TETRA-CHROMA DISPLAY: COLOR ACCURACY BETWEEN SOFT-PROOFING AND HARDCOPY

Jan Kaiser

Fomei a.s.

Abstract

This paper introduces tetra-chroma display unit that has, in contrast to the contemporary trichromatic displays, four primary colors. Extra fourth cyan light allows better reproduction not only region of cyan colors but also, thanks to advanced position of green primary light, orange and yellow colors. These both regions are printable through modern inkjet printers. Colorimetric driving is discussed in detail and also reproduction on the basis of spectral matching isn't omitted. An aim is to give for graphic designer or photographer solution that make easier preparation of their art work from the color accuracy point of view. Tetra-chroma display unit offers high quality soft-proofing.

1 Color gamuts of displays and printers

Position of contemporary three display primaries (in terms of chromaticity diagram) is given by compromise to cover with the given reproduction triangle the area of the most frequently occurred colors. As for green primary light in contemporary reproductive triangle, in contrast to the blue and red primary, is the most compromisingly located to achieve satisfactory reproduction of yellows as well as cyans. Due to this compromise, cyans and orange-yellows that are achievable in printing are not reproducible by the contemporary trichromatic display systems. This leads into poor function of soft-proofing – simulation of printed colors on the monitor [1].

On Fig. 1 below, there can be seen color gamuts of Eizo CG222W display and Epson Stylus PRO 7900 printer & UltraChrome HDR inks (configuration with Photo K) & Fomei REAL Velvet paper. REAL Velvet paper meets conditions on proofing paper type 1/2 according to ISO12647-2 standard, hence comparison of REAL Velvet color gamut with ISO Coated v2 gamut is reasonable to mark, too (see Fig. 1 below). As can be seen, although marked monitor profile has expanded gamut (today trend: moving from sRGB to Adobe RGB gamut), there are still regions of colors, that are printable but are not reproducible on monitor.

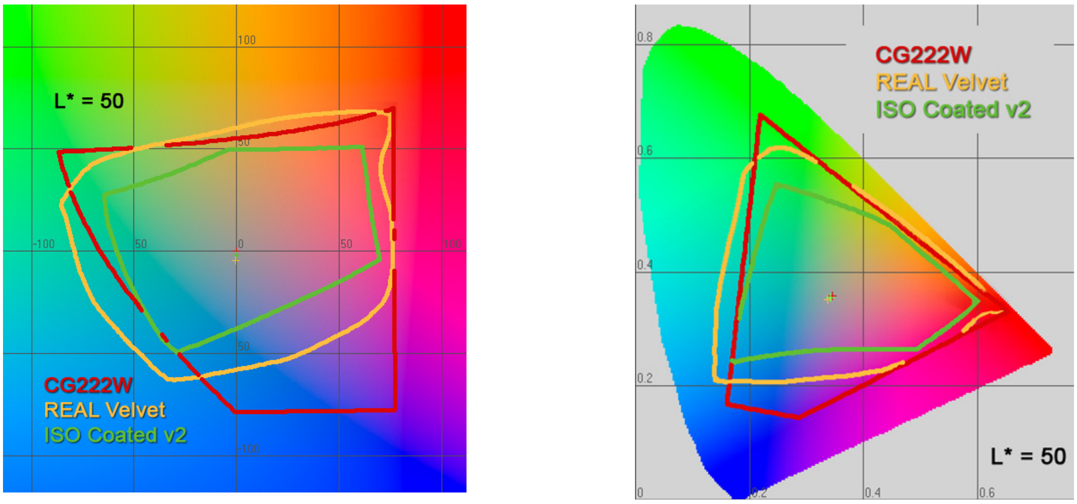

Figure 1: Projection of color gamuts into the ab plane of CIE Lab color space (on the left) and CIE xy chromaticity diagram (on the right)

The reproduction of really all existing colors is not desirable in every task since very often given imaging system cannot generate (or transmit) such color gamut and then statistical redundancy of the signals driving the display increases and gamut of reproduction is not exploited. By looking at contemporary reproduction triangle in CIE xy or CIE u'v' chromaticity diagram, it is evident, that cardinal significance has addition of the fourth reproduction light into area of cyans. Thanks to this cyan reproductive light, the green reproductive light would be shifted towards the spectrum locus similarly as in the case of NTSC standard. It means, that the choice of the new cyan primary light carries an advantageous position for green primary. The contemporary sRGB reproductive triangle and the new proposed RGCB tetragon is shown on Fig. 2 below. The position of R and B primary is in the case of RGCB the same as in sRGB specification (see Tab. 1). The new position of **G** primary is x_G = 0.26, y_G = 0.7, and new **C** primary has chromaticity coordinates as follows: x_C = 0.05, y_C = 0.6. The primary lights were not chosen too spectral to be achievable through different technologies. From the spatial resolution point of view, the addition of the fourth primary light still ensures the reach of the desired resolution not only for TV but also for graphic, fine art and scientific application. Contemporary possibilities of graphic cards and given displays allow trouble-free adding of the fourth light – the graphic cards offer a sufficient capacity and displays have so small image pixels that one picture element, which today consists of three pixels, can be created by four pixels without loss of quality in spatial resolution.

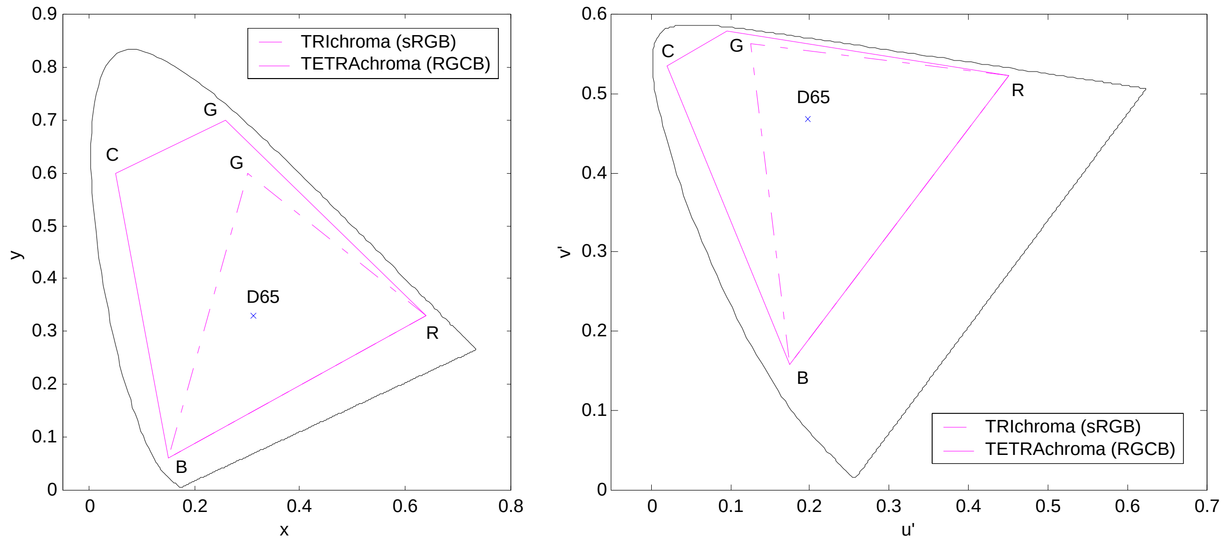

Figure 2: Conventional sRGB and proposed RGCB color gamut in CIE xy (left) and CIE u'v' (right) chromaticity diagram

The crucial task in the case of more than tri-chroma display unit is obtaining suitable control signals that drive the bright of the display primaries [2], [3]. Input signal, typically X, Y, Z tristimulus (accurately electrical analogues of CIE XYZ tristimulus) is converted into control signal, **c**, with number of elements 3 + N_{DF}, where N_{DF} represents a number of the degree of freedom. In other words, it is task where there are fewer equations than unknowns, that is, the underdetermined case, and an infinite number of solutions exist. Of these solutions, there are two with great practical value. First, solution that has a maximum number of zeros in the elements of control signal **c**. Second solution give a control signal **c** where the length or norm of **c** is smaller than other possible solutions. This solution, based on the pseudoinverse, is called the minimum norm solution.

In our case of the tetra-chromatic display system, a number of degrees of freedom N_{DF} = 1 and then the solution that has maximum number of zeros passes into the case of trichromatic system when always one from the four primaries has its bright equal to zero. This only mathematic solution is not utilizable in real display system because such solution does not encompass the necessary condition about the reference white light – this reference light has to be only one and has to lie in the gamut of given three primaries (into triangle created by these three primaries). It can be on the basis of Fig. 2 found out that e.g. $\mathbf{D_{65}}$ reference light is included only into triangles RGB and RCB and not in BGC and RGC reproduction triangle.

The minimum norm solution does not give only non-negative values of elements of control signal, **c**, and from this reason, such solution is not in real display system applicable, too. The negative bright of primaries cannot be made. In Fig. 3 below there is shown the area, which is covered in the case when all four primaries (elements of **c**) are non-negative. It can be readily seen, that minimum norm solution together with condition about non-negative bright of primaries does not ensure reproduction of the desired colour gamut. This reproducible area is in chromaticity diagram in Fig. 3 marked grey.

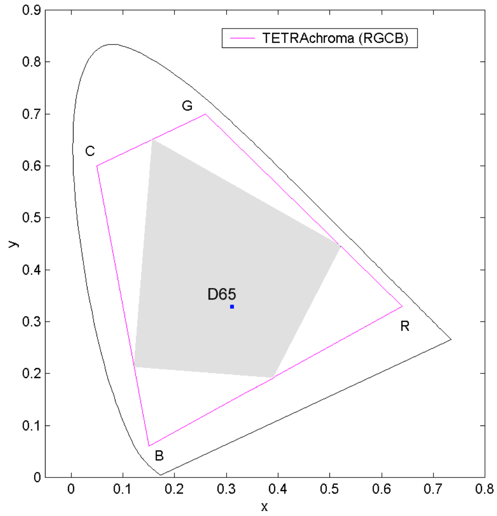

Figure 3: Reproducible area (grey) as a result of minimum norm solution with condition about non-negative elements of control signal **c**

The two presented solutions – with maximum number of zeros and with minimum norm do not lead to the suitable control signal, **c**, which could be used for driving of display primaries. Solution applicable in real display system will be introduced in following sections. These new solution are based on the division of given RGCB tetragon into triangles and offer corresponding colorimetric conversion. In addition, *virtual primaries* are established. The term virtual does not mean non-feasible; it means the primaries that are not physically implemented in the display. The division of RGCB region into desired sub-regions (in terms of 2D chromaticity diagram) has to satisfy the condition that the reference white light has to be only one and has to lie within each sub-region of RGCB tetragon ($\mathbf{D_{65}}$ reference light is chosen). The condition about reference light can be said also from the other side: The reference white light, which needs to be in given display system only one, has to be able to be reproducible (colorimetrically matched) via all sub-regions, from which the colour gamut of display system is assembled. In this way, the continuity between individual colour sub-gamuts (sub-regions) of the main (RGCB) colour gamut is achieved. The virtual primaries are modeled by real (in display physically implemented) primaries.

2 Tetra-chroma^4 Display Unit

The RGCB tetragon is in the case of Tetra-chroma^4 Display Unit divided into four triangles, where each triangle is created by two real primaries and one virtual primary. The new four virtual primaries are: yellow **Y**, green $\mathbf{G_2}$, cyan $\mathbf{C_2}$, and magenta **M**.

Note: To prevent the confusion between luminance primary of CIE XYZ system and Yellow virtual primary in Tetra-chroma^4 Display Unit, Yellow primary will be noticed as Y' on the places where the confusion could occur.

The **R**, **G**, **C**, **B** physically implemented primaries and virtual primaries of Tetra-chroma^4 Display Unit have following chromaticity coordinates

Table 1: CIE XY CHROMATICITY COORDINATES OF USED PRIMARIES AND REFERENCE LIGHT IN TETRA-CHROMA^4 DISPLAY UNIT

Primaries of Tetra-chroma^4 Display		
CIE xy	x	y
R	0.64	0.33
G	0.26	0.70
C	0.05	0.6
B	0.15	0.06

Virtual primaries of Tetra-chroma^4 Display		
CIE xy	x	y
M	0.395	0.195
Y'	0.545	0.4225
$\boldsymbol{G_2}$	0.155	0.65
$\boldsymbol{C_2}$	0.125	0.195

Reference white light		
CIE xy	x	y
$\boldsymbol{D_{65}}$	0.3127	0.3290

Graphical notation of the Tetra-chroma[4] Display Unit primaries in CIE xy and CIE u'v' chromaticity diagrams is shown in Figure below.

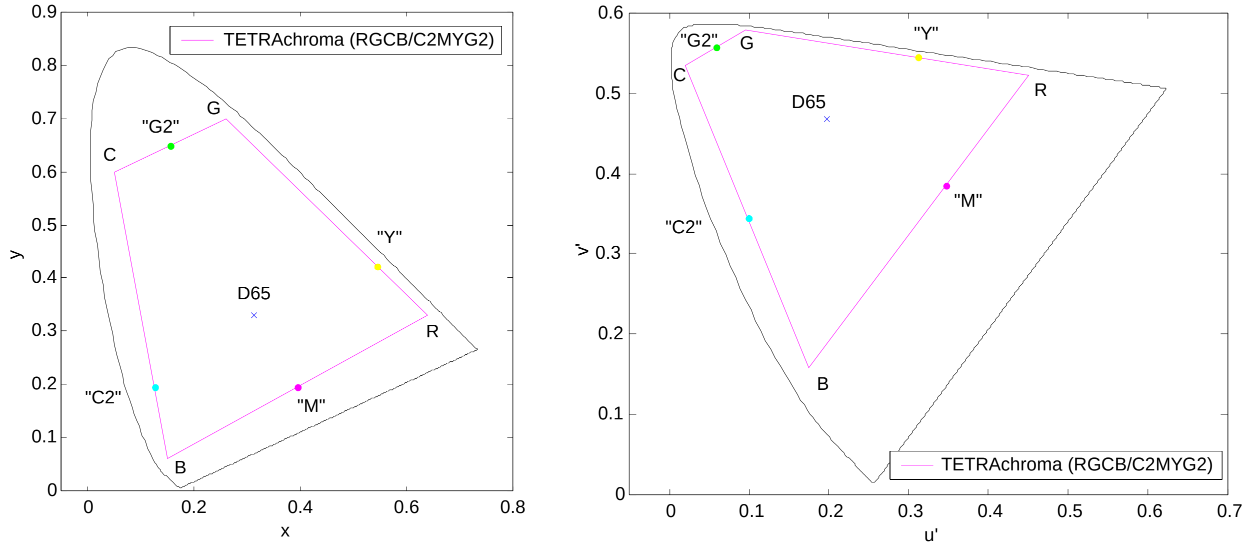

Figure 4: Primaries of Tetra-chroma[4] Display Unit in CIE xy (left) and CIE u'v' (right) chromaticity diagram

The four sub-gamuts, in which the Tetra-chroma[4] Display Unit is driven, are: MGC, YCB, G_2BR, and C_2RG. It means that each sub-gamut consists of two real and one virtual primary. These sub-gamuts are illustrated in chromaticity diagrams in Fig. 5. The mutual overlapping of individual sub-gamuts is marked, too. It can be readily seen that some colors can be reproduced through two or three or all four sub-gamuts. Virtual primaries were chosen in this way to be able to reproduce (colorimetrically match) in corresponding sub-gamuts the reference white light. The method of dividing the whole colour gamut into sub-gamuts containing reference light ensures continuity between individual sub-gamuts.

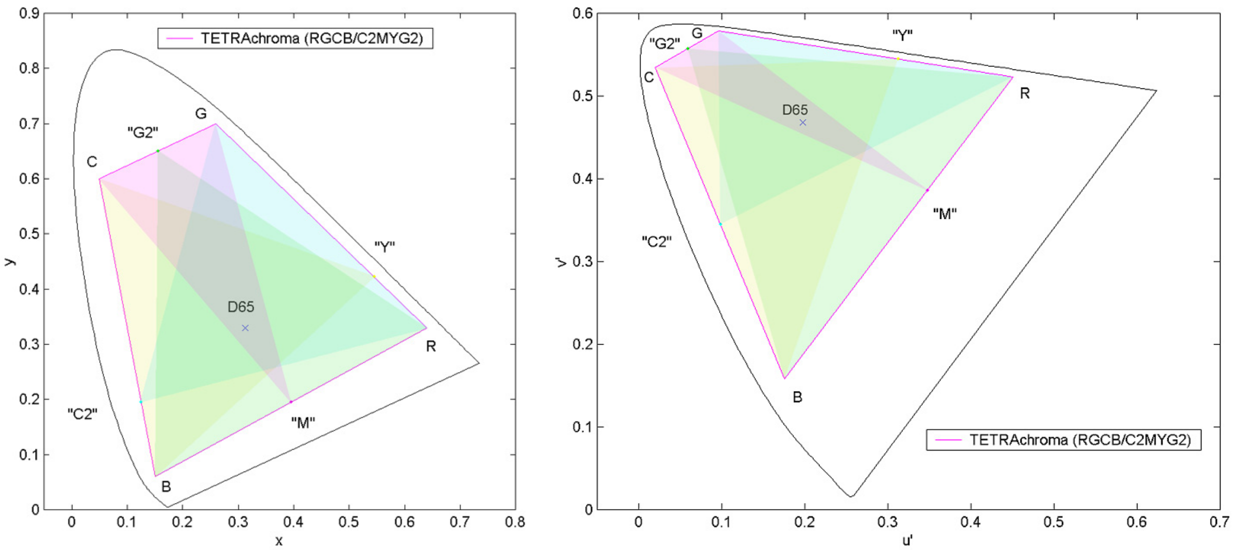

Figure 5: Four sub-regions of RGCB tetragon of Tetra-chroma4 Display Unit shown in CIE xy (left) and CIE u'v' (right) chromaticity diagram

3 Control Signals for the Tetra-chroma[4] Display Unit

To set the control signal, **c**, means to determine the relation between device independent quantity describing colors (e.g. CIE XYZ tristimulus) and suitable values for the display primaries driving. Control signals for Tetra-chroma[4] Display Unit driving represent tristimuli of corresponding sub-gamuts. These tristimuli – MGC, Y'CB, G_2BR, and C_2RG directly represent relative bright (gain) of corresponding primaries.

4 Reproduction of Virtual Primaries

The four virtual primaries in Tetra-chroma[4] Display Unit are reproduced with help of sub-gamuts on whose connectivity line between two real primaries the given virtual primary lies. From the Fig. 5 follows that

- **M** virtual primary is reproduced by **R** and **B** primaries from G_2BR sub-gamut
- **Y'** virtual primary is reproduced by **R** and **G** primaries from C_2RG sub-gamut
- $\mathbf{G_2}$ virtual primary is reproduced by **G** and **C** primaries from MGC sub-gamut
- $\mathbf{C_2}$ virtual primary is reproduced by **C** and **B** primaries from Y'CB sub-gamut

It can be readily seen that each virtual primary (e.g. $\mathbf{G_2}$) is matched by primaries from the gamut (in this case MGC) which is always created by the virtual primary (**M**), too, but this "matching" virtual primary (**M**) does not participate on the "matched" virtual primary ($\mathbf{G_2}$) reproduction since the "matched" virtual primary ($\mathbf{G_2}$) lies on the connectivity line of the remaining two primaries (**G** and **C**) of the sub-gamut that is participated on the "matched" virtual primary ($\mathbf{G_2}$) reproduction (MGC, see Fig. 5 above). If the light to be reproduced lies inside of RGCB gamut of Tetra-chroma[4] Display Unit, all four real primaries are always used by reproduction.

5 Sphere of Activity of Individual Sub-gamuts

Color lights in areas, where the sub-gamuts overlap each other (in terms of 2D chromaticity diagram, see Fig. 5 above), can be reproduced in two or three or four ways according to number of sub-gamuts that are mutually overlaid in position of the final light to be reproduced. All possibilities result in the same CIE XYZ tristimulus but in the different spectral distribution of reproduced light. In other words, metameric lights are displayed. It means, that when the spectral distribution of the original light is known (the case of spectral recording), such light can be through Tetra-chroma[4] Display Unit reproduced not only under the condition of colorimetric matching but also such light can be reproduced as accurate as possible in terms of spectral matching. The spectral distributions of in the display physically implemented primaries, $\mathbf{p}_R$, $\mathbf{p}_G$, $\mathbf{p}_C$, $\mathbf{p}_B$, have to be known. Then, such sub-gamut can be chosen, through which the reproduced light best matches with its original, **f**, in colour also from spectral viewpoint. This criterion is given by

$$\min\left(\mathbf{f} - \sum_{i=1}^{4} \mathbf{c}_i \cdot \mathbf{p}_i\right) \tag{1}$$

where **f** is the spectrum of the original light, and

$$\sum_{i=1}^{4} \mathbf{c}_i \cdot \mathbf{p}_i$$

is a spectrum composed from the primaries that participate on the original light reproduction. Although all four in the display physically implemented primaries are always used during reproduction, up to four possibilities of the light reproduction are given by sequence of the given light through individual sub-gamuts reproduction. In other words, the possibilities are given by the initial sub-gamut choice. The determined four variations of control signal represent four different ways of Tetra-chroma[4] Display Unit primaries driving that lead in reproduced light of different spectral distribution (different proportion of display primaries) but the same final CIE XYZ tristimulus. From this reason, such control signal, $\mathbf{c}_i$, can be chosen, by which the reproduced light has spectral distribution that is in the best match with spectral distribution of original light. Multispectral recording has to be naturally used in this case as well as spectral distribution of display primaries has to be known.

The other solution of division of spheres of activities of the individual sub-gamuts, above all when the multispectral recording is not available, can be based on the decision according to the position (in terms of chromaticity diagram) of the light to be reproduced with specified priority of individual sub-gamuts.

6 Conclusion

Color lights in areas of Tetra-chroma Display Unit, where the sub-gamuts overlap each other (in terms of 2D chromaticity diagram, see Fig. 5 above), can be reproduced in two or three or four ways according to number of sub-gamuts that are mutually overlaid in position of the final light to be reproduced. All possibilities result in the same CIE XYZ tristimulus but in the different spectral distribution of reproduced light. In other words, metameric lights are displayed. It means, that when the spectral distribution of the original light is known (the case of spectral recording), such light can be through Tetra-chroma Display Unit reproduced not only under the condition of colorimetric matching but also such light can be reproduced as accurate as possible in terms of spectral matching.

In many cases, soft-proofing is only toll for graphic designer to fine-tune his art-work. Tetra-chroma^4 Display Unit has sufficient gamut to accurate simulate all printable colors with contemporary inkjet printers.

References

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Jan Kaiser
Fomei a.s.
Digital Color Imaging
Machkova 587
500 11 Hradec Králové
Czech Republic

www.fomei.com
Kaiser@fomei.com
tel: +420 495 056 315
gsm: +420 603 587 898