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 TE0n. 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 HE11 mode and then radiated through the antenna. There are two main ways to convert TE0n mode to HE11 mode, namely, taking TE11 or TM11 as the intermediated mode and subsequently converting to HE11 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%.

Basic Theory 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 TE11 will couple out modes such as TM11, TE12, TE13, TM12 due to different radii. The mutual conversion relationship among different modes can be described by the following coupled wave equations [3]:

\[
\begin{align*}
\frac{dA_{mn}}{dx} &= -\frac{1}{2}\frac{d}{dx}\gamma_{mn} A_{mn} + \sum_{\ell=0}^{\infty} \frac{\lambda_{\ell}}{2\pi} C_{\ell}^{-\ell}(\gamma_{mn}) A_{(\ell+\ell)\ell mn} + \sum_{\ell=-\infty}^{\infty} A_{mn_{\ell}} C_{\ell}(\gamma_{mn})  \\
\frac{dA_{mn}}{dz} &= -\frac{1}{2}\frac{d}{dz}\gamma_{mn} A_{mn} + \sum_{\ell=0}^{\infty} \frac{\lambda_{\ell}}{2\pi} C_{\ell}^{-\ell}(\gamma_{mn}) A_{(\ell+\ell)\ell mn} + \sum_{\ell=-\infty}^{\infty} A_{mn_{\ell}} C_{\ell}(\gamma_{mn})
\end{align*}
\]

(1.1)

Where \( A_{mn}^+ \) and \( A_{mn}^- \) represent the magnitude of the forward and reverse waves, respectively. \( \gamma \) 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 TE11 can be quickly converted to a specific ratio of TM11. The contour function is as follows:

\[
r(z) = R1 + R2 * (r_{max} - k \sin(B(1 - z/L))) + \cos(B(1 - z/L)) + 0.5k \sin(B(1 - z/L))) / (r_{max} - r)
\]

(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):

\[
r(x) = k \sin(x) - \cos(x) - 0.5k \sin(2x)
\]

(1.3)

Where, \( x \) is between 0 and L, \( r_0 \) is the function value when \( x \) 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 function is as follows:

\[
r^2 = R1 + R2 * \left(1 + a \left(\frac{t - L}{L2}\right)^2\right)
\]

(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:

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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 represent the 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 HE$_{11}$ mode and formed a quasi-Gaussian beam.

**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.

**References**