

# HIGH STABILITY KLYSTRON MODULATOR FOR COMMERCIAL ACCELERATOR APPLICATION

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## Abstract

Diversified Technologies, Inc. (DTI) designed and developed a high stability modulator system for a commercial linear accelerator application. The DTI modulator delivers significant advantages in klystron performance through highly reliable functionality as well as flicker- and droop-free operation from 50-500  $\mu$ s up to 400 Hz (duty limited). The main assemblies on the DTI system consist of a controls rack, high voltage power supply (HVPS), modulator, and cooling manifolds for the modulator, high voltage power supply and klystron tube. Two HVPS (upgradeable to four) provide stable and accurate DC voltage which is used to drive a CPI VKP-8352C UHF-band pulsed klystron for the linear accelerator. A solid state series switch, based on DTI's patented design, provides both pulse control and arc protection to the klystron. Operating with four HVPS, the DTI modulator is able to operate at a maximum average power of  $\sim$ 750 kW at 105 kV, 47 A nominal. At the end of the initial contract, DTI provided two systems and a total of four HVPS (two of which are used with each system).

## INTRODUCTION

In 2021 Diversified Technologies, Inc. (DTI) completed the development and acceptance testing of two advanced, high voltage solid state klystron modulator systems for a commercial linear accelerator application. The modulators use a series-switch design that DTI has delivered to hundreds of clients over the last 25 years. Modulators based on this switch design are

operational at sites around the world for accelerators, radar transmitters, and industrial applications, and deliver extremely high-quality pulses for a wide range of klystrons, TWTs, and other high-power microwave tubes.

The modulator design provides significant advantages in klystron performance through highly reliable operation and significantly exceeded the contract requirements, as well as, flicker- and droop-free operation over a range of operating parameters. Each modulator system for this application includes two high voltage power supplies (upgradeable to up to four HVPS by a simple install of the additional HVPS), oil-filled modulator tank, controls cabinet, auxiliary electronics rack and cooling manifolds; the modulators connect to the klystron via high voltage output cables and other required interfaces (Fig. 1).

## SPECIFICATIONS

DTI met the contractual pulse width and flatness requirements with a modulator design which included:

- Two switching power supplies (capable of operating with up to four), providing stable and accurate DC voltage.
- A solid state series switch, based on DTI's patented design and 25 years of refinement, providing both the pulse control and the arc protection to the klystron.

The major client-defined specifications are summarized in Table 1.

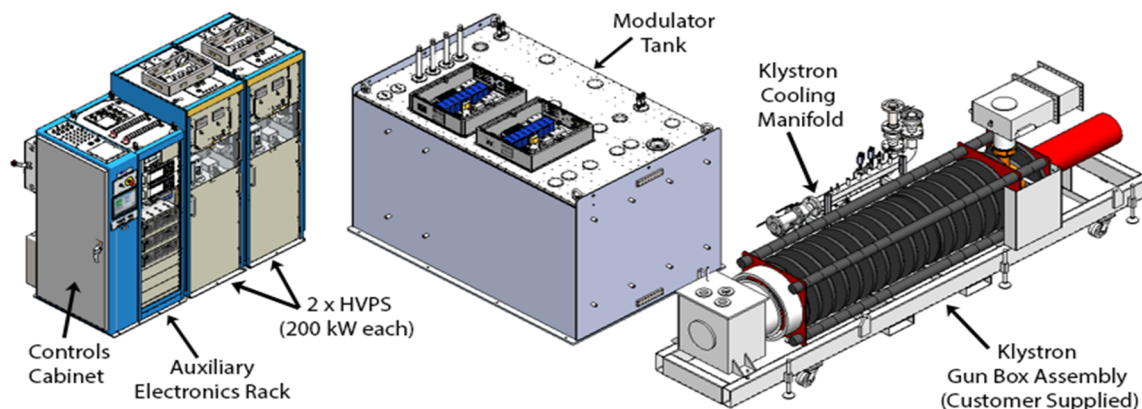


Figure 1. Modulator system major subassemblies.

Table 1. Klystron Modulator Specifications

Specification	Parameter
Voltage	105 kV
Current	47 A
Flat-Top Pulse Width	50-500 $\mu$ s
Pulse Frequency	1-400 Hz (within average power)
Average DC Power	<320 kW (2x HVPS) <750 kW (4x HVPS)
Flat-Top Ripple and Droop	<0.5%

## TECHNICAL DESCRIPTION

### High Voltage Power Supplies

The klystron modulator system operates with two standard DTI switching power supplies, each rated at 110 kV, 200 kW. Each HVPS uses a pulse width modulation (PWM) inverter to provide voltage and current regulation over the full output range. The system can operate with up to four power supplies which enables an average power capability of 750 kW (operating at 13.6% duty). Nominal output behavior is 0.1% ripple and voltage regulation, with fast response to transients. A heavy-duty high voltage cable connects the power supply to the modulator tank.

### Modulator

The key element of the modulator design is the high voltage solid state switch, which is comprised of series-connected IGBT modules, and operates at full cathode voltage. The IGBTs in the switch give redundancy: two of the six switch plates worth of devices can fail without affecting the ability of the switch to operate at full rated voltage.

Under normal operation, the switch acts as a modulator, controlling the pulses to the klystron. A secondary 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  $\mu$ s to disconnect high voltage from the klystron cathode.

A 10  $\mu$ F, 120 kV capacitor bank is located inside the modulator tank, and provides < 0.5% droop at up to 500  $\mu$ s pulses. In DTI's design, it is not necessary to discharge the capacitor when the load arcs. When an arc occurs the solid-state switch simply opens, allowing the capacitors to remain charged until the arc clears and operation can resume (often at the next scheduled pulse). This allows rapid conditioning of new klystrons, since they can arc repeatedly with minimal delay before the next pulse is applied.

### Controls Cabinet and Auxiliary Rack

The control cabinet houses the main system controls and interface, as well as most of the power distribution.

The cabinet is divided into separate compartments to accommodate AC power distribution, low voltage DC utility distribution, and a controls section which includes the Programmable Logic Controller (PLC) for system sequencing and other functions. The cabinet front panel provides an E-Stop button, touchscreen, and BNC monitor panel which allows convenient monitoring of buffered signals from the control board.

One half of the controls' cabinet enclosure consists of an auxiliary supply rack which houses power supplies for the ion pump and the focusing coils. The heater supply floats at cathode potential. The control and monitor signals for this supply are transmitted on a fiber-optic cable between ground and cathode; circuit boards convert between the electrical and optical signals.

The modulator tank HV controls enclosure is mounted on top of the Modulator Tank and provides drive power for the modulator switches and power supplies for other internal tank components

### Cooling Manifold

Separate cooling manifolds provide cooling flow loops for both the modulator and klystron components. The modulator cooling manifold (which can be mounted on the modulator tank) delivers water coolant to the modulator tank and each HVPS.

A separate klystron cooling manifold delivers water coolant to the klystron collector, body, and gun box. It also has spare circuits at the end users request for other facility requirements.

Flow, temperature, and pressure sensors are installed in the cooling loops to detect cooling faults and are routed to the PLC modules in the controls' cabinet.

## CONCLUSION

In 2021 DTI completed a Factory Acceptance Test for two klystron modulator systems, successfully demonstrating the desired specifications of the customer (Fig. 2). DTI's customer expects to be fielding the first of these systems in 2022.

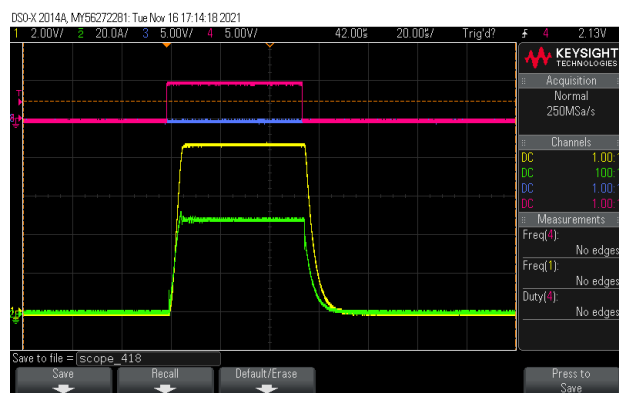


Figure 2. Pulsed Cathode Voltage, 105kV (scale 12kV/V), 55  $\mu$ s pulse width and 400 Hz repetition rate.