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DEVELOPMENT OF SOLID-STATE DRIVERS FOR THE NIF PLASMA ELECTRODE POCKELS CELL

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DEVELOPMENT OF SOLID-STATE DRIVERS FOR THE NIF PLASMA ELECTRODE POCKELS CELL

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Abstract – **Large aperture Plasma Electrode Pockels Cells (PEPC) are an enabling technology in the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory. The Pockels cell allows the NIF laser to take advantage of multi-pass amplifier architecture, thus reducing costs and physical size of the facility. Each Pockels cell comprises four 40-cm x 40-cm apertures arranged in a 4x1 array. The combination of the Pockels cell and a thin-film polarizer, configured in a 4x1 array, form an optical switch that is key to achieving multi-pass operation.**

Solid-state Plasma Pulse Generators (PPGs) and high current high voltage solid-state Switch Pulse Generators (SPGs) have been developed for use in the PEPC. The solid-state plasma pulse generators initiate and maintain plasma within the cells; each pulser is capable of delivering 60J of energy to each plasma channel. Deployment of the solid-state PPGs has been completed in NIF. The MOSFET-switched SPG is capable of delivering a requisite fast rise time, 17kV flattop pulse to the cells' nonlinear crystals. A complete software and hardware control system has been developed and is currently being tested for use on the solid-state SPGs. Also a transmission line modeling, development, and testing effort is in process, in support of NIFs' Advanced Radiographic Capabilities (ARC). Work is scheduled for completion by the end of the calendar year.

I. INTRODUCTION

The Plasma Electrode Pockels Cell (PEPC) is a key technology within NIF, working in conjunction with a thin-film polarizer to create an electro-optical switch in the main amplifier cavity. This optical switch allows the optical pulses to be trapped and then released, permitting NIF to take advantage of a four-pass architecture in the main amplifier, thus reducing costs and minimizing the required size of the facility while maximizing performance. [1]

In order to deliver the required excitations to the PEPC and achieve the 90º polarization of the laser light, two types of high voltage pulsers have been implemented for use in NIF. The Plasma Pulse Generators (PPGs) produce an equipotential surface on the face of the crystal and the Switch Pulse Generators (SPGs) deliver the necessary bias to cause the 90º rotation of the laser light. For several years these pulsers relied on thyratron-switched technology for the main switch. With new generations of solid state thyristors and MOSFET devices becoming available a transition from the thyratron-switched technology has been successfully achieved on both the PPGs and SPGs units. Currently, the solid-state version of the PPGs has successfully been deployed in the NIF facility. Four solid-state SPGs are fully functional. Deployment of these units is scheduled for the end of the calendar year in support of the Advanced Radiographic Capability (ARC) an enhanced optical diagnostic for NIF.

II. BACKGROUND

Discussed in detail in previous publications, the pulsed power aspects of the Plasma Electrode Pockels Cell (PEPC) subsystem are supported by four Plasma Pulse Generators (PPGs) and two Switch Pulse Generators (SPGs). [1,2] In conjunction they deliver ten independent excitations to the PEPC cell. The four PPGs provide eight excitations to produce the requisite equipotential surfaces on the faces of the potassium dihydrogen phosphate (KDP) crystal. The SPGs deliver the final excitation by impressing a uniform electric field between the faces of the crystal to produce the birefringence required to rotate the laser light.

III. SOLID-STATE PPG DESIGN AND IMPLEMENTATION

The Plasma Pulse Generators (PPGs) are deployed as standard 19" rack-mount chassis, requiring only 120 VAC power and an optical trigger for inputs. A simmer power supply in each PPG provides a low voltage, low current discharge that creates a plasma in each of the four plasma channels by initiating a glow discharge in the process gas. Once the supply detects a breakdown event, it reduces its output voltage and drops into a current regulated mode. Typically, the simmer event is started 300ms prior to the arrival of the main plasma discharge. It then extends for 100ms after the optical pulse has passed.

Each PPG also contains a capacitive discharge circuit used to increase the electron density in the plasma established by the simmer discharge. Early PPGs were equipped with a thyratron switch as the main switching mechanism but on-going improvements in semiconductor technology have permitted a transition to a single, optically-triggered thyristor. The transition has greatly decreased overall complexity of the

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units as well as decreased acquisition costs. A simplified schematic of the PPG is shown in **Figure 1**.

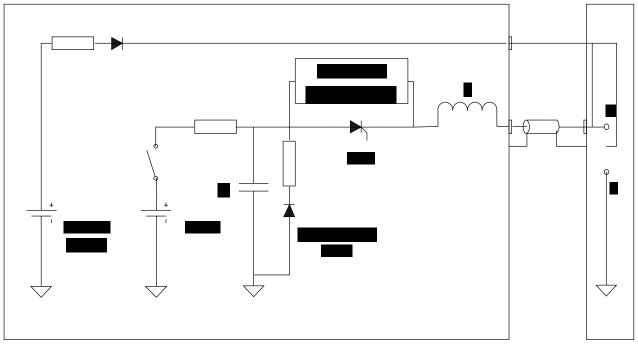

Figure 1. Simplified schematic of PEPC Solid-State PPG

Each PPG stores approximately 60J for delivery to the Pockels cell. The main discharge is delivered to the cell via RG-213. The PPG excitations to the Pockels cell are illustrated in the diagram in **Figure 2** and are visible in **Figure 3**.

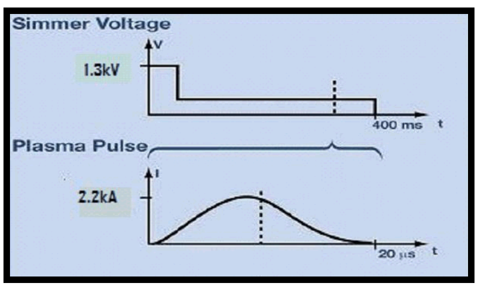

Figure 2. PPG Excitation to the Pockels cell

Figure 3. Visible Effects of PPG excitation to the Pockels cell

IV. ARC SWITCH PULSE GENERATOR DESIGN AND IMPLEMENATION

The current SPG design that has been implemented and deployed in large numbers in the NIF facility is based on a thyratron-switched 6.25Ω pulse forming line. The SPG delivers an excitation that results in a 300ns, 17kV, flattop pulse being applied to a nonlinear crystal to produce the required birefringence.

The addition of ARC to NIF places significant new requirements on PEPC that are not feasible with the current SPG design. The new requirements include having the PEPC turn “on” a second time about a microsecond after the first pulse. The second pulse is required for redirecting energetic reflections (an inherent aspect of employing short duration, high power laser pulses) into a beam dump. These reflections pose a threat to the low power “front end” of the laser. The concept is illustrated in the timing diagram **Figure 4**, Pass 1-4 represent PEPC standard operation, Pass 5 and 6 represent the energetic reflections needed to be safely trapped in a beam dump.

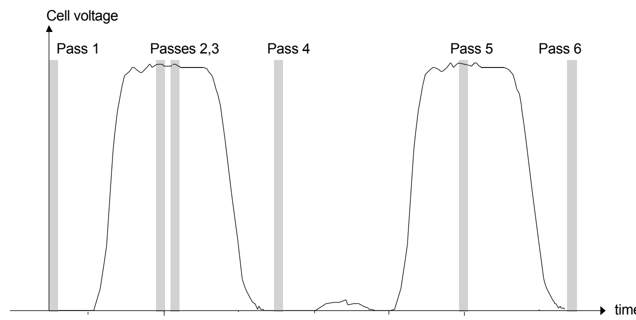

Figure 4. Relative timing of optical pulses and cell voltages for ARC PEPC

Solid-state SPGs are well suited for the task; the circuit topology offers many features including burst mode capability, variable pulse generation, frequency agility, variable pulse width, as well as fast rise and fall times.

A. Solid- State SPG Design

The ARC solid-state SPG employs a modular architecture, a characteristic of the inductive adder technology, pioneered at Lawrence Livermore National Laboratory (LLNL) for use in acceleration applications. [3] This circuit topology offers many features that make the solid-state SPG well-suited to meet ARC requirements and to be a drop-in replacement for the thyratron-based SPG. The new pulser provides the ability to generate flattop pulses with little droop, burst mode capability, continuously variable pulse separation/burst frequency agility. The pulse generator employs multiple, stacked 1:1 transformers in which each transformer primary is separately excited. Secondary windings are connected in series so that the modulator output is the sum of the primary voltages. The secondary is a continuous rod traversing all primaries. Modular in nature and well-adapted to printed circuit card implementation, the modulator implements a total of twenty-seven identical 750V stages to achieve the required 17kV output. The rise time of the output pulse is approximately 20ns while the fall time is purposely held to ≥ 20ns to avoid excessive voltage transients in the system. These rise-and-fall time parameters are achievable largely because of small inductance in the FET/capacitor/transformer primary loop. A simplified schematic of the solid-state SPG is shown in **Figure 5**.

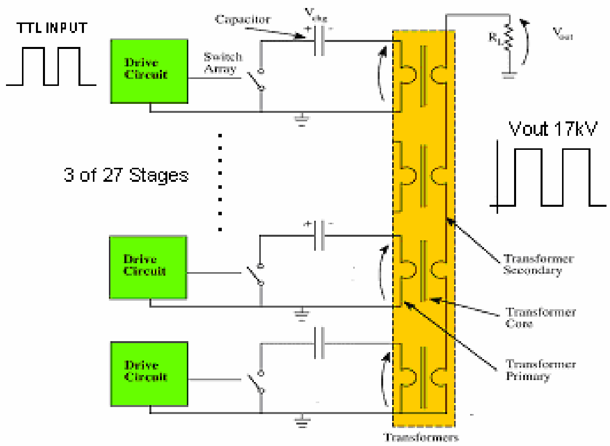

Figure 5. Simplified Schematic of the ARC Solid-State SPG

B. ARC Control System and Timing

PEPC timing, monitoring, and coordination with the rest of the NIF laser are controlled by the Integrated Computer Control System (ICCS). The pre-ARC version of the software adjusts the timing of a single trigger per SPG based on the voltage waveforms measured at the SPG output and at the PEPC cell on the other end of the cable. SPG and PPG pulses are monitored on oscilloscopes. The oscilloscope triggers are tied into a larger precision timing system for the whole NIF and serve as timing references. Diagnostic software takes the data from the oscilloscope, then checks pulse timing, amplitude, and overall waveform shape. An edge detection algorithm is used to measure the delay between the oscilloscope trigger and the SPG output pulse. The control loop is then closed when software adjusts the timing of the SPG trigger.

The ARC SPGs replaced the edge-triggering of thyratron-switched SPGs with level triggering, allowing the trigger input to determine the timing, width, and separation of output pulses. To make this change transparent to existing software and triggering systems, a TTL level pulse generator was placed between each original trigger and new SPG. A new software component configures the pulse generator to produce two pulses per trigger. The widths of the pulses, and the delay between them, can be independently configured on a GUI. The pre-ARC software still sees the system as one trigger, and uses the rising edge of the SPG output for closed-loop timing control.

The ARC diagnostic system required the addition of a second oscilloscope to monitor the second pulse delivered to the PEPC cell by the SPG. In the ARC diagnostic system one oscilloscope captures the first pulse and the newly added oscilloscope captures the second pulse. The trigger for the second oscilloscope is configured such that Δt between the rising edges of pulses 1 and 2 is the same as Δt between the oscilloscope triggers. Waveforms displayed on each oscilloscope thus appear at the same position. The new hardware arrangement eliminated the need to implement significant changes to the software.

C. ARC PEPC Transmission line modeling using PSpice

The purpose of the ARC PEPC Transmission Line modeling is to evaluate proposed modifications to eliminate or reduce the negative effects of cable reflections on the second pulse without resorting to excessively long cables (delaying reflections beyond the second pulse) between the pulser and load. The main goal is to maintain the baseline and pulse tops within ± 2% at the time the laser pulses arrive at the PEPC cell. Four PSpice transmission models were considered.

- Lossless
- Lossy
- RG217
- 5 stages of discrete RLC components

The first 3 models are included as library functions within PSpice version 10.3i. The transmission models were evaluated in the circuit shown in **Figure 6** where the double pulse source is simulated with two series connected pulse voltage sources. The eight transmission lines are connected in parallel and are terminated into an effective 7.5 Ω in series with 75 nH inductor; these were designed for the original PEPC to modify the rise-and-fall times of the applied pulse. The 5.9 nF capacitor represents the impedance of the Pockels cell.

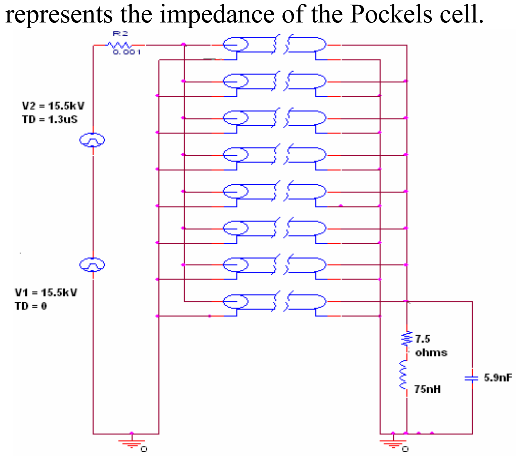

Figure 6. ARC Pulser Transmission Line PSpice Model

The results of the PSpice analysis were compared to the actual output waveform seen from the PEPC cell. All of the library function models produce similar results, with the lossless transmission line model, unexpectedly, more closely matching the actual output waveform measured at the PEPC cell. The lossy model did not provide as close of a match to the actual measured results. The RG217 model excessively attenuated the amplitude and showed features on the reflection waveform that did not exist in our measurements. The five-stage discrete RLC did not provide the BW fidelity to produce a rectangular pulse. This approach would require a much larger number of stages then would be practical for this effort, to be effective.

The waveform comparison between the actual measured pulses and the pulses generated by the lossless model are shown **Figure 7**. The cable reflection effects produced by the model, to the first order, match that of the measured pulse, in terms of timing, shape, and amplitude. The most significant difference is that the reflections in the measured pulse appear to be rectified. Including a more detailed model of the source is expected to provide more insight to this phenomenon.

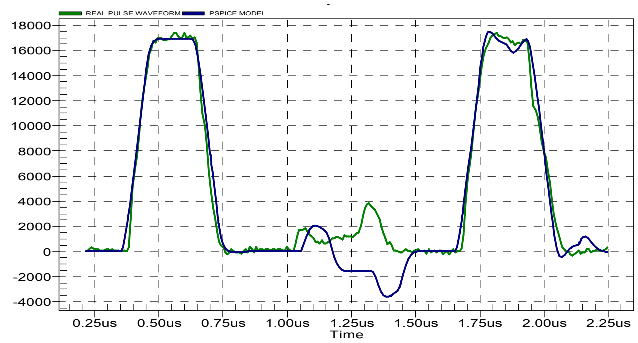

Figure 7. Comparison of real and Lossless model waveform pulses. The green trace is the real waveform and blue is the simulated.

The Lossless model was first checked with the ideal condition of having the source impedance match the effective characteristic impedance of 8 cables connected in parallel, 6.25 Ω. As expected no reflections were observed. However the output amplitude was reduced by half.

We are now evaluating the matching source impedance in parallel with ultra fast recovery diodes; the model is shown in **Figure 8**. The preliminary results shown in **Figure 9,** shows that some improvement was achieved without significant loss of voltage. The improvements are recognized in terms of reduction of amplitude and pulse width of the reflections.

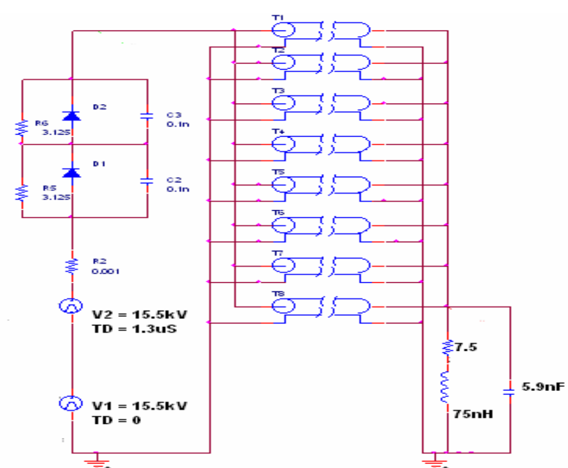

Figure 8. Matching source impedance PSpice Model

In the near future we plan to do the following:

- Model the Pulser Source in more detail to understand the rectification of the reflections at the load.
- Measure the turn on time of the diode before prototyping an impedance matching circuit
- Evaluate a magnetic diode if the silicon diode is not fast enough.

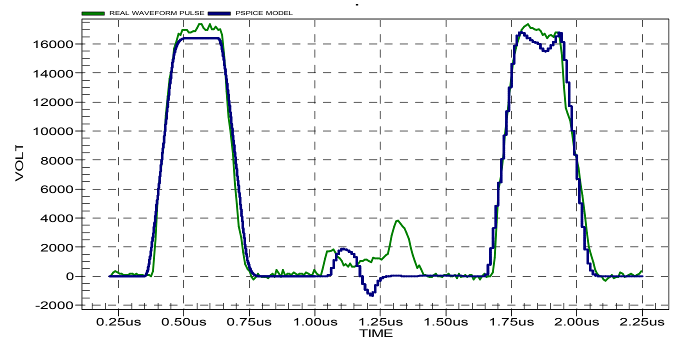

Figure 9. Comparison of real pulse (Green Trace) and model waveform pulses (Blue Trace). From modeling in Figure 8.

We plan to use this model to evaluate and develop more impedance matching concepts to improve the mitigation of reflections before implementing an actual realization. Our goal is to develop, test, and deploy improvements prior to installing the ARC PEPC system in NIF. It may not be practical to eliminate the reflections completely, but by reducing the amplitude and duration of the cable reflections along with the strategic use of the pulsers' agility, ARC PEPC can be successfully deployed.

V. CONCLUSION

Solid-state Plasma Pulse Generators (PPGs) and solid-state Switch Pulse Generators have been developed for use in the PEPC. At this present time, the solid-state version of the PPGs has successfully been deployed in the NIF facility. Now our primary mission is to deploy the solid-state SPGs in the ARC system by the end of this calendar year.. In an effort to deliver a fully functional system several activities are being performed in parallel, including control system (hardware and software) development, testing, and modeling, development, and testing, of transmission line matching schemes.

VI. REFERENCES

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