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A High Power Cross-Field Amplifier at X-Band* A

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Abstract

A high power cross-field amplifier is under development at SLAC with the objective of providing sufficient peak power to feed a section of an X-Band (11.424 GHz) accelerator without the need for pulse compression. The CFA being designed employs a conventional distributed secondary emission cathode but a novel anode structure which consists of an array of vane resonators alternatively coupled to a rectangular waveguide. The waveguide impedance (width) is tapered linearly from input to output so as to provide a constant RF voltage at the vane tips, leading to uniform power generation along the structure. Nominal design for this tube calls for 300 MW output power, 20 dB gain, DC voltage 142 KV, magnetic field 5 KG, anode-cathode gap 3.6 mm and total interaction length of about 60 cm. These specifications have been supported by computer simulations of both the RF slow wave structure as well as the electron space charge wave interaction. We have used ARGUS to model the cold circuit properties and CONDOR to model the electronic power conversion. An efficiency of 60 percent can be expected. We will discuss the details of the design effort.

I. Introduction

The cross-field amplifier (CFA) (Fig. 1) has been considered as a potential RF source to power the Next Linear Collider (NLC). It is a compact, low beam impedance device that can be manufactured at relatively low cost. In many applications, the CFA has been shown to generate very high peak powers at reasonable efficiencies. The NLC, however, calls for power and frequency requirements beyond those of existing tubes. SLAC has undertaken to develop a CFA capable of producing 100MW RF output power with a pulse width of 100 ns at X band without the need for pulse compression. The first experimental tube did not perform up to specifications. We will report here the design effort that went into the second planned CFA, taking into considerations the difficulties encountered in the first tube.

II. Design Considerations

The first design operated at the backward-wave space harmonic with a phase shift of 225 degrees/section and employed a cold platinum cathode. It had suffered from current limitations because of the interference at the cathode by the underlying forward-wave fundamental. At high enough RF fields, this fast-wave component could affect the back-bombarding electrons so as to cut off secondary emission. The new design will synchronize with the backward-wave fundamental with a phase shift of 150 degrees/section and will use a Beryllium oxide cathode which may allow higher peak power since it has a higher secondary yield and lower peak energy. The backward-wave mode is preferred because power can be generated in a shorter distance and the modulation of the reentrant beam is also minimized.

The second CFA will have a waveguide-coupled anode structure[1] (Fig. 2) with an overall lower impedance to increase peak power output at an optimal RF field of 100 kV across the vane tips. Higher RF fields are avoided to reduce problems with current depletion as discussed above, anode heating, and breakdown at the output, as well as to improve power production and phase stability at the input. To maintain this RF level throughout the tube, it is necessary to taper the impedance by making it high at the input end and low at the output end. A linear taper can be achieved by varying the guide width.

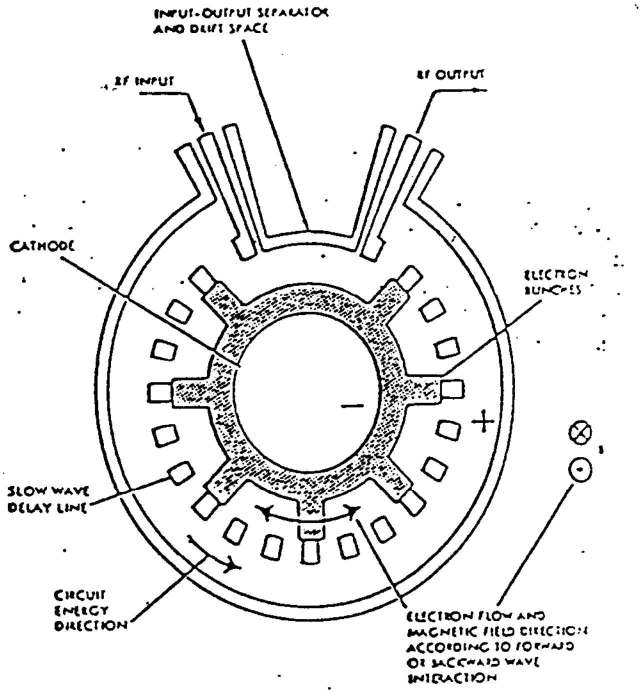

Fig. 1 Schematic of a CFA showing vanes, input, output and sever (drift space with no RF which isolates input and output).

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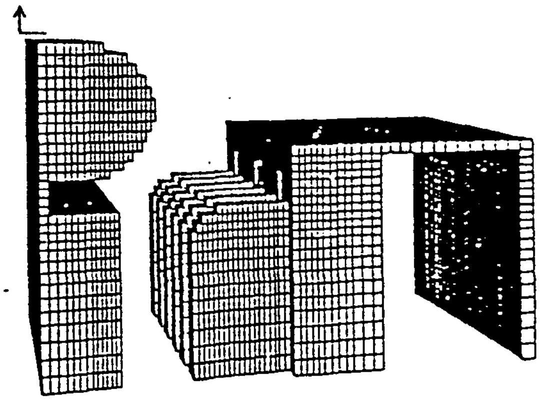

Fig. 2 ARGUS model of the upper half of a CFA section. To the left is the cathode and endhat. To the right is the waveguide coupled anode structure. Three coupling slots can be seen between the resonator and the waveguide.

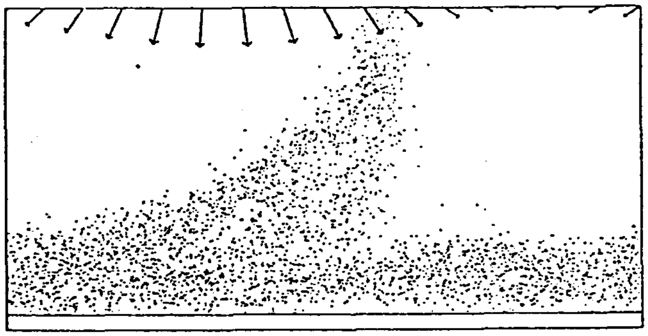

Fig. 3 Simulation of one (slow wave) wavelength of electron distribution showing electron hub and spoke.

III. Design Tools

The waveguide-coupled anode circuit is a 3-D periodic structure that supports both forward and backward waves. We have used the 3-D electromagnetic code ARGUS[2] with quasi-periodic boundary conditions to study the properties of the cold circuit. Dispersion curves and circuit parameters such as impedances can be obtained for the travelling wave modes.

Because CFA's are inherently nonlinear devices accurate modelling of the beam-circuit interaction is essential for design purposes. We have developed a simulation model based on the 2-D PIC code CONDOR[3] to evaluate the performance (e.g. gain and efficiency) of a CFA tube. The calculation of the beam-circuit interaction is similar to that described by Yu, Kooyers and Buneman[4]. The main advance of our model over previous simulations is the realistic tracking of absorption and secondary emission[5]. The simulation region is an integral number of wavelengths long, with periodic boundary conditions and time integration corresponds to progression in space around the tube. Fig. 3 is a time shot of the interaction showing spoke formation from the elctron hub.

IV. Mode Contamination and Competition

Some CFA's have operated successfully with the waveguide-coupled circuit but mode contamination is a concern. Mode purity can be maintained if the circuit is matched. One criteria for the matching is that the voltages across the resonators be equal. This means in effect that the vaned anode structure is unperturbed by the slotted guide so we can treat each separately. We use ARGUS to determine the dimensions of each structure for the appropiate phase shift at 11.424 GHz (150 degrees for the anode and 60 degrees for the slotted guide). The final dimensions for the coupled circuit are obtained by joining the two together and then making the adjustments to correct for any frequency shift.

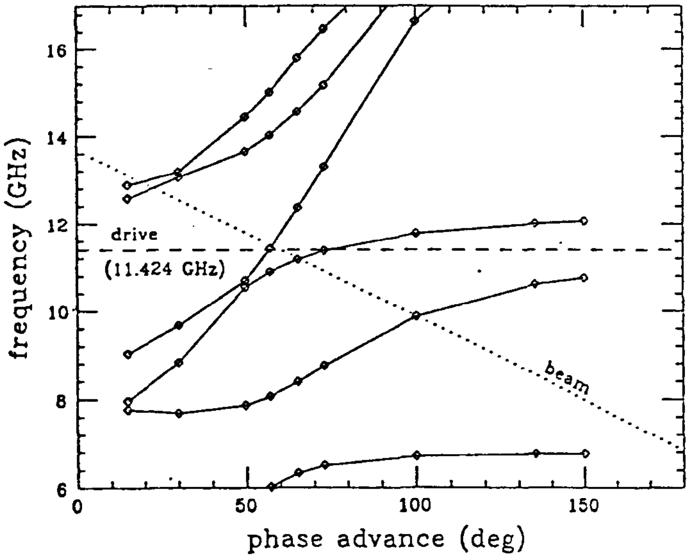

Fig. 4 Dispersion curves for the coupled structure near the input end.

A set of dispersion curves generated by ARGUS for the composite structure near the input end is shown in Fig. 4. An operating point can be identified near the 70 degree phase advance. Also evident is a high frequncy slot mode at a lower phase advance that can interact with the beam and which ARGUS found to have a high impedance. CONDOR simulations including this mode (at low amplitude) and the operating mode showed that the competing mode had enough gain to attain a power level high enough to interfere with the tube operation. A possible remedy being considered is to insert lossy material to selectively damp out this mode.

V. Power Generation and Efficiency

From our CONDOR simulations we have calculated the power generation rate and efficiency versus RF field strength as shown in Figs. 5 and 6. Based on these results, a good operating point has been identified with power generation near 300 MW and total efficiency of over 60 percent. The specifications for this tube are given in the table in section VI.

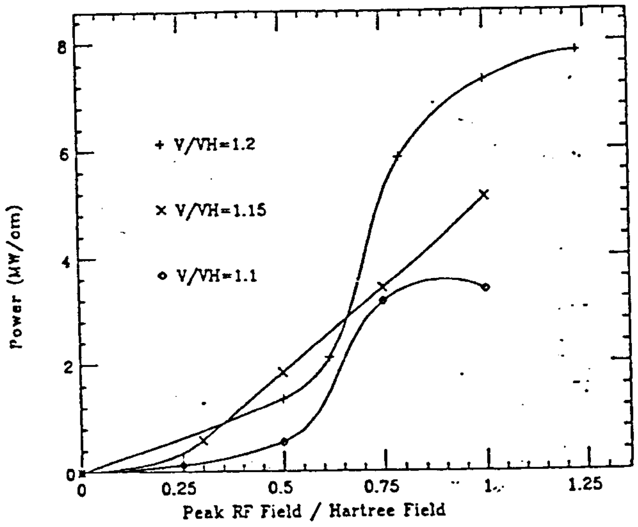

Fig. 5 Power generation rate vs. normalized RF field strength shown for three values of DC voltage/Hartree voltage.

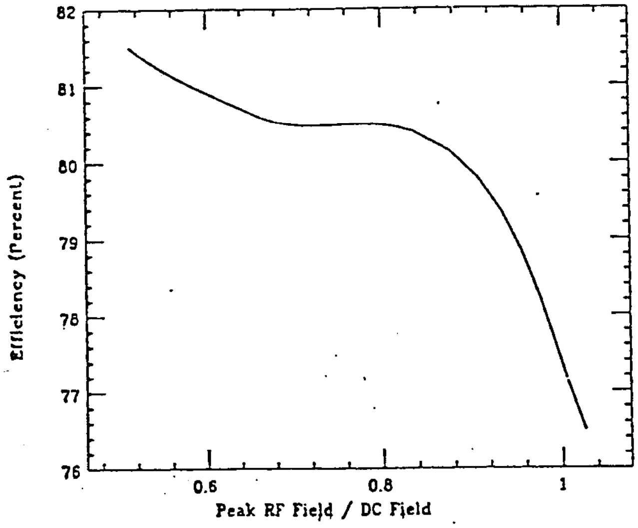

Fig. 6 Efficiency vs. normalized RF field strength.

VI. Table of Tube Specifications

Cathode dimensions: radius = 10.16 cm;
height = 1.65 cm
Anode dimensions: radius = 10.52 cm;
height = 1.65 cm
Anode-Cathode gap = 3.63 mm
Pitch = 2.67 mm
Vane dimensions: height = 1.65 cm,
depth = 4.98 mm
Vane gap width: inner = 1.016 mm; outer = 2.032 cm;
triangular
Waveguide dimensions: height = 1.905 cm;
depth = .762 to 7.62 cm
Slot dimensions: height = 1.905 cm;
depth = 4.57 mm; width = .508 mm
Frequency: 11.424 GHz
Peak Power Output: 300 MW
Power Generation Rate: 6 MW per cm of circumference
RF Pulse Width: 100 ns
Pulse repetition rate: 360 pps
Anode Voltage: 142 kV
Anode Current: 2600 Amp
Peak RF Voltage Across Vanes: 100 kV
Efficiency $\eta_e \cdot \eta_c = .72 \times .9 = 0.65$
Gain: 17 db
RF Drive Power: 6 MW
Emitter: Beryllium Oxide cold cathode
Cathode current density: 41 Amp/cm^2
Number of anode resonators: 225
Average anode dissipation: 40 W/cm^2 at 100 ns
Peak anode dissipation: 1.1 MW/cm^2
Mean anode bombardment energy: 27 kV
Phase shift per resonator: 150 degrees
Phase velocity: 7.31 $\times 10^7$ m/s
Hartree voltage: 118 kV
DC magnetic field: 5 kGauss

VII. References

[1] J. Feinstein and R. Collier, "A Class of Waveguide-Coupled Slow-Wave Structures," *IRE Transactions on Electron Devices,* pp. 9-15, January, 1959.

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