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Delivery of wide colour gamut image content through SDTV and HDTV delivery systems

BT Series
Broadcasting service (television)

International Telecommunication Union

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REPORT ITU-R BT.2250

Delivery of wide colour gamut image content through SDTV and HDTV delivery systems

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Introduction

Colour is a fundamental element that determines perceived image quality. Although no television programmes are currently produced using a wide colour gamut image system, there have been moves to extend the colour gamut of video beyond that of existing television systems. One such example is the ongoing study on EHRI and UHDTV. Other examples include D-Cinema and computer-based electronic imaging. Such content with a wide colour gamut would be potential sources of broadcast programmes that enhance the perceived image quality. It is highly desirable to establish a method that will enable delivery of wide colour gamut SDTV and HDTV programmes, i.e. a method of colorimetric standard conversion. Such a method should be compatible with the current television video standards.

There would be several possible ways to implement such a method. One way could be to clip the wide-colour-gamut primary video signal levels that exceed the amplitude range permitted by Recommendations ITU-R BT.601 and ITU-R BT.709 respectively. Another way could be to rescale the wide-colour-gamut primary video signals, so that they never exceed the permitted amplitude range. A third way could be to use a balanced mix of clipping and rescaling, in order to optimize the perceptual result of the delivery.

The method described in Annex 1 is based on colour science and is expressed in a series of formulas. Sample values of wide colour gamut sources expressed in tristimulus values are transformed into $Y'C'_BC'_R$ signals of either SDTV as per Recommendation ITU-R BT.601 or HDTV as per Recommendation ITU-R BT.709. At a display, the $Y'C'_BC'_R$ values are transformed to display's RGB primary values. It should be noted that the reproducible colour gamut is constrained by the display primaries. Some manipulation (mapping) may be required to handle those colours outside the display's gamut for appropriate reproduction.

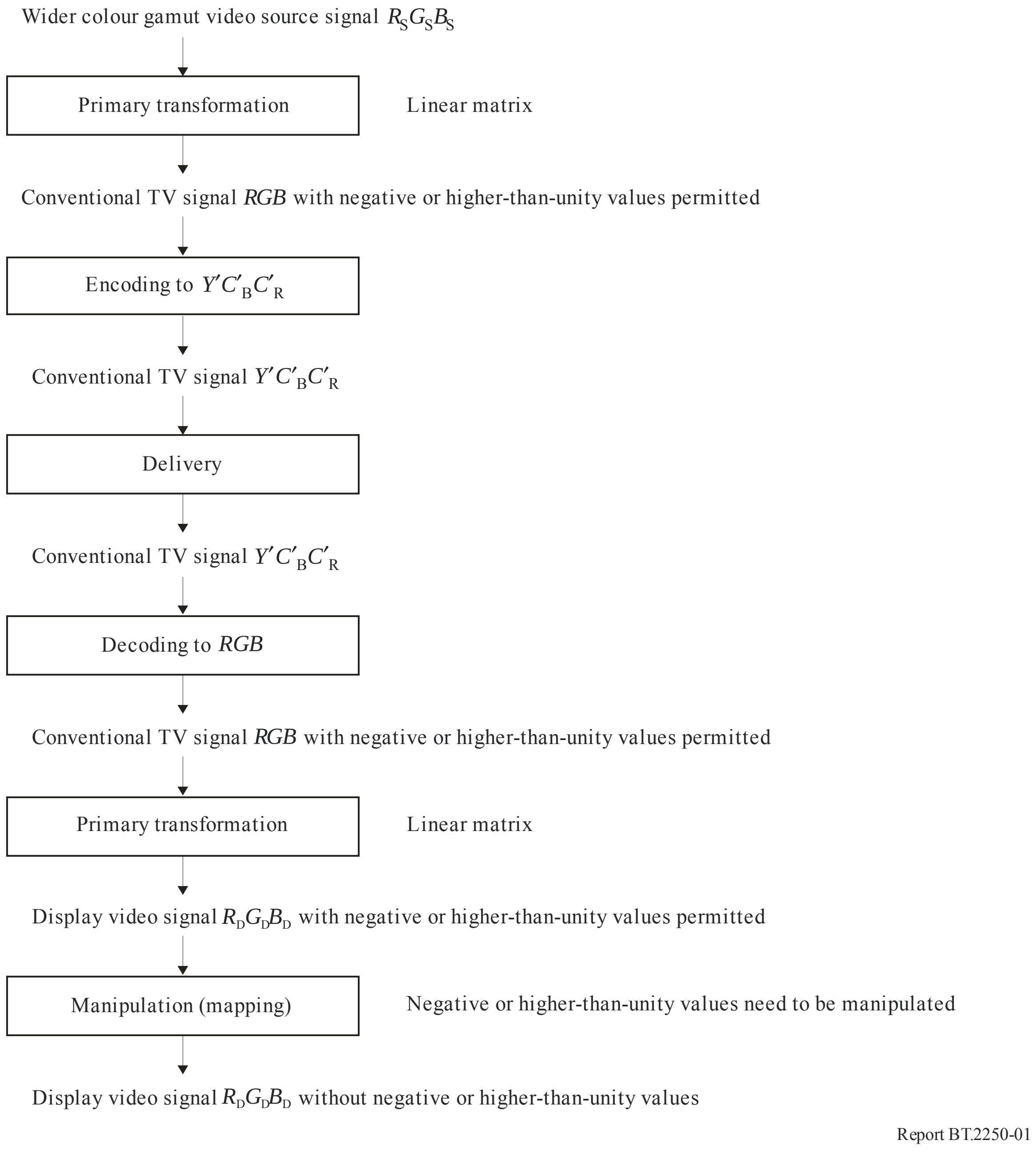
Annex 1

Method of delivering wide colour gamut image content through SDTV and HDTV

Figure 1 shows a flow chart of signal processing assumed in the method.

FIGURE 1

Flow chart of signal processing for delivering wider colour gamut image in the conventional TV signals



NOTE − Processing for the non-linear characteristics (gamma) before and after the linear matrix for the primary transformation is omitted in this Figure for simplicity.

1 Source signal

Sample values of wide colour gamut sources are expressed in tristimulus $R_SG_SB_S$ values with the CIE *x y* chromaticity coordinates of the reference white and of the RGB primaries as shown in Table 1.

TABLE 1

Chromaticity coordinates of the reference white and RGB primaries for wide colour gamut sources

Chromaticity coordinates (CIE, 1931)		x	y	z
Reference white		x_{SW}	y_{SW}	$z_{SW} = 1-(x_{SW}+y_{SW})$
Primaries	Red	x_{SR}	y_{SR}	$z_{SR} = 1-(x_{SR}+y_{SR})$
	Green	x_{SG}	y_{SG}	$z_{SG} = 1-(x_{SG}+y_{SG})$
	Blue	x_{SB}	y_{SB}	$z_{SB} = 1-(x_{SB}+y_{SB})$

Normalization factors C_{SR}, C_{SG} and C_{SB} for the RGB primaries of the wide colour gamut source are specified by equation (1-1).

$$\begin{bmatrix} C_{SR} \\ C_{SG} \\ C_{SB} \end{bmatrix} = \begin{bmatrix} x_{SR} & x_{SG} & x_{SB} \\ y_{SR} & y_{SG} & y_{SB} \\ z_{SR} & z_{SG} & z_{SB} \end{bmatrix}^{-1} \begin{bmatrix} x_{SW} / y_{SW} \\ 1 \\ z_{SW} / y_{SW} \end{bmatrix} \tag{1-1}$$

Normalized primary matrix for the source (NPM_S) is specified by equation (1-2).

$$NPM_S = \begin{bmatrix} x_{SR} & x_{SG} & x_{SB} \\ y_{SR} & y_{SG} & y_{SB} \\ z_{SR} & z_{SG} & z_{SB} \end{bmatrix} \begin{bmatrix} C_{SR} & 0 & 0 \\ 0 & C_{SG} & 0 \\ 0 & 0 & C_{SB} \end{bmatrix} \tag{1-2}$$

2 Destination signal

The destination signals are either SDTV as per Recommendation ITU-R BT.601 or HDTV as per Recommendation ITU-R BT.709. The chromaticity coordinates of the reference white and RGB primaries for SDTV and HDTV are shown in Table 2.

TABLE 2

Chromaticity coordinates of the reference white and RGB primaries for SDTV and HDTV

Television format		SDTV				HDTV	
		625-line		525-line			
Chromaticity coordinates (CIE, 1931)		*x*	*y*	*x*	*y*	*x*	*y*
Reference white (D_{65})		0.3127	0.3290	0.3127	0.3290	0.3127	0.3290
Primaries	Red	0.640	0.330	0.630	0.340	0.640	0.330
	Green	0.290	0.600	0.310	0.595	0.300	0.600
	Blue	0.150	0.060	0.155	0.070	0.150	0.060

Normalized primary matrices for SDTV and HDTV (NPM_{625}, NPM_{525}, and NPM_{HDTV}) and their inverse matrices are specified by equations (2-1) through (2-6), respectively. The normalized primary matrices are derived from the chromaticity coordinates shown in Table 2.

$$NPM_{625} = \begin{bmatrix} 0.4306 & 0.3415 & 0.1784 \\ 0.2220 & 0.7067 & 0.0713 \\ 0.0202 & 0.1296 & 0.9393 \end{bmatrix} \quad (2\text{-}1)$$

$$NPM_{625}^{-1} = \begin{bmatrix} 3.0634 & -1.3934 & -0.4758 \\ -0.9692 & 1.8760 & 0.0416 \\ 0.0679 & -0.2288 & 1.0691 \end{bmatrix} \quad (2\text{-}2)$$

$$NPM_{525} = \begin{bmatrix} 0.3935 & 0.3653 & 0.1917 \\ 0.2124 & 0.7011 & 0.0866 \\ 0.0187 & 0.1119 & 0.9584 \end{bmatrix} \quad (2\text{-}3)$$

$$NPM_{525}^{-1} = \begin{bmatrix} 3.5060 & -1.7398 & -0.5441 \\ -1.0690 & 1.9778 & 0.0352 \\ 0.0563 & -0.1970 & 1.0500 \end{bmatrix} \quad (2\text{-}4)$$

$$NPM_{HDTV} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \quad (2\text{-}5)$$

$$NPM_{HDTV}^{-1} = \begin{bmatrix} 3.2410 & -1.5374 & -0.4986 \\ -0.9692 & 1.8760 & 0.0416 \\ 0.0556 & -0.2040 & 1.0570 \end{bmatrix} \quad (2\text{-}6)$$

3 Transformation of primary sets

The source $R_sG_sB_s$ values are transformed into television linear RGB values. The relevant equation should be used for each of the destination television formats.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{625} = NPM_{625}^{-1} \cdot NPM_S \begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} \quad (3\text{-}1)$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{525} = NPM_{525}^{-1} \cdot NPM_S \begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} \quad (3\text{-}2)$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{HDTV} = NPM_{HDTV}^{-1} \cdot NPM_S \begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} \quad (3\text{-}3)$$

Derived RGB values that are negative or larger than a unity should be retained.

4 Non-linear transfer characteristics

The linear RGB values are transformed into television non-linear R′G′B′ values. The following non-linear transfer characteristics should be applied to the linear RGB values.

If $R, G, B \geq \beta$,

$$R' = \alpha R^{0.45} - \alpha + 1 \quad (4\text{-}1)$$

$$G' = \alpha G^{0.45} - \alpha + 1 \quad (4\text{-}2)$$

$$B' = \alpha B^{0.45} - \alpha + 1 \quad (4\text{-}3)$$

If $-\beta < R, G, B < \beta$,

$$R' = 4.5R \quad (4\text{-}4)$$

$$G' = 4.5G \quad (4\text{-}5)$$

$$B' = 4.5B \quad (4\text{-}6)$$

If $R, G, B \leq -\beta$,

$$R' = -\alpha(-R)^{0.45} + \alpha - 1 \quad (4\text{-}7)$$

$$G' = -\alpha(-G)^{0.45} + \alpha - 1 \tag{4-8}$$

$$B' = -\alpha(-B)^{0.45} + \alpha - 1, \tag{4-9}$$

where α and β are the solutions to the following simultaneous equations:

$$\begin{cases} 4.5\beta = \alpha\beta^{0.45} - \alpha + 1 \\ 4.5 = 0.45\alpha\beta^{-0.55} \end{cases} \tag{4-10}$$

The simultaneous equations provide the required condition that prevents discontinuity between the transfer functions, and they yield

α = 1.09929682680944 ... and β = 0.018053968510807 ...

When the precision is not critical, it may be allowed that α = 1.099 and β = 0.018.

5 Luminance and colour-difference equations

The non-linear R′G′B′ signals are encoded to luminance and colour-difference $Y'C'_BC'_R$ signals using the equations specified below for SDTV and HDTV.

$$\begin{bmatrix} Y' \\ C'_B \\ C'_R \end{bmatrix}_{SDTV} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.299/1.772 & -0.587/1.772 & 0.500 \\ 0.500 & -0.587/1.402 & -0.114/1.402 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{5-1}$$

$$\begin{bmatrix} Y' \\ C'_B \\ C'_R \end{bmatrix}_{HDTV} = \begin{bmatrix} 0.2126 & 0.7152 & 0.0722 \\ -0.2126/1.8556 & -0.7152/1.8556 & 0.5000 \\ 0.5000 & -0.7152/1.5748 & -0.0722/1.5748 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{5-2}$$

6 Quantization of luminance and colour-difference signals

The luminance and colour-difference $Y'C'_BC'_R$ signals are quantized as specified below for SDTV and HDTV.

$$D'_Y = \mathrm{INT}\left[(219\,Y' + 16)\cdot 2^{n-8}\right] \tag{6-1}$$

$$D'_{CB} = \mathrm{INT}\left[(224\,C'_B + 128)\cdot 2^{n-8}\right] \tag{6-2}$$

$$D'_{CR} = \mathrm{INT}\left[(224\,C'_R + 128)\cdot 2^{n-8}\right] \tag{6-3}$$

where *n* denotes the bit length of the quantized $Y'C'_BC'_R$ signals and INT[] returns the value of 0 for fractional parts in the range of 0 to 0.4999 ... and +1 for fractional parts in the range of 0.5 to 0.9999 ...; i.e. it rounds up fractions of 0.5 or above. The values of the quantized $Y'C'_BC'_R$ signals are limited to a range from 2^{n-8} to $254 \times 2^{n-8}$.

The resultant quantized Y′C′BC′R signals can be used in the same manner as normal SDTV and HDTV signals.

7 Processes at a display

When the quantized Y′C′BC′R signals converted from wide colour gamut image content are fed to a display, the following sequence of processes needs to be conducted. These are the inverses to the processes described above.

7.1 Inverse quantization of Y′CB′CR′ signals

$$Y' = \left(\frac{D'_Y}{2^{n-8}} - 16 \right) / 219 \tag{7.1-1}$$

$$C'_B = \left(\frac{D'_{CB}}{2^{n-8}} - 128 \right) / 224 \tag{7.1-2}$$

$$C'_R = \left(\frac{D'_{CR}}{2^{n-8}} - 128 \right) / 224 \tag{7.1-3}$$

7.2 Derivation of non-linear R′G′B′ signals

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}_{SDTV} = \begin{bmatrix} 1.000 & 0.000 & 1.402 \\ 1.000 & -0.114 \times 1.772 / 0.587 & -0.299 \times 1.402 / 0.587 \\ 1.000 & 1.772 & 0.000 \end{bmatrix} \begin{bmatrix} Y' \\ C'_B \\ C'_R \end{bmatrix} \tag{7.2-1}$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}_{HDTV} = \begin{bmatrix} 1.0000 & 0.0000 & 1.5748 \\ 1.0000 & -0.0722 \times 1.8556 / 0.7152 & -0.2126 \times 1.5748 / 0.7152 \\ 1.0000 & 1.8556 & 0.0000 \end{bmatrix} \begin{bmatrix} Y' \\ C'_B \\ C'_R \end{bmatrix} \tag{7.2-2}$$

7.3 Derivation of linear RGB signals

If $R', G', B' \geq 4.5\beta$,

$$R = \left(\frac{R' + \alpha - 1}{\alpha} \right)^{\frac{1}{0.45}} \tag{7.3-1}$$

$$G = \left(\frac{G' + \alpha - 1}{\alpha} \right)^{\frac{1}{0.45}} \tag{7.3-2}$$

$$B = \left(\frac{B' + \alpha - 1}{\alpha} \right)^{\frac{1}{0.45}} \tag{7.3-3}$$

If $-4.5\beta < R', G', B' < 4.5\beta$,

$$R = R' / 4.5 \tag{7.3-4}$$

$$G = G' / 4.5 \tag{7.3-5}$$

$$B = B' / 4.5 \tag{7.3-6}$$

If $R', G', B' \leq -4.5\beta$,

$$R = -\left(\frac{R' - \alpha + 1}{-\alpha} \right)^{\frac{1}{0.45}} \tag{7.3-7}$$

$$G = -\left(\frac{G' - \alpha + 1}{-\alpha} \right)^{\frac{1}{0.45}} \tag{7.3-8}$$

$$B = -\left(\frac{B' - \alpha + 1}{-\alpha} \right)^{\frac{1}{0.45}} \tag{7.3-9}$$

7.4 Transformation to display's primaries values

Finally, the RGB values are transformed to display's primary values $R_D G_D B_D$ with the CIE *x y* chromaticity coordinates of the reference white and of the RGB primaries as shown in Table 3.

TABLE 3

Chromaticity coordinates of the reference white and RGB primaries for a display

Chromaticity coordinates (CIE, 1931)		***x***	***y***	***z***
Reference white		x_{DW}	y_{DW}	$z_{DW} = 1 - (x_{DW} + y_{DW})$
Primaries	**Red**	x_{DR}	y_{DR}	$z_{DR} = 1 - (x_{SR} + y_{DR})$
	Green	x_{DG}	y_{DG}	$z_{DG} = 1 - (x_{SG} + y_{DG})$
	Blue	x_{DB}	y_{DB}	$z_{DB} = 1 - (x_{DB} + y_{DB})$

Normalization factors C_{DR}, C_{DG} and C_{DB} for the RGB primaries of the display are specified by equation (7.4-1).

$$\begin{bmatrix} C_{DR} \\ C_{DG} \\ C_{DB} \end{bmatrix} = \begin{bmatrix} x_{DR} & x_{DG} & x_{DB} \\ y_{DR} & y_{DG} & y_{DB} \\ z_{DR} & z_{DG} & z_{DB} \end{bmatrix}^{-1} \begin{bmatrix} x_{DW} / y_{DW} \\ 1 \\ z_{DW} / y_{DW} \end{bmatrix} \quad (7.4\text{-}1)$$

Normalized primary matrix for the display (NPM_D) is specified by equation (7.4-2).

$$NPM_D = \begin{bmatrix} x_{DR} & x_{DG} & x_{DB} \\ y_{DR} & y_{DG} & y_{DB} \\ z_{DR} & z_{DG} & z_{DB} \end{bmatrix} \begin{bmatrix} C_{DR} & 0 & 0 \\ 0 & C_{DG} & 0 \\ 0 & 0 & C_{DB} \end{bmatrix} \quad (7.4\text{-}2)$$

Display's primary values are derived by using the relevant equation for each of the television formats.

$$\begin{bmatrix} R_D \\ G_D \\ B_D \end{bmatrix} = NPM_D^{-1} \cdot NPM_{625} \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{625} \quad (7.4\text{-}3)$$

$$\begin{bmatrix} R_D \\ G_D \\ B_D \end{bmatrix} = NPM_D^{-1} \cdot NPM_{525} \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{525} \quad (7.4\text{-}4)$$

$$\begin{bmatrix} R_D \\ G_D \\ B_D \end{bmatrix} = NPM_D^{-1} \cdot NPM_{HDTV} \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{HDTV} \quad (7.4\text{-}5)$$

The reproducible colour gamut is constrained by the display primaries, i.e. the resultant $R_DG_DB_D$ values that are negative or larger than a unity cannot be displayed. Some manipulation (mapping) is required to handle those colours outside the display's gamut for appropriate reproduction. In doing so, it is cautioned that simple clipping would change hue.

Appendix 1

Transmissible colour gamut

This Appendix shows the transmissible colour gamuts created by the delivering method. Figures 2, 3 and 4 show the contour plots of the gamuts when wide gamut content is delivered to 625-line SDTV, 525-line SDTV, and HDTV, respectively. The contours are drawn for each normalized Y at an interval of 0.1 on the CIE 1931 xy chromaticity diagram. The RGB primaries and reference white are also shown.

FIGURE 2

Transmissible colour gamut delivered to 625-line SDTV

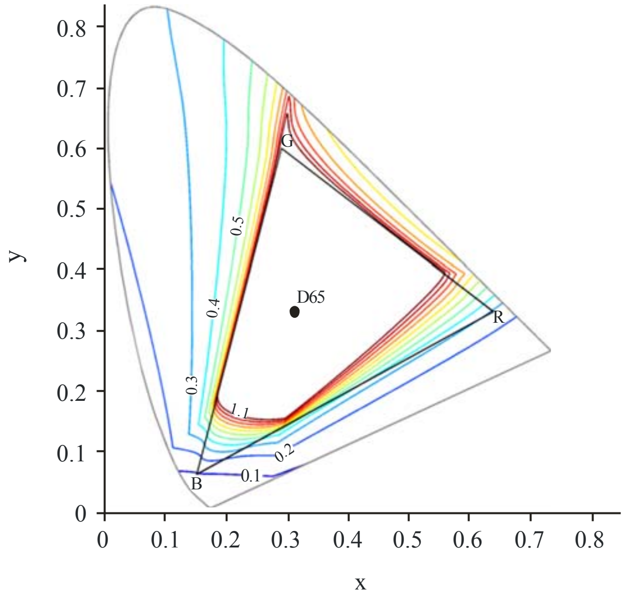


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FIGURE 3

Transmissible colour gamut delivered to 525-line SDTV

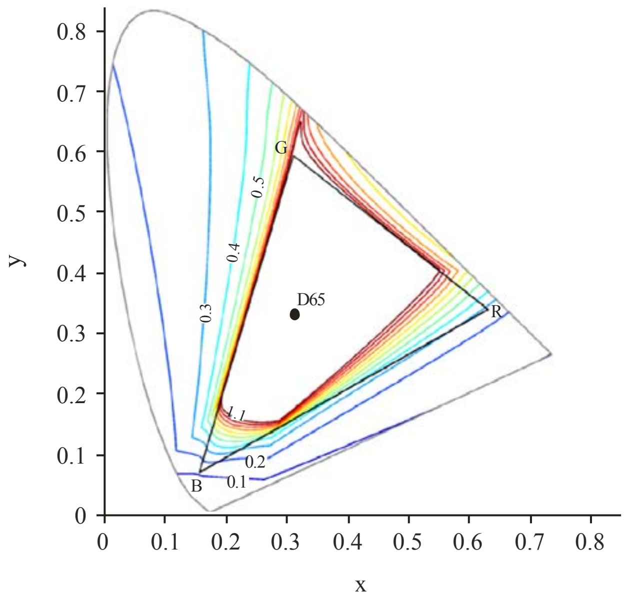

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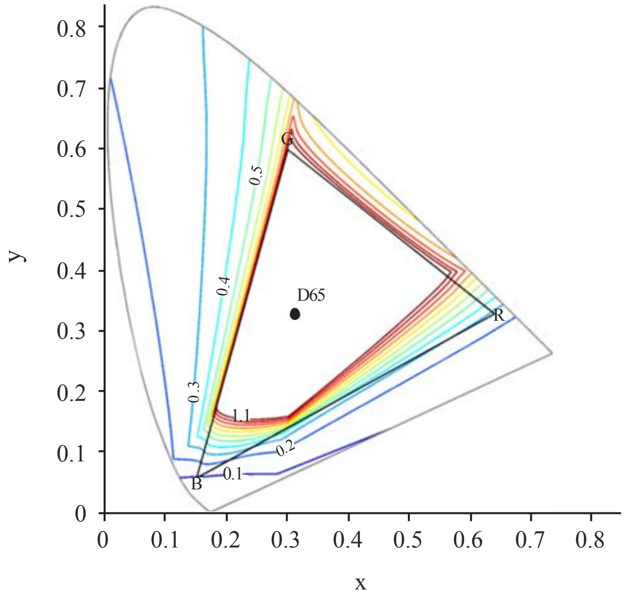
FIGURE 4

Transmissible colour gamut delivered to HDTV



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