DESIGN OF A 95 GHz, MULTI-MEGAWATT GYROKLYSTRON AMPLIFIER FOR ADVANCED ACCELERATORS

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Abstract

In this paper we present a three-cavity design of a gyroklystron at 95 GHz. We discuss the design of the magnetron injection gun (MIG), the magnetic field coils, and the three-cavity microwave circuit. The MIG produces a 500 kV, 30-70 A small-orbit annular beam with an average perpendicular-to-parallel velocity ratio of 1.5 and a parallel velocity spread below 5%. The MIG requires a control anode with a voltage of about 65 kV, a magnetic compression of about 30, and a cathode loading near 10 A/cm^2. The circuit magnetic field is about 28.7 kG. The microwave circuit has a first harmonic TE_{011} input cavity that is driven at 47.5 GHz, and second harmonic TE_{021} buncher and output cavities which are resonant at 95 GHz. A peak power of 7.56 MW is obtained with 51.6 dB gain and 33.6% efficiency.

1 INTRODUCTION

The range in frequencies near 95 GHz is currently of great interest for radar applications due to low atmospheric absorption. Because of the dependence of breakdown on frequency, there is also interest to develop an amplifier for high energy RF acceleration of electrons in W-Band. The power tubes that are commercially available at these frequencies have maximum output powers of about 3 kW and research tubes have peak powers below 100 kW. At the University of Maryland, we have a program to develop high power gyrotron amplifiers for electron-positron collider applications. We have designed, constructed, and tested a variety of gyroklystron tubes, including a second harmonic, two-cavity tube which produced peak powers above 30 MW at 19.7 GHz [1]. In this paper we scale this 19.7 GHz tube to 95 GHz. There are two main parts to the system: the MIG design is presented in the next section followed by the design of the microwave circuit.

2 MAGNETRON INJECTION GUN

The magnetron injection gun, which generates our injected beam, is shown in Fig. 1. The gun design is based on the 19.7 GHz gun. A scaling code was used to obtain the starting dimensions. After being scaled, the design was adjusted by changing the boundaries in both anodes and the cathode until the required parameters were obtained with the minimum velocity spread. The square mesh code *Egun* was used to simulate the performance of the electron gun. To verify the accuracy of our results, a numerical check on the code calculations was done by varying the number of rays and the number of particles until convergence was found. Accurate results were obtained when we used a mesh size of 0.05 cm (20 mesh/cm) and when we

Fig.1 The 500 kV, 45 A Electron Gun Simulation

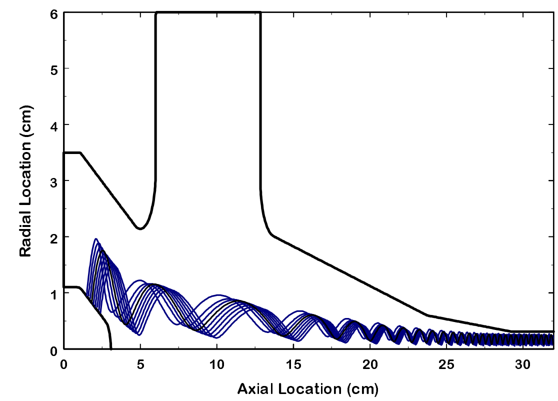
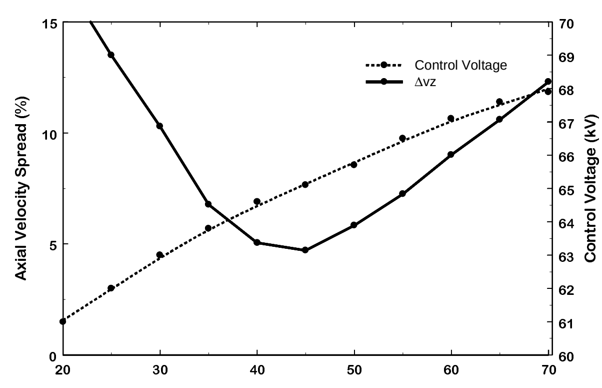


Table I: Electron gun specifications and simulated performance.

Emitter radius (cm)	0.78
Emitter width (cm)	0.958
Emitter angle (deg)	20
Cathode loading (A/cm^2)	9.58
Cathode magnetic field (G)	900
Cathode-anode gap (cm)	2.262
Average velocity ratio	1.5
Axial velocity spread (%)	4.69
Average beam radius (cm)	0.163
Peak anode field (kV/cm)	81
Peak cathode field (kV/cm)	94
Space-charge current (A)	98

Fig. 2 Dependence of Velocity Spread on Current



modeled the beam with 17 rays. All simulation results presented here were obtained with those values.

Our optimal gun was designed for minimum velocity spread at a current of 45 A. The parameters of the gun and the results of the simulation are summarized in Table I. The control voltage required to produce the proper velocity ratio is 65.1kV and the magnetic compression is about 30. At 10 A/cm^2, the cathode loading is a little high, but well within the state-of-the-art. The electric field is less than 100 kV/cm, everywhere.

Because the cathode angle is low, the beam is nonlaminar and the axial velocity spread varies significantly with beam current as shown in Fig. 2. As expected, the minimum velocity spread occurs at 45 A. The axial velocity spread remains below 10% for all currents between 30 A and 65 A. The change in control anode voltage required to keep α approximately 1.5 throughout this range in currents is $\pm$ 3.5 kV.

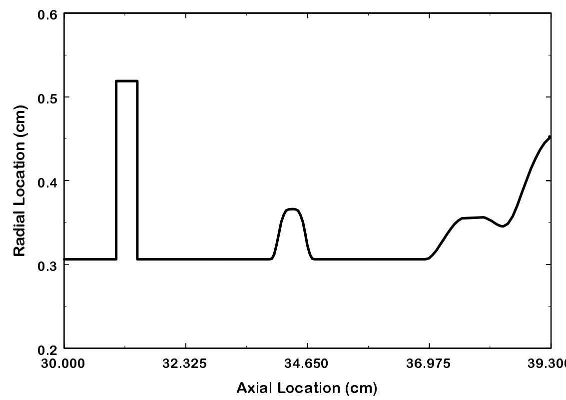
For the gun output beam we are mainly concerned with the velocity spread because of the strong dependence of efficiency on this value. Decreasing the control anode voltage can lower the axial velocity spread and then the velocity ratio would be lowered as well. Lowering the velocity ratio makes the tube more stable but decreases the efficiency. Changing the control voltage from 58-69 kV varies α from 1 to 2.

3 MICROWAVE CIRCUIT

Our amplifier circuit is made of input, buncher, and output cavities that are connected by drift regions. The input cavity interacts at the first harmonic in the TE_{011} mode. Simulations showed that a buncher cavity was necessary in order to increase the power that can be extracted from the output cavity at the second harmonic (in the TE_{021} mode). A picture of the circuit design is shown in Fig. 3. The starting parameters for the circuit came from scaling the input and output cavities from the 19.7 GHz design and adding the buncher cavity. The buncher and output cavities have dolph-chebychev radial transitions. This proved in simulations to minimize the mode conversion from the TE_{02} to the TE_{01} mode. The initial dimensions were adjusted to get the desired first (47.5 GHz) and second harmonic (95 GHz) frequencies. This is done using a simulation code called *Coax*. This code takes for input the cavity's dimensions and starting points for the frequency and Q search. It then iterates the frequency and Q until it finds a solution. The azimuthal mode is an input to the code, but a field plotting routine is required to verify that the mode found by *Coax* has the correct radial and axial mode numbers.

After the dimensions were modified to the correct values, two different codes were used to get the system efficiency. These codes are *Hpm_gen* and *Gycoax*. Both codes are partially self-consistent, but they take very different approaches to solving the problem and serve as a check of the results. Furthermore, *Gycoax* has been compared extensively to experimental results for several gyroklystrons and has always given good agreement.

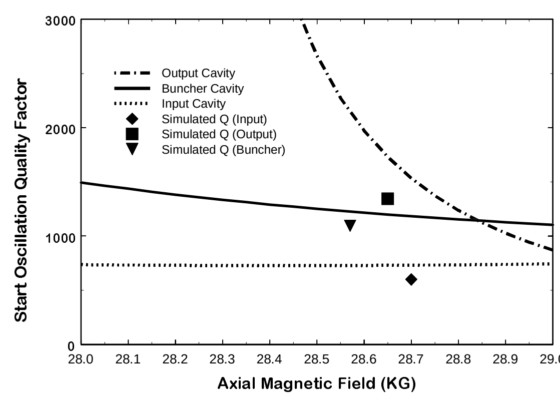
Fig. 3 The 95 GHz Circuit Design



The dimensions of the microwave circuit and the simulated results from *Hpm_gen* are given in Table II. Note that the quality factors are at least an order of magnitude below the resistive Q of a copper cavity. That means that over 90% of the output power can be extracted from the system and that the buncher Q must be realized with additional loss (e.g. lossy ceramics [1]).

To assure stability another code was used: *Qpb*. This code gives the Q (for each cavity) below which the device will be stable. This result and the simulated Q for each cavity (given by *Hpm_gen* and *Coax*) are shown in Fig. 4. The simulated Qs are positioned at the average magnetic field in each cavity. The system is clearly seen to be stable.

Fig. 4 The Start Oscillation Threshold



In Fig. 5, we plot the relationship between efficiency and velocity spread as computed by both large-signal codes. Note that the agreement is quite good. Our MIG is predicted to produce a beam with 4.7% spread. We can see from the figure that the efficiency for an ideal beam (zero velocity spread) is over 36%. Note that this our design's efficiency is less than 3% lower than that of the ideal beam and that the efficiency remains above 30% for velocity spreads up to about 6.5%

4 SUMMARY

The three-cavity gyroklystron presented in this paper is predicted to produce over 7 MW at 95 GHz – more than 2 orders of magnitude above the state-of-the-art for amplifiers. This high power is obtained from the interaction between a second harmonic output cavity and a 45 A, 500 kV beam that is produced by a double-anode MIG. According to simulations, the beam quality is sufficiently high to produce an interaction efficiency of 33.6% with a high gain (<50 dB). The tube is predicted to be zero-drive stable. In the future we hope to build and test this microwave system.

REFERENCES

[1] V. L. Granatstein and W. Lawson, "Gyro-Amplifiers as Candidate RF Drivers for TeV Linear Colliders" IEEE Trans. on Plasma Science, vol. 24, pp. 648-665 (1996).

Fig. 5 Dependence of Efficiency on Velocity Spread

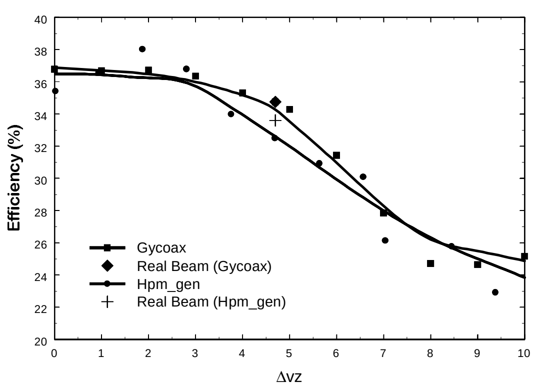


Table II: Microwave circuit parameters and simulated results.

Input Cavity	
Drive frequency (GHz)	47.5
Operating mode	TE_{011}
Resistive quality factor (Q)	600
Radius (mm)	5.19
Length (mm)	4.00
Input drive power (W)	52
Buncher Cavity	
Maximum radius (mm)	3.663
Length (mm)	20.20
Required Q	1075
Output Cavity	
Main section radius (mm)	3.457
Overall length (mm)	23.70
Required Q	1345
Drift regions	
Radius (cm)	0.306
Length I-B (cm)	2.50
Length B-O (cm)	2.09
Amplifier performance	
Power (MW)	7.56
Efficiency (%)	33.6
Gain (dB)	51.6