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DESIGN AND COLD TESTING OF A HIGH PEAK POWER X-BAND GYROKLYSTRON

W. Lawson, J. Calame, V. L. Granatstein, P. E. Latham, J. McAdoo, G. S. Park, C. D. Striffler, and F. J. Williams

Laboratory for Plasma and Fusion Energy Studies
University of Maryland
College Park, MD 20742

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and

K. R. Chu, J. L. Seftor, P. Vitello, and K. Ko

Science Applications International, Inc.
McLean, VA 22102

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Introduction

The main goal of the University of Maryland's gyroklystron project is to develop an efficient, high power, high gain, phase controllable amplifier at 10 GHz. While peak powers of several hundred megawatts are ultimately of interest, our initial experimental design values include 30 MW of output power in 1 μs pulses with a gain in excess of 50 dB. The 30 MW power level represents an enhancement of almost three orders of magnitude over the current state-of-the-art in gyroklystron amplifiers.[1,2] This enhancement will be achieved by going to high beam energies ($\gamma = 2$) and overmoded cavities (TE^o_{01}). Outlined in this report are the steps being taken to realize our goal.

The Modulator

The experiment will be driven by a modulator similar in design to those used by the SLAC klystron.[3] Several pulse-forming networks (PFN's) in parallel will be resonantly charged to 50 kV by a dc supply. The PFN's will be switched through a 20:1 pulse transformer to the electron gun. The modulator will supply sufficient current for the gun and for a resistor divider that will provide the control anode voltage. The modulator currently under construction in our laboratory will have a repetition rate of 10 pps and a 500 kV flat top of approximately 1 μs.

The Magnetron Injection Gun

The starting point for our Magnetron Injection Gun (MIG) design is a set of adiabatic trade-off equations collected by Baird and Attard.[4] The replacement of one trade-off equation by the Hull cutoff condition and the inclusion of relativistic corrections has improved the accuracy of these equations. A further improvement was made by the addition of an expression for the spread in guiding center radius.

Nominally, the beam has an average guiding center radius of $b_o = 8$ mm, a gyroradius of $a_o = 4.29$ mm, a transverse velocity of $v^o_{\perp o} = 0.718$ c, and an axial velocity of $v_{zo} = 2v_{\perp o}/3$. For these parameters, a magnetic compression > 10 must be chosen if the electric field on the emitting surface of the cathode is to remain below 50 kV/cm. Current densities in the range 6-10 A/cm^2 are being considered to achieve total currents between 120-200 A (corresponding to gun powers of 60-100 MW). These large current densities are a significant fraction of the limiting current densities at the required magnetic compression ratios. Consequently, large angle cathodes (> 30^0 half-cone angles) and laminar flow beams are being considered. For the expected gun parameters, total beam thicknesses < 2.5 a_o are possible ($\Delta b/a_o$ < 50%).

The design value from the trade-off equations is used as the initial input to a gun simulation code. Currently, we are using a square mesh, finite difference, electron trajectory code developed by W. B. Herrmannsfeldt.[5] The code is used to fine tune the shapes of the cathode and control anode and to determine the shape and location of the accelerating (full voltage) anode. Because of the relatively high current density, the simulation is carried through to the opening of the input cavity. Preliminary results indicate that a beam thickness of = 2.5 a_o is feasible. Also, the spread in axial velocity due to electron optics has been brought well below the 10% total spread in v_z anticipated in the cavity design.

The Magnet System

The nominal magnetic field in the interaction region is 5.65 kG. This field will be provided by a set of (identical) water-cooled pancake coils. The flexibility of this system is sufficient to enable a flat field region (< 0.1% variation) of 25 cm. This design has been achieved without the use of pole pieces. The length of the compression region (cathode center to input cavity entrance) is 46 cm. The magnetic field is provided in this region by a large gun coil placed over the cathode and by an additional pancake coil placed in the middle of the compression region. Magnetic field tapering will be accomplished by adjusting the postion and currents of the various coils.

The Gyroklystron Circuit Design

The primary tool used in the design of our gyroklystron circuit is a partially self-consistent code developed by K. R. Chu.[6] The code assumes a single EM mode from an ideal circular cavity and then uses an iterative process to determine the correct amplitudes and phases of the fields in each cavity in the presence of the beam.

An initial 30 MW design was reported[6] assuming that a beam of 500 kV, 200 A, and a thickness of 3 a_o traversed four equally spaced TE^o_{01} cavities in a uniform magnetic field. To avoid linear start oscillation currents, it was necessary to have low Q cavities (Q = 300 in the input and buncher cavities and Q = 100 in the longer output cavity). With zero axial velocity spread, 35% efficiency was achieved. With $\Delta v_z/v_{zo}$ = 10%, an efficiency of 28.1% with a large signal gain of 56 dB was obtained. Consequently, a beam power of 100 MW was needed to produce = 30 MW of microwave power.

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There are several reasons to expect higher ultimate efficiencies. First, the actual beam thickness should be reduced ($\approx 2.5\ a_o$) and the axial velocity spread might be lower. More importantly, the effect of tapering the magnetic field and cavity walls has not yet been considered. Stagger tuning the penultimate cavity is another possibility not yet under investigation. If we can achieve an efficiency of 50% or more (as obtained in some gyrotron oscillators[7,8]), only a beam power of 60 MW would be required.

The gyroklystron circuit code is currently being improved and expanded. For example, actual (cold) field profiles for partially open-ended resonators have been included in the code. Soon the code will model tapered magnetic fields and the effect of space-charge potential depression. These improvements will enable us to better design gyroklystron circuits.

The Preliminary Gyroklystron Circuit

In order to test some of our design concepts in simple geometry, it was decided to design and build a preliminary two cavity gyroklystron. The available input power is somewhat limited, and since a two cavity system has inherently less gain than a four cavity system, a lower beam power was considered so that non-negligible efficiencies could be achieved. The beam power was to be reduced simply by reducing the cathode current. Unfortunately, prohibitively high Q's and low currents forced us to abandon the design in favor of a three cavity system.

A satisfactory three cavity design has been obtained even with the (possibly) pessimistic values of $\Delta b_o = a_o$ and $\Delta v_z/v_{zo} = 10\%$. The magnetic field was fixed at 5.65 kG, the input power was bounded by ($\leq$) 1 kW, and the efficiency was "maximized" with respect to the remaining circuit parameters given the constraints:

1) Start oscillation currents were not exceeded.
2) Resonances with unwanted cavity modes were avoided.
3) Q's were held to within experimental bounds.
4) Cavities were adequately isolated.

The circuit parameters and predicted results are shown in Table I. The beam current was 30 A; all other beam parameters were specified previously. The start oscillation current in the output cavity was 36.7 A. The space charge potential depression was negligible ($\leq$ 1%) as was the power loss to the walls (< 10 kW/cm^2 peak). This system is expected to produce 5 MW output with a gain of nearly 40 dB and should be an impressive first experiment.

Unfortunately, the drift tubes are not cutoff to the fundamental (TE^o_{11}) mode and so a concept for mode suppression has to be implemented. Two techniques are being considered; one involves drift tubes made of connected rings and backed by microwave absorbers.[9] Preliminary results indicate that this technique will sufficiently lower the Q's for the TE^o_{11} mode in the drift space. The isolation of these drift spaces for the TE^o_{01} mode is currently under investigation. Narrow band injection techniques for the input cavity such as the ring converter and multiple rectangular waveguide exciter appear to be sufficient for the narrow-band gyroklystron and are also currently under investigation by our group.

TABLE I. The three cavity gyroklystron design for input power 0.52 kW, gain 39.6 dB, and efficiency 31.3%.

Cavity	Radius (cm)	Length (cm)	Q
1	2.43	2.28	2000
2	2.34	2.40	2000
3	2.11	3.00	2000
Drift Tube	**Radius (cm)**	**Length (cm)**	**Isolation**
1	1.50	8.40	100 dB
2	1.50	4.80	57 dB

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