

CATHODE MODULATION OF HIGH POWER RF OUTPUT TRIODES OF THE ISIS LINAC

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Abstract

The Linear Accelerator at Rutherford Appleton Labs has provided particle acceleration for the ISIS Synchrotron since 1984. Solid-state cathode modulators have recently replaced hard-tube tetrodes, previously used for anode modulation of the high power RF triodes. This has afforded a reduction in equipment complexity and volume leading to significant savings both in capital and operating costs. These advantages benefit ISIS by not only improving reliability and availability but allow more economical consideration of the proposed development to increase beam current from 200 μ A to 300 μ A [1].

1 INTRODUCTION

The RF excitation for each of the four ISIS Linac cavities is provided by a Thomson TH116 triode operating in grounded grid configuration with pulsed anode modulation. A parallel pair of English Electric CW1600 tetrodes switch the 40kV voltage from a capacitor bank to provide the modulation. The TH116 is self-biased into class AB by a cathode bias resistor. A large platform, isolated to 40kV, houses the CW1600 and associated equipment for modulator operation.

Parasitic oscillation in the series switch tube has, in the past, created severe electromagnetic noise problems, affecting local electronics. These have largely been cured, but occasional problems are still encountered.

Replacement modulator tubes are relatively expensive and this coupled with possible future developments has provided the impetus behind cathode modulation.

On-line development time is severely restricted on operational machines like ISIS. Should new systems prove unsatisfactory, old systems must be easily re-instated. Fast and simple re-configuration is therefore an essential requirement for new systems.

2 ANODE MODULATION

At the time of its design, anode modulation was employed because it was readily available and an established technology. A block diagram of the system at ISIS is shown in Fig. 1. There are several disadvantages with series tube modulation: -

- At the operating current, the modulator tube drops up to 6kV
- Each tube requires a filament supply of 10V at 300A therefore 6kW dissipation.
- 40kV isolation transformer for filament supplies
- 40kV mains isolation transformer for screen and grid supplies also for peripheral equipment
- Fibre-optic link required for grid drive signal
- CW1600 requires anode water cooling and grid/screen air cooling.

In addition, the platform housing the modulator tubes measures approximately 1.8m x 2.1m x 0.9m , giving a volume of 3.4m³. A photograph of the high voltage platform is shown in Figure 2.

Power consumed by the modulator tube is as follows: -

	kW per tube	kW per system	kW per 4 systems
Filament	3.0	6.0	24.0
Power lost in tubes*	6.0	12.0	48.0
Cooling Fans	-	1.0	4.0
Auxiliaries	1.0	2.0	8.0
Totals	10.5	21.0	84 kW

* based on 4kV drop at 120A with 2.5% duty cycle

Currently, the modulator tube replacement rate is around 2.5 per year and costs £20k.

3 CATHODE MODULATION

Cathode modulation allows the full capacitor bank voltage to be used for RF generation. A suitable high value resistor is placed in series with the 3 Ω cathode resistor, as shown in Figure 3 and with DC anode volts applied, the TH116 is self biased close to cut off by approximately \sim 40mA. The RF power tube has to dissipate an extra \sim 1kW of power, but this is within the anode power capability of the TH116. For cathode modulation to be feasible, a fast, low impedance, high current switch is required in parallel with the high value resistor.

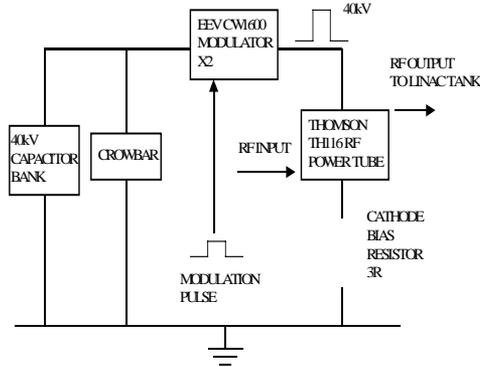


Figure 1. ISIS Linac TH116 Anode Modulation



Figure 2. ISIS Linac anode modulator hardware showing the 40kV platform, CW1600 tetrodes, screen and grid power supplies and isolation transformers

3.1 Switching Device Selection

The main criterion for switch selection is based on the ISIS requirements of 200A at a working voltage of less than 800V (the maximum rating of the RF bypass capacitors). Other considerations are complexity, hence reliability, of the device and its drive circuit, conduction and switching losses, availability and cost. A Gate Turn-Off Thyristor (GTO) was considered but the Insulated Gate Bipolar Transistor, (IGBT), has been developed to a point nearer to that of an ideal switch. The problems of 'latch-up' have been eliminated and device ratings have improved considerably. Conduction losses are similar to a GTO, but switching losses are superior. A Semikron IGBT device was selected on the basis of its low inductance package, rectangular safe operating area and constant $V_{CE(sat)}$ levels.

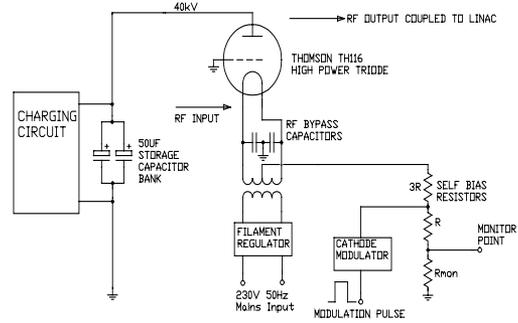


Figure 3. Cathode Modulation Schematic showing the inclusion of a series resistance R for self bias

3.2 Prototyping

A Westcode WG6016FR12 GTO was used for initial testing, suitable circuitry being developed to achieve reliable switching in the laboratory. However, installed on the TH116 it proved very difficult to switch off the GTO reliably.

A first prototype based on an SKM 200GA 123D IGBT proved very successful and reliable both in the laboratory and when connected in the cathode circuit of the TH116. This unit was installed on the lowest power linac cavity in December 1997 and ran successfully for several cycles before removal.

A second unit, using a higher power rating IGBT, an SKM 400GA 173D, shown in Fig. 5, was installed on the highest power cavity in March 1998 and is still in operation. A circuit diagram is shown in Figure 4.

Fully engineered versions of the high power unit are under construction and are to be fitted on all four systems later this year.

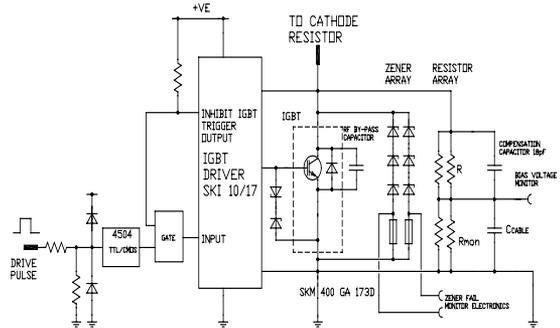


Figure 4. Circuit diagram of cathode modulator

3.3 Operational Experience

From early in its development, it was known that the absence of free space loading around the TH116 with dc anode volts > 10–12kV gave rise to parasitic

oscillation at ~ 800MHz. The application of RF drive to the tube input, before the modulation of the HT, suppressed this parasite.

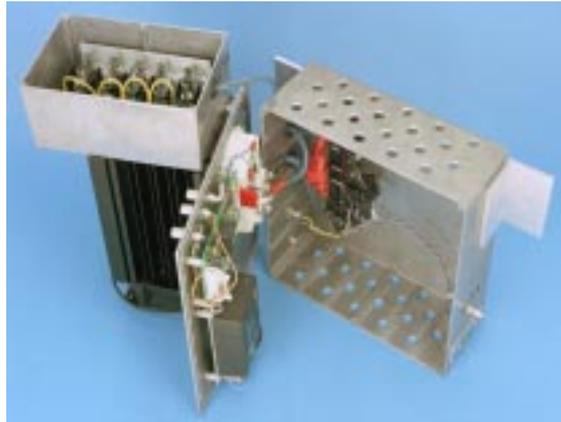


Figure 5. An open view of the prototype cathode modulator indicating the simplicity of the design

Applying RF drive to the TH116 input circuit before modulation is acceptable because the circuit remains a very good RF match. Initial tests using a DC anode voltage established that the parasite did not occur with the tube close to cut-off, but in the cathode modulation switch transition the parasite reappeared. However, parasite suppression in cathode modulation, using pre and post RF input drive results in a large increase in bias, giving pulsed voltages across the high value bias resistor before and after modulation, as shown in Figure 6.

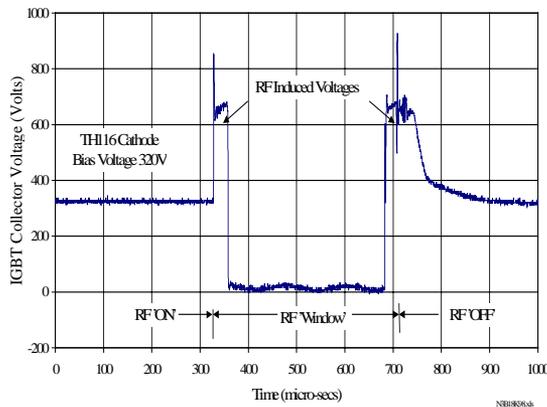


Fig. 6 IGBT collector voltage showing cathode bias voltage at 320V, IGBT switching and RF window.

Calculations on the co-axial RF input circuit of the TH116 shows that 280kW into the 50Ω input transforms to 1.8kV at the grid cathode. The decoupling capacitors are situated at the RF voltage

node, but would be destroyed by the increased bias developed by the RF across the large cathode resistor. Transient suppressors were not considered suitable to keep the voltage below 800V because the waveform of double pulses, shown in Figure 6, has a repetition rate of 50Hz. Therefore, a series parallel array of zener diodes was chosen to clamp the maximum bias voltage.

3.4 TH116 Tube Protection

With cathode modulation, protection of the TH116 power tube is required over the whole cycle. Protection against arc-over is provided by an over current trip triggering a crowbar.

The DC standing bias is also monitored outside the modulation pulse and the tube 'crowbarred' should the bias change by a significant amount. During the modulating time, switching of the IGBT is checked by a built-in slew rate monitor that is used to inhibit triggering of the IGBT.

To maximize operating time, there is considerable built in redundancy. Sufficient resistors are paralleled to form the bias resistor such that failure of one or two resistors does not significantly affect the standing bias. The resistors are run well within their power rating. In the zener array, extra parallel elements are included to allow running should several chains fail. The zeners typically fail short circuit, removal from the circuit is achieved using over current trips with trip indication.

3.5 Radiation

Proximity to possible sources of gamma and thermal neutron radiation made damage to power semiconductors an area of concern. Dosimeter measurements, over one 24-hour period, showed a maximum dose rate of less than 1.7 mSv/hr for gamma radiation and under 0.035 mSv/hr for thermal neutrons. At these radiation levels, lifetimes of several years are expected from the solid state devices.

4 CONCLUSION

Successful operational experience with prototypes on different ISIS Linac tanks has permitted the development of 4 fully engineered cathode modulators. These are to be installed and commissioned within the current long shutdown period.

5 REFERENCES

- [1] A Possible Upgrade for ISIS, M R Harold, R G Bendall, T A Broome, I S K Gardner, M G Glover, C R Prior, C W Planner and G H Rees. CLRC RAL. PAC 97, Vancouver, BC, Canada.