Overmoded Traveling Wave Tubes for MM and THz Applications

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***Abstract*—High power sources of coherent radiation, producing Watts to tens of Watts of average power, are needed for applications in the millimeter wave and THz regimes. Overmoded traveling wave tubes offer the possibility of meeting these requirements in rugged and simple to fabricate devices. Results on a 94 GHz overmoded TWT confirm the viability of this approach. Designs for a PBG amplifier operating at 250 GHz, based on the successful 94 GHz TWT, are described.**

I. INTRODUCTION

COHERENT sources of radiation at frequencies from 100 to 600 GHz are needed for applications in scientific research, defense, radar, communications, imaging, nondestructive testing etc. The gyrotron is capable of meeting these needs but the requirement of a superconducting magnet makes the gyrotron less desirable in many cases because of cost and siting issues. Traveling wave tubes have been developed at frequencies up to 94 GHz but are less well developed at higher frequencies. We have recently demonstrated first operation of an overmoded TWT at 94 GHz with a device gain of 21 dB and an output power of 27 Watts. When accounting for losses on input and output coupling, the TWT circuit achieved 27 dB of gain and 55 Watts of output power. These results are very promising for further extension of the overmoded TWT. Extensions are being planned to increase the output power at 94 GHz and the frequency to 250 GHz. Sources at 250 / 263 GHz are needed for research on Dynamic Nuclear Polarization NMR at 380 / 400 MHz.

II. RESULTS AT 94 GHZ

A 94 GHz overmoded TWT has been designed, fabricated, and successfully tested and is shown in Fig. 1 [1].

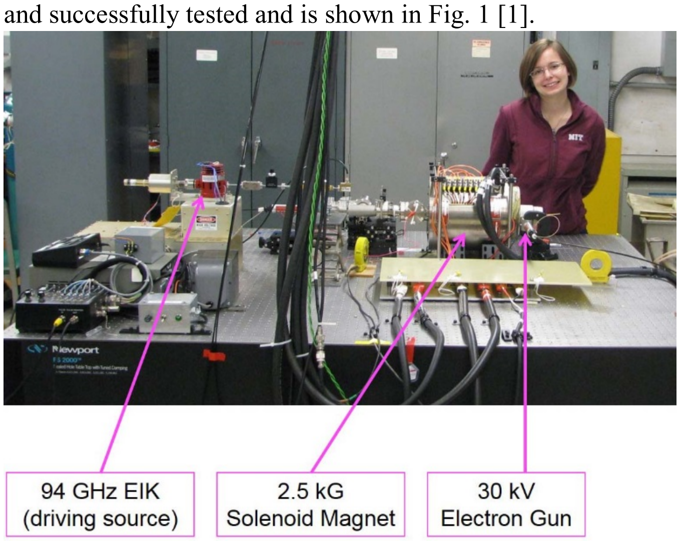

Fig. 1. The 94 GHz Overmoded TWT Experiment

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The TWT operates in the rectangular TM_{31} mode of the cavity, while lower order modes are suppressed using selectively placed strips of lossy dielectric. The 87-cavity TWT circuit was directly machined from Glidcop, a dispersion-hardened copper. The TWT was tested in a 0.25 T solenoidal magnetic field in 3 microsecond pulses. Operating at a voltage of 30.6 kV with 250 mA of collector current, the TWT was zero-drive stable and achieved 21±2 dB linear device gain with 27 W peak output power. Taking into account 3 dB of loss in both the input and output coupling circuits, the gain of the TWT circuit itself is 27±2 dB with 55 W of saturated circuit output power. Using the 3D PIC code CST Particle Studio, the linear circuit gain was estimated to be 28 dB and the saturated output power 100 W, in good agreement with the experimental results. The measured bandwidth of 30 MHz was significantly smaller than the predicted value of 250 MHz. The overmoded TWT is a promising approach to high power TWT operation at W-band and to the extension of the TWT to terahertz frequencies. The beam tunnel in the overmoded 94 GHz TWT is 0.8 mm in diameter which is about twice the diameter of alternative 94 GHz TWT designs, such as the folded waveguide TWT. We extend these experiments and other designs made at 94 GHz in making oversized structures that are capable of being fabricated with conventional machining to 250 GHz [2, 3].

III. 250 GHZ AMPLIFIER DESIGN

The photonic band-gap (PBG) based TWT amplifier design is shown in Fig. 2.

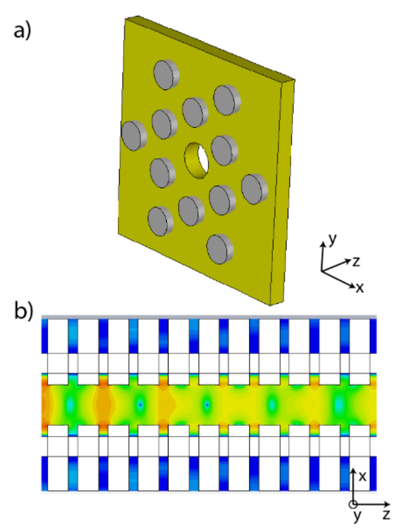

Fig. 2. a) A single period of the 250 GHz amplifier design, where the grey cylinders are 0.36 mm diameter stainless steel rods that form 0.2 mm long PBG cavities between the yellow copper plates. The overall period is 0.41 mm. b) A CST MWS simulation of the electric fields transmitted at 250 GHz.

The PBG TWT is designed for operation at 20 kV, 200 mA with an oversized beam tunnel that is 0.45 mm in diameter CST Microwave Studio is used to calculate the dispersion of the structure and the coupling impedance for a 0.4 mm diameter electron beam. The coupling impedance is calculated to be 2.9 Ohms. The dispersion of the lowest order TM mode of the PBG amplifier is shown in Fig. 3 along with the dispersion for a 20 kV electron beam.

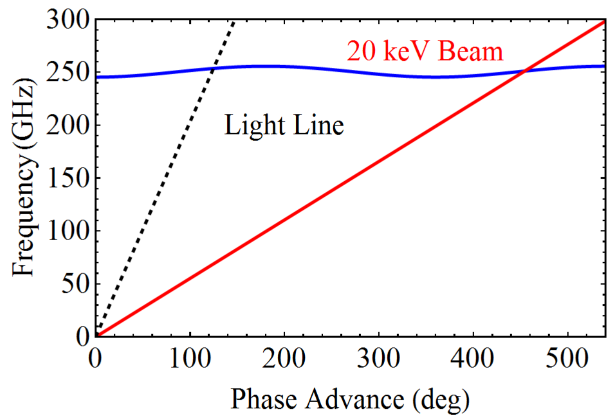

Fig. 3. Dispersion curve (blue) for the PBG amplifier. The beam line for a 20 kV electron beam is shown in red as well as the light line in blue.

Using CST Particle Studio and a nonlinear TWT code developed at MIT we can estimate the output power of the PBG amplifier. The CST PIC simulations also use input and output couplers which were designed to couple microwaves in these simulations. Shown in Fig. 4 is the gain for an input power of 10 mW, comparing linear Pierce theory with the MIT code and the CST PIC simulations.

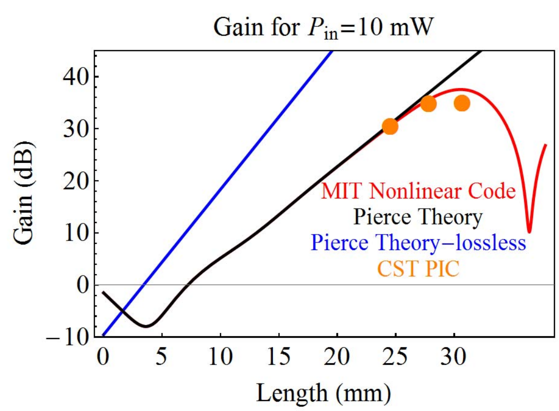

Fig. 4. Gain curves vs. Length for the PBG TWT amplifier operating at 20 kV, 200 mA. Shown is the gain using lossless Pierce theory (blue), Pierce theory with ohmic loss and space-charge (black), the nonlinear MIT code (red), and CST PIC simulations (orange dots) for *f*=250.6 GHz.

The linearity of a 60 period long (*L*=24.6 mm) structure was also investigated with CST and compared to the nonlinear MIT TWT code. The device was observed to saturate at an output power of 35 W, and the linear gain of the amplifier was found to be about 30.5 dB, as shown in Fig. 5.

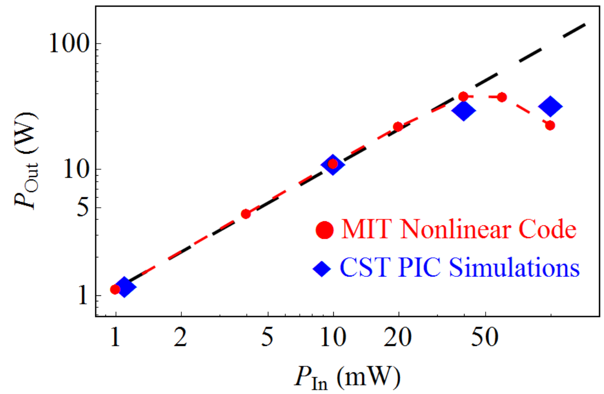

Fig. 5. Power out vs power in comparing CST simulations (blue) with the nonlinear TWT code (red) for a structure that is 24.6 mm long.

In addition, several CST simulations were run with different input frequencies for the 24.6 mm long structure in order to measure the bandwidth of the device. This is shown in Fig 6, where the 3 dB bandwidth was found to be about 600 MHz. The low bandwidth is partially due to the input and output couplers which were used in the simulations, and further optimization will be done to improve the bandwidth to 1 GHz which is useful for DNP/NMR spectroscopy.

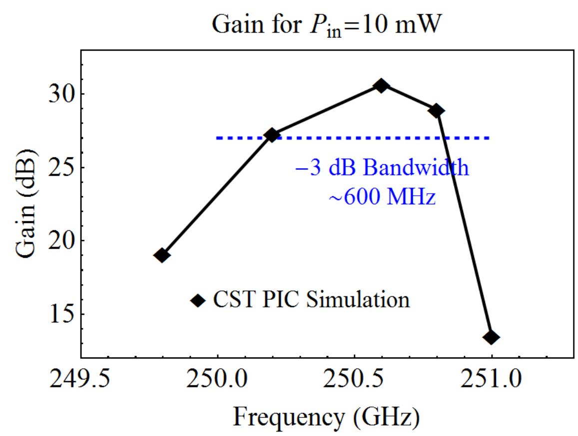

Fig. 6. Gain of the PBG amplifier vs. frequency. A 600 MHz bandwidth is measured for the 24.6 mm long structure.

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References

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