Design of a 100 MW, 17 GHz Second Harmonic Gyroklystron Experiment

W. Lawson, P.E. Latham, V. Specht, M.K.E. Lee, Q. Qian,
J.P. Calame, B. Hogan, V.L. Granatstein, M. Reiser, and C.D. Striffler
Electrical Engineering Department and Laboratory for Plasma Research
University of Maryland, College Park MD 20742, USA

Abstract

At the University of Maryland, we are exploring the suitability of gyroklystrons for linear collider applications. In this paper we discuss the design of a two-cavity, coaxial gyroklystron that is designed to produce over 100 MW in 1 μs pulses at the second harmonic of the cyclotron frequency. We detail modifications that will be required of our test facility, present the simulated performance of a 400 MW, 500 kV single-anode Magnetron Injection Gun, and describe the design of the coaxial microwave circuit.

I. INTRODUCTION

In an effort to expand the frontiers of high-energy physics, e^--e^+ colliders with center-of-mass energies approaching 1 TeV are being planned. These machines will require efficient, reliable, pulsed microwave amplifiers with peak power levels that exceed the current state-of-the-art. At the University of Maryland, we have been performing a sequence of experiments based on the cyclotron resonance instability. Initial studies with fundamental mode two-cavity gyroklystrons have produced over 24 MW of power at 9.87 GHz in 1 μs pulses with 32% efficiency and 34 dB gain in the TE_{01} mode [1]. Recent experiments with two-cavity second harmonic tubes have produced nearly 30 MW of power at 19.76 GHz with 27% efficiency [2]. This performance level represents the maximum we can achieve with our current test facility.

We are currently undertaking a major upgrade of our facility that will enable us to pursue amplifiers in the 100 MW range. Table 1 summarizes the major parameter differences between the current (100 MW) and future (400 MW) test facilities. The facility is shown schematically in Fig. 1. Upgrades to our line-type modulator include doubling the number of PFNs to eight, increasing the current capability of our thyratrons, and reorganizing the HV tank to decrease stray capacitance. The latter modification should yield a 14% increase in our voltage capability, as indicated in Table 1. The eight water-cooled magnetic field coils will remain unchanged but the current capability of the supply which drives the gun coil will be doubled. No modifications are required for the magnetron modulator, but the magnetron itself will be replaced with a lower frequency, more efficient one. Furthermore, the output waveguide (nonlinear tapers, beam dump, and output window) and the microwave diagnostics will have to be replaced. Finally, we will need a new electron gun and microwave circuit. Progress on the designs of these components is described below.

Table 1: System parameters.

Parameter	100 MW System	400 MW System
Beam voltage (kV)	440	500
Beam current (A)	225	800
Velocity ratio	1.0	1.5
Avg. beam radius (cm)	0.78	3.10
Circuit magnetic field (kG)	5.45	5.05
Output frequency (GHz)	19.75	17.14
Drive power (kW)	100	200

II. ELECTRON GUN

A single-anode Magnetron Injection Gun (MIG) was selected for the electron gun because of its simpler configuration, wider range [3], and absence of an intermediate voltage requirement. The new beam guiding center (Table 1) was selected to keep the current density in the circuit region equivalent in the two systems. The standard design formalism was followed [4] and EGUN [5] was used to perform the simulations.

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Table 2: MIG parameters

A. Specifications	
Cathode radius (cm)	9.58
Emitter strip length (cm)	1.67
Cathode half-angle	40°
Magnetic compression ratio	9.9
Cathode loading (A/cm^2)	5.95
B. Performance	
Axial velocity spread (%)	6.70
Space-charge limiting current (A)	2,190
Peak electric field (kV/cm)	90.0
Avg. emitter electric field (kV/cm)	51.6
Beam thickness (cm)	1.28

Table 3: Microwave circuit parameters.

Section	Inner radius (cm)	Outer radius (cm)	Length (cm)
A. Input Cavity, Q = 60			
1	2.000	4.205	2.000
B. Drift Tube			
1	2.325	3.825	5.000
C. Output Cavity			
1	2.234	3.920	0.978
2	1.914	4.205	0.922
3	2.358	3.798	0.422
4	2.356	4.415	—

The electrode shapes, together with the beam envelopes, are shown in Fig. 2. The key parameters are listed in Table 2. The magnetic compression is fairly low and the beam voltage and cathode loading have been achieved before [4]. The velocity spread indicated is at the nominal current of 600 A and is due to ballistic considerations only,. The emitter strip is curved by ±4° to minimize this spread. The peak cathode field is also comparable to the previous gun. The anode electric field nowhere exceeds 30 kV/cm. The nominal current is less than 28% of the space-charge limit. Beam electrode clearance in the circuit region is approximately 1.1 mm.

The dependence of velocity spread on beam current is shown in Fig. 3. The current affects the velocity ratio due to self-field effects; these are compensated for by adjusting the magnetic field at the cathode. Axial spread approaches 6.4% as the current approaches zero and remains below 9% through the entire current range. This wide current range is directly attributed to laminar flow in the single-anode MIG.

III. MICROWAVE CIRCUIT

A schematic of the coaxial two-cavity microwave circuit is shown in Fig. 4 and the nominal circuit parameters are given in Table 3. The input cavity is defined by sharp transitions in the radial wall. It is driven in the TE_{011} mode at half the output frequency via a slot in the outer wall. The quality factor is defined in part by two thin carbon-impregnated Aluminum-Silicate rings located against the cavity end walls. The drift tube will be loaded with various lossy ceramics to achieve stable operation. The radii are chosen so that only the TE_{11}, TE_{21} and TE_{31} modes are not cut off at the operating frequency. The output cavity operates predominantly in the TE_{021} mode at a point relatively close to cutoff. There is an intermediate step in the radius of the main section to minimize the amount of power in the TE_{01} mode which is directed into the drift region.

With an axial velocity spread of 9.5% and a pitch angle of 1.5, this circuit achieved 25% efficiency; with no velocity spread the efficiency was around 35%. The relatively low efficiency is due to interaction with the third harmonic, which accelerates rather than decelerates particles. This places a constraint on the magnetic field and reduces our operating parameter range. We are looking into ways to decrease the effectiveness of the third harmonic interaction and thus increase our efficiency.

We are currently considering two changes in the microwave circuit. The first is to incorporate a TE_{031} output cavity. This would increase the separation to neighboring modes and promote stable operation. The second change is to use nonlinear tapers rather than abrupt transitions to define the output cavity. This should help improve mode purity and the left-to-right power ratio.

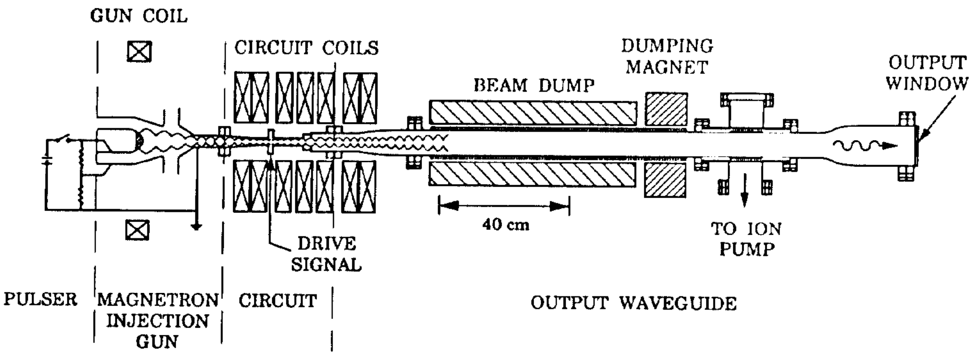

Figure 1: The gyroklystron test facility.

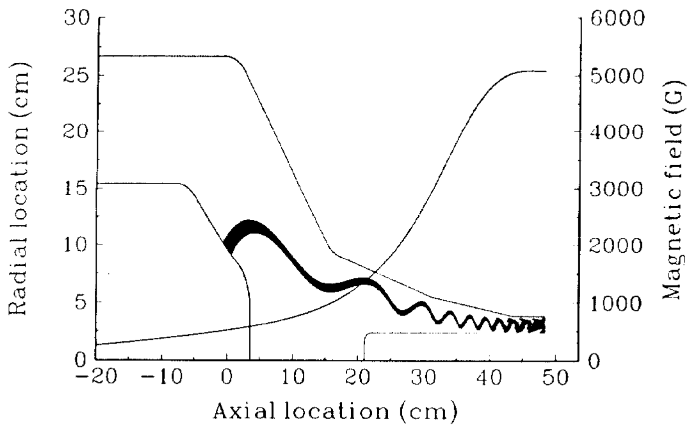

Figure 2: Electrode shapes, axial field profile, and beam envelope of the single-anode MIG.

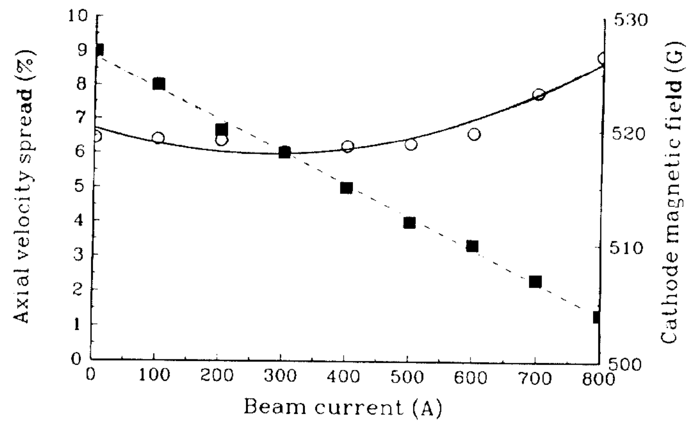

Figure 3: The dependence of velocity spread on current. The circles indicate spread; the squares denote cathode magnetic field.

IV. REFERENCES

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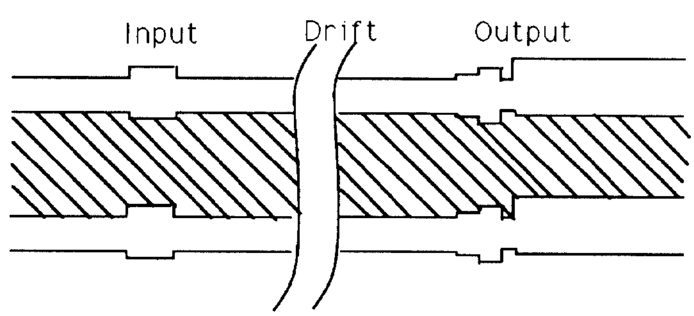

Figure 4: The coaxial microwave circuit.