Studies of an X-Band Three-Cavity Gyroklystron with Penultimate Cavity Tuning

S. Tantawi, W. Main, P.E. Latham, H. Matthews, W. Lawson, C.D. Striffler and V.L.Granatstein
Laboratory for Plasma Research and Department of Electrical Engineering
University of Maryland, College Park, Maryland 20742

Abstract

We present experimental results of a 10 GHz TE_{01} mode three-cavity gyroklystron. The beam is produced by a pulse line modulator and magnetron injection gun, which can operate to 433 kV and 225 A with 1 μs flat-top and at a rep rate of 3 Hz. Microwave power is measured by a mode-selective directional coupler and flowing methanol calorimeter. Mode purity is determined by a large anechoic chamber. Initial testing of the first three-cavity circuit has produced a peak power of 23 MW with efficiency of 27% and pulse energy of 36 J. We have a maximum gain of 39 dB at a peak power of 21 MW.

I. INTRODUCTION

The University of Maryland is developing a three-cavity gyroklystron to demonstrate the feasibility of this type of device as an RF source for future TeV linear colliders. To achieve TeV energies, over a thousand phase-locked RF drivers will be required. For this reason it will be important to have RF sources with high gain. To achieve high gain will require a gyroklystron with 3 or more cavities. As a proof of principle our first effort was a two-cavity device which gave encouraging results[1].

A diagram showing the major components of the system appears in Figure 1. The magnetron injection gun (MIG) is designed to give optimum beam quality at 500 kV, 160 A and and α=1.5. At these parameters the velocity spread is 7% [2]. Our modulator produces pulses with flat-top of 1 μs and is currently capable of repetitive operation at 3 Hz up to 433 kV and 225 A. The axial magnetic field is produced by four separate circuits which allow us to vary the magnetic compression to the circuit and also the field profile in the circuit region independently. The circuit is designed for 5.85 kG and the maximum attainable flat field is 6.5 kG.

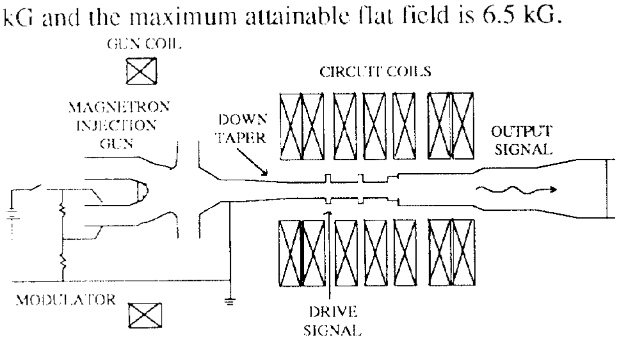

Figure 1. Schematic diagram of gyroklystron system.

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Figure 2 shows the microwave circuit. Key features of this RF circuit are the remotely tunable buncher cavity and lossy dielectrics. We tune the cavity by simultaneously inserting two metal rods (OD=0.2 in) with rounded ends from opposite sides of the cavity. The tip of the rods can travel from the drift tube radius outward to 5 mm outside the cavity, but most of the 100 MHz tunability occurs while the probes are well into the cavity.

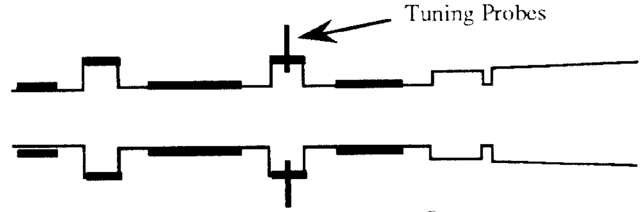

Figure 2. The three-cavity gyroklystron circuit showing the tuning probes and lossy dielectrics. The lossy dielectrics appear as darkened regions in the cavities and drift regions.

In this device the drift regions are not cutoff for all modes and the cavities are over-moded. Due to the Larmor radius of the beam electrons, the drift regions can not be reduced to cutoff all modes without significantly reducing the beam power. To isolate the cavities we loaded the drift regions with lossy dielectric liners, and to prevent parasitic oscillations in the cavities we loaded the radial wall of the cavities with lossy dielectrics (Fig. 2). In the cavities the ε and geometry of the dielectrics were optimized to increase mode selectivity. In the drift regions the dielectrics were optimized to maximize the attenuation of parasitic modes and provide adequate isolation between the cavities[3].

Input power for the gyroklystron was produced by a pulsed magnetron capable of 2 μs pulses of 100 kW. Forward and reverse power were monitored and coupling varied from 30% to 70% depending on the beam parameters.

II. EXPERIMENTAL RESULTS

A. Amplifier operation

This device gives the best power and gain at our highest voltage of 425 kV and current of 212 A. Magnetic field tapering and penultimate tuning are also very important. The best results were achieved with the guide field 33% higher at

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the input cavity than at the output cavity and zero penultimate tuning. This case gave 23 MW with efficiency of 27%, gain of 31 dB and total pulse energy of 36 J. Figure 3 shows scope traces of the microwave signal for this case. The best power from a flat field experiment was 12 MW at 5.7 kG and the buncher cavity tuned 16 MHz below the other cavities. Table I summarizes the experimental results for the tapered and flat field cases and Figure 4 shows the magnetic field profile for these cases.

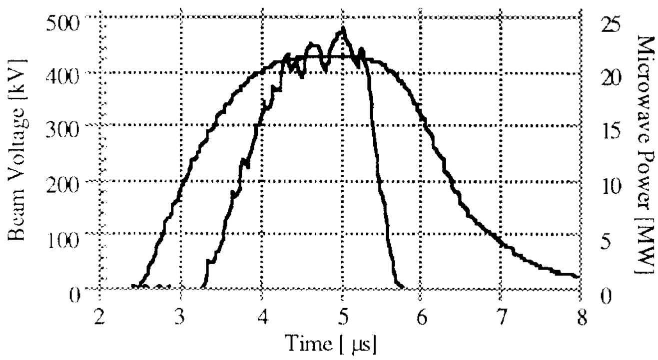

Figure 3. Time dependance of the microwave power and beam voltage.

Bz [kG]	α	Power [MW]	Efficiency %	Gain dB
33% taper	0.66	23	27	31
5.0	0.63	11	13	30
5.7	0.71	12	15	27

Table I. Comparison of results for tapered and flat magnetic field at beam parameters 425 kV and 212 A.

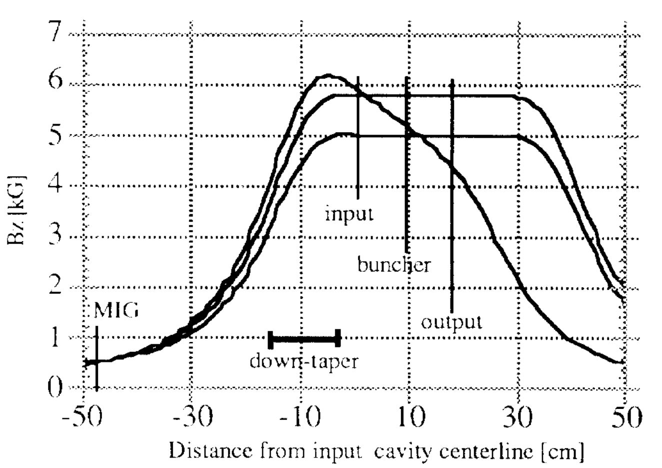

Figure 4. Comparison of magnetic field profiles for flat fields at 5.8 kG and 5.0 kG and a tapered field (B_{in}/B_{out}= 1.33).

The device gives the best gain with the same 33% taper but with the buncher cavity tuned 24 MHz lower than the other cavities. In contrast to standard klystrons which require positive penultimate tuning, the gyroklystron requires negative tuning due to the inverse relation of energy and phase in the electron orbits. Here the gain is 39 dB with peak power of 21 MW and efficiency of 25%. Figure 5 shows the dependance of gain on penultimate tuning for the tapered field described above.

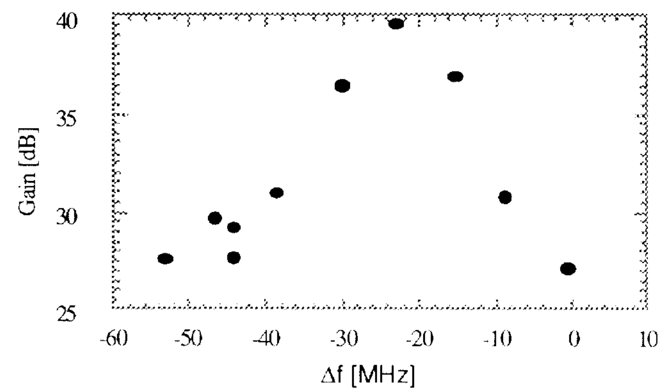

Figure 5. The dependance of gain on penultimate cavity tuning at 420 kV, 212 A and a tapered field (B_{in}/B_{out}= 1.33).

Figures 6 and 7 are contour plots of the measured efficiency and gain vs. beam voltage and current. These plots show that increasing the beam voltage improves the gyroklystron's performance in both power and gain. The dependance on beam current is different. The best output power is achieved slightly below the maximum current and the best gain is achieved at the lowest beam current. These experiments were made with a tapered magnetic field and zero penultimate tuning.

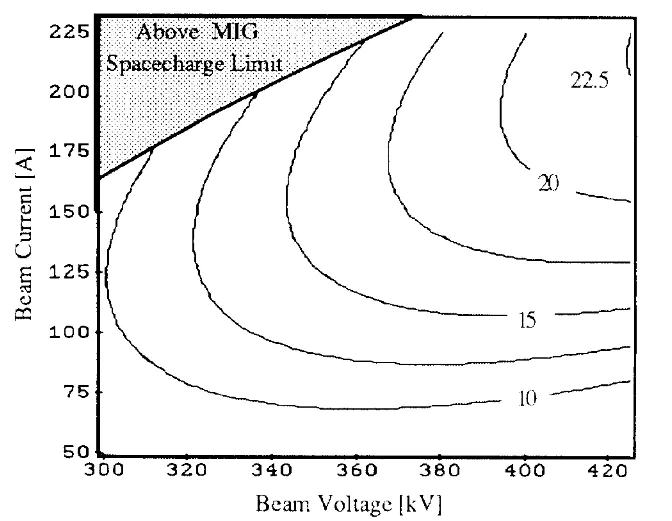

Figure 6. Contour plot of least squares fit to measured Power in megawatts for a tapered magnetic field (B_{in}/B_{out}= 1.33).

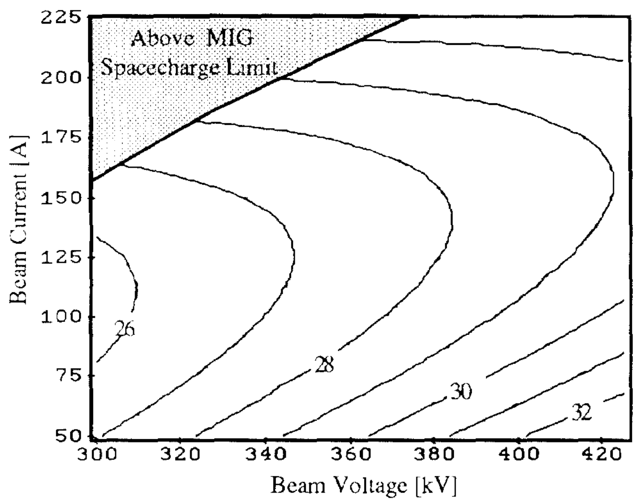

Figure 7. Contour plot of least squares fit to measured gain for a tapered magnetic field (B_{in}/B_{out}= 1.33).

B. Stability

The three factors which limit the power in this tube are the beam voltage limit of 430 kV set by the modulator, a beam instability in the down-taper region (Fig. 1) , and saturation of the output cavity. The modulator is currently being redesigned to allow operation to 500 kV.

The instability in the down-taper region is activated when the beam reaches a certain level of perpendicular momentum ($P_\perp$). If $P_\perp$ is further increased by reducing the magnetic field at the MIG, strong oscillations in the range 6-8 GHz occur in the down-taper region. The onset of these oscillations can be moved to higher $P_\perp$ by increasing the field in the down-taper region (even though this also has the effect of increasing $P_\perp$) or by operation at higher input power. We believe that some of the input power leaks into the down-taper region stabilizing this instability.

Saturation in the output cavity occurs when either $P_\perp$ or the bunching of the beam is increased past a certain point. The beam bunching can be optimized either by reducing the input power, or lowering the gain of the circuit. The gain can be lowered by detuning the buncher cavity or altering the taper in the magnetic field.

The operation and stability of the device is best demonstrated by experimental results at three different magnetic fields: flat field at 5.7 kG, flat field at 5.0 kG and a tapered field (Fig. 4). Comparing the two flat field experiments (Table I), the case at 5.7 kG has a higher field in the down-taper region. This higher field gives better mode suppression, and thus the 5.7 kG case gives the higher α. This is consistent with the slightly higher output power observed in the 5.7 kG case.

The tapered field case is very interesting. Although its α is less than the 5.7 kG flat field case, its output power is almost two times higher (Table I). In addition, flat field experiments with output cavity fields equal to that of the tapered field case give significantly less output power. For this reason we believe that decreasing the guide field across the output cavity region is necessary to achieve high power. In this tapered field case, the field decreases 6% across the output cavity. Because the guide field extends well beyond the end of the microwave circuit, we suspect that a helpful traveling wave interaction may also occur there. This interaction might also benefit from the tapered field. A numerical study to better understand the effects of guide field tapering at the output cavity is now underway.

III. FUTURE WORK

The second three-cavity gyroklystron circuit will be tested in May 91. This circuit will use a more lossy down-taper so that higher α can be achieved. In addition, the quality factor (Q) of the output cavity will be increased from 200 to 350. The first circuit was made with lower Q anticipating operation at 500 kV and α = 1.5. At our current operating parameters an output cavity with a Q of 300 will operate at 50% of the start oscillation current, thus the increased Q should not reduce the stability of the circuit.

IV. REFERENCES

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