Sony Corporation

Color Matching Between OLED and CRT

White Paper

V1.0

February 15th, 2013

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

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

2. Color Measurement and Human Eye Perception

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

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

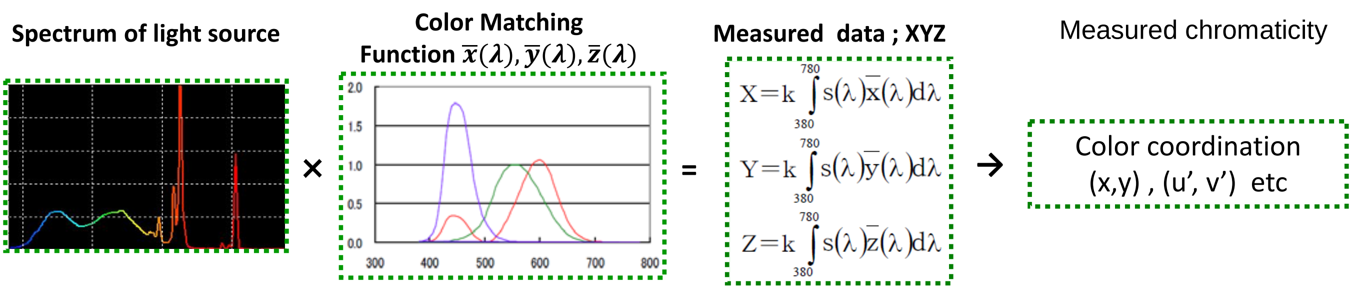

Figure 1 Measurement Calculation of Color Analyzer

Most color analyzers in operation today are based on the CIE1931 XYZ colorimetric system and the color 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)

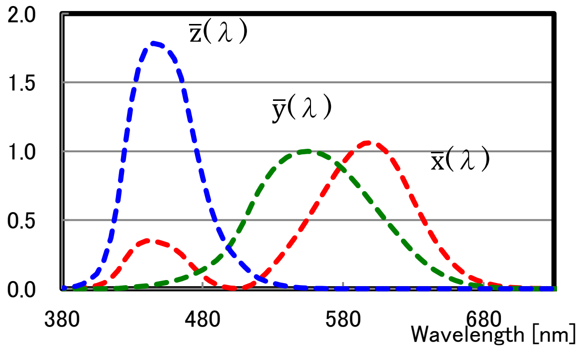

Figure 2 CIE1931 Color Matching Function

On the other hand, the human eye also perceives colors, basically by the same principle as these color 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 color. In other words, these cones theoretically play a similar role as the color matching functions when measuring colors, and it may be said that it is this function that differs in characteristics of each individual (refer to Figure 3).

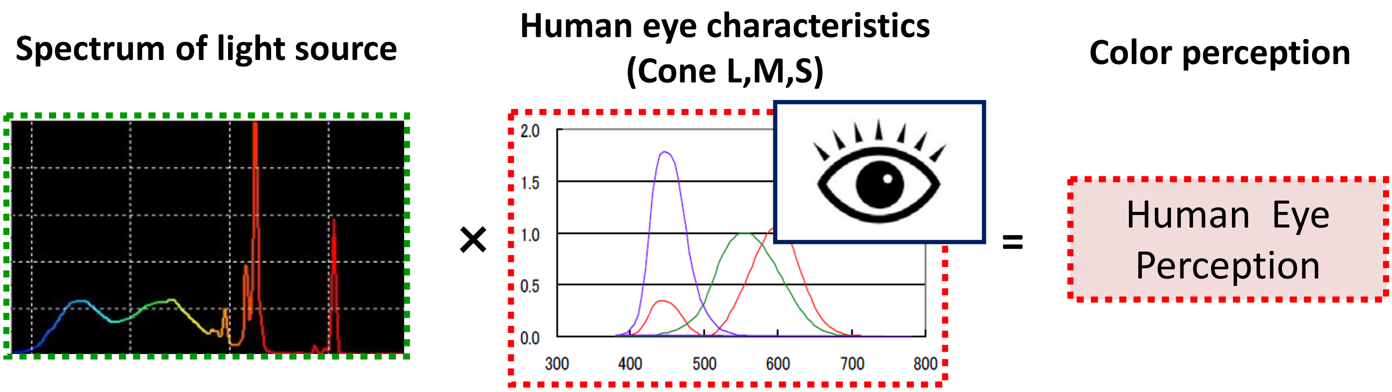

Figure 3　Human Eye Perception

3. Why Colors Don't Match

The phenomenon of different color 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 color (more than 4 colors).

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

(a) CIE1931 color 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 color perception with just one set of color matching functions.

As our color 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 color 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 color matching difficult are described in Figure 5.

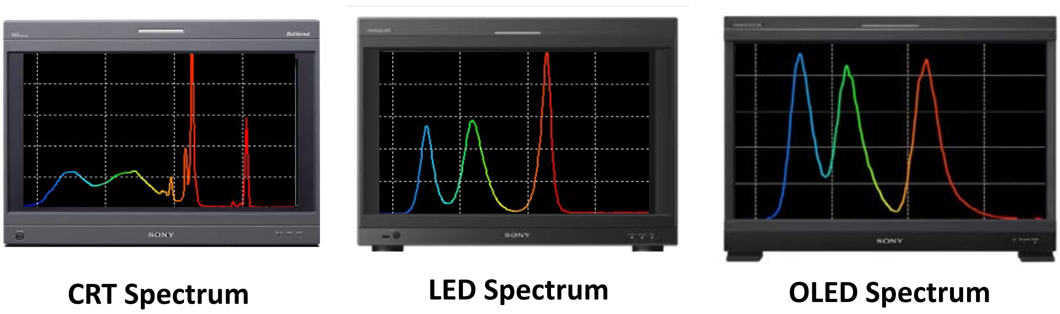

Figure 4　Difference of Spectrum

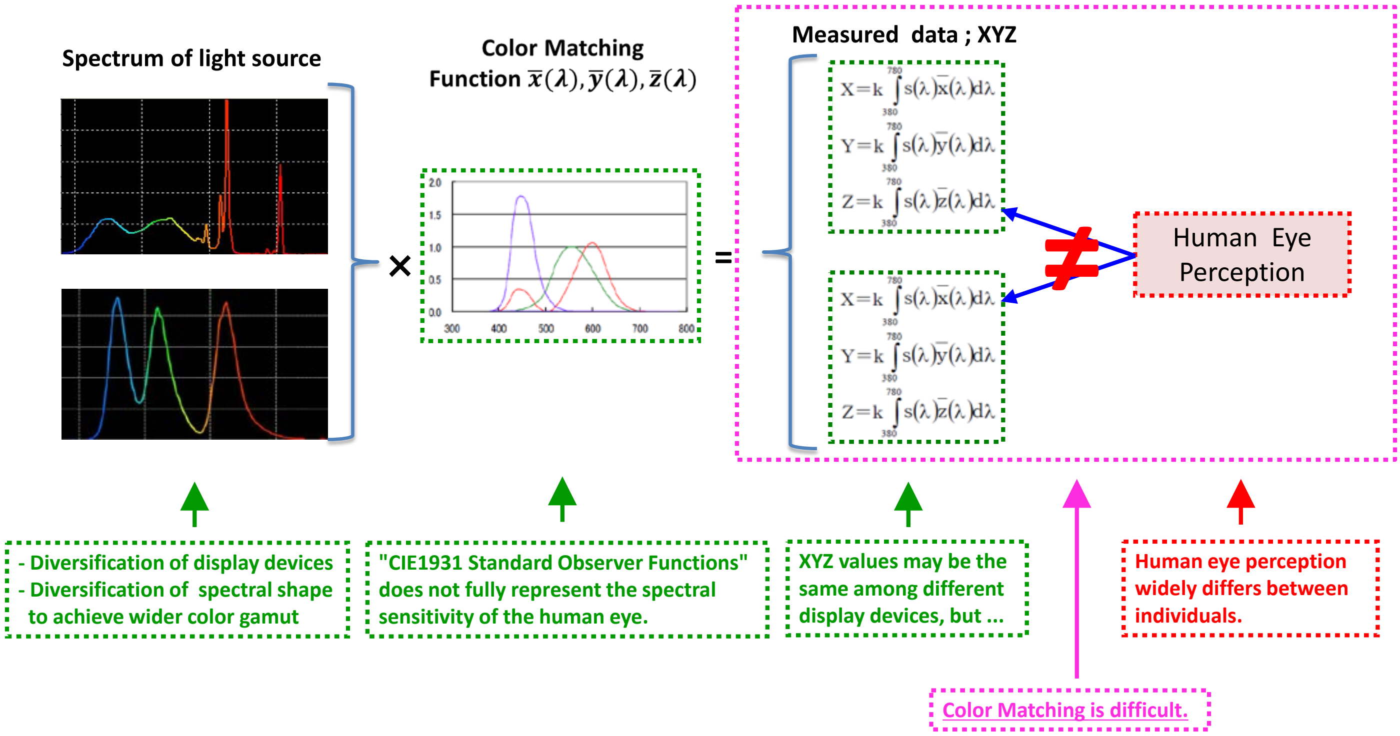

Figure 5 Why Color Matching is Difficult

4. Color Matching CRT and OLED

So how can we improve color matching?

Sony asked Konica Minolta Optics, Inc. which is a Japanese colorimetric measurement manufacturer, for their help in this study. The study of Konica Minolta Optics, Inc. also suggests that the reason why colors don't match is because the CIE1931 color 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 color perception that there is a need for modifications to the CIE 1931 definitions. One such modification is the "Judd modified color matching functions" used to supplement the "CIE1931 color matching functions" because it improves color matching.

This "Judd modified color matching function" is a revision of CIE1931 color matching functions, researched by Judd in 1951 and later improved by Vos in 1978 (cf. Figure 6). The difference between the CIE1931 color 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 color matching functions do not match the characteristics of the human eye. Through our studies, we feel that by implementing Judd we can improve color matching between different display technologies.

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

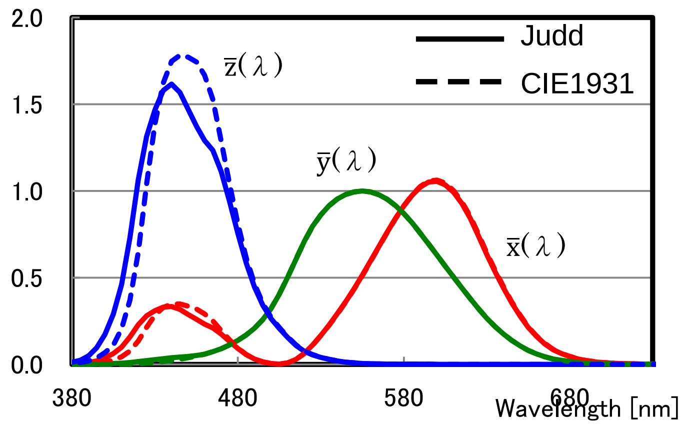

Figure 6 CIE1931 color matching function and Judd modified color matching function

5. How color matching is performed using "Judd modified color matching functions"

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

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

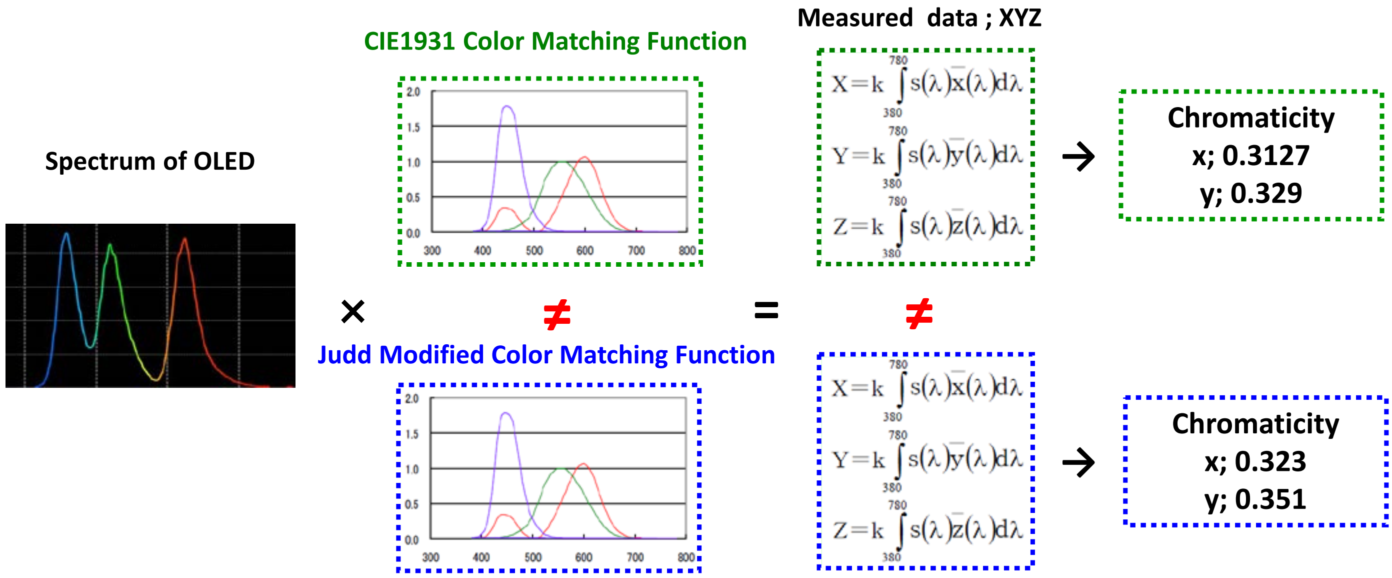

Figure 7 Different Color Matching Function Leads to Different Chromaticity

Since colorimeters only use the "CIE1931 color matching function", the colorimeter indicates (0.3127, 0.329) when measured at the upper part of Figure 7.

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

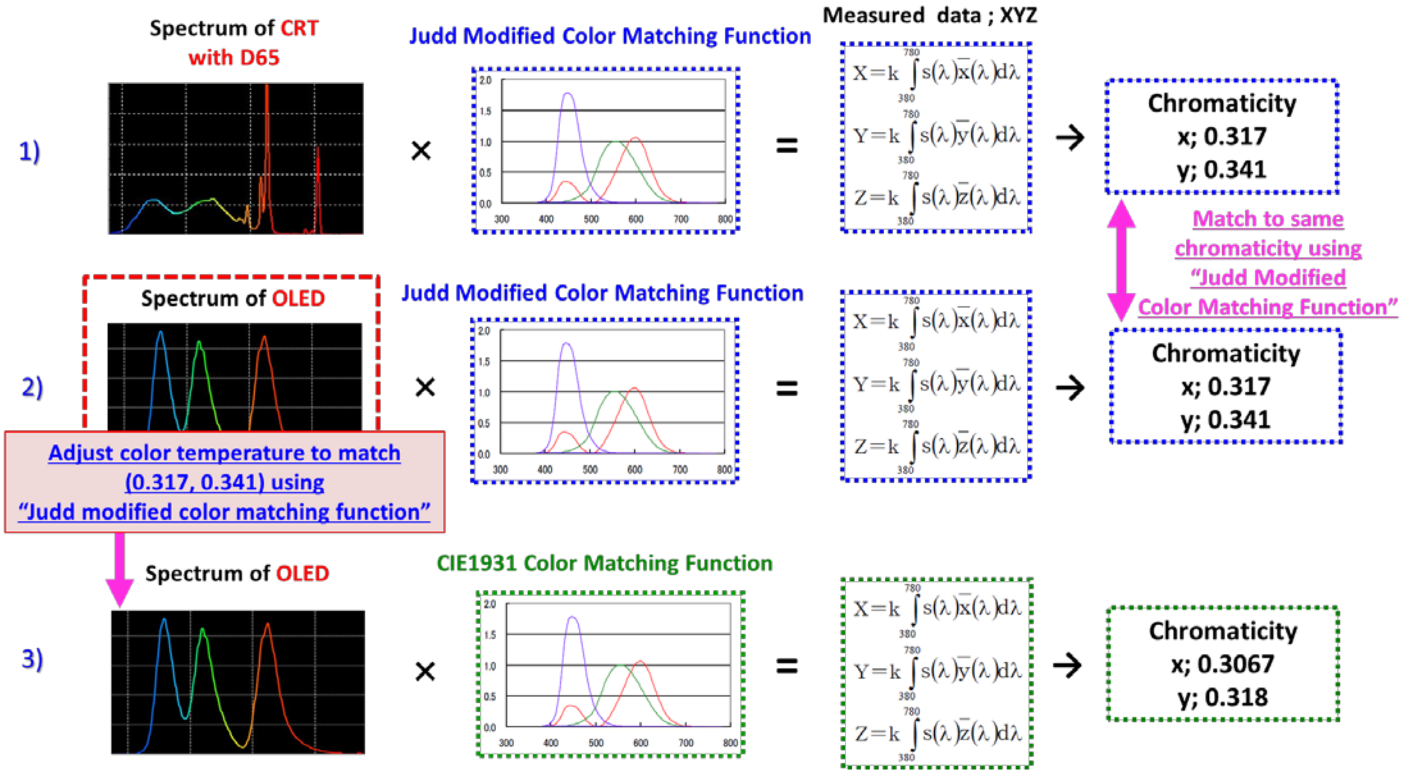

Figure 8 Color Matching CRT and OLED using "Judd modified color matching function"

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 color 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 color matching functions".
3) Due to the OLED's spectrum combined with the "CIE1931 color matching functions", this value would be (0.3067, 0.318). This would be the chromaticity point of OLED when measured using CIE1931 standard colorimeter.

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 color of the OLED using the "Judd modified color matching functions". The offset values (-0.006, -0.011) would be the same whatever the color temperature、

6. Validity of "Judd modified correction color matching functions"

We have verified the validity of "Judd modified correction color matching functions" with color 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 color 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 color 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 color 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 color 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 color matching function" with OLED.

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

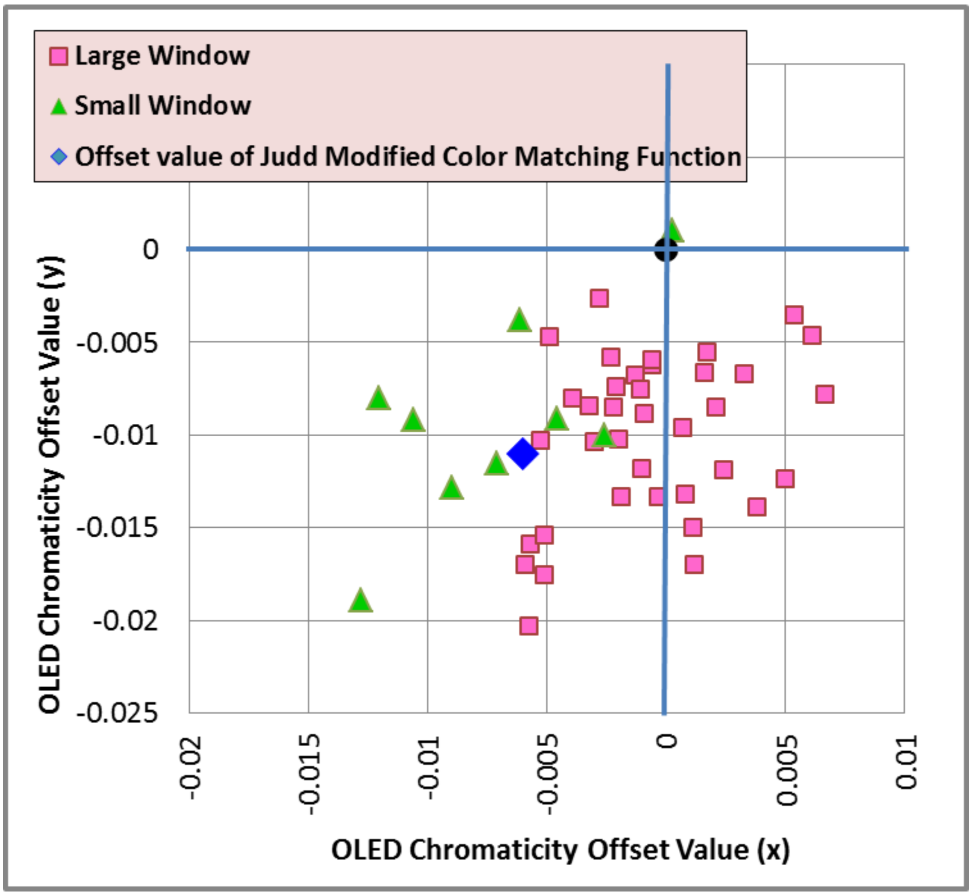

Figure 9　Color Matching Test Results and Offset

7. Applicable OLED model

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

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

i.e. When "D65" is selected, the measurements of color 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):

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

$(x, y) = (0.3067, 0.3180)$ for D65

This will significantly improve color matching with CRT. Color matching can be performed with higher accuracy when used in conjunction with manual color temperature adjustment or our "Monitor_Auto White Adjustment" software.

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

*1 Color Profile "D-Cine" in BVM-E series does not require offset.
*2 BVM-E/F series only