# Broadband THz Gyrotron Based on a Pulse Magnet

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***Abstract*—This paper presents the recent development of a 0.33 THz pulse gyrotron, operating on the fundamental harmonic co-rotating $TE_{62+}^{(1)}$ mode. It employs a novel pre-bunched interaction circuit. The pulse magnet generates a time varying magnetic field to tune the radiation frequency via backward wave interaction. The optimized system is capable of generating radiation power about 1 kW ~ 2 kW during 330 GHz ~ 340 GHz. The compact pulse gyrotron is promising in scientific research and industrial applications.**

## I. INTRODUCTION

THz radiation generated by gyrotron is applied to drive the dynamic-nuclear-polarization (DNP) enhanced NMR, which would greatly increase the high-field NMR sensitivity and bring revolution to the biomedical and material research [1]. Until now, the gyrotron is the best available high-power THz source to drive DNP-NMR system. Furthermore, gyrotron with broadband capability is especially attractive for a series of advanced applications [1-4].

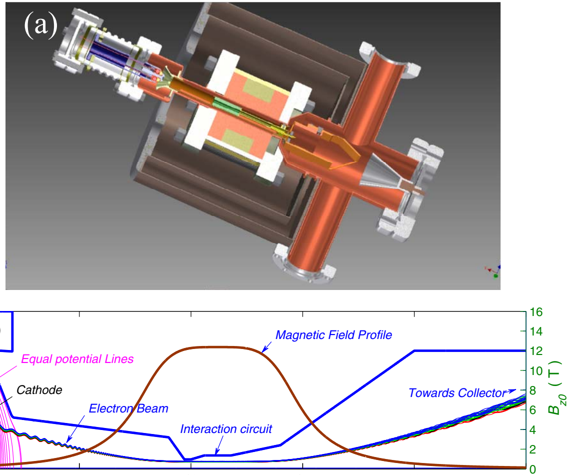

**Fig. 1** (a) The mechanical design of the 0.33 THz pulse gyrotron system. (b) The single-anode electron gun and the magnetic field profile.

In order to improve the tunable frequency bandwidth, the THz gyrotron reported in this paper selects a backward-wave interaction circuit to replace the traditional open cavity circuit [1]. The system design is shown in Fig. 1(a). The system consists of a compact pulse magnet, a single-anode MIG, a broadband interaction circuit, and an internal mode convertor. The output power radiates through a broadband Brewster window. The overall size of the pulse gyrotron system is very compact, as small as 25 cm X 25 cm X 42cm. Fig. 1 (b) shows the magnet profile and the single-anode electron gun. The electron beam is accelerated by the voltage of 20 kV and current of 0.5 A. When the highest magnetic field changes between 12.3 Tesla ~ 13.3 Tesla, without any assistant magnet coils in the gun region, the pitch factor of the electron beam varies between 1.6 ~ 1.2, and the axial velocity spread varies between 3.5% ~ 2.0%. Generally speaking, the electron optical system guided by the pulse magnetic field maintains a concise configuration and the electron beam parameters are very suitable for broadband tunable gyrotron application.

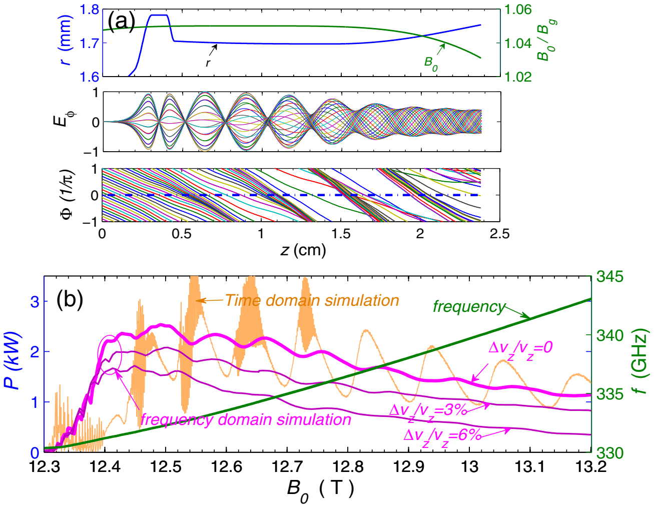

**Fig. 2** (a) The pre-bunching cavity, wave profile and phase-space bunching, and (b) output power simulation.

## II. BROADBAND INTERACTION CIRCUIT

One of the factors limiting gyrotron applications is the narrow-band operation, even approximated to single frequency, due to the open-cavity interaction circuit. As shown in Fig. 2, this pulse gyrotron employs a pre-bunched backward-wave interaction circuit to realize broadband operation capability. Systematical stability investigation demonstrates that between 12.3~13.2 Tesla there is a stable single-mode operation window for the designed co-rotating $TE_{62+}^{(1)}$ mode. And other competing modes will be naturally suppressed by such a complex circuit, including the competing modes $TE_{14\pm}^{(1)}$, $TE_{13,3+}^{(2)}$, $TE_{14,3+}^{(2)}$, and $TE_{4,3\pm}^{(1)}$. Both time-domain simulation and frequency-domain simulation are carried out. Assuming simulation using an electron beam with voltage of 20 kV, current of 0.5 A, and pitch factor of 1.5, the circuit can generate broadband coherent radiation with peak power 2.5 kW and tunable bandwidth exceeding 10 GHz in each pulse. Frequency nonlinear theory simulation reveals that electron beam velocity spread degrades the output power but imposes no influence on the tunable bandwidth. With assistant of the time-domain multi-mode simulation, it is again revealed that

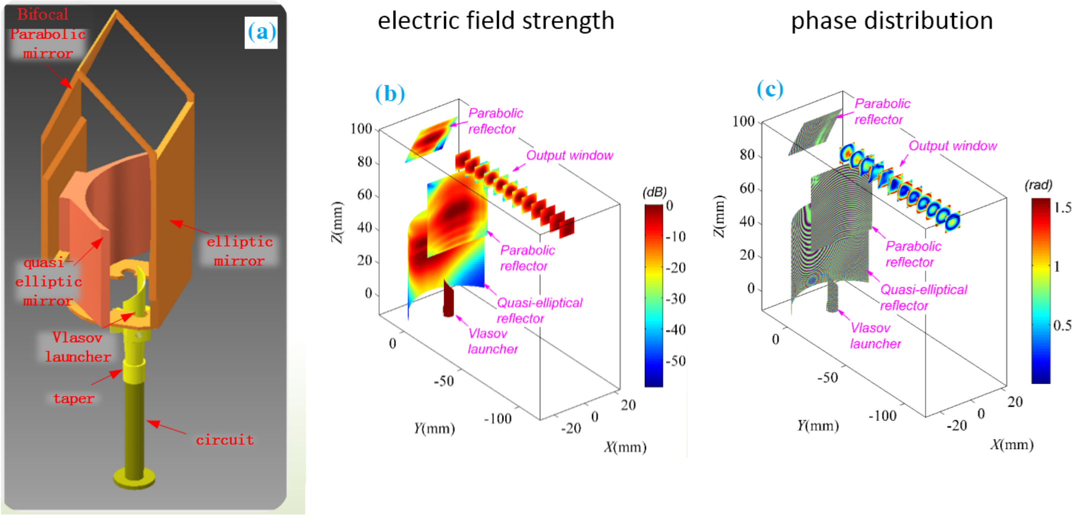

Fig 3 (a) The mechanical configuration of the broadband Qausi-Optical mode converter, (b) simulated field strength distribution, and (c) phase distribution

the co-rotating $TE_{62+}^{(1)}$ mode is sufficient to suppress all the transverse competing modes, but it encounters competition from a higher-order axial mode of the $TE_{62+}^{(1)}$ mode. As a result, the output power demonstrates trivial self-modulation between 12.3~12.7 Tesla. Future experiment will consider load lossy material in the pre-bunching cavity to suppress such axial mode competition. Other than the axial mode competition, the time-domain simulation also demonstrates that the output power fluctuates around the power curve generated by the frequency domain nonlinear code. This strong fluctuation may be induced by the reflections from the downstream boundaries. In other words, in the real system, the output power is with high sensitivity to reflection disturbance.

Since the gyrotron operates on the backward wave interaction with wave number $k_z$ much larger than that in a gyromonotron, the output power is sensitive to electron beam velocity spread due to velocity induced Doppler-shift spread $\Delta v_z k_z$ . As shown in Fig. 2(b), when the electron beam velocity spread increases from 0 to 6%, the peak power is reduced to about half of the maximum value. It's interesting that the power curve under $\Delta v_z = 6\%$ condition is more smooth than that of the $\Delta v_z = 0$. This is due to the fact that the backward-wave reflected by the upstream short transfers the power into the forward wave and the forward wave is slightly disturbed by the electron beam. Larger spread in electron beam velocity suppresses the coupling with forward wave power, hence the electron beam with larger velocity spread generates more smooth power curve.

## III. Broadband Quasi-Optical Mode converter

The broadband pulse gyrotron will employ a broadband Brewster window. Since the Brewster window requires a linearly polarized THz wave, a broadband internal Quasi-Optical mode converter is specially developed. Figure 3(a) shows the mechanical design of the QO converter. The QO mode converter is with a larger aperture Vlasov launcher, a quasi-elliptic mirror, a standard elliptic mirror, and a bifocal parabolic mirror. The simulated field distribution and phase distribution by using the vector diffraction theory are shown in Fig. 3(b) and Fig. 3(c), respectively. It is revealed that only the longitudinal focusing function of the QO converter is sensitive to the frequency, while the transverse focusing function is frequency independent. The Vlasov launcher selecting a larger aperture is the key to suppress the frequency sensitivity. The QO converter system converts the waveguide $TE_{62+}^{(1)}$ mode into the free space Gaussian beam in an extraordinarily broad bandwidth between 320 GHz ~ 340 GHz, maintaining the converter efficiency higher than 80%. The smallest beam waist on the output window is about 2.5 mm. This broadband QO converter provides strong support for the broadband THz gyrotron.

## IV. Conclusion

The preliminary design works related to a novel broadband coherent 0.33THz pulse gyrotron is presented in this paper. The pulse gyrotron provides a time varying magnetic field. The circuit selects a pre-bunching-cavity-loaded backward-wave circuit to generate broadband radiation due to magnetic tuning. The system consists of a broadband QO mode converter to transfer the waveguide $TE_{62+}^{(1)}$ mode into free-space Gaussian beam. This pulse gyrotron would be very promising in future advanced THz applications.

## Acknowledgement

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