Compensation for Liquid Crystal

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Abstract

Normally white TN-LCD is the preferred solution in active matrix display thanks to easy production, fast response and good white balance. However, it is has poor viewing angle properties and correction films are difficult to design. We present the mathematics of designing a compensating film and discuss various technological solutions for making

1. Introduction

TFT-LCD (thin film transistor liquid crystal display) is challenging the CRT in all applications. As multi user applications such as desktop display and home TV are targeted, the improvement of viewing angle is a major challenge.

TN-LCD (twisted nematic) was chosen at the beginning of multiplexed LC-display because of its achromaticity and its high threshold that allows passive addressing. None of these advantages are important for active matrix display and other solutions such as IPS (in-plane switching) or VAN (vertically aligned nematic) looks more promising. However Twisted nematic still remains the main production thanks to its good yield, high open aperture ratio and short response time.

2. Normally white TN-LCD

The deformation of untilted nematic liquid crystal obeys to the same physical laws as the buckling of a rod: the action of the electric field (respectively the load of the rod) is quadratic and will not generate deformation when below a threshold related to the coupling to the cell boundary (respectively the stiffness of the rod). Above this threshold, the deformation will take place in either direction; the ambiguity can be released by introducing a small pretilt (respectively a bending of the rod). It can be understood from the mechanical analogy that the response time is very long in the vicinity of threshold and decrease as deformation grows.

The physiological response of eye is such that small intensity variations can be detected in the dark gray domain which could not be seen in the light gray domain. Therefore, it is important in order to have short response time in the dark gray level, to choose the cross polarizer structure also known as “normally white” because it is at the white level when voltage is switched off. A further advantage of cross polarizer structure is that transparent spacers will not appear as white spot on dark level.

The correction of normally white TN-LCD will aim at the darkest possible black level, the lightest white level and the most homogeneous transition from black to white.

3. Gray level inversion

The main problem with gray level happens in the direction pointed at by the LC-director in the center of the cell. These directions have a minimum birefringence for intermediate voltage. The luminance in these directions is increasing when voltage is high; this results in gray inversion. Black appears as a silver gray to the observer. This half of the conoscope is referred as the gray inversion domain. There is no report of any solution to solve that problem that some except for limiting the observation domain to the other half of the conoscope. In absence of correction film, this half has poor contrast and is almost unusable. It is the role of LCD compensation film to increase the contrast in this domain.

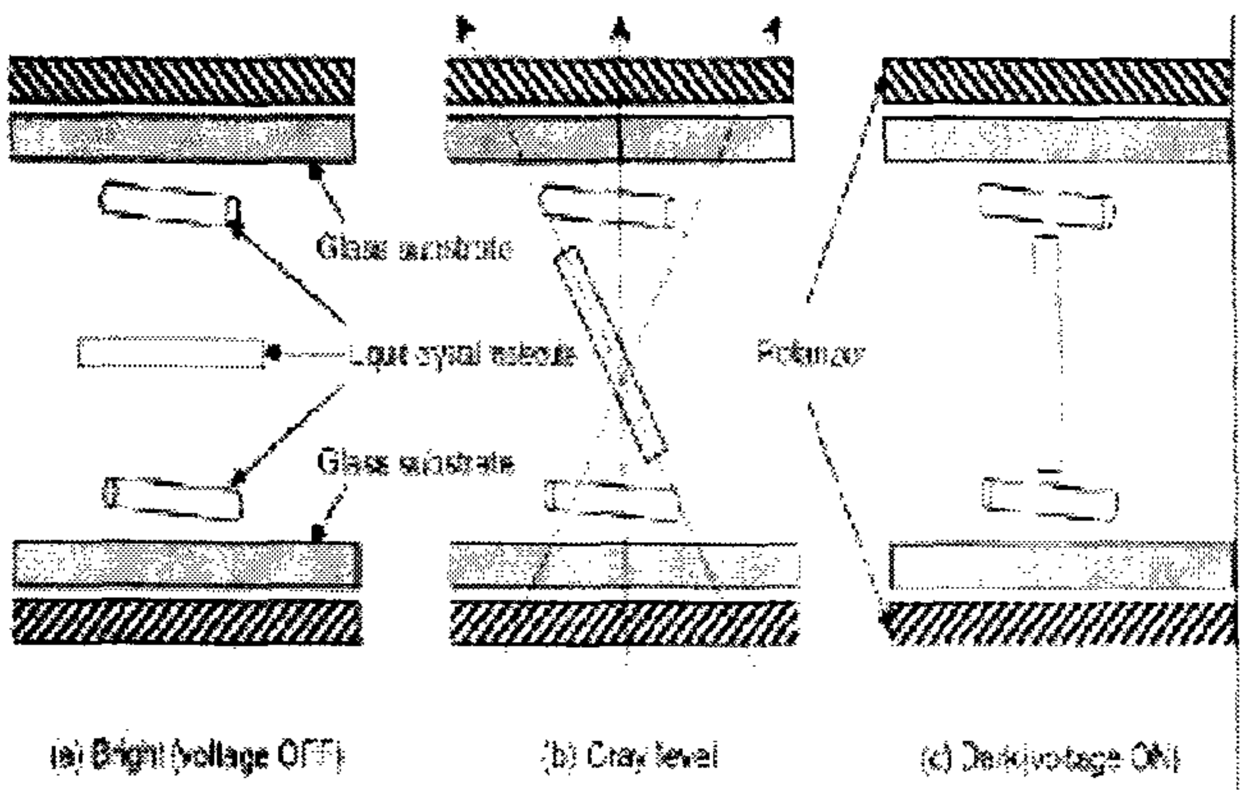

Figure 1 : Deformation of the center of the cell pointing at gray inversion domain

3. Correction of black level

When voltage is high, the center of the cell has a strong axial anisotropy which induces a birefingence varying as the square of incidence angle (i). This anisotropy strongly degrades the off axis contrast. Furthermore, there is some splay deformation near the boundary from the homeotropic alignment of the center to the homogeneous alignment of the anchored molecules. This boundary acts both as a conventional in-plane birefringence (ii) and an oblique birefingence (iii)

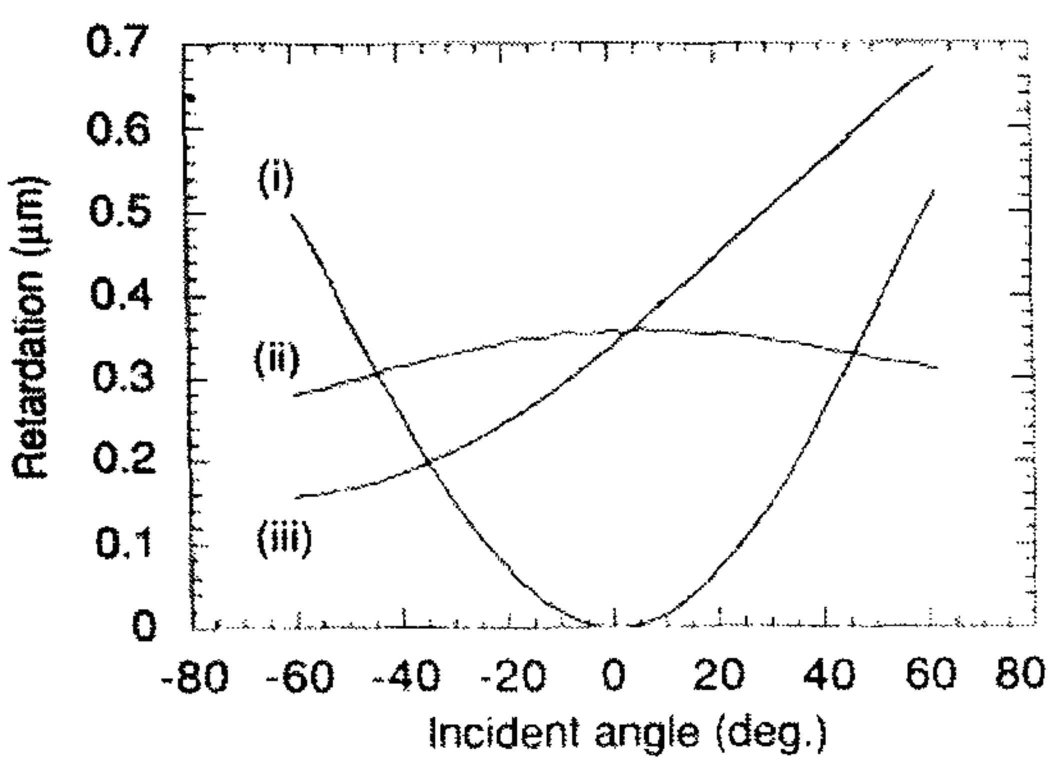

Figure 2 Retardation of perpendicular birefringence (i), in-plane birefringence (ii) and oblique birefringence (iii)

The optical activity of the cell can be represented by a product of Jones matrices corresponding to the successive layers of the cell:

$$J = J_1 * J_2 * J_3 * \ldots J_{n-1} * J_n$$

in this product, 2 X 2 matrices are preferred because reflected waves are negligible and cannot be taken into account by the correction. Each matrix is dependant of three parameters corresponding to the wavelength and direction of incidence.

It is unlikely to find a layer that acts as an inverse matrix J^1 for all values of wavelength and viewing angle. A solution was proposed by Baur in 1990: each individual layer J_i is composed of a uniaxial media with given orientation and birefingence. A layer of same direction an inverse birefringence will compensate exactly the layer J_i . If such layers are stacked in the reverse order to the cell, compensation occurs for all value of three parameters.

$$J_1 * J_2 \ldots J_{n-1} * J_n * J_n^{-1} * J_{n-1}^{-1} \ldots J_1^{-1} = I$$

where "I" is the identity matrix.

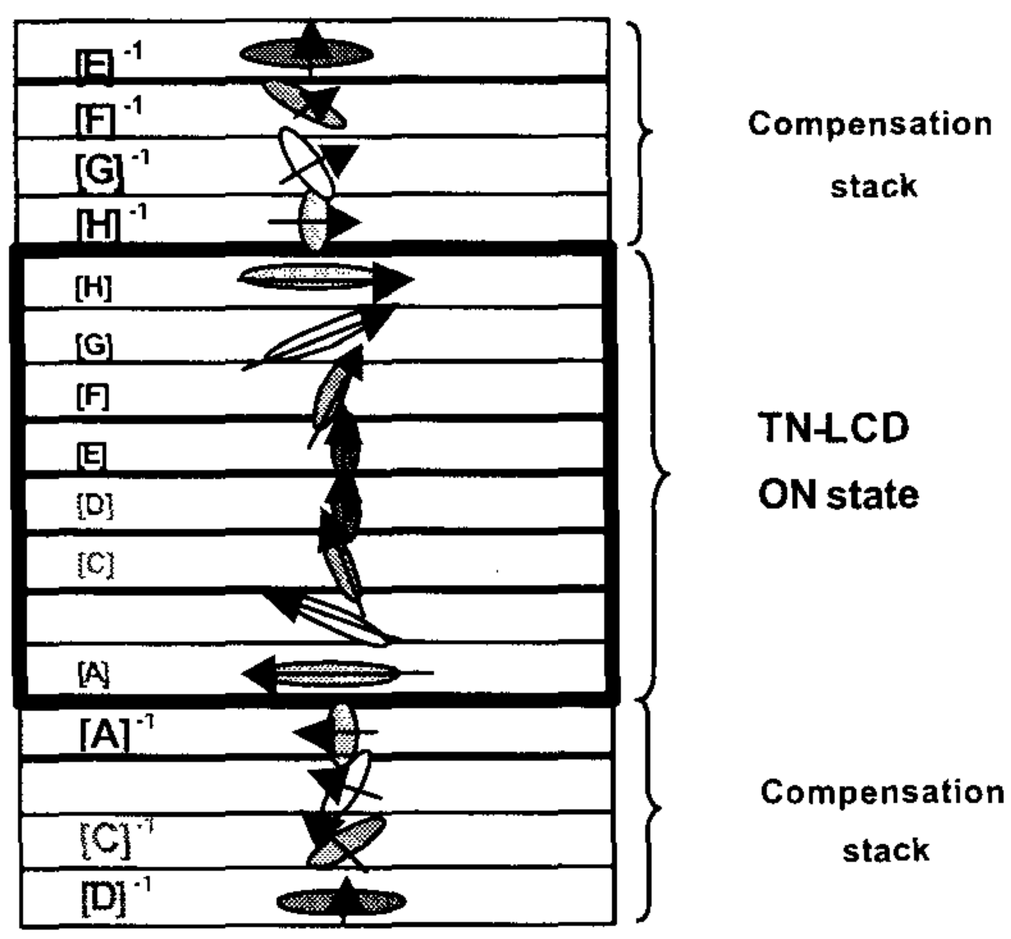

Figure 3 Stacking of cell and compensation layers in reverse order

The degree of achievement of present display is such that the off axis extinction ratio is better than the one of crossed polarizer. This is due to the fact that polarizers are E-type: the three dimensional media has one axis of absorption, the emerging polarization is perpendicular to the absorption axis and to the propagation axis in the media. Therefore, the actual objective is not to obtain a Jones matrix equal to identity but to generate off axis a rotation that will, in any direction, match the emerging direction of one polarizer with the perpendicular of the other.

Practically, the stack is preferably symmetric so that the outside of the compensator compensates the center of the cell and the inside compensates the adjacent boundary.

4. Realization of birefringent compensation layers

Most polymer films when stretched will develop some birefringence. In the most general case, birefringence will be biaxial i.e. the indices of refraction along the stretching direction, the normal to the film and transverse direction are all different. Bi-directional stretching makes uniaxial film with ordinary index in-plane.

The main difficulty in realizing the compensation layers is the obliquity of some layers. For obvious symmetry reasons, obliquity cannot be obtained from the simple stretching of a polymer film. Three main processes can be considered to obtain such a film:

- oblique evaporation of heavy metal oxydes.
- alignment of LC molecules
- realization of mesostructure by holography.

Oblique evaporation of metal oxydes has been extensively studied by T. Motohiro et al in Toyota central research lab [1]. Associated with in-plane birefingence, these films have the potential for compensating viewing angle, [2] there is no report of commercial realization.

Liquid crystal birefingence is most widely used for compensation film. A large majority of commercial films are made of discotic liquid crystal polymer [3] [4]. In opposition to calamitic liquid crystal, discotics have a low extraordinary index of refraction. The liquid crystal is deposited on an orientation layer. Because the surface energy at air interface is different from the one at orientation layer, this generates a splay deformation.

Calamitic liquid crystal polymer can also compensate the viewing angle. The vertical stucture at the center of the cell is compensated by two crossed layers which are oriented nearly in-plane [5]. The original structure was dramatically improved by splitting the 2 layer correction film on both side of the display [6]. The drawback of this solution is that at least two layers are needed on each side; the advantage is that the synthesis and handling of calamitic molecules are much easyer than the ones of disc of discotic molecules.

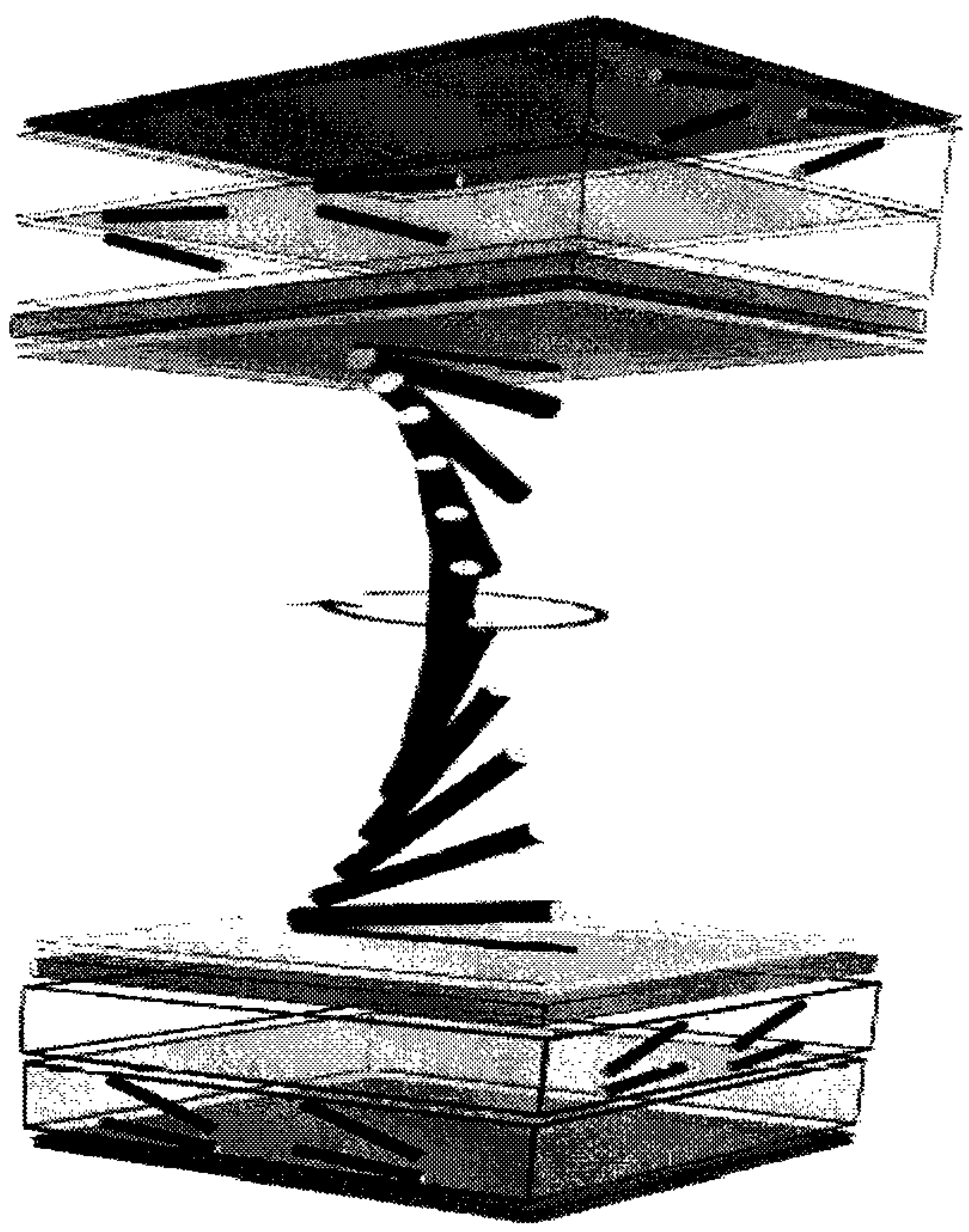

Figure 4 Compensation by calamitic LC polymer

Holographic mesostructures are easy to produce and can be adjusted in tilt and retardation. Although often referred as "form birefringence" the nature of optical effect is quite similar to natural birefringence: the permittivity of the media is equal to the mean permittivity when electric field lie along the index layers whereas the inverse permittivity is averaged across the layers. The result is a birefringence:

$$n_o - n_e = \Delta n^2 / n$$

a significant birefringence can only be obtained if the index modulation Δn of the holographic grating is high enough. Some photopolymers can record gratings with an index modulation equal to 0.06; this is enough for the tilted part of the birefringence of the compensation film but the axial birefringence must be introduced by some other mean such as using a stretched substrate [7]. Although the original film is produced by a sophisticated holographic bench, the film can be copied from a master by monochromatic illumination.

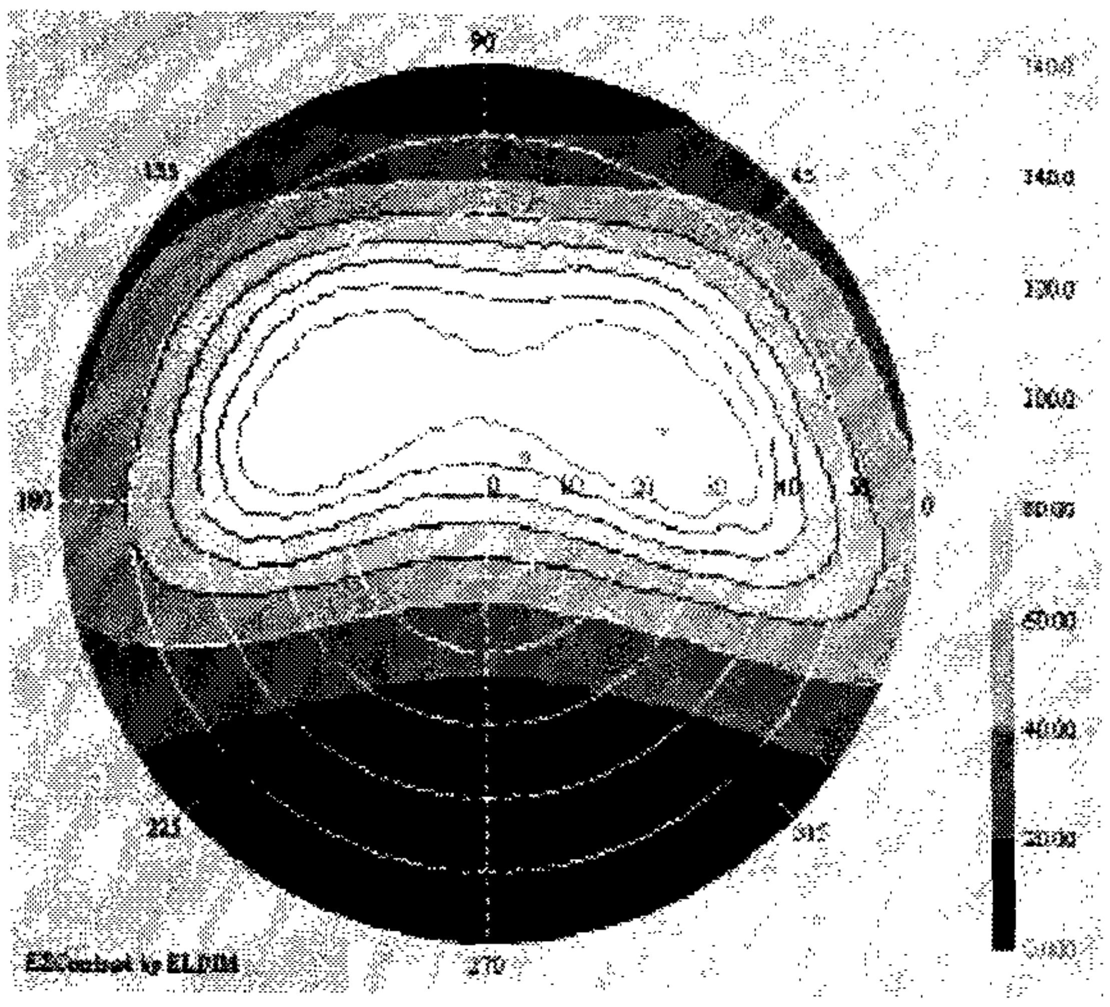

Figure 5 Conoscope of LCD Compensation by holographic film

4. Conclusion

The compensation of the black level of normally white TN-LCD can be nearly perfect. In the future, more than one technical solution for compensation film is likely to be on the market.

There is a real limitation of normally white TN-LCD as far as gray inversion is concerned. Unfortunately, the gray inversion domain is adjacent to the normal of the display. As the latest production line can handle with very large screen, alternative to the TN-LCD may be needed such as Vertically Aligned Nematic (VAN) or In-plane switching (IPS). These alternatives also suffer from optical limitation and the experience gained at compensating the TN can profit to the optimization of other displays

5. References

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