MODE COMPETITION IN HIGH POWER GYROKLYSTRON AMPLIFIERS*

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Abstract

Stability of multi-cavity gyroklystron amplifiers against parasitic modes is studied. The insertion of lossy dielectrics into the cavities and drift sections played a primary role in mode suppression in our two cavity system. Comparison between the theory and experiment of this method of mode control is presented. In addition, a three cavity design that incorporates large amounts of lossy dielectric is presented with its predicted nonlinear efficiency and gain.

I. Introduction

A serious problem facing the development of high power, multi-cavity gyroklystron amplifiers is the excitation of unwanted modes. The modes with the lowest start oscillation currents, and thus the hardest ones to suppress, are the whole-circuit modes. These arise when radiation is partially reflected by the discontinuities associated with the cavities, the nonlinear tapers, and the output window. These modes often extend over the whole circuit (thus their name), leading to an efficient linear interaction (linear efficiency scales as the third power of the interaction length).

There are two methods of suppressing unwanted modes: load the cavities or decrease the reflections. In the two-cavity gyroklystron under development at the University of Maryland (see the paper in these proceedings by W. Lawson et al.), we have employed both methods: lossy dielectrics have been placed in the drift sections and the output section has been modified to reduce the reflections off the nonlinear uptaper, as shown in Fig. 1. In this paper we compare the theory and experiment of various schemes for loading the cavities and drift sections with lossy dielectric. We also present a three cavity design with its predicted nonlinear efficiency and gain, and we calculate the required amounts of suppression needed for stable operation.

II. Suppression of Unwanted Modes–Lossy Dielectrics

The use of lossy dielectrics to suppress unwanted modes appears simple. There are, however, a number of considerations. The two most important are choosing the real and imaginary parts of the dielectric constant and deciding on a configuration, e.g., alternating rings of dielectric and metal versus solid dielectric. For high power tubes, the knowledge of the dielectric properties over a rather large frequency band, in our case 6-20 GHz, is essential. Thus, the issues of measuring both the real and imaginary parts of the dielectric constants and modeling the system numerically are important.

To model the dielectric loaded complex circuit, we have developed a code based on the scattering matrix method.[1] Our code, "CASCADE", assumes cylindrical symmetry and allows one region of lossy dielectric material (e.g., vacuum for $r < r_0$ and dielectric for $r_0 < r < r_w$ where r_w is the outer wall radius). In addition, we have a particle pushing code that allows us to calculate the start oscillation current in a complex dielectric loaded circuit.

Early mode suppression strategies for the drift regions used alternating dielectric and metal rings, see Fig. 2a. The dielectric rings turned out to be only slightly lossy ($\epsilon \simeq 9.7 + .05i$) and thus we had to rely on resonant effects to achieve attenuation. These alternating structures worked well near resonance but had limited bandwidth (~300 MHz). Preliminary beam tests on the two-cavity system revealed that unwanted oscillation occurred from 6 to 20 GHz. Steps to improve the suppression of modes for the two cavity system are described in the accompanying paper [W. Lawson et al].

To achieve attenuation over the range 6 to 20 GHz we are considering a nonresonant absorbing system for the three cavity circuit. Figure 2 shows the difference between a resonant, Fig. 2a, and nonresonant, Fig. 2b, absorbing system. By using a single piece of high loss material we form an absorber for which the attenuation per unit length is less frequency dependent. Figures 3a and 3b compare the measured and computed TE_{11} attenuation versus frequency for a resonant and nonresonant system. Figure 3a shows the attenuation of the 6-ring resonant absorber of Fig. 2a, both from experimental measurement and from CASCADE. The difference in the location of the resonance between the two curves can be removed by changing the dielectric constant used in the calculation by less than 5%. This difference is either due to an error in the measurement of ϵ, batch to batch variations in the dielectric material, and or the frequency dependence of the material.

In our gyroklystron the operating mode in all three cavities is the TE_{011} cavity mode. To isolate the cavities, the TE_{01} mode attenuation in the drift section between cavities must be greater than the intercavity gain, which is

40 dB between the input and buncher cavities and 20 dB between the buncher and output cavities. To achieve this attenuation in the nonresonant system we place a smooth metal drift section 1.5 cm long on each side of the input and buncher cavities and on the upstream side of the output cavity, see Fig. 4. These regions also isolate the TE_{01} mode at 9.85 GHz in the cavities from the absorbing structures, which could alter the Q of the cavities. At 9.85 GHz the TE_{01} mode is evanescent in these regions and is isolated by 12 dB/cm. Thus, in the first drift region the necessary isolation of 40 dB plus a 10 dB safety margin can be achieved if the 4.25 cm dielectric region has attenuation greater than 3.3 dB/cm. In the resonant system of Fig. 2a the metal rings used to adjust the resonance also cutoff the TE_{01} mode and thus this system achieves very good isolation in the operating mode.

For other than the operating mode, the absorbing structure is designed by optimizing the attenuation in the least attenuated mode. Depending on the frequency and kind of dielectric used, the least attenuated mode can be one of a number of hybrid modes which exist in a lossy dielectric lined tube. The regions in frequency or liner geometry where these modes cross generally give the best attenuation. Experience with the two cavity system has shown that attenuation of 1-2 dB/cm for the least attenuated mode is acceptable. In practice we measure the attenuation in the least attenuated mode by injecting the TE_{11} mode.

We used our scattering matrix code CASCADE to test different combinations of ϵ and thickness. We found that for low loss dielectrics such as $\epsilon = 4.6 + 0.66i$ the TE_{01} mode is sufficiently isolated only if the thickness is less than 2mm, whereas the least attenuated mode is sufficiently attenuated for thicknesses above 4.5 mm. For a lossy dielectric such as $\epsilon = 42 + 18i$ the TE_{01} is sufficiently isolated for any thickness; however, there is no thickness where the least attenuated mode is sufficiently attenuated. Between these extremes there is a combination that satisfies the requirements for both modes; this is $\epsilon = 6.2 + 2i$ and a thickness of 3 mm. This ϵ is close to the values attainable with carbonized aluminum silicate.[2] The carbonization process yields a nonuniform ϵ, so it is difficult to model our samples, however, the attenuation achieved by these samples is close to that predicted by CASCADE.

III. Three Cavity Design

Figure 4 shows the three-cavity system and Table I shows the operating parameters predicted by our nonlinear amplifier code. This code optimizes system operation by varying geometries and magnetic field. The quality factors are set relative to start oscillation current in the operating mode, assuming the field profiles for an all metal wall structure. The input and buncher cavities have dielectric loading and have similar design. The quality factor of the output cavity is almost completely diffractive. The drift tube is loaded with a nonresonant absorber as described in Section II.

Table 1: Beam parameters and operating parameters predicted by our nonlinear amplifier code.

Beam:	Power	80 MW
	Voltage	500 kV
	Velocity Ratio (α)	1.5
	Velocity Spread	6.8%
	Center Radius	0.79 cm
	Guiding Center Spread	0.268 cm
	Axial Magnetic Field	0.5–0.6 T
System:	Frequency	9.85 GHz
	Input Cavity Q	225
	Buncher Cavity Q	225
	Output Cavity Q	170
	Theoretical Efficiency	42%
	Theoretical Gain	60 dB

We used a start oscillation current code to design the cavity loading. The code shows that the finite quality factor of the cavity due to wall losses will not be enough to suppress oscillations for both the TE_{011} and TE_{021} modes. All other cavity modes are stable for magnetic fields around the operating point of 5.69 kG. Thus, the dielectric loading of the cavity should discriminate against the TE_{021} mode. This will reduce the Q of that mode considerably while leaving the Q of the TE_{011} mode high enough for efficient bunching of the beam. The structure which we found that works the best is a simple ring of lossy dielectric placed on the radial wall of the cavity. To operate at 70% of the start oscillation current with a beam of 160 A requires a cavity Q of 320. Figure 5 shows the computed start oscillation current of different modes after loading the cavities with dielectrics. As shown, the start oscillation current is well above 200 A for the operating mode.

We are in the process of computing the start oscillation currents for whole tube modes. The three cavity circuit will be cold tested in the near future and installed in the GKL system to study its amplification properties in the next few months.

References

1. J.M. Neilson, P.E. Latham, M. Caplan, and W.G. Lawson, IEEE Trans. on Microwave Theory and Techniques **37**, 1165 (1989).

2. J.P. Calame and W. Lawson, submitted to IEEE Trans. Electron Devices Part II (1990).

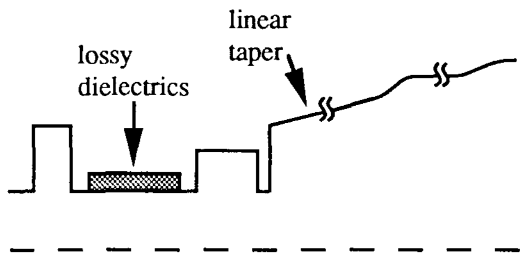

Figure 1. Two cavity design with lossy dielectrics in the drift region and a linear taper following the output cavity.

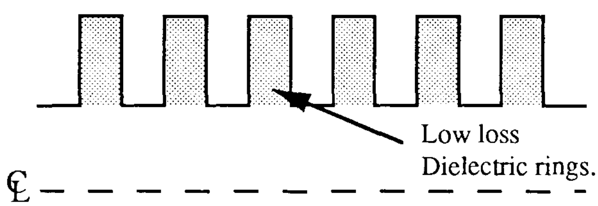

Figure 2a. Resonant absorber circuit attenuates strongly at certain desired frequencies. Metal rings adjust resonant frequency and cutoff operating mode.

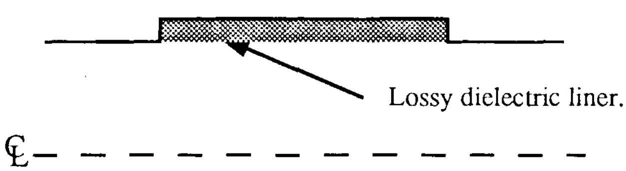

Figure 2b. Nonresonant absorber circuit attenuates over wide frequency range. Lossy dielectric attenuates operating mode and other undesired modes.

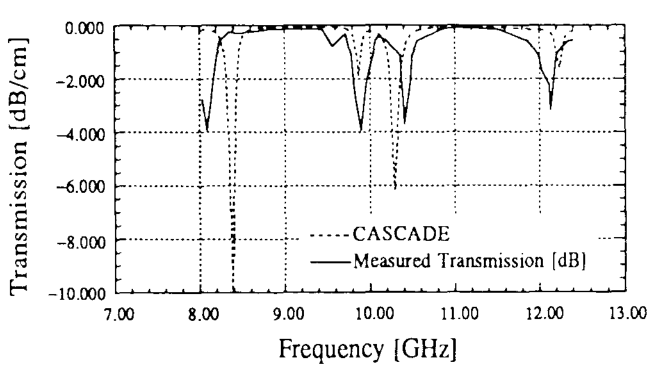

Figure 3a. Comparison of scattering matrix code "CASCADE" with measurement, for resonant microwave absorber circuit of Fig. 2a.

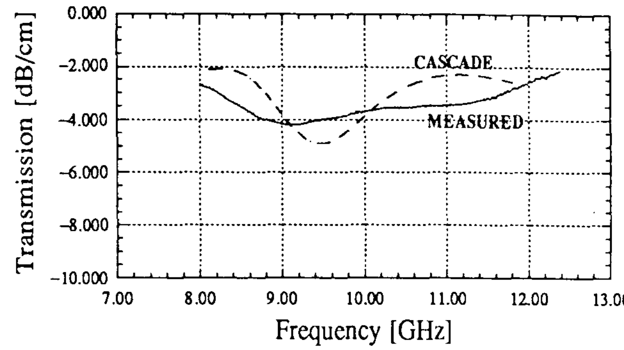

Figure 3b. Comparison of scattering matrix code "CASCADE" with measurement, for the nonresonant absorber circuit of Fig 2b.

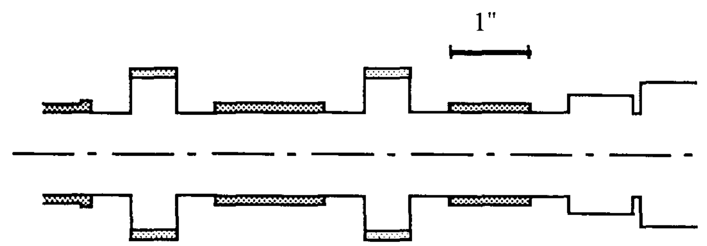

Figure 4. Scale drawing of three-cavity circuit design.

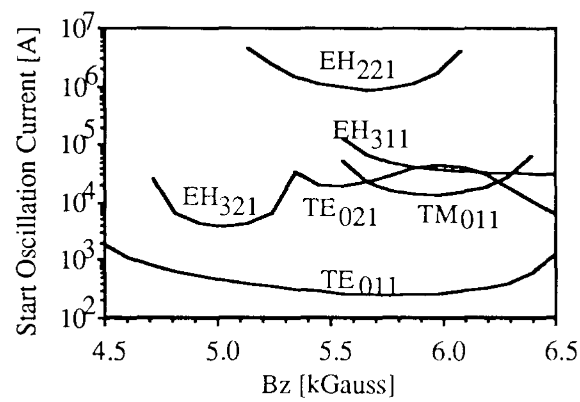

Figure 5. Results of SOC for the input and buncher cavity design. The TM_{010} mode is not unstable in this region of magnetic field. The operating current is 160 A.