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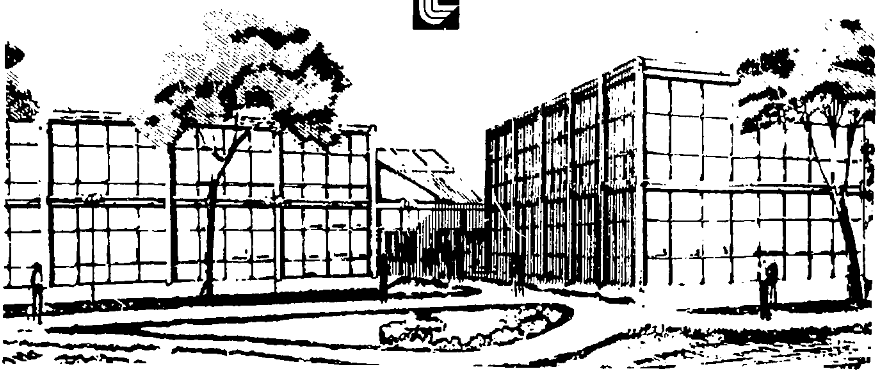

Driving Pockels Cells in Multi-Arm Lasers*

by

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Introduction

This paper describes the method used to drive Pockels cells on the 20-arm Shiva laser for inertial confinement fusion research at the Lawrence Livermore Laboratory. Shiva became operational last fall, and has just completed a series of 20-arm target shots. It uses two Pockels cell gates in each laser arm for suppression of amplified spontaneous emission (ASE) that can damage or destroy the target before the main pulse arrives. Two additional Pockels cells are used in the preamplification stages, so that a total of 42 cells must be driven by the pulser system.

Pockels Cell Load Requirements

Each Pockels cell is a capacitive load that is driven with a 50-ohm coaxial cable. The capacitance is about 20 or 50 pF, depending upon Pockels cell size (25 mm or 50 mm diam). The cable is terminated with a

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second 50-ohm "get lost" cable at the cell, Figure 1. The voltage waveshape across the Pockels cell is given by $1-e^{-t/\tau}$ for a step input applied to the cable, where the time constant $\tau = ZC/2$, Figure 2. For a 25 mm (20 pF) cell, τ = 20 x 50/2 = 500 psec, and for a 50 mm (50 pF) cell, τ = 50 x 50/2 = 1250 psec. It is desirable therefore that the pulser provide a risetime ~1 nsec, so that the intrinsic capability of the Pockels cells is not degraded.

It is also desirable that the Pockels cell gates be normally open to facilitate alignment of the 20 arms with a steady-state laser. A few seconds before the laser is pumped, however, the gates must be biased closed by applying a 7 kV dc voltage to the cables. Just before the switched-out laser pulse arrives, the gates must be opened with a 9 kV fast-rise, 20 to 60 nsec wide electrical pulse. The 7 versus 9 kV voltage difference accounts for dc versus pulse response of the Pockels cells. It is important that the electrical pulse falls - and that the gates close again after passage of the main laser pulse in order to prevent reflected light from amplifying backwards down the chain. A few seconds later, after inactivation of the laser, the 7 kV bias must be turned off to restore the gates once again to their open, or transmitting mode. The complete required voltage history is given in Figure 3.

Pulser Design Criteria

The initial design was for a pulse generator to provide these voltages into 50 parallel 50-ohm cables, so that any number up to 50 Pockels cells could be driven. The dc bias voltage was applied to the center conductor of each coaxial cable, and the pulse voltage superimposed thereon. The general arrangement of this pulser is shown in Figure 4. 50 pulse cables, each cut to the appropriate length, were arranged in a circle with all of the braids common, and connected to the

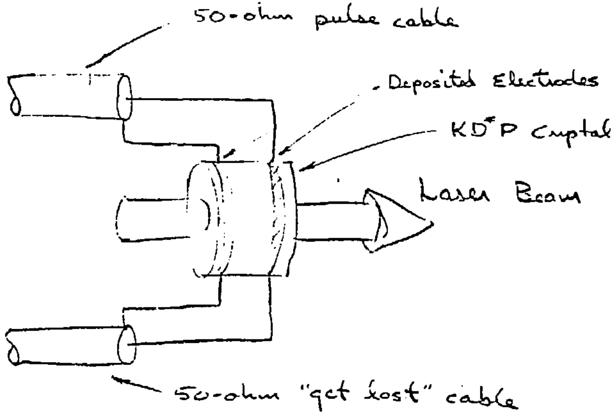


Figure 1 Pockels Cell Layout

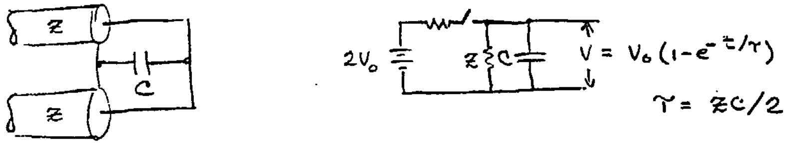


Figure 2 Pockels Cell Schematic and Equivalent Circuit.

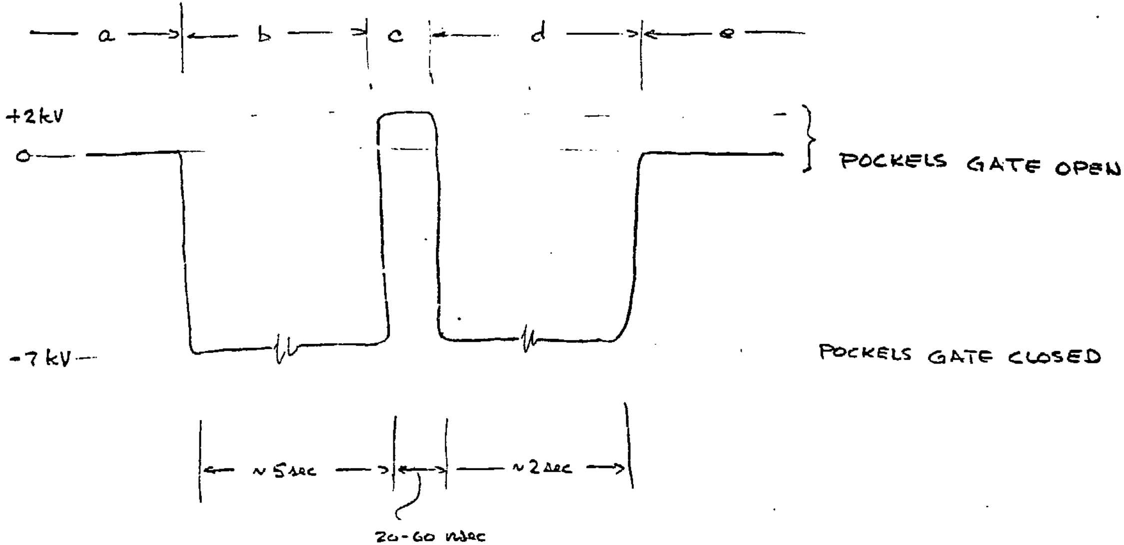


Figure 3 Voltage history of the pockels cell gate pulse:

a. Normally zero voltage, with pockels gate open.
b. Minus 7 kV dc at ~ minus 5 seconds, pockels gate closed.
c. Plus 9 kV pulse at ~ minus 10 nsec with ≤ 2 nsec risetime and 20-60 nsec pulsewidth. (2 kV overshoot compensates for pulse response.)
d. Minus 7 kV dc until ~ plus 2 seconds
e. Zero voltage, pockels gate open.

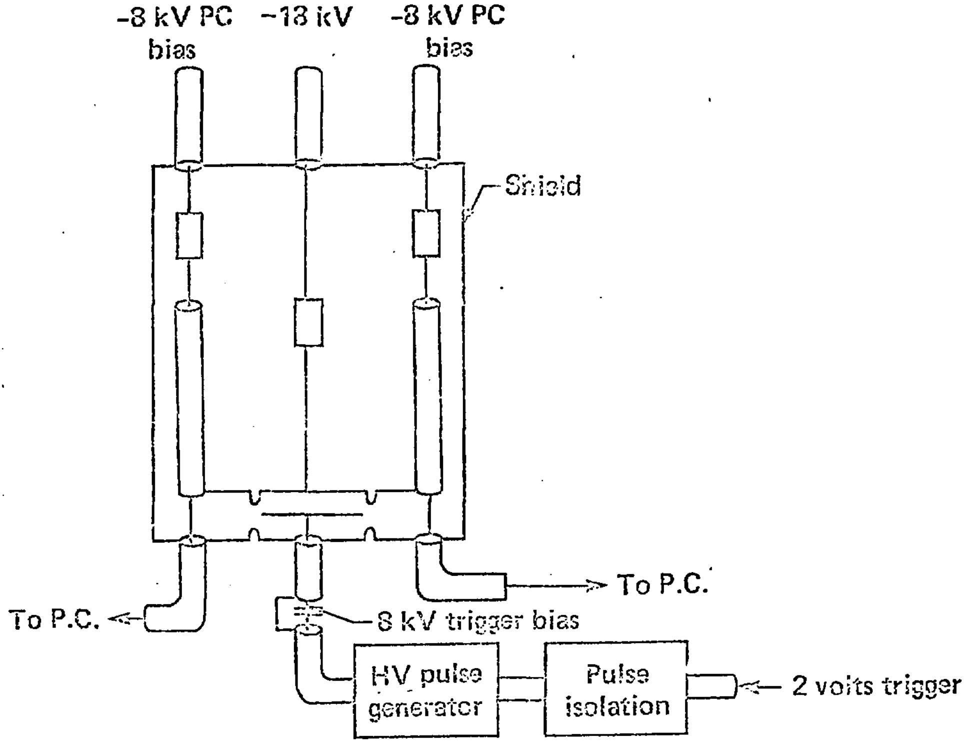


Figure 4. Arrangement of the Pockels cell pulser using a mid-plane triggered spark gap switch.

high side of a spark gap switch. The center conductor of each pulse cable was hard-wired across the gap to the center conductor of its matching output cable. The ground shields of the output cables were tied together and connected to the ground side of the spark gap. Thus when the braids of all the pulse cables are charged negatively, and the gap is fired, an inverted (positive) pulse of half the charge voltage is sent down each output cable. The time duration of this pulse is simply the two-way transit time of the pulse cable.

This arrangement is convenient because it allows dc bias voltage control to be fed to each Pockels cell via the free end of each pulse cable, using resistive isolation.

<u>Switch Design Criteria</u>

The requirement upon the spark gap switch is a rather stringent one. It must drive a one-ohm load via a one-ohm 20 kV source, and provide about one nsec risetime in order to preserve the fast-pulse capability of the Pockels cells. The equivalent circuit of this pulser is shown in Figure 5. A time constant of 1 nsec for a one-ohm load will require the inductance to be $L = 2Z\tau = 2 \times 1 \times 1 = 2$ nH. The current for a 10 kV pulse into one ohm is 10 kA. The initial current rate of rise is $(di/dt)_{max} \approx V_o/Z\tau = 10/1 \times 1 = 10$ kA/nsec.

The only known switch that would provide this performance and that could also be dc-charged and allow a reasonable pulse repetition rate, is a high pressure gas spark gap. A gas gap has a resistive phase, of time duration given approximately by J.C. Martins formula

$$T_R = 88 \left(\frac{\rho}{\rho_{stp\ air}}\right)^{1/2} \Big/ \left(E^4_{MV/m} Z\right)^{1/3} \text{ nsec.}$$

if one uses pressurized SF_6 gas, then $\rho/\rho_{stp\ air} = 5\ P_{atm}$, and $E/P \sim 7$ MV/m · atm; therefore, for a 2 ohm circuit impedance,

$$T_R = \frac{88(5P)^{1/2}}{\left[\left(\frac{E}{P}\right)^4 P^4\ Z\right]^{1/3}} = \frac{88 \bullet 5^{1/2}}{(7^4 \bullet 2)^{1/3}\ P^{5/6}} = \frac{12}{P^{5/6}}$$

The highest practical pressure for SF_6 is about 12 atmospheres, so the shortest resistive time for the gap is $12/12^{5/6} = 1.5$ nsec unless a multiple-channel gap is employed. For example, a 3-channel, 12 atm SF_6 gap will provide $1.5/3^{1/3} = 1.0$ nsec resistive time because the impedance each gap drives increases by three. A 1.5 to 2 nsec resistive time was considered adequate for this requirement, however, and the pulser was developed using a small 3-electrode pressurized SF_6 spark gap switch.

The spark gap length $\ell = V/E$, and for 12 atm. SF_6 at 7 MV/m · atm, $E = 12 \times 7 = 84$ MV/m. Therefore, for 20 kV holdoff, $\ell = 20 \times 10^3/84 \times 10^6 = 2.4 \times 10^{-4}$m or about 10 mils. The inductance of a single channel gap can be designed to be less than 40 nH/cm, so for this gap $L < 40 \times 2.4 \times 10^{-2} = 1$ nH. Since this provides an L/2Z time constant of $1/2 \times 1 = 0.5$ nsec, it is apparent that the limitation on the gap risetime will be established by the resistive time phase of the gas, provided that care is taken to keep the gap inductance very low.

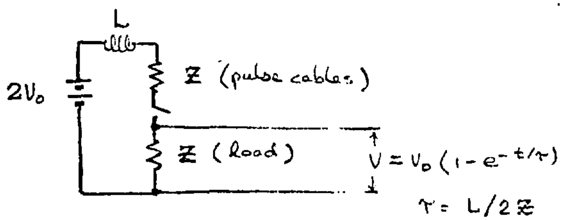


Figure 5 Equivalent Pulser Circuit

The Shiva Pulser System

The actual system that was constructed for Shiva comprised one six-way and two twenty-way pulsers. The dual twenty-way design was chosen because it was expected that the two sizes of Pockels cells (25 mm and 50 mm) would operate most efficiently at different voltages. So in the Shiva system, one twenty-way pulser drives all the 25 mm cells in the 20 laser arms, and the second 20-way pulser drives all the 50 mm cells.

The six-way pulser drives the two 25 mm Pockels cells on the preamplifier table. By adding this pulser to the system, we avoid the need to add a hundred feet or so of delay cable between each Pockels cell and its 20-way pulser. This cable would otherwise be required because the laser beam takes about 150 nsec to travel between the preamplifier table cells and the cells on the laser arms.

The Shiva system is set up so the 6-way pulser is triggered from a master pulse generator that is fed a low-level signal from the oscillator switch-out table. The six-way then drives the two preamp-table Pockels cells and it also provides delayed triggers to each of the two 20-way pulsers. The mid-plane voltage to the 20-way gap trigger electrodes is conveniently fed through the trigger cables in the same way that bias voltage is provided to the Pockels cells. The two additional 6-way outlets are used for monitoring purposes.

A pulse terminator is provided at the ends of each of the "get-lost" cables to prevent the signal from reflecting back to the Pockels cell. These terminators are 50-ohm resistive dividers, each with a series capacitor added so that the Pockels cells can be given dc bias. In addition, the resistive divider provides a 100:1 voltage reduction, with a BNC output connector that allows the pulse to any cell to be monitored.

A picture of the six-way pulser is shown in Figure 6. The Pulsar Pulspak 10A trigger generator is at the bottom; a monitoring terminator is laying on the Pulspak; the knob at the bottom of the 6-way pulser controls the trigger-pin setting via a worm gear. SF_6 pressure cables are connected at the bottom of the spark gap. Only one output cable is shown connected. The six pulse forming cables are wound up above the gap. They are each 20 feet long to provide a 60 nsec pulse. The ends of these cables are connected to a plate at the top of the pulser, with the insulation and center conductors fed through. A 20 megohm resistor connects these conductors to the cables bringing in the bias and the 20-way trigger pin voltages.

Figure 7 shows one of the 20-way pulsers, with all cables attached. Bias voltage is fed from the top - as with the six-way (except here it is one voltage common to all cells). The charge cable for the spark gap is seen just above the gap. Normally, these pulsers are encased in metal jackets to prevent high frequency noise from radiating into the laser bay.

Pulser Performance

The three pulsers have been operating on the Shiva laser since October 1977. In the initial setup, some maintenance problems were encountered because the spark-gaps were pulsed up to 10 pps for hours at a time. Very close spacings are used, and sharp-edged Elkonite trigger electrodes are required. In about 10^5 pulses, the trigger pin edges become worn and the gap cannot be set for low jitter operation.

In the present mode of operation, the gaps are fired just a few dozen times a day, so they operate for weeks with no attention. Normally, an occasional few minutes of minor tweaking will establish low jitter performance.

The scope traces, Figure 8 show the waveshape from one of the 20-way pulsers. Each trace is 10 shots overlaid, with the scope trigger taken from the monitor output of the 10 kV Pulsepak trigger generator. Thus the jitter shown is through two spark gaps. The Pulsepak fires the six-way, and the six-way fires the 20-way that is being monitored.

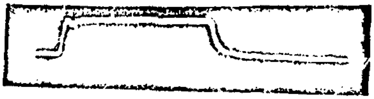
Figure 8a shows the complete 60 nsec waveshape of the 9 kV pulse. Figure 8b shows the leading edge of the pulse at 2 ns/cm sweep speed. This trace confirms the calculations of ~2 nsec risetime. Note that the system jitter through both gaps can be held to less than one nsec.

The gap producing these pulses was operated at 68 psig SF_6 with about 18 mils gap spacing. The gap voltage was 18 kV and the sharp-edge trigger pin voltage was 7 kV (both voltages were negative). It is an easy matter to set the trigger pin, since the worm-gear arrangement provides precision control - one full turn of the knob is about 1.25 mils adjustment of the pin.

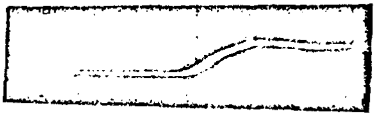
Conclusions

In the Shiva system, all of the Pockels cells operate at the same voltage (7 kV bias and 9 kV pulse). Because of this, a 40-way pulser may be more desirable than two 20-ways because one spark gap is easier to maintain than two. Another possibility that we are presently exploring is to use a hydrogen thyratron in place of the 6-way gap. With specialized trigger and pulse compression techniques, it may be possible to achieve about 5 nsec rise when only 6 cables are switched. This would be adequate for the Shiva or similar laser systems.

This type of pulse generator has many interesting applications. It



a. 20 nsec/cm.



b. 2 nsec/cm

Figure 8. Twenty-way pulser waveforms.
Ten traces are overlaid in each picture.

could be designed to hold off 100 kV or so. The spark gaps are very low inductance - the present gaps are less than 2 nH. The voltage is variable over a wide range - the Shiva gaps will operate from less than 2 to over 40 kV.

Because we have noticed multi-channeling in the gaps, we are confident that they could be designed to drive up to 100 cables, and still provide a few nsec risetime.

As we have noted, the pulser makes an ideal trigger generator for synchronized parallel or series firing of many gaps. One big advantage is that the trigger pin bias voltage can be fed to each individual gap via the trigger pulser itself, eliminating the need for a myriad of separate voltage dividing strings. A second advantage is that the fast-rise, flat-topped trigger pulse produces voltage doubling in even a fairly capacitive trigger electrode.