PLANNED BEAM TRANSPORT AND TWO-CAVITY AMPLIFIER EXPERIMENTS ON THE UNIVERSITY OF MARYLAND GYROKLYSTRON*

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Abstract

The University of Maryland Gyroklystron Laboratory is developing a high peak power Gyroklystron for linear supercollider applications. This paper describes the final experimental installation, the planned beam propagation studies, and the first experimental gyroklystron circuit.

Introduction

The next generation of linear colliders require high peak power microwave amplifiers at frequencies (8-30 GHz) significantly above current klystrons.[1] The gyroklystron appears to satisfy the power and frequency requirements while promising the high gain (60 dB), high efficiency ($\gtrsim$ 40%), and phase stable operation desired for accelerator work.[2] The University of Maryland Gyroklystron Laboratory is developing an X-band amplifier with 30-40 MW peak power and pulse length of 1-2 μsec as the first stage of gyroklystron research for accelerator applications. To achieve these results, extensive investigations of both the beam quality and the properties of dielectric-loaded drift tubes are underway.

The Experimental Facilities

A schematic of the gyroklystron experiment is shown in Fig. 1. Most of the details of individual components are found elsewhere,[3] here we present a brief status report of the laboratory construction.

The Modulator – A command-trigger, line-type modulator capable of 1 μsec flat top pulses at 500 kV and 400 A is complete. Over 20,000 full voltage shots have been fired into a resistive load at up to a 2 Hz trigger frequency.

The Magnets – Installation of the water cooled, DC powered magnet system is in progress. Seven pancake coils with a 14.5 cm diameter bore provide a 25 cm flat field region with maximum field of ~ 7 kG. A separate gun coil adjusts the field strength at the cathode to obtain a magnetic compression of 12.

*This work is supported by DOE.
†Physical Sciences, Inc., Alexandria, Va.

The Gun – A double anode, 500 kV Magnetron Injection Gun (MIG) has passed all high voltage tests. The thermionic cathode operates in a highly loaded regime (~ 40% of the space charge limit) while producing beams between 120 A and 240 A with predicted velocity axial spreads of less than 10%.

The RF Transport System and Beam Dump – The RF transport system consists of a 25 cm long non-linear taper, an 85 cm long water cooled beam dump, a 25 cm long perforated waveguide for pump access, a 35 cm long non-linear taper, and a 12.7 cm diameter Beryllia output window. A transverse field magnet, located at the exit of the beam dump, prevents accelerated particles from striking the output window. All the transport system components are complete. Cold testing for reflection and mode conversion is in progress. The predicted mode conversion is less than .1% and overall reflection is calculated to be less than .4%.

Microwave Diagnostics – After the output window and outside the vacuum system, a mode selective ($TE^{\circ}_{01} \rightarrow TE^{\square}_{10}$) 50 dB directional coupler provides a low power signal for envelope detection and spectrum analysis. Concurrently, a nonresonant water load calorimeter provides the average power measurement. These components are under construction. A single shot pulsed calorimeter, which fits between the directional coupler and the water load, is currently being designed.

Tube Processing Facility – To permit rapid construction and testing of microwave tube structures, a vacuum tube processing center has been developed at the University of Maryland. This facility includes: a hydrogen/vacuum brazing furnace, a carbonization furnace, an air kiln, a chemical processing station and a dust-free assembly station. The processing center has already proven its versatility during the manufacture of lossy dielectrics for cold testing of both the input cavity and the drift tube.

Microwave Circuit Design

Gyroklystron theory predicts and other experiments demonstrate that the most important parameters for gyroklystron operation are the beam quality, the intercavity coupling, and RF mode control. All of these effects have been examined during the microwave circuit design. The main design code self-consistently calculates the large signal beam microwave in-

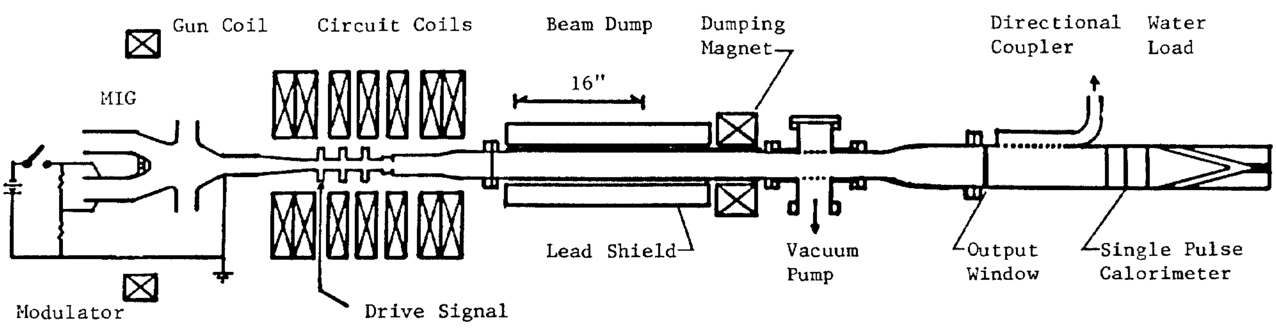

Fig. 1. The University of Maryland 30 MW, 10 GHz Gyroklystron.

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teraction. A second code calculates realistic field profiles for complex cavity geometries including lossy dielectrics. The realistic field profiles provide the design of realizable cavities (by determining f_0 and Q analytically), and allow the calculation of start oscillation currents for competing "whole tube" modes. These modes occur because the drift tubes are not cutoff for many electromagnetic waves. The start oscillation currents for some competing modes are shown in Fig. 2. To combat these spurious oscillations, the intercavity drift tubes are dielectrically loaded. The dielectric loading is then optimized by calculating the start oscillation currents for the competing "whole tube" modes.

Because of the strong dependence of gyroklystron performance on these parameters, the first two experiments scheduled are electron beam diagnostics and a two cavity gyroklystron circuit.

Beam Diagnostics

A combination of eight probes is being used to characterize the electron beam quality of the gyroklystron. These diagnostics are designed to measure the electron distribution function of the beam in configuration space. A brief list of each probe's purpose is included in Table I. A beam diagnostics chamber, which holds all three non-invasive probes and any three invasive probes, has been constructed to fit into the interaction region of the gyroklystron. Careful layout and shielding in the diagnostics chamber allow all six probes to be operated simultaneously.

The Rogowski coils at the entrance and exit of the interaction region are permanent installations. They measure the beam current traversing the gyroklystron tube. The capacitive probes aid in beam alignment and measure the beam line charge density. These two measurements are used to determine the average beam alpha, $v_\perp/v_z$.

All of the probe data acquisition and scanning are remotely controlled from a GPIB (IEEE 488) network on a PC/XT computer. Eight channels of digital data, with a sampling rate of 100 Msamples/sec per channel, and providing greater than 50 MHz analog bandwidth per channel, can be recorded at a firing rate between $^1/_2$ and 1 Hz. Simultaneously, probes are repositioned in the beam between shots with a resolution and repeatability of better than 50 μm. Bias voltages on the Langmuir probes and wire scanners are also remotely controlled. The bias supply provides positive or negative DC voltages of up to 25 kV. Ripple is less than 1% RMS and regulation is repeatable to 125 Volts.

Two Cavity Circuit

A two cavity gyroklystron experiment, shown in Fig. 3, is being pursued to provide information for optimizing the input coupler design, the dielectric cavity loading, and the dielectrically loaded drift tube assembly. The two cavity experiment is essentially identical to the ultimate four cavity design except the drift tube is longer to provide proper phase bunching for high gain. A comparison of the input and output cavities of both tubes is listed in Table II. The expected performance of the two cavity gyroklystron is 33% efficiency at 27 dB gain yielding about 26 MW at 10 GHz.

The input cavity requires a resistive Q of about 225 for the TE_{01} mode and much lower Qs for other competing modes. Two thin, carbon-impregnated dielectric annuli placed on the end walls of the cavity have yielded the proper frequency and Q in cold testing. Analytic results have demonstrated this to be a readily "tunable" loss mechanism for future cavity designs. The input microwave power is injected through a resonant coupler. The coupler consists of a standard X-band waveguide attached to the outer wall of the input cavity with the broadwall parallel to the tube axis. A capacitive iris in the rectangular waveguide adjusts the coupling coefficient. Final cold tests of the design are in progress.

Ideal inter-cavity drift tubes are cutoff to the TE_{01} mode and all lower order competing modes. For the 30 MW, 10 GHz Gyroklystron, the beam power requirements yield beam sizes which cannot fit in cutoff waveguides for the TE_{11}, TE_{21} and TM_{01} modes at 10 GHz. Theoretical calculations indicate that "whole tube" modes will generate spurious oscillations in these modes. Cold tests of drift tubes consisting of alternating metal and lossy dielectric washers have shown sufficient attenuation to eliminate these "whole tube" modes. Also, the dielectric loss has been maximized for the TE_{01} mode.

Table I. Probes for Beam Diagnostics

Type of Probe	Probe	Number	Measurement	Comments
Non-invasive, fixed position	Rogowski coils	2	beam current	3 mV/A output; 10 kHz-50 MHz
	Capacitive probes	2	line charge density	3 × 120° sectors; beam alignment
	Diamagnetic loop	1	$\int_0^{R_0} B_z(r)dr$	transverse energy; potential depression
Invasive, radial motion	Langmuir probes	2	$V(r, z_1)$	200 V resolution; fluctuation studies
	Differential Electric probes	2	$E_r(r)$	100 V/mm resolution
	B-dot loops	2	$\dot{B}_z(r), \dot{B}_\theta(r)$	1.2 mm diameter, 10 turn, 1 mV/10gauss
	Displacement current monitor	1	$J_z(r)$	1mV/$\frac{1Amp}{cm^2}$; calibrates B-dot loops
	Wire scanner	1	$\int n_e d\ell$	Abel transform to get $n_e(r)$

The gyroklystron is designed as an endfire system with a diffractive output cavity. The output cavity Q is sufficiently larger than the minimum Q required for power extraction, so that a simple coupling iris provides the diffractive output. Analytic results of a mode expansion code for the output cavity Q and frequency have been verified by cold testing.

Discussion

At this time, all of the components required for the beam transport experiments are in final installation. The transport experiments will begin later this spring. Additional components required for the two-cavity experiments are under construction, with completion expected in early summer. At that time the two-cavity experiments will be started.

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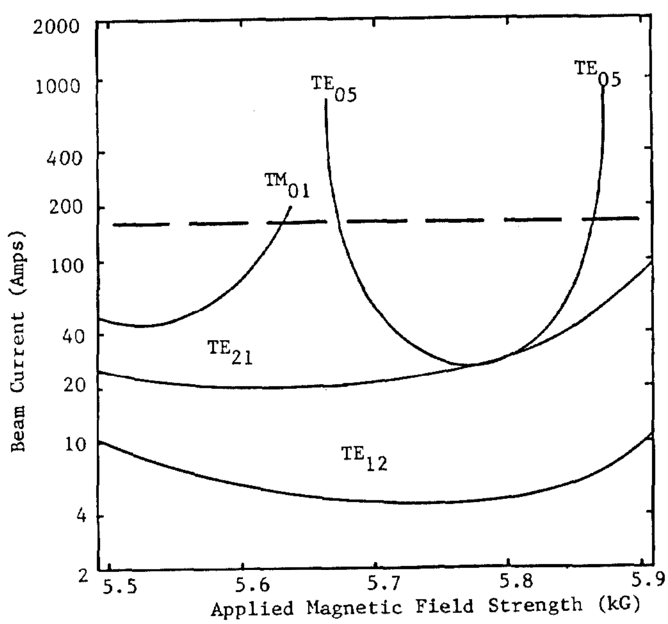

Fig. 2. Start oscillation current versus applied magnetic field strength for some of the competing "whole tube" modes in the two-cavity gyroklystron.

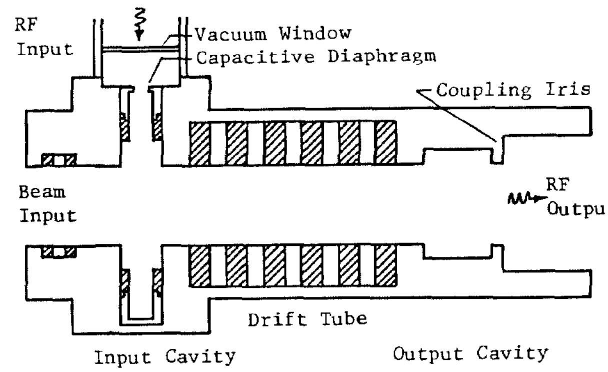

Fig. 3. Schematic of the planned two-cavity gyroklystron experiment showing the placement of the lossy dielectric rings (cross-hatched sections).

Table II

	2-Cavity Design	4-Cavity Design
Input Cavity		
Q	225	235
f (Ghz)	9.85	10.000
Length (cm)	1.53	1.53
Radius (cm)	4.50	4.50
Output Cavity		
Q	165	180
f (GHz)	9.85	9.995
Length (cm)	2.38	2.38
Radius (cm)	2.11	2.11
Coupling Iris		
Length (cm)	.33	.336
Radius (cm)	1.50	1.50
Drift Tube		
Length (cm)	9.00	3.90-5.40
Radius (cm)	1.50	1.50