Fast Optical Response Time based on Transient LC Director Control in the Liquid Crystal Display

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Abstract

New driving waveform which can be inferred by analyzing fundamental LC mechanism is suggested. The main idea of the new waveform is the stabilizing LC layer fast in the cell by controlling the middle director of LC layer. Consequently, we can get not only numerical reduction of optical response merely but also the change of dynamic transmittance from applied voltage exactly

1. Introduction

Recently, Liquid crystal display has been widely used for television and moving picture applications. As a result, the many related new techniques and methods are suggested. Especially, the fast optical response technique is studied on various methods such as LC material, LC mode, and Driving schemes, etc.. The simple method for fast response time is to improve LC physical properties such as lower rotational viscosity, higher birefringence and shorter chiral pitch[1]. OCB(Optically Compensated Bend) mode and FLC(Ferroelectric Liquid Crystal) mode is also studied[2, 3].

To realize the motion picture, it is important to improve the response time not between white and black state but between all gray levels. So, it needs to add Driving schemes such as overdrive method[4], Dynamic Capacitance Compensation(DCC) method[5], Feedforward Driving(FFD) method[6] and Dynamic Contrast Compensation(DCC) method[7] to the above improvement. Even if all these methods using voltage waveform improve the response time to some extent, since they cannot control the dynamically changed transmittance effectively, there is much room for the improvement of response time. Therefore, this paper suggests the new control method that uses LC director considering the dynamically changed transmittance. By considering the LC director, the transmittance is stabilized faster and the response time is also faster.

2. Theory

Figure 1 shows the basic concept that is generally used for fast inter-gray response time. Instead of applying final target voltage directly, in this method, the voltage waveform is made by adding additional voltage to final voltage during some time. Therefore, it is important to decide the magnitude and applied time of additional voltage for fast response time. Until now, the suggested method that uses the voltage waveform selects the capacitance or transmittance as decision characteristics.

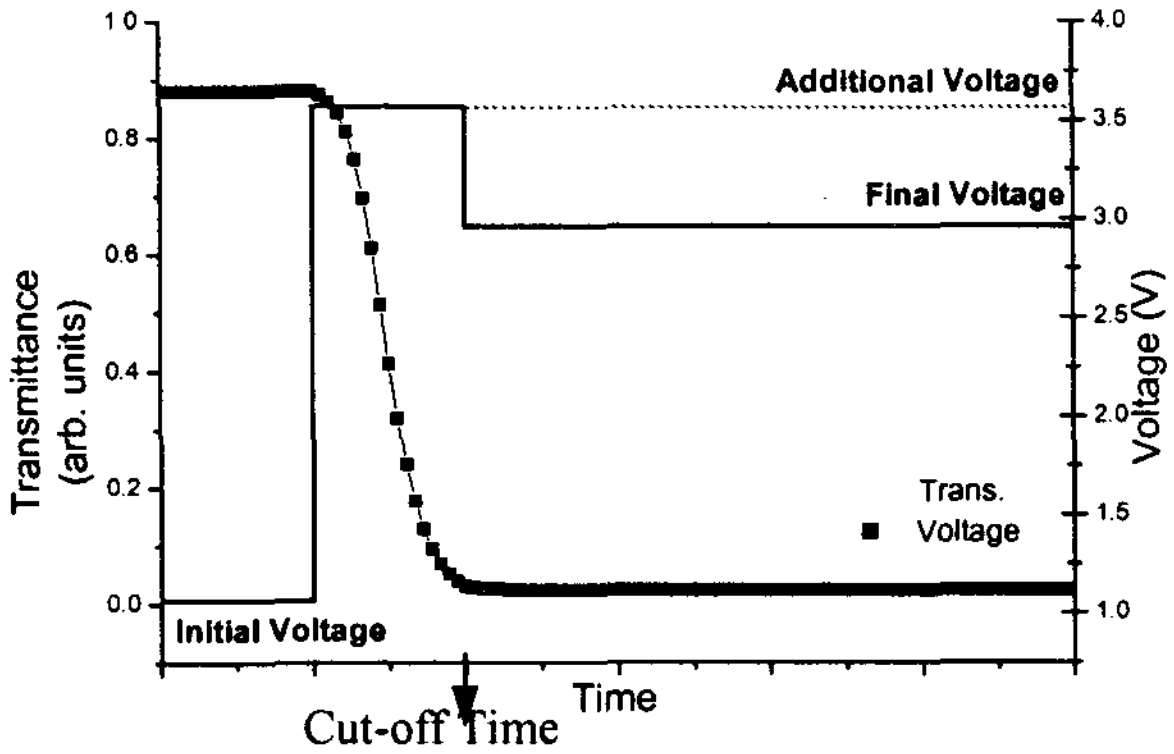


Figure 1. General waveform of fast response driving and exact change of transmittance

However, the optical response time is difficult to stabilize fast if we use the previous methods not because those methods use the dynamic behavior but because they only use the static characteristics. For example, in the method that uses the transmittance, the transmittance arrives at the target transmittance temporarily at the end of the cut-off time. But after the cut-off time, the transmittance is deviated from the target transmittance and more time is needed to arrive at the target transmittance back. So it can be known that the new method is needed in order to overcome these dynamic characteristics for fast response time.

In order to search for the new method in the basic point of view, the following is considered. In 90° twist nematic cell, extraordinary normally white mode, the LC director $\vec{n}$ moves depending on the three elastic constant k_{11}, k_{22}, k_{33} and the external electric field E. So the Gibbs' free Energy F is

$$F = \frac{1}{2}k_{11}(\nabla\cdot\vec{n})^2 + \frac{1}{2}k_{22}(\vec{n}\cdot\nabla\times\vec{n})^2 + \frac{1}{2}k_{22}|\vec{n}\times\nabla\times\vec{n}|^2 - \frac{1}{2}\varepsilon\vec{E}\cdot\vec{E} \qquad (1)$$

Denoting the rotational viscosity by γ_1, the equation of director motion is defined as Euler's equation for Cartesian coordinates.

$$\gamma_1\frac{\partial n_i}{\partial t} = \frac{d}{dx_j}\left(\frac{\partial F}{\partial n_{i,j}}\right) - \frac{\partial F}{\partial n_i} + \lambda n_i, i = 1,2,3 \qquad (2)$$

The solution of the Euler's equation means that the LCs move through the passage of the minimization of Free Energy. In this equation, it can be acknowledged that the free energy can be expressed as the LC director, so it depends on the structure of LC directors. Especially, we suppose that the middle LC director reflects effectively the LC dynamics and the transmittance because the middle director is affected most highly by the external electric field with many degrees of freedom. Hence, this paper suggests that the new voltage waveform method that uses the control of middle director in LC layer is more effective for fast response time

3. Simulation and Results

First, in order to show the relation of free energy and transmittance, several computational simulations are executed. In this paper, for more sensitive calculation, the commercial program LCD Master (manufactured by Shintech Inc.) is used.

Figure 2 is the simulation graph of static and dynamic transmittance changing with Gibbs' free energy. All transmittance is divided into 64 levels for easy applying voltage. In this figure, the dot-line corresponds to the dynamic case. The initial white state is L63, and this initial states fall to the L39 and L0 respectively as time goes. The solid line means the stabilized states at each gray after the infinite time goes, that is, static state. The dot line means that the dynamic transmittance by the free energy moves through the transient change and then is stabilized after a long time. Therefore, it can be known that the origin of slow LC response come from "the Stabilization of LC director".

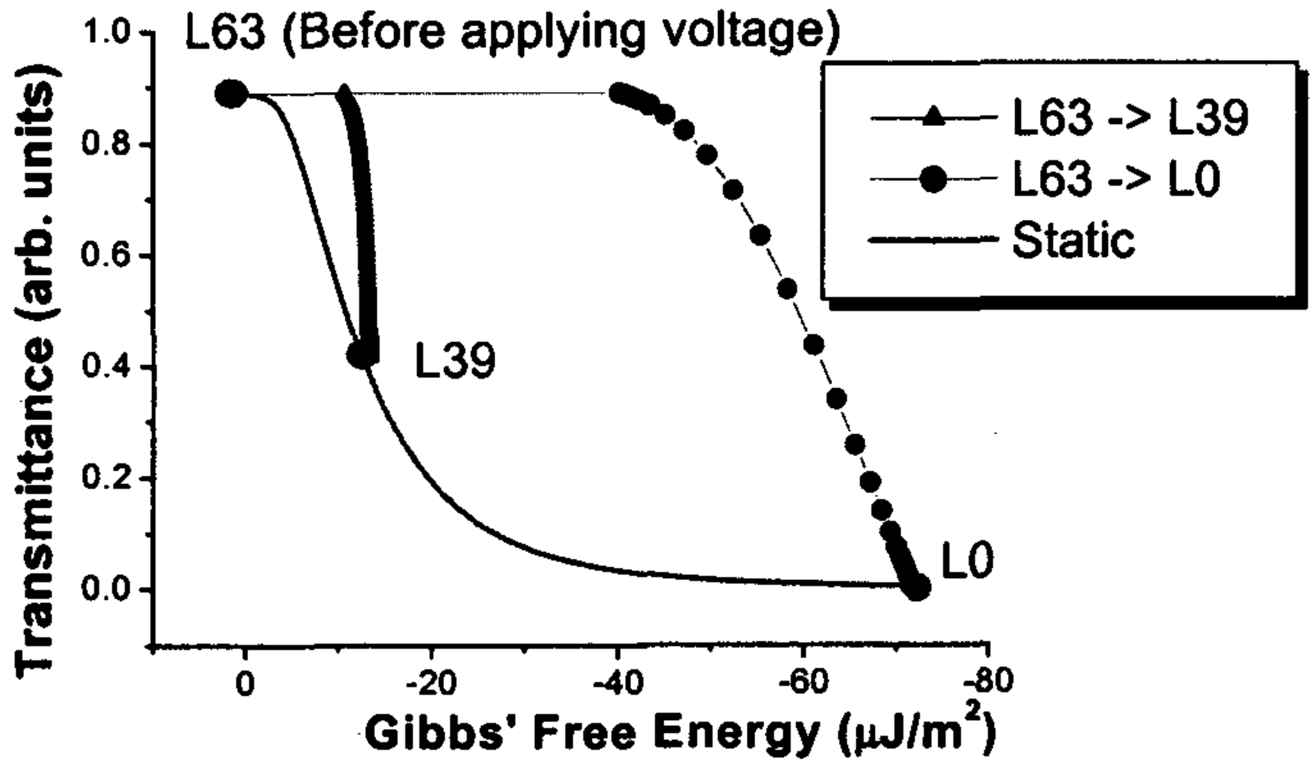


Figure 2. Simulation results by comparing dynamic transmittance L63, L39 with static transmittance curves.

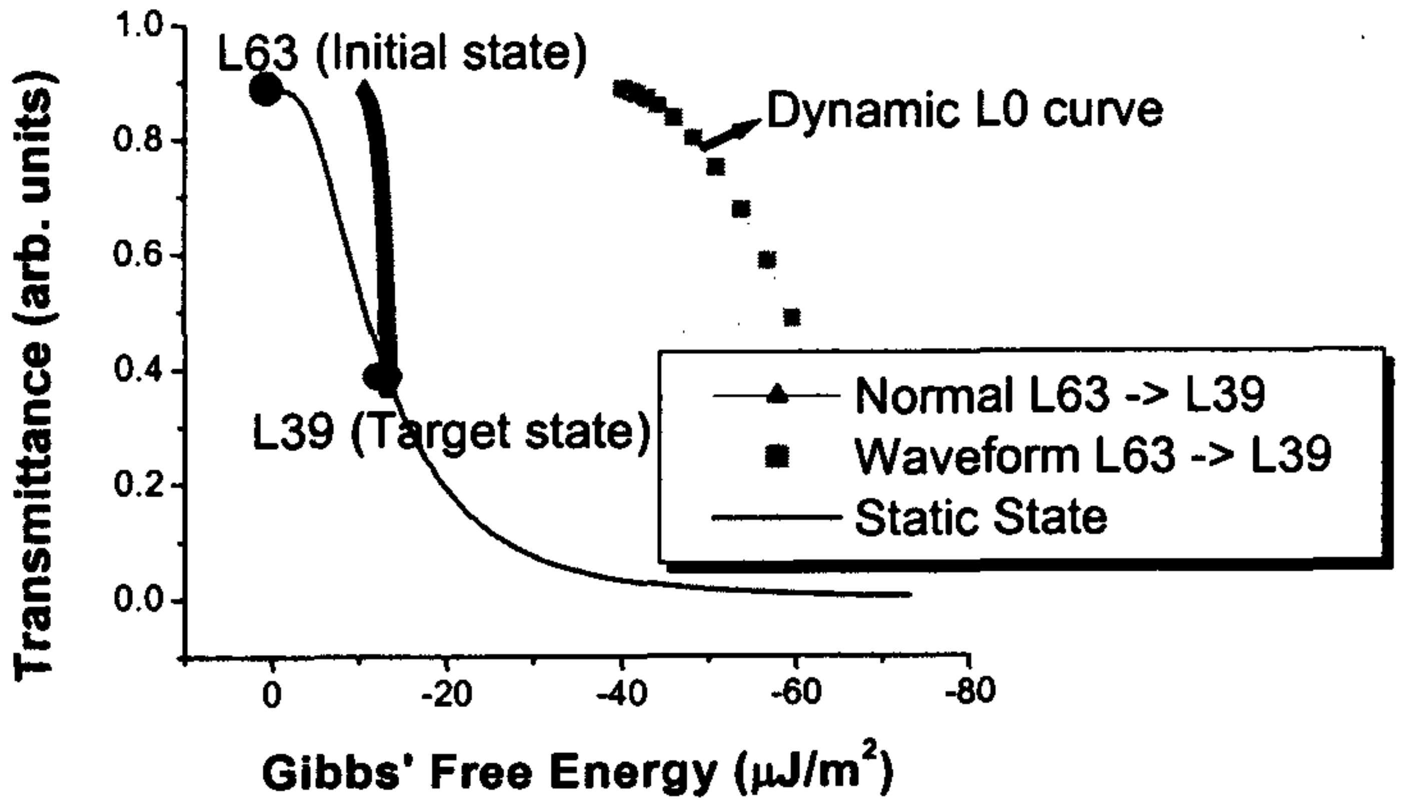


Figure 3. Simulation results by waveform from L63 to L39 via using dynamic L0 route.

In the figure 2, it is also shown that the response time from L63 to L39 graph takes more than 100ms if the direct driving method is used. The interval of dots corresponds to the 1ms. Figure 3 shows the result when the voltage waveform method is used. In this figure, it is assumed that the route from L63 to L39, that is, from the white state to middle gray state is needed. However, if the dynamic L0 curve is observed cautiously, it can be shown that the time that arrives at the same transmittances of L39 is faster than the time of the dynamic L39 curve. The voltage waveform method uses this way of changing the voltage from L63 to L39 via L0 for fast stabilization of transmittance. Using the dynamic L0 curve, the transmittance arrives at nearby L39 within the 12ms. The voltage waveform method is faster than general driving.

On the other hand, it is a very important to decide the magnitude or the applied time of the additional voltage for fast stabilization of transmittance. Previous methods such as DCC, FFD, and Overdrive method determined these value of the additional voltage according to the capacitance or transmittance that reflect the static characteristics. However, the minimized free energy of Euler's equation (2) is related to the LC director distribution. Accordingly, for the dynamic control, the LC director should be considered. To make the matter simple, it is assumed that the flexible middle director leads all of other directors because the middle directors suffer an easy change from the applied voltage and free energy. Here, the middle director means theta (tilt) angle because middle phi (twist) angle is always invariant in the Twist Nematic (TN) mode.

In order to compare the middle-theta method with the previous methods, the following simulation is executed. Figure 4 shows the dynamic middle-theta, capacitance, and transmittance at each gray-level as time changes. The voltage waveform method for fast response time should decide the one of two values, that is, the cut-off time or the magnitude of additional voltage. For easy comparison, the cut-off time is adjusted fixing the magnitude of additional voltage. Therefore, we would select the time during which the additional voltage is applied. We define these cut-off times as t_θ, t_C, t_T, which correspond to the middle theta, capacitance, transmittance respectively. For instance, for acquiring the fast response time from L63 to L39, L0 that has fixed voltage can be chosen as an additional voltage. In this case, the time of the L0 graph that pass through the same middle-theta, capacitance, and transmittance value of the stabilized L39 can be selected respectively. This case is the rising time in the Figure 4 and the same method also is applied to the falling time.

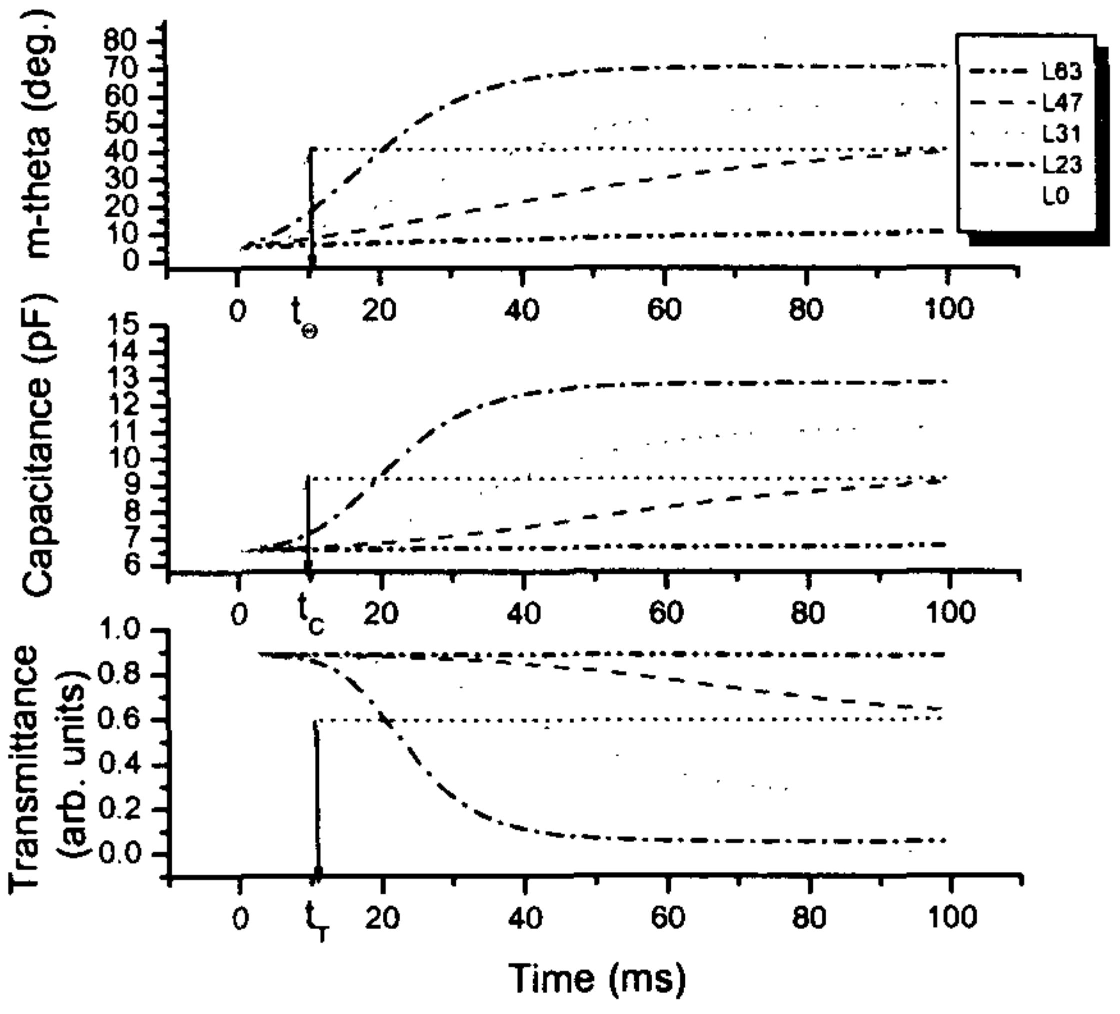
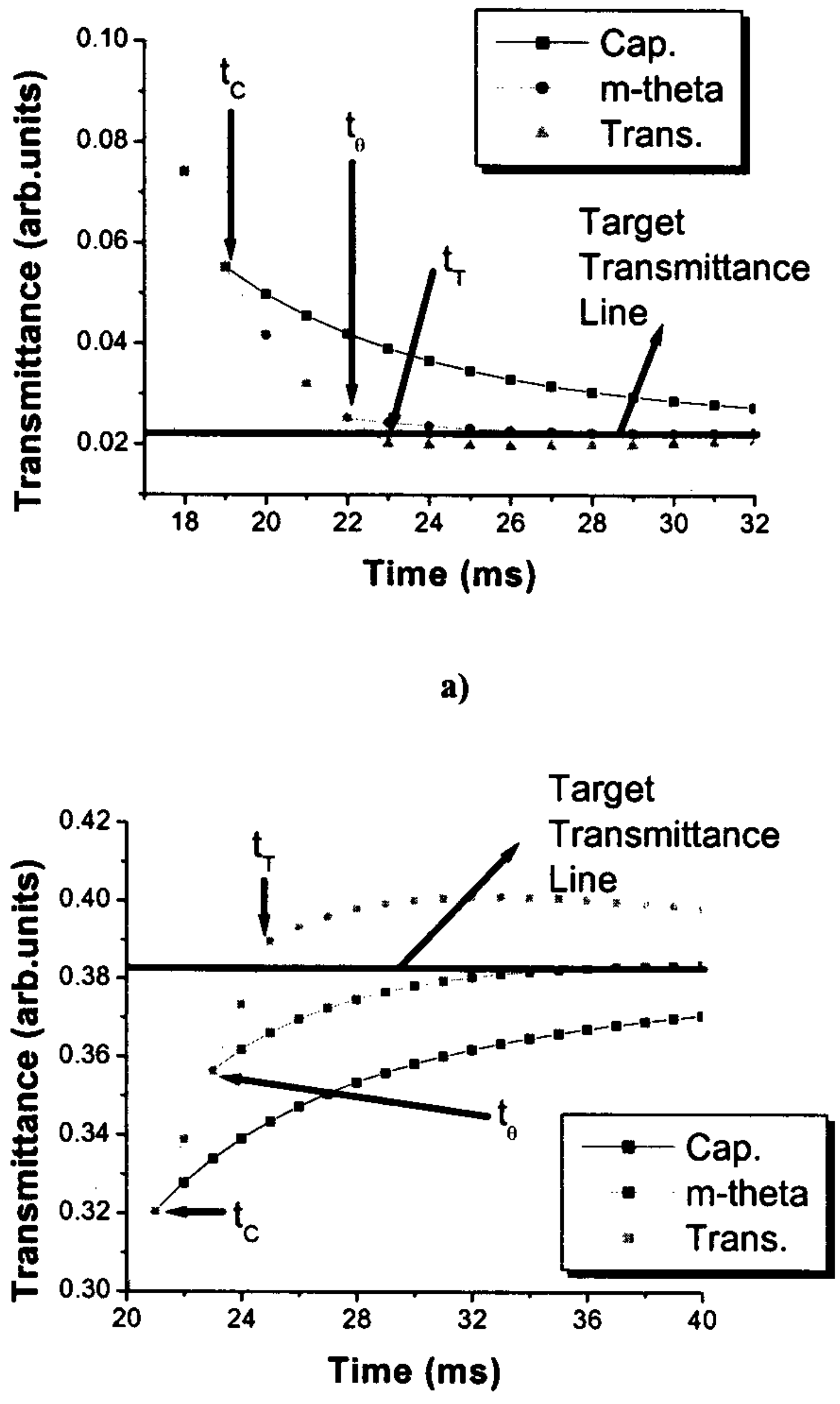


Figure 4. Simulation graph of dynamic Cap., trans., and m-theta changing with rising time between gray level. And selection of waveform time in each method.

These three cut-off times can be applied to the real response time. The result is shown in the figure 5. In this case, the rising time uses the passage from the initial L63 to the final L7. The L0 is used for the additional voltage. The decay time also uses the passage from initial L0 to L39, which use the additional voltage L55. In this figure, we have focused on the time interval near three cut-off times. In rising time, the cut-off time at each three cases is applied respectively. At each case, the transmittance is stabilized to the target L7 transmittance with different response time after each cut-off time. The simulation result of rising time is expressed in figure 5-a. The similar result of LC falling time is expressed in figure 5-b. The arrow points out each cut-off time. In this result, Figure 5 shows how the equilibrium state of each waveform method is acquired. In these curves, to have fewer dots means the fast optical response time from cut-off point to stable transmittance because one dot is 1 ms order. The middle theta diagram shows that transmittance is approaching fast to the target static transmittance. The other waveform makes the transmittance overshoot the static target transmittance in the first frame and generate the distortion of optical response. The movement using the middle theta method is much the same as the critical damping oscillation and the movements using other method are much the same as overdamping motion.



a)

b)

Figure 5. Optical response of voltage waveform.
a) rising time, b) falling time.

Figure 6 shows the difference between methods we have stated. The Ideal transmittance curve is the transmittance we want to acquire. This case is the same that the LCs have the very fast response time. Here, L39 and L7 are alternatively applied. The transmittance in normal method doesn't reach the point we want. In the method using capacitance, the same phenomenon occurs. However, in the method using transmittance, the transmittance is overflowed to the target transmittance, so more time is needed to acquire the target transmittance. On the other sides, the method using the middle theta stabilizes the transmittance to the target effectively.

In result, it can be known that the dynamic transmittance change should be considered for the inter-gray fast response time, and the method we suggest is superior to the other method.

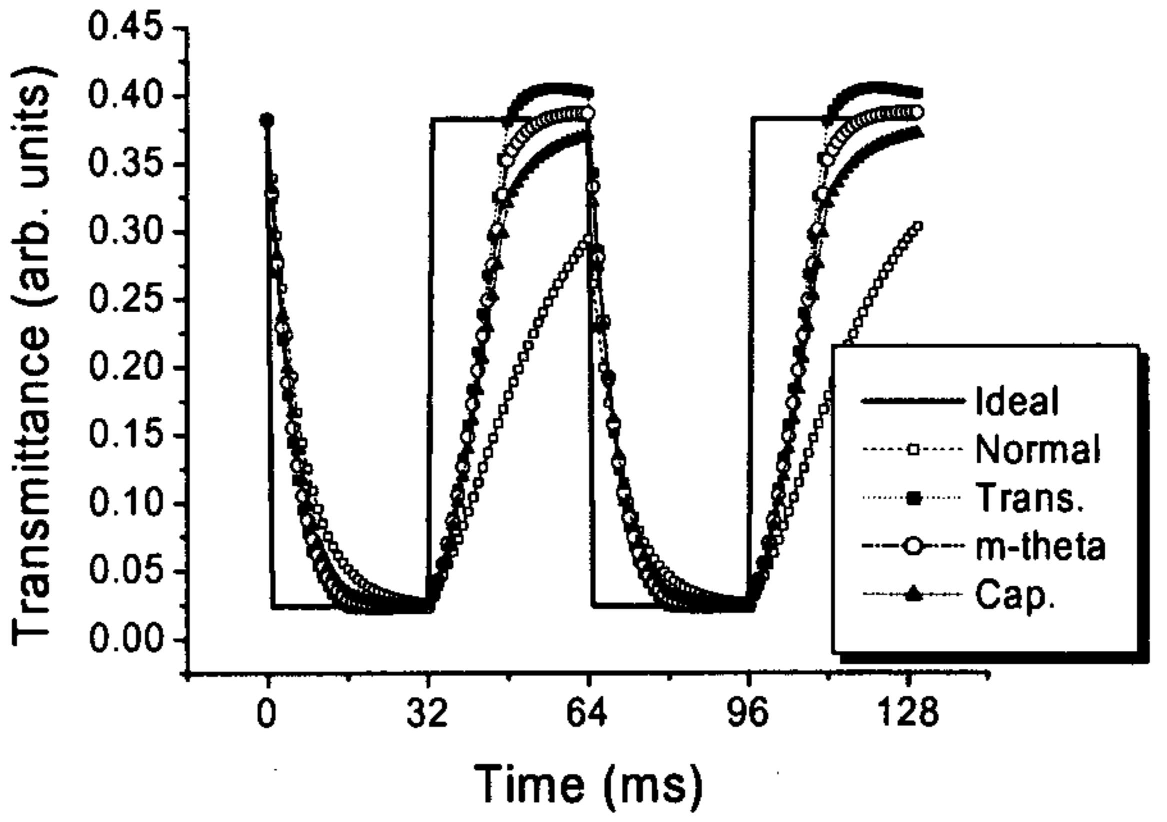


Figure 6. The dynamically changed transmittance depending on the operation method

4. Conclusion

The voltage waveform method gives many ideas reducing the optical response time. The exact transmittance transition between inter-grays needs to design the voltage waveform minimizing distortion of the optical response. The new idea we suggest is the following. The stabilization of middle director affects the other layer's director to move naturally to the equilibrium point and to restrain over-damped oscillation of transmittance. Therefore the dynamic transmittance is affected by the middle theta graph more effectively. In this paper, the new voltage waveform scheme related to the middle director of LC structure is suggested. This method is unlike previous method using the static capacitance or transmittance value and can make the dynamic change of transmittance stabilized effectively. As a result, the fast response time can be easily acquired. However, more study is also needed for real application.

5. References

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