EXPERIMENTAL DESIGN OF 100 MW X-BAND AND Ku-BAND GYROKLYSTRONS

W. Lawson, J. P. Calame, P. E. Latham, J. Cheng, V. L. Granatstein, and M. Reiser
Electrical Engineering Department and Institute for Plasma Research
University of Maryland
College Park, MD 20742 USA

Abstract

In this paper we present design plans for experiments with fundamental and second-harmonic gyroklystrons which are expected to produce output powers above 100 MW at 8.568 and 17.136 GHz, respectively. We describe the required modifications to our existing test bed and simulation results for a 500 kV, 480-720 A single-anode magnetron injection gun which was designed at the University of Maryland and is currently under construction. We also detail the designs of two-cavity amplifier circuits and discuss the simulated performances which indicate efficiencies of 40% and 35% are possible for the fundamental and second harmonic experiments, respectively.

Introduction

At the University of Maryland, we have been exploring the feasibility of using gyroklystrons and gyrotwystrons to drive the next generation of linear colliders [1] - [4]. Our current work has culminated in peak powers of about 30 MW in 1 μs pulses near both 10 GHz and 20 GHz with fundamental and second harmonic gyroklystron interactions, respectively. The beam voltage has hovered near 450 kV and beam powers have always been about 100 MW. The gain achieved in two-cavity tubes has typically been near 30 dB. These results represent a significant increase beyond the previous state-of-the-art in peak power level for similar gyro-amplifiers, but are still below the currently anticipated requirements. We have formulated plans to modify the present system to enable us to exceed the 100 MW level for output power. The major changes required are detailed in the sections below.

The Test Bed and Electron Gun

Currently, our modulator is capable of producing 460 kV, 400 A pulses with 1 μs flat tops. About half of this current is diverted to a resistive divider as dictated by the needs of our double-anode magnetron injection gun. With minor adjustments, we will increase the voltage capability to 500 kV. By doubling the number of pulse-forming networks (from 4 to 8), we will increase the current capability to 800 A.

We have designed a single-anode magnetron injection gun which will allow us to fully exploit the upgraded modulator. This gun has a sufficiently large emitter strip radius to keep the current density levels at the same value as our present gun. Fig. 1 shows the overall layout of the system and Fig. 2

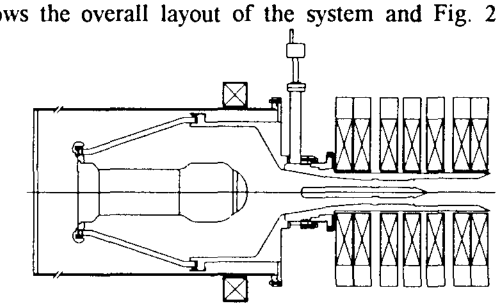

Figure 1. The experimental set-up.

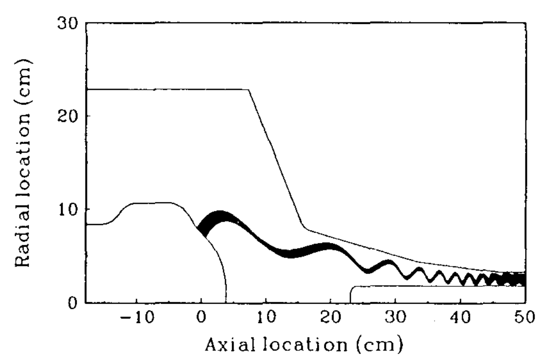

Figure 2. The magnetron injection gun layout.

depicts the electrode layout and the simulated beam trajectory. In Fig. 3, the time evolution of the average perpendicular-to-parallel velocity ratio at the nominal operating point is displayed. A velocity ratio of 1.5 is achieved at the entrance to the microwave circuit via an adiabatic magnetic compression ratio of 8.8. In Fig. 4. we plot the dependence of velocity spread on beam current; we maintain a constant velocity ratio of 1.5 by adjusting the cathode magnetic field. A wide range of currents are accessible with velocity spreads well below 6 % to 400 A and below 10% to 720 A. This gun is currently under construction at Varian.

The existing magnets and supplies will be used on the new system, with the single exception that the

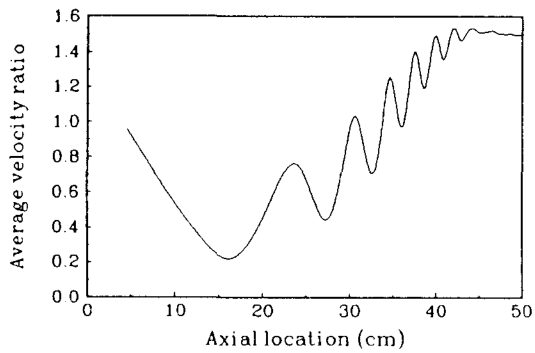

Figure 3. The evolution of average velocity ratio.

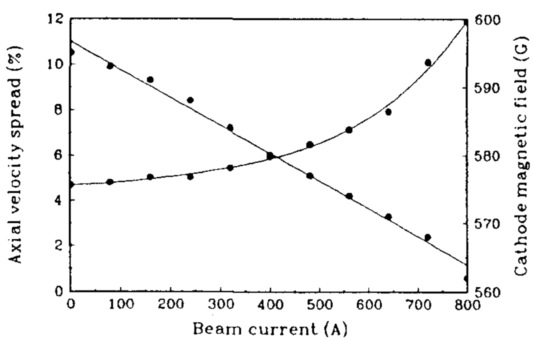

Figure 4. The axial velocity spread as a function of beam current.

gun coil will require twice as much current due to a decreased compression ratio. To allow a little more flexibility with our magnet system, we will decrease the nominal magnetic field so that the cyclotron frequency corresponds to three times the current SLAC frequency. Most of the existing vacuum hardware will be utilized on the new system. The magnetron drive, all of the output waveguide (including two non-linear uptapers), and most of the microwave diagnostics will have to be replaced. Much of the new hardware has already been procured or designed. In particular, we have designs for two mode-selective directional couplers which utilize secondary rectangular arms that spiral around the main 5 inch diameter circular arm. A liquid calorimeter will be employed for average power measurements and an anechoic chamber will by used to investigate mode purity.

The Fundamental Tube

The first tube attempted on the new test bed will be a fundamental harmonic two-cavity coaxial gyroklystron. A rough schematic of the tube is shown in Fig. 5 (with a second-harmonic output cavity). The required input cavity has a quality factor of about 50. Drive power will be coupled through two slots in the radial wall separated by 180°. The cavity will be realized by a dip in the inner conductor radius to 1.1 cm that extends about 2.29 cm.

The drift tubes will be heavily attenuated with two layers of lossy dielectrics on the outer conductor, and one layer on the inner conductor. The ceramics will be either non-porous BeO-SiC or carbonized alumino-silicate. The final arrangement of ceramics will depend on cold-test results for fundamental mode attenuation. The inner and outer radial dimensions are 1.83 cm and 3.33 cm, respectively. This represents a beam clearance of about 1.1 mm. The length of the drift tube is 9 cm. The inner conductor will be supported by CVD diamond pins.

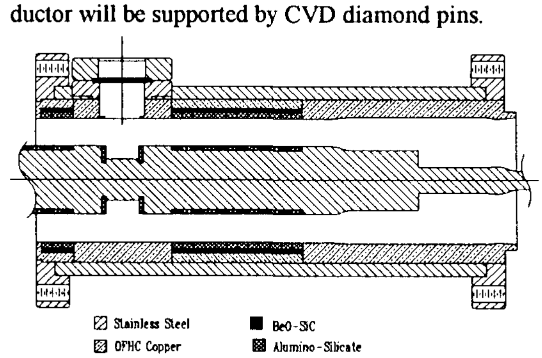

Figure 5. The coaxial second-harmonic circuit.

The output cavity is realized by decreasing the inner radius to 1.01 cm and increasing the outer radius to 3.59 cm. The main cavity length is 1.7 cm. Axial energy extraction is accomplished with an output lip that is 0.9 cm in length and has the same radial dimensions as the drift tube. The required cavity Q of 122 is below the start-oscillation threshold for all instabilities.

The expected efficiency from our large-signal code is shown in Fig. 6 as a function of axial velocity spread. The maximum predicted efficiency is about 42%. The fall-off in performance with increasing velocity spread is fairly weak, with nearly 40% efficiency expected at the simulated nominal beam spread of 6 %.

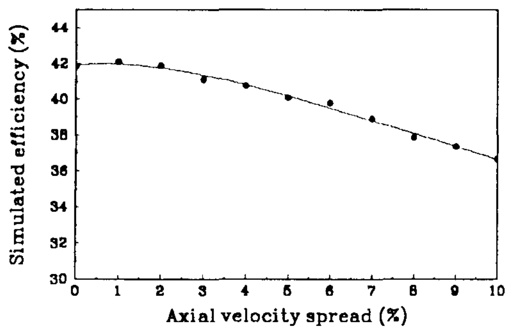

Figure 6. Predicted first harmonic performance.

The Second-Harmonic Tube

The second harmonic tube is realized by replacing the fundamental tube's output cavity with one that resonates at twice the drive frequency Two output cavity designs are being considered at this time. The first is a simple cavity that is realized by increasing the outer radius to 3.651 cm over a 3 cm transition length. All radial wall transitions are smooth to minimize mode conversion. The main cavity length is 0.64 cm. Axial energy extraction is accomplished with an output lip that has a 0.1 cm flat section after a 1 cm transition length and has an outer radial dimension of 3.58 cm. The Q of the cavity is 529 and the predicted ratio of power traveling into the drift tube compared to the power flow into the output waveguide of -24 dB.

The expected efficiency is nearly 35% at the simulated electron beam axial velocity spread of 6%. Start oscillation simulations indicate that the cavity is marginally stable.

The second configuration we are considering is a complex TE_{02}/TE_{03} cavity (depicted in Fig. 5). The overall physical length is 10.6 cm. All transitions are smooth except for the TE_{02}/TE_{03} interface. The Q of the cavity is 295 and the predicted ratio of power traveling into the drift tube compared to the power flow into the output waveguide of -36.5 dB. The output mode purity is expected be in excess of 96% (in the TE_{03} mode). While this cavity is inherently more stable than the preceding one, to date we have only achieved simulated efficiencies of 20%. Mode competition with third harmonic operation seems to be the limiting factor, and we are exploring ways to improve this efficiency further.

Summary

We are in the advanced stages of quadrupling the effective power capability of our modulator. We have a promising design for a state-of-the-art magnetron injection gun which is currently under construction. We have designed and are building all the auxiliary microwave hardware required for our test bed and have designs of second and first harmonic two-cavity coaxial tubes that should be 35% - 40% efficient. The combined effect is that we expect to produce, in the near future, microwave amplification at frequencies and power levels that are anticipated to be required of future linear colliders.

References

[1] W. Lawson, *et al.*, Phys. Rev. Lett., vol. 67, p. 520 (1991).
[2] S. Tantawi, *et al.*, IEEE Trans. Plasma Sci., vol. 20, p. 205 (1992).
[3] H. W. Matthews *et al.*, IEEE Trans. Plasma Sci. (in press).
[4] P. E. Latham, *et al.*, Phys. Rev. Lett., vol. 72, p. 3730 (1994).