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TECHNICAL REPORT

colour
inside

Electronic display devices –
Part 2-3: Measurements of optical properties – Multi-colour test patterns

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IEC TR 62977-2-3, which is a technical report, has been prepared by IEC technical committee 110: Electronic display devices.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
110/781A/DTR	110/800A/RVDTR

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62977 series, published under the general title *Electronic display devices*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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INTRODUCTION

Current display measurement standards mainly use simple test patterns to estimate the display performance. These test patterns would typically contain only one colour, or a colour with a black background. However, as recent research has shown, modern display electronics can be content-aware, and adjust the display rendering based on the input image content. Therefore, multi-colour test patterns that more closely simulate realistic image content are recommended in order to better represent the display performance.

This Technical Report discusses the impact of the display drive electronics and image processing on the display rendering behaviour, and reviews research results that demonstrate the need for multi-colour test patterns and average picture level loading considerations.

ELECTRONIC DISPLAY DEVICES –

Part 2-3: Measurements of optical properties – Multi-colour test patterns

1 Scope

This part of IEC 62977, which is a Technical Report, reviews the impact of test pattern colour content and image loading on the measured display's photometric and colorimetric performance. Experimental data for several display technologies is presented to demonstrate the need for using a broader range of colours in the test patterns, and measuring the display at an image loading level appropriate for the intended application.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
signal pixel
smallest encoded picture element in the input image

3.1.2
pre-gamma average picture level
average input level of all signal pixels relative to an equivalent white pixel driven by a digital RGB input

Note 1 to entry: Unless otherwise stated, the pre-gamma average picture level (*APL*) will simply be referred to as average picture level in this document.

Note 2 to entry: the *APL* will normally be expressed as a percentage, where a full white screen at maximum drive level would be 100 % *APL*.

3.2 Abbreviated terms

APL	average picture level
CIE	Commission Internationale de L'Eclairage (International Commission on Illumination)
LUT	look-up tables
OLED	organic light emitting diode
RGB	red, green, and blue
sRGB	standard RGB colour space as defined in IEC 61966-2-1
WRGB	white, red, green, and blue

4 Colour-managed displays

4.1 Legacy displays

Early displays had driven electronics that directly controlled the pixel elements. As illustrated in Figure 1, the independent drive electronics in these legacy displays resulted in a direct correlation between the input signal and the primary colour emitters. The direct link between input signals to pixel output meant that there was only one unique combination of R, G, and B that gave the desired colour. This simplified that calibration process which ensured that the display had proper colorimetric additive mixing. For example, equal input signal levels to the red, green, and blue channels would have created a proportional grey level. Standard colour spaces, such as the sRGB colour space (IEC 61966-2-1), utilize this additivity property. Current displays that strive to accurately reproduce the encoded colour information in this colour space also need to exhibit the additive mixing property.

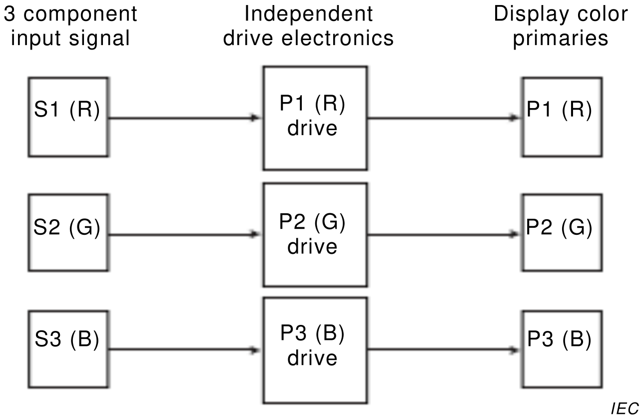

Figure 1 – Legacy model

4.2 Modern displays

As colour display technology has advanced over the years, so has the colour management of display devices. Display designers have introduced multi-primary pixel formats, and can apply real-time image processing based on specific pixel values contained in the frame to dynamically change how the image is rendered. Modern display electronics often include look-up tables (LUTs) as a programmable conversion interface between the input signal and pixel output (see top schematic in Figure 2). The use of LUTs allows the physical primary colours to be abstracted to conceptual primary colorants, where these colorants could be tailored to achieve the desired colour gamut. But the colorimetry of these systems may not necessarily follow colorimetric additive mixing. In addition, as the processing power of the electronics has increased, the image processing can also analyse the upcoming image frame and dynamically change the LUT for the desired appearance.

The use of LUTs has enabled an input signal from only one RGB component to activate more than one primary emitter (see for example the bottom schematic in Figure 2). For multi-primary displays, there may be several combinations of primary emitters that can produce the desired colour. The calibration of the LUT defines how the input signal will be rendered, which will not necessarily result in the expected colorimetric additive mixing based on the input signals. This lack of additivity can have an impact on how accurately the intended image content is rendered. In addition, the lack of additivity also means that the colour gamut area may not be accurately represented by just measuring the response of the R, G, and B inputs in turn. The colour gamut area may no longer be bounded by the triangle connecting the RGB chromaticity coordinates in the CIE 1931 or 1976 chromaticity diagram (see CIE 15).

Given this ambiguity, it is important to test how well the display renders luminance and colour relative to the intent of the input content. If the content is intended for viewing on sRGB displays, then the colour management should be tested to verify that the colours are rendered correctly. In addition, if the display also employs dynamic colour management, then the performance of the display can depend on the type of test pattern used. A set of colour test patterns have been developed to address these issues, and serve as the recommended patterns that should be used to evaluate displays. These patterns are a best effort attempt to create a technology-neutral input signal that uniformly samples the colour gamut and queries the colour-managed response of the display in a fair manner. The value of these colour test patterns is illustrated by comparing them to traditional single-colour box patterns.

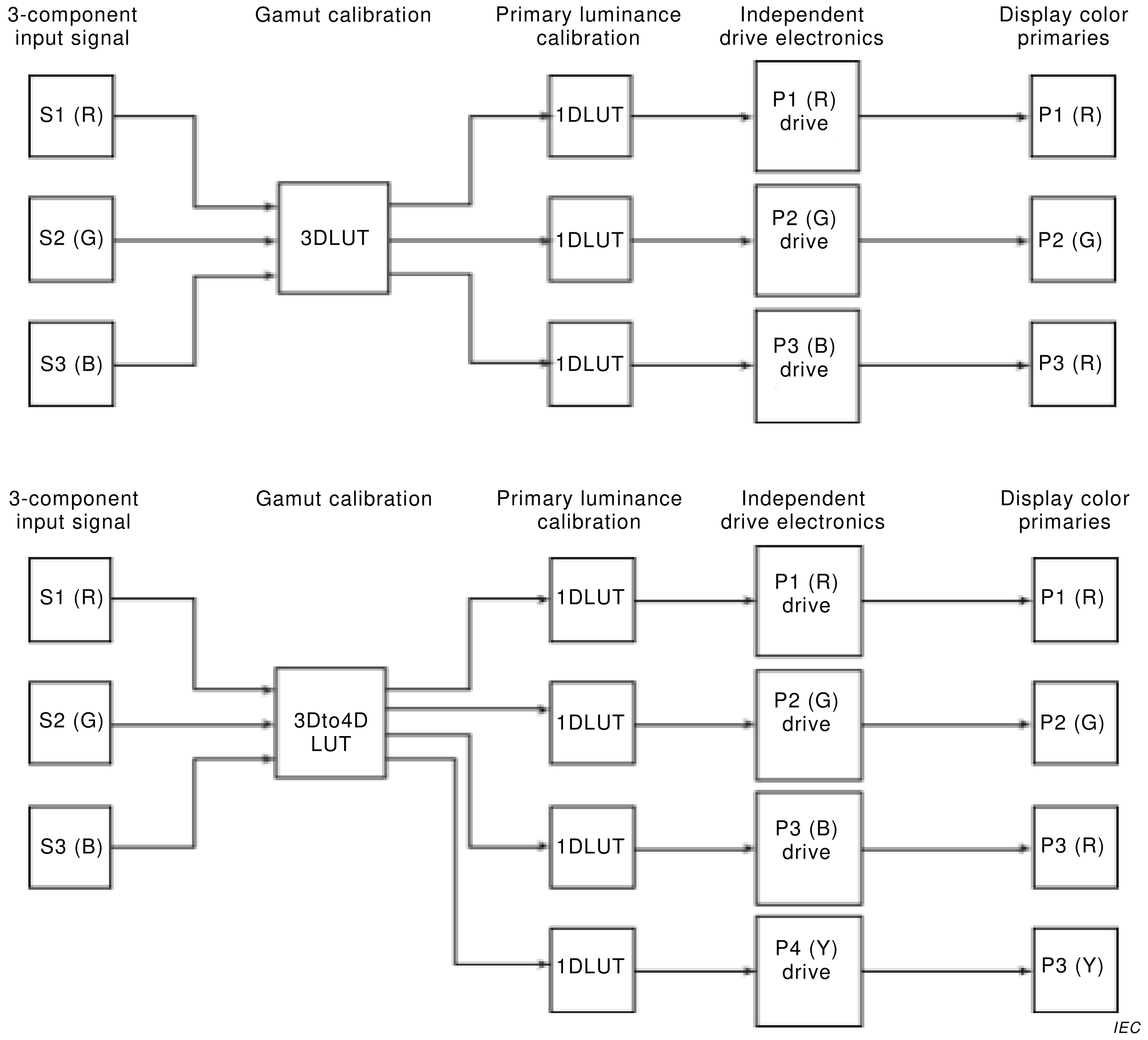

Figure 2 – Example of modern drive models

5 Results

Prior research on multi-primary projectors demonstrated that some colour-managed systems adapted to the rendered test pattern. The colour management system in some displays would preferentially boost the white luminance/illuminance output on white images. However, this white luminance could not be achieved in more natural colour images. This was demonstrated for a projector by Kelley *et al* using the set of three RGB test patterns shown in Figure 3. [1][1] Each coloured box was scaled to 1/3 the dimension of the screen. The red, green, and blue boxes were rendered by applying a maximum input signal to the respective RGB channel. As each pattern was rendered in turn, the red, green, and blue illuminance was measured for

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[1] Figures in square brackets refer to the bibliography.

each colour at all of the nine equally-spaced locations at the image plane. An average illuminance for each colour was then determined from the nine locations. By using these patterns on several WRGB projectors, Kelley showed that the average additive colour white illuminance ($E_{R+G+B} = E_R + E_G + E_B$), or colour-signal white illuminance, was up to 2,3 times smaller than the average full screen white illuminance.[1] Therefore, the illuminance of the white pattern did not equal the sum of the illuminance values for the R, G, and B primary colours. This lack of colour additivity indicates that the display cannot render a standard colour space, and may suggest a potential problem in the colour management. The benefit of the colour-signal white pattern (Figure 3) has been recognized by the display industry, and included as an important measurement in an industry standard.[2] For these patterns, the R, G, and B primary colours are rendered as nine equal sized boxes in the screen area. Measurements are taken at the centres of each box.

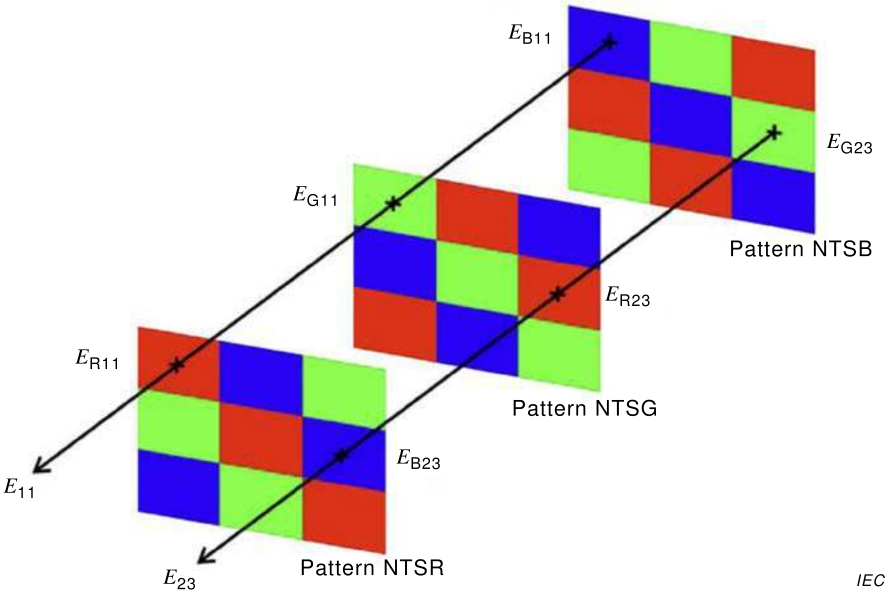


Figure 3 – Example of RGB checkerboard patterns

In a separate experiment, the introduction of even a small amount of colour in an otherwise full white screen also showed a dramatic impact. Figure 4 illustrates the example where each coloured box was 0,3 % of the active area. In this example, the average white illuminance of a laser phosphor hybrid projector measured at the nine locations was found to drop by 60 % when the small amounts of colour were added between the measurement locations (see Figure 4).

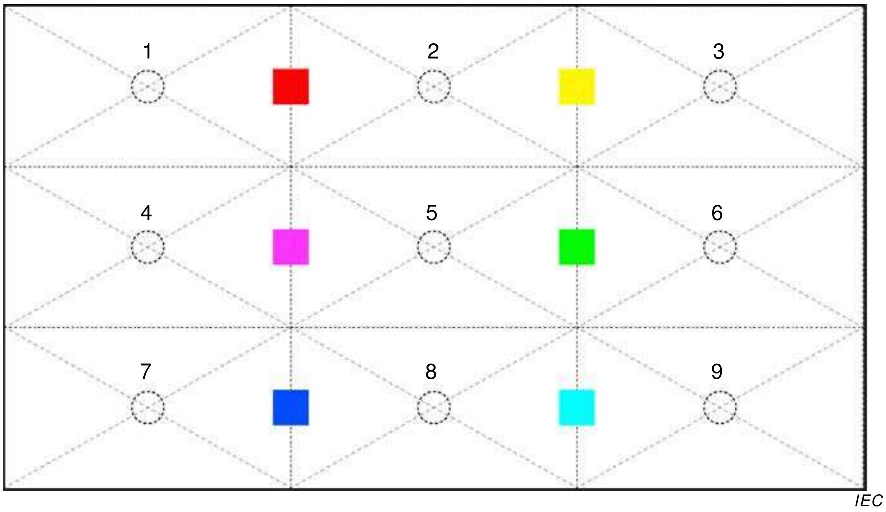


Figure 4 – Example of test pattern with low colour content, where measurement locations are identified by the circles

An additional experiment with the hybrid projector compared the spatially averaged white illuminance of a full white screen to the RGB checkerboard (see Figure 3), and an RGB and white checkerboard pattern (see Figure 5). In these patterns, the R, G, and B primary colours and white are rendered as nine equal-sized boxes filling the screen area. Each colour is rendered at its maximum signal level. Measurements were taken at the centres of each box. The colour-signal white illuminance (E_{R+G+B}) of the RGB checkerboard was 69 % lower than the full screen white illuminance. When a white colour was added to the RGB checkerboard, the colour-signal white illuminance of the RGB and white checkerboard (see Figure 5) dropped to 72 % of the full screen white illuminance. The colour-signal white illuminance of the RGB and white checkerboard pattern did not equal the illuminance of the white box in the RGB and white pattern, nor the full screen white. Therefore, due to the lack of colour additivity of this display ($E_W \neq E_R+E_G+E_B$), the most representative white value for natural images would be that measured from the RGB and white checkerboard pattern.

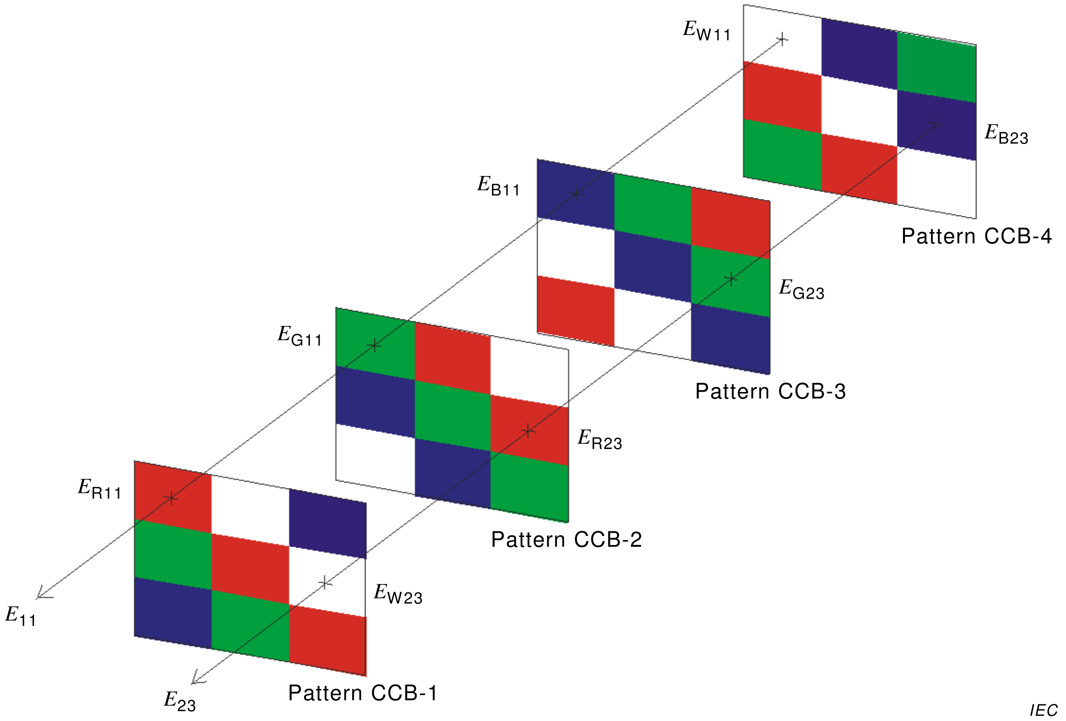


Figure 5 – Example of RGB and white test pattern

In addition to the test pattern colour dependence observed for some colour-managed display systems, there are also display technologies (liked PDPs, OLEDs, and local dimming LCDs) that are affected by the pattern size. In the case of OLEDs, the luminance may be subject to drive electronic limitations, where there is less drive current available to each pixel for images requiring a large number of emitting pixels. Therefore, the display is sensitive to the amount of image loading required by the input signal. The boxes of the RGB and white checkerboard pattern are scaled (see Figure 6) to address the APL loading effect. The area scaling of the coloured rectangles is adjusted to manipulate the APL loading on the display. For Figure 6, the R, G, and B primary colours and white boxes are centred about the measurement locations shown in Figure 4, but the boxes are scaled to 1/9 the vertical and horizontal dimension of the screen. The amount of APL loading is input-referred, assuming it is an RGB digital input. The percent APL is defined as:

$$APL(\%) = 100 \times \frac{\sum_{i=1}^{N} PL_{\mathrm{i}}}{N} \tag{1}$$

where the summation is over all signal pixels in the active area, PL_{i} is the normalized signal pixel level of each pixel relative to the maximum white level, and N is the total number of signal pixels. A 5 % to 6 % APL loading level is a practical lower limit for the pattern in Figure 6, and it is presumed that the display has achieved its highest luminance levels. An example calculation of the top left pattern in Figure 6 is given by:

[(7 primary colours x 1/3 of white) + (2 white boxes x 3/3 of white)]

x [(1/9)^2 fractional area of boxes] = 5,3 % APL (2)

A 100 % APL loading level corresponds to a maximum white signal input for all signal pixels in the active area. Table 1 shows an example of measured luminance data for a commercially available RGB and WRGB OLED display using the colour pattern in Figure 6. In this example, the percent difference between the colour-signal white luminance ($L_{\mathrm{R+G+B}} = L_{\mathrm{R}} + L_{\mathrm{G}} + L_{\mathrm{B}}$) and the average luminance of the white box L_{W} was actually higher for the RGB display. This suggests that the colour management was better for this WRGB display than the RGB display.

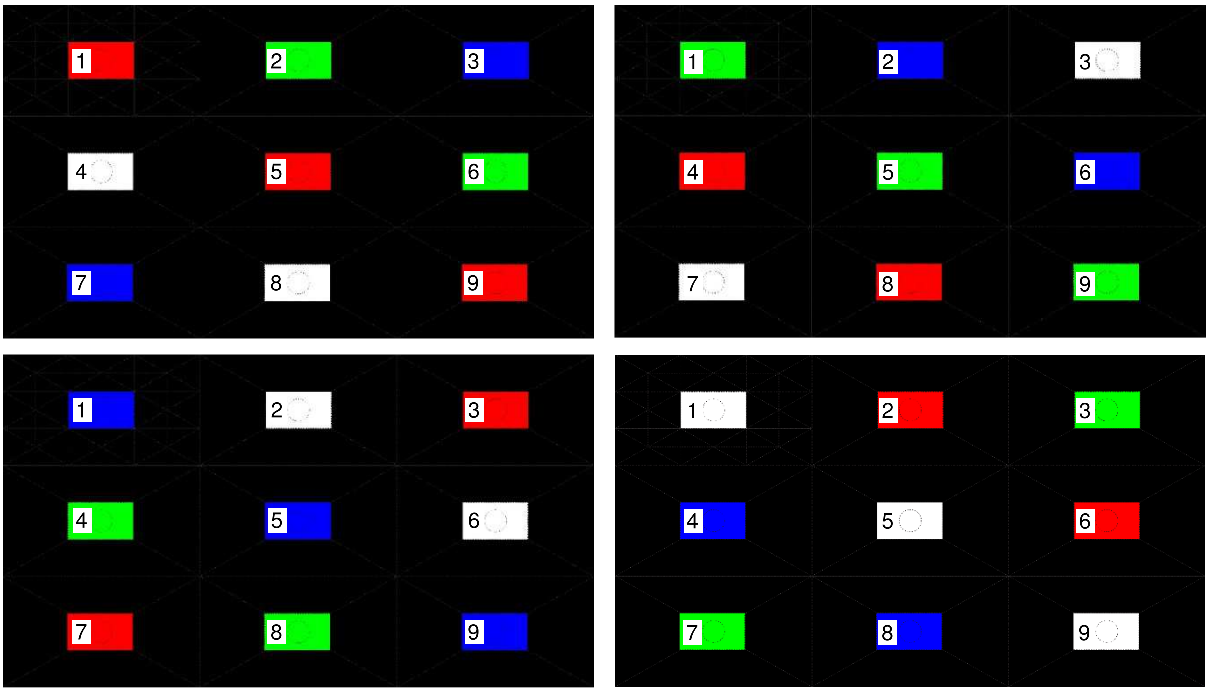
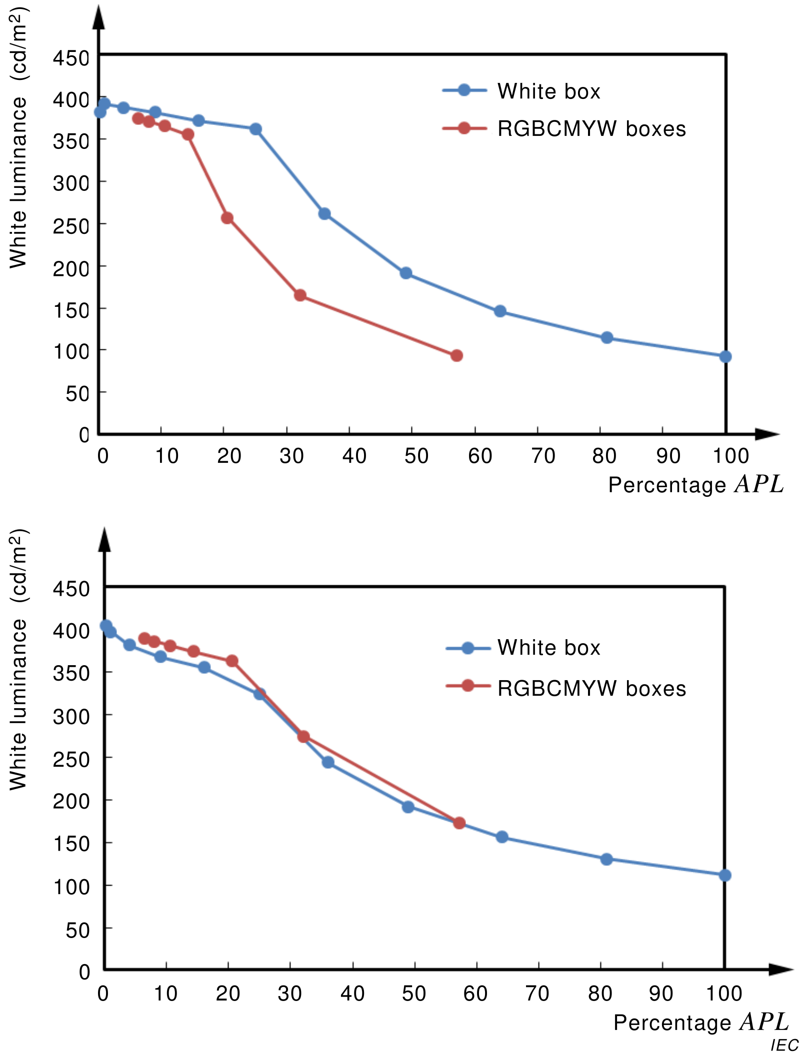


Figure 6 – Low APL loading series of red, green, blue, and white test patterns

Table 1 – Example luminance data for an RGB and WRGB OLED display

Display technology	**Average luminance** (cd/m^2)				$\frac{(L_w - L_{\mathrm{R+G+B}})}{L_{\mathrm{R+G+B}}}$ (%)
	Red	**Green**	**Blue**	**White**	
WRGB OLED display	78,4	268,2	38,2	393,9	2
RGB OLED display	88,7	218,7	28,6	380,4	13

The response of the OLED display to the input signal can be investigated further by measuring the APL loading behaviour of the display. Figure 7 illustrates different loading behaviours between the traditional single white centre 4 % box compared to the multi-colour pattern shown in Figure 8. The APL loading of each test pattern was increased by uniformly enlarging the size of the individual boxes, where the APL loading levels for Figure 8 are given in Table 2. The loading behaviour is observed to be different for the commercial RGB versus the WRGB OLED display. The APL loading response of the RGB display did not seem to depend on the presence of the background colour content. However, the presence of colour did impact the loading behaviour of the WRGB OLED, especially at the higher load levels. Therefore, since realistic images will typically contain a variety of colours, the sampling of red, green, blue, cyan, magenta, yellow, and white boxes used in Figure 8 would be a more appropriate test pattern for APL loading and colour measurements.



NOTE Measured results usie the test pattern in Figure 8 with a centre white box compared to a single centre white 4 % box.

Figure 7 – Example signal loading behaviour for an WRGB (top) and RGB (bottom) OLED display

When evaluating the APL loading response of the display, the shape of the loading profile is not as important as how consistently the display can maintain that shape for all colours. This issue is illustrated in Figure 9. In this evaluation, the luminance and colour in the pattern (see Figure 8) was measured at increasing levels of APL loading. The loading measurements were repeated in turn for the red, green, blue, cyan, magenta, and yellow boxes in the pattern. The top graph in Figure 9 shows that each of the colours measured on the WRGB display had virtually the same loading profile. This confirmed that the luminance ratio between the colours was maintained. Since the luminance ratio between colours determines what colour is rendered by the display, a consistent luminance ratio means that the colour gamut will be stable through the range of loading levels. This is demonstrated by the relatively flat (brown) colour gamut area line shown in the top graph in Figure 9. The gamut area is the area enclosed by the RGB triangle in the CIE 1976 chromaticity diagram and is calculated as:

$$A_{\mathrm{u'v'}} = 256{,}1 \times \left| (u'_{\mathrm{R}} - u'_{\mathrm{B}})(v'_{\mathrm{G}} - v'_{\mathrm{B}}) - (u'_{\mathrm{G}} - u'_{\mathrm{B}})(v'_{\mathrm{R}} - v'_{\mathrm{B}}) \right| \qquad (3)$$

where the subscripts R, G and B refer to the red, green and blue primaries, respectively. In contrast, the bottom graph in Figure 9 shows some variation in the APL loading profiles for each of the colours measured on the RGB display. This variation induced the larger change in the colour gamut area for the RGB display with APL loading.

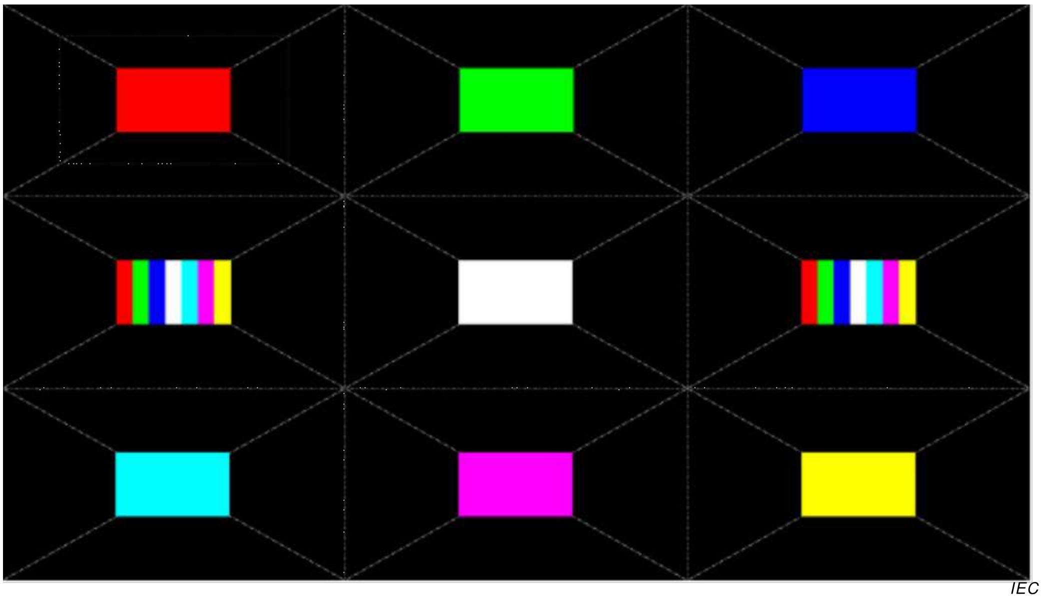


Figure 8 – Example of a low APL loading test pattern with small box size

Table 2 – Scaling the size of the colour boxes in the APL loading pattern relative to the screen dimensions

Box dimensional scaling (relative to screen dimension)	**Percentage of coloured screen area** %	**Percent APL (equivalent white area)** %
1/9	11	6,3
1/8	14	8,0
1/7	18	10
1/6	25	14
1/5	36	21
1/4	56	32
1/3	100	57

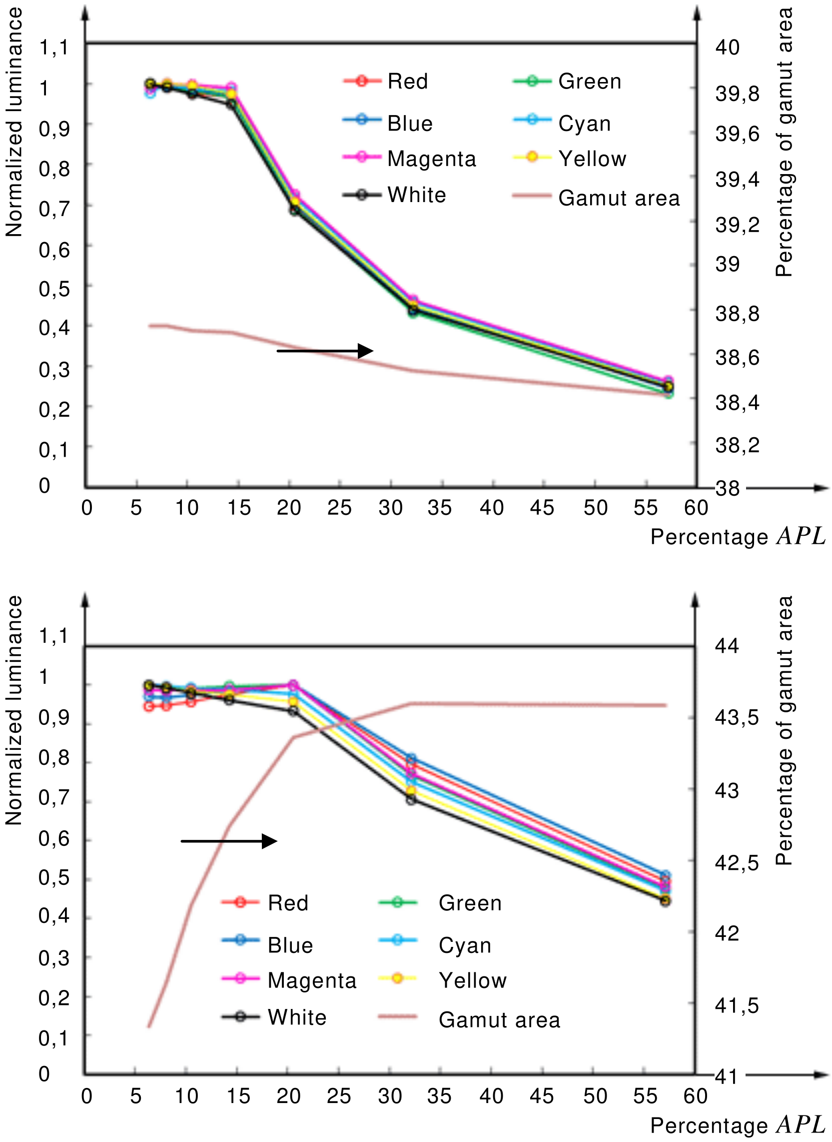


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Figure 9 – Example of *APL* loading profiles of a WRGB OLED display (top) compared to an RGB OLED display

6 Conclusion

These results demonstrate the value of using multi-colour test patterns in characterizing the photometric and colorimetric performance of multi-primary and standard RGB displays. It was shown that the luminance/illuminance values, and *APL* loading profiles, can be different with multi-colour patterns than for single colour patterns. Since the multi-colour patterns more closely resemble natural colour imagery, they are more likely to represent the results in actual applications. In addition, for display technologies that have a significant dependence on the amount of image *APL* loading, the best estimate of how the display will perform when rendering realistic images is to use test patterns with *APL* loading levels comparable to the intended application.

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