

---

Sony Corporation

# Colour Matching Between OLED and CRT

White Paper

V1.0

February 15<sup>th</sup>, 2013

# Colour Matching Between OLED and CRT

## 1. Background and Purposes

In recent years, flat panel displays has become the mainstream for professional monitors used in Live production, Broadcast Stations, Post Production, and so on, due to the many benefits over CRTs.

In 2011, Sony released the award winning BVM-E250 reference monitor using the company's OLED (Organic Light Emitting Diode) panel resulting in performances exceeding the CRT, which had been the de facto standard for so many years. Sony's OLED technology provides accurate black reproduction and quick pixel response which cannot be achieved by other display technologies.

However, when matching colours between a CRT and other flat panel displays such as LCD (especially with LED backlight) or to OLED, viewer perception of the colour match may not agree, even though they are calibrated to the same xy chromaticity values. In the case of OLED, the colour looks greenish compared to CRT.

This paper explains this phenomenon and the countermeasure taken by Sony.

## 2. Colour Measurement and Human Eye Perception

The XYZ colourimetric values measured by a colour analyzer probe are calculated as a multiplication of the two below:

- the colour spectrum of the display device.
- the colour matching functions used as a spectral sensitivity characteristic of human's eyes:  $\bar{x}(\lambda)$ ,  $\bar{y}(\lambda)$ ,  $\bar{z}(\lambda)$

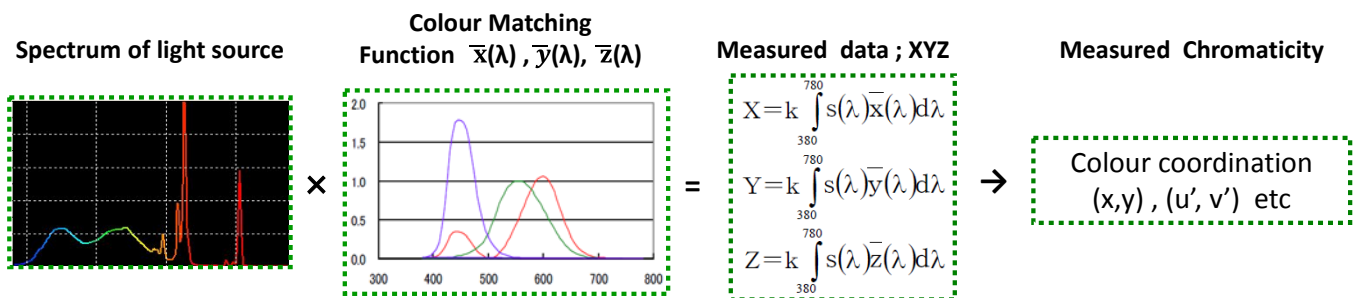


Figure 1 Measurement Calculation of Colour Analyzer

Most colour analyzers in operation today are based on the CIE1931 XYZ colourimetric system and the colour matching functions in use for calculation are the "CIE1931 Standard Observer Functions" which is an average of isochromatic experiments based on 17 people. This standard was defined in 1931. (refer to Figure 2)

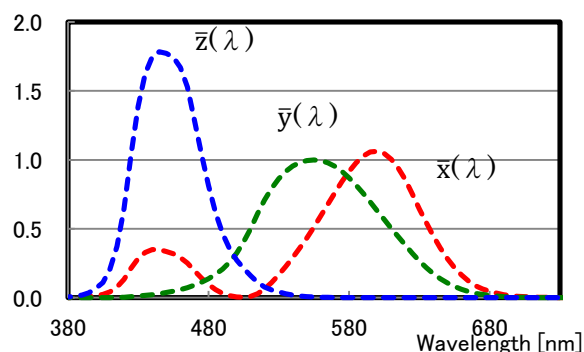


Figure 2 CIE1931 Colour Matching Function

On the other hand, the human eye also perceives colours, basically by the same principle as these colour analyzers.

The human eye has three photoreceptor cells (cones) defined as (L, M, S). These three cones filter and absorb the light source in the retina, and then convert this sensation into an electrical signal which is recognized as colour.

In other words, these cones theoretically play a similar role as the colour matching functions when measuring colours, and it may be said that it is this function that differs in characteristics of each individual (refer to Figure 3).

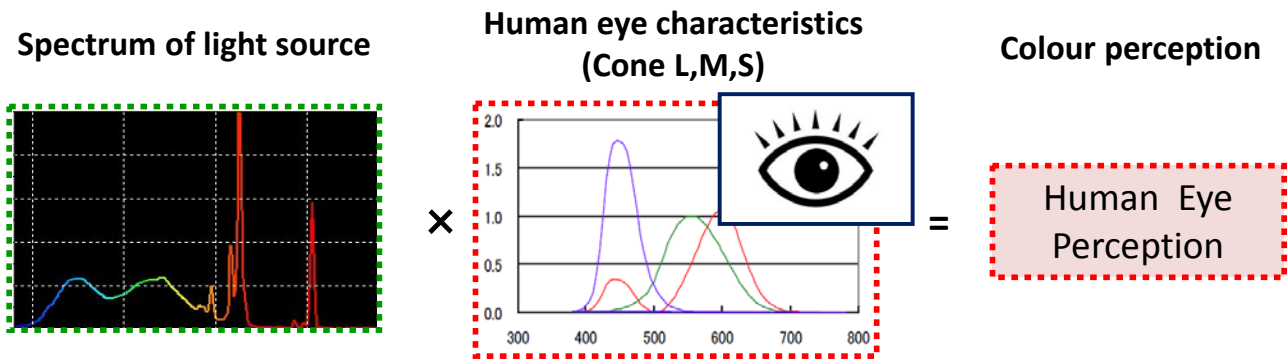


Figure 3 Human Eye Perception

### 3. Why Colours Don't Match

The phenomenon of different colour perception to the human eye between CRT and different display devices is known not only with OLED, but also with other display devices such as LCD with LED backlight, projectors and display devices with multi-primary colour (more than 4 colours).

Cases where colour matching is difficult are reported even among researchers dealing with colour perception. And considering the principle of measuring colours, the following two factors can be the cause:

- (a) CIE1931 colour matching functions may not fully represent the spectral sensitivity of the human eye.
- (b) Human eye perception widely differs between each individual, making it difficult to specify colour perception with just one set of colour matching functions.

As our colour matching experiment in the latter part of this paper shows, it is suggested that the variation of individuals (b) has more of an effect than (a).

While colour matching was not a problem in the CRT era, it has become more difficult in recent years with the advent of different devices such as LED backlight or OLED, due to the fact that the spectral distribution used from these light source differs (refer to Fig. 4).

The factors that make colour matching difficult are described in Figure 5.

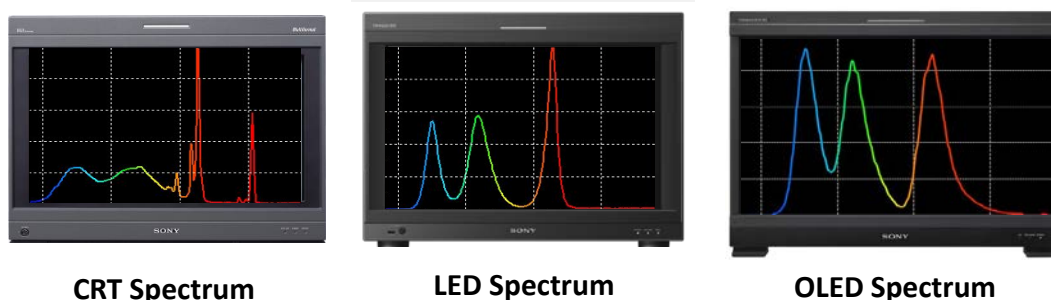


Figure 4 Difference of Spectrum

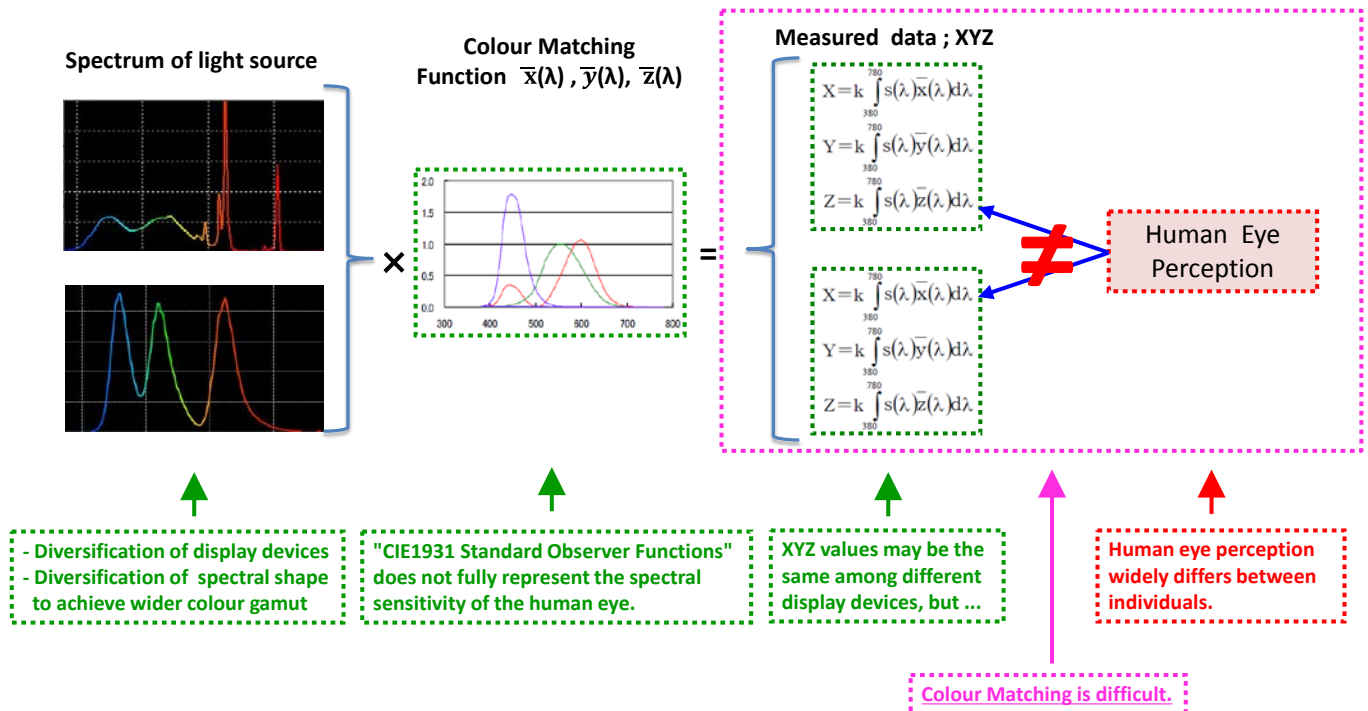


Figure 5 Why Colour Matching is Difficult

#### 4. Colour Matching CRT and OLED

So how can we improve colour matching?

Sony asked Konica Minolta Optics, Inc. which is a Japanese colourimetric measurement manufacturer, for their help in this study. The study of Konica Minolta Optics, Inc. also suggests that the reason why colours don't match is because the CIE1931 colour matching functions does not fully represent the spectral sensitivity of the human eye.

We also found during this study that it is widely known among researchers dealing with colour perception that there is a need for modifications to the CIE 1931 definitions. One such modification is the "Judd modified colour matching functions" used to supplement the "CIE1931 colour matching functions" because it improves colour matching.

This "Judd modified colour matching function" is a revision of CIE1931 colour matching functions, researched by Judd in 1951 and later improved by Vos in 1978 (cf. Figure 6). The difference between the CIE1931 colour matching functions is the shape of the short wavelength region (both  $\bar{x}(\lambda)$  and  $\bar{z}(\lambda)$ ).

This revision was made because there had been research reports that show short-wavelength region of CIE1931 colour matching functions do not match the characteristics of the human eye. Through our studies, we feel that by implementing Judd we can improve colour matching between different display technologies.

\* The reason CIE1931 colour matching functions is still the standard in use for colourimeters, is because changing this colourimetric system is not preferred. Therefore "Judd modified colour matching functions" have not been adopted by the CIE.

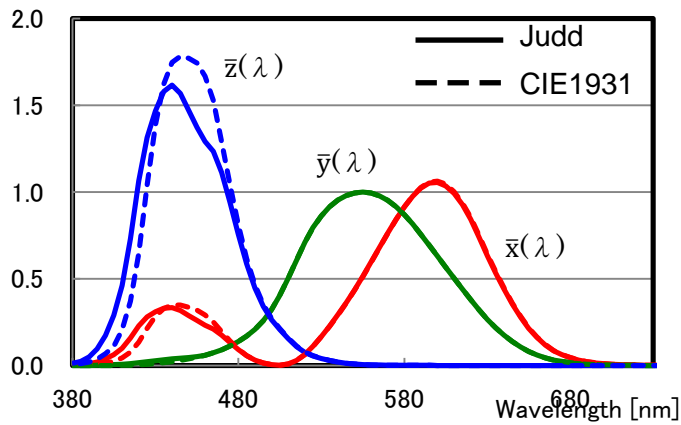


Figure 6 CIE1931 colour matching function and Judd modified colour matching function

### 5. How colour matching is performed using "Judd modified colour matching functions"

Even when the colours between displays visually match each other, the values of calculated chromaticity point will be different when you change the colour matching function.

Figure 7 shows the measurement of chromaticity point D65 when measured by the "CIE1931 colour matching functions" and then using the same process, measured using the "Judd modified colour matching functions".

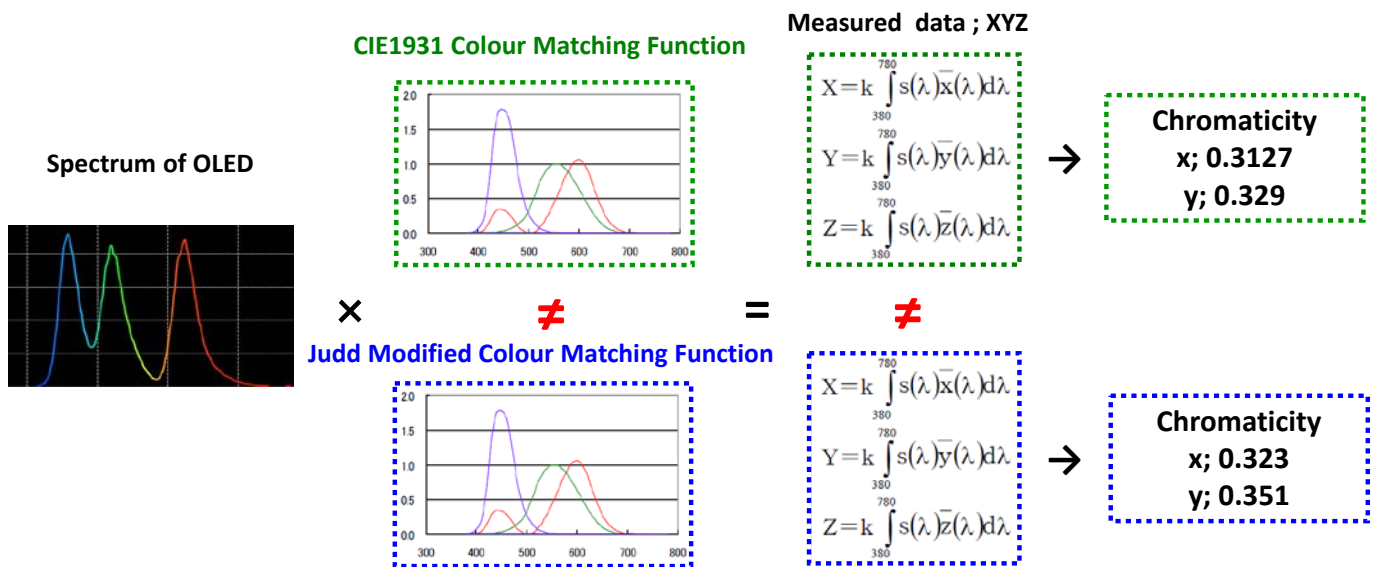


Figure 7 Different Colour Matching Function Leads to Different Chromaticity

Since colourimeters only use the "CIE1931 colour matching function", the colourimeter indicates (0.3127, 0.329) when measured at the upper part of Figure 7.

If there was a colourimeter were to use a "Judd modified colour matching function" then we would see the values shown at the lower part of the diagram. But since such colourimeter doesn't exist, we will match colours like the method shown in Figure 8.

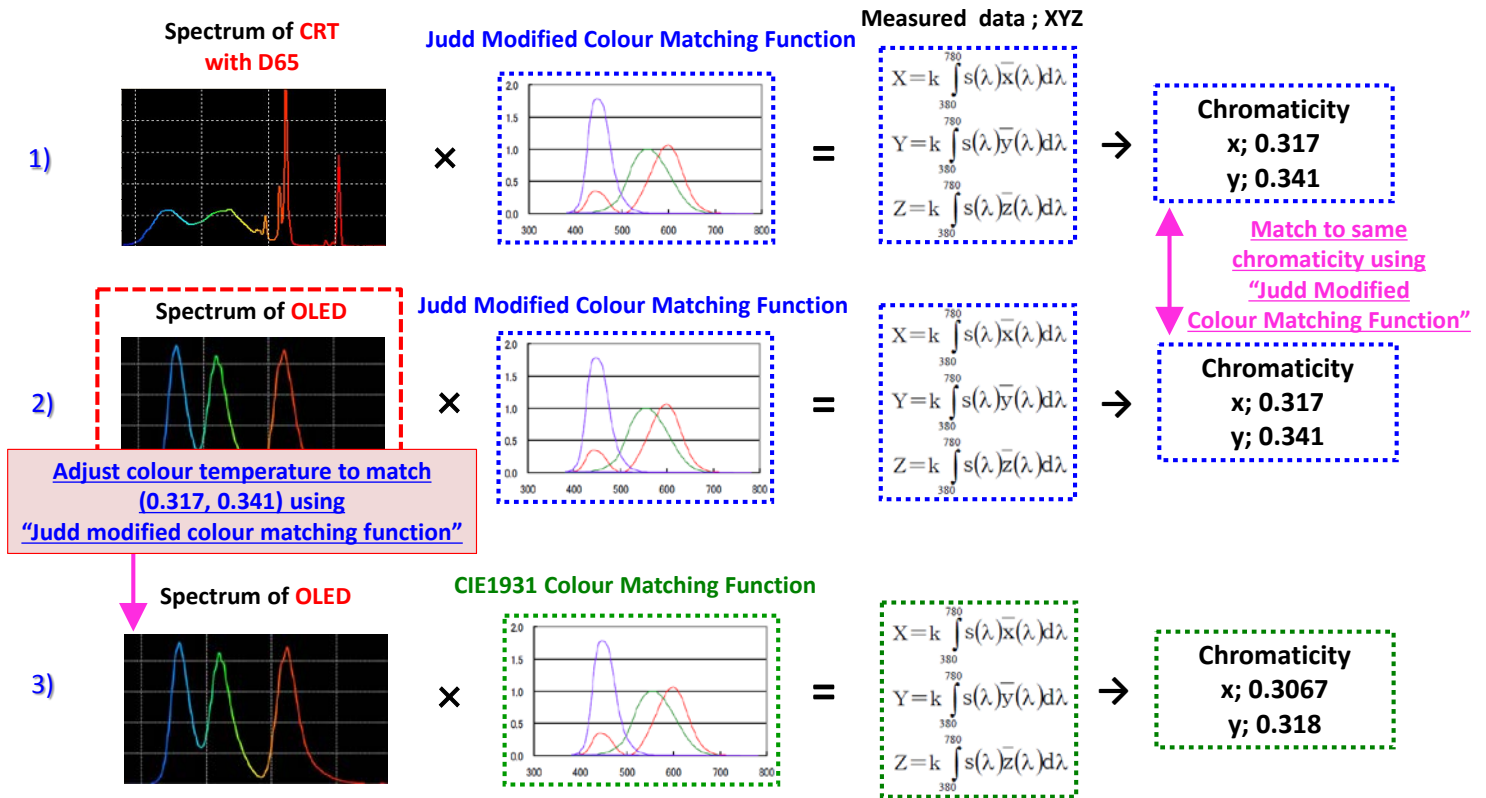


Figure 8 Colour Matching CRT and OLED using "Judd modified colour matching function"

- 1) When CRT actually displays a D65 white field (0.3127, 0.329) measured as CIE1931, the calculated value of chromaticity point using CRT's spectrum using "Judd modified colour matching functions" would be (0.317, 0.341).
- 2) Next, we would adjust the white balance of OLED to match the same calculated value of chromaticity point using a "Judd modified colour matching functions".
- 3) Due to the OLED's spectrum combined with the "CIE1931 colour matching functions", this value would be (0.3067, 0.318). This would be the chromaticity point of OLED when measured using CIE1931 standard colourimeter.

Simply put, using our CIE meter and applying an offset of (-0.006, -0.011) to the CRT's chromaticity point of (0.3127, 0.329) would be equivalent to a matching colour of the OLED using the "Judd modified colour matching functions". The offset values (-0.006, -0.011) would be the same whatever the colour temperature.

## 6. Validity of "Judd modified correction colour matching functions"

We have verified the validity of "Judd modified correction colour matching functions" with colour matching tests where we displayed a D65 (0.3127, 0.329) referenced image on a CRT and by adjusting the OLED's white balance to have matched them using simple eye observations. We have prepared two patterns of window (large and small) for this colour matching test.

Figure 9 shows the tests results. Chromaticity point (x, y) of this graph is shown as an unmodified CIE1931 value. Vertical and horizontal axis is the applied offset of chromaticity point (x, y) applied to OLED in order to match the colour to CRT's D65 (0.3127, 0.329).

In other words, if the test results land at point of origin (0,0), it means that the colour of OLED matched to this

individual person with chromaticity point of (0.3127, 0.329).

This test shows that to most people, OLED without an offset (point of origin) results in the y value being relatively high compared to the CRT, which means the OLED will look greenish. It also shows that while there is a variation between each person's acuity, the offset of OLED with the "Judd modified colour matching functions" applied sits nearly in the middle of this variation.

Konica Minolta Optics, Inc. has made a organoleptic evaluation of these results and verified the validity of the offset using "Judd modified colour matching function" with OLED.

We have concluded that colour matching OLED monitors using "Judd modified colour matching functions" offers better results than by using the "CIE1931 Standard Observer Functions" alone. In the finding of these results, Sony has applied this offset to its TRIMASTER EL™ OLED monitor factory white point adjustments.

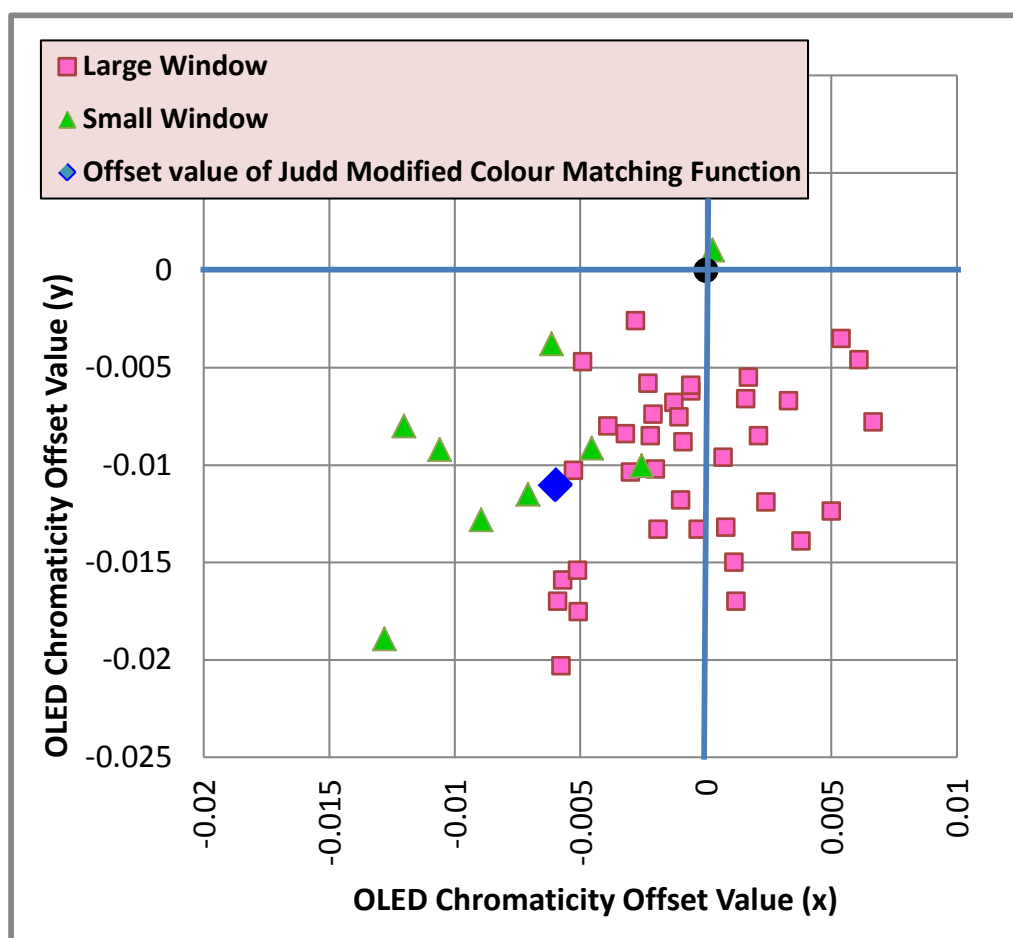


Figure 9 Colour Matching Test Results and Offset

## 7. Applicable OLED model

This offset based on the "Judd modified correction colour matching function" will be applied to the following models effective from 2012 autumn shipping.

In other words, when you measure the preset colour temperature (D65, D93, etc.) of these units, there will be an offset applied. \*1

i.e. When "D65" is selected, the measurements of colour analyzer (probe) will typically be (0.3067, 0.318).

### **Effective Models:**

BVM-E250/F250/E170/F170	From Version 1.21 or over
PVM-2541/1741	From Serial No. 3100001 or over
PVM-741	From Serial No. 3000001 (initial serial no.) or over

### **Offset Values (from reference white point):**

$$(\Delta x, \Delta y) = (-0.006, -0.011)$$

$$(x, y) = (0.3067, 0.3180) \text{ for D65}$$

This will significantly improve colour matching with CRT. Colour matching can be performed with higher accuracy when used in conjunction with manual colour temperature adjustment or our "Monitor\_Auto White Adjustment" software.

Offset based on "Judd modified colour matching function" can be applied to the monitor by upgrading the monitor firmware to Ver. 1.21 or over. \*2

---

\*1 Colour Profile "D-Cine" in BVM-E series does not require offset.

\*2 BVM-E/F series only