ON THE CALCULATION OF NOISE TEMPERATURE IN BEAM-WAVEGUIDE SYSTEMS

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1. Introduction

At the NASA Deep Space Network (DSN) Goldstone Complex, located in the Mojave Desert in California, several different designs of 34-meter-diameter beam-waveguide (BWG) antennas have been fabricated and tested. For deep space use, system noise temperature is a critical parameter. At the start of the BWG antenna project, noise temperature contributions due to BWG mirror spillover were not clearly understood. It was at first assumed that spillover power was eventually absorbed by cold sky or by a cold front-end receiver. However, this assumption turned out to be incorrect and an empirical relationship between the calculated spillover energy and noise temperature was developed. When attempting to use the empirical data from one BWG design to predict performance of another design also proved to be erroneous, and it became apparent that an accurate analytic procedure that included the effects of the beam waveguide shroud was required.

The major contributors to noise temperature in a beam waveguide are the spillover past the mirrors, and the conductivity loss in both the BWG shroud walls and reflecting mirrors.

The analytical method extends the approach of [1], which computes the waveguide modes that are propagating in the oversized waveguides. Reference [1] describes a physical optics (PO) integration procedure of the currents of the BWG mirrors using a Green's function appropriate to the circular waveguide geometry. Once all the modes in the waveguide are known, it is a simple matter to use standard approximations to determine the attenuation constant and thus the conductivity loss if the conductivity of the wall material is known. Also, all energy that propagates toward, but spills past, a BWG mirror is assumed to be lost in the walls of the BWG as well. The noise temperature is computed assuming that both loss components see ambient temperature, The conductivity loss in the reflecting mirrors is a straight-forward calculation and the corresponding noise temperature is linearly added to the other noise contributors.

Utilizing a very sensitive radiometer, noise temperature measurements were made at the Cassegrain focus and the focal point in the basement pedestal room. Differencing these two measurements yields the contribution in the BWG optics.

The new analytical prediction method is compared to the experimental data and some observations are made regarding the various noise contributors.

2. The DSS-13 Research and Development Antenna

The DSS-13 34-meter research and development antenna (Fig. 1) is an integral part of the advanced systems program and a test bed for technologies aimed at introducing BWG antennas and Ka-band (32-GHz) frequencies into the DSN. The design of the center-fed BWG consists of a beam magnifier ellipse in a pedestal room located below ground level that transforms a 22-dB gain feedhorn into a high-gain 29-dB gain pattern for input to a standard four-mirror (two flat and two paraboloid) BWG system. The design of the upper section of the BWG is based on a Geometrical optics (G.O.) criteria, 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 0.25-dB loss, which was determined by comparing the gain of a 29-dB gain horn feeding the dual-shaped reflector system with that obtained using the BWG system at X-band.

The first measurements of the noise temperature at X-band showed that the BWG system contributed 8.9 K to the system noise temperature [2]. Early estimates based upon expectations that the spillover energy eventually was absorbed by the cold sky were much lower. Since the 8.9 K noise temperature from the BWG was unacceptable, and knowing that the spillover energy sees a high noise temperature, a design effort to optimize the G/T was undertaken [3]. The optimization used an empirical technique for computing noise temperature that assumed the spillover energy (calculated by ignoring the shroud) sees an average temperature determined by measurement. This proved to be reasonably accurate and the optimized design based upon using a 24.2-dB gain horn for a feed was installed and tested. The measured noise temperature contribution of the BWG using the 24.2-dB horn was 2.0 K. Table 1 shows the percent spillover past each BWG mirror calculated by using the new analytical method that includes the effects of the shroud. Assuming that the spillover energy sees ambient temperature, and adding the mirror reflectivity and shroud conductivity losses yields a calculated temperature of 8.7 K for the 22.5-dB horn vs. a measured 8.9 K, and a calculated value of 1.6 K for the 24.2-dB horn vs. a measured value of 2.0 K.

3. The Antenna System Research Task (ARST) Antenna

A second BWG design that used a single curved parabolic mirror, three flat mirrors, and a near-field Cassegranian dual reflector optics was constructed. It was originally used for an X-band experiment and was subsequently modified for use at S-band in the DSN. Since the original mirror design was for X-band, there is considerable spillover energy in the BWG at S-band. Using the empirically determined constants from the DSS-13 BWG system predicted an antenna noise temperature of 70 K. When the measured noise temperature was 39 K it was obvious that the new analytical technique was necessary to predict the noise temperature when there was no measured data to determine the empirically derived constants. The new technique predicts a BWG noise temperature contribution of 42.9 K.

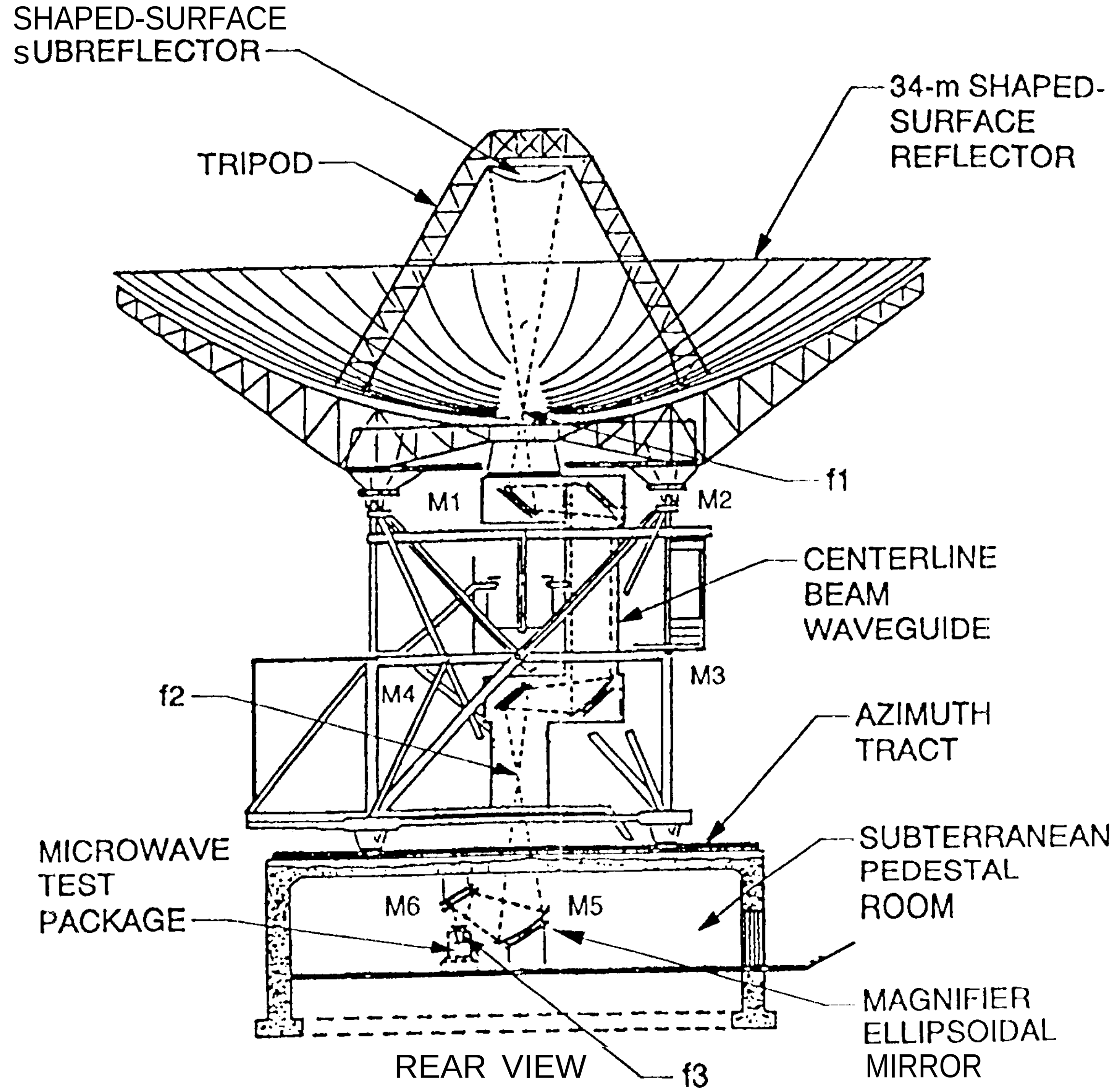

Figure 1. NASA Beam-Waveguide Antenna

Table 1. Spillover Energy in 11 SS-13 BWG System

	22.5-dB Horn		24.2-dB Horn	
Mirror	Spillover % Each Mirror	Total Spillover %	Spil lover % Each Mirror	Tots] Spillover %
M6	0.36	0.36	0.0	0.0
MS	1.02	1.38	0.12	0.12
M4	0.25	1.63	0.0	0.12
M3	1.04	2.67	0.20	0.32
M2	0.04	2.71	0.0	0.32
M1	0.03	2.74	0.0	0.32

4. Conclusions

The major contributor to noise temperature in a BWG system is the spillover energy past the mirrors. The contribution from the conductivity loss in both the mirrors and shroud is small. The analytical technique that includes the effects of the shroud has been shown to be a reasonably accurate method to predict noise temperature.

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References

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