

## DESIGN NOTE

# A high-voltage pulse measuring system based on the Kerr effect

John Phillip and T A Prasada Rao

Laser Laboratory, Department of Physics, Indian Institute of Technology, Madras 600 036, India

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**Abstract.** The performance of a high-voltage pulse measuring system based on the Kerr effect is investigated with benzoyl chloride, *o*-nitrotoluene, acetophenone, acetonitrile, benzaldehyde and ethyl methyl ketone for the first time along with nitrobenzene and acetone that are well known. These investigations have been carried out using high-voltage pulse fields ranging from  $4 \times 10^5 \text{ V m}^{-1}$  to  $10^7 \text{ V m}^{-1}$ . The experimentally determined electric field from the Kerr signal and the applied field show good agreement.

## 1. Introduction

High-voltage pulse measuring techniques based on the Kerr effect have been studied by various authors (Ettinger and Venezia 1963, Wunsch and Erteza 1964, Cassidy *et al* 1968) using nitrobenzene as the Kerr medium. The advantages of a Kerr cell high-voltage measuring system over conventional methods are due to the electrical isolation between the pulse circuit and the detection system, which is extremely helpful in eliminating the induced voltages and the ground currents in the measuring system, the high-frequency response of the system that allows the measurement of pulses with nanosecond risetimes, and good resolution and accuracy.

If a light beam of frequency  $\omega_1$  passes through a liquid subjected to an electric field, the refractive index for the light polarized parallel to the electric field direction is different from the refractive index for the light polarized perpendicular to the field direction. The phase difference  $\delta$  between the parallel and perpendicular components of light after traversing the liquid is given by

$$\delta = 2 \pi l B E^2 \quad (1)$$

where  $l$  is the length of the Kerr cell,  $B$  the Kerr constant and  $E$  the electric field strength. The phase difference  $\delta$  can be determined from the light intensity  $I$ , using a crossed polarizer and analyser, by the relation

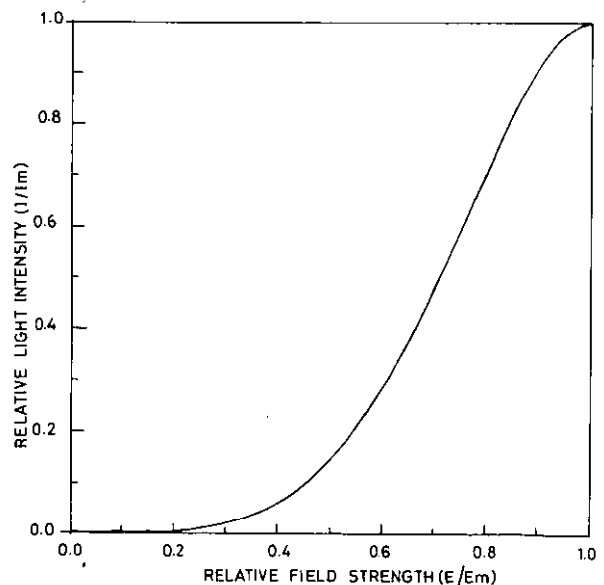
$$I = I_0 \sin^2 (\delta/2) \quad (2)$$

where  $I_0$  is the maximum intensity of the probe beam. The intensity  $I$  at any instant depends on the strength

of the electric field due to the applied voltage given by (Wunsch and Erteza 1964)

$$I/I_m = \sin^2 [\pi/2(E/E_m)^2] \quad (3)$$

where  $I_m$  is the maximum intensity transmitted by the system and  $E_m$  is the electric field strength required to produce the first transmission maximum. The relative intensity  $I/I_m$  of the transmitted beam as a function of relative field strength  $E/E_m$  is shown in figure 1. Maximum transmission occurs when  $E/E_m$  becomes 1, 1.732, 2.236, etc, and minimum transmission occurs when



**Figure 1.** The relative transmitted light intensity as a function of relative field strength.

$E/E_m$  becomes 0, 1.4142, 2.0, etc. The relative strength  $E/E_m$  of the field due to an applied voltage is determined using an oscilloscope and photomultiplier tube. The equations (Cassidy *et al* 1968)

$$E/E_m = [n + (2/\pi) \sin^{-1} (I/I_m)^{1/2}]^{1/2} \quad (4)$$

$$E/E_m = [(n + 1) - (2/\pi) \sin^{-1} (I/I_m)^{1/2}]^{1/2} \quad (5)$$

have been used to determine the relative field strengths  $E/E_m$  for increasing and decreasing values of  $I/I_m$ , respectively. Here  $n$  is the number of maxima and minima traced by the waveform prior to the instant of measurement.

## 2. Experimental set-up

Kerr cells of length  $l = 5$  cm with electrode separations of 0.2, 0.5 and 0.7 cm were constructed for the investigations. A DC power supply up to 25 kV was used to induce birefringence in the medium. A helium-neon laser of 5 mW power was used as a probe beam. The electric field vector of the beam had to be oriented at  $45^\circ$  to the polarization of the birefringent liquid for maximum sensitivity (Benoit 1949). The output of the photomultiplier tube (RCA IP28) was taken from a resistive load and was fed to an Iwatsu oscilloscope (250 MHz) fitted with a polaroid camera. The high-voltage electric pulse that causes birefringence was also recorded simultaneously using a Tektronix P6015 high-voltage probe (1:1000) for better accuracy. In order to avoid saturation upon the photomultiplier tube, Schott filters were used in this experiment. The experimental arrangement is shown in figure 2.

## 3. Results and discussion

A typical photograph of the photomultiplier tube output signal and the voltage pulse recorded simultaneously when  $E/E_m < 1$  in benzoyl chloride is shown in figure 3. This photograph shows the Kerr signal following the applied voltage pulse without being modulated. For values of  $E/E_m > 1$ , a modulated signal output is obtained and the applied voltage can be determined accurately using equations (4) and (5). A typical modulated Kerr signal and the applied electric pulse in benzoyl chloride is shown in figure 4. Values of the Kerr constant

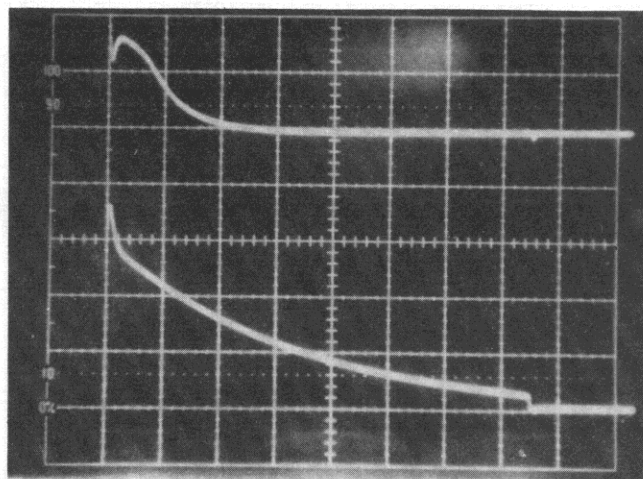


Figure 3. Polaroid photograph of the Kerr signal (upper trace) and the high-voltage pulse (lower trace) when  $E/E_m < 1$  in benzoyl chloride.

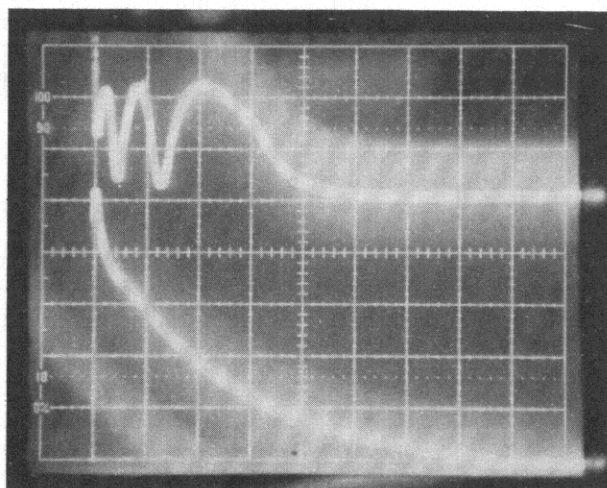


Figure 4. Polaroid photograph of the Kerr signal (upper trace) and the high-voltage pulse (lower trace) when  $E/E_m > 1$  in benzoyl chloride.

obtained in eight pure liquids (Philip and Prasada Rao 1990) are given in table 1. The variation of  $V_{max} (E_m \cdot d)$ , required to produce the first maximum transmission for different liquids with electrode separations is shown in figure 5. The values of  $E/E_m$  obtained from the Kerr signal intensities  $I/I_m$ , for an electrode separation 0.2 cm,

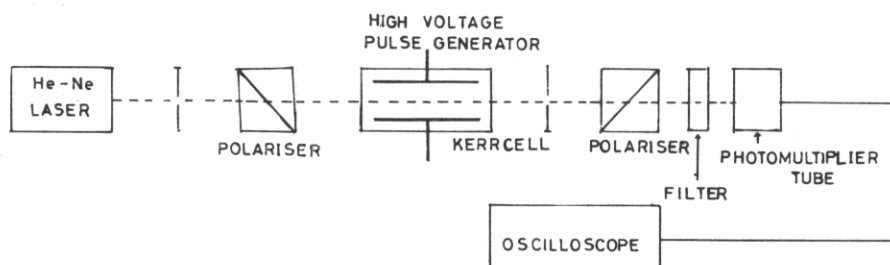


Figure 2. The Kerr electro-optical system.

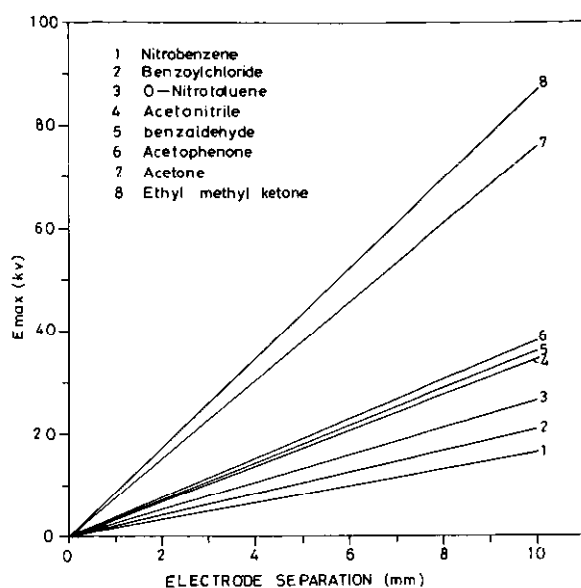


Figure 5. Electrode separation against first maximum transmission voltage.

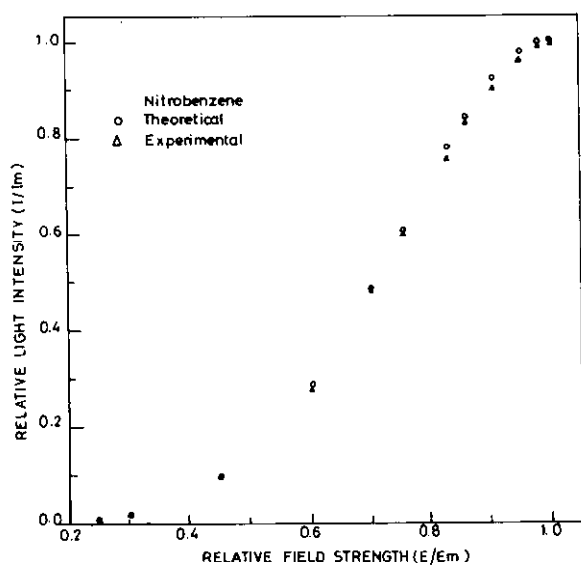


Figure 6. Relative transmitted light intensity as a function of relative field strength in nitrobenzene.

are compared with the values obtained theoretically using equation (3) for nitrobenzene and acetonitrile and are shown in figures 6 and 7, respectively. Excellent agreement is found between the theoretical and experimental values in all the liquids investigated. Field distortion was low in the cell with a 0.2 cm electrode separation, and considerable in the cells with 0.5 cm and 0.7 cm separations. In the cell with a 0.2 cm electrode separation, internal corona was observed for values

Table 1. Experimental values of the Kerr constant.

Liquid	Kerr constant, $B$ ( $10^{15} \text{ m V}^{-2}$ )
Acetonitrile	832
Benzaldehyde	764
Acetophenone	691
Acetone	172
Ethyl methyl ketone	132
o-nitrotoluene	1433
Nitrobenzene	3552
Benzoyl chloride	2260

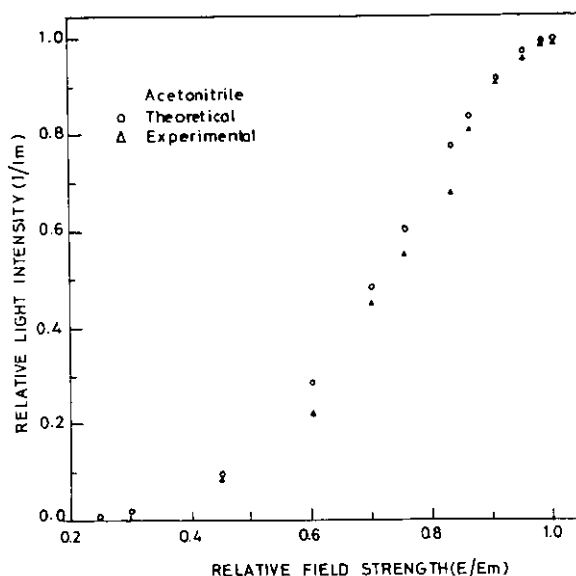


Figure 7. Relative transmitted intensity as a function of relative field strength in acetonitrile.

$E/E_m > 4$ : this could be avoided by using cells with a greater electrode separation at higher voltages.

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