ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPME021

PULSED HIGH POWER AMPLIFIERS

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Abstract

Diversified Technologies, Inc. (DTI) is building two solid-state klystron transmitters for Lawrence Berkeley National Laboratory and Daresbury Laboratory in England. The units are similar, and part of a push by DTI to establish a standard laboratory transmitter.

Index Terms — Klystron; Daresbury; LBNL; Solid-State Modulator; High Voltage Pulse-Transformer

INTRODUCTION

Diversified Technologies, Inc. (DTI) will deliver in 2014 two solid-state pulsed klystron transmitters. Though not identical, the units are similar in design, and will be provided to Lawrence Berkeley National Laboratory (LBNL) and Daresbury Laboratory in England.

DTI's goal across these two projects is to develop a complete, replicable package for the high peak power laboratory transmitter market. The modulator is a pulse transformer-coupled hybrid system, including ancillary klystron components (i.e., focus coil, socket) but not the actual klystron tube. The RF will include a drive amplifier, simplified protection circuitry, and two pieces of waveguide. A simple PLC-based controller is incorporated into the transmitter.

MODULATOR

Both systems employ a relatively simple modulator, which consists of an energy storage capacitor, a high voltage series switch, a step-up pulse transformer, and a passive pulse-flattening circuit. This arrangement gives an extremely flat pulse and allows the use of a moderate value of storage capacitor. The DTI switch can open or close as commanded, so the pulse width is adjusted by the gate pulse to the system. Each system will employ a 35 kV primary voltage supplied by a DTI high voltage switching power supply. The high primary voltage allows optimization of all components to give a simple, reliable, and high stability system.

DTI HIGH VOLTAGE SOLID-STATE SWITCHES

A high voltage switch is a crucial, proven building block of most DTI transmitters. The switch consists of a series/parallel combination of commercially-available insulated gate bipolar transistors (IGBTs). Under normal operation, the switch acts as a modulator, controlling the pulses to the pulse transformer. In addition to providing pulsing, another important function of the switch is circuit protection. When a klystron gun arc occurs, the fault is sensed and the switch will open in less than 1 μs to disconnect high voltage. The current rate of rise is limited to a safe value by the inductance of the pulse transformer. This rapid current interruption minimizes the fault energy deposition in the klystron gun which promotes a long and stable valve lifetime. These characteristics make the solid-state opening switch an ideal building block for high availability applications such as particle accelerators and mission critical radars. A large high voltage design margin is included at both the individual switch stages and for the overall switch assembly, so that several switch module failures could be tolerated without affecting system performance.

Table 1: Key specifications of PHPA with Thales TV 2022X Klystron

Specification	Value	Unit
Peak RF Power	25	MW max
Average RF Power	2.5	kW max
Pulse width	10	microseconds
Repetition rate	10	Hz
Anode Voltage	270	kV
Beam Current	250	A
Voltage Flatness	1%	better than
Voltage reproducibility	0.1%	better than
Pulse to pulse jitter	5	nanoseconds

PULSE TRANSFORMER

The high primary voltage of the DTI switch allows a moderate transformer step-up ratio (10:1). This gives fast rise and fall times and good efficiency. The transformer will have a bifilar wound secondary on a sloped basket (constant gradient). The transformer design is optimized to work with the small passive bouncer circuit to give a very good flat top. A commercial power supply in the rack supplies the DC core reset current for the transformer, fed through a core reset inductor. DTI's pulse transformers are typically built by Stangenes Industries (Palo Alto, CA) to our detailed specifications. DTI has built similar transformer-coupled modulators up to 500 kV and 500 A.

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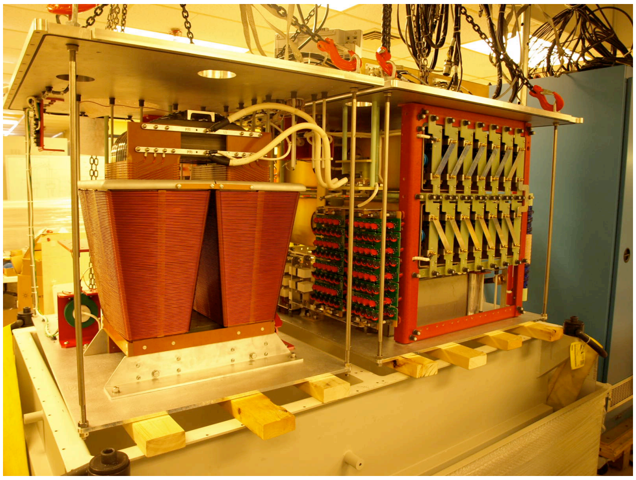

Figure 1: The LBNL unit suspended above tank. On the left is the tapered pulse transformer; on the right, diodes and solid-state switch array. Far right: power supply cabinets.

SYSTEM PERFORMANCE

Klystron pulse voltage flatness and stability are crucial to proper linac operation. The DTI design will be designed for proper operation with both of the specified klystrons and will meet all technical specifications of the Compact Linear Accelerator for Research and Application (CLARA); simulated pulses are shown in Figure 1. The modulator will give good pulse fidelity over all conditions but will be optimized near the nominal peak power of the preferred klystron. DTI systems are inherently amenable to modification for potential system upgrades in the field. The modulator will have the capability to run approximately 10% over the nominal output voltage of 350 kV. If required, the pulse transformer turns ratio may be changed to adapt to higher voltages within the peak current rating of the switch. The 200 kW HVPS has a substantial margin over the 162 kW requirement. A second power supply may easily be added to double the average power at any time in the future.

The simple DTI pulse circuit includes a filter capacitor, a nearly ideal high voltage switch, and straightforward pulse transformer to give a very flat pulse with rapid rise and fall times. Any small imperfections are removed by the passive pulse compensation circuit (bouncer). The flat top deviation will be +/- 0.07% or better. Pulse to pulse voltage stability will be better than 0.1 %. Pulse-to-pulse timing variation is low in DTI systems and will meet the < ±4 ns specification. When combined with the flat pulse, RF phase errors are minimized.

RELIABILITY

DTI has installed high voltage transmitter systems for numerous high reliability and high maintainability applications, such as military shipboard radars and high power physics experiments. A combination of conservative design and low operating temperatures (typically 20 – 30 °C junction temperature rise in the IGBTs) contributes to the high reliability of DTI's equipment. The majority have had no known field failures after initial commissioning; DTI systems have achieved over 120 system-years of failure free operation.

DTI's high voltage solid-state opening switch technology minimizes the stress on the system in the event of a fault (such as a tube arc). This contributes to long tube life and high availability and allows for rapid recovery in the event of most faults. In addition, these diagnostics allow for the rapid detection and isolation of repetitive or hard faults in the overall system.

The estimated mean time to repair (MTTR) with the recommended spares on site is 4 hours. This results in a system availability of 99.99 %.

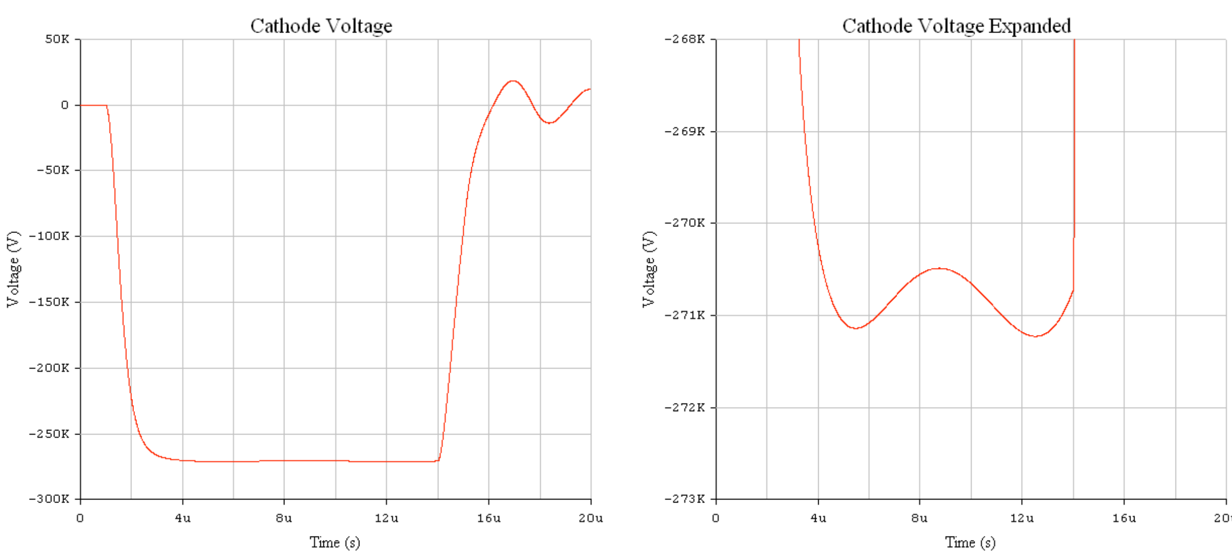

Figure 2: Left: Simulation of voltage pulse into the klystron with passive pulse shape compensation (bouncer circuit). Right: The same, with data range altered to illustrate voltage deviation. The total deviation is less than 500 volts (0.15%).