Modeling of a 1700-MHz Cluster Cavity of Planar Triodes*

Daniel E. Rees and Carl Friedrichs
Los Alamos National Laboratory

Abstract

In this paper we present the modeling and design of a 1700-MHz cluster-cavity vacuum tube amplifier. We used a three-dimensional, finite-difference code (MAFIA) to characterize the modes that the resonant structure of the amplifier will support. We describe the characteristics of the tube, including performance predictions.

I. INTRODUCTION

As frequency increases into the microwave region, the maximum power output of gridded tubes decreases. Combining several amplifiers is often necessary to achieve medium power (20 - 50 kW). A typical method is to use one or more external combiners; an alternate approach is to use a cluster cavity. In a cluster cavity, a number of gridded tubes are combined in a single resonant structure. As the number of tubes in the cavity increases, the resonant structure must be enlarged; this may cause the circumference to become comparable with multiples of the design wavelength. For this reason higher-order modes must be characterized to determine which is appropriate for amplifier design and to ensure that undesirable modes are avoided. We used a three-dimensional, finite-difference code (MAFIA) to characterize the modes that the structure would support and to modify the cavity design in order to select the desired mode.

II. CLUSTER CAVITY

A. Mechanical Description

We will consider the feasibility of a resonant structure that supports a combination of 4 planar triodes without external combiners. Only the output resonator will be described. The input structure will be similar in mechanical design; however, it will be dimensionally different to allow for a different impedance transformation. Figure 1 is a mechanical drawing of the output resonator. It consists of four rectangular waveguide sections, all feeding into a coaxial section. A direct tap to the center conductor of the coaxial section couples power out of the resonator. Four gridded tubes are located approximately a quarter guide wavelength from the end wall of each waveguide section. The end wall is adjustable in position, to allow each tube to be independently loaded. The tubes are operated common grid with a DC anode voltage of approximately 6 kV. An RF contact connects the grid to the bottom surface of the waveguide, and a "sandwich" capacitor isolates the DC bias of the anode and provides a low RF impedance bypass between the anode and the upper surface of the waveguide. The sandwich capacitor is analyzed as a radial mode structure whose radius is adjusted to present an RF short between the bias surface and top wall of the guide.

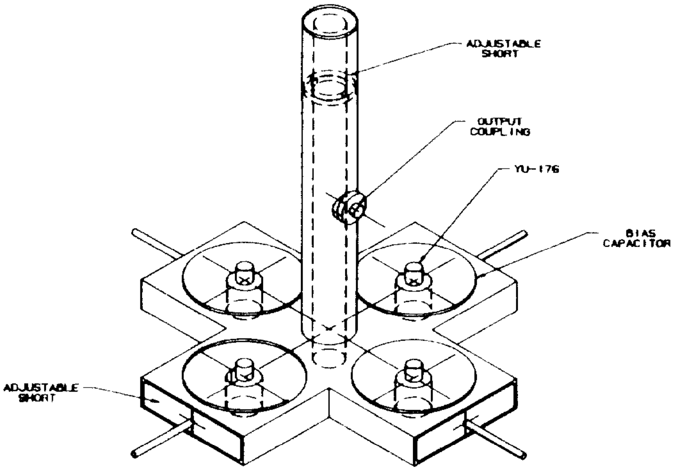

Figure 1. Cluster-cavity output resonator.

Past designs for cluster-cavity amplifiers have attempted to symmetrically populate cylindrical cavities with a number of planar triodes. These designs have experienced difficulties presenting uniform loading to tubes in the cluster and providing independent adjustment to the loading of individual tubes. The design we describe locates the planar triodes in sections of rectangular waveguide with movable end walls that provide each tube with an independent loading adjustment. In addition, the waveguide sections help to increase the resonant frequency of the dipole and quadrapole modes (which cause non uniform loading) with respect to a cylindrical structure of comparable size.

B. Analysis of Modes in the Cavity Structure

As illustrated in Figure 1, the output resonator is quite large compared to a wavelength at 1700 MHz (approximately 6.95 inches); for this reason, it is necessary to determine the modes that the resonator will support. The mode selected must be symmetric in each arm of waveguide cross. An axially asymmetric mode at the frequency of operation would result in uneven loading of the planar triodes. If the intersection of adjacent waveguide sections is examined, it is seen that the perimeter of the square containing all points of intersection is more than one wavelength at 1700 MHz; thus, the structure will support axially asymmetric modes. The width of the rectangular waveguide is selected such that only the lowest-order mode (TE10 mode) is supported by the guide. The selected circumference for the coaxial section is less than a wavelength, to ensure that higher-order coaxial modes are

---

*Work supported and funded by the US Department of Defense, Army Strategic Defense Command, under the auspices of the US Department of Energy.

0-7803-0135-8/91$01.00 ©IEEE

not present; however, the length of the coaxial section is not sufficient to suppress axially asymmetric modes in the waveguide cross.

The composite structure is analyzed using the three-dimensional electromagnetic code MAFIA [1]. MAFIA produces a set of finite-difference equations for the electric and magnetic field vectors of the three-dimensional structure, the solution of which yields the frequency domain solution of Maxwell's equations. The output resonator geometry for the MAFIA simulation is shown in Figure 2. Note, that the structure shown in this figure and in Figures 3 and 4 illustrates the effect of the mesh quantization on the original structure. This is especially apparent in the simulation of circles where MAFIA distorts the circular form. The distortion can be corrected by increasing the number of mesh points (but this requires additional computer time). The quantization level of Figure 2 is considered sufficient for understanding the modes the output resonator will support.

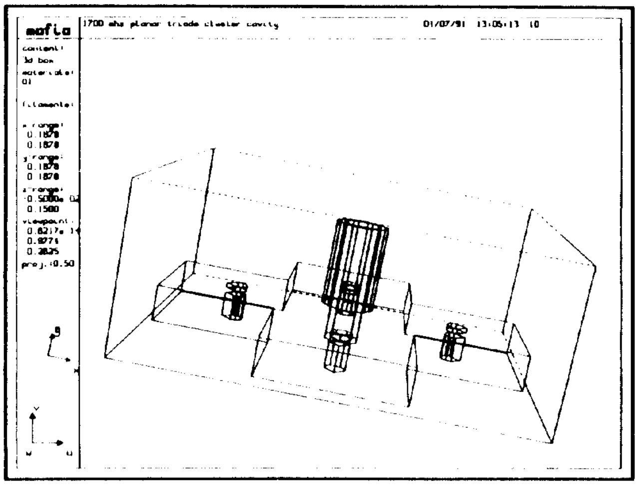

Figure 2. MAFIA plot of output resonator geometry.

Two outputs from the MAFIA simulation are depicted in Figures 3 and 4. These outputs represent the desired mode of operation at 1700 MHz and the nearest axially asymmetric mode at 1807 MHz. The plots lie along a plane dividing the top and bottom of the waveguide cross and illustrate E field vectors in and out of the plot. On the basis of Figures 3 and 4, the output resonator provides axial symmetry at 1700 MHz, which maintains uniform triode loading in each arm of the waveguide section, and the cutoff frequency of the closest asymmetric mode is sufficiently removed from the operating frequency that no design complications arise.

C. *Tube Selection and Characteristics*

At 1700 MHz, the only gridded tubes available are planar triodes. The tube we selected is the YU-176 EIMAC planar triode, designed for use at up to 2 GHz. This tube requires less than 25 W of heater power and can operate at a DC plate voltage (grid pulsed) of up to 10 kV. For 2-msec pulses at a 10-Hz rate, the cathode can support a DC plate current during the pulse of 2 A. The cluster-cavity amplifier will be operated class AB with the grid grounded and cathode pulsed (equivalent to grid pulsed). By pulsing the cathode voltage, the tubes can be biased class A or class AB during the RF pulse, and avoid the quiescent current during the interpulse period normally associated with these classes of operation. The operating characteristics for the YU-176 tubes are given in Table 1.

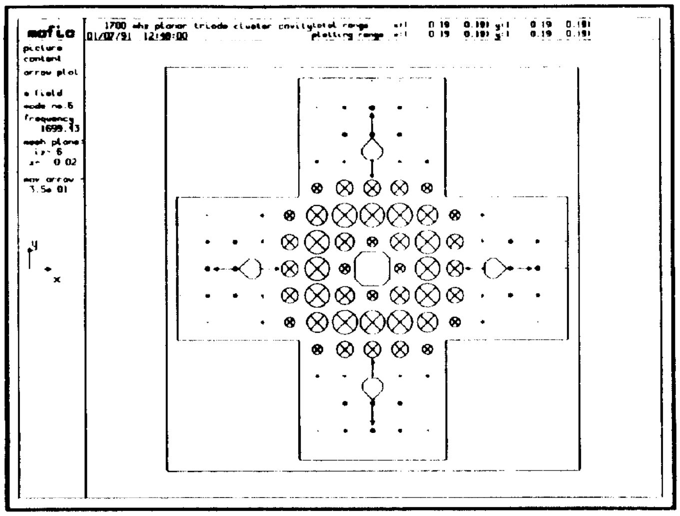

Figure 3. MAFIA electric field plot of desired mode of operation.

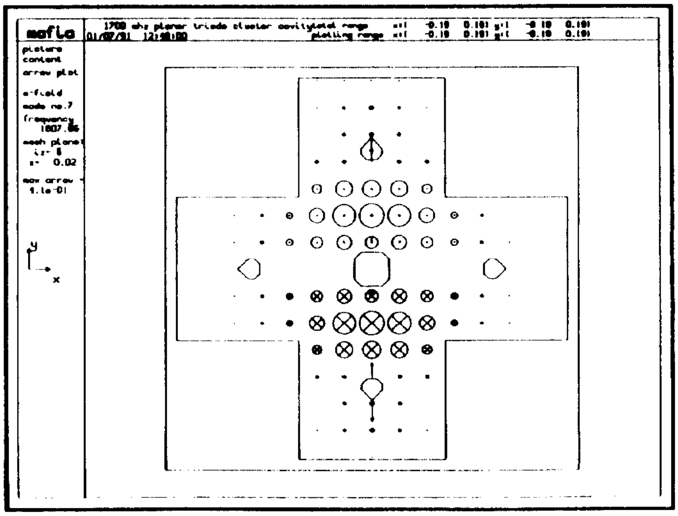

Figure 4. MAFIA plot of closest asymmetric mode.

Table 1
YU-176 Operating Characteristics

DC Plate Voltage	8000.0 VOLTS
DC Cathode Bias	60.0 VOLTS
DC Plate Current	2.626 AMPS
DC Grid Current	0.146 AMPS.
DC Cathode Current	2.772 AMPS
Fundamental Peak Plate Current	4.535 AMPS.
2nd Harmonic Peak Plate Current	2.827 AMPS
3rd Harmonic Peak Plate Current	1.079 AMPS.
FundamentalPeak Cathode Current	4.811 AMPS
Peak Plate Swing	3000.0 VOLTS
Output Power	6802.0 WATTS

Table 1
Continued

RF Plate Load	662.0 OHMS
Peak CathodeSwing	80.0 VOLTS
Drive Power	192.4 WATTS
RF Cathode Input Resistance	16.6 OHMS
Plate Dissipation	14531.0 WATTS
Grid Dissipation	2.0 WATTS

These characteristics provide a combined power in excess of 25 kW with an efficiency of approximately 30 percent.

D. Model of Resonant Structure

The resonant structure is modeled as a series of coaxial, radial, and waveguide transmission lines. The position of the coupling point relative to the center of the structure is calculated to provide an impedance transformation from 50 Ω to 662 Ω in the output resonator and 16.6 Ω in the input resonator. The position of the adjustable-length short is calculated to cancel the reactive portion of the impedance at the coupling point. The resulting response of the output resonator is presented in Figure 5.

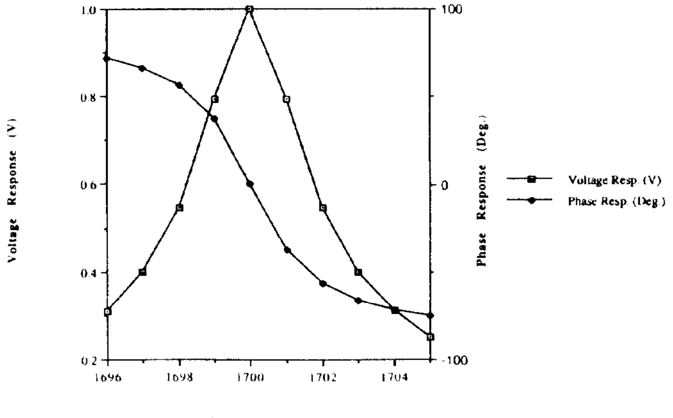

Figure 5. Calculated phase and amplitude response of output resonator.

III. CONCLUSION

A number of planar triodes can be combined in a resonant structure to increase the power level of vacuum tube amplifiers at high frequencies, resulting in a low-cost source of RF for medium-power applications.

IV. REFERENCES

[1] Los Alamos Accelerator Code Group, "MAFIA Users Guide," LA-UR-90-1307, November 14, 1989, Los Alamos National Laboratory.