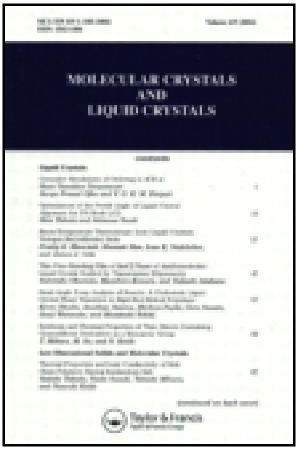

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The Measurement of Response Time in Polymer Dispersed Liquid Crystals (PDLC) Receiving Dual Frequency Stimulation

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THE MEASUREMENT OF RESPONSE TIME IN POLYMER DISPERSED LIQUID CRYSTALS (PDLC) RECEIVING DUAL FREQUENCY STIMULATION

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This paper reports on Electro-Optic properties of Polymer dispersed liquid crystals (PDLC) in response to different frequencies and voltages. Depending on different signals, we can design displays for dynamic images. The turn-off time from a high frequency signal turns out to be 67 times faster than the turn-off time from a low frequency at 70 volts. We can use this time difference to design drive schemes for different purposes. Additionally, applying simultaneous high frequency and low frequency, we find that driving voltage can significantly increase the multiplexing potential of an LC display.

Keywords: dual frequency; liquid crystal; PDLC; response time

INTRODUCTION

The dielectric constant measured parallel to the long axis of a nematic liquid crystal, $\varepsilon_{\|}$, is highly dependent of frequency as well as temperature, while the dielectric constant measured perpendicular to the long axis, $\varepsilon_{\perp}$, is virtually independent of frequency. Thus, a liquid crystal exhibiting a positive dielectric anisotropy ($\Delta\varepsilon = \varepsilon_{\|} - \varepsilon_{\perp} > 0$) at a low frequency may exhibit a negative dielectric anisotropy ($\Delta\varepsilon = \varepsilon_{\|} - \varepsilon_{\perp} < 0$) at a sufficiently high frequency.

In 1974, H. K. Bucher, R. T. Klingbiel, and J. P. VanMeter researchers in the Kodak company's laboratories, presented ⌈Frequency-addressed liquid crystal field⌋ used by Kodak 11650 & 15320 liquid crystals. They reported on the possibilities for improving the voltage threshold and dynamic

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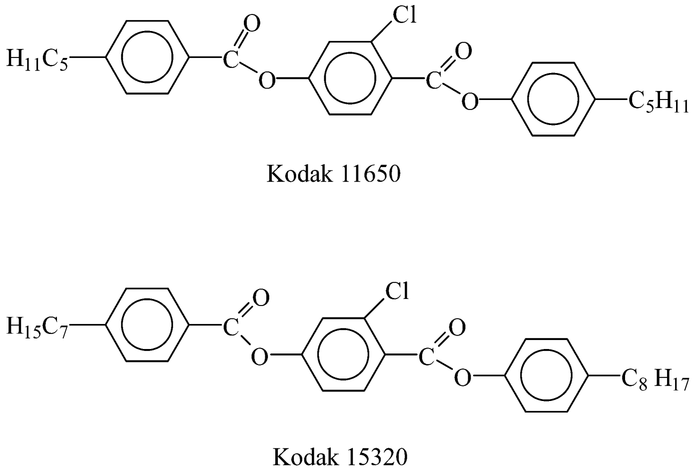

FIGURE 1 The molecular structure of liquid crystals [7].

TABLE 1 Physical Properties of UV-Curable Polymer NOA65

Refractive index (23°C)	1.52
Viscosity (mPa.S)	1000
Tensile (psi)	1500
Modulus (psi)	20000

response of electro-optical effects by means of a two-frequency addressing scheme [1].

In 1977, Jacques Robert and Bruno Dargent reported on multiplexing techniques for liquid-crystal displays. The surveyed two-frequency addressing systems reduce the image-change time and increase the

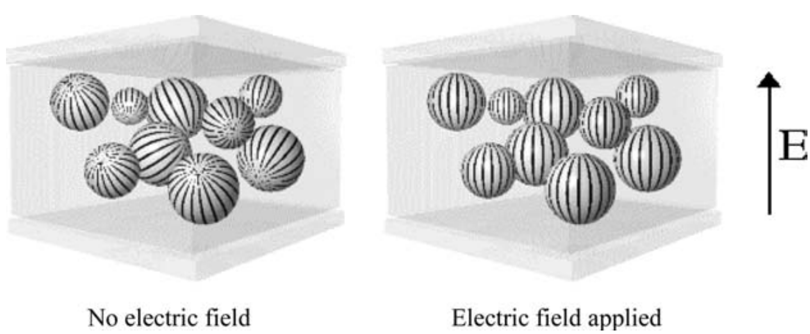

FIGURE 2 PDLC droplets configurations and orientations [8].

TABLE 2 Dielectric Anisotropy Values of Liquid Crystals

Kodak 11650:Kodak 15320 = 1:1 Test temperature 31°C		Cell Gap: 5 μm Voltage: 1 Vp-p	
Frequency	$\varepsilon_{\parallel}$	$\varepsilon_{\perp}$	$\Delta\varepsilon$
60 Hz	11.58696	– 0.47011	12.05707
1 kHz	6.692308	4.364366	2.327942
2 kHz	6.495681	5.714286	0.781396
3 kHz	5.793931	5.510703	0.283227
4 kHz	5.367361	5.505892	– 0.13853
5 kHz	5.000000	5.466153	– 0.46615
6 kHz	4.705466	5.447746	– 0.74228
7 kHz	4.470796	5.426325	– 0.95553
8 kHz	4.287487	5.416667	– 1.12918
9 kHz	4.136098	5.430129	– 1.29403
10 kHz	4.036518	5.427014	– 1.39050

contrast ratio and increase viewing angle for a given complexity liquid crystal display [2]. In 1999, D. K. Yang and M. Xu *et al.*, at Kent State published a study on developing dual frequency cholesteric liquid crystal reflective displays. They not only researched the material states of liquid crystal cells but also designed drive schemes for displays [3]. Therefore, the dual frequency liquid crystal display has attracted considerable attraction from both fundamental and practical viewpoints.

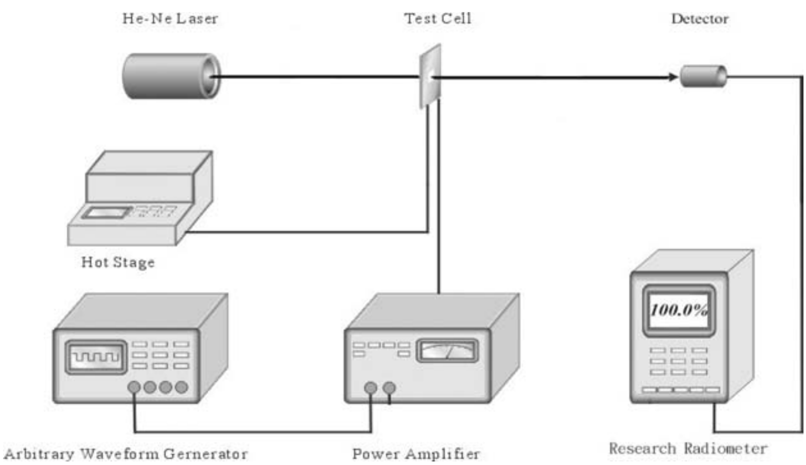

FIGURE 3 The experimental set-up for the measurement of the V (voltage) – T (transmittance) curve.

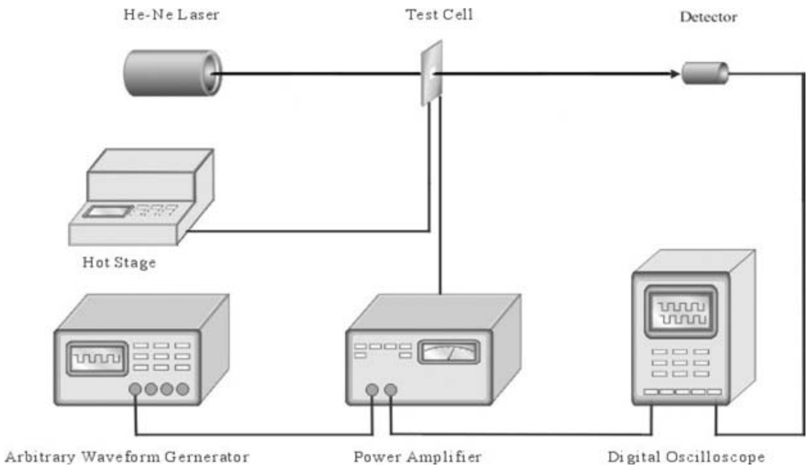

FIGURE 4 The experimental set-up for the measurement of the response time.

For PDLC systems, in 1992, Zeyong Lin, and James J. Sluss *et al.*, published a paper on the use of dual-frequency addressing to control the response behavior of PDLC films showing potential applications in scanning-mode operations of a video displays. Additionally, it has been shown that applying simultaneous high frequency and low frequency driving voltages can significantly increase the multiplexing potential of a PDLC display. The uses of dual-frequency addressing improve the response time and reduce the hysteresis effect associated with PDLC films [4].

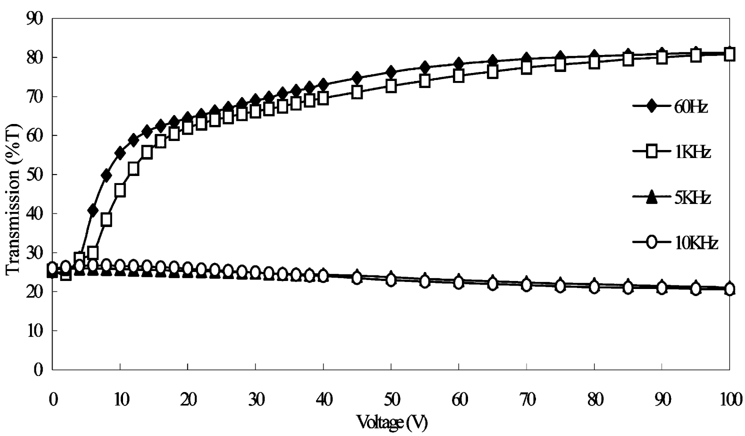

FIGURE 5 The V (voltage) – T (transmittance) curve of PDLC.

Unfortunately, PDLC systems developed to date, that can utilize dual-frequency addressing, tend to exhibit high threshold voltages (90–100 V) and long response times compared with traditional displays. In this paper, we report on the effect of using dual frequency addressing in PDLC devices and reducing response times successfully.

EXPERIMENTS

Dual frequency response liquid crystals Kodak 11650 [*p*-Pentylphenyl 2-chloro-4- (*p*-pentylbenzoyloxy) benzoate] and Kodak 15320 [*p*-octylphenyl 2-chloro-4- (*p*-heptylbenzoyloxy) benzoate] are shown in Figure 1. In our experiments the PDLC was mixed with UV-curable adhesive NOA65 (Norland shown in Table 1) in a ratio by weight of Kodak 11650:Kodak 15320:NOA65 = 1:1:1. The cell gap between two ITO-coated glass substrates was 20 μm. After the cell was filled with the mixture by capillary action at approximatley 50°C, it was exposed to 6 mW/cm^2 UV radiation (G-CSUN Co., Ltd. Model: UC-600) to form PDLC.

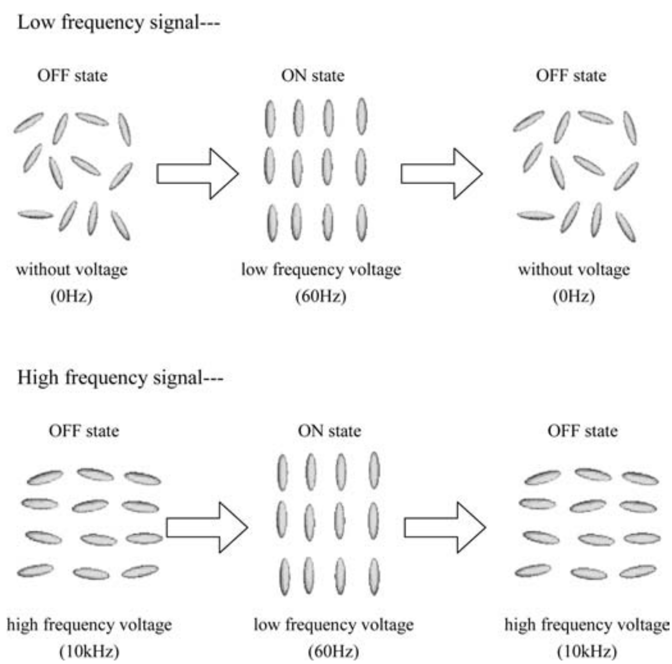

FIGURE 6 Liquid crystal arrangements receiving low and high frequency signals [9].

After the cell was completed, we could estimate the arrangement of liquid crystals in the cell with and without electric stimulation shown in Figure 2. First, we tested crossover frequency of LC without NOA65 by HP 4192A LF impedance analyzer. The $\varepsilon_{\perp}$ and $\varepsilon_{\parallel}$ was measured by homeotropic and homogenous aligned sandwich cell. The results are shown in Table 2 using the formula $\in_r = C/C_0$, where $\in_r$ is specific dielectric constant, C is capacity and C_0 is capacity in vacuum. To measure threshold voltage of the cell, we check by V(voltage)–T (transmittance) curve. The set-up to measure V-T curve is shown in Figure 3. The sample was placed on a hot stage to provide a uniform temperature. The percent transmittance (%T) was measured using a He/Ne laser emitting 633 nm light; the laser beam was directed through the liquid crystal cell; the intensity of the beam transmitted through the sample was measured with a detector. The arbitrary waveform generator providing the driving waveform was 60 Hz and amplified to a desired voltage by the power amplifier.

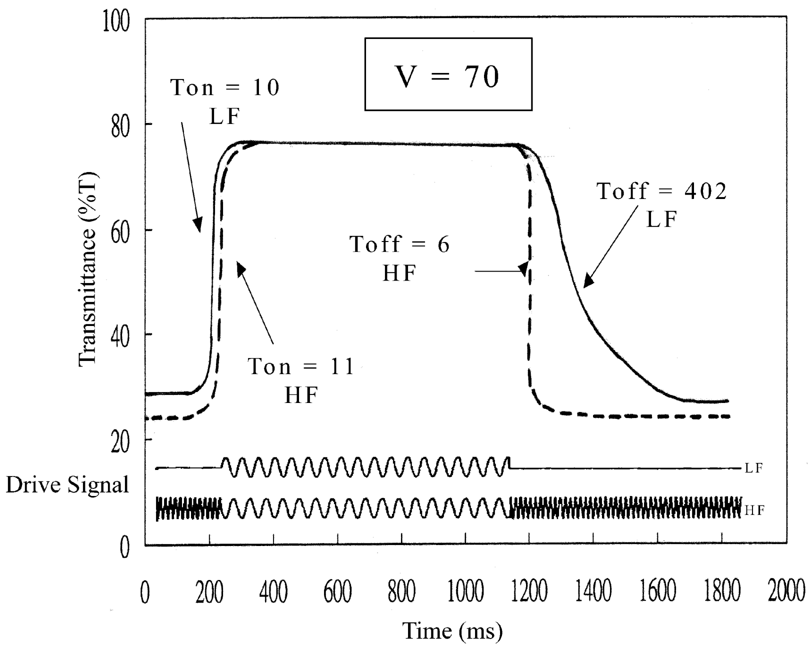

FIGURE 7 The response time of PDLC (70 V). T_{on} is rise time. T_{off} is fall time. LF is low frequency signal (solid line). 0 Hz (0 V) → 60 Hz (70 V) → 0 Hz (0 V). HF is high frequency (dotted line). 10 kHz (70 V) → 60 Hz (70 V) → 10 kHz (70 V).

The set-up to measure response time is shown in Figure 4, which is similar to the outfit used to measure the V-T curve. We just replaced the research radiometer with a digital oscilloscope.

RESULTS AND DISCUSSIONS

According to the result shows that the crossover frequency is between 3 kHz and 4 kHz. Furthermore, we can estimate that the exact value of crossover frequency of these liquid crystals is 3.6 kHz at 31°C.

We also can check threshold voltage by V-T curve as shown in Figure 5. This diagram indicates cells that are in the on and off states while stimulation is below 3.6 kHz (low frequency). But they are usually off when stimulation is over 3.6 kHz (high frequency) in this case. The threshold voltage of the liquid crystal is about 7 V at low frequency. When higher than crossover frequency which is $\Delta\varepsilon < 0$, the transmittance gradually decreases because the more voltage provided in the liquid crystals with a uniform orientation which lay down to the cell as shown in Figure 6.

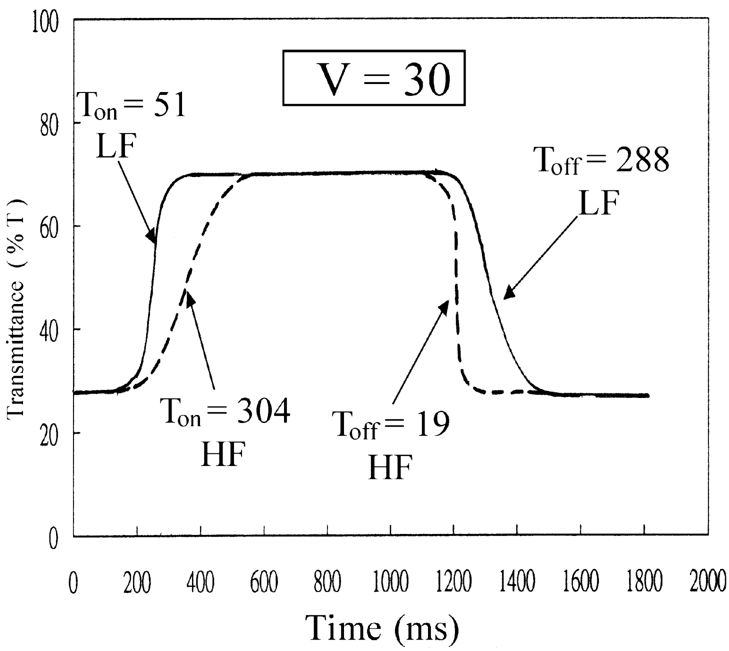

FIGURE 8 The response time of PDLC (30 V). T_{on} is rise time. T_{off} is fall time. LF is low frequency signal (solid line). 0 Hz(0 V) → 60 Hz (30 V) → 0 Hz (0 V). HF is high frequency (dotted line). 10 kHz (30 V) → 60 Hz (30 V) → 10 kHz (30 V).

Because of the change of sign of the dielectric anisotropy when changing the driving frequency of the display voltage from f_{LF} to f_{HF}, very fast turn-off times can be obtained with dual frequency addressable LC materials [5]. The measurements in Figure 6 show an example for the response improvement upon actively switching a polymer dispersed liquid crystal display. The active turn-off time T_{off} (HF) turns out to be 67 times faster than the passive turn-off time T_{off} (LF) (Fig. 7). The turn-on time T_{on} (LF) induced by the signal LF is similar to that corresponding to the frequency change T_{on}(HF) of signal HF.

In LF signal, after the voltage was turned off, the liquid crystal was in a polydomain structure with many defects. The defects scatter light and reduce the transmittance slowly [6]. That is, the defects were produced quickly but disappeared slowly. Therefore, the liquid crystal needed more response time. A high frequency field makes the liquid crystal align parallel to cell, and therefore can make the material transform from homeotropic texture to homogeneous texture faster. The high frequency field helped

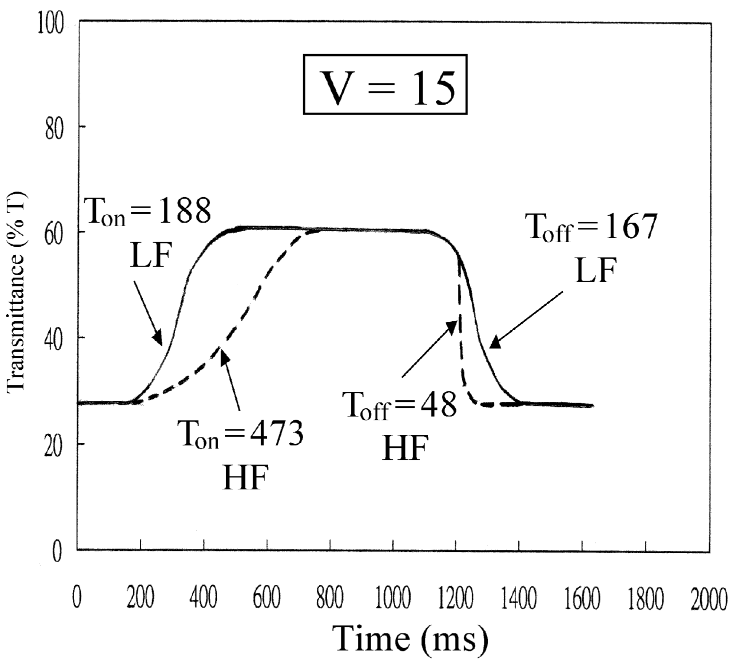

FIGURE 9 The response time of PDLC (15 V). T_{on} is rise time. T_{off} is fall time. LF is low frequency signal (soild line). 0 Hz (0 V) → 60 Hz (15 V) → 0 Hz (0 V). HF is high frequency (dotted line). 10 kHz (15 V) → 60 Hz (15 V) → 0 kHz (15 V).

greatly to eliminate the defects and restore the material to the homogeneous texture [6].

We also tested other voltages as shown in Figures 7–10 . Comparing we found that transmittance was higher, and rise time was shorter while increasing voltages, but fall time depends on high or low frequency; when increasing voltages, fall time is higher for LF signal and lower for HF signal. The most important thing we discovered is the discrepancy in fall times. In other words, we can use this time difference to design drive schemes we need. It is no doubt that higher voltage has large fall time discrepancy.

To take the data of Figure 7 for example, we can design a drive scheme combining low and high frequencies. When a low-frequency voltage and a high-frequency voltage are applied simultaneously, their aligning effects may cancel each other and reduce crosstalk [3]. The advantage this has over the conventional display is that the frequency can be switched directly from on to off without turning off the voltage. The PDLC material can be used to make multiplexed displays with a passive matrix. Therefore, the dual frequency display of PDLC is more suitable to display dynamic images.

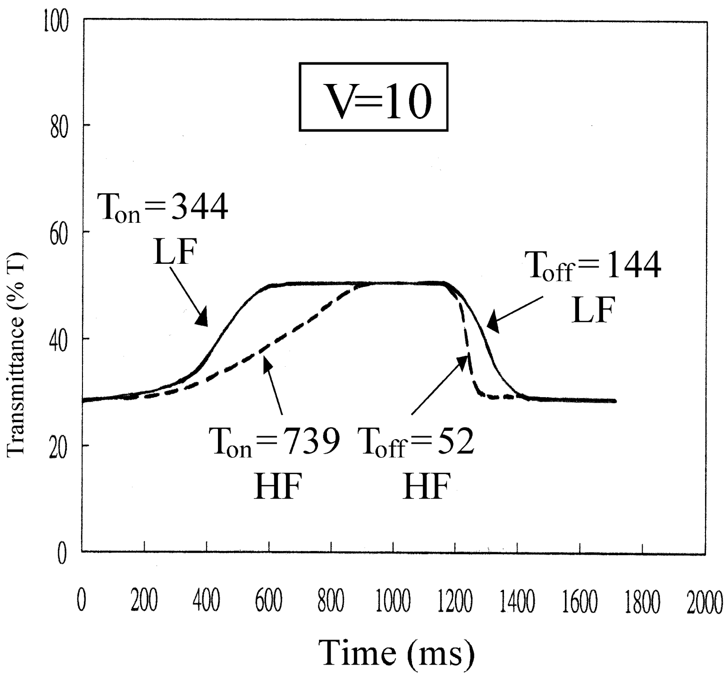

FIGURE 10 The response time of PDLC (10 V). T_{on} is rise time. T_{off} is fall time. LF is low frequency signal (solid line). 0 Hz (0 V) → 60 Hz (10 V) → 0 Hz (0 V). HF is high frequency (dotted line). 10 kHz (10 V) → 60 Hz (10 V) → 10 KHz (10 V).

CONCLUSIONS

We have taken a new look at the advantages of using dual frequency addressing as applied to PDLC displays. The turn-off time of a high frequency signal turns out to be 67 times faster than a low frequency at 70 volts. We can use this time difference to design drive schemes we need. Dual frequency addressing leads to reduction of the response time and an increased control of the optical response not possible in a single frequency addressed system.

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