Dependence of Antenna Cross-polarization Performance on Waveguide-to-Coaxial Adapter Design

Vince Rodriguez, Edwin Barry, Steve Nichols
NSI-MI Technologies
Suwanee, GA, USA
vrodriguez@nsi-mi.com

Abstract—Antennas utilized as probes, sources, and for gain comparison are typically specified to have excellent cross polarization levels, often on the order of 50 dB below the primary polarization component. In many cases, these antennas are fed with a Waveguide-to-Coaxial adapter, which can be sourced from a multitude of vendors. Depending on the design and construction of the adapter, and the distance from the excitation probe to antenna aperture, the adapter itself can contribute significantly to the degradation of the polarization purity of the antenna. These adapters typically use one of several methods to achieve a good impedance match across their bandwidths, including tuning screws, posts and stubs. These tuning elements may be arranged asymmetrically and can cause the waveguide to be over-moded locally. Additionally, there is wide variance in the distance separating the adapter excitation probe and waveguide electrical flanges, which may not be long enough to suppress the higher order modal content. In this paper, we study the effects of adapter to antenna aperture coupling, including the coupling of fields local to the current probe. The analysis concludes with recommendations to ensure that the antenna polarization purity is optimized.

Keywords: Standard Gain Horns, Gain Measurements

I. INTRODUCTION

One methodology for measuring the gain of antennas is to use gain standards as described in a section of IEEE Std 149 [1]. The Standard states that the gain of the reference antenna shall be accurately known and that a high degree of polarization purity is necessary. The document mentions dipoles and pyramidal horns as suitable reference antennas. A typical set of pyramidal horns used as references is shown in Figure 1.

Pyramidal horns are more commonly used as gain standards than dipoles because they are less impacted by range issues [1]. Another convenient factor is that pyramidal horn gain can be calculated with reasonable accuracy using the data and approach described in [2]. This technique results in a smooth gain curve, but others have shown through modeling and measurements that pyramidal horn gain curves exhibit some ripple versus frequency [3, 4]. Taking this into account, the Standard [1] recommends using an accuracy for the computed smooth pyramidal horn gain curve of ±0.25dB for frequencies above 2.6GHz and of ±0.5dB for frequencies below 2.6GHz. Bodnar [3, 4] has shown that this variation from the smooth curve may be smaller than the numbers suggested in [1]. If better gain accuracy is desired, a precision calibrated gain standard is required [1].

Pyramidal standard gain horns (SGH) also typically have excellent polarization purity. Reference [1] states that pyramidal standard gain horns are likely to be slightly elliptical with Axial Ratio (AR) higher than 40dB. This 40dB AR (or assuming perfect polarization) for the SGH is used in the literature when describing gain measurement approaches [5, 6]. The present paper will show that a significant degradation in AR over a given beamwidth can occur when the SGH is combined with a waveguide-to-coaxial adapter. A series of numerical analyses will show that the cross polarization of a SGH is related to the distance between the coaxial feed point and the location where the flare of the horn begins.

II. DIFFERENCES BETWEEN STANDARD GAIN HORNS

Typically horns have a section of waveguide attached to the flare of the horn as the units shown in Figure 1. The length of the waveguide section between the flare and the horn is not defined by [2], resulting in variation between manufacturers. Sometimes the horns do not have a waveguide section at all as shown in Figure 2.
When obtaining a standard gain horn, it is usual to acquire them with a waveguide to coaxial adapter. These adapters have a similar inconsistency in the waveguide length from the coaxial feed point to the flange. Figure 3 shows two X-band waveguide to coaxial adapters available commercially that have different lengths between the feed point and the flange.

When a SGH is attached to a waveguide to coaxial adapter, the total length of waveguide between the coaxial feed point and the flare can be quite different. It is possible to combine a SGH that has a short waveguide section with a waveguide to coaxial adapter that also has a short waveguide section resulting in minimal length of waveguide between the coaxial feed point and flare of the horn.

### III. NUMERICAL RESULTS

The effects of the waveguide section length on the cross polarization were analyzed numerically by preparing a model of a typical SGH using CST Suite. The waveguide to coaxial adapter is included in the model as shown in Figure 4.

The horn is modeled as a perfect electric conductor (PEC) with absorbing boundary conditions to terminate the simulation domain. Asymmetries that may appear in real products related to manufacturing tolerances or to tuning stubs or screws are not included in this initial portion of the analysis.

A parametric analysis is performed where the length of the coaxial section $L_{\text{wg}}$ is changed from 0.25 inches to 2 inches in steps of 0.25 inches. Figure 5 shows the section of waveguide that is being adjusted.

The realized gain of the horn is computed as well as the patterns in both principal planes for the co-polar component and the cross-polar component. The results in Figure 6 show that there is a small change in gain as the length of the waveguide section is varied. This variation is less than 0.1 dB. Since it does not seem to be related to the length of the waveguide, it may be caused by numerical error related to meshing the geometry.

In Figure 7 the patterns for different lengths of waveguide at 8.2 GHz are shown for the H plane in both co-polar and cross polar orientations. What appears to be a single outer co-polar plot is actually a plot of all 8 waveguide lengths, indicating minimal co-polar impact. The inner set of cross-polar plots show a bit of variation, even at 8.2 GHz, the lowest frequency of operation for the X-band pyramidal horn.
Figure 7. Co-polar and cross-polar patterns at 8.2GHz.

Figure 8. Co-polar and cross-polar patterns at 12.4GHz.

Figure 9. Cross-polarization for the X-band SGH at different frequencies and different lengths of waveguide section, versus angle.

It may be of interest to look at the field distribution inside the waveguide. Figure 10 shows the field distribution for the $L_{wg}=2$ inches case at plane A (see figure 5) right after the feed location at 8.2GHz. The connector probe enters the waveguide at the top edge ($y=0.2$ inches). This is compared with the distribution shown on Figure 11, which shows the 12.4GHz field distribution.

Figure 10. Field distribution at 8.2 GHz. The field is normalized to the highest field level in the plane.

Figure 11. Field distribution at 12.4 GHz. The field is normalized to the highest field level in the plane.

Notice that while the on-axis cross-polarization does not change (this is a perfect case model) the shorter waveguide increases the cross polarization for a 30° beam to values higher than -40dB as the frequency increases.
Notice that the field intensity near the waveguide wall is much higher at 12.4GHz (Figure 11) than at 8.2GHz (Figure 10). This seems to indicate a higher cross polar component, since the field must be normal to the PEC walls of the waveguide. Clearly there is a change in the distribution between 8.2 and 12.4GHz near the coaxial feed point inside the waveguide.

Figure 12 and Figure 13 show the distribution at the start of the flare of the horn (plane B in Figure 5) for $L_{wg}=2$ inches. Clearly the added waveguide has made the distribution of the field at the extreme frequencies of the band very similar. The field structure clearly indicates a TE01 mode propagating in the waveguide.

IV. EFFECTS OF TUNING SCREWS

Many waveguide to coaxial adapters have tuning screws that are used to improve matching across the band. These screws are often offset from the centerline of the waveguide as shown in Figure 14, and they create disturbances to the field that are asymmetrical. A tuning screw was added to the previous waveguide to coaxial and standard gain horn model in CST Suite to examine its effect on cross-polarization.

Figure 15 and Figure 16 shows the asymmetry at two frequencies by showing the field distribution close to the feed (plane A in Figure 5).

Further simulations show that the tuning screw also adds a level of asymmetry to the normalized cross-polarized pattern. Four frequencies were analyzed with 2 different lengths of waveguide between the coaxial feed point and horn flange. The results in Figure 17 show a slight asymmetry at all frequencies, but the most visible change is observed at 12.4 GHz on the peaks nearest to the null. Note that the longer waveguide section not only improves the cross polarization levels, but also makes the patterns more symmetrical.
Figure 17. Cross polarization for the shortest and longest waveguide sections. Notice that the longer waveguide eliminates the asymmetry from the tuning screw.

The results show that there are multiple benefits to having a waveguide section between the waveguide to coaxial feed point and the beginning of the flare of the horn. With a sufficiently long waveguide section, the innate cross-polarization purity of the horn is preserved when a waveguide to coaxial adapter is used. And asymmetric performance caused by tuning screws in adapters can be mitigated.

This numerical modeling exercise was initiated because of some anomalies observed when combining adapters and gain horns to investigate what may be causing unexpected results. These simulations are a good diagnostic step in the process, but it will also be interesting to make some measurements with shorter and longer waveguide sections to confirm this analysis.

V. CONCLUSIONS

The length of the waveguide section between a waveguide to coaxial adapter assembled with a standard gain horn has been shown to affect the resulting cross polarization performance. The present work concentrated on an X-band pyramidal horn, but similar analyses can be performed at other frequencies. The effect of asymmetric tuning screws on the waveguide to coaxial adapters used with standard gain horns was also analyzed, and the impact of waveguide section length on asymmetric performance was illustrated.

Measurements should be done to confirm the series of numerical exercises presented in this paper. Meanwhile this analysis provides clear evidence that it is important to have a sufficient length of waveguide to attenuate all the higher order modes that can be generated at the coaxial feed point. These higher order modes appear to be more significant at the upper end of the SGH frequency band. Given the variation on the lengths of off-the-shelf waveguide to coaxial adapters, it may be prudent to add a section of waveguide between the adapter and the horn. Horns that have integrated waveguide to coaxial adapters and a waveguide section optimized for best cross polarization performance should also be considered.

REFERENCES


