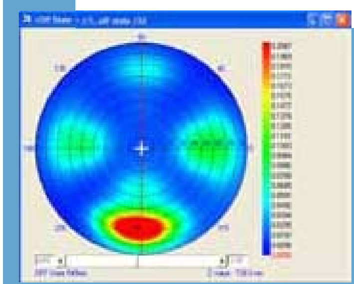
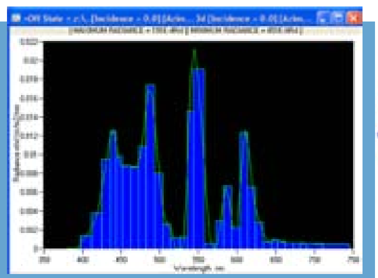
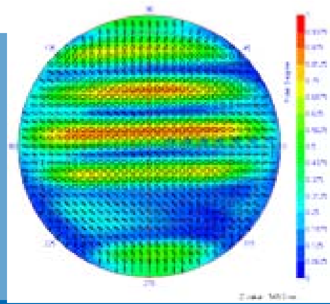
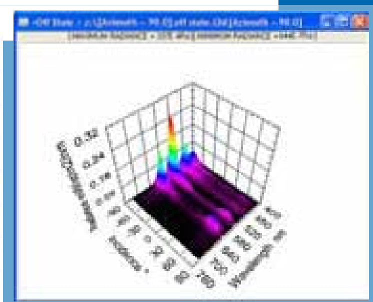
MULTISPECTRAL VIEWING ANGLE ANALYSER









REVOLUTIONARY SYSTEM FOR FULL SPECTRAL AND POLARIZATION MEASUREMENT IN THE ENTIRE VIEWING ANGLE

EZContrastMS80 & EZContrastMS88

ADVANCED LIGHT ANALYSIS by ELDIM

cnc optical laboratory

Stitching Interferometer

Leybold A700QE in clean room environment

First hemispheric lens during QA by stitching interferometry

Optic alignment in clean room environment

High performance Fourier Optics viewing angle instrument

ELDIM manufactures viewing angle instruments based on Fourier optics for more than 10 years. Over the years the system capacities have been increased both for very grazing angles and large spot size. Multispectral series uses the most advanced optical design with incidence up to 88°.

High Efficiency

One of their key features is the patented optical configuration which allows controlling the angular aperture of the system independently of the measurement spot size.The very high light collection efficiency allows measurement up to very extreme grazing angles (88°) with an excellent accuracy. This is a key advantage compared to solution based on standard Fourier optics as shown below

High Speed

The full viewing cone is measured with high incidence and azimuth angular resolution within seconds for luminance and minutes for radiance. Full characterization of films and components can be made in several minutes when several days would be necessary using goniometric solutions.

High accuracy

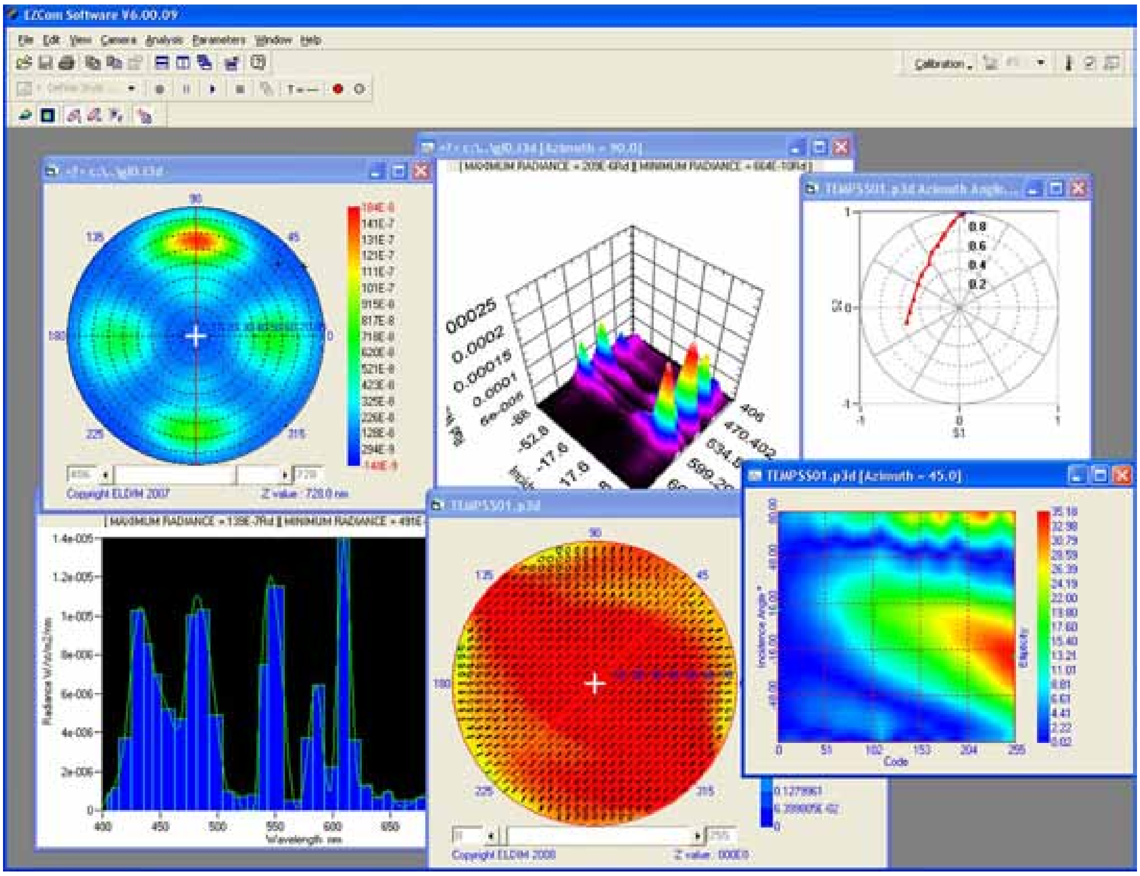
All ELDIM systems follow a strict manufacturing, quality controls and calibration procedures. Spectral response of each CCD camera is characterized and each filter is design for each spectral response and controlled by spectrophotometry. Dedicated tools and procedures have been developed to calibrate the systems up to very grazing angles.

High reliability

ELDIM is manufacturing itself all the key components of its systems. The quality of the optics is optimum thanks to advance technologies such as magneto-rheological polishing or stitching interferometry. Antireflective coatings and optical alignments are realized in-house to reduce straight light and parasitic polarization. Optical alignment and mounting is made inside clean rooms. All the system are tested intensively during several days before delivery.

Radiance, luminance, color & polarization

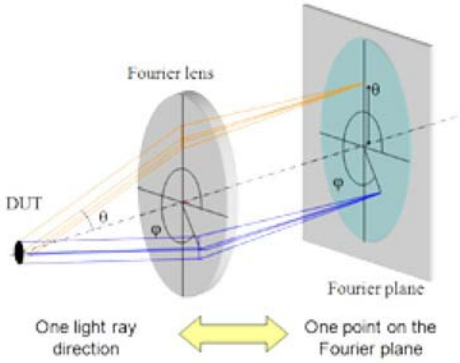
EZContrastMS can measure not only the radiance versus wavelength but also the complete polarization state of the light. Polarization state is very useful in many situation as to improve contrast on LCDs, characterize films and components or measure the 3D behavior of polarization based stereoscopic displays.



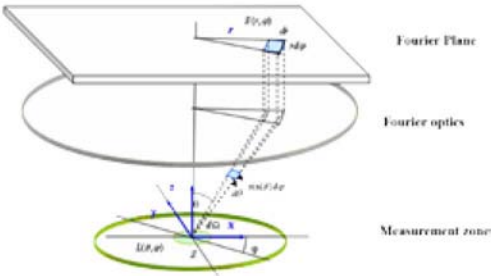
EZContrastMS comes with a complete open software solution for automated measurement and data analysis. All the features can be addressed by others softwares using Microsoft ActiveX technology. Programming examples are provided with the software.

Some characteristics of the EZCom 6 sofware package

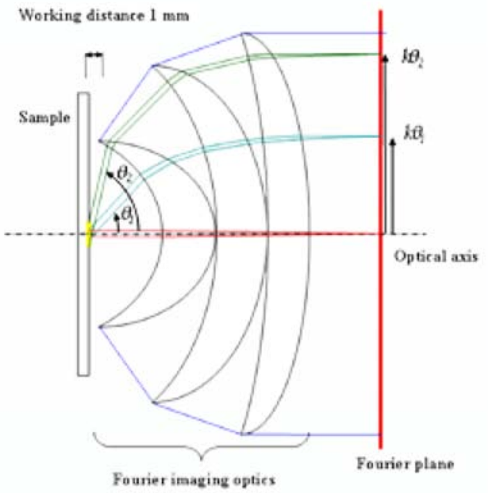
Features	Details	ActiveX	Version
Measurement capacities	Styles for radiance measurement with independent parameters for each filter	Yes	Standard
	Single Filter measurement possible	Yes	Standard
	Polarization measurement with 7 configurations	Yes	Option
Multispectral radiance data	Component to manage and display 3D radiance data	Yes	Standard
	Cross sections versus incidence , azimuth or wavelength	Yes	Standard
	Data export to excel or any other software	Yes	Standard
	Calculation of color and luminance	Yes	Standard
	Grey level analysis of radiance data	Yes	Standard
Multispectral polarization data	Component to manage and display 3D polarization data	Yes	Option
	Cross sections versus incidence , azimuth or wavelength	Yes	Option
	Data export to excel or any other software	Yes	Option
	Stokes vector computation ,display and export	Yes	Option
	Grey level analysis of polarization data	Yes	Option
Color data	Component to manage and display color data	Yes	Standard
	Data export to excel or any other software	Yes	Standard
	Color systems: XYZ, Lxy, Lu'v', Lu*v*,Lab, Color temperature, Dominant wavelength	Yes	Standard
Luminance data	Component to manage and display luminance data	Yes	Standard
	Data export to excel or any other software	Yes	Standard
	Grey level analysis of luminance data	Yes	Option



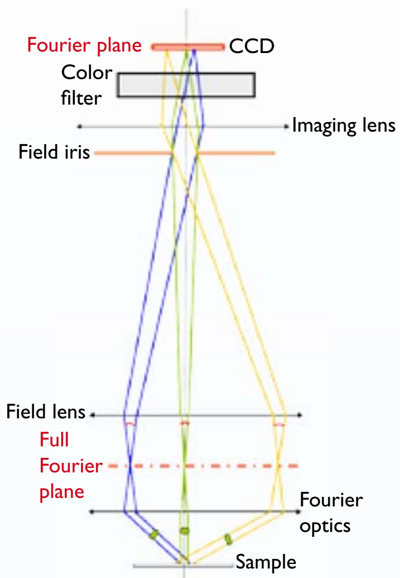
Principle of Fourier optics



How to calculate the illumination on the Fourier plane



Schematic diagram of a standard Fourier optics



Patented ELDIM optical configuration with cosine compensation

Fourier Optics Trends

Collection efficiency

A Fourier optic is simply a lens (or a collection of lenses) that collects the light emitted by a small surface and refocus rays of light on a plane -called the Fourier plane- at a position that depends on their incidence and azimuth angles. The illumination of an elemental surface on the Fourier plane defined by a radius r and an azimuth angle φ is given by :

$$E(r,\varphi)rdr = L(\theta,\varphi)S\sin(\theta)\cos(\theta)d\theta$$

$L(\theta,\varphi)$ is the luminance of the object and S the surface analyzed by the Fourier optics.

Simple lens

For a simple lens of focal length f one can derive the simple expression:

$$r = f\tan(\theta) \qquad dr = \frac{f}{\cos^2(\theta)}d\theta$$

So the illumination becomes:

$$E(r,\varphi) = L(\theta,\varphi)S_0\frac{\cos^4(\theta)}{f^2}$$

The efficiency varies with the $\cos^4\theta$ of the incidence angle and is therefore very small for angles higher than 40°. Not very surprisingly a simple lens acts thus as a Fourier optics but is completely inefficient to make luminance and color measurement above 40° of incidence.

Fourier optic

A conventional Fourier optic is a combination of lenses with increasing radius of curvature that collects the light emitted by the surface and redirect the different rays emitted at different incidence angles along the optical axis of the system. Generally, three to five lenses are required for this purpose. For very large angular apertures, the first lens is a quasi-complete hemisphere. The angular dependence becomes linear in the Fourier plane and:

$$r = k\theta$$

The illumination in the Fourier plane can then be recalculated as follows:

$$E(r,\varphi) = L(\theta,\varphi)S_0\frac{\cos\theta\sin\theta}{k^2\theta}$$

The efficiency of the system becomes less sensitive to the incidence angle than previously as shown in the figure. Nevertheless it is always going down to zero for grazing incidences and this optical design remains therefore inefficient at incidence angles higher than 60-70°. The coverage of a wide angular range requires to further combine this Fourier optic with another optical setup.

Fourier optics with cosine compensation

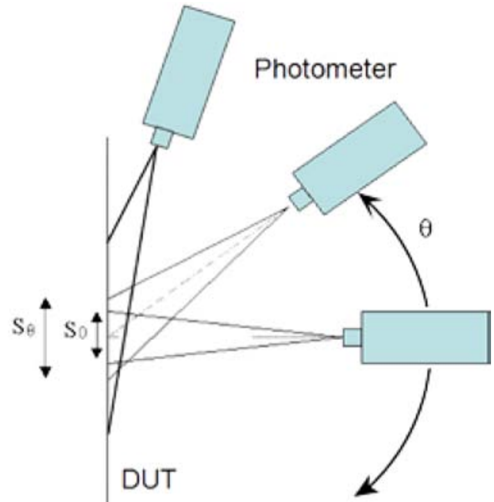
This configuration has been patented by ELDIM ([1-2]). The Fourier optics plane is imagined onto the detector using a field lens and an imaging lens. An iris is located on an intermediate plane which is complex conjugate of the surface of the display. The first interest of this optical setup is that this iris defines the size of the measurement spot on the display surface independently of the angular aperture of the instrument. So, large measurement spot sizes up to 6mm with angular apertures as high as ±88° can be obtained. The second interest is that the spot size increases with the incidence angle in the same way as for a goniometric system. The minimum spot size is obtained at normal incidence and increases with the cosine of the angle as follows:

$$S(\theta,\varphi)=\frac{S_0}{cos(\theta)}$$

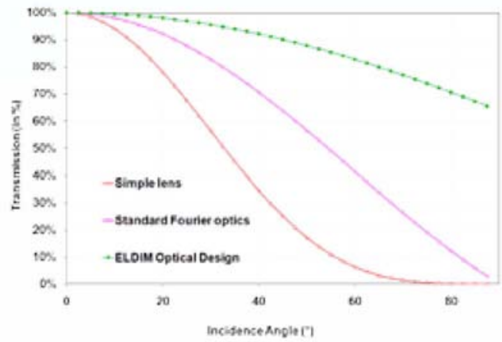
And the illumination in the Fourier plane can then be recalculated as following:

$$E(r,\varphi)=S_0 L(\theta,\varphi)\frac{\sin(\theta)}{k^2\theta}$$

The efficiency of the instrument is now drastically increased compared to the previous configurations. The optical system can work up to 88° keeping efficiency higher than 65% even at this very grazing angle.



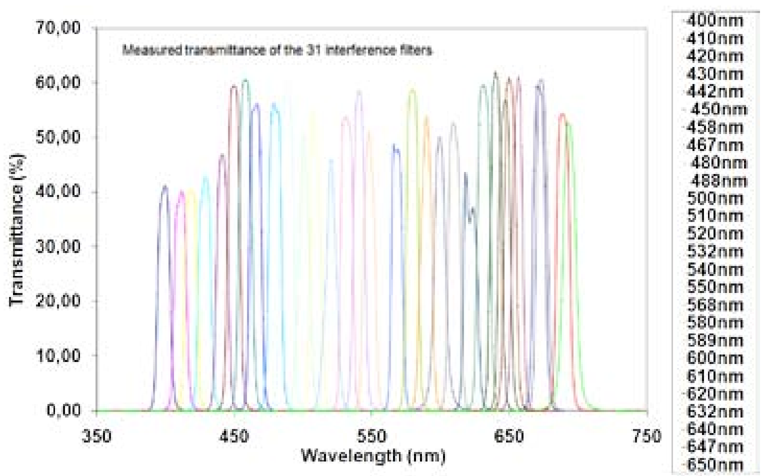
Spot size changes with the incidence for goniometer-based systems

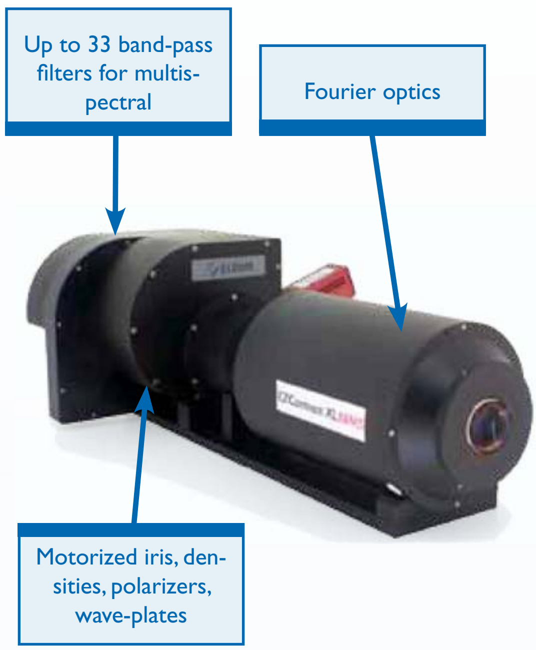


Theoretical transmittance of three different types of Fourier optics setups

Radiance accuracy

Inside EZContrastMS different automated wheels allow selection of the light beam using 31 band pass filters regularly distributed in the visible range. The system makes automatically a quasi spectral image of the full Fourier plane at each filter wavelength and the sequence is repeated for all the filters. The system is calibrated in an absolute way to reconstruct the spectral radiance of the object at each incidence and azimuth angle. Measurement spot size can be adjusted automatically. System response can be adapted to very bright sources with neutral densities. Polarizers and wave-plates allow full polarization analysis of the light.

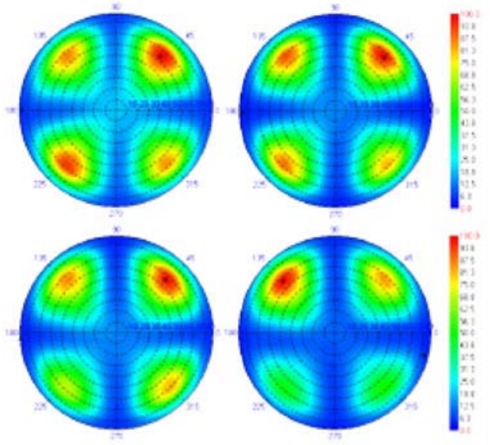




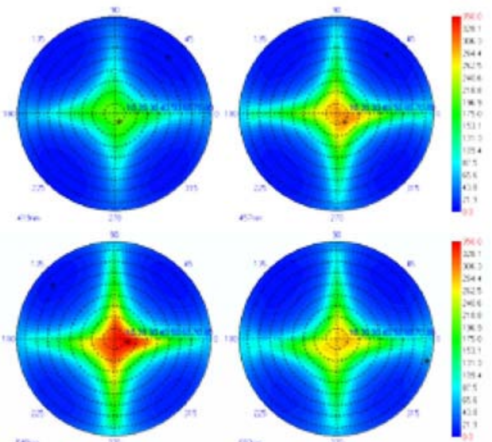
EZContrastMS system with its main coomponents

([1]) "Device for determining the contrast of a display screen as a function of the observation direction", Patent US270863, September 26th 1989

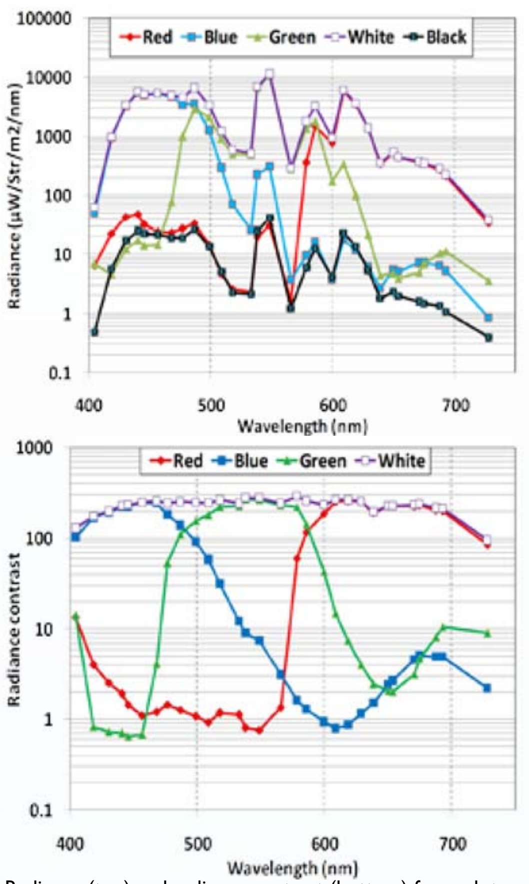
([2]) "Device for measuring spatial distribution of the spectral emission of an object", Patent US6804001, April 26th 2002



OFF state radiance obtained at four different wavelengths on a LCD



Radiance contrast obtained at four different wavelengths on a LCD



Radiance (top) and radiance contrast (bottom) for each type of pixel measured at normal incidence

Ultimate LCD light emission study

Multispectral measurement of display emission is extremely powerful to analyze in details the performances. All the key components of LCD displays exhibit strong dependence versus wavelength (polarizer efficiency, transmittance of diffusive films and the polarization modulation of the liquid crystal itself). Full angular and radiance analysis allow better understanding of the LCD performances.

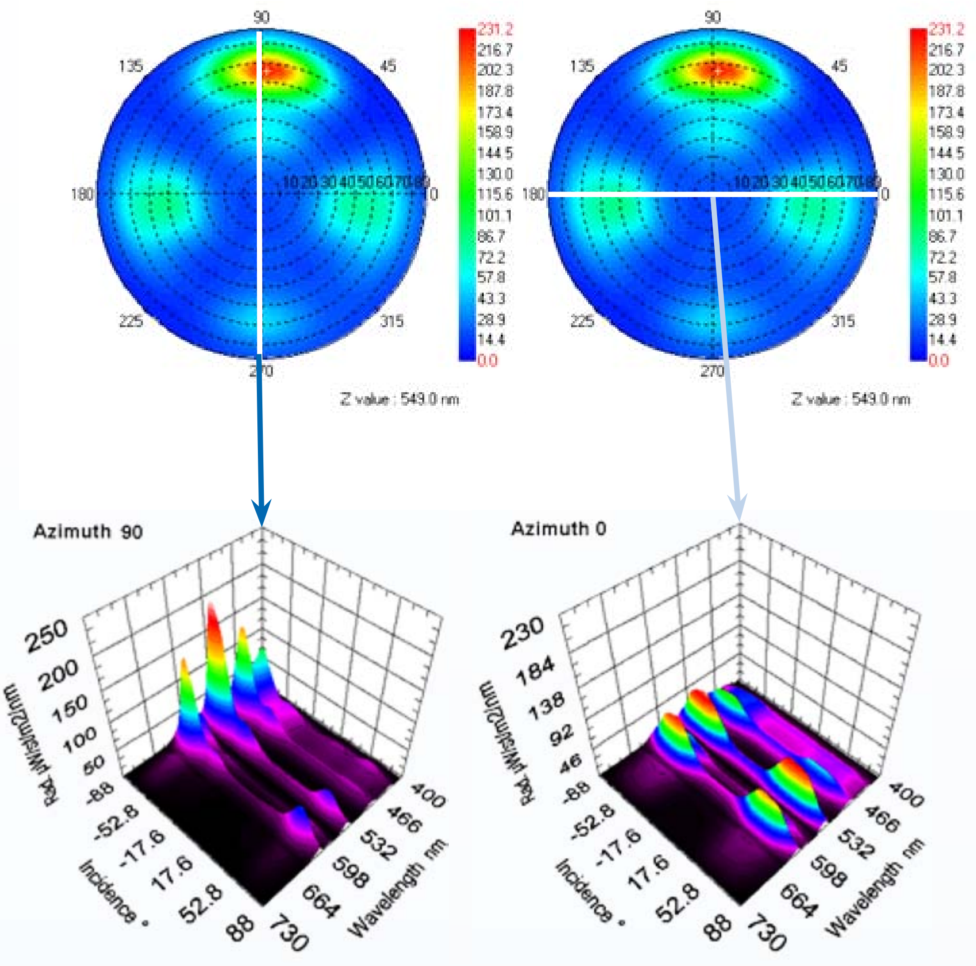
Radiance contrast

In addition to standard luminance contrast, the radiance contrast can be evaluated at each wavelength and angle and the performances of the display measured more precisely.

Color emission

From multispectral measurements of R, G and B states it is possible to calculate the radiance contrast for R, G and B pixels separately at any angle and wavelength. Color behavior can be better understood and improved.

Multispectral measurement of an emissive LCD in OFF state: full viewing angle at 693nm (top) and cross sections at 0° azimuth (bottom right) and 90° azimuth (bottom left)



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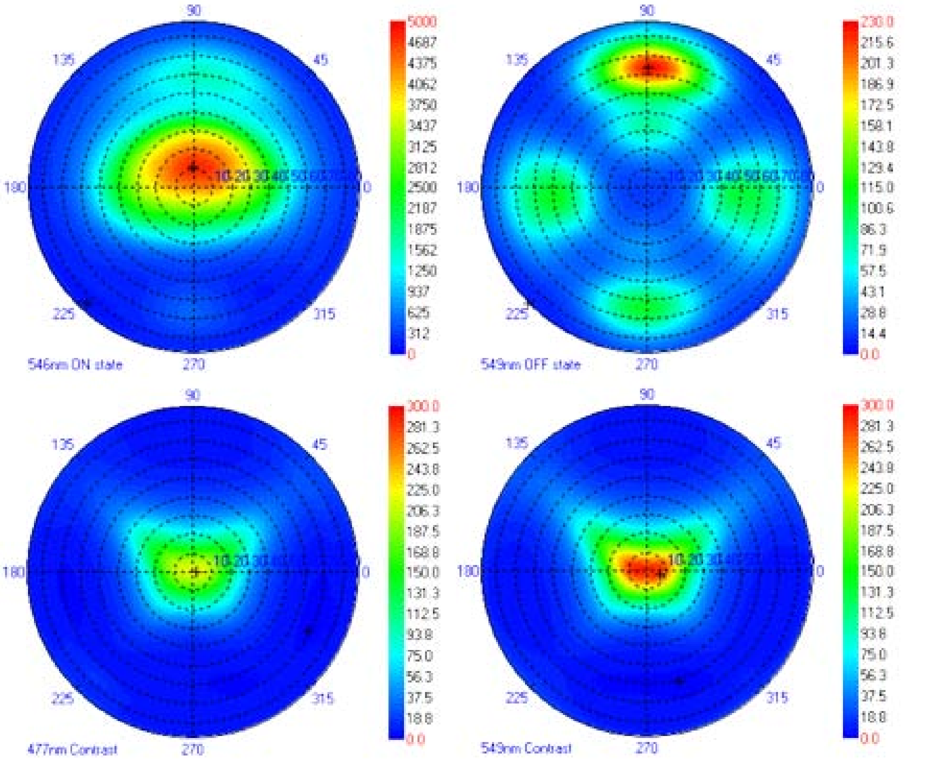
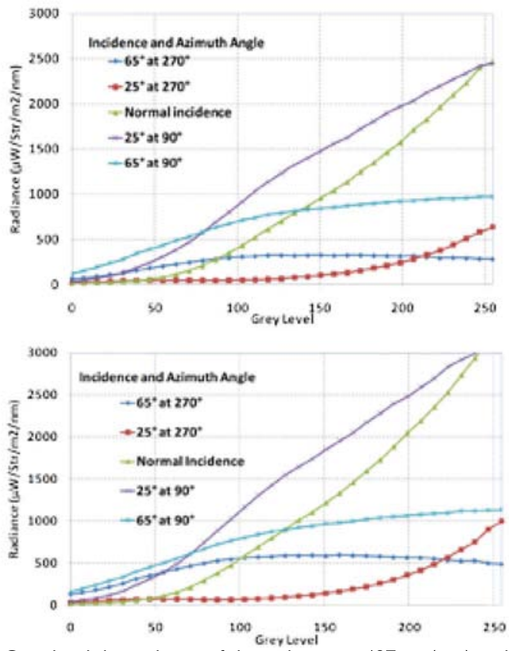


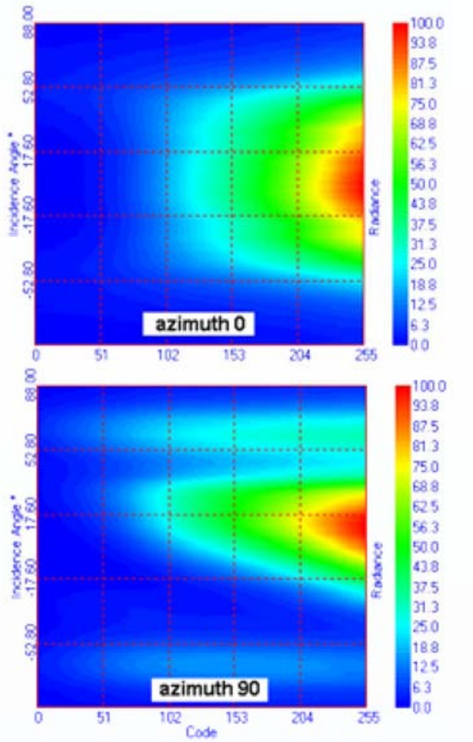
Radiance at 549nm for ON state (top left) and OFF (top right) and radiance contrast at 477nm (bottom left) and 549nm (bottom right)



Grey level dependence of the radiance at 487nm (top) and 549nm (bottom): five angles are selected

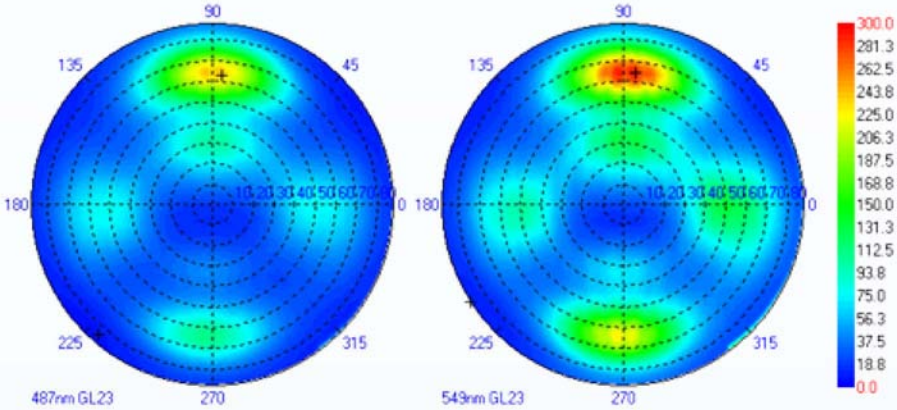
Grey level analysis

Isocontrast curves are usually used to evaluate the viewing angle characteristics of LCDs. For grey level scales images, this is not sufficient. Viewing angle grey level analysis of luminance and lightness measured using Fourier optics instrument has been proposed earlier([1]). The same type of analysis can be made with EZContrastMS using radiance instead of luminance or lightness. The angular pattern of radiance for a given grey level is dependent on wavelength. It is then possible to make a complete grey level analysis of the LCD emission at each wavelength. Fine dependence versus wavelength and incidence can be detected([2]).



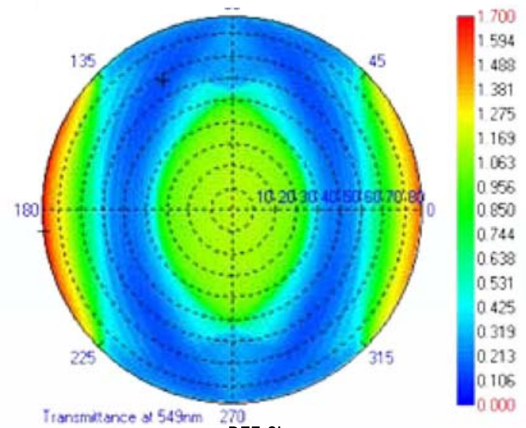
Grey level dependence of radiance along azimuth 0 and azimuth 90. The wavelength is fixed at 549nm and values are relative

([1]) J. Hirata, Y. Hisatake, M. ishikawa, "Viewing angle evaluation method for LCDs with gray scale images", J. of SID, 405 (1993)
([2]) P. Boher, "Viewing angle and spectral characterization of LCDs and their components", IDW meeting, Japan, December (2008)

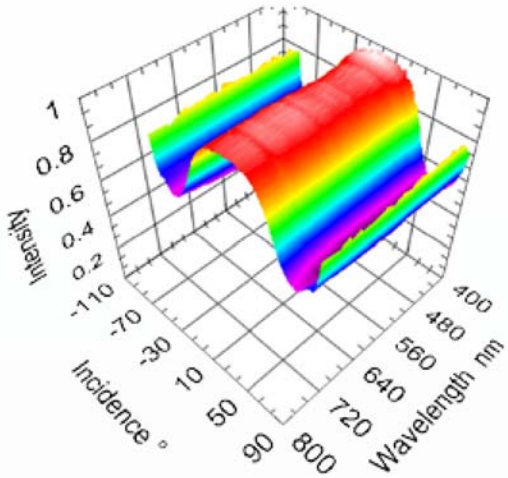


Radiance pattern at 487nm (left) and 549nm (right) for grey level 23

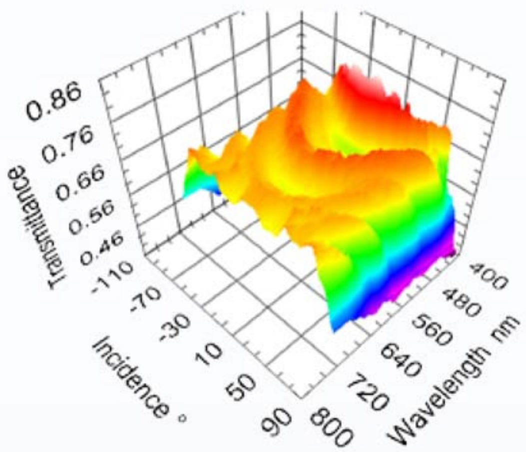
ELDIM's LEDSource



BEF film



Diffuser film



DBEF film

LCD component characterization

Accurate simulation of LCDs require a good knowledge of the optical properties of any component includes in their structure. Characterization must be made versus angle and wavelength to be able to predict emission on the full cone. **EZContrastMS** is the tool of choice for this task.

Speed & accuracy

ELDIM can provide a reference near Lambertian white source to make transmittance measurements. Stabilized light emission is ensure between 400 and 700nm with an excellent homogeneity and no residual polarization. Each film is fully characterized within minutes instead of hours or days with goniometric solutions.

Specular & diffused contributions

Inside the LCD structure, the components are submitted to an illumination that covers a large range of angles. Most of the time the specular contribution goes with a diffused contribution that can be important. Standard component characterization using collimated light beams is not capable to measured the diffused component outside the specular reflected or transmitted beam. Using quasi Lambertian illumination provided by the **LEDSource** and **EZContrastMS**, more realistic properties combining specular and diffused contributions are automatically obtained.

White LEDSource specifications

Stability	*From 5% to 100%*	±0.3%
Linearity	*From 5% to 100%*	±0.5%
Luminance	*Min* *Max*	70Cd/m² 1400Cd/m²
Uniformity	*90% of diffusive surface* *70% of diffusive surface*	±4% ±2%
Angular response	*intensity at 10° incidence* *intensity at 30° incidence*	99.7% 97.6%
Non polarized state	*Polarization degree*	<2%
Diffuser size	*Working area (mm)*	135x135
Housing size	*LxWxH (mm)*	295x280x50
Weight	*Kg*	2.5

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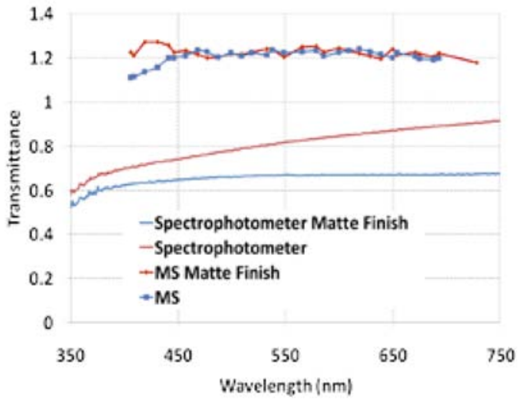
Films & Components

Brightness enhancement films

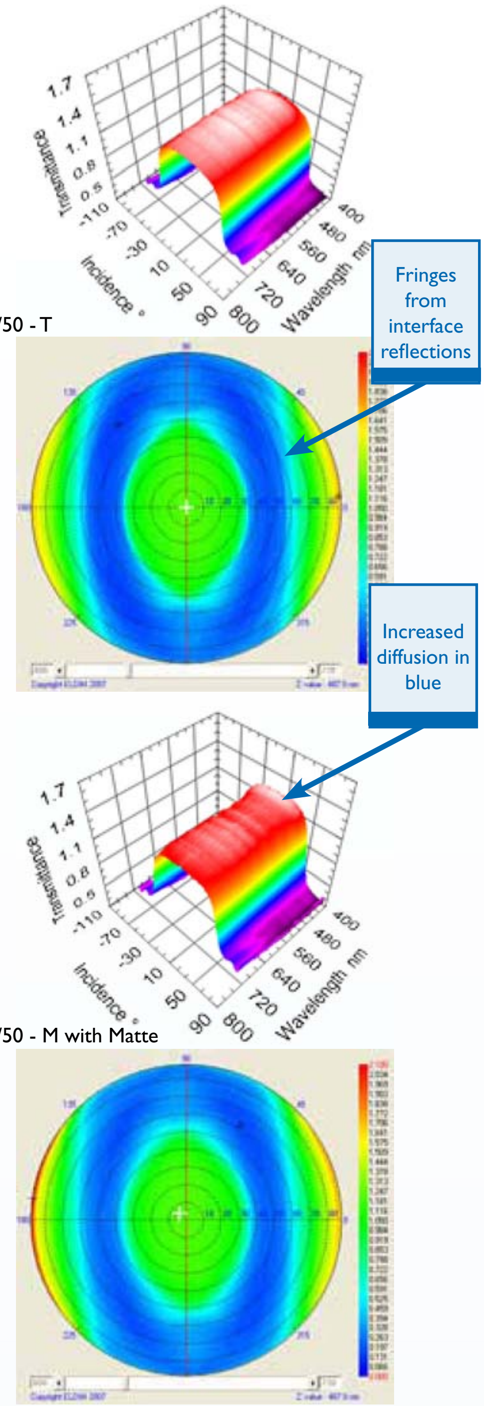
Brightness Enhancement Films (BEF) are widely used in the design and manufacture of LCD screens and large-screen TVs. They increase backlight brightness towards the on-axis viewer. The BEF is a micro-replicated prism array as schematically represented below. Near normal incidence rays are reflected back for backlight recycling. We have measured two films with a prism periodicity of 50µm and with or without matte finish on the other side. Normal incidence spectral transmission has been measured using a Perkin Elmer LAMBDA 45UV/Vis spectrophotometer (cf. figure). The transmittance is lower with matte finish because of the addition light loss of the specular beam due to light diffusion. Multispectral measurements are reported below. The shape of the viewing angle transmittance pattern is characteristic of a prismatic structure. Near normal incidence rays are reflected back for backlight recycling. Along the grooves the reflection coefficient is reduced when it is increased above 1 in the perpendicular direction and at high angles. The transmission coefficient is of course different than using the spectrometer because of the different illumination configuration (cf. figure). Multispectral results are in fact more realistic for the intended using conditions of the films. Small differences can be detected between the two films. In particular and increase diffusion in the blue with matte finish and detection of small interference fringes in the low transmission region for the film without matte finish. These differences are enhanced on the polarization measurements of the same films (see polarization section).



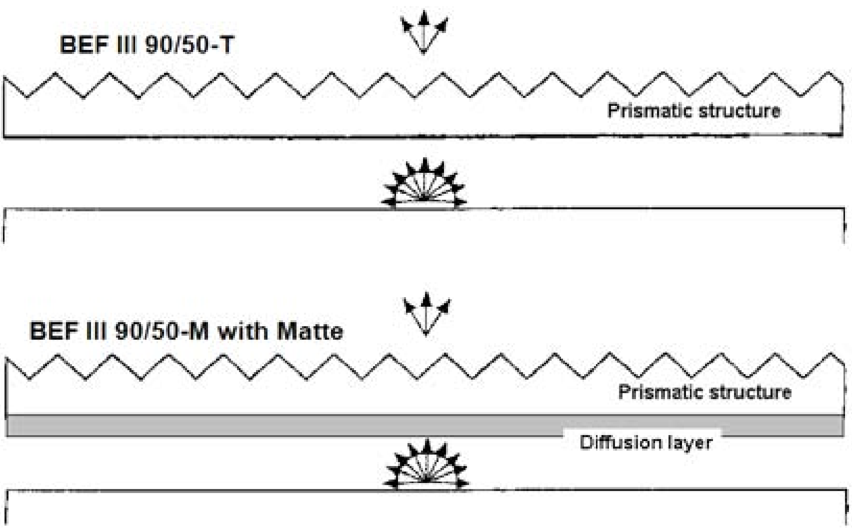
Transmittance of the two BEF films at normal incidence measured by a spectrometer and EZContrastMS

BEF III 90/50 - T

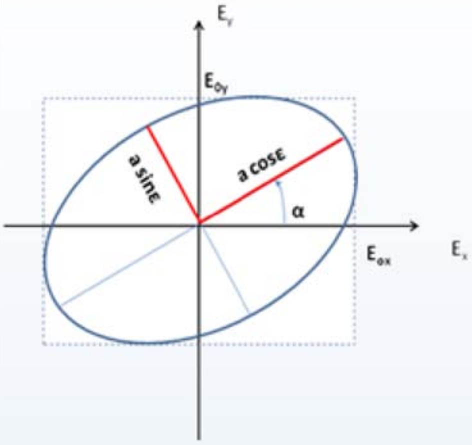
BEF III 90/50 - M with Matte



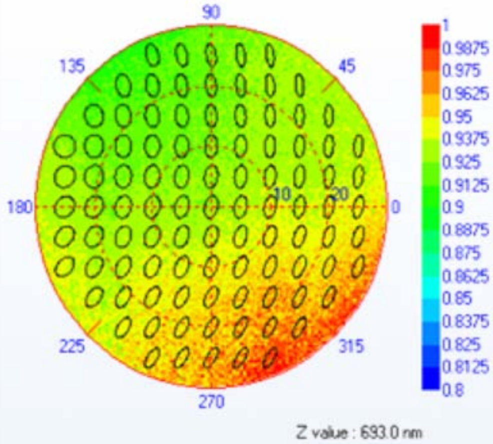
Multispectral measurements of two BEF films: vertical cross section and full viewing angle at 487nm. Small differences can be detected with (bottom) and without (top) matte finish



Structure of the two BEF films



Definition of elliptic parameters of polarized light



Polarization of LCD without top polarizer at 693nm

Polarization analysis

Light can have different states of polarization. It can be randomly polarized (or unpolarized). This is generally the case for natural light. It can also be linearly polarized. In this case the electric field is oscillating always in the same plane. In any case the electric field characterizing any light wave can be separated into two components:

$$E_l = E_{polarized} + E_{unpolarized}$$

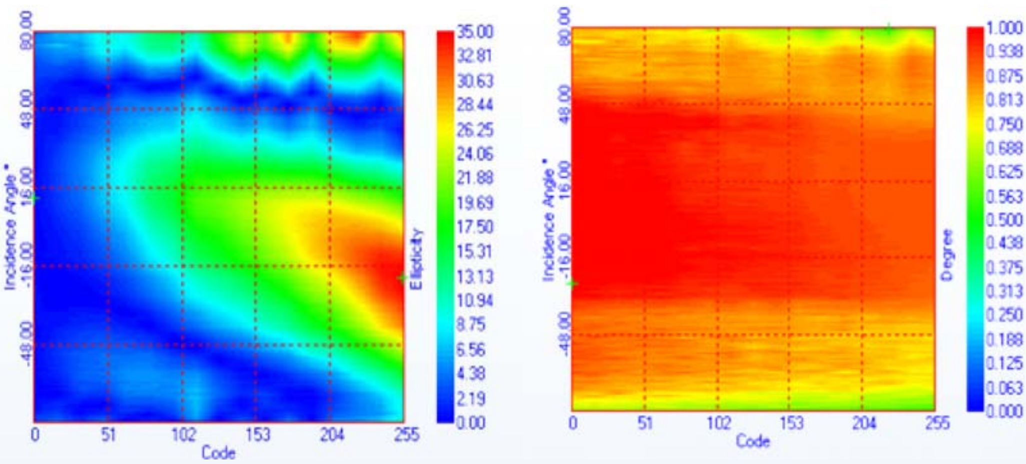
The polarized component can be defined by its elliptical coefficients (ellipticity ε and orientation α) as shown hereafter. Unpolarized light component is defined by the degree of polarization ρ given by the ratio of the intensity due to polarized component over the total light intensity. The three previous parameters can be combined with the intensity to provide Stokes vector.

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

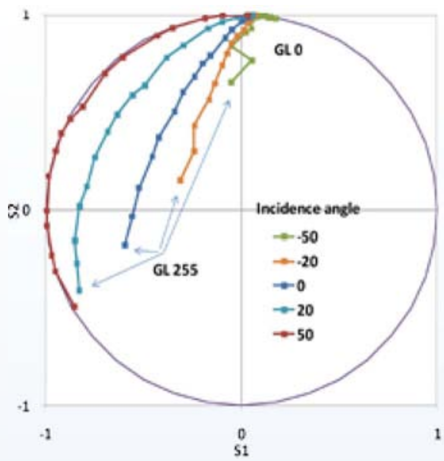
EZContrastMS system can be provided with a polarization option that's includes three polarizers at different orientations (0, 45 and 90°) and two wave-plates at different orientations (45 and 135°). The system performs automatically seven measurements with different polarization configurations and computes the polarization parameters and the Stokes vector.

LCD performances

Polarization analysis of the light emitted by a LCD is very informative on the efficiency of the liquid crystal cell as polarization modulator. Unpolarized light detected in OFF state is for example directly related to the quality of the black level of the display and to the contrast in radiance or luminance. A powerful way to follow in details the crystal cell switching is to remove the top polarizer of the LCD and to measure the polarization state modulated by the cell versus grey level. The liquid crystal cell rotation acts as a wave-plate and the light linearly polarized in OFF state becomes nearly circular polarized for ON state. The polarized light can be followed in all its details versus angle and wavelength. Stokes vector can be computed at any angle and wavelength for each grey level.



ellipticity and polarization degree versus grey level and incidence angle



Stokes vector versus grey level at 549nm

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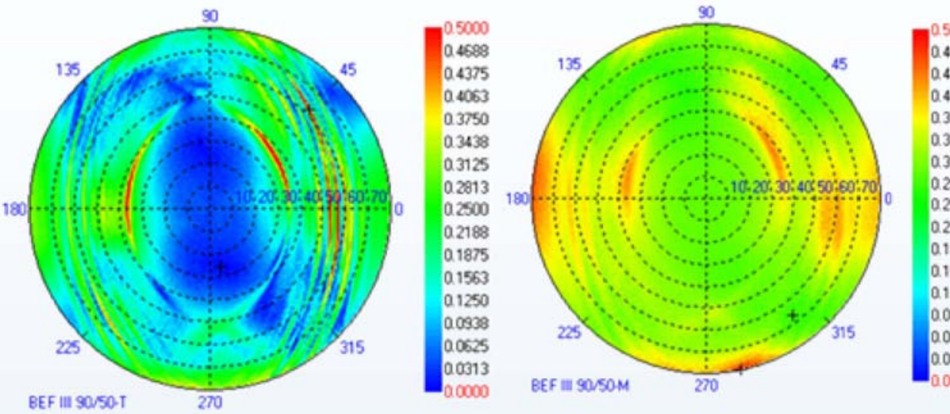
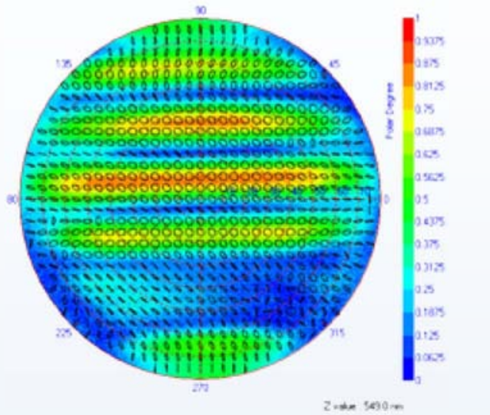


Comparison of two BEF films at 633nm with and without mate diffusor



Polarization state at 549nm for left eye view. Polarization ellipse and degree of polarization are reported simultaneously

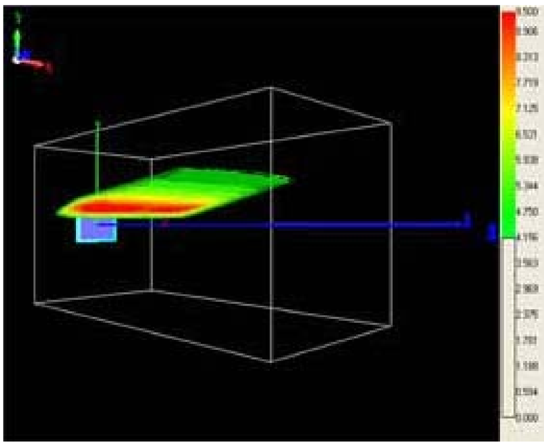
Component characterization

Polarization efficiency of the polarizers must be analyzed in details for correct prediction of LCD performances. Also many films and components can have an impact of the polarization of the light and consequently some influence on the performances. EZ-ContrastMS with ELDIM reference white source make this characterization easy and fast. The impact of the different components in terms of polarization is important like for example for the BEF films analyzed in page 9. We have measured the spectral polarization dependence of the same two BEF films. Polarization degree and ellipticity at 633nm are reported above. In contrast with the transmittance properties, the difference between the two films is extremely clear when comparing the polarization properties. The light is linearly polarized for BEF without matte finish and quasi circular with BEF and matte finish.

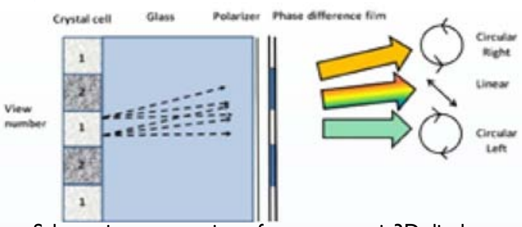
Stereoscopic 3D displays

Polarization based stereoscopic 3D display can be characterized directly by measuring the polarization state of its light emission versus angle and wavelength using EZContrastMS (*). Multispectral viewing angle polarization measurements have been performed for right view ON and left view OFF and the opposite. For the display under investigation, we notice a vertical modulation of the ellipticity and the polarization degree. This vertical modulation is due to a perspective effect induced by to the location of the retarder film with regards to the crystal cell. Indeed, the film retarder is located on the display top surface. The thickness of the top glass modulates the polarization of one view along vertical from right circular state to left circular state. So only one restricted part of the space in front the display is available for correct 3D perception. In addition, the three polarization components exhibit a strong variation with wavelength. In particular the ellipticity never reaches its best value (circular state at ±45°). The polarization state is nearly circular at 530nm but drop down rapidly in the blue and red regions because of the behavior in 1/λ of the retarder sheet. These two features are the main source of imperfection of the display that exhibit a small qualified binocular viewing space with limited 3D contrast.

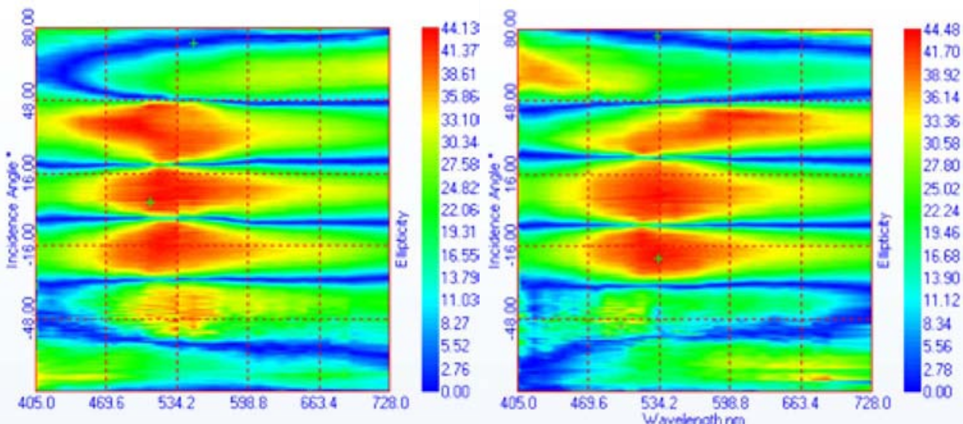
(*) P. Boher, " Multispectral polarization analysis of circular polarizer stereoscopic 3D display", IDW meeting, Japan, December (2009)



3D contrast using three measurement locations of a stereoscopic3D display (box 1000x1000x2000mm)



Schematic cross section of a stereoscopic3D display

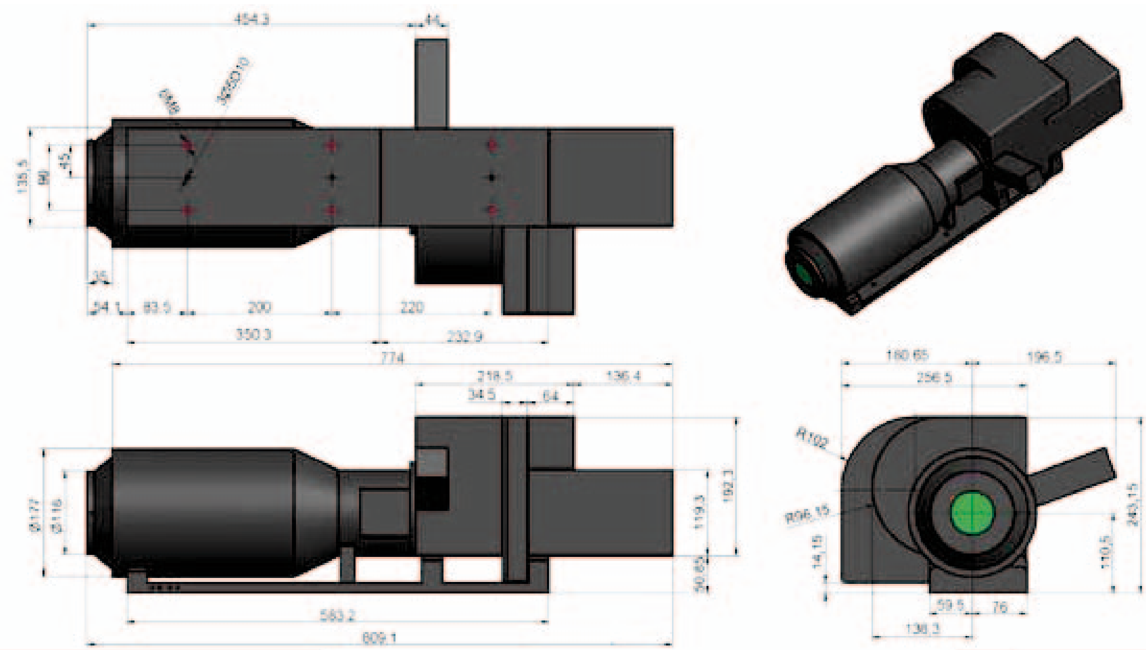


Ellipticity angle for left eye view (left) and right eye view (right) versus wavelength and incidence angle along vertical azimuth

Major specifications of EZContrastMS

Specifications		EZContrastMS88	EZContrastMS80
Field	*Incidence angle* *Azimuth angle*	±88° 0-360°	±80° 0-360°
Measuring area	*Maximum diameter* *Other diameter (optional)*	2mm 1mm, 500µm or 300µm (*1)	
Density	*Optional*	0.5, 1.0 or 2.0 (*1)	
Polarization	*Optional*	3 Polarizers (0, 45, 90°) and 2 wave-plates (*1)	
Optimum distance	*Ensure light coming from same spot at any angle*	1mm	3.7mm
Spectral specs	*Standard* *Optional* *Spectral data extraction*	31 band pass filters on the visible range 400-700nm 2 additional band pass filter (between 700 and 900nm) Interpolation with step between 1 and 5nm	
Measurement time	*Radiance with full resolution* *Radiance with half resolution* *Polarization with full resolution*	<6mn (*2) <3mn (*2) <15mn (*2)	
Accuracy	*Wavelength resolution (nm)* *Wavelength accuracy (nm)* *Stray light (%)* *Angular resolution (deg)* *Radiance (W/Str/m²/nm)* *Chromaticity* *Ellipticity & polarization direction* *Polarization degree*	10 1 (*3) <0.1 (*4) 0.25 ±3% 0.002 (for any stimulus) ±2° up to 60° ±2% up to 60°	10 1 (*3) <0.1 (*4) 0.25 ±3% 0.002 (for any stimulus) ±2° up to 50° ±2% up to 50°
Repeatability	*Radiance* *Luminance* *Chromaticity*	±0.5% (*2) ±0.5% (*2) 0.001(*2)	
Using condition	*Temperature range* *Humidity range*	0 to 40°C 0-85% non condensing	
Interface		USB 2.0	
Power		AC adapter (100-240V 50/60Hz)	
Current consumption		70W	
Weight		65Kg	55Kg

Outer dimension (unit mm)



*(*1) Driven by software*
*(*2) Measurement times are highly dependent on the target and on the conditions. Given times are for a source with a radiance level higher than 10mW/Sr/m2/nm at all the wavelength and already determined exposition times for all the filters .*
*(*3) Band pass filters with a FWHM of about 10nm: the reported accuracy is on the band pass central wavelength position.*
*(*4) For one filter with regards to the maximum of radiance observed on all the other filters.*

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