Design of 94GHz TE11-HE11 Mode Converter

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Abstract: *Based on the coupled wave theory, a corresponding parameter optimization program was compiled. In order to achieve mode conversion and phase matching in the shortest length, a two-stage structure is adopted. Optimized by a numerical calculation program, the TE11-HE11 mode converter with a working frequency of 94GHz and the port diameter from 4mm to 18mm was designed. Its conversion efficiency reached 99% while its length was only 69mm.*

Keywords: converter; structure; coupling

Introduction

As a high power millimeter wave source, gyrotron has important applications in phased array radar, plasma heating, millimeter wave communication, controlled thermonuclear fusion and other systems [1]. Its output mode is generally TE_{0n}. The polarization directions of these modes are unstable and the axial radiation pattern is hollow cone, which is not conducive to directly radiate [2]. Thus, these modes are generally converted into HE_{11} mode and then radiated through the antenna. There are two main ways to convert TE_{0n} mode to HE_{11} mode, namely, taking TE_{11} or TM_{11} as the intermediated mode and subsequently converting to HE_{11} mode. Since the slots of corrugated waveguide are easily broken down at high power, the smooth wall mode converter is proposed. In this paper, based on the coupled wave theory, a numerical parameter optimization program is compiled, and a smooth wall waveguide is designed. Simulation results by HFSS show that the conversion efficiency is 99%.

BACIC THEROY OF COUPLING WAVE

Because of the irregular waveguide structure, the electromagnetic wave transmitted in the circular waveguide will arise a series of new coupled modes. The diameter change mode converter with input TE_{11} will couple out modes such as TM_{11}, TE_{12}, TE_{13}, TM_{12} due to different radii. The mutual conversion relationship among different modes can be described by the following coupled wave equations [3]:

$$\frac{dA_{mn'}^{+}}{dz} = -\frac{1}{2}\frac{d(\ln\gamma_{mn'})}{dz}A_{mn'}^{-} - \gamma_{mn'}A_{mn'}^{+} + \sum_{+mn} A_{mn}^{+}C_{(mn')(mn)}^{++} + \sum_{-mn} A_{mn}^{-}C_{(mn')(mn)}^{+-} \qquad 1.1$$

$$\frac{dA_{mn'}^{-}}{dz} = -\frac{1}{2}\frac{d(\ln\gamma_{mn'})}{dz}A_{mn'}^{+} + \gamma_{mn'}A_{mn'}^{-} + \sum_{+mn} A_{mn}^{+}C_{(mn')(mn)}^{-+} + \sum_{-mn} A_{mn}^{-}C_{(mn')(mn)}^{--}$$

Where A_{mn}^{+} and A_{mn}^{-} represent the magnitude of the forward and reverse waves, respectively. γ is the propagation constant, and C is the coupling coefficient.

DESIGN OF MODE CONVERTER

Design of mode converter: In order to achieve mode conversion and phase matching in the shortest length, a two-stage structure is adopted. A new type of adjustable curve is used in the first structure. By adjusting the multiple parameter values of the curve, the converter can realize smooth connection at the port, and the input mode TE_{11} can be quickly converted to a specific ratio of TM11. The contour function is as follows:

$$r(z) = R1 + R2*(r_{\max} - k\sin(B(1 - z/L)) + \cos(B(1 - z/L)) + 0.5k\sin(2B(1 - z/L)))/(r_{\max} - r) \qquad 1.2$$

R1 is the radius of the input port, and R2 represents the radius of the output port. The k is adjusted so that the derivative of the contour function at z is zero at the port. The parameter is the maximum value of the function (1.3):

$$r(x) = k\sin(x) - \cos(x) - 0.5k\sin(2x) \qquad 1.3$$

Where, x is between 0 and L, r0 is the function value when x is equals to 0. B is the value of x when function (1.3) takes the maximum value.

The second section of the structure adopts a parabolic structure to reduce the coupling between the modes while achieving phase matching and large changes in port size. Its contour function is as follows:

$$r2 = R1 + R2*\left(1 + a*\left((t - L)/L2\right)^{2}\right) \qquad 1.4$$

Where, $a = (R3 - R1)/R2 - 1$, L2 is the length of the second section of the structure.

Parameter optimization: The differential equations are obtained by the coupled wave equation and solved by the fourth-order Runge-Kutta method. The calculation process is shown in Fig.1. The optimized structural parameters are shown in TABLE I and TABLE II:

TABLE I. Structure parameter of first part

R1(m)	R2(m)	L(m)	r_0	r_{max}	k	B
0.002	0.003	0.013	-1	-0.99998	-100	0.00667

TABLE II. Structure parameter of second part

R1	R2	R3	a	L	L2
0.002	0.003	0.009	4/3	0.013	0.056

The result calculated by numerical optimization program is shown in Fig.2. The x label is length of mode converter, y label is power of mode converter. Red line is power curve of TE_{11} mode while the blue line represents power curve of TM_{11}, and the green line represent the power curve of TE_{12}. At the output port of the mode converter, the relative power of the TE_{11} mode is 0.8436, and the relative power of the TM_{11} mode is 0.1466, which indicates that the TE_{11} mode is converted into the HE11 mode and formed a quasi-Gaussian beam.

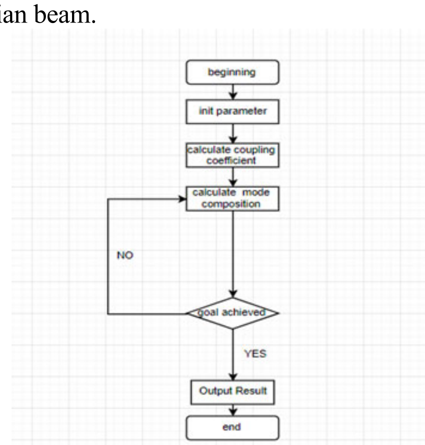

Fig.1. The Flowchart of calculation process

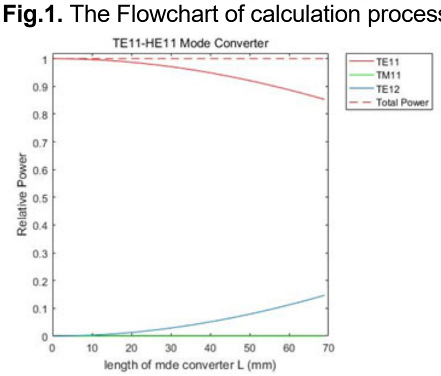

Fig.2. Relative Power curve of each mode along the x axis

SIMULATION

Using the obtained parameters of the third part, the model is built using simulating software, and its outline is shown in Fig. 3. The length of the whole mode converter is 69mm.

Fig. 4 shows an electric field diagram of the y-z profile obtained by simulation. It can be seen that the electric field of the emitted electromagnetic waves converges toward the output port. The electric field diagram at the output port is shown in Fig. 5 and the energy is concentrated at the center, which is an ideal Gaussian beam. In the center of the output port, the maximum power is 3.6kV / m, and the RF breakdown field strength of the metal surface in the vacuum is known to be 1 MV / cm. Based on this information, the power capacity of this mode converter has reached the MW level.

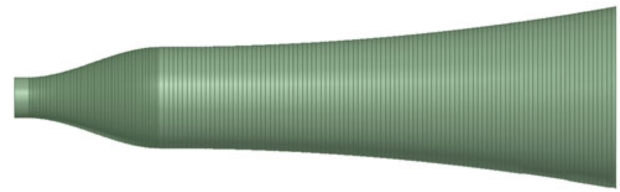

Fig. 3. Outline of the mode converter

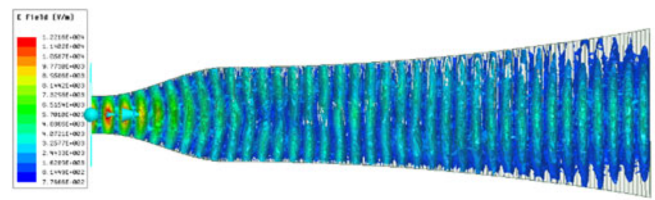

Fig.4. Electric field diagram of the y-z profile

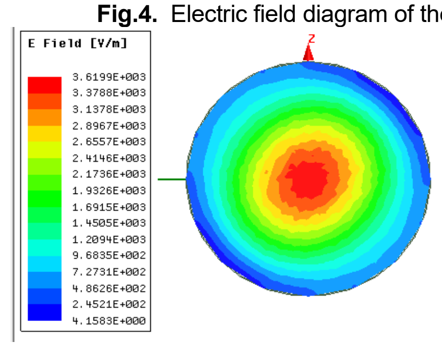

Fig.5. Electric distribution diagram of output port

Conclusion

Based on the coupled wave theory, a 94 GHz TE_{11}-HE_{11} mode converter is designed. This converter adopts a two-stage structure to convert TE_{11} mode to HE_{11} mode compactly and efficiently. It can be seen from the simulation that a stable quasi-Gaussian beam is formed at the output of the mode converter, the conversion efficiency reaches 99%, and the power capacity of the mode converter reaches MW level, which provides a reference for the research of the mode converter.

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