# A Wideband 140 GHz, 1 kW Confocal Gyro-Traveling Wave Amplifier

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***Abstract*— The experimental results of a zero-drive stable, short pulse 140 GHz gyro-traveling wave amplifier are presented. The amplifier has achieved a linear gain of 34 dB, a saturated bandwidth of over 1.5 GHz, and an output power of over 820 W peak at a beam voltage of 38 kV, beam current of 2.7 A, and beam pitch factor of 0.6. The gyro-TWT operates in the HE(0,6) mode of a quasi-optical confocal waveguide.**

## I. Introduction And Theory

A 140 GHz gyrotron amplifier [1] is being developed for use in Electron Spin Resonance (ESR) spectroscopy experiments at the MIT Francis Bitter Magnet Laboratory. The amplifier has a quasi-optical interaction structure comprised of two confocal mirrors following earlier work at MIT [2]. The mode selectivity of the confocal waveguide allows for operation in the $HE_{06}$ mode, a high order mode which is analogous to a $TE_{03}$ mode of a cylindrical waveguide without the concomitant mode competition. The interaction structure features a diffractive loss mechanism that improves stability and is easy to fabricate at the mm and sub-mm wave frequencies.

Two mirrors with equal radii of curvature $\mathbf{R_c}$, separated by distance $\mathbf{L_\perp}$ have mirror aperture width **2a**. Fig. 1 shows this geometry in cross section with normalized power contours for $\mathbf{R_c}$=$\mathbf{L_\perp}$=6.90mm, and aperture size of **2a**=6.0mm. The resulting field patterns are nearly Gaussian in the *x*-direction. The electron beam is positioned to interact primarily with two maxima of the electric field. The confocal waveguide is less susceptible to oscillations in lower order modes as their wider footprint on the mirrors leads to greater diffraction loss.

The amplifier circuit consists of three 7cm amplifier sections with $\mathbf{R_c}$=6.90mm and **2a**=4.8mm separated by two quasi-optical severs to limit the gain in each section. Severs are constructed simply by narrowing the mirror aperture size. For tuning purposes, the mirror spacing is $\mathbf{L_\perp}$=6.82mm. A photograph of the completed interaction circuit is shown in Fig. 2.

## II. Results

The formation of the $HE_{06}$ mode was verified in cold test by a perturbation technique similar to a bead-pull in the transverse direction of the waveguide. This technique revealed that the operating mode is excited over a bandwidth of about 1.5 GHz. In addition, a double-disc output window was installed to reduce parasitic oscillations and access higher gain. To date, the amplifier has achieved 34 dB linear gain and over 820W maximum peak output power with zero-drive stability.

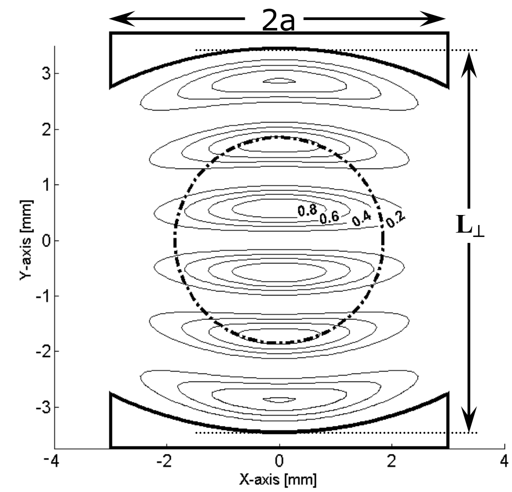


Figure 1. The confocal geometry and normalized power contours for the $HE_{06}$ mode. The two cylindrical mirrors have a radius of curvature $R_c = L_\perp$. The annular electron beam position is indicated by the dash-dot circle.

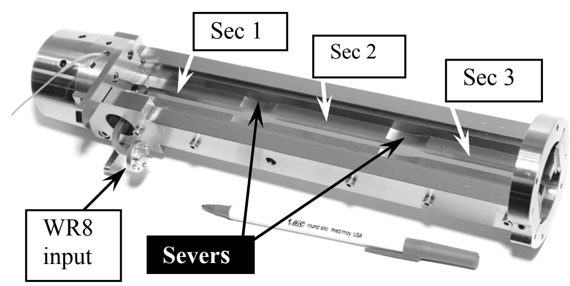


Figure 2. The completed three-section confocal interaction circuit. Total circuit length is 25 cm.

The measured peak output power versus frequency is plotted in Fig. 3 at 38.5 kV, 2.5 A, and an axial magnetic field of 5.05 T. The measured saturated bandwidth is 1.5 GHz. The simulation curves show a best fit for α=0.54 and a parallel velocity spread of approximately 3.5% (perpendicular spread of 12%). Velocity spread and low α-value are major factors affecting gain and bandwidth. The simulation solves the set of self-consistent equations for a gyro-TWA with an arbitrary waveguide [3].

In Fig. 4, an adjustment of operating parameters to 37.7 kV and 2.7 A produced a peak output power of over 820 W at a bandwidth of approximately 0.8 GHz. The best fit in the simulation was for α=0.57 and a parallel velocity spread of 4.0%.

The α-value is lower than expected and has a profound effect

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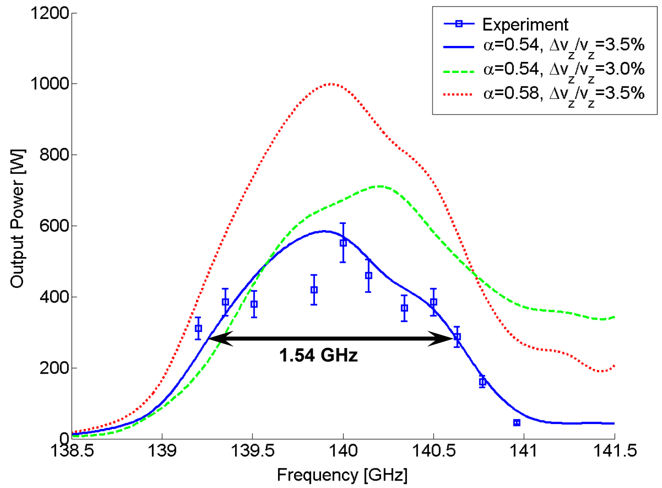


Figure 3. Measured peak output power (markers) and simulations (curves) at 38.5kV, 2.5A. The simulation fit is best for α=0.54, $\Delta v_z/v_z$=3.55%. The experimental bandwidth has been measured at over 1.5 GHz.

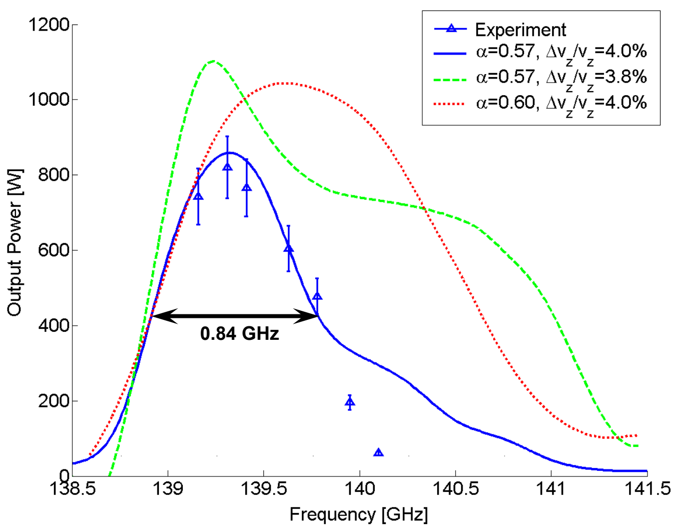


Figure 4. Measured peak output power (markers) and simulations (curves) at 37.7kV, 2.7A. The simulation fit is best for α=0.57, $\Delta v_z/v_z$=4.0%. The experimental power has been measured at over 820 W.

on the gain and output power. Velocity spread is equally important and severely restricts gain and bandwidth. Therefore, a new operating point was sought for the electron gun. Simulations using EGUN [4] indicate that higher α-values of 0.7 to 0.8 are obtainable at 40-45kV while simultaneously lowering the perpendicular velocity spreads.

In Fig. 5, the measured linear gain at 37 kV, 2.7 A is compared to a simulation at α=0.6, $\Delta v_z/v_z$=3.5%. The ripple present on the measurement is attributed to resonances in the input transmission line that were not included in the simulation. The peak zero-drive stable gain in the experiment was measured to be 34 dB.

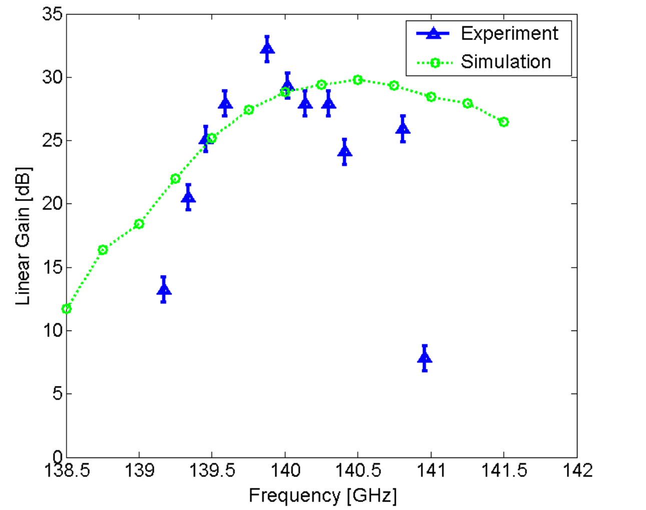


Figure 5. Measured linear gain at 37kV, 2.7A. The simulation fit is best for α=0.6, $\Delta v_z/v_z$=3.5%.

The amplifier has been tested with pulses as short as 4 ns FWHM at peak output powers up to 400 W with no measurable pulse broadening. No source capable of injecting a pulse shorter than 4 ns is available at our laboratory at this time.

## III. CURRENT ACTIVITY

The bandwidth is now limited to 1.5 GHz by irregularities in the input coupler section, which also negatively impacts coupling efficiency. Electromagnetic simulations put an estimate of the coupler bandwidth at over 4 GHz. A new version of the amplifier circuit is being installed for wider bandwidth and for better coupling of the input power. A new electron gun operating point is predicted to raise the α-value for higher gain and output power.

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## REFERENCES

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