Model Validation for Sectoral Horn Antennas in Metal Enclosures

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1. Introduction

Given requirements for a waveguide-fed antenna having medium gain but broad azimuthal (H-plane) beamwidth, an E-plane sectoral horn is a logical choice. We have similar requirements in WR-112 and WR-187 waveguide where we choose the horn width to be the waveguide width to provide the broadest beamwidth. The aperture height and horn length are then optimized using Feko (www.feko.info) a commercial Method of Moments (MoM) code to provide the most compact size for roughly 12 dBi gain. The fabricated horns are measured and show excellent agreement to the model results. The next step was to design a metal enclosure for these horns with dielectric front face to serve as a radome. This enclosure perturbs the pattern shape but can also enhance the boresight gain for a proper choice of cavity size. We describe the enclosure model and show that performance is sensitive to the radome and back wall position for a given cavity size. For the isolated horns we establish the initial radome position by using a fixture to allow accurate positioning of the radome in front of the horn and select the position that minimizes the measured VSWR at the desired frequency. We constructed a mockup of the horn enclosure for model validation. We present measured results, compared to the Feko model for the isolated horns and also the enclosed horns with radome.

2. Antenna Design

Sectoral horn design is well established with a wealth of available design data normalized to the operating wavelength, λ. This design data is typically for horn lengths of 6λ with aperture sizes of 2λ and larger [1]. Our aperture and horn lengths are less than 3λ so design data are either not available or on the far lower range of the design nomograph. We picked a horn length of 2λ from the aperture to the waveguide rather than from the aperture to the horn apex as in the design data. We then optimized the horn geometry over narrow ranges near the starting values using the Simplex Nelder-Mead optimizer in Feko with the default settings. The final design results in a WR112 sectoral horn having length 2.13λH and aperture length 2.44λH. With WR187 waveguide the length is 2.18λL with an aperture length 2.89λL.
Our main objective for the horn enclosure was to maintain broad azimuthal (H-plane) coverage with maximum gain for the compact size selected. The most critical dimension for pattern shape was the enclosure depth measured from the horn aperture to the enclosure back wall. The final selection is based on the broadest pattern without sacrificing the main beam gain. The WR-112 horn is centered in an enclosure having $3.66\lambda_h$ square cross section with back wall $2.74\lambda_h$ from the aperture. The WR187 horn is centered in an enclosure having $3.8\lambda_d$ square cross section with back wall $2.37\lambda_d$ from the aperture. The final design parameter is the radome position which we construct from 1/16-inch ABS plastic modeled with relative dielectric constant, $\varepsilon_r = 2.53$, and loss tangent, $\tan\delta = 10^{-3}$. The Feko model uses a probe fed waveguide which is not completely representative of the actual coaxial to waveguide coupler. So we established this final parameter based on the measured VSWR for different radome positions rather than model results. The radome position is adjusted to minimize the input reflection coefficient at the desired operating frequency. The result is a radome located at $0.75\lambda_h$ and $0.5\lambda_d$ from the horn aperture for the WR112 and WR187 horns, respectively. A comparison between the H-plane pattern for the isolated horns and the enclosed horns with radome at these positions are shown in Fig. 1. The calculated radome losses are not included in these results being typically 7% or >92% antenna efficiency. As can be seen in the comparisons, the main beam gain is enhanced while the pattern shape is slightly perturbed but this pattern perturbation does not hinder performance. A mockup of the enclosure was fabricated for model validation. Once the model is validated it can be used to evaluate system performance for such aspects as operation at different heights over ground.

3. Antenna Measurements

The horn antennas were fabricated from billet Al using an electrostatic discharge machine (EDM). We use standard coaxial cable to waveguide adapters installed directly on the horn flange. The realized gain for the isolated horns were measured in the ARL tapered anechoic chamber [2]. The measured patterns compared to the Feko model for the WR112 horn are shown in Fig. 2 (a) and (b) in the elevation (E-plane) and azimuthal (H-) planes, respectively. The WR187 pattern comparisons are shown in Fig. 3. As can be seen the agreement is excellent being within the ±0.25 dB measurement error.

**Fig. 1.** H-plane comparison of sectoral horns for (a) WR112 and (b) WR187 waveguide.

(a) (b)
Fig. 2. WR112 sectoral horn antenna pattern comparison for (a) E-plane and (b) H-plane.

Fig. 3. WR187 E-plane sectoral horn pattern comparison for (a) E-plane and (b) H-plane.

Next, we installed the horns in the mockup enclosures with radome mounted at the previously established positions. Note that the metal enclosure walls extend past the horn aperture all the way to the radome. The radome losses are offset by the improved impedance match with the radome installed so the measured gain with the radome in place is only reduced ~0.5 dB. With our surrogate enclosure it is difficult to exactly set the back wall position to that required in the model so there can be slight discrepancies between the modeled and measured geometry. Even so, the agreement is good as shown in Fig. 4 (a) and 4 (b) for the WR112 and WR187 H-plane patterns, respectively. The WR112 result indicates a difference in the back wall position between the model and mockup enclosure so this measurement will be repeated. Once finalized, the design provides a completely enclosed antenna protected from the elements or debris which could impact performance, while improving the antenna main beam gain and reducing back lobes.

4. Discussion

We described the design for a compact E-plane sectoral horn antenna in two different frequency bands. We then installed these horns symmetrically in a metal enclosure and showed that gain can be increased with reduced back lobes without significantly distorting the azimuthal pattern shape. The final design represents the smallest enclosure possible without reducing performance. The back wall and radome position were found to be the most critical parameters affecting the antenna gain and
pattern shape. The radome position is determined empirically based on the input VSWR. The optimum radome position determined in the model did not correspond to the optimum position determined empirically. This represents matching the aperture to the source in the model versus the actual horn and coupler.

Normally the radome is placed at \(\lambda/2\) from the aperture to minimize the field incident on the radome, but this depends on the standing wave pattern between the aperture and radome and assumes the field is at a peak at the horn aperture. For WR112 the model indicates a zero field point near \(0.72\lambda_H\) rather than the position \(0.75\lambda_H\) determined empirically. For WR187 the model indicates a zero field point near \(0.56\lambda_L\) rather than the position \(0.5\lambda_L\) determined empirically. Thus, optimizing this parameter based on model results can be misleading unless the feed representation closely approximates the actual source and waveguide configuration. Except for the radome, the horn and enclosure are completely designed and optimized based on model results.

We obtained good agreement with measurements which serves to validate our Feko model. Subsequent parameter studies based on this model can then be accomplished with high confidence. This justifies the extra effort involved in fabricating and measuring the horns installed in a mockup enclosure for model validation. For example, the horn enclosure is installed on other metallic structures such as a vehicle and the influence of these nearby metal surfaces can be evaluated using the Feko model. In many cases the influence is small but could be important to evaluate numerically before installation of the enclosed horn. Once validated, a numerical evaluation provides significant cost and time savings compared to fabrication and test of parameter variations. The model can be extended to evaluate other geometry variations with high confidence such as operation over soil, blockage effects or the influence of nearby antennas.

References