Design of a Wideband 140 GHz, 1 kW Gyro-Amplifier

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Abstract: *The design and simulation results for a 1 kW, 140 GHz gyro-amplifier are presented. A bandwidth of over 4.5 GHz has been achieved in simulation with peak saturated gain of over 52 dB. The HE_{06} mode of a confocal cylindrical waveguide is chosen as the operating mode and distributed loss is employed via diffraction to stabilize the circuit. The amplifier will be capable of amplifying short pulses on the nanosecond scale.*

Keywords: gyrotron amplifier; traveling wave tube; quasi-optical; confocal waveguide

Introduction

A novel, low voltage, short pulse gyro-amplifier is under development for pulsed Dynamic Nuclear Polarization (p-DNP) and Electron Paramagnetic Resonance (EPR) spectroscopy experiments in the Francis Bitter Magnet Laboratory at the Massachusetts Institute of Technology, Cambridge, MA. In DNP, the Signal-to-Noise Ratio of the spectrum can be increased by factors of several hundred by polarizing the sample with millimeter-wave radiation near the electron Larmor frequency [1]. Nanosecond-scale pulses can excite EPR spectra several hundred megahertz wide.

Amplifier system

The spectrometer system consists of three major sub-systems: The transceiver sends low power pulses to the input of the gyro-amplifier and detects the p-DNP/EPR signals, the gyro-amplifier, and the spectrometer probe. 50 to 100 mW phase-controlled nanosecond-scale pulses at 140 GHz will be amplified by the gyro-amplifier and delivered to the sample. The pulse sequence can last up to 20 μs with a maximum repetition rate of 1 kHz. A novel feature of this amplifier is its low beam power, which makes it difficult to achieve wide bandwidth and high gain. The specifications for the gyro-TWT are listed in Table 1.

Confocal Interaction Structure

A quasi-optical confocal interaction circuit was attractive for this application because it provides a diffractive mechanism for distributed loss without use of ceramics or other lossy dielectrics [2]. A confocal structure also promises ease of sever construction and simplified input coupler design, and it delivers electromagnetic fields at the output that are already Gaussian in one plane for transmission through a low-loss, quasi-optical corrugated waveguide. The geometry and electric field pattern of the HE_{06} mode in confocal waveguide are shown in Fig. 1.

Analysis in HFSS [3] revealed sensitivity in loss rate of only 0.7 dB/cm for up to 10% misalignment with respect to the mirror spacing and only 0.2 dB/cm for lateral translation of up to 8% of the aperture size. A comparison of the loss rates from a confocal cylindrical waveguide theory developed by Boyd and Gordon [4] and HFSS is shown in Fig. 2 for R_c=6.9mm at 140 GHz.

Table 1. Amplifier Specifications

Max. output power	1 kW peak
Min. pulse width	1 ns or less
Minimum bandwidth	1 GHz
Saturated gain	≥ 50dB

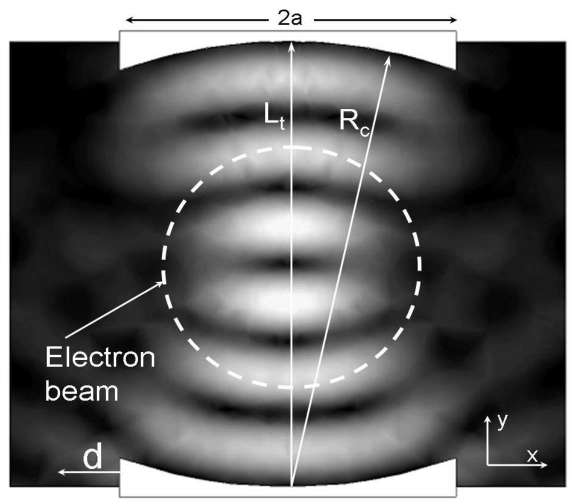

Figure 1. The geometry of the confocal waveguide overlaid with the HE_{06} electric field pattern (HFSS) and electron beam. For the confocal system, the mirror separation equals the mirror curvature ($R_c=L_t=6.9mm$). The value $a=2.45mm$ is the aperture size and d is the lateral misalignment.

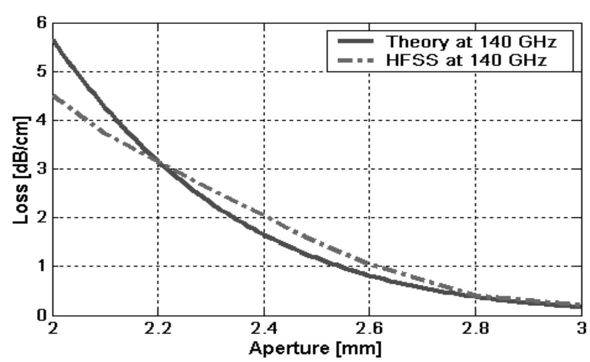

Figure 2. Comparison of loss rates between the confocal cylindrical theory and HFSS.

Table 2. Design Operating Parameters

Beam voltage, V_0	30 kV
Beam current, I_0	2.0 A
Beam pitch factor, α	0.7
Beam radius	1.9 mm
Input power	10 mW
Center frequency	140 GHz
Peak magnetic Field	4.9 T
Operating mode	HE_{06}

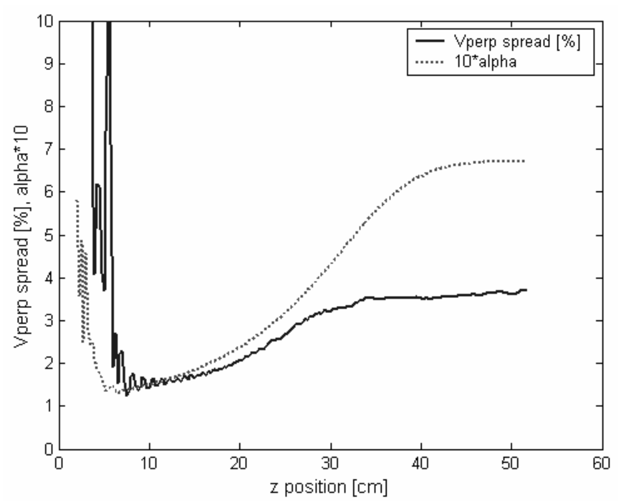

Figure 3. EGUN simulation of VUW-8140 electron beam characteristics.

Electron gun

The electron beam is placed at the second radial maximum of the HE_{06} operating mode due to the availability of a Varian (now CPI, Inc.) VUW-8140 triode electron gun. Using a magnetic compression factor of 24, the gun produces a 1.88 mm beam radius at the entrance to the interaction circuit.

The electron gun was originally designed for operation at 65 kV and has been modeled at 30 kV for the current experiment with EGUN [5]. Simulations show that a velocity pitch factor of 0.70 and transverse velocity spread of under 4% at the entrance to the interaction region are achievable. Fig. 3 shows relevant outputs of this simulation.

Simulation of Gyro-TWT

The confocal gyro-TWT has been simulated using a nonlinear code developed at MIT for confocal gyro-TWT structures [2]. The structure used in the simulation contained three sections 70mm long separated by two 20mm sever sections (30 dB loss per sever). The severs were implemented using a small aperture of 1.5mm. For a loss rate of 2.0 dB/cm in the interaction circuit, this code revealed that the specifications for the gyro-TWT are within reach using the operating parameters in Table 2. Fig. 4 shows a peak power from the simulation of 1.9 kW at a -3 dB bandwidth of over 4 GHz with 4.5% perpendicular velocity spread.

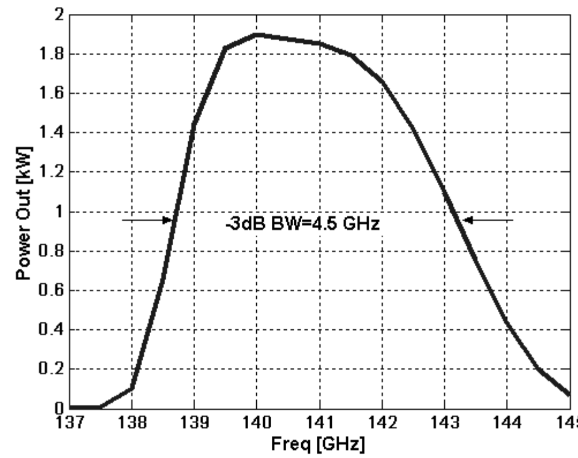

Figure 4. The power versus frequency predicted by a nonlinear code.

Superconducting Magnet

A 6.2 T superconducting magnet was acquired from Magnex Scientific, Ltd. The magnet is actively shielded to reduce the stray magnetic fields. The magnet has a 28 cm, +/-0.5 % flat field and a 127 mm warm bore.

Discussion

A 140 GHz short pulse gyro-amplifier is being developed using a novel low power beam and confocal cylindrical interaction circuit. Simulations with a nonlinear code show the specifications are within reach.

A cold test confocal structure is being fabricated to verify the simulation of the structure in HFSS. This structure will also be used to evaluate the input coupler design.

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