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A fast, high voltage, high frequency modulator at BNL

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DISCLAIMER

A FAST, HIGH VOLTAGE, HIGH FREQUENCY MODULATOR AT BNL*

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Abstract

A high voltage modulator has been built and tested at Brookhaven National Laboratory. Its function is to drive the gun anode of the RHIC Electron Lens(e-lens). It is capable of outputting a square wave of 10kV and a continuous rep rate of 80kHz. The pulse width is continuously adjustable from 500ns to DC. The rise time and the fall time (10%-90%) are under 50ns.

I. INTRODUCTION

Two counter-rotating particle beams consisting of polarized protons are circulated in the Relativistic Heavy Ion Collider (RHIC) at near light speed. To compensate the head-on beam-beam interactions, two e-lenses are being installed in the RHIC 10 o'clock intersection region.

The electron gun produces electron beams and the electron beam current is controlled by the anode modulator. The modulator is required to work in four modes, as shown in Table 1.

Table 1. Anode Modulator Modes

Modes	DC	Parasitic	Setup	Diagnostic
On Time	10ms	500~1000 ns	500~1000 ns	Variable 500ns-DC
Off Time	500~1000 ns	11.7-12.2us	10ms	Variable
Freq.	<=100Hz	78.8kHz	<=100Hz	<=100Hz

The maximum output voltage is 15kV. We are presently using 10kV.

The rising or falling edges must occur exactly in a space between two adjacent polarized proton bunches without impacting them, and must also couple with the BPM pick-ups to provide a robust signal for processing. A leading and trailing edge rise and fall time of under 50ns is required.

In the parasitic mode, the modulator is required to pulse once for every revolution of the particle beams in the RHIC rings. This translates to 12.7us, or 78.8kHz in terms of frequency. We are using 80kHz.

II. DESIGN

A push-pull circuit, as seen in Figure 1, is suitable to produce all of the required four modes of operation. Uc is the cathode bias voltage that floats the modulator to maximum -10kV. Anode voltage U1 (with respect to Uc) extracts electron beams out of the electron gun. Anode bias voltage U2 (with respect to Uc) inhibits the electrons from being extracted. U2 is adjustable from -1kV to 0V, but is normally set to -500V.

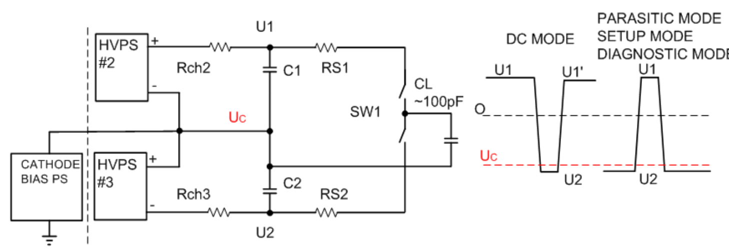

Figure 1. Simplified modulator schematic

The push-pull switch SW1 is the key component needed to achieve both the required quick rise time and fall time, and the quick pulse width variation at such high voltage. A stacked MOSFET switch (HTS301-03-GSM from Behlke) has been selected to accomplish this. Direct Liquid Cooling (DLC) is required for high frequency high power operation.

RS1 and RS2 are used for damping and for shorting protection. They share power dissipation with the switch and are liquid cooled as well.

CL, the capacitance between the anode and the cathode of the gun, is estimated to be 100pF. Normally C1 would be at least 10 times that of CL in order to achieve the shortest transition times, but for operation in the DC mode, due to the energy charge to the load, the recovery voltage U1′ is less than the DC level U1. The greater the capacitance of C1, the less the voltage difference. During the modulator development phase, arcing occurred in the

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electron gun. This arcing resulted in the failure of two Behlke switches in the modulator prototype. It was determined that the energy stored in C1 was too great for the Behlke switch to handle under those conditions. Therefore, to preserve the integrity of the expensive Behlke switch, a 500pF value was selected for C1. To facilitate the voltage drop, a charge circuit is added, as seen in Figure 2.

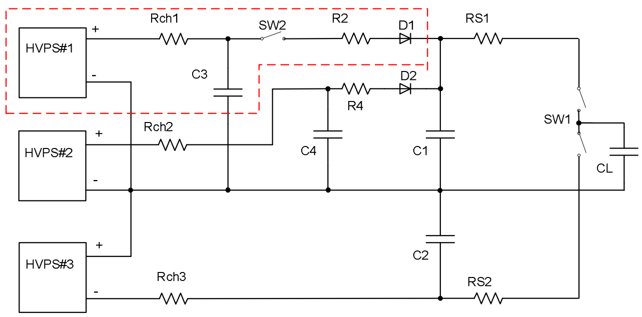
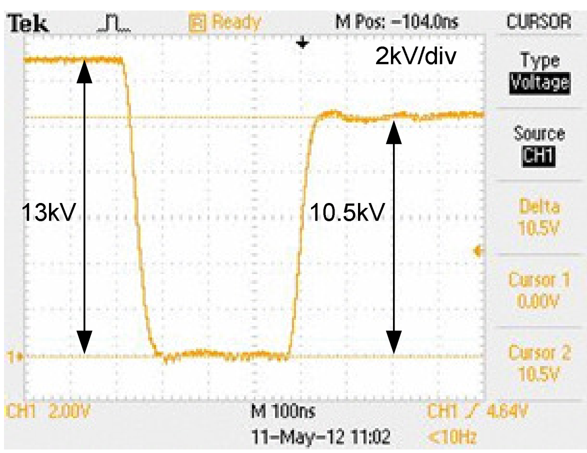
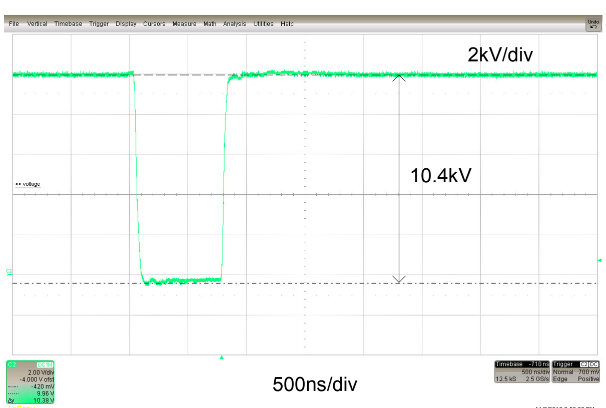


Figure 2. Upgraded modulator schematic

Figure 2 shows that HVPS#1 and SW2 have been added to the original modulator schematic. By controlling the on time of switch SW2, we gain more control of the output voltage wave shape.



(a) Before the upgrade



(b) After the upgrade

Figure 3. Modulator output voltage waveforms

The comparisons before and after this equipment upgrade are shown in Figure 3. As seen in (a), the recovery voltage was much lower than the charge voltage; while in (b), the recovery voltage was tuned to match the charge voltage.

The modulator picture is seen in Figure 4.

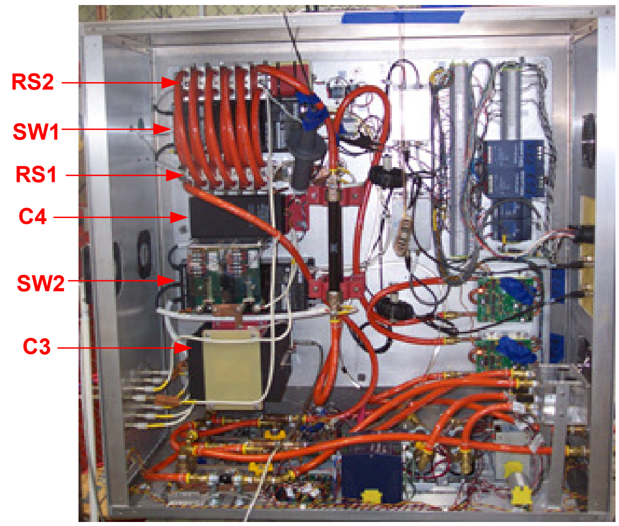


Figure 4. e-lens anode modulator

Switch SW1 dissipate the majority of the power, so it must be liquid cooled. Galden HT-135 was first used but it caused the pump and the flow sensors to fail due to the accumulating high voltage static charge. Switching to 3COM's fluorinert FC-40 proved to be effective.

There are two enclosed cooling loops. There is a pump and a heat exchanger in each loop. Loop #1 includes the main switch SW1; Loop #2 includes the charging switch SW2, charging resistor R2, discharge resistor RS1 and RS2, and auxiliary power supply heat sinks for SW1 and SW2. A large pump (Laing E10) is used in Loop #1 and Loop #2's pump is a Laing D5. Both Laing E10 and D5 are magnetically coupled so there is no shaft seal to leak. The heat is taken out by cooling water flowing through the heat exchangers.

Two Allen-Bradley SLC551 PLCs are incorporated to control the modulator. One PLC is at the floated cathode level, and the other is at ground level. They communicate with each other via Ethernet.

One PanelView serves as the human/machine interface for the local controls. Remote control is accomplished via three Power Supply Interface (PSI) units.

The control timing which is synchronized with the RHIC polarized proton bunches is transferred to the modulator control racks via fiber optic cables.

The modulator plays a very important role in the e-lens Machine Protection System (MPS). It reacts to the commands from and provides readbacks to the MPS.

III. TEST RESULTS

The modulator was tested on the electron gun in a test stand for all four modes of operation. The modulator output voltage waveform is shown in Figure 5.

By changing the polarity of the trigger to SW1, the modulator can easily switched between the DC mode and other modes. However, for the DC mode, HVPS#1 and HVPS#2 voltages, SW1 and SW2 triggers need to be tuned properly in order to have a perfect negative pulse. Figure 5 shows the anode modulator positive pulsed output voltage. The inverted pulsed output voltage is shown in Figure 3 (b).

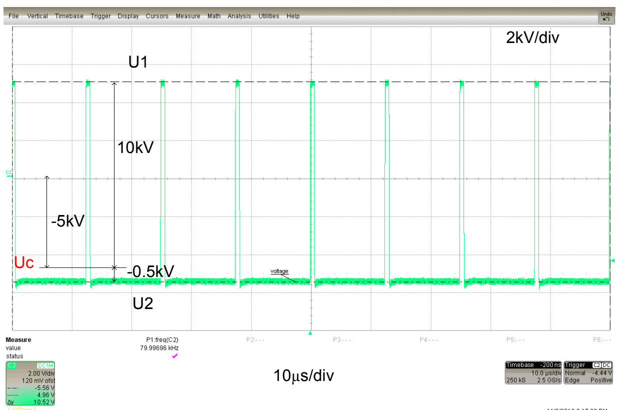


Figure 5. Modulator output voltage

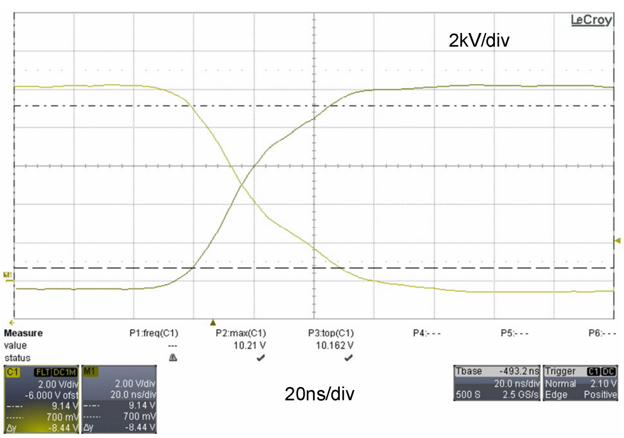


Figure 6. Modulator output voltage rise and fall time

Both the rise time and the fall time (10%-90%) are just under 50ns, as seen in Figure 6. The flat top flatness is 3%.

The modulator was tested for heat buildup at 80kHz and 10kV. The cooling fluid temperature was monitored closely in both component cooling loops as well as the cooling water temperature. The coolant temperature in both of the loops peaked at <40°C. This is well below the Behlke switch manufacturer's maximum temperature specification of 55°C.

At 80kHz, the pulse to pulse stability is better than 0.3% after a 30-minute warm up. The rise time jitter is less than 1ns and the fall time jitter is about 2ns.

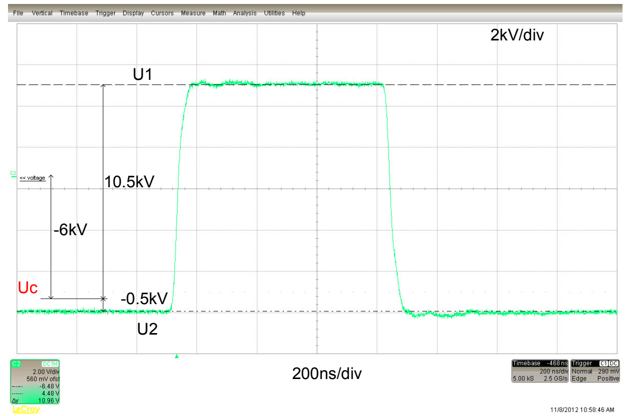


Figure 7. Modulator output voltage at 10kV and 80kHz

IV. SUMMARY

This document represents the culmination of months of labor by physicists, engineers, draft people, and technicians of many varied disciplines at BNL. It describes a liquid cooled, small sized modulator capable of producing fast, high voltage, high frequency pulse with excellent rise and fall time and accuracy.

V. REFERENCES

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