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REDUCTION OF BRIGHTNESS NON-UNIFORMITY IN RMS RESPONDING MATRIX DISPLAYS

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INTRODUCTION:

In passively addressed RMS responding dot matrix LCDs pixels differ in brightness depending on the pattern displayed, although they should be identical. This brightness non-uniformity is mainly due to small deviations in the RMS voltage across the pixels from their intended value. E.g. consider a matrix LCD where N = 200 lines must be multiplexed. The maximum Selection Ratio SR (Von/Voff) in this case is 1.073 [1], which means that the electro-optic characteristics should be steep enough to switch between "ON" and "OFF" for a 7% change in RMS voltage. Hence even a 1% deviation in the RMS voltage is sufficient to introduce a noticeable brightness change. In this paper we will discuss various factors contributing to this brightness non-uniformity.

THE DIELECTRIC RELAXATION OF THE LIQUID CRYSTAL:

Brightness non-uniformity observed in dot matrix panels may be influenced by a number of cell technology parameters including the LC itself. Basically, the frequency dependence of the threshold voltage Vth of the transmission voltage curve is reflected in this brightness non-uniformity.

The dielectric anisotropy of the liquid crystal $\Delta\epsilon = \epsilon// - \epsilon^{\perp}$ is known to show frequency dependent behaviour. For commonly used STN LC materials this had been assumed to occur at higher frequencies than those relevant to the multiplexing waveforms.

This was found not be true by considering two Merck LC mixtures ZLI-3276 and ZLI-2293. The experimental ϵ-data were obtained at Merck Laboratories, Darmstadt, and were kindly made available to us. The data are plotted in Figure 1 ; the frequency of the applied sinusoidal waveform varies between 50 Hz and 50 kHz. $\epsilon^{\perp}$ remains practically constant, while beyond some frequency value $\epsilon//$ gradually reduces (for ZLI-3276 it starts at about 10kHz). When square waveform excitation is used , the dielectric torque which is responsible for director realignment must be summed over all frequencies in which the power is distributed. The effective dielectric constants were calculated this way from the data shown in Figure 1. These dielectric constants were used to evaluate the transmission voltage curves for double cell (DSTN) configurations with crossed polarizers using the DIMOS software of AUTRONIC Gmbh, Karlsruhe with the following parameters: cell thickness of 7.5 μm, pretilt angle of 5° and twist angle of 240° along with appropriate values for the birefringence and the elastic constants. The results are shown in Figure 2. In the case of ZLI-3276 and ZLI- 2293 the shift was 30 mV and 10 mV, respectively. These results were confirmed experimentally. Hence, it is worth considering the actual composition of the LC mixture to improve brightness uniformity.

INFLUENCE OF THE ORIENTING LAYER:

In terms of equivalent circuits, the LC pixel is usually described as shown in Figure 3. The ratio of $V_{lc}/V_{applied}$ will depend on the frequency of the applied waveform. For typical R and C values of the orienting layer and the LC layer the model of Figure 3 predicts an increase of Vlc for increasing frequencies.
The model of Figure 3 is an over simplification, since the series resistance nor the dielectric relaxation of the LC mixture is considered. To verify the influence of the aligning layer experiments were done on 180° STN cells using the Merck liquid crystal ZLI-2293. A number of (rubbed) polymeric alignment layers P1-P5 are examined; each has a thickness of 500 Å, a (bulk) resistivity higher than $10E+^{15}$ Ohm.cm and a dielectric constant of 3.0.
The following table gives the increase in applied voltage at 1 kHz and 5 kHz compared to 100 Hz for maintaining the 50% transmission value (at 100 Hz).

ALIGNING LAYER	P1	P2	P3	P4	P5	I.T.O.
Increase in mV at 1 kHz	45	25	5	70	20	2
Increase in mV at 5 kHz	135	85	25	175	70	20

For comparison purposes, the results obtained without a polymer aligning layer (rubbed I.T.O. acts in this case as orienting medium) are included in this table. These results indicate the influence of the aligning layer. The differences may be explained by assuming the electrical properties (viz. ρ and ϵ) of the 500 Å thick polymeric layers to be different from their bulk values and/or the equivalent model to be incorrect.

DISTORTION IN THE ADDRESSING WAVEFORMS

The reduction in the RMS voltage across the pixels due to the distortion in the drive waveform depends on the number of transitions in the waveform and the resistances present on the row and column side of the matrix.

In terms of equivalent circuits, the LC capacitor C must be charged through a resistor R. Depending on the frequency f of the externally applied drive waveform and on the values of C and R the ratio β of the RMS voltage across the LC element and the RMS voltage of the applied square wave may deviate significantly from the value 1.0. The higher the frequency is, the larger the RMS voltage of the applied waveform has to be in order to achieve the same RMS voltage across the pixel.The relative shift δVf, defined as: $\delta Vf = \beta(f) - \beta(25\ Hz)$ can be approximated by: 2*f*R*C , which leads to δVf = 5% when R = 5 kOhm, C = 1 nF and f = 5 kHz. A 5% variation of Vth is definitely not acceptable in highly multiplexed LCDs. It is obvious from this simple model considered that both the resistor and the capacitor values should be as low as possible. As far as the resistor is concerned (i.e. the I.T.O.resistance, the output impedances of the drivers and the resistance of the interconnection)its value cannot be reduced beyond a certain practical limit.

The capacitor C can be reduced by using thicker LC layers and/or LC materials with lower ϵ-values. Increasing the LC layer thickness is not attractive because of the resulting larger switching times of the electro-optical effect. The choice of the dielectric constants $\epsilon//$ and $\epsilon^{\perp}$ is mainly determined by requirements on the value of Vth and the steepness of the transmission voltage curve. Due to different values of $\epsilon//$ and $\epsilon^{\perp}$ (and also because of the different relaxation behaviour of these dielectric constants) the frequency dependent shift of the transmission voltage curve is dependent on the applied voltage.

This was confirmed experimentally for a 180° DSTN configuration with steepness V90%/V10% = 1.15 (at 100Hz) by measuring the voltage shifts $\delta 1$ at V10% and $\delta 2$ at V90% in the frequency range 100 Hz to 5 kHz. The results are given in the following table.

Frequency square wave	V10% (V)	V90% (V)	Steepness
100 Hz	2.046	2.353	1.150
1 kHz	2.099	2.443	1.164
5 kHz	2.146	2.537	1.182

$\delta 1 = 100$ mV $\delta 2 = 184$ mV

The brightness non-uniformity can be further reduced by choosing a proper polarity reversal sequence wherein the number of transitions is independent of the data displayed [2,3,4] in the columns; however, the frequency components appearing across the pixels still depend on the displayed pattern. Thus the choice of the polarity reversal sequence is influenced by the frame frequency and the Vth versus frequency behaviour. In addition to the above factors the polarity reversal sequence should not introduce any DC component across the pixels nor flicker.

INFLUENCE OF THE ADDRESSING TECHNIQUES:

The Improved Alt and Pleshko Technique (IAPT) [5] is used in almost all commercial displays due to its low supply voltage requirement. Figure 4 shows a typical voltage level generator (VLG) for IAPT. The following relation must be satisfied to achieve the maximum selection ratio.

$$|V_1-V_2| = |V_2-V_3| = |V_4-V_5| = |V_5-V_6| = |V_1-V_5|.N^{-1/2} = |V_2-V_6|.N^{-1/2}$$

The above relation may not be satisfied exactly due to the tolerance in the resistor values and errors in the output voltages of the operational amplifiers (used as buffers).

Apart from a reduction in the SR this will result in a

-- RMS voltage across the pixel which depends on the pattern, and

-- DC voltage across the pixel although the polarity of the addressing waveforms is reversed periodically.

The following expressions give the RMS voltage across a pixel in terms of the voltage levels V_1 to V_6, n (the number of "ON" pixels in a column) and N (the number of lines multiplexed) taking into consideration the polarity reversal of the addressing waveforms for a DC free operation.

$$V_{on} = [\{(V_1-V_6)^2+(V_6-V_1)^2+(n-1)\ ((V_5-V_6)^2+(V_2-V_1)^2) +(N-n)\ ((V_5-V_4)^2+(V_2-V_3)^2)\}/2N]^{1/2}$$

and

$$V_{off} = [\{(V_1-V_4)^2+(V_6-V_3)^2+n\ ((V_5-V_6)^2+(V_2-V_1)^2) +(N-n-1)(V_5-V_4)^2+(V_2-V_3)^2)\}/2N]^{1/2}$$

The DC voltage across the pixels due to errors in the VLG is

$$V_{DC} = [\{(n-1)(V_5-V_6+V_2-V_1) +(N-n)\ (V_5-V_4+V_2-V_3)\}/2N]$$

The RMS voltage across the pixels without any error in VLG is

$$V_{ION} = [2(N+N^{-1/2})/N]^{1/2}.(V_1-V_6)\ (N^{1/2}+1)^{-1}$$

and $V_{IOFF} = [2(N-N^{-1/2})/N]^{1/2}.(V_1-V_6)\ (N^{1/2}+1)^{-1}$

The deviation in the RMS voltage can be translated to the maximum change in the transmission of the display using the factor s=(SR - 1)*100 . The percentage change in transmission across the "ON" and "OFF" pixels is given by the following expressions.

$$T_{ON} = [(V_{ON}-V_{ION})/(V_{ION}.s)].100$$

and

$$T_{OFF} = [(V_{OFF}-V_{IOFF})/(V_{IOFF}.s)].100$$

The error in the voltage levels either add or cancel to each other. Only the worst cases resulting in a large percentage change in the transmission of the "ON" and "OFF" pixels are used to specify the maximum tolerances allowed for the components in the VLG. For example when resistors with 5% tolerance and operational amplifiers with 6 mV maximum offset voltage are used the maximum change in the transmission of the "ON" and "OFF" pixels is ± 38% and ±44% respectively (mux 200 assumed) and the maximum DC voltage across the pixels will be 79 mV.
Hence the contrast will be very poor for certain difficult patterns in this case. However, the brightness uniformity and contrast will be usually better when the error in the bias voltages compensate each other or when less difficult patterns are displayed.

The Alt & Pleshko Technique (APT) [1] requires 5 voltage levels for generating the addressing waveforms. A typical VLG required for APT is shown in Figure 5 . The following relation must be satisfied for a maximum selection ratio:

$$|V_1-V_3| = |V_5-V_3| = |V_2-V_3|.N^{½} = |V_4-V_3|.N^{½}$$

However this relation may not be exactly satisfied due to deviations in the voltage levels in the VLG. It can be easily verified that the resulting RMS voltage across the "ON" and the "OFF" pixels is independent of the number n. Hence any error in the voltage levels in the VLG does not lead to brightness non-uniformity. Experimentally it was found that a 10% change in the value of R2 in the VLG did not lead to additional non-uniformity. However, the error in the VLG will introduce a DC voltage across the pixels although the polarity is reversed periodically.
Moreover the unselected rows remain at the same voltage level irrespective of the polarity reversal sequence. Hence the brightness non-uniformity due to the distortion in the row waveforms is minimum for APT. However, the supply voltage for APT is much higher as compared to IAPT.

The calculations outlined above (where the voltage levels are assumed to be stabilized under varying load conditions) are useful to improve the brightness uniformity of the display.

CONCLUSION:

The brightness non-uniformity observed in matrix LCDs increases with the number of lines multiplexed and a large number of parameters both in cell technology and drive electronics must be considered to minimize this non-uniformity.

REFERENCES:

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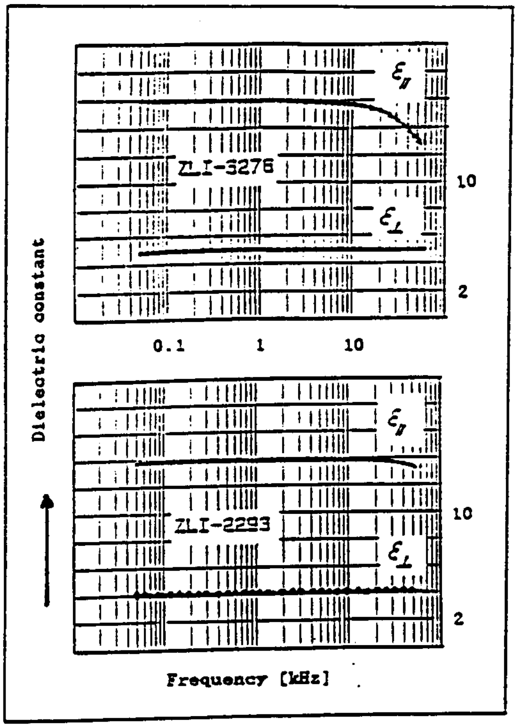
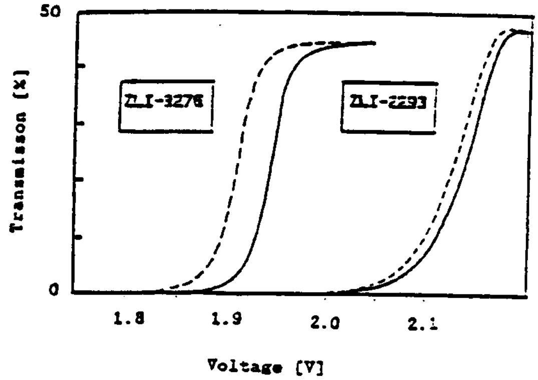
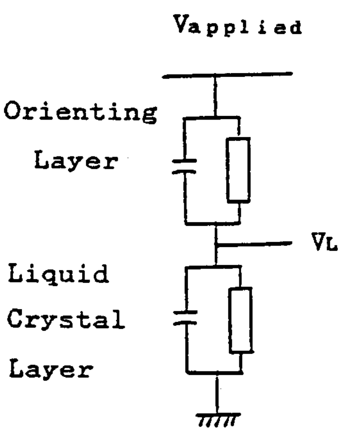
[4] Y.Kaneko et.al., SID Digest, 412 (1990)
[5] H.Kawakami et.al.,SID-IEEE Biennal Disp.Conf., 50 (1976)



<u>Figure 1</u>
The frequency dependence of ϵ//, $\epsilon^{\perp}$ for ZLI-3276 and ZLI-2293

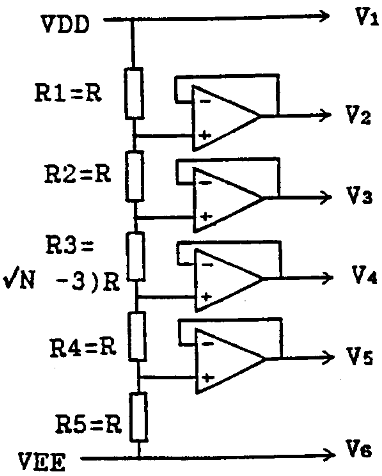


<u>Figure 2</u>
Transmission - Voltage curves for DSTN with square wave excitations of 100Hz and 5kHz. The solid lines refer to 5 kHz.



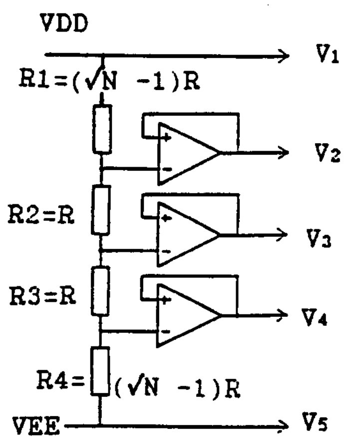
<u>Figure 3</u>

Equivelent circuit of a pixel.



<u>Figure 4</u>

Typical VLG for IAPT



<u>Figure 5</u>

Typical VLG for APT