DEVELOPMENT OF HIGH-GAIN SECOND-HARMONIC GYROKLYSTRON FOR ACCELERATOR APPLICATIONS*

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Abstract

In this paper we present the current status of the gyroklystron program at the University of Maryland. We have been studying multi-cavity gyroklystron microwave tubes as possible drivers for future linear colliders. A three cavity second harmonic circuit has produced about 28 MW of peak power with an efficiency of about 13% and gain of approximately 26 dB. Further investigation of this circuit was impeded by technical problems relating to the performance of a defective annular emitter. A four cavity circuit has been designed, constructed and underwent preliminary experimental testing. This tube produced pulses with a peak power of 18.5 MW, corresponding to an efficiency of 7% and a gain of 23dB. The poor performance of this circuit can be attributed to a significant instability in the input cavity of the circuit. Additionally, a new output waveguide system has been designed, which will allow coupling of our four cavity circuit to an accelerator structure.

1 INTRODUCTION

The Gyroklystron program has been an ongoing research initiative at the University of Maryland for over a decade. We have designed and experimentally tested various microwave tubes, primarily aiming at developing gyroklystrons capable to drive future linear colliders above X-band.

In recent years we were able to produce 75 MW of peak power at 8.57 GHz, utilizing a three-cavity first harmonic coaxial system [1]. Based on these results, we decided to pursue frequency-doubling configurations. We designed and tested a three-cavity second harmonic tube. We have also designed and manufactured a four-cavity second harmonic circuit which is at the experimental testing stage. A novel output waveguide system has been designed to transport and mode convert the microwave power that originates in the gyroklystron (in the TE_{02} coaxial mode) and is delivered (equally split) into two standard WR62 waveguides (in TE_{01} mode). This scheme was envisioned to allow our four-cavity tube to drive a Ku-Band accelerator structure being developed by the Haimson Corporation [2].

2 THREE CAVITY CIRCUIT

A diagram of the circuit can be seen on Fig. 1. The tube possesses a coaxial configuration with the inner conductor supported by two tungsten pins. This coaxial geometry allows the drift regions to be cutoff to the operating modes at the operating frequencies, minimizing cross-talk amongst the different cavities. Both inner and outer conductors are lined with lossy ceramics in the drift regions as well as in the input region of the tube (prior to the first cavity) in order to improve the stability of the circuit to spurious modes. Drive power for the circuit is provided by a 150kW coaxial magnetron, and is injected

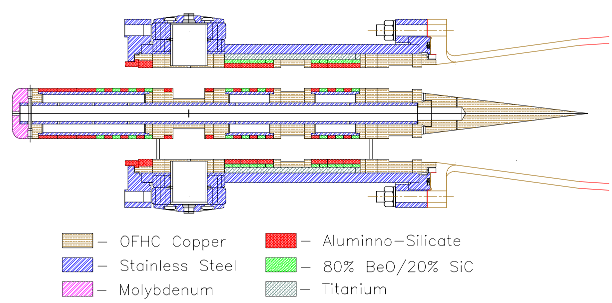

Figure 1: The Three cavity second harmonic circuit

into the input cavity through a single radial slot. The input cavity operates in the TE_{011} mode around 8.57 GHz. Both the second (buncher) and output cavities operate in the TE_{021} mode with a frequency twice that of the drive frequency. The characteristic features of the various cavities can be seen on Table 1.

Table 1: Characteristics of Cavities for 3-cavity circuit

Cavity	f_{Res} (GHz)	Q	Mode
Input cavity	8.585	54	TE_{011}
Buncher cavity	17.136	390	TE_{021}
Output cavity	17.115	310	TE_{021}

The behavior of the theoretical design is displayed in Fig. 2. These curves exhibit the dependency of the efficiency of the design as a function of input drive power, for different values of the velocity ratio (alpha). The peak power for a velocity ratio of 1.4 is above 80 MW, corresponding to an efficiency of about 34% and a gain of about 49 dB. Note that even if velocity ratios as low as 1.0 occur, an output power around 30 MW should still be possible.

* This work was supported by the United States Department of Energy, Division of High Energy Physics.

The experimental testing of the three cavity second harmonic circuit was done with the output microwaves

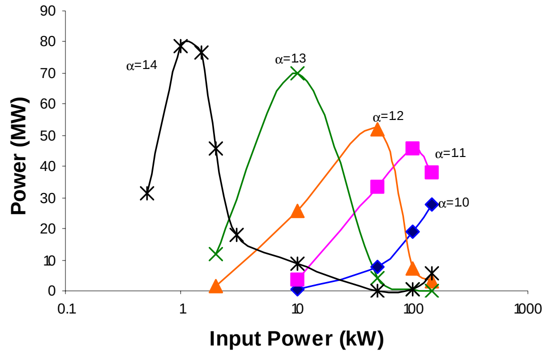

Figure 2: Computer simulation results from three cavity tube performance.

being transmitted into an anechoic diagnostic chamber. In this chamber the microwave power was measured using a diode, and this measurement was further corroborated either by a peak power analyzer or a diode measurement of the signal from a directional coupler.

The results validated the theoretical design, and amplified microwave signals were indeed confirmed. However, technical difficulties associated with a faulty MIG emitter prevented us from conducting a full study of the potential of the circuit. In short, we have recently discovered that the custom annular emitter in our MIG has a significant temperature variation, which leads to an undesired azimuthal asymmetry in the electron beam produced by the gun. This phenomenon not only affected the operation and efficiency of our tube, but also led to an accelerated erosion of the tungsten support pins.

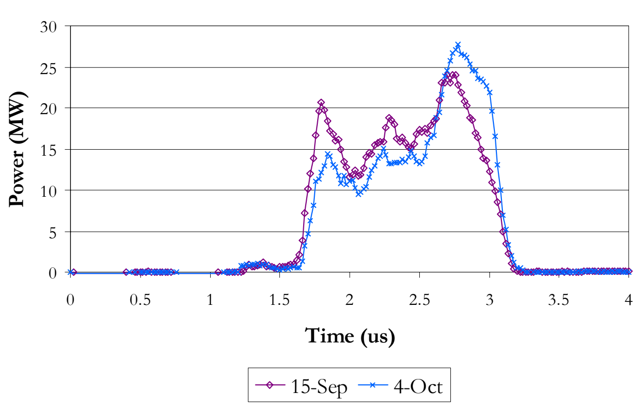

Figure 3: Output signals from 3 cavity gyroklystron, exhibiting nearly 30 MW of peak power.

Thus a premature collapse of the inner conductor took place. Therefore, the results presented here reflect only the initial data we were able to collect. The highest value of output power obtained was 27.7 MW, yielding an efficiency of 13.3% and a gain of 26 dB [3]. The output microwave pulses from two different days are displayed in Fig. 3.

3 FOUR CAVITY CIRCUIT

The four-cavity circuit is very similar to the three-cavity tube, as can be seen in Table 2. The basic difference lies in the addition of an extra cavity (identical to the buncher cavity in the 3-cavity tube) to increase the gain of the circuit.

Table 2: Characteristics of Cavities for 4-cavity circuit

Cavity	f_{Res} (GHz)	Q	Mode
Input cavity	8.585	54	TE_{011}
Buncher cavity	17.136	390	TE_{021}
Penultimate cavity	17.136	390	TE_{021}
Output cavity	17.115	310	TE_{021}

The theoretical drive curves for this design can be seen in Fig. 4. For a velocity ratio (alpha) of 1.4, our simulations predict this design will yield a peak efficiency of 35% with a gain of 57 dB. This gain should allow us to use a solid-state oscillator in conjunction with a 1 kW TWT to drive the gyroklystron tube, resulting in better phase control over the output microwaves.

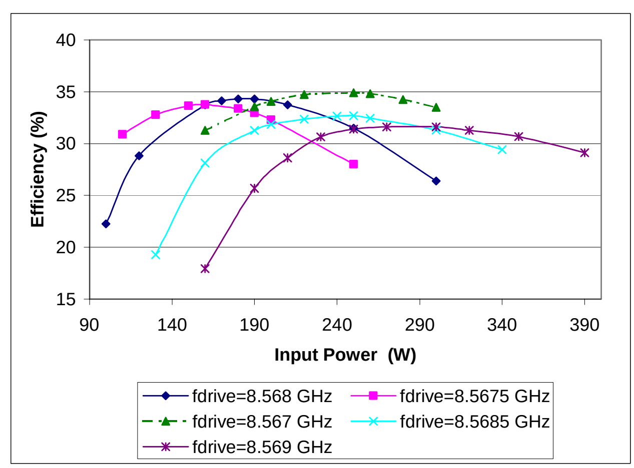

Figure 4: Theoretical drive curves for the 4 cavity circuit (for a number or different drive frequencies).

This tube has been manufactured and underwent preliminary experimental testing. During the assembly of this circuit we oriented the tungsten support pins facing the cold spot of the emitter, thus lessening the erosion of the pins.

Testing of this tube revealed the presence of an instability in the input cavity of the circuit. The signal observed in the input cavity due to the instability can be seen in Fig. 5. This instability is directly related to the velocity pitch ratio (α): the onset of the instability occurs when α is approximately 1, and it grows rapidly as α increases. Thus the instability effectively limits the operation of the gyroklystron circuit to α less than 1, which is significantly below the design value of 1.4.

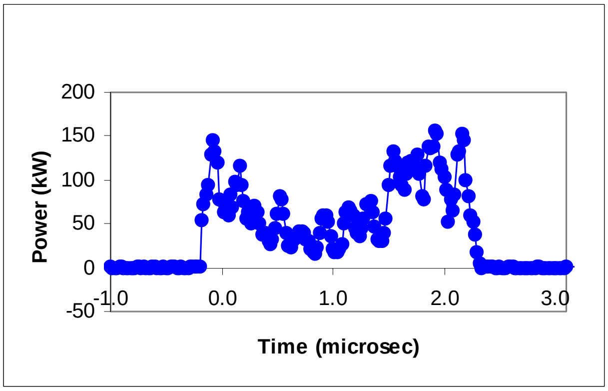

Figure 5: Signal observed in input cavity due to instability.

Under these conditions, performance of the tube was poor. The highest peak power observed was 18.5 MW, corresponding to an efficiency of 7 % and a gain of 23.3 dB. The pulse with highest peak power can be seen in Fig. 6. We are currently re-designing the input cavity in order to weaken the instability, thus improving the performance of the four-cavity gyroklystron.

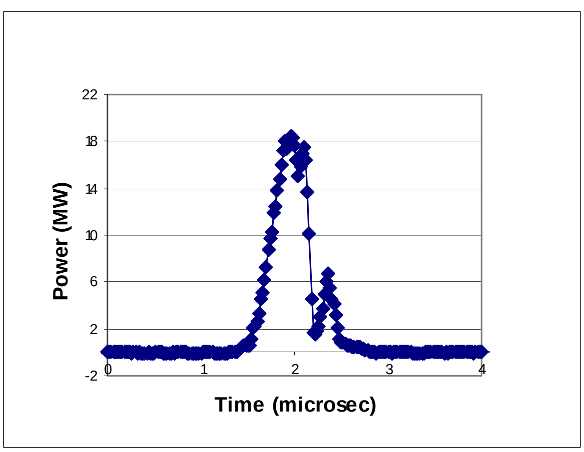

Figure 6: Highest output signals from four cavity circuit.

Once the tube's performance has been improved, the gyroklystron will be utilized to energize a 17.136 GHz accelerator structure [2]. Then, the anechoic chamber will be replaced by a specially designed output waveguide system which will transport the microwave power from the gyroklystron to the accelerator.

This new output waveguide incorporates a series of tapers as well as two types of mode converters. A periodic rippled-wall converter is used to convert the TE_{02} mode generated in the output cavity of the gyroklystron into the TE_{01} mode. Later, a new type of converter is used to transform the TE_{01} circular mode into the TE_{20} rectangular mode. This new circular-to-rectangular mode converter was originally devised at SLAC [4] and redesigned for our system. A prototype of this converter was manufactured and tested [5]. Following this converter, a bifurcation divides the power equally into two WR62 waveguides (as shown in Fig. 7). The microwave power is then transported in the TE_{01} mode via the WR62 waveguides into the dual feeds of the accelerator structure.

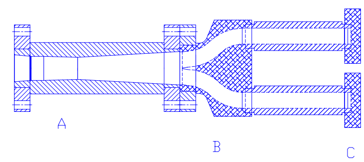

Figure 7: Schematic of part of new output waveguide system (A - circular to rectangular mode converter; B - Bifurcation; C- WR62 waveguides).

4 FINAL REMARKS

We have constructed and tested three and four cavity second-harmonic gyroklystron circuits aimed at driving an accelerator structure. In order to couple to the accelerator, an entirely new system of mode converters and waveguides has been designed and is well into the construction phase.

At present, we are working on resolving the experimental problems which have limited the success of our second harmonic tubes. The input cavity is being re-designed in order to reduce instabilities. Additionally, we have developed a new design for future MIG emitters as well as a precise manufacturing procedure which should greatly improve its temperature uniformity.

Furthermore, a new MIG electron gun is being designed which should enhance the overall performance of our microwave tubes.

REFERENCES

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