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NEW RF SYSTEM FOR FIRST DRIFT TUBE LINAC CAVITY AT LANSCE*

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Abstract

From 2014-2016, the three highest power 201 MHz power amplifier (PA) systems were replaced at the Los Alamos Neutron Science Center 100 MeV DTL. The initial DTL cavity provides 4.25 MeV of energy gain and has been powered by a Photonis (RCA) 4616 tetrode driving a 7835 triode PA for over 30 years. It consumes 110 kW of electrical power for tube filaments, power supplies and anode modulator. The modulator is not required with modern tetrode linear amplifiers. In 2020 we plan to replace this obsolete 6 tube transmitter with a design using a single tetrode PA stage without anode modulator, and a 20 kW solid-state driver stage. This transmitter needs to produce less than 400 kW, and will use a coaxial circulator. Cooling water demand will reduce from 260 to 70 gal/min of pure water. High voltage DC power comes from the same power supply/capacitor bank that supplied the old system. The old low-level RF controls will be replaced with digital LLRF with learning capability for feedforward control, I/Q signal processing, and PI feedback. All high-power components have been assembled in a complete mock-up system for extended testing. Installation of the new RF system is to begin in January of 2020.

PRESENT RF POWER SYSTEM

Since LANSCE (and LAMPF before that) was commissioned in 1972, the 201.25 MHz RF PAs used a triode vacuum tube, the 7835 developed in 1958 by RCA. This was similar to the RF amplifiers for injector linacs at Fermilab and at Brookhaven National Laboratory. Amplitude modulation for pulse formation and for field (gradient) regulation was provided with a HV modulator consisting of a chain of pulse amplifiers using four more tubes. Another RF tube, a Photonis (RCA) 4616 tetrode, was incorporated as a driver for the triode. Low level rf control used a split function analog system, where the large pulse modulator controlled the RF amplitude, with an electronic phase shifter inserted before the power amplifiers for phase modulation. Installation of new RF amplifiers using high power tetrodes (Diacrodes®) was completed for DTL cavities 2-4 in 2016 [1]. At this time, digital low level (dLLRF) controls were installed for those systems. The new RF amplifiers are linear, like solid state PAs (SSPA) and IOTs, and use I/Q low level RF control topology. This simplified the design of the amplifier systems and reduced the number of tubes used by 50%, with only two types remaining.

The first DTL cavity at LANSCE continues to operate using the old RF amplifier cascade (Fig. 1) operating with reduced voltages. It was not replaced in the earlier upgrade. This RF system continues operating using old components remaining from the prior upgrades. This "orphan" amplifier system has several lingering problems for long-term sustainability. The working condition of legacy spare tubes is uncertain except for recorded hours of service. The high-power test set was removed in 2017 to make space for other projects. The triode amplifier requires over 18 hours for a tube change. Finally, this RF amplifier cascade continues to operate using the split-function analog LLRF and lacks the advanced capabilities of dLLRF. Reduced bandwidth of the anode modulator limits the effectiveness of LLRF controls in this system, affecting beam quality throughout LANSCE.

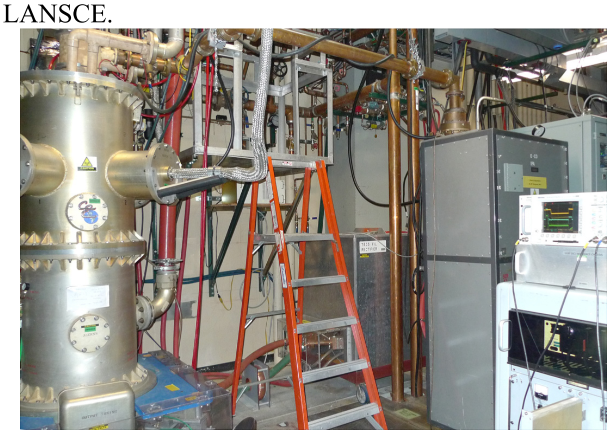

Figure 1: Legacy triode and tetrode RF amplifiers.

REPLACEMENT RF SYSTEM

Amplifiers

The block diagram in Fig. 2 represents the new chain of amplifiers with a circulator for DTL cavity 1.

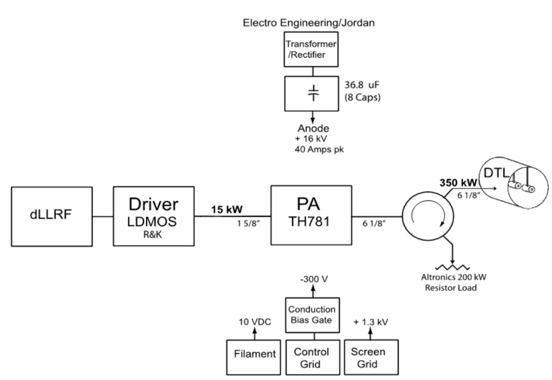

Figure 2: New RF amplifiers: SSPA and tetrode stage.

In 2004, the first TH781 tetrode and a matching Thales cavity amplifier were tested up to 510 kW at 20% DF [2]. This pushed the amplifier and tube beyond the manufacturers recommendations but proved that there was sufficient headroom. Typical power at module 1 (with beam) has

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been 350 kW to 380 kW. Thales engineers suggested that a single tetrode in their TH18781M cavity circuit would deliver this power at 15% duty factor into a matched load. This is the PA for RF module 1. Figure 3 shows how the amplifier cavity circuit is installed in a cabinet along with ancillary power supplies and a cooling blower. This is similar to the intermediate power amplifier used as a driver stage for the Diacrodes®. Figure 4 shows the two operating points from measured data.

Figure 3: Front and rear views of tetrode PA.

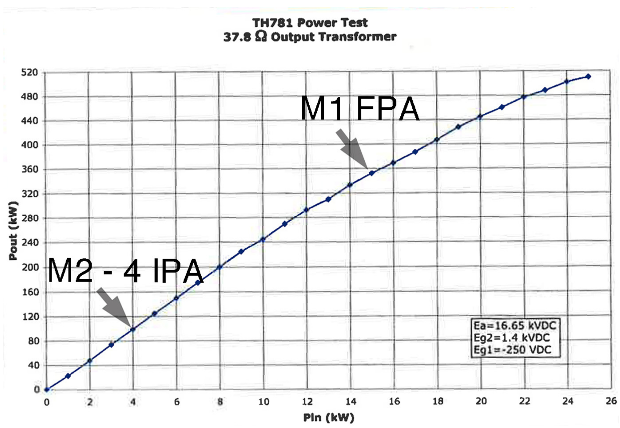

Figure 4: Operating point for tetrode, both configurations.

A 20 kW SSPA has been obtained from R&K Company to provide 15 kW of drive power to the TH781. This compact amplifier (Fig. 5) is water cooled, and consists of eight 3 kW pallets, with each one combining 4 NXP MRF1K50H transistors. The pallet outputs are combined in a 8-way radial coaxial combiner. With 24 push-pull LDMOS transistors operating at 45% of their saturated capability, there is ample power headroom and excellent linearity.

A circulator with 6-1/8 inch coaxial lines is used to present an excellent match to the PA regardless of the resonance controller setting or occurrence of multipactor in the DTL cavity. Mega Industries, LLC has built this circulator as shown in Fig. 6. Measured insertion loss is 0.04 dB at center frequency.

Figure 5: 20kW SSPA.

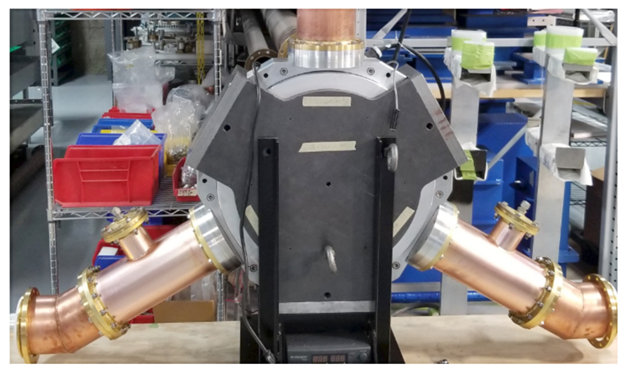

Figure 6: Coaxial circulator.

Power Supplies

The new PA will receive anode DC power from our existing power supply consisting of transformer, rectifier, capacitor bank, and crowbar system without requiring significant changes. There is considerable power savings without the anode modulator between the anode power supply and the PA. Ancillary power supplies for filament power, screen and control grid, are provided from commercial switch-mode power supplies mounted in the amplifier cabinet, seen in the left side of Fig. 3.

Cooling Infrastructure

Deionized water flow for the tetrode, cavity amplifier, circulator and SSPA will be 70 gal/min. The old RF system required 260 gal/min of deionized water. New pumps using variable frequency drives were installed in 2019, to realize savings for the entire RF plant. A single ionized water loop provides cooling water for a resistive dummy load for the circulator, made by Altronic Research.

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CONTROLS

Fast Protection and Monitoring System

FPMS provides fast logic for protection of the amplifiers, transmission lines, power coupler and DTL from excessive tube currents and RF power faults. This field programmable gate array (FPGA) logic system is reprogrammable to accommodate changes in functionality depending on where it is used. The logical elements are designed with two Cyclone® III FPGAs. Final calibration of various analog read backs is accomplished using multiplying DACs for gain setting along with setting trip points. FPMS provides timing for the grid bias voltage pulses in the tetrode and the RF drive from dLLRF. In the event of faults, it can disable these outputs in less than 3 µS. A special circuit takes the derivative of the DTL field voltage sample and generates a fast logic shutoff signal if the signal collapses rapidly (<20 uS) indicating a spark in the linac. This interlock, plus excess reflected power conditions, immediately turns off the RF drive and lowers the grid bias for all tubes to cutoff voltage level, then recovers them on the successive pulse. It will retry for a predetermined number of sequential pulses before shutting off the RF command switch to require operator intervention. Other signals such as tube over-currents, line arcs, and internal PA sparks, will turn the system off immediately on the first occurrence. A fast crowbar may also fire to discharge the anode capacitor bank.

FPMS displays RF peak power levels from eight directional couplers, indexed by an adjustable sample gate during the RF pulse. RF power sensors were developed using Analog Devices ADL5510 envelope detector integrated circuit along with an embedded PIC microprocessor. This has sufficient accuracy and wide dynamic range to compete with commercial power meters and is much less expensive. The PIC handles calibration by way of offset values and sends the correct measurements via serial interface for display on the front panel of FPMS.

A serial data communication interface is provided for interface to the human machine interface (HMI). All of the sampled analog signals at the selected index point and the status of the various fault indicators are transferred to a cRIO controller, described below.

FPMS also provides calibrated buffered outputs of all monitored analog signals for local oscilloscopes. All I/O is routed through a RF filtering network before going to the main logic board. We have found this system to be very reliable as well as flexible for design improvements since it was first implemented in the other RF amplifiers five years ago.

Industrial Controller with HMI

National Instruments cRIO provides the slower control system for the amplifiers including sequencing for warm up and cool down and interlocks for loss of water or air cooling. It also checks each power supply for valid operation before continuing start up sequencing. This system provides HMI with a touch screen and also interfaces with the global EPICS control system at LANSCE. All of the sampled analog readings here are also available in applications at the operations control room.

dLLRF

Shortcomings of the 47 year old analog LLRF system require upgrading to dLLRF as explained on page 1. This is a copy of the system used for the other DTL RF systems since 2016. It uses down conversion to ~25 MHz, where the demod/modulation functions are implemented using the I/Q sampled method [1]. The basic controls and signal processing are accomplished using FPGAs [3]. Embedded EPICS allows setting of control parameters and uploading of waveforms. PI algorithms work on the I and Q data with feedback from a DTL sample. Two feedforward terms are also used, one being a beam current signal from a pickup at the MEBT and another using iterative learning from previous pulses. The dLLRF supplies vector modulated RF drive to the 20 kW SSPA. At the beginning of flat-top, the PI gains are enabled to stabilize the field. Further information may be found in the references.

SYSTEM TESTING

The entire RF system, without linac, has been constructed in our test building for the other 201 MHz RF systems. It uses an Allen Bradley RSLogix® PLC instead of cRIO for slow controls and HMI. High voltage DC is obtained from the same power supply/capacitor bank that powers the 2.5 MW Diacrode® test set. A 500 kW RF water load absorbs the RF power after the circulator. Once everything is tested, various chassis will be moved into mock-up racks that will be relocated to the accelerator equipment gallery in early January of 2020.

INSTALLATION

Since the LANSCE operating period is until holidays in December, the removal of the old RF system and the installation of new components cannot start until the accelerator shuts off for the annual maintenance period. The work will be completed in late March, and followed by a period of testing, calibration and commissioning before turnover to operations on the first of May.

CONCLUSION

The initial DTL cavity at LANSCE is powered by a legacy RF system consisting of vintage amplifiers and anode modulator. For various reasons, it is no longer viable to continue supporting this system alongside the new RF amplifiers that were completed in 2016. In 2020 it will be replaced with a design using a single tetrode PA stage without anode modulator, and a 20 kW solid-state driver stage. All components of this system are being tested offline in a mock-up system. Demolition of the old system begins at the end of this year and installation of the new RF system is expected to be complete by April of 2020. We acknowledge the contributions of the RF technicians, engineers and the mechanical group in AOT-Division at LANSCE.

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REFERENCES

[1] J. T. M. Lyles, W. C. Barkley, R. E. Bratton, M. S. Prokop, and D. Rees, "Design, Fabrication, Installation and Operation of New 201 MHz RF Systems at LANSCE", in *Proc. LINAC'16*, East Lansing, MI, USA, Sep. 2016, pp. 564-567. doi:10.18429/JACoW-LINAC2016-TUPLR046

[2] J. T. M. Lyles, S. Archuletta, J. Davis, L. Lopez, and G. Roybal, "Test Results for the New 201.25 MHz Tetrode Power Amplifier at LANSCE", in *Proc. EPAC'04*, Lucerne, Switzerland, Jul. 2004, paper TUPKF058, pp. 1078-80.

[3] S. Kwon *et al.*, "Fpga Implementation of a Control System for the LANSCE Accelerator", in *Proc. IPAC'16*, Busan, Korea, May 2016, pp. 2771-2773. doi:10.18429/JACoW-IPAC2016-WEPOR044