

# A KLYSTRON POWER SYSTEM FOR THE ISIS FRONT END TEST STAND

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## *Abstract*

Diversified Technologies, Inc. (DTI) has delivered a fully solid state Klystron Power Supply for the ISIS Front End Test Stand to Rutherford Appleton Laboratory in the UK. The system includes two 220 kW switching power supplies, a 110 kV solid state hard switch pulse modulator, mod anode and filament power supplies, klystron fault protection, and interfaces to the ISIS controls. This paper will address the design and construction of the KPS system, as well as test results from the installation at RAL in February 2009.

## I. INTRODUCTION

In December 2008, Diversified Technologies, Inc. delivered a Klystron Power Supply (KPS) (Figure 1) for the ISIS Front End Test Stand at Rutherford Appleton Laboratory. The new power supply will drive the Toshiba E3740A klystron in preparation for construction of a system to demonstrate high quality intense chopped beams. DTI's system represents a significant advance in solid-state high power accelerator technology based upon a hard switch developed for the US Department of Energy (DOE) to meet similar requirements for the International Linear Collider (ILC).

DTI engineered the system to deliver several significant advantages to ISIS including eliminating the need for a large pulse transformer, eliminating the crowbar for greater system availability and klystron reliability, reducing the available arc energy and simplifying the mod-anode voltage control.

The pulse modulator specifications for the KPS Front End Test Stand are summarized in Table 1. A simplified schematic of the modulator is shown in Figure 2.

### A. *High Voltage Switching Power Supply*

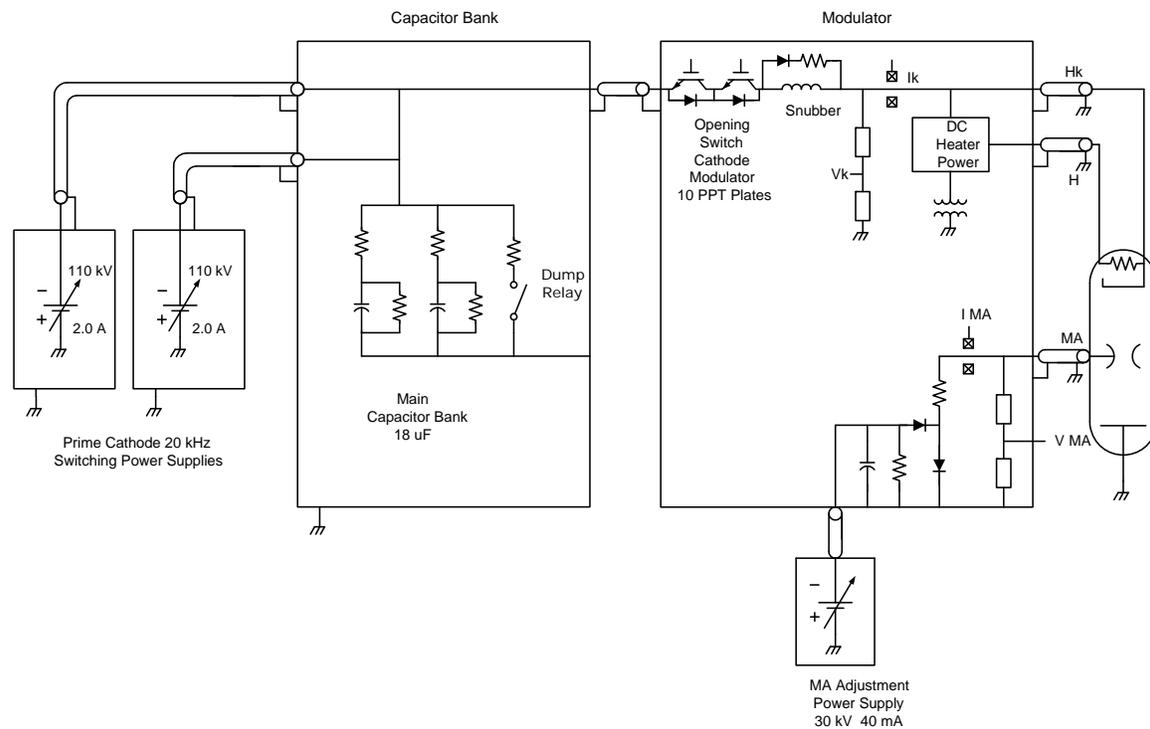
The klystron prime power is generated by two high voltage switching power supplies, each capable of producing 220 kW CW power at 110 kV (maximum)

**Table 1.** Key specifications - KPS modulator.

Parameter	Modulator Specification
Cathode Voltage	-110 kV
Cathode Current	45 A
PRF	50 Hz
Beam Pulse Width	500 $\mu$ s to 2.0 ms
Droop	5%
Duty Cycle	10% maximum



**Figure 1.** KPS System for ISIS front end test stand.



**Figure 2.** KPS/ISIS system schematic

with 0.1% regulation. These power supplies are parallel combined to meet the overall system power requirement. The system is capable of operating at lower average power in the event that either power supply goes off-line.

### B. Modulator Tank

The modulator tank contains the series cathode switch, heater supply, and modulator controls (housed above the tank lid). The modulator tank includes integral lifting mechanisms, which preclude the need for an overhead crane to install / checkout the equipment. This mechanism can be seen in operation in Figure 1.

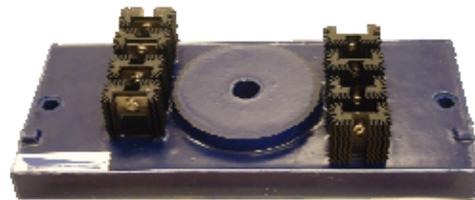
### C. Solid State Series Switch

The main solid-state switch consists of a series stack of commercially available IGBTs, built with DTI's proven approach to series switching. The main solid-state switch consists of a stack of ten switch-plates connected in series to provide a maximum voltage standoff of 150 kV. A single switch plate, rated at a voltage of 15 kV and peak currents of 500 A, is shown in Figure 3. This switch presents a very low impedance, low voltage drop (~250 V) path between the capacitor bank and the cathode, so the cathode voltage remains constant, independent of the beam current.

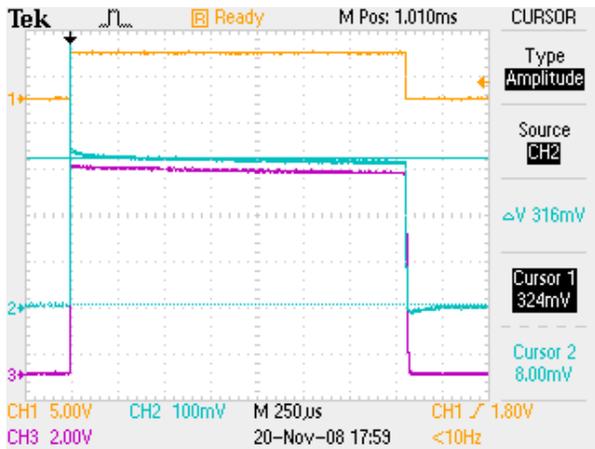
The main solid-state switch serves two functions. First, it delivers HV pulses to the klystron under normal operation conditions (Figure 4). Secondly, the solid-state switch protects the klystron against arc

damage (Figure 5). Fast current sensors in the modulator recognize the presence of an arc when the current in the switch exceeds a preset fault threshold value. When this occurs, the switch responds by opening in  $\sim 1 \mu\text{s}$  to disconnect the high voltage from the klystron. The series inductor and diode between the solid-state switch and the klystron cathode provide current limiting, allowing the pulse risetime to be balanced against the peak current when the switch is closed (and, critically, limiting the peak current prior to switch opening in the event of a cathode arc). For a long pulse system, such as ISIS, this inductor limits the voltage pulse risetime to the  $\sim 5 - 10 \mu\text{s}$  range, providing ample time for the switch to open before significant arc energy is developed.

After the arc extinguishes, the switch can resume operation of the modulator – typically after only a



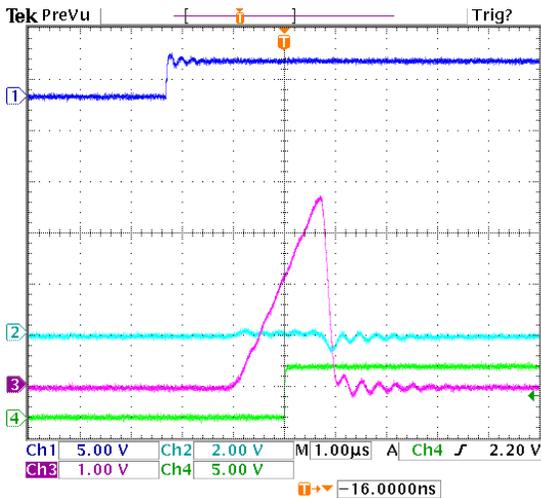
**Figure 3.** Pulsed Power Transistor (PPT) switch-plate capable of switching 15,000 V at 500 A. Ten of these plates comprise the main switch of the KPS modulator. Approximate dimensions of this switch-plate is 13" x 6" x 3" high.



**Figure 4.** RAL KPS Modulator Output Pulse into Resistive Load (100 kV, 42 A, 2 ms).

couple of missed pulses, as opposed to shutting down the modulator system (which is not uncommon in systems protected by a crowbar). For this reason solid-state switches have gained wide acceptance.

Cathode pulsing allows mod-anode voltage control by simply adjusting the mod-anode power supply voltage, independent of cathode voltage (unlike a resistive divider). Cathode pulsing also eliminates the need to reverse bias the mod-anode with respect to cathode, as the beam is fully cut off when the cathode switch is open. This approach eliminates the need for separate push-pull switches on the mod-anode, as the diodes allow this circuit to operate passively.



**Figure 5.** Scope trace from #40 AWG Arc Test wire. Shorting the cathode to ground through a length of #40 AWG wire leaves the wire intact, due to DTI's rapid fault detection and current limiting circuitry. Switch opening occurs approximately 700 ns after the threshold current limit is reached, and the peak current remains below ~150 A. .

## II. FAST FAULT AND TIMING

Fast fault and timing signals (RF and arc faults, modulator triggers, etc.), pass through the modulator control chassis, which handles all high-speed fault signals and actions for equipment protection, managing the modulator opening switch. Transmitter timing signals are validated for pulse width, duty cycle, wide-pulse, and over-frequency protection. The high-speed analog signals (cathode voltage, cathode current, body current, etc.) are buffered and sent to front panel BNC jacks for monitoring by an oscilloscope.

Typically, many fault indications may be generated in a transmitter fault situation. The fast logic latches and displays the first fault and subsequent faults in any fault sequence. Faults are displayed on LEDs and passed to the PLC/PC for display and logging. This functionality is crucial to klystron and transmitter protection and troubleshooting. It also allows the PLC to define customized arc-counting and arc-handling algorithms for klystron seasoning, troubleshooting, and operation. The Microwave Control Unit (MCU) will also respond to fast RF faults detected in the output waveguide or circulator, or provided from other subsystems in the MILLSTONE transmitter, such as waveguide arcs beyond the circulator.

### A. Control System Interface

The KPS Front End Test Stand is controlled and monitored via fast control and monitoring that provides fast response, hard-wired fault detection, and safety shutdown (Figure 6). The fault monitoring provides a 'first fault indicator', allowing rapid diagnosis of any fault conditions which may occur by latching the initial fault signal received. All controls for the power supplies, modulators, and other equipment are available through front panel settings.

Overall system control, including the transmitter, water, power, RF, etc., will be installed and integrated by ISIS personnel.



**Figure 6.** Modulator Controls, including fast fault detection and first fault identification.



**Figure 7.** Toshiba klystron installed in the ISIS KPS Test Stand.

### **III.INSTALLATION AND OPERATION**

The KPS Front End Test Stand was fully tested into a resistive load at DTI in December 2008, with RAL participation. It was shipped to RAL, installed and tested in the ISIS facility with the klystron (Figure 7), in April 2009. Due to the extent of the in-plant testing, and the reliability of the solid state design, the entire installation and final acceptance testing was completed in approximately one week. The system is currently operational at ISIS.