Gain Comparison of a 3D-Printed Horn and an Electroformed Horn*

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***Abstract*— The National Institute of Standards and Technology (NIST) has used the three-antenna extrapolation method to determine the on-axis gain of three horn antennas in the WR8 frequency band. One antenna is an electroformed μ=±1 probe with gain of about 9 dB. The second antenna is an electroformed pyramidal horn with a nominal gain of 15 dB. The third antenna is a 3D-printed corrugated horn with nominal gain of 24 dB. The gains of these horns are measured and compared to the predicted value. Our preliminary measurement results show that the 3D-printed horn has a gain that is substantially less than that expected based on its geometry. The two electroformed antennas are closer to their predicted gain values.**

I. Introduction

This There is interest in climate monitoring in the 118 GHz molecular oxygen absorption band. The desire is to place instruments for this purpose on nanosatellites as described in [1]. To reduce costs and increase availability of parts, 3D-printed horns are being considered. The University of Colorado at Boulder (UCB) recently designed and manufactured a prototype corrugated 3D-printed circular-aperture horn and requested that NIST measure its gain and pattern.

A visual inspection of the 3D-printed corrugated horn reveals that the surface of this horn is significantly rougher than that of a similarly electroformed horn. We desire to know if this surface roughness leads to larger ohmic losses than in an electroformed horn or if there are other effects.

To determine if the gain is affected, we determined the on-axis gain of this prototype 3D-printed corrugated horn, plus an electroformed pyramidal standard gain horn and an electroformed μ=±1 probe using the three-antenna extrapolation method [2]. These gains were compared to values predicted by simulations from a finite element method solver for the μ=±1 probe and pyramidal horn and to a directivity value supplied by UCB for the 3D-printed horn [3]. UCB's directivity value is based on the design dimensions of the 3D-printed horn. [Note: the difference between gain and directivity is the ohmic loss.] The predicted gains/directivity of the antennas at 118.75 GHz are shown in Table I. The standard horn and the μ=±1 probe are gold plated to reduce ohmic loss. The 3D-printed conical horn is made of sintered aluminum.

NIST used the three-antenna extrapolation method [2] to determine the gains of the three antennas at 118.75 GHz. The NIST CROMMA (Configurable RObotic MilliMeter-wave Antenna) facility [4] was used to perform the extrapolation measurements. The extrapolation method fits the power received as a function of separation distance to a power series in 1/(separation distance)^n. The leading term in the power series is proportional to the pair gain $\sqrt{G_i G_j}$. By making measurements of three antennas in three unique pairs (1 vs 2, 1 vs 3, and 2 vs 3), we can determine the gain of all three antennas without knowing any of them *a priori*. For more details on this method, see [2].

TABLE I. THEORETICAL GAINS (DB) AT 118.75 GHZ.

Antenna type	Gain (dB)	[Directivity (dB)]
μ=±1 probe (electroformed)	8.94	
Pyramidal horn (electroformed)	15.40	
3D-printed corrugated circular horn		24.75

II. Three-Antenna Measurements

AMTA The gains of the electroformed μ=±1 probe (with nominal gain of 9 dB), the electroformed standard gain horn (with nominal gain of 15 dB) and the 3D-printed horn with nominal directivity of 24 dB were measured at 118.75 GHz with the three-antenna extrapolation method. The three antennas are shown in Figures 1-3. The results are found in Table II.

Table 3 contains a summary of the sources of uncertainty and the estimated uncertainty due to each source. Table III shows that the main source of uncertainty is due to signal drift. While the NIST antenna ranges are undergoing renovation, the NIST CROMMA facility is housed in a temporary location with much poorer temperature control than the permanent facility. This poorer temperature control leads to significantly larger signal drift. Typical measurement uncertainty for this type of measurement would be less than ±0.2 dB.

III. DISCUSSION

As we can see, the gain of the 3D-printed corrugated horn is more than 4 dB below the directivity predicted by calculation. This implies ohmic losses of about 4 dB. In contrast, the pyramidal horn and the μ=±1 probe have measured and predicted gains that are within the measurement uncertainty. This is consistent with predicted ohmic losses of less than 0.1 dB. We believe that this difference is due to the surface roughness of this prototype 3D-printed corrugated horn and the lower density and conductivity of the material used in fabricating the horn. We expect these to significantly increase the ohmic losses and hence to reduce the gains, particularly as the frequency of operation increases.

TABLE II. GAINS (DB) AT 118.75 GHZ FROM THREE-ANTENNA EXTRAPOLATION METHOD.

Antenna	Gain (dB)
μ=±1 probe (electroformed)	8.60 ± 0.5
Electroformed horn, model 1	15.47 ± 0.5
3D-printed corrugated circular horn	20.32 ± 0.5

TABLE III. GAINS UNCERTAINTIES AT 118.75 GHZ.

Source of uncertainty	Gain uncertainty (dB)
Signal drift	0.5
Multiple reflections	0.1
Mismatch	0.01
Alignment	0.05
Polynomial fit	0.1
Noise	0.05
RSS	**± 0.5**

IV. FUTURE WORK

To further explore the effects of 3D printing, we plan to measure the on-axis gains of three 3D-printed pyramidal horns and an electroformed pyramidal horn at 112, 118 and 125 GHz. These horns have a nominal gain of 24 dB. To test our hypothesis that the ohmic losses are increased by the surface roughness, we plan on polishing one of the 3D printed horns and retesting it to see if the gain improves. We also plan on polishing another horn and plating it with gold to test the effects of different material used in the 3D printing process as compared to the electroforming process.

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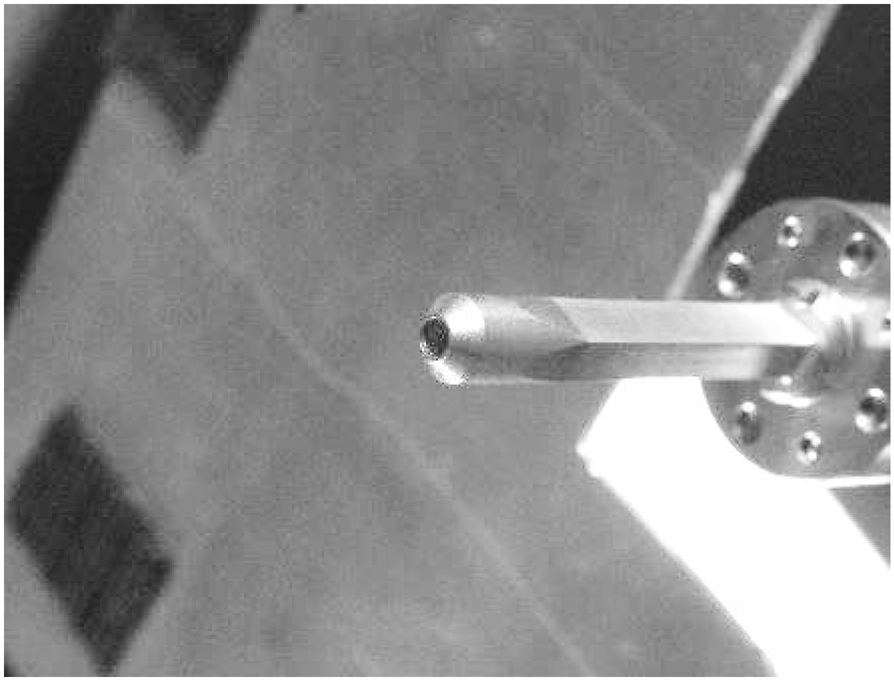

Figure 1. Photo of WR8 μ=±1 probe

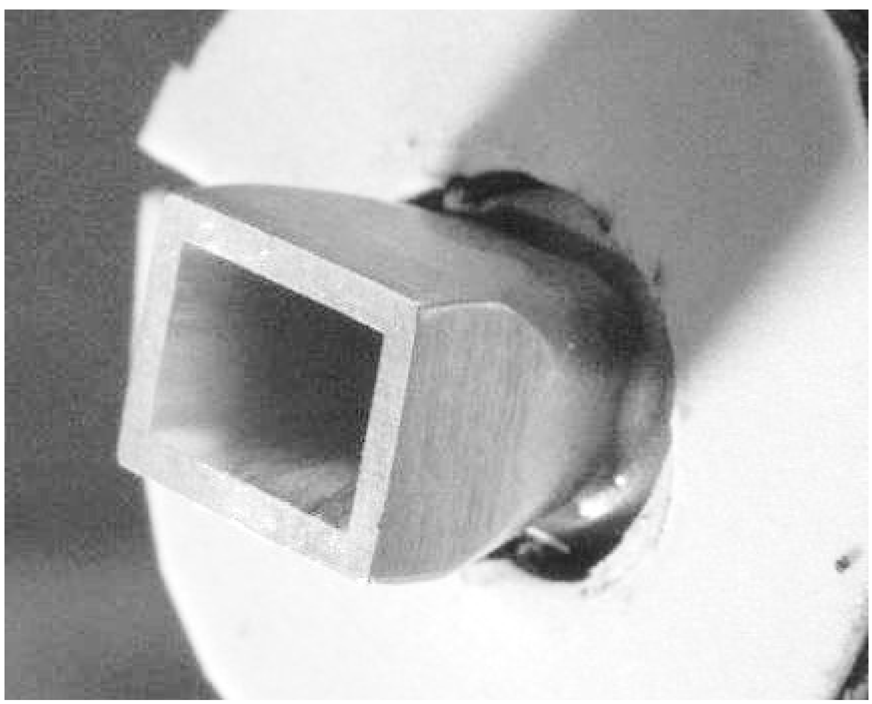

Figure 2. Photo of WR8 15 dB standard gain horn

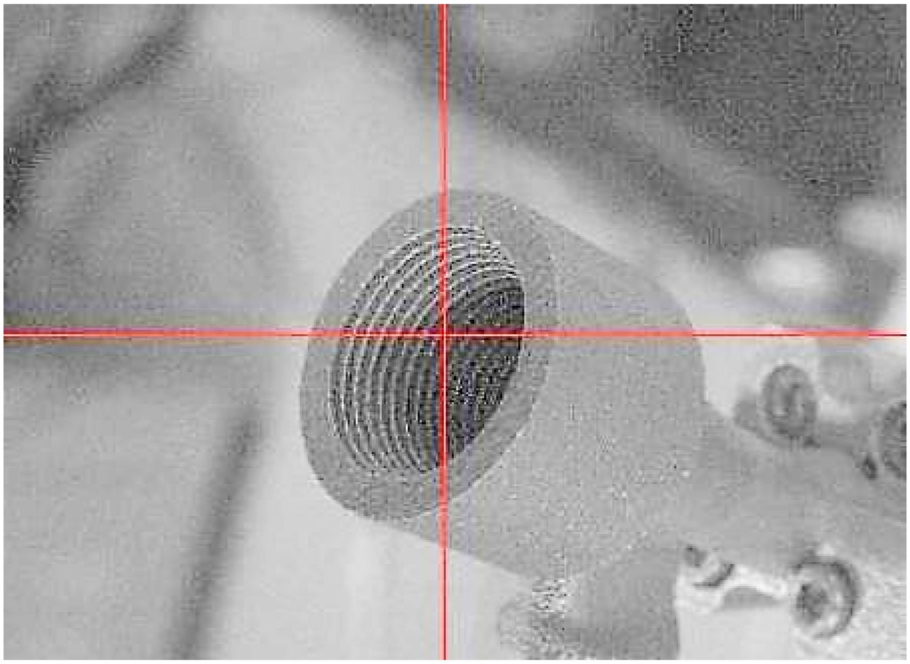

Figure 3. Photo of WR8 corrugated 3D-printed horn with alignment crosshairs.