

# SOLID STATE TRANSMITTER FOR A 2 MW KLYSTRON

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## Abstract

Diversified Technologies, Inc. (DTI) built, tested, and successfully installed a transmitter for a 2 MW, 500 MHz VKP-8208A klystron manufactured by Communications and Power Industries, Inc. (CPI). The transmitter design is based upon a hard switch topology that DTI previously delivered to the ISIS Front End Klystron Test Stand at Rutherford Appleton Laboratory, UK. The full transmitter power system, pictured in Figure 1, consists of two 200 kW switching power supplies, a capacitor bank, a 100 kV solid-state hard switch modulator, control racks, and RF output and monitoring hardware. The modulator's specifications are shown in Table 1. Descriptions of the system design and final installation are presented throughout this paper.

## ARCHITECTURE

### Power Supplies

The klystron beam power is generated by two high voltage power supplies, each capable of producing 200 kW CW power at 100 kV, with ~0.1% regulation. DTI has provided supplies of this type in a number of high power radar transmitters. In this design, the transmitter can operate at lower average power in the unlikely event a single power supply goes off-line.

Table 1. Specifications 2 MW Klystron Transmitter.

Parameter	Modulator Specification
Cathode Voltage	-100 kV
Cathode Current	50 A
Voltage Regulation	0.1%
PRF	Up to 1 kHz
Beam Pulse Width	20 to 500 us
Droop	3%
Duty Cycle	5% maximum

### Capacitor Bank

The capacitor bank is sized to meet the 3% droop specification without the need for additional compensation or regulation. The 11.25  $\mu\text{F}$  capacitor bank requires its own oil tank, which includes the bleed and dump resistors required for safe operation of the system. This represents a large capacitor bank for a DTI transmitter system. If the required pulsewidth were longer than 500  $\mu\text{s}$ , or the droop specification were tighter than 3%, this system would have been built with either a LC bouncer circuit, or an active regulator, to maintain the flat top of the pulse. The power supplies and capacitor bank as installed are shown in Figure 2

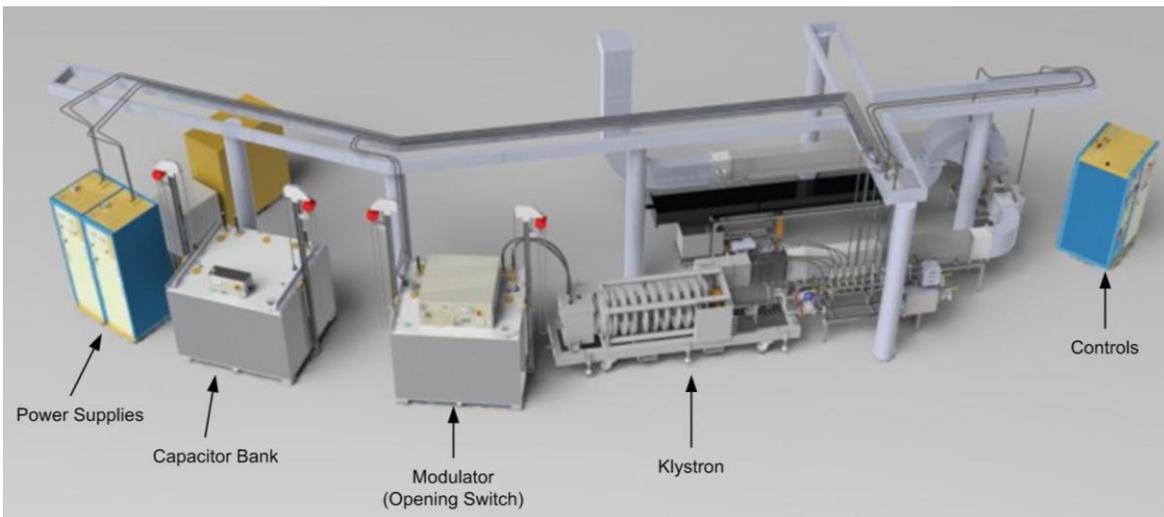


Figure 1. Rendering of full system assembly.



**Figure 2. Installation of the 2 MW klystron transmitter. View shows DTI's high voltage power supplies (left) and capacitor tank (right).**

### **Modulator**

The main solid-state switch consists of a series stack of commercial IGBTs, built with DTI's patented approach to series switching. This switch presents a very low impedance, low voltage drop (~320 V) path between the capacitor bank and the cathode, so the cathode voltage remains constant, independent of the beam current.

The modulator tank containing the solid-state switch is shown in Figure 3. The entire modulator assembly lifts directly out of the oil, without the need to disconnect any cables, for service.

The main solid-state switch serves two functions. First, it delivers HV pulses to the cathode of the klystron under normal operation conditions. Figure



**Figure 3. Switch plate array in the transmitter's modulator. The entire assembly is submerged in oil.**



**Figure 4. Scope shot of 100 kV pulse into resistive load, 520 µsec Ch1 V<sub>k</sub> 99 kV (10 kV/div); Ch2 I<sub>k</sub> 41A (10A/div).**

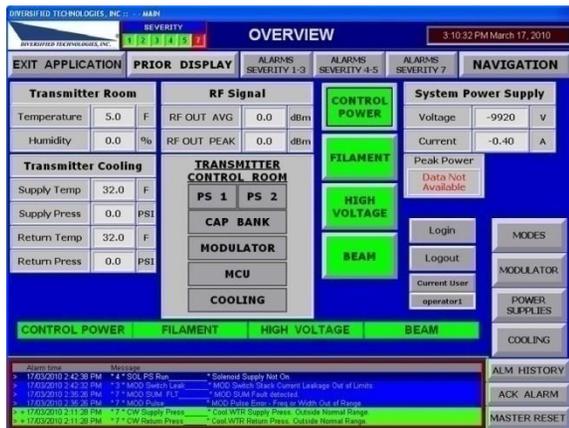
4 shows a typical pulse. Secondly, the solid-state switch protects the klystron against arc damage. Fast current sensors in the modulator recognize the presence of an arc when the current in the switch exceeds a preset fault threshold value. When this occurs, the switch responds by opening in ~ 1 µs to disconnect the high voltage from the klystron.

### **RF Systems**

The delivered 2 MW Transmitter was a 'turn-key' system, including everything from facility power to the antenna waveguide. In addition to the power supplies and modulator driving the klystron, DTI specified, purchased, installed, and tested all of the RF components for the system. This included the RF driver, circulator, dummy RF load,



**Figure 5. Controls racks for the 2 MW klystron transmitter.**



**Figure 6. Screen shot of the transmitter overview touch screen control.**

waveguide, fault protection, and cooling / air handling for the RF system. Controls and interlocks for the RF systems were integrated into the overall transmitter controls, discussed below.

### **Controls**

The entire 2 MW klystron transmitter is controlled and monitored (Figure 5) through a three-level system. The first level, fast control and monitoring, provides fast response, hard-wired fault detection, and safety shutdown. The second level provides supervisory automatic controls and slower response fault detection via a commercial programmable logic controller (PLC). The third level consists of a PC based Graphical User Interface for local operator control and monitoring.

### **Interactive Touch Screens**

The baseline DTI operator interfaces use standard WindowsCE/Intel integrated color touch screen monitors (Figure 6). Communication between displays and PLCs is by standard Ethernet, using readily available switches.

All personnel safety interlocks (including the Kirk key system, door interlocks, capacitor discharge relays, and “panic” shutoff buttons) are fail-safe hardwired, with status monitored by the PLC. The PLC cannot reset or override such safety switches.

The automatic control system has four main sequential modes of operation, representing the major steps in transmitter activation (or, in reverse, shutdown). The control system handles all status checks, system enables, and other operations required for activating (in turn) Control Power,

Filament Heaters, High Voltage, or Modulator/RF Enable. The system will automatically enforce sequencing through the modes required to reach each level of operation - for example, high voltage cannot be turned on before the filament is on and warmed up. Faults will shut the system down only as far as necessary.

### **STATUS/CONCLUSION**

The entire transmitter was successfully integrated and tested with CPI’s VKP-8208A klystron at the customer’s site in 2011, where it continues to operate today (Figure 7).



**Figure 7. Installation of DTI’s transmitter for a 2MW, 500 MHz klystron. Note the blue high voltage power supplies and light gray modulator tank in the far back, klystron, water manifold and black waveguide in the center and RF driver, microwave control unit, PLC and graphic interphase unit in the foreground.**