# THYRATRON MODULATORS FOR THE SUPERCONDUCTING SUPERCOLLIDER DRIFT TUBE AND COUPLED CAVITY LINACS

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## ABSTRACT

Maxwell Laboratories has designed and is building two different types of modulators for the Superconducting Supercollider (SSC) in Waxahachie, Texas. The modulators will drive the klystrons for the Drift Tube Linac (DTL) and the Coupled Cavity Linac (CCL). A total of 11 CCL modulators will be built and 5 DTL modulators will be built. Several interesting features have been incorporated into the design of the modulator. One of these features is the use of a bank of off-the-shelf switching power supplies to charge the PFN. The pulse width for both modulators is greater than 70 µs which translates into a long pulse mode of operation for the thyratrons. The modulators were designed with an extensive computer control system which allows the modulators to be remotely controlled from the computer which controls the entire supercollider facility.

## MODULATOR PARAMETERS AND SPECIFICATIONS

The required performance parameters and specifications for the CCL and DTL modulators are listed in Tables 1 and 2.

**Table 1**
**CCL Modulator Parameters**

| Parameter | CCL Modulator |
|---|---|
| Output Voltage | 230 kV |
| Output Current | 200 A |
| Maximum Pulse Width | 75 us |
| Minimum Pulse Top | 60 us |
| Pulse Flatness | < ±0.25% |
| Repetition Rate | 10 pps |
| Quantity | 11 |
| Klystron | TH-2143 |

**Table 2**
**DTL Modulator Parameters**

| Parameter | DTL Modulator |
|---|---|
| Output Voltage | 125 kV |
| Output Current | 64 A |
| Maximum Pulse Width | 105 us |
| Minimum Pulse Top | 90 us |
| Pulse Flatness | < ±0.25% |
| Repetition Rate | 10 pps |
| Quantity | 5 |
| Klystron | TH-2140 |

## MODULATOR SUBSYSTEMS

### Charging Subsystems

Both modulators utilize a bank of Maxwell CCDS 835 power supplies operating in parallel. Each individual CCDS supply can provide a charging rate of 8 kJ/s with an output voltage of 35 kV. The CCL modulator utilizes five supplies for a charging rate of 40 kJ/s and the DTL modulator utilizes two supplies for a charging rate of 16 kJ/s. The CCDS power supplies charge the PFN directly during the inter-pulse period with a constant current. Each supply is connected to the PFN through an "or-ing" diode. The "or-ing" diodes prevent current from flowing back into one of the other power supplies in the event of a power supply failure.

These "or-ing" diodes allow a bank of supplies to continue to operate in the event one or more of the supplies should fail. In fact, both modulators were designed so that the failure of one power supply would not affect modulator operation. Should one supply fail, the modulators can continue to operate at full power (i.e. full voltage and full rep rate). In the case of the CCL units, the modulator could even continue to operate at full voltage, but at a lower rep rate if all but one of the supplies should fail.

Another advantage of the CCDS power supply approach is that the bank of supplies can provide excellent regulation (typically <0.1%) with much lower stored energy than that required by a typical resonant charging scheme. The CCDS operation at high frequencies (≈40 kHz) reduces the size of the magnetics in comparison with that of a typical 60 Hz resonant charging scheme, therefore reducing the power supply volume. These power supplies are also highly efficient, operating with typical efficiencies of greater than 90%.

### PFN Subsystem

The PFN for both modulators is a 20 stage Rayleigh design with tunable inductors. Maxwell capacitors are utilized in both the designs with the CCL unit using 0.35 µF steel case capacitors and the DTL unit using 0.086 µF plastic case capacitors.

The inductors for the PFN in both modulators are manufactured using copper tubing wound over a G-10 cylindrical form. Inside the G-10 form is a copper tuning slug which is adjusted to vary the inductance, allowing the PFN impedance to be adjusted. This, in turn, allows tapering of the PFN impedance to compensate for pulse transformer droop and also minimize the flat top ripple by adjusting the impedance along the line. In the case of the CCL modulator, the inductance range is from ~7.0 – 11.0 µH and the DTL unit has an inductance range from ~60.0 – 90.0 µH. A photo of the CCL PFN and klystron filament power supply in the enclosure during the construction phase is shown in Figure 1.

### Thyratron Subsystem

The thyratron for switching the PFN in the DTL modulator is a ITT F-307 and the thyratron in the CCL modulator is a ITT F-331. Both tubes have been optimized to operate at the long pulse width required by the two different klystrons. The F-307 is a dispenser cathode tube while the F-331 uses a standard oxide cathode. The tubes are mounted on top of an aluminum enclosure by means of a plug-in socket. All of the grid bias, auxiliary discharge, grid driver, heater, and reservoir circuitry is housed in the enclosure below the thyratron. The thyratron filament and reservoir are powered with high efficiency, compact, solid state switching power supplies which provide excellent adjustability and regulation. Grid bias voltages and auxiliary discharge power are

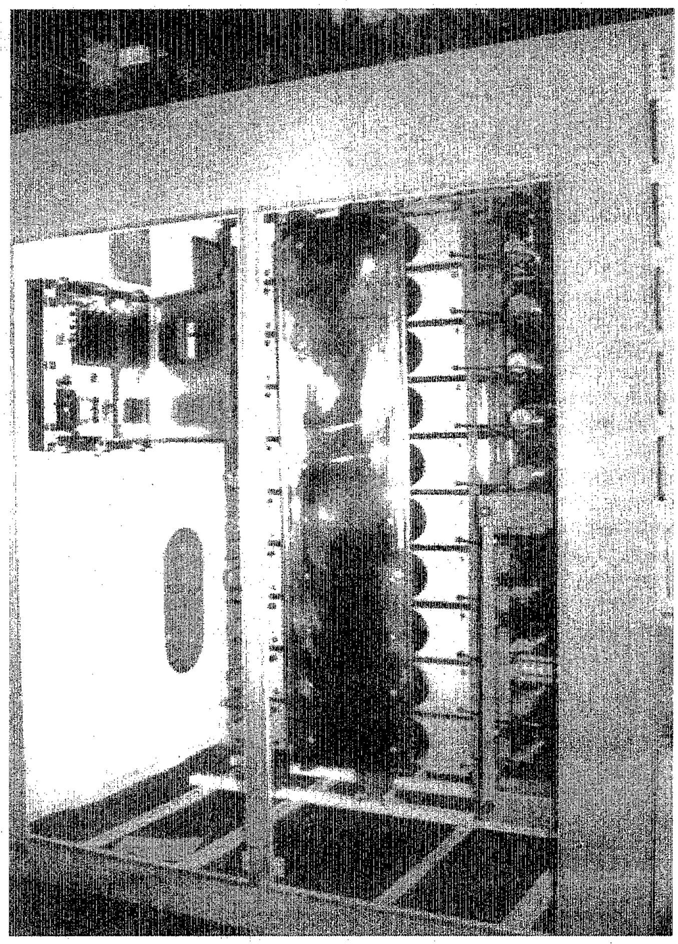

*Figure 1. The CCL PFN uses 20 metal case Maxwell Capacitors and has inductors which are tunable from 7.0 – 11.0 μH. The Klystron filament supply is also visible in this photo.*

supplied with linear power supplies. The grid drive trigger is supplied with a Maxwell designed and life-tested solid state circuit with fiber optic trigger input. A photo of the thyratron subsystem is shown in Figure 2.

Klystron Filament Supply

The klystron filament power supply is an AC power supply which uses a phase-fired phase controller to control the voltage at the filament terminals. The phase controller is capable of voltage regulation of <1%. The control circuitry of the phase controller also has ramp-up circuitry to limit the cold inrush current to the klystron filament. A fast overcurrent interlock will shut down the gate drive to the phase control SCR's in the event of an overcurrent condition. The output voltage and current monitors are true RMS monitors and are sent back to the control system as a set of DC voltages proportional to the RMS voltage and current. Since both klystrons require similar heater power, the same filament power supply design is used in both cases.

Klystron Auxiliaries

The klystron magnet power for the DTL and CCL modulators is provided with standard off-the-shelf switching power supplies. The DTL unit requires three power supplies. The body magnet supply is a 250 VDC, 20 A supply, the collector magnet supply is a 60 VDC, 16 A supply, and the gun magnet supply is rated at 60 V and 16 A. The CCL unit requires only one magnet supply and is powered by two 250 V, 40 A power supplies operating in parallel. The vac-ion pumps for both klystrons are powered with Varian "Mini-Vac" supplies.

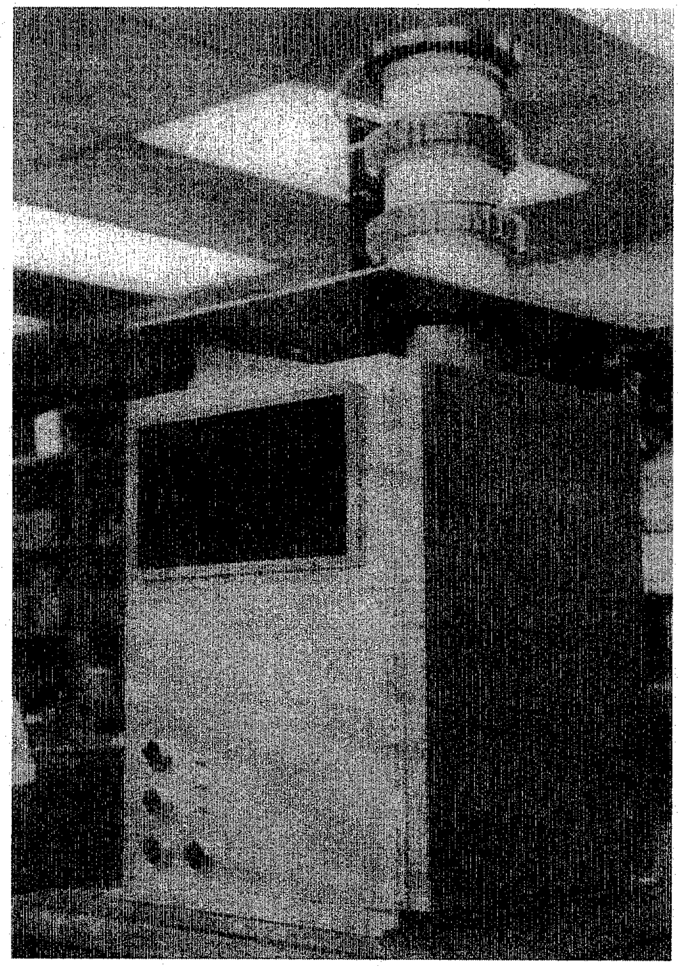

*Figure 2. The thyratron subsystem has a socketed thyratron for easy replacement. All supplies and trigger circuits are contained in the enclosure below the thyratron.*

Pulse Transformer, Tank and Enclosure

The pulse transformers for the CCL and DTL modulators are manufactured by Stangenes Industries and have bi-filar secondary windings for providing klystron heater filament power. The CCL transformer has a 1:13.25 step up ratio and the DTL unit has a 1:8.3 step up ratio.

The pulse transformers sit in the pulse transformer tank which is attached to the main enclosure. The klystron and lead shielding mount directly onto the top of the pulse transformer tank lid. The pulse transformer tank, in addition to structurally supporting the klystron and lead shield, is also designed to allow the pulse transformer to be vacuum impregnated. The double wall of the pulse transformer tank also serves as a safety containment vessel for the oil.

The pulse transformer tank and modulator enclosure are mounted together as one unit. This allows air skids to be inserted under the modulator enclosure so that the enclosure, pulse transformer tank, klystron and lead shield can be moved as a single unit. In the event of a klystron or modulator failure, the entire unit would be removed from the klystron gallery and a new modulator and klystron would be moved in.

Controls

The modulators are designed to be controlled from a remote computer. This remote computer can be either the main SSC facility control computer or a stand alone external computer. To interface with the remote computer, an extensive control system has been implemented which is capable of monitoring over 150 digital and analog input and output signals. In addition to monitoring this I/O, the control system also contains circuitry to shut down the appropriate subsystems in the event of a fault.

To incorporate all of these functions, the control system is a modular design which consists of five types of Maxwell designed custom control cards housed in a modified VME chassis. These five card types include the Digital Input / Output, Analog Input / Output, Peak Detector, Window Comparator, and Hardwire Logic Controller.

Five Digital I/O cards are required in order to account for all of the different I/O signals. These digital cards interface all of the digital signals between the control computer and the modulator and communicate these signals along the VME backplane for monitoring by the hardwire logic controller. The three Analog I/O cards interface all of the analog signals between the control computer and modulator and also transmit these signals on the VME backplane for monitoring by the window detector cards. The single peak detector card monitors the pulsed analog signals and captures the peak values for monitoring by the window detector. The four window detector cards monitor the analog signals and will initiate the appropriate inhibit to the hardwire logic controller so that the appropriate actions can be taken in the event of an out-of-range fault. The single hardwire logic controller ensures that the appropriate actions take place in the event of a fault.

The logic functions for the control cards are implemented with electrically programmable logic devices (EPLDs). The EPLDs will allow changes to the controls (i.e. change an inhibit level) to be made without extensive control circuitry modification. The EPLDs are also used to incorporate an electronic "keying" of the cards to their respective I/O cable. Should a cable be plugged into the wrong card, the power to the card will be shut down, preventing any possible damage to the card or circuitry at the other end of the cable.

All communications to and from the controls in the modified VME chassis are routed through a multi-layer Signal Conditioning / Filtering / Interconnect board. This board provides the required level shifting as well as noise filtering for the control signals.

External Control Unit

To test and control the modulators as a stand alone unit during checkout and acceptance testing, an external control unit is provided which will allow the modulators to be operated as if it were connected to the SSC control computer. The external control unit has full redundancy with the modulators hardwire logic controller for fault handling.

The external control units consist of a 486 based personal computer which is connected to a standard VME crate with a National Instruments VME controller card. The National Instruments controller card allows the PC to act as an embedded controller in the VME chassis. The standard VME crate houses several off-the-shelf digital and analog I/O cards for sending and receiving the digital and analog signals from the modulator.

The sequential machine control is accomplished by the PC which is programmed using Microsoft C code. The operator interface graphics display is performed on the PC through the National Instruments LabWindows software package. LabWindows provides a push-button type control panel on the computer display for controlling and monitoring the modulator. A photo of the External control system computer screen is shown in Figure 3.

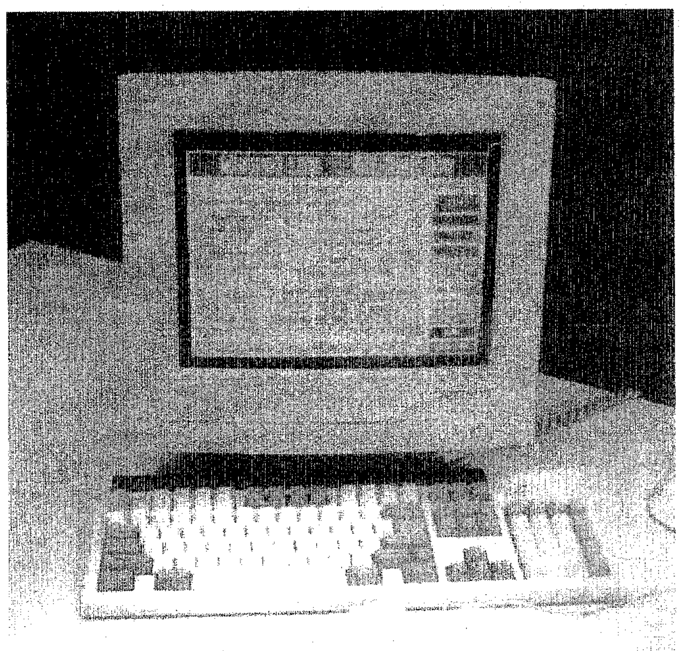

*Figure 3. The LabWindows control screen allows controls and access to the modulator parameters. The computer is redundant to the hardwire logic controls at the modulator.*

## CONCLUSIONS

Maxwell has designed and is building two different types of klystron modulators for the SSC laboratories. One modulator, of which 11 are being built, is to provide power for generating rf for the Coupled Cavity Linac, and the other modulator, of which five units are being built, is to power the Drift Tube Linac. Both of these modulators use switching power supplies to directly charge the PFNs. The PFN energy is then switched with a thyratron into the pulse transformer and on to the klystron. Extensive controls for monitoring and controlling the modulator from the SSC computer are also provided.