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POCKELS CELL PULSE-STACKERS

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Abstract

The general transmission characteristics of a pulse-stacking system consisting of an etalon and a cylindrical-ring electrode Pockels cell Q-switch are discussed. A voltage pulse-forming network capable of switching the Pockels cell transmission on the necessary time scales is presented and the outputs of a simple pulse-stacker configuration are calculated for different voltage waveforms. These results indicate that an efficient (∿1% total pulse energy transmission) Pockels cell pulse-stacker can be constructed, which can provide a variable, faster-than-exponential rise in transmitted pulse intensity.

The current schemes for achieving net energy gain from laser-fusion microexplosions require adiabatic compression of the fuel by tailored laser pulses whose intensities rise in a peculiar faster-than-exponential fashion.[1-3] As pulses with the desired behavior cannot be generated directly by a laser oscillator, some means of modifying the original intensity distribution must be found. One method, known as pulse-stacking, is to split a single pulse into a number of pulses, change their intensities by appropriate amounts, and recombine them with appropriate delays to yield a pulse of the desired intensity distribution. Numerous pulse-stacking schemes have been proposed in the past.[4] Among these, passive schemes have been noteworthy because they require almost no attention after they have been fabricated and aligned. However, these schemes are generally handicapped because a single device can only provide a narrow range of pulse durations and risetimes. In this work, we found that a simple active pulse-stacker, consisting of an etalon and a cylindrical-ring electrode (CRE) Pockels cell, could generate extremely flexible risetimes and pulse durations. We believe that this type of device can be invaluable during the research phase of laser-fusion programs.

Figure 1 illustrates the basic design of this type of pulse-stacker. A single subnanosecond pulse incident on the etalon generates a train of pulses whose amplitudes decrease in time. As this pulse train enters a CRE Pockels cell placed between crossed polarizers, the voltage across the Pockels cell electrodes is optically switched from the full-wave voltage to zero. This causes the transmission of the pulse train through the second polarizer to rise rapidly from zero to a maximum value and then fall rapidly back to zero. The superposition of the decaying etalon output on the Pockels cell transmission yields a pulse envelope that rises rapidly in time to a smooth maximum (which occurs somewhat earlier in time than the Pockels cell transmission maximum) and then decays even more rapidly back to zero.

For a pulse of intensity I_0 incident on an etalon of spacing d, the intensity of the m^{th} output pulse from the etalon is

$$I_m = I_0(1 - r)^2(1 - R)^2 R^{2m-2} ,$$

where R is the reflectivity of the mirror surfaces and r is the reflectivity of the etalon's other surfaces (Fig. 2). The delay of the m^{th} output pulse with respect to the first output pulse is

$$D_m = (m - 1)\tau ,$$

where $\tau = 2d/c$ is the round trip time of the etalon. Mutual alignment of the pulses from the etalon is easily accomplished by making the mirror surfaces sufficiently parallel. In Fabry-Perot interferometers, angular

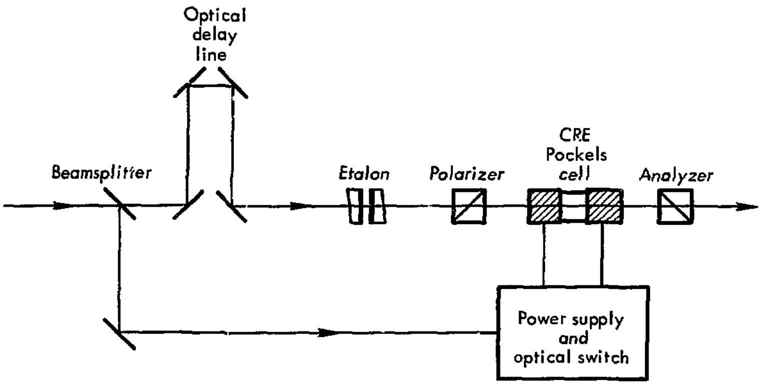

Fig. 1. Schematic diagram of a Pockels cell pulse-stacker.

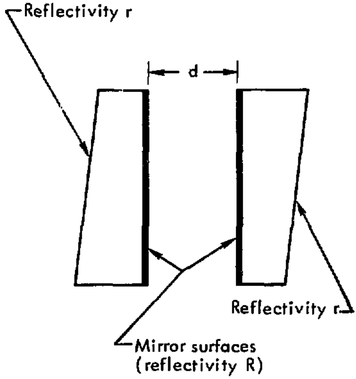

Fig. 2. Detail of the etalon.

alignments of better than 0.1 μrad are routinely achieved. This corresponds to a linear displacement of less than 10 μm at a distance of 100 m, which is adequate for the applications envisioned. Variation of the pulse spacing is easily achieved by translating one of the mirrors along the beam axis. The etalon mirrors are wedged to prevent unwanted secondary pulses from appearing in the output pulse train.

When a pulse, initially polarized along the y axis and with a wave-vector lying along the z axis, propagates through a Pockels cell operated in the longitudinal mode, a component polarized along the x axis is generated. The magnitude of this component is given by

$$E_x = E_{y0} \sin(\phi/2) ,$$

where E_{y0} is the magnitude of the incident field and the phase shift $\phi(t) = n_0^3 r_{63} \omega/c V(t)$.[5] The value n_0 is the linear refractive index of the nonlinear crystal, r_{63} is the appropriate electrooptic coefficient, ω is the frequency of the incident radiation, and V is the applied voltage. The intensity transmitted by the polarizer-Pockels cell system is

$$I_x(t) = AI_y \sin^2[\phi(t)/2] ,$$

where A is the attenuation of the polarizers and Pockels cell at maximum transmission. Combining the etalon output with the Pockels cell transmission yields

$$I_m \approx I_0 A(1 - R)^2 R^{2m-2} \times (1 - r)^2 \sin^2\left[\frac{\pi}{2} \frac{V(t)}{V_{1/2}}\right] ,$$

where $V_{1/2} = \pi c/n_0^3 r_{63} \omega$ is the half-wave voltage.

To be useful for fusion experiments, the voltage across the Pockels cell must be switched on nanosecond time scales w. .n picosecond jitter. One method of accomplishing this is with an optically-triggered avalanche transistor circuit similar to those developed for ultrafast streaking cameras.[6] Such a circuit is shown

In Fig. 3. An avalanche transistor string is connected across the electrodes of the Pockels cell and the full-wave voltage is applied. A portion of the initial laser pulse strikes an avalanche phototransistor in the string causing an avalanche breakdown. The voltage across the electrodes collapses to zero in a time of the order of a few nanoseconds with the jitter in beginning the collapse being of the order of 25 ps. This low jitter allows the voltage collapse to be timed to coincide with the arrival of the pulse train from the etalon. A simple optical delay line may be used to achieve the timing. A variable capacitor connected across the electrodes allows the duration of the collapse to be varied over more than an order of magnitude.

The voltage waveform during the collapse is approximately one-half cycle of a sinusoid. Thus

$$I_m = I_0 A(1 - R)^2 R^{2m-2} \times (1 - r)^2 \sin^2\left[\frac{\pi}{2}\cos(\alpha_m) + \frac{\pi}{2}\right],$$

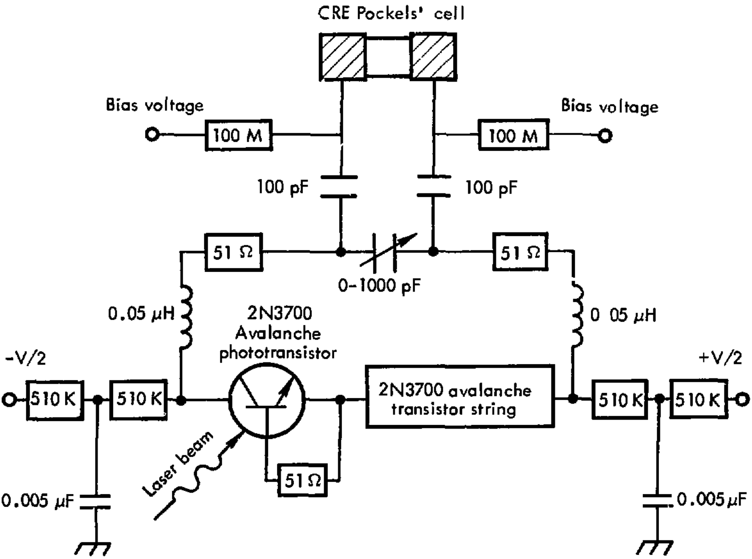

Fig. 3. Circuit diagram of the Pockels cell power supply and optical switch.

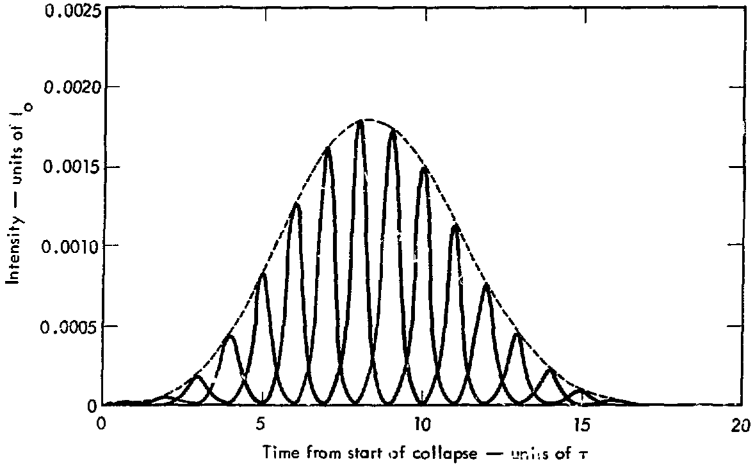

Fig. 4. Output pulse train for A = 1, R = 0.9, r = 0, and $V(0) = 2\ V_{1/2}$.

where $\alpha_m = \pi m\tau/T$ and T is the total collapse time. This is plotted in Fig. 4 for the case A = 1, r = 0, R = 0.9, and T = 20τ. Only the rising portion of such a pulse envelope is useful for laser compression applications. However, the existence of the falling portion is not detrimental to these applications because almost all the energy generation will take place shortly after maximum intensity (and compression) are reached.[1] Summing the intensities transmitted in only the rising portion of the pulse envelope, we find that approximately 0.5% of the incident pulse intensity is transmitted in a usable form. Higher efficiencies can undoubtedly be obtained by optimizing mirror reflectivities, the number of transmitted pulses, etc.

A slightly different pulse envelope can be obtained by delaying the arrival of the pulse train at the Pockels cell until after the voltage collapse has begun. The effect of a 10% delay is shown in Fig. 5 for the same system parameters as Fig. 4. The efficiency of this arrangement is approximately 0.7% for these values of the system parameters.

Another variation is to slightly reduce the initial voltage on the Pockels cell such that the transmission at t = 0 is nonzero. Figure 6 shows the resulting pulse envelope for an initial voltage, $V(0) = 1.8\ V_{1/2}$, and for the same system parameters as Fig. 4. The efficiency of this arrangement is approximately 0.9% for these values of the system parameters.

A still different pulse envelope can be obtained by applying a bias voltage across the Pockels cell. For example, Fig. 7 shows the resulting pulse envelope when a bias voltage $V(0) = 2\ V_{1/2}$ and $V(T) = -V_{1/2}$ is applied to a system with the parameters of Fig. 4. The efficiency of this arrangement is approximately 0.6% for these values of the system parameters.

It is obvious that by combining any of the possible variations (etalon spacing, initial pulse delay, voltage collapse duration, voltage magnitude, and bias voltage) still different pulse envelopes can be obtained. Similarly, if a different voltage waveform can be generated by some means, pulse envelopes of another general shape can be obtained. In addition, the rise- and fall-time characteristics of any of these envelopes could be considerably enhanced

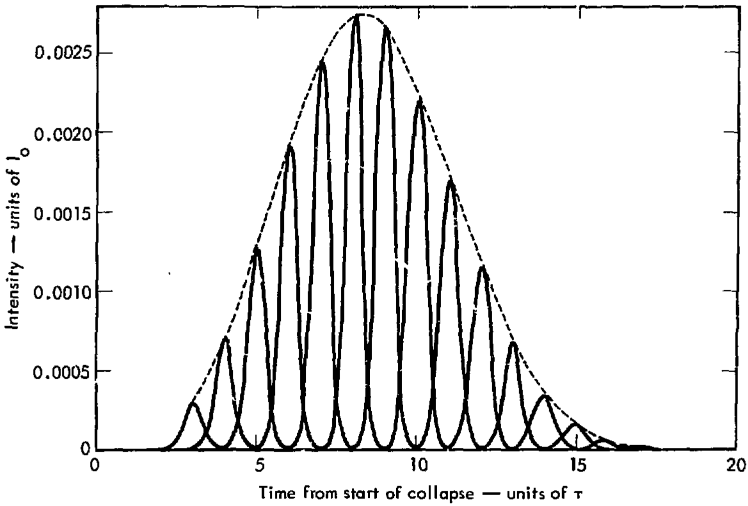

Fig. 5. Output pulse train for $A = 1$, $R = 0.9$, $r = 0$, and $V(0) = 2\ V_{1/2}$, with an additional 10% delay in the arrival of the first pulse at the Pockels cell.

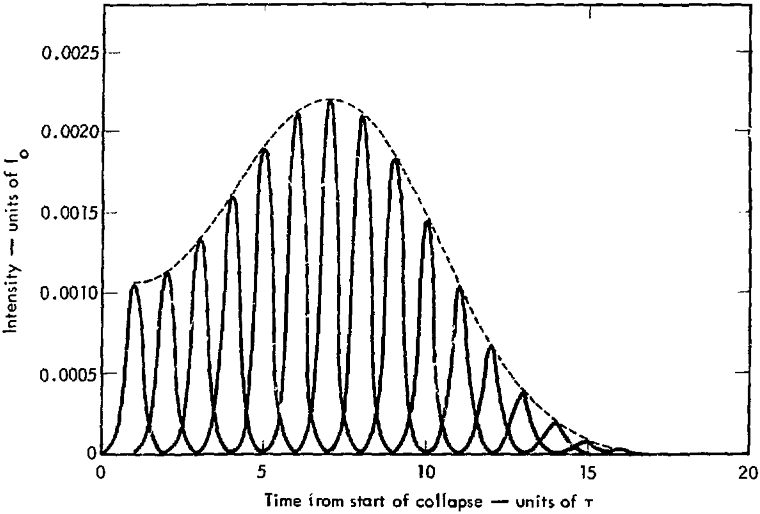

Fig. 6. Output pulse train for A = 1, R = 0.9, r = 0, and $V(0) = 1.8\ V_{1/2}$.

by placing a saturable absorber after the Pockels cell, although this would dramatically reduce the efficiency. On the basis of the foregoing discussion and examples, we conclude that Pockels cell pulse-stackers can provide extremely variable output pulses for a variety of applications. These devices should be invaluable for laser-fusion research.

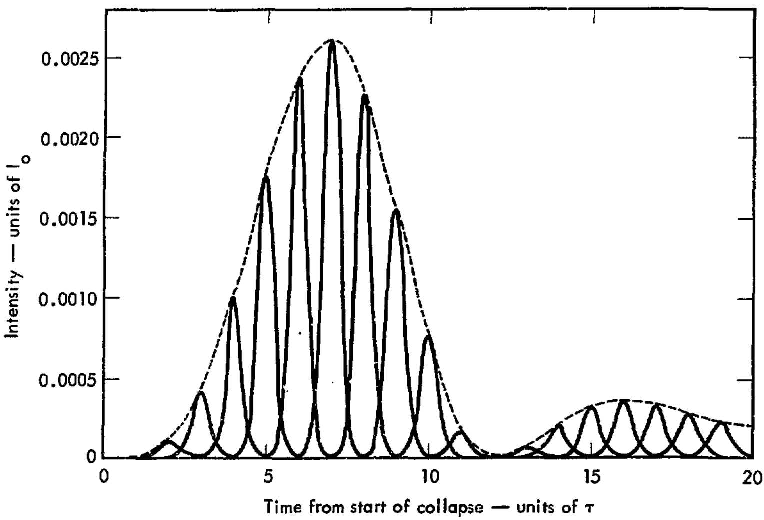

Fig. 7. Output pulse train for A = 1, R = 0.9, r = 0, and $V(0) = 2\ V_{1/2}$, with an added bias voltage such that $V(T) = -V_{1/2}$.

Acknowledgment

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