Design of a Ka-band HE_{11} Mode Corrugated Horn for the Faraday Rotator

Fang Li*, Guo Liu, Li Wang and Yong Luo

School of Physical Electronics, University of Electronic Science and Technology of China,

Chengdu, Sichuan, 610054, China,

* Contact: 201421040332@std.uestc.edu.cn

Abstract—**Faraday rotator is an important components used as isolator in transmission line of millimeter wave radar system. To verify the property of faraday rotator for the application, a microwave measurement is required, which needs a HE_{11} motivation mode. In this paper, a short Ka-band HE_{11} mode corrugated horn for faraday rotator was designed and simulated. This corrugated horn converts a TE_{11} mode into HE_{11} mode in Ka-band with a reflection under -28 dB and a HE_{11} mode conversion efficiency of above 99%. In addition, the mode conversion contents closes to desired HE_{11} mode over a bandwidth of 4 GHz. The length of this corrugated horn is 44mm and the input radius is 6mm, and has produced a well-formed lineal polarized HE_{11} mode. In addition to exhibiting a high converter and broad bandwidth, this corrugated horn is short and simple for microwave measurement.**

INTRODUCTION

A gyro-TWT (gyrotron traveling wave tube) [1] is strong attractive coherent radiation source in millimeter wavelength rage for its perfect characteristics of high peak power, high gain, and high efficiency, which are suited to many applications such as high resolution radar, communication system, military electronic countermeasure systems and space research. However, Gyro-TWT as a radiation source may be destroyed by the reflection caused by load mismatching or environment changing, which needs to be isolated effectively. Faraday rotator [2] as nonreciprocal component is widely used to make isolators and circulators in the transmission line to solve this problem with its property of making the linearly polarized plane wave in propagation has a non-reciprocal rotation. In contrast to waveguide isolator, faraday rotator has many advantages such low insertion loss, high isolation and high power handing capabilities. Since 1980s, many faraday rotators based on ferrite were proposed including transmission-type and reflection-type. Transmission-type obtains broader bandwidths while reflection-type can get lower insertion loss and higher power handing capability with reduced thickness of ferrite plate.

In order to characterize the rotation of faraday rotator before high power testing, a low power microwave measurement should be performed, where HE_{11} excitation mode is essential, which possesses perfect linear polarization with very low side-lobe and cross-polarization, and 98% of whose power concentrated on the main lobe. In microwave measurement system, the HE_{11} mode can be generated from TE_{10} via the mode conversion sequence: TE_{10}–TE_{11}–HE_{11}. A lot of TE_{11}-HE_{11} mode converter have been analyzed and developed for several decades. Some employ circumferentially corrugated waveguide [3], the HE_{11} mode purity was 99%, the cross-polarization and reflection were below -29dB and -50dB. Some employ smooth-walled horn which can be relatively easier to fabricate with approximates properties of main beam efficiency, cross-polarization response and beam symmetry. Others employ profiled corrugated horn with the sine squared, exponential profile or dual profile, which had shown to meet electrical requirements typical of radio astronomy application with more compact structure. And the dual profile corrugated horn will be studied in this paper for microwave measurement of faraday rotator.

In this paper, measurement and corrugated horn design are given in Sec.2, modeling and simulation results are given in Sec.3. A brief conclusion about this paper is given in Sec.4.

DESIGN OF MEASUREMENT SYSTEM AND CORRUGATED HORN FOR FARADAY ROTATOR

A. Microwave Measurement System Designing

Fig.1 showed microwave measurement system of faraday rotator. The output signal from vector network analyzer (VNA) through a sequence of mode converter becomes a HE_{11} mode and radiated. The polarization filter on each side of the faraday rotator are set at 45° to the axis, and it passes a wave with its polarization perpendicular to the wires and reflect the parallel polarization. The vertical axis of polarization is first rotated 45° clockwise as it passes through the faraday rotator. After reflection, it undergoes an additional 45° rotation by the nonreciprocal property of the faraday rotator and is then deflected by the wire-grid polarization filter. Thus transmission path is port 1 to port 2 or port 2 to port 1 with the reflection been isolated [4, 5].

As in the microwave measurement system, two ports of VNA is not a standard waveguide, a coaxial-waveguide is required to convert the coaxial to standard waveguide, which works on TE_{10} mode. And the HE_{11} mode can be generated from TE_{10} via the mode conversion sequence: TE_{10}–TE_{11}–HE_{11}. Using the TE_{11} mode as polarized intermediate mode as it has the advantage that all converters can be made without bends. TE_{10}-TE_{11} mode converter is realized by a square-to-circle waveguide which is coaxial. The length of TE_{10}-TE_{11} mode converter is several waveguide wavelength and can get a wide bandwidth. The input size of TE_{10}-TE_{11} mode converter is a standard rectangle waveguide (W22) at Ka-band. The output radius of TE_{10}-TE_{11} mode converter should agree with the input radius of TE_{11}-HE_{11} corrugated horn, so that the different components can be connected without space and eliminate the reflection.

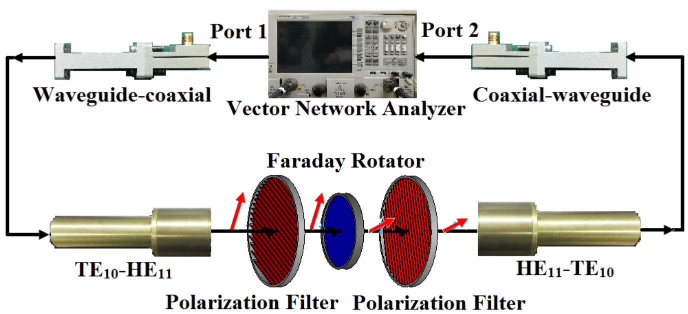

Fig. 1 Design of the microwave measurement system for faraday rotator

B. Corrugated Horn for Faraday Rotator

A corrugated horn with excellent performance in our application possesses low reflection, desired mode contents, and high conversion efficiency in a wide frequency. In addition, it should be compact, easily fabricated and convenient for microwave measurement. In our design, the TE_{11}-HE_{11} corrugated horn is achieved by a double-profiled circular waveguide, which was circumferentially corrugated. Conversely, the HE_{11} mode can be converted to TE_{11} mode by use this spline-profile corrugated horn in the opposite direction, which can be used as receiving components. In some application, a pure sin squared profile, compact horns with overall dimensions about two-thirds those of the original linear horn. Double-profiled corrugated horn can make the size more compact, and the amount of excitation of hybrid modes depends on the position of the point connecting. In this article, two different profiles (shown in eq.1) was connected. At the connecting point, the derivative of these two profiles are 0. In this way, the two profile can realize transition smoothly without break, and it can eliminate the wave reflection because of the mismatch. This connecting point L_1 in this article is $L/2$, and the total length of corrugated horn is 44mm. The slot depth is gradually changed from a half of wavelength to a quarter of wavelength to make the impedance matched. The profile $R(z)$ (shown in Fig. 2 (a)) of the circular waveguide are as follows:

$$R(z)=\begin{cases} R_{in}\sqrt{1+\left(\dfrac{z}{1.3\cdot k_0\cdot R_{in}^2}\right)^2} & 0\le Z\le L_1 \\ 2R_a-R_{in}\sqrt{1+\left(\dfrac{L-z}{1.3\cdot k_0\cdot R_{in}^2}\right)^2} & L_1\le Z\le L \end{cases} \qquad (1)$$

Where k is the free space wave number, L is the total length of the horn, R_{in} is the input radius, R_a is the first profile's output radius.

Besides, the depth d, period p and duty ratio (r) of corrugated are very important parameters for the corrugated horn. In this paper, the depth varied from a half of wavelength to a quarter of wavelength, which satisfied the law shown in eq. 2. The period is chosen as $\lambda_0/3$ and the duty cycle equals to half of period. The output radius of corrugated horn is 8mm and operates at the frequency of 34 GHz. The structure along the axis shows in Fig. 2 (b).

$$d(z)=\frac{\lambda}{2}-\left(\frac{\lambda}{4}\right)^N \qquad (2)$$

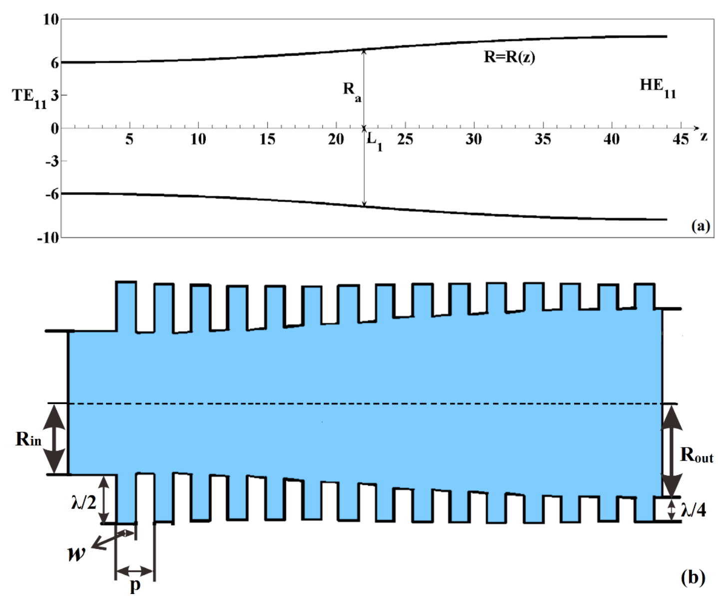

Fig. 2 Geometry and profile of the corrugated horn. (a) Inner diameter R(z) of the waveguide (b)The cross-section of corrugated horn along the axis.

SIMULATION

The structure parameters were set, optimized and verified by the CST MWS (CST Microwave Studio). It was found in the simulation that this double-profile corrugated horn was able to meet requirements in mode conversion efficiency, desired mode contents, and a lineal polarization, which was important for microwave measurement. Simulated mode contents, desired mode contents and conversion efficiency of corrugated horn is shown in Fig .4. The normalized powers of TE_{11} and TM_{11} mode are close to the desired consist ratio 85%

TE_{11} and 15% TM_{11} [7], and the total conversion efficiency are above 99% over a bandwidth from 32-36 GHz, while reflection under -28dB over a bandwidth from 30-38 GHz (shown in Fig. 3). Fig. 5 shows the output field distribution of the corrugated horn compared to standardized HE_{11} mode. The simulation were carried out for 32, 34 and 36 GHz. The normalized power shows an axisymmetric pattern and the center of the output containing about 98% of the radiated power, which were close to distribution of standardized HE_{11} mode. It can be demonstrated that a well-formed HE_{11} mode over a bandwidth from 32-36 GHz with low reflection, high conversion efficiency, desired mode contents and field distribution pattern.

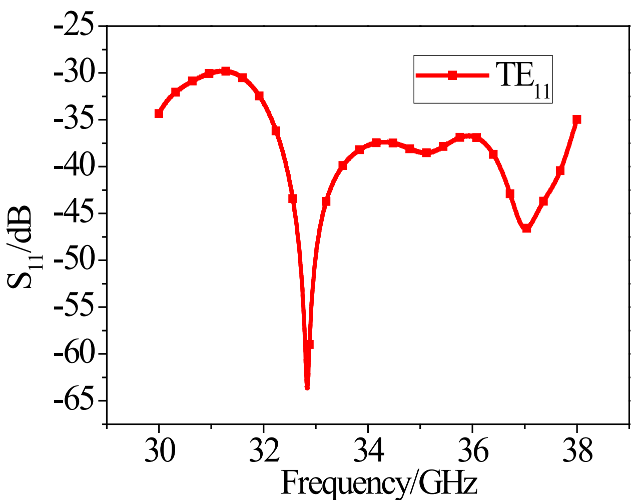

Fig. 3 Reflection coefficient of corrugated horn.

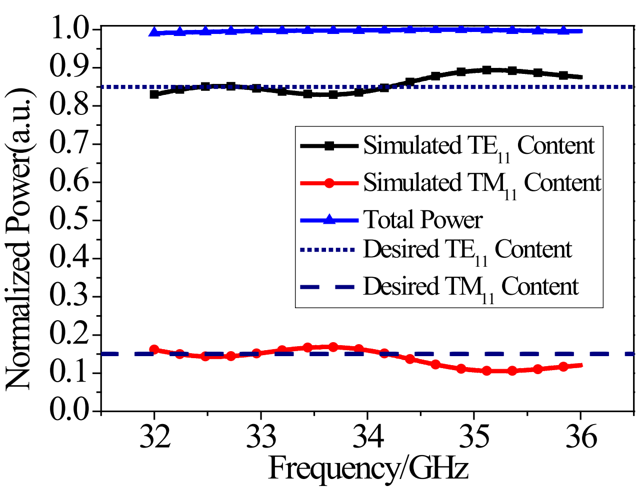

Fig. 4 Simulated vs. desired mode contents and conversion efficiency of corrugated horn.

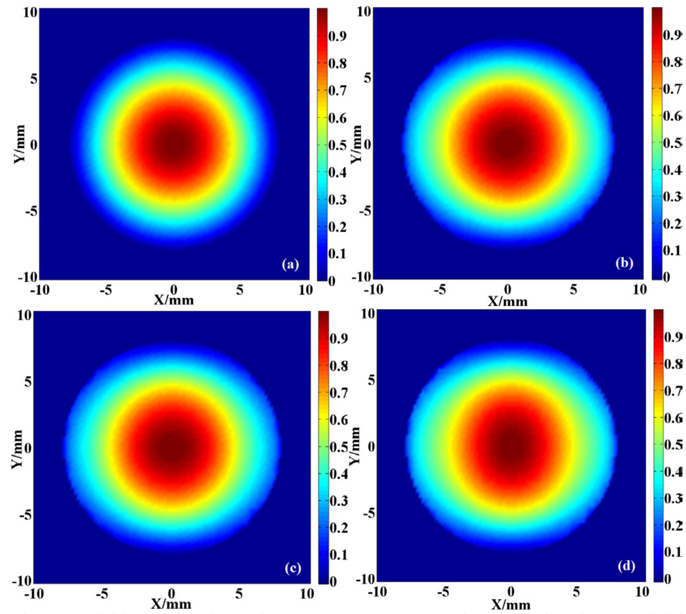

Fig. 5 Field distribution of output port (contour in normalized). (a) Field distribution of standard HE_{11} mode; (b)field distribution of corrugated horn output at 32 GHz; (c)field distribution of corrugated horn output at 34 GHz; (d)field distribution of corrugated horn output at 36 GHz

CONCLUSIONS

A HE_{11} mode corrugated horn for the performance microwave measurement of a Ka-band faraday rotator had been designed and simulated. Through optimization and simulation, it was demonstrated that the HE_{11} mode corrugated horn can meet requirements of a well-formed HE_{11} mode with high mode conversion efficiency, low side-lobe and cross-polarization. It is expected to fabricated this HE_{11} mode corrugated horn and testing its transmission and reflection.

REFERENCES

Denisov G. G., Bratman V. L., Cross A. W., et al.: ‘Gyrotron traveling wave amplifier with a helical interaction waveguide’, *Physical review letters*, 1998, 81, (25), pp. 5680-5683

William D. Fitzgerald: ‘A 35-GHz Beam Waveguide System for the Millimeter-Wave Radar’, The Lincoln Laboratory Journal, 1992, 5, pp. 245-272

Thumm M.: ‘High power mode conversion for linearly polarized HE_{11} hybrid mode output’, *International Journal of Electronics*, 1986, 61, (6), pp. 1135-1153

Dionne G. F., Weiss J., Allen G.: ‘Nonreciprocal magneto-optics for millimeter waves’, *IEEE Transactions on Magnetics*, 1988, 24, (6), pp. 2817-2819

Hunter R., Robertson D., Goy P., et al.: ‘Design of High-Performance Millimeter Wave and Sub-Millimeter Wave Quasi-Optical Isolators and Circulators’, *IEEE Transactions on Microwave Theory & Techniques*, 2007, 55, (5), pp. 890 - 898

Liu H, Lou Z, Wang H, et al.: ‘Precise Design of Millimeter Wave Quasi-Optical Faraday Rotators’, *Journal of Infrared Millimeter & Terahertz Waves*, 2009, 30, (4), pp. 401-409

Sakaguchi M., Idei H., Kubo S., et al.: ‘Quasi-Optical High Purity HE_{11}-Mode Exciter for Oversized Corrugated Waveguide Transmission’, *Plasma & Fusion Research*, 2012, 7, (2405037), pp. 1-4

T.-L. Zhang, Z.-H. Yan, F.-F. Fan, et al.: ‘Design of a Ku-Band Compact Corrugated Horn with High Gaussian Beam Efficiency’, *Journal of Electromagnetic Waves & Applications*, 2011, 25, (1), pp. 123-129

Mun Seok Choe, Kwang Hoon Kim, EunMi Choi: ‘A comprehensive analysis of a TE_{11} to HE_{11} mode converter for an oversized F-band corrugated waveguide’, *Journal of Electromagnetic Waves & Applications*, 2013, 27, (17), pp. 2221-2238