

# THYRATRON REPLACEMENT\*

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Thyratrons in high-power, short-pulse accelerators have a limited lifetime, making it desirable to replace the thyratrons with solid-state devices. One possibility, thyristors, are being developed for this application; they have not, to date, demonstrated the reliability needed for installation in the short pulse, high peak power RF stations used in many pulsed electron accelerators. An alternate solid-state device, the insulated-gate bipolar transistor (IGBT), readily operates at the speed needed for accelerators, but commercial IGBTs cannot handle the voltage and current required. It is, however, possible to assemble these devices in arrays to reach the required performance levels without sacrificing their inherent speed. Diversified Technologies, Inc. (DTI) has patented and refined the technology required to build these arrays of series-parallel connected switches. Under a DOE contract, DTI is currently developing an affordable, reliable, form-fit-function replacement for the klystron modulator thyratrons at SLAC.

**Keywords :** Thyratron, SLAC, Solid-State Switch, Klystron, Modulator

## 1. INTRODUCTION

The Stanford Linear Collider (SLC) has used thyratrons in its klystron modulators since its inception in 1963. While the thyratrons function, they need replacement every 10,000 hours at a cost of \$13,000 each, plus labor. Furthermore, periodic maintenance is required to adjust their reservoir heater voltage over the thyratron lifetime. As the Stanford Linear Accelerator Center (SLAC) continues to run its accelerator over the next two decades, replacing the thyratrons with a solid-state switch that would last 25 years or more, and does not need maintenance, would provide significant savings – both in the avoided cost of thyratrons as well as the labor in replacing and adjusting them.

SLAC is presently funding the development of a solid-state switch, based on thyristor technology, to replace the thyratrons. The difficulty is that a fast rising current in a thyristor tends to be carried in a small region, rather than across the whole device, and this localized current concentration can cause a short circuit failure.

## 2. DESIGN

An alternate solid-state device, the insulated-gate bipolar transistor (IGBT), can readily operate at the speed needed for the accelerator, but commercial IGBTs cannot handle the voltage and current required. It is, however, possible to assemble these devices in arrays to reach the required performance levels without sacrificing their inherent speed. Diversified Technologies, Inc. (DTI) has patented and refined the technology required to build these arrays of series-parallel connected switches. DTI has shipped more than 500 systems leveraging this technology, which have been operating in facilities around the world for many years.

DTI has begun this effort with careful consideration of potential candidate IGBTs, identifying the optimal device based on price and performance in single-device tests, determining the gate drive performance necessary to allow high-current operation, and targeting the development of a multi-device switch plate. In the second Phase of this SBIR, DTI will develop the gate drive for the system, then design, build, and test a complete switch that is small enough to be integrated into the existing cabinet. These switches

will be delivered to SLAC, and their performance and reliability will be demonstrated in a SLC modulator.

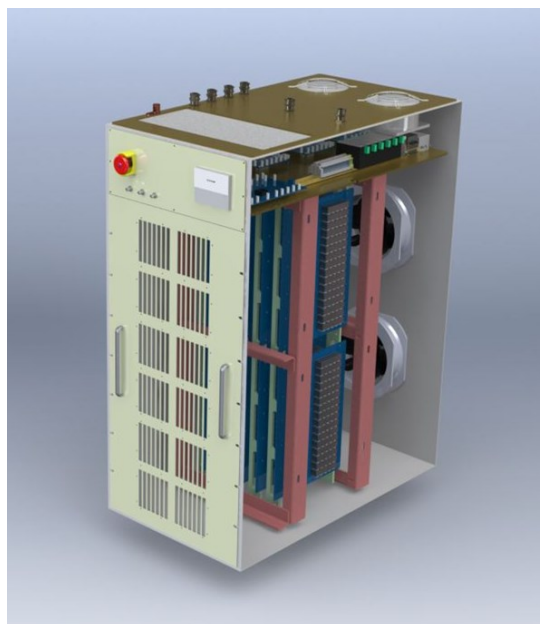


Fig. 1. Artist's conception of thyratron-replacement solid-state switch array. Target specifications are detailed in Table 1.

## 3. MOTIVATION

The market for thyratrons is in decline. As newer solid-state modulators are deployed, and older thyratron systems are taken out of service, the demand for thyratrons has diminished significantly. In response, several vendors have either gone out of business or stopped manufacturing thyratrons, further diminishing their availability. It is not clear how long the supply of thyratrons for these legacy systems will continue, making a solid-state thyratron replacement critical for their continued operation and support.

For this and other reasons, the thyratrons in many klystron modulators represent a major expense in operation – not only from the increasing cost of replacement, but from the labor involved both in such annual replacement and in the need to adjust them for proper operation during their relatively short life.

Most of these systems, including commercial medical accelerators, were designed decades ago, before solid-state switches were available. Even today, the cost of transitioning from thyratrons and pulse-forming networks to solid-state modulators remains prohibitive for many of these systems, despite the declining availability of thyratrons. Consequently, DTI anticipates a wide range of benefits from the development of a cost-effective, drop-in replacement for the thyratrons in operation in commercial and scientific systems around the world.

#### 4. CURRENT LIMITS

The current in the application is large, so to minimize the size and cost of the modulator, each IGBT should carry the maximum current possible. The IGBT chosen will have the highest current possible consistent with the risetime; higher current devices have a longer risetimes.

Another limit to the current is the gate voltage; this should be as high as possible, consistent with reliability. The gate voltage also needs to have a fast risetime to minimize the switching losses.

The current rate-of-rise in an IGBT is limited mainly by the inductance in the emitter lead of the device. As  $di/dt$  is increased, the inductive voltage drop on the emitter lead increases, reducing the gate voltage on the device itself. This raises the conduction voltage drop, increasing the power dissipated in the device. Higher power dissipation raises the device temperature, which in turn limits device reliability. Therefore, low inductance in the emitter lead is required for both speed and reliability.

DTI is investigating the following steps to increase the ability of the devices to handle  $di/dt$ :

- Use of more devices in a smaller package. Since both the current per device and the package inductance are lower, there will be a smaller inductive decrease in the gate voltage. The tradeoff is that the overall switch will use more components; however, these smaller parts are cheaper.
- Development of a gate drive that produces an initially-high voltage to overcome the  $di/dt$  drop, then decreases to keep the device gate voltage below the maximum allowed.
- Packaging the devices with a Kelvin connection (Figure 2), where the lead between the emitter and the gate drive does not carry current. This substantially reduces the inductive voltage drop.

Table 1. Solid-State Switch Specifications

Pulse Voltage	48 kV
Pulse Current	6.3 kA
Fault Current	17.8 kA
Pulse Width	6.0 us
Risetime	1 us
Repetition Rate	120 Hz
Lifetime	20 Years

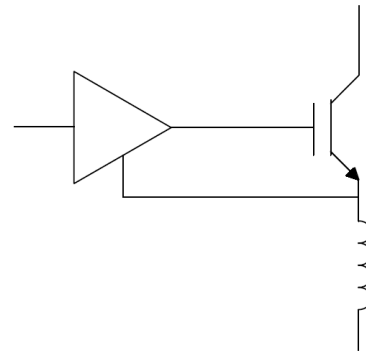


Fig. 2. Schematic diagram of a Kelvin connection.

#### 5. MECHANICAL DESIGN

For this effort to be practical and cost-effective, the thyatron replacement switch must readily fit in the existing cabinet with minimum modifications required for its installation. The volume available for the new switch is that of the existing thyatron chassis which includes the thyatron and heater supplies. Applying this 17" x 17" x 37" volume to the new switch with 2080 devices, the volume per device would be 5.1 in<sup>3</sup>. This means that the switch will need to be very tightly packed. There is certainly room for the devices themselves, but providing the required cooling and voltage standoff (preferably with air) presents a challenge.

Forced air cooling will be used to cool the thyatron replacement switch. Twin fans mounted in the back will be used to draw outside air into the front of the unit through grill-air filter into the ten switchplates shown in Figure 1. Air baffles (not shown) will direct air over either extrusion or pin fin heat sinks attached to each IGBT. After passing over the heatsinks on the switchplates, the air exits the cabinet through the two fans at the rear of the cabinet.

#### 6. FUTURE PLANS

DTI will continue testing candidate devices and drives while being mindful of final cost. Following successful development, fabrication, and demonstration of the thyatron replacement switches for SLAC, DTI plans to make the switch assembly commercially available, targeting other legacy systems still using thyatron pulse-forming network pulse modulators.

#### Notes

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