Design of a Multi-kW, 600 GHz, Second-Harmonic Gyrotron

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***Abstract*—We present a design study of a pulsed 600 GHz gyrotron operating at the second harmonic for a planned experiment based on a 12 T cryogen-free superconducting magnet and a Varian VUW-8010 electron gun. Threshold current studies and multimode simulations indicate that stable single operation at output powers over 10 kW is achievable.**

I. Introduction And Background

As part of an effort to develop near-THz gyrotrons for remote sensing, materials processing, and dynamic nuclear polarization (DNP) enhanced nuclear magnetic resonance (NMR) applications, we have carried out a design study for a pulsed, second harmonic gyrotron operating at 600 GHz. Previously, a 460 GHz gyrotron operating at the second electron cyclotron harmonic and a 250 GHz first harmonic gyrotron were constructed specifically for use in DNP-enhanced NMR [1-3]. We are interested in increasing the output power to the kilowatt range at higher frequencies while employing existing equipment in initial experiments.

The gyrotron will employ a 12 T cryogen-free magnet being fabricated by Cryomagnetics, Inc. and a Varian VUW-8010 electron gun originally designed for a 35 GHz gyrotron. Adiabatic scaling laws were used to determine the approximate parameters of a suitable electron beam that can be produced by this gun in the axial magnetic field profile of the 12 T magnet. Next, a range of high-order TE modes were evaluated for strong second harmonic coupling to the electron beam and relative freedom from competition with modes operating at the first harmonic. Based on these studies the TE_{57} mode was chosen as the operating mode and a point design for a multi-kW pulsed gyrotron has been obtained. A CW version will be developed following hot tests of the present design.

II. Results

In order to promote coupling to volume modes, eliminate whispering-gallery modes, and minimize beam interception, the electron beam radius was constrained to be roughly half the cavity wall radius. Possible second harmonic modes that can operate in the magnetic field gap between the TE_{04} and TE_{53} first harmonic modes include the TE_{57}, $TE_{10,5}$, and TE_{38} modes. The cavity and electron beam parameters assumed in the calculations are given in Table I. The output *Q* factor was chosen to be twice the minimum diffraction *Q*. To estimate the Ohmic losses, the cavity wall conductivity was taken to be one fifth of the theoretical room temperature conductivity of copper. The results of starting current calculations for these modes are shown in Fig. 1. The calculations assume a Gaussian axial field profile in the cavity and a cold beam. Figure 1 shows that the TE_{57} mode should be relatively free from mode competition with both first and second harmonic modes at a beam current of 2 A. This was verified using a nonlinear, slow-time-scale, multimode code to investigate the stable operating regime of the TE_{57} mode [4]. Single-mode output was obtained from approximately 11.75 T to 11.825 T. The peak electronic efficiency was 15%, corresponding to a peak RF power generation of 14 kW. The peak Ohmic dissipation is about 4 kW limiting this design to low duty factor operation. Other aspects of the design are under investigation and available results will be presented.

Table 1. Beam and Cavity Design Parameters

Beam Voltage	60 kV
Beam Current	2 A
Cathode Emitter Radius	7 mm
Magnetic Compression Ratio	40
Beam Velocity Ratio	1.5
Maximum Magnetic field	12 T
Beam Radius	1.05 mm
Cavity Radius	2.16 mm
Cavity Length	10 mm
2^{nd} Harmonic Mode *Q*	7200
1^{st} Harmonic Mode *Q*	2400

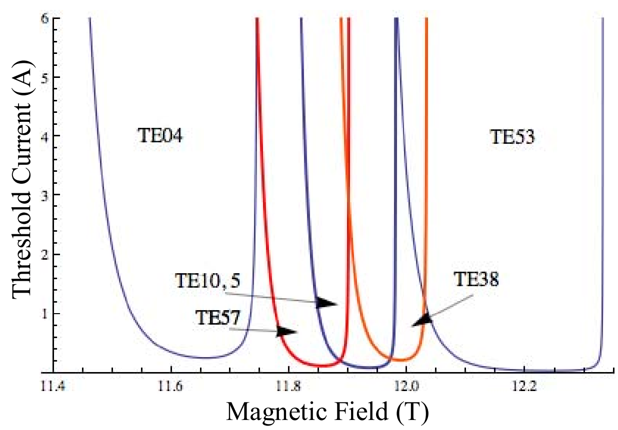

Figure 1: Threshold currents for the TE_{57} mode and competing first and second harmonic modes.

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