

OPERATION OF A 17.14 GHz GYROKLYSTRON FOR ADVANCED ACCELERATORS

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Abstract

We present the design results for our second harmonic coaxial gyrokystron tubes, which are expected to produce over 80 MW of peak power at 17.14 GHz in 1 μ s pulses. The beam voltage and current are 470 kV and 540 A, respectively, and the applied magnetic field is about 5 kG. The input cavity operates near the cyclotron frequency at 8.57 GHz; all other cavities operate near the second harmonic at 17.14 GHz. The expected interaction efficiency is 34 - 37% and the gain is 47 - 60 dB, for 3 and 4 cavity tubes, respectively. We also present the design of a 4th harmonic tube which utilizes the same electron beam as in our 17.14 GHz experiments, but has an output cavity which operates near the 4th harmonic of the cyclotron frequency. The 4th harmonic tube is predicted to produce 40 MW of peak power at 34.27 GHz with an efficiency in excess of 15%.

1 INTRODUCTION

At the University of Maryland, we have been investigating the performance of gyrokystron amplifiers as potential candidates to drive the next generation of linear colliders. Our most recent investigation has focused on the interaction between a 500 kV, 250 MW annular beam and coaxial gyrokystron circuits with the goal of producing about 100 MW of amplified power in a 0.5 T magnetic field.

Our first experiments resulted in peak powers of about 80 MW at 8.6 GHz via the interaction with a three-cavity, first harmonic gyrokystron circuit. [1] The efficiency and gain were about 32% and 30 dB, respectively. We are currently conducting experiments with a three-cavity second harmonic gyrokystron circuit which is designed to produce comparable power and efficiency at 17.14 GHz. This tube is described in Section 2. We are also designing a fourth harmonic tube which is expected to produce output power at 34.27 GHz. Details of that design are discussed in Section 3. Our results and future plans are detailed in the final section.

2 SECOND HARMONIC CIRCUITS

A schematic of the second harmonic circuit is shown in Fig. 1. The circuit dimensions are given in Table 1. The inner conductor is required so that the drift regions will be cut-off to the operating modes in the cavities. Thus, the inner conductor radius is transitioned to zero abruptly in

the drift region which precedes the input cavity and gradually in the region after the output cavity. Lossy ceramics are placed in the drift regions both on the inner conductor and on the outer conductor in an attempt to suppress spurious drift tube oscillations.

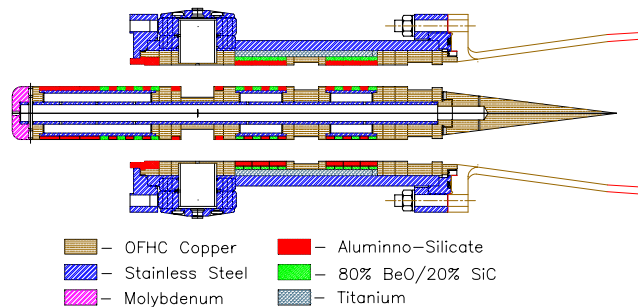


Figure 1. The 3 cavity 2nd harmonic gyrokystron circuit.

Table 1. The microwave circuit cavity parameters. All dimensions are in cm.

Component	Length	Inner radius	Outer radius
Input cavity	2.286	1.100	3.325
Buncher	1.694	1.605	3.525
Output cavity	2.210	1.650	3.490
Drift tube	3-5	1.825	3.325

The input cavity is the same as for the first harmonic tubes and consequently operates at 8.6 GHz in the TE₀₁₁ mode. The cavity is defined by an abrupt radial transition on the inner conductor. The quality factor (Q) of 50 is derived in part from the coupling aperture which connects the cavity to the input waveguide and in part from the lossy ceramics which are adjacent to the cavity in the drift region. The Q is about 70% of the required Q for self-oscillation.

The buncher cavity is designed to operate in the TE₀₂₁ mode at a resonant frequency of 17.136 GHz and a quality factor of 390. The cavity is defined by similar abrupt radial transitions on both the inner and outer conductors in order to minimize mode conversion from the TE₀₂ mode to the TE₀₁ mode. [2] The quality factor is determined completely by the lossy ceramics which are located in the drift regions adjacent to the cavity.

The output cavity is also designed to operate near the second harmonic of the cyclotron frequency in the TE₀₂₁ mode. The measured resonant frequency and quality factor are 17.116 GHz and 310, respectively. The cold-cavity resonant frequency is lowered to account for beam loading. The quality factor is dominated by the radial lip at the end of the cavity which permits axial extraction of the microwave power.

A small signal code (QPB) is used to check the stability of the cavities to spurious modes at the nominal beam parameters. All cavities are expected to be zero-drive stable at the design point. Another code (MAGYKL) [3] is used to determine the large signal properties of the microwave circuit. The simulated results for the nominal operating point are given in Table 2. The drive power is about 1 kW at 8.658 GHz. The average beam velocity ratio is 1.4 and the assumed axial velocity spread is about 6%. The magnetic field is varied throughout the circuit to optimize performance; the average value is given in the table.

Table 2. The simulated results.

Parameter	Value
Beam voltage (kV)	470
Beam current (A)	540
Peak power (MW)	80
Gain (dB)	49
Efficiency (%)	32
Magnetic field (T)	0.51

Simulated Efficiency as a Function of Input Power and Alpha

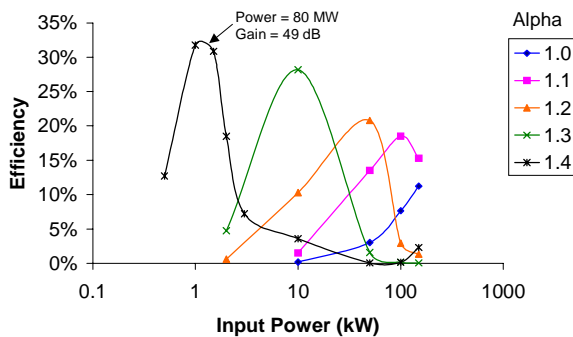


Figure 2. MAGYKL simulation results for the 3 cavity second harmonic tube

The dependence of output power on drive power is indicated in Fig. 2 for a number of different average velocity ratios (α). The curves are terminated at 150 kW of drive power because that is the maximum power available from our magnetron. As indicated in the figure, both the gain and efficiency are a strong function of velocity ratio.

3 FOURTH HARMONIC CIRCUIT

A picture of our fourth harmonic tube is shown in Fig. 3. The basic idea is to utilize the first harmonic drive cavity and the second harmonic buncher cavity of the circuit which is described in the previous section, but to replace the output cavity with one that operates at 34.272 GHz in the TE₀₄₁ mode. To optimize performance of the tube, the quality factors of all cavities have been adjusted, as have the drift tube lengths, the magnetic field profile, and the dimensions of the output cavity.

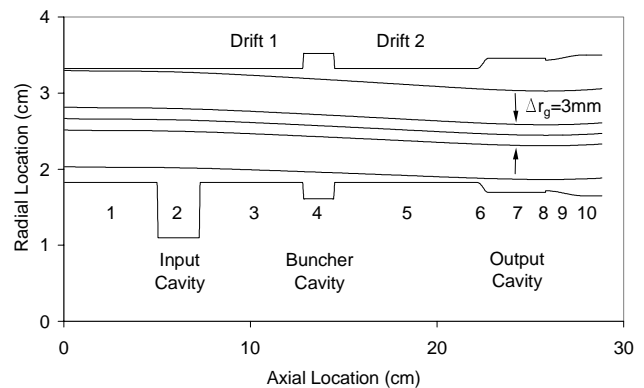


Figure 3. The fourth harmonic cavity circuit and the beam trajectory envelope

The optimal results to date include a peak efficiency of about 15%. The beam parameters are the same as indicated in Table 2, so the net peak power is somewhat under 40 MW. The required magnetic field increases strongly throughout the circuit. The effect of this tapering on the magnetic field is indicated by the reduction of the average beam radius indicated in Fig. 3. Efficiency is limited by a number of effects. Foremost are the degradation due to velocity spread and guiding center. The guiding center spread is indicated in Fig. 3. It is comparable to the size of the radial variation of the TE₀₄₁ mode, hence the beam coupling varies significantly across the range in guiding centers.

The relatively large required quality factors and mode competition are two other concerns. The start oscillation curves for the operating modes of the three cavities are given in Fig. 4. The required Qs are also indicated in the figure. They are placed at the average magnetic field for each cavity. For the best results, all cavities must be run at or above the start oscillation threshold. The Qs of the input and buncher cavities can be lowered to much more comfortable levels with a small sacrifice in efficiency and a somewhat larger sacrifice in gain. However, the output cavity is well into the oscillation threshold for many modes. (Recall that only the operating mode is shown in the figure, but many other modes have comparable curves.) Furthermore, the output cavity Q of ~2400 is a significant fraction of the resistive quality factor, so much of the power would be absorbed in the cavity walls.

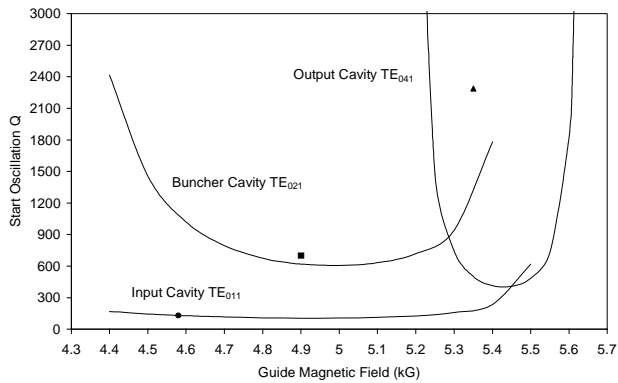


Figure 4. The start-oscillation curves for the operating modes of each of the cavities

4 SUMMARY AND FUTURE PLANS

We have recently had a failure of the gun emitter and our electron gun is currently under repair. The three cavity circuit has been completely fabricated and cold tested and we are awaiting the completion of the repair. The system is expected to produce 80 MW of peak power in a 1 μ s pulse at 17.136 GHz with an efficiency of 32% and a gain of 49 dB.

At this point, fourth harmonic operation appears to suffer from low efficiency due in part to the sensitivity of the circuit to both spread in guiding center and axial velocity spread. While we will continue to look for ways of improving simulated performance, designs of second harmonic systems have predicted excellent performance at 34.272 GHz. [5] The only drawback of the 2nd harmonic system is that the required magnetic field is twice as high as that for the 4th harmonic system.

In the next few years we will be working to inject the output signal from our gyrokystron into an accelerating structure [4]. To that end we have designed a high-gain, 4 cavity second harmonic system that has a number of features necessary to interface with the structure. First, the gain is sufficient so that we can replace our magnetron with a TWT drive system which will be capable of correcting systematic phase variations. The gain curve is shown in Fig. 5 for two different output cavity quality factors. As seen in the figure, the gain does not depend strongly on the output cavity Q and the circuit can be driven to saturation with a power of about 100 W. Second, the output waveguide has a sequence of mode converters that converts the TE₀₂ circular waveguide output signal and divides it evenly into fundamental mode in standard WR62 rectangular waveguide. We expect to commence testing the 4 cavity circuit as soon as testing of the 3 cavity circuit is complete.

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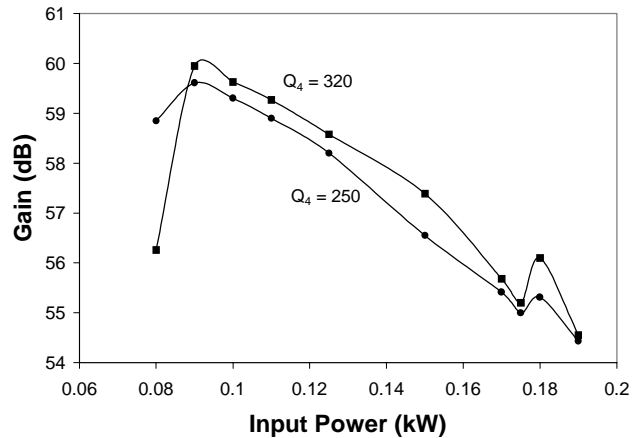


Figure 5. The gain curves of the 4 cavity, second harmonic circuit as a function of drive power for two different output cavity quality factors