Research on Broadband High-power Compact Oversized TE_{01} Hexa-polar Waveguide Bend

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Abstract: *This paper proposes a broadband compact and oversized TE_{01} hexa-polar waveguide bend in Ka-band. Due to the introducing of hexa-polar waveguide, the degeneration between the TE_{01} mode and TM_{11} mode is destroyed. The influence of the relative perturbation on the coupling capacity is analyzed and the waveguide bend is designed based on the analysis results. The results prove that it achieves a transmission bandwidth with 9.6 GHz at the 95% level for TE_{01} mode (relative bandwidth is over 30%).*

Keywords: Gyro-TWT; waveguide bend; oversized waveguide; transmission line.

INTRODUCTION

Gyro-TWT is a kind of source being able to provide high power and wide frequency band millimetre wave, and it is commonly used in such as high energy physics research devices, military radar and so on [1], [2]. TE_{01} mode is chosen as the operating mode in most of gyro-TWTs system for its low loss in the transmission line. The waveguide bend which can change the propagation direction of the beam and make the system compact is usually used. To operate in gyro-TWT system, it should have small reflection, high power transmission capacity, and wide bandwidth. In circular waveguide, the TE_{01} mode and the TM_{11} mode are degenerated. The TE_{01} mode can be massively converted to TM_{11} mode in circular waveguide bend, which leads to a great decline of the TE_{01} mode purity at output port.

Adding periodic perturbations on the waveguide cross-section, the spectrum of eigen-modes in the circular waveguide can be changed, which is help to improve/suppress the mode conversion ability. Based on elliptical waveguide, a high power oversized waveguide bend with the relative bandwidth over 21% was designed [4]. However, a long circular-to-elliptical transformer should be used in the elliptical waveguide bend. To overcome this drawback and improve the bandwidth further, the hexa-polar waveguide bends are considered in this paper. The waveguide bend based on the hexa-polar cross-section is designed. The degeneration between TE_{01} mode and TM_{11} mode is destroyed in the hexa-polar waveguide, which can weaken mode conversion from the operating mode to the undesired modes. Besides, due to its high similarity with circular waveguide, a short waveguide transformer can be realized. The angler perturbation of the hexa-polar waveguide is analyzed, and an oversized hexa-polar waveguide bend is designed for Ka-band transmission line according to the analysis results.

HEXA-POLAR WAVEGUIDE BEND AND COUPLING THEORY

The analytical expression of the inner wall of the hexa-polar waveguide in polar coordinate system is as follows:

$$R(\varphi) = R_0 + R_1 \cos(6\varphi) \tag{1}$$

R_0 specifies the radius of initial circular wall and R_1 is the amplitude of the disturbance. The shape of hexa-polar waveguide cross-section is showed in Fig.1.

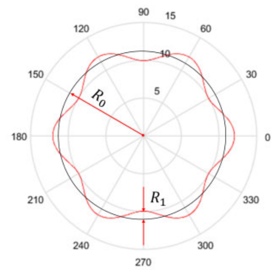

Fig. 1. Cross-sectional shape of hexa-polar waveguide

The coupled-wave differential equations [4]:

$$\begin{aligned} \frac{dA^{+}_{m'n'}}{dw} &= -j\beta_{m'n'}A^{+}_{m'n'} + j\sum_{mn}\left[C^{+}_{(m'n')(mn)}A^{+}_{mn} + C^{-}_{(m'n')(mn)}A^{-}_{mn}\right] \\ \frac{dA^{-}_{m'n'}}{dw} &= j\beta_{m'n'}A^{-}_{m'n'} - j\sum_{mn}\left[C^{-}_{(m'n')(mn)}A^{+}_{mn} + C^{+}_{(m'n')(mn)}A^{-}_{mn}\right] \end{aligned} \tag{2}$$

where A^{+}_{mn} and A^{-}_{mn} represent the amplitude of the forward wave and the reflected wave respectively. $C^{+}_{(m'n')(mn)}$ and $C^{-}_{(m'n')(mn)}$ are the coupling coefficients between mode $(m'n')$ and mode (mn). $\beta_{m'n'}$ is the phase constant of mode $(m'n')$.

Coupling capacity which is used to measure coupling ability of two modes can be calculated as

$$Q = \left|\frac{C_{mn}}{\beta_m - \beta_n}\right| \tag{3}$$

In this equation, β_m and β_n are the propagation constants of m mode and n mode respectively. Obviously, a large difference between the propagation constants of two modes can efficiently suppress their conversion ability.

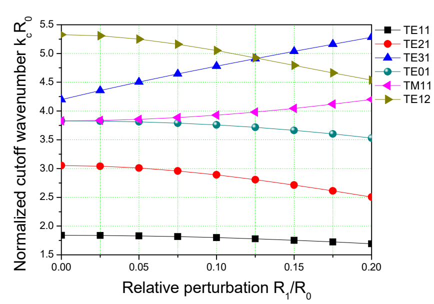

Fig. 2. Normalized cutoff wavenumber as function of relative perturbation in hexa-polar waveguide

Fig. 2 shows the normalized cutoff-wavenumber varies with the change of relative perturbation in hexa-polar waveguide. In hexa-polar waveguide, the TE_{01} mode and TM_{11}

mode are no longer the degeneration mode. It can be found that the difference between the cutoff wavenumbers of TE_{01} mode and TM_{11} mode would increase as the relative perturbation changes. According to (3), a large perturbation would efficiently suppress the power conversion between the TE_{01} mode and TM_{11} mode in the hexa-polar waveguide bend. Though a large disturbance helps to suppress mode conversion between of TE_{01} and TM_{11} mode, a large relative perturbation will increase the length of hexa-polar-to-circular transition.

DESIGN AND COMPARISON

According to the theoretical analysis, a Ka-band oversized TE_{01} waveguide bend based on the hexa-polar waveguide is designed. The average waveguide radius of the hexa-polar waveguide bend is chosen as 11 mm. An axis arc bending structure is used for the 90º TE_{01} mode waveguide bend. The normalized disturbance of 0.095 is chosen. The input/output radius of the circular waveguide is set as 16mm. The turning radius of the bend and the length of waveguide transformer are optimized to obtain a maximum transmission efficiency. The detailed structure parameters of the designed waveguide is shown in Tab 1.

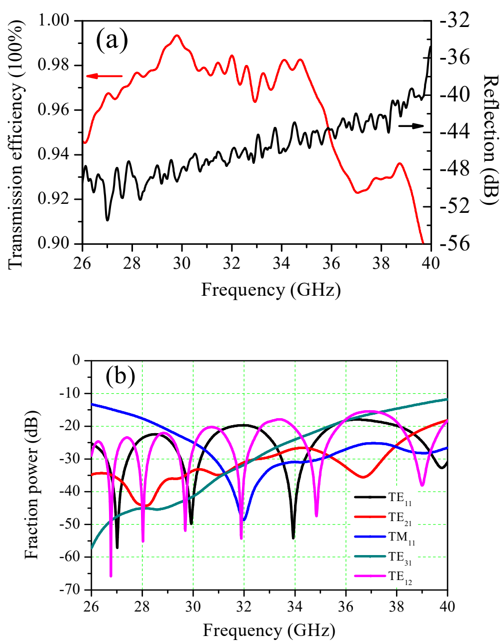

Fig. 3. (a) Normalized magnitude and the reflection of the whole structure. (b) Fraction power of the whole structure.

The performance of the proposed hexa-pole waveguide bend is investigated with the help of CST Microwave Studio [5], and the results are shown in Fig.3. From 26.2 GHz to 35.9 GHz, the relative bandwidth over 30%, the transmission efficiency of TE_{01} mode is over 95%, and the reflection is less than -34 dB. The maximum transmission efficiency of 99.3% is obtained at 30 GHz. Except for the TE_{01} mode, some parasitic modes such as TE_{11} mode, TE_{21} mode, TE_{31} mode, and TM_{11} mode are also generated. In the range of 26.5 GHz to 38 GHz, the fraction power of these modes with lower than -15 dB is obtained at the output port of bend.

The electric field distribution changes located in the symmetric plane of proposed waveguide bend at 31 GHz is shown in Fig. 4. The symmetric field distribution coincide with the input port beam is obtained at the output port, which indicates that a high-purity TE_{01} mode is outputted. Noted that the symmetric field distribution is destroyed at the middle of the bend, the field of one side is stronger than that of the other side, the reason is that some undesired modes are generated.

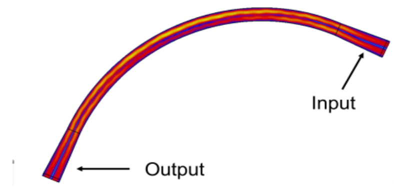

Fig. 4. Simulated electric field distributions of the hexa-polar waveguide bend at 31 GHz.

To make a comparison, the specific structure parameters and transmission performance of the proposed waveguide bend and the elliptical waveguide bend in [4] are shown in Table I. Obviously, these results show that the proposed hexa-polar bend has superior advantages both in structure and bandwidth.

TABLE I. PARAMETERS AND PERFROMANCE COMPARISON LIST

parameters	Elliptical	Hexa-polar
Turning curve	Arc	Arc
Long half axis(mm)	12.4	/
Short half axis(mm)	10.3	/
R0(mm)	/	11
R1(mm)	/	1.05
Cross-sectional area(mm2)	401.24	381.86
Radius of bend(mm)	295	350
Length of converter(mm)	220	90
Total length of bend(m)	0.903	0.730
Bandwidth	Over 7 GHz	Over 9.5GHz

CONCLUSION

An oversized high power TE_{01} waveguide bend is designed with the proposed hexa-polar waveguide. The results show that the proposed waveguide bend has a bandwidth over 9.5 GHz (relative bandwidth is over 30%) with a high transmission efficiency over 95% and its structure is compact.

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