Design and Implementation of THz Ultra Gaussian Corrugated Feed Horn

Yuan Yao*[1], Yonghui Cao[1], Ying Liu[1], Junsheng Yu[1], and Xiaodong Chen[1],

[1]School of Electronic Engineering, Beijing University of Posts and Telecommunications.
No.10 Xitucheng Road, Haidian District, Beijing, China.
yaoy@bupt.edu.cn

Abstract

A novel THz Ultra Gaussian corrugated feed horn is proposed in this paper, which combines a sine-squared and a straight parallel profile to excite and couple the HE_{11} and HE_{12} modes at the optimum range of inputs. The center frequency is 0.34THz and the bandwidth is larger than 10%. The maximum fundamental mode Gaussian power coupling efficiency increases to approximately 99.8% in this design. Typically, this corrugated feed horn achieves sidelobe and cross-polar levels around -37 dB and -50 dB. Both the simulation and measurement results are given to illustrate the performance of the proposed horn. The measured results meet the simulated results very well.

1. Introduction

The sub-millimeter and THz spectrums are promising bands. Many applications in this band such as security imaging, antenna measurement, beam transport and control require antennas with high directivity, low return loss, wide bandwidth high polarization purity and low sidelobe levels [1]. It is well known that a corrugated horn has low cross polarization (typically about 25 dB or less) and a symmetric radiation pattern [2]. Corrugated horn antennas are frequently used as the feed elements in ground-based reflector antennas for satellite and deep space communications [3]. Nowadays the design and performance of corrugated horns can be analyzed accurately with the help of horn analysis software for every single corrugation. The horn analysis software can help us calculate the co-polar and cross-polar beam patterns to evaluate our design strategies [4].

The paper [5] presented the Gaussian beam-mode analysis of the operation of a corrugated feed horn. An analytical expression for the position of the phase center is derived and the coupling between two horns is calculated. Almost 98% of the power is carried in the fundamental Gaussian mode. However, some high performance antenna systems require higher performance horns, so the higher order HE_{1n} modes and higher order Gaussian modes need to be taken into account since they can have very significant effects. The energy in these higher order modes is usually responsible for the sidelobe and cross-polar levels of the far-field pattern of the horn antenna and they can cause resonances in the frequency response of low loss quasi-optical systems. Typically, the linearly tapered design achieves sidelobe and cross-polar levels around -27 dB and -30 dB, respectively, which is insufficient for some high performance applications.

This paper proposed a dual profile horn instead of the single linear profile design. The dual profile is consisted of a sine-squared profile with a straight parallel section. The maximum fundamental mode Gaussian power coupling efficiency increases from 98.1% for HE_{11} only, to 99.8% for $HE_{11} + HE_{12}$ using this kind of structure. And the sidelobe and cross-polar levels is around -37dB and -50dB in this design.

2. Horn Design

The structure of the proposed THz Ultra Gaussian corrugated feed horn is shown in Fig. 1.

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

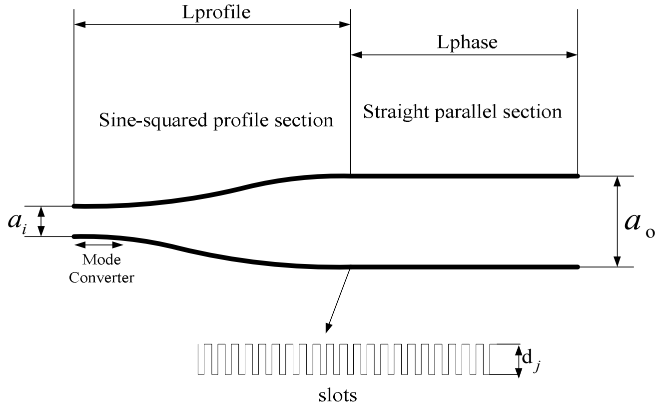


Fig.1. New sine-squared/parallel corrugated horn profile

It uses a sine-squared profile to reach the desired aperture radius a_0. The overall length of this profile section, $L_{profile}$, is chosen to excite the required HE_{11} and HE_{12} amplitudes for optimum coupling to a fundamental Gaussian. The sine-squared a(z) profile is given by (1):

$$a(z)=a_i+(a_0-a_i)[(1-A)\frac{z}{L_{profile}}+A\sin^{\rho}(\frac{\pi}{2}\frac{z}{L_{profile}})] \tag{1}$$

Where a_i is the aperture radius at the throat and a_o is the radius at the aperture. The parameter $L_{profile}$ is the length of the sine-squared profile section, and where z is a local coordinate along the horn axis, with z = 0 at the input and z = L at the output. Furthermore, the parameter A is an adjustable parameter weighting between the linear. A typical profile with A = 0.7 would have a length L of around $2.4a_0^2/\lambda_0$ where λ_0 is the free-space wavelength. And the parameter ρ is a real-valued exponent in the range from 0.5 to 5 which is 2 in this design.

The HE11 and HE12 modes will not be in phase at sine-squared profile point and will generally produce a poor antenna pattern with axial nulls in the near field. However, by adding a straight section of corrugated guide to the profiled horn can brought back these modes into phase without exciting any additional modes. The required overall length of this phasing section, L_{phase} depends on the relative phase velocities of the HE11 and HE 12 modes, and the original phase mismatch. The detailed parameter for the Gaussian corrugated feed horn design is given in Table.1. To validate the performance of the corrugated feed horn design, a prototype was fabricated and the photo of the prototype is shown in Fig. 2.

The mode converter is variable-depth-slot type [6]. It is consisted by 6 slots at the throat. The depth of the jth slot d_j in the sine-squared section and straight parallel section can be calculated by (2):

$$d_j=\exp(\frac{4\lambda_c}{2.114(k_c a(z))^{1.134}}) \tag{2}$$

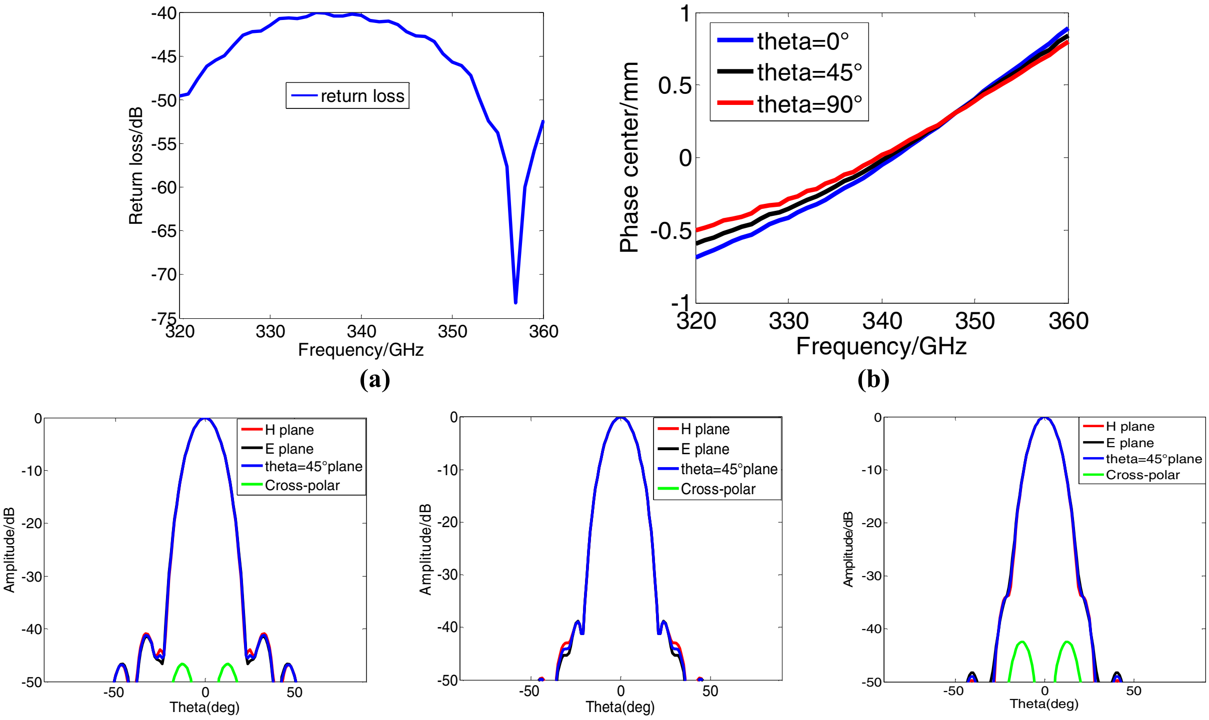
Table.1. The parameters for the Gassian corrugated feed horn

Length of profile section	19.1mm	Total Number of slots	201
Length of phase section	16.3mm	Number of slots in profile section	108
Input radius	0.4mm	Width to pitch ratio	0.72
Output radius	2.7mm	Slot depth in phase section	0.22mm

Fig.2. Fabricated corrugated horn

3. Simulation and Measurement Results

The simulation results of the corrugated feed horn was carried out via CHAMP, which is a general software tool for design and analysis of a rotationally symmetric feed horn possibly illuminating rotationally symmetric reflectors and scattering structures. To verify the performance of Ultra Gaussian Horns, the far field measurement was carried out to evaluate the co-polar pattern of the horns. Fig.3 shows the simulated results of the corrugated horn.



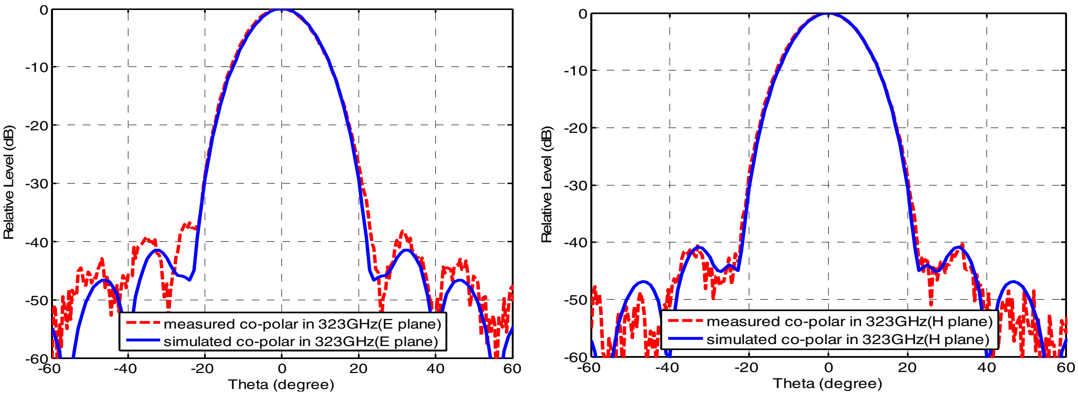
(a) **(b)**

(c) **(d)** **(e)**

Fig.3. Simulated results of the corrugated horn: (a) return loss (b) phase center (c) radiation pattern in 323GHz (d) radiation pattern in 340GHz (e) radiation pattern in 357GHz

Fig.3 shows the return loss of the horn is under -40dB from 323GHz to 357GHz, the phase center deviation is less than 0.1mm in 340GHz when θ=0° , θ=45° and θ=90° , the sidelobe levels are -38.8dB, -37.1dB, -35.8dB in 323GHz, 340GHz and 357GHz, and the cross-polarization levels are -45.4dB, -52.9dB, -52.9dB, respectively.

Because there is no appropriate signal source, the horn is tested at 323GHz. The testing result is shown in Fig.4.



(a) **(b)**

Fig. 4. The test and simulation results of the 323GH: (a)E plane results (b)H plane results

Fig.4 compares the measured and simulated co-polar in 323GHz in E plane and H plane. Considering the measurement error, the correspondence between the measured results and the simulated results is very well, especially the main lobe. The performance of these ultra gaussian horns is impressive.

4. Conclusion

A novel THz Ultra Gaussian corrugated horn was simulated in CHAMP. A prototype of the corrugated feed horn was fabricated successfully. Both the simulated and measured results demonstrate that the corrugated horn which combines a sine-squared and a straight parallel tapered internal profile achieves better sidelobe and cross-polar levels.

5. Acknowledgments

This work was supported by the CAEP THz Science and Technology Foundation under the Grant No.CAEPTHZ201210.

6. References

[1] Schwerthoeffer, U. and Adel, H., “Design and implementation of a Ka-band corrugated feed horn for reflector antennas,” IEEE Antennas and Propagation Society International Symposium, 2013, pp.396-397.

[2] Kenneth Browne, Chi-Chih Chen and Walter D. Burnside, “A novel design of a miniature wideband corrugated horn Antenna employing unique sinusoidal shaped ridges,” IEEE Antennas and Propagation Society International Symposium, 2008, pp. 1-4.

[3] Jamnejad, V. and Hoorfar, A., “Design of corrugated horn antennas by evolutionary optimization techniques,” *IEEE Antennas and Wireless Propagation Letters*, vol. 3, 2004, pp. 276-279.

[4] Johannes E. McKay, Duncan A. Robertson, Paul A.S. Cruickshank, Robert I. Hunter, David R. Bolton, Richard J. Wylde and Graham M. Smith, “Compact wideband corrugated feedhorns with ultra-low sidelobes for very high performance antennas and quasi-optical systems,” *IEEE Transactions on Antennas and Propagation*, vol. 61, 2013, pp. 1714-1721.

[5] R. J. Wylde, “Millimetre-wave Gaussian beam-mode optics and corrugated feed horns,” *IEE Proceedings-H: Microwaves, Antennas and Propagation*, vol. 131, no. 4, 1984, pp. 258–262.

[6] Granet, C and James, Graeme L., “Design of corrugated horns: a primer,” *IEEE Antennas and Propagation Magazine*, vol. 47, 2005, pp. 76-84.