Design of TE_{01} to HE_{11} Mode Converter at 35GHz

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Abstract: *Mode conversion is hugely vital for the transmission and measurement of high power microwaves. In this paper, the TE01-HE11 high-efficiency high-power mode converter with TM11 as the intermediate mode is designed by numerical simulation, and the operating frequency is 35GHz. In the calculation process, in order to solve the problem of the ohmic losses caused by the metal wall, we used the rematch phase technique to improve the conversion efficiency. We then used the Commercial Microwave Studio software for modeling analysis. Finally, experimental tests were performed on the processed TE_{01}-TM_{11} and TM_{11}-HE_{11} mode converters. Experimental results verify the accuracy of numerical simulation.*

Keywords: TE01-TM11 mode converter; TM_{11}-HE_{11} mode converter; experimental results

Introduction

Mode conversion plays an important role in the transmission and conversion of high power microwave. High-power microwave sources, such as gyrotrons and amplifiers, typically have symmetric volume modes (TE_{0p}, p»1) or whispering gallery modes (TE_{mp}, m»1, p=1,2). Those modes are unsuitable for direct application. Therefore, mode converters are used to convert those modes into the ones that are suitable for use, such as HE_{11} mode. Literature [1] introduces two effective wave structure that could produce an HE_{11} mode.

The output mode and its power and frequency determine the type of mode transition that is required in high-power microwave systems. Mode converters are generally classified into quasi-optical mode converters and waveguide mode converters [2-3]. This paper studies the waveguide mode converter[4].Considering the output power of TE_{0n} mode is about 100-200kW, the conversion for over-modular circular waveguide can be adopted[5-6]. Specifically, the sequence-TE_{01} (90° axis bending waveguide) -TM_{11} (curved waveguide structure with variable curvature)-HE_{11} (circumferentially corrugated waveguide and the depth of corrugation is from zero to 1/4 wavelength)--is employed. The frequency range is 34.0GHz-36.0GHz, waveguide radius is 16mm, and the centre frequency is 35GHz.

The model in this paper is to optimize the length of the aluminum waveguide, the structure disturbance and other parameters by using the numerical calculation program, so as to obtain the efficient mode conversion efficiency. Finally, it processes and tests things. The results show that it can meet the requirements of compact broadband transmission and conversion.

The Theory of Bending a Circular Waveguide

The inhomogeneities in the waveguide cause energy coupling between the propagation modes in the waveguide, resulting in a mode transition. Coupled wave theory is to derive coupled wave equations[5] by combining transmission line equations using the expansion theory of orthogonal functions. The basic equation of the axis bending circular waveguide can be written as follows:

$$\frac{dA^{+}_{m'n'}}{dz} = -j\gamma_{m'n'}A^{+}_{m'n'} - j\sum_{mn}\left[C^{+}_{(m'n')(mn)}A^{+}_{mn} + C^{-}_{(m'n')(mn)}A^{-}_{mn}\right] \tag{1}$$

$$\frac{dA^{-}_{m'n'}}{dz} = j\gamma_{m'n'}A^{-}_{m'n'} + j\sum_{mn}\left[C^{+}_{(m'n')(mn)}A^{-}_{mn} + C^{-}_{(m'n')(mn)}A^{+}_{mn}\right] \tag{2}$$

Where A^{+}_{mn} and A^{-}_{mn} represent the amplitudes of the forward and backward waves of the mn^{th} mode respectively. The equation $\gamma_{mn} = \alpha_{mn} + j\beta_{mn}$ indicates the propagation constant of the mn^{th} mode, where α_{mn} is the attenuation constant for circular waveguides, and β_{mn} is the wave number. $C^{+}_{(m'n')(mn)}$ stands for the coupling coefficient between mn^{th} and $m'n'^{th}$ modes. $C^{-}_{(m'n')(mn)}$ stands for the coupling coefficient between the forward $m'n'^{th}$ mode and the backward mn^{th} mode.

In the process of converting the TE_{01} mode to the TM_{11} mode, the input and output modes have the same phase constant in the smooth circular waveguide. Therefore, when the curvature of the curved circular waveguide is constant, the critical angle of the mode converter can be expressed as:

$$\theta_c = \frac{3.5317\lambda_0}{2\sqrt{2}a_0} \tag{3}$$

Where λ_0 is the wavelength in free space, a_0 is the inner radius of the waveguide. When the angle is θ_c, TE_{01} can be completely converted to TM_{11}. The boundary conditions of the converter are as follows.

$$A^{+}_{mn}\Big|_{z=0} = \left[(1,0),(0,0),\cdots(0,0)\right]^{T} \tag{4}$$

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$$A^{-}_{mn}\Big|_{z=L}=\left[(0,0),(0,0),\cdots(0,0)\right]^{T} \quad (5)$$

By solving the boundary conditions (1), (2), (3), and (4) of the coupled wave, the field distribution of the forward wave A^{+}_{mn} and the backward wave A^{-}_{mn} can be obtained.

Since the TE_{01} and TM_{11} modes have E-H degeneracy, their phase constants are the same, which causes strong coupling between the waveguides. In general, We can achieve mode conversion with a large bending axis.

The Test of The Radiation Pattern

As we can see Fig.1 is overall structure of the mode converter.To increase the reliability of measurement, we first test the 90° bending structure. Then we check the sinusoidal axis bending structure of TE_{01}-TM_{11} mode converter. At last, we examine the TM_{11}-HE_{11} mode converter. The measured radiation patterns are shown in Fig. 2, Fig.3 and Fig.4。

The TM_{11} port of the TE_{01}-TM_{11} mode converter is loaded into the open circular waveguide. The TE_{01} mode is fed into the TE_{01} port to measure the distribution of the TM_{11} radiation field. Finally, the microwave is radiated outward via a corrugated horn attached to the HE_{11} end.

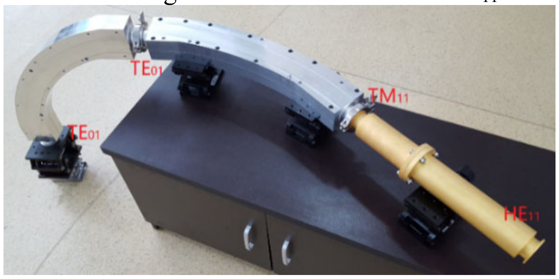

Fig.1 Overall structure of the mode converter

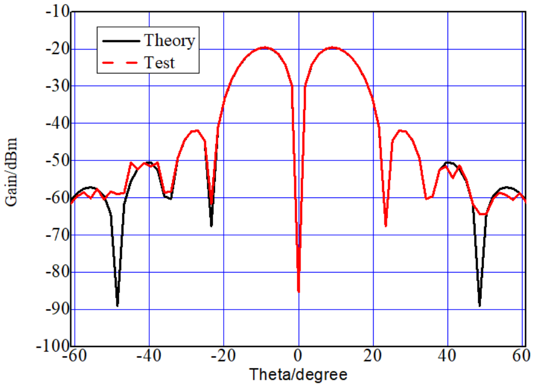

Fig. 2 The radiation pattern of TE_{01} mode 90° bending

Then we measure the S parameters of the converter. S_{21} and S_{11} parameters are -0.07dB and -22.9dB respectively at the 35GHz centre frequency. The reflection loss is also quite small. The parameter waveform is consistent with the previous simulation results and the bandwidth shown in the wave is also acceptable.

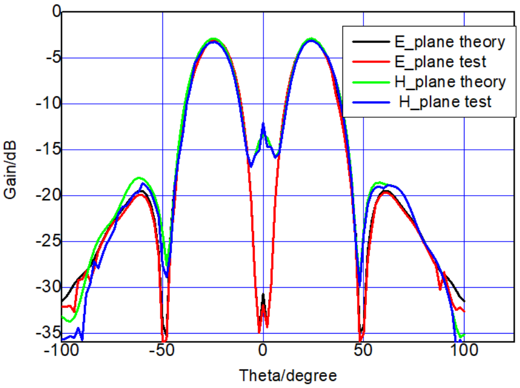

Fig. 3 The radiation pattern of the TE_{01}-TM_{11} mode converter

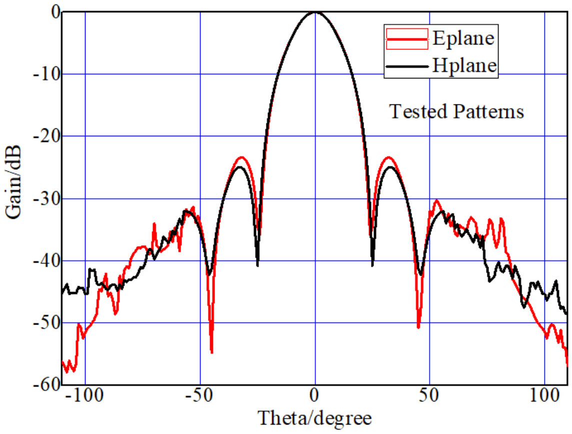

Fig. 4 The radiation pattern of the TM_{11}-HE_{11} code converter

Conclusion

Numerical analysis and experimental tests were carried out using TE_{01}-TM_{11} and TM_{11}-HE_{11} mode converters with the gyrotron traveling wave tube. The results show that the mode converter works well in the TE_{01}-TM_{11}, TM_{11}-HE_{11} mode conversion, which is in good agreement with the calculation results.

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