Progress In Electromagnetics Research C, Vol. 24, 197–206, 2011

DESIGN OF BROADBAND CIRCULAR POLARIZATION TRUNCATED HORN ANTENNA WITH SINGLE FEED

T. H. Gan* and E. L. Tan

School of EEE, Nanyang Technological University, Nanyang Avenue 639798, Singapore

Abstract—This paper presents the design of a broadband circular polarization truncated horn antenna with single feed. It does not require any complex feeding structure and uses only a coaxial feed extended with a simple electric field coupling probe. The corners of the horn are truncated to generate circular polarization modes, and a broad axial ratio bandwidth which is insensitive to the probe feed dimension is achieved. Simulated and measured results of an S band truncated horn antenna are presented. The antenna has a broad 3 dB axial ratio bandwidth of 26% with aperture efficiency of 60%.

1. INTRODUCTION

Circular polarization (CP) antennas are preferred for satellite applications as they yield higher probability of communication link. For such long distance communication, horn antennas are commonly used as feeds for high gain reflector antennas. In most cases, horn antennas with single feed are of linear polarization [1], whereas dual linear horn antennas [2, 3] with dual feeds and 90° hybrids are required to radiate CP. However, the performance of dual linear horn antennas such as the ridged horn antenna suffers from manufacturing and assembling tolerances [4].

In [5], an L-shaped probe can be used to generate CP with about 20% 3 dB axial ratio bandwidth. However, the axial ratio is sensitive to the probe dimension and the antenna must be fed by a coaxial line. In [6], a coaxial to waveguide adapter that generates CP was designed using polarization twisting and phasing structure. However, the 3 dB axial ratio bandwidth is only 5%. Orthomode transducer (OMT) can

Received 25 August 2011, Accepted 30 September 2011, Scheduled 6 October 2011
* Corresponding author: Theng Huat Gan (gant0008@ntu.edu.sg).

be integrated into dielectric load horns to generate CP [7]. It has dual band and dual polarization capabilities. But such design requires phase shifter, hybrid and power dividers. In [8], mode converting antenna that generates CP from coaxial transverse electromagnetic modes was designed. The structure is complicated as metal plates need to be inserted into the coaxial waveguide to obtain the CP modes. In [9], an oval shape waveguide polarizer was fed into a pyramidal horn antenna and a 3 dB axial ratio bandwidth of 18% was obtained Note that the cross section dimensions of the polarizer and horn antenna at the transition are different and they must be impedance matched to minimize the generation of higher order modes.

In this paper, we present the design of a broadband CP truncated horn antenna with single feed. It does not require any complex feeding structure and uses only a coaxial feed extended with a simple electric field coupling probe. The corners of the horn are truncated to generate CP modes, and a broad axial ratio bandwidth which is insensitive to the probe feed dimension is achieved. Simulated and measured results of an S band truncated horn antenna are presented. The designed antenna has a measured 3 dB axial ratio of 26% with aperture efficiency of 60%. All simulations are carried out using HFSS [10].

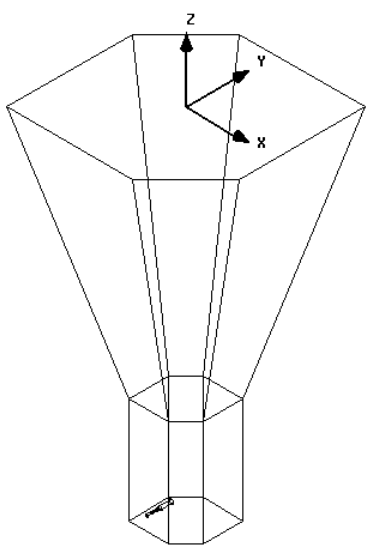


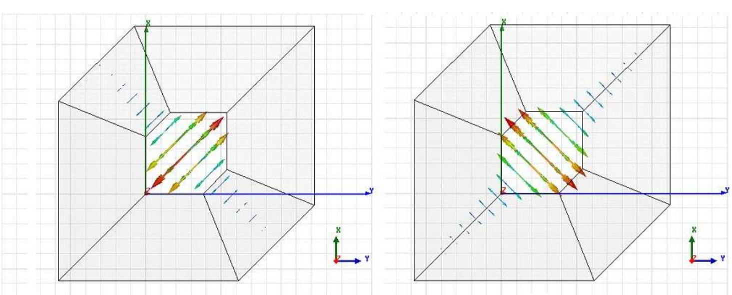
Figure 1. Geometry of truncated horn antenna.

2. DESIGN OF TRUNCATED HORN ANTENNA

Figure 1 shows the geometry of the truncated horn antenna. It consists of a feeding waveguide and an aperture section. The feed waveguide is a square waveguide with truncated corners. It functions as an integrated cut corners waveguide polarizer which is flared open linearly to obtain higher radiation gain. The input is a coaxial feed extended with a simple electric field coupling probe. The cross section of the truncated horn antenna is similar to a single feed truncated microstrip antenna [11–13].

A square microstrip antenna can be modeled using a cavity model with magnetic side walls resonating TM mode [14]. Meanwhile, a square waveguide can be modeled using a cavity model resonating TE mode with electric side walls. The two cavity models are dual and the basic operating principles of the truncated microstrip [15] can be used to describe the truncated horn antenna. The truncation of the corner of a square waveguide generates two orthogonal degenerate modes with cutoff frequencies given by [16]. The phase difference of these two orthogonal modes is adjusted to 90° by properly selecting the truncation of the corners. The sense of the CP depends on which corners are truncated relative to the probe. The probe couples energy into the feed waveguide and is not involved in generating the degenerate modes as the modes are generated by the geometry of the truncated horn antenna.

Figure 2 shows the electric field vectors of the degenerate modes in x-y plane at the base of truncated horn antenna. The electric field vectors in Figure 2(a) are directed in $+45°$ while the electric field vectors in Figure 2(b) are directed in $-45°$. These two modes



(a) (b)

Figure 2. Electric field vectors of the degenerate modes in x-y plane at the base of truncated horn antenna. (a) $E_{\|}$ mode. (b) $E_{\perp}$ mode.

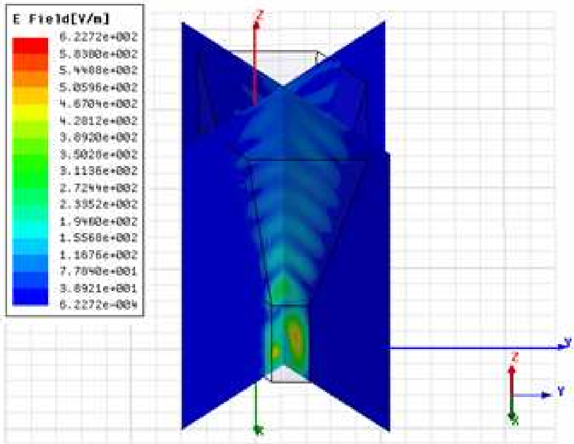


Figure 3. Magnitude of electric fields along the diagonals of the truncated horn antenna ($\phi = \pm 45°$).

are orthogonal and directed along the diagonals. The magnitude of the electric fields along the diagonals of the truncated horn antenna ($\phi = \pm 45°$) is shown in Figure 3. The regions of high electric field intensity along the two cuts are 90° out of phase. Therefore, along the feed waveguide, the two degenerate modes are orthogonal and 90° out of phase. This forms the CP modes which will propagate towards the horn aperture and radiates CP.

As mentioned above, the feed waveguide is a square waveguide with truncated corners. Its dimensions (before and after truncation) can be determined using the Q factor. The fractional bandwidth ($\mathrm{BW}_{\mathrm{fractional}}$) of the square waveguide is used to estimate the Q factor [15]

$$Q = \frac{\mathrm{VSWR} - 1}{\mathrm{BW}_{\mathrm{fractional}} \times \sqrt{\mathrm{VSWR}}} \tag{1}$$

A square waveguide is symmetrical in the transverse plane and will propagate TE_{10} and TE_{01} modes concurrently. The higher order modes of TE_{20}, TE_{02}, TE_{11} and TM_{11} will be able to propagate at $2f_c$, where f_c is the cutoff frequency of the dominant mode. Thus the theoretical fractional bandwidth for the dominant mode is approximately 66%. Using (1), the Q factor is 1.07 when the $\mathrm{BW}_{\mathrm{fractional}}$ is 0.66 and the Voltage Standing Wave Ratio (VSWR) is 2.

Figure 4 shows the top view of the truncated horn antenna in terms of A_w, B_w, A_a and B_a. A is the width of the waveguide after truncation and B is the width of the square waveguide (before

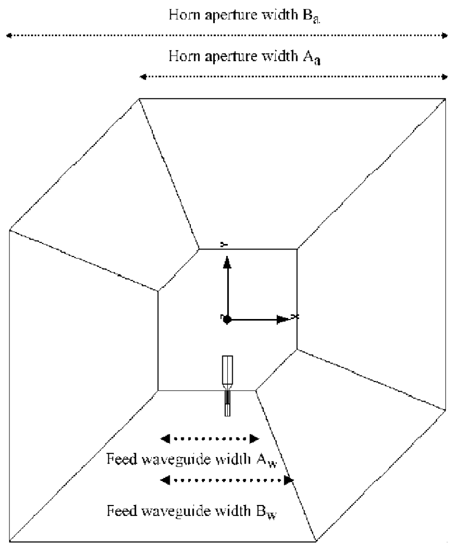


Figure 4. Top view of truncated horn antenna in terms of A_w, B_w, A_a and B_a. The single electric field coupling probe is fed along the y-axis.

truncation). Subscript "w" denotes the feed waveguide while subscript "a" denotes the truncated horn antenna aperture. Referring to the figure, the single electric field coupling probe is fed along the y-axis and is of Type A [12]. The dimension for A_w and B_w can be approximated using:

$$\frac{B_w}{A_w} = 1 + \frac{1}{2Q} \tag{2}$$

Equation (2) can be obtained by substituting Q with $2Q$ in the Type B formula [17] as it is known that the relative change in area $(\frac{\Delta S}{S})$ for Type B is twice of Type A when Q is fixed. Note that for the truncated horn antenna, good CP performance is not obtained using the original Type A formula [18].

The gain of truncated horn antenna is increased by linearly flaring the feed waveguide A_w and B_w to a larger opening A_a and B_a. The peak gain required determines the aperture area. The flare angle is chosen to obtain the optimum phase deviation on the aperture surface. The normalized directivity curve of the electric plane sectoral horn is used to obtain the flare angle [19]. The electric field coupling probe is approximately $\frac{\lambda_g}{4}$ from the short circuit wall and it is used to excite the waveguide modes. The diameter and height of the probe can be varied to obtain a good impedance match.

3. SIMULATED AND MEASURED RESULTS

An S band Right Hand Circular Polarization (RHCP) truncated horn antenna was designed and simulated using HFSS. The antenna

Table 1. Dimensions of S band truncated horn antenna (in millimeters).

Feed waveguide width A_w	76
Feed waveguide width B_w	108
Feed waveguide length	200
Horn aperture width A_a	239
Horn aperture width B_a	339
Horn flare length	493
Probe diameter	7.6
Probe height	27
Probe distance from wall	45

Figure 5. Fabricated truncated horn antenna.

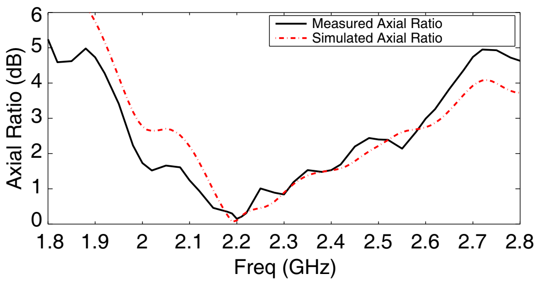


Figure 6. Simulated and measured axial ratio in the boresight direction.

dimensions are provided in Table 1. The photograph of the fabricated truncated horn antenna is shown in Figure 5.

The radiation pattern of the truncated horn antenna is measured in an anechoic chamber and its S_{11} is measured by a vector network analyzer Anritsu 37347A. Figure 6 shows the simulated and measured axial ratio in the boresight direction. The measured axial ratio is better than 3 dB from 2.0 GHz to 2.6 GHz, thus the 3 dB axial ratio bandwidth is 26%.

By performing some simulations, we find that the 3 dB axial ratio bandwidth does not change significantly when the diameter of the electric field coupling probe is varied from 1.3 mm to 16 mm. Similar observation is found when the height of the electric field coupling probe is increased to 54 mm. This shows that the 3 dB axial ratio bandwidth is insensitive to the probe feed dimension.

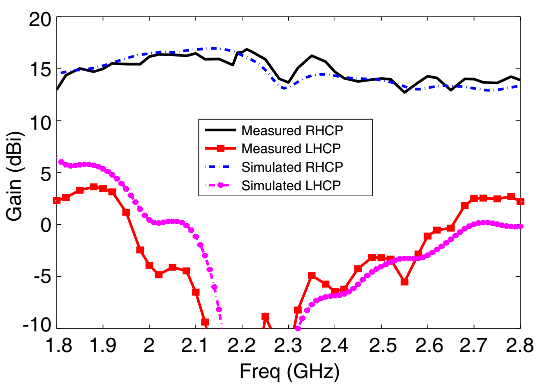


Figure 7. Simulated and measured gain in the boresight direction.

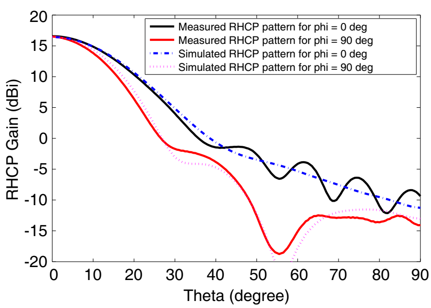


Figure 8. Simulated and measured RHCP gain pattern at 2.2 GHz.

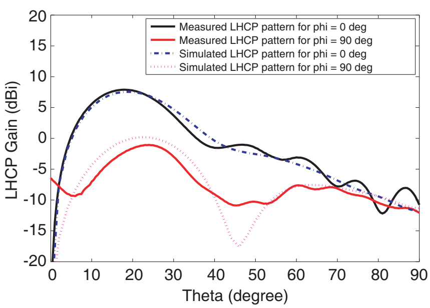


Figure 9. Simulated and measured LHCP gain pattern at 2.2 GHz.

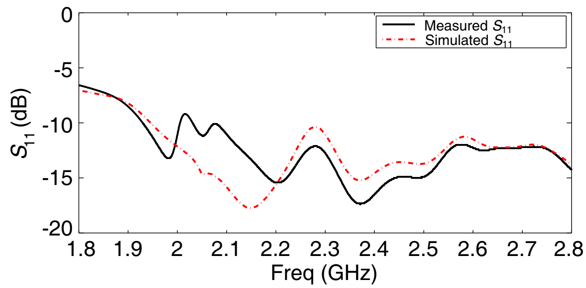


Figure 10. Simulated and measured S_{11} (dB) response.

Figure 7 presents the simulated and measured gain in the boresight direction. The RHCP gain is about 14 dBi to 16 dBi within the 3 dB axial ratio bandwidth. The simulated and measured RHCP and LHCP gain pattern is shown in Figures 8 and 9. Referring to Figure 8, the measured peak RHCP gain at 2.2 GHz is 16.58 dBi, thus the aperture efficiency is 60%. The simulated and measured S_{11} (dB) response is shown in Figure 10. It is better than -10 dB from 2.05 GHz to 2.80 GHz.

4. CONCLUSION

In this paper, the design of a broadband CP truncated horn antenna has been presented. It does not require any complex feeding structure and uses only a coaxial feed extended with a simple electric field coupling probe. The corners of the horn have been truncated to generate the CP modes, and a broad axial ratio bandwidth which is insensitive to the probe feed dimension has been achieved.

An S band truncated horn antenna has been designed, simulated, fabricated and measured. It has a bandwidth of 2.0 GHz to 2.6 GHz and may be used for Tracking, Telemetry and Command (TT&C) in satellite communications. The measured 3 dB axial ratio bandwidth is 26% with aperture efficiency of 60%. A circulator can be connected to the horn to separate the uplink (2.025 GHz to 2.110 GHz) and downlink (2.20 GHz to 2.29 GHz) signals. By using a waveguide transition, the truncated horn antenna may be fed from a rectangular waveguide TE_{10} mode to handle higher input power.

ACKNOWLEDGMENT

The authors would like to thank Sing Who Chee of DSO National Laboratories for his assistance in the fabrication and measurement of the antenna.

REFERENCES

1. Olver, A. D., P. J. B. Clarricoats, A. A. Kishk, and L. Shafai, *Microwave Horns and Feeds*, IEEE Press, London, New York, 1994.
2. Ononchimeg, S., G. Otgonbaatar, J.-H. Bang, and B.-C. Ahn, "A new dual-polarized horn antenna excited by a gap-FED square patch," *Progress In Electromagnetics Research Letters*, Vol. 21, 129–137, 2011.
3. Dehdasht-Heydari, R., H. R. Hassani, and A. R. Mallahzadeh, "A new 2–18 GHz quad-ridged horn antenna," *Progress In Electromagnetics Research*, Vol. 81, 183–195, 2008.
4. Jacobs, B., J. W. Odendaal, and J. Joubert, "The effect of manufacturing and assembling tolerances on the performance of double-ridged horn antennas," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 10, 1279–1290, 2010.
5. Fukusako, T. and L. Shafai, "Design of broadband circularly polarized horn antenna using an L-shaped probe," *IEEE Antennas and Propagation Society International Symposium 2006*, 3161–3164, 2006.
6. Jeon, K. J., K. J. Lee, T. K. Lee, J. W. Lee, and K. W. Lee, "Circular polarization generating coaxial to waveguide adapter for horn antenna," *Proceedings of the Fourth European Conference, Antennas and Propagation (EuCap)*, 2010.
7. Zhang, Z. H., "An integrated coaxial circular polarized OMJ/OMT for dual band application," *IEEE Antennas and Propagation Society International Symposium 2005*, Vol. 2a, 647–650, 2005.
8. Yuan, C. W., Q. X. Liu, H. H. Zhong, B. L. Qian and Z. Q. Li, "Circularly polarized mode-converting antenna," *Electronics Lett.*, Vol. 42, No. 3, Feb. 2006.
9. Jung, Y. B., "Ka-band polarizer structure and its antenna application," *Electronics Lett.*, Vol. 45, No. 18, Aug. 2009.
10. ANSYS inc., High Frequency Structure Simulator.

11. Richards, W. F., Y. T. Lo, and D. D. Harrison, "An improved theory for microstrip antennas and applications," *IEEE Trans. Antennas Propag.*, Vol. 29, No. 1, 38–46, Jan. 1981.
12. Yang, S. S., K.-F. Lee, A. A. Kishk, and K.-M. Luk, "Design and study of wideband single feed circularly polarized microstrip antennas," *Progress In Electromagnetics Research*, Vol. 80, 45–61, 2008.
13. Ooi, T. S., S. K. A. Rahim, and B. P. Koh, "2.45 GHz and 5.8 GHz compact dual-band circularly polarized patch antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 24, Nos. 11–12, 1473–1482, 2010.
14. Lo, Y. T., D. Solomon, and W. F. Richards, "Theory and experiment on microstrip antenna," *IEEE Trans. Antennas Propag.*, Vol. 27, No. 2, 137–145, Mar. 1979.
15. Carver, K. R. and J. W. Mink, "Microstrip antenna technology," *IEEE Trans. Antennas Propag.*, Vol. 29, No. 1, 2–24, Jan. 1981.
16. Levy, R., "The relationship between dual mode cavity cross-coupling and waveguide polarizers," *IEEE Trans. Microwave Theory Tech.*, Vol. 43, No. 11, 2614–2620, Nov. 1995.
17. Milligan, T. A., *Modern Antenna Design*, 2nd edition, John Wiley and Sons, New Jersey, 2005.
18. James, J. R. and P. S. Hall, *Handbook of Microstrip Antennas*, Peter Peregrinus Ltd., 1989.
19. Balanis, C. A., *Antenna Theory — Analysis and Design*, 3rd edition, John Wiley and Sons, New Jersey, 2005.