Compact Oversized TE01-to-TE11 Mode Converter based on Deformed Waveguide

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Abstract: *A Q-band oversized TE_{01}-to-TE_{11} mode converter is designed for high power transmission line of gyro-TWTs. To obtain a compact and broadband structure, the deformed circular waveguide, named quad-polar waveguide, which can improve the conversion capacity of between TE_{01} mode and TE_{11} mode is introduced. The axis perturbation is synthesized by iteration method. Validated by simulation software, the designed mode converter has the efficiency over 95% in the range of 46.9 GHz to 49 GHz.*

Keywords: Gyro-TWT; mode converter; oversized waveguide; transmission line.

Introduction

Gyrotron-traveling-wave tube (gyro-TWT), a promising amplifier with high power and broad bandwidth in millimeter wavelength range, has attracted great attention for military and civilian applications such as high-resolution imaging radar, microwave weapon systems, and space debris detection [[1]]. However, the general output mode from gyro-TWTs is TE_{01} mode which is unsuitable to be used directly and needs to be converted to Gaussian-like HE_{11} mode by mode conversion. An available scheme is TE_{01}-TE_{11}-HE_{11} mode conversion, which has the advantage that all converters can be made without bends and the polarization plane can be changed fast by rotating the TE_{01}-to-TE_{11} mode converter around its axis [[2]]. However, it is difficult for the traditional TE_{01}-to-TE_{11} mode converter with fixed perturbation periods and perturbation amplitudes to achieve high conversion efficiency in a small number of coupling periods. The synthesis methods have great improvements in suppressing the parasitic modes and promoting the conversion efficiency but not in bandwidth [[3], [4]]. Using the multi-iteration method the bandwidth could be efficiently improved but the cost is that the length would greatly increase [[5]]. To improve the bandwidth and avoid large size, the deformed waveguide has been considered. An elliptical waveguide rather than circular waveguide is used to synthesize TE_{01}-to-TE_{11} mode converter [[6]] which has a relative bandwidth of 19% at length of 550 mm. However, due to the high eccentricity, the total length of the circular-to-elliptical transition is up to 600 mm. To obtain a compact broadband TE_{01}-to-TE_{11} mode converter, the quadpolar waveguide is adopted in this paper. Due to its high similarity between circular waveguide, the transition structure can be achieved in a short length. Moreover, compared with circular waveguide TE_{01}-to-TE_{11} mode converter, the proposed mode converter has a broader bandwidth.

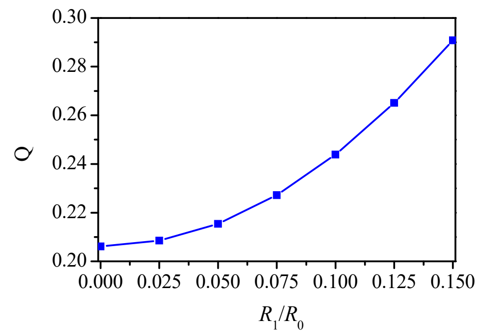

Figure 1. Dependence of the conversion capacity Q on the relative deformation

Mode coupling in mode converter

The power conversion between two modes in waveguide bend can be described by the coupled-wave differential equations as follow [5]

$$\frac{dA_1(z)}{dz} = -j\beta_1 A_1(z) + jc(z) A_2(z)$$
$$\frac{dA_2(z)}{dw} = -j\beta_2 A_2(z) + jc(z) A_1(z) \quad (1)$$

with β_1 and β_2 represent the propagation constant for mode A_1 and A_2, respectively. $A_1(z)$ and $A_2(z)$ are the normalized magnitude along the waveguide axes. c is the coupling coefficient which depends on the curvature of waveguide axis. The conversion capacity between mode A_1 and A_2 can be described by Q

$$Q = \frac{2c}{\beta_1 - \beta_2} \quad (2)$$

A high Q stands a strong power conversion, which means the power of mode A_1 can totally be converted into mode A_2 in a short conversion length. Besides, the less numbers of perturbation periods, the broader bandwidth of mode converter can be achieved. Therefore, the promotion of conversion capacity is helpful to improve the bandwidth.

To promote the TE_{01}-to-TE_{11} conversion capacity, a deformed waveguide, names quadpolar waveguide, is adopted in this paper. The inner surface of quad-polar waveguide is expressed in the polar system of coordinates (r, φ) as follows

$$R(\varphi) = R_0 + R_1 \cos(4\varphi) \quad (3)$$

Where R_0 is the average waveguide radius, and R_1 is the deformation amplitude. The dependence of TE_{01}-to-TE_{11} conversion capacity on the relative deformation R_1/R_0 is shown in Fig. 1, in which the frequency is set as 49 GHz and the average radius is set as 11 mm. It can be seen that the conversion capacity increases as the relative deformation increases. However, the large relative deformation requires a long transition.

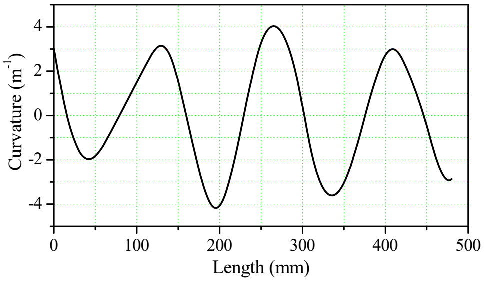

Figure 2. Curvature along the axis of the mode converter

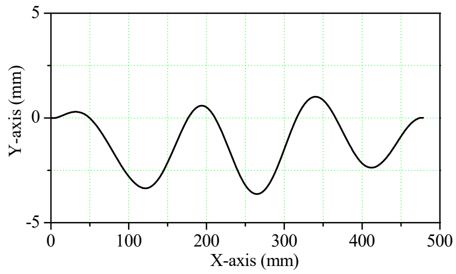

Figure 3. Axis profile of TE01-TE11 mode converter

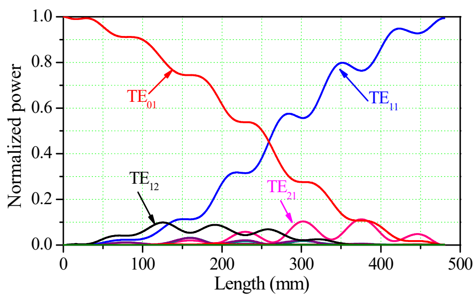

Figure 4. Coupling process of three frequency point along axis

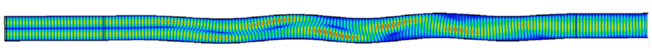

Figure 5. Electric field distribution along the propagation axis

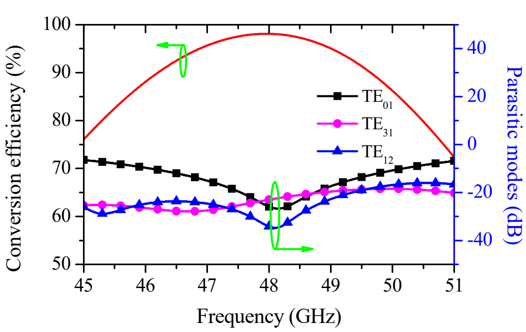

Figure 6. Conversion efficiency and parasitic modes of the whole structure

Design results and discussion

Based on the aforementioned analysis results, a Q-band TE_{01}-TE_{11} mode converter has been designed using the quadpolar waveguide. The average radius R_0 is set as 11 mm, and the perturbation amplitude R_1 is set as 1 mm. The axis curvature is optimized by iteration method, as shown in Fig. 2. The length of the quadpolar waveguide is set as 480 mm, approximately 3.5 times the beat-wavelength. The axis curve is calculated using the integration of the curvature and the results is shown in Fig. 3.The coupling process of the center frequency 48 GHz along the waveguide axis is shown in Fig. 4. As expected, the injected TE_{01} mode is gradually converted to the desired TE_{11} mode as it propagates along the waveguide axis, and a nearly full conversion is obtained at the output port. Except for the desired TE_{11} mode, a few parasitic modes are also generated at the output port. The most abundant parasitic mode is TE_{01} mode, of which content is less than 1% at the output port of mode converter. Note that a small amount of TE_{21} mode and the TE_{12} mode are generated at the middle of mode converter. However, they are transformed into the TE_{11} mode as the beam propagates along the mode converter, and a nearly full power transformation is realized at the output port.

To facilitate the connection with the others components, two circular-to-quadpolar linear transitions are placed in the input/output port of the quadpolar mode converter. The radius of circular waveguide is set as 12 mm and the length of the two transitions respectively is 100 mm and 80 mm. The performance of whole structure, including the elliptical waveguide bend, two circular-to-quadpolar transitions, is validated with CST Microwave studio [[7]]. The electric field distribution along the waveguide axis at frequency of 48 GHz is shown in Fig. 5. The symmetric field with no energy on center is gradually converted to a field with maximum field on center, which indicates that the TE_{01} mode is being converted to TE_{11} mode. The calculated results are shown in Fig. 6. The conversion efficiency is over 95 % in the range of 46.9 GHz to 49 GHz, and a maximum of 98.5 % is obtained at 48 GHz. The mainly parasitic mode is TE_{01} mode which is less than -15 dB in the operating band.

Conclusion

To achieve the compact broadband oversized TE_{01}-TE_{11} mode converter, the quadpolar waveguide is proposed in this paper. Using the iteration method, the curvature of the waveguide axis is optimized. The designed mode converter has a conversion efficiency over 95% in the range of 46.8 GHz to 49 GHz and a maximum of 98.5 % is obtained at 48 GHz. The obtained results show that the proposed mode converter can enable a compact, efficient, and broadband high-power millimeter-wave transmission line.

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