IEC 61966-2-4

Edition 1.2 2021-07
CONSOLIDATED VERSION

INTERNATIONAL STANDARD

colour inside

Multimedia systems and equipment – Colour measurement and management – Part 2-4: Colour management – Extended-gamut YCC colour space for video applications – xvYCC

IEC 61966-2-4:2006-01+AMD1:2016-04+AMD2:2021-07 CSV(en)

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INTERNATIONAL
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ICS 00.000

ISBN 978-2-8322-1004-4

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IEC 61966-2-4

Edition 1.2 2021-07
CONSOLIDATED VERSION

REDLINE VERSION

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IEC 61966-2-4:2006-01+AMD1:2016-04+AMD2:2021-07 CSV(en)

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IEC 61966-2-4 edition 1.2 contains the first edition (2006-01) [documents 100/967/CDV and 100/1026/RVC] and its corrigendum 1 (2006-11), its amendment 1 (2016-04) [documents 100/2457A/CDV and 100/2601/RVC] and its amendment 2 (2021-07) [documents 100/3535/CDV and 100/3597/RVC].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendments 1 and 2. Additions and deletions are displayed in red, with deletions being struck through. A separate Final version with all changes accepted is available in this publication.

International Standard IEC 61966-2-4 has been prepared by IEC technical committee 100: Audio, video and multimedia systems and equipment.

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

IEC 61966 consists of the following parts, under the general title *Multimedia systems and equipment – Colour measurement and management:*

Part 2-1: Colour management – Default RGB colour space – sRGB

Part 2-2: Colour management – Extended RGB colour space – scRGB

Part 2-4: Colour management – Extended-gamut YCC colour space for video applications – xvYCC

Part 2-5: Colour management – Optional RGB colour space – opRGB ~~(under consideration)~~

Part 3: Equipment using cathode ray tubes

Part 4: Equipment using liquid crystal display panels

Part 5: Equipment using plasma display panels

Part 6: Front projection displays

Part 7-1: Colour printers – Reflective prints – RGB inputs

~~Part 7-2: Colour printers – Reflective prints – CMYK inputs (proposed work item)~~

Part 8: Multimedia colour scanners

Part 9: Digital cameras

~~Part 10: Quality assessment (proposed work item)~~

~~Part 11: Quality assessment – Impaired video in network systems (proposed work item)~~

Part 12-1: Metadata for identification of colour gamut (Gamut ID)

Part 12-2: Simple Metadata format for identification of colour gamut

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INTRODUCTION

After the publication of IEC 61966-2-1, Amendment 1, the sYCC colour encoding was used to capture, store and print extended colour gamut for still image applications. Users received pleasant benefit by exchanging and reproducing wide-gamut colour images.

Recently, various kinds of displays that are capable of producing a wider gamut of colour than the conventional CRT-based displays are emerging. However, most of the current video contents that are displayed on conventional displays, are rendered for the sRGB-gamut. Users of wide-gamut displays could benefit from wide-gamut colour images by video colour encoding that supports a larger colour gamut.

This standard defines the “extended-gamut YCC colour space for video applications”. It is based on the current implementation of YCC colour encoding that is used in the video industry (namely ITU-R BT.709-5) and extends its definition to the wider gamut of colour range.

MULTIMEDIA SYSTEMS AND EQUIPMENT – COLOUR MEASUREMENT AND MANAGEMENT –

Part 2-4: Colour management – Extended-gamut YCC colour space for video applications – xvYCC

1 Scope

This part of IEC 61966 is applicable to the encoding and communication of YCC colours used in video systems and similar applications by defining encoding transformations for use in defined reference capturing conditions. If actual conditions differ from the reference conditions, additional rendering transformations may be required. Such additional rendering transformations are beyond the scope of this standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-845:1987, *International Electrotechnical Vocabulary (IEV) – Part 845: Lighting*

ITU-R Recommendation BT.601-5:1995, *Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios*

ITU-R Recommendation BT.709-5:2002, *Parameter values for the HDTV standards for production and international programme exchange*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those concerning illuminance, luminance, tristimulus, and other related lighting terms given in IEC 60050-845, apply.

3.1
scene-referred colour encoding
representation of estimated colour-space coordinates of the elements of an original scene, where a scene is defined to be the relative spectral radiance

3.2
output-referred colour encoding
representation of estimated colour-space coordinates of image data that are appropriate for specified output device and viewing conditions

3.3
extended gamut
colour gamut extending outside that of the standard sRGB CRT display defined in IEC 61966-2-1

3.4
luma
luminance signal as defined by SMPTE/EG28:1993

NOTE 1 To avoid interdisciplinary confusion resulting from the two distinct definitions of luminance, it has been proposed that the video documents use "luma" for "luminance, television" (i.e., the luminance signal).

NOTE 2 Video systems approximate the lightness response of vision by computing a luma component Y' as a weighted sum of non-linear (or gamma-corrected) R'G'B' primary components. Luma is often carelessly referred to as luminance.

4 Colorimetric parameters and related characteristics

This clause defines colorimetric parameters and the related characteristics of reference capturing devices.

4.1 Primary colours and reference white

The CIE chromaticities for the reference red, green, and blue primary colours, and for reference white CIE standard illuminant D65, are given in Table 1. These primaries and white point values are identical to those of ITU-R BT.709-5.

Table 1 – CIE chromaticities for reference primary colours and reference white

	Red	Green	Blue	White/D65
x	0,640 0	0,300 0	0,150 0	0,312 7
y	0,330 0	0,600 0	0,060 0	0,329 0
z	0,030 0	0,100 0	0,790 0	0,358 3

4.2 Opto-electronic transfer characteristics

Opto-electronic transfer characteristics are defined as follows.

If $R, G, B \leq -0{,}018$,

$$\begin{aligned} R' &= -1{,}099 \times (-R)^{0{,}45} + 0{,}099 \\ G' &= -1{,}099 \times (-G)^{0{,}45} + 0{,}099 \\ B' &= -1{,}099 \times (-B)^{0{,}45} + 0{,}099 \end{aligned} \tag{1}$$

If $-0{,}018 < R, G, B < 0{,}018$,

$$\begin{aligned} R' &= 4{,}50 \times R \\ G' &= 4{,}50 \times G \\ B' &= 4{,}50 \times B \end{aligned} \tag{2}$$

If $R, G, B \geq 0{,}018$,

$$\begin{aligned} R' &= 1{,}099 \times (R)^{0{,}45} - 0{,}099 \\ G' &= 1{,}099 \times (G)^{0{,}45} - 0{,}099 \\ B' &= 1{,}099 \times (B)^{0{,}45} - 0{,}099 \end{aligned} \tag{3}$$

where R,G,B is a voltage normalized by reference white level and proportional to the implicit light intensity that would be detected with a reference camera colour channel; R',G',B' is the resulting non-linear primary signal.

4.3 YCC (luma-chroma-chroma) encoding methods

The encoding equations from the primary RGB (red-green-blue) signal: R',G',B' to the YCC (luma-chroma-chroma) signal: Y',Cb',Cr' is defined by the following two methods. It is important to follow one of the encodings in the specified application.

xvYCC601, which is implemented mainly in the SDTV (standard-definition television) applications as defined in ITU-R BT. 601-5, is defined as follows:

$$\begin{bmatrix} Y'_{601} \\ Cb'_{601} \\ Cr'_{601} \end{bmatrix} = \begin{bmatrix} 0{,}299\,0 & 0{,}587\,0 & 0{,}114\,0 \\ -0{,}168\,7 & -0{,}331\,3 & 0{,}500\,0 \\ 0{,}500\,0 & -0{,}418\,7 & -0{,}081\,3 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{4}$$

NOTE The coefficients in equation (4) are from ITU-R BT.601-5 which defines Y' of YCC to the three decimal place accuracy. An additional decimal place is defined above to be consistent with the other matrix coefficients defined in this standard.

xvYCC709, which is implemented mainly in the HDTV (high-definition television) applications as defined in ITU-R BT. 709-5, is defined as follows:

$$\begin{bmatrix} Y'_{709} \\ Cb'_{709} \\ Cr'_{709} \end{bmatrix} = \begin{bmatrix} 0{,}212\,6 & 0{,}715\,2 & 0{,}072\,2 \\ -0{,}114\,6 & -0{,}385\,4 & 0{,}500\,0 \\ 0{,}500\,0 & -0{,}454\,2 & -0{,}045\,8 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{5}$$

4.4 Digital quantization methods

Quantization of YCC (luma-chroma-chroma) signal: Y',Cb',Cr' is defined as follows.

For 8-bit representation:

$$\begin{aligned} Y_{\text{xvYCC(8)}} &= \text{round}[219 \times Y' + 16] \\ Cb_{\text{xvYCC(8)}} &= \text{round}[224 \times Cb' + 128] \\ Cr_{\text{xvYCC(8)}} &= \text{round}[224 \times Cr' + 128] \end{aligned} \tag{6}$$

For n-bit (n > 8) representation:

$$\begin{aligned} Y_{\text{xvYCC}(N)} &= \text{round}\left[(219 \times Y' + 16) \times 2^{n-8}\right] \\ Cb_{\text{xvYCC}(N)} &= \text{round}\left[(224 \times Cb' + 128) \times 2^{n-8}\right] \\ Cr_{\text{xvYCC}(N)} &= \text{round}\left[(224 \times Cr' + 128) \times 2^{n-8}\right] \end{aligned} \tag{7}$$

NOTE Bit levels "from 0 to 2^{N-8}-1" and "from 255 × 2^{N-8} to 2^N-1" (0 and 255, for the case of 8-bit encoding) are used exclusively for synchronization and are not allowed for storing colour values. Levels from "2^{N-8}" to "255 × 2^{N-8}-1" (from 1 to 254, for the case of 8-bit encoding) are available.

5 Encoding transformations

5.1 Introduction

The encoding transformations between xvYCC values and CIE 1931 XYZ values provide unambiguous methods to represent optimum image colorimetry of the captured scene. Scene colorimetry is defined as relative to the white objects, assuming that the exposure is properly controlled. It should be noted that dynamic range compression is needed when storing the wide dynamic range images (see Annex A for descriptions). Additionally, if the condition of the capturing device deviates from the ideal condition defined in Clause 4, operations such as colour compensation, colour correction and a certain degree of colour rendering can be performed. However, the methods for these operations are beyond the scope of this standard.

5.2 Transformation from xvYCC values to CIE 1931 XYZ values

For 24-bit encoding (8-bit/channel), the relationship between 8-bit values and Y',Cb',Cr' is defined as:

$$\begin{aligned} Y' &= \left(Y_{\text{xvYCC(8)}} - 16\right)/219 \\ Cb' &= \left(Cb_{\text{xvYCC(8)}} - 128\right)/224 \\ Cr' &= \left(Cr_{\text{xvYCC(8)}} - 128\right)/224 \end{aligned} \tag{8}$$

For N-bit/channel ($N > 8$) encoding, the relationship between N-bit values and Y',Cb',Cr' is defined as:

$$\begin{aligned} Y' &= \left(\frac{Y_{\text{xvYCC}(N)}}{2^{N-8}} - 16\right)\Big/219 \\ Cb' &= \left(\frac{Cb_{\text{xvYCC}(N)}}{2^{N-8}} - 128\right)\Big/224 \\ Cr' &= \left(\frac{Cr_{\text{xvYCC}(N)}}{2^{N-8}} - 128\right)\Big/224 \end{aligned} \tag{9}$$

For xvYCC_{601} encoding, the non-linear Y',Cb',Cr' values are transformed to the non-linear R',G',B' values as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1{,}000\ 0 & 0{,}000\ 0 & 1{,}402\ 0 \\ 1{,}000\ 0 & -0{,}344\ 1 & -0{,}714\ 1 \\ 1{,}000\ 0 & 1{,}772\ 0 & 0{,}000\ 0 \end{bmatrix} \begin{bmatrix} Y'_{601} \\ Cb'_{601} \\ Cr'_{601} \end{bmatrix} \tag{10}$$

NOTE The possible range for non-linear R'G'B'$_{(601)}$ calculated from, for example, equation (10) will be between -1,0732 and 2,0835.

For xvYCC_{709} encoding, the non-linear Y',Cb',Cr' values are transformed to the non-linear R',G',B' values as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1{,}000\ 0 & 0{,}000\ 0 & 1{,}574\ 8 \\ 1{,}000\ 0 & -0{,}187\ 3 & -0{,}468\ 1 \\ 1{,}000\ 0 & 1{,}855\ 6 & 0{,}000\ 0 \end{bmatrix} \begin{bmatrix} Y'_{709} \\ Cb'_{709} \\ Cr'_{709} \end{bmatrix} \tag{11}$$

NOTE The possible range for non-linear R'G'B'$_{(709)}$ calculated from, for example, equation (11) will be between -1,1206 and 2,1305.

The non-linear R', G', B' values are then transformed to linear R, G, B values as follows.

If $R', G', B' \le -0{,}081$

$$R = -\left(\frac{R' - 0{,}099}{-1{,}099}\right)^{\frac{1}{0{,}45}}$$
$$G = -\left(\frac{G' - 0{,}099}{-1{,}099}\right)^{\frac{1}{0{,}45}} \qquad (12)$$
$$B = -\left(\frac{B' - 0{,}099}{-1{,}099}\right)^{\frac{1}{0{,}45}}$$

If $-0{,}081 < R', G', B' < 0{,}081$

$$R = R'/4{,}50$$
$$G = G'/4{,}50 \qquad (13)$$
$$B = B'/4{,}50$$

If $R', G', B' \ge 0{,}081$

$$R = \left(\frac{R' + 0{,}099}{1{,}099}\right)^{\frac{1}{0{,}45}}$$
$$G = \left(\frac{G' + 0{,}099}{1{,}099}\right)^{\frac{1}{0{,}45}} \qquad (14)$$
$$B = \left(\frac{B' + 0{,}099}{1{,}099}\right)^{\frac{1}{0{,}45}}$$

The linear R, G, B values are transformed to CIE 1931 XYZ values as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0{,}412\,4 & 0{,}357\,6 & 0{,}180\,5 \\ 0{,}212\,6 & 0{,}715\,2 & 0{,}072\,2 \\ 0{,}019\,3 & 0{,}119\,2 & 0{,}950\,5 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (15)$$

NOTE When the capturing device performs dynamic range compression of the brighter-than-white (for example, specular) components, the compressed colours will be displayed at the top-end range of the "reference" display as described in Annex C. In this case, the XYZ tristimulus values of the compressed components represent the colorimetry of the rendered scene, not the colorimetry of the original scene.

5.3 Transformation from CIE 1931 XYZ values to xvYCC values

The CIE 1931 XYZ values can be transformed to linear R, G, B values as follows:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3{,}241\,0 & -1{,}537\,4 & -0{,}498\,6 \\ -0{,}969\,2 & 1{,}876\,0 & 0{,}041\,6 \\ 0{,}055\,6 & -0{,}204\,0 & 1{,}057\,0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (16)$$

In the xvYCC encoding process, negative RGB tristimulus values and RGB tristimulus values greater than 1,0 are retained.

The linear R,G,B values are then transformed to non-linear R',G',B' values as follows.

If $R,G,B \le -0{,}018$,

$$\begin{aligned} R' &= -1{,}099 \times (-R)^{0{,}45} + 0{,}099 \\ G' &= -1{,}099 \times (-G)^{0{,}45} + 0{,}099 \\ B' &= -1{,}099 \times (-B)^{0{,}45} + 0{,}099 \end{aligned} \quad (17)$$

If $-0{,}018 < R,G,B < 0{,}018$,

$$\begin{aligned} R' &= 4{,}50 \times R \\ G' &= 4{,}50 \times G \\ B' &= 4{,}50 \times B \end{aligned} \quad (18)$$

If $R,G,B \ge 0{,}018$,

$$\begin{aligned} R' &= 1{,}099 \times (R)^{0{,}45} - 0{,}099 \\ G' &= 1{,}099 \times (G)^{0{,}45} - 0{,}099 \\ B' &= 1{,}099 \times (B)^{0{,}45} - 0{,}099 \end{aligned} \quad (19)$$

The relationship between non-linear R',G',B' and xvYCC$_{601}$ is defined as follows:

$$\begin{bmatrix} Y'_{601} \\ Cb'_{601} \\ Cr'_{601} \end{bmatrix} = \begin{bmatrix} 0{,}299\,0 & 0{,}587\,0 & 0{,}114\,0 \\ -0{,}168\,7 & -0{,}331\,3 & 0{,}500\,0 \\ 0{,}500\,0 & -0{,}418\,7 & -0{,}081\,3 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \quad (20)$$

The relationship between non-linear R',G',B' and xvYCC$_{709}$ is defined as follows:

$$\begin{bmatrix} Y'_{709} \\ Cb'_{709} \\ Cr'_{709} \end{bmatrix} = \begin{bmatrix} 0{,}212\,6 & 0{,}715\,2 & 0{,}072\,2 \\ -0{,}114\,6 & -0{,}385\,4 & 0{,}500\,0 \\ 0{,}500\,0 & -0{,}454\,2 & -0{,}045\,8 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \quad (21)$$

NOTE If the capturing device is capable of storing Y' greater than 238/219 (or 1,086 758), dynamic range compression can be performed at this stage. Please refer to Annex A for the descriptions.

and quantization for xvYCC for 24-bit encoding (8-bit/channel) is defined as:

$$\begin{aligned} Y_{\text{xvYCC(8)}} &= \text{round}[219 \times Y' + 16] \\ Cb_{\text{xvYCC(8)}} &= \text{round}[224 \times Cb' + 128] \\ Cr_{\text{xvYCC(8)}} &= \text{round}[224 \times Cr' + 128] \end{aligned} \quad (22)$$

For 24-bit encoding, the xvYCC values shall be limited to a range from 1 to 254 according to equation (22).

For N-bit/channel ($N > 8$) encoding, the relationship is defined as:

$$
\begin{aligned}
Y_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[\left(219 \times Y' + 16\right) \times 2^{n-8}\right] \\
Cb_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[\left(224 \times Cb' + 128\right) \times 2^{n-8}\right] \\
Cr_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[\left(224 \times Cr' + 128\right) \times 2^{n-8}\right]
\end{aligned}
\qquad (23)
$$

For N-bit/channel encoding, the xvYCC values shall be limited to a range from "2^{N-8}" to "$254 \times 2^{N-8}$" according to equation (23).

Annex A
(informative)

Compression of specular components of Y’ signals

This annex describes an example method for the dynamic range compression of the specular components that are brighter than white in Y' (or Luma) signal.

In xvYCC colour encoding, linear R,G,B values after equation (8), or non-linear R',G',B' values after equations (9) to (11) are not limited between 0 and 1. After the YCC quantization (equation (14)), the value range will be limited as follows:

Y' signal: -15/219 to +238/219 (or -0,068 493 to +1,086 758)

Cb',Cr' signal: -127/224 to +126/224 (or -0,566 964 to +0,562 500)

For the surface colours, Y' signals shall be in the range of 0 and 1, while over-ranged values (greater than 1,0 or smaller than 0,0) in Cb' and Cr' are used for storing saturated colours.

However, if the specular components that are brighter than white exist in a captured image, there will be pixels with Y' signals greater than “1”. These components should be compressed (or clipped) into the given quantization range. An example for the specular compression method is provided in Figure A.1.

NOTE Different proprietary compression methods in either Y’ components or R’G’B’ components are used in practice.

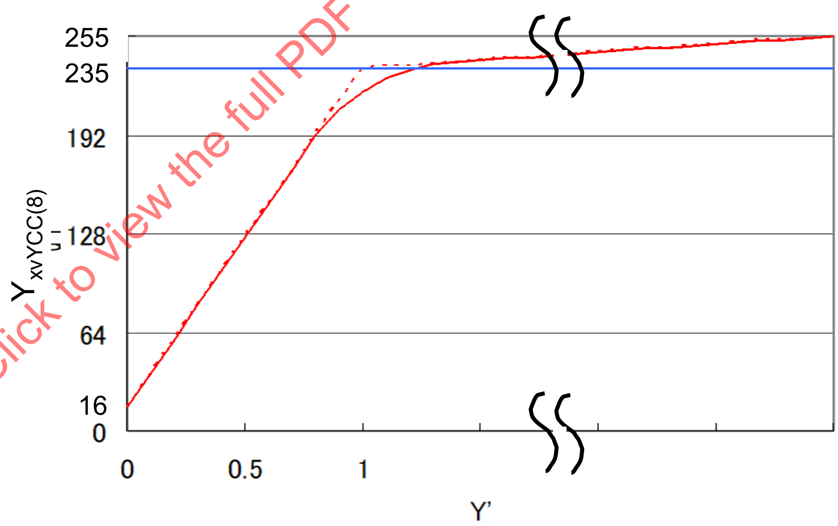


Figure A.1 – Example of the specular compression method

Annex B
(informative)

Default transformation from 16-bit scRGB values to xvYCC values

B.1 Introduction

This annex describes the default transformation from scRGB (as defined in IEC 61966-2-2) to xvYCC. Since the dynamic range of scRGB is wider than that of xvYCC, dynamic range compression (or clipping) for brighter than white colours is needed in the transformation (see Annex A for details).

B.2 Transformation from scRGB values to 8-bit xvYCC

The relationship between 16-bit scRGB values and linear $R_{\mathrm{scRGB}}, G_{\mathrm{scRGB}}, B_{\mathrm{scRGB}}$ values is defined as follows:

$$\begin{aligned} R_{\mathrm{scRGB}} &= \left(R_{\mathrm{scRGB(16)}} \div 8\,192{,}0\right) - 0{,}5 \\ G_{\mathrm{scRGB}} &= \left(G_{\mathrm{scRGB(16)}} \div 8\,192{,}0\right) - 0{,}5 \\ B_{\mathrm{scRGB}} &= \left(B_{\mathrm{scRGB(16)}} \div 8\,192{,}0\right) - 0{,}5 \end{aligned} \quad \text{(B.1)}$$

The linear $R_{\mathrm{scRGB}}, G_{\mathrm{scRGB}}, B_{\mathrm{scRGB}}$ values are then transformed to non-linear R', G', B' values as follows.

If $R_{\mathrm{scRGB}}, G_{\mathrm{scRGB}}, B_{\mathrm{scRGB}} < -0{,}018$

$$\begin{aligned} R' &= -1{,}099 \times \left(-R_{\mathrm{scRGB}}\right)^{0{,}45} + 0{,}099 \\ G' &= -1{,}099 \times \left(-G_{\mathrm{scRGB}}\right)^{0{,}45} + 0{,}099 \\ B' &= -1{,}099 \times \left(-B_{\mathrm{scRGB}}\right)^{0{,}45} + 0{,}099 \end{aligned} \quad \text{(B.2)}$$

If $-0{,}018 \le R_{\mathrm{scRGB}}, G_{\mathrm{scRGB}}, B_{\mathrm{scRGB}} \le 0{,}018$,

$$\begin{aligned} R' &= 4{,}50 \times R_{\mathrm{scRGB}} \\ G' &= 4{,}50 \times G_{\mathrm{scRGB}} \\ B' &= 4{,}50 \times B_{\mathrm{scRGB}} \end{aligned} \quad \text{(B.3)}$$

If $R_{\mathrm{scRGB}}, G_{\mathrm{scRGB}}, B_{\mathrm{scRGB}} > 0{,}018$,

$$\begin{aligned} R' &= 1{,}099 \times \left(R_{\mathrm{scRGB}}\right)^{0{,}45} - 0{,}099 \\ G' &= 1{,}099 \times \left(G_{\mathrm{scRGB}}\right)^{0{,}45} - 0{,}099 \\ B' &= 1{,}099 \times \left(B_{\mathrm{scRGB}}\right)^{0{,}45} - 0{,}099 \end{aligned} \quad \text{(B.4)}$$

The relationship between non-linear R', G', B' and xvYCC_{601} is defined as follows:

$$\begin{bmatrix} Y'_{601} \\ Cb'_{601} \\ Cr'_{601} \end{bmatrix} = \begin{bmatrix} 0{,}299\ 0 & 0{,}587\ 0 & 0{,}114\ 0 \\ -0{,}168\ 7 & -0{,}331\ 3 & 0{,}500\ 0 \\ 0{,}500\ 0 & -0{,}418\ 7 & -0{,}081\ 3 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \quad \text{(B.5)}$$

The relationship between non-linear R', G', B' and xvYCC_{709} is defined as follows:

$$\begin{bmatrix} Y'_{709} \\ Cb'_{709} \\ Cr'_{709} \end{bmatrix} = \begin{bmatrix} 0{,}212\ 6 & 0{,}715\ 2 & 0{,}072\ 2 \\ -0{,}114\ 6 & -0{,}385\ 4 & 0{,}500\ 0 \\ 0{,}500\ 0 & -0{,}454\ 2 & -0{,}045\ 8 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \quad \text{(B.6)}$$

NOTE If the capturing device is capable of storing Y' greater than 238/219 (or 1,086 758), dynamic range compression can be performed at this stage. See Annex A for the descriptions.

and quantization for xvYCC for 24-bit encoding (8-bit/channel) is defined as:

$$\begin{aligned} Y_{\text{xvYCC(8)}} &= \text{round}\left[219 \times Y' + 16\right] \\ Cb_{\text{xvYCC(8)}} &= \text{round}\left[224 \times Cb' + 128\right] \\ Cr_{\text{xvYCC(8)}} &= \text{round}\left[224 \times Cr' + 128\right] \end{aligned} \quad \text{(B.7)}$$

For 24-bit encoding, the xvYCC values shall be limited to a range from 1 to 254 according to equation (22).

For N-bit/channel ($N > 8$) encoding, the relationship is defined as:

$$\begin{aligned} Y_{\text{xvYCC}(N)} &= \text{round}\left[\left(219 \times Y' + 16\right) \times 2^{n-8}\right] \\ Cb_{\text{xvYCC}(N)} &= \text{round}\left[\left(224 \times Cb' + 128\right) \times 2^{n-8}\right] \\ Cr_{\text{xvYCC}(N)} &= \text{round}\left[\left(224 \times Cr' + 128\right) \times 2^{n-8}\right] \end{aligned} \quad \text{(B.7')}$$

For N-bit/channel encoding, the xvYCC values shall be limited to a range from "2^{N-8}" to "254 × 2^{N-8}" according to equation (23).

Annex C
(informative)

xvYCC/ITU-R BT.709 and sYCC/sRGB compatibility

Annex B of IEC 61966-2-1 provides an explanation for the compatibility between sRGB and ITU-R BT.709. ITU-R BT.709 specifically describes the encoding of the "reference" video camera, which will produce an "excellent" image when the resulting image is viewed on a "reference" display. IEC 61966-2-1 provides a clear and well-defined "reference" display for a dim viewing environment.

Figure C.1 illustrates both the sRGB colour space and the extraction of the reference display specifications (with its viewing conditions) implicit in ITU-R BT.709. By building on this system, the sRGB colour space provides a display definition that can be used independently from ITU-R BT.709 while maintaining compatibility. The tree, first arrow, camera, second arrow and circled display represent the same concepts as in Figure C.1. The bottom display is identical to the targeted ITU display and is intended to show that sRGB is simply the targeted display of the ITU capture/display system, independent of the capture encoding space.

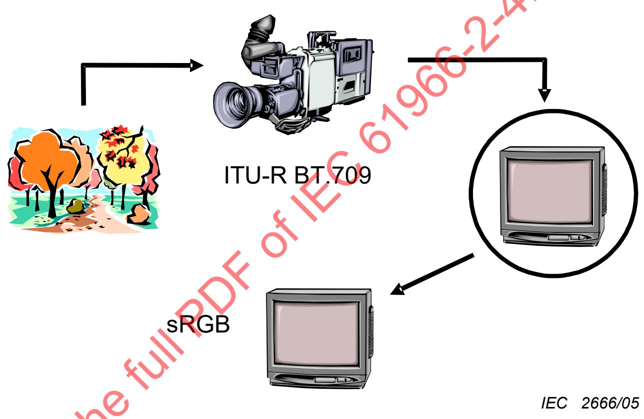


Figure C.1 – Relationship between ITU-R BT.709 and sRGB

However, this system was based on the CRT displays whose RGB chromaticity is within a certain tolerance of the sRGB specification. With the emergence of novel displays based on other technologies (for example, LCDs, PDPs, etc.) that are capable of displaying wider colour gamut, the demands for extended-gamut colour space encoding increased. IEC 61966-2-1, Amendment 1, was published to answer those needs for storing and exchanging out-of-sRGB-gamut saturated colours between devices. This sYCC colour space is adopted in the Exif file format (JEITA CP-3451) and is now in widespread use in still imaging applications.

On the other hand, ITU-R BT.709 colour space is utilized for storing and exchanging in most of the video applications. Therefore, this standard is intended to provide a solution for extending the gamut of ITU-R BT.709, like sYCC colour space extended the gamut of sRGB colour space.

Figure C.2 illustrates the same flow as Figure C.1, but ITU-R BT.709 is now replaced by extended-gamut colour space: xvYCC, and sRGB is replaced by sYCC.

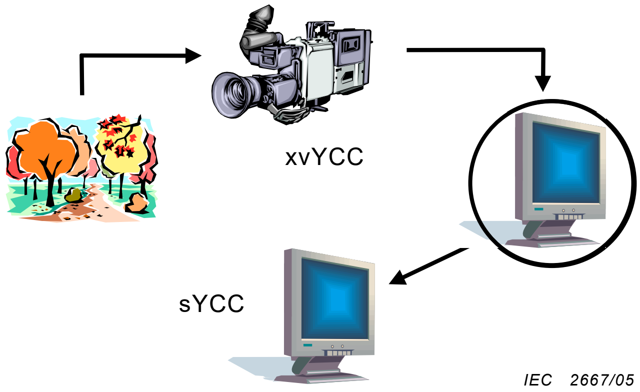


Figure C.2 – Relationship between xvYCC and sYCC

Annex D
(informative)

Recommended usage of IEC 61966-12-2 for this standard

While this standard provides wider colour gamut for consumer electronic (CE) imaging devices, it does not specify the target gamut in which captured and/or computer-generated video contents are rendered, stored, transmitted and then displayed. IEC 61966-12-2 provides a very useful scheme for describing the target gamut for video contents exchange between CE imaging devices.

Usually CE imaging devices render video contents into a “standard” target display, which is widely used by general users. In most cases, those target display devices can be described by the IEC 61966-12-2’s structure. The scope of IEC 61966-12-2 is based on a unique profile of additive three-primary-colour type displays. Therefore, IEC 61966-12-2 is recommended for the use in video exchange in CE imaging devices.

On the other hand, IEC 61966-12-1 has much higher flexibility with three classes of profiles (full, medium and simple). However, as written in the introduction of IEC 61966-12-2, it will be a limitation for CE devices, if a sender device and a receiver device are "based on the IEC 61966-12-1 standard", but cannot understand and interpret the structure of all three classes of profiles, as specified below:

a) the receiver device cannot handle the Gamut ID of incoming contents, if the sender device sends only full or medium profile;
b) the sender device should convert a full profile to a simple one for CE-devices, if the receiver can receive the simple profile only. But the conversion is not possible for all the cases.

NOTE Items a) and b) have been copied from the introduction of IEC 61966-12-2.

Informative notes on other extended-gamut colour spaces:

Recently, some other extended-gamut colour spaces have been proposed, such as ITU-R BT.2020 or SMPTE ST 428-1 (XYZ), which have much wider gamut than generally used displays, or sometimes primary colours are defined outside of existing colours (i.e. virtual colours). In most cases, the gamut of generally used displays in the market is different from the very wide gamut of those recently proposed extended gamut colour spaces. The reflection exposed above can also be applied, in such cases.

Annex E
(informative)

xvYCCext – a method for encoding extended luminance signal

E.1 General

Recently, video standards for wide colour gamut and high dynamic range (HDR) colour space encoding, such as ITU-R BT.2020 (UHDTV) and ITU-R BT.2100 (HDR), were established. In contrast to the previous colour spaces, such as ITU-R BT.709 (high definition television) and IEC 61966-2-4 (xvYCC), it is a very demanding challenge for the display industry to realize wide colour gamut and/or high luminance displays. Therefore, recent mass produced displays for consumer electronics covered only a certain range of wide colour gamuts and high-luminance image contents.

To address this issue, the IEC standard xvYCC (IEC 61966-2-4) specified the extended wide colour gamut region in 2006. In addition, this annex specifies the extended high-luminance signal using the overhead region of xvYCC. This extended high-luminance region is able to encode and reproduce the high-luminance signal up to two times more than luminance of the reference white (R = G = B = 1) of the standard dynamic range (SDR) (i.e. SDR-white).

As written in Annex A of this document, specular components can be recorded using a vendor-specific specular compression method for xvYCC signals. This Annex E describes a method of encoding an extended luminance signal, called xvYCCext. This coding can be used to exchange extended luminance signals. When both the encoder and the decoder use this same encoding method (xvYCCext), specular components will be recovered as defined.

E.2 Extended opto-electronic transfer characteristics

SDR range (R, G, B ≤ 1) of the opto-electronic transfer function (OETF) is already defined in Formulas (1) to (3). The expanded high-luminance signals are additionally encoded by the following Formulas (E.1) to (E.4), where R, G, B is the light linear signal that is normalized by reference white luminance, and R′, G′, B′ is the resulting non-linear signal.

If $t_1(=1) \le R, G, B \le t_2(=1{,}2)$,

$$R' = d \cdot \ln(R - e) + f$$
$$G' = d \cdot \ln(G - e) + f \qquad \text{(E.1)}$$
$$B' = d \cdot \ln(B - e) + f$$

NOTE ln(.) is the natural logarithm.

$$\text{with} \left\{ \begin{array}{l} \gamma(L_W) = a + b / L_W{}^{c}, \\ \text{with a} = 0{,}106\,535,\ \text{b} = -1{,}073\,59,\ \text{c} = 1{,}080\,25 \\ d = \dfrac{\gamma(L_W) \bullet t_2^{\gamma(L_W)} \bullet (t_2 - t_1)}{t_2 - 2{,}202\,204 \bullet \gamma(L_W) \bullet t_1^{0{,}55} \bullet t_2^{\gamma(L_W)}} = \dfrac{\gamma(L_W) \bullet (t_2 - 1)}{t_2^{1-\gamma(L_W)} - 2{,}202\,204 \bullet \gamma(L_W)} \text{ for } t_1 = 1 \\ e = 1 - 2{,}202\,204 \bullet d \\ f = 1{,}099 \bullet t_1^{0{,}45} - 0{,}099 - d \bullet \ln(t_1 - e) = 1 - d \bullet \ln(1 - e) \text{ for } t_1 = 1 \end{array} \right\} \qquad \text{(E.2)}$$

As a first step, the SDR-white luminance (L_w in cd/m[2]) dependent gamma values $\gamma(L_w)$ will be determined using given constants (a, b, and c) and a given L_w. Then, the further required values (d, e, and f) are determined by Formula (E.2). With these obtained values, the intermediate functions given in Formula (E.1) are calculated.

If R, G, B > t_2 (= 1,2),

$$R' = O(L_w) + R^{\gamma(L_w)}$$

$$G' = O(L_w) + G^{\gamma(L_w)} \quad \text{(E.3)}$$

$$B' = O(L_w) + B^{\gamma(L_w)}$$

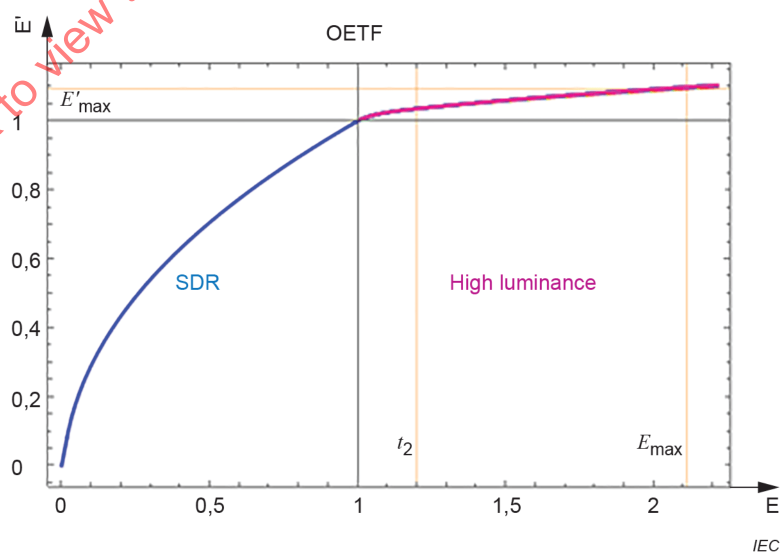
$$\text{, with } O(L_w) = f - t_2{}^{\gamma(L_w)} + d \cdot \ln(t_2 - e) \quad \text{(E.4)}$$

Formula (E.3) is an approximation function in a certain luminance range of the PQ-OETF of ITU-R.BT.2100 and depends on a luminance of SDR-white (L_w) and the offset $O(L_w)$.

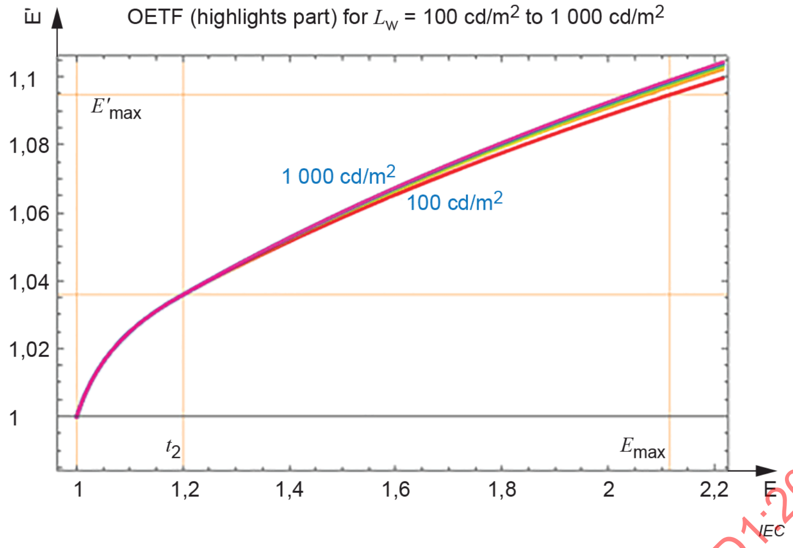
Figure E.1 shows an example of the high luminance region of xvYCCext. Over the reference white (E = 1), the gamma function $E^{\gamma(L_w)}$ is applied in order to include high-luminance colours such as specular and fluorescence, called "Super-white" [24].

NOTE E denotes linear R, G, B and E' denotes non-linear R', G', B'.

Formulas (E.1) and (E.3) are the approximation to OETF of ITU-R.BT.2100. The purpose of the first small region (1 < E < 1,2(= t_2)) described by the smoothing function (Formula (E.1)) is to maintain smooth transitions between SDR-OETF and the extended high-luminance OETF (Formula (E.3)). Formula (E.1) fulfils the same derivative values with the neighbour OETFs Formula (3) and Formula (E.3) at the boundaries E = 1 and E = 1,2 (= t_2).



a) Range for E = (0, 2,2)



b) high luminance range for E = (1, 2,2)

Figure E.1 – High luminance region of OETF for the variation of the reference white luminance from 100 cd/m² to 1 000 cd/m²

In the display industry, the relative signal mapping is usual because white luminances of displays are individual. In contrast, PQ-OETF of ITU-R BT.2100 is the function of the absolute luminance. With varying luminance of the reference white, the shape of OETF in the extended region ($1 < E' \leq 1{,}09475$) for "Super-white" will be changed accordingly, where E' = 1,094 75 denotes a maximum non-linear signal of encoding, considering upper headroom of xvYCC for the full range of HDR-10bit system.

The complex equation of OETF of ITU-R BT.2100 is approximated by the gamma function $E^{\gamma(L_w)}$ considering of luminance L_w of the reference white at E = 1.

The fitting coefficients (a, b, c) are so optimized that the sufficient average error $\left(\text{Mean}\left|OETF_{PQ}(E)-\left(O(L_w)+E^{\gamma(L_w)}\right)\right|\right)$ of the approximation below 0,054 percent for L_w= 2 000 cd/m² (0,55 levels for 10-bit encoding and 2,2 levels for 12-bit encoding). Figure E.2 shows the approximation error in dependence of the reference white luminance from 100 cd/m² to 2 000 cd/m². The mean error increases slightly in proportion to the reference white luminance.

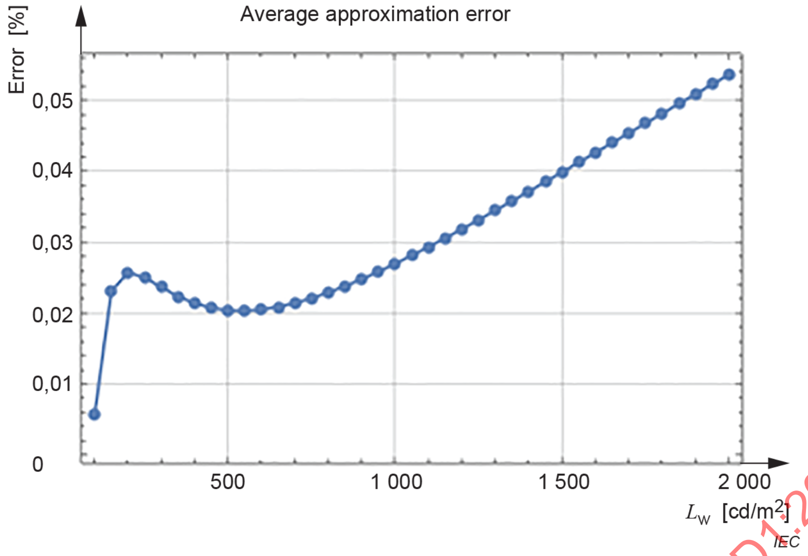


Figure E.2 – Approximation error of OETF

Figure E.3 shows the result of the fitted gamma values in dependence of the white luminance for the range of 100 cd/m^2 to 2 000 cd/m^2. The gamma values are changed from 0,090 8 to 0,106 2.

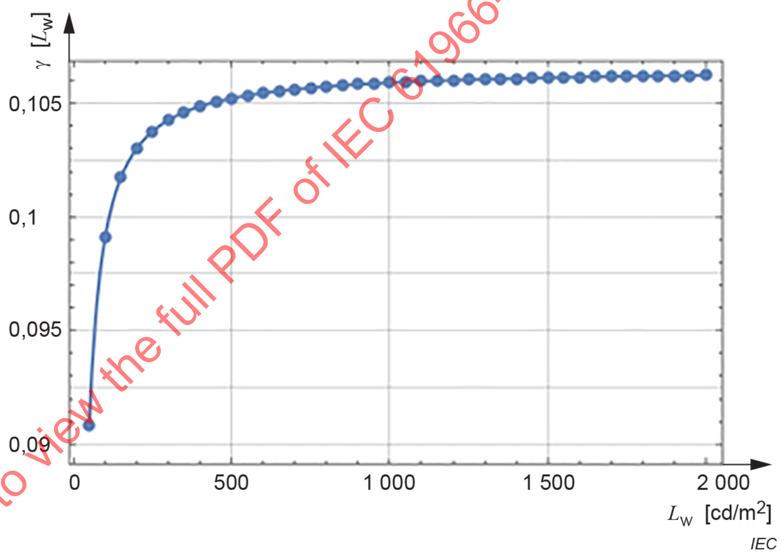


Figure E.3 – Approximated gamma values in function of reference white luminance

The expanded OETF is able to encode the high-luminance signal to a value of more than two times that of the SDR-white luminance. This factor is shown in Figure E.4 for the range of 100 cd/m^2 to 2 000 cd/m^2 as a typical luminance range of displays on the market.

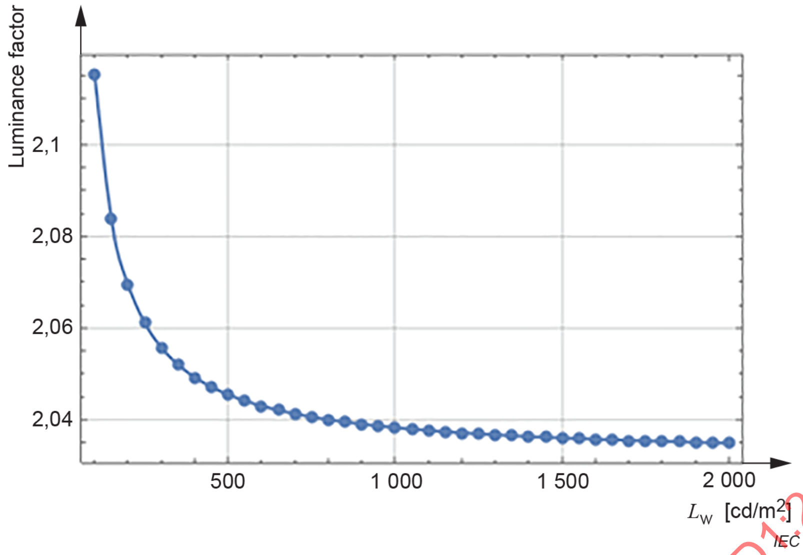


Figure E.4 – Encoderable luminance in multiples of SDR-white luminance

E.3 Extended electro-optical transfer characteristics

EOTF conversion for the SDR range (R', G', $B' \leq 1$) is described in Formula (12) to Formula (14). EOTF conversion for the extended high-luminance region is as follows.

If $1 \leq R', G', B' \leq 1{,}035\ 91$ (= $E'(t = 1{,}2)$),

$$R = \mathrm{Exp}\left((R' - f)/d\right) + e$$

$$G = \mathrm{Exp}\left((G' - f)/d\right) + e \qquad \text{(E.5)}$$

$$B = \mathrm{Exp}\left((B' - f)/d\right) + e$$

If $R', G', B' > 1{,}035\ 91$,

$$R = \left(R' - O(L_W)\right)^{1/\gamma(L_W)}$$

$$G = \left(G' - O(L_W)\right)^{1/\gamma(L_W)} \qquad \text{(E.6)}$$

$$B = \left(B' - O(L_W)\right)^{1/\gamma(L_W)}$$

NOTE For proper encoding and decoding of xvYCC with the extended high-luminance signal, the metadata of IEC 61966-12-1 and IEC 61966-12-2 can be used.

E.4 Digital quantization methods

Signal conversion between the nonlinear R'G'B' and xvYCC signal is defined in Clause 4 and Clause 5. And the n-bits digitalization of xvYCC is also defined in these clauses. For proper encoding of the extended range of the high-luminance signals, more than 10 bits are required.

E.5 Image processing consideration

The xvYCCext would be used for signal coding with extended luminance. If the luminance (Y) in the xvYCCext domain changes significantly for a given constant chroma, the hue can shift in the YCbCr domain owing to the enormous compression of signals by OETF. To ensure image processing with a constant colour tone, it is preferred that the xvYCCext signal is firstly converted into standard signals (e.g. linear light RGB, tri-stimulus XYZ (see 5.2)), uniform colour space of CIELAB, CIE-CAM02 or HLG of ITU-R-BT-2100), and processed in these colour spaces.

As an example, a corresponding HLG signal (E'_{HLG}) of ITU-R.BT.2100 is transformed from xvYCCext (E') as follows.

$$E'_{\mathrm{HLG}} = OETF_{\mathrm{HLG}}\left(EOTF\left(E'\right)\right)$$

$$\text{with } E'_{\mathrm{HLG}} = \left\{R'_{\mathrm{HLG}}, G'_{\mathrm{HLG}}, B'_{\mathrm{HLG}}\right\} \text{ for HLG and } E' = \left\{R', G', B'\right\} \text{ for xvYCCext}. \tag{E.7}$$

First, EOTF(E') transform can be performed with Formula (E.5) and Formula (E.6), and Subcluse 5.4 to Subclause 5.6. Then, the linear signal $E = \{R, G, B\}$ can be transformed into the non-linear HLG signal using $\mathrm{OETF}_{\mathrm{HLG}}$ as follows.

$$E'_{HLG} = \begin{cases} \sqrt{3 \cdot E} & \text{for } 0 \le E < \dfrac{1}{12} \\ a \cdot \ln\left(12 \cdot E - b\right) + c & \text{for } \dfrac{1}{12} \le E < 1 \end{cases}$$

$$\text{with } a = 0{,}178\,832\,77,\ b = 1 - 4a,\ c = 0{,}5 - a \cdot \ln(4 \cdot a) \tag{E.8}$$

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IEC 61966-2-4

Edition 1.2 2021-07
CONSOLIDATED VERSION

FINAL VERSION

colour inside

Multimedia systems and equipment – Colour measurement and management – Part 2-4: Colour management – Extended-gamut YCC colour space for video applications – xvYCC

IEC 61966-2-4:2006-01+AMD1:2016-04+AMD2:2021-07 CSV(en)

CONTENTS

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MULTIMEDIA SYSTEMS AND EQUIPMENT –
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Part 2-4: Colour management –
Extended-gamut YCC colour space
for video applications – xvYCC

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This Final version does not show where the technical content is modified by amendments 1 and 2. A separate Redline version with all changes highlighted is available in this publication.

International Standard IEC 61966-2-4 has been prepared by IEC technical committee 100: Audio, video and multimedia systems and equipment.

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

IEC 61966 consists of the following parts, under the general title *Multimedia systems and equipment – Colour measurement and management:*

Part 2-1: Colour management – Default RGB colour space – sRGB

Part 2-2: Colour management – Extended RGB colour space – scRGB

Part 2-4: Colour management – Extended-gamut YCC colour space for video applications – xvYCC

Part 2-5: Colour management – Optional RGB colour space – opRGB

Part 3: Equipment using cathode ray tubes

Part 4: Equipment using liquid crystal display panels

Part 5: Equipment using plasma display panels

Part 6: Front projection displays

Part 7-1: Colour printers – Reflective prints – RGB inputs

Part 8: Multimedia colour scanners

Part 9: Digital cameras

Part 12-1: Metadata for identification of colour gamut (Gamut ID)

Part 12-2: Simple Metadata format for identification of colour gamut

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INTRODUCTION

After the publication of IEC 61966-2-1, Amendment 1, the sYCC colour encoding was used to capture, store and print extended colour gamut for still image applications. Users received pleasant benefit by exchanging and reproducing wide-gamut colour images.

Recently, various kinds of displays that are capable of producing a wider gamut of colour than the conventional CRT-based displays are emerging. However, most of the current video contents that are displayed on conventional displays, are rendered for the sRGB-gamut. Users of wide-gamut displays could benefit from wide-gamut colour images by video colour encoding that supports a larger colour gamut.

This standard defines the "extended-gamut YCC colour space for video applications". It is based on the current implementation of YCC colour encoding that is used in the video industry (namely ITU-R BT.709-5) and extends its definition to the wider gamut of colour range.

MULTIMEDIA SYSTEMS AND EQUIPMENT – COLOUR MEASUREMENT AND MANAGEMENT –

Part 2-4: Colour management – Extended-gamut YCC colour space for video applications – xvYCC

1 Scope

This part of IEC 61966 is applicable to the encoding and communication of YCC colours used in video systems and similar applications by defining encoding transformations for use in defined reference capturing conditions. If actual conditions differ from the reference conditions, additional rendering transformations may be required. Such additional rendering transformations are beyond the scope of this standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-845:1987, *International Electrotechnical Vocabulary (IEV) – Part 845: Lighting*

ITU-R Recommendation BT.601-5:1995, *Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios*

ITU-R Recommendation BT.709-5:2002, *Parameter values for the HDTV standards for production and international programme exchange*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those concerning illuminance, luminance, tristimulus, and other related lighting terms given in IEC 60050-845, apply.

3.1
scene-referred colour encoding
representation of estimated colour-space coordinates of the elements of an original scene, where a scene is defined to be the relative spectral radiance

3.2
output-referred colour encoding
representation of estimated colour-space coordinates of image data that are appropriate for specified output device and viewing conditions

3.3
extended gamut
colour gamut extending outside that of the standard sRGB CRT display defined in IEC 61966-2-1

3.4
luma
luminance signal as defined by SMPTE/EG28:1993

NOTE 1 To avoid interdisciplinary confusion resulting from the two distinct definitions of luminance, it has been proposed that the video documents use "luma" for "luminance, television" (i.e., the luminance signal).

NOTE 2 Video systems approximate the lightness response of vision by computing a luma component Y' as a weighted sum of non-linear (or gamma-corrected) R'G'B' primary components. Luma is often carelessly referred to as luminance.

4 Colorimetric parameters and related characteristics

This clause defines colorimetric parameters and the related characteristics of reference capturing devices.

4.1 Primary colours and reference white

The CIE chromaticities for the reference red, green, and blue primary colours, and for reference white CIE standard illuminant D65, are given in Table 1. These primaries and white point values are identical to those of ITU-R BT.709-5.

Table 1 – CIE chromaticities for reference primary colours and reference white

	Red	Green	Blue	White/D65
x	0,640 0	0,300 0	0,150 0	0,312 7
y	0,330 0	0,600 0	0,060 0	0,329 0
z	0,030 0	0,100 0	0,790 0	0,358 3

4.2 Opto-electronic transfer characteristics

Opto-electronic transfer characteristics are defined as follows.

If $R, G, B \le -0{,}018$,

$$\begin{aligned} R' &= -1{,}099 \times (-R)^{0{,}45} + 0{,}099 \\ G' &= -1{,}099 \times (-G)^{0{,}45} + 0{,}099 \\ B' &= -1{,}099 \times (-B)^{0{,}45} + 0{,}099 \end{aligned} \tag{1}$$

If $-0{,}018 < R, G, B < 0{,}018$,

$$\begin{aligned} R' &= 4{,}50 \times R \\ G' &= 4{,}50 \times G \\ B' &= 4{,}50 \times B \end{aligned} \tag{2}$$

If $R, G, B \ge 0{,}018$,

$$\begin{aligned} R' &= 1{,}099 \times (R)^{0{,}45} - 0{,}099 \\ G' &= 1{,}099 \times (G)^{0{,}45} - 0{,}099 \\ B' &= 1{,}099 \times (B)^{0{,}45} - 0{,}099 \end{aligned} \tag{3}$$

where R, G, B is a voltage normalized by reference white level and proportional to the implicit light intensity that would be detected with a reference camera colour channel; R', G', B' is the resulting non-linear primary signal.

4.3 YCC (luma-chroma-chroma) encoding methods

The encoding equations from the primary RGB (red-green-blue) signal: R', G', B' to the YCC (luma-chroma-chroma) signal: Y', Cb', Cr' is defined by the following two methods. It is important to follow one of the encodings in the specified application.

$xvYCC_{601}$, which is implemented mainly in the SDTV (standard-definition television) applications as defined in ITU-R BT. 601-5, is defined as follows:

$$\begin{bmatrix} Y'_{601} \\ Cb'_{601} \\ Cr'_{601} \end{bmatrix} = \begin{bmatrix} 0{,}299\,0 & 0{,}587\,0 & 0{,}114\,0 \\ -0{,}168\,7 & -0{,}331\,3 & 0{,}500\,0 \\ 0{,}500\,0 & -0{,}418\,7 & -0{,}081\,3 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{4}$$

NOTE The coefficients in equation (4) are from ITU-R BT.601-5 which defines Y' of YCC to the three decimal place accuracy. An additional decimal place is defined above to be consistent with the other matrix coefficients defined in this standard.

$xvYCC_{709}$, which is implemented mainly in the HDTV (high-definition television) applications as defined in ITU-R BT. 709-5, is defined as follows:

$$\begin{bmatrix} Y'_{709} \\ Cb'_{709} \\ Cr'_{709} \end{bmatrix} = \begin{bmatrix} 0{,}212\,6 & 0{,}715\,2 & 0{,}072\,2 \\ -0{,}114\,6 & -0{,}385\,4 & 0{,}500\,0 \\ 0{,}500\,0 & -0{,}454\,2 & -0{,}045\,8 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{5}$$

4.4 Digital quantization methods

Quantization of YCC (luma-chroma-chroma) signal: Y', Cb', Cr' is defined as follows.

For 8-bit representation:

$$\begin{aligned} Y_{\mathrm{xvYCC(8)}} &= \mathrm{round}\left[219 \times Y' + 16\right] \\ Cb_{\mathrm{xvYCC(8)}} &= \mathrm{round}\left[224 \times Cb' + 128\right] \\ Cr_{\mathrm{xvYCC(8)}} &= \mathrm{round}\left[224 \times Cr' + 128\right] \end{aligned} \tag{6}$$

For n-bit (n > 8) representation:

$$\begin{aligned} Y_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[(219 \times Y' + 16) \times 2^{n-8}\right] \\ Cb_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[(224 \times Cb' + 128) \times 2^{n-8}\right] \\ Cr_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[(224 \times Cr' + 128) \times 2^{n-8}\right] \end{aligned} \tag{7}$$

NOTE Bit levels “from 0 to 2^{N-8}-1” and “from 255 × 2^{N-8} to 2^{N}-1” (0 and 255, for the case of 8-bit encoding) are used exclusively for synchronization and are not allowed for storing colour values. Levels from “2^{N-8}” to “255 × 2^{N-8}-1” (from 1 to 254, for the case of 8-bit encoding) are available.

5 Encoding transformations

5.1 Introduction

The encoding transformations between xvYCC values and CIE 1931 XYZ values provide unambiguous methods to represent optimum image colorimetry of the captured scene. Scene colorimetry is defined as relative to the white objects, assuming that the exposure is properly controlled. It should be noted that dynamic range compression is needed when storing the wide dynamic range images (see Annex A for descriptions). Additionally, if the condition of the capturing device deviates from the ideal condition defined in Clause 4, operations such as colour compensation, colour correction and a certain degree of colour rendering can be performed. However, the methods for these operations are beyond the scope of this standard.

5.2 Transformation from xvYCC values to CIE 1931 XYZ values

For 24-bit encoding (8-bit/channel), the relationship between 8-bit values and Y',Cb',Cr' is defined as:

$$\begin{aligned} Y' &= \left(Y_{\text{xvYCC}(8)} - 16\right)/219 \\ Cb' &= \left(Cb_{\text{xvYCC}(8)} - 128\right)/224 \\ Cr' &= \left(Cr_{\text{xvYCC}(8)} - 128\right)/224 \end{aligned} \tag{8}$$

For N-bit/channel ($N > 8$) encoding, the relationship between N-bit values and Y',Cb',Cr' is defined as:

$$\begin{aligned} Y' &= \left(\frac{Y_{\text{xvYCC}(N)}}{2^{N-8}} - 16\right)\Big/219 \\ Cb' &= \left(\frac{Cb_{\text{xvYCC}(N)}}{2^{N-8}} - 128\right)\Big/224 \\ Cr' &= \left(\frac{Cr_{\text{xvYCC}(N)}}{2^{N-8}} - 128\right)\Big/224 \end{aligned} \tag{9}$$

For xvYCC$_{601}$ encoding, the non-linear Y',Cb',Cr' values are transformed to the non-linear R',G',B' values as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1{,}000\ 0 & 0{,}000\ 0 & 1{,}402\ 0 \\ 1{,}000\ 0 & -0{,}344\ 1 & -0{,}714\ 1 \\ 1{,}000\ 0 & 1{,}772\ 0 & 0{,}000\ 0 \end{bmatrix} \begin{bmatrix} Y'_{601} \\ Cb'_{601} \\ Cr'_{601} \end{bmatrix} \tag{10}$$

NOTE The possible range for non-linear R’G’B’$_{(601)}$ calculated from, for example, equation (10) will be between -1,0732 and 2,0835.

For xvYCC$_{709}$ encoding, the non-linear Y',Cb',Cr' values are transformed to the non-linear R',G',B' values as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1{,}000\ 0 & 0{,}000\ 0 & 1{,}574\ 8 \\ 1{,}000\ 0 & -0{,}187\ 3 & -0{,}468\ 1 \\ 1{,}000\ 0 & 1{,}855\ 6 & 0{,}000\ 0 \end{bmatrix} \begin{bmatrix} Y'_{709} \\ Cb'_{709} \\ Cr'_{709} \end{bmatrix} \tag{11}$$

NOTE The possible range for non-linear R’G’B’$_{(709)}$ calculated from, for example, equation (11) will be between -1,1206 and 2,1305.

The non-linear R',G',B' values are then transformed to linear R,G,B values as follows.

If $R',G',B' \leq -0{,}081$

$$R = -\left(\frac{R' - 0{,}099}{-1{,}099}\right)^{\frac{1}{0{,}45}}$$
$$G = -\left(\frac{G' - 0{,}099}{-1{,}099}\right)^{\frac{1}{0{,}45}} \qquad (12)$$
$$B = -\left(\frac{B' - 0{,}099}{-1{,}099}\right)^{\frac{1}{0{,}45}}$$

If $-0{,}081 < R',G',B' < 0{,}081$

$$R = R'/4{,}50$$
$$G = G'/4{,}50 \qquad (13)$$
$$B = B'/4{,}50$$

If $R',G',B' \geq 0{,}081$

$$R = \left(\frac{R' + 0{,}099}{1{,}099}\right)^{\frac{1}{0{,}45}}$$
$$G = \left(\frac{G' + 0{,}099}{1{,}099}\right)^{\frac{1}{0{,}45}} \qquad (14)$$
$$B = \left(\frac{B' + 0{,}099}{1{,}099}\right)^{\frac{1}{0{,}45}}$$

The linear R,G,B values are transformed to CIE 1931 XYZ values as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0{,}412\,4 & 0{,}357\,6 & 0{,}180\,5 \\ 0{,}212\,6 & 0{,}715\,2 & 0{,}072\,2 \\ 0{,}019\,3 & 0{,}119\,2 & 0{,}950\,5 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (15)$$

NOTE When the capturing device performs dynamic range compression of the brighter-than-white (for example, specular) components, the compressed colours will be displayed at the top-end range of the "reference" display as described in Annex C. In this case, the XYZ tristimulus values of the compressed components represent the colorimetry of the rendered scene, not the colorimetry of the original scene.

5.3 Transformation from CIE 1931 XYZ values to xvYCC values

The CIE 1931 XYZ values can be transformed to linear R,G,B values as follows:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3{,}241\,0 & -1{,}537\,4 & -0{,}498\,6 \\ -0{,}969\,2 & 1{,}876\,0 & 0{,}041\,6 \\ 0{,}055\,6 & -0{,}204\,0 & 1{,}057\,0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (16)$$

In the xvYCC encoding process, negative RGB tristimulus values and RGB tristimulus values greater than 1,0 are retained.

The linear R,G,B values are then transformed to non-linear R',G',B' values as follows.

If $R,G,B \leq -0{,}018$,

$$\begin{aligned} R' &= -1{,}099 \times (-R)^{0{,}45} + 0{,}099 \\ G' &= -1{,}099 \times (-G)^{0{,}45} + 0{,}099 \\ B' &= -1{,}099 \times (-B)^{0{,}45} + 0{,}099 \end{aligned} \tag{17}$$

If $-0{,}018 < R,G,B < 0{,}018$,

$$\begin{aligned} R' &= 4{,}50 \times R \\ G' &= 4{,}50 \times G \\ B' &= 4{,}50 \times B \end{aligned} \tag{18}$$

If $R,G,B \geq 0{,}018$,

$$\begin{aligned} R' &= 1{,}099 \times (R)^{0{,}45} - 0{,}099 \\ G' &= 1{,}099 \times (G)^{0{,}45} - 0{,}099 \\ B' &= 1{,}099 \times (B)^{0{,}45} - 0{,}099 \end{aligned} \tag{19}$$

The relationship between non-linear R',G',B' and $xvYCC_{601}$ is defined as follows:

$$\begin{bmatrix} Y'_{601} \\ Cb'_{601} \\ Cr'_{601} \end{bmatrix} = \begin{bmatrix} 0{,}299\,0 & 0{,}587\,0 & 0{,}114\,0 \\ -0{,}168\,7 & -0{,}331\,3 & 0{,}500\,0 \\ 0{,}500\,0 & -0{,}418\,7 & -0{,}081\,3 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{20}$$

The relationship between non-linear R',G',B' and $xvYCC_{709}$ is defined as follows:

$$\begin{bmatrix} Y'_{709} \\ Cb'_{709} \\ Cr'_{709} \end{bmatrix} = \begin{bmatrix} 0{,}212\,6 & 0{,}715\,2 & 0{,}072\,2 \\ -0{,}114\,6 & -0{,}385\,4 & 0{,}500\,0 \\ 0{,}500\,0 & -0{,}454\,2 & -0{,}045\,8 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \tag{21}$$

NOTE If the capturing device is capable of storing Y' greater than 238/219 (or 1,086 758), dynamic range compression can be performed at this stage. Please refer to Annex A for the descriptions.

and quantization for xvYCC for 24-bit encoding (8-bit/channel) is defined as:

$$\begin{aligned} Y_{\text{xvYCC(8)}} &= \text{round}[219 \times Y' + 16] \\ Cb_{\text{xvYCC(8)}} &= \text{round}[224 \times Cb' + 128] \\ Cr_{\text{xvYCC(8)}} &= \text{round}[224 \times Cr' + 128] \end{aligned} \tag{22}$$

For 24-bit encoding, the xvYCC values shall be limited to a range from 1 to 254 according to equation (22).

For N-bit/channel ($N > 8$) encoding, the relationship is defined as:

$$\begin{aligned} Y_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[(219 \times Y' + 16) \times 2^{n-8}\right] \\ Cb_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[(224 \times Cb' + 128) \times 2^{n-8}\right] \\ Cr_{\mathrm{xvYCC}(N)} &= \mathrm{round}\left[(224 \times Cr' + 128) \times 2^{n-8}\right] \end{aligned} \tag{23}$$

For N-bit/channel encoding, the xvYCC values shall be limited to a range from "2^{N-8}" to "$254 \times 2^{N-8}$" according to equation (23).

Annex A
(informative)

Compression of specular components of Y' signals

This annex describes an example method for the dynamic range compression of the specular components that are brighter than white in Y' (or Luma) signal.

In xvYCC colour encoding, linear R,G,B values after equation (8), or non-linear R',G',B' values after equations (9) to (11) are not limited between 0 and 1. After the YCC quantization (equation (14)), the value range will be limited as follows:

Y' signal: -15/219 to +238/219 (or -0,068 493 to +1,086 758)

Cb',Cr' signal: -127/224 to +126/224 (or -0,566 964 to +0,562 500)

For the surface colours, Y' signals shall be in the range of 0 and 1, while over-ranged values (greater than 1,0 or smaller than 0,0) in Cb' and Cr' are used for storing saturated colours.

However, if the specular components that are brighter than white exist in a captured image, there will be pixels with Y' signals greater than "1". These components should be compressed (or clipped) into the given quantization range. An example for the specular compression method is provided in Figure A.1.

NOTE Different proprietary compression methods in either Y' components or R'G'B' components are used in practice.

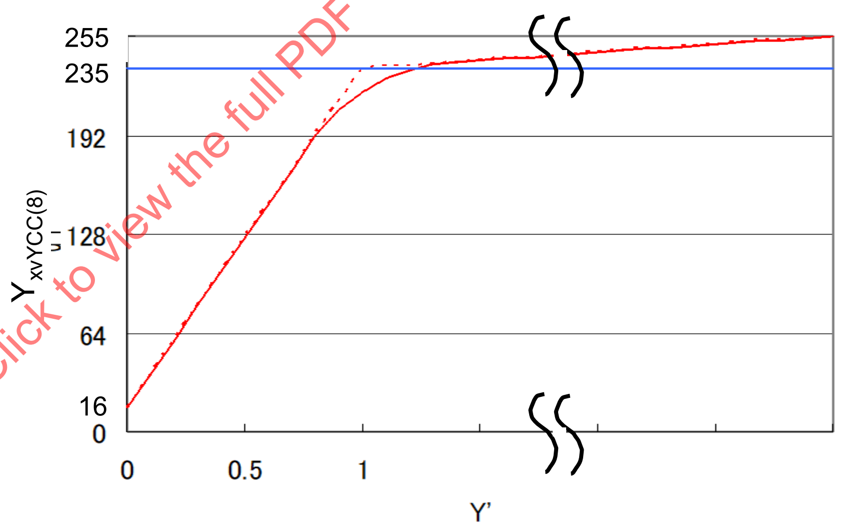

Figure A.1 – Example of the specular compression method

Annex B
(informative)

Default transformation from 16-bit scRGB values to xvYCC values

B.1 Introduction

This annex describes the default transformation from scRGB (as defined in IEC 61966-2-2) to xvYCC. Since the dynamic range of scRGB is wider than that of xvYCC, dynamic range compression (or clipping) for brighter than white colours is needed in the transformation (see Annex A for details).

B.2 Transformation from scRGB values to 8-bit xvYCC

The relationship between 16-bit scRGB values and linear $R_{\text{scRGB}}, G_{\text{scRGB}}, B_{\text{scRGB}}$ values is defined as follows:

$$\begin{aligned} R_{\text{scRGB}} &= \left(R_{\text{scRGB}(16)} \div 8\,192{,}0\right) - 0{,}5 \\ G_{\text{scRGB}} &= \left(G_{\text{scRGB}(16)} \div 8\,192{,}0\right) - 0{,}5 \\ B_{\text{scRGB}} &= \left(B_{\text{scRGB}(16)} \div 8\,192{,}0\right) - 0{,}5 \end{aligned} \tag{B.1}$$

The linear $R_{\text{scRGB}}, G_{\text{scRGB}}, B_{\text{scRGB}}$ values are then transformed to non-linear R', G', B' values as follows.

If $R_{\text{scRGB}}, G_{\text{scRGB}}, B_{\text{scRGB}} < -0{,}018$

$$\begin{aligned} R' &= -1{,}099 \times \left(-R_{\text{scRGB}}\right)^{0{,}45} + 0{,}099 \\ G' &= -1{,}099 \times \left(-G_{\text{scRGB}}\right)^{0{,}45} + 0{,}099 \\ B' &= -1{,}099 \times \left(-B_{\text{scRGB}}\right)^{0{,}45} + 0{,}099 \end{aligned} \tag{B.2}$$

If $-0{,}018 \leq R_{\text{scRGB}}, G_{\text{scRGB}}, B_{\text{scRGB}} \leq 0{,}018$,

$$\begin{aligned} R' &= 4{,}50 \times R_{\text{scRGB}} \\ G' &= 4{,}50 \times G_{\text{scRGB}} \\ B' &= 4{,}50 \times B_{\text{scRGB}} \end{aligned} \tag{B.3}$$

If $R_{\text{scRGB}}, G_{\text{scRGB}}, B_{\text{scRGB}} > 0{,}018$,

$$\begin{aligned} R' &= 1{,}099 \times \left(R_{\text{scRGB}}\right)^{0{,}45} - 0{,}099 \\ G' &= 1{,}099 \times \left(G_{\text{scRGB}}\right)^{0{,}45} - 0{,}099 \\ B' &= 1{,}099 \times \left(B_{\text{scRGB}}\right)^{0{,}45} - 0{,}099 \end{aligned} \tag{B.4}$$

The relationship between non-linear R', G', B' and xvYCC_{601} is defined as follows:

$$\begin{bmatrix} Y'_{601} \\ Cb'_{601} \\ Cr'_{601} \end{bmatrix} = \begin{bmatrix} 0{,}299\ 0 & 0{,}587\ 0 & 0{,}114\ 0 \\ -0{,}168\ 7 & -0{,}331\ 3 & 0{,}500\ 0 \\ 0{,}500\ 0 & -0{,}418\ 7 & -0{,}081\ 3 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \quad \text{(B.5)}$$

The relationship between non-linear R', G', B' and $xvYCC_{709}$ is defined as follows:

$$\begin{bmatrix} Y'_{709} \\ Cb'_{709} \\ Cr'_{709} \end{bmatrix} = \begin{bmatrix} 0{,}212\ 6 & 0{,}715\ 2 & 0{,}072\ 2 \\ -0{,}114\ 6 & -0{,}385\ 4 & 0{,}500\ 0 \\ 0{,}500\ 0 & -0{,}454\ 2 & -0{,}045\ 8 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \quad \text{(B.6)}$$

NOTE If the capturing device is capable of storing Y' greater than 238/219 (or 1,086 758), dynamic range compression can be performed at this stage. See Annex A for the descriptions.

and quantization for xvYCC for 24-bit encoding (8-bit/channel) is defined as:

$$\begin{aligned} Y_{\text{xvYCC}(8)} &= \text{round}\left[219 \times Y' + 16\right] \\ Cb_{\text{xvYCC}(8)} &= \text{round}\left[224 \times Cb' + 128\right] \\ Cr_{\text{xvYCC}(8)} &= \text{round}\left[224 \times Cr' + 128\right] \end{aligned} \quad \text{(B.7)}$$

For 24-bit encoding, the xvYCC values shall be limited to a range from 1 to 254 according to equation (22).

For N-bit/channel ($N > 8$) encoding, the relationship is defined as:

$$\begin{aligned} Y_{\text{xvYCC}(N)} &= \text{round}\left[\left(219 \times Y' + 16\right) \times 2^{n-8}\right] \\ Cb_{\text{xvYCC}(N)} &= \text{round}\left[\left(224 \times Cb' + 128\right) \times 2^{n-8}\right] \\ Cr_{\text{xvYCC}(N)} &= \text{round}\left[\left(224 \times Cr' + 128\right) \times 2^{n-8}\right] \end{aligned} \quad \text{(B.7')}$$

For N-bit/channel encoding, the xvYCC values shall be limited to a range from "2^{N-8}" to "$254 \times 2^{N-8}$" according to equation (23).

Annex C
(informative)

xvYCC/ITU-R BT.709 and sYCC/sRGB compatibility

Annex B of IEC 61966-2-1 provides an explanation for the compatibility between sRGB and ITU-R BT.709. ITU-R BT.709 specifically describes the encoding of the "reference" video camera, which will produce an "excellent" image when the resulting image is viewed on a "reference" display. IEC 61966-2-1 provides a clear and well-defined "reference" display for a dim viewing environment.

Figure C.1 illustrates both the sRGB colour space and the extraction of the reference display specifications (with its viewing conditions) implicit in ITU-R BT.709. By building on this system, the sRGB colour space provides a display definition that can be used independently from ITU-R BT.709 while maintaining compatibility. The tree, first arrow, camera, second arrow and circled display represent the same concepts as in Figure C.1. The bottom display is identical to the targeted ITU display and is intended to show that sRGB is simply the targeted display of the ITU capture/display system, independent of the capture encoding space.

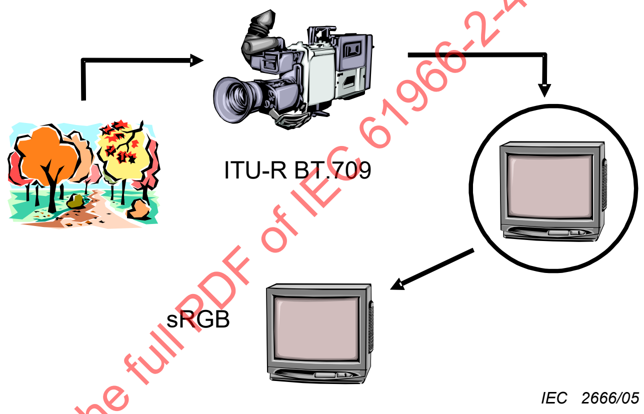

Figure C.1 – Relationship between ITU-R BT.709 and sRGB

However, this system was based on the CRT displays whose RGB chromaticity is within a certain tolerance of the sRGB specification. With the emergence of novel displays based on other technologies (for example, LCDs, PDPs, etc.) that are capable of displaying wider colour gamut, the demands for extended-gamut colour space encoding increased. IEC 61966-2-1, Amendment 1, was published to answer those needs for storing and exchanging out-of-sRGB-gamut saturated colours between devices. This sYCC colour space is adopted in the Exif file format (JEITA CP-3451) and is now in widespread use in still imaging applications.

On the other hand, ITU-R BT.709 colour space is utilized for storing and exchanging in most of the video applications. Therefore, this standard is intended to provide a solution for extending the gamut of ITU-R BT.709, like sYCC colour space extended the gamut of sRGB colour space.

Figure C.2 illustrates the same flow as Figure C.1, but ITU-R BT.709 is now replaced by extended-gamut colour space: xvYCC, and sRGB is replaced by sYCC.