Angle of view polarization characterization of LCDs

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Abstract

Performances of LCDs are generally evaluated in terms of luminance and color versus viewing angle. In the present paper we show that this type of display can be favorably characterized in terms of polarization. We show that ELDIM EZContrast instrument can be used to measure the degree of polarization the light and the ellipticity and polarization direction of the polarized component. This measurement is made versus incidence angle between 0 and 88° and for all the azimuth angles. Important differences between the displays can be detected and related to their internal structures when luminance and color profiles are quite similar.

1. Objectives and Background

LCD operation and optimization depends on the use of sophisticated polarization compensation. The aims of these compensators are to optimize overall polarization state in order to achieve the highest contrast. This optimization is made for the highest viewing angle for optimized appearance [1]. The entire LCD structure can be modeled to predict its polarization properties [2]. So the polarization state of light emitted by the display versus incidence and azimuth angles is important to measure in addition the standard luminance and color information.

Fourier optics instruments first introduced by ELDIM in 1994 are now widely used to measure viewing angle properties of LCDs. We present here a new option available with EZContrast instruments which is capable to evaluate the full polarization state of the light emitted by the displays in addition to luminance and color information.

2. Theory of light polarization

Electric field characterizing any light wave can be separated in two components:

$$E_t = E_{polarized} + E_{unpolarized} \qquad (1)$$

The polarized component can be defined by its elliptical coefficients (ellipticity and orientation) represented on the figure below.

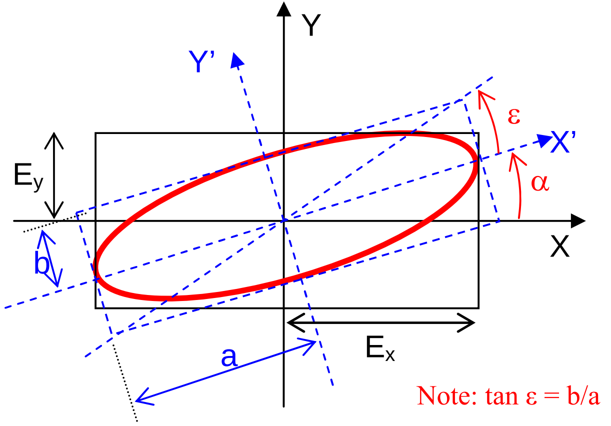

Fig. 1: Definition of elliptic parameters.

Based on this representation, we are able to estimate intensity of such a polarized light going through a polarizer whose polarization angle is at angle θ:

$$I(\theta) = \frac{A_0}{2}(1 + \cos 2\varepsilon \cos 2(\theta - \alpha)) \qquad (2)$$

Unpolarized light component is only defined by the degree of polarization ρ given by the ratio of intensity due to polarized component over the total light intensity. In case of perfectly polarized light, ρ=1 and in case of complete unpolarized light ρ=0.

$$\rho = \frac{I_{polarized}}{I_{total}} \qquad (3)$$

In order to be able to completely describe light polarization state, we thus need three parameters:

- The polarization orientation α
- The polarization ellipticity ε
- The degree of polarization ρ

3. Stokes vector and Mueller formalism [3]

These three previous parameters can be combined to a fourth one (light intensity) to provide Stokes vector. The four Stokes parameters can be defined as:

$$S=\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}=I.\begin{bmatrix} 1 \\ \rho.\cos 2\varepsilon.\cos 2\alpha \\ \rho.\cos 2\varepsilon.\sin 2\alpha \\ \rho.\sin 2\varepsilon \end{bmatrix}$$

Link to orientation, ellipticity and degree of polarization is direct.

Mueller matrix can handle propagation of partially polarized light through optical systems. It transforms Stokes vector by successive multiplications with 4x4 matrices belonging to individual optical elements. Using this formalism, we can compute the effect of a single polarizer and combination of polarizer and a wave-plate on this Stokes vector. For a measurement with one polarizer whose orientation is θ, Stokes vector becomes:

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}=\underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & -\sin 2\theta & 0 \\ 0 & \sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{Rotation\ \ -\theta}.\underbrace{\begin{bmatrix} 1/2 & 1/2 & 0 & 0 \\ 1/2 & 1/2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}}_{Perfect\ polarizer}.\underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta & 0 \\ 0 & -\sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{Rotation\ \ \theta}.\begin{bmatrix} I_e \\ Q_e \\ U_e \\ V_e \end{bmatrix}$$

Adding a wave-plate with phase φ and orientation β between polarizer and light source will lead to modify Stokes vector as following:

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}=\overbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & -\sin 2\theta & 0 \\ 0 & \sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}^{Rotation\ \ -\theta}.\overbrace{\begin{bmatrix} 1/2 & 1/2 & 0 & 0 \\ 1/2 & 1/2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}}^{Perfect\ polarizer}.\overbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta & 0 \\ 0 & -\sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}^{Rotation\ \ \theta}.$$

$$\underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\beta & -\sin 2\beta & 0 \\ 0 & \sin 2\beta & \cos 2\beta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{Rotation\ \ -\beta}.\underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cos\varphi & \sin\varphi \\ 0 & 0 & -\sin\varphi & \cos\varphi \end{bmatrix}}_{Wave\text{-}plate\ \ \varphi\ phase}.\underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\beta & \sin 2\beta & 0 \\ 0 & -\sin 2\beta & \cos 2\beta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{Rotation\ \ \beta}.\begin{bmatrix} I_e \\ Q_e \\ U_e \\ V_e \end{bmatrix}$$

On the two equations above, I_e, Q_e, U_e and V_e stands for the 4 Stokes parameters of the source we are trying to identify and I, Q, U and V stands for the 4 Stokes parameters of the source associated to the different polarizer/retarder wave-plate used. We only measure intensity so we only deal with I component of these two equations.

Three measurements with a single polarizer will be required to extract Q_e and U_e. It can be shown that:

$$\frac{M(\theta)-M(\theta+\pi/2)}{M(\theta)+M(\theta+\pi/2)}=\frac{Q_e}{I_e} \qquad (4)$$

$$\frac{2M(\theta+\pi/4)-M(\theta)-M(\theta+\pi/2)}{M(\theta)+M(\theta+\pi/2)}=\frac{U_e}{I_e} \qquad (5)$$

Three additional measurements combining polarizer and wave-plate are necessary to get information on the degree of polarization. Please note that in order to eliminate all unnecessary component of the equation, θ and β should satisfy $|\theta-\beta|=\pi/4$

$$\frac{M(\theta,\beta+\pi/2)-M(\theta,\beta)}{M(\theta,\beta)+M(\theta+\pi/2,\beta)}=\frac{V_e}{I_e}\sin\varphi \qquad (6)$$

$$\frac{M(\theta,\beta+\pi/2)-M(\theta+\pi/2,\beta)}{M(\theta,\beta)+M(\theta+\pi/2,\beta)}=\frac{Q_e}{I_e}\cos\varphi \qquad (7)$$

We can see from (6) and (7) that the retardation phase of the wave-plate can be deduced from the measurement. A perfect quarter wave plate is then not necessary and a variation of the retardation versus wavelength can be admitted.

4. Calibration measurements

ELDIM EZContrast was modified in order to be able to achieve the different measurements necessary to extract the different Stokes coefficients. Traditionally, polarizers oriented 0°, 45° and 90° are already present in the equipment. Two wave-plates oriented at -45° and 45° were added to this existing configuration.

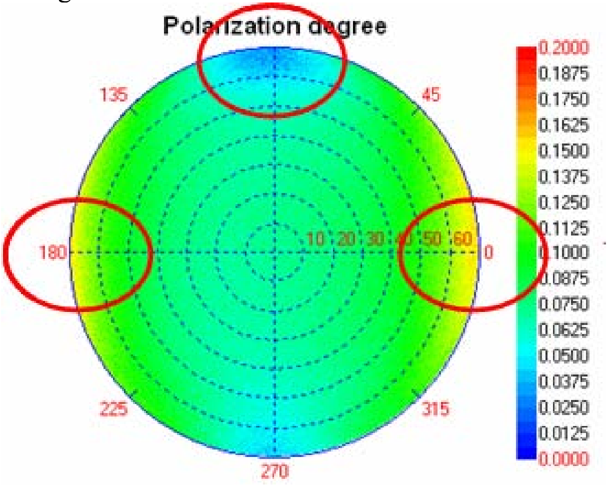

Fig. 2: Measured degree of polarization of unpolarized source at 550nm.

Measurements were performed on an opal diffuser illuminated by monochromatic light coming from an integrating sphere. We thus consider that light coming from this source is totally unpolarized. Wavelength of the source was controlled through a monochromator.

First results show a non uniformity of the degree of polarization of the sample especially at high angles. This actually comes from the inner polarization of the optics of the EZContrast. This parasitic polarization should be taken in account when unknown samples are measured. It is part of the calibration and system dependant.

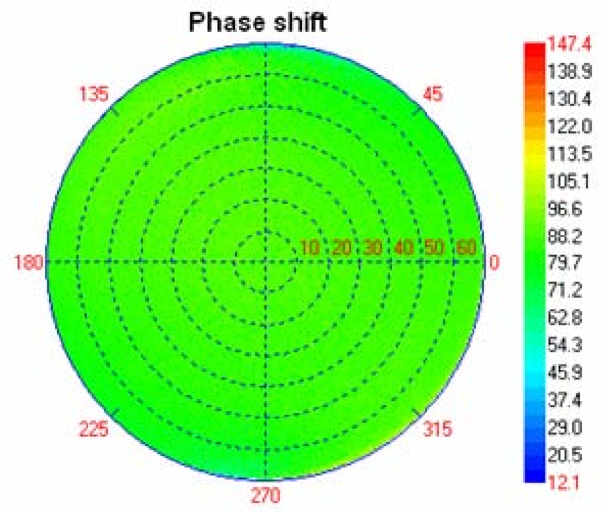

Fig. 3: **Wave-plate phase shift measured with unpolarized source at 550nm.**

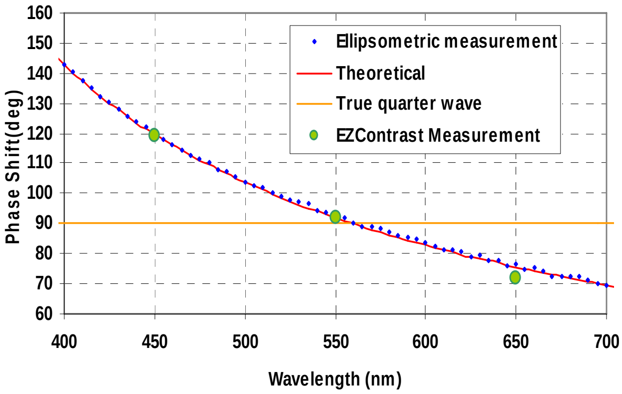

Fig. 4 **Comparisons of wave-plate phase shift as a function of wavelength.**

We also analyze the evolution of the phase shift of the wave-plate as a function of the viewing angle and the wavelength of the source. As expected, phase shift is almost independent of the viewing angle (cf. fig. 3). Comparisons between phase shift measured with this method and theoretical values or ellipsometric measurements are very similar.

5. Measurements on DBEF and LCD

We now present some measurements on one Dual Brightness Enhancement Film (DBEF) and one one liquid crystal display (LCD).

In case of DBEF, peculiar constitution of the film itself produces some unexpected effects. Degree of polarization evolves regularly and symmetrically due to regular structure of film. Ellipticity remains very low and orientation is quite constant for every viewing angle.

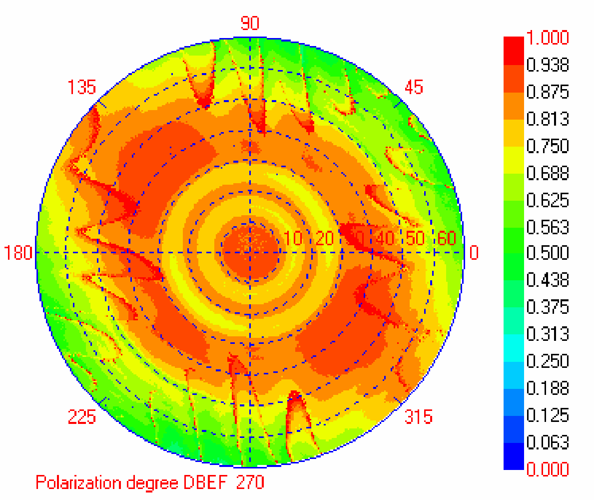

Fig. 5: **Degree of polarization of light after DBEF transmission.**

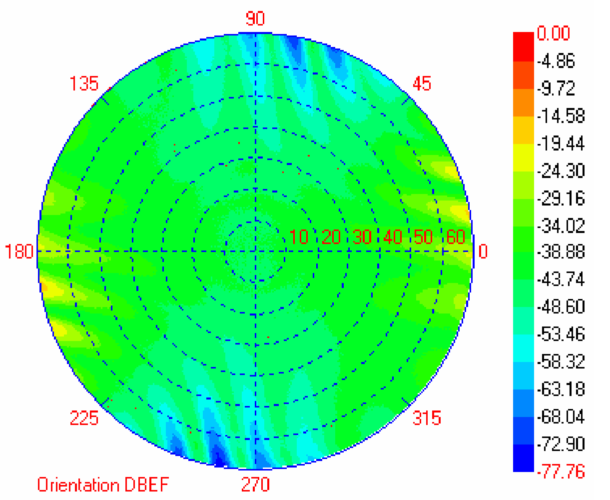

Fig. 6: **Polarization orientation after DBEF transmission.**

An additional phenomenon disturbs this polarization for some wide angles introducing shift in the orientation and increasing of the ellipticity.

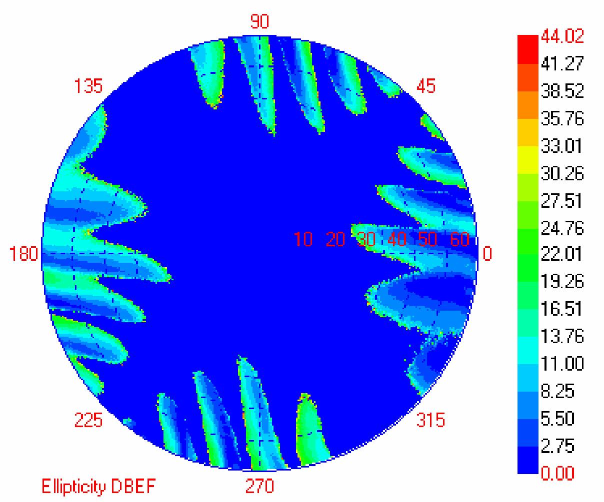

Fig. 7: Ellipticity of polarization for DBEF sample.

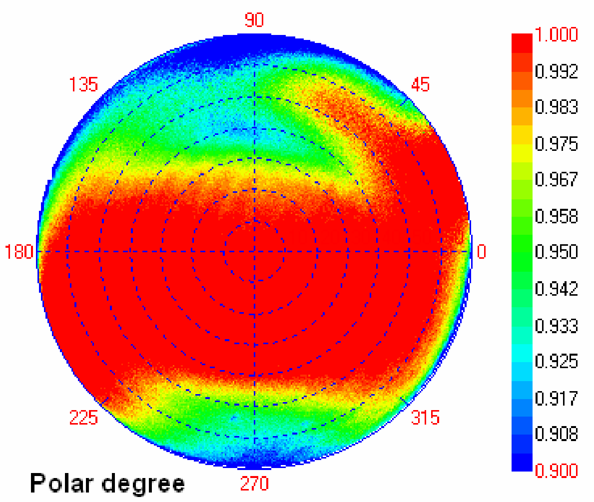

Fig. 8: Polarization degree of the LCD sample.

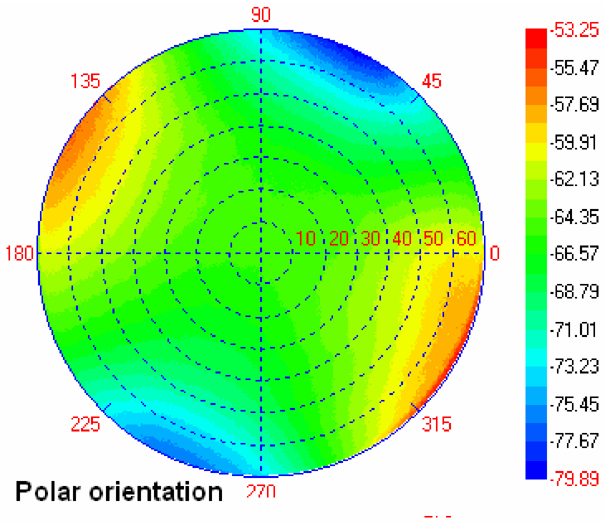

Fig. 9: Orientation of polarization for the LCD sample.

Same analysis can be performed on a LCD. Since LCD is a polarization device, the measured polarization degree remains higher than 0.9 even for wide angles (cf. fig. 8). We observe also a slight distortion of the orientation of the polarization as a function of the incidence angle inherent to liquid crystal properties and polarizer imperfections (cf. fig. 9). Comparisons between polarization orientation and luminance measurement of the sample show some links between the different observed behaviors (e.g. the azimuth along which luminance remains important corresponds to the azimuth where orientation shift is the slowest).

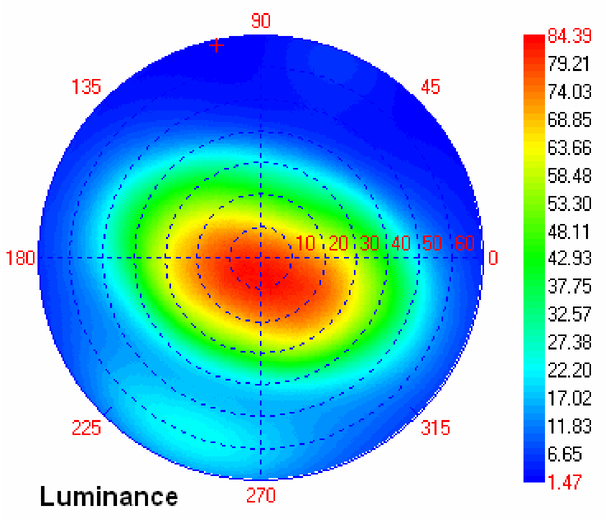

Fig. 10: Luminance of the LCD sample.

5. Conclusion

Polarizers and wave-plates associated with Fourier optics allow getting a full viewing angle polarization characterization of any sample. By this mean, all key components of LCD can be characterized separately: from backlight and diffuser to brightness enhancement films or polarizers themselves. Comparisons between polarization properties and effects on color and luminance measurement can be easily made for a better understanding of the LCD behavior.

6. References

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[3]. H. G. Tompkins and E. A. Irene, Handbook of Ellipsometry pp45-66 (2005).