An overmoded 140 GHz, 1 kW quasioptical gyro-TWT with an internal mode converter

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Abstract—The design and experimental study of a 140 GHz, 1 kW gyro-traveling wave tube (Gyro-TWT) operating in the HE\textsubscript{66} mode of a confocal waveguide is presented. A combination of quasi-optical gain sections with dielectric loaded severes enables high gain operation with mode selectivity. A nanosecond-scale 120 mW pulse driver at 140 GHz was demonstrated. This input driver pulse will be amplified by the Gyro-TWT and the resulting output high-power short pulse will be transmitted to an EPR spectrometer probe. A quasi-optical mode converter utilized to transform the higher order operating confocal mode into a Gaussian-like beam was designed and cold tested. The simulated and measured Gaussian beam patterns of the output mode converter are in good agreement.

I. INTRODUCTION

A 140 GHz Gyro-TWT is being developed for use in an electron paramagnetic resonance (EPR) spectroscopy experiment at MIT [1]. The amplifier is designed to amplify nanosecond scale pulses for EPR measurements. Previously, nanosecond scale pulses at a power level of close to 1 kW have been achieved at frequencies as high as 94 GHz, but not at 140 GHz or higher [2, 3]. The short pulse capability requires wide bandwidth and high phase stability. CW operation is much easier to achieve at low electron beam power, whereas an amplifier would lend itself to high power phase-stable short pulses [4]. The Gyro-TWT is inherently capable of wide bandwidth, high gain, short pulses and high phase stability. The design goals of the amplifier are an output power > 1 kW with gain over 45 dB, and a bandwidth exceeding 1 GHz. The amplifier has a quasi-optical interaction structure comprised of two confocal mirrors following earlier work at MIT [5].

II. DESIGN OF QUASIOPTICAL GYRO-TWT

The present work describes a new amplifier design for improved gain and output power. The new amplifier circuit consists of three 72-mm long gain sections separated by severes. The gain sections consist of two mirrors with equal radii of curvature $R_c$=6.8 mm and aperture width $2a = 5$ mm, separated by a distance $L_A = R_c$ from each other. The severes are made of alternating sections of lossy dielectric ceramic and metal rings. Each lossy sever section has three axial periods of 5 mm and a total length of 15 mm. The loss of each sever is calculated to be greater than 20 dB at 140 GHz according to HFSS simulations. This new sever reduces reflections into the gain section, enabling stable operation without oscillations. The new sever has higher loss than the diffractive sever used in prior experiments [1]. Assuming a beam pitch factor of 0.75 and 5% perpendicular velocity spread, nonlinear simulations at 140 GHz predict that the Gyro-TWT will produce 2.7 kW of saturated output power and a saturated gain of 42 dB for a 35-kV 2-A electron beam with beam radius of 1.9 mm. The relevant design parameters of the Gyro-TWT are summarized in Table 1.

Table 1. Gyro-TWT design parameters

| Frequency | 140 GHz | Beam current | 2 A |
|-----------|---------|--------------|-----|
| RF output power | > 1 kW | Beam pitch factor | 0.75 |
| Operating mode | HE\textsubscript{66} | Saturated Gain | > 40 dB |
| Beam voltage | 35 kV | Magnetic field | 5.07 T |

III. MODE CONVERTER

After amplification, the operating HE\textsubscript{66} confocal waveguide mode is converted into a Gaussian beam by an internal quasi-optical mode converter before being sent to the EPR probe.

The mode converter consists of a uniform confocal section, an uptaper confocal section, two dimples and two mirrors. Fig. 1 shows the HFSS 3-D output mode converter geometry. The complex magnitude of the electric field at the midplane of the mode converter is also shown in Fig. 1. Fig. 2 (a) shows the simulated pattern at the output plane labeled in Fig. 1. The mode converter was built and cold tested using as an input driver an Extended Interaction Klystron capable of generating 100 W with pulse-width of 2\,$\mu$s over 139.2 to 142 GHz. The Gaussian output mode pattern was measured at the end of the mode converter using a pyroelectric camera PyroCam III from Spiricon, Inc and the result is shown in Fig. 2(b). As can be seen from the mode patterns in Fig. 2, good agreement is observed between measurement and simulation.

IV. SHORT PULSE INPUT DRIVER

We have designed, built, and tested a nanosecond scale pulse driver using an X-band mixer switch [2] with an upconverter to 35 GHz and a Virginia Diodes, Inc. x 4 multiplier to 140 GHz. Fig. 3(a) shows the circuit diagram. A 8.75 GHz master oscillator source is split between an X-band gated mixer having a 4 GHz IF bandwidth and a MITEQ third harmonic active multiplier that generates 26.25 GHz output.
These signals are summed in another mixer to generate a 35 GHz pulse. The 35 GHz signal is then fed into a 140 GHz amplifier multiplier chain, which is capable of generating an output power of up to 120 mW. Tuning of the frequency synthesizer about the 8.75 GHz frequency results in tuning of the output at full power over a frequency range of 138–142 GHz. Present pulse length is limited by the nanosecond-scale pulse generator gate. Fig. 3(b) shows measured signals from the nanosecond-scale pulse generator gate and from the 120 mW output pulse at 140 GHz.

The input driver signal will enter the amplifier structure through a side-facing 1.27 cm diameter, 3.27 mm thick window which is designed to be transparent at 140 GHz. Then the 140 GHz signal propagates into an overmoded 1.27 cm diameter copper waveguide in the TE_{11} mode. Near the input of the Gyro-TWT, a downtaper guides the 140 GHz input into a short section of fundamental WR8 waveguide with a 90° H-plane bend. The measured loss of the input transmission line including the isolator and other diagnostics was 10 dB at 140 GHz.

This recently redesigned 140 GHz, 1 kW Gyro-TWT with an internal mode converter is being fabricated and is expected to be tested during the summer.

![Figure 1. Cross section view of the output mode converter with two dimples and two mirrors.](image1)

![Figure 2. Mode converter output electric field profile; (a) HFSS simulation and (b) measurement. Each figure is a square with a side length of 12.4 mm.](image2)

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