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MULTI-PRIMARY REPRODUCTION OF TV IMAGES PRODUCED BY SDTV, HDTV AND UHDTV SYSTEMS

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ВІДТВОРЕННЯ ТЕЛЕВІЗІЙНИХ ЗОБРАЖЕНЬ СИСТЕМАМИ, ЩО ПОБУДОВАНІ НА ВИКОРИСТАННІ ДЕКІЛЬКОХ ПЕРВИННИХ КОЛЬОРІВ, ВИРОБЛЕНИХ В СИСТЕМАХ ТБСЧ, ТБВЧ ТА ТБНВЧ

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Annotation. An analysis of colorimetric characteristics of television images reproduction systems based on use several primary colors, more than three is presented. The case is considered when multi-primary reproduction of images produced in UHDTV system is used. Quantitative evaluations of the transmitted and reproducible color gamut are presented.

Анотація. Проведено аналіз колориметричних характеристик систем відтворення телевізійних зображень, заснованих на використанні декількох, більше ніж трьох, основних кольорів. Розглядається випадок, коли використовується відтворення з числом основних кольорів, більшим трьох, зображень, вироблених у системі ТБНВЧ. Наведено кількісні оцінки області передаваних і відтворюваних кольорів

INTRODUCTION

Table 5 of the Report ITU-R BT.2246-1 [1] gives a complete classification of methods to expand the colour gamut of image systems. The success of the new systems is based on the implementation of the end devices, and from this point of view the two types of reproducing devices – laser and based on the use of multi-primary color (MPC) have great prospects.

Colour gamut transmitted in the UHDTV system is defined by triangle of colors specified in Recommendation ITU-R BT.2020, and can be realized completely or partially, depending on the technology of image reproduction.

In some cases source signals for SDTV and HDTV can be produced from UHDTV signals. It may be supposed that for some applications colour gamut of UHDTV systems can be used for SDTV and HDTV.

There are two alternative variants of technology.

The laser variant is complex and expensive. In [2] an example based on the use of lasers with a wavelength corresponding to the primary colors coordinates given in Table 1 is shown. Triangle of colors for this example of reproduction system is presented in comparison with the triangle of ITU-R BT.2020 in Figure 1.

Table 1 – The chromaticity coordinates of the primary colors and reference white for example of reproducing system implementation given in [2]

Primary colors and reference white	Chromaticities coordinate	
	x	*y*
R	0.713	0.287
G	0.175	0.793
B	0.135	0.042
W	0.3127	0.0329

Area of a primaries triangle of this reproducing system is 95 % of the area of the standard UHDTV triangle colors area. The currently implemented scanning options for reproducing laser system is similar to the

standard HDTV. Thus, in [2] a reproducing system, the level of which corresponds to the level of colorimetry of UHDTV system, but by resolution of images to HDTV system, is presented

Variant based on MPC. Realization based on the MPC is not designed for the use of basic monochromatic colors, and is therefore limited in terms of colorimetry system. Today the most interesting technical solution regarding colorimetry system is the application of reproducing systems with more than three primary colors. The publications [3–9] include embodiments of the reproducing devices with 4, 5 and 6 primary colors.

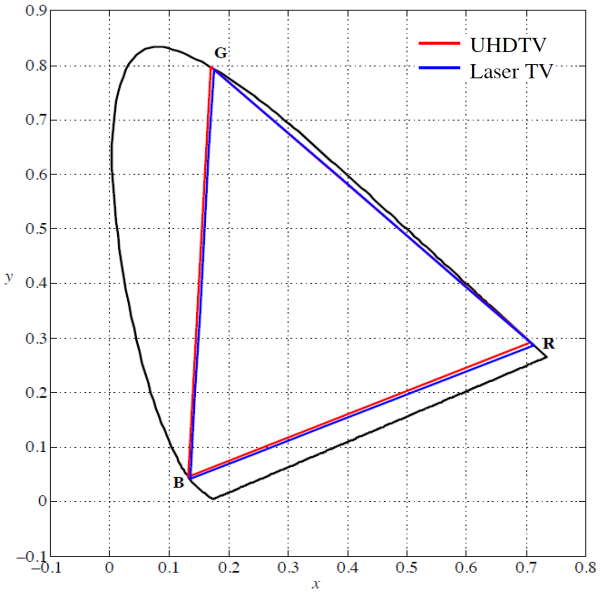

Figure 1 – CIE *x,y* chromaticity diagram of the laser TV system

Colour gamut, which can be reproduced by such systems, depends on the implementation of the principles and parameters, and is of considerable interest, since such systems are more perspective than the laser systems, despite the obvious drawback of the limited area of reproduced colors. This work provides examples of reproducing systems, based on the use of 4, 5 and 6 primary colors, as well as an assessment of reproducible color gamut. MPC technology is used for different types of implementation of displays, and can be considered the most effective technology of realization with an extended area of reproducible color gamut.

This document provides an assessment of area of color gamut that can be transferred in the UHDTV systems built in accordance with the Recommendation ITU-R BT.2020 and reproduced in the MPC systems.

REPRODUCTION OF IMAGES BY SYSTEMS BUILT ON THE BASIS OF MULTIPLE PRIMARY COLORS PRODUCED IN SYSTEMS SDTV, HDTV, UHDTV

Systems in which the source signals are signals of three primary colors RGB, these signals can be converted into image signals representing an arbitrary number of basic colors $S_1, S_2, \ldots S_n$.

In this case, the absolute color coordinates in the CIE *XYZ* are determined taking into account the specified coordinates of primary colors of image reproducing system – $X_i, Y_i, Z_i, i = 1, 2, \ldots n$ (including coordinates of the reference white color x_W, y_W for a given brightness *Y*) and image signals $S_1, S_2, \ldots S_n$.

The coordinates of the image colors CIE-31 are defined by equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_1 & X_2 & \ldots & X_N \\ Y_1 & Y_2 & \ldots & Y_N \\ Z_1 & Z_2 & \ldots & Z_N \end{bmatrix} \cdot \begin{bmatrix} S_1 \\ S_2 \\ \vdots \\ S_N \end{bmatrix}$$

This equation may correspond to the inverse equation, but it is impossible to construct such equation because the transformation matrix is not square, but rectangular. In this case, the choice of primary colors and their coordinates for transform is a problem as the inverse transform, we are faced with uncertainty. The literature on the subject offers a number of relevant transformations [3–9] and proposals for the technical implementation of these systems [10–14]. Since this problem can be solved by different methods of transformation and there are a great choices, it can be assumed that the source colour within area of color gamut that

can be transmitted at a given brightness will be reproduced within the area of color gamut defined by the polygon of *N*-component primary color reproducing system.

Thus, for a given brightness of each region transmitted and reproduced colors can be constructed as the intersection of these areas. On the basis of this principle in the following sections are examples of data transmitted and reproduced colors for the cases when the UHDTV system implemented in accordance with Recommendation ITU-R BT.2020, as well as the reproduction system is the display with *N* primary colors.

THE SYSTEM WITH FOUR PRIMARY COLORS

This section provides the projection of the colour gamut, transmitted in light-to-light UHDTV system with the characteristics defined in Recommendation ITU-R BT.2020, and as a reproduction system is supposed to use the system with the number of primary colors equal four.

The projections are presented on the plane of CIE-31 chromaticity coordinates and on the plane of Cartesian coordinates of a'_M, b'_M uniform color space J', a'_M, b'_M, obtained with use of proposed by Luo et al. [15] transformation of color space J, a_M, b_M of CIECAM02 [16], which is the most perfect colour appearance model at present time [17].

Here J – lightness; $a_M = M \cdot \cos h$, $b_M = M \cdot \sin h$ – chroma Cartesian coordinates, M – colorfulness, h – hue angle. The curves were constructed for relative luminance values, $Y \in \overline{0,1}$, for adaptation level $L_A = 0,2\, L_W$, where L_W – the maximum brightness of reference white in cd/m^2.

Table 2 – CIE-31 *x,y* coordinates of the four primary reproduction system primaries with additional yellow (Ye) primary

Coordinates	Value of primary colors			
	R	G	B	Ye
x	0.677	0.154	0.147	0.456
y	0.315	0.773	0.045	0.535

Adapting luminance is taken equal L_A = 50 cd/m^2, which corresponds to the maximum luminance of 250 cd/m^2 on white, average environment accepted. Reference white is D_{65}.

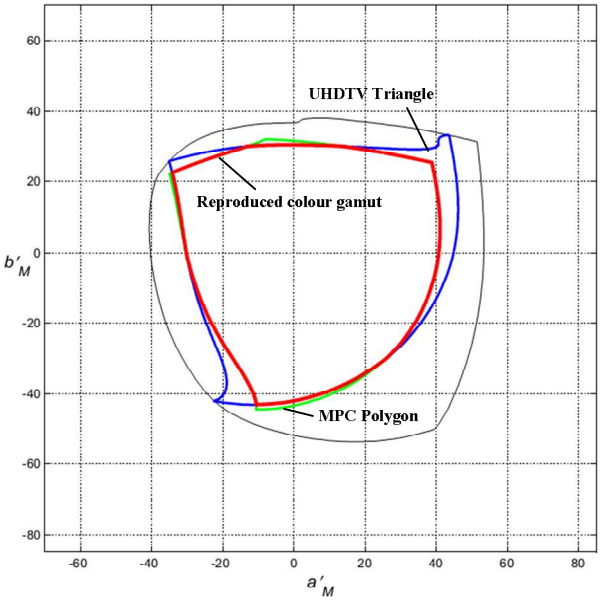

Figure 1 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional yellow for Y = 0.05

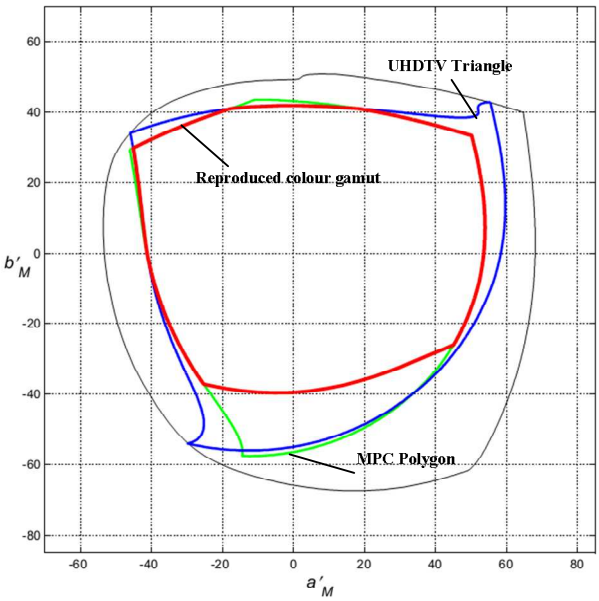

Figure 2 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional yellow for Y = 0.25

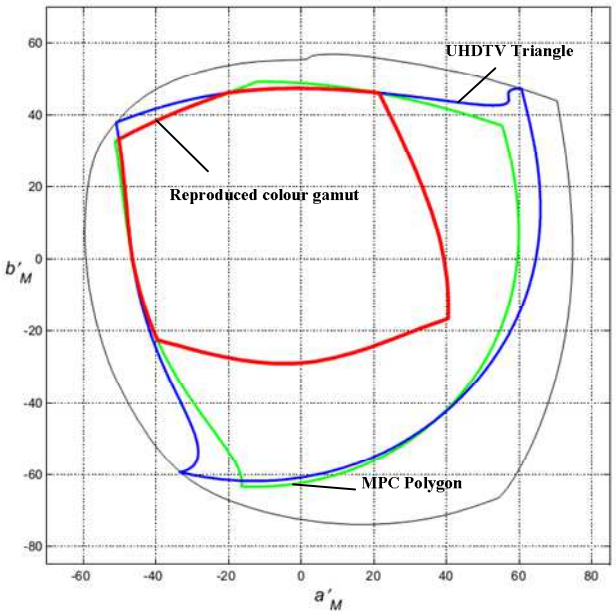

Figure 3 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional yellow for $Y = 0.5$

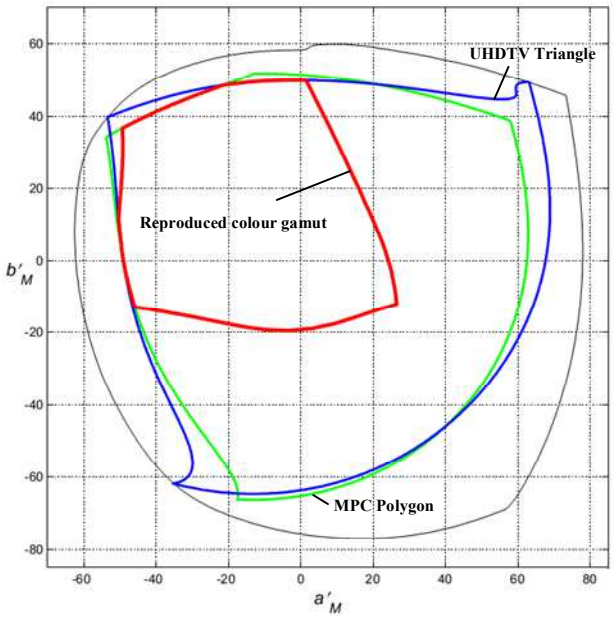

Figure 4 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional yellow for $Y = 0.7$

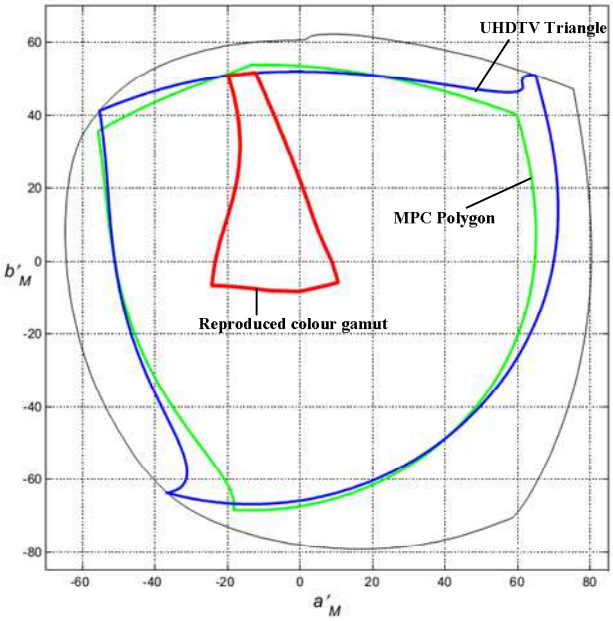

Figure 5 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional yellow for $Y = 0.9$

Table 3 – CIE-31 *x,y* coordinates of the four primary reproduction system primaries with additional cyan (C) primary

Координаты	Значения			
	R	G	B	C
x	0.64	0.26	0.15	0.05
y	0.33	0.70	0.06	0.60

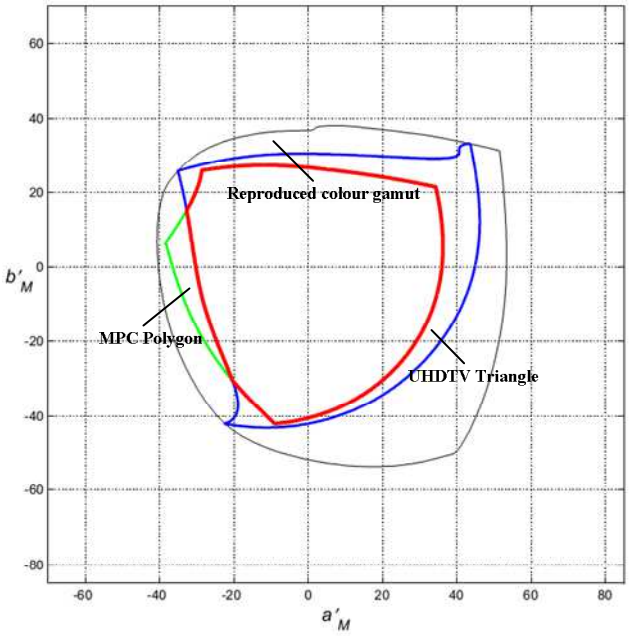

Figure 6 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional cyan for $Y = 0.05$

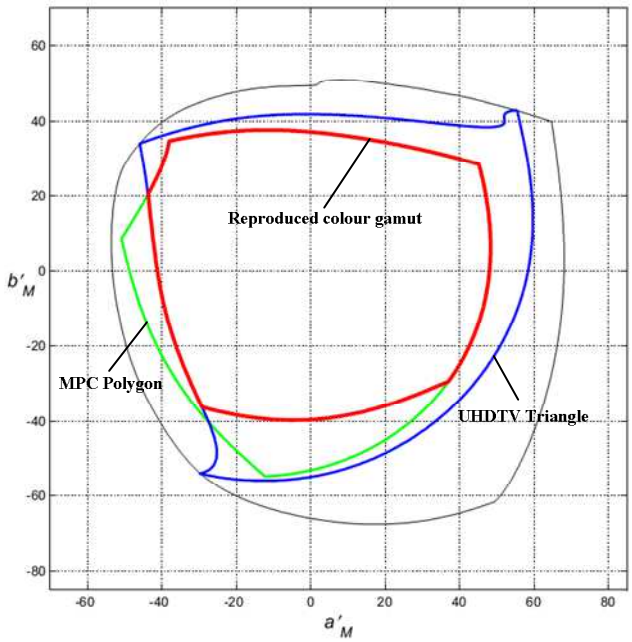

Figure 7 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional cyan for $Y = 0.25$

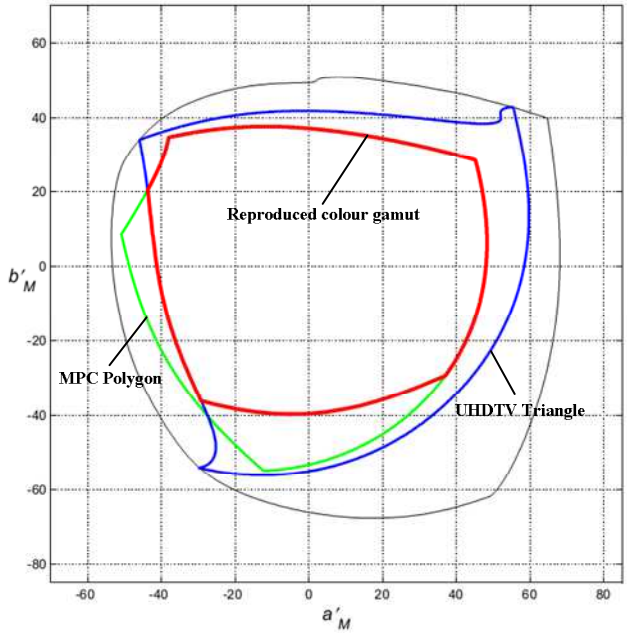

Figure 8 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional cyan for $Y = 0.5$

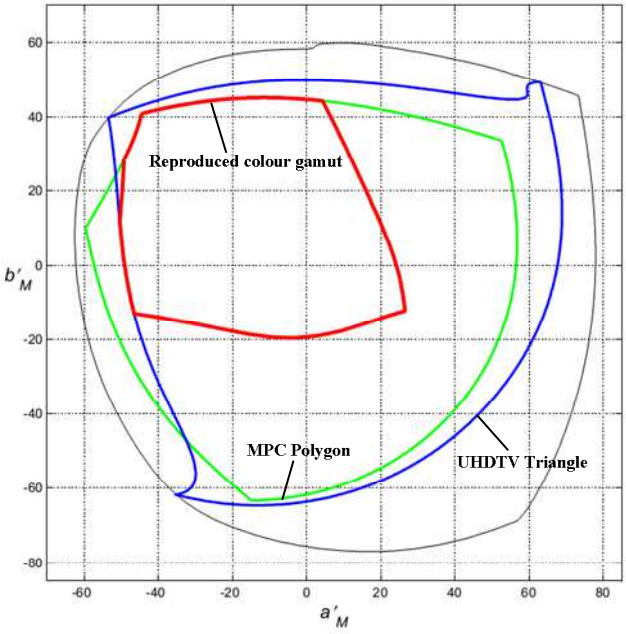

Figure 9 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional cyan for $Y = 0.7$

This section provides the projection of the colour gamut, transmitted and reproduced in light-to-light UHDTV system with characteristics defined in Recommendation ITU-R BT.2020, and as a reproduction system is supposed to use the system with the number of primary colors equal five.

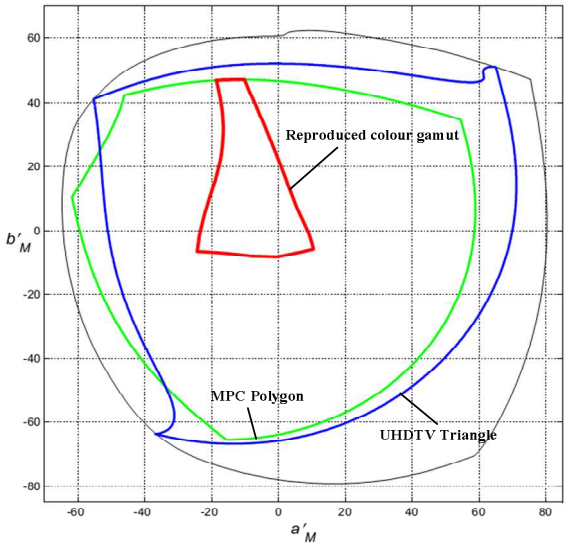

Figure 10 – Area of transmitted and reproduced chromaticities through light-to-light system, when used four colors reproduction with additional cyan for $Y = 0.9$

THE SYSTEM WITH FIVE PRIMARY COLORS

CIE-31 *x,y* coordinates of the four primary reproduction system primaries with additional cyan

Table 4 – CIE-31 *x,y* coordinates of the four primary reproduction system primaries with additional yellow and cyan primaries

Coordinates	Values				
	R	G	B	Ye	C
x	0.67	0.15	0.14	0.49	0.13
y	0.32	0.71	0.08	0.49	0.19

Adapting luminance is taken equal $L_A = 50$ cd/m^2, which corresponds to the maximum luminance of 250 cd/m^2 on white, average environment adopted.

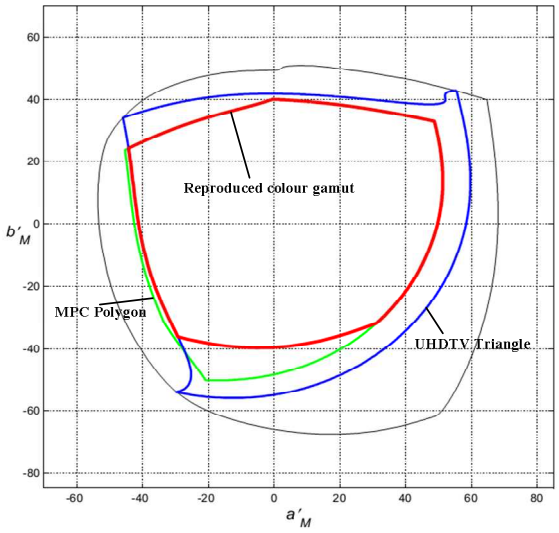

Figure 11 – Area of transmitted and reproduced chromaticities through light-to-light system, when used five primary colors reproduction with additional yellow and cyan for $Y = 0.05$

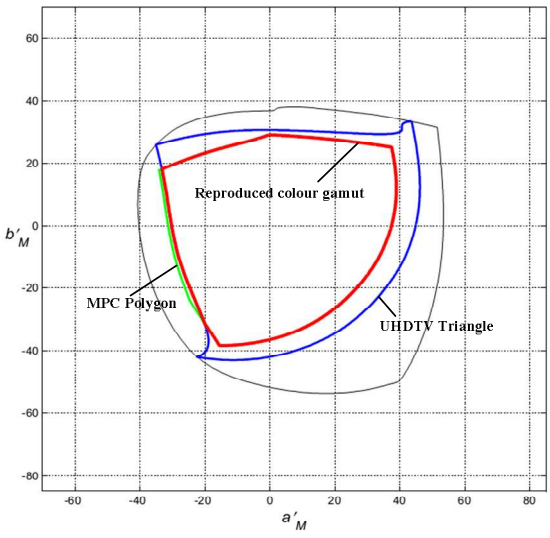

Figure 12 – Area of transmitted and reproduced chromaticities through light-to-light system, when used five primary colors reproduction with additional yellow and cyan for $Y = 0.25$

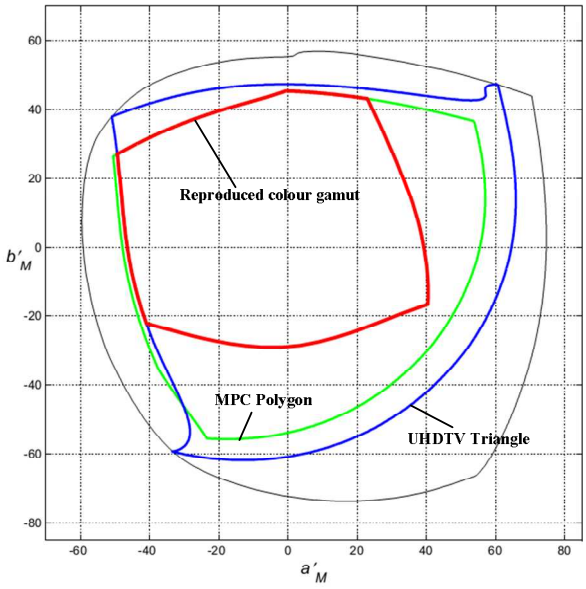

Figure 13 – Area of transmitted and reproduced chromaticities through light-to-light system, when used five primary colors reproduction with additional yellow and cyan for $Y = 0.5$

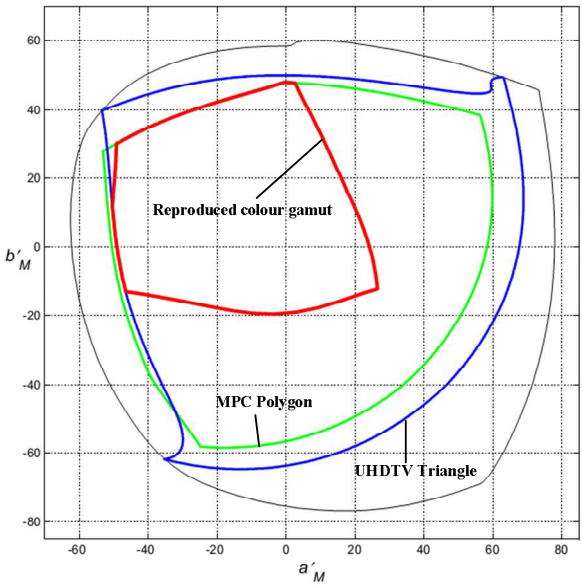

Figure 14 – Area of transmitted and reproduced chromaticities through light-to-light system, when used five primary colors reproduction with additional yellow and cyan for $Y = 0.7$

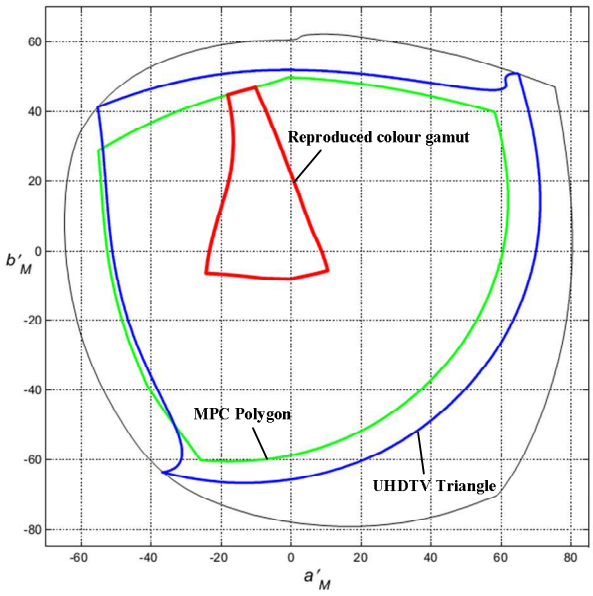

Figure 14 – Area of transmitted and reproduced chromaticities through light-to-light system, when used five primary colors reproduction with additional yellow and cyan for $Y = 0.9$

THE SYSTEM WITH SIX PRIMARY COLORS

CIE-31 *x,y* coordinates of the six primary reproduction system primaries are shown on Figures 6, 7.

Table 5 – CIE-31*x,y* coordinates of the reproduction system primary colors [6]

Coordinates	Values					
	P_1	P_2	P_3	P_4	P_5	P_6
x	0.1711	0.1371	0.0823	0.3455	0.6239	0.6738
y	0.0317	0.0678	0.7099	0.6478	0.3638	0.2930

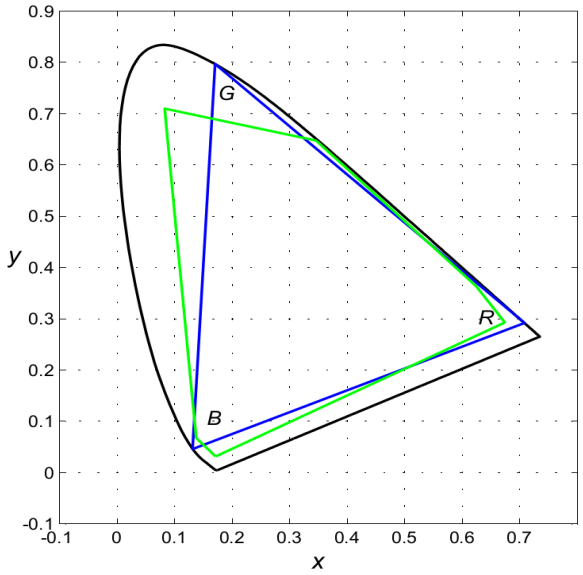

Figure 15 – UHDTV color primaries triangle and six-primary reproduction system [6] color primaries polygon, presented in *x*,*y* chromaticity coordinates

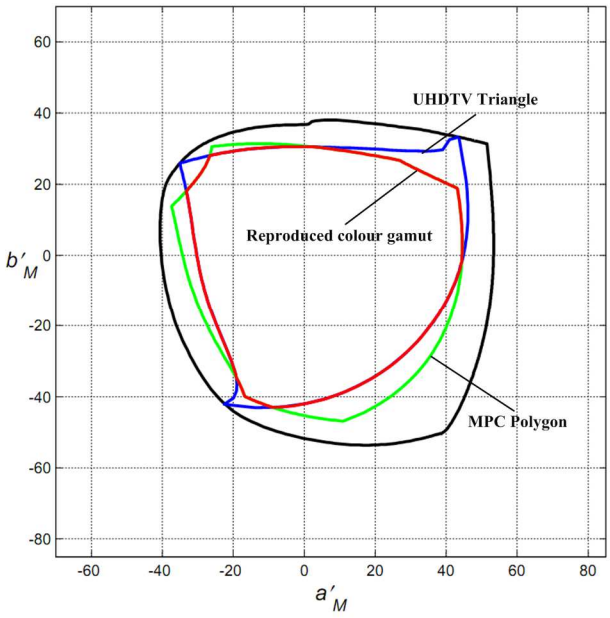

Figure 16 – Area of transmitted and reproduced chromaticities through light-to-light system, when used six primary colors reproduction [6] for $Y = 0.05$

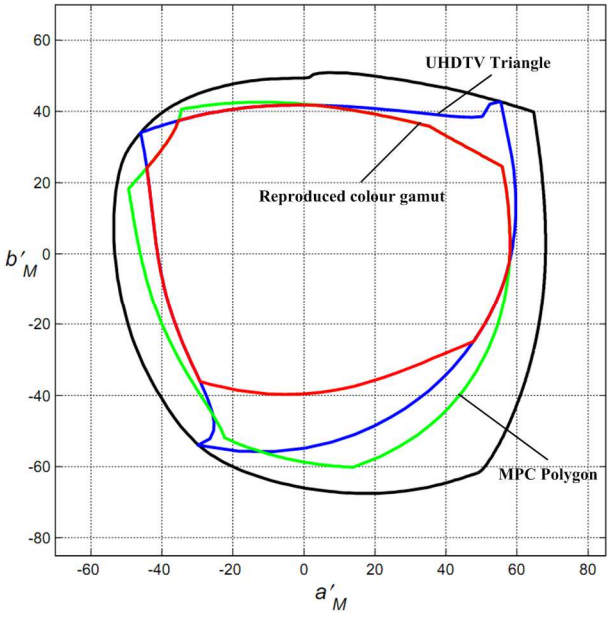

Figure 17 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary colors reproduction [6] for $Y = 0.25$

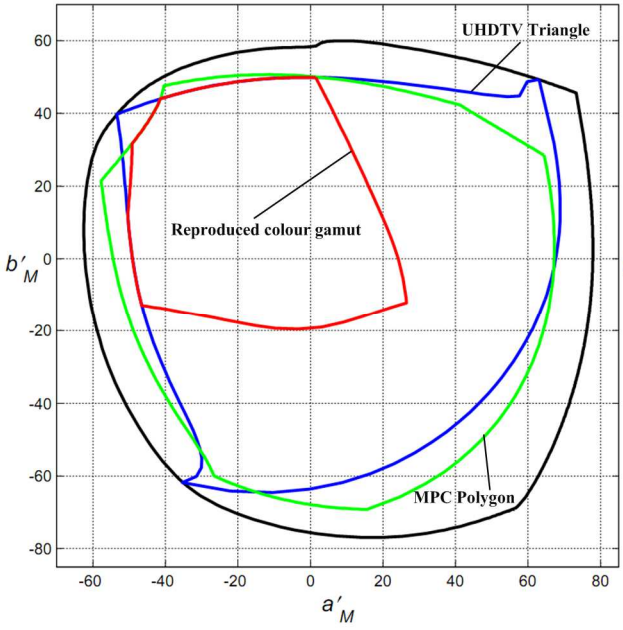

Figure 18 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary colors reproduction [6] for $Y = 0.5$

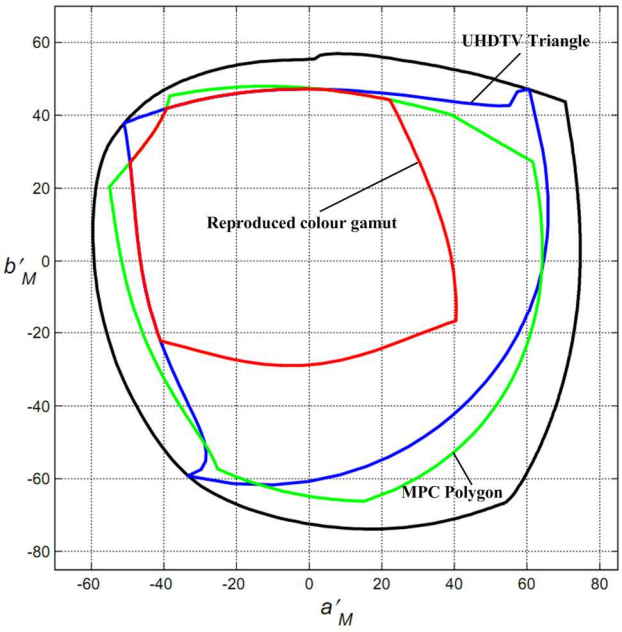

Figure 19 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary colors reproduction [6] for $Y = 0.7$

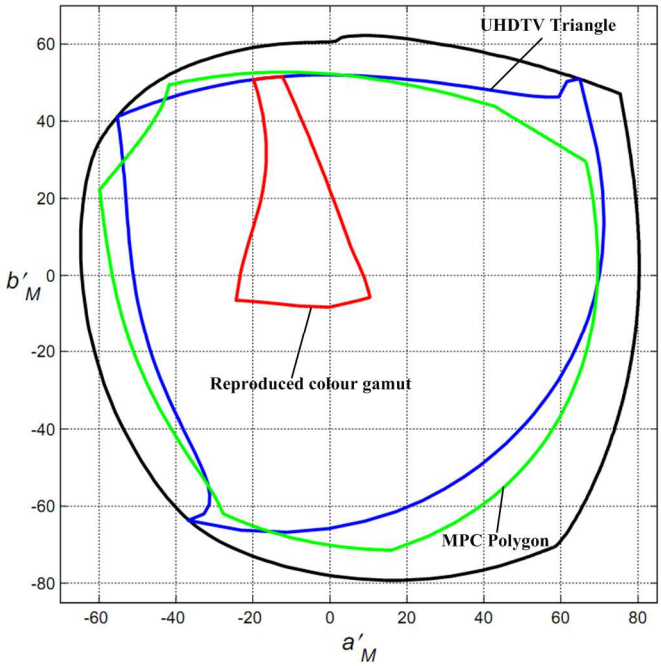

Figure 20 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary colors reproduction [6] for $Y = 0.9$

Table 6 – CIE-31*x*, *y* coordinates of the primary colors in the reproduction system [7]

Coordinates	Values					
	P_1	P_2	P_3	P_4	P_5	P_6
x	0.1451	0.1643	0.0588	0.3080	0.6083	0.6941
y	0.0302	0.0124	0.5196	0.6804	0.3901	0.3012

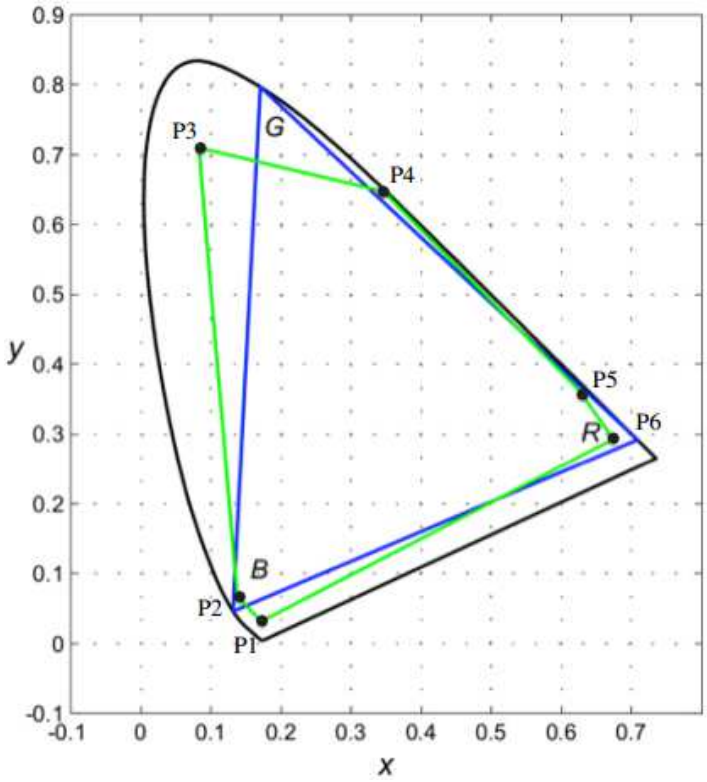

Figure 21 – UHDTV color primaries triangle and six-primary reproduction device color primaries [7] polygon, presented in *x,y* chromaticity coordinates

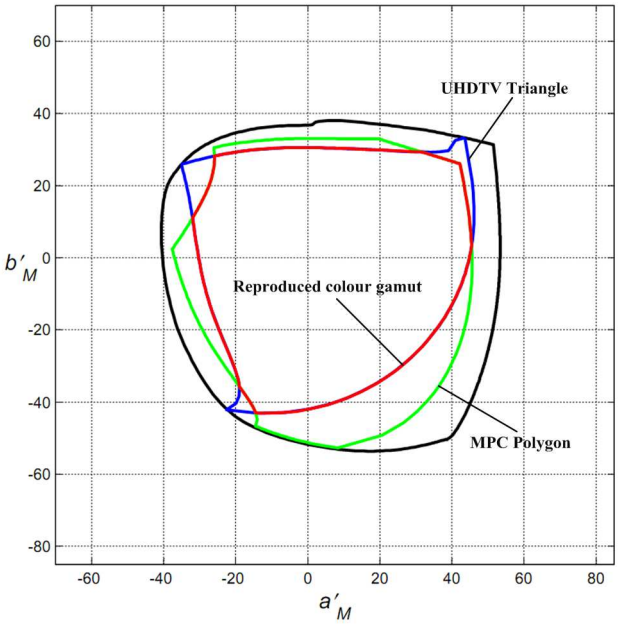

Figure 22 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary [7] colors reproduction for $Y = 0.05$

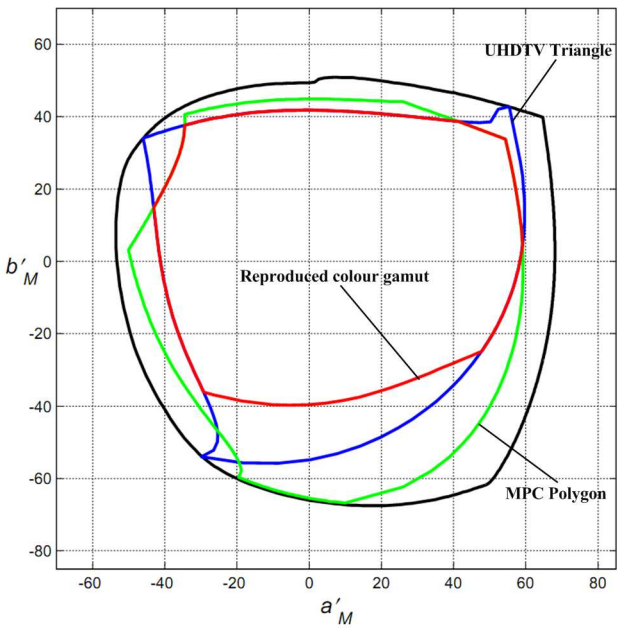

Figure 23 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary [7] colors reproduction for $Y = 0.25$

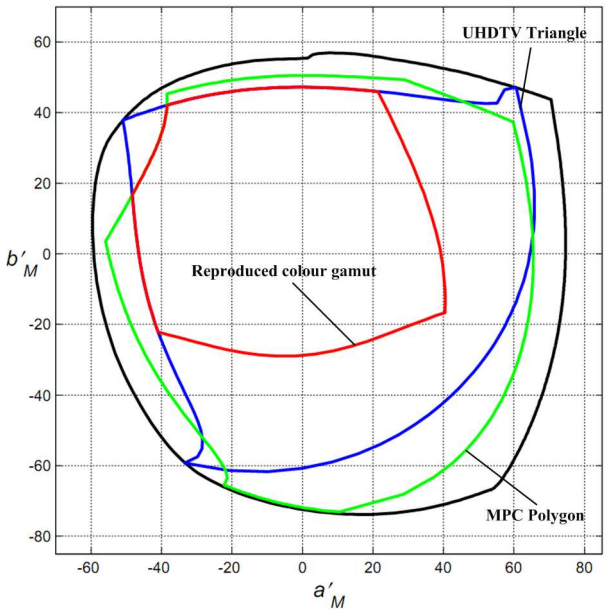

Figure 24 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary [7] colors reproduction for $Y = 0.5$

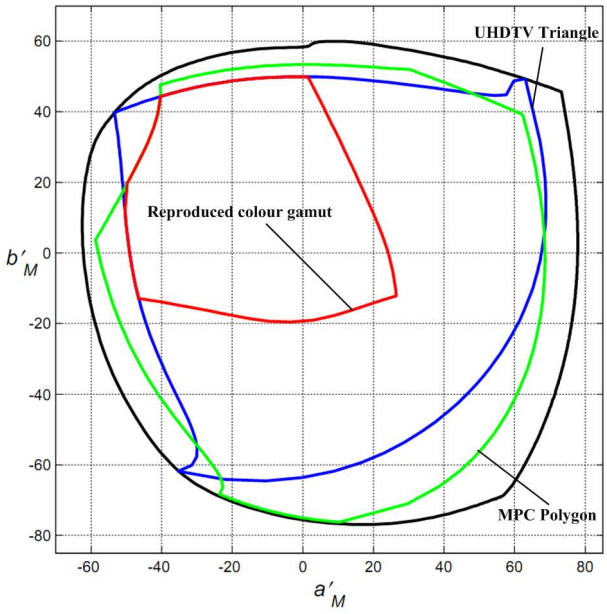

Figure 25 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary [7] colors reproduction for $Y = 0.7$

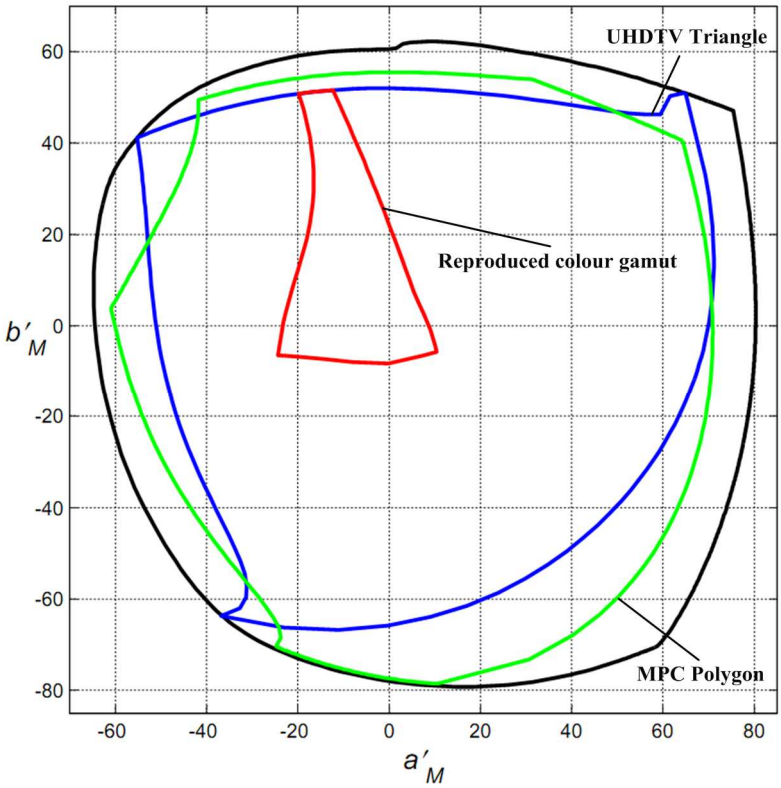

Figure 26 – Area of transmitted and reproduced chromaticities through light-to-light UHDTV system, when used six primary [7] colors reproduction for $Y = 0.9$

The presented data show that on condition that presentation in uniform color space used the primaries polygon of six primaries reproducing device is close to the boundary of chromaticity diagram. This means that if TV system colour primaries would be CIE-31 X,Y,Z primaries at image reproduction by such multi-primary devices, taking into account color gamut representation in uniform color space, TV system would reproduce perceptually almost all colors, existing in the nature.

In the case of image transmission with use UHDTV standard [1] multi-primary reproducing devices with six color primaries reproduce perceptually almost all color gamut transmitted by UHDTV system.

The data presented to some extent characterize UHDTV opportunities at multi-primary reproducing devices use and demonstrate the effect of presentation the colorimetric characteristics of TV systems in the uniform color space.

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