32-channel arbitrary waveform generator for bistable nematic devices

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All commercially available liquid crystal nematic displays use cells with strong surface anchoring conditions and under field bulk monostable texture distortions. About ten years ago, a technological research line started to study liquid crystal nematic displays with intrinsic bistable textures. It implies pixels with two distinct stable states in the absence of field, but electrically switchable. Bistability allows infinite multiplexing for passive matrix displays: It suppresses the need of refreshing permanent informations. At present, commercial active matrix displays behave like bistable displays by means of electronic elements (TFT or diodes), one for each pixel. This is not an intrinsic bistability, because it is due to external active devices placed on the screen surface. The aim of the present research is to design a suitable and flexible experimental setup to create addressing waveforms for passive electro-optical intrinsically bistable devices. © *2004 American Institute of Physics.* [DOI: 10.1063/1.1753103]

I. INTRODUCTION

Presently, all nematic liquid crystal displays use cells with strong surface anchoring conditions and bulk monostable texture changes. These monostable devices are characterized by one stable state T_s in the absence of the electric field **E** and by an excited state T_e in the presence of **E**. When the field is switched off, the nematic texture relaxes back to the unique equilibrium stable configuration T_s.

A technological approach is based on the possibility to develop liquid crystal nematic displays with intrinsic bistable textures.[1] This is a relevant new property for future liquid crystal displays (LCDs). It implies two optically distinct stable nematic textures in the absence of the external field, but electrically switchable, as in the case of SmC* materials.[2] The advantage is that nematics are widely used for practical devices, whereas SmC* liquid crystals remain at the experimental stage. In principle, bistability allows infinite multiplexing for passive matrix displays. Moreover it suppresses the need of refreshing permanent frames and it should decrease the power consumption. At present, pixels of commercial active nematic matrix displays possess a frame memory (which could be considered a kind of bistability) by means of external electronic elements [thin film transistor (TFT) or diodes], one for each optical element. This bistability is not intrinsic, because it is due to external active devices placed on the screen surface.

Intrinsic nematic bistable systems can be classified into two groups: first, the bulk bistable devices in which the nematic textures changes with fixed boundary conditions;[3–6] second, the surface bistable devices, in which the surface anchoring orientation is changed.[7,12]

The aim of the present research is to design a suitable experimental setup to create addressing waveforms for these passive electro-optical bistable devices. We studied two different systems: The first one is based on controlled creations and annealing of surface defects when breaking a surface anchoring;[7] the second one is based on the induced bulk order reconstruction.[5] The main technological problem is to have a versatile electronic system with high output voltage (±50 V) and short time resolution (down to the microseconds range) for the driving electric signal. For this reason we developed a 32-channel arbitrary waveform generator *Novacaine*. In this article, we present the main features of this electronic device and some applications on real samples.

II. NOVACAINE

The Novacaine hardware has been designed and built by HP-Labs in Bristol, whereas the software has been designed by one of the authors (G.L.). Novacaine is intended as a fully flexible waveform generator with the following features:

- 32 channels
- ±40 V output on each channel, allowing up to ±80 V in differential modes
- 13 bit resolution on each channel
- 7.000 step waveform memory
- Programmable high-impedance disconnect on each output
- 5 μs timer resolution—200 kHz maximum output rate
- PC parallel port interface
- Drivers using LABVIEW 5.1
- Single shot or infinite loop control modes
- Update waveform during output allowed

A. System description

In Fig. 1 it is represented the block diagram of the arbitrary waveform generator.

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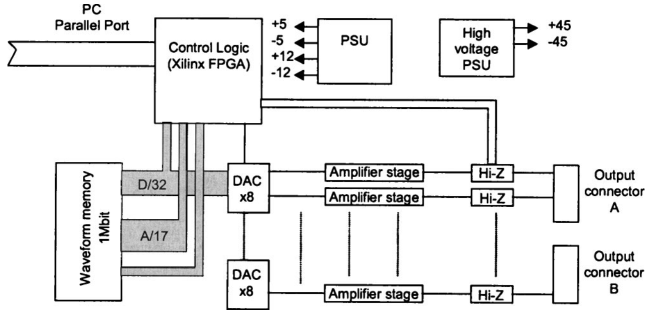

FIG. 1. Novacaine system block diagram.

Novacaine is connected to a PC via a parallel port. The waveform is loaded into a 32×128 K bit static random access memory (SRAM) by a Xilinx FPGA-XC3195A (field programmable gate array). For each waveform point it is necessary to specify the voltage, the time duration (24 bit counter with 2.5 μs resolution) and also the high-output impedance that enables every single output channel.

When the waveform generation is enabled, by setting the suitable register bits in the control logic, the waveform data is transferred to four MAX547 Octal 13-bit digital-to-analog converter (DACs), whose output is clocked synchronously into the input of a high voltage amplifier (gain 10) stage. This prevents any ripple error as the DACs are loaded in sequence.

The analog output is fed via optoisolators to the output connectors, 16 channels for each connector. When the optocouplers are turned off (as defined by a pattern stored in the waveform memory) the output impedance is high.

In Fig. 2 we show the printed circuit board (pcb) of Novacaine. We used a SRAM-FPGA architecture, that is an array of logic-cells (configurable logic block) that communicate each other and with I/O cells via routing channels.[9] In this case, SRAM cells are used to control the state of pass transistors, which can establish connections between cells. As SRAM cells are volatile, programmable read only memory (PROM) has been used to program them each time the board is powered up. The 32 outputs of Novacaine come from 32 identical and independent paths. Each path contains a DAC, an amplifier stage, and an optocoupler.

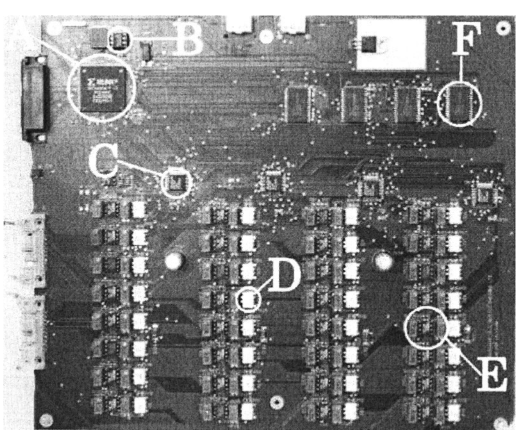

FIG. 2. The pcb of Novacaine: A: FPGA; B: PROM; C: DAC; D: optocouplers; E: high voltage amplifier; F: SRAM.

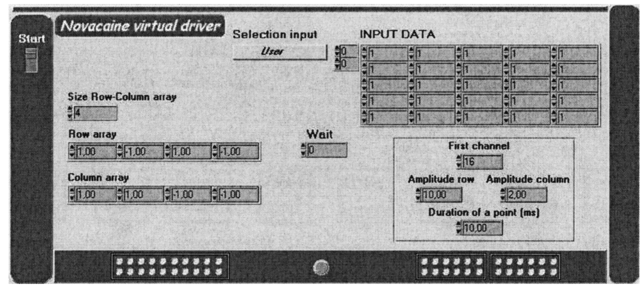

FIG. 3. *Nova*: virtual multiplexing driver projected to address passive nematic liquid crystal matrix.

B. Software description

To control the hardware, we have developed a virtual driver in LABVIEW 5.1[10] that programs Novacaine to work as an electronic driver to multiplex up to a 16×16 LCD matrix.

Figure 3 shows the front panel of *Nova*, the virtual multiplexing driver that we have designed. We can dynamically control the shape, the amplitude, and the time length of the row and column addressing signals.

The row signals are programmed to address the rows in sequential mode (starting from *First channel*). The column signals contain the information that has to be displayed. The voltage for each pixel in the matrix is the difference between corresponding row and column electric potentials.

The pixel can be in the *on*, *off*, or *memory* state, putting the value +1, −1, or 0 in the *INPUT DATA* matrix (see Fig. 3).

The *Selection input* allows us to pass from *user* to *character*, *number* or *video* modes. In the *user* mode, we can select the state for each pixel of the matrix. In the *character* or *number* mode, we have designed a particular pattern to be displayed (i.e., the letter A or the number 2). For the *video* mode, we can test the capability of the matrix to display a simple sequence of frames.

The subroutines scheme used to program Novacaine is shown in Fig. 4. We have designed the *Nova* driver using a top-down procedure: We have subdivided the multiplexing procedure into simple steps, each of them carrying out a specific task. In the lower level there are subroutines that communicate, via parallel port, with Novacaine and pass data to be stored in the SRAMs.

The system is programmed and controlled by accessing a set of registers in the control logic. The register address is set by sending the value on port 378h (LPT1 on the PC) and toggling the address strobe line 37A.3h, and then the data value on port 378h and toggling the data strobe line 37A.1h. This task is performed by *lpt1-Novacaine*, *In port*, and *Out port* subroutines.

As the internal memory is 32 bits wide and the parallel port can only interface 8 bits wide, an intermediate step is required. To write a memory location in the waveform memory, the data must first be written to the memory write data registers. This task is performed by the *write mem* subroutine.

The *load wave* subroutine is the procedure that takes the data from the higher subroutine (i.e., *Row Gen* and *Col Gen*) and organizes it to be passed to the lower subroutine of No-

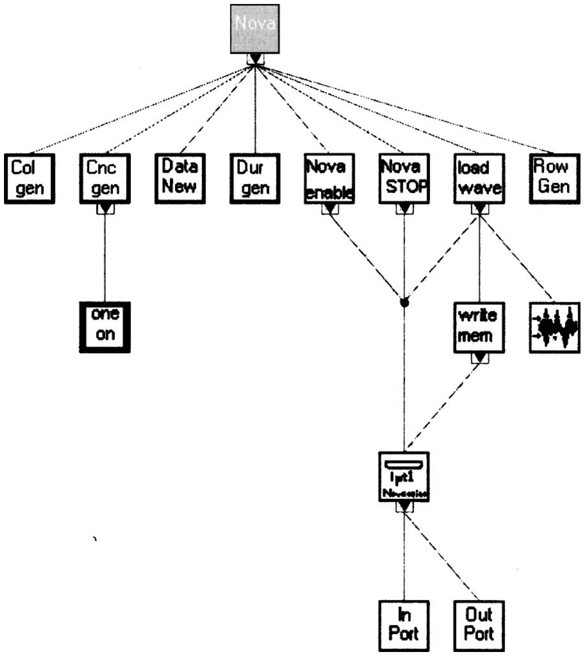

FIG. 4. Hierarchy structure of *Nova*: each block is a subroutine.

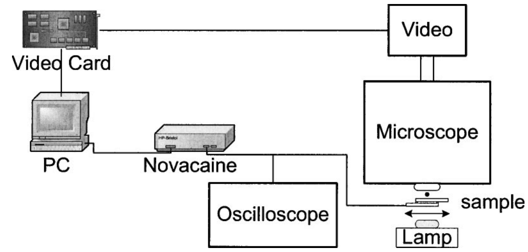

FIG. 5. Experimental setup to multiplex liquid crystal matrix.

vacaine. The waveforms data are organized in a cluster, which is a data structure that groups different types of data. The data structure in memory is organized in a sequence of 18×32 bit words so that the waveform memory is deep enough to give ~7.000 clusters:

• Words 0–15: 32×13 bit channel data values, padded to 2×16 bit words in each location

• Words 16: 32 high impedance bit values. 0 gives output driving low Z, 1 gives high Z

• Words 17: Timer value before next waveform point, 24 bits are valid, with each count=2.5 μs giving a maximum time between steps of 41.9 s.

In the higher level of programming, we have designed all the others subroutines that enable Novacaine to be used as a multiplexing liquid crystal display driver. So the *Col gen* and *Row gen* subroutines carry out the task to generate the column and row addressing signals. The *Dur gen* defines, for each point in the row and column waveform, the delay time before the next waveform point is applied. The *Cnc gen* and *One on* subroutines define which channel must be in high impedance or not. At last, in the *Data New* subroutine, we control which pattern of data (*user, character, number* or *video* modes) has to be displayed in the liquid crystal matrix.

III. MULTIPLEXING EXPERIMENTAL SETUP

The experimental setup used to address our samples is showed in Fig. 5. Our samples are cells made by using two transparent conductive indium-tin-oxide (ITO) coated glass plates in a sandwich configurations. The samples, filled with the nematic, are observed between crossed polarizers using an optical microscope. The image captured by the polarizing microscope can be acquired by a PC.

Novacaine is connected to the same PC by means of the parallel port. The waveforms, generated by Novacaine, are probed by an oscilloscope and then they are applied to our sample.

The physical electric connections between Novacaine outputs and the experimental sample cell are obtained by means of the sample holder, whose scheme is shown in Fig. 6. The holder uses anisotropic conductive layers that allow us to make a vertical electric contact between the ITO strips deposed on each plate of the cell and the electric path on the holder.

A. Checking monostable passive matrix

To verify the suitability of our experimental multiplexing hardware and software system we began to address a simple monostable twisted nematic cell. This kind of sample is similar to the typical nematic structure of commercial liquid crystal displays. The electro-optical switching is based on the Frèedericksz transition.[11]

The cell is made by two parallel transparent glasses which contain the nematic liquid crystal 5CB (pentyl cyano biphenyl) that has a strong positive dielectric anisotropy at room temperature, $\epsilon_a \approx 14$. The electrodes are thin transparent indium-tin-oxide (ITO) films deposed on the boundary glasses. The cell thickness is 1.9 μm, measured before filling the cell with an interferometric method.

In Fig. 7, we show the voltage waveforms applied to the passive monostable twisted liquid crystal 5×5 matrix display addressed by Novacaine. In this case V_R is the amplitude of the row waveform, is 2 V, V_C is the amplitude of the column waveform, is 1 V, and Δt, is the time length of one pulse of the addressing waveform is in the range of milliseconds. A photograph of an addressed image of the 5×5 passive matrix is shown in Fig. 8.

B. Checking surface bistable nematic display-SBiND

At present, most of practical planar bistable liquid crystal nematic cells[3,7,8] are asymmetric with respect to the middle plane parallel to the boundary plates. This kind of asymmetry induces an electro-optical response dependent both on the amplitude of the external electric field and on its polarity. For this reason it is important to develop multiplexing schemes to exploit these properties.[13,14]

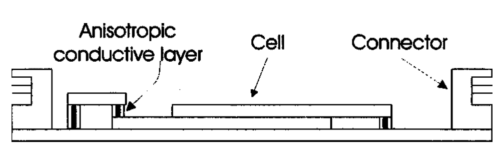

FIG. 6. Sample holder (lateral view).

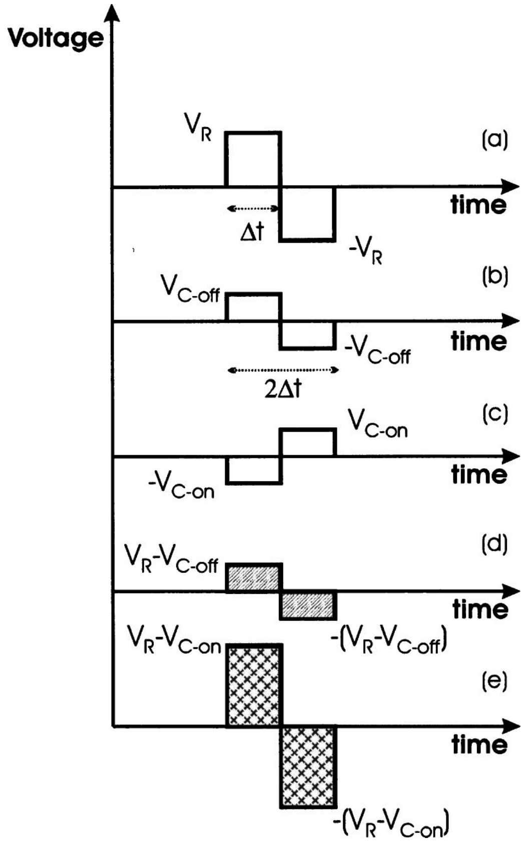

FIG. 7. Voltage waveforms to drive a 5×5 pixel matrix display. The waveforms applied in the rows (a), in the columns for an *off* (b), or *on* (c) pixel. The pixel waveforms across an *off* (d) or *on* (e) pixel.

In Fig. 9 is showed an oscilloscope image of the waveforms generated by Novacaine to multiplex SBiND.[7]

As in the previous case, samples are made by two parallel transparent glasses coated by ITO. To achieve the anchoring breaking condition, now, one plate is treated with ortho-decyl-dimethyl-[3-trimethoxy silil)-propyl] ammonium chloride to obtain homeotropic alignment, while the other one is treated with an oblique SiO evaporation under vacuum to produce weak planar anchoring.[15] Also in this case, the

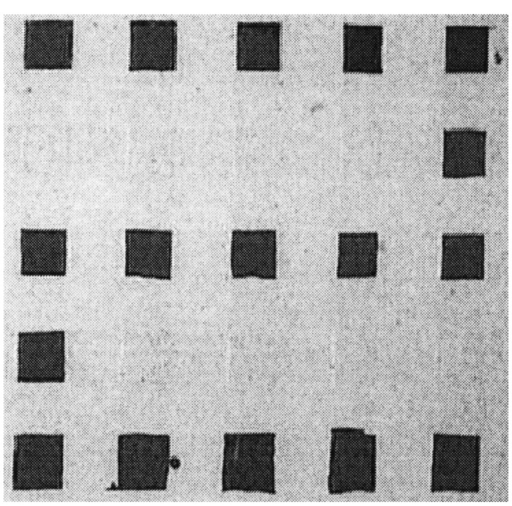

FIG. 8. Microscope image of a 5×5 monostable cell addressed by Novacaine using a passive matrix multiplexing scheme.

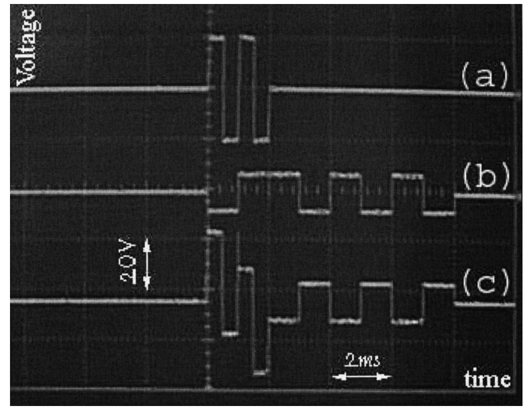

FIG. 9. Image from the oscilloscope. Signals generated by Novacaine to multiplex SBiND display: (a) row waveform; (b) column waveform; and (c) pixel waveform.

cell is filled with 5CB. The cell thickness is 1.6 μm measured before filling the cell with an interferometric method. More details can be found in Ref. 7.

The method used to address this cell is the (polar amplitude duration method) PADM. In the PADM scheme, see Fig. 10, the rows are sequentially selected by an electric signal composed by two bipolar pulses of equal length $2t_{pR}$ and amplitude $\pm V_R$. The row waveforms do not transport any data information to the pixels. The column signals, composed by a bipolar impulse of length $2t_{pC}=4t_{pR}$ and amplitude $\pm V_C$, decide if a pixel in the matrix display is in the *on* or *off* states.

Since the pixel voltage is the difference between the row and column voltages, a pixel will be in the *on* state if it is addressed by a waveform where the last rectangular pulse has an amplitude greater than the writing threshold, see Fig. 11. On the contrary a pixel will be in the *off* state if it is addressed by a waveform where the last but one rectangular pulse will have an amplitude greater than the erasing threshold and the last rectangular pulse is low enough to have no effect on the switching.

C. Checking order reconstruction bulk in a nematic cell

Another way to achieve the nematic intrinsic bistability[5,6] is based on the biaxial order reconstruction that can be induced in a suitable cell by means of a fast external electric field. Also in this case, the two conductive glass plates are arranged in the usual planar sandwich configura-

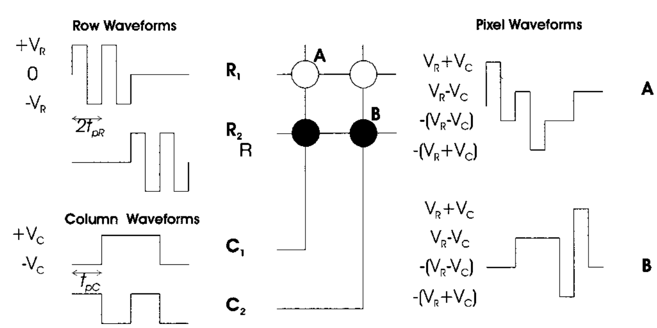

FIG. 10. PADM (polar amplitude duration method).

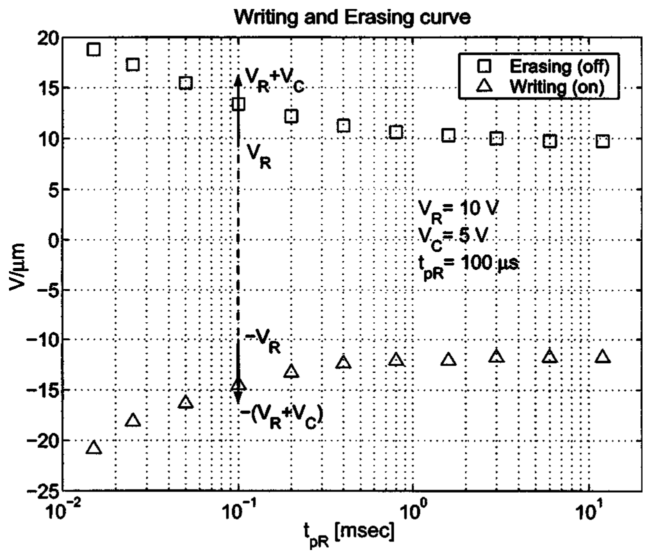

FIG. 11. Erasing and writing curve of the SBiND pixel: V_R, V_C are amplitude voltage of the addressing row and column signal. t_{pR} is the length of a single rectangular pulse that composed the row waveform.

tion and the two internal surfaces are now treated to give a pretilted anchoring alignment. The two boundary plates are oriented to give a starting distorted splayed texture T_p. The sample that we have investigated is filled with the liquid crystal Merck E7 (cyanobiphenyl compound). The strong oblique symmetrical anchoring on the two plates is produced by means of a suitable polymeric coating (rubbed polyamid acid LQ1800 from Hitachi). The cell thickness has been fixed at $d=1.9\,\mu$m. The starting state T_p, see Fig. 12, can be transformed in a π-twisted texture T_b by means of strong enough bipolar rectangular electric signals. In this case, we were only interested to verify the possibility to induce the $T_p \rightarrow T_b$ transition. We have excited the sample with rectangular signals similar to those used for the passive matrix as shown in Fig. 7. Obviously, in this case, the signal amplitude must be much higher than the passive matrix addressing ($V=15$ V for $\Delta t=0.1$ ms). We have positively verified the possibility to multiplex this transition in a 5×5 matrix by means of Novacaine.

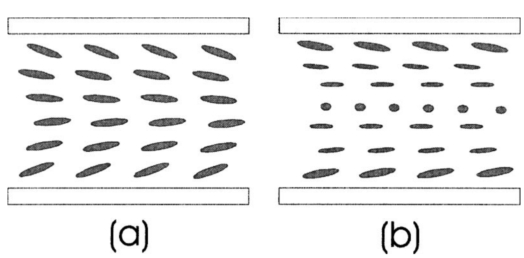

FIG. 12. (a) T_p state is a slightly splayed texture and (b) T_b state is a quasi-π-twisted texture.

IV. DISCUSSION

Like some other electronic addressing devices developed by other experimental research groups,[16] Novacaine is a programmable waveforms generator. Novacaine, in particular, has 32 independent channels, high and fast outputs. This instrument is able to easily multiplex any kind of nematic passive matrix, from usual twisted panels to novel intrinsic bistable displays. It is unique for its flexibility and the main limitation is due to the relatively few external channels, which allows us to address only up to 16×16 pixel matrix. Nevertheless the main scheme of Novacaine is easily expandable. By adding internal multiplexing drivers, Novacaine could be simplified to obtain practical portable devices, that could be reduced to a simple LCD chip multiplexer for innovative nematic display.

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