# Design and Development of an 8 to 12 GHz Circularly Polarized Two Element Horn Antenna Array with High Isolation

J. B. du Toit[1] D. E. Baker[1] A. J. Booysen[1]

*Abstract* – **This paper presents design considerations and measured results for a two element 8 to 12 GHz horn antenna array for transmit/receive applications requiring high isolation. Circular polarization is achieved by incorporating a five layer meanderline circular polarizer over the aperture of the horn antenna. The measured axial ratio for operational antennas including protective radomes is less than 0.85 dB over the entire frequency band. The antennas are fitted with waveguide-to-coax adapters and achieve a VSWR ≤ 1.5:1 in the fully assembled condition. Installed isolation of better than 78 dB is achieved over most of the frequency band at a prescribed antenna separation of 500 mm.**

## 1 INTRODUCTION

An X-band application required a two horn transmit and receive assembly with specific absolute gain coverage in azimuth and elevation. In addition there had to be high isolation (78 dB) between the horn antennas including mounting structures. Equal responses to vertically and horizontally polarized incident signals were required. The platform was to be stabilized in roll, pitch and yaw. Because the azimuth beamwidths had to be controlled independently, a pyramidal horn was analyzed and constructed to achieve the desired spatial coverage.

A meanderline circular polarizer [1] was developed and installed over the horn apertures. The target axial ratio (AR) for the meanderline polarizer was 1.5 dB over the 1 dB beamwidth. The spacer thickness as well as the track design was optimized for minimum AR over the 8 – 12 GHz frequency band. To further improve the AR a resistive card was used to absorb the cross polarized field component of the horn antenna.

To measure the high levels of isolation the array was placed inside an anechoic chamber (typical reflectivity of 50 dB) with time gating being implemented to minimize the impact of indirect signals reflecting off the anechoic chamber walls between the two antennas. The desired isolation of 78 dB was achieved for the maximum allowed spacing of 500 mm between the antenna elements.

## 2 HORN ANTENNA

The first part of the design was to develop a pyramidal horn antenna with specific gain and beamwidths. Because of the nature of the platform, the E-plane beamwidth has to be about half of the H-plane beamwidth to achieve the required gain values and coverage. The preliminary design was done by using the analytical equations from [2] which predict pyramidal horn antenna gain and patterns from the aperture fields. The final antenna design was verified using FEKO [3]. The design was realized with a horn with an E-plane aperture of 85 mm, an H-plane aperture of 60 mm and a length of 122 mm. This gave theoretical half power beamwidths at the center of the band (10 GHz) of nominally 34° in the H-plane, 19° in the E-plane and a gain of 17 dBi. The gain comparison is shown in Figure 1. The patterns correspond down to the -20 dB level. The only difference is the presence of small gain oscillations which are known to exist from measured results [4].

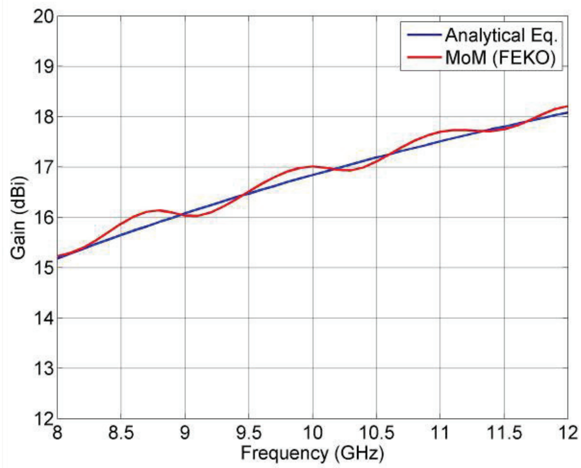


Figure 1: Simulated gain of pyramidal horn antenna.

The gain and beamwidth requirements were met by the pyramidal horn. The horn antenna was provided with a low-cost waveguide-to-coax adapter of in-house design. The adapter has a VSWR of less than 1.15:1 into a matched waveguide load.

[1] Saab Electronic Defence Systems, 185 Witch-Hazel Avenue, Highveld Technopark, Centurion, South Africa
e-mail: johan.dutoit@za.saabgroup.com, dirk.baker@za.saabgroup.com, riaan.booysen@za.saabgroup.com, tel.: +27 12 674 3500

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## 3 POLARIZER DESIGN

The antennas required equal responses to vertically and horizontally polarized incident signals as well as different E- and H-plane beamwidths. A transmission polarizer attached to the horn aperture is the easiest way to meet this requirement. Because of time constraints and the planned roll stabilization it was decided to use a slant 45° multi-layer polarizer to obtain a 45° polarization rotation for the vertically polarized horns. The slant linear polarizer efficiently converts the inherently vertical polarization of the horn antenna to slant 45° [5], [6]. The horn can then receive vertically, horizontally and left or right circularly polarized signals with a 3 dB polarization loss, while maintaining all the desirable features of the horn antenna (patterns, VSWR, gain). The five layer polarizer, designed using the cascade matrix method [6] achieved a reflection coefficient of -25 dB.

However, as the main project progressed it became clear that the desired roll stabilization of the system to maintain the slant 45° polarization to 45° ± 5° would not be achieved in time and would be too expensive. It was then decided to use circular polarization rather than slant 45° by making use of a meanderline polarizer in front of each antenna aperture. This enabled the system designers to have much more leeway on the roll specification without any loss on signal strength for a given roll angle or linear polarization. The target axial ratio for the horn antenna with circular polarizer was 1.5 dB.

Meanderline polarizers [1] and [5] to [8] are transmission polarizers similar to the slant polarizers in that they systematically change the polarization; in this case from vertical linear to circular. This is accomplished by multiple (often identical) sheets of meandering lines set at 45° to the main incident polarization. This splits the incident field into equal components parallel and perpendicular to the meanders. The two components have different phase transmission properties though the structure, one being capacitive and the other conductive. Thus by using the correct number of layers and spacings one can create a 90° phase shift between the two components resulting in circular polarization for the emerging wave. Because this design is phase critical the usable bandwidth is usually limited to about 3:1 for 3 dB AR. This is in contrast to the 30:1 or more obtainable bandwidths of the slant polarizer. This meanderline structure can also be analyzed using the cascade matrix method. The design parameters given in [5] were implemented and analyzed for this frequency band; the calculated axial ratio result is shown in Figure 2. An AR of just over 1 dB is predicted for the meanderline polarizer.

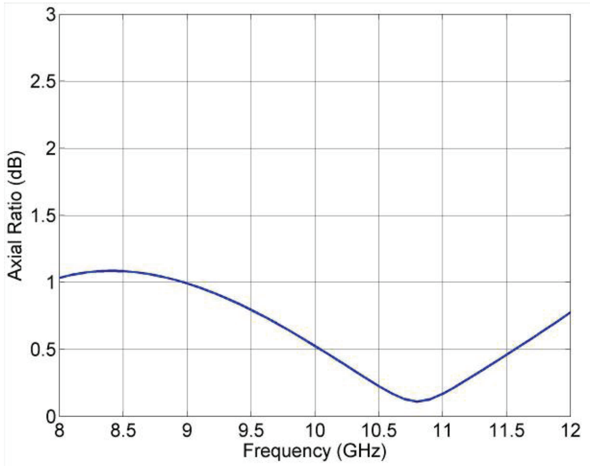


Figure 2: Calculated axial ratio for a five layer meanderline polarizer.

## 4 POLARIZER OPTIMIZATION

The calculated AR is about 1 dB but when the polarizer was attached to the horn a significantly worse AR of around 2 dB was measured. Testing other combinations of polarizers and horn antennas confirmed that the polarizer was working as predicted. This was true only for antennas with very good cross polarization characteristics. The meanderline polarizer is aligned such that the meanders are set a 45° to the incident polarization. If the polarizer is rotated through 90° the sense of circular polarization emerging from the polarizer is changed. Conversely, any H-polarized field present will result in a circularly polarized field opposite to that of the desired sense and will thus degrade the AR of the total field.

The IEEE definition of axial ratio $r$ is

$$r = \frac{\rho_c + 1}{\rho_c - 1} \quad (1)$$

where $\rho_c$ is the polarization ratio = $E_R/E_L$. $E_R$ and $E_L$ are the electric field amplitudes for the right or left circularly polarized components of the wave, respectively.

Let us consider a linearly polarized transmitting horn with a cross polarization of -30 dB relative to the principal polarization. A vertically polarized incident field at the input aperture of the polarizer produces $E_R$ = 1.0 V/m at the exit aperture of the polarizer. Assuming the same transmission loss through the polarizer, the horizontally polarized field will produce a left circularly polarized field with amplitude $E_L$ = 0.032 V/m. Inserting these values in Equation 1, we get $r$ equal to 1.066. Expressing this in dB we get AR = 0.556 dB. This is significant if the AR design goal for the polarizer is less than 1 dB.

The inherent linear cross polarization of the horn antenna supporting the meanderline polarizer can rapidly degrade the AR even when the horn has relatively good cross polarization of -30 dB. It is imperative to reduce or completely remove the linear cross polarization component. This can be done by reducing the basic cross polarization of the horn; this may not be easy to do for a low-cost pyramidal horn. Alternately the cross polarized component can be attenuated by absorbing it in a thin resistive card set at 90° to the principal polarization (the H plane for a conventional vertically polarized pyramidal horn). For this application a polyester film was coated with carbon loaded paint and inserted into the horn. This eliminates the cross polarization and results in a greatly improved AR for the horn and polarizer combination.

The final measured boresight axial ratio (Figure 3) is very low at less than 0.85 dB over the full band. Figure 4 shows the VSWR of the horn antenna fitted with the waveguide-coax adapter. The additions of the resistive card and the polarizer have very little effect. The patterns are also very well behaved (Figure 5), with a consistently low axial ratio, even for wide angles off boresight.

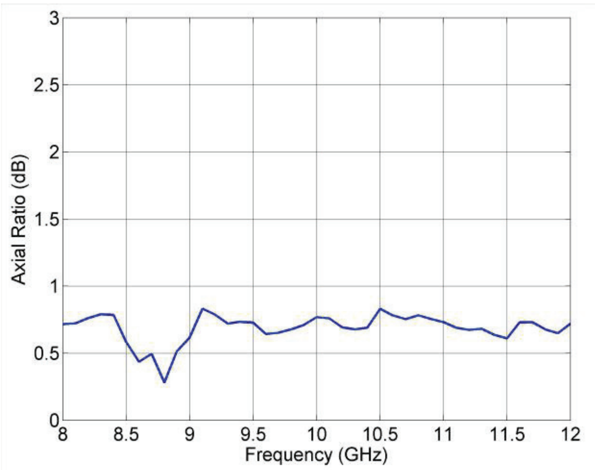


Figure 3: Measured axial ratio of the horn antenna with resistive card and meanderline polarizer.

## 5 ISOLATION TESTING

The final step was to integrate two of these horn antennas with polarizers onto a custom mounting fixture. Figure 6 shows a photograph of the two horn array in an anechoic chamber. The isolation was required to be more than 78 dB for the two horn array. The largest problem with this requirement is not so much reaching the design goal, but being able to test whether it has been achieved.

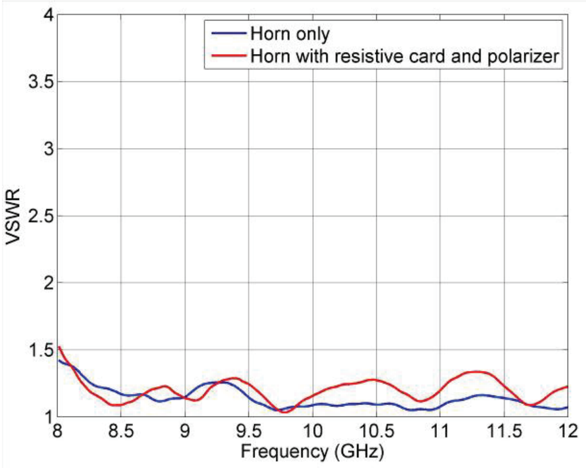


Figure 4: Measured VSWR of the horn antenna with and without resistive card and meanderline polarizer.

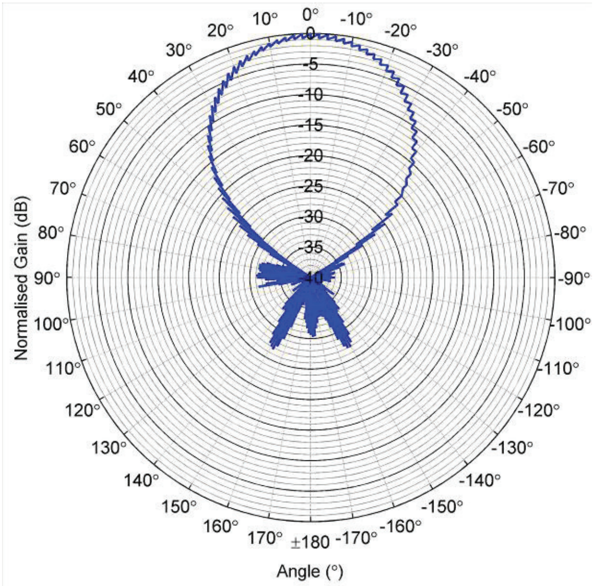


Figure 5: Measured axial ratio azimuth pattern of the horn antenna assembly at 10 GHz.

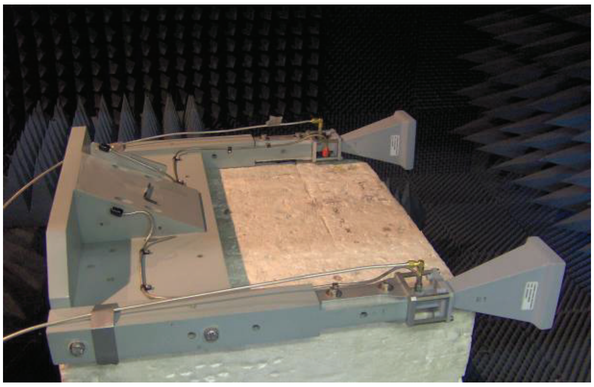

Figure 6: Photograph of the two horn array on the mounting fixture in an anechoic chamber.

To be able to accurately test transmission coefficient values which lie mostly between 80 and 90 dB, the setup to be used must have a noise floor of at least 10 dB below this. This means that great care has to be taken when setting up the measurement. The low-loss test cables into the anechoic chamber use up almost 20 dB of the available dynamic range.

A vector network analyzer (VNA) with a 100 Hz IF bandwidth and a -110 dBm noise floor was used. To reduce any undesired coupling paths between the horns the integrated two horn array was placed inside an anechoic chamber. The pyramidal absorber of the anechoic chamber provides about 50 dB absorption at these frequencies. The reflected signals from the polystyrene mounting block, the walls and especially the floor are still too large to measure the small direct signal between the antennas. To overcome the problem of undesired signals the built-in time domain function of the VNA was used to gate out signals arriving later in time than the direct coupling. The array must be set up with enough distance between itself and any reflections so that the direct signal can be isolated and measured on its own.

Using this measurement setup many aspects of the antenna integration onto the platform were optimized for isolation. This included the placement of the horns, the mounting and the size of the polarizers which create significant diffracting edges. The final measured isolation between the two circularly polarized antennas mounted on the platform at a distance of 500 mm is shown in Figure 7. The isolation is better than 78 dB over most of the band. At 8 GHz the thin fiberglass radome degraded the isolation to 75 dB, but the final result was still acceptable for system integration.

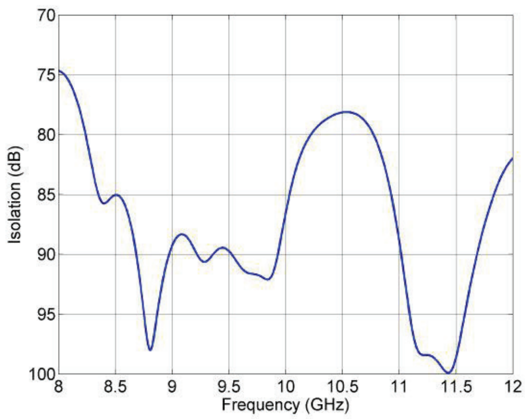


Figure 7: Measured isolation between the horn antenna assemblies in the two element array.

## 6 CONCLUSION

This paper has described the development of a two element 8 to 12 GHz horn array. The preliminary design of the pyramidal horn was done using aperture field based analytical equations. These results compared very well with full-wave simulated results. The design of a slant 45° polarizer as well as a meanderline circular polarizer was discussed and theoretical results calculated with the cascade matrix method were presented.

The effect of linear cross polarization of the horn on the AR of the exit wave from the meanderline polarizer was discussed. A cross polarization 30 dB down from the principal polarization degrades the AR by almost 0.6 dB. The use of a resistive card greatly improved not only the boresight AR but also the AR over the entire antenna pattern. The measured boresight AR of the horn/polarizer combination with a protective radome was shown to be below 0.85 dB over the entire band. The measured VSWR of the complete horn antenna was shown to be well below 1.5:1.

The difficulties of testing high transmission isolation between antennas were discussed and the advantages of using time domain gating were shown. The final measured isolation is shown to be better than 78 dB over 95% of the band; it was slightly degraded at 8 GHz by the external protective radome.

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