A NEW 201.25 MHZ HIGH POWER RF SYSTEM FOR THE LANSCE DTL*

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Abstract

Long pulses of high proton current (greater than one millisecond at 17 mA) at LANSCE are limited by the duty factor (DF) of the 201.25 MHz RF system powering the 100 MeV DTL. The operating point of the existing triode final power amplifiers (FPA) is approximately 75% of the published maximum anode dissipation rating, but is at 90% of the allowable limit with a margin of safety for tuning excursions, voltage standing wave effects and electron tube manufacturing variations. A new RF power system is under development for increasing both peak power and DF. The FPA uses a Thales TH628 Diacrode® with pyrolytic-graphite grids. It doesn't require the large anode modulator of the present triode system. Lower mains power consumption and reduced water-cooling requirements are some advantages of this scheme. A TH781 tetrode is being tested as an intermediate stage, using a Thales cavity amplifier. When installed, the new system will reduce the total number of electron power tubes from twenty-four to seven for the LANSCE DTL. Aspects of the RF modeling, mechanical design, RF testing, and other system considerations will be presented.

1 DTL RF POWER LIMITATIONS

Each of four tanks of the 100 MeV DTL at LANSCE is driven by a power system consisting of a solid state driver stage, a tetrode (Burle Industries 4616) intermediate power amplifier (IPA) and a triode (Burle 7835V4) FPA. The RF stage for the first tank operates at greatly reduced power, while in tanks 2 through 4 the power levels are approximately 3.5 kW for the driver, 120 kW for the IPA, and 2.5 to 3 MW for the FPA. In order to raise average proton current for the spallation neutron target above 100 μA, higher peak current from the H- ion source and possibly longer macro pulses may be utilized. Added to this future power load is the need to support dynamic proton radiography experiments, isotope production and neutron research. In a typical cycle, all 120 pulses per second are used, with RF pulses of up to a millisecond in length. This high average power causes anode dissipation as high as 75% of the manufacturer's rating (300 kW) for some of the FPA triodes. This is 90% of our protective shutdown limit, providing some margin for error. These amplifiers were designed over 30 years ago, and are difficult to maintain at the consistent high reliability needed for the present operating schedule.

The plate voltage is simultaneously pulsed on and adjusted by the amplitude feedback controller in order to regulate the tank fields. This requires an additional four power tubes in each floating deck high voltage modulator. Over 600 kW DC power is dissipated in all four modulators. The replacement 201.25 MHz RF power system is being developed to remove these shortcomings and enable higher duty factor and peak power. With only seven power tubes, this new DTL RF plant will deliver both higher peak power and high duty factor, with lower AC mains power and cooling requirements[1].

2 COMPONENTS REQUIRED

2.1 New or Significantly Modified Items

The following subsystems will be replaced or extensively modified for the project:

- FPA and IPA cavity amplifiers
- Filament power supplies for each amplifier
- Water cooling manifold with valves, flow interlocks, and gauges
- Timing & protective logic bins (change to a PLC)
- RF amplitude control using low level electronics
- Larger RF driver for tetrode amplifier at tank 1

Additional components need to be added to the system with the new amplifiers. The FPA Diacrode® is a four element tube and both grids can be biased to optimize its power gain, linearity or efficiency. The present FPA triode is self-biased with a cathode resistor and operates in a saturated condition. The new additions are:

- Screen and control grid power supplies
- Solid state pulse modulators for grid bias
- 35.5 cm (14 inch EIA) diameter coaxial circulators
- Full peak power loads for circulators
- Additional directional couplers
- Detectors and logic for control and diagnostics

2.2 Reused Items

The existing HV capacitor banks, transformer/rectifiers, and heat removal systems will continue to be used. LANSCE replaced the external water-cooling towers with modern units in 2002. The elimination of the modulators will reduce the cooling load, even with the additional water required for the circulators and loads. The 35.5 cm diameter coaxial transmission lines to the linac tanks will be reused. The existing anode, screen and control grid power supplies for the IPA will also be redeployed. The existing solid-state driver stage will be used for DTL tanks 2 through 4. Figure 1 shows the basic configuration for one high power RF module.

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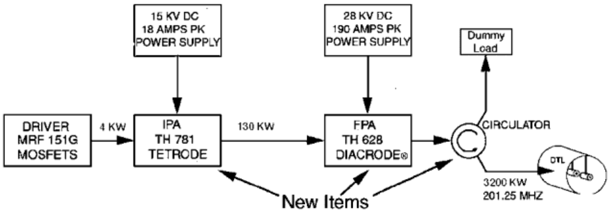

Fig. 1: Major Components of RF Module for Tanks 2 - 4

3 IPA AND DRIVER

3.1 Intermediate Power Amplifier

The THALES TH781 tetrode was selected with a THALES cavity amplifier to provide as much as 15 dB power gain to cathode-drive the FPA. This compact linear amplifier has been tested at various operating points at THALES; two applicable test points are summarized in table 1. It will be used as a stand-alone amplifier with a 15.5 cm coaxial circulator to drive the first DTL tank at 400 kW, in place of the existing tetrode IPA, triode FPA, and FPA anode modulator. For tanks 2 through 4, the TH781 will function as the IPA, providing approximately 130 to 150 kW of RF power to the new FPA. Figure 2 shows the new amplifier assembled in its enclosure with cooling, interlocks, filament power supply, and various flow switches / air sensors in place.

Table 1: TH781 Performance (THALES)

Power Output (kW)	500	200
Anode Current (A)	36	25.2
Anode Voltage (kV)	19	13.1
Screen Voltage	1200	1200
Control Grid Voltage	- 350	- 350
Power Input (kW)	16	9
Duty Factor (%)	1	20

Figure 2: New IPA Ready for Testing

3.2 Driver

There are two variations of driver/preamplifier required. For tanks 2 through 4, the tetrode IPA will drive the Diacrode® FPA, and the gains are similar to the present system. The existing American Microwave Technology solid-state drivers have operated with high reliability for eight years, with very few outages. They are capable of 5.5 kW peak at 15% DF using combined water-cooled MRF151G mosfets, and will be reused for the new system[2]. At DTL tank 1, the tetrode stage needs approximately 14 kW of drive, beyond the capability of these amplifiers. Band II television transmitters are capable of this performance, but with the penalty of high cost, large size, excess bandwidth and complexity. Magnetic resonance imaging systems have demonstrated linear solid-state amplifiers with 10 kW at 10% DF[3]. We are investigating these from several manufacturers to drive the tetrode at tank 1.

4 FINAL POWER AMPLIFIER

4.1 New RF Power Device Available

The THALES TH628 Diacrode® is utilized in a new FPA being developed at LANSCE. This four element double-ended tube uses pyrolytic graphite grids, a thoriated-tungsten mesh cathode, and a multiphase-cooled anode rated to dissipate 800 kW[4]. The FPA operates as a class AB_2 linear amplifier, eliminating the need for an anode voltage modulator. Performance of the TH628 has been measured at the manufacturer’s facility and three significant operating points are noted in table 2. We will operate one of the tubes at three MW peak and the other two at slightly lower output. The highest power tests have demonstrated that the Diacrode® may be suitable for other DTLs operating at lower duty factor but higher peak current, such as injectors for proton synchrotrons.

Table 2: TH628 Performance (THALES)

Power Output (kW)	4500	4070	3000
Anode Current (A)	220	206	168
Anode Voltage (kV)	32	29.5	26
Screen Voltage	1600	1600	1600
Control Grid Voltage	- 500	- 500	- 560
Power Input (kW)	174.6	155	115
Duty Factor (%)	1.5	5	20
RF/DC Efficiency (%)	64	67	68.7

4.2 Development of Cavity Amplifier

A double-ended RF circuit can raise the power capability of a gridded- vacuum tube by increasing the active length inside the tube to nearly λ/8. The so-called “dead head” region above the active region at the top of the tube is replaced with seals and connections to a second external cavity circuit. In the TH628, the anode/screen circuit is connected at each end of the tube, while the input cathode/grid circuit is folded back inside the center of the filament structure and is connected only at the bottom of the tube. The drive voltage peak is centered in the active zone with the input circuit.

The LANSCE cavity amplifier being developed is shown in figure 3. Considerable thought has gone into making an amplifier to produce > 3 MW peak at the high altitude of Los Alamos (2133 m). The design has been simulated with Superfish and Fortran transmission line calculations, and the fundamental mode electric field is low across the 12 cm ceramic seals of the tube[5]. Eliminating the pressurized vessel of the existing 7835 FPA will significantly reduce tube change out time, which now takes a minimum of 12 hours when the O-rings, RF contact spring/fingers and hoses are inspected or replaced.

Large diameter super power tubes have the potential to generate energy with modes beyond the fundamental TEM condition[6][7]. The anode/screen grid spacing inside the TH628, for example, supports TE_{21} and TE_{31} at approximately 780 and 1168 MHz as demonstrated with Superfish. They are observed at slightly higher frequencies with the amplifier at THALES. An odd number of mode suppressors are being added to the LANSCE amplifier adjacent to the ceramic seals of the tube. Reduced-height terminated waveguide is useful as an absorptive high pass filter, as demonstrated by THALES. It is preferable to design mode suppression into the amplifier early, instead of as an afterthought. Unfortunately, the effects of these modes cannot be observed until the amplifier is powered. They may depend on interaction with the electron beam as well as the mechanism for coupling into the external circuit, set by the cavity dimensions around the seal area of the tube.

Fig. 3: New FPA

Fig. 4: Circulator at Low Power Test

5 THREE PORT COAXIAL CIRCULATOR

5.1 New Coaxial Circulator

High power coaxial circulators have been demonstrated by Advanced Ferrite Technology (AFT) for the 267 MHz Chalk River CW test amplifier (23.2 cm coax), and the 160 MHz MIT-Lincoln Lab Altair radar transmitters at Kwajalein Atoll (35.5 cm coax). Each FPA at LANSCE will use circulator for the 35.5 cm transmission line to the linac. AFT has produced a 1728 kg Y-junction circulator for this application (figure 4).

Low power testing by the manufacturer has demonstrated that reasonable insertion loss and isolation can be achieved with this large circulator. The unit will be shipped to Los Alamos soon and tested at full power using an existing 7835 FPA.

6 PROGRESS AND SUMMARY

We are progressing on the major tasks for the RF system upgrade. The IPA stage is nearly complete and ready for testing. The FPA stage is still in development, and only low-level measurements have been accomplished. Improved blocking capacitors and parasitic mode suppressors are being developed. Power supplies for both amplifiers are installed. A new circulator has been designed and fabricated, and will be delivered to LANSCE for power testing shortly. Manufacturers have been identified for a high power solid-state driver/preamplifier for the new tetrode amplifier for the first DTL. A programmable logic controller is being assembled to operate the test set for the amplifiers. Additional personnel have been assigned to work in parallel designing the coaxial transmission line layout and engineering the cooling water system.

Each component will be thoroughly tested alone before an overall system test is performed. The RF module for the first DTL tank will receive the initial hardware, with a single tetrode driven by a high power solid-state amplifier. Then the complete module for one of the highest power systems will be replaced, keeping the old systems operating on the other two. Finally, we will replace the entire plant, and gain the complete benefits of the new design.

7 REFERENCES

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