

## DESIGN OF A NEW VHF RF POWER AMPLIFIER SYSTEM FOR LANSCE\*

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### Abstract

A major upgrade is replacing much of the 40 year-old proton drift tube linac RF system with new components at the Los Alamos Neutron Science Center (LANSCE). When installed, the new system will reduce the total number of electron power tubes from twenty-four to eight in the RF powerplant. A new 200 MHz high power cavity amplifier has been developed at LANSCE. This 3.2 MW final power amplifier (FPA) uses a Thales TH628 Diacrode<sup>®</sup>, a state-of-the-art tetrode that eliminates the large anode modulator of the triode-based FPA that has been in use for four decades. Drive power for the FPA is provided by a new tetrode intermediate power amplifier (and a solid-state driver stage). The new system has sufficient duty-factor capability to allow LANSCE to return to 1 MW beam operation. Prototype RF power amplifiers have been designed, fabricated, and assembled, and are being tested. High voltage DC power became available through innovative re-engineering of an installed system. Details of the electrical and mechanical design of the FPA and ancillary systems are discussed.

### DTL RF SYSTEM

The LANSCE proton linac uses an Alvarez DTL powered at 201.25 MHz to accelerate both H<sup>+</sup> and H<sup>-</sup> beams from 0.75 to 100 MeV in four tanks, for injection into a 805 MHz coupled-cavity linac to reach 800 MeV. High peak RF power (~ 3 MW) along with significant average power (~300 KW) is typically required from the RF system. All four systems use the same amplifier lineup in their RF systems: a Burle Industries 4616 tetrode is used in a pressurized-air RCA Y1068 amplifier for the intermediate power amplifier (IPA), driving a Burle Industries 7835V4 triode in a pressurized Continental Electronics final power amplifier (FPA). Twenty-four tubes are used for the four DTLs, with five different types including anode modulator tubes. We plan to replace the old IPA and FPA stages with modern amplifiers using new power tubes having higher average power capability. The goal is to reduce the number of power tubes in use to eight, with only two unique types used in the DTL. Elimination of the power-consuming series anode modulator for each FPA reduces system complexity, operating costs and downtime. Higher anode dissipation capability in the FPA tubes will reduce the frequency of tube failures, and increase beam availability at LANSCE.

### INTERMEDIATE POWER AMPLIFIER

A Thales TH781 power tetrode has been chosen to replace the 4616 IPA stage for the modernization project. It is a compact pyrolytic graphite-gridded tube, with efficient anode and screen grid cooling. A Thales TH18781 cavity amplifier incorporates water and air-cooling, and has been fitted into a standard electronics rack at LANL. It was tested in 2004, with sufficient output to cathode-drive the future FPA at 120 to 150 kW [1]. This is compatible with the FPA described in subsequent sections. Optimal anode voltage was 14 kV DC, and current was 6.4 Amps quiescent, and 20.4 Amps peak at 159 kW pulsed power. Stage gain is 15 dB with 54.5% DC to RF efficiency. Drive power is provided by existing high gain MOSFET power amplifiers capable of up to 5.5 kW. The first DTL needs lower peak power and will use the same TH628 FPA without the tetrode IPA. A unique 25 kW solid state amplifier will be utilized as a driver in this system, as we have concerns about the long-term availability of electron tubes at this moderate power level.

### FINAL POWER AMPLIFIER

Previous papers have discussed the advantages of using the Thales TH628 Diacrode<sup>®</sup>, a double-ended tetrode, for high power at very high frequencies. Developmental aspects of the LANSCE cavity amplifier were published [2][3][4]. Design and fabrication of a revised final configuration of this amplifier has been our focus for the past year, with a goal to produce 3.2 MW peak power at 15% duty factor, at the Los Alamos elevation (2133 m above sea) without pressurization. The final configuration of the amplifier has a different output circuit and has provisions for cooling and DC bias connections for the tube electrodes. The Diacrode<sup>®</sup> has wide ceramic seals with anode plus screen grid (g2) contact rings on both upper and lower portions. The design is common-grid configuration with a full wavelength resonant output circuit having  $3\lambda/4$  in the lower portion and  $\lambda/4$  in the upper slave cavity. This places a standing wave voltage anti-node at the center of the active region inside the TH628. All of the input resonant circuitry is single-ended, connecting only to the bottom of the Diacrode<sup>®</sup>. This includes the heater/cathode contacts. The following paragraphs describe the new FPA further. Figure 1 shows the major components and the finished amplifier design.

### Input Circuit

A tuned cathode circuit applies RF voltage across the cathode to control grid (g1) in the TH628, and is constructed from concentric copper tubes, one for cathode and one carrying 1000 amperes DC for filament power.

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Both grid transmission-line circuits are made from silver-plated copper cylinders, with brazed flanges at the lower supporting surface. The inner diameter of the g1 line is part of the input circuit, along with the outer diameter of the cathode line, with a line impedance of  $46.1\Omega$ . The cathode contact of the TH628 terminates the upper end of the input resonator. A 7.9 cm diameter coaxial feeder applies drive power directly to the cathode line through a series quarter-wave transformer in the input feeder. The outer diameter of the g1 line is tuned with a shorting plane ("piston") to place a RF voltage node between g1 and g2 at the active region inside the TH628. Actually this voltage is made nonzero to neutralize feedthrough voltages from the inter-electrode capacitances. Water-cooling for g2 connections and DC bias for both grids is carried through this same g1-g2 resonator space, removing them from the high power circuits.

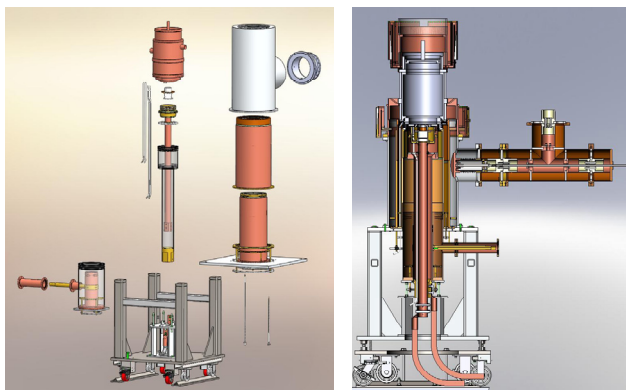


Figure 1: FPA main components, and assembled

### Grid Circuits

The g1 and g2 lines are each made from two cylinders. The raw material began as forgings of C10100 OFHC copper. This was selected due to availability from a supplier, although C11000 ETP would have been adequate. These were machined to the exact dimensions with contact strip grooves and other necessary features. Next, they were electroplated with  $15\ \mu\text{m}$  of silver before being pressed together. A 0.5 mm thick sleeve of fluorinated ethylene propylene (FEP) thermoplastic surrounds the upper (inner) contact cylinder and is heated to shrink tightly with minimal entrapped air. The longer outer line is then heated to  $177\ \text{deg C}$  to create clearance, and the two cylinders are pressed together. After cooling there is a slight interference fit to compresses the FEP dielectric and make a high quality DC blocking capacitor.

The g2 line is the inner conductor for the lower output circuit, where circulating current reaches  $2100\ \text{A/m}$  near the TH628 connector ring. A 48.2 cm ID outer cylinder has been chosen for tuning range using another piston while allowing capacitive coupling of the output power into a 23.3 cm diameter  $50\Omega$  coaxial feeder. The resonator line Z is  $13.4\Omega$ . Superfish and Fortran codes were both used to analyze and optimize the geometry [5]. The end result is that the 201 MHz radial E-fields are lower at the

ceramic seal of the TH628 and high at the output coupling capacitor ( $\sim 650\ \text{kV/m}$ ). The screen grid DC bias is 1600 VDC, applied to the upper cylinder of the blocker capacitor assembly through a shielded copper tube.

### Output Circuit

The lower output cavity for the prototype has been constructed from a solid billet of T6061 aluminum. Material is cut away to produce the desired interior geometry with air-cooling ports and the output feeder without using welds. The entire piece is coated with  $13\ \mu\text{m}$  of electroless nickel, then electroplated with  $25\ \mu\text{m}$  of silver on the interior surfaces to improve RF conductivity. An alternative approach of using a copper cylinder was eliminated due to cost and weight.

A separate collar is fastened to the upper flange of the lower output cavity. This piece contains an integral B+ blocking capacitor made from two layers of 1.5mm thick FEP pressed like the two grid DC blocking capacitors. The top ring of this part connects to the anode contact ring through spring fingers, and allows air to exhaust from the cavity across the ceramic seal. At the top of the TH628 a short  $\lambda/4$  slave output circuit is constructed with a blocking capacitor made from Kapton<sup>®</sup> polyimide film and a water-cooled tuning piston. Both upper and lower blocker capacitors have five reduced-height waveguide mode suppressors mounted around the circumference, adjacent to the ceramic seals. The purpose of these is described in previous work [6], and it is important that they be mentioned here.

The output power coupler is a copper capacitor plate adjacent to the high E-field region near the vertical center of the g2 line. It extends from the center conductor of the 23.3 cm output feeder. A copper bellows extends the center conductor to the plate to allow adjustment of coupling to the resonator. This varies the transformation from the  $50\Omega$  feeder to the plate resistance of the TH628 to optimize the efficiency and gain over a wide range, from 300-3200 kW. It can be adjusted while operating at full power, as the mechanism is introduced through a grounded quarter-wave stub as part of the output feeder. This part can be seen on the right side of figure 1.

Additional components are designed to provide a safety enclosure around the TH628, support a B+ voltage feedthrough/RF bypass capacitor, provide air cooling ports and extend the water cooling hoses to minimize HV leakage. The enclosure can be seen in the drawing in figure 2. The upper and lower waveguide mode suppressors and water cooling hoses can be seen around the Diacode<sup>®</sup> inside the safety enclosure.

## TEST FACILITY

Over the past two years we have constructed a high power test facility (fig. 3) for these prototype amplifiers that will also be used for component and tube testing for the production systems. The project has been able to reuse a facility with ample power and water-cooling utilities

that was part of the Low Energy Demonstrator Accelerator (LEDA). DC filament power supplies, g2 and g1 bias power supplies and anode power are all installed. The g1 bias power supply is a unique design developed to switch between cutoff (-650V) and high-current conduction levels, to modulate each tube's electron beam from zero to quiescent (class B) bias at the linac duty factor. It uses three high power insulated-gate bipolar transistors that are driven via timing logic. A shunt resistance is switched in during the conduction state using one IGBT, to minimize power dissipation during cutoff. G1 (conduction) and g2 DC bias both come from commercial 3 to 10 kW power supplies with low stored energy

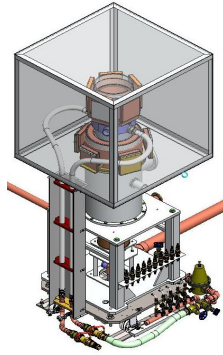


Figure 2: FPA enclosed.

Anode power is provided from a new capacitor bank containing 225  $\mu\text{F}$ , charged to 28 kV DC, along with a crowbar device and resistors. The charging power supply is required to deliver up to 40 Amps. This represents a respectably large and costly unit. The idle LEDA facility contained two-megawatt CW beam supplies, made by Continental Electronics. They make use of a novel method to gain high efficiency without resorting to mains frequency SCR phase control for regulation. With a series stack of 96 small 1.1 kV DC power supplies, each powered by a separate isolated transformer secondary, the overall unit could provide up to -95 kV at 21 Amps. With re-engineering done by the manufacturer and our engineers, the wiring of the individual IGBT-switched power modules was reconfigured to make a power supply capable of up to 45 kV at 40 Amps, with the negative terminal grounded as required for a gridded tube [7]. The power supply and capacitor bank were successfully tested at maximum pulsed current load (200 Amps) in December of 2009, using a  $\frac{1}{2}$  Megawatt tetrode-based pulsed modulator borrowed from the LANSCE RF equipment. This was done to validate our power supply design before connecting it to the FPA.

A coaxial water load system using a weak electrolyte solution was developed and tested in a parallel program [8]. This has been installed in the new test facility with a small heat exchanger and pump. There is a location for removing one section of coaxial transmission line to test a

companion Y-junction circulator for the FPA. This device is one of the largest built by AFT, with 35.5 cm diameter coaxial ports, weighing 1728 kg.



Figure 3: Test facility showing FPA test platform on left, capacitor bank in middle, water load/circulator on right

## CONCLUSION

A new generation of VHF power amplifiers has been developed for the DTL at LANSCE to continue operating as a leading high power proton linac. The IPA has been tested satisfactorily. The FPA is in the final steps of assembly. A high power test facility is ready to allow full-power testing of these new RF components in the summer of 2010.

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