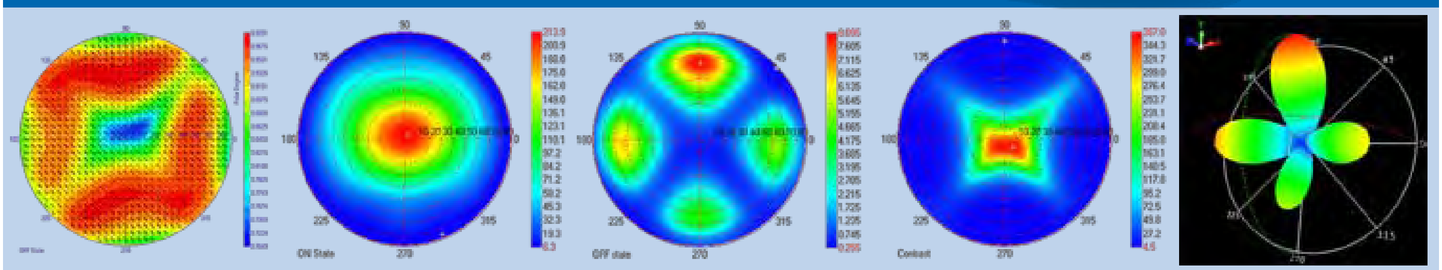
VIEWING CONE MEASUREMENT



THE WORLD LEADER FOR FOURIER OPTICS VIEWING ANGLE INSTRUMENTS
FOR LUMINANCE, CHROMATICITY, RADIANCE & POLARIZATION

EZLite, EZContrastL80, EZContrastL80W, EZContrastXL88 & EZContrastXL88W

ADVANCED LIGHT ANALYSIS by **ELDIM**

EZContrastXL88

EZContrastL80

High performance Fourier Optics viewing angle instrument

ELDIM has been manufacturing viewing angle instruments based on Fourier optics for more than 15 years. 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. Extreme grazing angles (88°) are measured with an excellent accuracy thanks to a very high light collection efficiency .

High Speed

The full viewing cone is measured with high incidence and azimuth angular resolution within seconds for luminance and chromaticity and minutes for radiance.

High Accuracy

Every **ELDIM** system follows a strict manufacturing and calibration procedures. Spectral response of each CCD sensor is measured and each filter -designed on purpose- is controlled by spectro-photometry.

High Efficiency

ELDIM uses a patented optical configuration that allows optimum light collection even at very high angles. This cosine compensation matches the behavior of a spectro-photometer on a goniometric stage.

High Reliability

ELDIM is manufacturing on its own all the key components of its systems. The quality of the optics is optimum thanks to advanced technologies such as magneto-rheological polishing or stitching interferometry. Antireflective coatings and optical alignments are also performed in house to reduce straight light and parasitic polarization.

CNC (Computer Numerically Controlled) systems for grinding, polishing and centering

First hemispheric lens on stitching interferometer

EZLite

EZContrastXL88W

Comparison to other techniques

Viewing angle properties are certainly among the most common characteristics measured on any type of displays. Historically, goniometers were the first equipments used to perform angular measurements. Main drawback of those systems is the "one after each other" nature of the measurements which results in very long acquisition times if more than a few directions are required. **ELDIM** has introduced Fourier optics instruments in 1993(*). A specific optic is designed in order to convert angular field map into a planar one allowing very rapid measurements of the full viewing cone with high angular resolution. Our systems have been improved throughout years to reach extremely high performances at every level. Some technical insights are reported hereafter. Recently for viewing angle measurements, hemisphere based imagers have been introduced. But they're suffer from very poor light collection efficiency, tradeoffs between angular resolution and efficiency and important parasitic light (**).

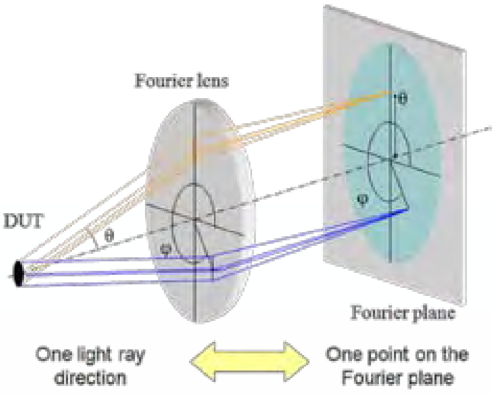
Best technical solution for viewing angle measurements is clearly the Fourier optics approach. There is no strong theoretical limitation neither for light collection efficiency nor for angular resolution. The **ELDIM** optical design that includes cosine compensation allows accurate measurements up to 88° and 6mm spot size.

(*) T. Leroux, "Fast contrast vs. viewing angle measurements for LCDs", Proc. 13th Int. Display Research Conf. (Eurodisplay 93), 447 (1993)
(**) V. Collomb-Patton, P. Boher, T. Leroux, "Comprehensive Survey on Viewing Angle Measurement Devices: A Theoretical Study", SID, San Antonio, 17.4 (2009)

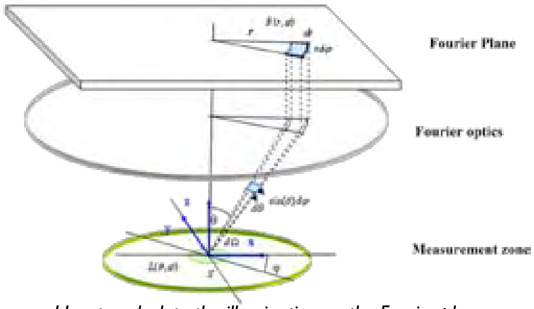
Description of the EZContrastXL88 with its main components

Lens alignment in clean room

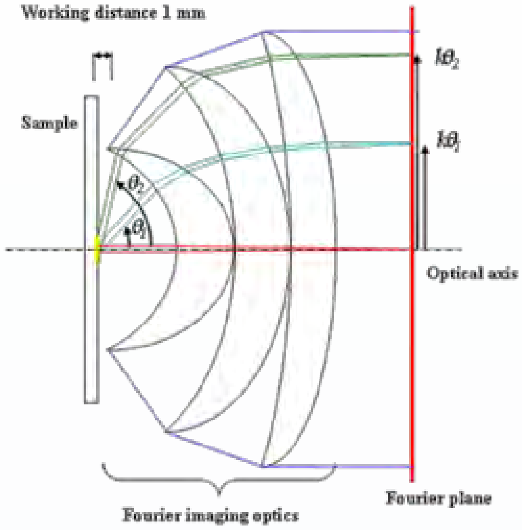
Electron beam evaporator with ion beam assistance



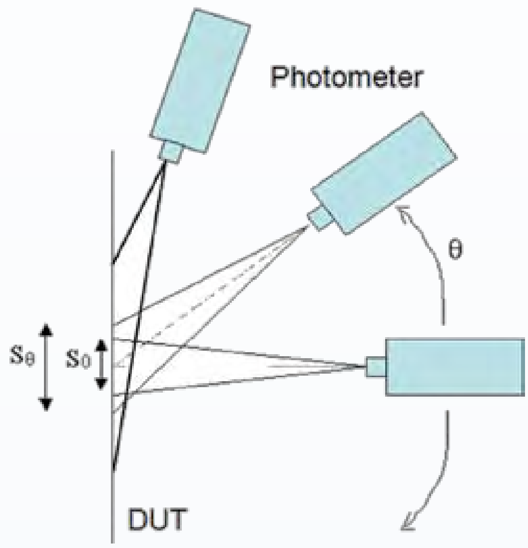
Principle of Fourier optics



How to calculate the illumination on the Fourier plane



Schematic diagram of a standard Fourier optics



Spot size changes with the incidence for goniometer-based systems

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(θ,φ) 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:

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

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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** (*). The Fourier optics plane is imaged 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 effective spot size increases with the incidence angle. 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 follows:

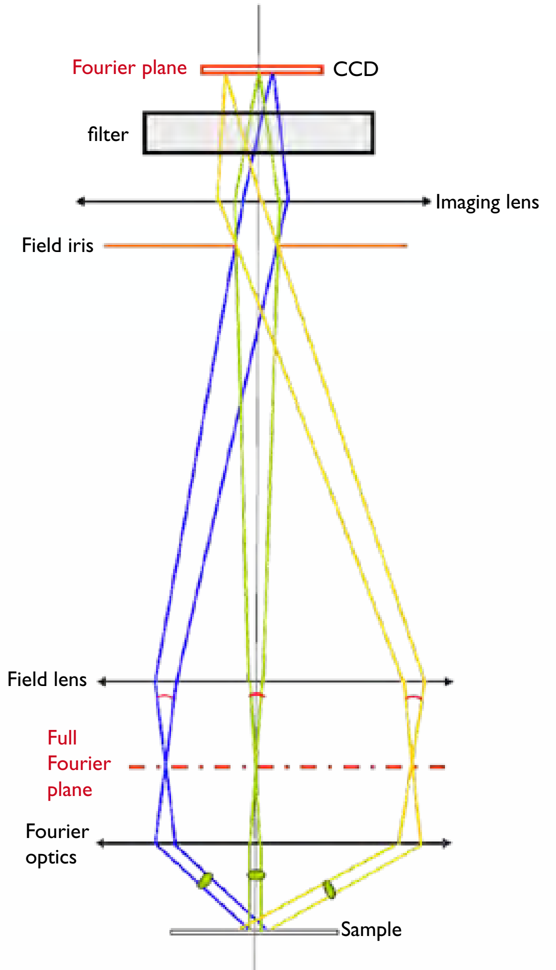
$$E(r,\varphi) = S_0 L(\theta,\varphi) \frac{\sin(\theta)}{k^2\theta}$$

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.

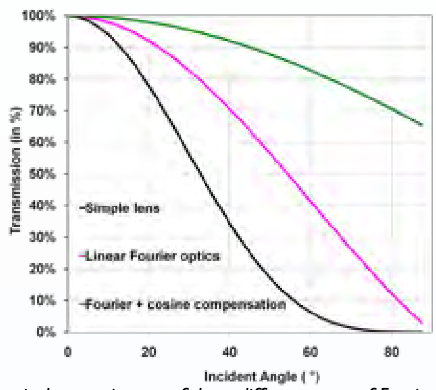
Color accuracy

Systems based on color sensors must be excluded because of the impossibility to correctly adjust the spectral response to CIE requirements. Most commercial systems use monochrome sensors and additional color filters. They must however be designed and manufactured with great care in order to achieve accuracy. **ELDIM** systems are based on a set of 5 color filters designed specifically for each CCD sensor. These filters are built as a combination of different color glasses that work in absorbance. Advantages lie in a very good accuracy because of the design adaptation to each CCD sensor and in an excellent durability.

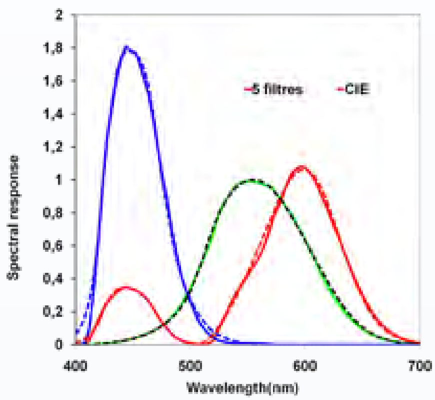
(*) "Device for determining the contrast of a display screen as a function of the observation direction", Patent US270863, September 26th 1989



Patented ELDIM optical configuration with cosine compensation



Theoretical transmittance of three different types of Fourier optics setups

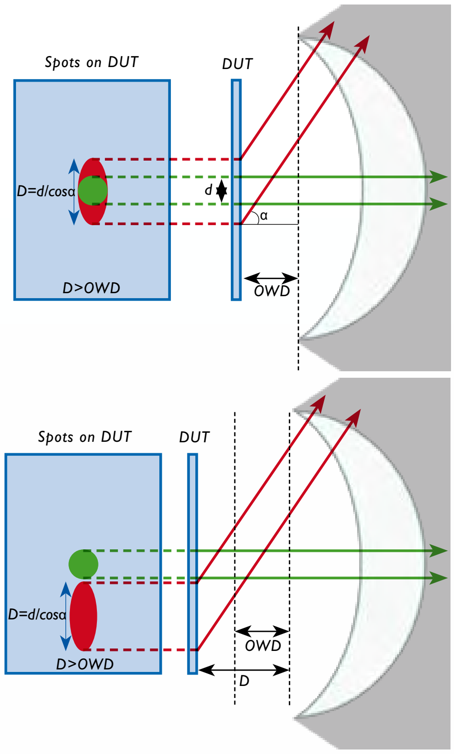


Spectral response of an EZContrast system using 5 color filters matched to CCD sensor

Working Distance

Impact of working distance

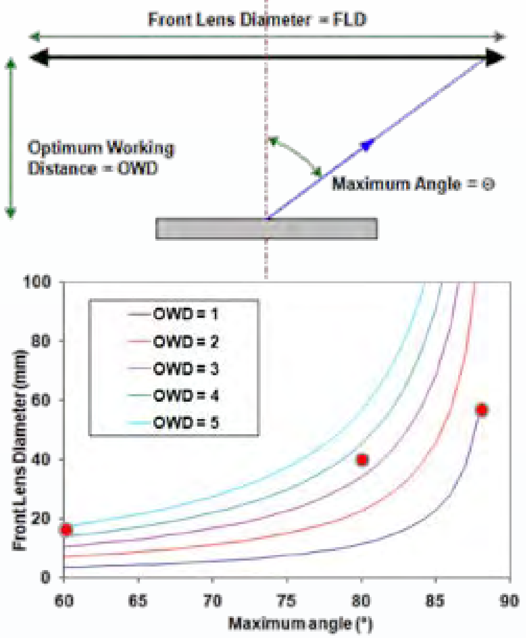
An **ELDIM** Fourier optics system has an optimal working distance in the range of 1 to 4mm depending on its angular aperture. In contradiction with what is generally thought, this working distance is not critical since the system is collecting "plane waves" at each angular direction. Exact focusing is not required and the system can easily work at larger distances. The impact on the measurement is only that measurement spot centers are not perfectly superposed while varying the incidence angle under focus. This behavior can be related to misalignment of a goniometer axis and has exactly the same type of impact on the measurement results.



Impact of the distance on the light collection with Fourier optics instrument: at optimum working distance OWD all the angles are measured at the same location (top); if the distance is higher than OWD all the angles are not measured at same location (bottom).

Optimum working distance and angular aperture

Even if a Fourier optics system is generally a quite complex combination of lenses, the first front lens dimension obeys to very simple geometrical considerations. The front lens diameter depends on the maximum angle achievable by the instrument and on the optimum working distance. An optimum working distance as high as possible is generally preferable for practical considerations. Nevertheless for very large angle of view instruments the requirements in terms of lens diameter becomes critical. A system working up to 80° can be made with a working distance of 5mm quite easily. On the contrary, if the maximum angle is pushed up to 88° a working distance of 1mm gives already quite large front lens (60mm).

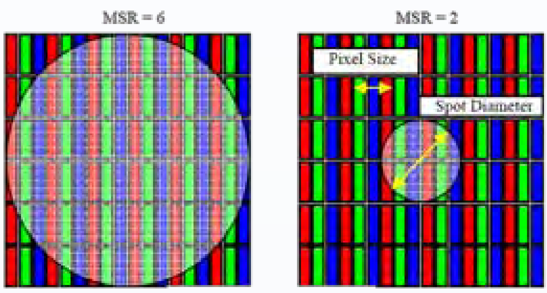


Relation between front lens diameter and OWD: Front lens sizes for ELDIM system are indicated as red points.

Measurement Spot Size

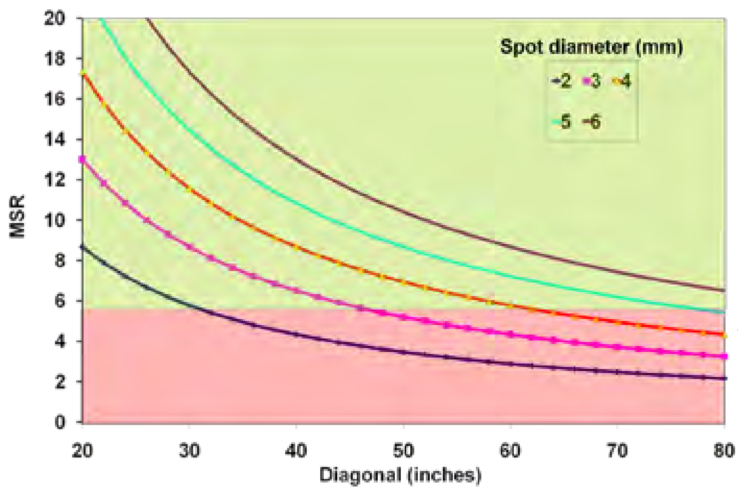
Why a large spot size is needed for displays?

Accurate characterization of the optical emission of displays requires light integration from a given number of pixels. Facing a continuous increase in display size, the pixel has also been enlarged. Using a simplified geometrical model and the MSR parameter (Measurement Spot Ratio) we have shown that a measurement stability better than ±1% is assured if MSR is above 6 (*). We can thus easily predict which minimum measurement spot diameter (MSD) is required depending on the display diagonal and definition. A 6mm MSD is for example sufficient up to 80" diagonal for 16/9 format screens with a 1080x1920 definition.



$$MSR = \frac{SpotDiameter}{PixelSize}$$

Definition of MSR



MSR versus display diagonal for 1080x1920 resolution

(*) P. Boher, "ELDIM's Fourier optics enhance characterization of large LCDs", Display Devices, summer (2006)

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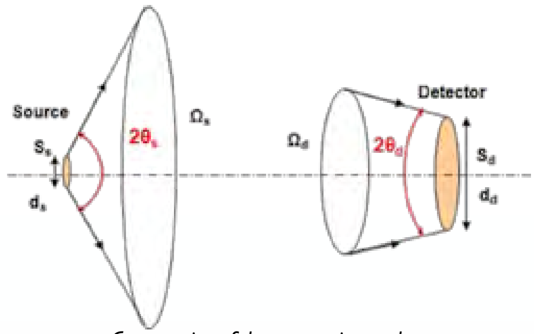
How to achieve a large spot size with Fourier instrument

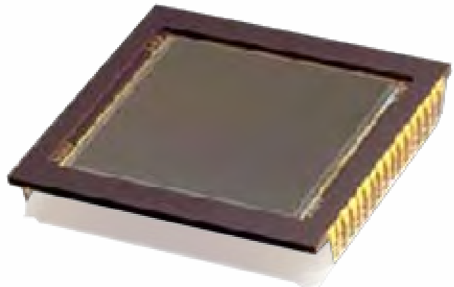
Achieving simultaneously a wide angular aperture and a large spot size is a technical challenge. The main constraint lays into the conservation of the geometric étendue. This general principle is the consequence of the energy conservation and can be expressed as:

$$S_s\Omega_s = S_d\Omega_d$$

S_s and S_d are respectively the surfaces of the source and the detector, and Ωs and Ωd the solide angles of the light on the source and on the detector. If we need at the same time a large spot size on the source and a high angular aperture, a very big detector is required otherwise the whole angular range will not be covered by the sensor. **ELDIM** uses 16M pixels CCD sensors for **EZContrastXL80W** and **EZContrastXL88W** taking interest more in their large size than in the great number of pixels.



Conservation of the geometric etendue

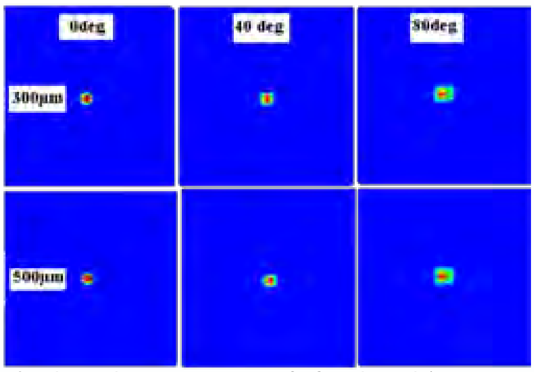


16M pixels CCD are 37x37mm large

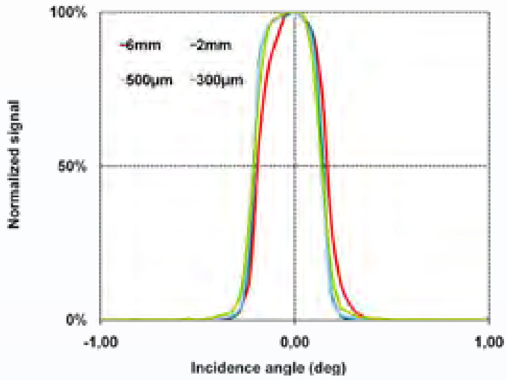
Angular Resolution

The capacity to separate two light rays with very close directions defines the angular resolution. In Fourier optic systems it depends on the optical design, the CCD resolution and the quality of the optics. The theoretical angular resolution of the **EZContrast** instruments is calculated from their optical design. It is supposed to be ±0.17° for the XL88W model that works up to 88° of incidence with a maximum spot size of 6mm diameter.

The practical angular resolution has been measured at various incidence angles using a goniometer with a collimated beam, as summarized in the neighboring table. It is very close to the theoretical value demonstrating the good quality of the optics.



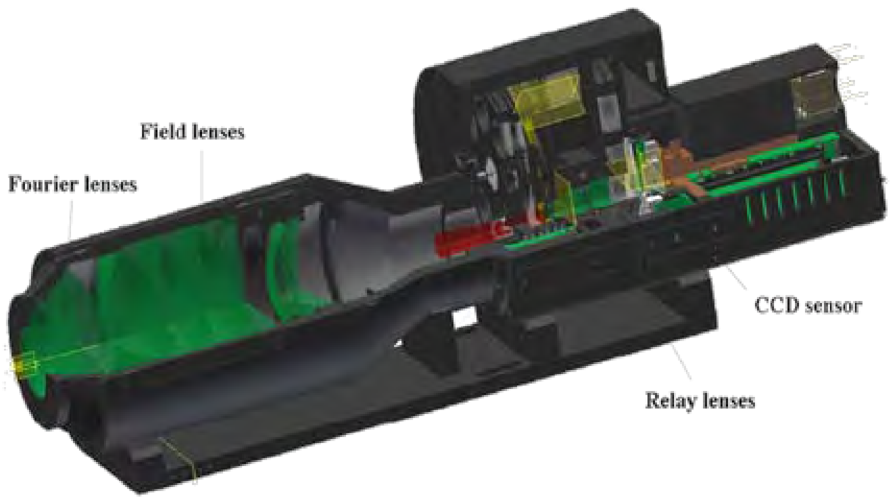
Angular resolution measurements for 3 angles and 4 spot sizes



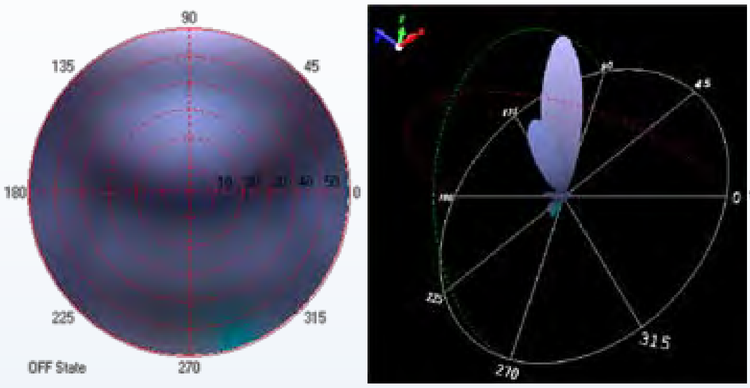
cross sections for 4 spot sizes (300µm, 500µm, 2mm and 6mm) and at normal incidence

Spot size (mm)	300µm	500µm	2mm	6mm
0° (deg)	±0.17	±0.17	±0.18	±0.18
40° (deg)	±0.16	±0.16	±0.18	±0.20
80° (deg)	±0.24	±0.24	±0.26	±0.24

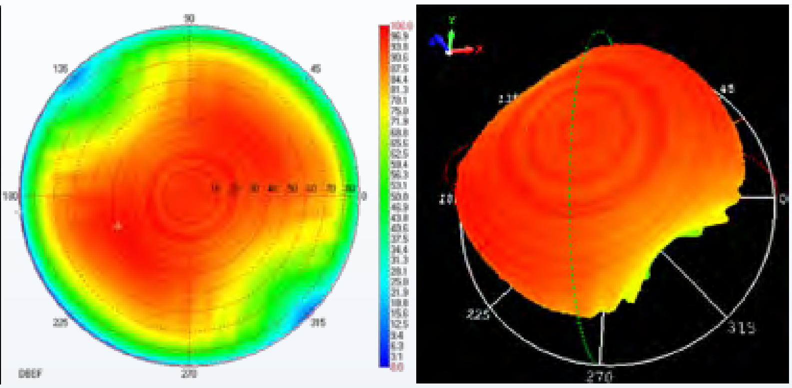
Angular resolution measured for the 4 spot sizes on EZContrastXL88



Main components of a EZContrastXL88 system



Color measurement on OFF state on LCD



Transmittance of a DBEF film

Data Analysis & Applications

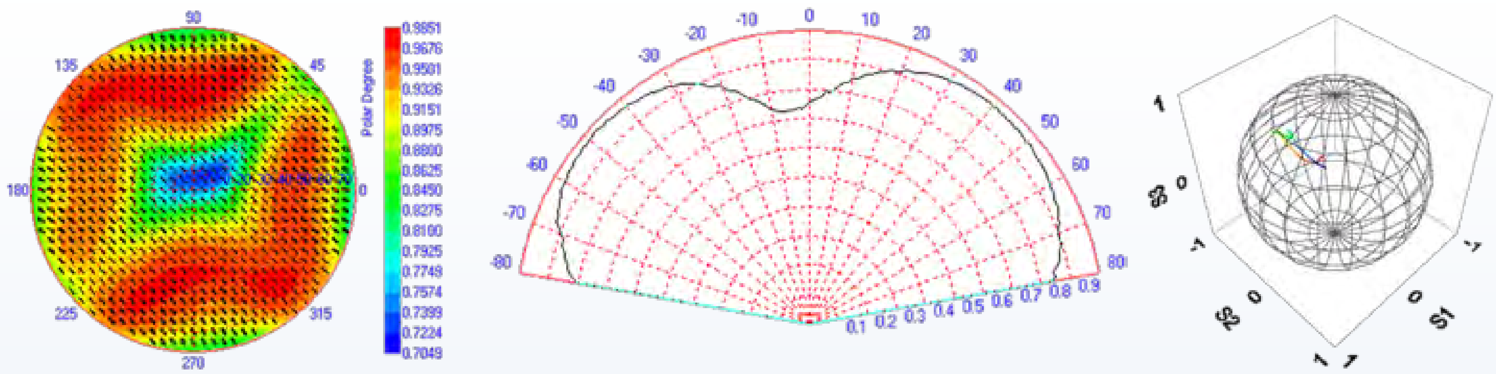
Standard data analysis

Each **ELDIM** viewing angle instrument comes with a software that allows all standard analysis than can be made on viewing angle measurements. Many possibilities are offered to display the data in different ways. 3D representations are for example very useful to visualize the emission cone simultaneously in terms of luminance and chromaticity. All the standard units for luminance and chromaticity are available. Standard computations such as luminance contrast or color difference can be made. Even more complex computation with different data can be performed. The viewing angle measurements can be immediately analyzed with comprehensive, integrated graphs, charts and spreadsheets for:

- Luminance
- Illuminance
- CIE Chromaticity Coordinates (x,y u',v, a*,b*')
- Correlated Color Temperature (CCT)
- Contrast ratio
- Ellipticity and polarization orientation
- Degree of polarization
- Stokes vector

Data and graphs can be easily exported to other Windows applications. Data can also be interpolated in the Fourier plane and exported in different format for direct use in simulation softwares.

Operation	Details
All	Flip, rotate , Restriction
	Low pass filter, Median filter, 2° average
	Norh Polar, East Polar, Horizontal Vertical coordinates
	Cross section (Horizontal, Vertical and free), Isocurves, False Color representation, 3D representation,
Luminance	Sum, subtraction, add constant
	Multiplication, Division, Multiplication by constant
	Inversion
Chromaticity	Color unit: xy, u'v', Lu*v* or La*b*
	Extract X,Y,Z, x, y, u',v',L*,u*,v*,a*,b*, color temperature
	Difference inside map



Polarization measurement on OFF state on LCD (left), cross section in polar (middle) and on Poincaré sphere (right)

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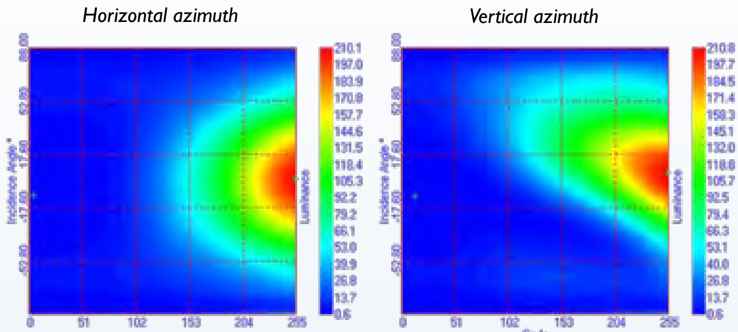
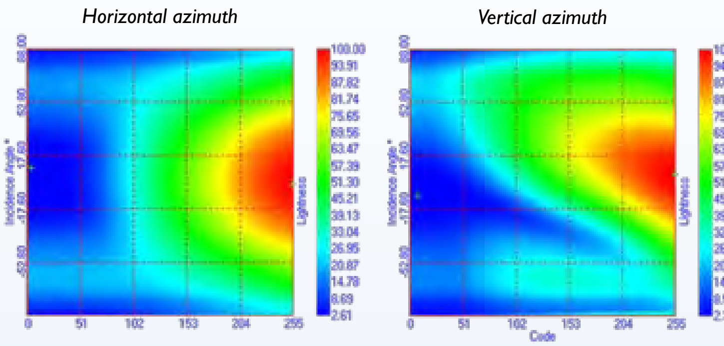


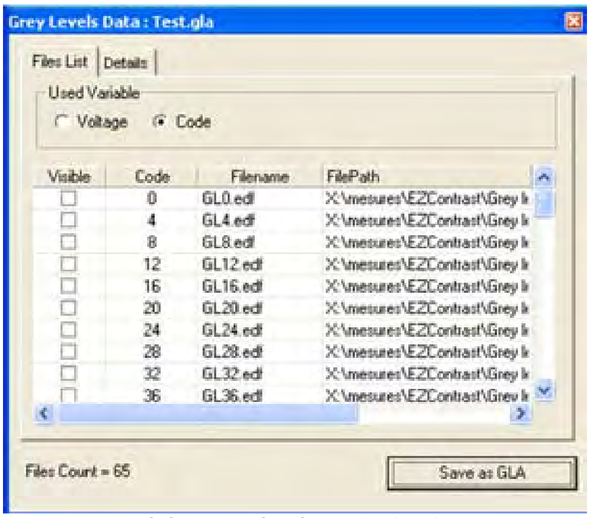
Luminance versus grey level and incidence angle along 0°(left) and 90°(right) azimuths



Normalized lightness versus grey level and incidence angle along 0°(left) and 90°(right) azimuths

Grey level analysis

Although the Iso-Contrast curves are useful for LCDs displaying bi-level images, they are not suitable for LCDs displaying grey scale images. That's why a specific toolbox has been developed: the grey level analysis that allows displaying grey level measurements in different ways and also calculating Reverse Images (RI), Excessively Dark Images (EDI) and Excessively Bright Images (EBI) (*). This option works in luminance and also in radiance and polarization mode.



Software interface for grey level analysis

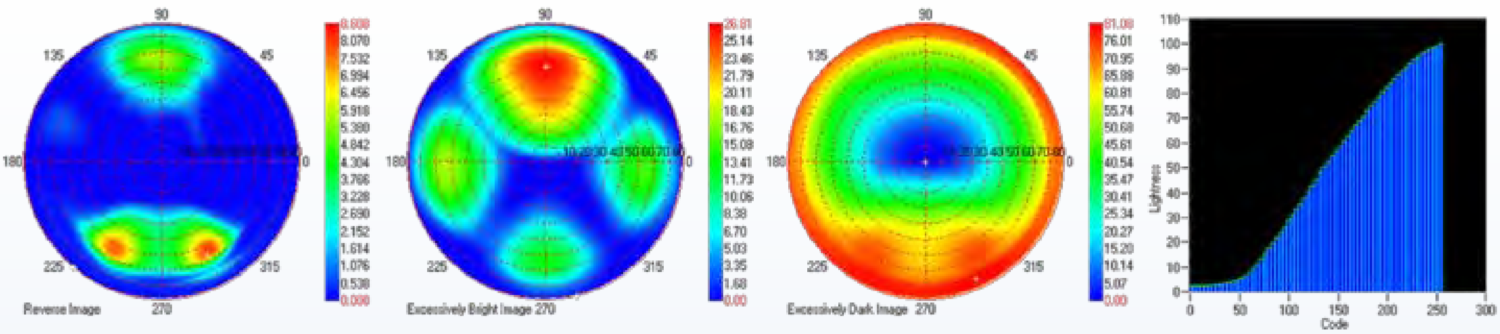
Viewing angle evaluation method

The T-V curve of an LCD is measured at normal incidence. The transmission values are then normalized to the maximum transmission. From the normalized transmission values, normalized lightness values L* are obtained as (*) :

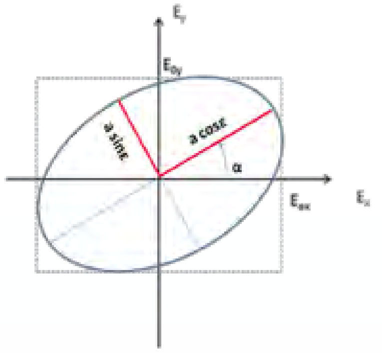
$$L^*(V) = 116x\left[\frac{Y(V)}{Y_0}\right]^{1/3} - 16$$

where Y(V) is the luminance of the transmission for an applied voltage V and Y0 is the maximum luminance for the normal incidence. The normalized lightness-voltage or lightness-grey level is then computed for all the angles and all the voltages (or grey levels). All the data can be saved and exported easily. Comparison between different types of LCD becomes much more powerful.

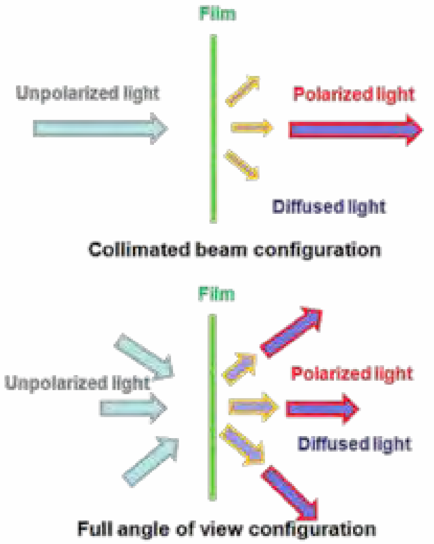
(*) Hirata J., Hisatake Y., Ishikawa M., Shoji M., Tanaka Y. & Hatoh H., "Viewing Angle Evaluation Method For LCDs with Grey Scale Image", J. of SID, 405 (1993)



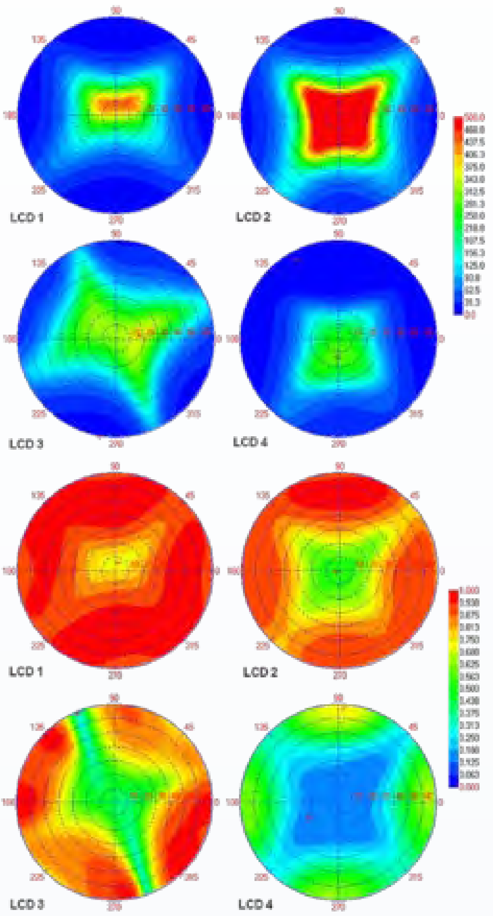
RI (far left), EBI (middle left), EDI (middle right) and normal incidence brightness dependence (far right) for one LCD



Definition of elliptic parameters of polarized light



collimated beam and full angle of view transmittance measurements



Luminance contrast (top) and polarization degree (bottom) of the light in OFF state for 4 different LCDs

Polarization Option

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:

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

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.

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

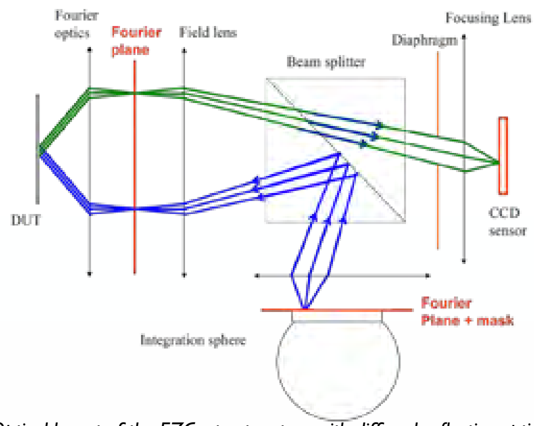
Each **ELDIM EZContrast** system can be provided with a polarization option that's includes three polarizers at different orientations (0, 45 and 90°) and two wave-plates at different orientations (45 and 135°). The system performs automatically seven measurements with different polarization configurations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

This option is useful to characterize an LCD component under realistic using conditions. Indeed, standard collimated beam characterization using polarimeter only measures the specular component. Using **EZContrast** with dedicated Lambertian white source, both specular and diffused component are measured simultaneously. This technique can be applied to all kinds of films like polarizers, BEF, DBEF with sometimes surprising results like for example for DBEF films that can exhibit periodic structures(*). Applied to LCDs, the technique can give useful information to improve OFF state. Luminance in OFF state must be as low as possible and the polarization state of this residual light is useful to understand the origin of light leakage. As shown in the figure, there is a direct correlation between the luminance contrast and the polarization degree at OFF state . LCD 4 shows for example a great amount of unpolarized light at any angle what leads to a very low luminance contrast and to suspect its polarizers to be of poor quality.

(*) P. Boher, "ELDIM's Fourier optics enhance characterization of large LCDs", Display Devices, Spring (2008)

Reflective Options

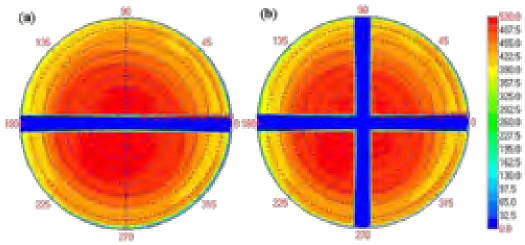
In contrast with all other techniques, **ELDIM** Fourier optics instruments are able to illuminate the sample under test while measuring at the same angles. The illumination is made across the Fourier optics using a beam splitter and an additional focal system that reconstructs the first Fourier plane at another location perpendicular to the optical axis of the system. One point on this illumination Fourier plane corresponds to one angle on the sample. Two illumination options are available that correspond to different illumination modes.



Optical layout of the EZContrast system with diffused reflective option

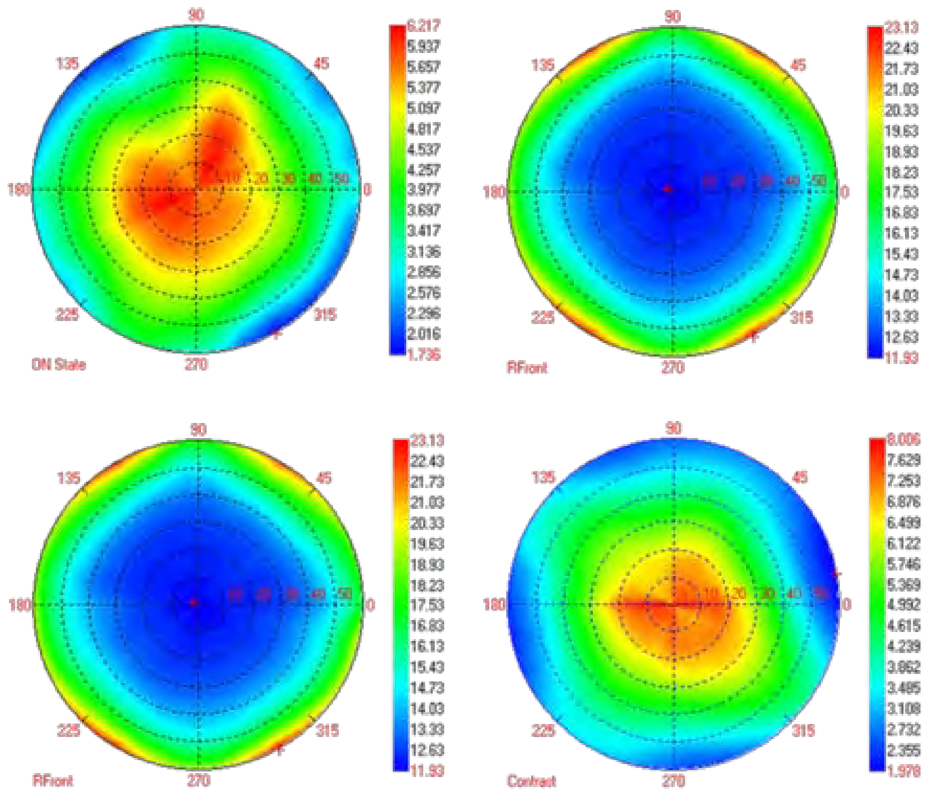
Diffused reflective option

The illumination is made using an integrating sphere and additional masks located on the illumination Fourier plane. Light is injected inside the integration sphere using a xenon lamp and an optical fiber. Monochromatic and white illuminations are available. For reflective displays, D65 illumination is generally used. Ulbrich mask is especially useful to illuminate in full diffused illumination except along one specific azimuth. A specific option for small reflective displays has been developed that includes automated display rotation in addition to the diffused reflective option. For one display position, two measurements in full diffused illumination and with Ulbricht mask are performed. With very simple assumptions, it allows separating the intrinsic reflection due to the liquid crystal cell from the top surface reflection for all the angles along the specific azimuth. The same procedure can be repeated while rotating the display at different azimuth angles and all the results can be combined in the same Fourier plane diagram to give an overall view of the display properties.

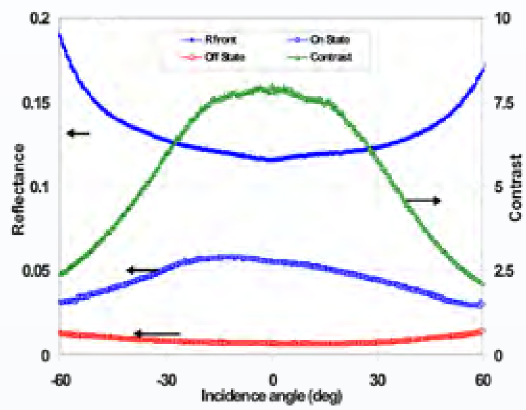


EZContrast measurements on a mirror with Ulbricht mask (a) and cross mask (b)

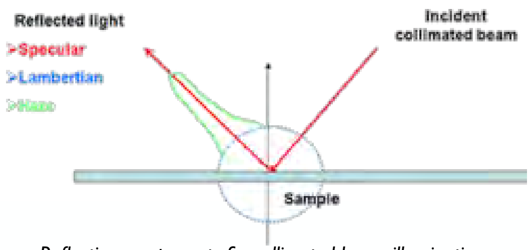
Measurement setup for reflective displays with Z stage and rotation stage for display



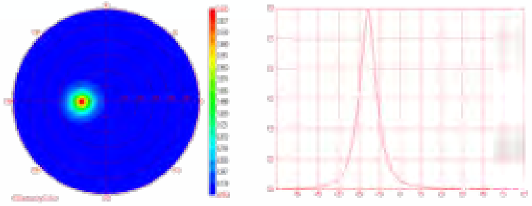
ON state, OFF state, contrast and front reflectance for the full Fourier plane measured on an IPOD reflective display



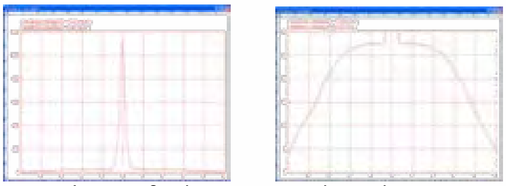
ON state, OFF state, contrast and front reflectance along one azimuth 0 for an IPOD reflective display



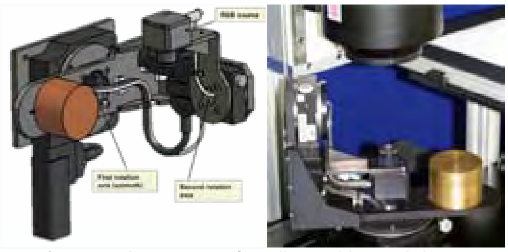
Reflection components for collimated beam illumination



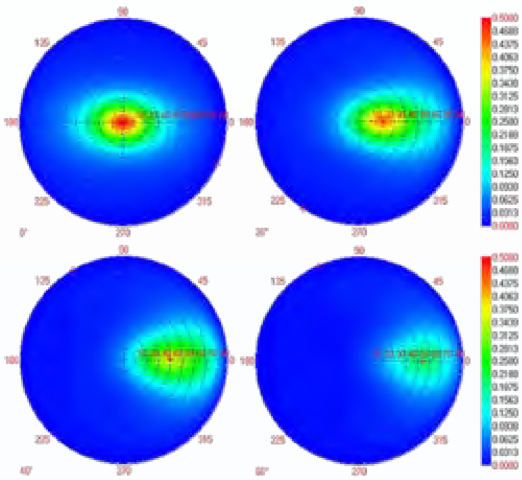
Front glass reflection



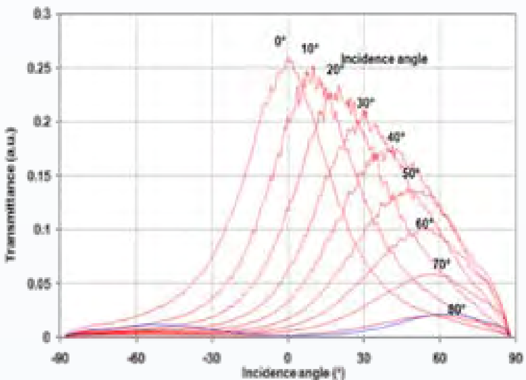
Interest of multi-exposure to enhance dynamic



Automated goniometer for collimated beam lighting



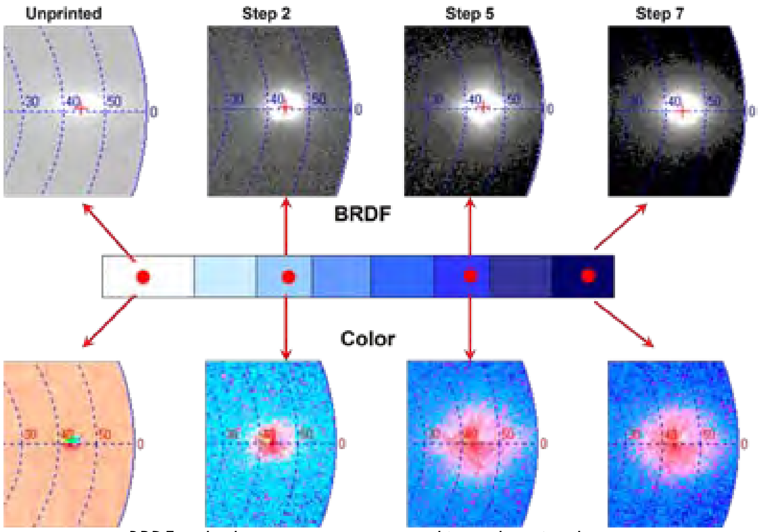
Film transmittance with 4 collimated beam incidences



Film transmittance horizontal azimuth

Collimated beam reflective option

The illumination is made with a small optical filter located on the Fourier illumination plane and a white light source with filters. This location which corresponds to the incident angles on the sample can be controlled manually or automatically. Full reflective pattern of the sample is measured in one measurement. Specular, haze and Lambertian contributions are measured simultaneously. Multi-exposures can be performed to enhance the dynamic.



BRDF and color measurements on a white and a printed paper

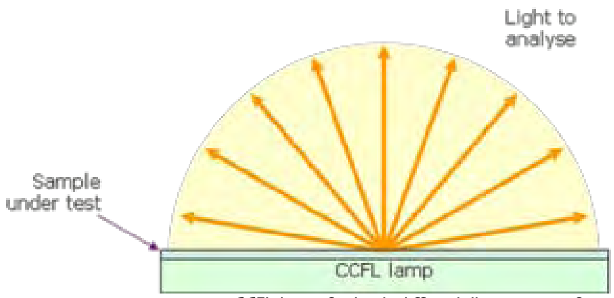
Transmissive options

Collimated beam transmissive option

In this configuration the light source is a collimated RGB LED lamp fixed on a goniometer. The operator controls both the illumination and incident angular position of the collimated beam via the remote PC. The software enables an auto alignment of the **EZContrast** optical axis with the goniometer. Prior to the measurements, the light source is a very narrow collimated beam based on 3 independent red, green and blue LEDs. The divergence of the beam is below +/- 0.03°. The goniometric illumination covers the 0-360° azimuth, 0-90° incidence angles with an accuracy of 0.025°. Full angular characterization of thin films and LCD component becomes very easy and rapid.

Diffuse transmissive option

The illumination is a white near Lambertian reference lamp based on a CCFL backlight. Its spatial uniformity is below 1% and its long term stability below 0.5%. Films under test are directly set onto the front opal plate of the lamp.



With CCFL in place

CCFL lamp for back diffused illumination of samples

Automated Systems

With each Fourier optics instrument **ELDIM** can provide different setup adapted for most of the using conditions. An automation which drives all the setup, makes measurements and data analysis is also available.

Laboratory set with Z axis

The laboratory setup includes a stable structure with granite base and motorized Z axis. Adjustments in most of the configurations becomes easier. Small XY table for use with medium size displays can be also provided.

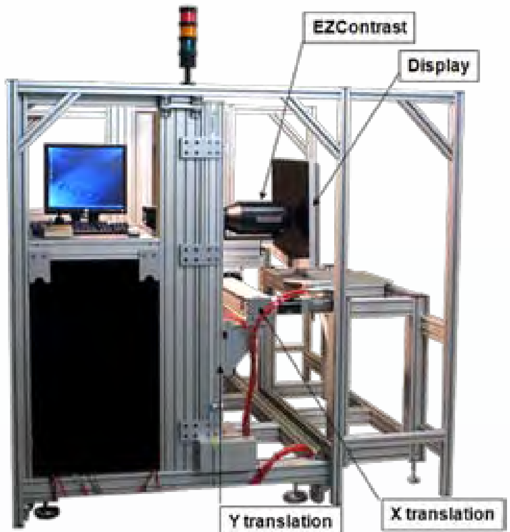
XYZ for large size displays

With the development of large size displays for TV application, the need to check the emission properties on the entire surface of the display becomes mandatory. **ELDIM** proposes a dedicated automated system designed to meet demands in LCD research and development as well as in quality control. Displays up to 80 inches of diagonal are positioned in front of an XYZ table on which the **EZContrast** system moves. Additional homogeneity and response time measurements can be included in the same setup.

High speed XYZ table

For quality control purpose high speed cartography is also available. The display up to 60 inches of diagonal is positionned on a fixed panel holder. The **EZContrast** equipment moves rapidly in front of any point of the display using a 3 axis high resolution positioning stage. X and Y are equipped with linear motors. The XYZ table is mounted on a rigid structure with vibration isolation modules and a granite frame that integrates the linear motors. The granite stiffness ensures excellent movement performances without any vibration induced by the system. XY table is equipped with absolute position sensors that avoid any positioning error. Repeatability is below 0.5µm for hundreds of movements.

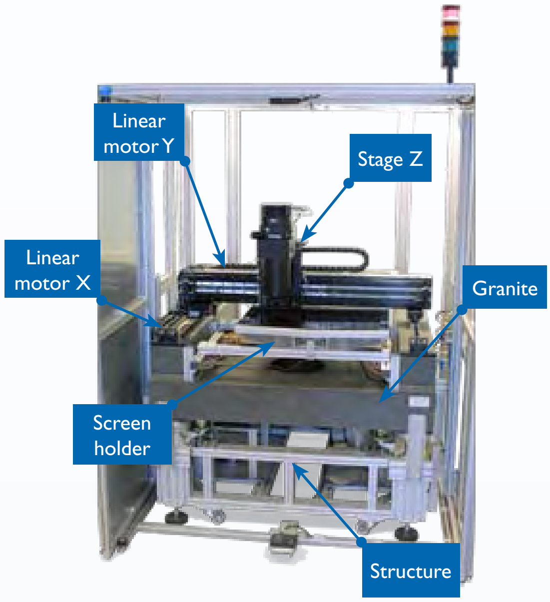
Laboratory set with automated Z axis



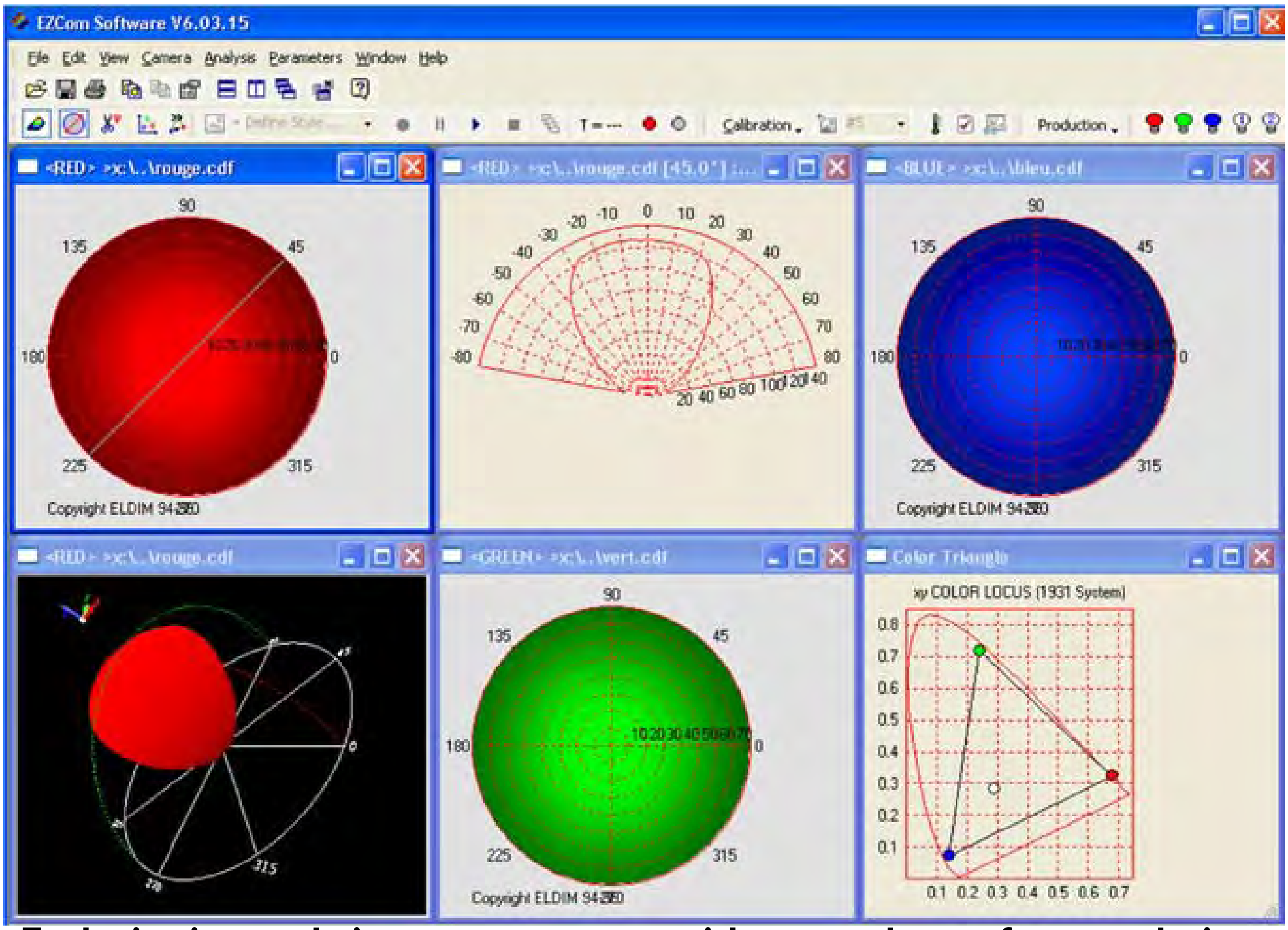
Automated XYZ table for large size displays

Model	Display position	Movements			Length (mm)			Speed (cm/s)		
		x	y	z	x	y	z	x	y	z
Automated Z	Horizontal	/	/	Stepping motors + ball screws	/	/	300	/	/	20
Automated XYZ	Vertical	Brushless motors	Brushless motors	Brushless motors	1700	1050	150	20	20	20
High speed XYZ	Horizontal	Linear motors	Linear motors	Stepping motors + ball screws	800	600	100	100	100	20

Some characteristic of the different standard automated systems



High speed automated XYZ table



Each viewing angle instrument comes with a complete software solution for measurement and data analysis.

Some characteristics of the EZCom 6 sofware package for Viewing Cone measurements

Features	Details	Version
Measurement capacities	Luminance measurements	Standard
	Color measurements	Standard
	Polarization measurements	Option
Data analysis	Luminance contrast	Standard
	Color unit: xy, u'v', Lu*v* or La*b*	Standard
	Color intensity, Color Difference, Color Dispersion, Color Triangle, Color Temperature, Equivalent Wavelength	Standard
	Cross section (Horizontal, Vertical and free), Isocurves, False Color representation, 3D representation,	Standard
	Smoothing Filtering, Rotation, Clipping, R.O.I. extraction, Averaging, Contour extraction, Moiré removal	Standard
	Grey Level analysis	Option
	Polarization Ellipticity, Polarization orientation and Polarization degree	Option
	Stokes vectors	Option
Data export	Copy to clipboard	Standard
	Fourier plane interpolation and saving in text and excel format	Standard
	Multi-spots statistics	Standard
Programming capacities	All features can be controlled by OCX interface	Standard
	Examples of automated measurements and analysis provided	Standard
Additional softwares	Software automation with XYZ table	Option

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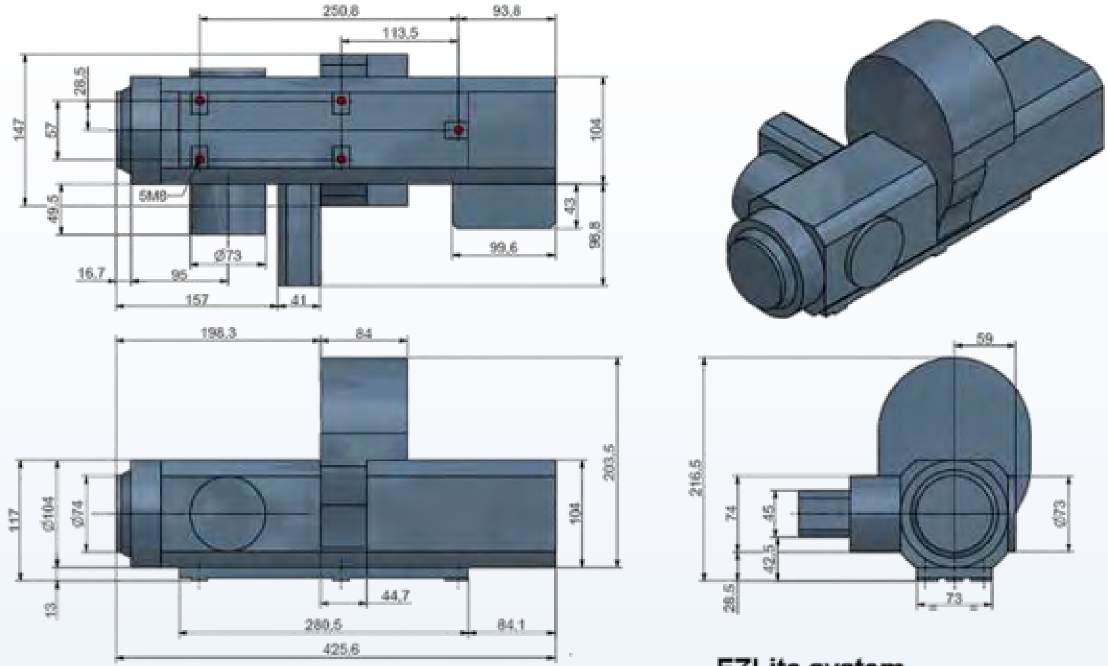
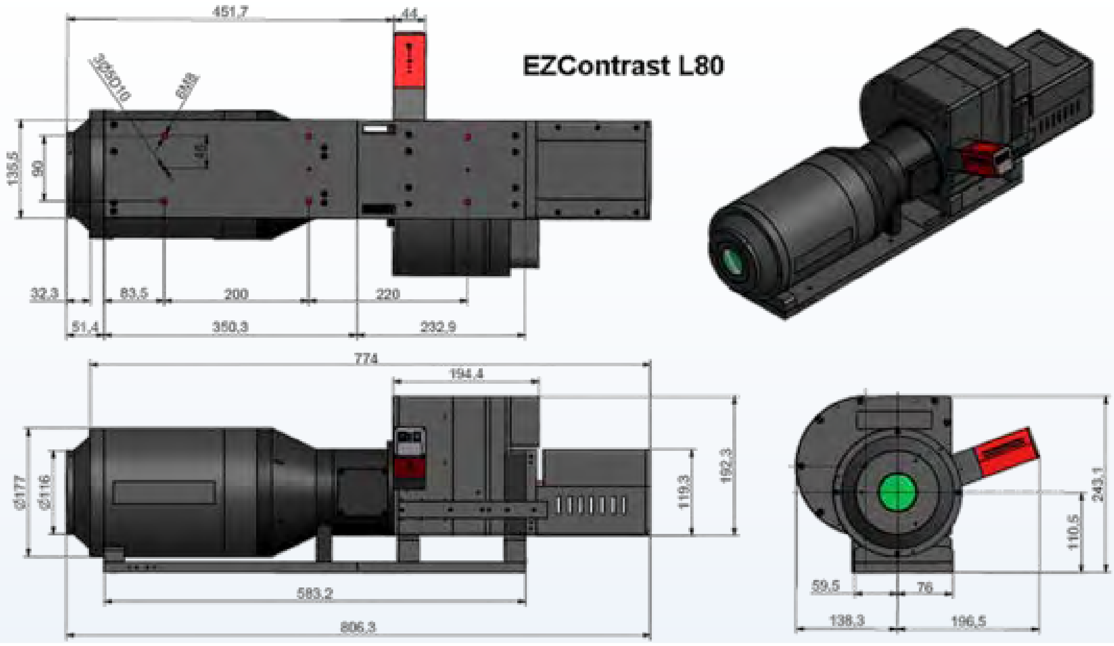
Outer dimension (unit mm)

EZLite

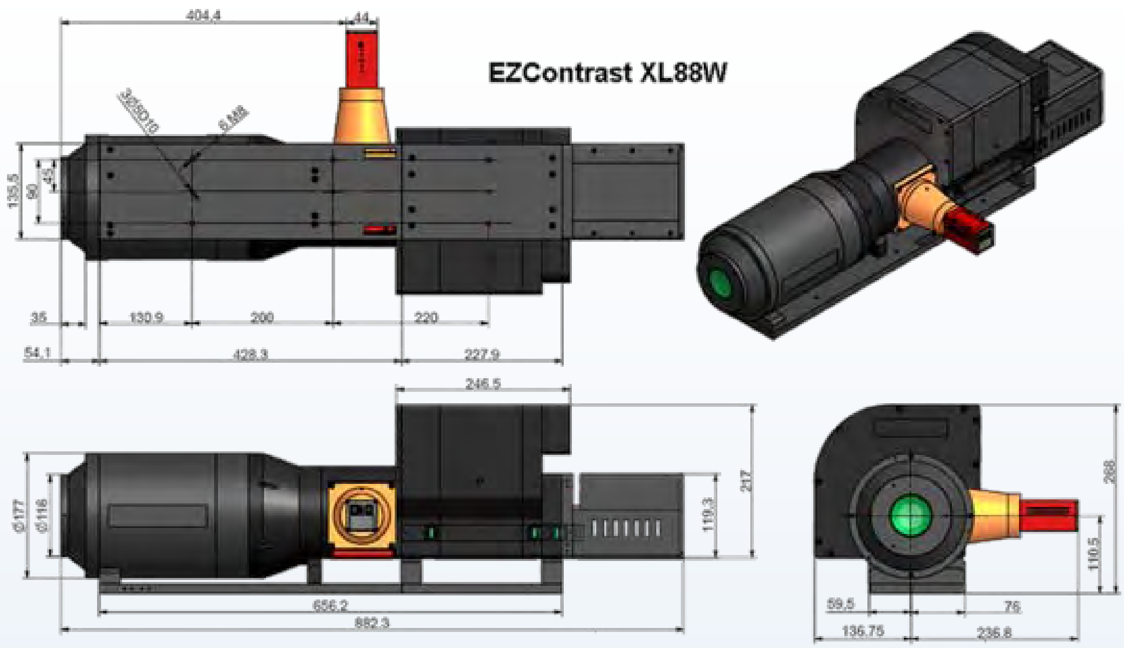


EZLite system

EZContrastL80



EZContrastXL88W



Major specifications of Viewing Cone Series instruments

Common specifications		EZLite	EZContrast L80	EZContrast L80W	EZContrast XL88	EZContrast XL88W
Field coverage	*Incident angle* *Azimuth angle*	0-60° 0-360°	0-80° 0-360°		0-88° 0-360°	
Measuring area	*Maximum diameter* *Minimum diameter* *Number of diameters* *Selection mode*	2mm 83µm No limit Manual	2mm 100µm 5 Automated	6mm 300µm 4 Automated	2mm 100µm 5 Automated	6mm 500µm 4 Automated
Optimum distance	*Ensure light coming from same spot at any angle*	4.5mm	3.7mm	2.5mm	1mm	
Sensor	*Peltier cooled CCD grade 1* *Resolution* *A/D converter*	Yes 1.5M 14-16 bits	Yes 6M 14-16 bits	Yes 16M 14-16 bits	Yes 6M 14-16 bits	Yes 16M 14-16 bits
Chromaticity	*Color Filters* *Additional Filters*	5 (*1) Any type	5 (*1) 3 possible	5 (*1) No	5 (*1) 3 possible	5 (*1) No
Neutral densities	*For luminance adjustment* *Selection mode*	On request Manual	0.5, 1, 2, 3 Automated			
Polarizing elements	*For polarization measurements*	3 pol , 2WP Manual	3 pol , 2WP Automated	Not available	3 pol , 2WP Automated	Not available
Reflective options	*Collimated & diffused*	Available	Available	Not available	Available	Not available
Spot viewer	*For position adjustment*	B&W BNC	Color CMOS camera, USB 2.0 interface			
Interface		USB 2.0				
Measurement Modes	*Luminance* *Chromaticity* *Polarization (option)*	Yes Yes Yes, Manual	Yes Yes Yes, Auto	Yes Yes No	Yes Yes Yes, Auto	Yes Yes No
Luminance Range	*Minimum (cd/m2)* *Maximum (cd/m2)* *Maximum with density (option)*	0.001 700 (*2) 700 000	0.001 1000 (*2) 1 000 000	0.001 400 (*2) 500 000	0.001 1000 (*2) 1 000 000	0.001 400 (*2) 500 000
Accuracy	*Angular position* *Angular resolution* *Luminance* *Chromaticity (x,y) RMS* *Stokes vector (option)*	±0.2° ±0.75° ±3% (*3) 0.002 (*4) ±3% (*5)	±0.3° ±0.3° ±3% (*3) 0.002 (*4) ±3% (*5)	±0.2° ±0.2° ±3% (*3) 0.002 (*4) ±3% (*5)	±0.3° ±0.3° ±3% (*3) 0.002 (*4) ±3% (*5)	±0.2° ±0.2° ±3% (*3) 0.002 (*4) ±3% (*5)
Repeatability	*Luminance* *Chromaticity (x,y) RMS* *Stokes vector (option)*	±0.5% (*6) 0.001 (*6) ±0.5% (*6)	±0.5% (*6) 0.001 (*6) ±0.5% (*6)	±0.5% (*6) 0.001 (*6) ±0.5% (*6)	±0.5% (*6) 0.001 (*6) ±0.5% (*6)	±0.5% (*6) 0.001 (*6) ±0.5% (*6)
Measurement time	*Luminance* *Chromaticity* *Polarization (option)*	< 10s (*7) <30s (*7) Manual	< 10s (*7) <20s (*7) <90s (*7)	< 10s (*7) <25s (*7) <90s (*7)	< 10s (*7) <20s (*7) <90s (*7)	< 10s (*7) <25s (*7) <90s (*7)
condition	*Temperature range standard* *Temperature range (option)* *Humidity range (non condensing)*	0 to 40°C No 0 to 60%	0 to 40°C -30 to 80°C 0 to 85%	0 to 40°C -30 to 80°C 0 to 85%	0 to 40°C -30 to 80°C 0 to 85%	0 to 40°C -30 to 80°C 0 to 85%
Power Supply	*110V - 200V* *Consumption*	Yes 90W				
Weight	*Weight* *Height* *Width* *Length*	7Kg 217mm 210mm 433mm	44Kg 243mm 335mm 671mm	52Kg 243mm 335mm 695mm	44Kg 243mm 214mm 784mm	52Kg 268mm 234mm 903mm

(*1) All the systems use 5 color filters matched on the CCD response (2 for X, 2 for Y and 1 for Z)
(*2) Maximum luminance is given for the maximum spot diameter
(*3) The accuracy is guarantied for any type of color stimuli in contrast to competitors that generally guaranty only reference white.
(*4) For A type illuminant
(*5) For a radiance level higher than 10mW/Sr/m^2/nm
(*6) For a luminance higher than 50Cd/m^2. This repeatability is given for full resolution. When a binning level N is used it is divided by a factor of N2. With standard CCD sensor and for a resolution of 375x250 the luminance repeatability is only ±0.03% !
(*7) Measurement times are highly dependent on the target and on the conditions. Given times are for a source with luminance level higher than 50Cd/m^2 or a radiance level higher than 10mW/Sr/m^2/nm and already determined exposition times for all the filters.

Specifications can be changed without notice

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