A Novel Design Technique for Beam-Waveguide Antennas

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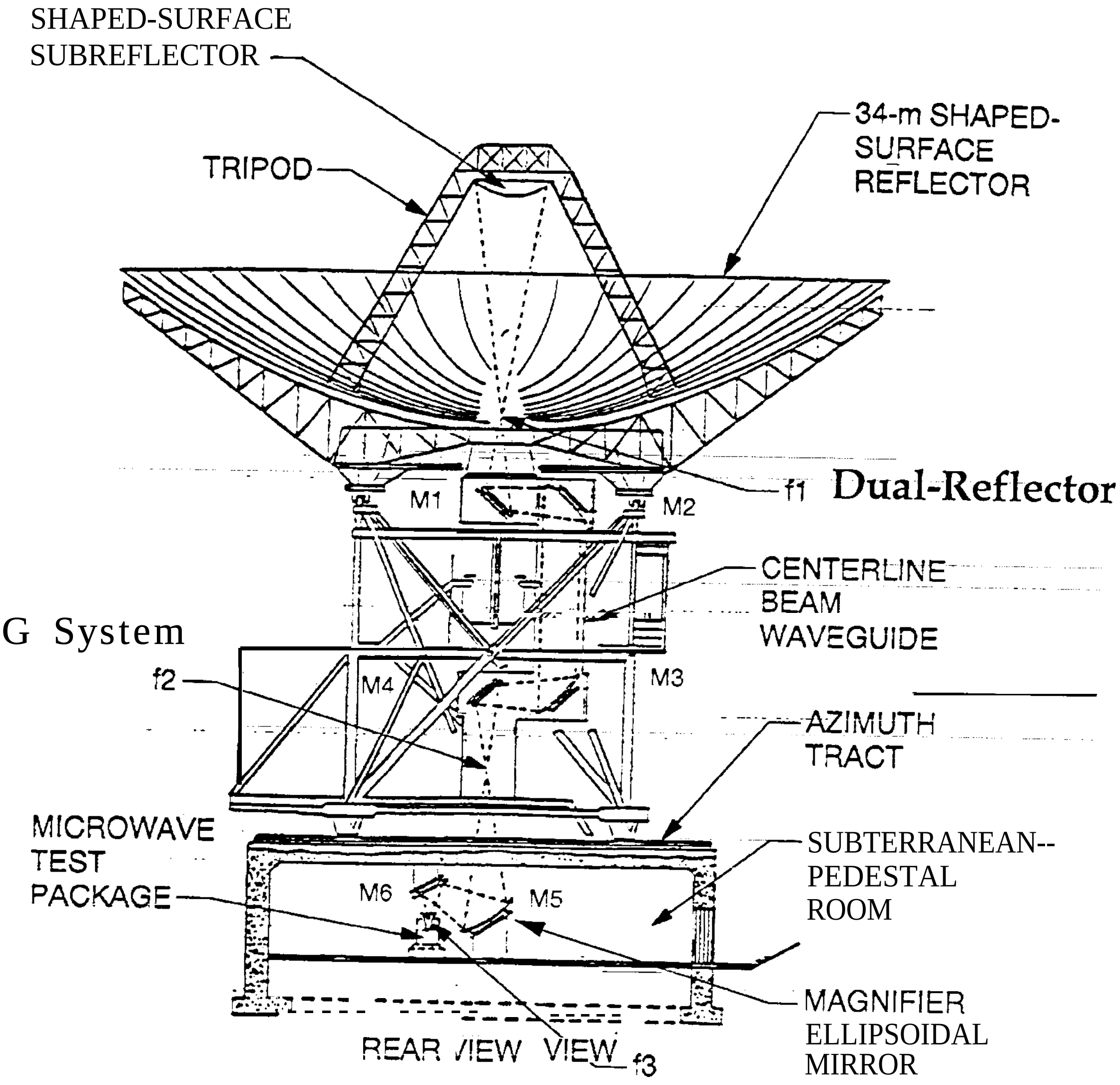
Beamwaveguide Systems

- Purpose - Move a focal point to a more convenient location through a system of mirrors
- Advantages - Feed horn and equipment in a stationary room below the antenna
- Disadvantages - Slightly lower antenna gain and higher noise temperature

BWG Design Techniques

- ◆ Geometrical Optics
- ◆ Gaussian Beam
- ◆ Physical Optics
- ◆ Focal Plane Analysis

NASA Beamwaveguide Antenna

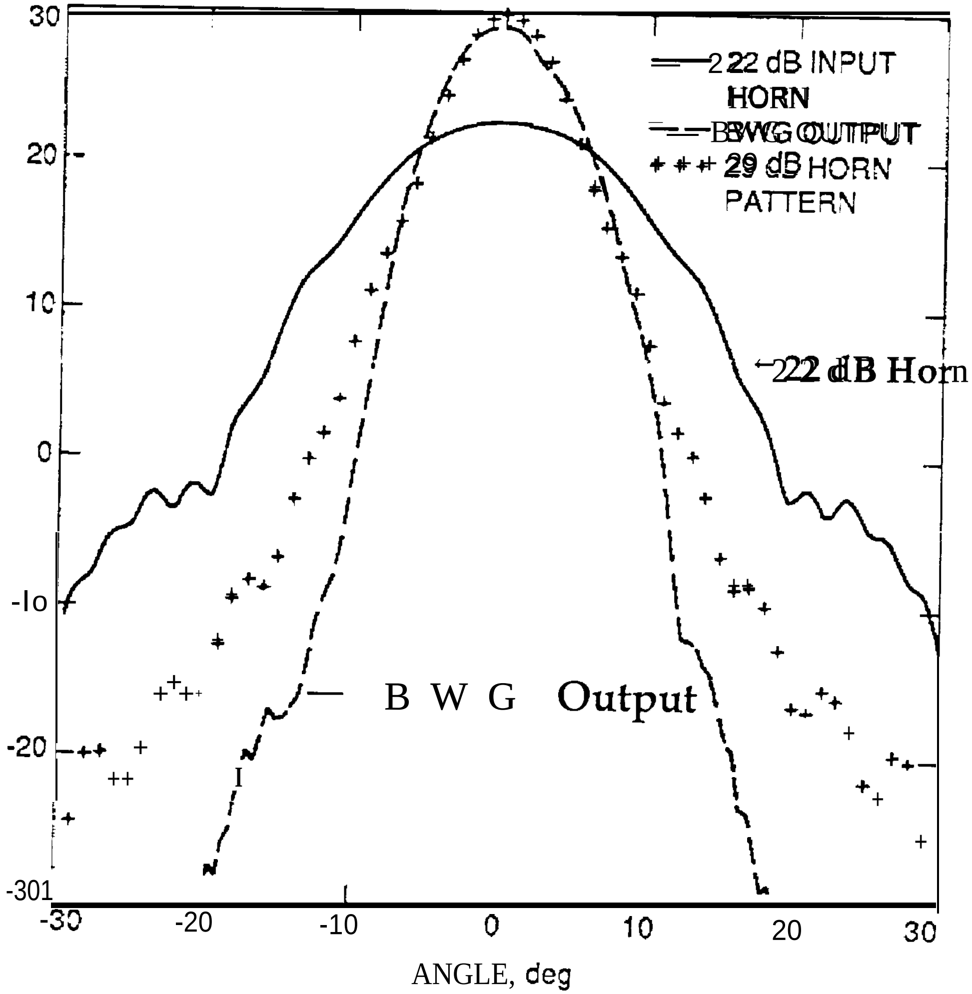


Dual-Reflector Focal Point

Input **to** Upper BWG System

Input **Focal** Point

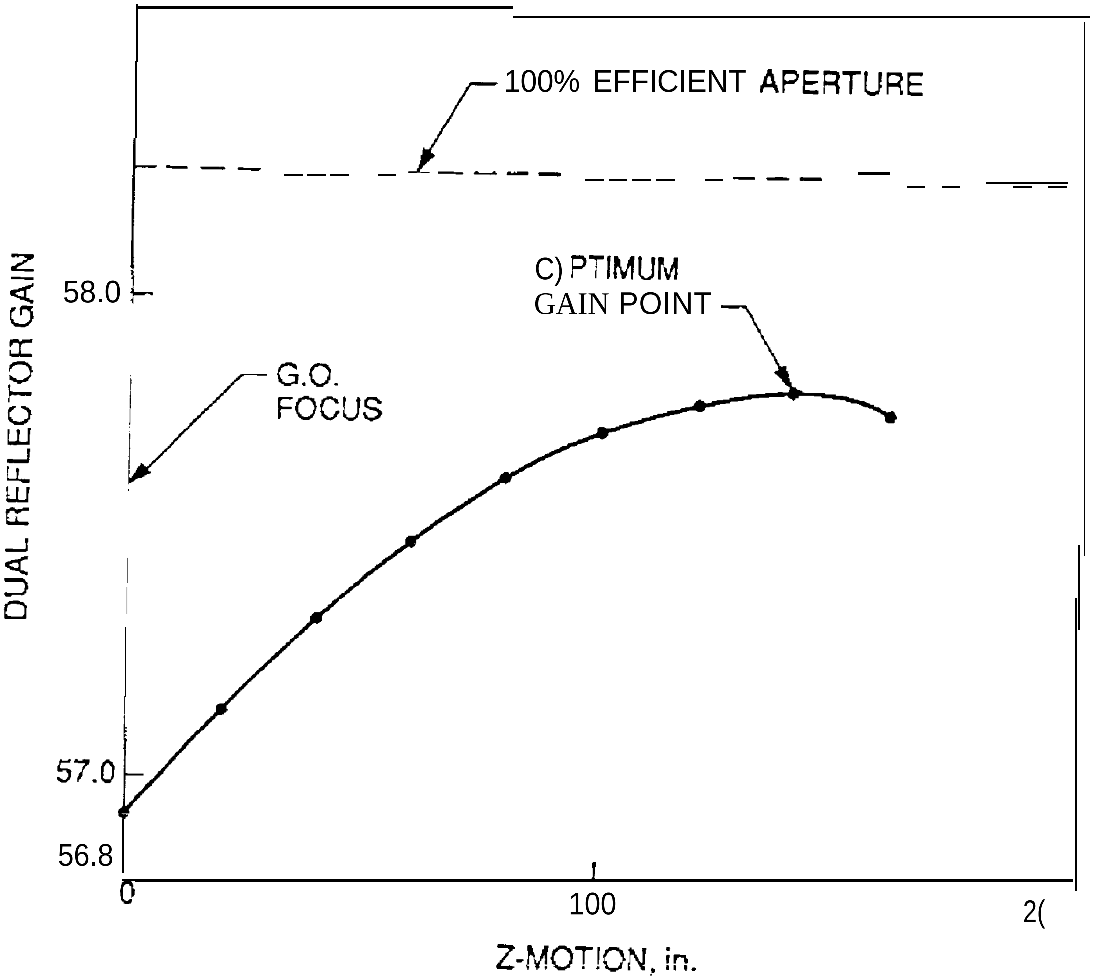
Beam Waveguide Input and Output Radiation Patterns at X-Band



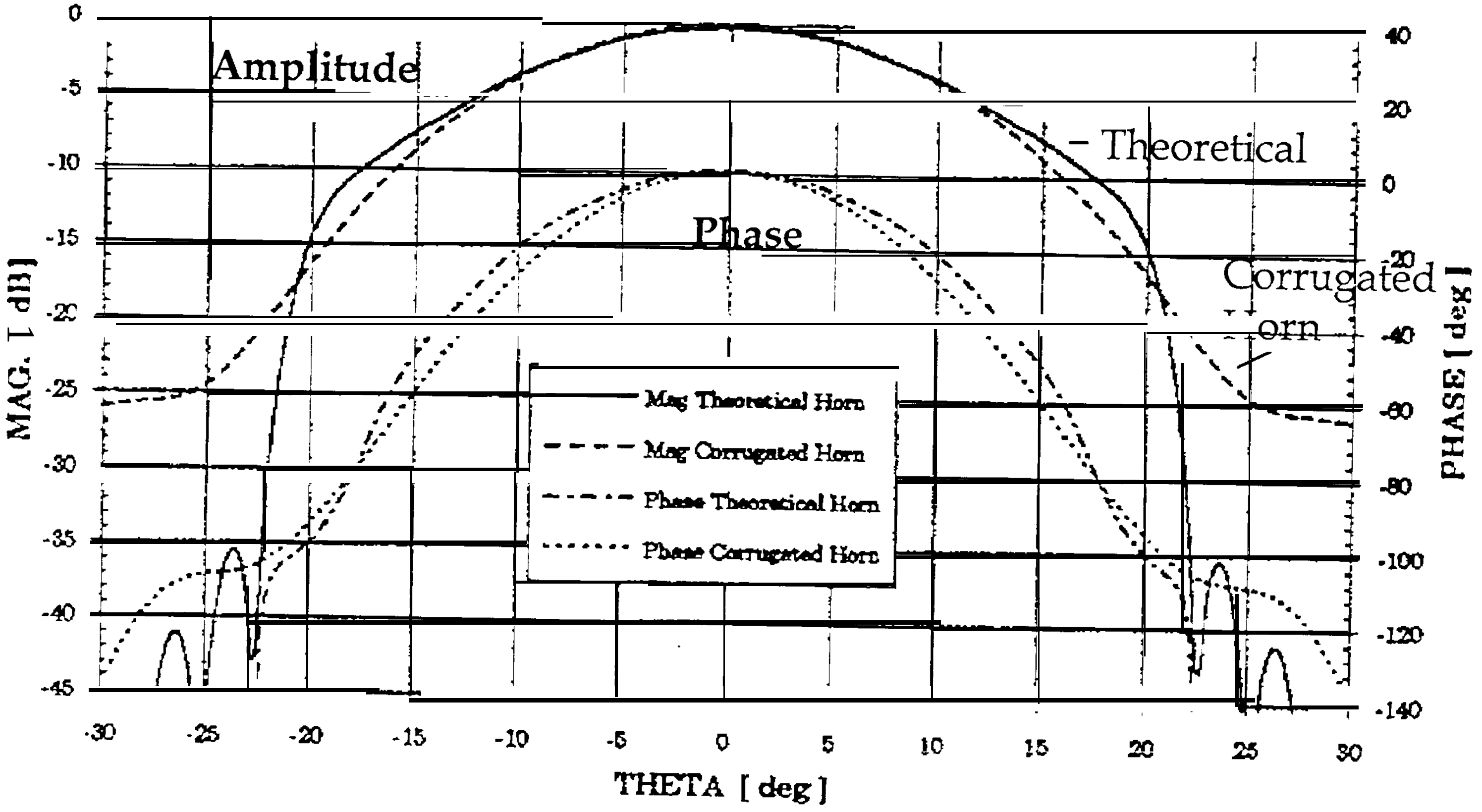
← 22 dB Horn Pattern (input)

— BWG **Output**

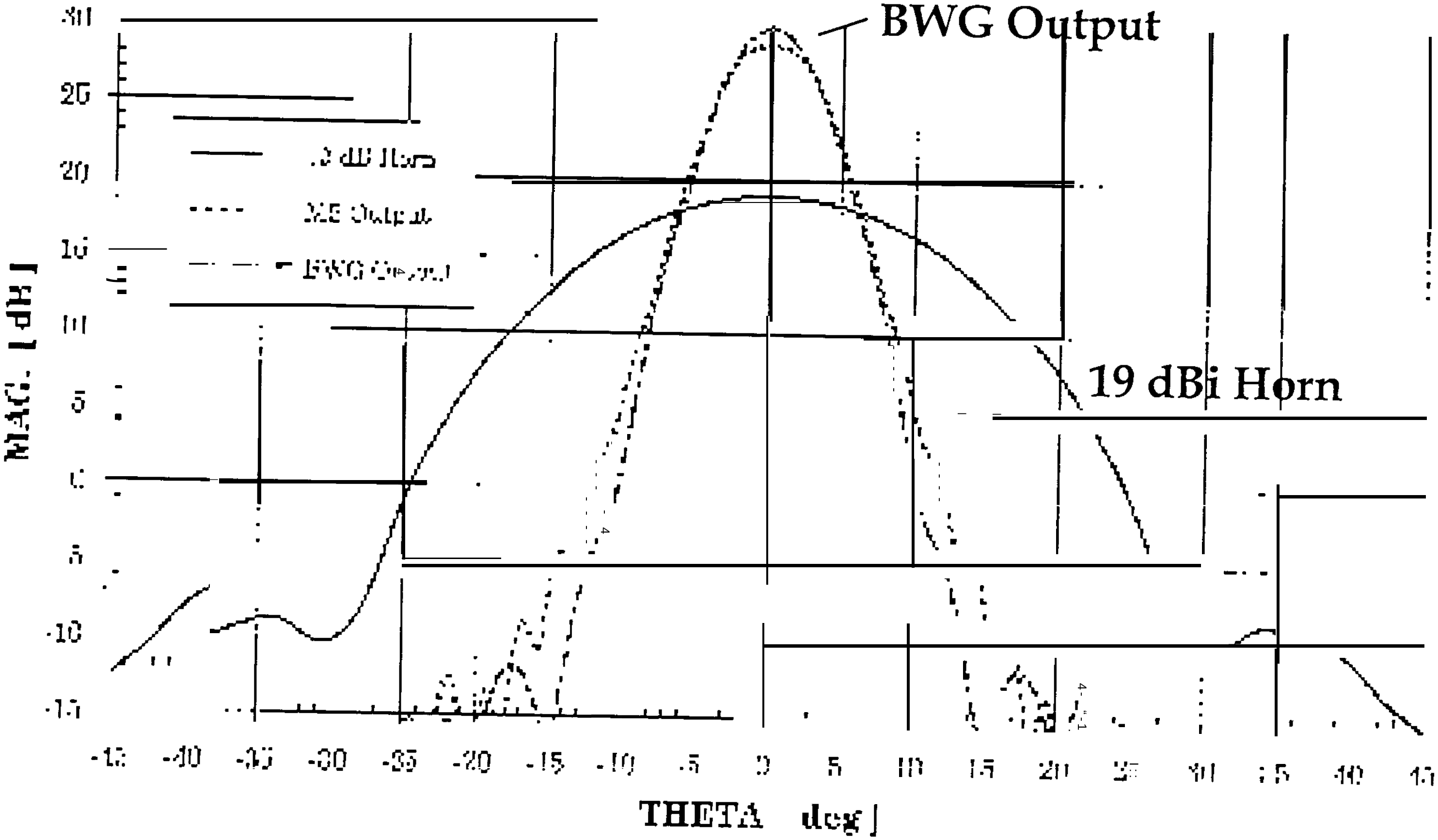
Beam-Waveguide Defocusing Curve at S-Band



E-Plane Near Field Horn Patterns



Beam-Waveguide Input and Output Patterns at S-Band



S-Band Calculations

	22-dBi Corrugated Horn [7]	19-dBi Corrugated Horn	Theoretical Horn
Spillover (%)			
M_6	---	0.41	---
M_5	2.05	2.46	0.24
M_4	1.57	0.70	1.19
M_3	5.91	0.73	0.86
M_2	5.55	0.96	1.29
M_1	1.36	0.26	0.46
Sub	---	1.14	1.94
Main	---	0.94	3.61
Efficiency			
Total Efficiency	0.48415	0.6827	0.69502
Gain (dB)	55.102	56.594	56.672
Noise Temperature			
Total Noise (K)	73.574	37.10	35.314
Total Noise (dB)	18.67	15.69	15.48
G/T (dB)	36.43	40.90	41.19

Noise Temperature predictions and Measurements (Kelvin)

System	S-band	
	Predictions	Measurement
LNA	8.3	8.72
Feed system (including LNA)	17.69	17.5
Antenna (TOTAL)	37.26	38.0

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Abstract The poor low-frequency performance of geometrically designed beam-waveguide antennas is shown to be caused by the diffraction phase centers being far from the geometrical optics mirror focus, resulting in substantial spillover and defocusing loss. To generate a new solution by a straightforward analytical design would prove cumbersome because of the large number of scattering surfaces required for the computation, Rather, a unique application was made of the conjugate phase-matching techniques to obtain the desired solution. A plane wave was used to illuminate the main reflector and the fields from the currents induced on the subreflector propagated through the BWG to a plane centered on the input focal point By taking the complex-conjugate of the currents induced on this plane and applying the radiation integral, the far-field pattern was obtained for a theoretical horn that maximizes the antenna gain. To synthesize a horn quickly and inexpensively, the theoretical horn was matched as well as possible by an appropriately sized circular corrugated horn and the new feed system has been implemented in the JPL Research and Development BWG as part of a dual S/X-band feed system. The new S-band feed system is shown to perform significantly better than the original geometrically designed system.

TABLE OF CONTENTS

1, INTRODUCTION

JPL has recently built a new 34-meter' beam-waveguide (BWG) antenna at Goldstone's Deep Space Station 13 site (1) SS-13), The design of the center-fed BWG consists of a beam magnifier ellipse (M_5) in a pedestal room located below ground level that transforms a 22-dB gain feedhorn pattern into a high-gain 29-dB gain feedhorn pattern for input to a standard four-mirror (two flat and two paraboloid) BWG system (see Figure 1). The design of the upper section of the BWG is based on a Geometrical Optics (GO) criteria introduced by Mizusawa and Kitsuregawa in 1973[1,2] which guarantees a perfect image from a reflector pair, The system was initially designed (Phase 1) for operation at 8.45 GHz (X-band) and 32 GHz (Ka-band) and has less than 0.2-dB loss (determined by comparing the gain of a 29-dB gain horn feeding the dual-shaped reflector system with that obtained using the BWG system) [3,4]. In Phase 2, S-band (2.3 GHz) is to be added.

If a standard 22-dB S-band horn is placed at the input focus (f_3) of the ellipse, the BWG loss is greater than 1.5 dB, primarily due to the fact that, for low frequencies, the diffraction phase centers are far from the GO-predicted foci, resulting in a substantial spillover and defocusing loss. This defocusing is especially a problem for the magnifier ellipse, where the S-band phase center at the output of the ellipse is 3 meters from the G.O. focus. If the input to the paraboloids were focused, the output defocusing would only cause a 0.3-dB loss.

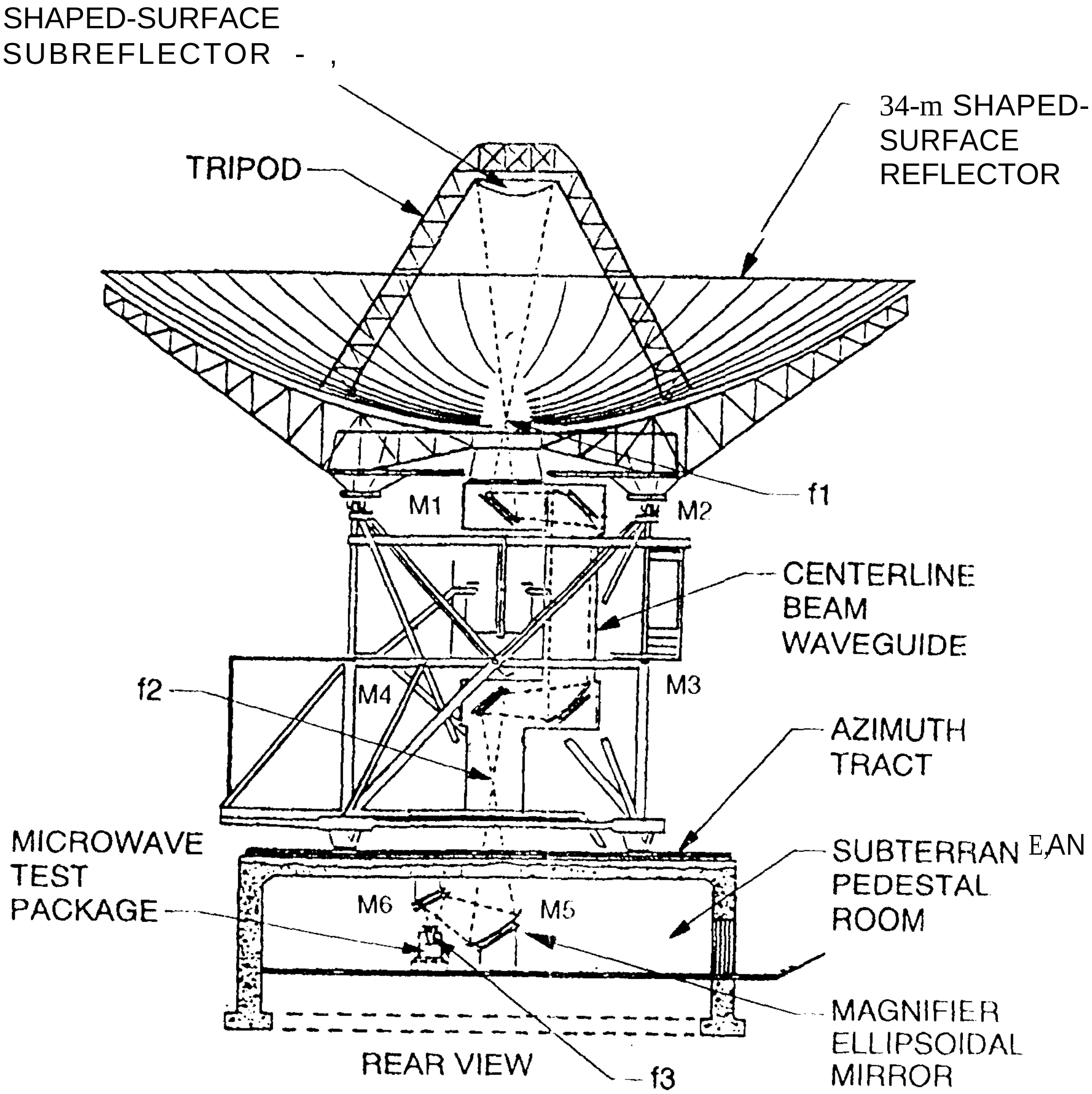

Figure 1. New **NASA** Beam-waveguide Antenna

A potential solution is to redesign the horn to provide an optimum solution for S-band, The question is how to determine the appropriate gain and location for this feed.

A straightforward analytical design would prove cumbersome because of the large number of scattering surfaces required for the computation. Rather, a unique application was made of the conjugate phase-matching technique to obtain the desired solution. **A** plane wave was used to illuminate the main reflector, and the fields from the currents induced on the subreflector were propagated through the BWG to a plane centered on the input focal point By taking the complex-conjugate of the currents induced cm the plane and applying the radiation integral, the far-field pattern was obtained for a theoretical horn that maximizes the antenna gain

To synthesize a horn quickly and inexpensively, the theoretical horn was matched as well as possible by an appropriately sized circular corrugated horn. The corrugated horn performance was only 0,2 dB lower than the optimum theoretical horn but 1.4 dB above the standard 22-dB horn, A system employing the corrugated horn was built and tested and installed in the 34m BWG antenna as part ofa simultaneous S/X-band receiving system,

2. THE PROBLEM

The basic design of the center-fed beam-waveguide antenna is shown in Figure 1, The shaped dual-reflector system (focal point f 1) is designed to provide uniform illumination with a 29.8-dB gain horn at the input, The upper four mirrors of the beam-waveguide (between f2 to f1) are designed to image the input (at f2) to the output (at f 1). Thus, to provide a 29.8-dB pattern output at f1 requires a 29.8-dB gain pattern at the input f2. The 29.8-dB gain pattern is generated by using a 22-dB gain horn at f3 (the input focus of the magnifier ellipse) to provide the required gain at the output focus of the ellipse (f2). Figure 2 compares the input and output patterns from the BWG system with the 29-dB gain horn at X-band. Sine.c the BWG project seeks to introduce S-band (2,3 GHz) into the antenna in the Phase 2 project, it is useful to inquire what happens when a 22-dB S-band horn is placed at the input focus of the ellipse. ignoring spillover past the BWG mirrors, the defocusing loss is 0.9 dB. The BWG spillover loss is 0.5 dB, yielding a total BWG 10ss of 1,4 dB. The principal cause of the defocusing loss is related to the fact that for low frequencies, the diffraction phase center at the cassegrain focus f_1 is far- 3.56 meters (140 inches) from the GO focus, This loss is illustrated in Figure 3, where a plot of gain versus the z-displacement motion of the BWG assumes that the entire BWG is moved relative to the focal point of the dual-reflector system at f_1. Only the aperture illumination, phase efficiency, dual-reflector spillover, and center blockage 1oss are included in the calculation; BWG internal spillover is ignored for this comparison since it would be tile same for each point of the curve in Figure 3. This defocusing is especially a problem for tile magnifier ellipse, where the S-band phase center at the output of the ellipse is 3.05 meters (120 inches) from the G.O. focus at f_2. Thus the input to tile two-paraboloid section is defocused, causing the majority of the spillover loss and adding to the defocusing of the paraboloid output, If the input to the upper BWG section were focused, the output would then be defocused by some 60 90 inches. However, this defocusing would cause only a 0.2- to 0.3-dB 10ss Efforts were made to determine if adjustment to the input pattern amplitude or phase would move the low-frequency diffraction phase center to the GO phase center at f_2 [5]. It was determined that if the ellipsoidal mirror were large enough (>30λ) it would be possible, but for smaller ellipsoids (18A in this case) it was not possible to move the focus all the way to the GO phase Center f_2.

3. FOCAL-PLANE METHOD

The goal of tile design was to maximize the gain over noise temperature (G/T) of the BWG antenna. Sine.c there are a large number of scattering surfaces (eight total), an optimization method that required repeated computation of the gain and noise temperature of the entire system would be rather time consuming, Instead, a unique application of the conjugate phase-matching technique (called the Focal-Plane Method) was tried, in this method, a uniform plane wave was used to illuminate the main reflector and the fields from the currents induced on the subreflector were propagated through the BWG (minors M_1, M_2, M_3, M_4, and M_5). Finally, the currents on a circular aperture with a 23λ diameter at the focal plane centered at f_3 (Figure 4) were computed. By taking the complex-conjugate of these currents and applying the radiation integral, the far-field pattern was obtained for a theoretical horn that should maximize the gain.

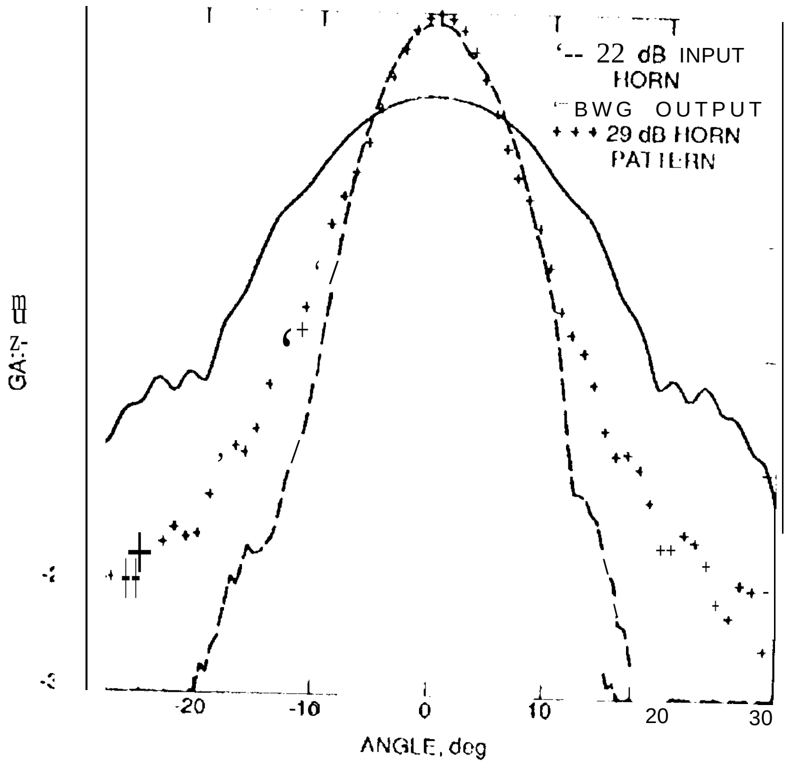

Figure 2. Beam-waveguide Input and Output Radiation Patterns at X-band

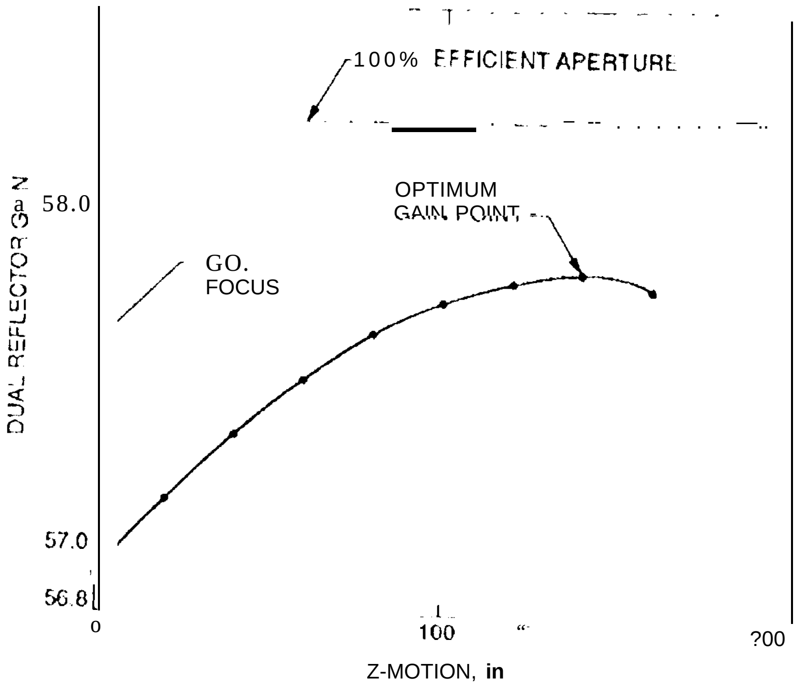

Figure 3, Beam-waveguide Defocusing Curve at S-band

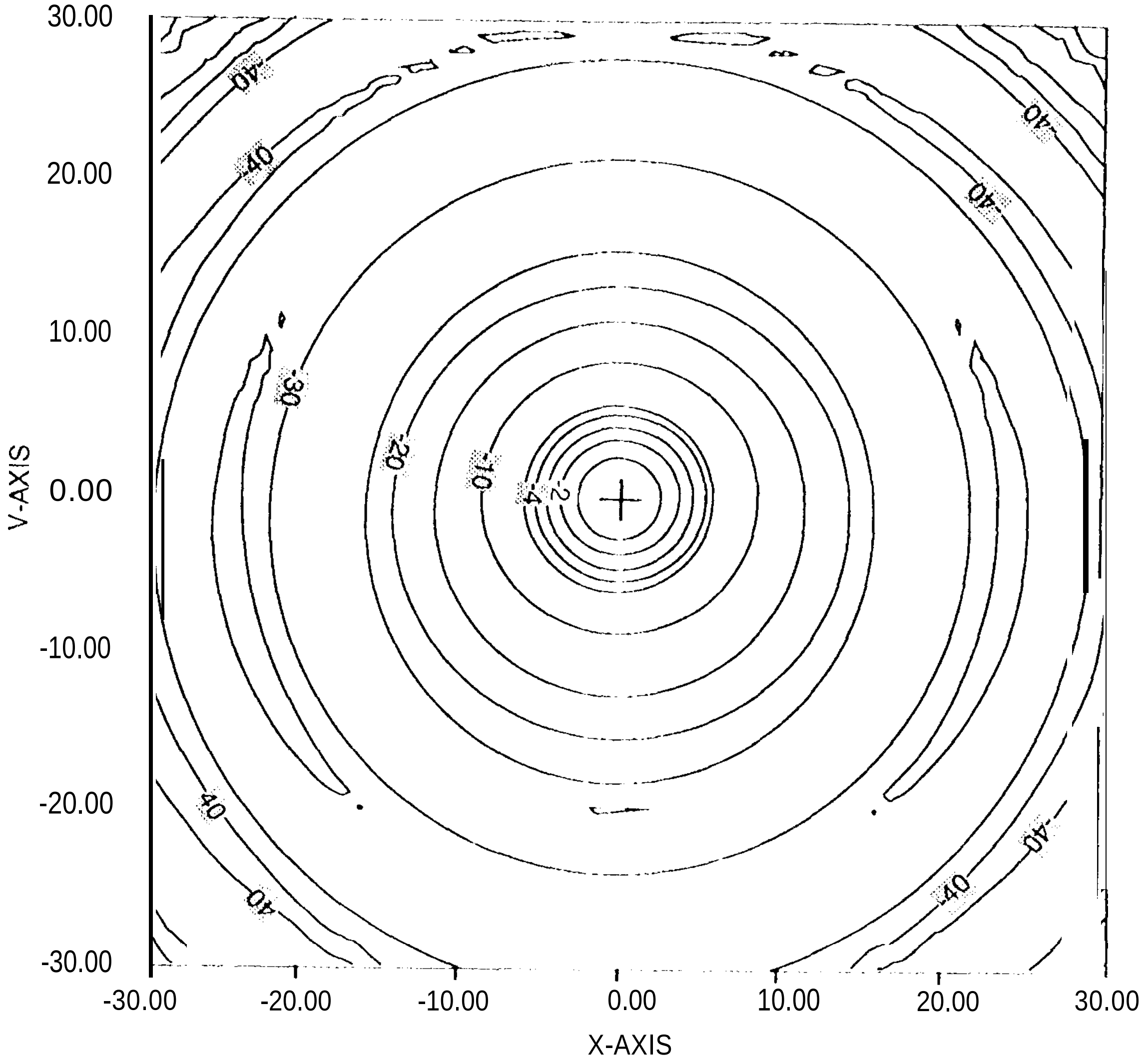

Figure 4. Contour Plot of Currents Induced on Plane Located at f_3 Using the Focal-plane Method

There is no *a priori* guarantee that the pattern produced by this method would be easily realized. However, the pattern is nearly circularly symmetric and the theoretical horn was able to be matched fairly well by a circular corrugated horn,

Figure 5 shows the near-field E-plane patterns of the theoretical horn and a 19-dBi circular corrugated horn. The agreement in amplitude and phase is quite good out to $\theta = 21°$, the angle subtended by M_5. The point of reference for the spherical wave expansion (SWE) coefficients used to generate the 19-dBi corrugated horn pattern was shifted until the radiation pattern matched the one of the theoretical horn centered at the focal plane f_3. By this method the position of the 19-dBi corrugated horn in the antenna could be determined. It turned out that the S-band corrugated horn's aperture position was 352.425 cm from the center of the magnifying, ellipsoid M_5.

The 19-dBi circular corrugated horn pattern was converted into a set of SWE coefficients which were then used in the physical optics (PO) analysis of the 34m BWG antenna at S-band, Figure 6 shows the input and output of the magnifying ellipse, M_5, along with the output

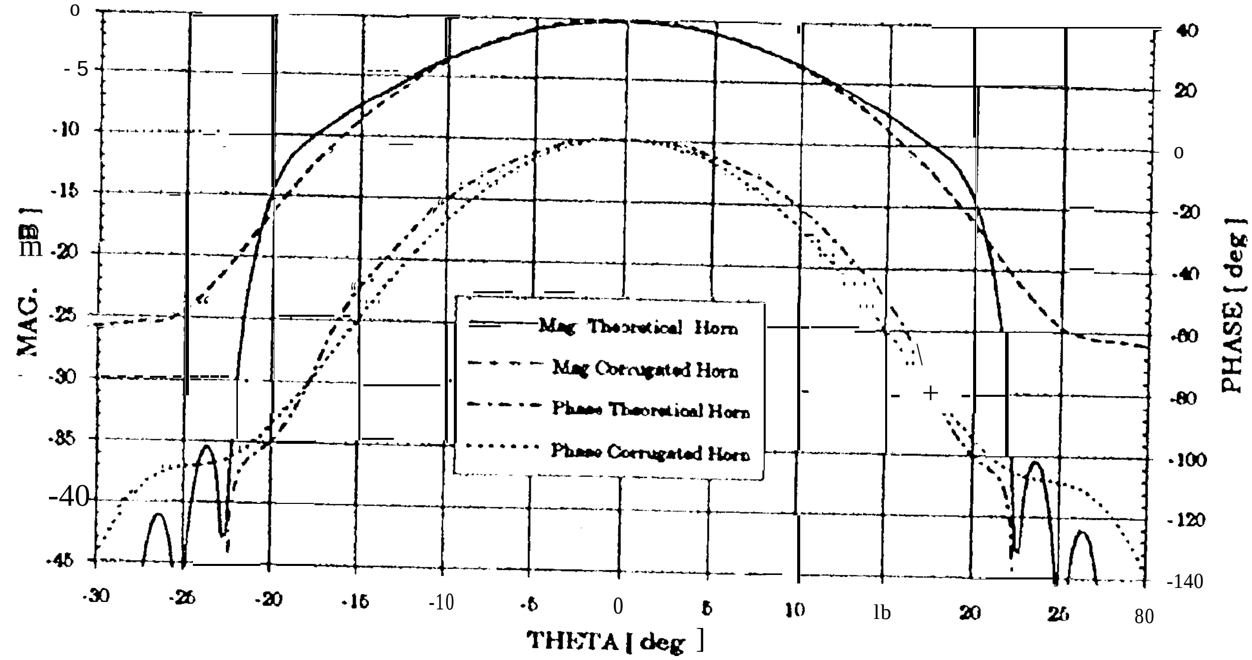

Figure 5. E-plane Near-field (R = 165”, Referenced to f_3) Patterns

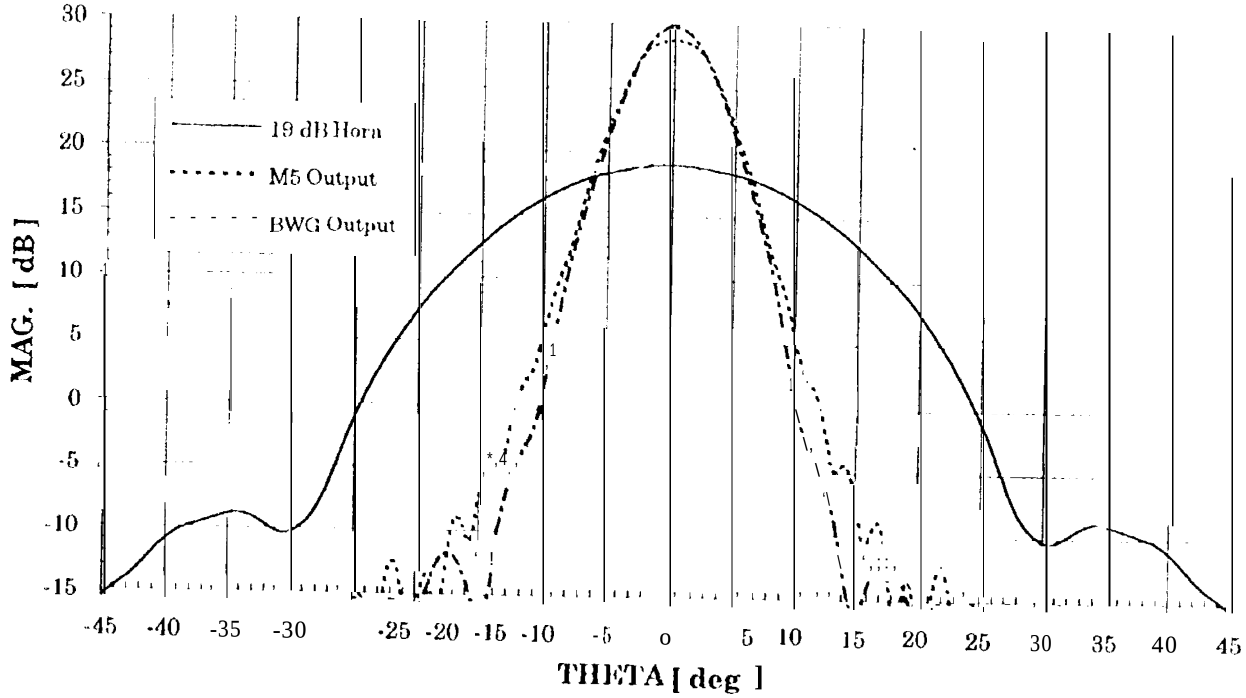

Figure 6. Beam-waveguide Input and output Radiation Patterns at S-band

of the BWG system The 19-dB pattern of the corrugated horn is magnified into a 28.7-dB pattern by the ellipse; the BWG mirrors add an extra 1.1 dB so that at the output of the system the gain of the pattern is 29.8 dB, the gain from which the dual-shaped system was synthesized.

Basically, the Focal-Plane Method provided an unexpected solution to the defocusing problem of the 34m BWG antenna at S-band: the use of a **lower** gain horn. Previous work done on the antenna at X-band and Ka-band had shown that its G/T would improve if corrugated horns with higher gains than the original-design 22 dB were used. For instance, an X/Ka-band feed system uses corrugated horns with gains of 25.0 dB and 26 dB, respectively [6], Thus, when the task of implementing an S-band feed system in the antenna was initiated, a solution which required a higher gain horn was expected.

Part of the skepticism was in the area of noise temperature. It was well known that a lower gain horn would contribute more spillover, which would increase the noise temperature of the system. What was not understood at the time was that the 19-dBi corrugated horn would only have a higher spillover loss at the first reflector, M_5, and that its performance through the remainder of the BWG system would be better than for the standard 22-dBi corrugated horn, Table 1, which lists PO and Jacobi-Bessel analysis results of the antenna at S-band, corroborates this observation, In this table, the spillover of the antenna mirrors, the antenna efficiency, and system noise temperature are listed for the 19-dBi corrugated horn and the

Table 1, S-band P.O. and Jacobi-Bessel Calculations

	22-dBi Corrugated Horn [7]	19-dBi Corrugated Horn	Theoretical Horn
Spillover (%)			
M_6	---	0.41	---
M_5	2.05	2.46	0.24
M_4	1.57	0,70	1.19
M_3	5.91	0.73	0.86
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Efficiency			
Total Efficiency	0.48415	0,6827	0.69502
Gain (dB)	55,102	56.594	56.672
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Total Noise (dB)	18.67	15.69	15.48
G/T (dB)	36.43	40.90	41.19

theoretical horn pattern predicted by the Focal-Plane Method, Also, for comparison purposes, the calculated performance of a 22-dBi corrugated horn is presented from [7].

4. BWG S/X-BAND FEED SYSTEM

The S-band feed is part of a simultaneous S/X-band receive system implemented on the new BWG antenna, The general configuration of the feed system, the detail design, and measured feed system performance are described in [8], the proceeding paper in this session, and the performance of the feed system installed in the BWG is given in the following section.

The predicted and measured noise temperatures of the S/X-band LNAs, microwave feeds, and the overall DSS-13 BWG antenna are shown in Table 2. The higher than standard DSN noise temperature measured for the X-band LNA is due to the age of the package, which was acceptable for its intended use. The predictions are calculated from the theoretical or measured loss of the individual component of each system, The measurements for the feeds were made at Goldstone before installation in the antenna pedestal room. The measurements for the overall antenna were made after the feed packages were installed and aligned in the pedestal room.

The predicted S-band efficiency from Table 1 was 68% and the measured efficiency was 67.5%, demonstrating the successful design and implementation. For comparison, the predicted X-band efficiency (at the rigging angle of 45°) was 72.7% and the measured efficiency, including the dichroic plate, was 70.1%.

5, CONCLUSIONS

A novel solution to the S-band design problems in a geometrically designed BWG system has been demonstrated. The proposed design was implemented as part of an S/X-band feed system in the DSS-13 antenna located at Goldstone, California The measured and predicted performance of the feed systems and the overall antenna agree very closely.

ACKNOWLEDGMENT

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Table 2, Noise Temperature Predictions and Measurements (Kelvin)

system	S-band		X-band	
	Predictions	Measurement	Predictions	Measurement
LNA	8.3	8.72	12.0	14.09
Feed system (including LNA)	17.69	17.5	23.07	24.0
Antenna (TOTAL)	37.26	38.0	32.9	33.0

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