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Analysis of the Optical Response Characteristics of the TFT-LCD

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A model, which takes into account the time dependence and voltage dependence of the dielectric constant of liquid crystal by using an equivalent circuit, is proposed to analyze the optical response characteristics of the TFT addressed LCD (TFT-LCD). The 30Hz flicker, which appears in the optical rise state of the TFT-LCD, can be calculated and analyzed numerically. The parameter M_{30}, which indicates the normalized amplitude of the 30Hz flicker, is reduced by increasing the storage capacitance (C_{ST}). M_{30} begins to saturate at C_{ST}=0.5pF. M_{30} is lower than 0.055 and the change in V_{COM} for minimizing M_{30} is +0.1V at C_{ST}=0.5pF.

1. Introduction

Recently, the development of TFT-LCDs has been accelerated[1), because of their high image quality in comparison with direct multiplexing LCDs. However, since the TFT-LCD is not operated in ideal static drive, the problem of the 30Hz flicker, especially in gray scale operation, still remains. We analyzed the optical response characteristics of the TFT-LCD numerically in order to investigate the 30Hz flicker. Several models have been proposed to calculate the optical response characteristics of the TFT-LCD[2)-4)]. We employed an equivalent circuit model because it is suitable for a large amount of calculation at high speed. Previously, an analysis using an equivalent circuit model showed that the asymmetric voltage in the LC caused the 30Hz flicker[4)]. However, it could not calculate the optical response characteristics of the TFT-LCD directly because it did not consider the time dependence of the dielectric constant of the TN-LC cell (ε_{LC}).

In this paper, we present the calculation method of the optical response characteristics of the TFT-LCD taking the time dependence and voltage dependence of ε_{LC} into account by using an equivalent circuit model. Then, the calculated results of the optical response characteristics of the TN-LC cell are compared with measurements. We analyze the 30Hz flicker which appears in the optical rise state of the TFT-LCD due to the gate-drain coupling capacitance (C_{gd}) and the change in LC capacitance (C_{LC})[5)].

2. Method of Calculation

Figure 1 shows a pixel equivalent circuit of the TFT-LCD. The following differential equation eq.(1) is obtained from this equivalent circuit and solved numerically:

$$
\begin{bmatrix}
C_X & -C_{SiN} & 0 & 0 \\
-C_{SiN} & C_{SiN}+C_{PI} & -C_{PI} & 0 \\
0 & -C_{PI} & C_{PI}+C_{LC}(V_{LC}(t),t) & -C_{LC}(V_{LC}(t),t) \\
0 & 0 & -C_{LC}(V_{LC}(t),t) & C_{LC}(V_{LC}(t),t)+C_{PI}
\end{bmatrix}
\times
\begin{bmatrix} \dot{V}_1 \\ \dot{V}_2 \\ \dot{V}_3 \\ \dot{V}_4 \end{bmatrix}
=
\begin{bmatrix}
C_{gd}\cdot\dot{V}_G+C_{ds}\cdot\dot{V}_S-\frac{V_1-V_2}{R_{SiN}}-\frac{V_1-V_{ST}}{R_{ST}}+I_{ds} \\
\frac{V_1-V_2}{R_{SiN}}-\frac{V_2-V_3}{R_{PI}} \\
\frac{V_2-V_3}{R_{PI}}-\frac{V_3-V_4}{R_{LC}} \\
\frac{V_3-V_4}{R_{LC}}-\frac{V_4-V_{COM}}{R_{PI}}
\end{bmatrix}, \quad (1)
$$

$$C_X=C_{SiN}+C_{gd}+C_{ds}+C_{ST}, \quad (2)$$

$$\dot{V}=dV/dt, \quad (3)$$

$$C_{LC}(V_{LC}(t),t)=\varepsilon_0\cdot\varepsilon_{LC}(V_{LC}(t),t)\cdot S_{PIXEL}/d_{LC}, \quad (4)$$

$$V_{LC}(t)=V_3-V_4, \quad (5)$$

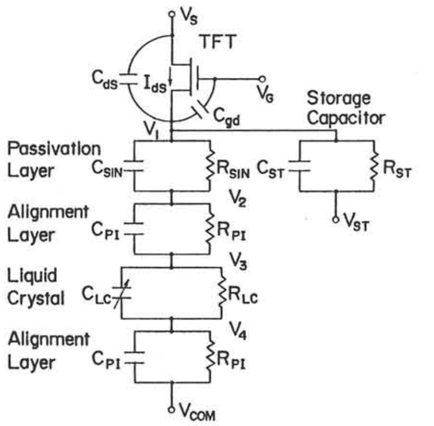

Fig.1 A pixel equivalent circuit.

where ε_{LC} is the dielectric constant of the TN-LC cell, I_{ds} is the drain current of the TFT, and S_{PIXEL} is the area of a pixel.

The capacitance of the TN-LC cell (C_{LC}) depends on time and voltage due to the dielectric anisotropy of the LC. We introduce eq.(3) to express the time dependence and voltage dependence of C_{LC}. The voltage dependence of ε_{LC} is given by the measurement of the capacitance voltage characteristics of the TN-LC cell. The time dependence of ε_{LC} are expressed by introducing the time dependence of orientation vector of the LC have a relaxation phenomenon to the change of applied voltage, as follows:

$$\varepsilon_{LC}(V_{LC}(t_0), t_0+\Delta t) - \varepsilon_{LC}(V_{LC}(t_0), t_0) = \{\varepsilon_{LC}(V_{LC}(t_0), \infty) - \varepsilon_{LC}(V_{LC}(t_0), t_0)\} \times \{1-\exp(-k\cdot\Delta t/\tau)\}, \quad (6)$$

where τ is the relaxation time, $\varepsilon_{LC}(V_{LC}(t_0), t_0)$ is the dielectric constant at $t=t_0$ with $V_{LC}(t_0)$. $\varepsilon_{LC}(V_{LC}(t_0), \infty)$ is the dielectric constant in the steady state

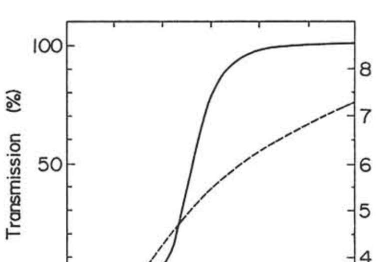

Fig.2 Transmission-Voltage characteristics (solid line) and Dielectric Constant-Voltage characteristics (dashed line) of the TN-LC cell.

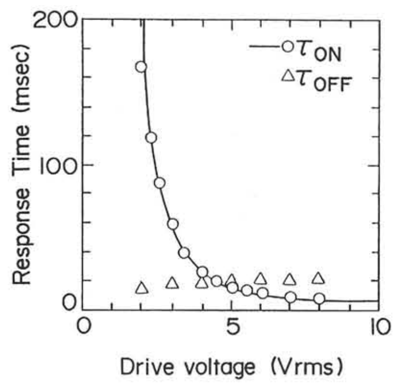

Fig.3 Response time of the transmisson as a function of drive voltage of the TN-LC cell: ○ is measured τ_{ON}, △ is measured τ_{OFF}, solid line is calculated τ_{ON} using eq.(7).

with $V_{LC}(t_0)$. $\varepsilon_{LC}(V_{LC}(t_0), \infty)$ is obtained from the measured voltage dependence of ε_{LC} of the TN-LC cell. Since the dielectric constant and the transmission of the TN-LC cell correspond 1 to 1, we assume that the relaxation time of ε_{LC} is equivalent to the response time of the transmission. Then, the following equations obtained from the continuum theory[6] are used:

when $\varepsilon_{LC}(V_{LC}(t_0), t_0) \leqq \varepsilon_{LC}(V_{LC}(t_0), \infty)$,

$$\tau = \tau_{ON} \propto \frac{\eta \cdot d_{LC}^2}{\varepsilon_0 \cdot \Delta\varepsilon \cdot V_{LC}(t_0)^2 - \pi^2 \cdot K_{ii}}, \quad (7)$$

where $\Delta\varepsilon = \varepsilon_{//} - \varepsilon_{\perp}$,

when $\varepsilon_{LC}(V_{LC}(t_0), t_0) > \varepsilon_{LC}(V_{LC}(t_0), \infty)$,

$$\tau = \tau_{OFF} = \text{constant}, \quad (8)$$

where η is the coefficient of viscosity, K_{ii} is the elastic constant. τ_{ON} is the time required from the time when the voltage is applied to the time when the transmission reaches 90% of its final value. τ_{OFF} is the time required from the time when the applied voltage becomes 0 V to the time when the transmission reaches 10% of its maximum value.

The characteristics of the TN-LC cell are measured to obtain the parameters for the calculation. The voltage dependence of ε_{LC} and transmission-voltage characteristics of the TN-LC cell are measured as shown in Fig.2. Figure 3 shows the response time of the transmission as a function of voltage. The calculated τ_{ON} using eq.(7) is also shown in Fig.3. τ_{OFF} is 20ms.

Current-voltage characteristics of the TFT are calculated by using the gradual-channel approximation[7]. The drain current in the off state is assumed to be proportional to the voltage between V_S and V_1, independent on V_G.

3.Results and Discussion

At first, we confirm that the calculation of the optical response characteristics of the TN-LC cell without TFT is possible using the above method. The optical response characteristics of the TN-LC cell are calculated and compared with the measurement. The TN-LC cell is driven by the static drive with amplitude voltage ΔV_S. Figure 4 shows the measured and calculated optical rise characteristics of the TN-LC cell. The measured and calculated optical fall characteristics of the TN-LC cell are shown in Fig.5. The calculated results are in agreement with the measured results. From these results, the optical response characteristics of the TN-LC cell can be calculated by using an equivalent circuit model in consideration of the voltage dependence and time dependence of ε_{LC}.

We numerically analyze the 30Hz flicker which appears in the optical rise state of the TFT-LCD due to C_{gd} and the change in C_{LC}[5]. C_{gd} and C_{ds} are 0.04pF and 0.02pF in the calculation. The TFT-LCD of 640(H)X240(V) pixels is driven by the frame inversion of the non-interlace method with the frame frequency of 60Hz. Figure 6 shows the input signal which is applied to a pixel. In the calculation, ΔV_S which produces the transmission of 0% is applied initially. ΔV_S is changed after voltages V_1, V_2, V_3, and V_4 reach the steady state. When the gate signal becomes V_G(ON) for the first time after ΔV_S is changed, the time is defined as t=0. The parameter M_{30} is defined to evaluate the 30Hz flicker, shown as follows:

$$M_{30} = F_{30}/T_m \quad (9)$$

where F_{30} is the amplitude of the 30Hz component of the calculated result and T_m is the mean transmission in a frame.

Figure 7 shows M_{30} as a function of the change in V_{COM} (ΔV_{COM}) without a storage capacitor. ΔV_S of 3.7V and 5.0V are the

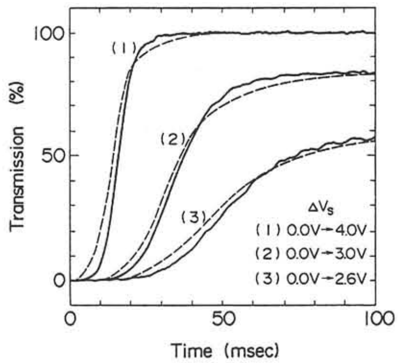

Fig.4 Measured(solid line) and calculated (dashed line) optical rise characteristics of the TN-LC cell.

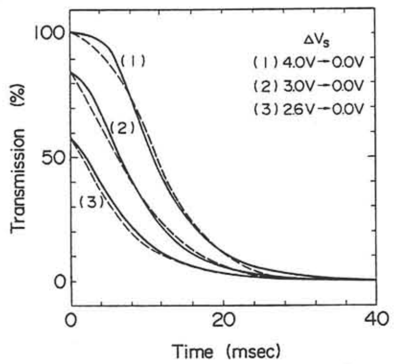

Fig.5 Measured(solid line) and calculated (dashed line) optical fall characteristics of the TN-LC cell.

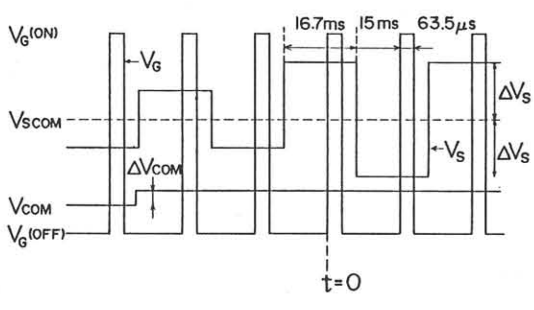

Fig.6 Input signal wave form
V_G(ON)=20V, V_G(OFF)=-5V, V_{SCOM}=10V, V_{COM}=4V

voltages which produce the transmission of 10% and 90%. ΔV_{COM} for minimizing M_{30} at ΔV_S=3.7V is +1.05V, and that at ΔV_S=5.0V is +1.60V. ΔV_{COM} for minimizing M_{30} varies depending on ΔV_S. This is because the drain voltage shift through C_{gd} (ΔV_{gd}) varies due to the change of C_{LC} with ΔV_S. Therefore, the 30Hz flicker can be minimized by adjusting V_{COM} in response to the ΔV_{gd} changes.

The optical rise characteristics of the

TFT-LCD with storage capacitor is calculated. Figure 8 shows M_{30} as a function of $C_{gd}/(C_{ST}+C_{LCm})$. T_{10}, T_{50}, and T_{90} represent the source signal amplitude which produce the transmission of 10%, 50%, and 90%, respectively. C_{LCm} is the mean capacitance of C_{LC} during a frame. M_{30} is reduced by increasing C_{ST} because the effect of C_{gd} and the change in C_{LC} becomes small. In the region where $C_{gd}/(C_{ST}+C_{LCm})$ is smaller than 0.06 (C_{ST} is larger than 0.5pF), M_{30} begins to saturate because the effect of C_{gd} and the change in C_{LC} becomes negligible. The calculated charging time (T_r) of the TFT is also shown in Fig.8. T_r is the time required from the time when V_G becomes V_G(ON) to the time when V_1 reaches 90% of source signal voltage. T_r is increased by increasing C_{ST}, but it is sufficiently shorter than the gate selecting time of 63.5μsec. When the storage capacitance of 0.5pF is added, M_{30} is lower than 0.055 which is much smaller than without a storage capacitor and T_r is shorter than 10μsec.

Figure 7 also shows M_{30} as a function of ΔV_{COM} at C_{ST}=0.5pF. ΔV_S of 2.8V and 4.5V are the voltages which produce the transmission of 10% and 90%. In comparison with the results without a storage capacitor, the difference of ΔV_{COM} for minimizing M_{30}, due to ΔV_S change, is nearly eliminated. Further, ΔV_{COM} for minimizing M_{30} with ΔV_S which produce the transmission of 90% is +1.60V without a storage capacitor, but becomes +0.1V with the storage capacitance of 0.5pF.

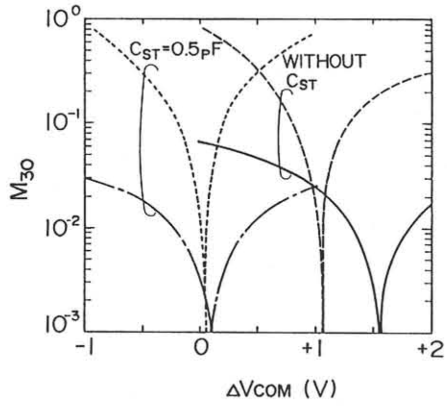

Fig.7 M_{30} as a function of ΔV_{COM}
solid line- ΔV_S=3.7V, dashed line- ΔV_S=5.0V
chain line- ΔV_S=2.8V, dotted line- ΔV_S=4.5V

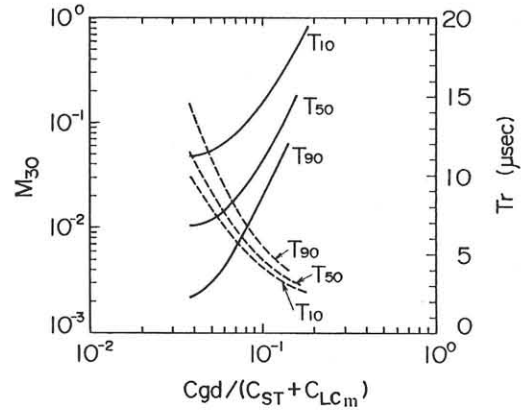

Fig.8 M_{30} as a function of $C_{gd}/(C_{ST}+C_{LCm})$ (solid line) and charging time (T_r) as a function of $C_{gd}/(C_{ST}+C_{LCm})$ (dashed line)

4. Conclusions

In order to analyze the optical response characteristics of a TFT-LCD, we introduce an equivalent circuit model which takes into account the time dependence and voltage dependence of ε_{LC}. The calculated results of the optical response characteristics of the TN-LC cell are in agreement with measurements. We analyzed the 30Hz flicker which appears in the optical rise state of the TFT-LCD due to C_{gd} and the change in C_{LC}.

The 30Hz flicker is reduced by addition of the storage capacitor. M_{30} is lower than 0.055, and ΔV_{COM} for minimizing M_{30} is +0.1V at C_{ST}=0.5pF. These values are much smaller than without a storage capacitor, and the charging time of the TFT is shorter than 10μsec at C_{ST}=0.5pF.

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