# Design and Simulation of Magnetron Injection Guns for a 0.5 THz Frequency-Tunable Gyrotron

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**Abstract:** *The design and simulation of magnetron injection guns (MIGs) for a 0.5 THz broadband continuously frequency-tunable gyrotron with the principle of multi-mode switching and axial mode transition via electrical tuning and magnetic tuning have been presented in this paper. Moreover, the variation of the electron beam quality including the velocity spread and the pitch factor with respect to the operating magnetic field $B_0$ and the operating voltage $V_0$ has also been studied.*

**Keywords:** Terahertz, magnetron injection gun (MIG), electron beam quality, frequency-tunable gyrotron.

## Introduction

Gyrotron is a coherent radiation source based on the electron cyclotron maser interaction. Frequency-tunable terahertz gyrotron with broadband tuning capability is attractive for modern and advanced applications such as dynamic nuclear polarization (DNP) enhanced nuclear magnetic resonance (NMR), electron spin resonance and accurate measurement of hyperfine splitting of positronium [1]-[2]. The operating mechanism of frequency-tunable gyrotron is multi-mode switching or axial mode transition through variation of the operating magnetic field and the beam energy [3]-[4]. However, changing the operating magnetic field and the operating voltage would inevitably lead to significant variations of the electron beam quality of the MIG which is one of the most important parts in a gyrotron. Therefore, It is vital to design a MIG with acceptable perpendicular velocity spread and pitch factor when the beam energy and the operating magnetic field are changed.

In this paper, two kinds of electron optical system containing a diode-type MIG and a triode-type MIG are designed to meet the requirement of the 0.5 THz broadband continuously frequency-tunable gyrotron. Besides, the variation of the electron beam quality including the velocity spread and the pitch factor with respect to the operating magnetic field $B_0$ and the operating voltage $V_0$ has also been studied.

## Result and analysis

Magnetron injection gun (MIG) is a crucial subsystem to the frequency-tunable gyrotron. The MIG operates in the regime of the temperature-limited emission. After being thermionically emitted from an indirectly heated ring cathode, the electrons move toward the interaction cavity in cyclotron motion due to the accelerate voltage and magnetic field. The perpendicular velocity spread $\delta v_{\perp} = (v_{\perp\max} - v_{\perp\min})/2v_{\perp}$, the pitch factor $\alpha$ which is the ratio of perpendicular to axial electron velocity are the key parameters of the MIG. For a broadband continuously frequency-tunable gyrotron, in order to realize a wide frequency-tuning range, the electron beam energy and the operating magnetic field will be changed in a large range. It is vital to design a MIG with acceptable perpendicular velocity spread and pitch factor when the operating beam energy and the operating magnetic field is changed. The main operating parameters of the 0.5 THz broadband continuously frequency-tunable gyrotron are presented in Table 1. The Magnetic Guidance System for the gyrotron is shown in Fig. 1.

**Table 1.** Operating parameters of the 0.5 THz broadband continuously frequency-tunable gyrotron.

| | |
|---|---|
| **Operating modes** | $TE_{5,7,q}$, $TE_{10,5,q}$, $TE_{3,8,q}$, $TE_{1,9,q}$ |
| **Nominal frequency** | 500-510GHz |
| **Magnetic field** | 9.09-9.29T |
| **Voltage** | 10.6-12.4kV |
| **Current** | <2A |
| **Beam radius $r_b$** | 0.805mm |
| **Output power** | Hundreds of watts |
| **Efficiency** | 1%-30% |

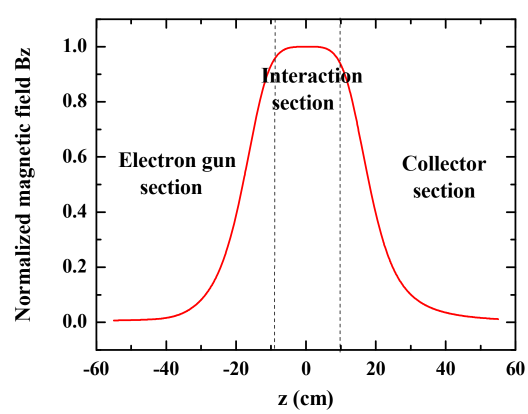


**Figure 1**. The Symmetric Magnetic Guidance System for the 0.5 THz broadband continuously frequency-tunable gyrotron.

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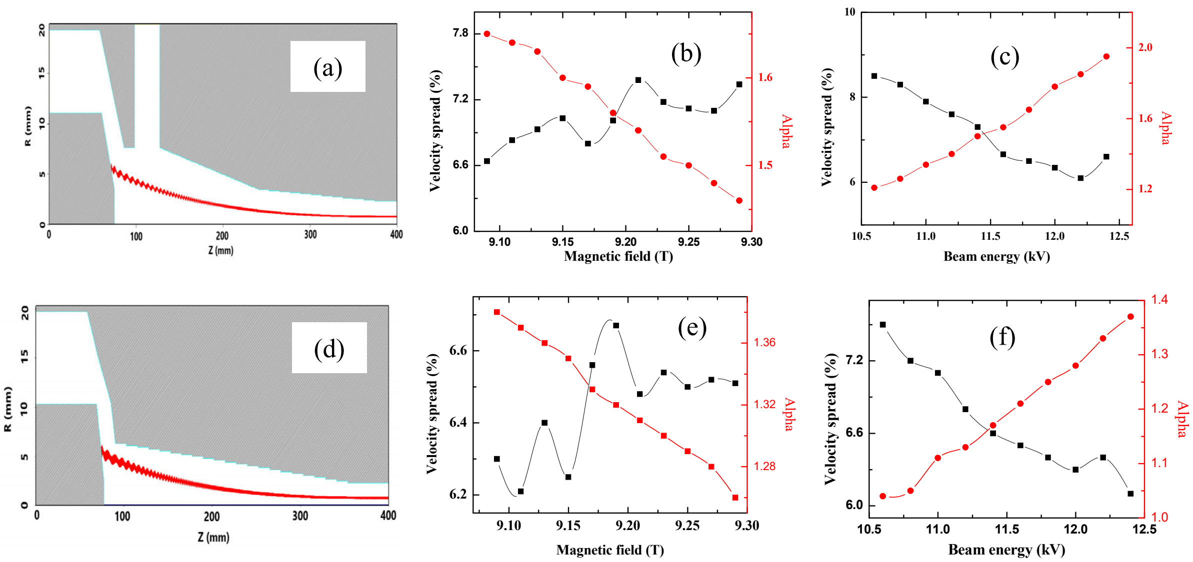


**Figure 2** . (a),(d) The MIG geometry as well as the electron trajectories for a 0.5THz broadband continuously frequency-tunable gyrotron. (b) ,(e) the transverse velocity spread and the pitch factor vs. the operating magnetic field at a given operating voltage of 12 kV. (c), (f) the perpendicular velocity spread and the pitch factor vs. the operating voltage at a given magnetic field of 9.25T.

The optimized triode-type MIG and diode-type MIG geometry as well as the electron trajectories calculated from a PIC code are shown in Fig. 2 (a) and (d). The perpendicular velocity spread and the pitch factor vs. the operating magnetic field $B_0$ (the magnetic field at the interaction section) and the operating voltage $V_0$ calculated from a PIC code are shown in Fig. 2 (b) (c) (e) (f). It is found that for the triode-type MIG, perpendicular velocity spread changes from 6.6% to 7.3% and the pitch factor varies from 1.46 to 1.65 when the operating magnetic field changes from 9.09 T to 9.29 T at a given operating voltage of 12 kV. The perpendicular velocity spread varies from 6% to 8.5% and the pitch factor changes from 1.21 to 1.95 when the voltage changes from 10.6 kV to 12.4 kV at a given operating magnetic field of 9.25 T. For the diode-type MIG, perpendicular velocity spread changes from 6.21% to 6.67% and the pitch factor varies from 1.26 to 1.38 when the operating magnetic field changes from 9.09 T to 9.29 T at a given operating voltage of 12 kV. The perpendicular velocity spread varies from 6.1% to 7.5% and the pitch factor changes from 1.04 to 1.37 when the voltage changes from 10.6 kV to 12.4 kV at a given operating magnetic field of 9.25 T. Moreover, more information could be obtained from the results. firstly, the electron beam quality is more sensitive to electrical tuning compared with magnetic tuning. Secondly, The perpendicular velocity spread has a smaller fluctuation in diode-type MIG. Actually, the diode-type MIG with a single anode is relatively a simple structure and easy to manufacture, while it is true for that better flexibility in tuning the electron beam parameters with adopting a triode-type MIG. As a consequence, these two kinds of MIG both meet the requirement of the 0.5 THz broadband continuously frequency-tunable gyrotron.

## Summary

Design and simulation of two kinds of electron optical system including a diode-type MIG and a triode-type MIG for 0.5 THz broadband continuously frequency-tunable gyrotron have been carried out in details in this paper. These two kinds of corresponding MIG can both meet the requirement frequency-tunable gyrotron well. Besides, the variation of the electron beam quality, when the operating frequency of the 0.5 THz multi-mode continuously frequency-tunable gyrotron is tuned by changing the operating magnetic field $B_0$ and the accelerate voltage $V_0$, has been studied based on a PIC code. It is found that the electron beam quality is more sensitive to electrical tuning compared with magnetic tuning. The perpendicular velocity spread has a smaller fluctuation in diode-type MIG. The diode-type MIG with a single anode is relatively a simple structure and easy to manufacture, while it is more convenient to tune the electron beam parameters with adopting a triode-type MIG. The optimized diode-type MIG and triode-type MIG are both promising candidates of the electron beam source for the 0.5 THz broadband continuously frequency-tunable gyrotron.

## References


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