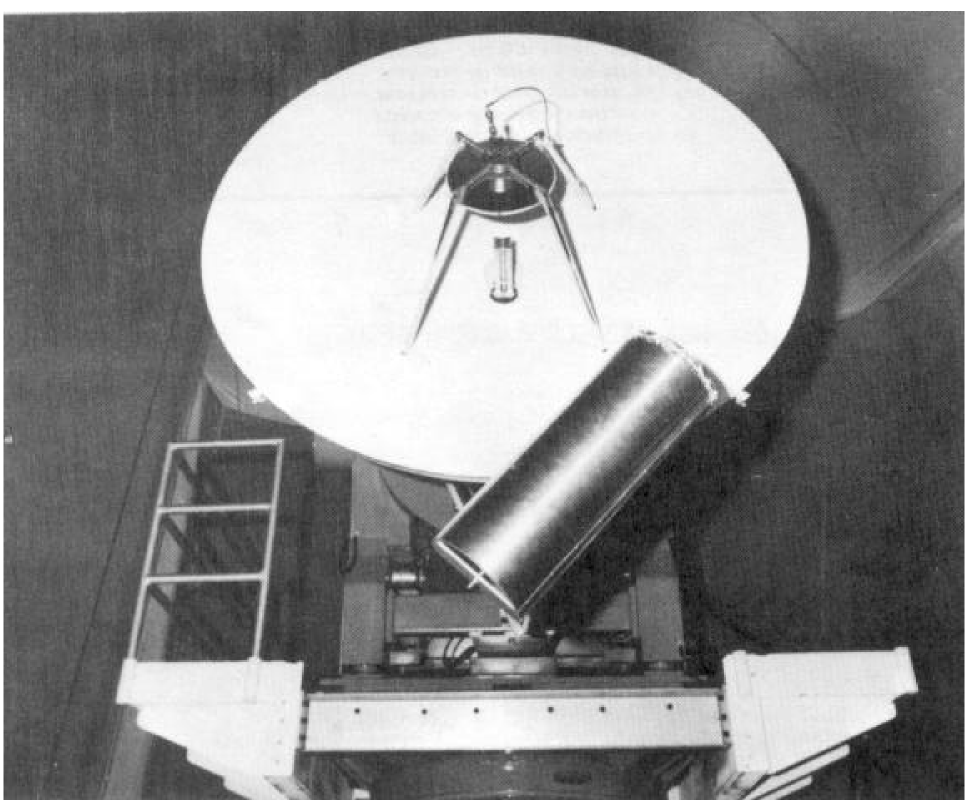


FIGURE 11: SW1 TEST - FRONT VIEW