Depolarization Phenomenon in Ku-Band Feed Horn Antenna

Ramesh Chandra Gupta, Jigar Pandya, K. K. Sood, Rajeev Jyoti

Abstract – **This paper provides a novel hybrid horn antenna configuration. This hybrid horn antenna is devised by combining stepped section, variable depth and width axial corrugated section and multi-slope profiled radial corrugated section. Good measured RF performance with this compact sized horn has been achieved. In horn antennas, particularly at Ku-and higher bands, a de-polarization phenomenon has been persistently encountered during its characterization. Typically, in a horn with excellent theoretical performance, non-zero cross-polarization is obtained on bore-sight. A detailed investigation revealed that the non-null cross-polarization is introduced due to the realized non-symmetric circular-to-rectangular smooth-walled transition. Detail of the depolarization issue is discussed; the empirical analysis for the phenomenon is given and a remedy for the same is suggested. Although this problem can occur at any frequency band, fabrication inaccuracies and precision presently achieved using CNC machine; makes it more severe at Ku- or higher frequency bands.**

Keywords – **Horn antenna, Ku-band antenna, cross-polarization, satellite antenna, feed system.**

I. Introduction

Currently, the use of Ku band in satellite communication/ broadcasting is increasing exponentially. Typically, horn and reflector antennas are used for spacecraft antenna requirements. For illuminating the reflector antenna, different types of horn antennas are described in literature [1]-[13] such as axial corrugated horn, choked horn, radial corrugated horn, multimode smooth-walled horn etc. Here, an innovative hybrid horn antenna is presented. This hybrid horn is derived by blend of stepped section, axial corrugated section and multi-slope profiled radial corrugated section. The hybrid horn antenna is filed for patent [14]. This hybrid horn has good measured RF performance along-with compact size. In Ku-band horn antennas, a de-polarization phenomenon is persistently encountered during pattern measurement, that is, non-zero cross-polarization is obtained on bore-sight. In the literature [1]-[13], this type of problem is not well treated or described in detail. The de-polarization phenomenon is discussed providing details with a Ku-band feed system as example. We have suggested a solution for the problem. The depolarization can be occurring axial corrugated horn, radial corrugated horn, smooth-walled multimode horn or any other types of horn antenna. It has been attempted to provide a diagnosis for the issue and a solution is also suggested. However, this problem can be take place at any band, but precision achieved using contemporary CNC (Computerized Numerical controlled)turning machines; it is more significant at Ku-band or higher frequency bands. The non-zero cross-polarization at bore-sight of the feed horn affects significantly XPI (cross-pol isolation) of the reflector antenna. Since XPI of secondary pattern is governed by cross-pol level of primary pattern, particularly in case of single shell shaped reflector antenna. This Horn uses blend of several (five) sections first time. This hybrid horn comprises stepped section, axial corrugated section and three sections of radial corrugated section with different linear slope. This horn is successfully developed for high power feed application to shaped reflector antenna for communication. Whereas, existing work [1]-[13] describes smooth-walled horn, radial corrugated horn, axial corrugated horn or blend of Horizontal and vertical corrugated horn etc. Cross-polar degradation due to fabrication is identified and addressed first time.

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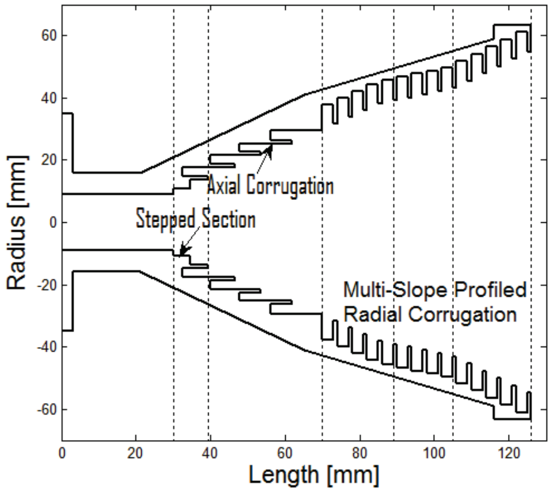
II. Realisation of Horn Antenna and Empirical Analysis for Depolarization

The horn antenna chosen as an example is a Ku-band hybrid corrugated horn, whose profile is shown in Fig. 1*a*, excited by the linearly x-polarized fundamental TE_{11} mode using a rectangular-to-circular transition and a coax-to-rectangular waveguide top launcher. The transition is smooth-walled type transition. Fig. 1*b* shows photo of fabricated horn. The horn was designed using the TICRA software package CHAMP based on the Mode Matching technique and Method of Moments, to achieve an edge-taper of -17 to -19 dB at 30° semi subtended angle. The operating band of the horn antenna is 10.95 GHz to 11.7 GHz. The horn antenna was fabricated using aluminium alloy 6061-T6 and later characterized at the Anechoic Chamber Facility at SAC (ISRO), Ahmedabad. If fabrication of the transition is not symmetrical, the polarization of E-field at input circular waveguide end is rotated by a small angle in comparison of the polarization of E-field fed at rectangular waveguide-side, as shown in Fig. 2.

The polarization in the transition rotates as it propagates from the source/adapter to the horn. The end pieces of the circular-to-rectangular transitions are polarization-sensitive. Several factors can cause an introduction of this undesirable polarization. One cause is out-of-round waveguides that result from non-standard manufacturing tolerances. Certain elliptic cause polarization rotation into unwanted states, while others have little effect. Additional sources of cross polarization include twisted and bent waveguides, offset flanges, and transitions. If E-vector (P) is rotated by an angle (α), it is resolved in co-polar component P_x and cross-polar component P_y. Complex polarization ratio (CPR) is given by



(a)

(b)

Fig. 1. Ku-Band Horn Antenna: Hybrid Horn Antenna:
(a) longitudinal profile, (b) photograph of fabricated hardware

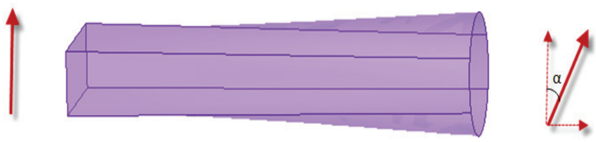


Fig. 2. Circular to rectangular waveguide transition and polarization rotation

$$CPR = \frac{P_y}{P_x},$$

$$CPR = P_{xp},$$

$$\frac{P_y}{P_x} = 10^{-P_{xp\_dB}/20}, \qquad (1)$$

where P_{xp} is cross-polar level with respect to peak and P_{xp_dB} is cross-polar level in dB.

The rotation angle (α) is given by

$$\alpha = -\arctan\left(\frac{P_y}{P_x}\right),$$

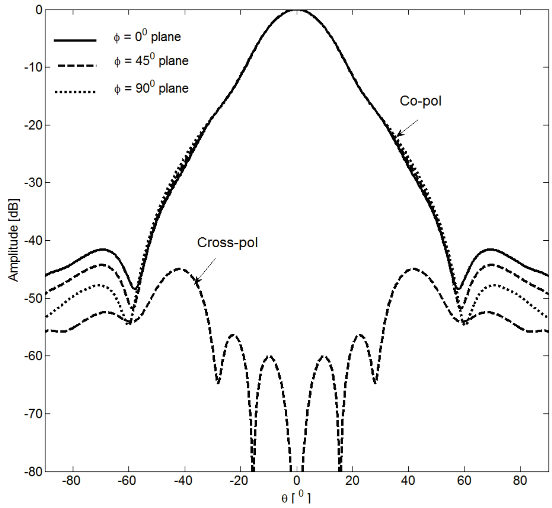
$$\alpha = -\arctan\left(P_{xp}\right),$$

$$\alpha = -\arctan\left(10^{-P_{xp\_dB}/20}\right), \qquad (2)$$

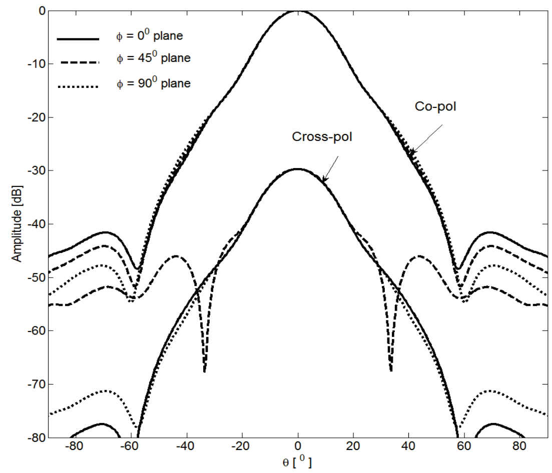
where arctan(·) is inverse tangent function of the given variable or angle.P_x component generates the TE_{11} mode of propagation while the P_y component the TE_{11}* mode in the horn antenna input port. It is desirable P_y component should be zero. In turn, the TE_{11} mode generates co-pol while the TE_{11}* mode generates cross-pol in the radiation pattern of the horn antenna. Theoretical radiation patterns can be obtained by transforming the pattern in rotated co-ordinates with a rotation angle (α) (Eq. (2)). Changes in dimension can depolarize also. The depolarization depends on asymmetry in cross-section as well as on longitudinal length of the transition. As reported in [13], a 0.2 percent change in diameter can produce a –40 dB cross-polarization component per wavelength of waveguide length. The transition is fabricated using wire-cutting CNC machine. Aluminium alloy 6061-T6 is used for fabrication of the transition. By proper reference in four orthogonal corner of the transition, asymmetry can be minimized. Hence depolarization can be reduced. The non-zero null cross-polarization of the horn degrades XPI (cross-pol isolation) of the reflector antenna. XPI is ratio of cross-pol component and co-pol component at any station point.

III. Result and Discussions

Predicted patterns of the hybrid horn antenna in the ϕ = 0°, 45° and 90° planes are shown in Fig. 3*a*. This pattern is horn antenna with perfect transition. A transformed pattern with polarization rotation by Eq. (2) is given in Fig. 3*b*. This pattern is obtained for horn antenna with imperfect transition. The coordinate used here is spherical coordinate system. The horn is radiating in direction of z-axis. x- and y- axes lie in aperture plane of the horn. Where, $\boldsymbol{\theta}$ is angle from z-axis and ϕ is angle from x-axis.



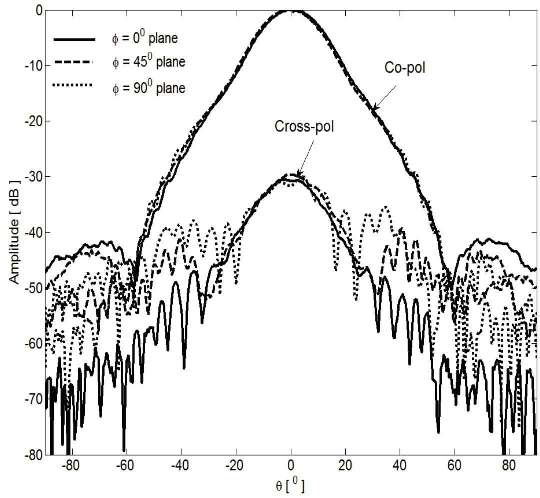
(a)



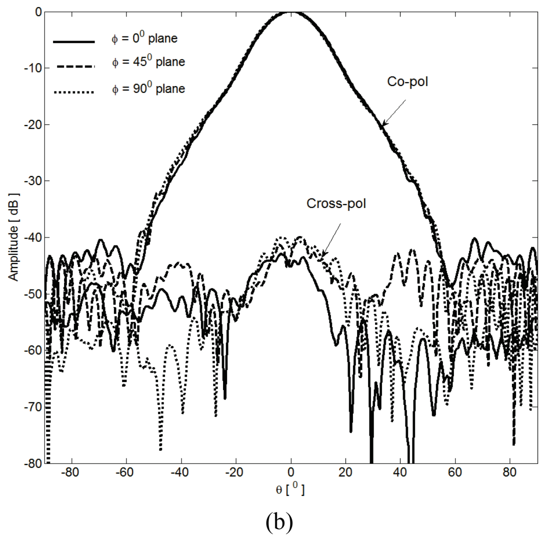
(b)

Fig. 3. Predicted pattern of hybrid horn antenna: (a) without any polarization rotation, (b) with polarization rotation 1.87°

The measured field in ϕ = 0°, 45° and 90° planes are shown in Figure 4. A relatively high cross-polar component, including a non-null on-axis, is noted, indicating lack of circular symmetry or a polarization misalignment (Fig. 4*a*). The axis of AUT and standard horn antenna is RF aligned and checked recursively. By systematic investigation, it is found that non-null cross-polarization is due to non-symmetric circular-to-rectangular transition. As per Fig. 1*a*, the reference for CMM (co-ordinate measuring machine) [15]-[16] is radius = 0 and length = 0, that is $(x,y) = (0,0)$. A coordinate measuring machine (CMM) is a instrument for measuring the physical dimensions of a horn antenna or some other mechanical structure. CMM may be manually controlled by a machinist or it may be computer controlled. Measurements are done by a probe attached to the third moving axis of the CMM. Probes may be mechanical or laser. CMM takes readings in six degrees of freedom and displays these readings in mathematical form. Figures and more details can be found in reference [15]-[16]. To perform the diagnostics, we go through the following steps: By CMM, ellipticity of corrugation, co-centricity of each corrugation, various dimensions of corrugation, etc. are measured and by analysis in HFSS, it is found they are not affecting depolarization in the horn pattern. Next by a detailed measurement of the circular-to-rectangular transition, it is found that the center of the rectangular end of transition is offset by 0.2 mm with respect to the circular end. The level of measured cross-polarization at boresight is -29.7 dB. For cross-polarization peak equal to -29.7 dB at boresight, polarization angle works out to be 1.87° and the corresponding pattern is shown in Fig. 3*b*. This polarization rotation is due to asymmetry present in transition which is verified by its CMM measurement. It can be seen in Fig. 4*b*, by improved fabrication of the transition, the level of non-null cross-polarization can be minimized significantly.



(a)

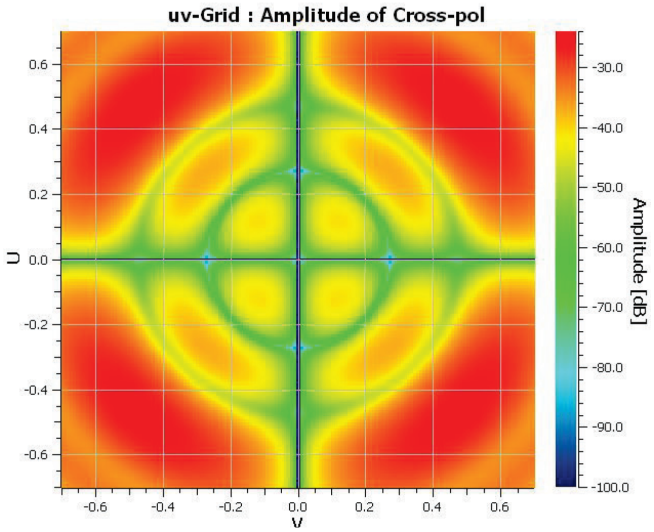


(b)

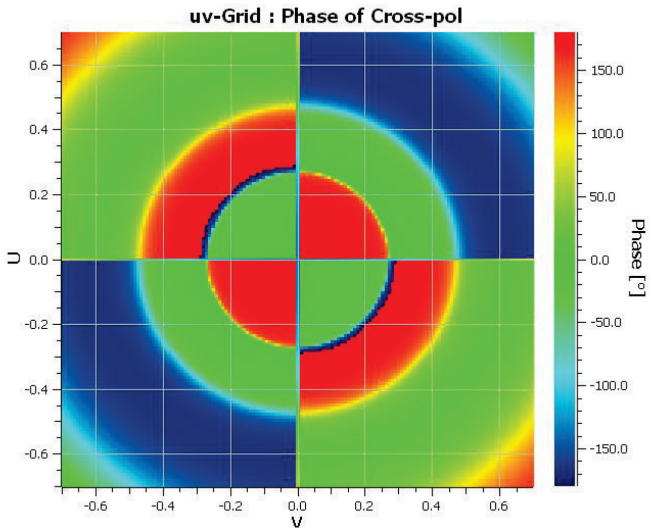
Fig. 4. Measured pattern of hybrid horn antenna: (a) with transition with significant asymmetry, (b) with new transition having very small asymmetry

A new circular-to-rectangular transition is fabricated by minimizing asymmetry in its longitudinal profile. A significantly better cross-polarization of -40 dB is achieved instead of the previously obtained level of -29.7 dB. The radiation pattern of the horn antenna with the new transition is shown in Fig. 4*b*.

Fig. 5 depicts amplitude and phase pattern of the far field of Ku-Tx Hybrid Horn antenna without depolarization due to asymmetry in rectangular to circular transition. We can observe phase in four quadrants are 180° out of phase with each other hence lower cross-polar level is achieved. The cross-pol at bore-sight is very low and has peak in four quadrants.



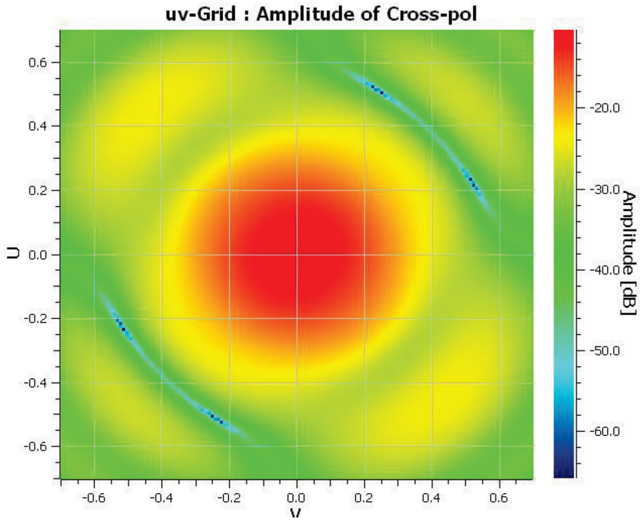
(a) Amplitude pattern



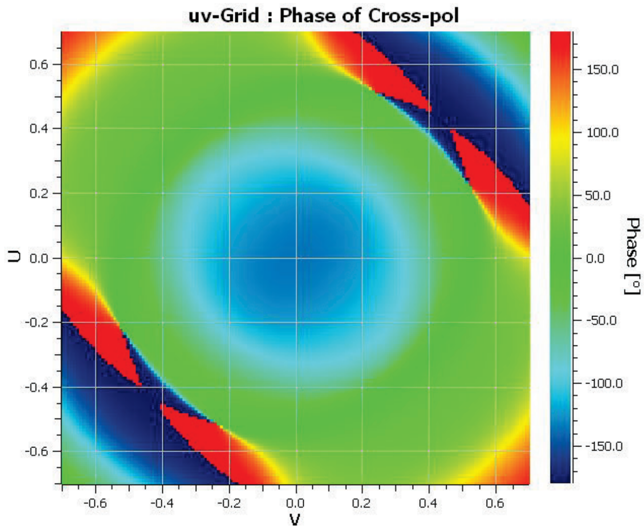
(b) phase pattern

Fig. 5. Amplitude and Phase of Cross-pol of Regular Horn antenna

Fig. 6 shows amplitude and phase pattern of the far field of Ku-Tx Hybrid Horn antenna with depolarization due to asymmetry in the transition. We can observe phase in four quadrants are not out of phase with each other hence poor cross-polar level is achieved. The cross-pol at bore-sight has peak value.



(a) Amplitude pattern



(b) phase pattern

Fig. 6. Amplitude and Phase of Cross-pol of depolarized Horn antenna

Next we measure S_{21} parameter of circular to rectangular transition in back to back configuration with 90º rotation. Circular port of both transitions are kept in contact with each other. Waveguide to coax adapters are connected at both rectangular ports. S_{21} parameter is measured with help of R&S Vector Network Analyzer (VNA). Thus the width of rectangular port of one transition remains with parallel with height of rectangular port of second transition. Rectangular Port 1 is excited with TE_{11} mode. Therefore, S_{21} is measure of cross-pol generation of at rectangular port 2 due to asymmetry in transition. In first case, both good circular to rectangular transitions are connected in back to back and S-parameters are measured using VNA. In this case, cross-pol is better than -45 dB. In second case, one good circular to rectangular transition and one faulty circular to rectangular transition (having asymmetry) are connected in back to back and S-parameters are measured using VNA. In second case, cross-pol is better than -31 dB. The measured cross-pol are compared in Fig. 7. When faulty transition is connected with horn antenna and pattern is measured in anechoic chamber the cross-pol of primary pattern is -29.7 dB and shown in Fig. 4*a*. When good circular to rectangular transition is connected with horn antenna and pattern is measured in anechoic chamber the cross-pol of primary pattern is -40 dB and shown in Fig. 4*b*.

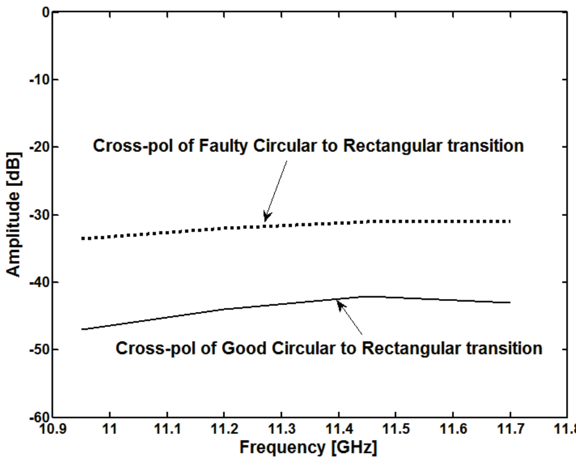


Fig. 7. Cross-pol of circular to rectangular transition

IV. Conclusion

A new hybrid horn antenna is designed and developed by combination of stepped, axial and radial corrugation section. Due to imperfect fabrication of a circular-to-rectangular transition, polarization rotation may occur, particularly at Ku- or higher bands. Consequently, a de-polarization phenomenon is observed resulting in non-null on-axis cross-polar pattern during measurements. By improved fabrication of the transition, the level of non-null cross-polarization can be minimized significantly.

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