BEVALAC INJECTOR FINAL STAGE RF AMPLIFIER UPGRADES

D. Howard, J. Calvert, R. Dwinell, J. Lax, A. Lindner, R. Richter, W. Ridgeway
Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720

ABSTRACT

With the assistance of the DOE In-house Energy Management Program, the Bevalac injector final stage RF amplifier systems have been successfully upgraded to reduce energy consumption and operating costs. This recently completed project removed the energy-inefficient plate voltage modulator circuits that were used in conjunction with the final stage RF amplifiers. Construction, design, and operating parameters will be described in detail.

INTRODUCTION

The energy saving realized at completion of the project was primarily obtained by eliminating the filament power required for operation of the Hard Tube Modulator system. This saving, coupled with that obtained by removal of the HTM water, air and electronic support systems, accounts for over 30 Kw per hour of operation.

The HTM system was used to key the plate voltage to two tubes, a TH-515 which provides 800 Kw of RF output power and a TH-516 which provides 2.4 MegaWatts. The tubes and their associated amplifier cavities are manufactured by Thomson-CSF and are used as the final RF amplifiers of the T1 and T2 sections of the LINAC portion of the Bevalac Local injector system[1].

First reported in the 1987 Accelerator Conference by J. Alonso et al, the proposal[2] to remove the HTM system was composed of two related but separate project phases. The first required modifying the amplifier structure to remove the ground connection to the final amplifier grid while maintaining a low impedance path for the grid-anode and grid-cathode RF circulating currents. This portion of the project was completed and tested during operation for a year before completing the second stage of the project. The second project provided a fixed source of DC grid bias for the TH-515 and a pulsed grid bias source for the TH-516. The bias voltages appropriately interlock the DC plate voltage supply to the final amplifiers.

GRID ISOLATION

The grid structures of both amplifiers have been modified as shown in Figure 1. The left side of the drawing shows the original structure. As is shown, the grid conductors extend concentrically over the ground cylinder on both the anode and cathode sides of the structure. The grid is insulated from ground on both sides by layers of Kapton. The distance from the anode circuit to the cathode circuit traveling through the structure is 1/4 wave length. Also shown is one of the 8 coaxes that provide a path for the bias voltage and amplifier grid currents. Limited drawing resolution does not show the Multi-Lam compression connectors imbedded in the grid cylinder to receive the coax center conductors.

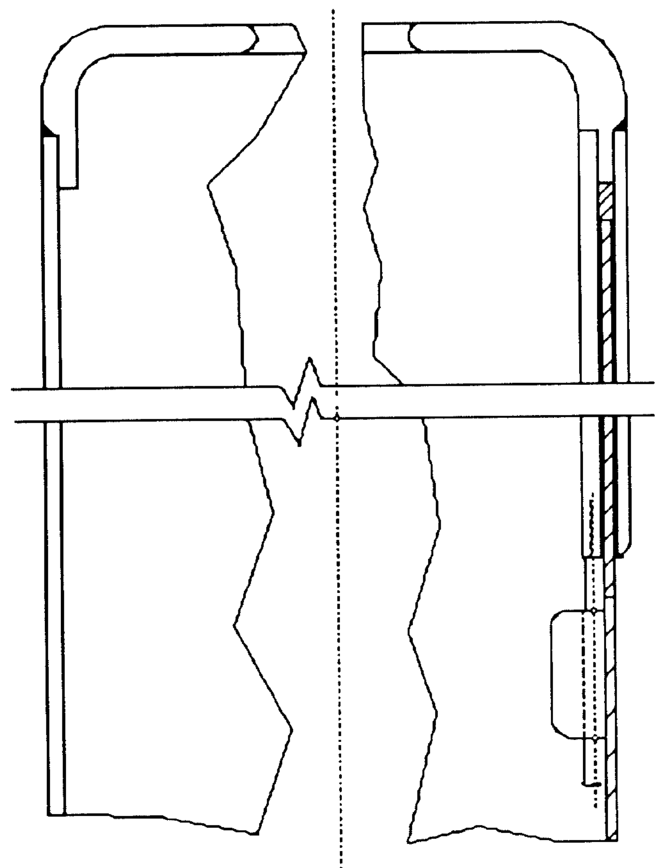

Figure 1.
(Not to scale)

The installation of the grid structure in the amplifier is shown in Figure 2. The distance from the grid cavity shorting plate to the connection point of the eight coaxes is intended to place the coax to grid conductor interface at the minimum point of grid-cathode RF circulating current thereby minimizing the RF voltage generated at the input to each coax.

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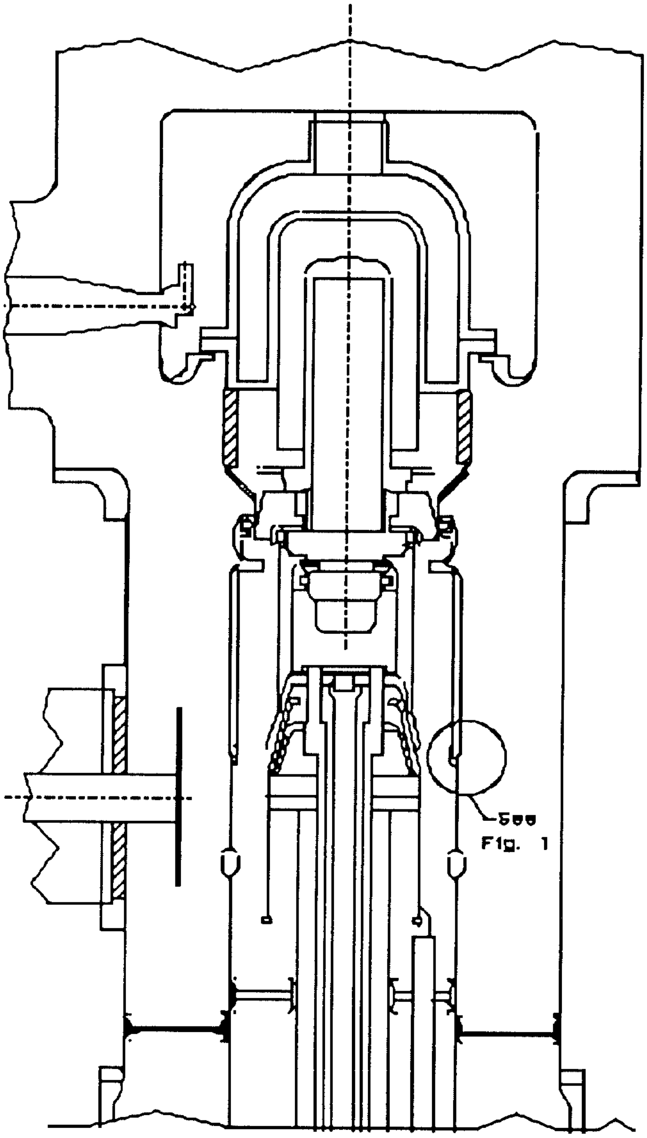

Figure 2.
(Not to scale)

RF DECOUPLING

The RF voltage generated at the inputs of the coaxes is reduced at the output end by employing an open ended, resonant, 1/2 wave length line, constructed to terminate each of the eight coaxes in the center of the resonator and by the use of individual in-line resistors placed in series with each coax. To provide maximum burden to the generated RF, the 10 ohm in-line resistors are placed radially, as close as possible to the minimum impedance point, defined at the center of the Coaxial Terminating Resonator. To reflect minimum impedance to the grid-coax junction, the eight coaxes are a 1/2 wave multiple from the grid to the in-line resistors.

Designed for operation at 200 Mhz, the Coaxial Terminating Resonator is the hub of the RF decoupling system. Shown in Figure 3, mounted on top of the Grid Bias Pulser Chassis, the CTR provides a RF decoupled connection point at its center for interfacing the grid bias voltage from the power supply to the grid. Another RF decoupled center connection point is provided as an input to the grid voltage sensing circuit which is used to interlock the amplifier plate voltage supply.

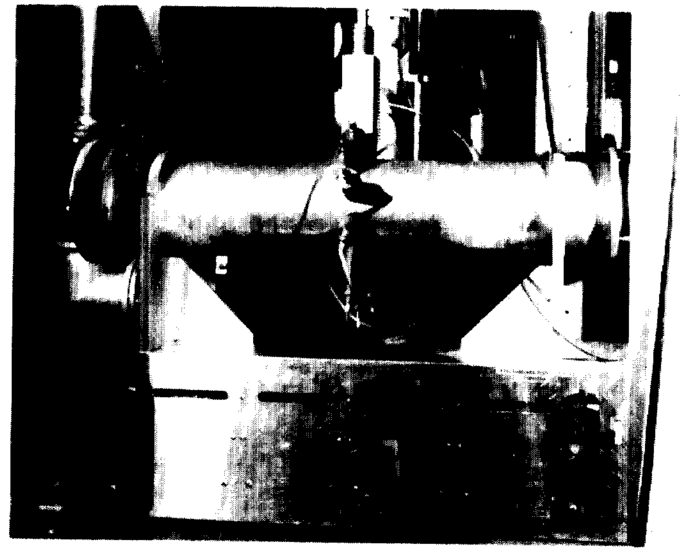

Figure 3.

GRID STRUCTURE TESTS

One grid structure was modified and a CTR was constructed for testing in the T2 system, to determine the integrity of the structure at full RF power. For these tests, the center conductor of the CTR, normally riding at the bias voltage potential, was connected to ground through a resistive network and the HTM left in service. The voltage drop across the network was monitored to determine the operational grid currents and to determine the condition of the isolated grid structure, as absence of output voltage during the On pulse would indicate a shorted grid structure. No abnormalities were observed during these initial tests, and another grid structure and CTR were constructed for installation on the T1 system.

During the first months of operation two failures in the area of the coax to grid interface were experienced. Shown in Figure 1, the clamps that secure the coax outer conductor to the ground structure in this area were modified to increase the center conductor clearance to the grounded clamps. These modified structures continued in service, under all operating conditions, with no further failures for over a year.

BIAS SYSTEMS

The bias system for T1 is a simple full wave bridge power supply. The DC output voltage is adjusted by the input Variac to ensure a cut-off condition for the TH-515 operating near Class B. The bias voltage increases during the pulse as determined by the product of grid current and resistance plus the effect of the grid current charging the power supply output capacitors. In the pulse Off condition, the capacitors are discharged to the preset bias voltage by bleeder resistors. The value of the bleeder resistance is adequate to discharge any observed or calculated TH-515 grid currents.

The T2 system is more complicated, as the available RF drive is insufficient to overcome the fixed bias. However, the new driver amplifiers[3] under construction at this time are calculated to deliver enough power to operate the T2 system in a fashion similar to T1. At present, to compensate for the inadequate RF drive, the bias voltage is connected to ground through series transistors during the On pulse. The operating grid voltage is determined by the product of grid current and all the grid circuit resistances plus the voltage drop across the series FETs. There are three primary circuit considerations associated with the design of the FET circuits:

* FET Current
* FET Voltage
* Minimizing series circuit resistance

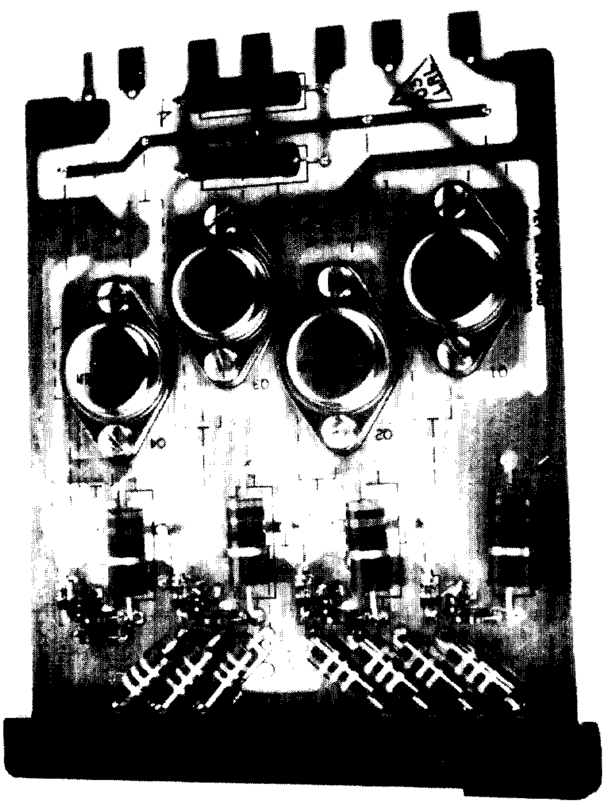

Figure 4.

The FETs are specified by the manufacturer to pass 5 Amps and hold off 1000 Volts. These conditions cannot be simultaneously met for times in excess of 5 usec, consequently fast switch time of the bias voltage is essential. As shown in Figure 4, there are four FETs mounted on each of four identical circuit boards to provide a maximum safe operating current of 80 Amps for the FET circuits. This is a conservative current rating for the calculated and the observed maximum grid currents. Also shown on the board are the 7 parallel resistors that act as a shunt for monitoring the grid currents during operation and 4 LEDs that indicate proper operation of each FET.

Quiescent voltage holding is easily obtained by the 1000 volt FETs; however, excessive transient voltages in the environment of high currents and fast switch times were a major concern. The circuit was modeled in Spice to ensure a fast and critically damped response. The 10 ohm resistors in-line with each coax from the grid going to the CTR are an integral part of the input impedance to the chosen pi filters, which are mounted on the back side of each FET circuit board. The filter output impedance is determined by the FETs and their associated series resistors.

HIGH POWER TESTS

Another 6 Kw per operating hour is saved by reducing the plate supply voltage for the TH-515 and TH-516 by 10 Kv to operate at 30 Kv and by the T1 system efficiency, which was dramatically increased by the addition of fixed bias.

The system did not run long before more breakdowns in the area of the grid to coax interface on the grid structure were observed. The metal clamp rings were replaced with Delrin clamps and the structures have had no further failures. The systems ran undisturbed for about three months when, in the process of on-line testing a spare TH-516, pitting was discovered on the operating tube in the area of the metal to glass seal, near the tube anode. The area was wrapped with Mylar tape. Later inspections revealed no further signs of sparking in the area or through the tape. The HTM system was reinstalled to prevent potential tube damage while a new anode corona shield is being machined. The new shield has not been installed as of this date.

ACKNOWLEDGEMENTS

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