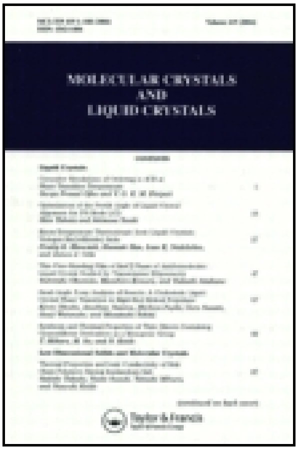

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Low Frequency Electrooptical Oscillations in a Liquid Crystal Display-Photoresistor System

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Version of record first published: 20 Apr 2011.

To cite this article: A. Derzhanski & N. Shonova (1983): Low Frequency Electrooptical Oscillations in a Liquid Crystal Display-Photoresistor System, Molecular Crystals and Liquid Crystals, 95:1-2, 91-99

To link to this article: http://dx.doi.org/10.1080/00268948308072411

Mol. Cryst. Liq. Cryst., 1983, Vol. 95, pp. 91–99
0026-8941/83/9502-0091/$18.50/0

Printed in the United States of America

Low Frequency Electrooptical Oscillations in a Liquid Crystal Display-Photoresistor System

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(Received May 15, 1982; in final form January 24, 1983)

The conditions for generating low frequency electrical and optical oscillations in a liquid crystal cell-photoresistor system with a frequency dependent electrooptical feedback are treated theoretically and verified experimentally. The equivalent circuit of the system may be represented by three RC groups. There is in this configuration a frequency where the phase shift will be η, and suitable condition for oscillations will arise. The equivalent circuit of the liquid crystal cell is considered and differential equations characterizing the transition are derived when applying a single rectangular pulse. A comparison between the theoretical and the experimentally plotted transient characteristics is made. The differential equation constants are determined from the experimentally obtained plots using the least squares method. The quasiresonance frequency of the liquid crystal cell is given by the solution of the differential equation. The obtained experimental data verifies the theoretical predictions.

INTRODUCTION

The trigger effect in a liquid crystal cell-photoresistor system with electrooptical positive feedback has been described in an earlier paper published by the authors.[1] It has been shown that at certain value of supply voltage and intensity of luminous flux the system exhibits two stable states:

a) first, when the liquid crystal cell is opaque and the photoresistor value is high.

b) second, when the liquid crystal cell is transparent and the photoresistor value is low.

The present paper deals with experimental and theoretical investigation of continuous electrooptical low frequency oscillations obtained in a serial connection of a liquid crystal cell, photoresistor, and voltage supply, illuminated by a common light source.

In our case, however, negative feedback for a DC voltage signal ($f = 0$) occurs. From the considerations made below, it is clear that this feedback is frequency dependent and the low frequency electrooptical oscillations may arise provided the phase shift equal to π and certain additional conditions are fulfilled.

An automatically controlled electrooptical stabilizer based on the presence of negative DC feedback between the liquid crystal cell and the driving circuit has been described by Chistjakov, *et al.*[2]

EXPERIMENTAL

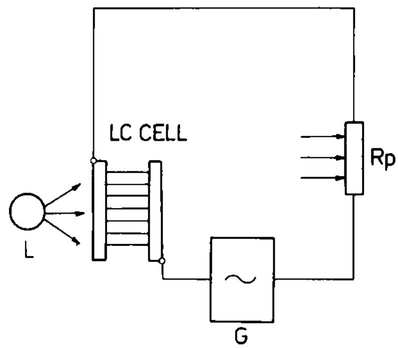
The principal set-up is shown in Figure 1a. In this case the liquid crystal cell, the supply source and the photoresistor are connected serially, i.e. there exists electrical feedback. The liquid crystal display is directly subjected to light source L. The intensity of the light transmitted is modulated by the change in the transparency of the liquid crystal cell; then the light illuminates the photoresistor. This is the optical feedback.

The system consists of two serially connected four-poles: the liquid crystal cell with electrical input and optical output, and the photoresistor with optical input and electrical output. The liquid crystal cell acts in a dynamic scattering mode (DSM); it then follows that the transparency of the liquid crystal element decreases with an increase in the input voltage. In the case when negative feedback occurs, this feedback may become positive if the total phase shift is equal to π.

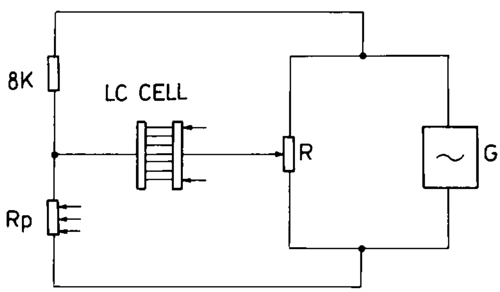
The liquid crystal cell used in our experiment has a "sandwich" construction, an active area of about 1 cm^2 and a thickness of 10 mm for the liquid crystal layer. The liquid crystal material was introduced between two glass plates covered inside by a transparent conductive layer of SiO_2. The liquid crystal possesses negative dielectric anisotropy (Merck 4). Its nematic phase exists at room temperature.

The photoresistor is of the type ϕ K–1, manufactured by Electroimpex Bulgaria (time constant $\tau_p = 1.5$ msec., $\alpha = R/R_0 = 5$, where R is the value of photoresistance and R_0 is the value of resistance in the dark). The current through the photoresistor is about 10 mA. The light source is an Na lamp with variable intensity. An AC power supply is used—20 Hz, about 20 V. In the experiment, a bridge circuit was used to obtain better sensibility and resistance fitting (Figure 1b).

Oscillations with a frequency of about 3.5 Hz and amplitude of 3,5 V were obtained and recorded by X-t recorder, type Endim 620.02 (Figure 2).



(a)



(b)

FIGURE 1

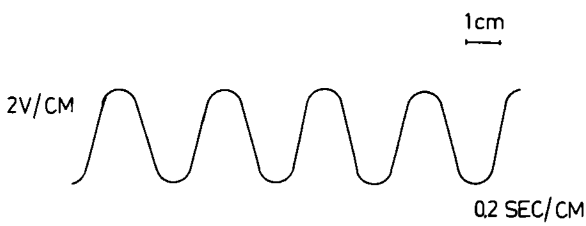


FIGURE 2

Determination of transient characteristic of a liquid crystal cell and analysis of its shape

From,[3,4] it is well known that transients in a liquid crystal cell are characterized by the following time factors:

τ_d–delay time
τ_r–rise time
τ_D–decay time
τ_d and τ_r are approximately proportional to U^{-2}.

The experimental set-up for determining the transient characteristic of the DSM liquid crystal cell is shown in Figure 3. The relay R is set into action by a symmetric voltage source with amplitude 12 V and duration 1. The liquid crystal cell is supplied by an audio-frequency generator through a contact of relay R. The signal from the photoelectric multiplier PEM giving the change of the Wehnelt cylinder of the oscilloscope is modulated through another contact of the relay R.

The experimentally determined transient characteristic of the liquid crystal cell is obtained by averaging four curves registered by the set-up shown in Figure 4.

The analysis of this characteristic permits us to make the following conclusions: the slope in the rise of the pulse, as well as in the fall, has two values corresponding to the two different processes which take place in the liquid crystal cell: the first section of the rise has a larger slope relative to the second section, while the falling part of the pulse possesses the opposite change in the slope: i.e. a smaller slope in the first section and an increasing slope in the second section. In addition, time constants are approximately equal in the values.

Figure 4 plots a theoretically evaluated transient characteristic for two RC groups. It is clear that there is substantial agreement between the theoretically calculated characteristic and the experimental curve.

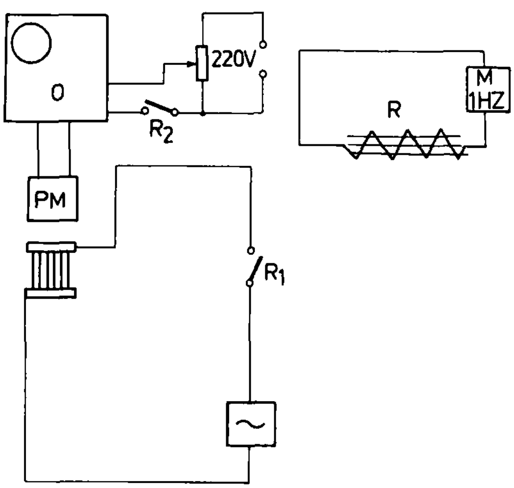


FIGURE 3

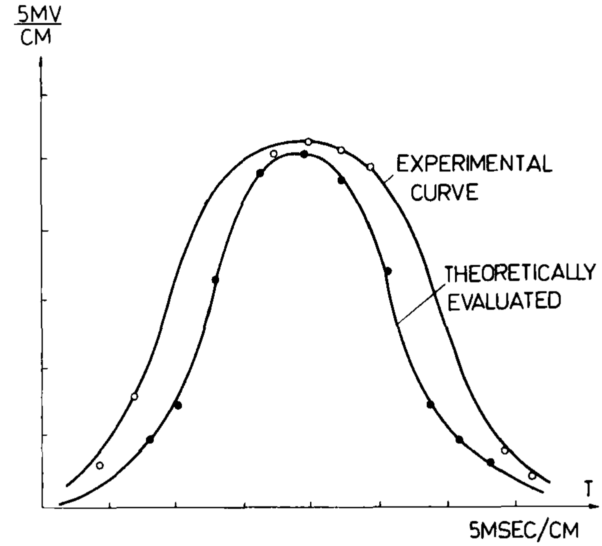


FIGURE 4

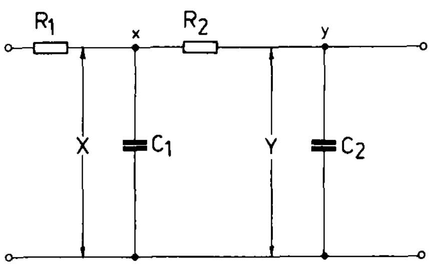


FIGURE 5

In conclusion, it follows that the liquid crystal cell exhibits the behavior of two RC groups with equal time constants in the transient regime (Figure 5).

Some theoretical considerations for calculating the frequency of oscillations

Using the conclusions in the previous part of this article, and taking into account that the photoresistor in a transient regime can be replaced by one RC group,[5] the equivalent circuit of the liquid crystal cell-photoresistor system can be shown as in Figure 6. The times corresponding to the RC

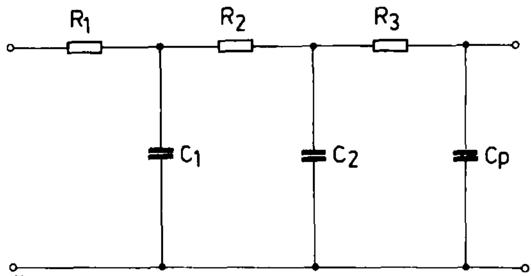


FIGURE 6

constants characterizing the liquid crystal cell are denoted by $\tau_1 = \tau_2 = \tau$. It is assumed that:

$$\tau_1 = \frac{1}{\omega_{r1}} = R_1C_1 \quad \text{and} \quad \tau_2 = \frac{1}{\omega_{r2}} = R_2C_2$$

Let X be the voltage at point x (Figure 5), and Y be the voltage at point y. Square wave voltage is applied at the input of the circuit given in Figure 5 with an amplitude U_0. The following relations based on the fundamental laws of electric circuit theory can be written:

$$\frac{dX}{dt} = \frac{i}{C} = \frac{U_0 - X}{R_1C_1} = \frac{U_0 - X}{\tau_1}$$

since

$$i = \frac{U_0 - X}{R_1} \quad \text{and} \quad R_1C_1 = \tau_1$$

we obtain:

$$\tau_1X' + X = U_0 \tag{1}$$

However:

$$Y' = \frac{X - Y}{R_2C_2}$$

and therefore:

$$\tau_2Y' + Y = X \tag{2}$$

If we differentiate once again with respect to t in Eq. (2), we shall obtain:

$$\tau_2Y'' + Y' = X' \tag{3}$$

Equations (1) and (3) represent system of two unknown, X and X'. The system can be solved and the final differential equation can be obtained in the form:

$$\tau_1\tau_2 Y'' + (\tau_1 + \tau_2)Y' + Y = U_0 \qquad (4)$$

The solution of differential Eq. (4), taking into account that:

$$\tau_1 = \tau_2 = \tau = \frac{1}{\omega_r}$$

is:

$$y(t) + U_0 = (B + At) \exp -\omega_r t$$

We assume in these calculations that the RC groups are decoupled, i.e. there is not mutual loading (this condition was realized in practice).

There is damping in the physical process and therefore ω_r is negative.

Using the transient characteristic from the experiment (Figure 4) and the method of the least squares[6] we can determine constants A and B:

(a) exp $\omega_r t$ is expanded in a series to the third power of t:

$$\exp \omega_r t = 1 + \omega_r t + \frac{(\omega_r t)^2}{2} + \frac{(\omega_r t^3)}{3} + \cdots$$

(b) the following expression is computed:

$$y(t) + U_0 = \exp \omega_r t[A(B + At) \exp \omega_r t + B]$$

$$= \left[1 + \omega_r t + \frac{(\omega_r t)^2}{2} + \frac{(\omega_r t)^3}{3} + \cdots\right](A + Bt)$$

$$= B + (A + \omega_r B)t + \omega_r\left(A + \frac{\omega_r B}{2}\right)t^2 + \frac{\omega_r^2}{2}\left(A + \frac{\omega_r B}{3}\right)t^3 + \cdots \qquad (5)$$

(c) using the method of the least squares for the average experimental transient curve:

$$a_1 = \frac{30 \times 70 \cdot 836}{2016} - 63 \times 4.428 = -0.33$$

$$a_2 = \frac{7.52}{84} = 0.09$$

$$a_3 = \frac{4.428}{8} + \frac{42 \times 0.033}{8} = 0.726$$

The third order function is of the type:

$$U_0 + y(t) = 0.726t + 0.09t^2 - 0.033t^3 \quad (6)$$

d) correlating equations (5) and (6) and equating the coefficients for the same power, we obtain:

$$B - U_0 = 0 \qquad A + \omega_r B = 0.726$$

$$\omega_r\left(A + \frac{\omega_r B}{2}\right) = 0.090$$

$$\frac{\omega_r^2}{2}\left(A + \frac{\omega_r B}{3}\right) = -0.033$$

The following quadratic equation for ω_r is obtained by eliminating A and B:

$$\omega_r^2 - 5\omega_r - 2{,}73 = 0 \qquad \omega_{r,1} = -0{,}5\ \text{sec}^{-1} \qquad \omega_{r,2} = 5{,}5\ \text{sec}^{-1}$$

For the reasons stated above, the negative root of ω_r is taken.

From the vector diagram shown in Figure 7, it can be seen that the first RC group rotates the input voltage at an angle γ. The second RC circuit shifts the input voltage once again by γ, so that the input voltage will be phase shifted after the first two RC groups at an angle $\pi - 2\gamma$. Let us denote the acute angle between the output voltage and the voltage from the two RC groups of the liquid crystal cell by Θ. It is clear that the following relations are valid:

$$\Theta = \pi - 2\gamma \qquad \frac{\Theta}{2} = \frac{\pi}{2} - \gamma \qquad \tan\frac{\Theta}{2} = \cot\gamma$$

$$\tan\Theta = \frac{R_3}{X_c} \qquad \cot\gamma = \frac{X_c}{R}$$

Taking into consideration that angle γ is small because the quasiresonance frequency of the liquid crystal cell is considerably smaller than that of the photoresistor, ($\omega_r = 10\ \text{sec}^{-1}$; $\omega_p = 1000\ \text{sec}^{-1}$, where ω_r is the quasi-resonance frequency of the liquid crystal cell, ω_p—quasiresonance frequency of the photoresistor), we can write the following:

$$\tan\frac{\Theta}{2} = \tan\frac{\Theta}{2}; \qquad \frac{R_3}{X_c} = \frac{\omega R_3}{C_p} = \frac{\omega}{\omega_p} \qquad \frac{X_c}{R} = \frac{1}{\omega RC} = \frac{\omega_r}{\omega}$$

where X_c is the capacitance of the two RC groups. We assume:

$$2\frac{\omega r}{\omega} = \frac{\omega}{\omega p}; \qquad \omega = (2\omega_r\omega_p)^{1/2}$$

From literature[7] it is known that ω_p of $\phi K - 1$ is equal to $2 \cap 10^2$. We obtain:

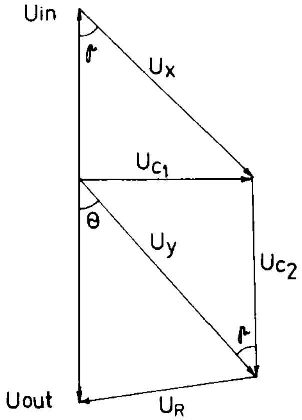


FIGURE 7

$$\omega = (2 \times 0.5 \times 6.28 \times 10^2)^{1/2} = 25.05 \text{ sec}^{-1};$$

$$f = \frac{25.05}{6.28} = 3.99 \text{ Hz}.$$

f is the frequency of oscillations.

CONCLUSION

Such a system, consisting of a liquid crystal display, photoresistor, a voltage supply and a light source produces sinusoidal electrooptical signals at a given interval of the supply voltage and intensity of the light source.

The measurement performed by experimental set-up shown in Figure 3 revealed that the oscillations obtained have a frequency of about 3,5 Hz. This value is in substantial agreement with the theoretically evaluated value of 3,9 Hz.

A set-up of this type can be utilized in automation, in optoelectronics, and in visual signalization displays. It possesses simplicity of construction and high operating economy.

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