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A 120kV IGBT MODULATOR FOR DRIVING A PIERCE ELECTRON GUN

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Abstract

An IGBT modulator has been developed to drive a 120 kV, 23 A Pierce electron gun. The modulator is capable of producing pulses up to 10 μs in width at repetition rates up to 10Hz with no active reset. The pulse rise time on the electron gun will be approximately 2 μs and the remaining 8 μs of flattop is tuned to have a ripple of less than 1 percent rms. The modulator technology was developed from a previous 50 kV prototype. The modulator consists of six boards, each with one EUPEC IGBT that drives a single common step-up transformer wound on METGLAS 2605SC cores. The six transformer cores share a common bi-filar output secondary winding. The modulator uses a fiber optic trigger system and has a high voltage cable output with an epoxy receptacle on the oil end and a ceramic receptacle on the vacuum end. The 120kV electron gun was manufactured by MDS Co. and will be used to generate sheet electron beams from the standard pencil beam produced by the Pierce electron gun.

I. INTRODUCTION

A solid state modulator was designed and fabricated at Los Alamos to drive a 120 kV, 23 A Pierce electron gun. The sheet beam will be generated from the round beam using a quadrupole doublet focusing system. The beam will be used in a new 95 GHz traveling wave tube [1]. The present 120 kV modulator design was based on an architecture developed by Kirbie [2] and is an extension of a 50 kV prototype developed by Siemens Medical Solutions USA [3].

Table 1. Modulator specifications.

Voltage	10-120 kV
Load impedance	5200 Ω
Pulse rise time	~2 μsec
Pulse width	4-10 μsec
Repetition rate	Single pulse – 10 Hz, 1 Hz nominal
Egun filament	8 V, 7.5 A (AC)

The design philosophy for this modulator stresses reliability, simple maintenance, and variable output voltage and pulse width. The performance factors such as fast rise time and compact size are secondary concerns. The project goal is to have a reliable, flexible solid state modulator that provides high voltage pulses to perform sheet beam research. The modulator specifications are summarized in Table 1.

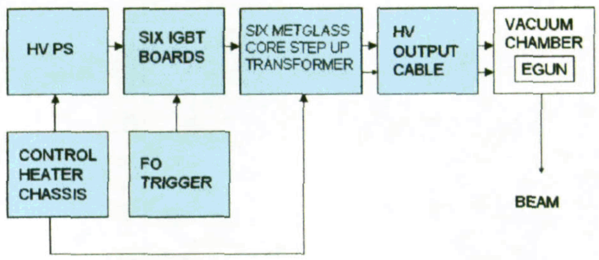

Figure 1. Block diagram of modulator driving electron gun.

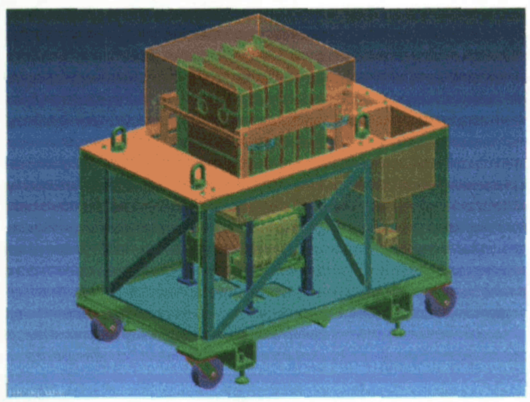

Figure 2. 3D CAD drawing of 120 kV IGBT modulator

A block diagram of the 120 kV modulator is shown in Figure 1. The design uses six capacitive discharge boards each with 100 μF and a single IGBT switch. Each board drives a single Metglas [4] core with four primary windings using one inch wide copper/Kapton clad stripline. The six Metglas cores form a transformer using a common secondary with 64 windings. The configuration provides a step-up ratio of 96:1 from the charge voltage on the primary capacitors on each board. Thus, to achieve an output pulse of 120 kV, each board must be charged to approximately 1300 V. The modulator output is connected to the Pierce electron gun with a Dielectric Sciences [5] high voltage cable rated at 160 kV. The electron gun is mounted in a vacuum chamber test bed.

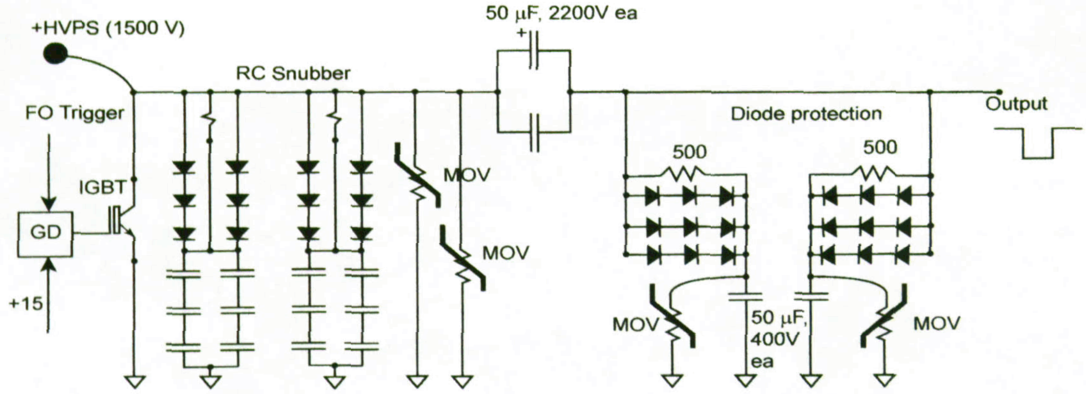

Figure 3. Circuit schematic of IGBT board.

The gun uses vacuum not oil for insulation. The high voltage cable is connected to the electron gun in vacuum using a Dielectric Sciences ceramic insulated feed through. The high voltage cable has three conductors and supplies both the filament power and high voltage to the gun. A 3D CAD model of the modulator is shown in Figure 2. The modulator is separated into an oil insulated section in the bottom which holds the transformer and the 120 kV portion of the system. The upper section is air insulated and holds the six IGBT boards in a vertical rack support. Since the boards only operate at 1300 V they do not need to be immersed in oil. The racks use a novel spring loaded cam clamping design to allow a high current connection from the boards to the transformer and allow a simple method of removing boards for maintenance.

II. IGBT BOARD

The schematic of the IGBT board is shown in Figure 3. The circuit uses a EUPEC [6] IGBT model FZ1200R33KF2 switch. Reliability is achieved by operating the IGBT well below its rated voltage of 3300V at only 1500 V maximum. The IGBT uses a CONCEPT [7] gate driver with fiber optic trigger model 1SD418F2. The main energy storage is two NWL 50 μF capacitors in parallel rated at 2200 V. Size is a secondary factor in the design. The boards are physically large with wide low inductance paths to the output. The board has protection devices including four MOVs, two RC snubbers and two diode circuits. The discharge circuit design is a hard tube modulator configuration. Only a few percent of the stored energy is discharged each pulse. The capacitive discharge boards are all identical and form a modular design. All six boards are used to drive the transformer primary in parallel. A photograph of one board is shown in Figure 4. All six boards mounted vertically in their rack in the modulator tank are shown in Figure 5.

III. TRANSFORMER

The high voltage transformer uses six Metglas 2605SC cores each driven by an IGBT board. The cores were procured from Siemens and were available from their previous development work. The cores are large and are gapped with 2 mils of Kapton. Each core has calculated B_{max} of 1.1 Tesla and measured B_{max} of 1.2 Tesla and saturation at about 12 μs. Since our requirement was 10 μs pulse width, it was determined that active rest was not required. The cores did not saturate within our time frame. This was verified experimentally. The modulator reliability was enhanced by not having active rest.

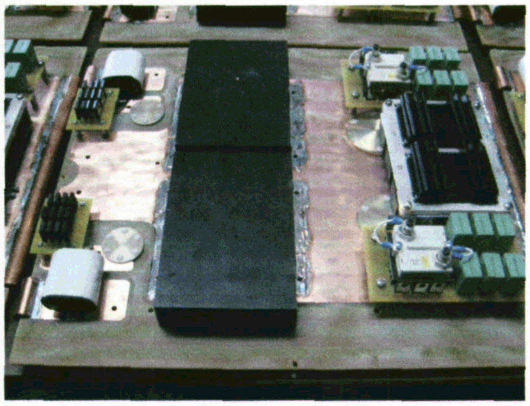

Figure 4. Photo of an IGBT board.

Figure 5. Photo of six IGBT boards in assembly rack.

Figure 6. Photo of six Metglas cores with copper tape primaries.

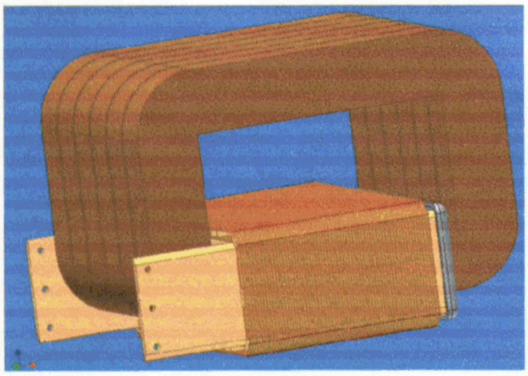

Figure 7. Six core transformer with common secondary.

The transformer parameters dominate the output pulse characteristics of the modulator so careful design, modeling and measurements were incorporated. The primary inductance was reduced by using short one inch wide stripline connections between the boards and cores. A simple secondary was designed which is common to the six cores. Large spacings were used to reduce the chance of breakdown. Our requirement of 2 μsec rise-time allowed us to improve reliability over performance. Rise-time could have been improved by using closer spacing of the secondary, tapered secondary baskets and even dual secondary. The secondary uses a bifilar winding to allow the filament current to be passed to the electron gun cathode for heating. The bifilar winding was calculated using relations derived by Glasoe [8].

The transformer parameters were measured with an HP4192A Impedance Analyzer and with an HP8751A Network Analyzer. The transformer model was based on work at SLAC [9]. The network analyzer allows a careful measurement of the transformer output L and C resonance. Figure 6 shows a photograph of the six wound cores. The core outer dimensions are 10 x 15 inches. Figure 7 shows a CAD drawing of the six cores with the secondary.

IV. CIRCUIT MODEL

The modulator was modeled using MicroCap [10] and the model is shown in Figure 8. All the modulator parameters were carefully measured and incorporated into the model. This allowed a detailed comparison between the measured output waveforms and the calculations. The electron gun load and high voltage cable were also measured and parameters incorporated into the model. The fairly high load impedance of 5200 Ω allowed a simple design to provide a flat output pulse. The parallel resistive load R_{trim} allowed the pulse shape to the load to be optimized. A final value of 5000 Ω provided an output pulse with no overshoot. The leakage inductance of the transformer was measured at 4.5 mH and was used in the model. A simple model of the IGBT board was used since the transformer and load dominated the output pulse characteristics. The value of R_{trim} was varied from 4000 to 12000 Ω both in the model and in experiments. A simple RL droop correction circuit was used to provide a 1% flat top pulse output. The optimal circuit parameters were found: R_{comp}= 350 Ω, L_{comp}= 1 mH. The output was modeled both with and without droop correction and compared to measured data.

V. ELECTRON GUN LOAD

The modulator load is the sheet electron beam test bed. A Pierce electron gun is mounted in a large vacuum chamber for simple configuration changes. The gun has a perveance of 0.53 μP. This gives a beam current of 23 A at 120 kV. The gun uses an M type cathode heated to 1070 deg C. The filament requirements are 8 V and 7.5 A. The load configuration is shown in Figure 9. A low inductance connection is made to the load by using cables and connectors from Dielectric Sciences. A three conductor 160 kV high voltage cable model 1104V is used to connect the modulator to the load. An epoxy

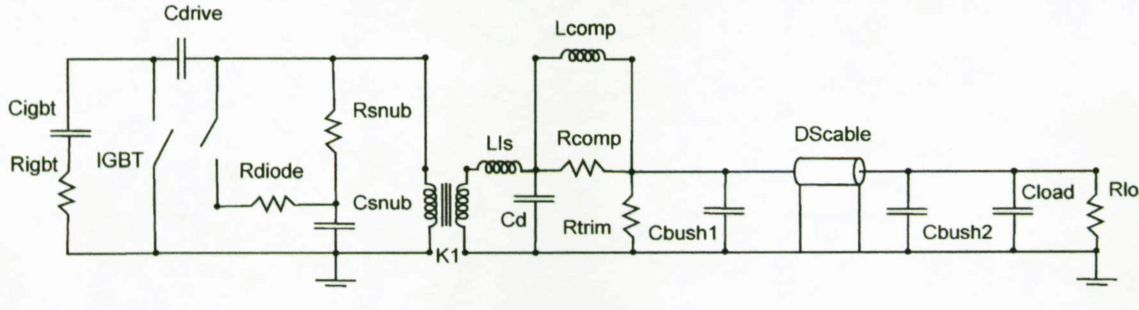

Figure 8. MicroCap circuit model of modulator.

receptacle (Dielectric Sciences part number DS1225B-2) in oil is used on the modulator side and a ceramic receptacle (part number DS 1386B-1) is used on the load side in vacuum. This combination of cable and connectors makes an excellent design for our experiment. The Pierce electron gun was designed and fabricated by MDS Co. [11]. The gun was designed to use vacuum insulation for our sheet beam test-bed.

VI. RESULTS

The IGBT boards were tested into a short circuit to determine the maximum current through the IGBT. It was found to be less than 400 A which is well below the maximum ratings of 1200 A.

The modulator output was tested to a maximum output voltage of 150 kV without any problems or arcing. The modulator was tested for continuous operation at 1 Hz without problems. The modulator output was measured first into a resistive load of 6000 Ω both to check reliability and adjust the shape of the output pulse. Figure 10 shows the measured pulse. The data in this figure does not have droop correction. The final droop correction will be applied after the pulse is measured into the electron gun load. Small changes in capacitance will affect the final pulse shape at the 1% level. The modulator will be tested into the electron gun load by June 2004.

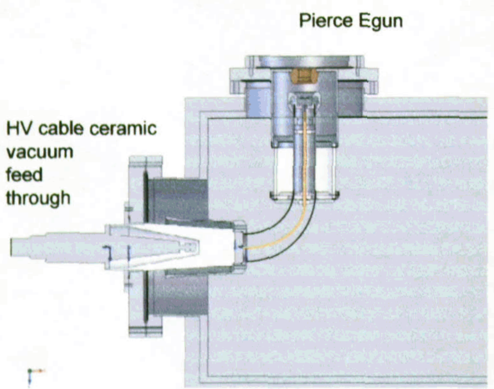

Figure 9. Electron gun load configuration in vacuum chamber

VII. CONCLUSION

A reliable solid state modulator was developed to drive an electron gun test-bed for sheet beam research. Size and performance were traded to increase reliability and simplify maintenance. A 1% flat top pulse of variable width and amplitude allows maximum flexibility in performing beam research.

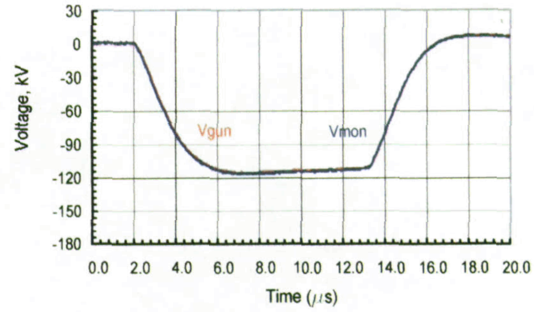

Figure 10. Modulator output pulse into 6000 Ω resistive load.

VIII. ACKNOWLEDGEMENT

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