Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

# The Effect of Dual-Frequency Addressing on the Electro-Optic Response of a PDLC Film

Zeyong Lin [a], James J. Sluss JR. [a], Theodore E. Batchman [a], Scott D. Heavin [b] & Bing M. Fung [b]

[a] School of Electrical Engineering and Computer Science, University of Oklahoma, Norman, OK, 73109-0370

[b] Department of Chemistry, University of Oklahoma, Norman, OK, 73109-0370

Version of record first published: 24 Sep 2006.

To cite this article: Zeyong Lin , James J. Sluss JR. , Theodore E. Batchman , Scott D. Heavin & Bing M. Fung (1992): The Effect of Dual-Frequency Addressing on the Electro-Optic Response of a PDLC Film, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 220:1, 29-38

To link to this article: http://dx.doi.org/10.1080/10587259208033426

*Mol. Cryst. Liq. Cryst.*, 1992, Vol. 220, pp. 29–38
Reprints available directly from the publisher
Photocopying permitted by license only

Printed in the United States of America



# The Effect of Dual-Frequency Addressing on the Electro-Optic Response of a PDLC Film

ZEYONG LIN, JAMES J. SLUSS, JR. and THEODORE E. BATCHMAN

*School of Electrical Engineering and Computer Science, University of Oklahoma, Norman, OK 73109-0370*

and

SCOTT D. HEAVIN and BING M. FUNG*

*Department of Chemistry, University of Oklahoma, Norman, OK 73109-0370*

*(Received December 9, 1991)*

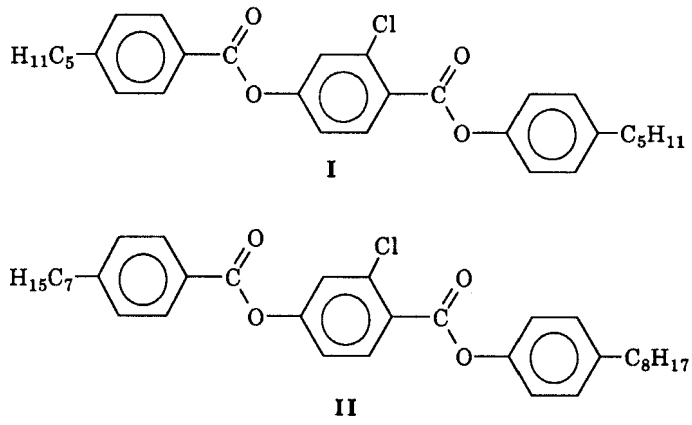
The effect of using dual-frequency addressing in the reduction of the response time in polymer dispersed liquid crystal (PDLC) displays has been investigated. The utilization of a second high frequency component of the driving voltage enables an added control of the waveform not possible in a single frequency addressed system. The use of dual-frequency addressing, combined with some special driving techniques, opens up the possibility of controlling the response of PDLC displays in sweeping-mode operations.

## INTRODUCTION

The presence of dielectric anisotropy in nematic liquid crystals is the basis for their applications in electro-optic devices. It has been established for some time[1–3] that the dielectric constant measured parallel to the long axis of a nematic liquid crystal, $\varepsilon_{\parallel}$, is highly dependent on frequency as well as temperature, while the dielectric constant measured perpendicular to the long axis, $\varepsilon_{\perp}$, is virtually independent of frequency up to the MHz range. Thus, a liquid crystal exhibiting a positive dielectric anisotropy ($\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp} > 0$) at low frequencies may exhibit a negative dielectric anisotropy at sufficiently high frequencies. The frequency at which $\Delta\varepsilon$ changes sign is called the cross-over frequency, and is highly dependent upon the structure and dipole properties of the liquid crystal. It usually ranges in values from kHz to MHz. The frequency dependence of $\Delta\varepsilon$ has been exploited to control the orientation of the liquid crystal director in an external field, especially by the use of dual-frequency addressing.[1–7]

In a PDLC sample, micro-droplets of liquid crystal material are evenly dispersed throughout a solid polymer matrix.[8–10] Liquid crystals exhibiting a positive $\Delta\varepsilon$ at

* Author to whom correspondence should be addressed.




I




II

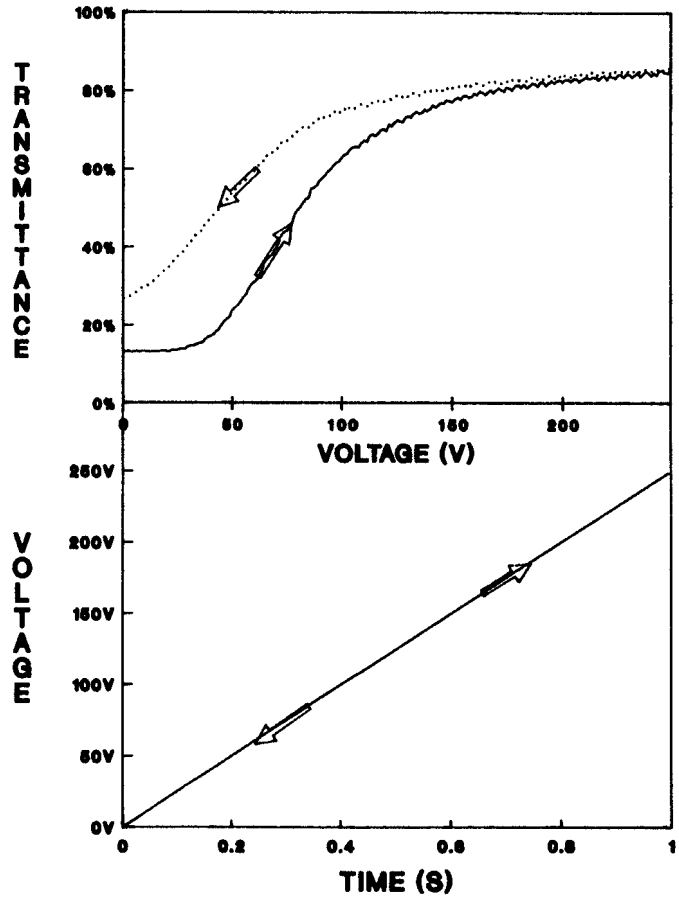



FIGURE 1 Top: Electro-optic response of the PDLC film demonstrating the hysteresis effect. The solid line indicates the response to an increasing voltage; the dotted line indicates the response to a decreasing voltage. Bottom: voltage ramp cycle driving the electro-optic response over a period of 2 seconds.

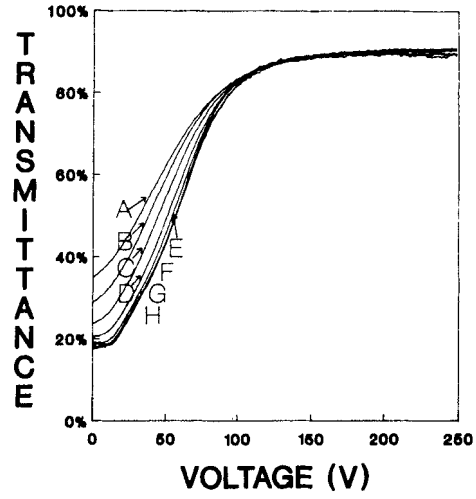



FIGURE 2 Electro-optic response of a PDLC film during the decreasing half of the voltage scan, demonstrating a reduction in hysteresis as the period of the voltage cycle is increased. Cycle time in s: A, 2; B, 4; C, 8; D, 16; E, 32; F, 64; G, 128; H, 256.

low frequencies align their optical axis parallel to an externally applied electric field. In this "on" state orientation, when the ordinary refractive index of the liquid crystal is properly matched to the isotropic refractive index of a suitable polymer, light directed normal to the sample is transmitted with a minimal amount of refraction and the sample appears clear. When the frequency of the applied field exceeds the crossover frequency, $\Delta\varepsilon$ becomes negative. The optical axis of the liquid crystal now aligns perpendicular to the electric field, driving the sample to the "off" state where it exhibits a milky white appearance. Compared to the "off" state at zero field, the "off" state induced by a high frequency (HF) field often exhibits an increased light scattering effect. Thus, the contrast ratio of the dual-frequency addressed sample can be higher than that of the single low frequency (LF) addressed sample.[4] Additionally, it has been shown that the multiplexing potential of a PDLC display can be significantly increased by applying simultaneous high frequency and low frequency driving voltages.[3,5] In this paper we report the use of dual-frequency addressing to improve the response time and to reduce the hysteresis effect associated with PDLC films.

## EXPERIMENTAL

*p*-Pentylphenyl 2-chloro-4-(*p*-pentylbenzoyloxy)benzoate (Kodak 11650) **I**, and its homolog *p*-octylphenyl 2-chloro-4-(*p*-heptylbenzoyloxy)benzoate (Kodak 15320) **II**, are two liquid crystals which exhibit cross-over frequencies low enough for dual-frequency applications.[2,4,5] A 1:1 weight ratio of these components exhibits a $\Delta\varepsilon$ of 6.1 at 50 Hz and a $\Delta\varepsilon$ of $-2.2$ at 10 kHz, 25°C.[2] Through the use of an Olympus 8071 polarizing microscope equipped with a Linkam PR-600 heating stage, we found that the nematic phase of the mixture was in the range of 15–98°C. The

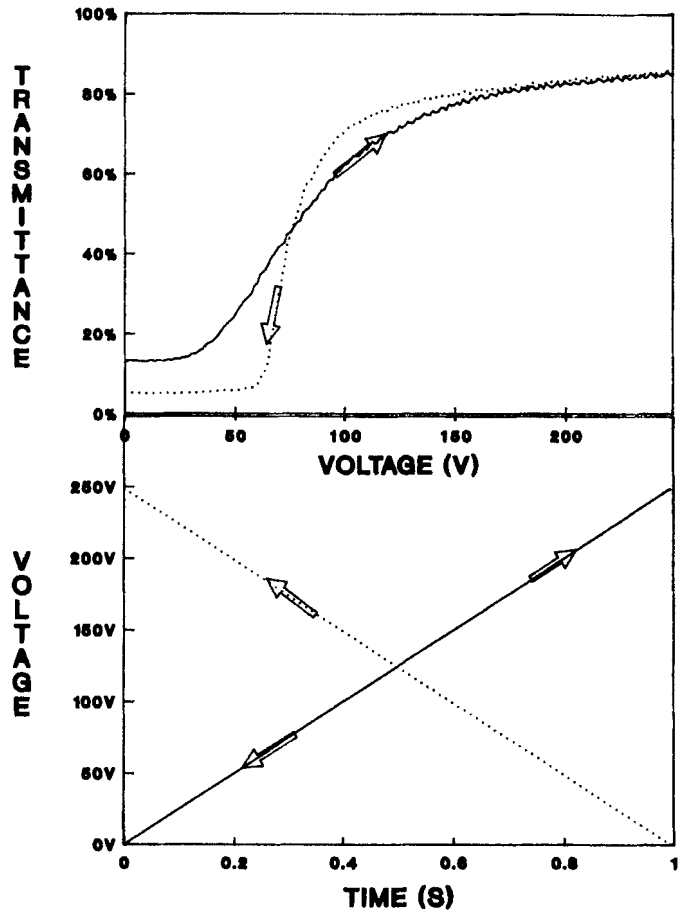



FIGURE 3 "Reverse" of the hysteresis effect on a PDLC film caused by the addition of a ramped HF component to the driving voltage during the decreasing half of the LF voltage cycle.

PDLC film was fabricated from the photopolymer NOA 65 (Norland Optical Adhesive), Kodak 11650 and Kodak 15320 in a 2:1:1 weight ratio. The construction of the experimental plate follows the procedure described by Vaz.[11] The photoactive polymer and liquid crystals were thoroughly mixed and sandwiched between two indium tin oxide coated glass substrates, separated by 25 μm glass micro-fibers (EM Chemicals). The sample was then placed on a heating state and cured under UV light at a constant temperature of 65°C. Measurements of the electro-optic response were performed according to procedures described previously[12]: the percent transmittance (%T) was measured using a He/Ne laser emitting 633 nm light; the laser beam was directed through a spatial filter and an iris to produce uniform illumination of the sample; the intensity of the beam transmitted through the sample was measured with a photodiode and monitored with a Zenith 386 personal computer (PC). For dual-frequency addressing, the driving waveforms were composed of a low frequency (1 kHz) component and a high frequency (6 kHz) component controlled with the PC and amplified to a desired voltage. The (%T) was calculated

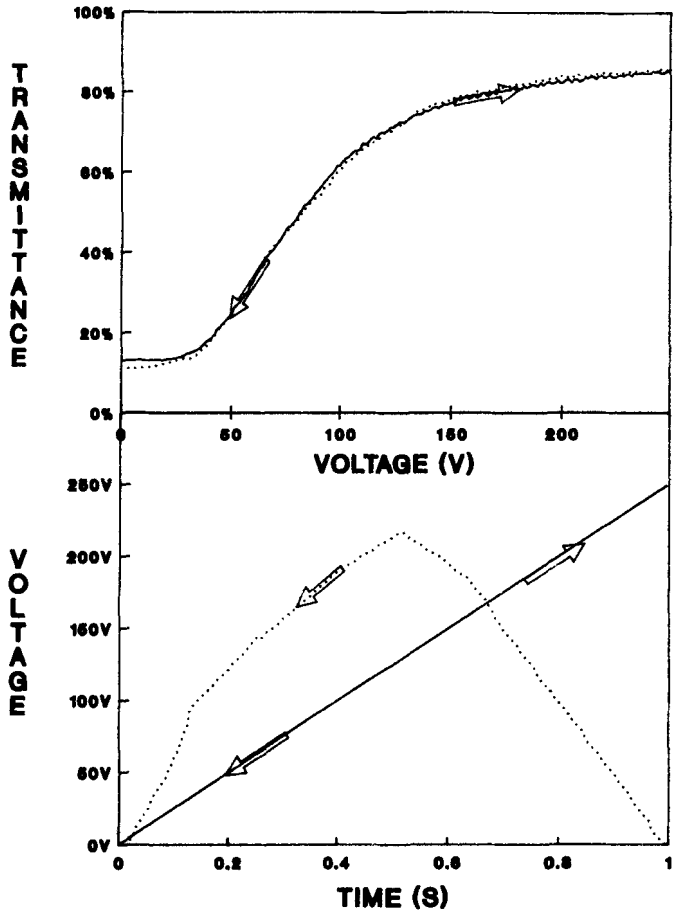



FIGURE 4 Electro-optic response of a PDLC film demonstrating the elimination of the hysteresis effect by using a "mapped" HF voltage component during the decreasing half of the LF voltage cycle.

with reference to a clear glass cell composed of a 25 μm thick transparent polymer film.

## RESULTS AND DISCUSSION

To study the hysteresis of the PDLC films, a LF sinusoidal waveform was ramped between 0 and 250 volts (peak-to-peak) to obtain the dependence of %T on voltage The result of the response for a ramping cycle of 2 s is shown in Figure 1. The solid curve is the response generated by the increasing half of the voltage cycle while the dotted curve is generated by the decreasing half of the voltage cycle. The difference in the shape and position of the two curves illustrates the familiar hysteresis effect commonly associated with PDLC displays.[13,14] The rates of both "switching on" and "switching off" depend on the rotational viscosity of the liquid crystal. In addition, the rate at which the liquid crystal directors align with the

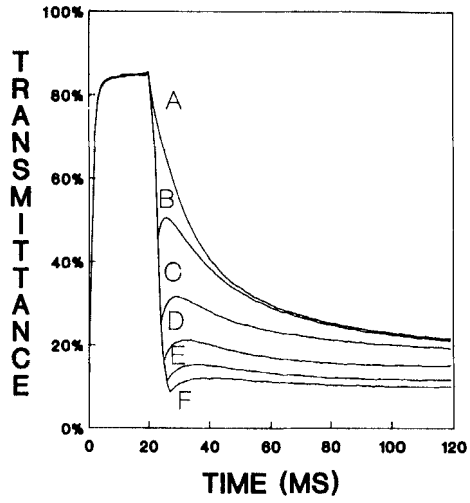



FIGURE 5 Electro-optic response of the PDLC film caused by an initial 20 ms LF pulse followed by a HF pulse, demonstrating the effect of the HF pulse width on the decay response. The widths of the HF pulses (in ms) were: A, 0; B, 3; C, 4; D, 5; E, 6; F, 7.

electric field during the increasing half of the voltage cycle is heavily dependent upon the driving voltage. Conversely, the rate at which the directors return to their original alignment in the decreasing voltage half-cycle is a diffusion controlled process determined by the surface interactions between the polymer and liquid crystal molecules at the droplet interface. These interactions are most likely responsible for the decreased decay times observed in PDLC's with smaller or sheared droplets compared to PDLC's which contain uniform spherical droplet shapes.[14–16] The difference in the two rate processes associated with the increasing and decreasing voltage results in the hysteresis effect. The extent of the effect is dependent upon the period of the cycle (Figure 2), and decreases rapidly with increasing cycle time.

To examine the effect of dual-frequency addressing, we used a short ramping cycle of 2 s to emphasize the hysteresis phenomenon, as shown in Figure 1. When a HF field is incorporated, the predominant force influencing director reorientation in the decreasing field is no longer derived from polymer/liquid crystal surface interactions, but rather from the electrical force associated with the HF field. If the HF component of the driving voltage is ramped to 250 V during the decreasing half of the LF cycle (see Figure 3), the optical response exhibits a very different form of hysteresis. Here, the HF field is superimposed on the LF field, causing the two forces to compete with each other. The actual orientation of the director depends on the relative magnitude of the two fields and the result is a highly reduced hysteresis effect. In fact, it was found that the effect can be almost completely eliminated by using a "mapped" high frequency waveform (Figure 4). Here, the voltage of the HF component is programmed so that the response during the decreasing half of the voltage cycle is forced to match the response of the increasing voltage half cycle. For the fast ramping experiment, the "mapped" HF waveform is somewhat dependent on individual samples because of variations in droplet size

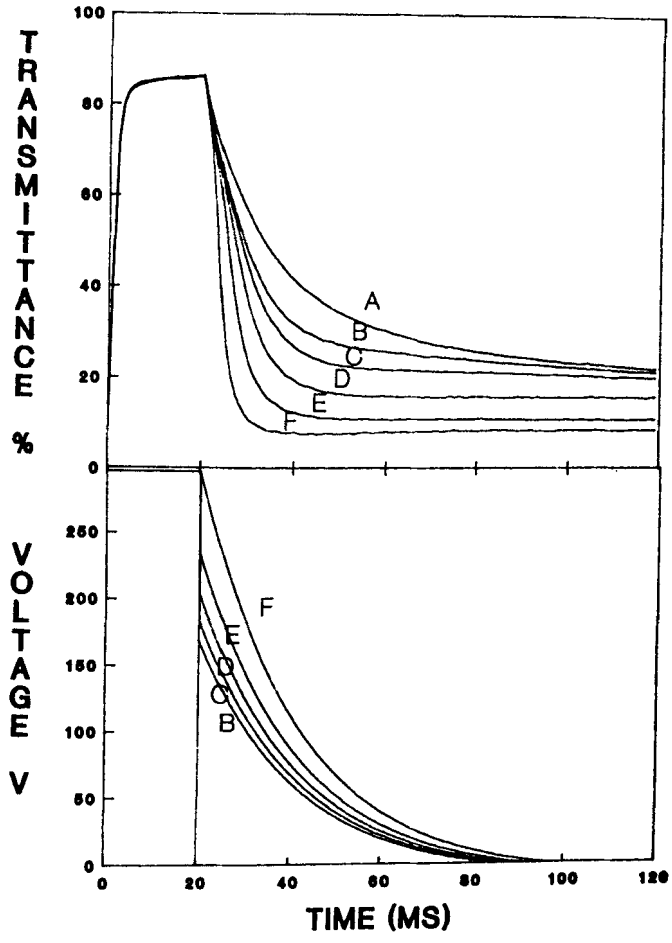



FIGURE 6 Removal of the overdrive in response associated with curves B–F in Figure 5 by applying the HF field in an exponentially decaying envelope.

and distribution from one sample to another. However, the results are more consistent when longer ramping periods are applied.

To study the optical response of the PDLC film to the different AC fields, pulsed waveforms were used. The PDLC film is turned "on" by a 20 ms low frequency pulse. At the end of the LF pulse, a HF pulse is applied which drives the PDLC towards the off state. The response curve depends on the duration of the HF pulse (see Figure 5). Using the HF component to turn off the optical response, the decay time of the PDLC film is reduced from 80 ms to 5 ms (HF pulse width $\geq$7 ms).

The increase in the contrast ratio caused by the overriding of the response exhibited by curves E and F in Figure 5 probably has no deleterious effect on PDLC electro-optic displays. Nevertheless, we have developed a method to eliminate the overriding effect by considering the physical basis of the optical response. The HF field forces the nematic director to align perpendicular to the field, resulting in a maximum amount of light dispersion. After the removal of the HF field, the

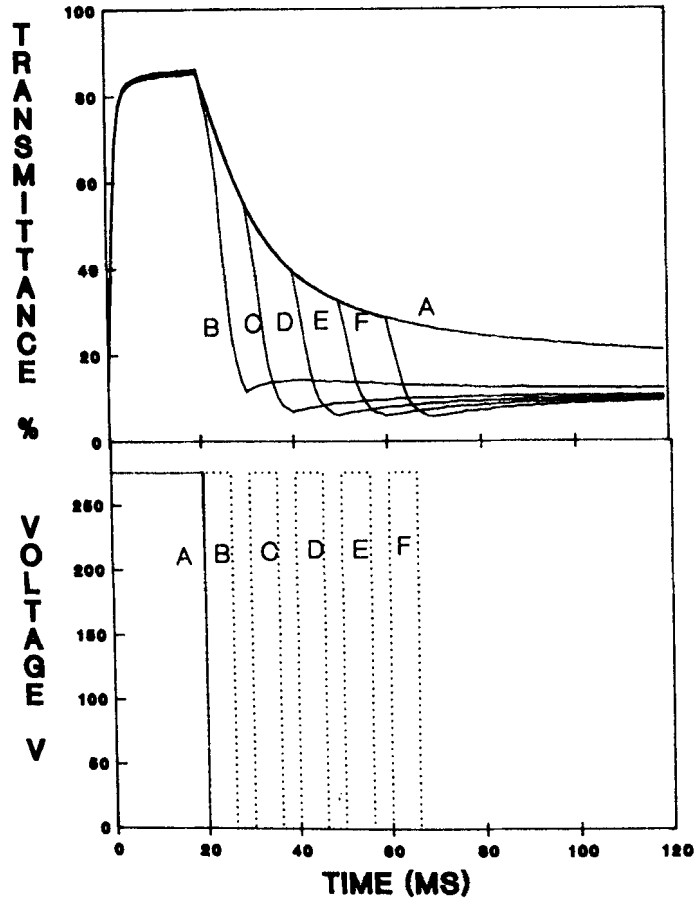



FIGURE 7 Control of the PDLC film decay response (top) by applying a rectangular HF pulse (bottom) at different times during the natural decay of the sample. Curves B through F are superimposed on curve A.

return to "random" alignment is expected to be an exponential process, again driven by the interactions associated with the polymer/liquid crystal interface. Therefore, a smooth optical response should be observed if the high frequency field is applied in an exponentially decaying envelope. Figure 6 shows that this is indeed the case. Here, the HF electric field near the end of the pulse is very weak, and the overdrive in response is not observed. The result is a smooth decay curve of controlled duration.

Another technique in controlling the decaying response of the PDLC is illustrated in Figures 7 and 8. Here a rectangular HF pulse (Figure 7) or an exponential HF waveform (Figure 8) is applied at different times during the natural decay of the sample. In effect, this enables a rapid termination of the transmittance decay at any desired time from 5 ms to 80 ms. It has been shown that the response time of PDLC films can be reduced by shearing the films to force the droplets into ellipsoidal shapes.[14] However, droplet shaping also causes the threshold voltage to

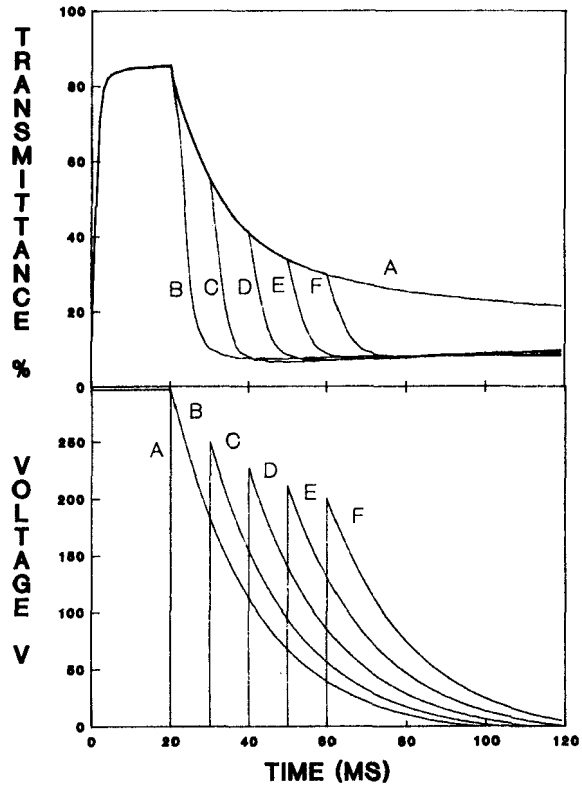



FIGURE 8 Control of the PDLC film decay response (top) by applying an exponentially decreasing HF waveform (bottom) at different times during the natural decay of the sample. Curves B through F are superimposed on curve A in the top figure.

increase, and the response time cannot be controlled as shown in Figures 7 and 8. The use of dual-frequency addressing to control the response behavior of PDLC films has a potential application in a scanning-mode operation of a video display, in which different pixels in a row or column are switched on consecutively, but switched off simultaneously.

## CONCLUSIONS

We have taken a new look at the advantages of using dual frequency-addressing as applied to PDLC displays. They include a reduction of the hysteresis effect and an increased control of the optical response not possible in a single frequency addressed system. Unfortunately, PDLC systems developed to date which can utilize dual-frequency addressing tend to exhibit high threshold voltages (90–100 V) and long response times. While extended fall times may be considered an advantage in the development of controlled response such as that shown in Figures 7 and 8, high voltage requirements and long rise times are not. The chloroesters **I** and **II**[2,4,5] and similar compounds[3,6,7] are used for dual-frequency addressing

because they exhibit low cross-over frequencies. However, some of their physical characteristics are not as attractive as those of compounds commonly used in other PDLC films and twisted nematic (TN) cells, and their cross-over frequencies are highly temperature dependent. Therefore, additional research is required in the structure and formulation of the PDLC film to overcome these problems so that the advantages of dual-frequency addressed systems can be fully utilized in practical applications.



## Acknowledgment

This work was supported by the Oklahoma Center for Applied Science and Technology (OCAST) under grant number AR9-045.

## References

1. M. Schadt, *J. Chem. Phys.*, **56**, 1494 (1972).
2. H. K. Bucher, R. T. Klingbiel and J. P. VanMeter, *Appl. Phys. Lett.*, **25**, 186 (1974).
3. M. Schadt, *Mol. Cryst. Liq. Cryst.*, **89**, 77 (1982).
4. N. A. Vaz and G. P. Montgomery, Jr., *J. Appl. Phys.*, **65**, 5043 (1989).
5. G. P. Montgomery, Jr. and N. A. Vaz, *Mol. Cryst. Liq. Cryst.*, **185**, 67 (1990).
6. S. Pirkl and J. Tucek, *Mol. Cryst. Liq. Cryst.*, **193**, 31 (1990).
7. A. A. Abbas-Zadeh, *Mol. Cryst. Liq. Cryst.*, **193**, 59 (1990).
8. J. W. Doane, A. Golemme, J. C. West, J. B. Whitehead, Jr. and B.-G. Wu, *Mol. Cryst. Liq. Cryst.*, **165**, 511 (1988).
9. J. L. West, *Mol. Cryst. Liq. Cryst.*, **157**, 427 (1988).
10. G. P. Montgomery, Jr., *Proc. SPIE*, **1080**, 242 (1989).
11. N. A. Vaz, G. W. Smith, *U. S. Patent* 4,728,547 (1988).
12. S. D. Heavin, B. M. Fung, R. B. Mears, J. J. Sluss, Jr. and T. E. Batchman, *Proc. SPIE*, **1455**, 12 (1991).
13. P. S. Drzaic, *Liq. Cryst.*, **3**, 1543 (1988).
14. J. D. Margerum, A. M. Lackner, J. H. Erdmann and E. Sherman, *Proc. SPIE*, **1455**, 27 (1991).
15. B.-G. Wu, J. H. Erdmann and J. W. Doane, *Liq. Crys.*, **5**, 1453 (1989).
16. J. Erdmann, J. W. Doane, S. Zumer, and G. Chidichimo, *Proc. SPIE*, **1080**, 32 (1989).