Electro-optic system for online light transmission control of polymer-dispersed liquid crystal windows

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Abstract. Polymer-dispersed liquid crystals (PDLCs) are formed by microdroplets of liquid crystal embedded in a flexibl matrix and sandwiched between transparent electrodes. Large area units (several square meters) can be easily prepared. Opaque, transparent, and intermediate light transmission states can be achieved by applying appropriate electric fields These features allow their use in active windows for illumination, greenhouse regulation, and privacy, both on buildings and vehicles. An electro-optic system based on a microcontrolled driver was implemented for on-line control of PDLC windows. The system may self-regulate daylight or may be used as remote control.

Subject terms: polymer-dispersed liquid crystals; electro-optic system; microcontrolled driver; on-line privacy control.

1 Introduction

Liquid crystals (LCs) feature a number of unique electro-optical properties, making them attractive for many applications. New applications have been suggested[1] for LCs dispersed in organic polymer matrices. The resulting polymer-dispersed liquid crystals (PDLCs) may be prepared as flexible wide-area thin film where LCs are forming microdroplets that strongly scatter visible light. PDLCs are customarily prepared with transparent electrodes on their outer surfaces. When an ac fiel is applied perpendicularly to the film the LC reorients and its optical characteristics vary. Refractive indices are chosen so that the refractive index of the reoriented LC matches the refractive index of the polymer. Under these circumstances, the material becomes transparent when switching with ac fields No polarizers are required for this opaque/transparent switching. Therefore, the transparent state can be highly transmissive, allowing the application of these film as optical switches. Electrically controllable intermediate transmission levels are available as well. This leads to the preparation of "smart" windows that regulate the light intensity inside buildings, greenhouses, and vehicles.[2] Thermal indoor regulation is also possible, although control of IR transmission by LCs is less reliable.[3]

In this work, a system able to stabilize 4, 8, or 16 transmission levels of a PDLC window is described and tested.

2 Experimental Procedure

Only visible light is intended to be regulated. The system includes two working modes. In the feedback mode, a lighting level selected by the user is maintained constant by modifying the window transparency, according to variations of external illumination over time. In the fixe mode, the user selects a fixe transparency of the window, regardless of illumination. This mode is more useful for indoor panels, e.g., use of the PDLC panel as a projection screen or to isolate a paneled room for temporary privacy. The transmission scale in both modes may be linear or logarithmic.

The PDLC window is regulated through a user interface consisting of a keyboard and an LCD display. A remote IR control has been constructed as well. Both interface and remote control interact with the central management system, which includes an 8-bit microcontroller (AT89C2051, Atmel). System state, working mode, and possible warning and error messages are shown in an Optrex 16 char×2 rows LCD display.

Such a system may be used as a cost-effective solution for a number of indoor and outdoor applications, including offices advertisements, building windows, and side windows of automobiles. Specification for outdoor applications are certainly more demanding from a materials point of view. In our case, the PDLC is assumed to meet the required specification to withstand actual working conditions. Yet the electric signals required for switching and transparency control may be modifie by external variables such as temperature. Therefore, a study on the PDLC response with electric signals is advisable.

3 Electro-Optical Characterization of PDLC Film

Experiments have been carried out using 30×40 cm, indium-tin oxide coated PDLC film from SNIA Ricerche (Italy). Films were characterized by measuring their complex impedance (modulus and phase) in a wide frequency range, 100 to 400 kHz, using an impedance and gain-phase analyzer HP-4194A (Fig. 1). This measurement allows the

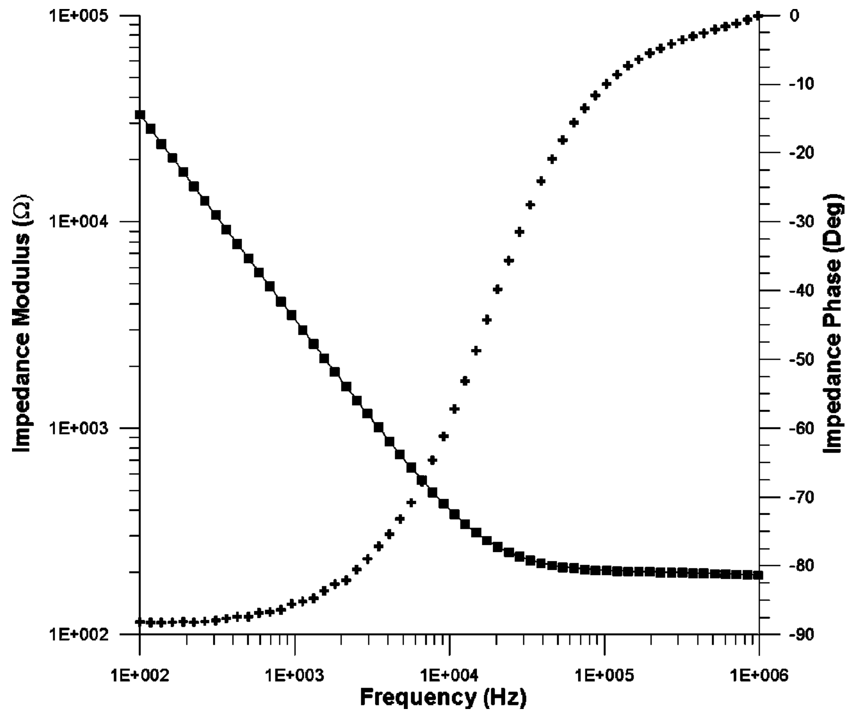

Fig. 1 Modulus (squares) and phase (crosses) of the PDLC fil impedance as a function of frequency.

selection of a convenient frequency range for the driver design. In principle, a working point must be selected where the PDLC shows a behavior as purely capacitive as possible (around −90° phase). The impedance in this point becomes imaginary, and no thermal dissipation would be expected.

In our case, this behavior is shown by the fil only at low frequency, $f<1$ kHz. On the other hand, the frequency cannot be arbitrarily reduced, for ionic effects may arise from degradation of the material.[4] A 60-Hz frequency is used, consequently due to the transformer included in the power stage which is optimized in that working frequency.

Figure 2 shows the electro-optical response of the PDLC fil when an ac electric signal of 60 Hz is applied. The material shows intermediate transmissions (gray scale) in a dynamic range of about 10 V rms. Above 20 V rms, the material saturates and the transmission becomes substantially constant. The region below this value may be used to generate intermediate transmission levels.

4 Prototype Features

Up to 16 different gray levels have been successfully produced. A block diagram of the driver is shown in Fig. 3. The driver is based on an 8-bit microcontroller that receives inputs from the user interface. The system also receives a digital signal given by a light sensor (light-frequency converter TSL 230, Texas Instruments). The signal frequency is linearly related to the light intensity. The control parameters currently implemented in the prototype are: mode (fixed

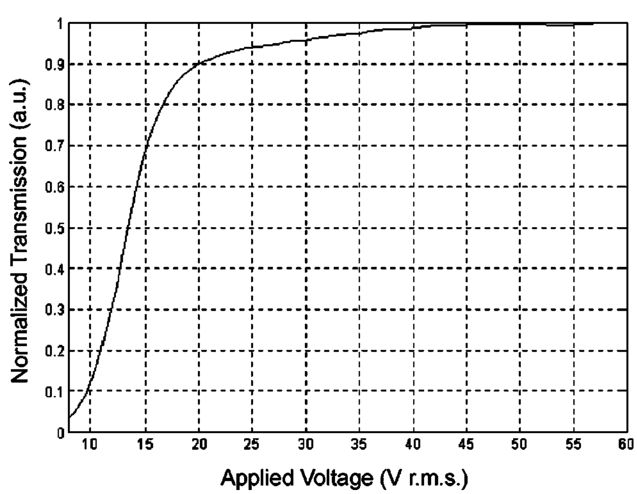

Fig. 2 Electro-optic curve of the PDLC film

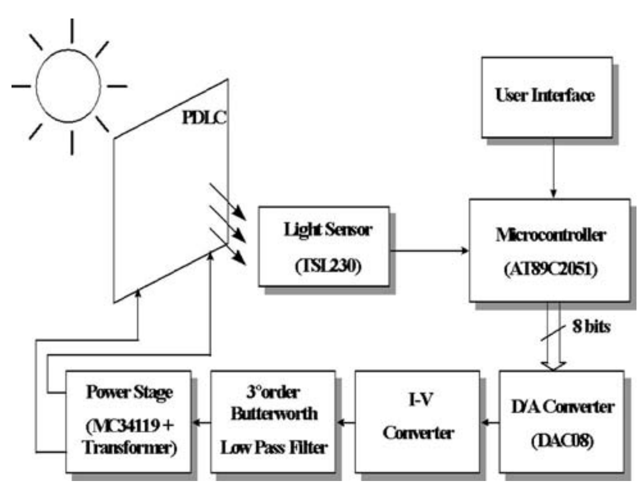

Fig. 3 Block diagram of the implemented driver.

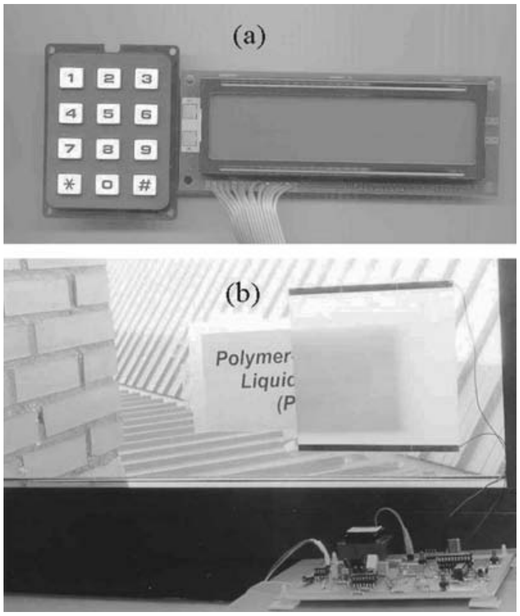

Fig. 4 (a) User interface and (b) designed electronics for addressing the PDLC film

constant voltage or feedback/closed loop), the number of programmable gray levels (4, 8, 16), and the scale (linear, log).

The system works as follows: the microcontroller counts the period coming from the optical sensor. The sensor is sampled every 100 ms. Eight sequential acquisitions are performed and averaged, so each 0.8 s the sensor is checking the optical radiation level. Once the illumination level is fixe by the user, the frequency is monitored continuously. If it increases (i.e., the illumination level increases), the microcontroller generates a digital feedback signal that is sent to a monolithic 8-bit high-speed current-output digital-to-analog converter (DAC0800, National Semiconductor), whose signal is sent to an I-V converter built with discrete electronic components. The output voltage is eventually filtere by a third order Butterworth filte and amplified A sinusoidal signal having the corrected amplitude is generated in this way, providing negative feedback to the PDLC film Figure 4 shows the implemented driver and user interface.

5 Results

Figure 5 shows an actual test of the prototype, switched to opaque, transparent, and an intermediate transmission level. The driver electronics can be used, in principle, with film of arbitrary size, except for the output power stage, which largely depends on panel consumption. This has been measured to be about 25 W/m^2 in our current working conditions.

The prototype is completed with a remote control IR unit. This unit is important for applications related to external illumination control and offic facilities, whereas it is obviously less relevant in other short range applications, such as automobiles. The IR system employs a standard infrared unit (Grundig) with an emission wavelength of 940 nm and a carrier frequency of 38 kHz, linked to an infrared remote control receiver (Kodenshi, PIC26043-SM). This is

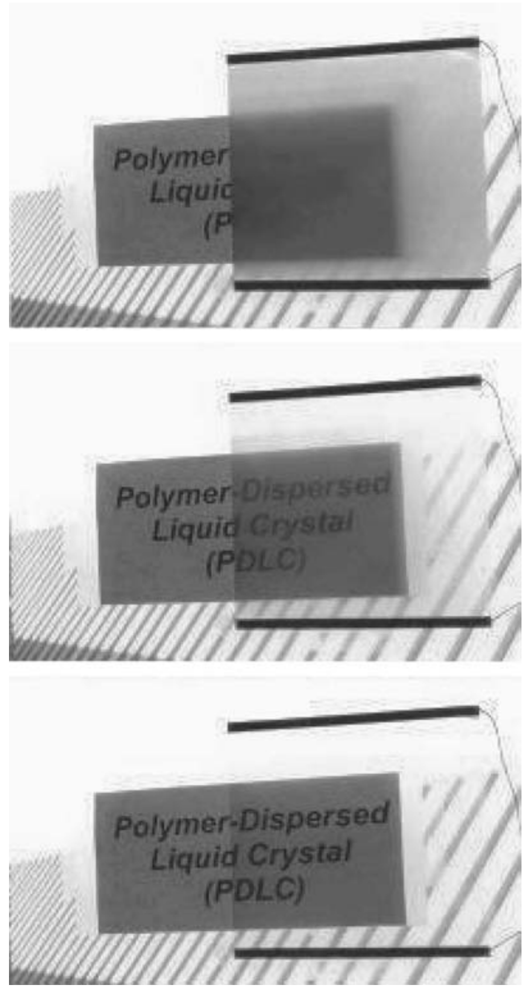

Fig. 5 Transmission of the PDLC fil for three different levels: opaque, intermediate, and transparent.

connected to the microprocessor, which interprets the code sent by the remote unit and generates the corresponding command. The remote control has been tested to be fully operative at distances up to 8 m, enough for architectural and decoration applications.

The differences among the competing technologies for use in variable light transmission windows should favor PDLCs in some aspects,[5] because of their high capacity of controlling the number and shape of variation (linear, log, etc.) of transmission levels by using an appropriate driver, as well as power consumption (if a time-multiplexed signal is used for addressing several panels reducing the overall consumption), among others.

On the other hand, it has been tested that for privacy control applications, the use of the four-levels option is sufficient If a more precise control of the transmission light is required (for instance, advertisement panels), either the eight-level option or higher should be chosen. Additionally, a linear or log variation should be selected depending on lighting external conditions of the PDLC panel.

6 Conclusions

A simple, cost-effective solution for dynamic control of lighting has been demonstrated. An 8-bit microcontroller system has been used to control light transmission of a polymer-dispersed flexibl liquid crystal film This fil can be sandwiched between standard glasses, giving switchable windows such applications as blinds and advertisement panels. Windows can be pixelated as well, allowing partial switching of selected areas. A number of options related to the number of gray levels and the gray-scale steps are left open so that the system can be customized for specifi tasks.

The control system can be easily extended to monitor and command several panels independently. The architecture of the prototype allows multiplexing of independent signals; therefore, a single control unit could be employed for overall ambient light and paneling distribution of big spaces, such as supermarkets, theaters, or offices

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