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Laser pulse selection with krytron triggered Kerr shutter

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Abstract A 16 kV krytron pulse generator and a 30 kV krytron activated spark gap are developed to operate a Kerr cell shutter. The shutter is used to select single picosecond light pulses from a mode locked laser and to separate nanosecond light signals from a free running laser.

1 Introduction

The selection of single picosecond light pulses from mode locked lasers is performed with Pockels cell or Kerr cell shutters. Pockels cell switching devices (half wave voltage $V_{\lambda/2} \simeq 4$ to 6 kV) are operated by laser triggered spark gaps (Morgan and Peacock 1971, Alcock and Richardson 1970), krytrons (Hyer *et al* 1975, Billman and Burnham 1970, Ley *et al* 1970, Hyde *et al* 1977, Scott *et al* 1976, Pearce and McLead 1977), avalanche circuits (Davis *et al* 1978, Brasseur *et al* 1975) and planar triodes (Martin *et al* 1979, Davis and Gagnon 1980). Kerr cell switches have a high half wave voltage ($V_{\lambda/2} = 10$ to 20 kV) and have only been used with laser triggered spark gaps (Von der Linde *et al* 1970, De Maria *et al* 1967). Semiconductor triggered Pockels and Kerr cell shutters are not applicable to pulse switching from mode locked or free running lasers since a single short (subnanosecond) light pulse is needed for reliable switching the semiconductor to the conductive state (Auston 1975, Lee 1977, Antonetti *et al* 1977, Mourou *et al* 1980).

In this paper a 16 kV krytron system and a 30 kV krytron activated spark gap system are described. The pulse generators are used to operate a Kerr cell shutter for the selection of single picosecond light pulses from a mode locked Nd–glass laser and for the separation of nanosecond pulses from a free running Nd–glass laser.

Kerr cell shutters yield higher blocking ratios (≈ 10000) than Pockels cell shutters (≈ 1000). The operation of Kerr cells with krytron pulse generators or krytron triggered spark gaps allows pulse selection at adjustable time positions. The amplitude fluctuation of the separated pulses is reduced to a few per cent. A synchronisation pulse generated in the krytron system is available for synchronisation of further switches and gating of detection systems (Biebl and Penzkofer 1980).

2 Krytron pulse generator

The krytron pulse generator consists of a trigger section, an avalanche transistor chain, two krytrons in series with high voltage charging facility and a pretrigger unit.

The circuit of the trigger section and the avalanche chain is described in a previous report (Biebl and Penzkofer 1980) and is only slightly modified ($R_8 = R_6 = 0$, $R_5 = 1\ \Omega$; a capacitor of 22 nF is added parallel to R_{11}). The krytron stage and the pretrigger section are shown in figure 1(*a*). Two krytrons KN22B (EG&G Electro-optics division data sheet K 550 B-2) in series are used (EG&G application note K550313-A, for high-voltage krytron systems see also Lippitsch *et al* 1978). The self-breakdown threshold of the krytrons is > 8 kV. A

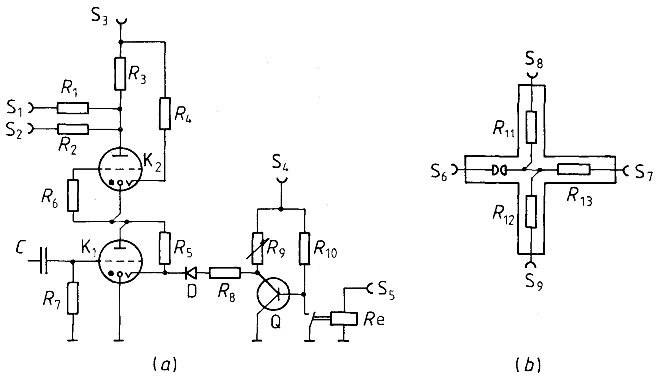

Figure 1 (*a*) Krytron pulse generator. Trigger section and avalanche chain is omitted. Resistors: $R_1 = R_2 = 45\ \Omega$, $R_3 = 40\ \mathrm{M\Omega}$, $R_4 = R_5 = 24\ \mathrm{M\Omega}$, $R_6 = R_7 = 1\ \mathrm{M\Omega}$, $R_8 = 220\ \mathrm{k\Omega}$, $R_9 = 175\ \mathrm{k\Omega}$, $R_{10} = 100\ \mathrm{k\Omega}$. Capacitor: $C = 500$ pF (6 kV). Krytrons: K_1 and K_2, KN22B (EG&G). Diode: D, 5AV60 (International Rectifier). Transistor: Q, BF459 (Siemens). Reed relay: Re (trigger threshold 1.5 V). (*b*) Spark gap. Resistors: $R_{11} = R_{12} = 50\ \Omega$, $R_{13} = 200\ \mathrm{M\Omega}$.

bias voltage V_K of up to 16 kV is applied at S_3. It charges two 50 Ω coaxial cables L_1 and L_2 which are connected to the krytron system at S_1 and S_2. The keep-alive current for the krytrons ($\simeq 300\ \mu$A) is derived from V_K with resistors R_4 and R_5. The krytrons are fired with a pulse from the avalanche chain via capacitor *C*. Before triggering the krytrons the keep-alive current through krytron K_1 is increased to about 600 μA for a duration of 1 ms by switching off transistor Q with relay Re. A voltage of $V_P \simeq 300$ V is applied to this pretrigger system at S_4 (see Cunin *et al* 1980).

When the krytrons are fired at time $t = 0$ to the conductive state, the pulse forming cables L_1 and L_2 are discharged and a voltage pulse of $V = V_K$ is generated between the ends of the cables starting at $t = l_1/v$ and lasting for a duration $\Delta t = (l_2 - l_1)/v$ (l_1, l_2, cable lengths, $v \simeq 0.66c \simeq 200$ mm ns^{-1} signal velocity). The resistors R_1 and R_2 are adjusted to optimum impedance matching to avoid voltage reflections.

For the krytron triggered Kerr cell system the cables L_1 and L_2 are connected to the electrodes of the Kerr cell. In the krytron activated spark gap only cable L_1 is used for firing the spark gap.

3 Krytron activated spark gap

The spark gap is shown schematically in figure 1(*b*). The distance between the two brass electrodes is about 1 mm. The self-breakdown threshold voltage V_B is regulated with pressurised nitrogen gas. The spark gap is connected to the krytron system by line L_1 (between S_1 and S_6). A high voltage V_S of up to 30 kV is applied at S_7. The pulse forming cables

L_1' and L_2' are attached at S_8 and S_9 and connected to the electrodes of the Kerr cell. The voltage across the spark gap electrodes $V_S - V_K$ is chosen slightly below the self-breakdown threshold V_B. When the krytron system is triggered the voltage at S_6 drops to zero and the spark gap fires immediately ($V_S \gg V_B$). The cables L_1' and L_2' are discharged and produce a voltage pulse of $V = V_S$ for a duration of $\Delta t = (l_2' - l_1')/v$ at the Kerr cell. The spark gap is recharged via resistor R_{13}. The applied operation principle is different from two-electrode laser triggered spark gaps (Bettis and Guenther 1970, Alcock *et al* 1970, Milam *et al* 1972, Deutsch 1968, Bradley *et al* 1969, Von der Linde *et al* 1970) and three-electrode systems triggered by a high voltage pulses (Kukhta and Logachev 1976, Pulsar associates application note P-0377, 1977).

4 Experimental setup

The performance of the Kerr cell shutter was tested with a Nd–glass laser in mode locked (with saturable dye) and free running mode (without saturable dye). The experimental setup is shown in figure 2. A beam splitter reflects a small part of laser light to photodetector PD1 which triggers the high voltage pulse generator PG (krytron system or krytron–spark gap system). The pretrigger relay is activated by a pulse generator PPG which is synchronised to the laser control unit LCU.

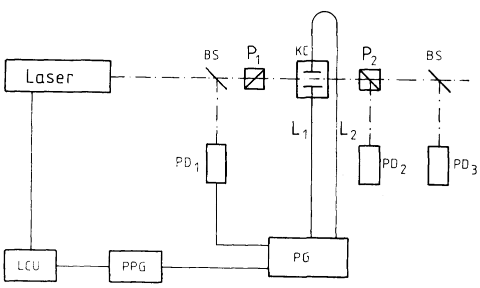

Figure 2 Experimental setup. BS, beam splitters; P_1, P_2 glan polarisers; KC, Kerr cell; PD_1–PD_3 photodetectors; L_1, L_2 pulse forming cables; LCU, laser control unit; PPG, pulse generator; PG, krytron pulse generator or krytron–spark gap system.

The glan polarisers P_1 and P_2 are crossed and the laser light is directed to photodetector PD_2. The high voltage pulse from the krytron or krytron–spark gap system changes the polarisation of the input light and polariser P_2 transmits light to detector PD_3.

5 Performance of pulse selection

Figure 3(*a*) depicts a light signal which is selected from the free running laser with the krytron triggered Kerr shutter. The difference length of the cables was $\Delta l = l_2 - l_1 = 1.7$ m. A voltage of $V_K = 16$ kV was applied to the krytron system for complete pulse switching. The separated pulse has a half width of 10 ns. Its width at one tenth of peak height is 15 ns.

A shorter pulse of 6 ns half width and 10 ns width at one tenth of peak height was selected with the krytron–spark gap triggered Kerr shutter as shown in figure 3(*b*). The same cable difference of $\Delta l = 1.7$ m was used. The optimum voltage at the spark gap increased to $V_S \simeq 26$ kV. The krytron voltage was adjusted to $V_K = 14$ kV. The spark gap was pressurised up to 0.8 MPa (8 bar) and the self-breakdown voltage was $V_B = 12$ kV.

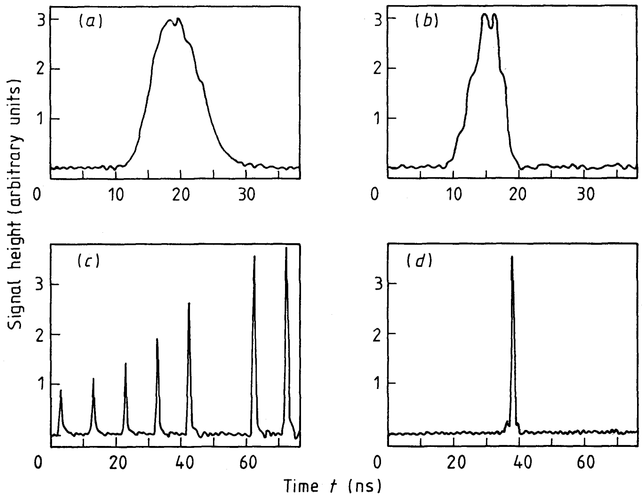

Figure 3 Pulse shapes. (*a*) Signal selected from free running laser with krytron triggered Kerr shutter. Cable difference $\Delta l = 1.7$ m; voltage $V_K = 16$ kV. (*b*) Pulse selected with krytron–spark gap triggered Kerr system. $\Delta l = 1.7$ m, $p = 0.7$ MPa (7 bar), $V_K = 14$ kV, $V_S = 25$ kV. (*c*) Mode locked pulse train detected with photocell PD_2. Krytron–Kerr shutter is used. $\Delta l = 1.7$ m; $V_K = 16$ kV. (*d*) Single picosecond pulse separated with krytron triggered Kerr shutter.

Figure 3(*c*) shows a mode-locked pulse train where one pulse was selected with the krytron–Kerr cell shutter (krytron parameters as in figure 3(*a*)). A selected single picosecond pulse is seen in figure 3(*d*).

The light transmission through the Kerr shutter is depicted in figure 4. The solid curve is calculated from the theoretical

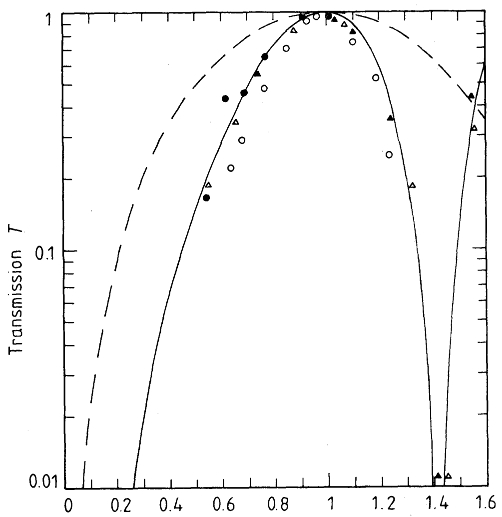

Figure 4 Light transmission through shutter. Full curve, calculated for Kerr shutter. Broken curve, calculated for Pockels cell switch. ○, krytron triggered Kerr cell with $\Delta l = 2.8$ m ($V_{\lambda/2} = 11.7$ kV); △, steady state transmission through krytron-Kerr cell system ($\Delta l = 18$ m, $V_{\lambda/2} = 9$ kV); ●, transient peak transmission through krytron–spark gap Kerr cell system with $\Delta l = 1.7$ m ($V_{\lambda/2} = 26$ kV); ▲, steady state transmission through krytron-spark gap activated Kerr system ($\Delta l = 18$ m, $V_{\lambda/2} = 13.4$ kV).

relation $T=\sin^2[(V/V_{\lambda/2})^2\pi/2]$. The open circles ($\Delta l=2.8$ m $V_{\lambda/2}=11.7$ kV) and triangles ($\Delta l=18$ m, $V_{\lambda/2}=9$ kV) were measured with the krytron triggered Kerr system. The closed circles ($\Delta l=1.7$ m, $V_{\lambda/2}=26$ kV) and triangles ($\Delta l=18$ m, $V_{\lambda/2}=13.4$ kV) were obtained with the krytron–spark gap Kerr shutter. The transmission $T(V/V_{\lambda/2})$ was found to be independent of Δl. The dashed line of figure 4 shows the theoretical transmission of a Pockels cell shutter ($T=\sin^2[\pi V/(2V_{\lambda/2})]$). A comparison of the transmission curves indicates that weak voltage pulses (e.g. from cable reflections) open the Kerr cell shutter less than a Pockels cell shutter.

The optimum switching voltage $V_{\lambda/2}$ depends on the difference of the cable length Δl as shown in figure 5(*a*). For large values of Δl, $V_{\lambda/2}$ reduces to a steady state value of 9 kV in case of the krytron–Kerr cell system and 13.4 kV for the krytron–spark gap–Kerr cell system (distance between Kerr plates 3.5 mm, length of Kerr electrodes 40 mm).

The half widths and 1/10-widths of the pulses separated

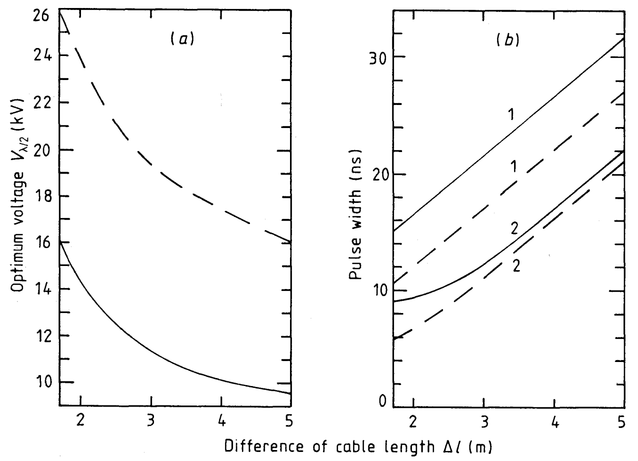

Figure 5 Experimental optimum switching voltage (*a*) and pulse widths (*b*) against difference length of charging cables. Full curves, krytron triggered Kerr shutter. Broken curves, krytron-spark gap triggered Kerr cell system. 1, pulse width at one tenth of peak height; 2, half width.

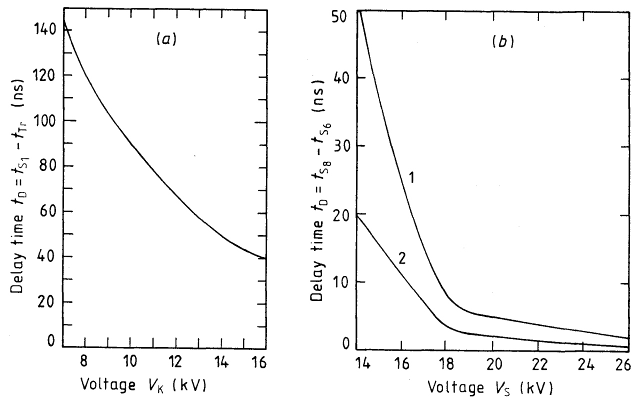

Figure 6 Delay times. (*a*) Krytron system. Measured delay time between onset of cable discharge and input trigger signal. (*b*) Spark gap. Time delay between cable discharge and voltage drop at input electrode. 1, nitrogen pressure $p=0.6$ MPa (6 bar), self-breakdown voltage $V_B=12$ kV, krytron voltage $V_K=14$ kV. 2, $p=0.8$ MPa (8 bar), $V_B=12$ kV, $V_K=14$ kV.

from the free running laser are shown in figure 5(*b*). The krytron–spark gap triggered Kerr shutter gives shorter pulse widths than the krytron triggered device.

The time delay between signal output at the high voltage pulse generators and the trigger input is analysed in figure 6. The time difference $t_D=t_{S1}-t_{Tr}$ between onset of cable decharging t_{S1} and the leading edge of the trigger signal at the trigger input t_{Tr} is plotted in figure 6(*a*). The standard deviation of the delay (jitter) was 1.5 ns at $V_K=16$ kV and increased to 2.5 ns at $V_K=9$ kV. Without pretrigger the delay increased by 10 ns and a jitter of 3 ns was measured at $V_K=16$ kV. The time delay in the trigger transistor and avalanche chain was 11 ns.

The time delay between firing the spark gap and removal of voltage at S_6, $t_D=t_{S8}-t_{S6}$, depends on the charging voltage V_S, on the nitrogen pressure p and the self-breakdown threshold V_B. Two curves are presented in figure 6(*b*). For pressure $p<0.5$ MPa (5 bar) the spark gap operates unreliably. The jitter of the complete krytron–spark gap system was 2.5 ns for $V_S \geqslant 20$ kV, $V_K=14$ kV, $p=0.6$–0.8 MPa (6 to 8 bar) and $V_B=10$ to 13 kV (see also Kukhta and Logachev 1976).

The switching position is easily varied with filters in the detector PD1. In the free running laser mode the signal height at the switching position fluctuated by 1.5% for both the krytron and krytron–spark gap Kerr shutter. In the mode locked case the height of the selected pulses varied by about 10%, when pulses were selected in the rising part of the pulse train. This pulse height selective switching results in a well defined switching position. Slight changes of the switching position occur due to variations in the shape of the pulse trains.

Outside the switching region the light transmission through the Kerr shutter was about 1.6×10^{-4}. The transmission of the picosecond pulse following the switched pulse is about 1% in the case of the krytron–spark gap Kerr shutter and about 5% in the case of the krytron–Kerr system (pulse separation is 10 ns). The light transmission through the shutter due to voltage reflections of the charging cables is about 2% in both systems.

The pulse selection was performed at a repetition rate of 0.1 Hz. The repetition rate is limited by recharging of the pulse forming cables and the recovery of the krytrons (EG&G data sheet K5500 B-2) and spark gap (EG&G data sheet G6000 E-1). A rate of up to 50 Hz should be possible.

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