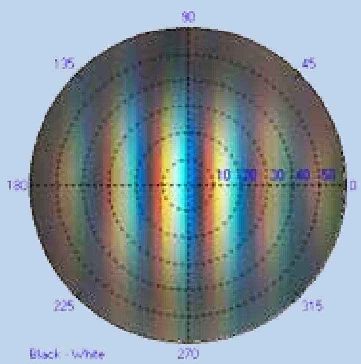
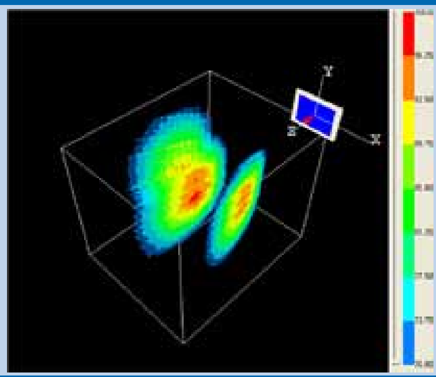
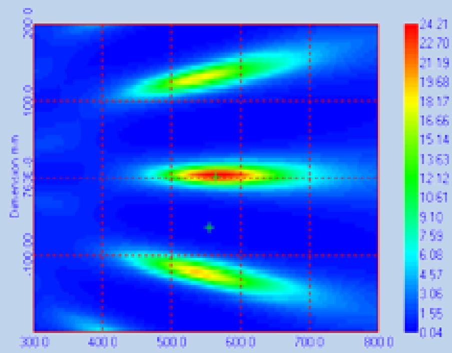
Autostereoscopic 3D display characterization



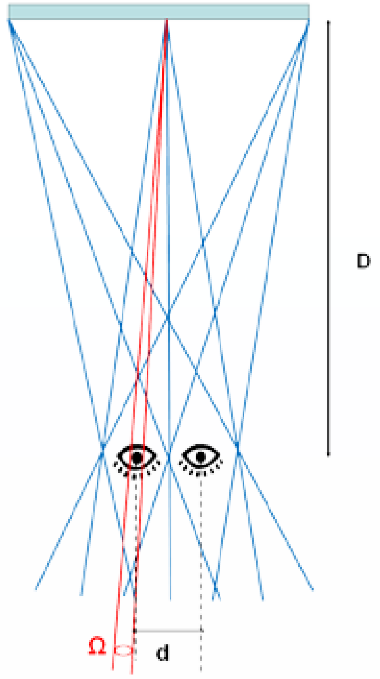




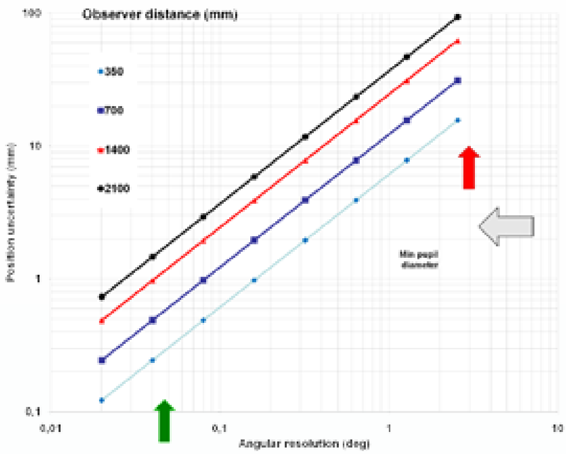
The world best solution to characterize accurately autostereoscopic 3D displays

VCMaster3D

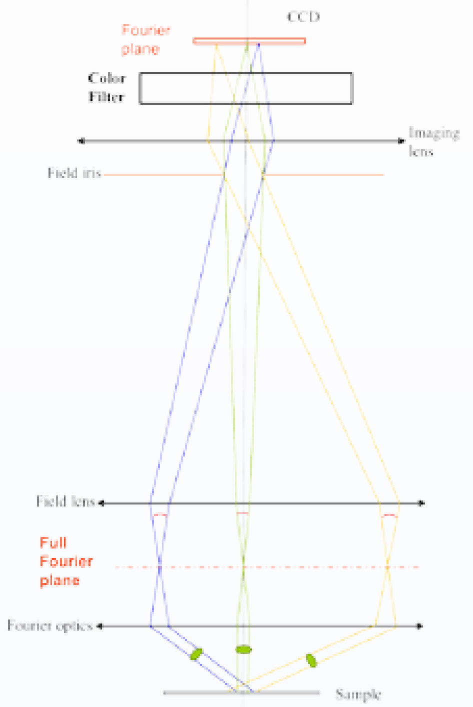
ADVANCED LIGHT ANALYSIS by ELDIM



Schematic of a twin view autostereoscopic display



Position uncertainty versus angular resolution



Schematic of patented optical principal of ELDIM Fourier optics instruments

Main requirements to characterize autostereoscopic displays

Autostereoscopic 3D display characterization is essentially a problem of angular emission. Each point of the surface of the display must emit two or more images that must arrive in the left and right eyes of the observer. A schematic drawing of the device shows immediately that reliable results can obtained only if accurate prediction of the light arriving in each eye of the observer can be made. For a viewing angle measurement made at one location on the display, the requirements in terms of angular resolution $\Delta\theta$ can be calculated easily. The position uncertainty Δx in the plane of the observer at a distance D of the display is given by:

$$\Delta x = D \tan \Delta\theta$$

This uncertainty must be lower than the mean pupil diameter of the human eye (let say 2mm). We see immediately that an angular resolution of 1 to 2° (red arrow) typical of spectrophotometers is unacceptable even for phone cell displays with short working distances. Standard ELDIM EZContrast systems show a resolution of ~0.5° which is not sufficient except for small displays. The system presented hereafter shows a angular resolution more than 10 times better (0.03°) which can cover requirements (green arrow).

High Efficiency

ELDIM manufacture viewing angle instruments based on Fourier optics for more than 10 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. The very high light collection efficient allows measurement up to very extreme grazing angles (88°) with an excellent accuracy.

High angular resolution

For 3D displays, the priority is made on the angular resolution using dedicated optical design with medium angular aperture (±50°) and large size CCD (16M pixels).

High accuracy

The color accuracy is ensured using 5 dedicated color filters adapted to the spectral response of each CDD. ELDIM is manufacturing itself all the key components of its systems.

High reliability

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.

VCMaster3D description

VCMaster3D mounted on automated Z axis table

VCMaster3D includes 5 color filters designed specifically for each CCD sensor. The Peltier cooled camera contents a large size 4000x4000 pixels size CCD detector. VCMaster3D includes also different wheels to adjust automatically the measurement spot size (4mm, 2mm, 1mm and 500µm) and the luminance level (flat densities). On VCMaster3DLi the same parameters can be adapted manually using different mechanical cartridges.

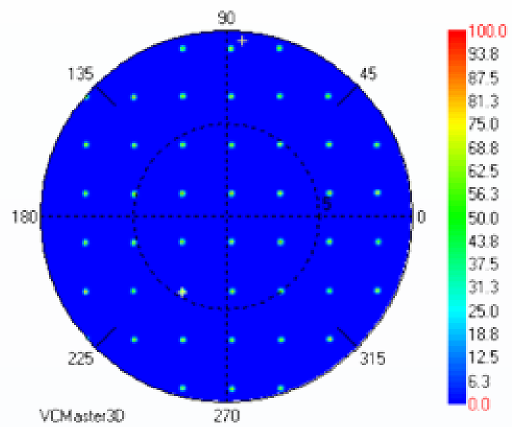
VCMaster3D can be provided with dedicated optical bench for easier alignment ad positioning. Manual and automated XY tables are also available to check the geometric correction of the emission at different locations on the 3D displays. FPDLite display driver with specific 3D display features is also available for easy control using any sub-pixel configuration. Completely automated systems with XYZ tables is also available.

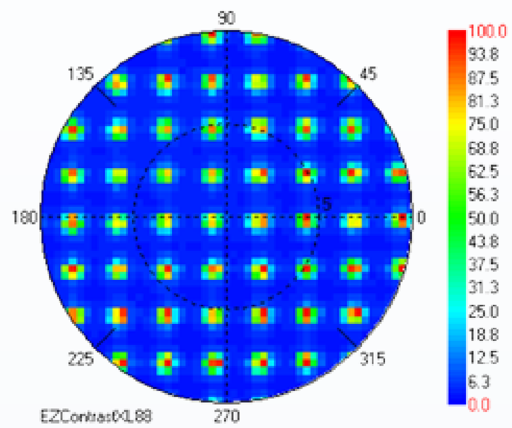
Practical angular resolution

Practical angular resolution of VCMaster3D has been measured using a small LED panel. LED are very small bright sources that can be controlled easily. Put in front of a VCMaster3D system at a quite large distance their offer the opportunity to check the practical angular resolution of the system on quasi all the angular aperture.

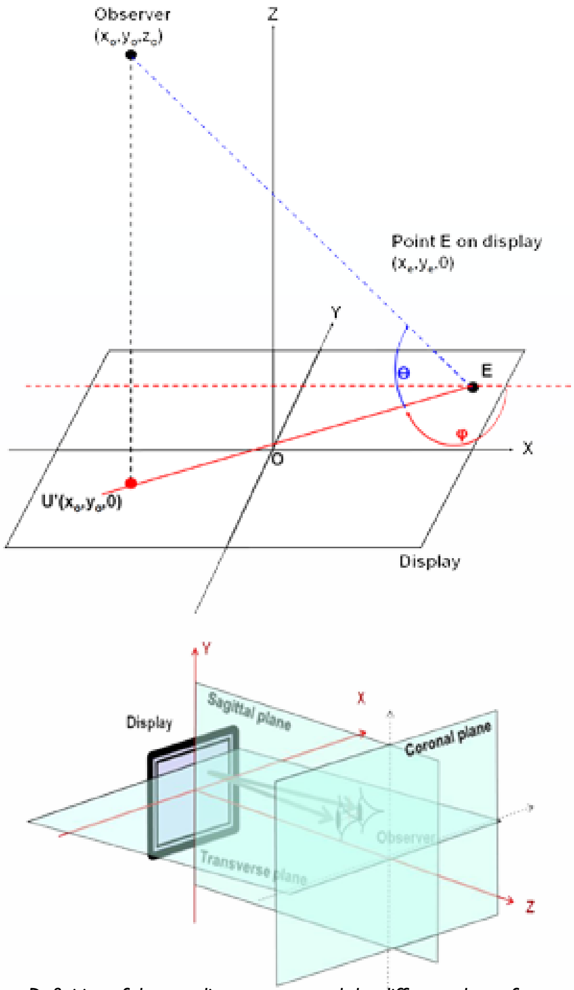
Results are very near the theoretical values :

- VCMaster3D exhibit a resolution better than 0.04°
- EZContrastXL88 gives a resolution of 0.5° in the same experimental conditions

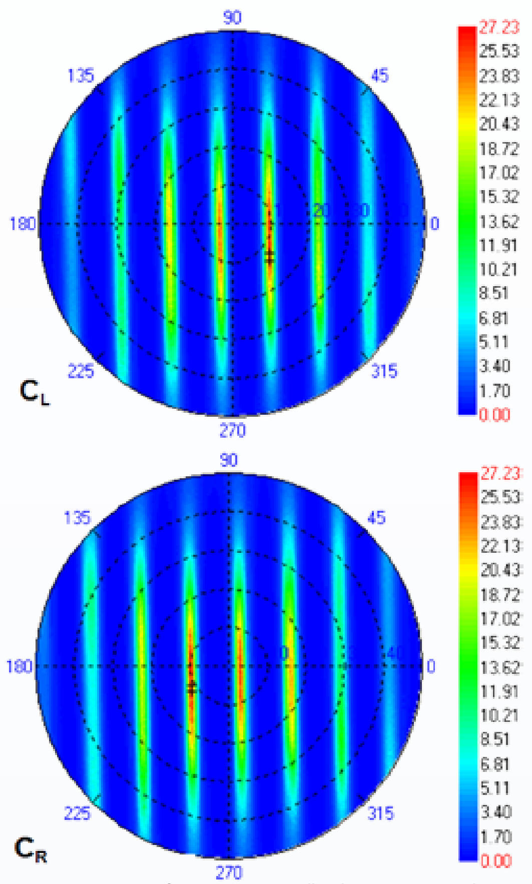




Measurement of angular reference source at 100mm with VCMaster3D and EZContrastXL88 : max angle of the display is 10°.



Definition of the coordinate system and the different planes for observer location



Luminance contrast of a twin view parallax barriers personal computer display for the left and right eyes in Fourier space

Computation of the 3D display properties in the observer space

Using Fourier optics viewing angle measurement it is possible to calculate the light arriving from this display location to an observer located in front of the display. The observer is defined by its coordinates in the XYZ referential. The origin O is always the display center. The X axis, Y axis and Z axis define the transverse, sagittal and coronal planes respectively as schematically reported in the figure. The observer position is supposed to be the center of its two eyes. The two eyes are always assumed parallel to the X axis. The interpupillar distance is fixed (generally 6.25cm).

Calculation of 3D contrast and 3D crosstalk

The quality of the 3D display for an observer is directly related to his capacity to see clearly the correct images with his right and left eyes. In case of thin view displays, we first calculate the two contrasts associated to each eye using the following equations:

$$C_R(\theta,\varphi) = \frac{Y_{WRBL}(\theta_R,\varphi_R) - Y_{BRBL}(\theta_R,\varphi_R)}{Y_{BRWL}(\theta_R,\varphi_R) - Y_{BRBL}(\theta_R,\varphi_R)} = \frac{1}{\chi_R}$$

$$C_L(\theta,\varphi) = \frac{Y_{BRWL}(\theta_L,\varphi_L) - Y_{BRBL}(\theta_L,\varphi_L)}{Y_{WRBL}(\theta_L,\varphi_L) - Y_{BRBL}(\theta_L,\varphi_L)} = \frac{1}{\chi_L}$$

(θ_R, φ_R) and (θ_L, φ_L) are the right and left eye positions in polar coordinates calculated as reported above. Y_{WRBL} is the luminance for white view on right eye and black view on left eye, Y_{BRWL} is the luminance for black view on right eye and white view on left eye, and Y_{BRBL} is the luminance for black view on right and on left eye. These two contrasts are nothing less than the inverse of the 3D crosstalk of right and left eyes χ_R and χ_L as introduced by Montgomery in 2001 [1]. We prefer to work with contrasts because there are quantities used every day in the field of standard displays. The 3D quality is optimum only when the two previous contrasts are maximized simultaneously. It is useful to combine the two contrasts to get what we call the 3D contrast for the observer given by.

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

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 dimensionally of the quantity as a contrast which can be compared directly to the standard contrast of displays.

[1] J. Montgomery, "Analysis of the performance of a flat panel display system convertible between 2D and 3D modes", Proc. SPIE, Vol. 4297, 2001

Definition of OVR

Maximum of 3D contrast indicates optimum viewing conditions for 3D effect. Computation on a large volume in front of the displays allows to define an Optimum Viewing Region (OVR) where 3D display is working correctly.

Extension to two or more locations

We suppose that viewing angle measurements have been made at M locations on the display. We can calculate a effective contrast respectively for right and left eye of the observer following:

$$C_R = \frac{\sum_{i=1}^{M} Y^i_{WRBL}(\theta^i_R,\varphi^i_R) - \sum_{i=1}^{M} Y^i_{BRBL}(\theta^i_R,\varphi^i_R)}{\sum_{i=1}^{M} Y^i_{BRWL}(\theta^i_R,\varphi^i_R) - \sum_{i=1}^{M} Y^i_{BRBL}(\theta^i_R,\varphi^i_R)}$$

$$C_L = \frac{\sum_{i=1}^{M} Y^i_{WRBL}(\theta^i_L,\varphi^i_L) - \sum_{i=1}^{M} Y^i_{BRBL}(\theta^i_L,\varphi^i_L)}{\sum_{i=1}^{M} Y^i_{BRWL}(\theta^i_L,\varphi^i_L) - \sum_{i=1}^{M} Y^i_{BRBL}(\theta^i_L,\varphi^i_L)}$$

- Yi_{WRBL} is the luminance for white view on right eye and black view on left eye coming from location i
- Yi_{BRWL} is the luminance for black view on right eye and white view on left eye coming from location i
- Yi_{BRBL} is the luminance for black view on right and on left eye coming from location i

A 3D contrast is then calculated using : $C = \sqrt{C_R * C_L}$

This procedure is extremely powerful to verify the design of the 3D display and to check the possible deviations in the manufacturing. 3 measurements locations are generally sufficient for this task. The OVR is really a picture of the 3D quality of the display and more parameters can be calculated (volume above given value, optimum viewing freedom along different directions…).

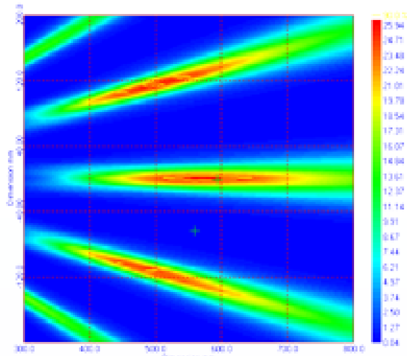
Standard parameters

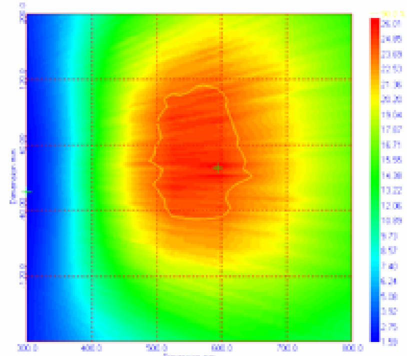
Good 3D contrast is not sufficient to obtain good display quality. Standard properties not related to 3D effect need to be optimized in the OVR. With the same method we can calculate luminance of ON state and OFF state seen by the observer using:

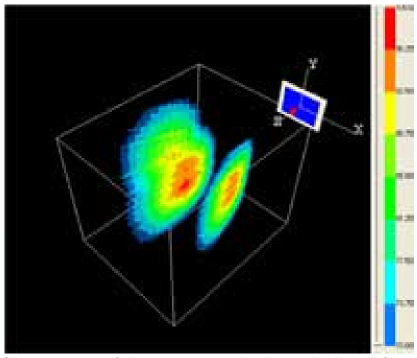
$$Y_{ONstate} = \sum_{i=1}^{M} \left[Y^i_{WRWL}(\theta^i_R,\varphi^i_R) + Y^i_{WRWL}(\theta^i_L,\varphi^i_L) \right]$$

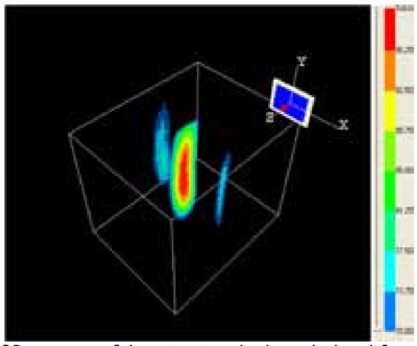
$$Y_{OFFstate} = \sum_{i=1}^{M} \left[Y^i_{BRBL}(\theta^i_R,\varphi^i_R) + Y^i_{BRBL}(\theta^i_L,\varphi^i_L) \right]$$

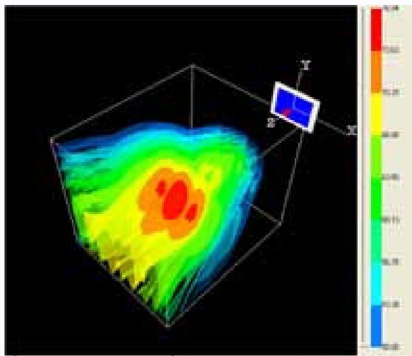
Standard parameters such as ON state and OFF state luminance and contrast are not necessarily optimum inside all the OVR. This point is extremely important to evaluate since 3D displays need also to be good for standard parameters. VCMaster3D allows this evaluation with the same set of measurements.

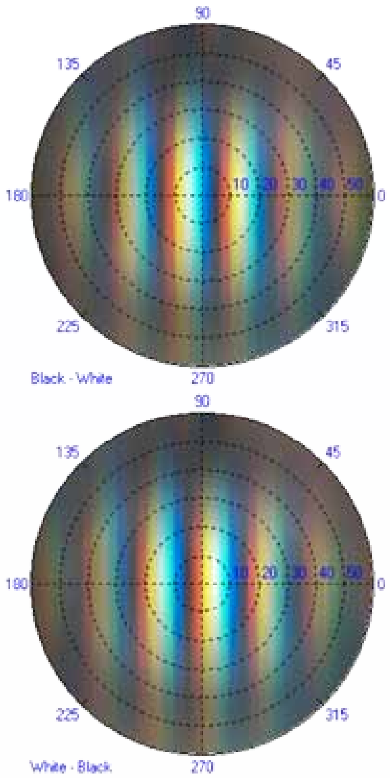

3D contrast in the Transverse plane


3D contrast in the Sagittal plane

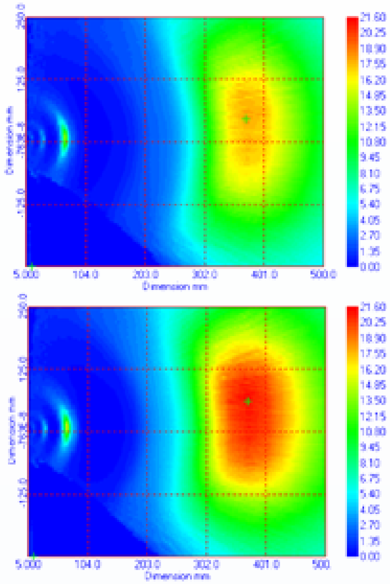

3D contrast of the twin view display calculated from central point measurement


3D contrast of the twin view display calculated from measurement s at three locations

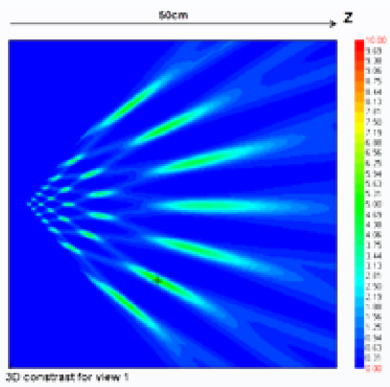

Standard contrast of the twin view display calculated from measurements at three locations



Color viewing angle measurements on lenticular barrier phone cell display



3D contrast on X and Y CIE components in the sagittal plane for a lenticular barrier phone cell display



3D contrast for view 1 on a parallax barrier mobile phone display with 14 views

Color shift

Color shifts could be also important source of imperfection for autostereoscopic displays. In the case of lenticular barrier displays for example this effect is difficult to reduce. The approach using 3D contrast ratio based on luminance can be extended using X and Z CIE components in addition to the luminance as for example in the case of one location:

$$C_R^X(\theta,\varphi) = \frac{X_{WRBL}(\theta_R,\varphi_R) - X_{BRBL}(\theta_R,\varphi_R)}{X_{BRWL}(\theta_R,\varphi_R) - X_{BRBL}(\theta_R,\varphi_R)}$$

and

$$C_L^X(\theta,\varphi) = \frac{X_{BRWL}(\theta_L,\varphi_L) - X_{BRBL}(\theta_L,\varphi_L)}{X_{WRBL}(\theta_L,\varphi_L) - X_{BRBL}(\theta_L,\varphi_L)}$$

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

Different OVR can be defined for the different CIE components and the color quality of the 3D display can be quantified comparing the different OVRs. If we have color viewing angle measurements at M locations on the display we can calculate directly the color difference between right and left eye of the observer. In Lab system this type of calculation provides directly a criterium for the color quality in the OVR.

Multiview 3D displays

In multiview displays the idea is to increase the OVR by generating multiple simultaneous viewing windows for a easier adjustment of the observer. The OVR can be defined in the same way as previously. We can define the contrast of view number i with regards to all the other views using:

$$C_i(\theta,\varphi) = \frac{Y_i(\theta,\varphi) - Y_B(\theta,\varphi)}{\frac{1}{N-1}\sum_{j\neq i}(Y_j(\theta,\varphi) - Y_B(\theta,\varphi))} = \frac{1}{(N-1)\chi_i(\theta,\varphi)}$$

$Y_i(\theta,\varphi)$ is the luminance at location (θ,φ) when white is applied to view i and black on the other views, $Y_B(\theta,\varphi)$ is the luminance at location (θ,φ) when black is applied to all the views simultaneously, and N is the total number of views of the display. $C_i(\theta,\varphi)$ is related to the inverse of the crosstalk of view i. The factor (N-1) is here to keep the scale of the contrast comparable for each type of display.

It is then possible to analyze in details the impact of all the views on the 3D properties:

- Recovery ratio between views
- Color shift and color quality
- Geometric corrections using multi-location analysis

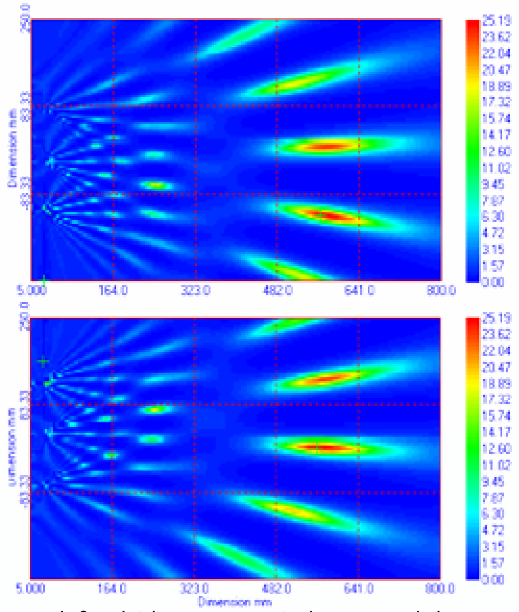
Characterization examples

We report hereafter three examples of characterization on auto-stereoscopic displays. The first one is a notebook twin view 3D display based on parallax barrier technique. The two other ones are multi-view 3D TVs : one 30" 3D TV with conventional LCD panel and additional parallax barrier; one 40" 3D TV with conventional LCD panel and lenticular lenses. Each display is measured at three locations (center and right and left sides).

notebook display

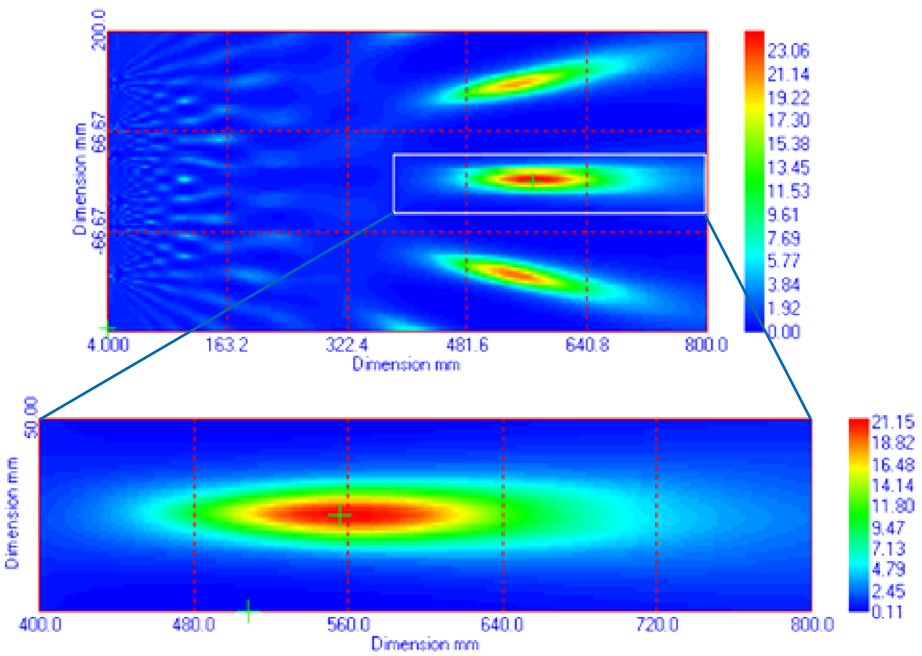
3D display notebook

The quality of the 3D display for an observer is directly related to his capacity to see clearly the right images with his right and left eyes. In case of thin view displays, we first calculate the two contrasts associated to each eye. It defines the EVS (Eye Viewing Space) for each eye, that is, the viewing space for each eye with high luminance contrast. This first step is a good way to check the design of the display and in particular the accuracy of the angular emission at center and borders.

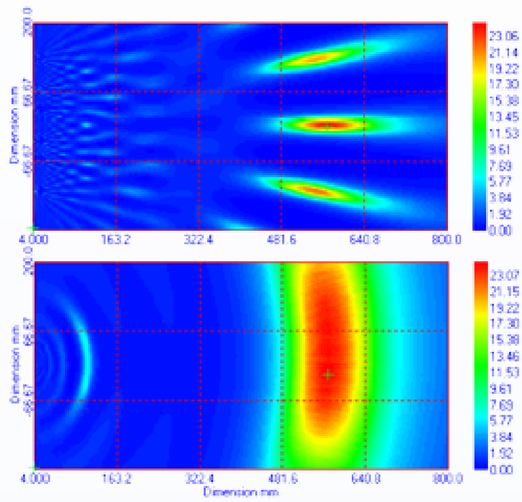


Left and right eye contrasts in the transversal plane

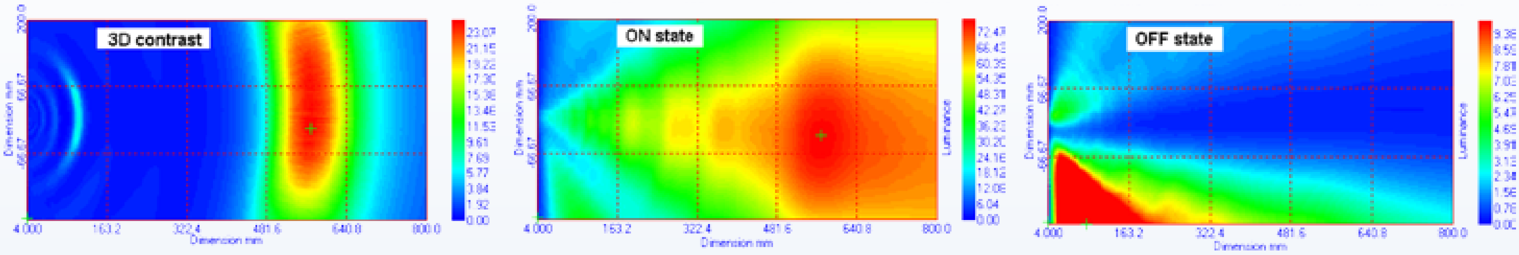
The 3D contrast is a combination of the two eye contrasts. It defines the OVR (optimum viewing region) in terms of 3D properties. In the present case, the OVR is quite reduced in space with very small dimension along the horizontal direction. It means that the observer must be exactly perpendicular to the display for optimum 3D observation. More precise computation can be made near the OVR in order to measure precisely the edges of the OVR and verify more closely the design of the display.



3D contrast of 3D display notebook in the transversal plane.
The main OVR is recalculated with more accuracy at the bottom.



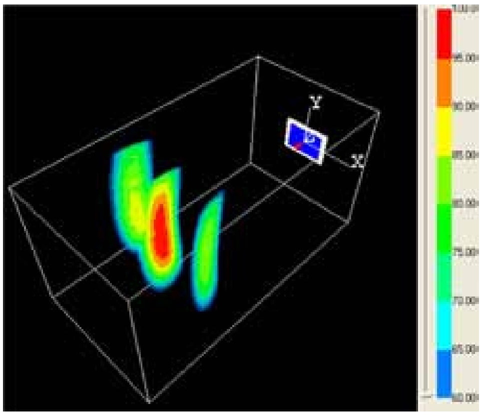
3D contrast in the transversal and sagittal planes



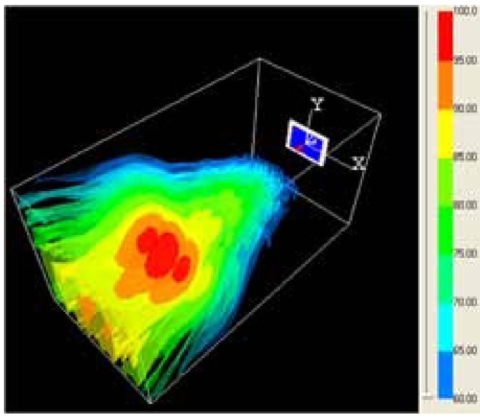
3D contrast and standard ON and OFF state in the sagittal plane

Standard parameters

The quality of the display depends not only on the 3D contrast which take care of the differences between the two eyes but also on the amount of light arriving inside the two eyes of the observer. Using the same method as previously the mean luminance value for the two eyes in ON state and OFF state and the standard contrast have been computed. In this particular case, the standard properties are good but in a volume smaller than the OVR. In particular along the vertical direction optimum standard contrast is obtained only when observer is near normal incidence. For simultaneous good 3D and standard observations conditions, the optimum position is only near normal incidence in front of the center.



OVR defined by 3D contrast



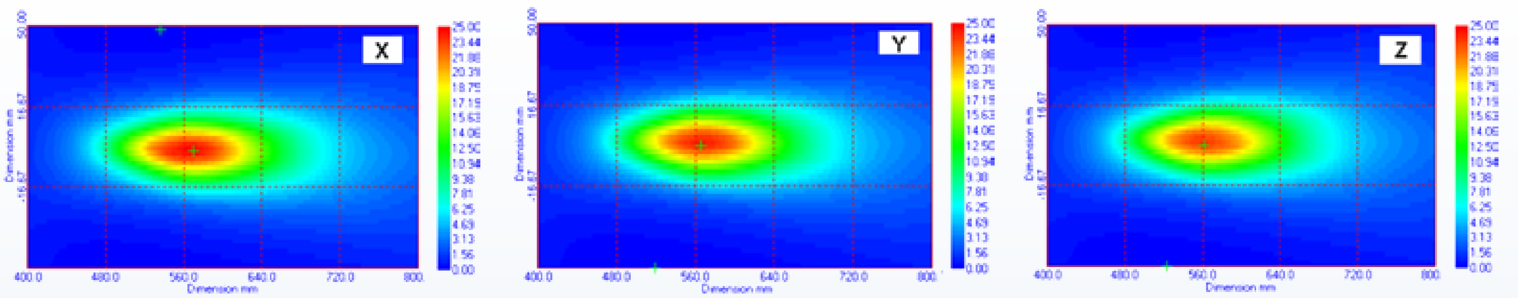
Volume defined by standard contrast

Color shifts

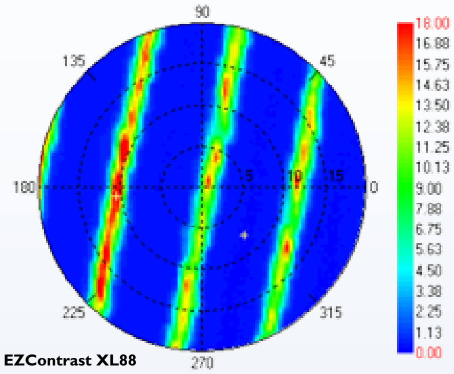
When parallax barriers are used in principle there is no chromatic effect. This point can be verified computing 3D contrasts for each CIE component. The smaller value for Y blue component is related to well-known technology problems for blue pixels but the color shifts are vey small as waited.

Summary for thin view 3D displays

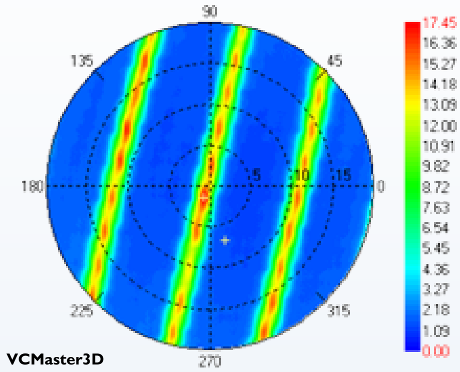
Measurements	Computation	Physical parameters
Luminance 1 location	3D contrasts	Check of local emission
Color 1 location	3D contrasts for XYZ	Local color shift
Luminance 3 locations	3D contrasts	Check of display design OVR volume, OVF, 3D contrast homogeneity
	ON, OFF state Standard contrast	Homogeneity on OVR
Color 3 locations	3D contrasts for XYZ	Global color shifts
	ON, OFF state	Simulation of color images



3D contrast for X (left), Y (middle) and Z (right) components.



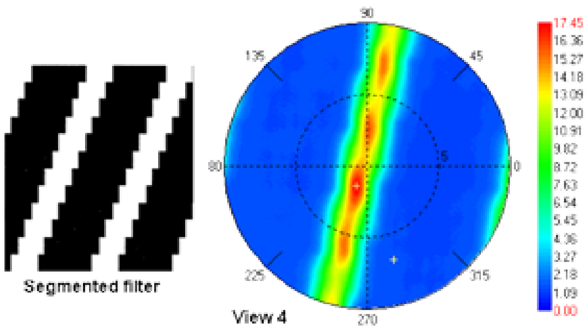
Luminance of view 4 using EZContrastXL88



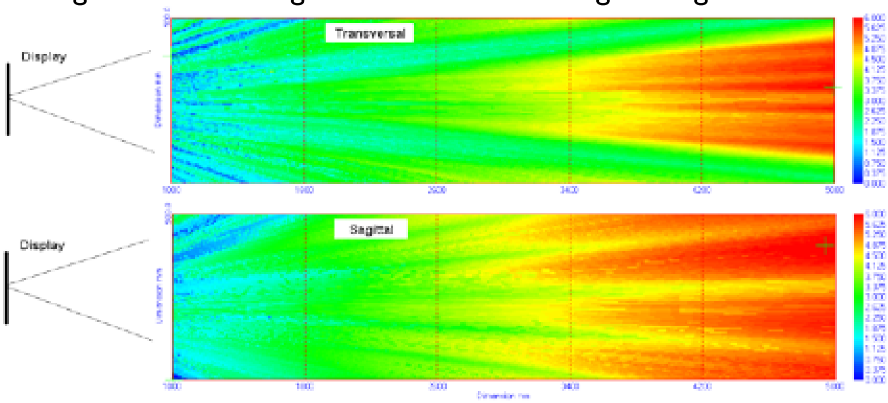
Luminance of view 4 using VCMaster3D

parallax barriers 3D TV

These large size TVs are based on high resolution LCD panels and parallax barriers. Eight views are emitted and the announced working distance is about 3m. These displays are based on segmented filters and their main apparent drawback is the lack of luminance. In addition, luminance measurements of the different views show strong luminance variations along the barriers. Using standard EZContrast instrument with limited angular resolution, it is impossible to understand the origin of these variations. Using a VCMaster3D it becomes clear that there are fluctuations due to the specific geometry of the segmented barriers which produce strong variations of angular contrast versus angle along the barriers.

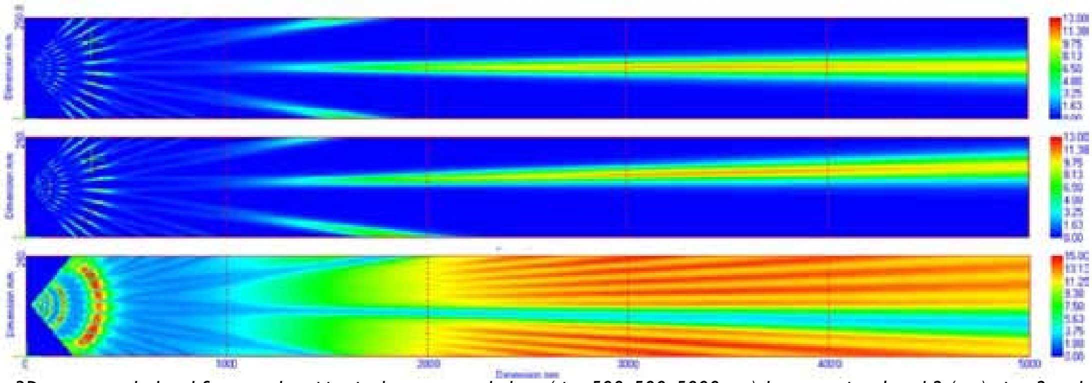


Luminance fluctuations due to the segmented filters

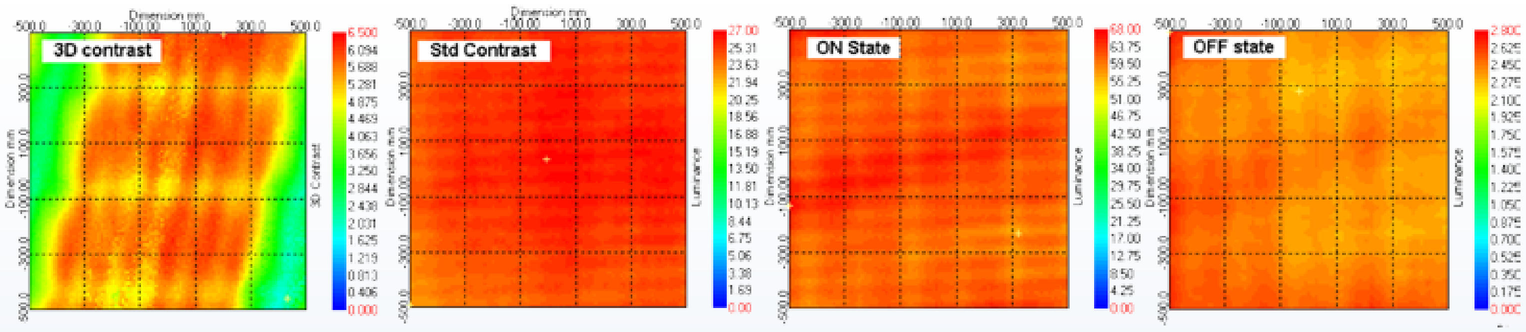


3D contrast in the transversal and sagittal planes

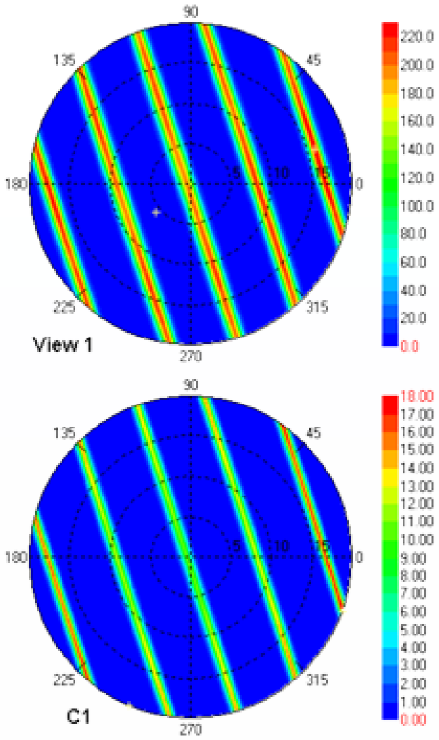
Computation in the observer space shows strong variations of the 3D contrast in the OVR. In addition the 3D contrast values are reduced. Standard parameters are relatively homogeneous compared to 3D one's even if the standard contrast is low.



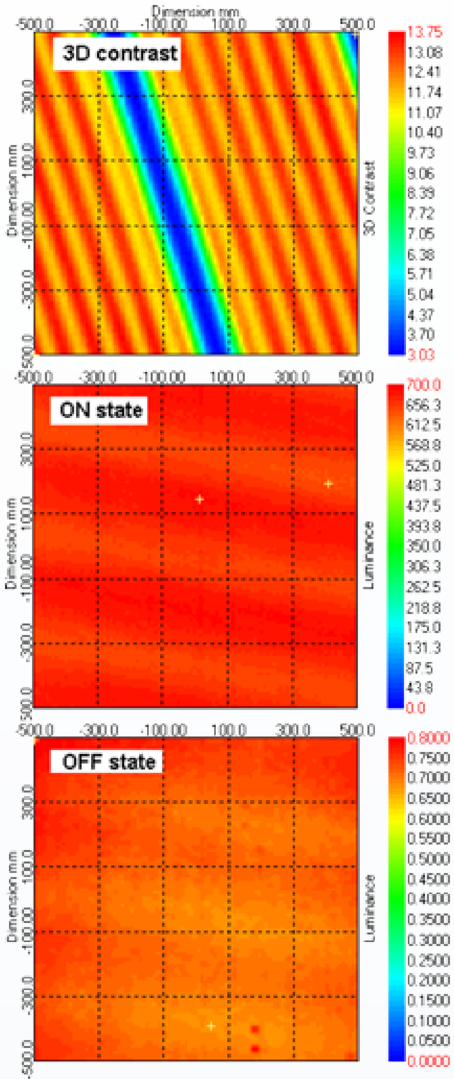
3D contrast calculated for central position in the transversal plane (size 500x500x5000mm): between view 1 and 2 (top), view 2 and 3 (middle) and combined 3D contrast (bottom)



Computation in the sagittal plane at 5m of the display



Luminance of view 1 and angular contrast of view 1

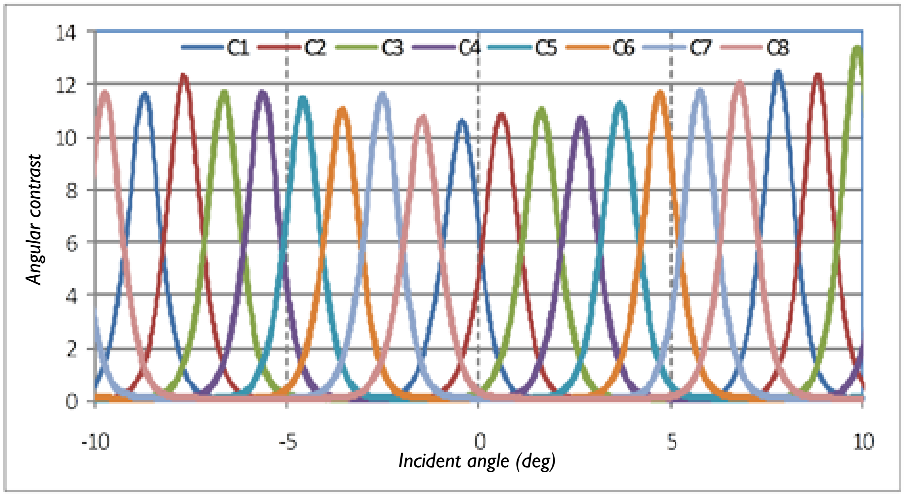


Computation in the sagittal plane at 5m of the display

Lenticular lenses 3D TV

This large size TV is based on high resolution LCD panel and lenticular lenses. Eight views are emitted and the announced working distance is about 4m. These displays exhibit a very high luminance for each view and no variations along the lenses.

The overlapping between adjacent view is nevertheless important because of the Gaussian like shape of the light emission perpendicular to the lenses. This behavior is not a measurement artifact but really due to the imperfect collimation of the lenticular lenses.

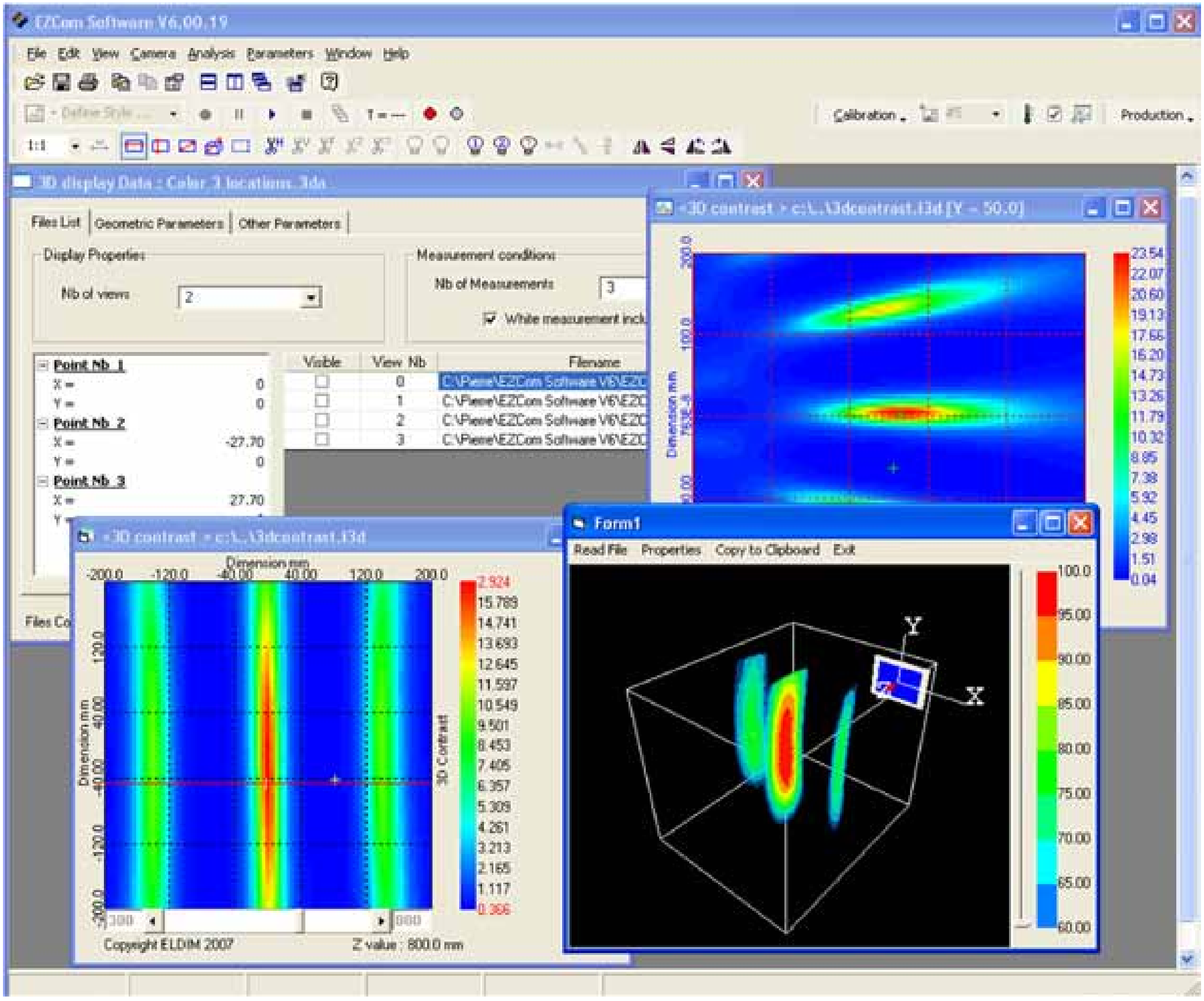


Angular contrasts perpendicular to the lenticular lenses show important overlapping

The 3D contrast is much higher than for the parallax barriers 3D TV but shows also fluctuations perpendicular to the lenticular lenses. This is due to the imperfect overlapping between views and represents the main drawback of this display. Standard parameters show excellent performances with a good homogeneity in space. Color shifts are also quite limited.

Multi-view 3D displays (in addition to previous features)

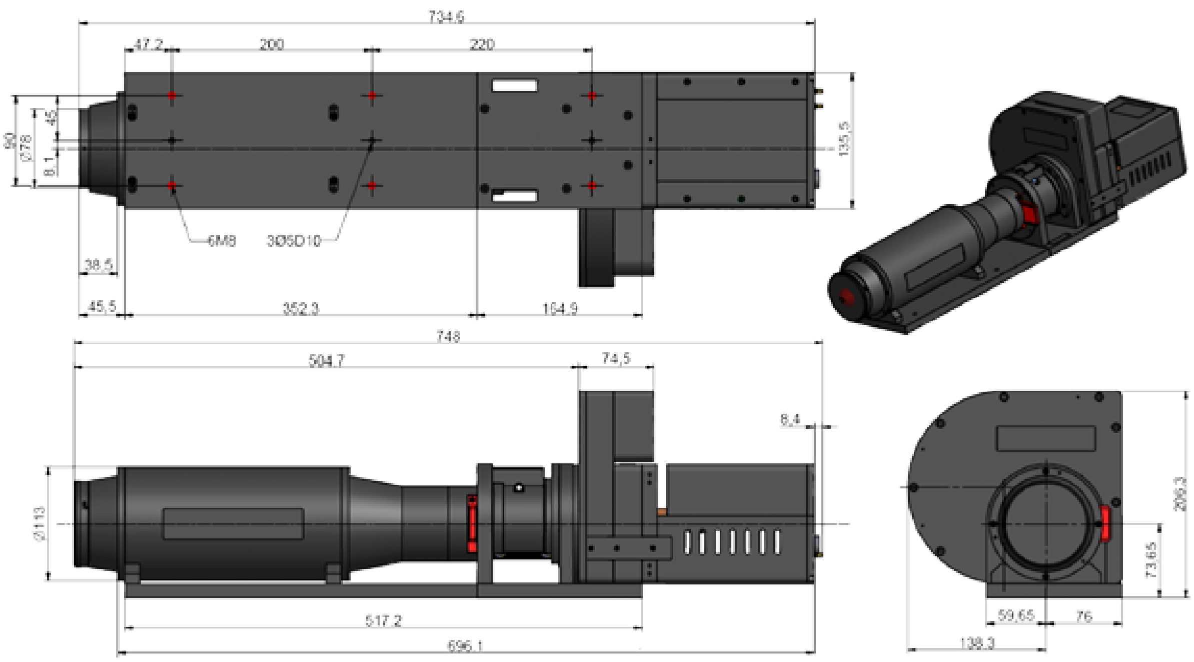
Measurements	Computation	Physical parameters
Luminance 1 location	3D contrasts	Overlapping between views Overlapping between OVRs
Color 1 location	3D contrasts for XYZ	Color shift between views
Luminance 3 locations	3D contrasts	Overlapping between views
Color 3 locations	3D contrasts for XYZ	Color shift between views



VCMaster3D comes with a complete software solution for measurement and 3D data analysis.

Some characteristics of the EZCom 6 sofware package for 3D displays

Features	Details	Version
Measurement capacities	Luminance measurements	Standard
	Color measurements	Standard
	XY automation with measurement control	Additional software
Data analysis for twin view displays	Angular contrast between views	Option
	3D contrast for one location in the observer space	Option
	3D contrast for up to 5 location s in the observer space	Option
	Computation of OVR volume, OVD, OVF…	Option
	3D display on the different parameters	Option
	Color shift between views	Option
Data analysis for multiview displays	Angular contrast between views	Option
	3D contrast for each view for one location in the observer space	Option
	3D contrast for each view and for up to 5 location s in the observer space	Option
	Combine 3D contrast for a given step between views	Option
	Computation of OVR volume, OVD, OVF and volume recovery rates	Option
	3D display on the different parameters	Option
	Color shift between views	Option
Standard analysis	Standard ON state , OFF state luminance and contrast in observer space	Option



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