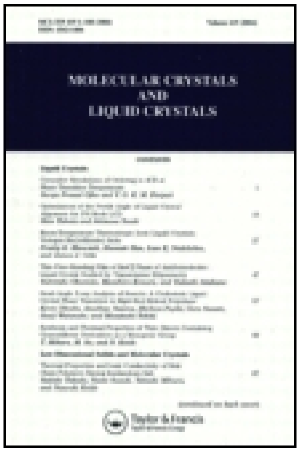

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Negative Delta-N Compensators For Improvement of LCD Angular Dependency

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NEGATIVE DELTA-N COMPENSATORS FOR IMPROVEMENT OF LCD ANGULAR DEPENDENCY

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Abstract To improve angular dependence of liquid crystal displays(LCDs), three LCD configurations are proposed. Two of these configurations correspond to transmissive LCDs and the remaining one to reflective LCDs. Each configuration includes negative Δ n compensators whose optical axes take the similar liquid crystal director profile.

1. INTRODUCTION

Normally-white twisted nematic (NW-TN) devices are widely used in LCDs. This NW-TN device, however, have strong angular dependence. To improve this angular dependence, application of a compensator has been proposed, whose Δ n takes a negative value and optical axis is perpendicular to its film surface.[1,2] This proposal is based on the approximation that a liquid crystal director profile under high voltage seems to be a homeotropic structure. However, this compensation method introduces a colored image problem. To solve this problem, an ideal compensator structure was constructed and another modified configuration for transmissive LCDs was found. This ideal compensator structure can be easily applied to reflective LCDs.

2. A BASIC PAIR

Before introducing new compensation structures, a pair of positive and negative birefringence layers, as shown in FIGURE 1, is investigated. These layers (P and N) are characterized by Δ nd values (Δnd_N and Δnd_P) and optical axis directions ($\vec{N}$, and $\vec{P}$).

This Δnd_N is assumed to be equal to $-\Delta nd_P$ and the direction $\vec{N}$ to be parallel to the $\vec{P}$ direction. In practical cases, the N layer and the P layer correspond to a liquid crystal layer and a compensator, respectively.

In cases of normally incident light, first the incident linearly-polarized light is deformed by the P layer and modified into elliptically-polarized state. However, the second layer N has the same birefringence amount of the first layer P except its sign and the light polarization is remodified into the initial polarization.

This can also be applied to obliquely incident cases. If the P's birefringence value decreases, the N's birefringence value increases and the total birefringence change is canceled out. In this way, the compensation function of this pair is maintained in obliquely incident cases.

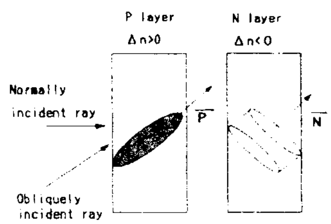

FIGURE 1
A basic pair for angular dependence compensation.

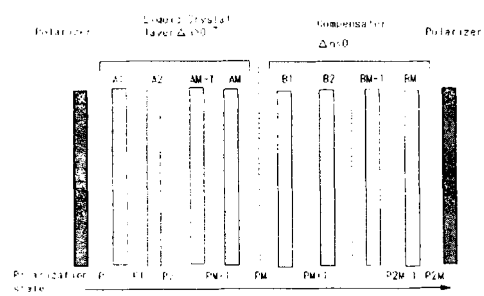

FIGURE 2 A single compensator configuration.

2. A SINGLE COMPENSATOR CONFIGURATION

Based on the above discussion, general compensator structures for any liquid crystal directors can be constructed. Referring to the configuration in FIGURE 2, this compensator structure for transmissive LCDs is explained. First, a liquid crystal director profile corresponding to a black image on a LCD screen is sliced into M layers. This director profile has twisted and tilted directors. However, if M takes a large value, the liquid crystal director in each sliced layer seems uniform. Each layer is named as $\mathbf{A}_j$ and each optical axis as $\vec{\mathbf{A}}_j$ (j=1...M). At the next stage, a compensator is assumed to have M uniform layers. Similarly, each layer is called $\mathbf{B}_j$, whose optical axis is called $\vec{\mathbf{B}}_j$. Birefringence amounts in the layers $\mathbf{A}_j$ and $\mathbf{B}_{M-j+1}$ is assumed to be $(\Delta \mathbf{nd})_j$, and negative-signed $-(\Delta \mathbf{nd})_j$, respectively. In addition to this assumption, $\vec{\mathbf{A}}_j$ is assumed to be parallel to $\vec{\mathbf{B}}_{M-j+1}$.

To explain the optical property of this configuration, each polarization state at each path stage is labeled as P0, P1,.....P2M. Using this notation, at the end of the LCD, the light takes the state PM. At the next moment, the light impinges into the layer B1 and its polarization state is changed into the state PM+1. However, this change (PM→PM+1) is found to have the opposite direction to the change (PM-1→PM) because the layers AM and B1 form a basic pair , as shown in FIGURE 1. This suggests that the state PM+1 is equal to the state PM-1. Repeating the same discussion for the layer AM-1 and the layer B2, it is found that the state PM+2 is equal to the state PM-2. After a sequence of iteration procedure, the state P2M is found to be equal to the state P0. This result suggests that the polarization state deformed by the LCD is recovered to the initial state by the compensator.

This recovery process can also be expected in obliquely incident cases because the recovery process is based only on the basic pair relations described in the previous section.

3. A DOUBLE COMPENSATOR CONFIGURATION

Modifying the single compesator configuration in FIGURE 2, another structure with two compensators can be obtained for transmissive LCDs, as shown in FIGURE 3. This structure has a liquid crystal layer, the first compensator and the second compensator. In the same manner as the previous compensator, the liquid crystal layer is sliced into 2M layers and the two compensators into M layers. After that, as shown in FIGURE 3, each layer is labeled as Bi, Aj, or Cj (i=1,...,2M, j=1,...,M). In this case, the following relations are settled. For the pair of the layers Cj and Bj, the former has negative sign -Δ nd, the latter has positive sign Δ nd and their optical axes are parallel. The same relations for the layers Aj and BM+j are assumed.

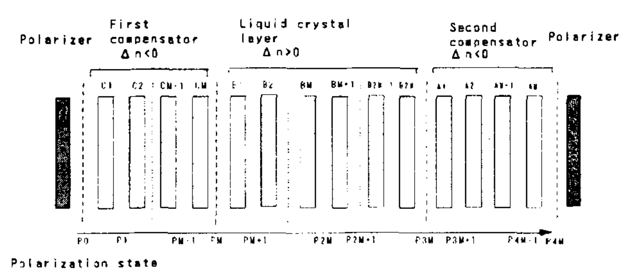

FIGURE 3 Double compensator configuration.

To explain the optical property of this structure for normal light incidence, each light polarization state at each path stage is labeled as Pj (j=1....4M). After passing out of the first compensator, the light has the polarization state PM. The light impinges the layer B1 and its state PM is changed into the state PM+1. Because the layers CM and B1 form a basic pair, the state PM-1 is equal to the state PM+1. In the same manner, the state P0 is equal to the state P2M. This result suggests that the polarization state deformed by the first compensator is recovered to the initial state by the left half of the LCD. This deformation-recovery function is also expected for the second compensator and the right half of the LCD, and thus, the conclusion that the state P2M is equal to the state P4M can be obtained.

A similar conclusion can be obtained for obliquely incident cases. If a crossed-polarizers configuration is settled, neither normally nor obliquely incident light can be transmitted, and there is a dark state in this LCD over a wide incident-angle range.

5. A REFLECTIVE CONFIGURATION

The above compensator construction method can be easily expanded to reflective LCD cases. In the reflective case, brightness is more important than a contrast ratio, and brightness angular dependence is a serious problem. A reflective configuration to resolve this problem is explained, referring to FIGURE 4 (a). This reflective configuration includes a compensator, a liquid crystal layer, a mirror reflector and a polarizer. As shown in the figure, the compensator and the liquid crystal layer are sliced into M uniform layers, labeled. To let the sliced layers A_j and B_{M-j+1} form a compensation pair, the former is assumed to have the same birefringence amount as the latter except its sign and an optical axis parallel to the latter's optical axis (j=1,...,M).

(a) (b)

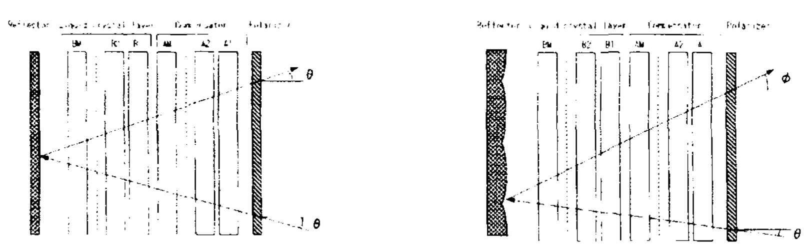

FIGURE 4 (a) Compensated reflective configuration with a mirror reflector. (b) Compensated reflective configuration with a rough surface reflector.

A linearly-polarized ray from the polarizer impinges the compensator and its polarization state is modified into a elliptically-polarized state. However, the liquid crystal layer recovers this state up to a linearly-polarized state just before the mirror. This recovery process is maintained over a wide incident angle range. The return path after being reflected on the mirror has the same recovery function and a linearly-polarized state is obtained just before the polarizer. From the this discussion, it is clarified that bright image nearly without angular dependence can be obtained.

In practical reflective LCDs, rough surface reflectors are widely used. In this case, as shown in FIGURE 4 (b), the reflected angle is not generally equal to the incident angle. Even in this case, the above compensation effect is available because the ray just before the reflector is linearly-polarized.

6. SIMULATION RESULTS IN THE APPLIED CASE TO NW-TN LCDs

To confirm these effects on angular dependence, numerical simulations applied to the NW-TN mode were carried out. Applying the single compensator configuration, that compensator have a negative Δ n value and a tilted twisted optical axis profile, corresponding to the liquid crystal director profile. FIGURE 5 (a) and (b) show fine structures of the NW-TN device and the compensated device. The contrast ratio features in FIGURE 6 (a) and (b) are simulation results for the NW-TN LCD and the compensated NW-TN LCD. This comparison shows the compensated LCD has improved angular dependence except for the 90-degree azimuth direction. This azimuth direction coincides with that of the midplane liquid crystal director.

In the double compensator case, the above compensator is divided into two parts and these are used as two compensators. Simulation shows this compensated LCD has the nearly same characteristics as in FIGURE 6 (b).

(a) (b)

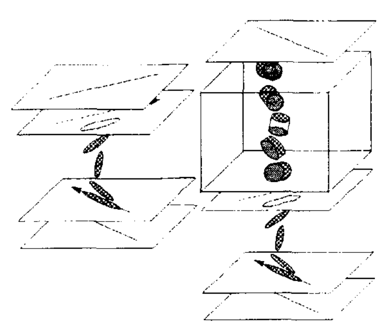

FIGURE 5
Fine configurations of a NW-TN device (a) and single compensation NW-TN device (b).

(a) (b)

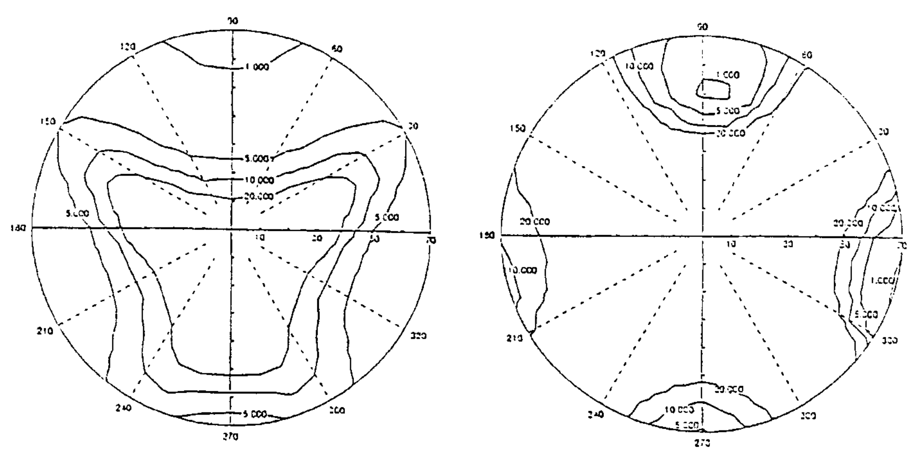

FIGURE 6 Angular dependence features of the NW-TN device (a) and the compensated NW-TN device (b).

7. CONCLUSION

Three compensator configurations to improve LCD angular dependence were constructed. Two of these can be applied to transmissive LCDs and the remaining one to reflective LCDs. Numerical simulation showed the former two can be expected to have improved angular dependence. The compensators in these configurations need to have a complicated optical axis profile. However, the approximated compensator was developed which corresponded to a double compensator configuration applied to a NW-TN device.[3]

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