

## **Polarized based stereoscopic 3D display characterization using Fourier optics instrument and computation in the observer space.**

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### **Abstract**

In this paper we propose a method to characterize polarization based stereoscopic 3D displays using Fourier optics viewing angle measurements. Luminance measurements in the full viewing cone while embedding the two glasses filters in the Fourier instrument are used to calculate contrast for each eye and combined 3D contrast. Simulation in the observer space can then be made to define the Qualified Monocular and Binocular Viewing Spaces (QMVS and QBVS) allowing direct comparison with autostereoscopic 3D displays.

### **Presentation Style**

Presentation preference: oral

### **Workshop**

3D : workshop on 3D/Hyper-Realistic Displays and systems.

### **1. Introduction**

All 3D displays have the same intrinsic method to provide 3D perception: the main idea is always to provide two different images in the left and right eye of the observer to provide the depth information. Even if many methods have been proposed to achieve this task, the two most common solutions are auto-stereoscopic 3D displays and polarization based 3D displays. In stereoscopic displays users have to wear glasses to ensure that left and right views are seen by the correct eye. We are interested here by the most common solution based on polarized glasses in combination with a device embedded inside the display to polarize differently two views. In the display under current investigation, a standard LCD panel is completed with an additional phase difference film that convert linearly polarized light in right and left circular polarized light depending on the pixel line. The images for left and right eyes are displayed simultaneously on even and uneven panel lines with half vertical resolution. The discrimination between the two images is performed with glasses that include a retarder and a polarizer with different orientation for left and right eyes. Up to now optical characterization of such displays is not available in the literature. Optical characterization of 3D displays is mandatory to optimize their performances and to make efficient comparison between them. Recently we have proposed a characterization method for auto-stereoscopic 3D displays based on ultrahigh angular resolution Fourier optics measurement and computation in the observer space [1-3]. This method is particularly efficient and provides quantitative parameters for easy comparison of auto-stereoscopic 3D displays with their QMVS and QBVS, 3D contrast, standard contrast and color shifts, for a complete picture of such display features. The main purpose of this paper is to propose the same type of characterization for polarization based stereoscopic 3D displays using viewing angle instrument in order to be able to compare the performances of the different types of displays.

### **2. Luminance viewing angle measurements**

Viewing angle measurements are performed with an ELDIM Fourier optics instrument including left and right eyes filters glasses (GL and GR). Three locations have been measured on the display surface (center, top center, bottom center). In each case and for each filter four measurements are realized: left view ON and right view OFF (LWRK), left view OFF and right view ON (LKRW), left and right views ON (LWRW) and , left and right views OFF (LKRK). Measurement results for the central location and GL are reported in figure 1. ON and OFF states have quite conventional viewing angle patterns while LWRK and LKRW show complementary behaviors under the form of limited angular regions. The lobe is probably limited vertically because of the perspective effect due to the location of the retarder film with regards to the crystal cell. In this display, the film is located on the display top surface (cf. figure 2). The perspective effect due to the thickness of the top glass modulates the polarization of one view along vertical. This perspective effect can be minimized only when the polarizer and phase difference films are integrated directly inside the cell. This is one of the weakness of this display. In fact the required right and left circular polarization states for the right and left eye views are not maintained for all the angles and so they will define Qualified Viewing Spaces (QVS) for 3D perception in front of the display, in the same way as auto-stereoscopic 3D displays. To ensure a correct 3D perception all over the display in spite of this vertical modulation of the polarization, the periodicity of the horizontal stripes on the phase difference film has been slightly reduced compared to the line periodicity. A sort of geometric correction of the modulation then takes place along the vertical of the display (in the same way as for auto-stereoscopic 3D displays). To characterize this effect, we have measured the luminance versus viewing angle at two additional locations (top center and bottom center).

### **3. Calculation in the 3D observer space**

#### ***a) Calculation method***

The quality of the 3D display for an observer is directly related to the capacity to display clearly the correct images in his right and left eyes. In case of stereoscopic displays, the two contrasts associated to each eye must be calculated using the two sets of measurements obtained with GL and GR filters. We propose the following equations:

$$C_L = \frac{Y_{LWRK}^{GL}(\theta_L, \varphi_L) - Y_{LKRK}^{GL}(\theta_L, \varphi_L)}{Y_{LKRK}^{GL}(\theta_L, \varphi_L) - Y_{LRRK}^{GL}(\theta_L, \varphi_L)} \quad (1) \quad \text{and} \quad C_R = \frac{Y_{LKRW}^{GR}(\theta_R, \varphi_R) - Y_{LRRK}^{GR}(\theta_R, \varphi_R)}{Y_{LWRK}^{GL}(\theta_R, \varphi_R) - Y_{LKRK}^{GL}(\theta_R, \varphi_R)} \quad (2)$$

- $(\theta_R, \varphi_R)$  and  $(\theta_L, \varphi_L)$  are the right and left eye positions in polar coordinates with regards to the measurement location
- $Y_{KLRW}$  is the luminance for white view on right eye and black view on left eye
- $Y_{LWRK}^{GL}$  and  $Y_{LWRK}^{GR}$  are the luminances for black view on right eye and white view on left eye using GL and GR filters respectively
- $Y_{RKLK}^{GL}$  and  $Y_{RKLK}^{GR}$  are the luminance for black view on both eyes

It is then possible to combine the two contrasts to get a combined contrast for the observer using.

$$C(\theta, \varphi) = \sqrt{C_R(\theta_R, \varphi_R) * C_L(\theta_L, \varphi_L)} \quad (3)$$

We take the product and not the sum because a good quality requires a good contrast for left and right eyes simultaneously. The square maintains the dimensionality of the quantity as a contrast. These calculations are very similar to those applied to auto-stereoscopic 3D displays but each contrast is obtained separately using the two GL and GR filters [1-3]. When different locations are analyzed simultaneously, the different contrasts for each eye are calculated using equations (1) and (2), and the minimum value of these contrasts for the different locations is taken using equation (4).

$$C_L = \text{Min}_{i=1}^M C_L^i \quad \text{and} \quad C_R = \text{Min}_{i=1}^M C_R^i$$

with M the number of measurement locations. Then the 3D Contrast which is calculated using equation (3).

#### b) Results

Angular contrasts have been calculated for the measurements reported in figure 1. The result for central location is reported in figure 4. These diagrams show sharp emissive horizontal bands at an angle around 9° to the top. The maximum of contrast is around 5 for right eye and 4 for left eye. These values are very low compared to those generally measured on auto-stereoscopic 3D displays even the worse (10 to 90 have been measured on different auto-stereoscopic 3D displays) but in agreement with what is reported in the literature [4]. In addition the contrast is not symmetric and clearly worse on one eye than on the other. Using the angular contrasts, the 3D contrast can be calculated for a given volume in front of the display. We have made different computation in a volume of 600x600x1200mm. Some results are reported in figure 5. As expected from the angular contrast, the QBVS is composed of one horizontal flat volume titled by about 9° vertically as shown in the cross section of sagittal plane. If we combine the measurement made at the three locations, the corresponding QBVS is similar to the one obtained for the central location but reduced in size as expected. It shows that the geometric correction is efficient. The resulting 3D contrast is nevertheless really low compared to what can be obtained on auto-stereoscopic displays. It means that each eye will see all the time the image intended for the other eye and it will produce "ghost effects" in some conditions.

#### 4. Conclusion

In this paper we have proposed a method to characterize polarization based stereoscopic 3D displays at three different levels. We first show that standard luminance viewing angle measurements including left and right glass filters can be used to calculate contrast for each eye and combined 3D contrast in the observer space. So, Qualified Monocular and Binocular Viewing Spaces (QMVS and QBVS) can be defined in the same manner than for autostereoscopic 3D displays allowing direct comparison of the two technologies with the same physical parameters. The display measured in the paper shows very low angular and 3D contrasts. In addition a vertical modulation of the contrast is detected that can be explained by the structure of the display itself.

#### 5. References

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2. P. Boher, T. Leroux, T. Bignon, V. Collomb-Patton, "A new to characterize autostereoscopic 3D displays using Fourier optics instrument", Electronic Imaging, San Jose, 2009
3. T. Leroux, P. Boher, T. Bignon, D. Glinel, "VCMaster3D: a new Fourier optics viewing angle instrument for characterization of auto-stereoscopic 3D displays", SID meeting, San Antonio, 2009
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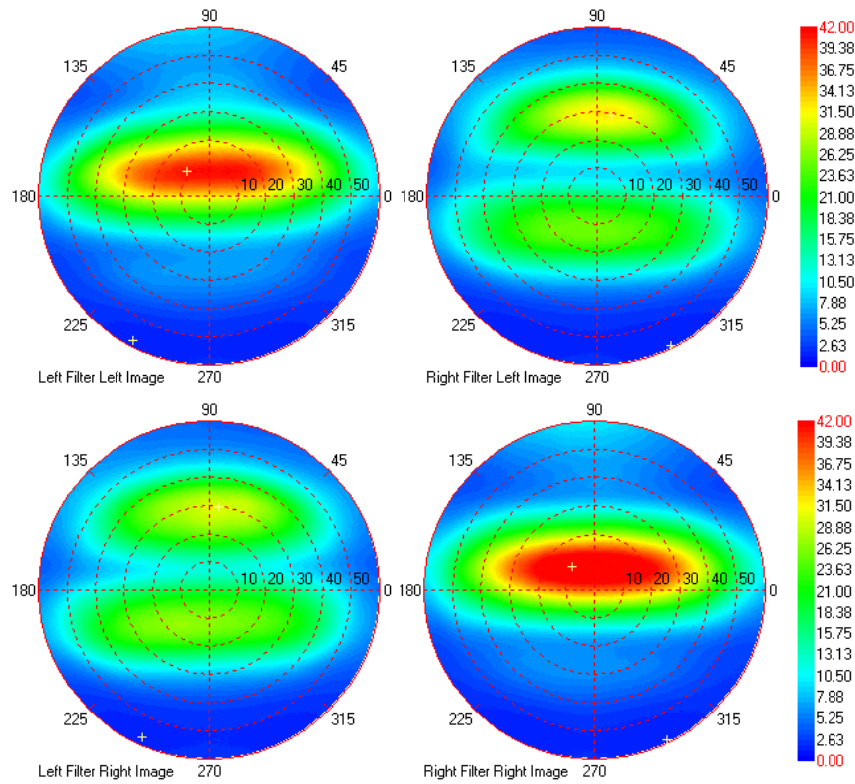


Fig. 1: Viewing angle measurements with left glass filter (left) and right glass filter (right) for left image (top) and right image (bottom)

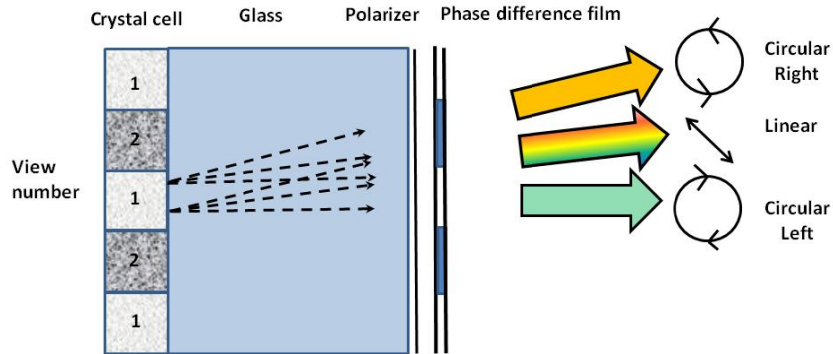


Fig. 2: Schematic cross section of a stereoscopic 3D display: when view 1 is ON state and view 2 OFF state light is circularly polarized near on axis but change of polarization state along vertical direction due to perspective effect.

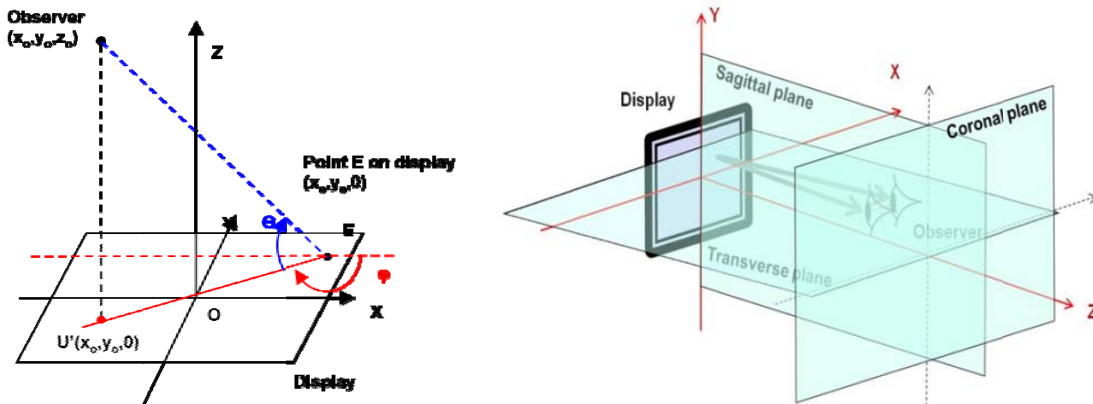


Fig. 3: Definition of the system of coordinates (left) and of the different planes for the observer location (right).

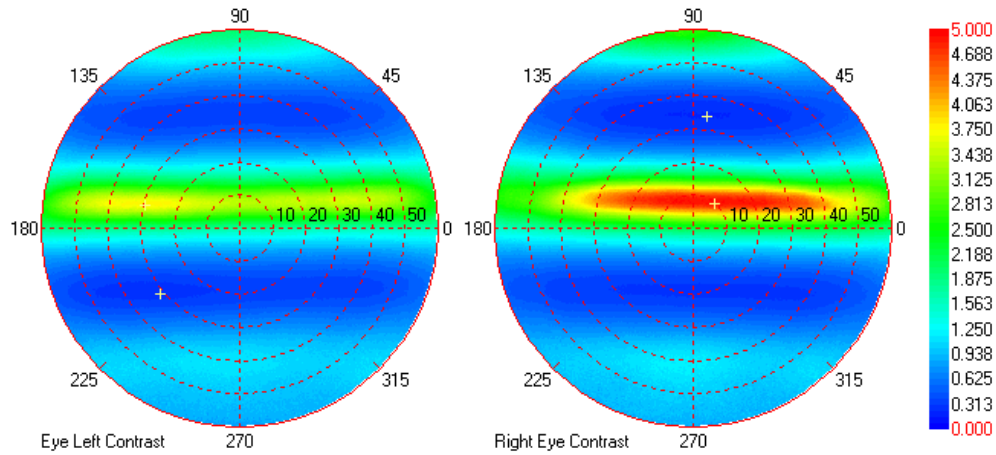


Fig. 4 Angular contrast for left and right at central location.

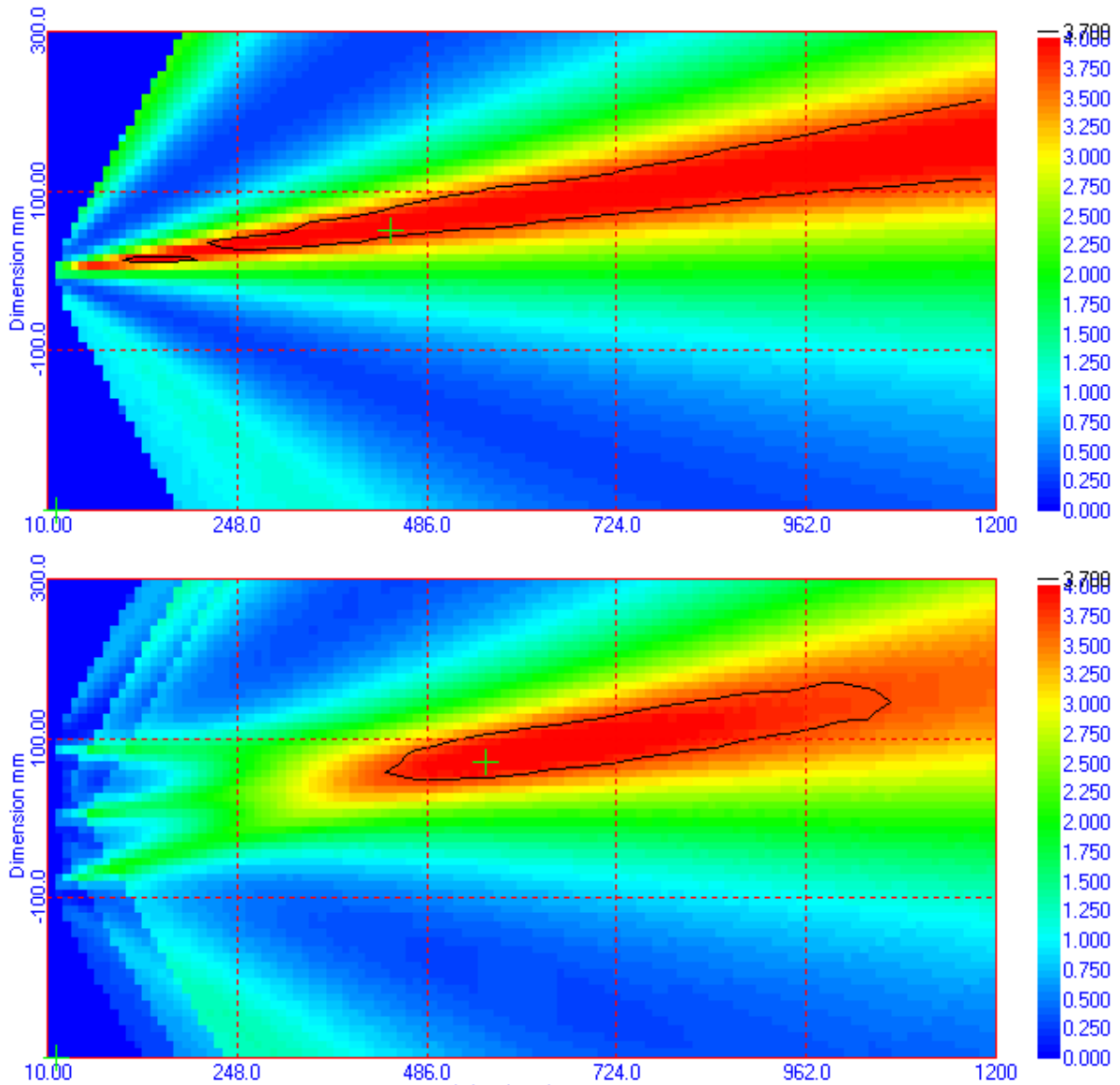


Fig. 5 3D contrast for central location (top) and three locations (bottom) in the sagittal plane (QBVS for  $C^{3D} > 3.7$ ).