

## Liquid Crystal Display (LCD) Monitors for ECDIS Applications

### Update Report

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This report assesses the visual quality of LCD display monitors for ECDIS<sup>1</sup> application. It is based on evaluation of a stand-alone model from NEC which employs the latest (as of August 2001) liquid crystal technology, providing high brightness, high contrast ratio and wide viewing angle. It also measures the screen performance of a 14" Toshiba notebook computer display, for application of a notebook computer to ECDIS.

The study concludes that the stand-alone LCD display is capable of reproducing ECDIS colours, with several caveats:

- A new calibration procedure is necessary to account for the different display properties from CRTs. This is particularly important for characterising lower luminance colours
- For night viewing, the display must be modified to reduce the backlight luminance level
- The display does not perform well when viewed off axis

There is additional opportunity to use the broader performance envelope of the LCD display to provide a brighter display for daytime use on the bridge

The notebook computer display exhibited disappointing performance, and showed inadequate contrast to reproduce the full colour range required for ECDIS, and very poor off-axis viewing performance, resulting in performance unsuitable for general use on a ship's bridge.

The study revealed that there are some performance advantages available from flat panel LC displays. They are more than twice as bright as a CRT is, and as a result offer better daytime viewing in high ambient light situations. The brightness adjustment on an LC display works independently of the colour channels (unlike the CRT) so it can be operated without affecting the colours on the screen. This makes the control much more useable to the mariner.

The study also revealed that the CRT calibration procedures used for ECDIS will not work for LC displays. A calibration model was used for this evaluation, but it needs further refinement to be practical.



<sup>1</sup> Electronic Navigation Chart and Display System

## Introduction

In 1999, an initial LCD performance evaluation report was prepared. It showed that liquid crystal (LC) technology was not ready to provide the performance required for precise ECDIS use. The displays tested lacked contrast, light output, and colour range. They would not darken sufficiently for night use, and they severely distorted colours when viewed off axis.

In the ensuing two years, much development has taken place. Displays are brighter, higher contrast, offer a wider colour range, and make wide viewing angle claims.

This report is an update on the initial performance evaluation three years ago. It evaluates the visual performance inherent in the display, and attempts to perform calibrations of the target displays.

The report starts by reviewing the performance trends in flat panel displays, and goes on to evaluate the measured performance of two displays. It concludes with a discussion of performance areas for further evaluation, and some ideas for improving the compatibility between LCD performance and ECDIS requirements.

## LCD Performance Trends

Display manufacturers view the personal computer as the primary target market for their LCD flat panel displays. The volumes in this market are causing broad-based performance improvements, and ongoing cost reductions.

Initial panels introduced to this market were relatively small, (13" and 15"), and had limited colour, contrast and brightness. They were also expensive, and difficult to justify in comparison to a higher performance, lower cost CRT display. All this is changing. Panel sizes have increased; resolution, colour, contrast, brightness, and viewing angle have all seen major improvements; the cost is dropping at the same time.

Improved performance is being demonstrated in a number of areas.

- **Resolution:** Inexpensive panels are available supporting XGA resolution (1,024 x 768). Panels of SXGA (1,280 x 1,024) are readily available but more expensive, and panels of UXGA (1,600 x 1,200) are recently available on the market, and QXGA (2,048 x 1,536) are being demonstrated
- **Panel Size:** 18 and 20 and 22 inch panels are readily available. Larger sizes – up to 32" have been demonstrated. It is interesting to note that the 32" size is being developed for high end consumer digital television, which should have cost and performance benefits
- **Light Output:** Panels consistently output greater than 100 cd/m<sup>2</sup>, and many will deliver 200 cd/m<sup>2</sup>. Some speciality companies offer up to 1000 cd/m<sup>2</sup> through backlight modification. This development will bode well for the ECDIS market, where higher luminance displays could benefit viewing in very bright situations, such as sunlight on diffusing fog
- **Dark night application:** Manufacturers, in particular some involved in ECDIS displays, are developing backlight controls with very high dynamic range, suitable for dimming the display for night time application
- **Colour Resolution:** True 24 bit performance (8 bits per colour) is now available. This provides full colour resolution without dithering or added noise to achieve the correct overall colour

## LCD Tests

To evaluate the application to ECDIS, two displays were tested. The first is the NEC Multisync 1810X, a relatively recent product with NEC's XtraView wide viewing angle technology. The second display was a

14" notebook computer display, on a moderate to high end Toshiba notebook computer. This display was included in the evaluation to test the viability of a portable ECDIS system.

The NEC LCD measured is representative of state of the art LC performance. It offers the highest contrast ratio, and widest viewing angle of commercially available LC panels. The operation element on the panel (the glass, liquid crystal and drivers) are comparable to the elements used in most high performance speciality LC displays.

The tests consisted of the following:

- Measure overall brightness and contrast ratio
- Measure the colour co-ordinates of primary colours at a number of levels of brightness
- Measure the input value to output luminance of the display for each colour (transfer function)
- Measure the colour performance at a 45° viewing angle
- Measure the colour shift occurring with reduced backlight intensity
- Observe the interaction of Polaroid sunglasses with the display

The results are discussed in the next sections. Detailed results are tabulated in Annex 2 of the full report, available from the author, by request.

The overall performance is summarised in Table 1, see following page.

It was noted when measuring these displays that the conventional approaches used to calibrate CRT monitors would not work with LCD displays. Due to backlight leakage (see Performance Issues section) a modified calibration procedure was used to account for this difference.

## Performance Issues

A number of performance aspects for each of the NEC and Toshiba displays need more discussion, which will be given in the context of calibration procedures.

1. **Contrast Ratio and Backlight Leakage:** LCDs will not fully turn off when given a black signal. This is because the liquid crystal modulators in the display are not 'perfect', and as a result some light leaks through when the display is supposed to be turned off. The result of this is to add a small amount of white to every colour in the display. This reduces colour saturation, and reduces the usability of the display at night.  
In the NEC display measured, the leakage was 1/400 of the peak white, or about 0.5 cd/m<sup>2</sup>. This amount of light is greater than the darkest colours in the LOW\_BLACK table. This drives the need to be able to reduce the level of backlight illumination for adjusting display brightness. Achieving the dark tables by reducing the backlight also reduces the amount of contamination introduced to the targeted, leaving the possibility to achieve correct colour performance. In this report, this is referred to as backlight leakage.
2. **Colourimetry and Colour Gamut and Colour Calibration:** (For a description of colour gamut, see the sidebar 'Colour Gamut') Calibration was performed with the new IHO 3 table colour set.  
As mentioned above, when the LCD panel is set to black, (Input values of 0,0,0), there is some residual light that leaks through the LCD from the backlight. The effect of this backlight leakage is to contribute to any colour on the screen, and to diminish the ability to achieve saturated colours as the display gets darker, thus reducing the colour gamut with lower intensities.  
As a result, this causes the colour of the Red, Green and Blue primaries to change depending on the luminance level applied. A more complex display model needs to be used in calibration to account for this. For this study, a methodology was developed which accounts for the backlight leakage, and nulls it out of the calculation.

<b>Performance Summary</b>			
<b>Parameter</b>	<b>ECDIS requirement</b>	<b>NEC 1810X</b>	<b>Toshiba Satellite 3000</b>
<b>Resolution</b>	1,280 x 1,024	1,280 x 1,024	1,024 x 768
Notebook computers with their smaller displays tend to support lower resolution.			
<b>Brightness</b>	80cd/m <sup>2</sup>	208 cd/m <sup>2</sup>	126 cd/m <sup>2</sup>
Both displays have sufficient brightness. Of note is that the colour of white at maximum brightness is not the same as the colour specified for ECDIS, so correction will be necessary. This reduces the overall luminance output of the display. At a 45° viewing angle, the brightness on both displays diminished substantially, so a properly calibrated display will be too dim when viewed at 45° horizontally off axis.			
<b>Contrast Ratio</b>	Not specified	400:1 measured 300:1 specified	200:1
Contrast ratio is not specified for ECDIS displays. Contrast ratio compares brightness of peak white to the amount of light that is leaking through the display when it is turned to black. This leakage is very critical because it is always present and adds contamination to the desired colour. The effect is to wash out or desaturate the colour and is most pronounced on lower brightness colours. (See below)			
<b>Colourimetry / Calibration</b>	Must have large enough colour gamut to display all specified colours	Wide enough on axis. Magenta colour is slightly beyond the display capability, but within tolerance.	
See discussion below.			
<b>Viewing Angle</b>	Should be clearly visible to more than one observer (IMOPS 9.4)	Limited. Colour and brightness shifts below 45° off axis	Poor. Colour and brightness shifts well before 45°
See discussion below			
<b>Night Table Performance</b>	Must meet colour parameters defined	Backlight does not reduce sufficiently to achieve all colours	Back light does not reduce adequately to achieve all colours
See discussion below			
<b>White Point</b>	X=.280, y=.310	X=.320, y=.330.	X=.328, y=.340
Tuning the display to the required white point reduces light output and decreases contrast ratio. In the case of the two displays measured, there is adequate performance headroom to accommodate this.			
<b>Colour Depth</b>	24 bit	24 bit	<24 bit
A grey ramp exhibits slight luminance banding and colour shifting – indicating that the display is not capable of outputting true luminance values for all colours.			
<b>Polarisation</b>	Not Specified	Works with Polaroid glasses	Works with Polaroid glasses
Because the LCDs are polarised, they will interact with Polaroid sun glasses. Both displays had orientations which were compatible with Polaroid glasses. This puts a limitation on the orientation of the display – it must not be rotated 90° or it will extinguish with polarised sun glasses.			

Table 1: Performance Comparison Summary

Using this method, colour calibration was successful for the NEWDAY\_BRIGHT table. To achieve the correct luminance in the colours, the brightness control on the display was used to reduce the back light to 59 per cent of its peak value. This allows some headroom to brighten the display beyond ECDIS specifications, from 80 cd/m<sup>2</sup> to 135 cd/m<sup>2</sup>. The colour points are shown in Figure 1. Successful calibration can occur only if all the points are within the colour gamut available in the display (the triangle on the graph). This figure shows that the magenta colour point is slightly outside the capability of the NEC display. In the case of this display, it is within tolerance allowed.

Colour calibration of the HIGH\_BLACK table was likewise successful. It was calibrated with the display

set for minimum display brightness – about 21 per cent of peak brightness. The same magenta colour was slightly out of gamut, but within tolerance.

Colour calibration for LOW\_BLACK failed. The contamination due to backlight leakage was too large, and resulted in too much desaturation of the display colours. This failure was corrected by reducing the display output further with neutral density filters to 3 per cent of peak value.

3. **Viewing Angle:** The display on the bridge will not always be viewed directly on axis. While great strides have been made to address a wider viewing angle, there are still some significant shortcomings

NEC specifies a viewing angle of  $160^\circ (\pm 80^\circ)$ . This specification does not hold for critical viewing. At  $\pm 45^\circ$ , measurements showed that the light output diminished by a factor of 2 and the display colour shifted significantly towards blue compared to on-axis viewing. This creates a non-ideal viewing condition, where colours will not be true, although relativity will be maintained for high brightness colours. Lower brightness colours experience a higher degree of colour shift – in fact very low brightness colours will shift so far that the colour relationships invert and produce a negative of the original image

While Toshiba does not specify a viewing angle, worse performance degradation occurred, with luminance diminishing by a factor of almost 6 and lower luminance colours inverting - taking on their opposite hue due to the characteristics of the display. Additionally, the Toshiba display performance degraded rapidly with off axis viewing in a vertical direction. Just  $10^\circ$  off axis resulted in the contrast ratio reducing to 35:1. Reduction in contrast results in a display where actual colours on the screen will be significantly more washed out and hence more easily confused. The Toshiba display is not suitable for any off axis viewing

Viewing angle is a significant factor in the usability of the display on the bridge. For application on the bridge, these shortcomings must be considered, and provided for in practical implementations through swivel mounts or restricted viewing angles

4. **Night Tables:** To achieve the dark night performance, the displays measured were too bright for any setting of the brightness (backlight) control. In the case of the NEC display, it was possible to adjust the luminance by a factor of about 5 using this control. This left a peak brightness of more than 40 cd/m<sup>2</sup>. The LOW\_BLACK table has luminance values ranging from 0.1 to 5.0 cd/m<sup>2</sup>. To achieve the LOW\_BLACK colours, with the display set for 40 cd/m<sup>2</sup> it is necessary to use very low input (DAC) values. Lower values operate with significantly reduced colour gamut, resulting in the inability to achieve the required colours and required colour separations. The display was not able to achieve all the required colours for the LOW\_BLACK table.

To achieve acceptable performance, the display luminance must be further reduced through backlight control. A number of ECDIS manufacturers are providing modified backlight controllers which have a very wide control range, thus allowing the display to be set to achieve the colours required for the LOW\_BLACK table

5. **Natural White Point:** The natural white point is the colour of the display where the Red, Green, and Blue channels are fully driven, and therefore represents the brightest performance available from the display. ECDIS has defined a white point which is different from the natural white point of LCDs. White point can be adjusted electronically, but only by reducing the output of one or two of the red, green, or blue channels. This causes the display to work less efficiently and thus reduces the light output, dynamic range and contrast ratio of the display – all bad things for ultimate display performance.

Better system performance could be achieved by using a set of colours which represents the 'sweet spot' of the flat panel display performance. This would mean tuning the colours for the different white point of the LC display. This would result in a display that has higher brightness capability than available in a CRT, and provides equivalent colour differentiation in all operational modes.

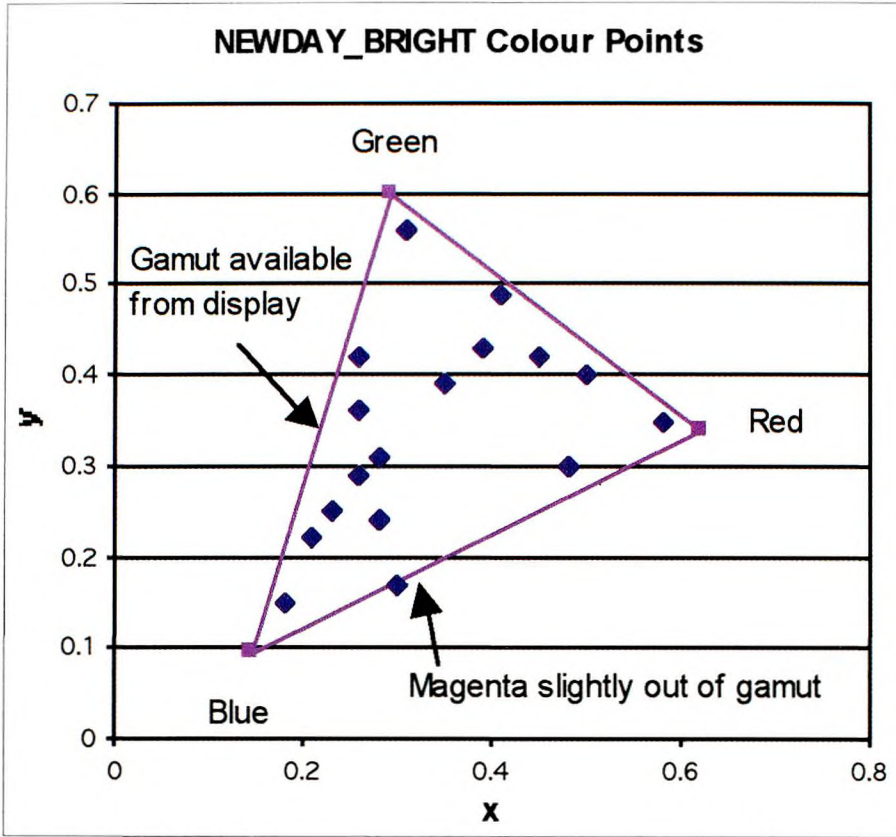


Figure 1: Plot of colour gamut of the NEC 1810x display and colours of NEWDAY\_BRIGHT. All colours are within the gamut of colour (triangle) possible from the display, with the exception of the magenta colour (noted on plot), which is outside gamut but within tolerance for the colour table

This does raise the issue of operating with different colour tables depending on the display type used. While this concept may be compatible with the latest thinking of the Colour and Symbols Working Group<sup>2</sup> for emphasising colour separation over absolute colour, it is outside the scope of this report to address this beyond the scientific possibility

6. **Bitdepth:** Bitdepth is the display's ability to show unique colours for every input value. For example, a 6 bit display will have only 2<sup>6</sup> or 64 steps per colour, an 8 bit display has 256 steps.

The NEC LCD display was tested with a uniform grey ramp input signal. The ideal display will show a totally uniform colour of grey across the ramp. The NEC LCD showed some slight coloration in several places on the ramp. These show that the response is not exactly linear, and some errors are occurring in the digital processing in the display. On evaluation, the errors were less than 1 bit (in 8) and quite useable for ECDIS

7. **Temperature Performance:** One aspect that was not tested was colour shift with temperature. All ECDIS must satisfy IEC 945 requirements for environmental conditions. Historically, LC performance has varied considerably with temperature, and significant colour variations would be expected. The newer generation of LC materials with higher contrast have reduced this effect. It should be noted that the results of this report were measured at room temperature, and do not consider any temperature related effects

8. **Brightness Control:** The brightness control on the LCD display controls the intensity of the light that pass-

<sup>2</sup> Working Group of the International Hydrographic Organisation



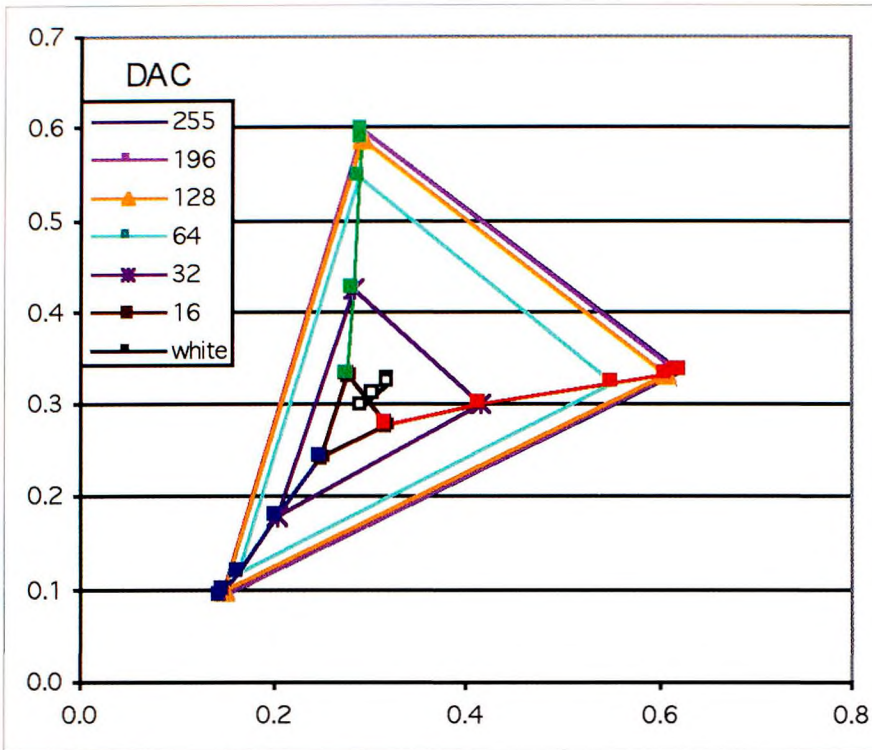


Figure 2: The outside triangle represents the colour gamut at full brightness of the display. With reduced input values (DAC values), the light output diminishes, and the colour gamut decreases, as shown by the smaller triangles due to the backlight leakage. This effect reduces the capability to show a wide range of darker colours, and poses difficulties for using the conventional calibration routines for CRTs

es through the display. It affects all colours uniformly. That means that user adjustment of this control will not upset the colour balance of the display, and all colours will remain the same, only the intensity changes. This is in contrast to the CRT, on which user adjustment of the brightness control causes lower intensity colours to disappear from the screen, resulting in destruction of some colour. This means that the brightness control may be fully accessible to the user without the danger of eliminating colours from the screen

Based on these tests, the NEC display, if given a wider range of backlight control, and limited viewing angles appears to be suited for ECDIS display use, achieving all colours in all colour tables. The Toshiba display has very poor off axis viewing characteristics, resulting in the need to view the display from a single on-axis viewpoint only, rendering it unsuitable.

## Development Issues

From the performance envelope measured, it can be concluded that flat panel displays have significant potential for ECDIS application.

With further and probably minimal engineering effort, it appears that the display can operate so as to meet the requirements currently set out in IEC 61174<sup>3</sup>. There is a larger opportunity to take advantage of some of the flat panel display properties to make a better picture than currently specified. This will occur through altering the IHO colour and brightness specifications to take advantage of LCD performance. In the process, an accurate and practical calibration procedure needs to be developed.

### 1. Display Development

The display performance for dark night is greatly improved if the overall brightness is managed by the backlight, as discussed above. Engineering work to provide a higher range of control over the backlight

<sup>3</sup> IEC 61174: ECDIS - Operational and performance requirements, methods of testing and required test results

will enable this. (Several ECDIS display manufacturers have implemented this.) In the absence of effective backlight control, the display brightness can be controlled by using inexpensive plastic neutral density filter material on top of the screen. This is clearly not a practical long term solution, but will work for limited use.

## **2. Calibration development for LCDs**

Display calibration remains an important aspect of ECDIS. ECDIS probably represents one of the most exacting applications of display technology, because:

- A very large amount and wide variety of display information has to be presented, distinguished and prioritised
- The information must be accurately displayed at very low luminance levels for night application
- The costs of making an error in recognition on the display are potentially very large

These points continue to be valid for all classes of displays potentially used for ECDIS, and drive the necessity to get the maximum performance from the display – which requires effective colour specification and calibration.

The process used in this study to calibrate the current displays required a relatively expensive spectrophotometer. The mathematical tools used were performed manually in computer spreadsheet. This is not practical for widespread application.

An accurate and practical calibration process needs to be developed. This process will account for the backlight leakage and its effect on colours displayed. A basis for this process is outlined in Annex 4 of the complete report available from the author. This needs to be further verified with a wider population of displays, and the process developed into a standard procedure.

## **3. Specification Development to Take Advantage of LCD Performance Envelope**

Flat Panel LCDs use different physical mechanisms from CRTs in creating a colour image for the user. The current ECDIS luminance and white points were set considering the limitations of the CRT display. Thus:

- Luminance is specified at 80 cd/m<sup>2</sup>. This was to accommodate the physical limitations of the CRT. The LCD has the potential to achieve 10 times this level and clearly this could be advantageous in very bright viewing conditions. The question remains whether the colour set is acceptable under IHO/IEC<sup>4</sup> specifications if the display is significantly brighter than current specifications
- Brightness Adjustment by the user: The brightness control on the CRT controls the black 'cut-off' of the display. It has the potential to lose low luminance information, so misadjustment of this control will cause lower luminance colours to change, and some low luminance details could be lost altogether. The Brightness adjustment on an LCD display changes the level of the backlight, independent of the colours on the screen. Backlight controllers under development have the ability to change backlight illumination by a range of up to 50 times, giving the user a very wide operating range for the display. Colour relationships should remain unaffected with this level of adjustment. In particular, controlling the display properties for dark night colours is a problem in CRTs. The display is only exercising 6 per cent of its dynamic range, and consequently achieving precise colour control at the bottom of the range is difficult. This is more easily achievable by using the back light to reduce the peak brightness of the LC display, allowing it to operate over its full electronic dynamic range. This was simulated using plastic neutral density filter, to achieve the effect of a darker backlight
- Peak Efficiency and white point: The maximum light output occurs at a different white point from ECDIS. For flat panel use, it would make sense to alter the white point to operate the display more

<sup>4</sup> International Hydrographic Organisation/International Electrotechnical Commission



efficiently. Alteration of the target white point will require changing the specification of most of the IHO colours to maintain sufficient perceptual colour separation

- Contrast – On to Off: The display's ability to achieve the required colours is dependent backlight leakage, and is measured as contrast ratio of the display. This also affects the visual relationship between black and other colours. The contrast capability of the display needs to be included in a comprehensive specification. This may be implied by specifying the acceptable luminance for black level – either as a ratio of peak white or in absolute terms
- Adjusting the specifications for colours will take advantage of the LCD's performance differences, and offers:
  - Higher maximum brightness
  - Very wide range of user brightness adjustment through backlight control
  - Higher efficiency of operation (better contrast, higher light output) through re-targeting the defined white point in ECDIS
  - Better control over night colours
  - Work would be required to specify. Set tests for and qualify new colour performance characteristics

## Conclusions

Performance of flat panel displays has improved substantially since evaluations performed 2 years ago. Their performance envelope has the potential to offer some significant benefits over and above the capabilities of CRT displays.

The stand alone LCD panel (NEC Multisync 1810X) was able to be calibrated to achieve proper colour and luminance for the NEWDAY\_BRIGHT and HIGH\_BLACK tables. The LOW\_BLACK table failed because the backlight on the display is too bright. ECDIS display manufacturers are addressing this, and it is expected that this will allow the display to pass calibration.

The laptop display demonstrated poor performance for general bridge applications, with inadequate viewing angle and contrast to achieve the required colours. It is not recommended for ECDIS use.

Several important findings have come from this study:

- The flat panel LCD offers greater luminance and better brightness control, than the current CRT displays. This will allow the display to be twice as bright as current CRT displays, and it is practical for the user to adjust the display brightness without risking changing the colours on the screen
- The improvements in display performance raise the issue of reviewing the colour specifications and making adjustments to colour tables and operational considerations to take advantage of this improved performance
- Calibration procedures currently outlined in IEC 61174 are not suitable for LCD calibration. A (slightly) more complex model than that currently specified appears to hold promise, but needs further development and refinement to verify applicability. It should be possible to create a single procedure with specific variations suitable for LCD or CRT

To achieve improved performance from flat panel LC displays, several things need to be accomplished:

- Determine an appropriate set of performance specifications, taking into account the opportunities pre-

### Colour Gamut Explained

Colour gamut is a means to describe the total colour range capability of a display.

Colours are specified in x, y co-ordinates, and the entire range of colours visible to the human eye is illustrated on the CIE 1931 Chromaticity diagram, below. The triangle represents the NEC LCD 1810 display measured in this study.

For a normal display, the colour gamut is defined by a triangle, with the colour co-ordinates of the primary colours at its vertices.

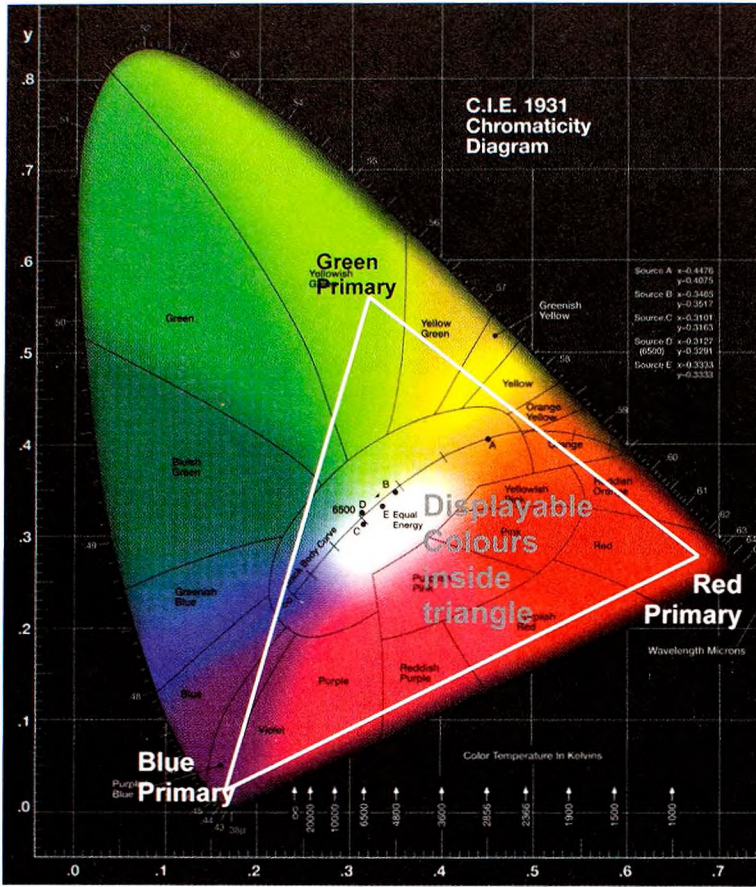


Figure 3: Calibration Challenge CIE colour space diagram showing colour gamut (triangle) of NEC 1810 display measured. The colour space diagrams in this report relate to this

### Calibration Process - CRT and LCD

Colour output from CRT monitors varies because of a number of different factors. Different manufacturers use different phosphors, which results in different primary colours. The relationship between voltage in and light out (transfer function) will be different for different display designs, and different set-up conditions.

The result is that the same input signal into two different monitors will show different colours on the screen.

If we want to define a specific colour on a display, and we know the specific colour co-ordinates of the red, green, and blue primary colours that make up the display, we can calculate precisely the amount of luminance needed from each primary to achieve the desired colour.

To achieve this, we will measure the primary colour co-ordinates of the RGB primaries on the display, and characterise the transfer function by measuring the light output corresponding to a range of input voltages (DAC output values from the computer) to the light output, for each of red, green, and blue.

Using this information, we can calculate the input DAC values necessary to achieve the desired colour.

In the case of the LCD, the calibration process is complicated because the backlight leakage is adding small amount of white luminance to all colours. This makes little difference for high luminance colours, but for lower luminance colours, it will reduce the saturation – or wash the colour out. Calibration of a LCD requires that this backlight leakage component be accounted for. This means that this leakage needs to be measured, and its value calculated in the process. For this report, this calculation was done manually, but for production application, it will need to be implemented into a useable software package.

CRTs when properly set have a fixed gamut that does not change with reduced input values.

sented by the display technology. It will be necessary to deviate from the current IHO colours developed for CRTs

- Develop a useable / practical calibration procedure
- Improve control over backlight luminance for dark night applications

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### **Biography**

Matthew Cowan, M.A. Sc., P.Eng. is a principal of the consulting firm Entertainment Technology Consultants. He specialises in characterisation of display performance, and display design to meet performance applications. In addition to electronic charting applications, he has worked extensively in display technology for digital cinema, where electronic displays will replace 35mm film in movie theatres, providing the look and feel of film.

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