



White Paper

Characteristics of Additive Color Mixtures and 3D-LUT Functions for Graphics Monitors

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Preface

Printing workflow digitization is becoming increasingly important in the printing industry. It allows for wide-color-gamut printing, printing of a variety of small-scale jobs, and digital printing on demand. These features match customers' demands, specifically high quality, cost-effectiveness and speed. In addition, the down-sizing of printing workflow through digitization is an important factor in the printing industry, as the industry has shrunk during the current recession. Monitor proofing, which checks print colors on a monitor, has become a de-facto standard in digital printing workflow, due to its cost-effectiveness and speed.

In order to achieve monitor proofing, the monitor needs to obtain exact color reproduction performance to substitute hard color proofing. The display quality of graphics monitors is steadily improving, and the accuracy of monitor additive-color-mixing characteristics is a key technology in terms of improving it.

This document explains monitors' additive-color-mixing characteristics, which are becoming an important element in meeting exacting image quality demands of graphics monitors, and gives an outline of the 3D-LUT function, which is an original technology for improving additive-color-mixing characteristics.

The Mechanism of Color Display on LCD Monitors

The principle of color display

As shown in the diagram below, a pixel consists of three sub-pixel colors - red, green and blue.

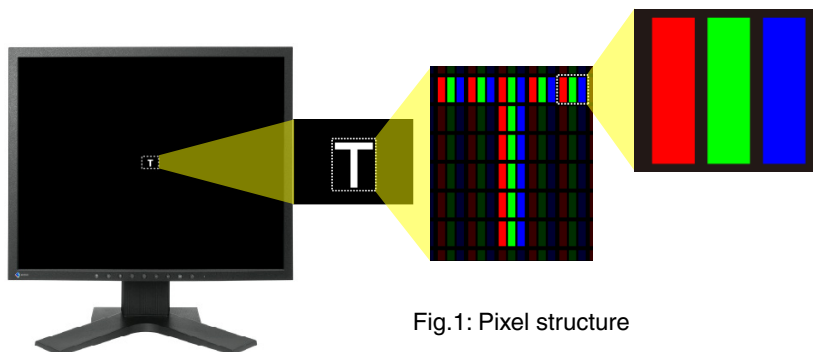


Fig.1: Pixel structure

Additive color mixing generally involves mixing colors of light. It is used in computer monitors (and televisions) to produce a wide range of colors using only the three primary colors - red, green and blue.

Red + Green + Blue = White (Additive color mixing)

Thus, a monitor can reproduce various colors, such as white, black, yellow, magenta, and cyan by adjusting the combination of the brightness of three primary colors. In theory, if a monitor can display 256 tones of each of red, green and blue, the total number of colors it can display is 16.77 million.

$256 \times 256 \times 256 = 16.77$ million colors

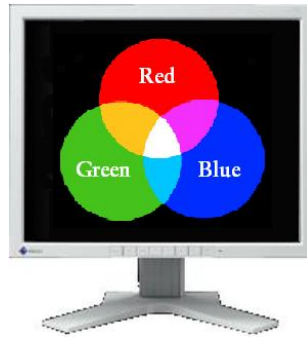


Fig.2: Color display by combining the three primary colors

Method of displaying colors on an LCD monitor

In an LCD monitor, as shown in the following diagram, a backlight illuminates the screen, passing through red, green and blue color filters, and creating the three primary colors. These colors are then mixed, and displayed on the screen. This color filter is a very thin film - one micrometer thick. Thus, the red filter only allows light with a red wavelength to pass through it, while it absorbs other wavelengths.

In this way, the RGB light which passes each filter is mixed together and reproduces a color. LCD monitors can change the brightness of each color by control of the backlight with a liquid crystal layer, and can represent many colors with this combination.

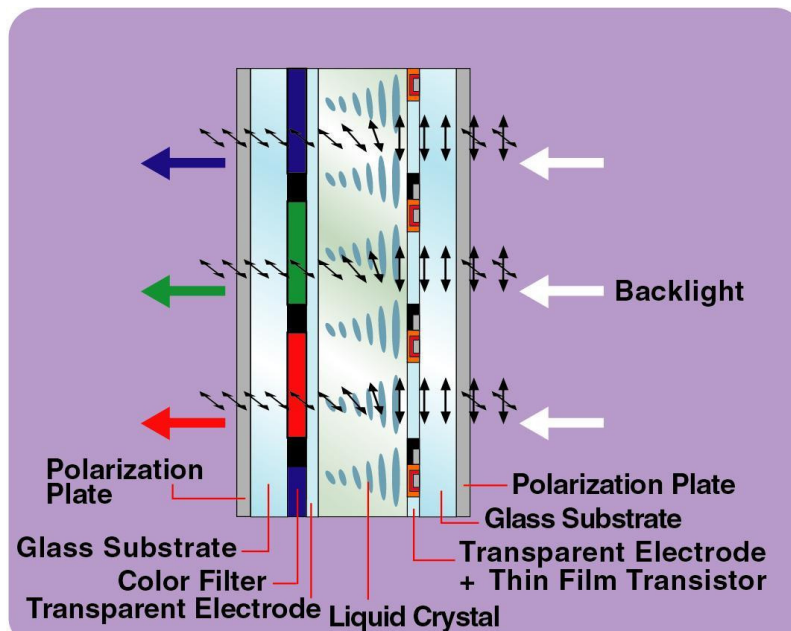


Fig.3: Section view of an LCD monitor

Additive Color Mixing Characteristics of LCD Monitors

Accuracy of additive-color-mixing of LCD monitor

The graph in Fig.4 shows the theoretical value of additive color mixing in light-blue and actual measurement value of a monitor in red. The color difference of both of these in the graph is a delta E of 0.86 on average and a maximum delta E of 2.34. The maximum delta E of 2.34 is significantly different, and this can be recognized visually.

In particular, areas in green circles in the graph have large differences between their theoretical and actual measured values. These areas are close to the primary colors of the monitor's RGB, because printing colors are somewhat outside of them. However, in the case of high quality printing, such as wide-color-gamut printing, the areas cannot be disregarded.

In this way, if a monitor does not have accurate additive color mixing, it cannot be used to proof printing colors on-screen.

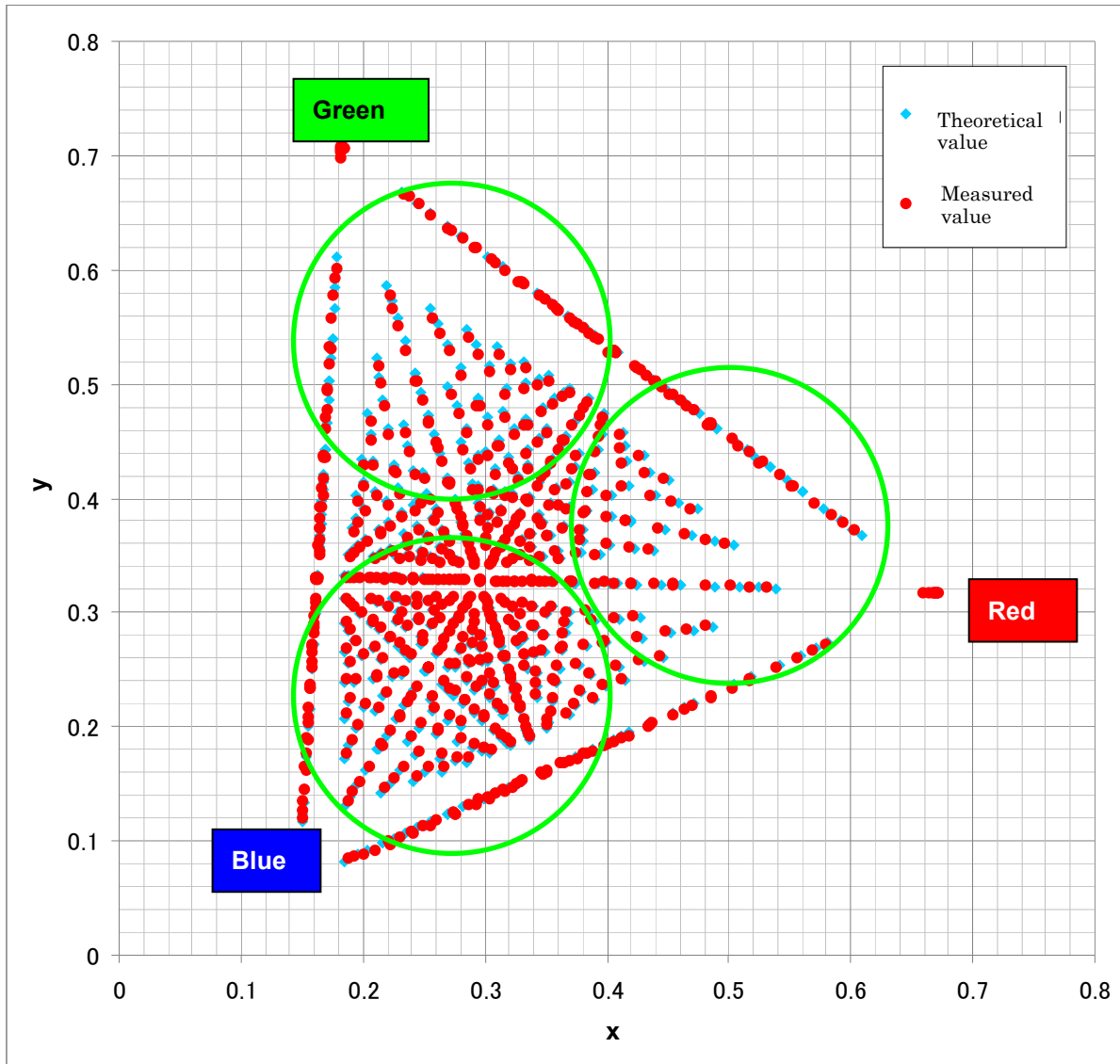


Fig.4: Divided LCD model

Causes of poor accuracy in additive color mixing

Why do actual monitors have reduced additive color mixing accuracy? The following reasons are believed to be causes based on monitor architecture and monitor theory.

- (1) LCD monitors display color images projected from a backlight and through an RGB color filter. However while each RGB color filter should only transmit a specific range of light wavelengths, in practice it accidentally also transmits light with wavelengths outside of this range.
- (2) When liquid crystal elements are actuated in each sub-pixel, not only the target pixel but also some adjoining pixels are influenced by voltage leaks and other effects. (Light may leak through other colors.)
- (3) There are individual differences between color filters and liquid crystal material, which have an influence on additive color mixing, and their characteristics change due to deterioration accompanying aging.

In order to achieve a monitor with ideal additive-color-mixing characteristics ($W = R + G + B$), a variety of advanced technology is required to overcome the above factors.

The 3D-LUT Function and Its Availability

The 1D-LUT function

Using LUTs (Look-Up Tables) is one method of correcting monitors' additive-color-mixing characteristics.

All ColorEdge models incorporate a LUT for accurate color and gray scale rendering. A typical 1D LUT adjusts color on separate tables for each red, green, and blue.

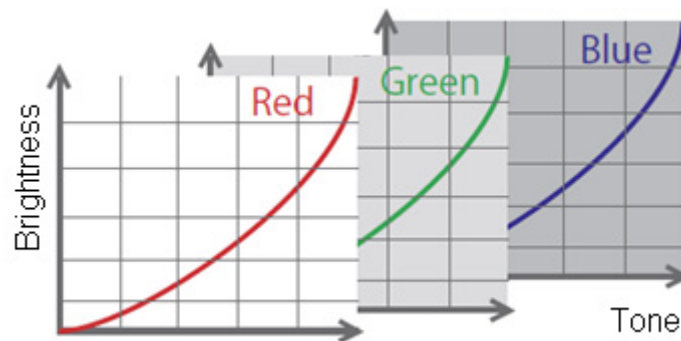


Fig.5: Illustration of 1D-LUT

The 3D-LUT function

The latest EIZO models utilize a new EIZO-developed 3D LUT. A 3D LUT corrects colors on a single, mixed-color cubic table.

In a typical 1D-LUT, when displaying a certain mixed color, the monitor displays three colors individually. If the LCD panel has less additive color mixing, the monitor displays the color less accurately. However, a 3D-LUT utilizes a cubic table (Fig.6), which has red, green, and blue as its axes. The monitor can compensate a certain color at any point on the display by using a 3D-LUT.

A 3D LUT improves the monitor's additive color mixture (combination of RGB), a key factor in its ability to display neutral tones

- Before 3D-LUT compensation
- After 3D-LUT compensation

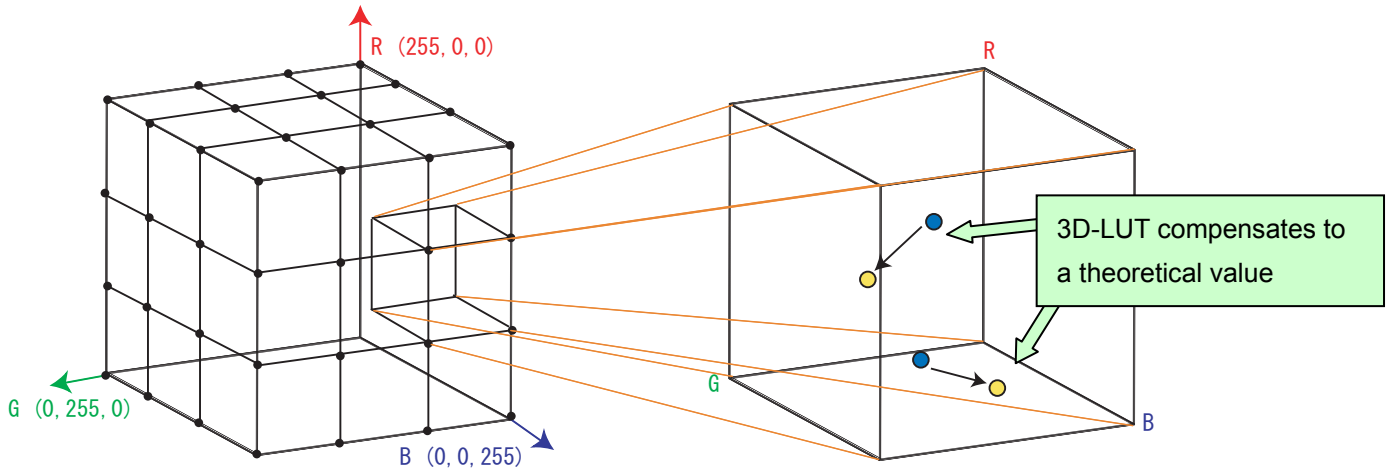


Fig.6: Visual representation of a 3D-LUT

Availability of 3D-LUT

The graphs in Figs.7 to 9 show the measuring of 728 color patches, and compare additive-color-mixing characteristics between a conventional 1D-LUT and a 3D-LUT. Monitors utilizing 3D-LUTs have a 59% improvement for the average delta E and a 58% improvement for the maximum delta E (refer to the table below).

In this way, using a 3D-LUT improves additive-color-mixing characteristics and the monitor’s color reproduction, as shown with these results, and using this feature affords a more precise management environment.

<Differences between theoretical values and measured values>

	Average (ΔE)	Maximum (ΔE)
1D-LUT	0.86	2.34
3D-LUT	0.35	0.98
Difference between 1D-LUT and 3D-LUT	0.51 (Improvement in accuracy of about 59%)	1.36 (Improvement in accuracy of about 58%)

<The amount of color difference improvement with 3D-LUT>

	Average (ΔE)	Maximum (ΔE)
Red area (color patch including R255)	0.33	1.50
Green area (color patch including G255)	0.24	0.64
Blue area (color patch including B255)	0.48	1.16

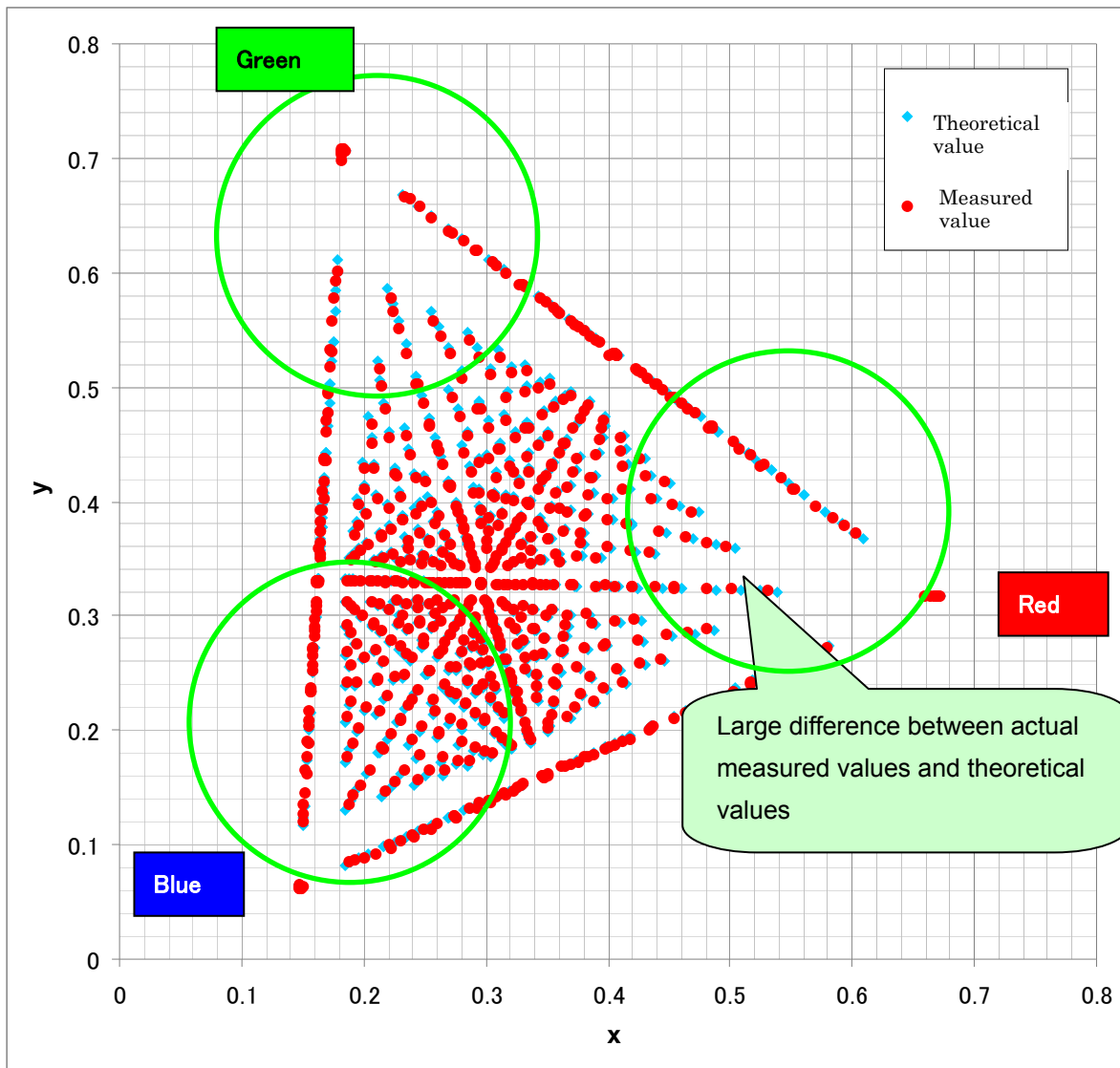


Fig.7: 1D-LUT measurement results

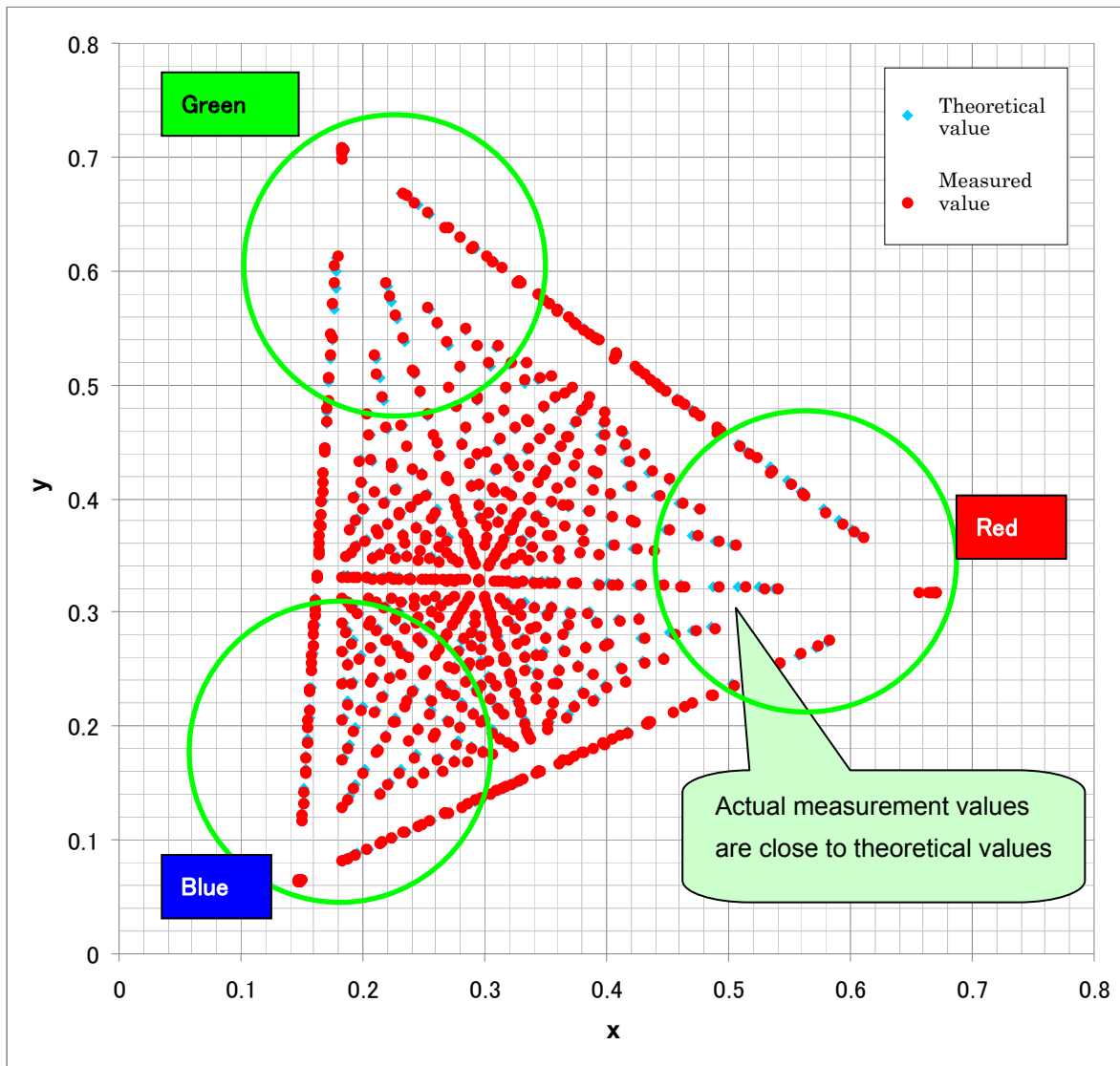


Fig.8: Measurement result of 3D-LUT

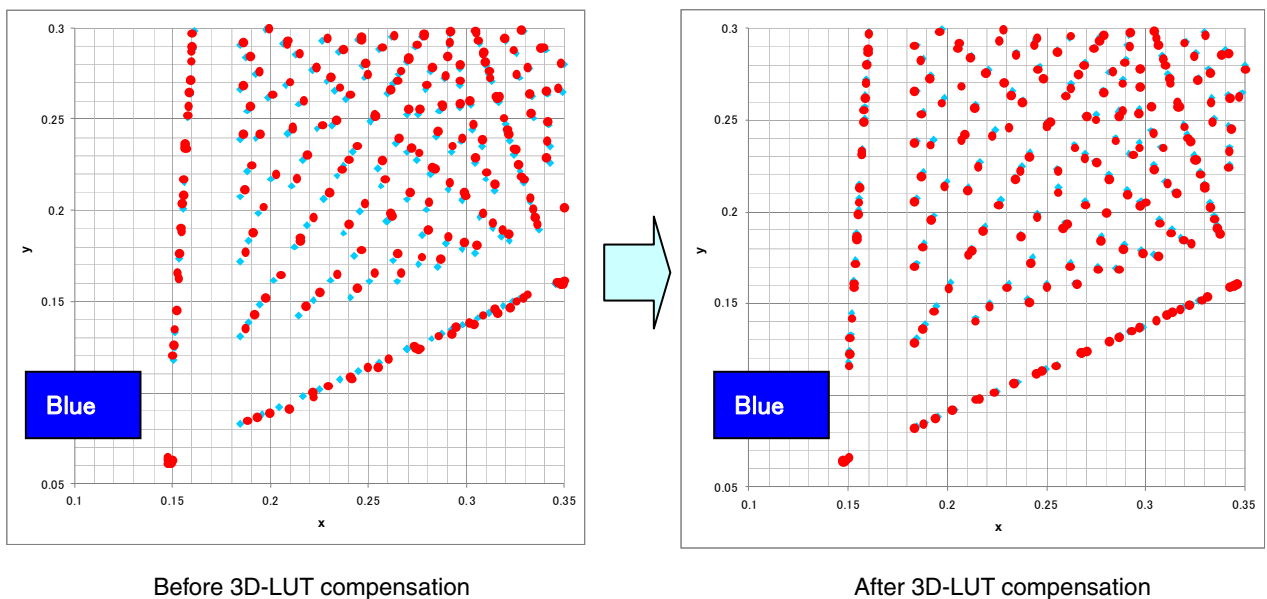


Fig.9: 3D-LUT measurement result (enlargement of Blue area)

Summary

The following is a summary of this White Paper;

- (1) Additive-color-mixing is the most important factor in displaying exact colors demanded by the graphics market.
- (2) Almost all LCD panels have poor additive-color-mixing. It is difficult to correctly display colors with poor additive-color-mixing.
- (3) 3D-LUT compensation is the most effective way of improving additive-color-mixing.

As outlined above, selecting a monitor with 3D-LUT will result in superior additive-color-mixing and a precise color management environment, as demanded by the graphics market.