Numerical Calibration of Standard Gain Horns and OEWG Probes

Donald G. Bodnar

dbodnar@mi-technologies.com

MI Technologies
1125 Satellite Blvd, Suite 100
Suwanee, GA 30024

ABSTRACT

The gain-transfer technique is the most commonly used antenna gain measurement method and involves the comparison of the AUT gain to that of another antenna with known gain. At microwave frequencies and above, special pyramidal horn antennas known as standard-gain horns are universally accepted as the gain standard of choice. A design method and gain curves for these horns were developed by the US Naval Research Laboratory in 1954. This paper examines the ability of modern numerical electromagnetic modeling to predict the gain of these horns and possibly achieve greater accuracy than with the NRL approach.

Similar computational electromagnetic modeling is applied to predict the gain and pattern of open-ended waveguide probes which are used in near-field antenna measurements. This approach provides data for probes that are not available in the literature.

Keywords: Calibration, Gain, Horns, OEWG, Probes, Open-Ended-Waveguide Probes, SGH, Standard Gain Horns

1. Standard Gain Horns

The gain-transfer technique is the most commonly used antenna gain measurement method and involves the comparison of the AUT gain to that of another antenna with known gain. At microwave frequencies and above, special pyramidal horn antennas known as standard-gain horns are universally accepted as the gain standard of choice. A design method and gain curves for standard gain horns (SGH) was developed by Slayton of the US Naval Research Laboratory (NRL) in 1954 [1]. The NRL approach provides a convenient closed form expression for the gain in terms of Fresnel integrals. Measurements by institutions around the world [2] have shown that the NRL formula has an accuracy of ± 0.5 to ± 0.25 dB depending on the frequency range of the horn. A physical horn must be sent to a calibration laboratory if greater accuracy is desired. For example, NIST [3] quotes measured gain uncertainties of 0.2 dB from 1 to 75 GHz using near-field scanning and 0.10 dB from 2 to 30 GHz using the three antenna and range extrapolation methods combined.

Careful measurements of standard-gain horns show a ripple in the gain versus frequency plot which is not present in the smooth gain curves predicted by the NRL approach. This paper examines the ability of modern numerical electromagnetic modeling to predict the gain of these horns and possibly achieve greater accuracy than with the NRL approach. The objective is to see if numerically calculated SGH gain curves could replace the NRL gain curves and in some cases reduce the need for gain calibration of these horns by a standards laboratory.

2. NRL Model

The gain of an antenna in a given direction is the ratio of the radiation intensity (power per unit solid angle) in that direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. This IEEE definition of gain does not include losses from impedance and polarization mismatches.

The NRL approach models the aperture distribution of the horn as a dominate $_{TE10}$ mode amplitude distribution with a quadratic phase distribution that is different in the E- and H-plane directions. The far-field from this aperture distribution is obtained in closed form in terms of Fresnel integrals and produces a smooth, monotonically increasing gain versus frequency curve.

The NRL approach determines the horn aperture dimensions and the length of the flare once the desired gain and the input waveguide dimensions are specified. The NRL design determines the horn dimensions such that (a) the specified gain is achieved, (b) the gain is maximum when the slant length of the horn is held fixed, and (c) the horn has equal half-power beamwidths.

The NRL approach neglects diffraction that occurs at the edges of the aperture and reflections from the waveguide to flare junction. These diffracted and reflected fields interfere with the field produced by the NRL assumed aperture distribution and create a ripple versus frequency in the far-field gain.

3. Numerical Modeling

Computational electromagnetic codes are commercially available that can determine the performance of a wide variety of antennas. FDTD, FEM and MoM formulations have been developed to solve Maxwell's equations subject to the antenna's boundary conditions.

The commercial software program FEKO [4] was used for the following analysis and the Multilevel Fast Multipole Method (MLFMM) was used in the MoM solution. The SGH was modeled as an infinitely thin and perfectly conducting structure. Figure 1 shows a typical triangular mesh used in the calculations. Edge lengths for the triangular mesh elements were varied from λ/7 to λ/14, and it was determined that λ/10 triangles provide sufficient accuracy.

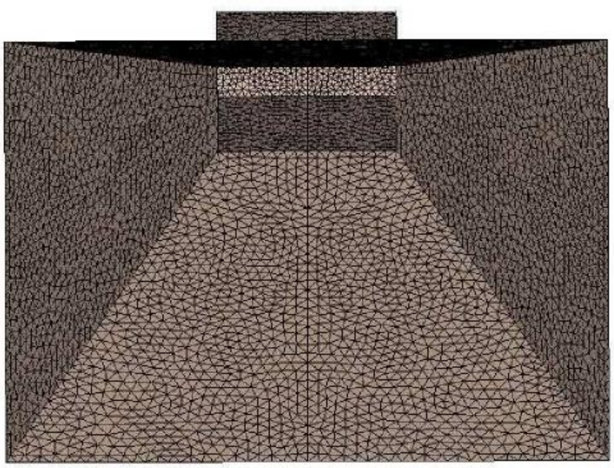
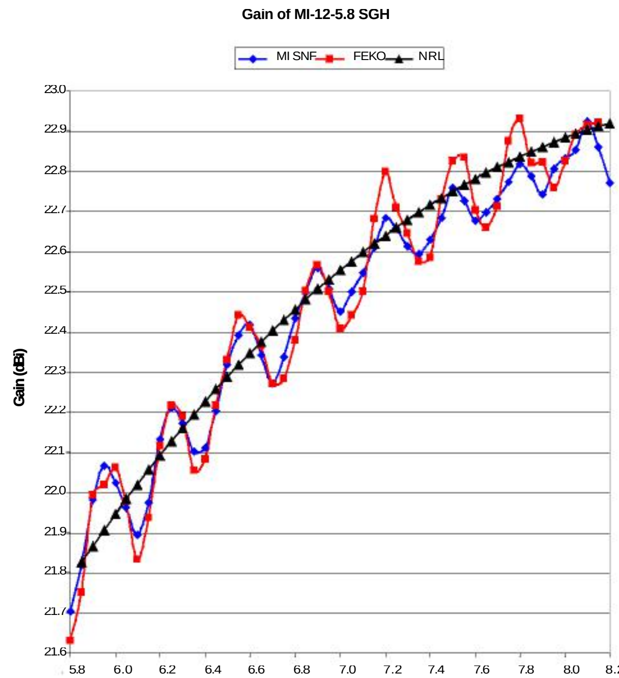


Figure 1. Typical mesh for SGH calculations.

4. Horn Results

Spherical near-field directivity measurements were made by MI Technologies on a XB-band (WR-137) standard gain horn and Figure 2 shows a comparison between measured and FEKO calculated gain. Gain and directivity are essentially equal for this antenna since the ohmic loss in the horn is very small. Excellent agreement between the computed and measure gain is shown. Notice that the locations of the peaks and valleys in the gain versus



frequency curve are accurately predicted by FEKO.

Frequency (GHz)

Figure 2. Comparison of calculated and measured gain of a XB–band (WR-137) standard gain horn.

An inter-range measured gain comparison by seven calibration organizations of X-band (WR-90) standard gain horns was reported in 1996 [5]. Different measurement techniques were used by the different organizations. Swept frequency gain measurements were made by four of the organizations and their measured data is compared with the calculated gain in Figure 3. The computed gain accurately reflects the location of the peaks and valleys in the gain versus frequency curve. In contrast, the NRL approach predicts a smooth, monotonically increasing gain versus frequency curve. It should be observed that differences of up to 0.2 dB exist between the gain measured by the different calibration organizations and that an uncertainty of 0.1 dB typically exists in the measured gain from any one organization. In addition, two identically constructed SGH's were tested and a difference of 0.1 dB between them was observed at the upper end of X-band.

The current numerical modeling of the X-band horn predicts gain that agrees with measured data to within about 0.1 dB at the low end of X-band and predicts slightly higher gain (about 0.2 dB) than measured at the upper end of X-band. Additional work is required to determine how to improve the modeling to get better agreement at the upper not. Wall thickness is included in the numerical model end of the band.allowing analysis of any size waveguide.

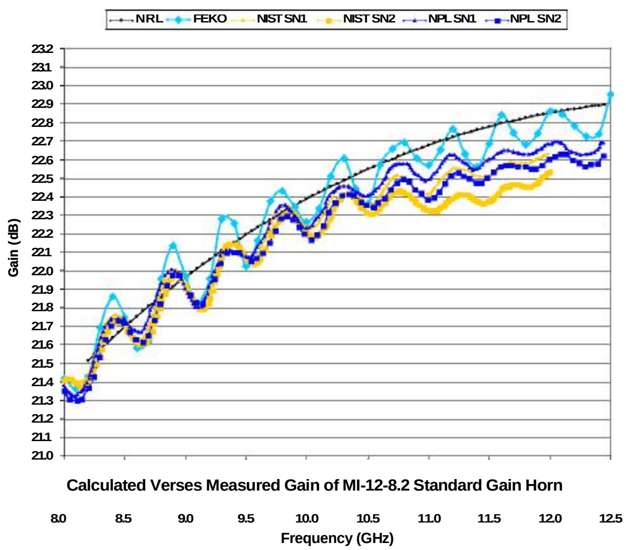


Figure 3. Comparison of calculated and measured gain of an X-Band (WR-90) standard gain horn.

5. OEWG Probes

A popular probe antenna for making near-field antenna measurements is the open-ended waveguide probe (OEWG). Yaghjian [6] at NBS (now NIST) developed a model for the OEWG that combined analytical formulas and measured reflection coefficient data (Yaghjian's [illegible]). Numerical modeling of OEWG probes was undertaken since Yaghjian probe data (a) is only available for a small number of probes, (b) only provides E-plane and H-plane patterns, (c) provides reduced accuracy at Ku-band and smaller waveguide sizes due to wall thickness, and (d) provides no cross-polarization data. Probe data was calculated using FEKO and a full MoM solution. A typical mesh for the OEWG probe is shown in Figure 4. Figures 5 and 6 show excellent agreement between the measured and computed amplitude and phase of [illegible] for an X-band (WR-90) probe indicating that the modeling approach works well for the OEWG. The plotted phase data uses Yaghjian's phase convention instead of the IEEE convention. In addition, the numerical modeling provides the cross-polarized as well as the co-polarized probe pattern while Yaghjian's model does

6. Summary

FEKO MoM numerical modeling of standard gain horn predicts gain ripples versus frequency as observed in the measured data. In contrast, the NRL approach predicts a smooth, monotonically increasing gain versus frequency curve. The FEKO numerical modeling predicts gain that agrees to within about 0.1 dB with measured data at the lower end of a waveguide band and predicts a slightly higher gain (about 0.2 dB) at the upper end of the band. Additional work is required to determine how to improve the modeling of SGH's at the upper end of the band.

Numerical modeling of OEWG probes was undertaken since probe data in the literature is only available for a small number of probes, only provides E-plane and H-plane patterns, provides reduced accuracy at Ku-band and smaller waveguide sizes due to wall thickness, and provides no cross-polarization data. Excellent agreement between computed and measured reflection coefficient data was obtained indicating that the FEKO modeling approach is adequate for the OEWG and eliminates the restrictions of the Yaghjian approach.

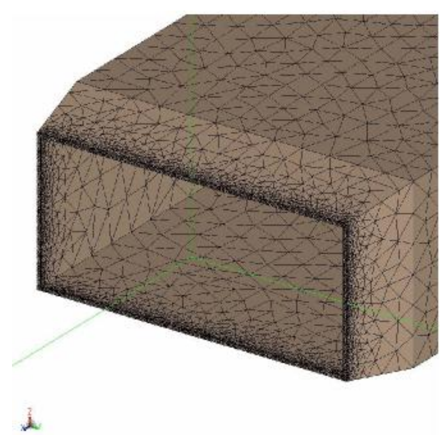


Figure 4. Typical triangular mesh used in OEWG model.

7. References

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6. Acknowledgements

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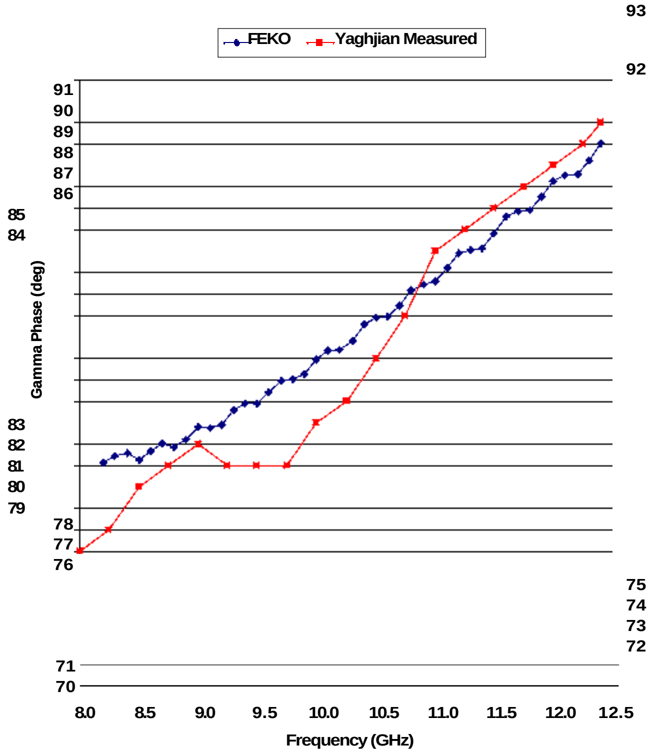

Figure 6. Computed versus measured phase of Γ for X-band (WR-90) OEWG probe.

Phase of Gamma for X-Band OEWG Probe

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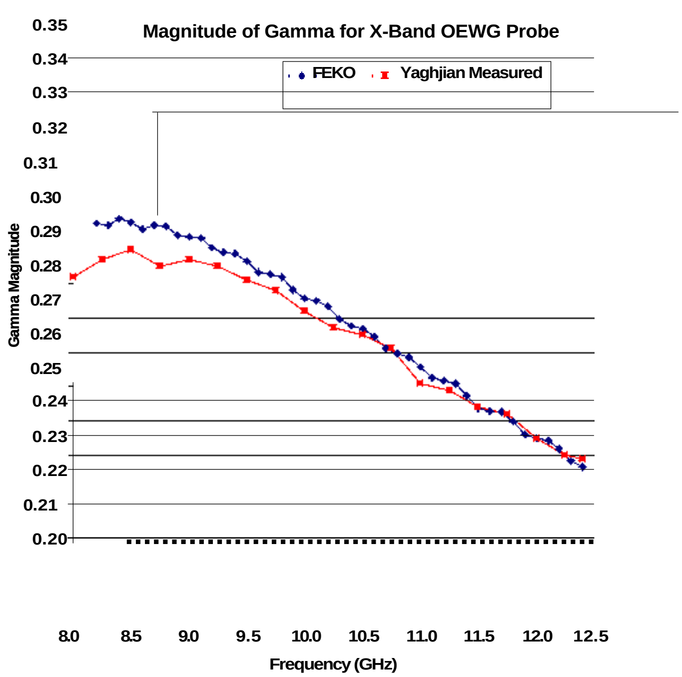

Figure 5. Computed versus measured magnitude of Γ

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