

Cross-talk in 3D displays

Richard Stevens

March 2004

March 2004

CROSS-TALK IN 3D DISPLAYS

R F Stevens
Centre for Electrical and Time Metrology
National Physical Laboratory
Teddington, Middlesex

ABSTRACT

Three-dimensional images may be displayed in a variety of ways but in general the principle is to present a pair of images with stereo disparity to the viewer's eyes. Leakage of optical signal from one image to the other is described as cross-talk and may degrade the ability of the observer to perceive the 3D image. Measurement of this parameter is essential to quantify the quality of the reconstructed image.

The work was carried out under contract to the NMS for Project 3.2 Milestone 1.6 of the Photonics programme "Developing the measurement infrastructure for standard display devices and novel devices".

© Crown Copyright 2004
Reproduced by Permission of the Controller of HMSO

National Physical Laboratory
Teddington, Middlesex, UK TW11 0LW

ISSN 1467-3932

Extracts from this report may be reproduced provided the source is acknowledged and the extract is not taken out of context.

We gratefully acknowledge the financial support of the UK Department of Trade and Industry (National Measurement System Policy Unit)

Approved on behalf of the Managing Director, NPL
by S Pollitt, Head, Centre for Electrical and Time Metrology

TABLE OF CONTENTS

1. INTRODUCTION	1
1.1 Three-dimensional images	1
1.2 Cross-talk	2
1.3 Sources of cross-talk.....	3
2. TEST DISPLAY AND IMAGES	5
2.1 Spatially encoded displays	5
2.2 Lenticular display for trials.....	5
2.3 Viewing zones.....	6
2.4 Test patterns.....	6
3. SPECTROPHOTOMETER MEASUREMENTS	7
3.1 Spectroradiometer	7
3.2 Collection optics.....	7
3.3 Measured field	8
3.4 Test patterns.....	8
3.5 Specifications of measuring system.....	8
4. EXPERIMENTAL	9
4.1 Experimental arrangement.....	9
4.2 Measurements	10
5. CONCLUSIONS	12
6. ACKNOWLEDGEMENT	12
7. REFERENCES	12
8. BIBLIOGRAPHY	13

FIGURES

Figure 1. Simple system for viewing stereo image pairs	1
Figure 2. Stereo display with superimposed images and spatially defined viewing zones ..	3
Figure 3a. Component images displaying a 2D image	4
Figure 3b. Component images with disparity to reconstruct depth	4
Figure 4. Interlaced images viewed in zones defined by lenticular display	6
Figure 5. Spectroradiometer optical system	7
Figure 6. Angle subtended by measured field	8

Figure 7. Measuring stereo display luminance	9
---	----------

Figure 8. Spectroradiometer and lenticular display with stereo-image of inclined test chart	10
--	-----------

TABLES

Table 1. Test patterns	8
-------------------------------------	----------

Table 2. Test patterns and measurements made with the CS1000 instrument.....	11
---	-----------

1. INTRODUCTION

1.1 Three-dimensional Images

In real life the human observer perceives a three dimensional image of a scene by fusing the images formed by both eyes. The images formed in the eyes are actually three-dimensional but each retina records a two-dimensional slice. It is sufficient to reconstruct the 2D images seen by each eye in order to reconstruct a 3D image in the brain. A variety of cues are used by the brain to interpret depth in the image but the main cue is stereo disparity (1).

Apart from true 3D images with depth and parallax as generated by lenses and mirrors or reconstructed by holography, the majority of 3D displays use a multiplexed spatial or temporal sequence of 2D images to give the impression of a 3D image.

Spatially multiplexed images may be divided into those viewed with special eyewear such as polarising or red-green glasses, and those not requiring special eyewear such as multiple projection systems and lenticular systems. Time-multiplexed systems may likewise be subdivided and may use special glasses with liquid crystal shutters.

Figure 1 shows a simple system for generating a 3D image from a stereo pair of 2D images. The observer uses binocular vision to combine the two images which differ by parallax effects corresponding to the different directions of view of the two eyes. This is the principle of the Wheatstone viewer which was popular in Victorian times. Although there will be inaccuracies in the reconstructed image, such as the lack of true depth which confines the focus of each eye to the plane of a two-dimensional image, the impression generated is that of viewing a three-dimensional object.

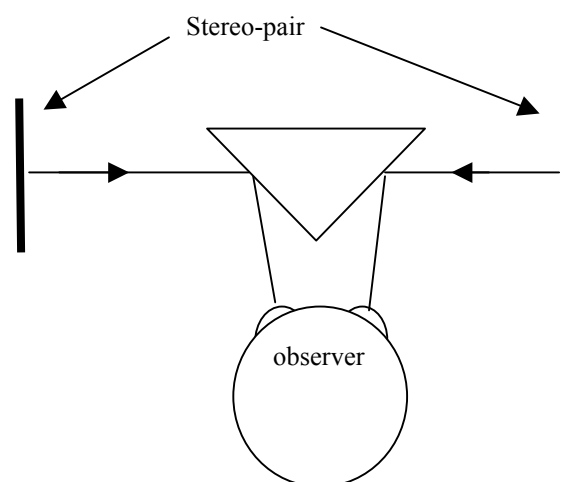


Figure 1. Simple system for viewing stereo image pairs

1.2 Cross-talk

Cross-talk is an important parameter in 3D imaging systems. In this context it describes the leakage of the optical signal in one channel of the viewing pupil to an adjoining channel. The channels may be the viewing zones in a spatially divided pupil or they may be temporally separated as in the case of a system that uses shuttered glasses to view alternating images. The effect of cross-talk is to generate ghost images that reduce the ability of the observer to fuse the two monocular views into a single 3D image, creating eye strain and lack of realism.

If each element of the stereoscopic pair is presented to the corresponding eye through an entirely separate channel, as in the system in figure 1, there is little chance of one view appearing in the channel corresponding to the other view.

In an anaglyph display, two spatially varying images are printed or presented on a screen as a superimposed pair. They are coded in different colours and when viewed through colour filters each image becomes apparent to the corresponding eye. It is a common experience that some of the “wrong” image is usually visible to each eye. A similar effect may occur with polarisation-encoded images, particularly when the viewer’s head is inclined and the polarisation axes no longer align with the image polarisation. In both cases a measure of the cross-talk is useful in describing the effectiveness of the system to reconstruct a 3D image.

During the evolution of displays a variety of ingenious methods have been devised to present the component images to the eye. Developments in modern technology such as large area LCD screens and microlens arrays have enabled more effective images to be generated. Viewing zones may be defined optically as indicated in figure 2 and the illumination may be directed to the correct eyes using lenticular screens as described in section 2.2. With spatially encoded viewing pupils it is common for a small region of high cross-talk to be found where both images are visible.

In time-sequential systems such as volumetric projection systems, the impression of a three-dimensional image is built up from a temporal series of two-dimensional components, relying on the natural persistence of human vision to merge the optical signals. If motion parallax is included the observer can move the viewing position and “see round” the image. Once again consideration has to be given to the need to present the correct views to the corresponding eyes and in this case, at the correct time.

It is well known that high image contrast helps accentuate the 3D effect but this conflicts with the need to minimise the effect of a ghost image from an adjoining channel. Ghosting of one image within its own channel may also be present due to reflections arising from secondary optical surfaces such as the front of rear-coated mirrors.

The effects of cross-talk in an image include:

- i) ghosting and loss of contrast
- ii) loss of 3D effect and depth resolution
- iii) viewer discomfort

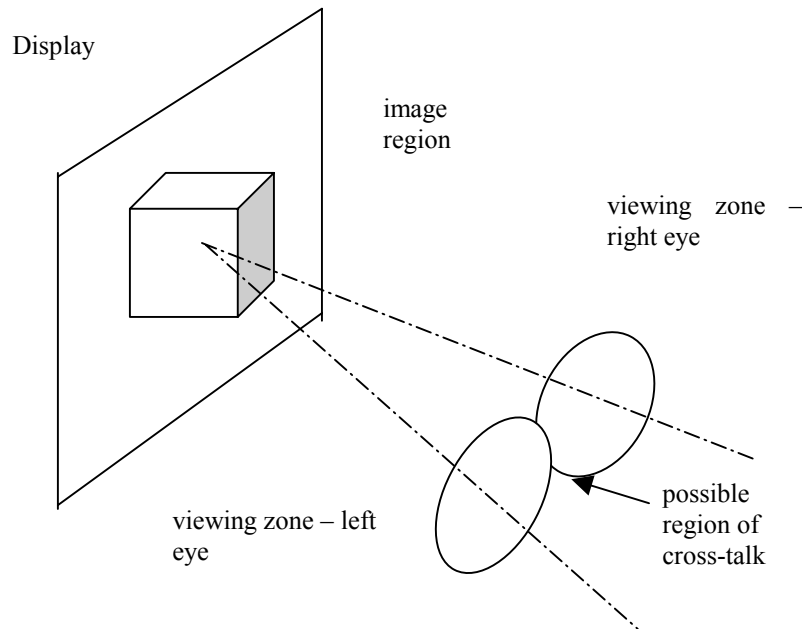


Figure 2. Stereo display with superimposed images and spatially defined viewing zones

1.3 Sources of cross-talk

Interest in the effects of cross-talk has grown with the growth in stereo-display technologies and some workers have clarified the differences between image contrast as defined for monocular images, viewer cross-talk and system cross-talk (2,3). The viewer's cross-talk depends on the ability of the viewer to filter the stereo pairs of images.

Consider a flat panel stereoscopic display shown in figures 3a and 3b. A pair of images is viewed through different channels for each eye and fused by the observer to give a three-dimensional representation. Any leakage of signal from an element of the image in one channel and at one position on the screen will appear against an image element in the other channel and in the same position relative to the screen. If there is to be no depth in the reconstruction, as is shown in figure 3a, the two images will be similar and one position on the screen will display the same image point in both channels.

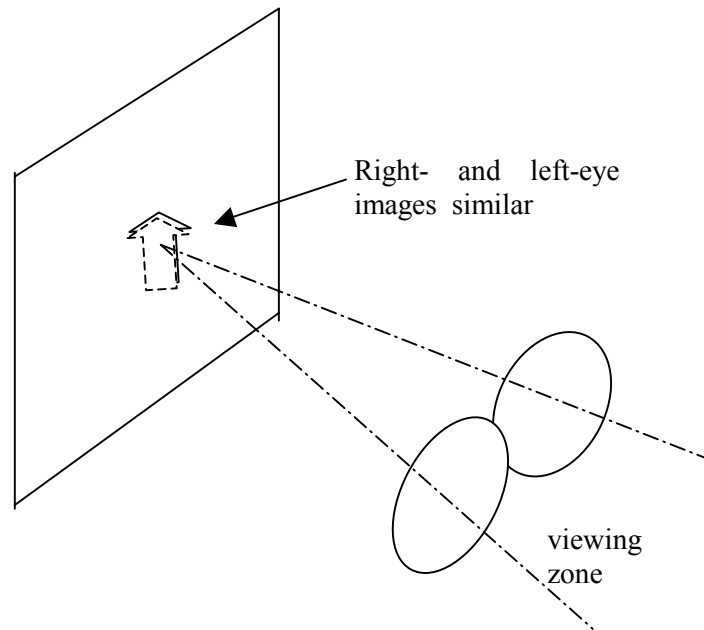


Figure 3a. Component images displaying a 2D image

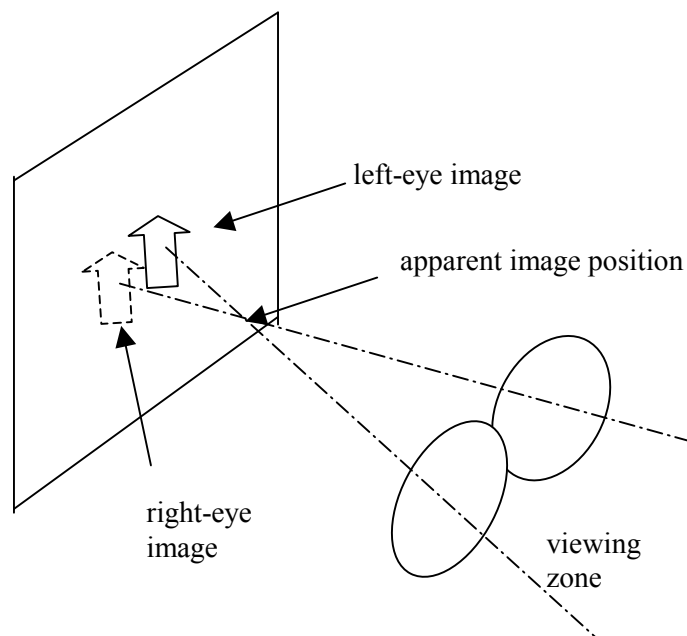


Figure 3b. Component images with disparity to reconstruct depth

For depth to appear in the reconstruction there will be a degree of disparity between the two images as in figure 3b. This means that if a signal corresponding to one point in the display leaks through to the other channel it will appear, for the same position relative to the display, against a different element of the image. The visible effect of that cross talk will then depend on the relative luminance of the image elements.

The amount of unwanted image that is visible to the wrong eye is due to:

- i) the system cross-talk. This is a measure of the optical performance for a stereo system and is independent of the contrast of the individual images.
- ii) the viewer cross-talk. This is defined as the ratio of luminance of the “wrong” image to the luminance of the “correct” image as seen by the observer. It will be a function of the image contrast and the disparity.

2. TEST DISPLAY AND IMAGES

2.1 Spatially encoded displays

As discussed above there are various systems for generating 3D images and each has its own characteristics and sources of cross-talk. For a measurement service at NPL it is reasonable to look for the type of display that might be available in large quantities in the future. Autostereoscopic displays have been the subject of much development in recent years (4). The availability of large area LCD screens which have precisely located pixels and the development of efficient reconfigurable parallax barriers and lens arrays have enabled a major manufacturer to launch a commercially available display that can switch between two and three dimensions (5).

2.2 Lenticular display for trials

Trials were carried out at NPL with a lenticular display borrowed from the Imaging Displays Group in the School of Computing at De Montfort University Leicester. The group is working on multi-viewer 3D television as part of the EU funded Advanced Three-dimensional Television System Technologies (ATTEST) project. Their system uses a commercial LCD screen with novel backlighting and optics to project multiple viewing zones. The locations of the exit pupils, or positions to be occupied by the observers eyes, are sensed using head trackers.

The display borrowed for these trials is a prototype formed from an NEC liquid crystal display with a 21 inch diagonal, rotated 90° to portrait format such that the pixel rows become columns. An array of cylindrical lenses with a pitch that matches the pixels of the LCD is mounted in front of the screen and aligned with the pixels. The function of the lens array is to steer light from alternate columns of the display to alternate viewing zones where an observer can view the three-dimensional image, as shown in figure 4.

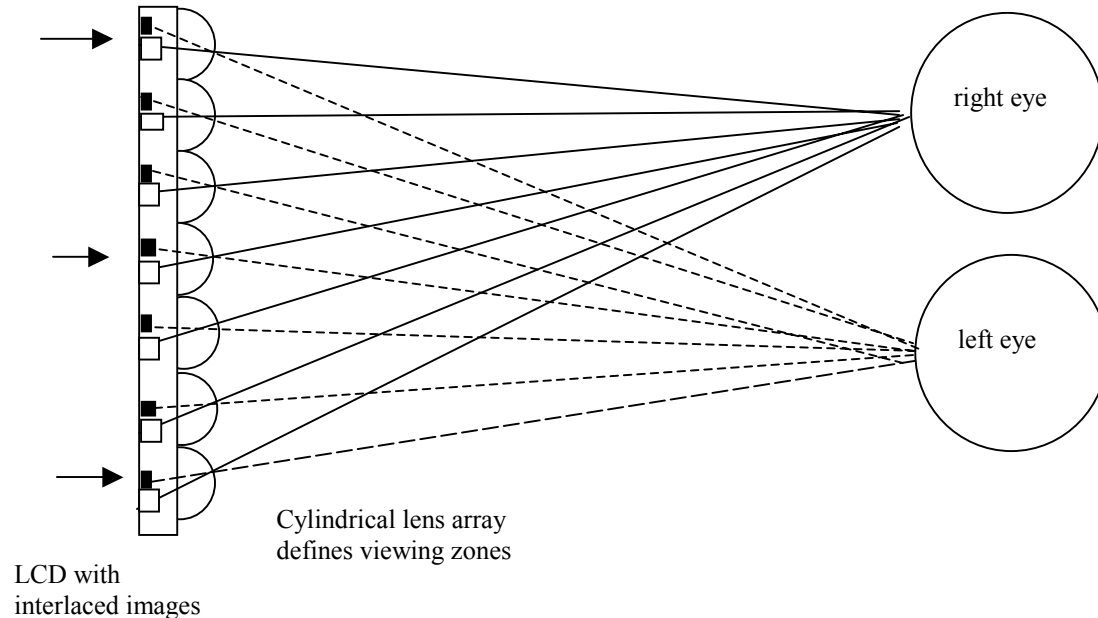


Figure 4. Interlaced images viewed in zones defined by lenticular array

In practice multiple viewing zones are created because light from one row of pixels can travel through more than one lens. This means several observers can see a three-dimensional image at once but care has to be taken to select suitable pairs of viewing zones to avoid seeing a pseudoscopic image.

2.3 Viewing zones

The LCD screen is backlit and the viewing zones can be seen projected on a screen placed in the viewing region. They are most distinct at a distance of 800 mm. At this distance an observer can see the screen free from the moiré pattern effects that appear when viewing at other distances. The moiré patterns can be explained as parallax effects between the screen and lens array.

2.4 Test patterns

De Montfort University supplied some 3D display images and we constructed screen test patterns ourselves.

The black and white cross-talk test images in their natural landscape orientation are 1600 pixels wide by 1200 pixels high. The images comprise of 1 pixel wide horizontal stripes that are alternately black and white.

3. SPECTROPHOTOMETER MEASUREMENTS

3.1 Spectroradiometer

The basic tool used in these measurements is a spectroradiometer model CS-1000A made by Minolta. An objective lens is used to focus incident light to a mirror that allows the observer to see the field of view. Some light is transmitted via a hole at the centre of the mirror, to an optical fibre that scrambles the illumination and transmits to a diffraction grating and an array sensor for spectral analysis. Spectral radiance, luminance and chromaticity are calculated by the processor.

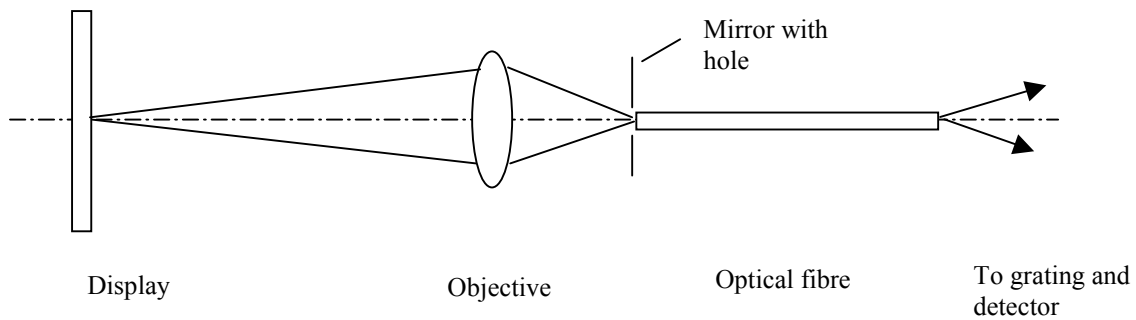


Figure 5. Spectroradiometer optical system

3.2 Collection optics

Two lenses are supplied with the instrument. One has a focal length of 50 mm and an aperture ratio of $f/1.4$. The effective aperture diameter is therefore 36 mm. The closest focusing distance is 400 mm. The other lens is a macrolens with a focal length of 50 mm and an aperture ratio of $f/2.8$. The diameter of the effective aperture is calculated as 18 mm.

Both these lenses collect light over a larger physical aperture than the eye and when measuring a display with a spatially encoded pupil it is necessary to mount a smaller aperture in front of the lens to limit the collection aperture to a diameter comparable with the human pupil. In this case an aperture diameter of 7 mm was chosen. The effect of using a larger aperture when measuring a display with a spatially encoded pupil may be to blur the distinction between viewing zones and increase the measured amount of cross-talk.

3.3 Measured field

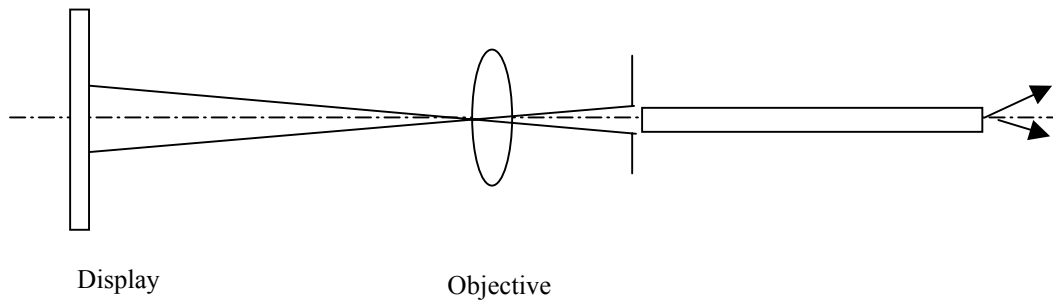


Figure 6. Angle subtended by measured field.

The area of field that is analysed by the spectrophotometer is limited by the aperture in the viewing optics that transmits light in the image plane to the collection fibre and detector. The manufacturer's specification states this subtends 1 degree. This corresponds to a field diameter of 14 mm at 800 mm and 9 mm at 500 mm.

3.4 Test patterns

Three test patterns were used with the detector in each of two positions separated by the interocular distance 65 mm. Measurement 3) sets a background level. Measurement 2) sets a level for the signal in channel 1. Measurement 1) sets a level for signal in channel 2.

Measurement	Test pattern	Channel 1	Channel 2
1)	1	0, 0, 0	255, 255, 255
2)	2	255, 255, 255	0, 0, 0
3)	3	0, 0, 0	0, 0, 0

Table 1. Test patterns

3.5 Specifications of measuring system

The system that has been developed is for 3D displays that use spatial encoding of the viewing pupil. The minimum diameter pupil element that can be resolved is 7 mm. At a viewing distance of 500 mm this subtends 8° .

The spectroradiometer is a Minolta CS-1000A with an acceptance angle of 1 degree.

The minimum viewing distance to the display is 500 mm and the corresponding screen area sampled is 9 mm.

From the manufacturer's data the maximum luminance that can be measured is 8000 cd/m^2 . From trials a practical minimum luminance that can be measured is 0.1 cd/m^2 . The luminance accuracy is given as $\pm 2\% \pm 1 \text{ digit}$.

Cross-talk values are derived from multiple measurements of luminance.

4 EXPERIMENTAL

4.1 Experimental arrangement

The lenticular display was mounted on a rotary table to enable adjacent viewing zones to be selected by rotating the display, shown in figure 7. The CS1000 spectroradiometer was fitted with a 7 mm aperture to restrict the cone angle subtended at the display and positioned at the optimum viewing distance of 800 mm.

Figure 8 shows the display with an image of an inclined test chart. The camera position has been chosen to be away from the optimum in order to accentuate the overlap of images seen from adjacent viewing pupils. The disparity between the pair of images is visible in the bottom left where the presence of cross-talk makes visible a ghost image of the chart inclined to the main image.

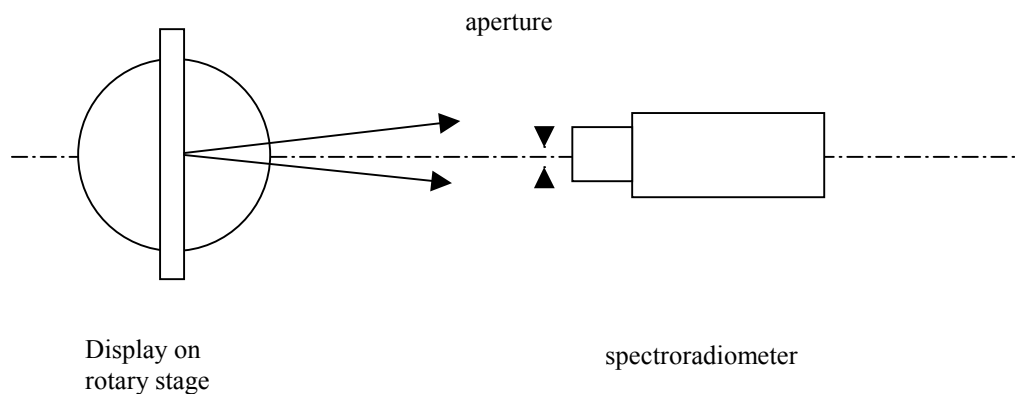


Figure 7. Measuring stereo display luminance.

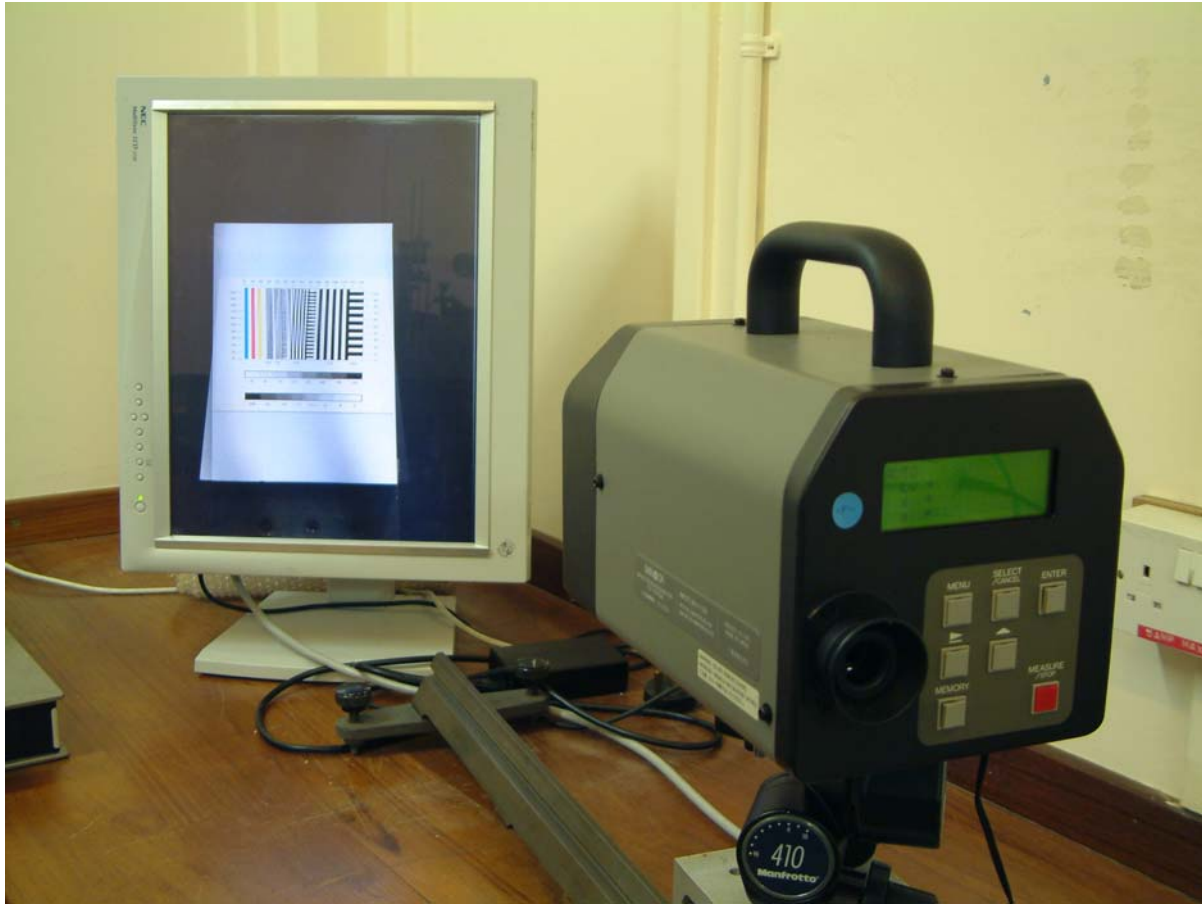


Figure 8. Spectroradiometer and lenticular display with stereo-image of inclined test chart

4.2 Measurements

Table 2 lists results of measurements made on the lenticular display using the CS1000.

The CS1000 and display were first positioned to measure channel 2.

The background level of 0.12 cd/m^2 for both channels off is modified to 0.62 cd/m^2 in channel 2 when channel 1 is on. There is leakage of 0.50 cd/m^2 from channel 1 to channel 2 (measurement 2 – 3). The CS1000 is then positioned to measure channel 1.

The signal in channel 1 is 32.24 cd/m^2 against a background of $0.11 \text{ cd/m}^2 = 32.13 \text{ cd/m}^2$ (measurement 5 - 6). The leakage or cross-talk into channel 2 from channel 1 is $0.5/32.13 = 1.6 \%$

Conversely the leakage from channel 1 into channel 2 can be calculated. With the CS1000 positioned to measure channel 1, there is leakage of 0.55 cd/m^2 from channel 2 to channel 1 (measurement 4 – 6). With the CS1000 positioned to measure channel 2, the signal in channel 1 is (measurement 1 – 3) 32.39 cd/m^2 .

The leakage into channel 1 from channel 2 is $0.55/32.39 = 1.7 \%$

Measurement number and test pattern		Channel 1	Channel 2	CS1000 sensing channel 2	integration time secs
1	000,000,000 255,255,255	off	on	32.51 cd/m ²	6
2	255,255,255 000,000,000	on	off	0.62 cd/m ²	123
3	000,000,000 000,000,000	off	off	0.12 cd/m ²	123
				CS1000 sensing channel 1	
4	000,000,000 255,255,255	off	on	0.66 cd/m ²	123
5	255,255,255 000,000,000	on	off	32.24 cd/m ²	6
6	000,000,000 000,000,000	off	off	0.11 cd/m ²	123

Table 2. Test patterns and measurements made with the CS1000.

5. CONCLUSIONS

Experience has been gained in the understanding and measurement of cross-talk in a 3D image imaging system. A lenticular display with a spatially encoded pupil has been measured and the system cross-talk found to be 1.7%. This was measured with a 7 mm viewing pupil at a viewing distance of 800 mm. This has given a firm background for further work in the measurement of cross-talk in 3D imaging systems

6. ACKNOWLEDGEMENTS

The author wishes to thank the Imaging Displays Group in the School of Computing at De Montfort University Leicester for the loan of the LCD lenticular display used in these tests, and Prof David Heeley, Professor of Experimental Psychology and Vision Science School of Social and Health Sciences, University of Abertay, Dundee and David R. Simmons. Department of Psychology, University of Glasgow for advice on human factors. Colin Campbell (NPL) fabricated the test images.

This document has been produced for the Department of Trade and Industry's National Measurement System Policy Unit (NMSPU) under contract number GBBK/C/011/09.

7. REFERENCES

- 1) Okoshi T. Three-dimensional Imaging Techniques. Academic Press. London 1976.
- 2) Kuo-Chung Huang et al. Measurement of Contrast Ratios for 3D Display. Proc SPIE vol 4080 (2000) pp78-86
- 3) Atsuo Hanazato. Subjective Evaluation of Cross Talk Disturbance in Stereoscopic Displays. 20th Int Display Research Conf, San Jose 25-28 Sept 2000
- 4) Woodgate G, et al Autostereoscopic 3D display systems with observer tracking Signal Processing: Image Communication vol 14 part 1-2 pp131-145, 1998
- 5) "3D displays jump out onto centre stage" Popular article in electrooptics, April/May 2003, pp13-18

8. BIBLIOGRAPHY

Frank Kooi et al. Visual Comfort of binocular and 3D displays. Proc SPIE vol 4299 (2001) pp586-592

Woods A et al. Characterising sources of ghosting in time sequential stereoscopic video displays. Proc SPIE vol 4660 (2002) pp66-77

Cees van Berkel Multiview 3D-LCD. Proc SPIE vol 2653 (1996) pp 32-39

Amamoto H. Optimum parameters and viewing areas of stereoscopic full-colour LED display using parallax barrier. IEICE transactions on Electronics. VolE83-C no 10 (2000)

Woodgate et al. "Flat panel autostereoscopic displays –characterisation and enhancement" Proc SPIE. Vol 3957 (153-164) 2000.

Woodgate G High efficiency reconfigurable 2D/3D autostereoscopic display". LP.1/G SID 03 Digest

Harrold J. "Performance of a convertible 2D and 3D parallax barrier autostereoscopic display"

Woodgate G et al. "Observer tracking autostereoscopic 3D display system." SPIE vol 3012 pp187-198 (1997)

Konrad J. Cancellation of image crosstalk in time-sequential displays of stereoscopic video. IEEE trans May 2000 vol 9 part 5 pp897-908.

Pastoor S. Human factors in 3D imaging. Heinrich Hertz Institute

Spedding V. "3D displays jump out onto centre stage" Electrooptics April/May 2003 pp13-18

Howard I, Rogers B. Binocular vision and stereopsis. Oxford University Press 1995.

Peter G J Barten "Contrast sensitivity of the human eye and its effect on the image" SPIE Optical Engineering Press.

S A Benton T E Slowe A B Kropp S L Smith. "Micropolarizer-based multiple viewer autostereoscopic display." Proc SPIE 3639 SPIE Symposium on Stereoscopic Displays and Applications X, pp 76-83, Feb 1999.