Tapered Tube, Microsecond Electron Beam Gyrotron Backward-Wave-Oscillators

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Abstract

Experiments have been performed to test microwave efficiency enhancement and pulselength extension of the gyrotron-backward- wave-oscillator (gyro-BWO) through the use of a tapered interaction tube. The MELBA accelerator has been utilized to generate electron beams with parameters: V=-0.7 to -0.8 MV, I=1-4 kA, and pulselengths from 0.5-1 μs. The microwave frequency is magnetically tunable in the range from 4.6-6 GHz. MAGIC code modeling has guided the experimental selection of taper magnitudes to enhance efficiency and pulselength. The optimal taper magnitude found in both the experiment and model has been a 10% downtapered tube, which gave a significant increase in both microwave tube power (factor of ~2, up to about 80 MW) and pulselength (≈ 30 % average increase up to 0.38 μs) over uniform tubes. Integrated microwave pulse-energy is also maximized for the 10% downtapered tube. Taper magnitudes larger than 10% gave reduced microwave power and energy.

I. INTRODUCTION

High power, long-pulse, microwaves have many applications in RF accelerators, defense electronics testing, and plasma heating. One of the major challenges has been to simultaneously generate multimegawatt microwaves while maintaining the microwave oscillation mechanism over a fraction of a microsecond. During the past several years, the uniform tube gyrotron-backward- wave-oscillator (gyro-BWO) [1,2] has shown considerable promise for both high power and long pulse operation [3]. Recently, improvement in gyro-BWO performance has resulted from tapered-interaction tubes [4]. A summary of gyro-BWO experiments on tapered interaction tubes is presented here.

II. EXPERIMENTAL CONFIGURATION

The experimental configuration is depicted in Figure 1. Electron beams are generated by the Michigan Electron Long Beam Accelerator, MELBA, at diode parameters: voltage = -0.7 to -0.8 MV, I_{diode}= 1-10 kA, and pulselengths=0.5-1 μs. A velvet button cathode is utilized, which reduces diode closure, to provide relatively flat current. The diode magnetic field coils are pulsed to generate about 1 kG magnetic field. A graphite anode apertures the e-beam to 5 cm diameter. The beam enters a solenoidal magnetic field coil on the transport tube, which generates 3-8 kG. This range of magnetic field allows the frequency to be magnetically tuned from 4.6-6 GHz. A number of interaction tubes and orientations were run: 1) copper tube with uniform cross section and 1.9 cm radius (20 cm long), 2) tapered tube, average radius of 1.9 cm with 10% decrease in direction of e-beam propagation (defined here as downtaper or - orientation), 3) tapered tube with average radius of 1.9 cm with 23% taper (both + and - orientations tested), 4) tapered tube with average radius of 1.9 cm with 43% taper (both + and - orientations tested). Microwaves were extracted by an S-band waveguide antenna at the diode-end of the machine.

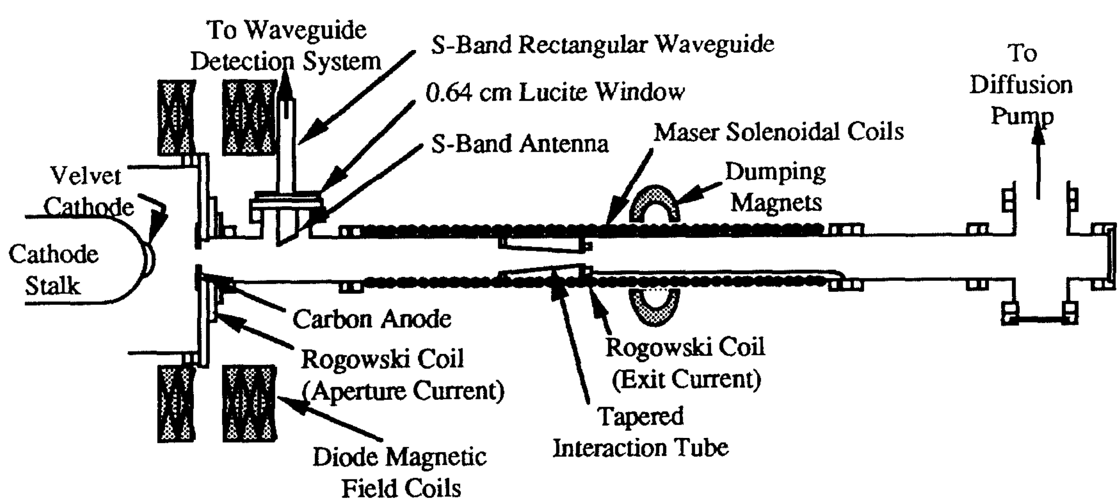

Figure 1. Experimental Configuration for tapered gyro-BWO.

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Recent frequency-swept measurements of the microwave coupling have shown a maximum coupling efficiency of -7.5 dB (~18%) between tube microwaves and this antenna. The gyro-BWO microwave output was split by directional couplers and further attenuated for measurement with calibrated diode detectors. Reflected microwaves were typically directed through a lucite window at the far end of the gyro-BWO into a large tank lined with microwave absorber.

III. EXPERIMENTAL RESULTS

Figures 2 and 3 show examples of gyro-BWO experimental signals detected for the uniform tube and the 10% downtapered tube. Voltage and current signals from MELBA are fairly flat over at least the first microsecond of the e-beam pulse. Generally, the microwave emission was longer and the power was higher for the 10% downtapered tube versus the uniform tube. Assuming the maximum value of coupling (≈18%) between the tube and antenna, the peak microwave tube power (up to about 80 MW) for the 10% downtapered tube is more than a factor of two higher than the peak tube power (≈30 MW) found thus far from the uniform tube. The high power microwave emission magnetic tuning band was much larger for the tapered tube, as expected.

MAGIC code simulations predicted that the gyro-BWO power enhancement from tapered tubes was expected to be optimal for the 10% downtapered case, out of all the cases run (±10%, ±23%, ±43%) This is in qualitative agreement with the experiments, which showed reduced power at tube tapers of ±23% and ±43%, relative to the uniform-tube case.

Significant increases in the microwave pulselength were also observed with the 10% downtapered-tube gyro-BWO, as seen in Figure 4. The average pulselength with the tapered tube was 380 ns compared with 300 ns for the uniform tube, about a 30% increase. By integrating digital oscilloscope microwave signals it was found that inferred integrated energy was also greater with the 10% downtapered tube, compared to the uniform case.

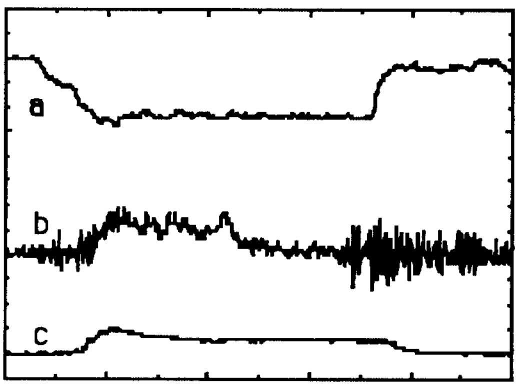


Figure 2. Data for gyro-BWO with uniform tube:
a) Beam voltage (310 kV/div),
b) Microwave detector signal (25 mV/div).
c) Transported beam current (2 kA/div),
Solenoidal field is 5100 G.
Time scale is 100 ns/div.

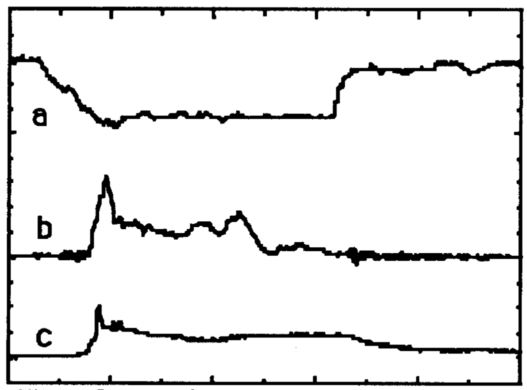
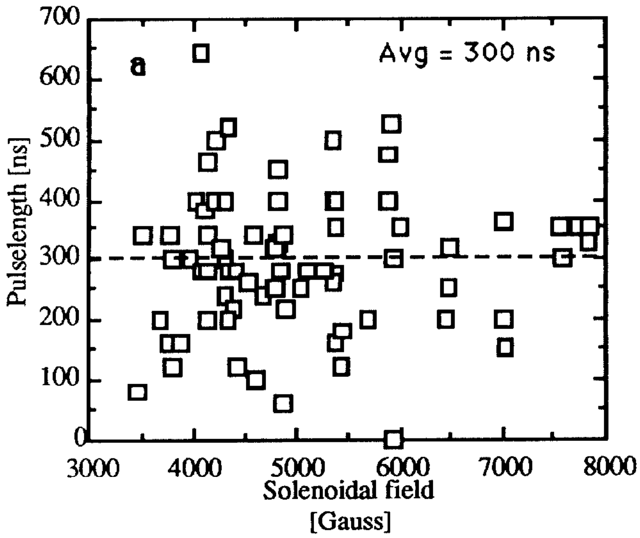


Figure 3. Data for gyro-BWO with 10 % downtapered tube:
a) Beam voltage (310 kV/div),
b) Microwave detector signal (100 mV/div).
c) Transported beam current (2 kA/div),
Solenoidal field is 5100 G.
Time scale is 100 ns/div.



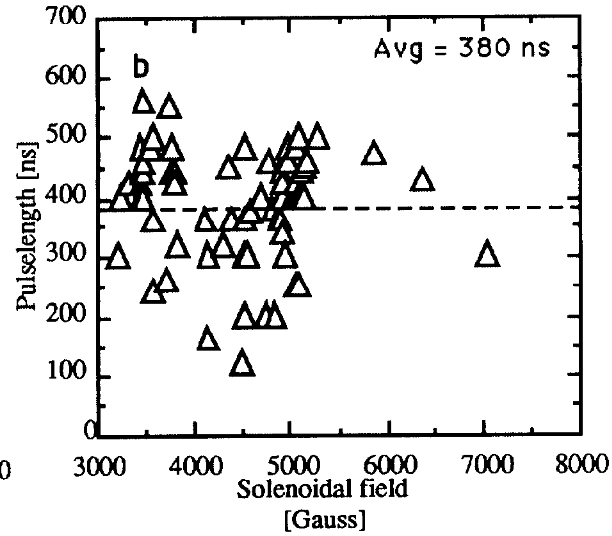


Figure 4. Microwave pulselength for gyro-BWO:
a) Uniform tube, and
b) Tube with 10% downtaper.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

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