

P-74: Calibration of a Fourier-Optics based Measurement System

Thierry LEROUX, Thibault BIGNON, Emmanuel CHAUVAT, Pierre BOHER, Jean Noël CURT
 ELDIM, 1185 rue d'Epron, 14200 Herouville St Clair, France

Abstract

We present new calibration tools dedicated to the last generation of Fourier optics viewing angle instruments developed at ELDIM. These instruments are capable to measure luminance and color at any azimuth and quasi all the incidence angles up to $\pm 88^\circ$. Accurate measurements at grazing angles are extremely difficult to realize by any technique just because of geometrical questions. The paper presents the procedure developed to calibrate the angles and the optical axis of the instrument, and its capacity to measure accurately the luminance and color in such a large angular aperture.

1. Introduction

The extension of the digital TFT-LCD TV market has increased drastically the requirements on the display in terms of luminance, color quality and viewing angle. Since its introduction on the market by ELDIM more than 10 years ago, Fourier optics based viewing angle instruments have long been recognized as powerful tools to measure these important characteristics [1-2]. Last generation of instruments are now capable to measure the luminance and the color up to $\pm 88^\circ$ for all the azimuths on large spot size up to 6mm. Nevertheless making accurate measurements at very grazing angle by any technique is not a simple task just because of simple geometrical reasons. For example, a measurement spot of only 1mm at normal incidence intercept a surface as large as 28mm at 88° of incidence. It means that the adjustment and the calibration of any measurement system (goniometer or Fourier optics system) must be made with very good accuracy. It is why ELDIM has developed recently a test stand to make all the calibrations steps of its EZContrast instruments with a maximum of accuracy in particular at very grazing angle. The present paper reports some details on this calibration system.

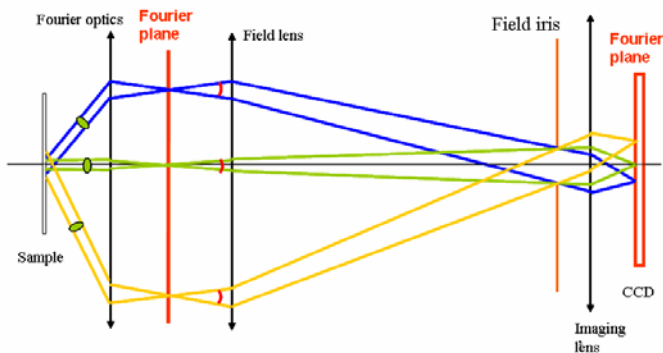


Figure 1: Schematic diagram of the ELDIM patented Fourier optics mounting for large angular aperture and independent control of the measurement spot size.

2. Fourier optics fundamentals

Fourier optics has the capacity to transform the angular response of a sample in spatial information that can be imaged by a 2D sensor (cf. figure 1). In practice, the Fourier optics is an

achromatic combination of different lenses (6 to 9) that collect quasi all the light coming from the display and focus each angle on an intermediate Fourier plane. A field lens and an imaging lens are then used to re-image the first Fourier plane on the CCD sensor. In the optical mounting patented by ELDIM, there is field iris before the sensor is complex conjugate of the display surface and allows adjusting the measurement spot size independently than the angular aperture. The consequence is that as represented in figure 2, the measurement spot size varies with the angle. It is what we call "cosine compensation". This unique feature allows getting a system transmittance above 60% even for very grazing angles up to 88° . As shown in figure 3, a simple lens becomes completely inefficient above 60° and Fourier optics without cosine compensation cannot be used above 70° .

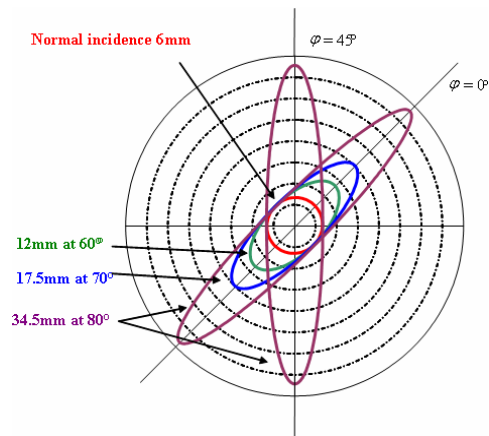


Figure 2: Spot size variation versus incidence angle. This "cosine compensation" allows to measure up to 88° .

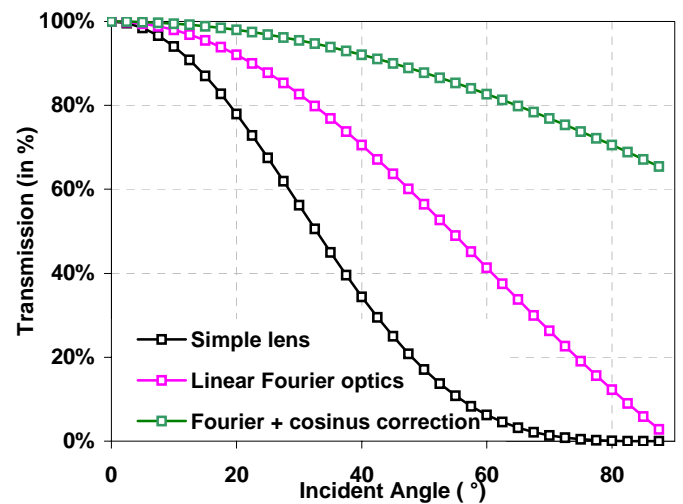


Figure 3: Transmittance of the patent ELDIM system compared to a simple lens and Fourier optics without cosine compensation.

3. Angular calibration

When calibrating Fourier optics viewing angle system a first step is to transform the pixel information on the CCD detector in absolute angles with regards to the display surface. A mechanical goniometer equipped with a collimated RGB LED source is used to make this task (cf. figure 4.a). The source is mounted on two motorized high precision rotation stages. One rotation stage has its rotation axis along the optical axis of the system and controls the azimuth angle. The other is perpendicular to the first one and control the incidence of angle. The accuracy on these angles is very good due to the mechanical stiffness of the system (better than 0.01°). The goniometer is installed in front the head of the EZContrast. An automated procedure has been developed to find the optical axis of the EZContrast and to calibrate a set of angle up to 88° at different azimuths in order to cover completely the angular aperture of the instrument (cf. figure 4.b). The estimated accuracy is found to be less than 0.15° for all the angles covered by the instrument and the calibration is made really up to 88° .

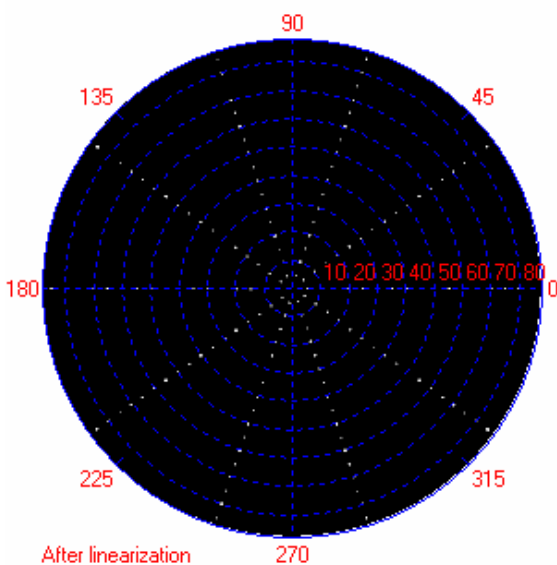
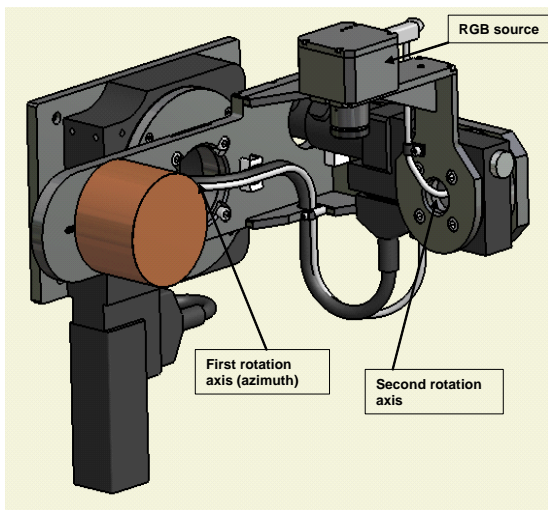


Figure 4: Two axis goniometer (top) and angle calibration result (bottom) after alignment and linearization

4. CCFL reference source

To calibrate the luminance measurement and compensate for the variable response of the optical system versus angle, a reference source with very good homogeneity and well know angular dependence emission is required. A good luminance even at very grazing angle (or in other words a Lambertian behavior) is also mandatory to get sufficient signal up to 88° . To solve this problem a new CCFL reference device has been developed at ELDIM (cf. figure 5). The device includes a CCFL backlight that is used as reference source and a dedicated electronic driver that measures and regulates the flux emitted by the backlight. The regulation ensures an emission at $\pm 0.3\%$ of the nominal value in the dynamic range 20-100% of the device.

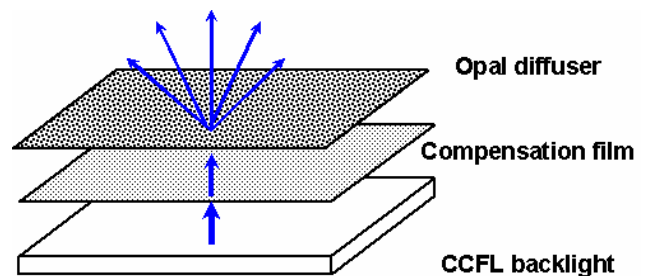
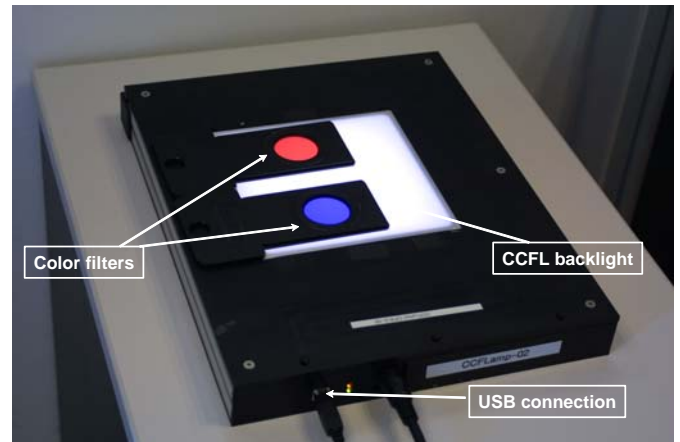


Figure 5: Photograph of the CCLF reference device with two color filters (top) and internal structure of the device (bottom).

For EZContrast calibration and especially for the high incidence angles, we need to have a very homogeneous source with an emission diagram close to a Lambertian one. The CCFL backlight alone is not sufficient. To increase the angular emission, we have added on top a opal diffuser and the homogeneity is ensured using an additional compensation film between the CCFL backlight and the opal diffuser (cf. figure 5.b). The design of the compensation film is made for each CCFL device measuring the near normal luminance of the system without compensation film using our MURATest video luminance meter (cf. figure 6.a). Then the compensation film is calculated and fabricated by printing technique. Finally the homogeneity of the emission is verified using the same MURATest system (cf. figure 6.b). Except near the borders the measured homogeneity is better than $\pm 2\%$ on all the CCFL surface.

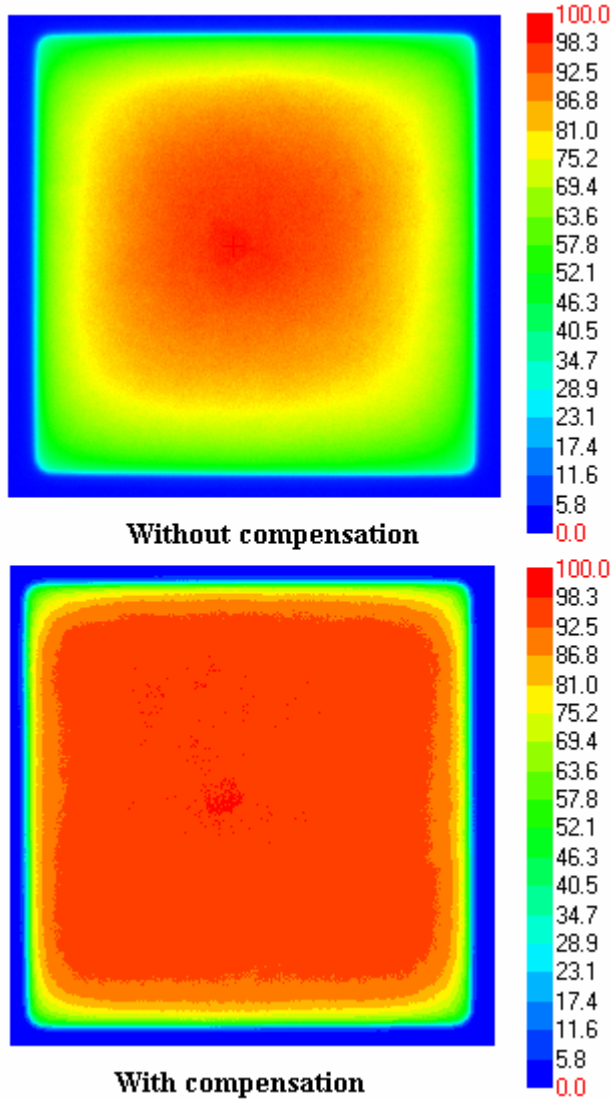


Figure 6: Emission homogeneity of the CCFL reference device measured by MURATest video luminance meter: the scale is normalized at 100% for the maximum luminance. The measurement is made without (top) and with (bottom) compensation film.

Then the absolute luminance of the device is measured using a Topcon SR3 system mounted on a reference goniometer. The position of the reference luminance meter can be adjusted precisely versus incidence angle up to 88°. We have verified that the emission is not azimuth depend. An example of such a measurement is reported in figure 7. We see that the effective luminance of our source is not far from a Lambertian one except at very grazing angle. Nevertheless the effective luminance is still about 30% at 88° and so the calibration of our instrument can be made easily and accurately. To make the calibration it is also necessary to be sure that the plane of the CCFL reference device is perfectly perpendicular to the optical axis of the system. In practice, the CCFL is mounted on a support that can be adjusted both in height and tilt and an automated procedure as been developed to adjust the position of the CCFL at the focus of the instrument and with the right orientation. A typical

EZContrast response without calibration is also reported in figure 7. We see that it follows quite well the Lambertian response thanks to the cosine compensation of the optics (cf. figure 3) except at very grazing angle. This behavior is very important to ensure that the system can measure accurately in the entire angular aperture. A system without cosine compensation (cf. figure 3) cannot be used above 70°.

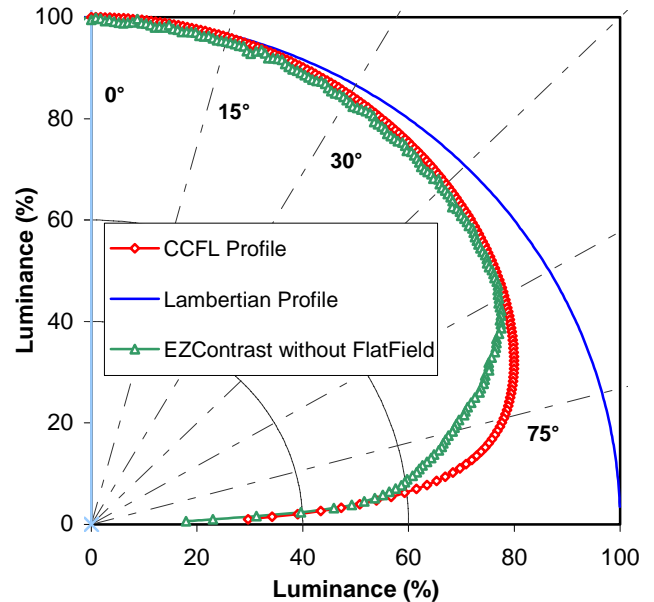


Figure 7: Angular emission of the CCFL reference device compared to a Lambertian source. The EZcontrast response without flat field calibration is also reported

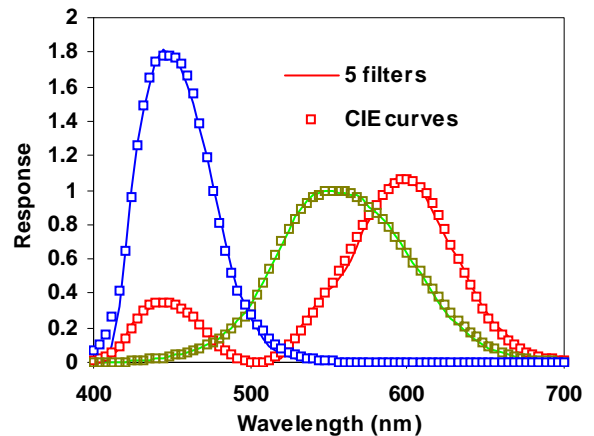


Figure 8: Spectral response of a EZContrast system compared to CIE curves. Five filters are used (1 for blue, 2 for green and red).

5. Spectral emission and color calibration

All the EZContrast systems are designed and built to ensure luminance and color measurements as accurate as possible. We use a monochrome Peltier cooled CCD detector and we measure the absolute spectral response of the system with regards to a NIST calibrated photodiode. Then dedicated color filters are

designed and fabricated to ensure that the spectral response of the system with its filters is perfectly matched to the CIE curves. Generally five filters are used (1 for blue, 2 for red and green). One experimental example is reported in figure 8. It is the only way to ensure a good accuracy in the entire chromatic plane. Nevertheless, the design and the fabrication of the filters is never perfect and the system requires to be calibrated in color accuracy at the end of the fabrication process. For the new generation of instruments we have decided to use the CCFL reference device in conjunction with gelatin filters. A first advantage is that the spectral emission of the CCFL device is generally near the spectral emission of the LCD displays. So, the calibration is more precise in the spectral regions of interest (cf. figure 9). A second advantage is that the gelatin filter covers a great part of the chromatic plane (cf. figure 10 and Table I). Then the accuracy of the instrument is improved in the majority of the chromatic plane.

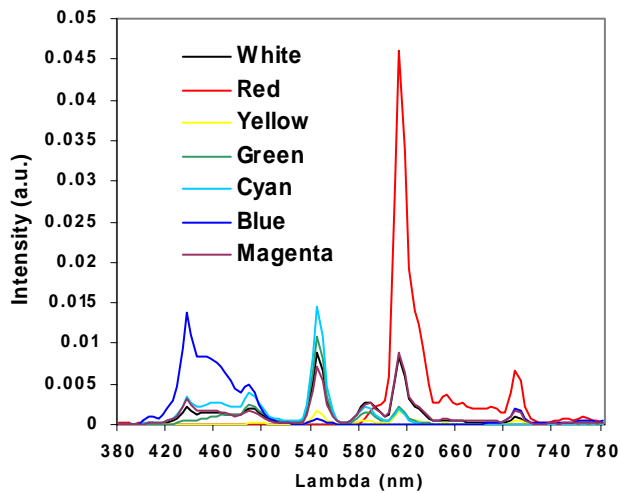


Figure 9: Spectral emission of the CCFL reference device measured by Topcon SR3

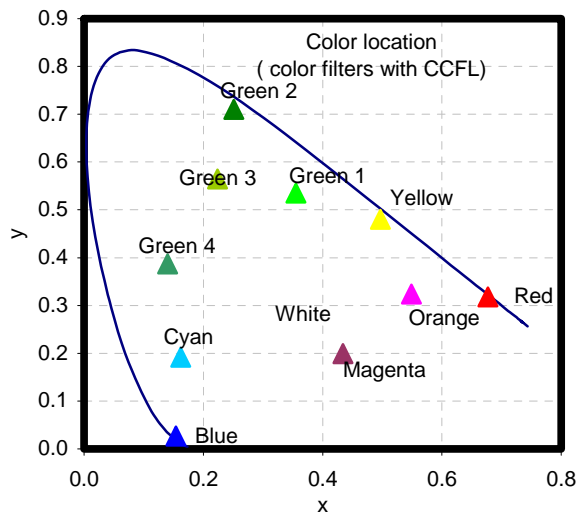


Figure 10: Calibrated colors using the gelatin filters with the CCFL reference device

	Colored filter	Color coordinates		Luminance
		x	y	Y(Cd/m²)
White	White	0.353	0.335	51009
Red	Bright Red(126)	0.677	0.318	7394
Orange	BistardPink(779)	0.549	0.324	38200
Yellow	Deep Amber(104)	0.497	0.480	745.66
Green 1	Lee Green(121)	0.355	0.535	581.70
Green 2	Twickenham Green(736)	0.251	0.710	71.41
Green 3	Dark Green(124)	0.224	0.565	246.42
Green 4	Millard Green(325)	0.140	0.387	48.94
Cyan	Lagoon Blue(172)	0.162	0.192	166.66
Blue	Tokyo Blue(071)	0.154	0.027	6.53
Magenta	Bright Pink(128)	0.434	0.199	186.16

Table I: Color coordinates and luminance of the CCFL device with gelatin filters

6. Conclusions

We have presented a new calibration procedure dedicated to Fourier optics viewing angle instruments. To improve the accuracy of the instruments new calibration tools have been developed taking care of the specific problem at very grazing angles that is clearly a serious problem for any measurement device. In order to make this, a goniometer has been first developed to calibrate the angles very precisely. This system can also be used to check the transmission properties of any light components such as polarisers, diffusers... A second tool dedicated to flat field, luminance and color calibration has also been developed. It is a CCFL based device controlled by a USB connection. The emissive part is homogeneous, calibrated in luminance and also in angle up to 88°. Its emissive pattern is near a Lambertian emitter and allows accurate calibration even at very grazing angles. Its spectral emission is also calibrated and allows more precise color and luminance calibration in the entire chromatic plane when used in conjunction with gelatin filters.

All the calibration tools are mounted on the same stand with the EZContrast system mounted on a vertical movement with easy loading and unloading and automated Z axis control. The calibration procedure is easy and automatic. Different calibration tools will be installed in the major LCD display countries in order to offer a more rapid and better recalibration of the ELDIM systems to the customers.

7. References

- [1] T. Leroux, "Fast contrast versus viewing angle measurements for LCDs", Proc. EURODISPLAY, 447, 1993
- [2] T. Leroux, C. Rossignol, "Fast analysis of LCD contrast and color coordinates versus viewing angle", SID Proceedings, 73, 1995