Large Orbit Electron Gun for a High-Order Harmonic Terahertz Radiation Source

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I. Introduction

The terahertz region of the electromagnetic spectrum (0.1 – 10 THz) is relatively unexplored compared to the other regions of the spectrum including microwave, X-ray, and infrared. Potential applications for terahertz abound. These include detecting hazardous chemicals, cancer cells, and hidden weapons. However the critical roadblock to full exploitation of the terahertz band is the lack of compact, powerful (> 100 mW) coherent terahertz radiation sources [1 – 4]. In order to address the above needs, we propose to investigate a novel terahertz radiation source based on a high-order harmonic gyrotron interaction. The device circuit dimension that makes use of the gyrotron interaction can be larger compared to the current state-of-the-art terahertz devices. Therefore, it can provide significantly higher power and efficiency. The device takes advantage of the concept that in harmonic devices the magnetic field requirement is reduced by a factor of *s* (harmonic number) so that the magnetic field can be supplied by a lightweight periodic permanent magnet (PPM) instead of a bulky solenoid magnet. This offers a new solution and significant promise for lighter and more practical terahertz systems for various applications. A large orbit electron gun and beam forming system for the terahertz device have been designed. Analytical calculations along with simulations were carried out to determine the axial velocity spread, the velocity ratio, the Larmor radius, and the guiding center radius. Based on the adiabatic theory and angular momentum conservation, the analytical analysis provides a basis for initial beam performance prediction. Beam parameters and electron gun configuration for the terahertz device is presented.

II. Large-Orbit Electron Gun

A large-orbit axis encircling electron gun was adopted for the terahertz gyro-oscillator. Produced by a cusp magnetic field, an axis-encircling large-orbit electron beam offers the advantage that it can be placed in the region of high electric field of the device. For effective interaction, high electron beam quality which is mainly characterized by low velocity spread, is essential for practical high power terahertz sources. Low velocity spread in the high transverse energy electron beam is critical to efficiency of gyrodevices. Compared to gyro-amplifiers, gyro-oscillators do not require much smaller longitudinal velocity spread. However, precise control of beam location and annular width are very important to device performance. The fields in the proposed slotted circuit fall off rapidly as the beam is moved away from the vane tips. Therefore the annular width of the hollow axis encircling electron beam must be small and beam ripple must be near zero. Advanced design codes were extensively used to model and predict performance of the beam transport and stability characteristics. The input electron beam parameters were derived and further optimized from a gun simulation code and the output beam parameters were sent to a 3D particle-in-cell code for accurate prediction of the device performance. The gun electrodes and magnetic pole piece electrodes were varied systematically and automatically through hundreds of iterations until the beam ripple (guiding center spread) and axial velocity spread were minimized. The beam emittance in the beam is significantly reduced by the relatively high cathode voltage employed. The high beam voltage has the advantage that it reduces the effect of thermal velocities and increases the ratio of plasma wavelength to the magnet period (λ_p/L). It is expected that the proposed operating voltage range will be adequate to result in such effects. In addition, a low perveance gun, which is common in slow wave devices such as TWTs, creates some unusual electron beam focusing problems associated with the proper containment of the electrons. In the proposed gyro-oscillator, the operating gun parameters exhibit high enough perveance so that it can be free from the problems associated with the low perveance case. A commercially available high current density cathode which yields current densities up to 30 A/cm^2 with a lifetime of 2000 hours will be employed in the gyro-oscillator. Figure 1 shows the dispersion diagram of the proposed compact microfabricated terahertz high-order harmonic gyrodevice. The device operates at $300\ GHz$ where beam and wave dispersion lines intersect each other. The specification of the high-order harmonic gyro-oscillator is listed in Table 1. The beam placement position in the waveguide can be determined by factors such as interaction strength and wall loading of the waveguide wall. The interaction strength can be maximized when beam is placed at the position where the electric field amplitude of each mode is maximum. All modes require certain beam position in the waveguide for maximum interaction. Figure 2 shows the relative electric field amplitude (H-fuction) versus r_c/r_w for the operating $TE_{10,1}$ mode, where r_c represents the guiding center radius and r_w is the radius of the waveguide wall. For the operating $TE_{10,1}$ mode, several peaks exist where beam-wave interaction will be maximized.

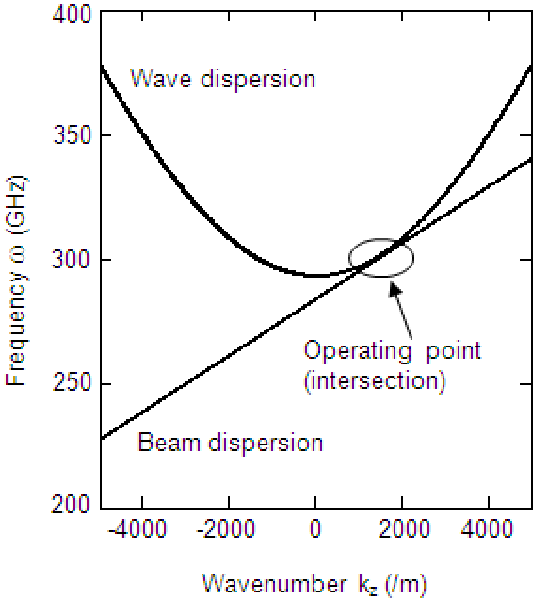

Figure 1: Dispersion diagram of the 300 GHz gyro-oscillator.

Table 1: Device and electron gun specifications for the high-order harmonic gyro-oscillator

Device Parameters	
Voltage	40 kV
Current	2.0 - 3.0 A
$\alpha = v_{\perp}/v_z$	1.5 - 2.0
$\Delta v_z/v_z$	5%
Magnetic field	1.1 Tesla
Operating frequency	> 300 GHz
Output power	> 1 kW
Circuit diameter	~ 700 µm
Mode	$TE_{10,1}$ (π mode)
Harmonic number	s =10

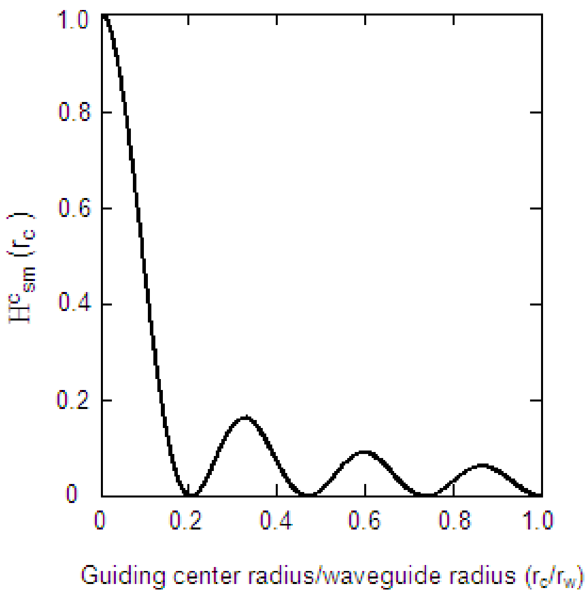

Figure 2: H-function vs. guiding center radius/waveguide radius. H-function describes the field strength as a function of guiding center radius.

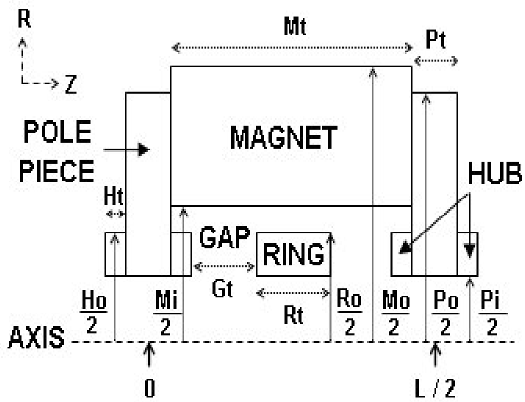

Figure 3: Cross sectional drawing of one periodic permanent magnet cell.

Figure 3 shows a cross sectional drawing of periodic permanent magnet for the terahertz system. The dimensions of periodic permanent magnet are described in Table 2.

Table 2: Periodic permanent magnet design parameters for the 300 GHz gyro-oscillator used in Figures 3.

Geometry	Dimension
Magnet thickness (Mt)	0.35″
Magnet inner dia. (Mi)	0.35″
Magnet outer dia. (Mo)	1.68″
Magnet material	Nd-Fe-B (Br=13.9 kG, Hc=12.9 kOersted)
Pole piece thickness (Pt)	0.3″
Pole piece inner dia. (Pi)	0.153″
Pole piece outer dia. (Po)	1.68″
Pole piece material	Iron
Hub material	Iron
Hub thickness (Ht)	0.05″
Hub outer dia. (Ho)	0.35″
Peak field (B_{peak})	11,026.73 Gauss

The performance of the large orbit axis-encircling electron gun employing the above periodic permanent magnet system will be presented.

References

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[3] U. S. News and World Report, “Catching T-Waves,” 2003.

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