Design of Q-band Broadband Rectangular Waveguide TE_{10} Mode to Circular Waveguide TE_{01} Mode Converter

Shuai Zong*, Yong Xu, and Guo Liu
School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu, Sichuan610054, China,
* Contact: paradise_zs112@126.com, xuyong01@uestc.edu.cn

Abstract-In this paper, a novel design of rectangular TE_{10} mode to circular TE_{01} mode waveguide converter with compact structure is presented. To begin with, the theoretical analysis is provided. Based on the principle of waveguide mode converter, a creative project with crisscross structure is obtained. As is shown in the project, this kind of waveguide mode converter totally consists of three segments. The first segment performs the transformation from rectangular TE_{10} mode to rectangular TE_{20} mode, and the second accomplishes the conversion from rectangular TE_{20} mode to TE_{22} mode of the crisscross waveguide, while the last section achieves the switching from TE_{22} mode to circular TE_{01} mode. According to the project suggested above, the 3D model of the converter is established in the powerful commercial software named by HFSS where the simulation and optimization of the waveguide converter is completed. Remarkable results are obtained via abundant simulation and optimization of the critical geometric dimension of the mode converter. The conversion efficiency of the converter over 33GHz to 50 GHz is considerably perfect approaching an average level at 99.9%, while the return loss is generally below -25dB.

INTRODUCTION

In recent years, domestically and abroad, plenty of magnificent progresses are achieved in the design and experiment of the gyrotrons and gyro-amplifiers (including gyro-TWTs and gyro-klystrons that generally operate at TE_{01} mode [1]. During transmitting in the circular waveguide, the TE_{01} mode has pretty small attenuation, which is of great significance when TE_{01} mode is applied as the transmitting mode for long distance transmission and as the operating mode of high-Q resonance cavity.

In the design of gyrotrons and gyro-amplifiers operating at TE_{01} mode, it is considerably necessary to perform the cold test experiment to ensure the property of the interaction circuit system of these devices, including testing the resonant frequency, Q-value of the resonance cavity [2], the transmission and reflection characteristics of the input couplers and the output windows [3]. As far as we know, the primary operation mode of dominant microwave sources in the laboratories is rectangular TE_{10} mode. Thus, it is of remarkable value to design more perfect converters to complete the transformation from rectangular TE_{10} mode to circular TE_{01} mode [4].

From the study of the conventional research of the circular waveguide TE_{01} mode converters, a fact is obtained that there are mainly three forms of the TE_{01} mode converter, namely fan-shaped converter, turning magnetic surface excitation converter and the sidewall coupling converter [5],[6]. The fan-shaped mode converter is produced by electrotyping technology, resulting the high cost and the complexity of manufactory [7], [8]. What's worse, the conversion efficiency is absolutely low and there are spurious modes during the transformation. Considering the different direction of the input and output of the magnetic surface excitation mode converter, it is not convenient for the system to be assembled. The arc-shaped structure of the second kind mode converter is difficult to be produced and its bandwidth is narrow [9-11]. While sidewall coupling mode converter achieves high conversion efficiency and broad bandwidth and has compact structure, due to the Y-type power divider network, the product technology demand is severe.

In order to meet the demand of cold test experiment in Q-Band, the principle and design scheme of broad bandwidth mode converter from rectangular TE_{10} mode to circular TE_{01} mode with compact structure is presented in the paper [12]. Based on the design scheme, 3D model is built in the popular commercial electromagnetic simulation software HFSS. In the paper, the first part is the theoretical analysis and design scheme of the TE_{01} mode converter, the second is the simulation results and the relative analysis and the third is the conclusion of the work.

DESIGN AND ANALYSIS OF THE TE_{10}-TE_{01} WAVEGUIDE MODE CONVERTER

A. The principle of the mode converter

To ensure that the rectangular waveguide TE_{10} mode is efficiently coupled into the circular waveguide TE_{01} mode and the waveguide wavelength is kept unchanged along the whole length of the device in the operating band, the physical structure of the converter needs to satisfy certain conditions that the structure of the converter must have ideal symmetry and the transition process between different parts should be as level and smooth as possible. Only by this method, can the perfect result be acquired that the purity of the circular TE_{01} mode is ensured and the conversion loss becomes low. In order to produce the converter successfully and easily, there is some necessary compromise between theoretical design and actual fabrication.

B. The design scheme of the TE_{10} -TE_{01} mode converter

The whole structure of the mode converter mainly consists of three sections. The structure of the first part is linearly gradient from rectangular waveguide to T-shaped waveguide, and then to another rectangular waveguide, realizing the conversion from rectangular TE_{10} mode to rectangular TE_{20} mode. The second one adopts the structure of a rectangular waveguide linearly gradient to the crisscross waveguide, completing the transformation from rectangular TE_{20} mode to the crisscross waveguide TE_{22} mode. The last one is formed by crisscross waveguide linearly gradient to circular waveguide, achieving the change from crisscross TE_{22} mode to circular waveguide TE_{01} mode. The 3D model of the mode converter based on crisscross structure is shown in figure 1. Through the transformation of the three segments, the conversion from rectangular TE_{10} mode to circular TE_{01} mode is achieved. And the mode conversion sequence is presented in figure 2.

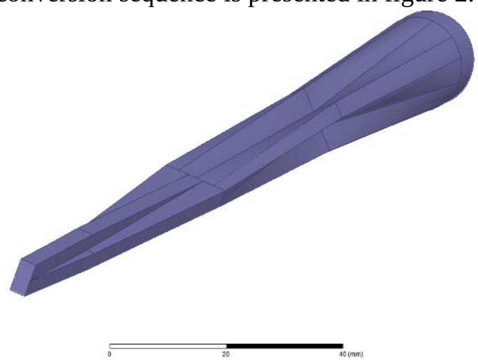


Fig. 1 The 3D model of TE_{10}-TE_{01} mode converter

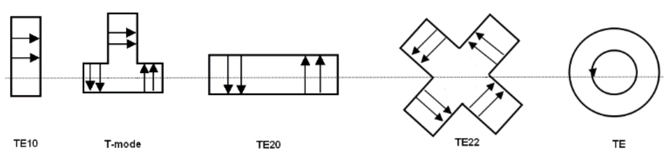


Fig. 2 The mode changing sequence of TE_{10}-TE_{01} mode converter

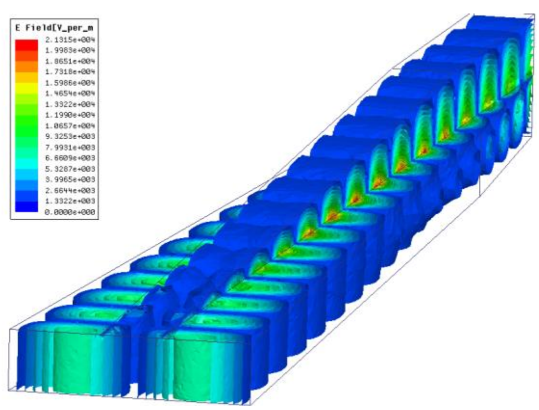
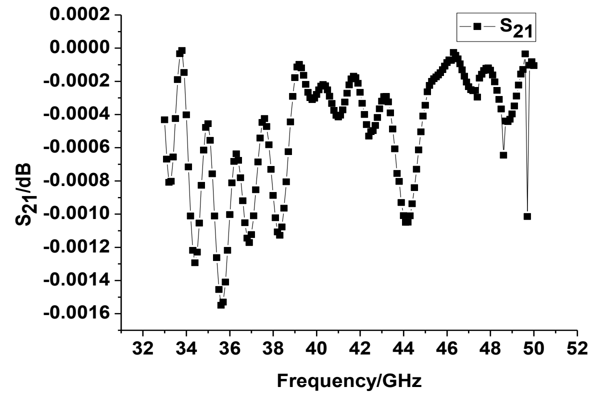


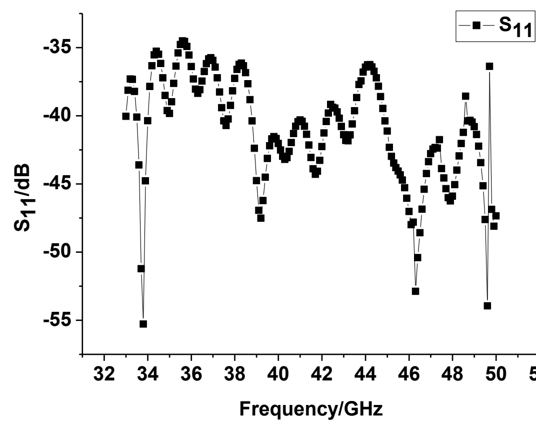
Fig. 3 The electric field distribution of the output port of the first part

THE SIMULATION RESULTS AND THE ANALYSIS OF THE TE_{10}-TE_{01} MODE CONVERTER

The simulation is performed in HFSS by building the 3D model in the simulation software. According to the technical index, it is significantly important to minimize the length of the converter on the condition that the conversion efficiency is kept perfect in the operation bandwidth. Every length of the three parts of the converter is built as an optimization variable that can be scanned to determine the most optimized length of each segment. As is shown in the following figures, better optimized results are presented.



(a)



(b)

Fig. 4 The transmission/reflection parameter of the first part
(a) The transmission parameter (b) The reflection parameter

In figure 3, the electric distribution of the output port of the first part is given, from which a conclusion can be acquired that the input TE_{10} mode is efficiently converted into TE_{20} mode.

As is shown in figure 4, the transmission and the reflection characteristic is presented. Without the loss in the conversion considered, the S_{11} is below -35dB in the whole Q-band, identifying the energy of TE_{10} mode reflected is less than one thousandth and the transmission energy is above 99.9%. Therefore, TE_{10} mode is considerably converted into TE_{20} mode.

Figure 5 is the electric field distribution of the output port of the second section of the converter. As the figure 5 shows, after transmitting in the second section, TE_{20} mode is converted to crisscross TE_{22} mode with high purity.

What's is shown in Figure 6 is the S_{21} parameter and S_{11} parameter of the second section. The figure 6 presents that S_{11} parameter of TE_{20} mode is less than -35dB and S_{21} is better than -0.0012dB in the whole Q-band, demonstrating that the transmitting energy is nearly 99%. Therefore, most of the energy of rectangular waveguide TE_{20} mode is successfully converted into the crisscross waveguide TE_{22} mode.

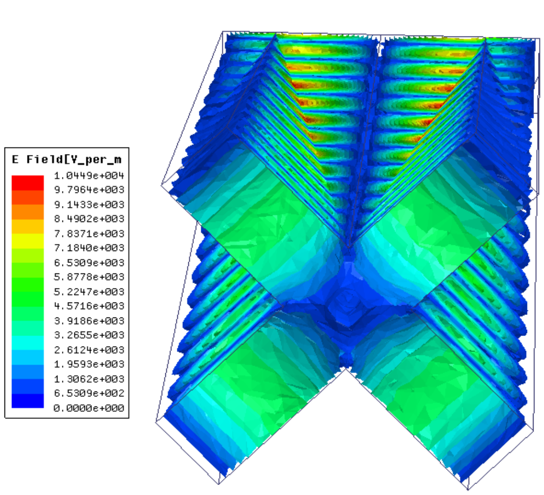


Fig. 5 The electric field distribution of the output port of the second part

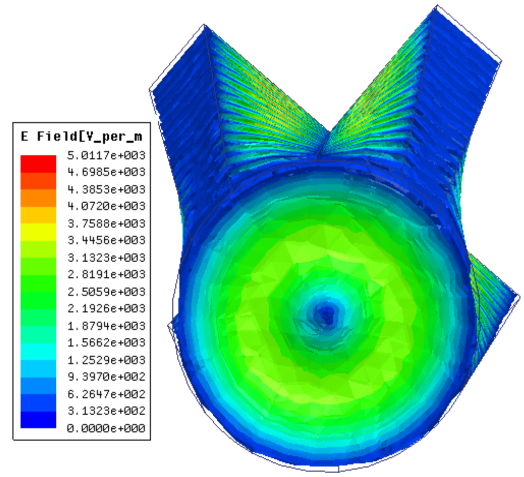
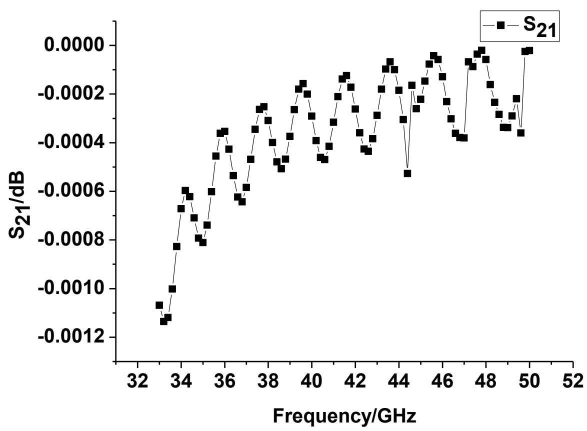
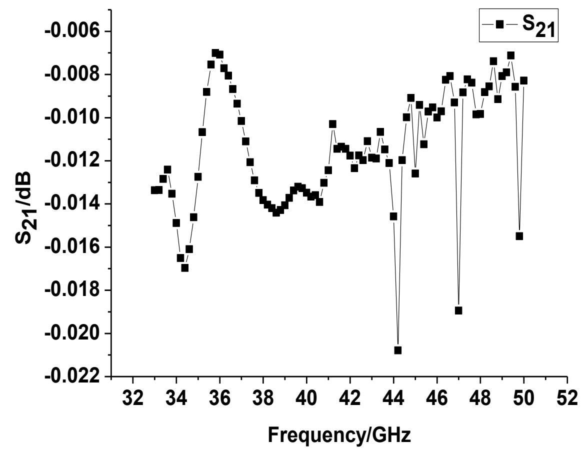


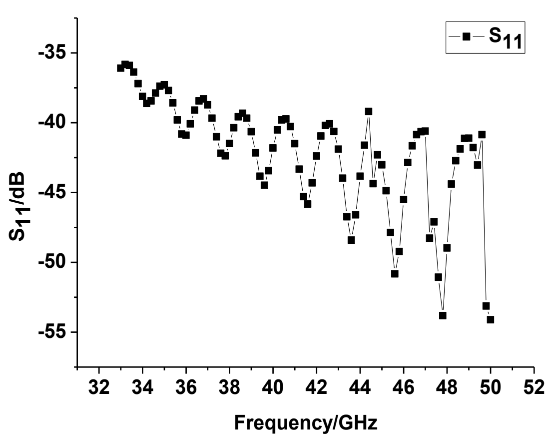
Fig. 7 The electric field distribution of the output port of the third part



(a)

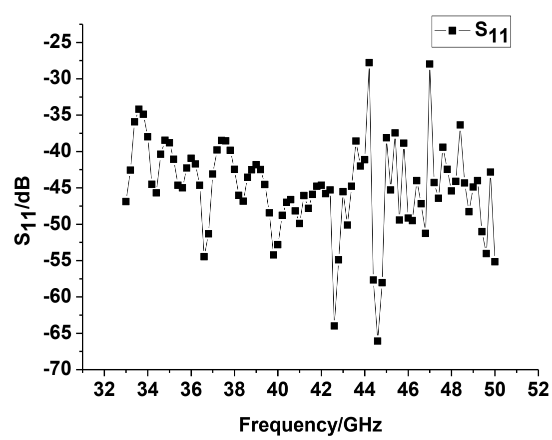


(a)



(b)

Fig. 6 The transmission/reflection parameter of the second part
(a) The transmission parameter (b) The reflection parameter



(b)

Fig. 8 The transmission/reflection parameter of the third part
(a) The transmission parameter (b) The reflection parameter

Figure 7 is electric field distribution of the output port of the third section, showing that crisscross waveguide TE_{22} mode is transformed into circular waveguide TE_{01} mode with high purity. As is shown in figure 8, the S_{21} parameter from TE_{22} mode to TE_{01} mode is above -0.018dB, while the S_{11} parameter of the TE_{22} mode is generally below -35dB, identifying that TE_{22} mode is efficiently converted into TE_{01} mode.

When the optimization of each of the three sections is completed, the whole TE_{10}-TE_{01} mode converter is assembled. As the figure 9 shows, the final field distribution of the output of the mode converter is vividly presented, indicating that the TE_{10} mode is efficiently converted to TE_{01} mode. And as the figure 10 presents, both the S_{11} parameter of the TE_{10} mode and the S_{21} parameter from TE_{10} mode to TE_{01} mode are perfect enough to meet the demand of the TE_{10}-TE_{01} mode converter.

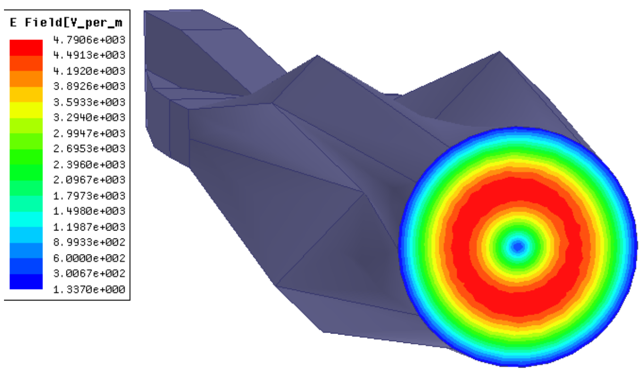
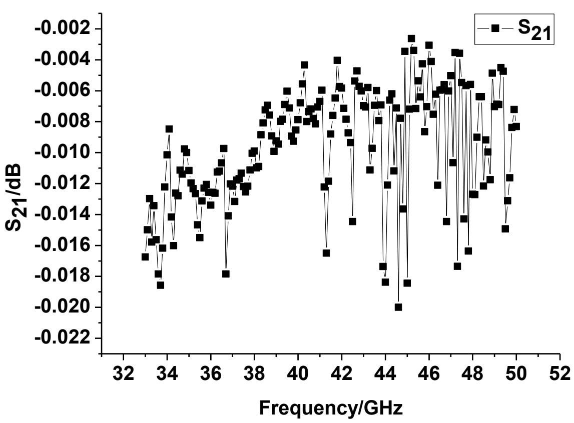
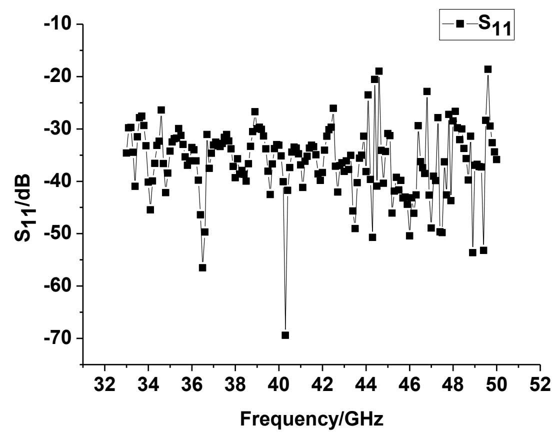


Fig. 9 The electric field distribution of the output port of the whole converter



(a)



(b)

Fig. 10 The transmission/reflection parameter of the whole converter
(a) The transmission parameter (b) The reflection parameter

CONCLUSIONS

The design of a broad-band TE_{10}-TE_{01} mode converter in Q-band is presented in the paper. Through plenty of simulation and optimization of the converter model by FEM (finite element method) in HFSS, a good result is obtained. As the simulation and optimization results shows, the conversion efficiency is more than 99% while the return loss is below -25dB. At the same time, the work presented in the paper can also supply some suggestion in the research of other mode converters.

REFERENCES

Chu K R. Overview of research on the gyrotron traveling-wave amplifier [J]. IEEE Transactions on Plasma Science, 2002, 30(3):903-908.

XU Yong, LUO Yong, WANG Jian-Xun. Design and experiment of high frequency circuit: fundamental wave gyroklystron amplifier with 34 GHz TE01 mode [J]. J. Infrared Millim. Wave, 2013, 32(6):531-537.

Xu Yong, Luo Yong, Li HongFu, Xiong CaiDong, Wang JianXun. Design of a New Type Broad-band Output Window for High Power Gyro-TWT. J. Infrared Millim.Waves.2013; 32(NO.2):6.

Chang C-F Ya T-H. High Performance of Circular TE01 Mode Converter. IEEE Transactions on Microwave Theory and Technologies. 2005; 53(12):5.

Du RenBo, Luo Yong, Niu XinJian. Design of High-power Millimeter Wave Corrugated Circular Waveguide Mode Converter. High Power Laser and Particle Beams. 2008; 20(1):4.

Ding YanFeng,Liu QingXiang, Zhang JianQiong. Design and Experiment Study of Overmode Bend Circular Waveguide. High Power Laser and Particle Beams. 2011; 23(8):6.

Zhu Min, Luo JiRun, Luan YuanTao, Guo Wei, Yuan GuangJiang. Bandwidth Property of the Converter with Sector Taper from a Rectangular Guide TE10 Mode to a Coaxial Guide TE01 Mode. Journal of Electronics & Information Technology. 2007; 29(6):3.

Wang WenXiang. Microwave Engineering Technology. Beijing: National Defense Industry Press; 2009 4.

Fu Hua, Li Hao, Jiang LiHui, Wu ZeWei, Li TianMing. Circular TE01 Mode Transducer at V-band. High Power Laser and Particle Beams. 2014; 26 (6):5.

Niu XinJian, Li HongFu, Xie ZhongLian. Analysis of High-power Millimeter Wave Circular Waveguide TM01-TE11 Mode Converter. High Power Laser and Particle Beams. 2002; 14(5):4.

Wang Qiang, Zhou HaiJing, Yang Chun, Li Biao, Ye Jian. Bandwidth Study of TE01-TE11 Mode Converter. High Power Laser and Particle Beams. 2013; 25(3):4.

Xu Yong, Luo Yong , Wang JianXun , Yan Ran, Pu YouLei, Wang Hui, Wang Li, Li HongFu, Xiong Caidong. Design of Ka-band TE10-TE01 Broad Band Mode Converter. Chinese Journal of Vacuum Science and Technology. 2013; 33(4):6.