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A TEST FACILITY FOR PCSS TRIGGERED PULSED POWER SWITCHES *

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Abstract

The cost and complexity of pulsed power systems continue to increase as researchers strive for more precise control and flexibility. Systems with large numbers of switches or large numbers of switch trigger times result in the need for more cost effective high performance triggering systems. These needs can be addressed by photoconductive semiconductor switches (PCSS) that have demonstrated sub-nanosecond jitter with up to 300kV switches. This previous work has motivated continued research into the trigger system parameters that allow for reliable cost effective operation.

To support this research a test-bed has been developed to allow testing with a variety of high voltage switches (HVSs) and switch configurations. The multiple sub-systems used in this test bed include: (1) the laser diode array (LDA) driver circuit, (2) the PCSS trigger circuit, and (3) the circuit that is switched by the HVS. Items of particular interest are: (1) the benefits and issues with pulse charging vs. DC charging the PCSS trigger system, (2) fiber coupled versus multi-filament laser diode PCSS triggering, (3) high bandwidth diagnostics to measure and determine the impact of sub-nanosecond rise time and jitter triggers for the HVS, and (4) the PCSS trigger circuits required to determine minimum voltage, current, and pulse width for optimal HVS triggering. Our testbed consists of, a single brick, from a linear transformer driver housing two 40 nF capacitors, the HVS being tested. Low inductance HVSs that can handle +/- 100 kVDC and 50 kA are being tested with this system. The laser diode array that triggers the PCSS can be located at the PCSS or in the screen room. The LDA is driven by a low energy avalanche trigger circuit that can be optically triggered and floated to the potential of the HVS.

This paper describes the requirements, methods, and the apparatus developed to determine the PCSS minimum electro-optical requirements for optimal HVS triggering. Specific current and voltage waveforms obtained from the sub-systems will be discussed along with the parameters adjusted to deliver a range of pulse widths, rise times, and energies to the HVS.

I. INTRODUCTION

PCSS devices are being tested in a range of applications [1]: compact particle beam accelerators; ground penetrating radar; fast gated cameras, optically activated firesets; semiconductor laser diode array drivers; electro-optic (Pockels cell) drivers; and high voltage (HV) trigger generators (TG) for gas discharge switches[2].

As part of a TG, a PCSS allows for improvements in performance, system design, and system cost. Commercially available electrical TGs cost ~$25k and use high voltage cables to carry the pulse to the HVS. PCSSs cost less than $20 each in bulk to manufacture, and a PCSS based TG to be constructed for less than $1k.

A PCSS TG can be designed to attach directly to the HVS and use a semiconductor laser for control. If the energy for the TG is derived from the charge across the HVS, then all HV cabling for the TG is eliminated. Line-of-sight optics is a concern when using laser controlled devices. In fact, line-of-sight optics is used to transport laser beams for direct optical HVS triggering, due to the 10's of millijoules required to trigger the HVS. However, this type of transport can result in significant maintenance requirements to maintain alignment and efficiency. Laser control of PCSS is low energy by comparison. A PCSS only needs microjoules of laser energy at ~850 nm to be activated, allowing the use of optical fibers for beam transport. Optical fibers replace line-of-sight optics and/or HV cables, and allow the use of laser diodes in place of higher power lasers, as shown in Figure 1.

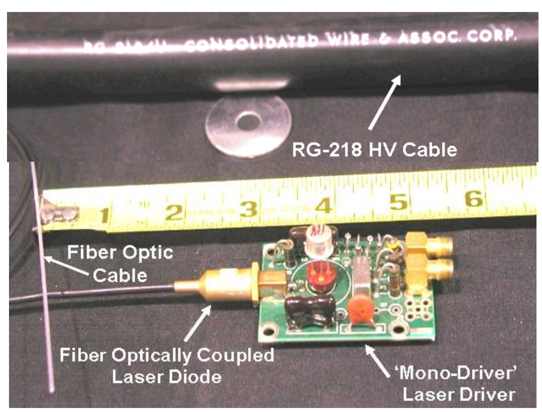

Figure 1. A semiconductor laser diode, its driver circuit, and fiber compared to a HV cable.

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TG performance can be significantly improved when based on PCSSs. In fact, performance marks of 100 ps rms jitter, 350 ps rise time, and 10^8 pulses have been demonstrated along with operating ranges up to 220 kV and 8 kA. Though, not all of these achievements have been demonstrated concurrently. For further discussion on PCSS capabilities and PCSS TGs refer to [1], [[2].

With the performance and transport capabilities mentioned above PCSS TGs impact system design, system layout, noise immunity, and cost. All of which are critical to pulsed power systems. Future systems, which include concepts 500,000 simultaneously triggered HVS [3], or 236 switches grouped and triggered sequentially for programmable current shaping, [4], will benefit from high performance lower cost PCSS based TGs.

In this paper, PCSS based TGs and the testbed, in which they are evaluated, are discussed. A block diagram of this system is provided in Figure 2 followed by a circuit diagram in Figure 3. The control system is a combination of manual operation of gas pressure and high voltage power and automated operation of the PCSS TG and diagnostics implemented with LabView [5]. The remainder of this paper will describe the sub-systems and present some measured results.

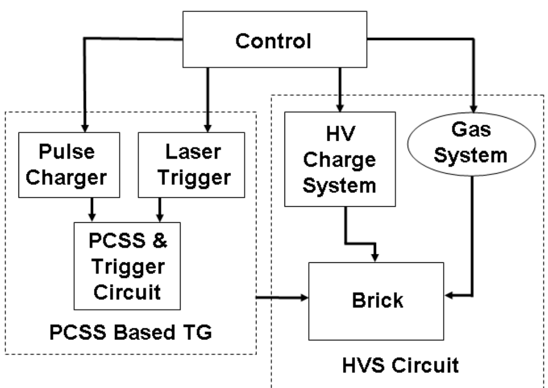

Figure 2. System block diagram.

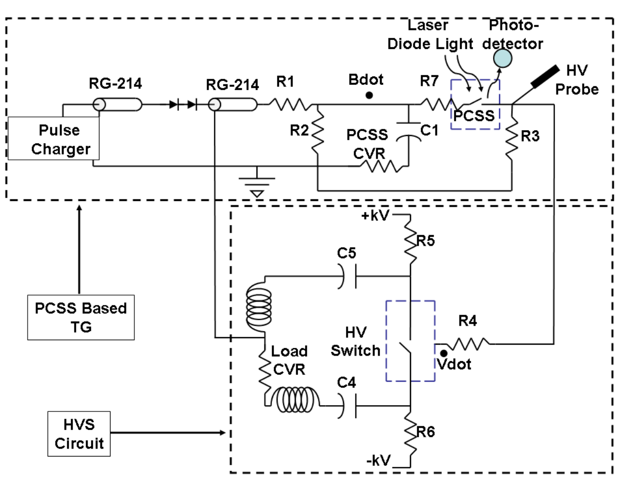

Figure 3. System circuit diagram

II. HVS CIRCUIT

The brick in the HVS circuit is a single stage Marx modeled after the layout used in the linear transformer driver designed by the HCEI [6]. This brick consists of two 40nF, 100kV capacitors, a HVS, and connects to a T&M research CVR for a load.

A number of HVSs have been installed and tested in the HVS circuit requiring the use of nitrogen, dry air, and SF6 based on the switch and the operating conditions. Pressures ranging from 5 to 130 psig have been used.

Charging of the brick capacitors was accomplished with a Hipotronics model #8220-100-F power supply capable of ±125 kV at 100mA. In addition, the HV charge system includes HV Ross relays to isolate the power supply from the brick.

III. PCSS BASED TG

A PCSS based TG generates an electrical pulse for triggering HVSs. Control of the PCSS is accomplished optically through a fiber using a low energy laser diode. Pulse charged PCSSs do not require neutron processing and can hold-off higher electric fields than DC PCSSs (70 kV/cm vs. 40 kV/cm). If the TG is pulsed charged from the electric field of the HVS, then an optical fiber is the only necessary external connection. Since our system requires the ability to test DC HVSs, a small pulse charger is included for the TG. Pulse charging is accomplished using a capacitive ring up circuit which connects to the capacitor, C1, in the trigger circuit through a diode stack, as indicated in Figure 3. This configuration provides 680ns wide charge pulses (FWHM) with up to a 40kV peak. Positive and negative polarity charge pulses are possible. Other adjustments to the charge circuit such as resistance, inductance, and capacitance allow for variation of the charge pulse.

A. PCSS laser trigger

Synchronizing the triggering of the PCSS with the pulse charger is necessary to ensure that a repeatable output is obtained from the PCSS based TG. The laser diode driver receives the command signal from a Stanford DG535 timing pulse delay generator and produces the laser pulse for triggering the PCSS. Two types of laser driver circuits have been utilized in this system. One referred to as the mono-driver, see Figure 1, which makes use of a single avalanche transistor and a capacitive discharge circuit (CDC) to generate an 25 ns pulse with a 10 ns risetime (width and risetime depend on the CDC capacitance). The other driver [7] is constructed from multiple Zetex avalanche transistors. This driver creates a 25-160 ps wide, 56-140 pJ pulse with a risetime of 20ps, which is dependent on the series resistance and capacitance used with the laser diode.

Optical transport is possible through a fiber delivering 1-3 μJs at 850-904 nm. An unfocused spot of laser energy located between the PCSS contacts is sufficient to trigger the PCSS into lock on mode and generate a single primary filament. An example of this setup is pictured in Figure 4. If the TG pulse current requires only one filament, there is no need for any additional optics. However, the spot size and location must be adjusted to optimize the PCSS performance.

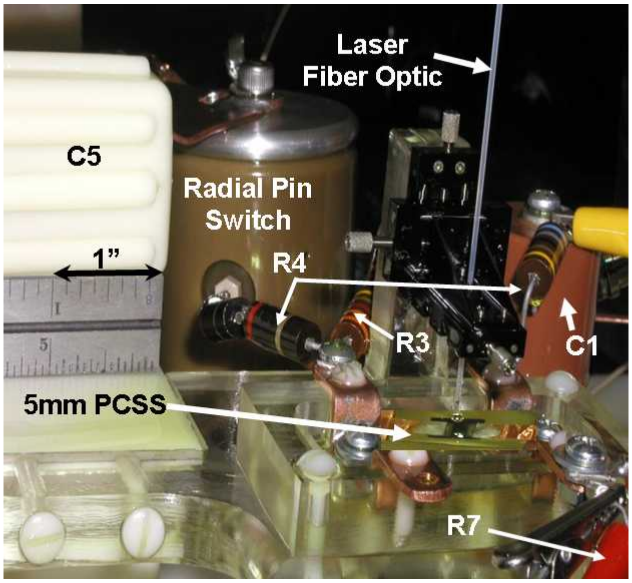

Figure 4. PCSS trigger circuit attached to HVS.

For higher currents, multiple filaments on the PCSS can be achieved with additional optical components. When the current per filament is on the order of 10-30A device lifetimes greater than 10^6 shots are possible. At higher currents per filament the lifetime of the PCSS is reduced [2]. As many as 30 parallel filaments have been demonstrated on a single PCSS using 1 mm cylindrical lenses and a large diameter laser pulse from a solid state laser [8]. Up to 24 parallel filaments have been produced with interdigitated contacts and small edge-emitting semiconductor laser diode arrays and line-of-sight optics to image the emitting edges onto the PCSS [9]. Compactness of the laser diode drivers enables the placement of the driver and the edge emitting diodes directly above the PCSS. The test-bed was recently reconfigured, as shown in Figure 5, to allow triggering with an edge emitting diode array and to allow the use of cylindrical optics required to use longer higher voltage PCSS. Testing is continuing with the higher voltage PCSS and single filament operation until lifetime in this configuration becomes inadequate.

B. PCSS trigger circuit

The compact PCSS trigger circuit and fiber optic control allow the TG to be located next to the HVS as shown in Figure 4. Close proximity to the HVS results in a low inductance circuit with nanosecond risetimes. To date trigger pulses up to 50 kV have been generated with PCSS TG [10]. The length of the PCSS is selected to match the voltage required for reliable trigger of the HVS.

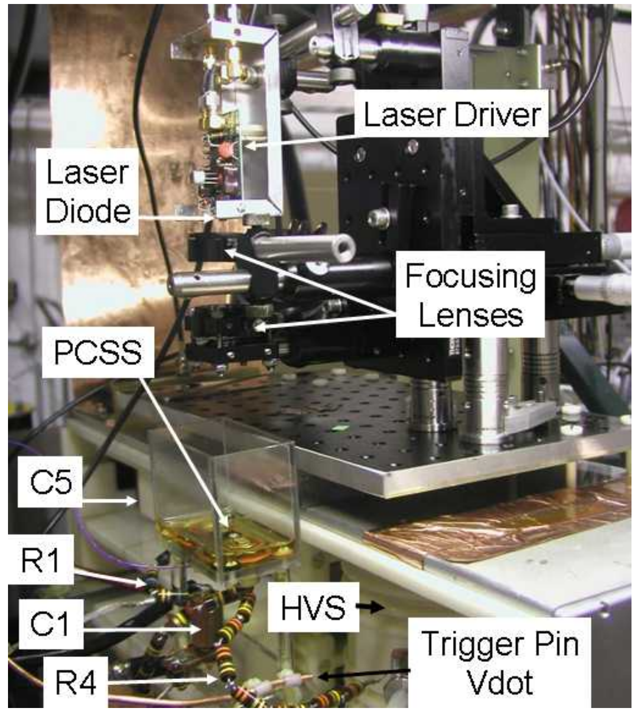

Figure 5. PCSS trigger circuit triggered by an edge emitting laser diode array.

IV. RESULTS

HVS trigger requirements vary depending upon the design of the switch. For example with a trigatron the voltage between the trigger pin and the electrode near the trigger pin can be a small fraction of the total voltage across the switch. A smaller amplitude trigger pulse can be used to trigger the trigatron and it is unlikely that the trigger pin will be raised to the voltage level at the opposite end of the HVS. Less stress on the trigger circuit is present because of these conditions. In Figure 6 a picture of a Perkin Elmer 81B trigatron located in the test configuration used by the PCSS TG. With this switch a total rms jitter of 1.16 ns was measured between the output of the DG535 pulse generator and the current out of the HVS operating with a 100kV charge. Advertised jitter for this switch is ~10-100 ns.

The radial pin switch (RPS) [11] in Figure 6 was also tested with the PCSS TG. This switch operates similar to a midplane switch. In this configuration, the switch was charged to ±50kV and 3.2 ns of jitter from the DG535 to the current out of the HVS was measured. Figures 7 and 8 show the waveforms produced by the TG and the RPS. One of the difficulties observed with midplane style switches was the possibility that the HVS could self-break the gap between the trigger pin and the HVS electrode that is charged opposite to the PCSS charge. If the PCSS is not closed at this time then the PCSS charge voltage and the HVS charge voltage add producing significantly more stress across the PCSS. To survive this additional stress much larger PCSSs and optical trigger energies are required.

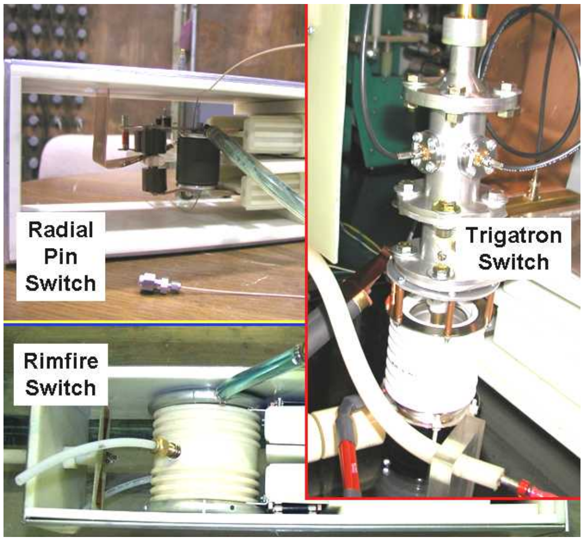

Figure 6. Switches triggered.

After successful triggering of 100kV class switches 200kV class HVSs are being tested. Such a switch, labeled the rimfire switch in Figure 6, was designed for the linear transformer driver by HCEI [6]. This switch is operated as a ±100kV DC charged switch.

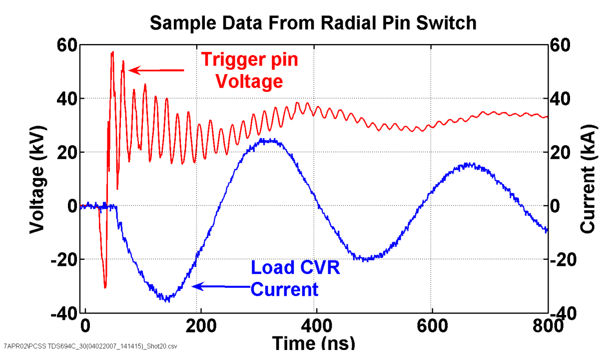

Figure 7. Example HVS Circuit Waveforms

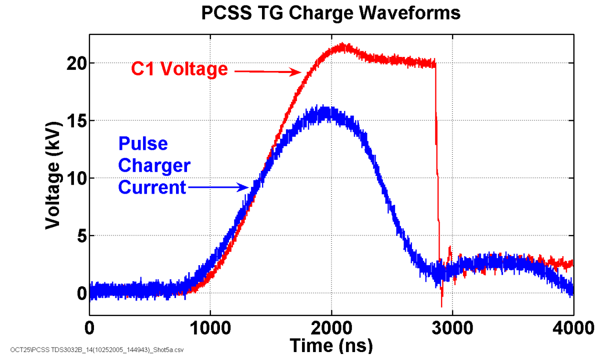

Figure 8. PCSS TG Waveforms

V. CONCLUSION

PCSS based TG offer significant benefits over the traditional electrical or optical TG. This paper has described the test facility used to demonstrate PCSS TGs and determine optimal triggering requirements from several HVS. The PCSS trigger circuit can be made compact and located near the HVS. Optical isolation is an integral part of the system due to the use of laser triggering of the PCSS. The test system described in this paper has demonstrated triggering of a 100 kV trigatron with 1.2 ns rms jitter and a ±50 kV radial pin switch with 3.2 ns rms jitter. Future testing is planned with a ±100 kV DC charged switch.

VI. REFERENCES

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