Study of Broadband Quasi-Optical Mode Converter for THz Gyrotron

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***Abstract*—This paper presents the design of a broadband quasi-optical mode converter for a 330 GHz TE62 mode tunable gyrotron. It consists of a Vlasov launcher and three reflector mirrors. A series of important considerations, including Vlasov launcher of reasonable radius, robust and simple system configuration, are the keys to realize stable and broadband mode converting. The optimized internal converter achieves well compatibility with the gyrotron electron-optical system and generates high-purity gaussian beam between 320 GHz ~ 340 GHz.**

I. INTRODUCTION

GYROTRON operates on the principle of relativistic electron cyclotron maser, and the cyclotron beam is capable of interacting with a high-order fast-wave mode, which generates supreme strong radiation in millimeter-wave-to-THz frequency range [1, 2]. By using the geometric optics principle and the vector diffraction theory, the quasi-optical (QO) mode converter is developed to convert the operating mode into a free-space guassian beam [3, 4]. Most of the conventional gyrotrons employ open-cavity interaction circuit and generate radiation on fixed frequencies. As a result, a conventional internal mode converter is normally optimized on a fixed operating frequency. Future THz gyrotron of broadband capability is especially attractive for imaging, coherent detect and bio-medical research. Accordingly, the broadband gyrotron is in pressing demand for the technology of broadband internal mode converter.

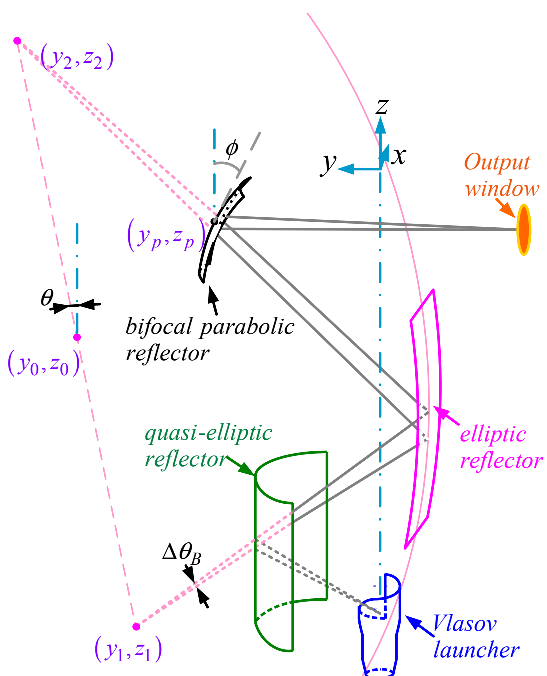

Fig. 1 Configuration of the broadband QO mode converter

II. SIMULATION

The configuration of the broadband QO mode converter for TE62 mode 330 GHz gyrotron is shown in Fig. 1. The Vlasov launcher launches the waveguide TE62 mode into the free-space THz rays. And then, the quasi-elliptical mirror reflects the diffractive THz rays and focuses the rays in the transverse cross plan. The second mirror is a standard elliptic mirror. It focuses the rays in longitudinal cross plan. The last mirror selects a bifocal parabolic mirror and converts the output rays into a transverse beam. The last mirror is carefully selected to avoid the electron beam interception and demonstrates better robust performance than a conventional phase correction mirror under broadband operation condition.

The Vlasov launcher is more frequency sensitive than any other components. The helical-cut Vlasov launcher releases the terahertz wave into free-space rays. At the entrance of the Vlasov launcher, the THz ray is with transverse angle $\cos\theta_c = m/x_{mn}$ and longitudinal angle $\tan\theta_B = k_\perp/k_z$. It's obvious that θ_c is frequency independent but θ_B is frequency sensitive, which means that only the longitudinal focusing is frequency sensitive. The key of the broadband QO converter becomes how to control the frequency sensitivity of the longitudinal focusing. Fig. 1(b) shows the sensitivity of the longitudinal angle θ_B to the normalized frequency ω_0/ω_c . It is revealed that, when close to the cutoff frequency, the longitudinal angle θ_B is quite sensitive, and when away from cutoff frequency, it becomes more robust.

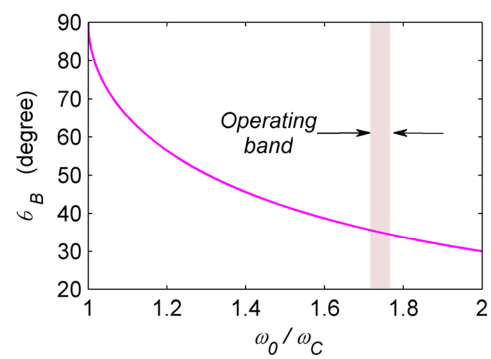

Fig. 2. The frequency sensitivity of the longitudinal angle θ_B of the THz ray inside the Vlasov launcher.

The field strength distributions of the broadband QO mode converter for TE62 mode 330 GHz gyrotron is shown in Fig. 4. A number of freedoms need to be optimized. The first step of converter synthesizing is to choose Vlasov launcher with reasonable large radius to reduce frequency sensitivity. When the launcher radius is relatively small and the operating frequency is close to the cutoff frequency, the longitudinal angle θ_B is quite sensitive to frequency variation, as previously shown in Fig. 2. On the other hand, when choosing larger launcher radius, the longitudinal angle θ_B becomes more robust. In our broadband QO converter, the Vlasov launcher adopts a reasonable radius and the operating band locates between $\omega_0 \in [1.715, 1.768]\omega_c$, where the longitudinal angle shifts as small as $\Delta\theta_B = 1.24^\circ$ in the operating band.

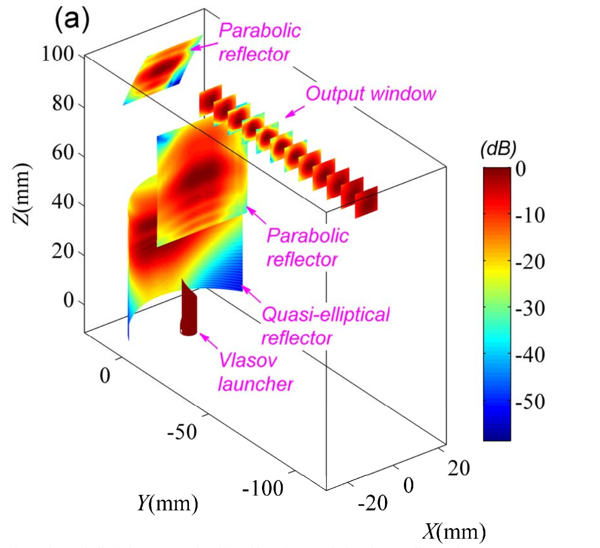

Fig. 3 Simulated field strength distribution of the broadband QO converter at 330 GHz.

On the quasi-elliptic reflector, the geometric optics predicts that the THz rays will be limited in the azimuthal range of $(\theta - \pi/2) \in (-\theta_c, \theta_c)$ in the transverse X-Y plane. However, the field strength from the vector diffraction theory reveals that the quasi-elliptic reflector collects only about 91% of the total power even in the extended range of $(\theta - \pi/2) \in (-1.6\theta_c, 1.6\theta_c)$, where the diffraction loss from the Vlasov launcher is considered as the major reason. It's interesting that, from the optimized results, both the quasi-elliptic reflector and the elliptic reflector are relatively far from their second focal points. In other words, each of the first two reflectors is similar to a parabolic mirror which reflectors the THz rays into nearly parallel directions. Finally, the last bifocal parabolic reflector collects these approximately parallel incident rays and focuses them at the output window. The last parabolic reflector with approximately parallel incident rays is also one of the considerations for suppressing the system frequency sensitivity.

Figure 3 also shows the Gaussian beam distribution along the output path. From the continuous evolution process of the field strength and the phase, the output THz beam achieves excellent Gaussian beam strength and phase distribution. On the output window, the THz beam achieves minimum transverse beam waist about 2.5 mm. On either side of the output window, the transverse beam waist gradually grows with distance away from the output window.

The broadband operation capability of the QO mode converter shown in Fig. 1 is especially attractive for broadband gyrotrons. After calculating the optimized field strength distribution on the output window at 330 GHz, the power converting efficiency on the output window with diameter of 10 mm is 83.3% and beam waist is about 2.5 mm. There are also some problems about the broadband operation. After checking the field distribution on the output window, the field patterns maintain quite stable on the output window respecting to frequency variations, but the pattern center demonstrates minor movement about 2 mm along Z-axis from 320 GHz to 340 GHz. Even a number of factors are previously applied to suppress the system frequency sensitivity, it cannot be completely eliminated. After calculating the total efficiency from the waveguide TE62 mode to free-space beam, the converting efficiency is above 80% in an extraordinarily broad bandwidth between 310 GHz ~ 340 GHz. The highest scalar Gaussian beam purity and the highest scalar Gaussian beam purity at 330 GHz are up to 99.2% and 98.4%, respectively. However, considering the focus center shifting due to frequency variation, the Gaussian beam purity sharply decreases when the frequency shifts away from the central frequency 330 GHz.

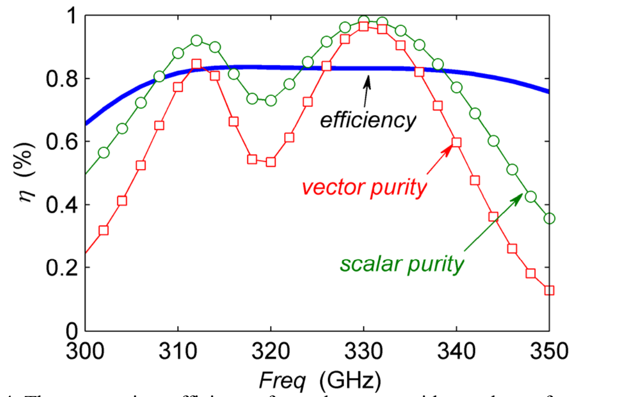

Fig. 4 The converting efficiency from the waveguide mode to free-space gaussian beam on the output window. The scalar Gaussian purity and vector Gaussian purity are also included, where output window is limited to diameter of 10 mm.

Considering all the conditions, when an output window with diameter of 10 mm is adopted, the Gaussian beam shifts only about 2mm, on the same order of the beam waist, and it brings little influence to the output efficiency. The QO mode converter is with excellent broadband operation capability.

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