Generalized parameter space diagrams for all liquid crystal displays

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Abstract

A generalized parameter space (PS) is presented where all the nematic liquid crystal display modes can be depicted. Normal ECB, TN, STN, OMI, etc modes can be located in the static or zero volt PS. The contrast ratio can also be shown on the dynamic PS when the on and off voltages are defined. The parameter space can be obtained for both transmittive and reflective LCD. The addition of a retardation film can also be incorporated. In the chromatic parameter space, the dispersion of the various operating modes can be indicated as well.

Keywords: LCD, parameter space, contrast ratio, chromaticity

1. Introduction

Many liquid crystal display modes have been proposed and demonstrated over the years. Most of them are based on the electrical manipulation of the twist angle of the nematic liquid crystal molecules. Commercially, the most common modes are the 90° TN and the 240° STN displays. The demand for better LCD is always present and optimization of existing LCDs is pursued constantly. New situations, such as the elimination of the rear polarizer, also require a better tool for optimizing LCD display modes.

We recently invented the parameter space (PS) approach to the study of LCD modes[1,2]. This PS approach has the merit that all the major LCD parameters are taken into account. Moreover, the relationship between the various modes can be seen clearly on the same PS. This PS can be applied to both transmittive LCD, as well as reflective LCD where there is only one polarizer. In this paper, we shall discuss some recent extension of that work to include more details in the PS and to make it even more useful. This includes the calculations of the contrast PS (CPS) and the chromatic PS (ChPS). We shall demonstrate some applications of the CPS and the ChPS in real situations of designing reflective LCDs.

2. Parameter space

The PS of the LCD is based on the observation that the transmittance or reflectance of a LCD at normal angle of incidence is completely defined by the parameters of $(\alpha, \gamma, \phi, \delta)$, where α is the input polarizer angle, γ is the output polarizer angle, ϕ is the twist angle and δ is the retardation of the LC cell given by $\pi d\Delta n/\lambda$. For the case of a single polarizer reflective display, there are only three parameters (α, ϕ, δ). For normal incidence, the reflectance can be calculated using the simple Jones matrix. The Jones matrix for the LC cell with uniform twist and zero tilt is given by[1,2]

$$\mathrm{M} = \begin{pmatrix} A - iB & -C - iD \\ C - iD & A + iB \end{pmatrix} \qquad (1)$$

where

$$\mathrm{A} = \cos\phi\cos\beta + \frac{\phi}{\beta}\sin\phi\sin\beta \qquad (2)$$

$$\mathrm{B} = \frac{\delta}{\beta}\cos\phi\sin\beta \qquad (3)$$

$$\mathrm{C} = \sin\phi\cos\beta - \frac{\phi}{\beta}\cos\phi\sin\beta \qquad (4)$$

$$\mathrm{D} = \frac{\delta}{\beta}\sin\phi\sin\beta \qquad (5)$$

In eq. (2)-(5),

$$\beta = [\,\delta^2 + \phi^2\,]^{1/2} \qquad (6)$$

$$\text{and} \quad \delta = \pi d\Delta n/\lambda \qquad (7)$$

$$\text{Finally,} \quad \Delta n = n_e(\theta) - n_o \qquad (8)$$

is the birefringence of the tilted liquid crystals and $n_e(\theta)$ is the extraordinary index at an average director tilt angle of θ and is given by the usual expression

$$\frac{1}{n_e^2(\theta)} = \frac{\cos^2\theta}{n_e^2} + \frac{\sin^2\theta}{n_e^2} \qquad (9)$$

With the above expressions, the PS can be calculated in a straightforward manner. For a transmittive display with input and output polarizers, the transmittance is given by

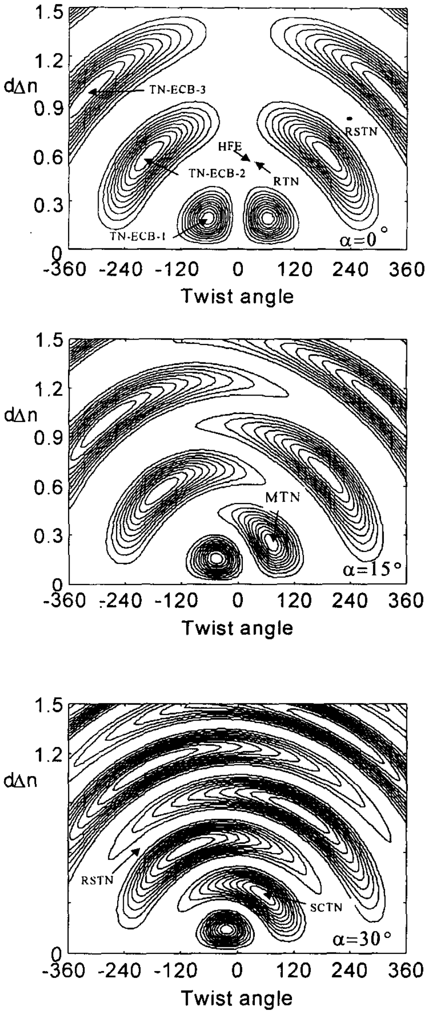
$$T = \left| \begin{pmatrix} \cos\gamma & \sin\gamma \end{pmatrix} \bullet M \bullet \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix} \right|^2$$

For a single polarizer reflective display, the reflectance of the reflectance is given by

$$R=\left|\left(-\sin\alpha\ \cos\alpha\right)\bullet H\bullet M(\phi)\bullet H^{-1}\bullet M(-\phi)\bullet\begin{pmatrix}\cos\alpha\\ \sin\alpha\end{pmatrix}\right|^{2} \tag{11}$$

where H is the rotation matrix

$$H=\begin{bmatrix}\cos\phi & \sin\phi\\ -\sin\phi & \cos\phi\end{bmatrix} \tag{12}$$



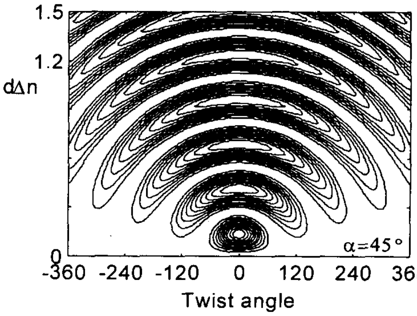


Fig. 1 Parameter space for a reflective display

Fig. 1 shows a series of PS diagrams for the reflective display. In here, there are only 3 parameters. The output polarizer angle is the same as the input polarizer angle.

3. Contrast Parameter Space

The PS given in the above section is only valid for the case of no applied voltage. Once a voltage is applied to the LCD, the Jones matrix formulation is no longer valid, and eq. (2-5) cannot be used. In this case, the calculation of the PS is much more tedious, but still possible.

The idea is still the same: given a voltage, the deformation of the LC alignment can be calculated using the conventional Euler-Lagrange equations[3]. Once that is known, the transmittance or reflectance of the LCD can be calculated using the multiple-slice approach[4]. The LC cell can be regarded as a stack of birefringent plates, each with its Jones matrix known. Here, the T and R is also dependent on the same set of parameters (α, γ, ϕ, δ). So a PS can be calculated for each applied voltage. For the case of a reflective display, the parameters are (α, ϕ, δ). Once the PS for select and nonselect voltages are obtained, a contrast PS can be calculated simply by obtaining the ratio of the 2 sets of curves.

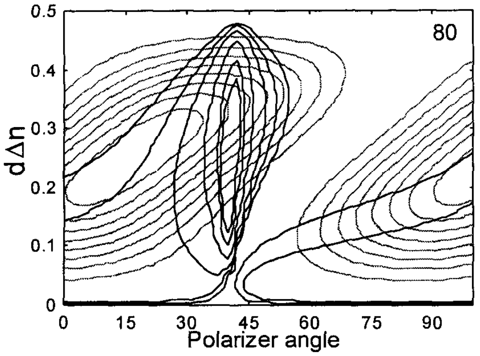


Fig. 2 Contrast parameter space

Figure 2 shows a CPS for the case of a reflective LCD with one polarizer. Here the twist angle ϕ is fixed to be 80° and (δ, α) are used as the parameters in the CPS. In the same diagram, we plot the reflectance curves and the contrast curves together in order to show the optimization of the reflective LCD.

4. Chromatic parameter space

In addition to the contrast PS with the application of an external voltage to the LCD, it is possible to extend the concept of the PS further to include the effect of chromatic dispersion to the display. For many instances, the transmittance or reflectance of the display has strong wavelength dependence. This is especially for birefringent mode or mixed mode displays. It is possible to show this effect on the PS by employing a color plot.

The idea is quite straightforward as well. For each set of parameters (α, γ, ϕ, δ), the transmittance is calculated as a function of wavelength. (It should be pointed out that the PS depicted in Fig. 1 and 2 are calculated for λ = 550nm only.) Then the spectrum is fitted to get the tristimulus or color coordinates of the display. The color of the display is indicated on the PS using a color representation.

In addition to the chromaticity or chrominance, it is also possible to calculate the luminance of the display for the particular data point. It is therefore possible to plot the luminance of the display assuming a broadband light source illuminating the display.

In general, for non-waveguiding modes, there is stronger chrominance and lower luminance. Fig. 3 and 4 show the ChPS for a transmittive LCD with cross polarizers, for the cases of α = 0 and α = 45°. In these figures, the color represents the appearance of the display, while the white lines are contours of constant luminance. It can be seen that for the waveguiding situation of ϕ = 90°, 180°, 270° in Fig. 3, the chromatic dispersion is small and the display appears as black or white. However, for the case of α = 45°, the chromaticity is strong. Moreover, the luminance decreases considerably, especially for higher retardation values. The peak transmittance does not reach 100% using white light as the input.

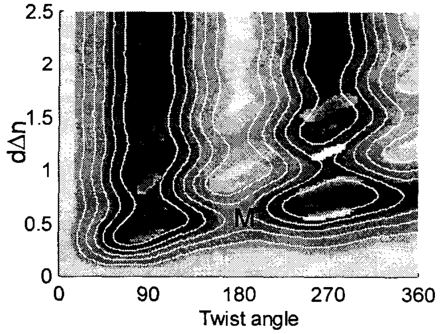


Fig. 3 Chromatic parameter space for α = 0.

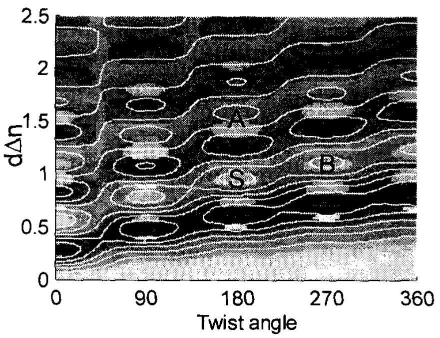


Fig. 4 Chromatic parameter space for α = 45°.

5. Summary

In this paper, we showed that there is a richness of physics that can be visualized using the PS approach to LCD displaying modes. Starting with the most basic PS using monochromatic light, one can derive a variety of different PS suitable for different situations for different kinds of optimization.

For example, if chromaticity is the most important criteria for a certain LCD design, then the ChPS should be used. However, if light utilization and efficiency is important, then the luminance PS should be used. Finally, if one strives for high contrast, the CPS should be employed. It is obvious from the CPS in Fig. 2 that maximum contrast does not overlap with maximum transmittance or reflectance.

Acknowledgements

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