Proceedings of the Linear Accelerator Conference 1990, Albuquerque, New Mexico, USA

INCREASING OUTPUT POWER OF A 850 MHZ TETRODE WITH A FLOATING-DECK MODULATOR*

Daniel Rees and Carl Friedrichs
Los Alamos National Laboratory, Los Alamos, NM 87545

Introduction

Designers of high-power amplifiers generally regard the region above 300 MHz as a domain dominated by velocity-modulated (klystron/TWT) devices. However, as the power requirements diminish, there are attractive alternatives. The high-power 850-MHz requirements of the ground test accelerator (GTA) program can be filled by 1-MW klystrons, but it would be more efficient to use a lower-power device for a 50-kW requirement. To meet the 850-MHz medium-power requirements, Los Alamos National Laboratory is developing an 850-MHz tetrode amplifier. These amplifiers will provide RF power to the momentum compactor and bunch rotator cavities of the GTA.

Available tubes provide only a limited safety margin for a low-risk design at the power levels and duty factor required for GTA cavities. At 850 MHz, the output power capability of available tubes is reduced because of transit time effects and limited anode voltage holdoff. Pulsing the anode of the output tetrode amplifier will allow higher output power with minimum design risk. A floating-deck modulator acts as a high-voltage/high-current switch, so voltage is applied to the anode of the gridded tube only during the rf pulse. The anode voltage holdoff capability of the tube is substantially enhanced by operating in this mode. This paper will describe the design of the floating deck modulator and its impact on the design risk of the 850-MHz tetrode amplifier.

Gridded Tube Limitations at 850-MHz

Gridded tubes at high frequencies are limited in power output for a number of specific reasons. For high-frequency operation, it is essential to minimize the output spacing (grid-to-plate spacing for a triode or screen-to-plate spacing for a tetrode) and the circumference. The circumference must be minimized to prevent the introduction of radial modes in the axially symmetric output cavity of the tube, and the output spacing must be decreased to minimize transit time effects. These factors result in a tube design that decreases in size with increasing frequency of operation. The decrease in size leads to a smaller emitting surface (reduced current capability) and a smaller anode (reduced dissipation capability). Also, the decrease in output spacing limits the anode voltage holdoff capability.

850-MHz Gridded -Tube Design

The tetrode amplifier currently under development at Los Alamos is being designed to satisfy a 50-kW requirement for the GTA. The design is for a 65-kW, 850-MHz, pulsed tetrode amplifier with a maximum pulsewidth of 2 ms and pulse repetition frequency of 10 Hz. The design power level is higher than required to provide for transport losses and control margin for the cavity phase and amplitude closed loop control system. The amplifier consists of four stages and will be operated class B.

The first three stages will consist of a solid-state driver and two tetrode amplifiers. The last stage uses a Burle 4632 tetrode amplifier. The output power from a gridded tube is the product of the fundamental component (850 MHz) of anode current and the anode voltage swing. The anode voltage swing is the product of the fundamental anode current and the rf resistance presented to the anode by the output resonant cavity. The midpoint of the swing is the bias voltage of the anode. As the electrons traverse from the screen to plate, they see a time-varying accelerating gradient (transit time effect). At lower frequencies the effect is negligible; however, at 850 MHz the transit time becomes a significant portion of a wavelength. The resulting time-varying accelerating gradient tends to debunch the electrons and results in decreased fundamental current, increased harmonic current content,[1] and reduced output power. To minimize this effect and boost the power capability of the gridded tube at 850 MHz, a floating-deck modulator has been designed. The modulator will pulse the voltage to the anode of the final stage of amplification for 2 ms, thereby increasing the anode voltage holdoff capability by 50% over the dc value. The increased voltage holdoff allows for a larger anode voltage swing and accelerating gradient resulting in increased output power and minimal transit time effects.

Burle 4632 Tetrode Amplifier

The 4632 tetrode will be used for the final stage of amplification. The 4632 has a continuous anode voltage rating of 10 kV which would limit the output power to 45 kW. In order to provide for a 65-kW design, a floating-deck modulator will pulse the anode voltage to 15 kV. The proposed operating conditions are listed in Table 1.

The currents, power, and rf resistances listed in the table are calculated from a Fourier analysis of the tube characteristics.[2] The circuit efficiency represents the resistive losses in the tube and cavity structure. The transit time efficiency is calculated by a one-dimensional simulation of electrons crossing the output gap of the 4632 tetrode under the bias conditions in the table in the presence of the time-varying rf voltage.[1] The modulator will provide a pulsed anode voltage to the 4632 of 15 kV at a minimum of 13.5 A anode current.

Modulator Design

Figure 1 contains a block diagram of the floating-deck modulator. The major components are a 20-kV power supply, two EIMAC 8960 switch tubes in parallel, hexfet cathode modulators, a 20-kV isolation transformer, a grid supply, a screen supply, an optical interface, a fault detection interface, a high-voltage insulated deck, and a high-voltage enclosure.

*Work supported by the US Department of Energy, Office of High Energy and Nuclear Physics.

Table 1
4632 Tetrode Operating Conditions
Cathode Drive

Parameter	Design
DC Plate Voltage	15000 volts
DC Screen Voltage	1500 volts
DC Cathode Bias	50 volts
DC Plate Current	13.5 A
DC Screen Current	000 A
DC Grid Current	2.5 A
DC Cathode Current	16.0 A
Fund.PK.PLT.Current	20.1 A
2ND HAR.PK.PLT.Current	6.6 A
3RD HAR.PK.PLT.Current	1.3 A
FundPK.CATH.Current	25.0 A
Peak Plate Swing	8000 volts
Clircuit Efficiency	95. %
Transit Time Efficiency	86. %
Output Power	65. KW
RF Plate Load	399. Ohms
Peak Cathode Swing	170.0 volts
Drive Power	2.1 KW
RF Cath.Input Resistance	6.9 Ohms
Plate Dissipation (peak)	108 KW
Plate Dissipation (avg)	2.2 KW

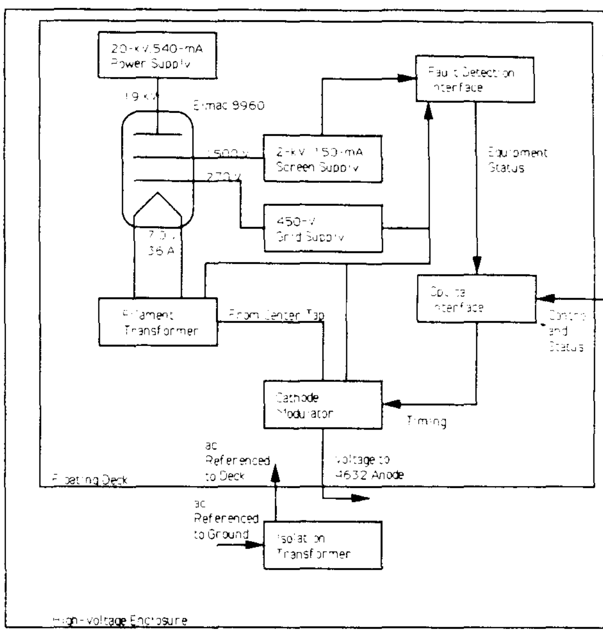

Fig. 1. Floating-deck modulator block diagram.

The EIMAC 8960 is a glass-envelope, air-cooled, power tetrode designed for pulse modulator or switch-tube service, operating at voltages to 50 kVdc or anode current as high as 12 A. The tube has a thoriated-tungsten filament, and the maximum average anode dissipation rating is 1200 W. Cooling is accomplished by radiation from the anode and by circulation of forced air through the base and around the envelope. The current required by the 4632 is in excess of the capability of a single 8960, so two 8960's are connected in parallel . The modulator operating point is calculated in Figure 2 based on a 270-Vdc grid bias. Figure 2 displays load lines for the 4632 and 8960 tetrodes. The curves have opposite slopes and the operating point is the intersection of the two curves. The curve for the 8960 tetrode is read from the EIMAC data sheet. The curve for the 4632 tetrode is calculated by varying dc anode voltage, with rf drive and screen voltage remaining constant. The horizontal axis in the figure represents the plate voltage drop across the EIMAC 8960. The voltage drop across the 4632 tetrode is 19 kV minus the drop across the 8960.

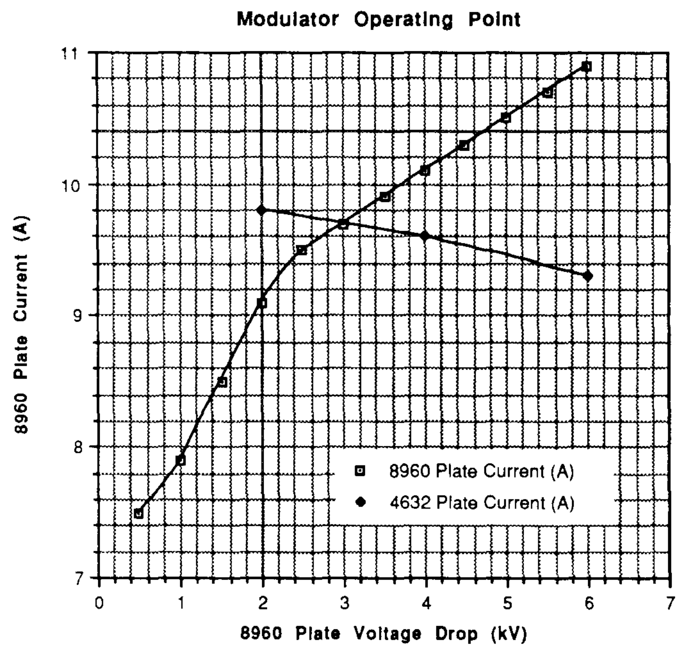

Fig. 2. Floating deck modulator operating point.

A 20-kVdc, 540-mA SCR controlled power supply will provide dc voltage to the anode of the 8960's. This supply provides a peak current of 27 A from an internal capacitor bank at the rated voltage and duty factor. The screen voltage for the 8960's is provided by a 2-kV, 150-mA high-voltage power supply, and the grid voltage is provided by a 450-Vdc unregulated power supply. An optical interface will receive a gating signal from the tetrode controller and pass back the status of the equipment. The gating signal will drive the hexfets connected between the cathodes of the 8960's and the deck. This will cause the tube to conduct and provide a pulsed voltage to the 4632 anode. From Figure 2 it can be seen that a 3-kV voltage drop will occur across the switch tube. Hence a supply voltage of 18 kV is needed to provide the 15-kV pulse to the anode of the 4632. A fault detection interface will monitor filament current, power supply voltages, and the cathode hexfet modulators for equipment faults. All equipment is contained within a metal enclosure called the floating deck. The potential of the floating deck is identical to the potential of the 4632 anode and will pulse from 0 Vdc to 15-kVdc with the rf pulse. The floating deck is contained within a high-voltage enclosure at ground potential. The floating deck and high-voltage enclosure are designed to minimize sharp corners or ridges that could lead to voltage breakdown. The 20-kV transformer provides ac power to the equipment

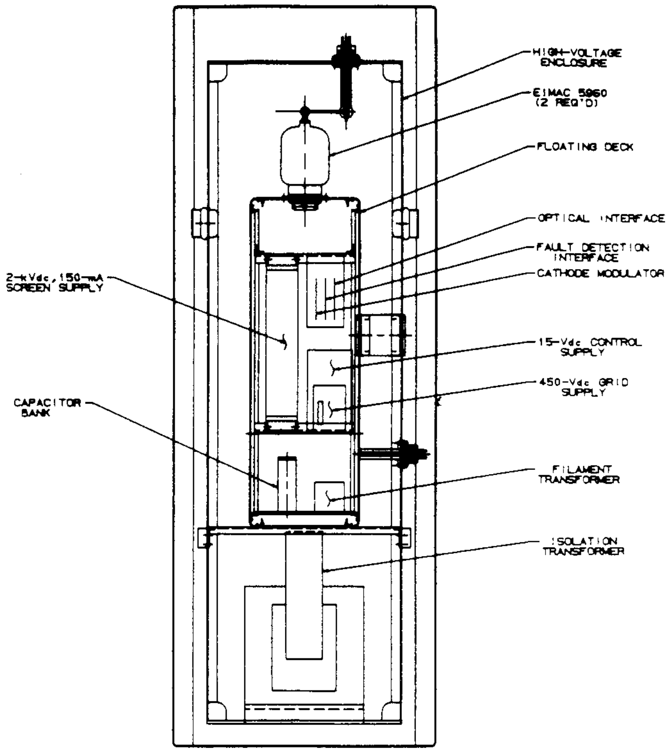

Fig. 3. Floating-deck modulator mechanmical layout.

within the floating deck. The secondary of the transformer is referenced to the deck potential. Figure 3 contains a mechanical drawing of the floating deck, power supplies, and high-voltage enclosure.

Status

A floating-deck modulator has been designed and tested. Tests were conducted using a resistive load to simulate the load line of the 4632 tetrode. The floating-deck modulator performed as designed and provided a pulsed voltage of 15 kV and a pulsed current of 13.5 A to the resistive load. The peak value of the pulsed voltage is variable by adjusting the operating parameters of the switch tube. When the development is complete for the 4632 tetrode cavity, the modulator will be integrated with the final stage of amplification for rf testing.

References

1. Humphries, "Numerical Simulation of Transit Time Effects in Gridded Tubes, Numerical Simulation in Pascal", Los Alamos National Laboratory, January 15, 1989.
2. Varian EIMAC, Care and Feeding of Power Grid Tubes, San Carlos California, 1967.