OPERATING CHARACTERISTICS OF 17.14 GHZ FREQUENCY-DOUBLING COAXIAL GYROKLYSTRONS*

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Abstract

In this paper we describe the present status of the gyroklystron program at the University of Maryland. We are presently studying multi-cavity gyroklystron microwave tubes as possible drivers for future linear colliders. A 3 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 4 cavity circuit has been designed, constructed and is about to undergo testing. Computer simulations performed on this design yield a theoretical prediction of 80 MW of peak power with an efficiency of 35% and a gain of 60 dB. Additionally, a new output waveguide system has been designed, to allow coupling of our 4 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

2.1 Circuit Design and Implementation

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

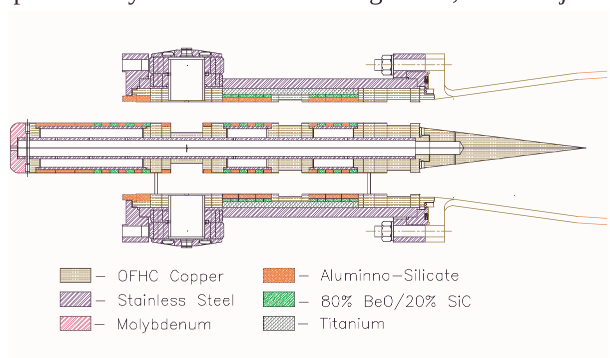

Figure 1: The Three cavity second harmonic circuit

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.

2.2 Experimental Results

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

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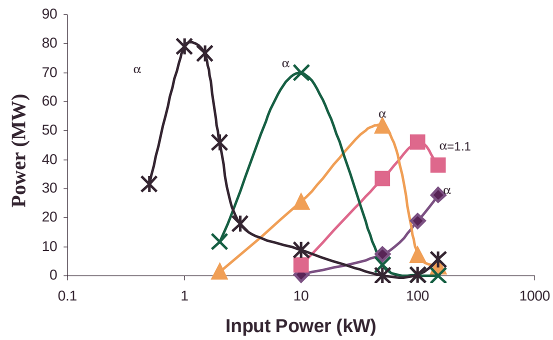

Figure 2: Computer simulation results from three cavity tube performance.

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. Thus a premature collapse of the inner conductor took place. Therefore, the results presented here reflect only the preliminary data we were able to collect.

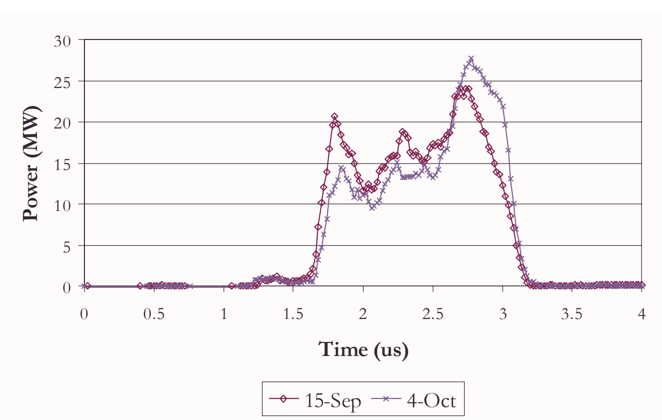

Figure 3: Output signals from 3 cavity gyroklystron, exhibiting nearly 30 MW of peak power.

The highest value of output power obtained was 27.7±2.4 MW, measured using the diode in the anechoic chamber. At this highest power point the beam had a potential of 400 kV and a current of 515 A, yielding an efficiency of 13.3%. The output microwave pulses from two different days are displayed in Fig. 3. The highest value of output power that was cross-checked with at least one other power measurement was 24.0±2.0 MW (10.4% efficiency) observed in the chamber and cross checked with the peak power analyzer signal corresponding to 26.1±2.4 MW. The FWHM (full width half-maximum) times for these pulses are 1.24 and 1.3 µs respectively.

The phase correlation of the signal is shown in Fig.4. The output from the phase circuit is shown and compared with the output pulse. The phase response shows a non-random behavior that repeated each shot, indicative of an amplified pulse.

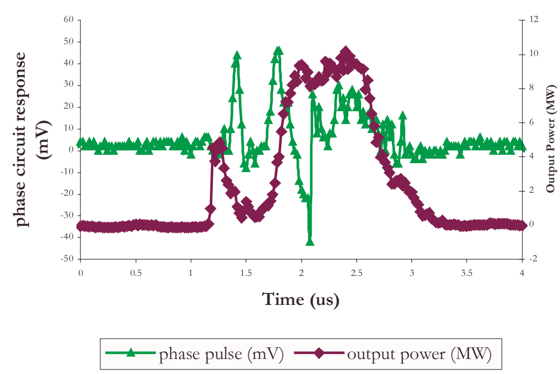

Figure 4: Comparison of output from phase correlation circuit and the output pulse

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. 5. 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.

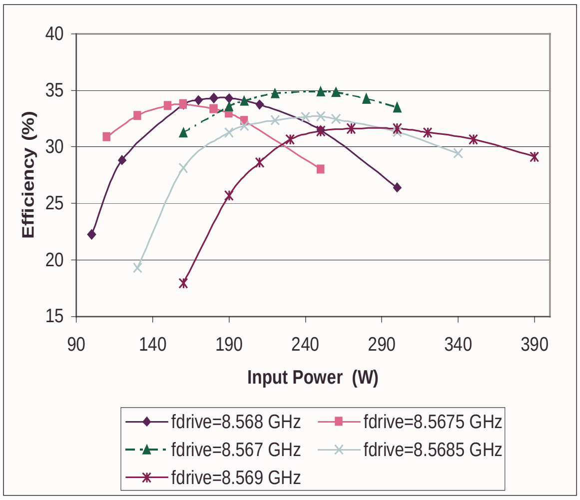

Figure 5: Theoretical drive curves for the 4 cavity circuit (for a number or different drive frequencies).

This tube has been manufactured and is about to enter experimental testing. We have also redesigned the uptaper region which follows the output cavity. This new coaxial uptaper (which can be seen on Fig. 6) has a complex multi-sectioned geometry, and was designed to reduce the mode conversion of the TE_{021} mode from about 5% (in the 3-cavity system) to less than 0.2%. Additionally, the inner transition of this taper performs the conversion from coaxial into circular modes.

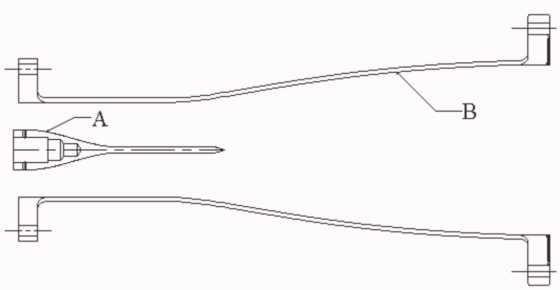

Figure 6: Schematic of Coaxial Uptaper
(A - Inner transition, B -Outer taper)

The preliminary experiments with this circuit will be carried out in the same manner as the three cavity circuit. The TE_{021} output signal will be injected into an anechoic chamber and a calibrated diode detector will serve as primary diagnostic.

However, once the tube's performance has been appropriately studied with the anechoic chamber, the gyroklystron will be utilized to energize a 17.136 GHz accelerator structure [2]. Thus, 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 [3] and redesigned for our system. A prototype of this converter was manufactured and tested. Following this converter, a bifurcation divides the power equally into two linear tapers which bring the wall dimensions to those of standard WR62 waveguide (as shown in Fig. 7). The microwave power is then transported in the TE_{01} mode via WR62 waveguides into the dual feeds of the accelerator structure.

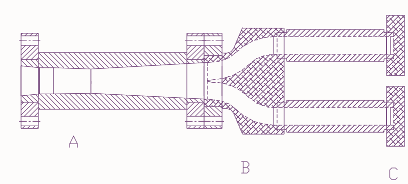

Figure 7: Schematic of part of new output waveguide system (A - circular to rectangular mode converter and rectangular taper; B - Bifurcation; C- Linear tapers into WR62 waveguides)

4 FINAL REMARKS

After much design and technical work we are about to engage in very exciting experiments. Our four cavity circuit is soon to be tested experimentally, and the components of the new output waveguide system (required for coupling to the accelerator structure) are in the fabrication stage.

We addressed the problem imposed by the faulty MIG emitter (which jeopardized our three cavity circuit) in a two-fold manner. In the four cavity circuit we oriented the tungsten support pins facing the cold spot of the emitter, thus lessening the erosion of the pins. Further, we have developed a new design for future MIG emitters as well as a precise manufacturing procedure which should greatly improve their performance.

5 REFERENCES

[1] Cheng, J., et al, 1999, Experimental Studies of a High-Power, X-Band, Coaxial Gyroklystron, IEEE Trans. Plasma Sci., 27, 1175-1187.

[2] Haimson, J. & Mecklenburg, B., 1999 A Linear Accelerator Power Amplification System for High Gradient Structure Research, in Advanced Accelerator Concepts, AIP Conference Proceedings 472, New York: AIP Press, 1003-1013.

[3] Tantawi, S., Private communication.