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PACS Component: Evaluation of Planar Dome 3 MP LCD Flat-Panel Display

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PACS Component: Evaluation of Planar Dome 3 MP Greyscale LCD Flat-Panel Display

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Summary

This report gives a technical evaluation of a Planar flat-panel display device (see Figure 1). The device is a greyscale display suitable for use in diagnostic medical imaging. It utilises an Active Matrix Liquid Crystal Display (AMLCD) with a three mega-pixel (3 MP) display matrix. The display was evaluated in combination with a Dome DX/PCI graphics card, recommended by Planar as being appropriate for use with this type of display and, together with the examples of the displays, loaned by them for the period of the evaluation.

The device was tested for luminance consistency and uniformity, variation of luminance with viewing angle, contrast resolution, spatial resolution and veiling glare; it was found to perform well under all tests.

The device was supplied with Dome's 'CXTra' software and a Planar luminance probe. The functionality of this calibration kit was investigated. The calibration kit is used to verify the result of the fully automatic display calibration.

Please note that the quality of the reproduced images within this report does not necessarily reflect the quality of the image as seen on the display device itself.

Figure 1. The Planar 2 MP colour (left) and 3 MP greyscale (right and centre) display

1 An introduction to display device technology

1.1 Liquid Crystal Display (LCD) Technology

With the advent of digital imaging systems it has become increasingly common to view medical images on electronic soft-copy display devices rather than film. This has many advantages, not least the cost-saving involved in not printing film and managing its storage. For many years the dominant technology in electronic displays has been the cathode-ray tube (CRT), as it has been in television viewing in the home. Recent years, however, have seen the development of a number of alternative technologies for such small displays, including plasma, liquid crystal and projected displays. This report evaluates a display that uses liquid crystal display technology.

Liquid crystals exist in a state that displays some of the characteristics of a solid (i.e. molecules in the crystal are fixed in orientation within the material) and some of the characteristics of a liquid (i.e. the molecules are free to move around while maintaining that fixed orientation). A substance can exist as a liquid crystal over a relatively narrow temperature range; any higher than this range and it becomes a normal liquid and any lower and it becomes a normal solid. Liquid crystals can exist in several different "phases" displaying different characteristics, and it is a particular instance of one of these phases that is used in liquid crystal displays – the "nematic" phase.

In the nematic state, the liquid crystals are naturally aligned. They can be forced to change their alignment by application of an electrical voltage across the crystal. The degree by which they change alignment can be controlled predictably by the amount of voltage applied. As the alignment changes, the polarisation of any light passing through the crystal is affected in a similarly predictable fashion. It is this property that makes liquid crystals suitable for use in display devices.

Liquid crystals are used in displays by sandwiching them between two layers of glass. On either side of this sandwich are placed two polarising layers. These two layers of polarising material have planes of polarisation that are perpendicular to each other. A backlight is placed on one side of the sandwich and the light from this passes through the first layer of polarising material, causing it to be polarised. The plane of vibration of the light is modified by the liquid crystal according to the alignment of the crystal, which in turn is controlled by the voltage across it. This voltage is applied by electrodes on one side of the liquid crystal cell, hence this particular construction is referred to as 'In-Plane Switching'. Finally, the transmitted light reaches the front polarising layer, and the amount of light allowed through this layer is dependent on the plane of vibration of the light in relation to this second polarising layer. By adjusting the orientation of the molecules, the plane of vibration of the light can be modified and thus the amount of light passing through can be controlled.

1.2 Advantages and disadvantages of LCD technology

Viewing angle

LCDs have a narrower usable viewing angle than CRTs due to the features of the technology used. Luminance and contrast can vary significantly as viewing angle changes. LCD devices should be viewed from directly in front of the display. However, it should be noted that recent advances in LCD technology are significantly increasing the usable viewing angle for such displays.

Refresh rate

The technology used to construct flat-panel displays means that there is no “flicker” apparent to the viewer. However, the screen refresh rate is relatively slow compared to CRT displays and so motion artefact can be apparent with moving or fast-changing images.

Luminance

Flat-panel displays are capable of high luminance and can work well in brightly-lit areas. However, they are often not capable of black levels as low as CRT displays and so often suffer from reduced contrast.

Resolution

The resolution of an LCD display is fixed at the time of manufacture. At the native resolution of the panel the resolution is exact. Should it be required to display images at different resolutions, the image data will need to be rescaled before display. This rescaling can introduce distortion in the displayed image.

Displays using CRT technology, however, can easily be switched between different resolutions without noticeable loss in display quality.

Size & shape

Flat-panel displays are, in general, lighter than CRT displays and have a smaller footprint. Their screens are flat, thus providing a more faithful reproduction of the original captured image.

Power consumption

Flat-panel displays consume less electricity and produce less heat than CRT displays.

Focus/sharpness

Where CRTs require careful focussing to produce the sharpest image, LCDs are perfectly sharp – although consideration must be given to any difference in resolution between image data and the display (see *Resolution,* above).

Geometric distortion

In general there is no geometric distortion with flat-panel LCD displays. If images require to be rescaled for display it is possible that this may introduce minor distortion.

Bad pixels and screen uniformity

LCDs can have “stuck” pixels - pixels which are permanently on or off. Some pixels may be improperly connected to adjoining pixels, rows or columns. Also, the panel may not be uniformly illuminated by the backlight resulting in uneven intensity and shading over the screen. The screen glass itself may also contribute to non-uniformity in the displayed image.

2 Evaluation methodology

The evaluation methodology used was based on the AAPM TG18[1] "Assessment of Display Performance for Medical Imaging Systems" document (see the References section of this report), with local variation as required. The devices were evaluated in a darkroom. Devices were evaluated as a complete system, i.e. the performance of the display was not separated from the performance of the supplied graphics controller card.

2.1 Tests performed

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[1] AAPM TG18: American Association of Physicists in Medicine, Task Group 18

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5. Assessment of software performance

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3 Device description

The supplied device was tested attached to a PC loaned to PACSnet by Planar:

Make and model: AMD Athlon 2800+

Operating System: Windows XP Professional version 2002 SP 1

CPU: AMD Athlon MP 2.13 GHz

RAM: 2 GB

HDD: 12.7 GB

Displays supplied:

Three displays were supplied for use during this evaluation. Two of the displays (display 1 and display 2) were 3 MP greyscale displays and one (display 3) was a 2 MP colour display. Displays 1 and 2 were intended for the display of diagnostic-quality images, display 3 was intended to display other information, e.g. patient worklists. All data in this evaluation report refers to the 3 MP greyscale displays unless otherwise noted.

Screen 1:	Model: Planar Dome C3 GRAY
	Part Number 528-0239-00
	Serial Number A3W-11581
Screen 2:	Model: Planar Dome C3 GRAY
	Part Number 528-0239-00
	Serial Number A3W-11596
Screen 3:	Model: Planar PX212M-BK
	Part Number 997-2683-00
	Serial Number A616350S0211K0088

Graphics cards supplied:

The PC had two graphics cards. One (card 1) was dedicated to driving the two high-resolution greyscale displays (displays 1 and 2) and the other was a standard PC video card (card 2), used for driving the colour displays (display 3).

Card 1: DOME DX/PCI

Card 2: ATI Radeon 9800 SE AGP 400 MHz

Memory: 128 MB

Planar Part Number 997-2859-00

3.1 Physical description of device

Figures quoted are those provided in the manufacturer's literature.

3.1.1. Size, weight

Casing dimensions:

The device has the following dimensions when not attached to its stand and in portrait mode:

Height: 485.9 mm

Width: 381 mm

Depth: 101.6 mm

Weight: 6.35 kg

Figure 2. The Planar 3 MP display stand and rear of display unit

3.1.2 Build quality

The displays were of the quality required for use in the expected environments. There were no reasons apparent that would cause any problems in normal use.

Figure 2 shows the rear of the display and its stand. The stand allows for the display to be adjusted for height, tilt and rotation between portrait and landscape orientation.

3.2 Operating conditions

Figures quoted are those provided in the manufacturer's literature.

3.2.1 Temperature and humidity range

Operating conditions:

Temperature: 10 °C to 40 °C

Humidity: 20 % to 80 % Relative Humidity (non-condensing)

Pressure: 860 - 1060 hPa

Storage conditions:

Temperature: -10 °C to 60 °C

Humidity: 30 % to 80% Relative Humidity non-condensing

Pressure: 860 - 1060 hPa

3.2.2 Fluid resistance

The device was not intended for use in areas where it might be exposed to water or other fluids. Its resistance to ingress of fluids was not tested.

3.2.3 Power supply requirements

Supply requirements to transformer:

100 - 240 V AC

50 / 60 Hz

2.0 A

Supply requirements to display

Power consumption:

Max: 90 W

Power saving mode: less than 6 W (USB hub not connected)

3.3 Technical description

Figures quoted are those provided in the manufacturer's literature.

3.3.1 Screen size

528 mm (20.8") diagonal (viewable image size 529 mm diagonal)

318 mm width x 423.9 mm height (in portrait mode)

3.3.2 Screen size – pixels

Available resolutions:

Portrait: 1536 x 2048, 768 x 1024, 600 x 800, 480 x 640

Landscape: 2048 x 1536, 1024 x 768, 800 x 600, 640 x 480

3.3.3 Pixel size and spacing

Quoted pixel spacing: 0.207 mm x 0.207 mm

3.3.4 Refresh rate

60 Hz

3.3.5 Luminance

700 cd/m^2 (typical)

Note that the display was set to a peak luminance below the maximum, to more accurately reflect typical use.

3.4 Display controller specification

Display configuration: Single- or dual-headed, portrait or landscape

Display depth: 8 bits per pixel greyscale up to 2048 x 2560 pixels (1 or 2 heads)

Display memory: 128 MB RAM

Graphics processor: Integrated into the memory controller

VGA controller: Full VGA support on high-resolution displays

Lookup table: 256-entry, 8-bit to 11.58-bit

Refresh rate: Programmable to 200 Hz (for single head)

Video output: Digital data up to 360 MP/S (for single head)

Bus interface: PCI local bus, 32-bit or 64-bit, up to 66 MHz

Power consumption: 20 watts

Software Configuration: Windows® 2000, Windows® XP, and Solaris. Supports DirectDraw compatible applications, and CXtra DICOM calibration software

Display controller palette: 8-bit greyscale, 24-bit truecolor

4 Assessment of display performance

4.1 Geometric distortion

The display was evaluated for geometric distortions by displaying the TG18-QC test image from the AAPM TG18 image suite.

In a LCD, pixel positions are fixed and are determined by the position of the individual cells. Therefore, in a properly designed and manufactured display, there should be no geometric distortion apparent.

In the display under evaluation there was, as expected, no discernible distortion in the horizontal or vertical direction.

To establish that there was no geometric distortion, a test pattern of squares (AAPM TG18-QC) was displayed and the size of the squares measured.

One square:	21 mm x 21 mm
Two squares:	42 mm x 42 mm
Four squares:	84 mm x 84 mm
Full screen horizontal (20 squares):	420 mm (i.e. 21 mm/square)
Full screen vertical (12 squares):	252 mm (i.e. 21 mm/square)

It was demonstrated that there was no measurable geometric distortion in the displayed test image. No distortion was seen in inspection of any other test images used during the evaluation.

4.2 Display reflections

No formal measurement of the reflectance of the display screen was performed. Subjectively, the display reflectance was similar to other displays in its class.

4.3 Luminance response

The display's maximum luminance and display function curve were set using the supplied Planar CXTra software. Use of the software was straightforward. For the calibration, the user was required to select a number of parameters for the calibration:

Measurement units: Metric (cd m^{-2}) or US (fL).

Display Function: A number of different curves are available: DICOM Part 14 Standard; CIE; Exponential; Log linear; linear; or user-defined.

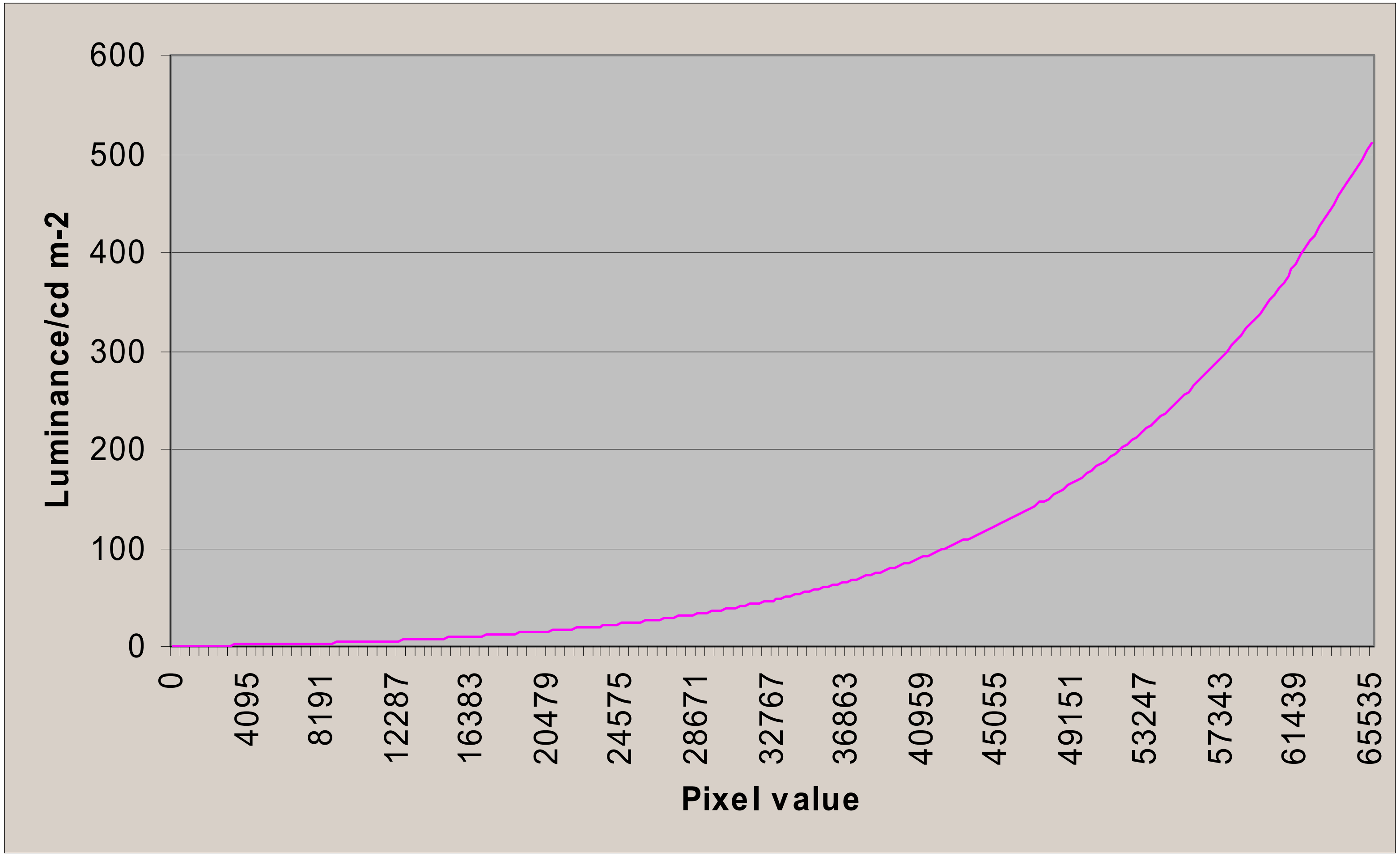
For the PACSnet evaluation, the display was set to the DICOM GSDF[2] using the CXTra calibration software and the display's internal luminance probe.

As can be seen from Figure 3, there is a smooth and steady increase in measured luminance as the image data pixel value increases. The shape of the curve matches that expected for a DICOM GSDF calibration.

Further discussion of the CXTra software can be found in clause 5 of this report.

[2] DICOM GSDF: Digital Imaging and Communications in Medicine Gray Scale Display Function

Figure 3. Luminance response for peak luminance = 500 cd m^{-2}, DICOM GSDF calibration curve



4.4 Luminance uniformity

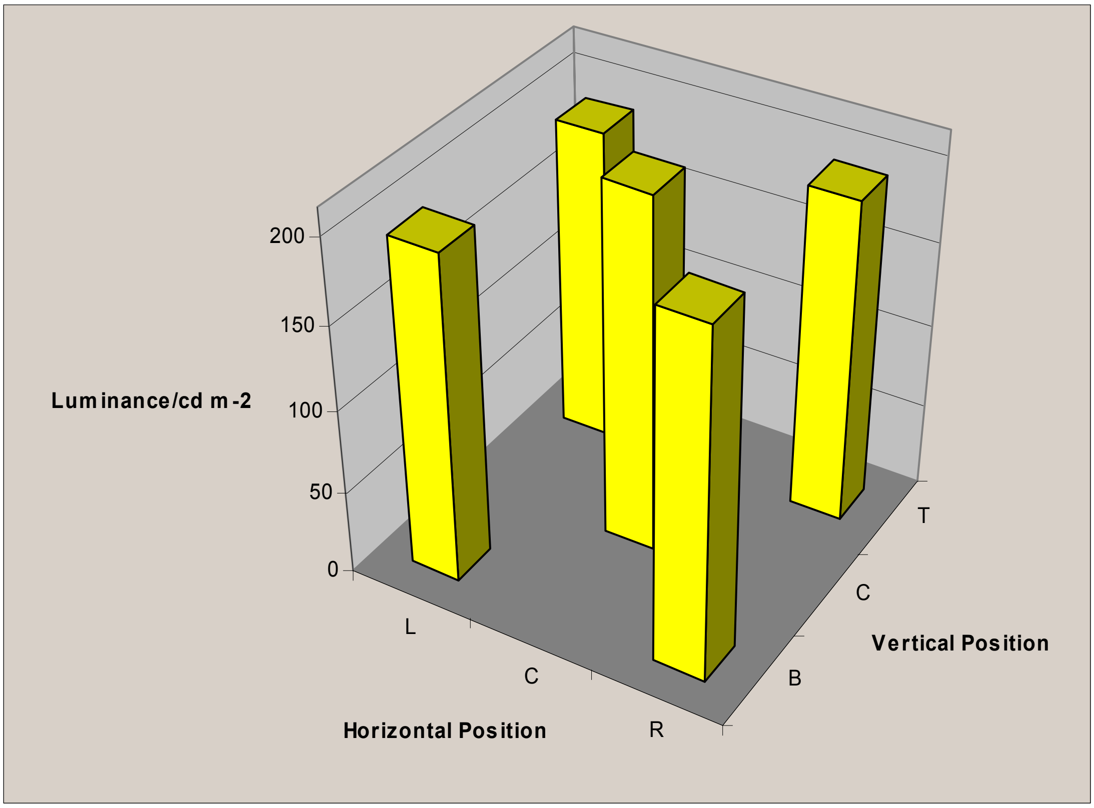
Luminance uniformity was measured by displaying the AAPM TG18 UN and TG18 UNL test image over the entire screen and making measurements of the luminance at 5 points over the screen for each image.

Using the UNL test image and PACSnet's luminance meter, mean results of the measurements (in cd/m2) were:

194		189
	212	
207		196

These results are plotted in figure 4.

Figure 4. Luminance uniformity



The AAPM TG18 Display Assessment protocol states that the maximum luminance variation should be less than 30%, this luminance variation being calculated by the formula $L_{var} = 200 * (L_{max} – L_{min})/(L_{max} + L_{min})$.

In the above case, the maximum variation is

$L_{var} = 200 * (212 – 189)/(212+189) = 11.5\%$

Using the UN test image and using the PACSnet luminance meter, mean results of the measurements (in cd/m^2) were:

2.41		2.38
	2.66	
2.59		2.42

In this case, using the same calculation technique as above, the maximum luminance variation is 11.1 %.

Whether measured using the TG18 UN test image or the TG18 UNL test image, the luminance variation over the display screen falls below the upper limit recommended by the AAPM and is therefore acceptable.

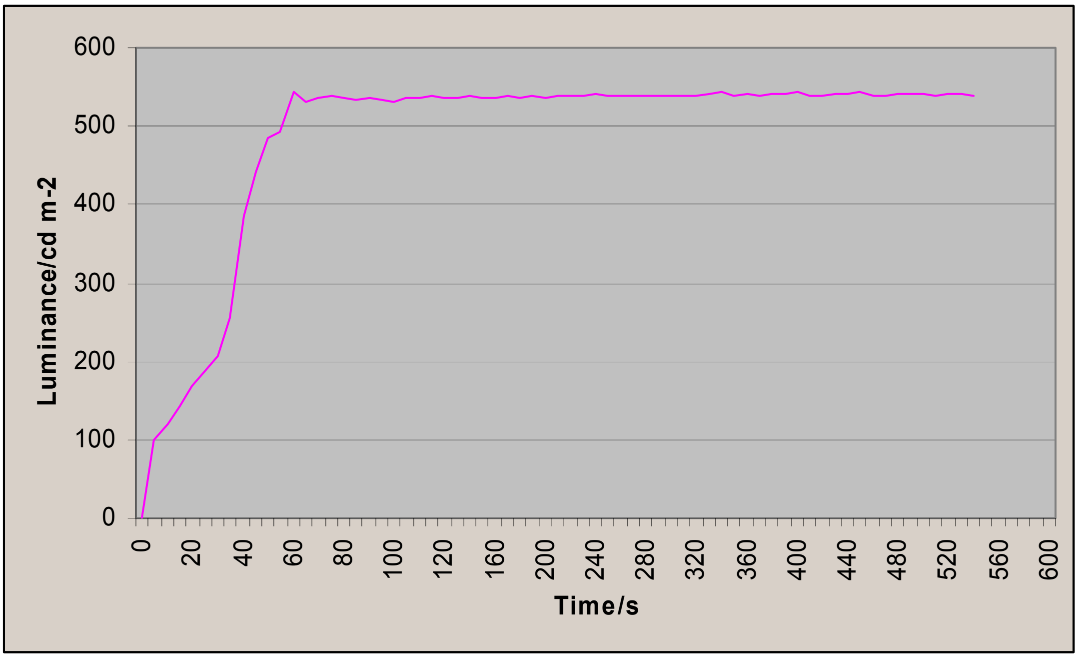
4.5 Luminance stability

The stability of the luminance of the display was measured, both short-term luminance changes following switching on the device and longer-term drift over several hours.

(i) Luminance changes following switching on the device.

To measure the luminance changes here (the “warm-up” time), the system was set up to display a white square at peak luminance at the centre of the display. The display was then powered on and luminance readings taken every few seconds until the display luminance had stabilised. Results are shown in figure 5.

Figure 5. Warm-up time

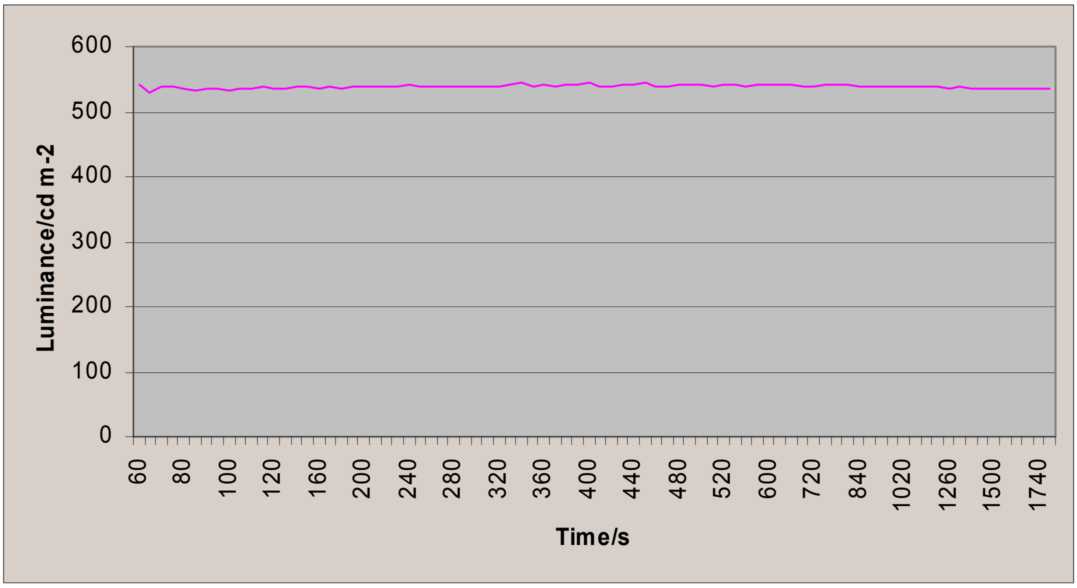


It can be seen that the device reached its target luminance after approximately one minute. In normal use, this would be well within the time required to start up the base PC and for the user to log in.

(ii) Long-term luminance drift.

To measure any long-term drift in luminance, the display was switched on and displayed a test image in the same manner as for the warm-up measurements above. Measurements were taken for a significantly longer period and the results are shown in figure 6. Following warm-up, the device remained at its target luminance.

Figure 6. Luminance stability



It can be seen that over the measurement period there was no significant drift in the peak luminance value measured.

4.6 Contrast ratio

The contrast ratio was measured using the method described by the American National Standards Institute (ANSI). This requires the display of a 4 x 4 “checkerboard” pattern, with eight areas at peak white and eight areas at black. The luminance of each of these areas is measured and the luminance ratio is calculated by dividing the mean luminance of the white areas by the mean luminance of the black areas. The display is masked, apart from an aperture for the area being measured, during this test.

Results:

Mean white luminance: 479.75 cd m^{-2}

Mean black luminance: 0.45 cd m^{-2}

Calculated contrast ratio: 1066:1

The calculated value of 1066:1 for the contrast ratio comfortably exceeds the minimum value of 400:1 recommended by the AAPM and is therefore acceptable.

The contrast ratio is quoted at “600:1 (typical)” in the Planar specification sheet for this display.

4.7 Spatial resolution

The display resolution was evaluated using the AAPM TG18 test image. As expected, the limiting factor for the resolution was the size of the pixels. With test images displayed at 1:1 image pixel:display pixel (i.e. at 1536 x 2048 pixels image size) there was no loss of spatial resolution.

4.8 Display noise

No objective measurement of display noise was possible since this requires use of specialist imaging equipment which is not within the PACSnet armoury.

Subjectively, however, noise levels appeared very low and did not interfere with use of the displays.

4.9 Angular dependency of luminance

The apparent brightness of displays can vary considerably with viewing angle. This is especially true for LCD flat-panel displays. This variation of luminance can affect not only the perceived brightness of the displayed image, but also its contrast. The same image viewed from different angles can convey quite different information. This can often be undesirable – for example, two people sat side-by-side looking at the same screen will expect to see the same image – but can sometimes be desirable, for example when personal information is displayed on screens in public areas. In this second case, if the useful viewing angle is very narrow then viewing the information on the screen can be restricted to a person positioned directly in front of the screen only.

Figure 7 shows the variation of peak luminance as viewing angle varies horizontally and figure 8 shows the variation of contrast ratio as viewing angle varies horizontally. Figures 9 and 10 show the variation of peak luminance as viewing angle varies horizontally and vertically, respectively. Each set of measurements was made with the display in landscape orientation.

Figure 7. Variation of luminance with viewing angle - horizontal

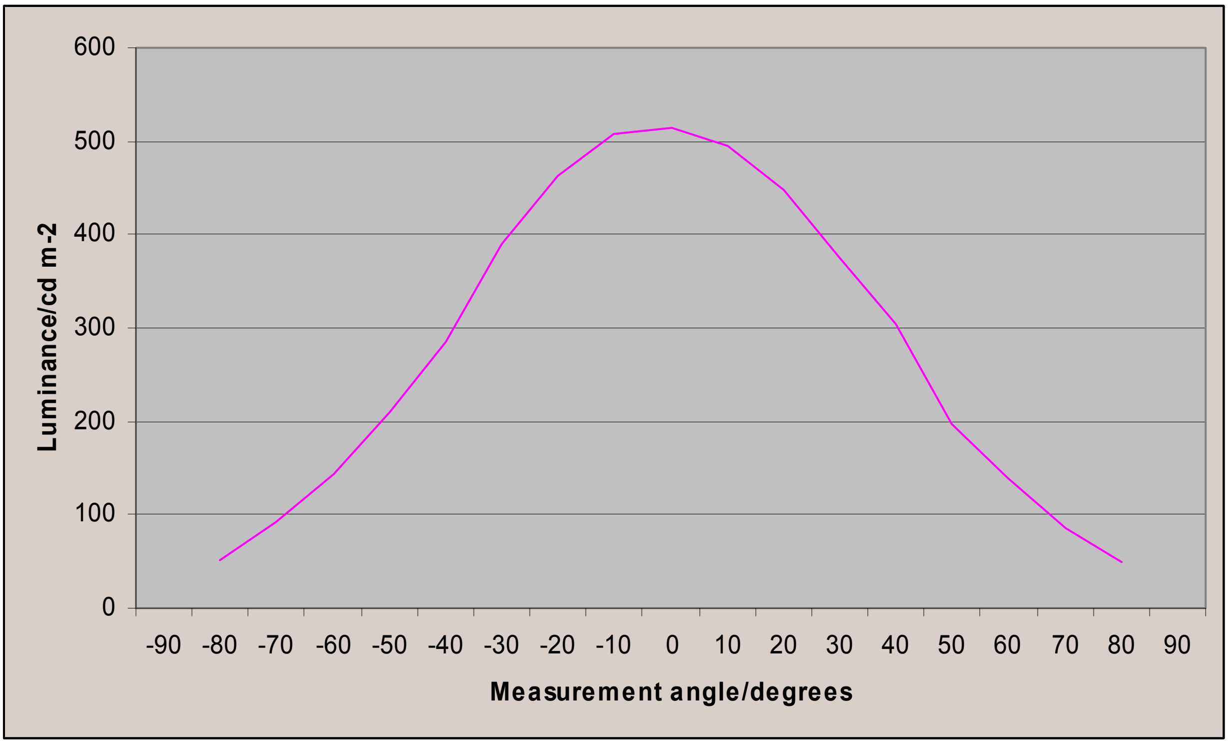


Figure 8. Variation of luminance ratio with viewing angle - vertical

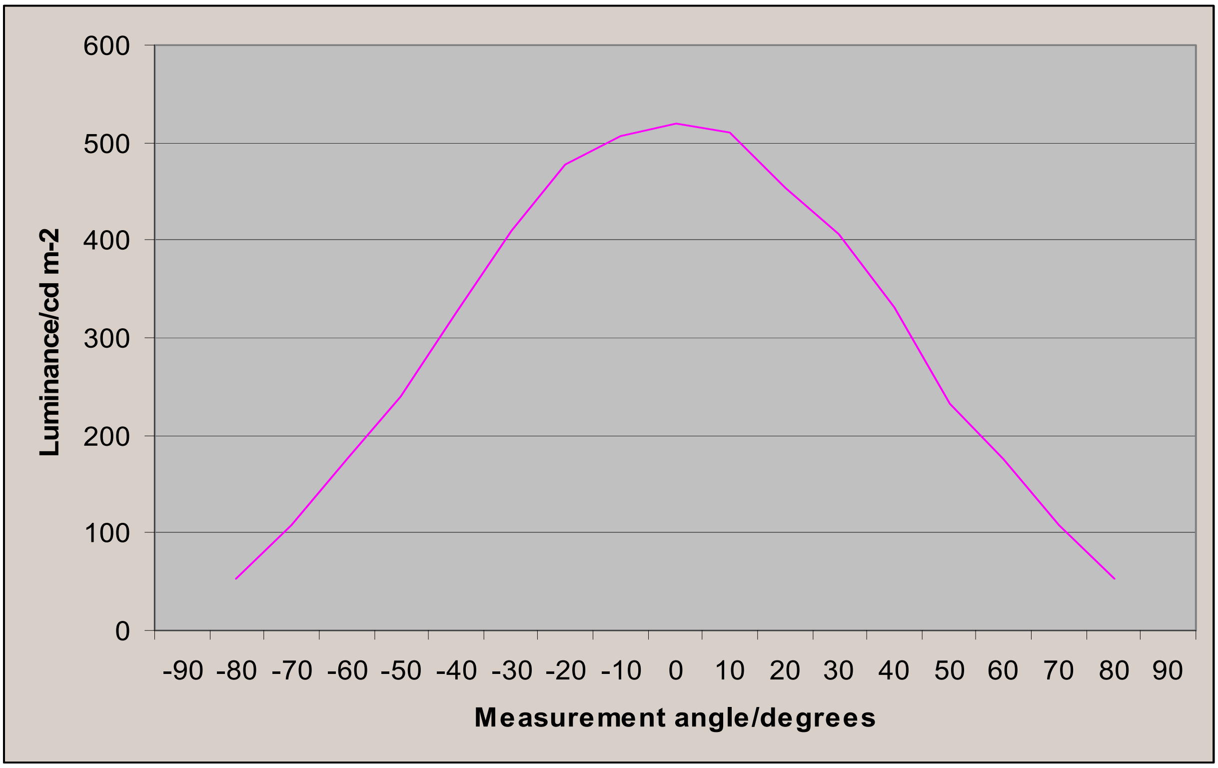


Figure 9. Variation of contrast ratio with viewing angle - horizontal

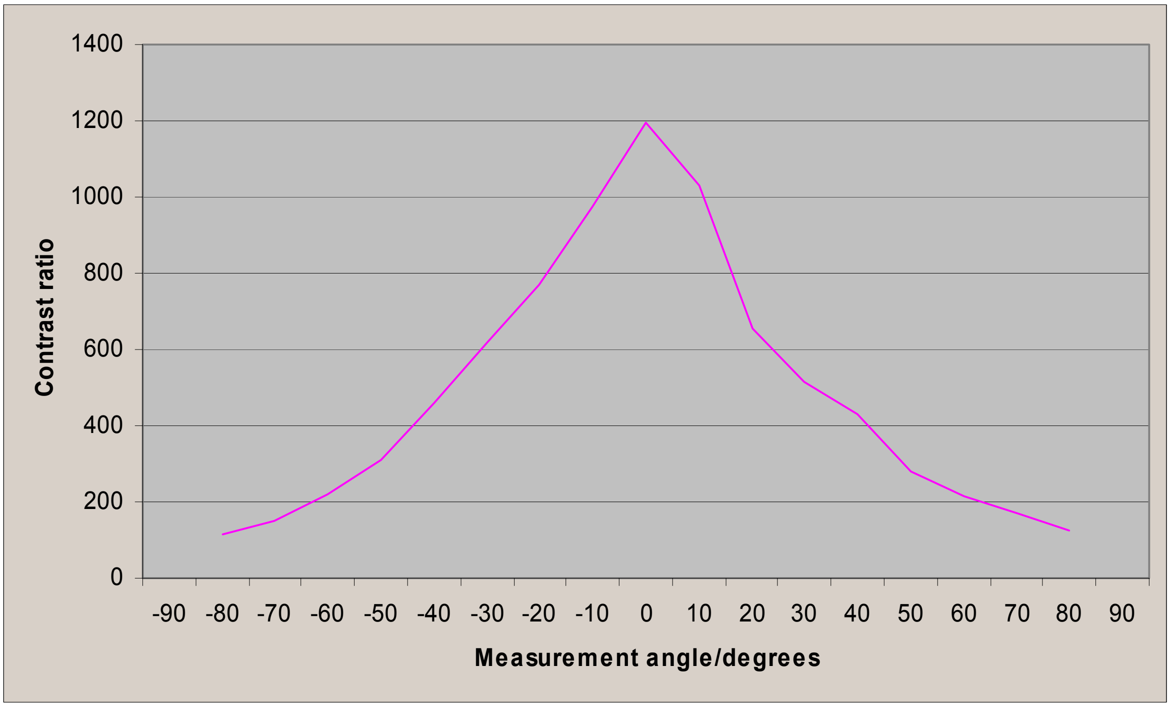
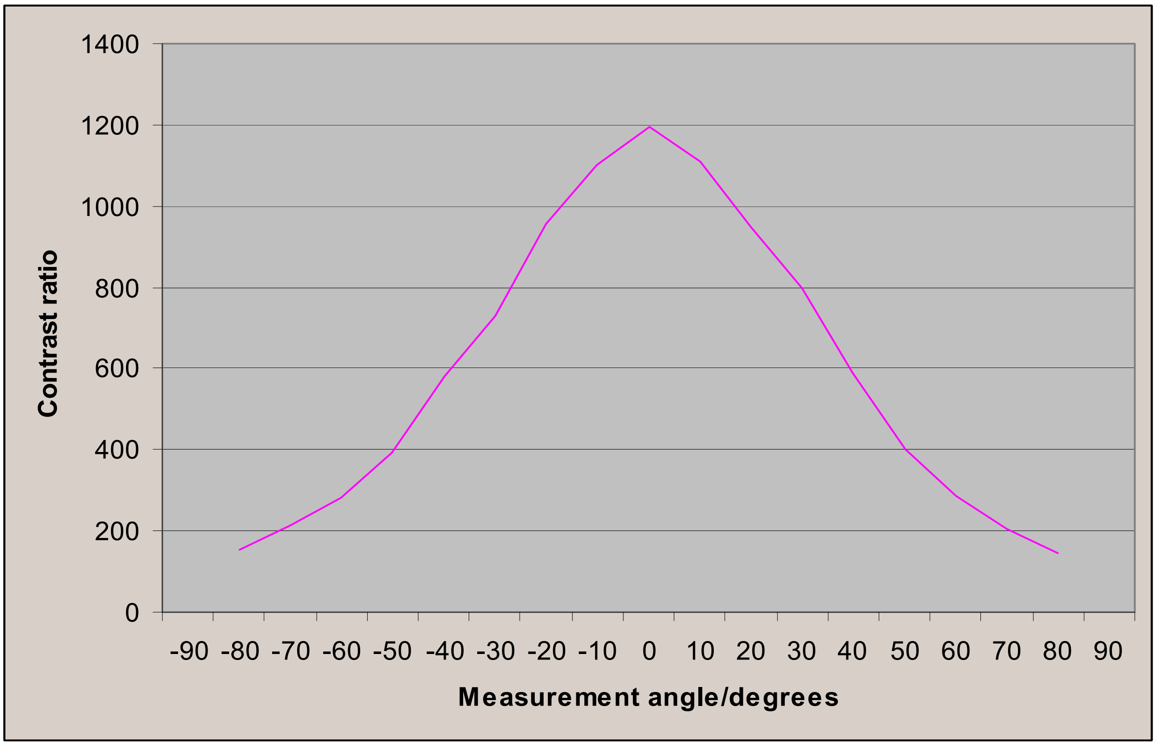


Figure 10. Variation of contrast ratio with viewing angle - vertical



4.10 Electronic cross-talk

Cross-talk is the unwanted leakage of electronic signal from one channel to another, usually adjacent, channel. In liquid crystal display systems this can lead to the intended luminance of a pixel (i.e. the intended voltage across the liquid crystal cell that forms the pixel) being modified away from the intended value.

There was no effect from cross-talk apparent on a visual inspection of the displayed image.

4.11 Pixel defects

There were no pixel defects apparent to a visual inspection of the display.

5 Assessment of software performance

5.1 Description of functionality offered

5.1.1 Display calibration software

The displays and the graphics card were supplied with Dome's 'CXTra' software. This software allows a display's calibration to be verified. It also allows the peak luminance of the display to be varied up to the maximum available from the backlight.

Calibration verification using the CXTra software is made using 256 calibration points. Calibration can be made to other calibration curves, i.e. to the DICOM[3] Part 14 Greyscale Display Function (GSDF), an exponential curve, a native calibration or no calibration. The CXTra software also allows the calibration to be checked and also keeps a record of calibration conformance and error logs.

The first stage of a calibration verification involves entering the various data values used in the automatic calibration. The minimum luminance, the maximum luminance, the number of points to be used in the calibration and the number of points to be used in the calibration check must all be entered. The user must also select the type of calibration curve to be used – in this case, the DICOM Part 14 GSDF.

Once the various values have been entered, the calibration verification can proceed. The calibration square is displayed on the screen and the luminance probe must be placed over this. See figure 11.

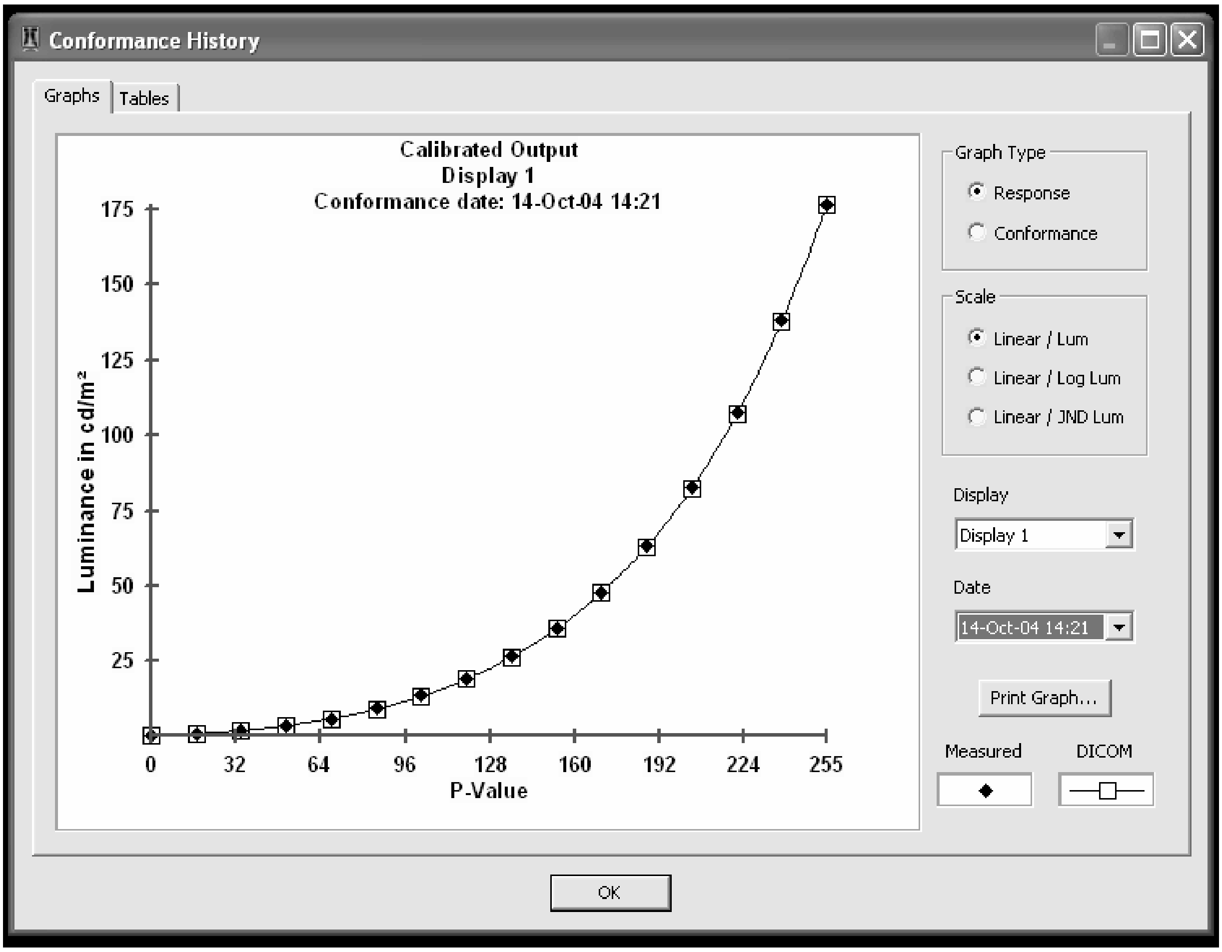
In order to perform the calibration verification, the software displays a square at the centre of the display. The Planar luminance probe is then placed over this square and the luminance measured. The square cycles through the chosen number of calibration values, the luminance being measured automatically with each new value.

[3] DICOM: Digital Imaging and Communications in Medicine

Figure 11. Calibration verification using the luminance probe

Following a calibration check, the software can display the results of the check, either as a table or a curve. A typical curve showing the results of a calibration check is shown in figure 12.

Figure 12. Look-up curve applied to input image data values



5.2 Testing functionality and ease of use

The various features of the Dome CXTra software were evaluated. The software was efficient and effective in use, adding useful extra functionality to the standard Windows features.

The CXTra software proved to be a useful tool. Calibration of the displays was automatically performed to the DICOM Part 14 Greyscale Display Function, as was checking of the calibration.

6 Conclusions

The Planar 3 MP LCD Flat-panel display is a well-manufactured product, with features that make it suitable for use in diagnostic medical imaging, including high contrast ratio, little luminance variation across the screen and good luminance stability over time. As is expected of displays using LCD technology, there is no geometrical distortion in the displayed image.

The display also offers good conformance to the DICOM Part 14 Greyscale Display Function, particularly when used in conjunction with the CXTra software.

7 References

AAPM On-Line Report No. 03: Assessment of Display Performance for Medical Imaging Systems, American Association of Physicists in Medicine (AAPM) Task Group 18, April 2005.

Digital Imaging and Communications in Medicine (DICOM) Part 14: Greyscale Standard Display Function, National Electrical Manufacturers Association, 2003

Data Projection Equipment and Large Screen Data Displays -- Test Methods and Performance Characteristics, American National Standards Institute (ANSI) IT7.215-1992, 1992.

8 Bibliography

Electronic Display Measurement: Concepts, techniques and instrumentation. Keller, Peter A., John Wiley and Sons, New York, 1997

Appendix 1: Luminance meter

The luminance meter used in this evaluation was a Hagner S3 Universal Photometer/Radiometer. This is a combined luminance and illuminance meter.

The light sensitive components of the meter are two silicon diodes, each filtered to give a spectral response close to that of the human eye (i.e. the spectral response correlates with the CIE 'standard observer' curve). One of the diodes is internal and is used for the measurement of luminance within a 1° circular field. The second, external, diode is used for the measurement of illuminance and was not used in this evaluation.

The meter is portable. It can be powered by either an internal 9V battery or an external 9-12 V DC power supply. The measurement range of the meter for luminance is 0.01 – 200,000 cd m^{-2}, with a quoted accuracy of ±3 % (±1 in the last digit). Its focussing range is 0.5 m - ∞. Polarised light (such as that typically emitted from an LCD flat-panel display) is measured correctly.

The dimensions of the meter are 270 mm x 130 mm x 70 mm. Its weight is 1.4 kg (or 2.0 kg in its carrying case).

Appendix 2: Manufacturer's comments

The following comments have been received from Planar regarding the contents of this report:

Note: The Dome C3 monitor has been replaced with its successor model Dome C3i. Apart from further performance improvements the Dome C3i is offered with a standard 10 year backlight warranty. More details can be found at www.planar.com/products/medical_displays_solutions/medicaldisplays.html

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20th September 2005