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Photography and graphic technology — Extended colour encodings for digital image storage, manipulation and interchange

Part 2: Reference output medium metric RGB colour image encoding (ROMM RGB)

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National foreword

This British Standard is the UK implementation of ISO 22028-2:2013. It supersedes DD ISO/TS 22028-2:2006 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee CPW/42, Photography.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Photography and graphic technology — Extended colour encodings for digital image storage, manipulation and interchange —

Part 2: Reference output medium metric RGB colour image encoding (ROMM RGB)

Photographie et technologie graphique — Codages par couleurs étendues pour stockage, manipulation et échange d'image numérique —

Partie 2: Codage d'image en couleurs RVB par référence de sortie par voie métrique

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

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The committee responsible for this document is ISO/TC 42, *Photography*.

This first edition cancels and replaces ISO/TS 22028-2:2006, which has been technically revised.

ISO 22028 consists of the following parts, under the general title *Photography and graphic technology — Extended colour encodings for digital image storage, manipulation and interchange*:

— *Part 1: Architecture and requirements*

— *Part 2: Reference output medium metric RGB colour image encoding (ROMM RGB)*

— *Part 3: Reference input medium metric RGB colour image encoding (RIMM RGB)* [Technical Specification]

Introduction

This part of ISO 22028 has been developed in order to meet the industry need for a complete, fully-documented, publicly-available definition of a wide-primary output-referred extended gamut red-green-blue (RGB) colour image encoding. This colour image encoding provides a way to represent output-referred images that does not limit the colour gamut to those colours capable of being displayed on typical monitors, as is the case with the sRGB colour encoding, or require the use of negative RGB colourimetry coordinates, as is the case with extended sRGB colour encodings like bg-sRGB.

An extended colour-gamut colour encoding is particularly desirable for professional photography applications. For example, colours used for company logos can be outside a monitor gamut and would therefore need to be clipped or compressed to a less saturated colour. Similarly, photographic prints can contain colours outside a monitor RGB colour gamut. By using a standard output-referred extended gamut colour image encoding, images containing such colours can be stored, interchanged, manipulated, and later printed, without limiting or distorting the colours of the final output.

The Reference output medium metric RGB (ROMM RGB) colour image encoding specified in this part of ISO 22028 meets the needs of these types of applications.

Photography and graphic technology — Extended colour encodings for digital image storage, manipulation and interchange —

Part 2: **Reference output medium metric RGB colour image encoding (ROMM RGB)**

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This part of ISO 22028 defines a family of extended colour-gamut output-referred RGB colour image encodings designated as reference output medium metric RGB (ROMM RGB). Digital images encoded using ROMM RGB can be manipulated, stored, transmitted, displayed, or printed by digital still picture imaging systems. Three precision levels are defined using 8-, 12- and 16-bits/channel.

2 Normative references

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

ISO 15076-1:2010, *Image technology colour management — Architecture, profile format and data structure — Part 1: Based on ICC.1:2010*

ISO 22028-1:2004, *Photography and graphic technology — Extended colour encodings for digital image storage, manipulation and interchange — Part 1: Architecture and requirements*

ISO 11664-1:2007, *(CIE S 014-1/E:2006) Colorimetry – Part 1: CIE standard colorimetric observers*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
adapted white
colour stimulus that an observer who is adapted to the viewing environment would judge to be perfectly achromatic and to have a luminance factor of unity; i.e. absolute colorimetric coordinates that an observer would consider to be a perfect white diffuser

Note 1 to entry: The adapted white can vary within a scene.

3.2
additive RGB colour space
colorimetric colour space having three colour primaries (generally red, green and blue) such that CIE XYZ tristimulus values can be determined from the RGB colour space values by forming a weighted combination of the CIE XYZ tristimulus values for the individual colour primaries, where the weights are proportional to the radiometrically linear colour space values for the corresponding colour primaries

Note 1 to entry: A simple linear 3 × 3 matrix transformation can be used to transform between CIE XYZ tristimulus values and the radiometrically linear colour space values for an additive RGB colour space.

Note 2 to entry: Additive RGB colour spaces are defined by specifying the CIE chromaticity values for a set of additive RGB primaries and a colour space white point, together with a colour component transfer function.

3.3
colorimetric colour space
colour space having an exact and simple relationship to CIE colorimetric values

Note 1 to entry: Colourimetric colour spaces include those defined by CIE (e.g. CIE XYZ, CIELAB, CIELUV), as well as colour spaces that are simple transformations of those colour spaces (e.g. additive RGB colour spaces).

3.4
colour component transfer function
single variable, monotonic mathematical function applied individually to one or more colour channels of a colour space

Note 1 to entry: Colour component transfer functions are frequently used to account for the nonlinear response of a reference device and/or to improve the visual uniformity of a colour space.

Note 2 to entry: Generally, colour component transfer functions will be nonlinear functions such as a power-law (i.e. “gamma”) function or a logarithmic function. However, in some cases a linear colour component transfer function can be used.

3.5
colour encoding
generic term for a quantized digital encoding of a colour space, encompassing both colour space encodings and colour image encodings

3.6
colour gamut
solid in a colour space, consisting of all those colours that are either: present in a specific scene, artwork, photograph, photomechanical, or other reproduction; or capable of being created using a particular output device and/or medium

3.7
colour image encoding
digital encoding of the colour values for a digital image, including the specification of a colour space encoding, together with any information necessary to properly interpret the colour values such as the image state, the intended image viewing environment and the reference medium

Note 1 to entry: In some cases, the intended image viewing environment will be explicitly defined for the colour image encoding. In other cases, the intended image viewing environment can be specified on an image-by-image basis using metadata associated with the digital image.

Note 2 to entry: Some colour image encodings will indicate particular reference medium characteristics, such as a reflection print with a specified density range. In other cases, the reference medium will be not applicable, such as with a scene-referred colour image encoding, or will be specified using image metadata.

Note 3 to entry: Colour image encodings are not limited to pictorial digital images that originate from an original scene, but are also applicable to digital images with content such as text, line art, vector graphics and other forms of original artwork.

3.8
colour rendering
mapping of image data representing the colour space coordinates of the elements of a scene to output-referred image data representing the colour space coordinates of the elements of a reproduction

Note 1 to entry: Colour rendering generally consists of one or more of the following:

— compensating for differences in the input and output viewing conditions;

— tone scale and gamut mapping to map the scene colours onto the dynamic range and colour gamut of the reproduction;

— applying preference adjustments.

3.9
colour space
geometric representation of colours in space, usually of three dimensions

[CIE Publication 17.4:1987, 845-03-25]

3.10
colour space encoding
digital encoding of a colour space, including the specification of a digital encoding method, and a colour space value range

Note 1 to entry: Multiple colour space encodings can be defined based on a single colour space where the different colour space encodings have different digital encoding methods and/or colour space value ranges. (For example, 8-bit sRGB and 10-bit e-sRGB are different colour space encodings based on a particular RGB colour space.)

3.11
colour space white point
colour stimulus to which colour space values are normalized

Note 1 to entry: It is not necessary that the colour space white point correspond to the assumed adapted white point and/or the reference medium white point for a colour image encoding.

3.12
continuous colour space values
real-valued, unbounded colour space values that have not been encoded using a digital encoding method

3.13
extended gamut
colour gamut extending outside that of the standard sRGB reference display as defined by IEC 61966-2-1

3.14
gamut mapping
mapping of the colour space coordinates of the elements of a source image to colour space coordinates of the elements of a reproduction to compensate for differences in the source and output medium colour gamut capability

Note 1 to entry: The term "gamut mapping" is somewhat more restrictive than the term "colour rendering" because gamut mapping is performed on colourimetry that has already been adjusted to compensate for viewing condition differences and viewer preferences, although these processing operations are frequently combined in reproduction and preferred reproduction models.

3.15
ICC profile
International Color Consortium's file format, used to store transforms from one colour encoding to another, e.g. from device colour coordinates to profile connection space, as part of a colour management system

3.16
image state
attribute of a colour image encoding indicating the rendering state of the image data

Note 1 to entry: The primary image states defined in this document are the scene-referred image state, the original-referred image state and the output-referred image state.

3.17
luminance factor
ratio of the luminance of the surface element in the given direction to that of a perfect reflecting or transmitting diffuser identically illuminated

[CIE Publication 17.4:1987, 845-04-69]

3.18
medium black point
neutral colour with the lowest luminance that can be produced by an imaging medium in normal use, measured using the specified measurement geometry

Note 1 to entry: It is generally desirable to specify a medium black point that has the same chromaticity as the medium white point.

3.19
medium white point
neutral colour with the highest luminance that can be produced by an imaging medium in normal use, measured using the specified measurement geometry

3.20
output-referred image state
image state associated with image data that represents the colour space coordinates of the elements of an image that has undergone colour rendering appropriate for a specified real or virtual output device and viewing conditions

Note 1 to entry: When the phrase "output-referred" is used as a qualifier to an object, it implies that the object is in an output-referred image state. For example, output-referred image data are image data in an output-referred image state.

Note 2 to entry: Output referred image data are referred to the specified output device and viewing conditions. A single scene can be colour rendered to a variety of output-referred representations depending on the anticipated output viewing conditions, media limitations, and/or artistic intents.

Note 3 to entry: Output-referred image data can become the starting point for a subsequent reproduction process. For example, sRGB output-referred image data are frequently considered to be the starting point for the colour re-rendering performed by a printer designed to receive sRGB image data.

3.21
tristimulus values
amounts of the three reference colour stimuli, in a given trichromatic system, required to match the colour of the stimulus considered

[CIE Publication 17.4:1987, 845-03-22]

3.22
veiling glare
light, reflected from an imaging medium, that has not been modulated by the means used to produce the image

Note 1 to entry: Veiling glare lightens and reduces the contrast of the darker parts of an image.

Note 2 to entry: In CIE Publication 122, the veiling glare of a display is referred to as ambient flare.

3.23
viewing flare
veiling glare that is observed in a viewing environment but not accounted for in radiometric measurements made using a prescribed measurement geometry

Note 1 to entry: The viewing flare is expressed as a percentage of the luminance of adapted white.

4 Requirements

4.1 General

Reference output medium metric RGB (ROMM RGB) is an extended gamut RGB colour image encoding for representing the colourimetry of output-referred image data in an output-referred image state on a reference medium. The output-referred image data has the intended colour appearance when viewed in a reference viewing environment. The image colourimetry is encoded in terms of an additive RGB colour space associated with a hypothetical additive colour device having a specified set of primaries, no cross-talk between the colour channels and a luminance dynamic range defined by an associated medium black point and medium white point.

Three different precision levels are defined, and shall be identified as ROMM8 RGB, ROMM12 RGB and ROMM16 RGB, for 8-, 12- and 16-bits/channel (24-, 36- and 48-bits/pixel) representations, respectively.

The image colourimetry shall be based on flareless (or instrument flare corrected) colourimetric measurements. All chromaticity and tristimulus values specified in this document shall be based on the CIE 1931 two-degree Standard Observer defined in ISO 11664.

Flareless colourimetric measurements should be considered equivalent to those obtained from real reflection media measured using the 0/45 geometry specified in ISO 13655 (without polarizing means). Therefore, colourimetric quantities referred to in this part of ISO 22028 should be considered to include a level of flare typical of such measurements.

The colour image encoding defined in this International Standard conforms to the requirements defined in ISO 22028-1:2004, Clause 5.

4.2 Reference viewing environment

The reference viewing environment shall be such that the adapted white has the chromaticity values of CIE Illuminant D_{50} (x_0 = 0,345 7, y_0 = 0,358 5).

The absolute luminance level of the adapted white in the reference viewing environment shall be 160 cd/m^2.

NOTE 1 This absolute luminance level is equivalent to that of a perfect white Lambertian reflector illuminated with 500 lx as specified in ISO 3664 for the practical appraisal of prints.

NOTE 2 The luminance of the adapting field can be assumed to be 20 % of the luminance of the adapted white.

The reference viewing environment shall be characterized by an “average” surround. This means that the area immediately surrounding the image border shall be assumed to be a uniform grey having the chromaticity values of CIE Illuminant D_{50} (x_0 = 0,345 7, y_0 = 0,358 5) and a luminance factor of 0,2 relative to the adapted white.

The reference viewing environment shall be assumed to have a level of viewing flare that is 0,75 % of the adapted white with the chromaticity values of CIE Illuminant D_{50} (x_0 = 0,345 7, y_0 = 0,358 5).

NOTE 3 If the actual output viewing environment differs significantly from that specified here, appropriate transformations might be necessary to determine the corresponding colourimetry that would produce the intended colour appearance in the reference viewing environment. However, for actual viewing environments similar to the reference viewing environment, it might not be necessary to make such adjustments. The reference viewing environment was selected to make such adjustments unnecessary for many practical applications.

4.3 Reference medium

4.3.1 Reference medium white point

ROMM RGB shall be an encoding of the colours of an image on a reference medium having a reference medium white point with the chromaticity values of CIE Illuminant D_{50} (x_0 = 0,345 7, y_0 = 0,358 5) and a luminance factor of F_W = 0,89 relative to the adapted white. Accordingly, the reference medium white point tristimulus values are $X_W = F_W X_0$ = 85,81, $Y_W = F_W Y_0$ = 89,00 and $Z_W = F_W Z_0$ = 73,42, where X_0 = 96,42, Y_0 = 100,00 and Z_0 = 82,49 are the tristimulus values of the adapted white.

NOTE 1 The luminance factor of 0,89 corresponds to a visual density of 0,050 6.

NOTE 2 The luminance factor of 0,89 corresponds to a reference medium white point luminance of 142 cd/m^2.

4.3.2 Reference medium black point

The reference medium shall have a reference medium black point with the chromaticity values of CIE Illuminant D_{50} (x_0 = 0,345 7, y_0 = 0,358 5) and a luminance factor of F_K = 0,003 091 1 relative to the adapted white. Accordingly, the reference medium black point tristimulus values are $X_K = F_K X_0$ = 0,298 0, $Y_K = F_K Y_0$ = 0,309 1 and $Z_K = F_K Z_0$ = 0,255 0.

NOTE 1 The luminance factor of 0,003 091 1 corresponds to a visual density of 2,509 9.

NOTE 2 The luminance factor of 0,003 091 1 corresponds to a reference medium black point luminance of 0,495 cd/m^2.

4.3.3 Reference medium primaries

The *x*-*y* chromaticity values for the ROMM RGB primaries shall be as given in Table 1. Rationale for the choice of these primaries is given in Annex A.

The colour space white point, corresponding to equal amounts of the three RGB primaries, shall have the *x*-*y* chromaticity values of CIE Illuminant D_{50} given as given in Table 1.

Table 1 — CIE chromaticities for reference medium primaries and white point

Reference medium primaries and white point	CIE chromaticities			
	x	*y*	*u'*[a]	*v'*[a]
Red	0,734 7	0,265 3	0,623 4	0,506 5
Green	0,159 6	0,840 4	0,050 0	0,592 5
Blue	0,036 6	0,000 1	0,050 0	0,000 3
White point	0,345 7	0,358 5	0,209 2	0,488 1

[a] The *u'*-*v'* chromaticity values for the RGB primaries and colour space white point given in this table can be derived from the *x*-*y* chromaticity values and are provided for information purposes.

4.3.4 Reference medium rendering intent

ROMM RGB is an encoding of the intended colour appearance of an output-referred image rendered to the reference output medium dynamic range and viewing environment. Images encoded in ROMM RGB may contain colours that are outside the colour gamut for an actual output medium. Therefore, in order to display an image encoded in ROMM RGB on an actual output medium, the colour values need to be mapped to those that can be produced on that medium. All such mappings should be designed to retain the encoded colour appearance as closely as possible. If the actual viewing environment is significantly different from the reference viewing environment, the colour mapping from ROMM RGB to the actual output medium should include appropriate colour appearance transformations to determine the corresponding colourimetry that will maintain the colour appearance of the ROMM RGB colour values in the reference viewing environment.

Image colourimetry encoded as ROMM RGB shall not contain colours outside the spectrum locus. Figure 1 shows that the ROMM RGB encoding gamut extends outside the spectral locus between 465 and 485, and between 530 and 570 nm. As both the spectrum locus and the ROMM RGB encoding boundary are constant in chromaticity, only the chromaticity needs to be considered when determining whether a particular ROMM RGB triplet is allowed.

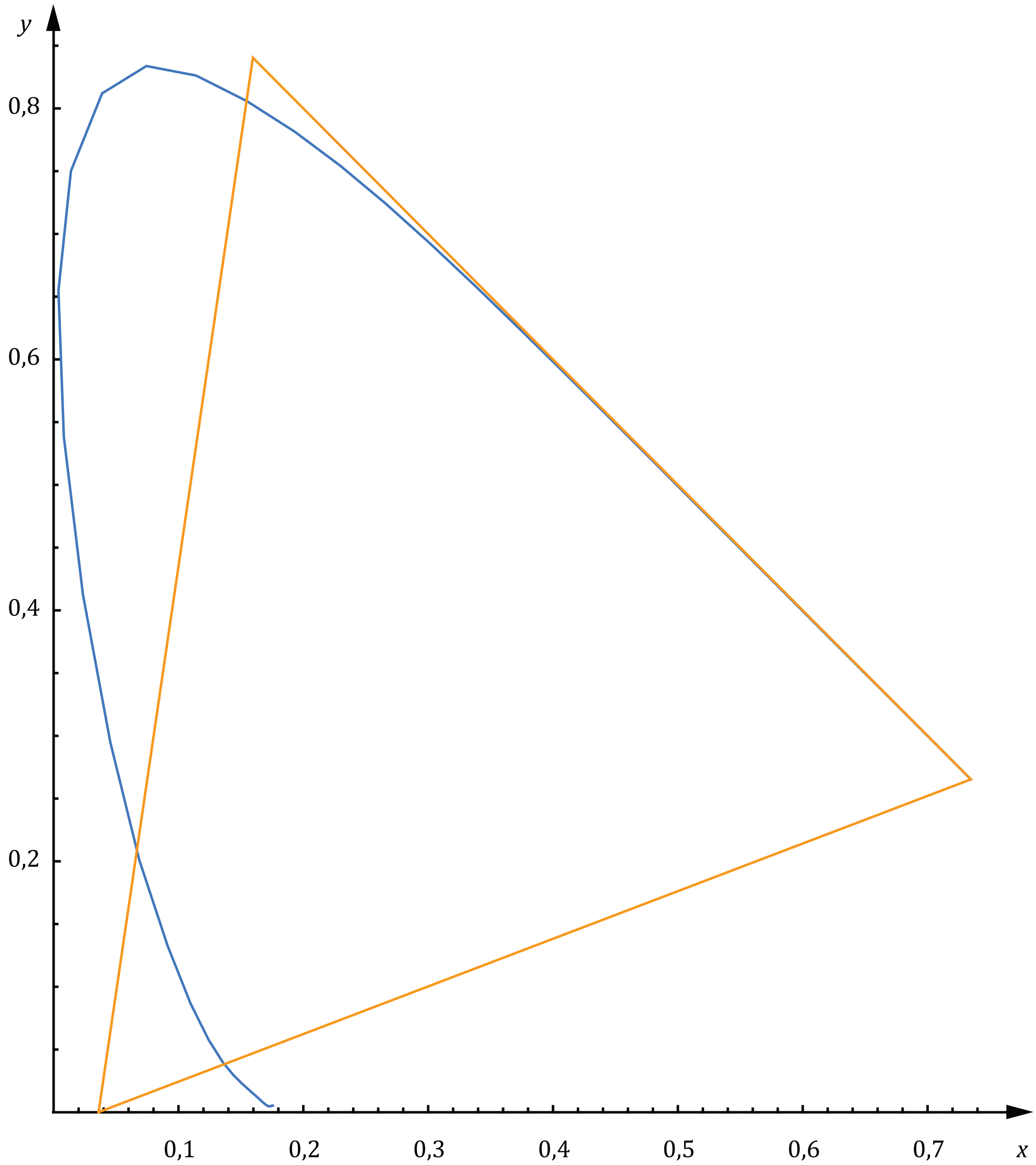


Figure 1 — *x,y* chromaticity plot of the spectrum locus and the ROMM RGB encoding gamut

Consideration should be given to the gamut limitations of real media in the process of performing colour rendering to produce image colourimetry for encoding as ROMM RGB. For example, if the encoded image colourimetry contains many colours which are far outside of the colour gamut for most real output media, the colour mapping from ROMM RGB to an actual output media will be forced to significantly distort these colours, which can lead to inconsistent results. The perceptual reference medium gamut specified in ISO 15076-1 provides a reasonable target colour gamut for colour rendering to produce image colourimetry for encoding as ROMM RGB. Figure 2 provides a view of the ROMM RGB encoding gamut and the ISO 15076-1 perceptual reference medium gamut.

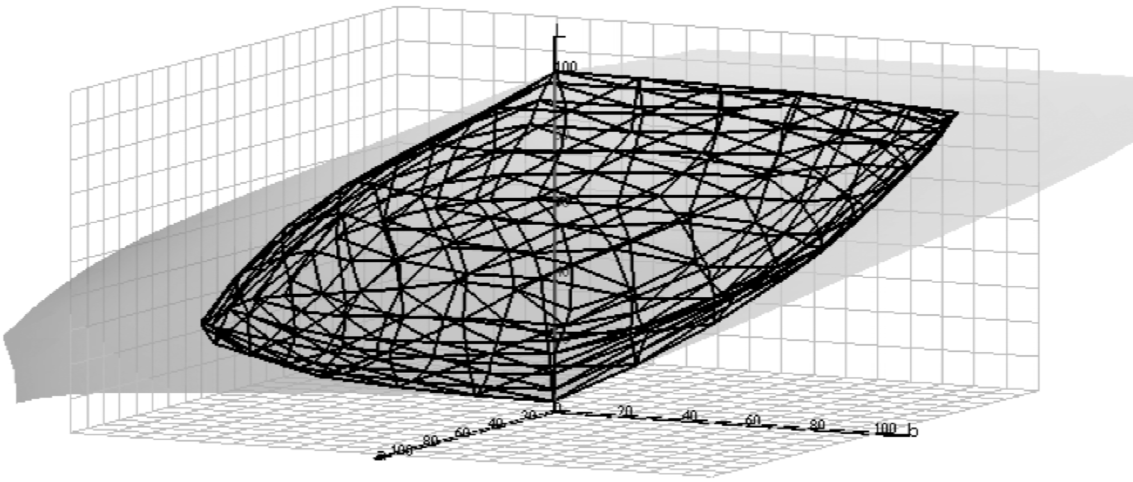


Figure 2 — Media-relative CIELAB plot of the ISO 15076-1 perceptual reference medium gamut (black wireframe) and the ROMM RGB encoding gamut (transparent gray)

NOTE In some cases, the colour appearance encoded in ROMM RGB might not be ideally suited for display on a particular real output media in a particular viewing environment. For example, the visual appearance of a high-quality transparency, brightly illuminated with a dark surround, will typically be different from that of a high-quality reflection print of the same scene viewed using a moderate illumination level. Therefore, in some applications, it can be desirable to alter the colour appearance description provided by the ROMM RGB encoding accordingly to produce the optimal image for the intended output media and viewing environment.

4.4 ROMM RGB colour image encoding

4.4.1 Encoding principles

ROMM RGB colour image encoding values shall be determined from tristimulus values of an image on the reference medium using a matrix transformation (see 4.4.3) followed by a colour component transfer function (see 4.4.4) and a digital encoding for one of three different bit-depths (see 4.4.5). The image tristimulus values shall be those that produce the intended colour appearance when viewed in the reference viewing environment.

NOTE Images intended to be viewed in other viewing environments, or on a medium different from the reference medium, can be encoded in ROMM RGB by first determining the corresponding tristimulus values that are expected to produce the intended colour appearance on the reference medium when viewed in the reference viewing environment. The corresponding tristimulus values can be determined by using an appropriate colour appearance transformation to account for the differences between the viewing conditions. Additionally, it might be necessary to account for differences in the media characteristics.

4.4.2 Tristimulus value normalization

The image tristimulus values shall be normalized such that the normalized Y tristimulus value of the reference medium white point is 1,0 and the normalized Y tristimulus value of the reference medium black point is 0,0.

$$X_N = \frac{(X - X_K)}{(X_W - X_K)} \frac{X_W}{Y_W}$$
$$Y_N = \frac{(Y - Y_K)}{(Y_W - Y_K)}$$
$$Z_N = \frac{(Z - Z_K)}{(Z_W - Z_K)} \frac{Z_W}{Y_W} \tag{1}$$

where X, Y and Z are the image tristimulus values; X_N, Y_N and Z_N are the normalized image tristimulus values; X_W, Y_W and Z_W are the tristimulus value of the reference medium white point given in 4.3.1; and X_K, Y_K and Z_K are the tristimulus value of the reference medium black point given in 4.3.2.

NOTE This normalization implies that the colour space white point luminance will be 142 cd/m^2, which is equal to the luminance level of the adapted white in the reference viewing environment (160 cd/m^2) scaled by the reference medium white point luminance factor (F_w = 0,89).

4.4.3 ROMM RGB conversion matrix

The following matrix shall be used to compute linear ROMM RGB continuous colour space values (R_{ROMM}, G_{ROMM} and B_{ROMM}) from the normalized image tristimulus values (X_N, Y_N and Z_N):

$$\begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix} = \begin{bmatrix} 1{,}3460 & -0{,}2556 & -0{,}051\,1 \\ -0{,}5446 & 1{,}5082 & 0{,}0205 \\ 0{,}0000 & 0{,}0000 & 1{,}2123 \end{bmatrix} \begin{bmatrix} X_N \\ Y_N \\ Z_N \end{bmatrix} \tag{2}$$

This matrix can be derived from the chromaticities given in Table 1, which should be considered to be the normative defining quantities.

NOTE This matrix will map normalized image tristimulus values with the chromaticity of D_{50} to equal linear ROMM RGB continuous colour space values. A neutral with a Y_N value of 1,0 will map to linear ROMM RGB colour space values of 1,0. A neutral with a Y_N value of 0,0 will map to linear ROMM RGB continuous colour space values of 0,0.

4.4.4 ROMM RGB colour component transfer function

The functional form of the ROMM RGB colour component transfer function shall be:

$$C'_{ROMM} = \begin{cases} 0{,}0 & \text{if } C_{ROMM} < 0{,}0 \\ 16 C_{ROMM} & \text{if } 0{,}0 \le C_{ROMM} < E_t \\ (C_{ROMM})^{1/1{,}8} & \text{if } E_t \le C_{ROMM} \le 1{,}0 \\ 1{,}0 & \text{if } C_{ROMM} > 1{,}0 \end{cases} \tag{3}$$

where C is either R, G, or B; C_{ROMM} and C'_{ROMM} are the radiometrically linear and nonlinear ROMM RGB continuous colour space values, respectively; and

$$E_t = 16^{1{,}8/(1-1{,}8)} \approx 0{,}001\,953 \tag{4}$$

NOTE The linear segment of the nonlinearity is used to impose a slope limit so as to minimize reversibility problems because of the infinite slope of the gamma function at the zero point.

4.4.5 ROMM RGB digital encoding function

The digital encoding function for the ROMM RGB colour space encoding is given by:

$$C''_{\mathrm{ROMM}} = Round\left(C'_{\mathrm{ROMM}} \times I_{\max}\right) \tag{5}$$

where C is either R, G, or B; C'_{ROMM} is the nonlinear ROMM RGB continuous colour space value; C''_{ROMM} is the digital ROMM RGB colour space encoding; $I_{\max}$ is the maximum integer value used for the digital encoding; and the *Round*( ) function returns the nearest integer value.

For ROMM8 RGB, $I_{\max}$ shall be 255.

For ROMM12 RGB, $I_{\max}$ shall be 4095.

For ROMM16 RGB, $I_{\max}$ shall be 65535.

NOTE 1 The digital encoding function maps a nonlinear colour space value range of 0,0 to 1,0 (corresponding to a linear colour space value range of 0,0 to 1,0) onto a digital code value range of 0 to $I_{\max}$.

NOTE 2 Table 2 shows sample neutral patch encodings for ROMM8 RGB, ROMM12 RGB and ROMM16 RGB.

Table 2 — Neutral patch encodings for ROMM8 RGB, ROMM12 RGB and ROMM16 RGB

Y	Y_N	**ROMM8 RGB**	**ROMM12 RGB**	**ROMM16 RGB**
0,309 11	0,000 00	0	0	0
0,40	0,001 02	4	67	1075
1,00	0,007 79	17	276	4417
10,0	0,109 27	75	1197	19156
20,0	0,222 02	111	1775	28402
35,0	0,391 14	151	2431	38904
50,0	0,560 27	185	2968	47500
75,0	0,842 15	232	3722	59569
89,0	1,000 00	255	4095	65535

NOTE 3 In some cases, it can be desirable to convert ROMM RGB images to a video RGB representation for purposes of image preview on a video display. A simple reference transformation between ROMM RGB and the sRGB colour encoding is given for information in Annex B. However, it can be preferable in some situations to utilize more sophisticated viewing environment and/or gamut-mapping transformations.

4.5 Inverse ROMM RGB transformation

4.5.1 General

The conversion of ROMM RGB colour space encoding values back to image tristimulus values is accomplished by inverting the digital encoding function given in Formula (5) and the colour component function given in Formula (3), and then applying the inverse of the matrix given in Formula (2), and the inverse of the normalization function given in Formula (1).

4.5.2 Inverse ROMM RGB digital encoding function

The inverse digital encoding function for the ROMM RGB colour space encoding is given by:

$$C'_{\mathrm{ROMM}} = \frac{C''_{\mathrm{ROMM}}}{I_{\mathrm{max}}} \tag{6}$$

where C is either R, G, or B; C'_{ROMM} is the nonlinear ROMM RGB continuous colour space value; C''_{ROMM} is the digital ROMM RGB colour space encoding; and I_{max} is the maximum integer value used for the digital encoding. The inverse digital encoding given in Formula (6) can be determined by inverting the digital encoding function specified in 4.4.5, which shall be considered to be the normative definition.

4.5.3 Inverse ROMM RGB colour component transfer function

Linear ROMM RGB continuous colour space values shall be calculated using Formula (7):

$$C_{\mathrm{ROMM}} = \begin{cases} \dfrac{C'_{\mathrm{ROMM}}}{16} & \text{if } 0{,}0 \le C'_{\mathrm{ROMM}} < 16E_{\mathrm{t}} \\ \left(C'_{\mathrm{ROMM}}\right)^{1{,}8} & \text{if } 16E_{\mathrm{t}} \le C'_{\mathrm{ROMM}} \le 1{,}0 \end{cases} \tag{7}$$

where C is either R, G or B; C_{ROMM} and C'_{ROMM} are the linear and nonlinear ROMM RGB continuous colour space values, respectively; and the definition of E_{t} is given in Formula (4). The inverse colour component transfer function given in Formula (7) can be determined by inverting the colour component transfer function specified in 4.4.4, which shall be considered to be the normative definition.

4.5.4 Inverse ROMM RGB conversion matrix

The conversion from linear ROMM RGB continuous colour space values (R_{ROMM}, G_{ROMM} and B_{ROMM}) to the corresponding normalized image tristimulus values (X_{N}, Y_{N} and Z_{N}) shall be given by:

$$\begin{bmatrix} X_{\mathrm{N}} \\ Y_{\mathrm{N}} \\ Z_{\mathrm{N}} \end{bmatrix} = \begin{bmatrix} 0{,}7977 & 0{,}1352 & 0{,}031\,3 \\ 0{,}2880 & 0{,}711\,9 & 0{,}0001 \\ 0{,}0000 & 0{,}0000 & 0{,}8249 \end{bmatrix} \begin{bmatrix} R_{\mathrm{ROMM}} \\ G_{\mathrm{ROMM}} \\ B_{\mathrm{ROMM}} \end{bmatrix} \tag{8}$$

This matrix can be derived from the chromaticities given in Table 1, which shall be considered to be the normative defining quantities.

NOTE When this matrix is applied to linear ROMM RGB continuous colour space values that are equal, normalized image tristimulus values with the chromaticity of D_{50} are obtained.

4.5.5 Inverse tristimulus value normalization

The conversion from normalized image tristimulus values to the corresponding image tristimulus values shall be given by:

$$X = X_N (X_W - X_K) \frac{Y_W}{X_W} + X_K$$
$$Y = Y_N (Y_W - Y_K) + Y_K$$
$$Z = Z_N (Z_W - Z_K) \frac{Y_W}{Z_W} + Z_K \qquad (9)$$

where X, Y and Z are the image tristimulus values; X_N, Y_N and Z_N are the normalized image tristimulus values; X_W, Y_W and Z_W are the tristimulus value of the reference medium white point given in 4.3.1; and X_K, Y_K and Z_K are the tristimulus value of the reference medium black point given in 4.3.2.

Annex A
(informative)

Selection of ROMM RGB colour encoding

The criteria that were used to select this colour encoding include the following:

— direct relationship to the colour appearance of the image;

— colour gamut large enough to encompass most real world surface colours;

— efficient encoding of the colour information to minimize quantization artefacts;

— simple transformation to/from ICC profile connection space;

— simple transformation to/from video RGB (e.g. sRGB);

— well-suited for application of common image manipulations such as tone scale modifications, colour-balance adjustments, sharpening, etc.;

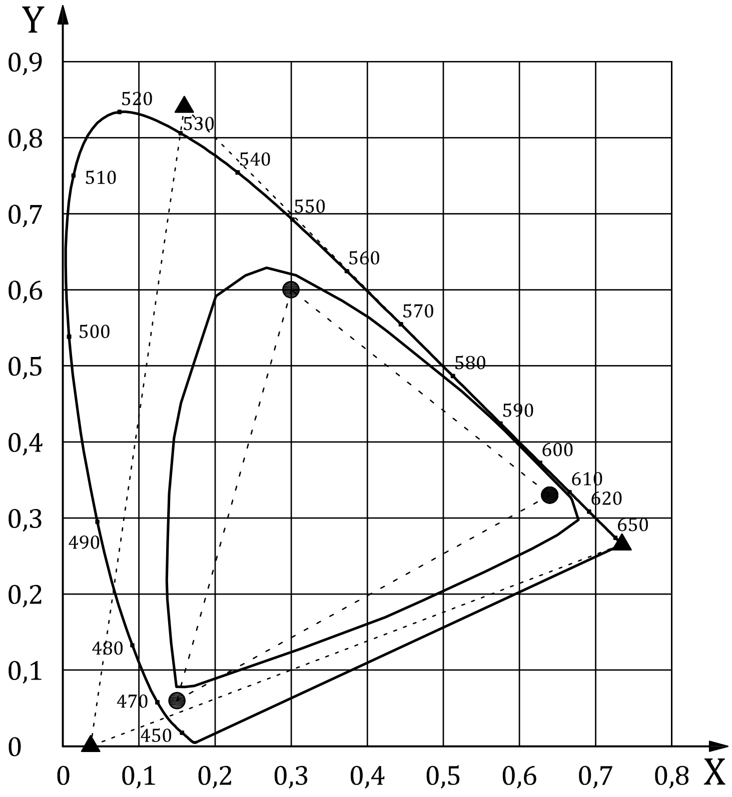
— compatible with established imaging workflows.

An additive RGB colour space with an appropriately selected set of "wide RGB" primaries is ideal for satisfying all of these criteria. When images are encoded using any such set of primaries, there is a direct and simple relationship to image colourimetery because the primaries are linear transformations of the CIE XYZ primaries. Wide RGB colour spaces have the additional advantage that simple LUT-matrix-LUT transformation can be used to convert to/from additive colour spaces such as PCS XYZ, video RGB (e.g. sRGB) and digital camera RGB.

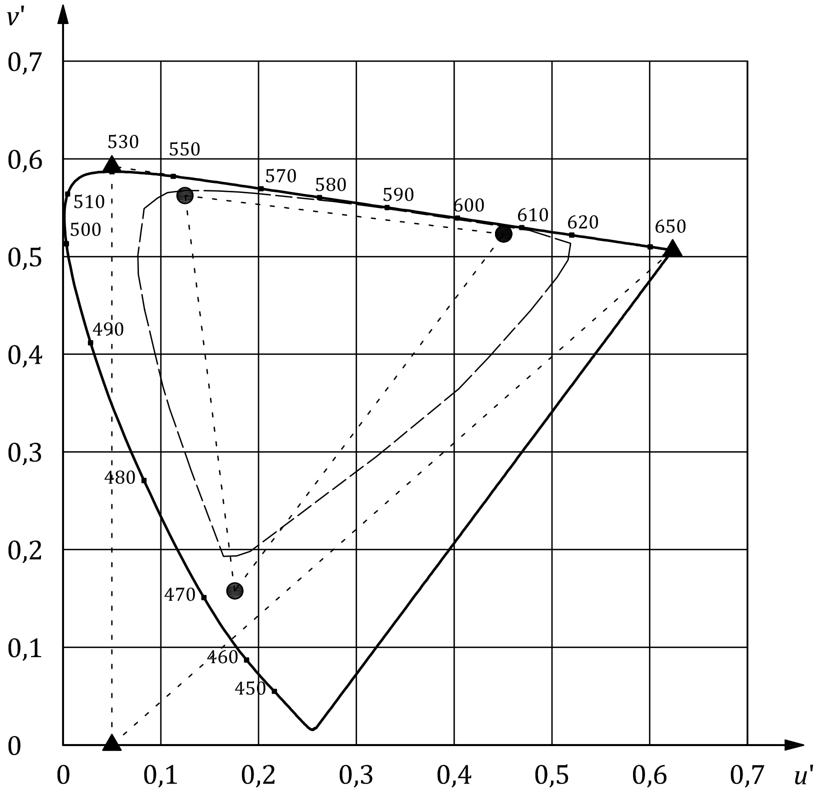
Two of the criteria that affect the selection of specific RGB primaries are somewhat conflicting. First, their chromaticities should define a colour gamut sufficiently large to encompass colours likely to be found in real scenes/images. At the same time, their use should result in efficient digital encodings that minimize quantization errors. Increasing the gamut can only be achieved by trading off against correspondingly larger quantization errors. If the primaries are chosen to include the maximum possible chromaticity gamut (i.e. the entire area within the spectrum locus), a significant fraction of the colour space would correspond to imaginary colours located outside that region. Therefore, in any encoding using such a colour space, there would be "wasted" code values that would never be used in practice. This would lead to larger quantization errors in the usable part of the colour space than would be obtained with different primaries defining a smaller chromaticity gamut. It is therefore desirable to choose primaries with a gamut that is "big enough" but not "too big."

Figure A.1 shows the primaries selected for ROMM RGB. These primaries encompass the gamut of real world surface colours, without devoting a lot of space to non-realizable colours outside the spectrum locus. Also shown for comparison are the sRGB primaries. It can be seen that the sRGB colour gamut is inadequate to cover significant portions of the real world surface colour gamut. In particular, it misses many important saturated colours near the yellow-to-red boundary of the spectrum locus.

One of the important requirements for ROMM RGB encoding is that it be well suited for the application of common image manipulations. Many types of common image manipulations include the step of applying nonlinear transformations to each of the channels of an RGB image (e.g. tone scale modifications, colour balance adjustments, etc.). The process of applying such nonlinear transformations will, in general, modify the relative ratios of the red, green and blue channel data. This can lead to hue shifts, particularly for highly saturated colours. Hue shifts are particularly problematic when they occur in a natural saturation gradient within an image. Such gradients tend to occur when rounded surfaces are illuminated by a moderately directional light source. In such situations, chroma increases with distance from the specular highlight and then decreases again as the shadows deepen.



a) *x-y* **chromaticity coordinates**



b) ***u′-v′*** **chromaticity coordinates**

Key

▲

ROMM RGB

●

sRGB

———

surface colours

Figure A.1 — Hue shifts for the ROMM RGB primaries resulting from a typical nonlinear tone scale

There is a trade-off between the colour gamut of the primaries, quantization artefacts, and the extent of the hue shifts that occur during rendering. If the primaries are moved out so as to increase the colour gamut, quantization artefacts will increase and the hue shifts introduced during the application of a nonlinear transformation will decrease. This results from the fact that the RGB colour space values will be clustered over a smaller range, thereby reducing the impact of nonlinear transformations. If the colour gamut is decreased by moving the primaries closer together, quantization artefacts diminish but hue shifts are generally larger and colour gamut is sacrificed.

Such hue shifts can never be completely eliminated, so the objective when optimizing the location of the primaries was to eliminate or minimize objectionable hue shifts at the expense of less noticeable or less likely hue shifts. Hue shifts for a particular colour can be eliminated when the colour lies on one of the straight lines passing through the primaries and the white point on a chromaticity diagram. During the selection of the ROMM RGB primaries, an optimization process was used to determine a set of primaries having acceptable hue shift characteristics.

Hue shifts introduced by the application of nonlinear transformations were examined during the process of selecting the ROMM RGB primaries by studying a chroma series for eight colour patches from the Macbeth Colour Checker™. These patches included red, yellow, green, cyan, blue, magenta, light flesh and dark flesh. Hue shifts in flesh tones and yellows, particularly in the direction of green, were considered to be the most objectionable. Examples of hue shifts associated with the selected ROMM RGB primaries are shown in Figure A.2. This plot shows a series of line segments connecting the *a**, *b** values before and after a typical nonlinear tone scale was applied to a chroma series in each of the eight colour directions. It can be seen that small hue shifts are introduced for the most saturated colours in the blue and cyan directions, but that the hue shifts elsewhere are quite small. An analogous set of hue shifts associated with a different set of extended gamut RGB primaries are shown in Figure A.3. It can be seen that the hue shifts for these primaries are significantly larger than those of the ROMM RGB primaries in almost every colour region. It should be noted that the exact hue shifts that are obtained for a particular set of colour primaries will be a function of the input colours and the nonlinearity, as well as the colour space where the hue shifts are calculated. While the ROMM RGB primaries were optimized with respect to a particular set of these variables, further analysis has shown that they perform quite well across a range of values.[2]

NOTE A number of criteria for characterizing and comparing extended-gamut colour image encodings have been developed by CIE TC8–05. These criteria have been documented in a report entitled "Criteria for the Evaluation of Extended-Gamut Color Encodings". Included in this report are example calculations applying the various metrics to ROMM RGB, as well as a number of other extended-gamut colour image encodings.

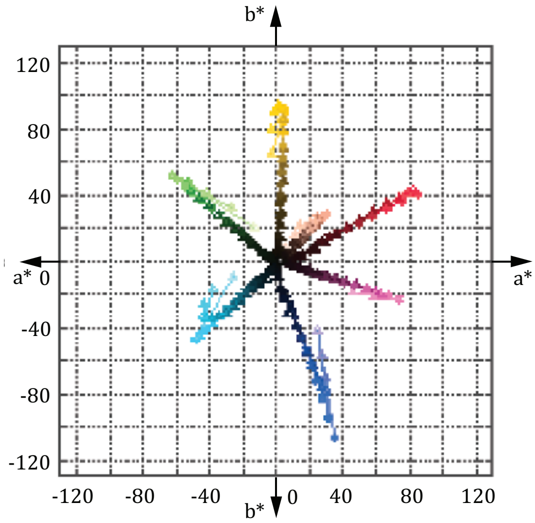


Figure A.2 — Hue shifts for the ROMM RGB primaries resulting from a typical nonlinear tone scale

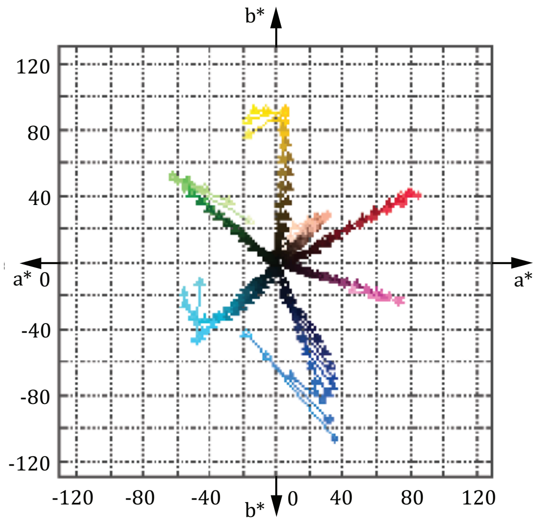


Figure A.3 — Hue shifts for an alternate set of extended gamut RGB primaries resulting from a typical nonlinear tone scale

Annex B
(informative)

Conversion between ROMM RGB and video RGB

In many cases, it will be desirable to convert ROMM RGB colour values to a video RGB representation for display on a monitor. This can be accomplished by combining the ROMM RGB to tristimulus value transformation described in 4.5 with an appropriate tristimulus value to video RGB transformation for the monitor. An example is a monitor that responds according to the sRGB specification. See IEC 61966-2-1:1999. Because the normalized tristimulus values associated with ROMM RGB are defined using a D_{50} white point, while sRGB is defined using a D_{65} white point, the first step in the conversion of the normalized tristimulus values to sRGB colour space encoding values needs to be a D_{50}-to-D_{65} chromatic adaptation. This can be accomplished using a von Kries chromatic adaptation transformation with the Hunt-Pointer-Estevez cone primaries as follows.

$$\begin{bmatrix} X_{D_{65}} \\ Y_{D_{65}} \\ Z_{D_{65}} \end{bmatrix} = \begin{bmatrix} 0{,}9845 & -0{,}0547 & 0{,}0678 \\ -0{,}0060 & 1{,}0048 & 0{,}001\,2 \\ 0{,}0000 & 0{,}0000 & 1{,}3200 \end{bmatrix} \begin{bmatrix} X_{D_{50}} \\ Y_{D_{50}} \\ Z_{D_{50}} \end{bmatrix} \tag{B.1}$$

Alternatively, other chromatic adaptation transforms could be used such as a Bradford chromatic adaptation transformation.

Since the white/black point luminance values and viewing environments for ROMM RGB and sRGB are specified to be somewhat different, it can be desirable in some cases to re-render the image accordingly to determine appropriate image colourimetry for the sRGB image. However, for most applications it can be acceptable simply to apply a chromatic adaptation transformation to the normalized tristimulus values as shown in Formula (B.1).

The sRGB colour space is defined using the phosphor primaries associated with ITU-R BT.709 “Basic parameter values for the HDTV standard for the studio and for international programme exchange” (formerly CCIR Recommendation 709). The conversion from normalized D_{65} tristimulus values to radiometrically linear RGB colour space values associated with these primaries is given by the following inverse phosphor matrix:

$$\begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} = \begin{bmatrix} 3{,}2406 & -1{,}5372 & -0{,}4986 \\ -0{,}9689 & 1{,}8758 & 0{,}0415 \\ 0{,}0557 & -0{,}2040 & 1{,}0570 \end{bmatrix} \begin{bmatrix} X_{D_{65}} \\ Y_{D_{65}} \\ Z_{D_{65}} \end{bmatrix} \tag{B.2}$$

Finally, the desired sRGB code values can be computed by applying the appropriate colour component transfer function,

$$C'_S = \begin{cases} 12{,}92\ C_S & \text{if } C_S \le 0{,}0031308 \\ 1{,}055\ C_S^{1/2{,}4} - 0{,}055 & \text{if } C_S > 0{,}0031308 \end{cases} \tag{B.3}$$

followed by a digital encoding function,

$$C''_S = Round(255 \times C'_S), \tag{B.4}$$

where C is either R, G, or B.

Conversion from ROMM RGB colour space encoding values to corresponding sRGB colour space values can therefore be accomplished by applying the inverse ROMM RGB nonlinearity given in Formula (7), followed by the matrices given in Formulae (8), (B.1) and (B.2), followed by the sRGB colour component transfer function given in Formula (B.3), and the digital encoding function given in Formula (B.4). The three sequential matrix operations can be combined by cascading the matrices together to form the following single matrix:

$$\begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} = \begin{bmatrix} 2{,}0564 & -0{,}7932 & -0{,}2632 \\ -0{,}2118 & 1{,}2490 & -0{,}0372 \\ -0{,}0152 & -0{,}1405 & 1{,}1556 \end{bmatrix} \begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix} \tag{B.5}$$

Thus, the transformation from ROMM RGB to sRGB can be implemented with a simple LUT-MAT-LUT chain.

Not all colours that can be encoded in ROMM RGB will be within the sRGB colour gamut. As a result, it can be necessary to perform some sort of gamut mapping to limit all of the colours to the appropriate gamut. The simplest form of gamut mapping is just to clip all of the linear sRGB colour space values to the range 0,0 to 1,0 before applying the colour component transfer function of Formula (B.3). However, this approach can result in noticeable hue shifts in certain cases. Superior results can be obtained using more sophisticated gamut-mapping strategies.

The conversion from sRGB back to ROMM RGB is simply an inverse of the steps that were just discussed. First, the inverse of the digital encoding function given in Formula (B.4) is applied to determine nonlinear RGB colour space values:

$$C'_S = C''_S / 255 \tag{B.6}$$

Next, the inverse of the sRGB colour component transfer function given in Formula (B.3) is applied to determine the linear RGB colour space values:

$$C_S = \begin{cases} \dfrac{C'_S}{12,92} & \text{if } C'_S \le 0,04045 \\ \left(\dfrac{C'_S + 0,055}{1,055}\right)^{2,4} & \text{if } C'_S > 0,04045 \end{cases} \tag{B.7}$$

Next, the inverse of the matrix in Formula (B.5) is used to compute the linear ROMM RGB colour space values,

$$\begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix} = \begin{bmatrix} 0,5230 & 0,3468 & 0,1303 \\ 0,0892 & 0,8627 & 0,0481 \\ 0,0177 & 0,1095 & 0,8729 \end{bmatrix} \begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} \tag{B.8}$$

Finally, the ROMM RGB colour component transfer function given in Formula (3) is applied to determine the nonlinear ROMM RGB colour space values, and the digital encoding function given in Formula (5) is applied to determine the corresponding integer values.

As noted above, many colours that can be represented in ROMM RGB colour encoding are outside the gamut of sRGB. As a result, the process of mapping an image from ROMM RGB to sRGB and back again will generally result in a loss of image information. Therefore, it is generally undesirable to use a video RGB colour space as an intermediate colour space during the process of manipulating a ROMM RGB image. It is better to apply the image manipulations directly to the ROMM RGB image, with the ROMM RGB to video RGB transformation used to provide an image for video preview purposes only.

On the other hand, if an original image is in a video RGB colour space, it will often be possible to convert the image to ROMM RGB for manipulation purposes, and then convert it back to the video RGB colour space again with only minimal losses due to quantization effects. These quantization effects can generally be reduced to negligible levels by using the 12- or 16-bit versions of ROMM RGB. However, if the manipulation process creates any colour values that are outside the video RGB gamut, these values will be clipped when the processed image is converted back to the original colour space.

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