TC42/WG18 98 - ______
TC130/WG3 98 - ______

ISO/TC42	**Photography**
WG18	**Electronic Still Picture Imaging**
ISO/TC130	**Graphic Technology**
WG3	**Prepress Digital Data Exchange**

WD 2 of ISO 17321

Graphic Technology and Photography -

Colour target and procedures for the colour characterisation of digital still cameras (DSCs).

14 September 1998

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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

International Standard ISO 17321 was prepared by a joint working group composed of representatives of Technical Committees ISO/TC42, Photography, and ISO/TC130, Graphic Technology.

Annexes B through E of this International Standard are for information only.

FOREWORD TO WD 2

This WD has been prepared from WD 1.1 by the project leader, Jack Holm, based on comments from ISO TC42, PIMA/ANSI IT10, IEC/TC100 PT 61966, and several experts in the ISO TC42/TC130 JWG. Interested parties are encouraged to participate in this work. If you would like to participate, please contact Mr. Holm at:

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WD 1.1 is available on the PIMA/ANSI IT10 web site:

www.pima.net/it10a.htm

WD 2, a summary of the comments received and their disposition, and a list of the experts currently participating in the development of this standard are available on the ISO TC42 web site:

www.pima.net/standards/iso/tc42/WG18.htm

0 Introduction

The spectral responses of the colour analysis channels of digital still cameras (DSCs) do not, in general, match those of a typical human observer, such as defined by the CIE standard colorimetric observer. Neither do the responses of different DSCs necessarily match each other. In characterising DSCs, it is therefore necessary to take account of the DSC spectral sensitivities, illumination, and reference colour space. This International Standard will address these considerations by defining a colour targets, metrology, and procedures for various situations. It will address the problem of such cameras under the most general picture taking conditions; where metameric colours and a range of illumination sources may be encountered. However, it will recommend procedures for more closely defined situations in which the illumination source and colorants being imaged are better known.

The DSC characterisations obtained using this International Standard are expressed as transformations. These transformations, when applied to raw DSC data, produce estimates of scene (or original) colorimetry. The most common transformation form is a set of tone reproduction curves (TRCs) for each DSC analysis channel, followed by a matrix, followed by a single TRC applied to each of the three channels produced by the matrix. The purpose of the first set of TRCs is to linearize the DSC data with respect to scene radiance, and normalize the data with respect to the adopted white point. These TRCs may vary from scene to scene because of DSC flare, even if the adopted white point remains constant. The matrix transforms the data from the linear DSC spectral space to estimates of scene colorimetry expressed in the linear original RGB colour space, which is also defined in this International Standard. Different matrices based on different scene spectral correlation assumptions, and obtained using each of the three methods described may be used with the same DSC. The final TRC converts the linear original RGB data to ISO original RGB data, which is a more perceptually uniform representation for encoding. This TRC is based on the EOCF of an IEC standard sRGB display without veiling glare, so that any scene dynamic range can be represented. In addition to being relatively uniform perceptually, data encoded in this manner has the advantage that if it is displayed on an ideal sRGB display, the colorimetry of the display when viewed in a dark room (with no veiling glare) will match the estimated colorimetry of the scene or original viewed under the capture illuminant, with the adopted white point transformed to that of the display (D_{65}) in the manner specified in this International Standard.

This International Standard also defines a DSC metamerism index for determining how accurately a DSC is able to analyse the colors in a scene.

This International Standard is written for use with any DSC intended for photographic or graphic arts applications. However, it may not be practical for any user to apply this International Standard to any DSC. A significant level of expertise in the field of digital colour reproduction is required, as is access to raw or unrendered DSC data. Many DSCs do not output raw or unrendered data. With such cameras, this International Standard can only be applied by manufacturers and testing laboratories with the capability of extracting the raw or unrendered data. Additionally, some of the measurement methods described in this International Standard require sophisticated and expensive measurement equipment. This International Standard is therefore intended primarily for use by manufacturers, testing laboratories, and professional users in cases where the DSC does output raw or unrendered data.

The technical experts who developed this International Standard recognize that a standard that could be applied generally to DSC output would be desirable. However, such a standard would not be meaningful in characterising the scene or original analysis capabilities of many DSCs because it would frequently be impossible to determine if colorimetric differences between the DSC data and the scene or original captured were due to analysis errors or proprietary rendering algorithms. The only way to make this distinction is if the rendering used is well documented and available, and the rendered data can be converted to unrendered data by inverting the rendering. This situation is unlikely to occur because one of the major differentiators in DSC performance is the rendering. Sophisticated rendering algorithms can be image dependent, and locally varying within an image. This makes it extremely difficult to reliably determine the exact rendering used by analysing captured test scenes.

Graphic arts and photography - Colour target and procedures for the colour characterisation of digital still cameras (DSCs)

1 Scope

This International Standard shall specify a colour target, metrology, and procedures for the colour characterisation of digital still cameras to be used for photography and graphic technology. Such characterisation shall be limited to DSC data that either has not been processed for colour, or has been processed to estimate scene or original colorimetry (as opposed to the colorimetry of a reproduction).

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

2.1 ISO 5/1 - 1984, *Photography - Density Measurements - Part 1: Terms, symbols, and notations.*

2.2 ISO 5/2 - 1991, *Photography - Density Measurements - Part 2: Geometric conditions for transmission density.*

2.3 ISO 5/4 - 1984, *Photography - Density Measurements - Part 4: Geometric conditions for reflection density.*

2.4 ISO 554 - 1976, *Standard atmospheres for conditioning and/or testing - Specifications.*

2.5 ISO 7589 - 1984, *Photography - Illuminants for sensitometry - Specifications for daylight and incandescent tungsten.*

2.6 ISO 12232 - 1998, *Photography - Electronic still-picture cameras - Determination of ISO speed.*

2.7 ISO 12641 - 1997, *Graphic technology - Prepress digital data exchange - Colour targets for input scanner calibration.*

2.8 ISO 14524 - 199X, *Photography - Electronic still picture cameras - Methods for measuring opto-electronic conversion functions (OECFs).*

2.9 CIE Publication No. 15.2 - 1986 *Colorimetry, 2nd edition.*

2.10 CIE Publication No. 17.4 - 1987 *International Lighting Vocabulary.*

2.11 IEC 61966-2-1 - XXXX *Colour measurement and management in multimedia systems and equipment - Part 2-1: Default RGB colour space - sRGB.*
Note: this reference is under development in IEC/TC100 and is currently at the CDV stage (equivalent to the DIS stage in the ISO).

2.12 ITU-R BT.709 - 1993 *Basic parameter values for the HDTV standard for the studio and for international programme exchange.*

3 Definitions

For the purpose of this International Standard, the following definitions apply.

3.1 appearance model: mathematical model which uses information about viewing conditions to estimate the subjective appearance of a coloured patch from colorimetric measurements of the patch. Since an appearance model only describes the scene or original, it does not consider the characteristics of any possible reproduction medium. (see preferred reproduction model, rendering, reproduction model)

3.2 colour matching functions: tristimulus values of monochromatic stimuli of equal radiant power [from CIE Publication 17.4, definition 845-03-23]. Here this term is additionally restricted to be linear combinations of the CIE $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ tristimulus functions described in CIE Publication 15.2 (see tristimulus values, spectral basis function).

3.3 colour space: geometric representation of colours in space, usually of three dimensions [from CIE Publication 17.4, definition 845-03-25]. Here this term is additionally restricted to be the three dimensional space whose basis functions are colour matching functions. (see colour matching functions, spectral space)

3.4 digital still camera: camera incorporating an image sensor which outputs a digital signal representing a still picture, or records a digital signal representing a still picture on a removable media, such as a memory card or magnetic disk.

3.5 dynamic range: term used to encompass the luminance and colour gamut range of a scene, original, or output medium.

3.6 effective visual density: base ten logarithm of the ratio of the luminance of the adopted white of a scene or original to the luminance of a measured area of the scene or original.

3.7 electro-optical conversion function (EOCF): relationship between the digital code values provided to an output device and the equivalent neutral densities produced by the device.

3.8 equivalent neutral density (END): measure of the amount of an analysis primary or rendering colorant in an imaging system with respect to some reference white luminance. The END is equal to the visual density or effective visual density of the analysed primary or colorant, when it is combined with the amounts of the other system primaries or colorants required to produce a visual neutral.

3.9 equivalent neutral luminance factor (ENLF): measure of the amount of an analysis primary or rendering colorant in an imaging system with respect to some reference white luminance. The ENLF is equal to the luminance factor of the analysed primary or colorant, when it is combined with the amounts of the other system primaries or colorants required to produce a visual neutral.

3.10 ISO original RGB colour space: colour space whose coordinates are tristimulus values determined using the ISO original RGB colour matching functions.

3.11 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 [from CIE Publication 17.4, definition 845-04-69]. Here this term is additionally restricted to be the ratio of the luminance of the adopted white of a scene or original to the luminance of a measured area of the scene or original.

3.12 preferred reproduction model: mathematical model that produces transformations which are applied to image data describing a scene or original to produce image data describing a pleasing reproduction. Preferred reproduction models are different from reproduction models in that the pleasing reproduction need not be an attempt to reproduce the appearance of the original. In fact, what is considered pleasing may depend on viewer preferences. The transformations produced by a preferred reproduction model are generally dependent on the characteristics of the scene or original and the output medium. (see appearance model, rendering, reproduction model)

3.13 rendering: transforming image data representing the colorimetry of a scene or original to image data representing the colorimetry of a reproduction. (see appearance model, reproduction model, preferred reproduction model)

3.14 reproduction model: mathematical model that produces transformations which are applied to image data describing a scene or original to produce image data describing a reproduction which is as close as possible to being an appearance match to the original. Transformations produced by reproduction models will generally depend on the dynamic range of the scene or original and the output medium. (see appearance model, preferred reproduction model, rendering)

3.15 spectral basis function: spectral radiance or response as a function of wavelength. (see colour matching functions)

3.16 spectral space: space spanned by a set of spectral basis functions. The set of colour spaces is a subset of the set of spectral spaces. (see colour space)

3.17 tristimulus values: amounts of the three reference colour stimuli, in a given trichromatic system, required to match the colour of the stimulus considered [from CIE Publication 17.4, definition 845-03-22]. (see colour matching functions)

3.18 visual neutral: image area with the same chromaticity as the adopted white. When stating that an image area is visually neutral, it is necessary to designate the adopted white. For reflection hardcopy images, the adopted white is typically considered to be either the media white or a perfectly diffuse reflecting surface illuminated by the illumination source.

4 ISO original RGB colour space specification

4.1 Colour matching functions ISO original RGB data represents an attempt to describe the colorimetry of a scene or original in terms of the ISO original RGB colour matching functions (see figure 1 and table 1). As such, it maintains the relative dynamic range and gamut of the scene or original. Because the data produced by a DSC is in a spectral space defined by its spectral sensitivities, it is generally not possible to exactly transform DSC data into the ISO original RGB colour space. The goal in determining transformations is to produce data representative of the best estimate of the colorimetry of the scene or original, expressed in terms of the ISO original RGB colour space. Different scene or original spectral radiance correlation statistics can result in different optimal transformations of the sensor data into ISO original RGB. The ISO original RGB colour matching functions are normalized so the sum of each set of tabular values is unity.

Table 1 - ISO original RGB colour matching functions.

Wavelength (nm.)	Red Colour Matching Fcn.	Green Colour Matching Fcn.	Blue Colour Matching Fcn.
360	0,00000607	-0,00000793	0,00006591
370	0,00001889	-0,00002530	0,00021159
380	0,00006085	-0,00008361	0,00070133
390	0,00018660	-0,00025929	0,00218008
400	0,00061892	-0,00087505	0,00737744
410	0,00182507	-0,00265490	0,02254979
420	0,00534222	-0,00813202	0,07018383
430	0,00973183	-0,01653557	0,15054992
440	0,00827488	-0,01854578	0,18961551
450	0,00136059	-0,01476652	0,19196896
460	-0,00966109	-0,00743208	0,18022954
470	-0,02223385	0,00460517	0,13803267
480	-0,03375985	0,01960905	0,08544943
490	-0,04434945	0,03572093	0,04632618
500	-0,05888499	0,05741170	0,02316940
510	-0,07772615	0,08813446	0,00748294
520	-0,08788155	0,11946833	-0,00482449
530	-0,07844089	0,13717982	-0,01111267
540	-0,05455603	0,14247027	-0,01460717
550	-0,01861838	0,13728293	-0,01592411
560	0,02805213	0,12339645	-0,01564742
570	0,08264932	0,10140447	-0,01418637
580	0,13892535	0,07372916	-0,01190079
590	0,18692331	0,04442162	-0,00925301
600	0,21541557	0,01921777	-0,00669803
610	0,21667082	0,00188974	-0,00459671
620	0,19151793	-0,00675544	-0,00301679
630	0,14707882	-0,00884267	-0,00186809
640	0,10395334	-0,00787906	-0,00111739
650	0,06634023	-0,00564813	-0,00063660

660	0,03876533	-0,00350241	-0,00034663
670	0,02059397	-0,00191444	-0,00017739
680	0,01103821	-0,00104623	-0,00009255
690	0,00536334	-0,00051499	-0,00004414
700	0,00268474	-0,00025881	-0,00002197
710	0,00136855	-0,00013193	-0,00001120
720	0,00068526	-0,00006606	-0,00000561
730	0,00034034	-0,00003281	-0,00000278
740	0,00016310	-0,00001572	-0,00000133
750	0,00007854	-0,00000757	-0,00000064
760	0,00003927	-0,00000379	-0,00000032
770	0,00001963	-0,00000189	-0,00000016
780	0,00000981	-0,00000095	-0,00000008
790	0,00000489	-0,00000047	-0,00000004
800	0,00000242	-0,00000023	-0,00000002
810	0,00000120	-0,00000012	-0,00000001
820	0,00000060	-0,00000006	0,00000000
830	0,00000030	-0,00000003	0,00000000

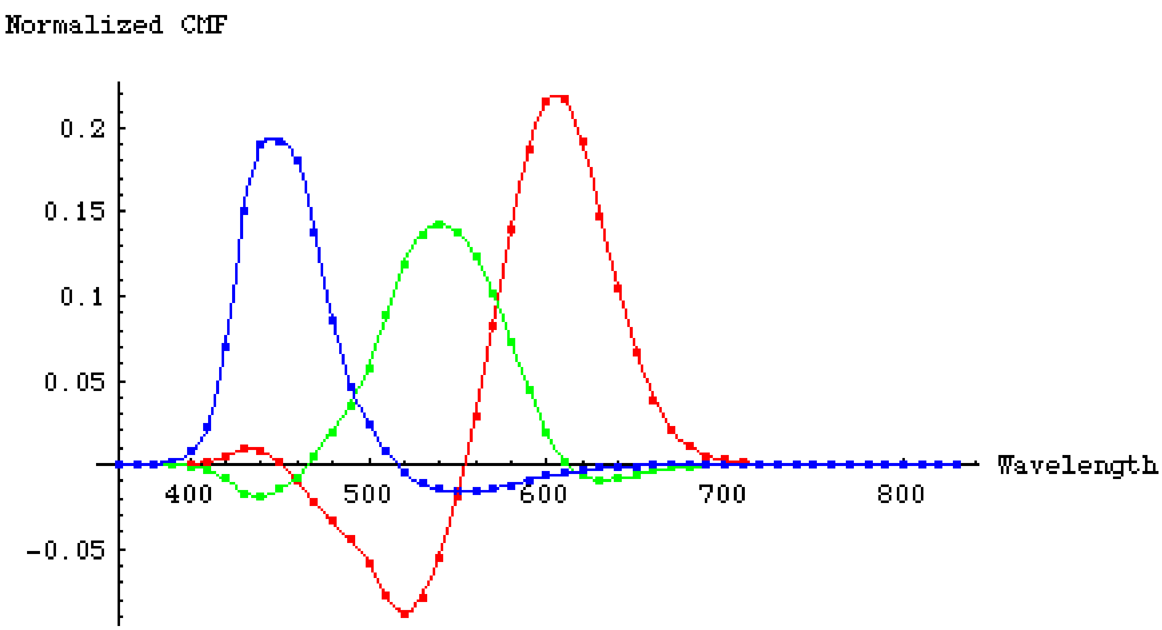

Figure 1 - ISO original RGB colour matching functions. (wavelength in nm.)

4.2 OECFs The ISO original RGB OECFs specify the relationship between the RGB digital code values and the ENDs or ENLFs of the scene or original. The ISO original RGB OECF for any of the R, G and B primaries is as follows:

If $C_{Lin} \leq 0{,}00304$ $$C_{DL} = C_{norm} \times k \qquad (1)$$

$$C_{norm} = C_{Lin} \times 12{,}92 \qquad (2)$$

$$C_{Lin} = 10^{-C_{END}} \qquad (3)$$

else if $C_{Lin} > 0,00304$ $C_{DL} = C_{norm} \times k$ (4)

$$C_{norm} = 1,055 \times C_{Lin}^{1/2,4} - 0,055 \quad (5)$$

$$C_{Lin} = 10^{-C_{END}} \quad (6)$$

where, for each of the R, G, and B primaries, C_{DL} is the primary digital level, C_{norm} is the primary normalized (non-linear) digital level, C_{Lin} is the primary ENLF, C_{END} is the primary END, and k is a constant equal to the number of digital levels used to encode the in-gamut input levels minus one. Normalization of C_{norm} is from zero to one. For ISO original RGB, the default k value is equal to 255; however k values of 1 023, 4 095, and 16 383 are allowed.

The choice of the reference white point luminance in the scene or original on which the ENDs and ENLFs are based is somewhat arbitrary. In particular, it may be difficult to select a reference white point luminance in scenes, and even if one is chosen there may be objects in the scene which have equal or greater luminances, and may or may not be neutral. These objects will appear to be out of gamut, but might be in gamut if a higher reference white point luminance were chosen. For this reason, this International Standard specifies that the reference white point luminance for scenes, which corresponds to an 8-bit digital code value triplet of {255, 255, 255}, should be assumed to have a luminance of 1,41 times that of a spectrally neutral diffuse 100% reflecting surface placed in the scene. This luminance value is also assumed to be 7,8 times the arithmetic mean luminance for statistically average scenes. The reference white point for hardcopy should be equal to that of a spectrally neutral diffuse 100% reflecting or transmitting surface illuminated by the source used to capture the hardcopy. The reference white points for both scenes and hardcopy shall exhibit the same relative spectral radiance characteristics as the adopted white point.

Figures 2 and 3 are plots of the ISO original RGB OECFs, which define the relation between digital levels and scene or original ENDs and ENLFs. It is important to realize that these values may be quite incorrect in an absolute sense. For example, a DSC may choose to set the reference white point luminance to be some number larger than 7,8 times the arithmetic scene luminance in order to capture an image under low illumination conditions, or to allow more headroom for specular highlights. Another DSC may set the reference white luminance at the recommended value, but the arithmetic mean luminance may then be half that of a Halon patch placed in a dim area of a scene. This will result in the reference white luminance being 3,9 times that of the Halon. If the same Halon patch is then moved to a part of the scene with five times as much illumination, it will have a luminance higher than the reference white luminance.

It is clear that the relationship of the luminance of a spectrally neutral diffuse 100% reflecting surface in a scene to the reference white luminance is somewhat arbitrary. The values specified are to establish aims that are consistent with ISO 12232. Whether these aims are met is only important to colour characterisation when one or more of the tristimulus values of some colour are larger than the corresponding value for the reference white. In this case the colour will be out of gamut unless extended bit gamut encoding is used.

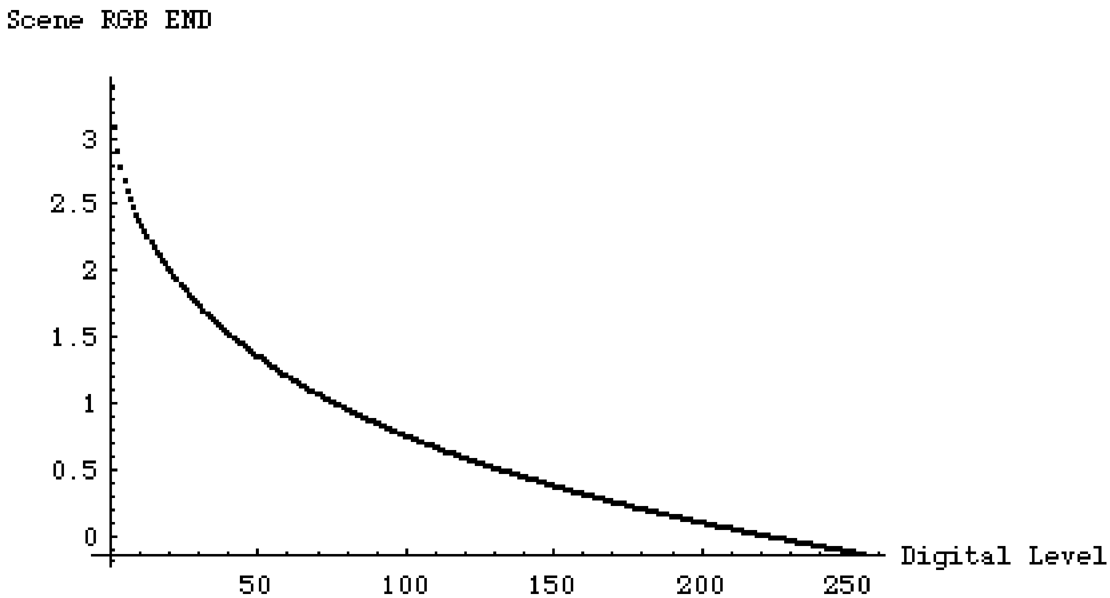

Figure 2a - The ISO original RGB OECF (for scenes, k = 255).
Note: The END of digital level zero is infinity. For illustration purposes, the reference white for the y-axis of this plot is a perfectly diffuse 100% reflecting surface, as opposed to the reference white of 1,41 times this value used to determine the standard ENDs.

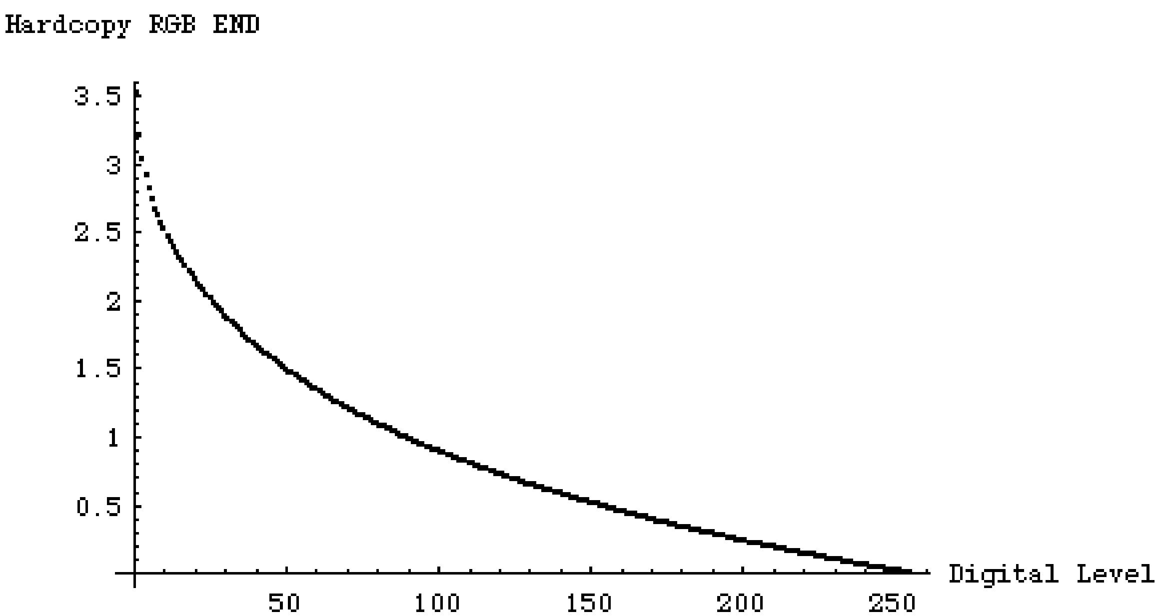

Figure 2b - The ISO original RGB OECF (for hardcopy, k = 255).
Note: The END of digital level zero is infinity. The reference white is a perfectly diffusing 100% reflecting or transmitting surface for both the y-axis and the standard ENDs.

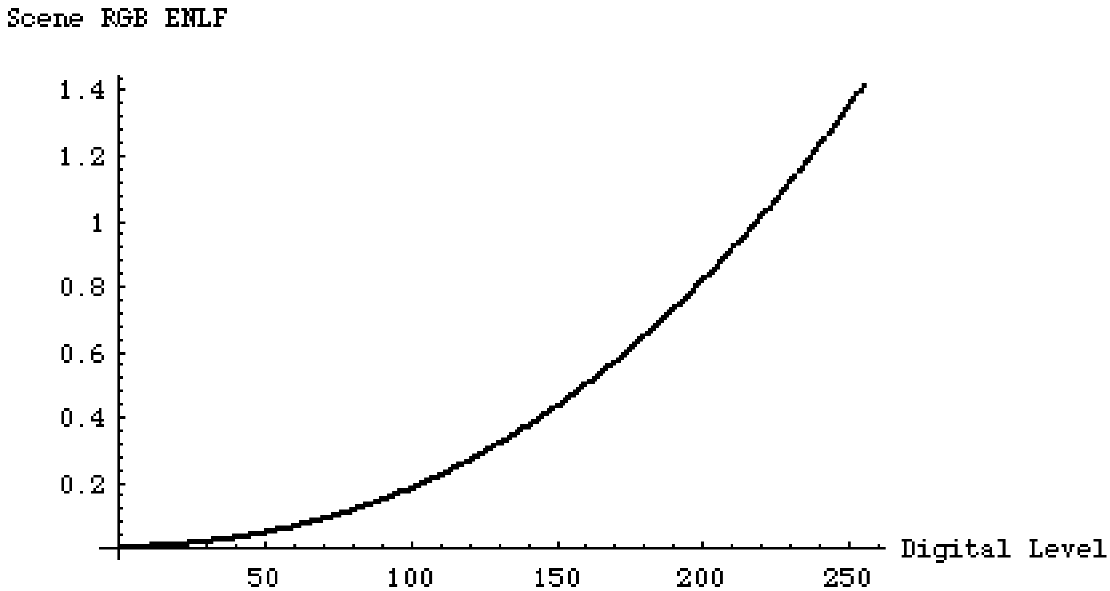

Figure 3a - Scene ENLF ISO original RGB plot.

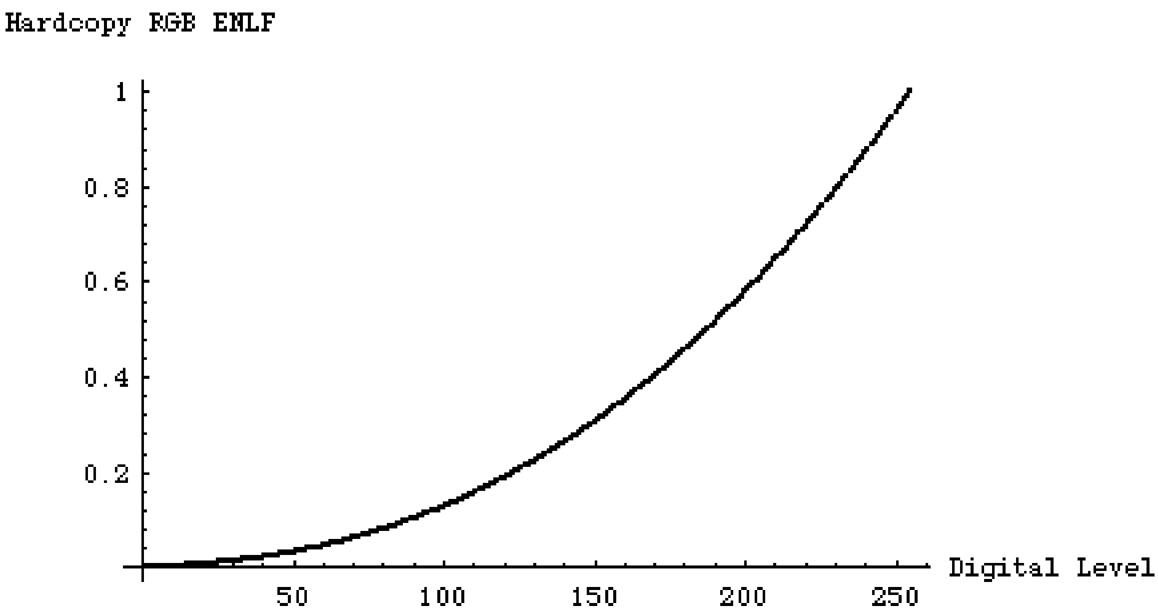

Figure 3b - Hardcopy ENLF ISO original RGB plot.

4.2.1 Linear original RGB In some cases, it may be desirable to refer to linear RGB values that are based on the ISO RGB colour matching functions but do not include the ISO original RGB OECF. To avoid confusion with values that do include the non-linear OECF, linear values should be specifically designated as *linear* original RGB. They may be absolute, or be normalized in some way, but should not be confused with ISO original RGB, which is non-linear.

4.3 Specifications for extended bit depth and/or extended gamut encoding ISO original RGB data is well suited for analysis. It is perceptually compact, easy to interpret and display, and this International Standard defines transformations from sensor data to ISO original RGB. The most significant limitations to the use of ISO original RGB are its limited bit depth capability and gamut. However, it is straightforward to extend both. The bit depth used for storage can be increased with the corresponding increase in the value of the constant k in equations 1 and 4.

Insight into extended gamut encoding can be obtained from the ISO original RGB colour matching functions, as shown in figure 1. The gamut limit relative to the reference white point can be determined by calculating ISO original RGB values for spectral colors at specified luminances. For example, the most extreme case is at a wavelength of 500 nm., where the colour matching function with the largest absolute value is the negative red function. If sufficient monochromatic energy is present at this wavelength to produce a digital count of 255 in the green channel, the corresponding count in the red channel will be -258, and the count in the blue channel will be 170. While the occurrence of this colour at this ENLF is not common, it is important to keep in mind that digital counts are based on ENLFs, not luminances. The luminance is calculated from the linear original RGB values using the following luminance conversion equation:

$$Y = 0{,}2126 \text{ Red ENLF} + 0{,}7152 \text{ Green ENLF} + 0{,}0721 \text{ Blue ENLF} \qquad (7)$$

The luminance of the {-258, 255, 170} triplet would therefore be about 53% of the reference white point luminance. This consideration applies to all saturated colours with luminances approaching the white point luminance, and ENLFs which are therefore greater than unity.

The recommendation for extended bit depth and gamut ISO original RGB is therefore to use the last bit for a sign, the second to last bit for gamut extension of the normalized linear values above unity, and any additional bits for extended bit depth. The minimum bit depth requirement for extended gamut is therefore 10-bits per channel with k = 255. If 16-bits per channel are available, it is possible to increase k to 16 383 and still encode a full perceptual gamut of colours. Table 2 lists bit depths and the associated k values for extended gamut encoding. Figure 4 shows the extended gamut ISO original RGB OECFs.

Table 2 - k values for various available bit depths.

per channel bit depth available	standard gamut	extended gamut
8	k=255	not recommended
10	not recommended	k=255
12	not recommended	k=1 023
14	not recommended	k=4 095
16	not recommended	k=16 383

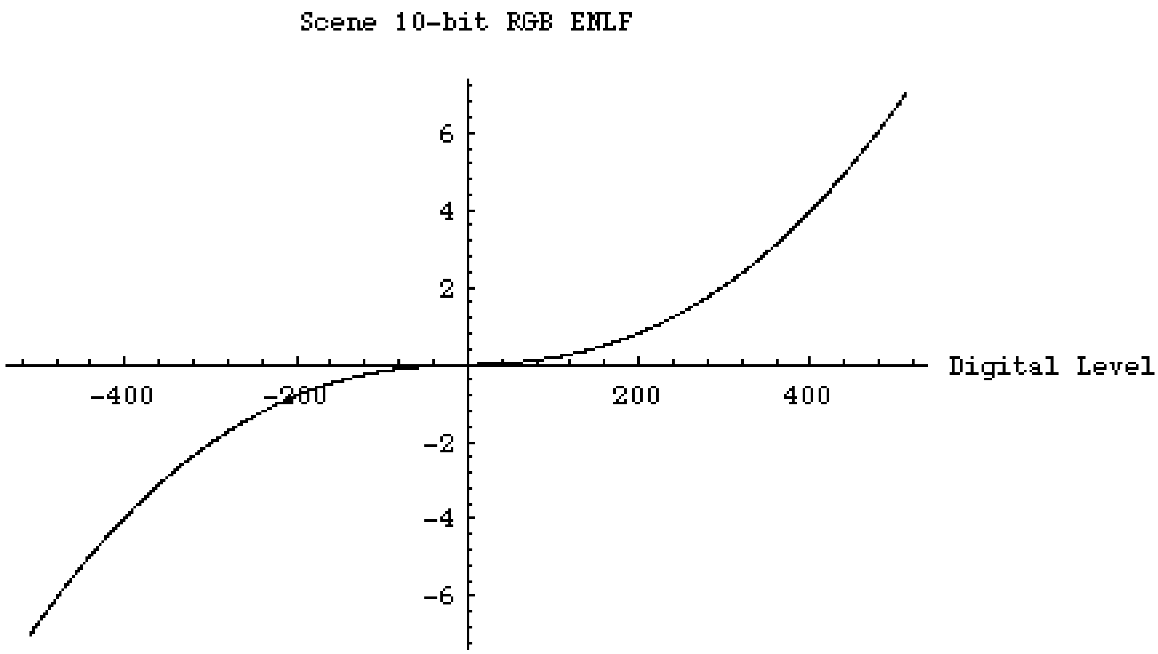

Figure 4a - 10-bit extended gamut scene ENLF OECF plot.
Note: For illustration purposes, the reference white for the y-axis of this plot is a perfectly diffuse 100% reflecting surface, as opposed to the reference white of 1,41 times this value used to determine the standard ENDs.

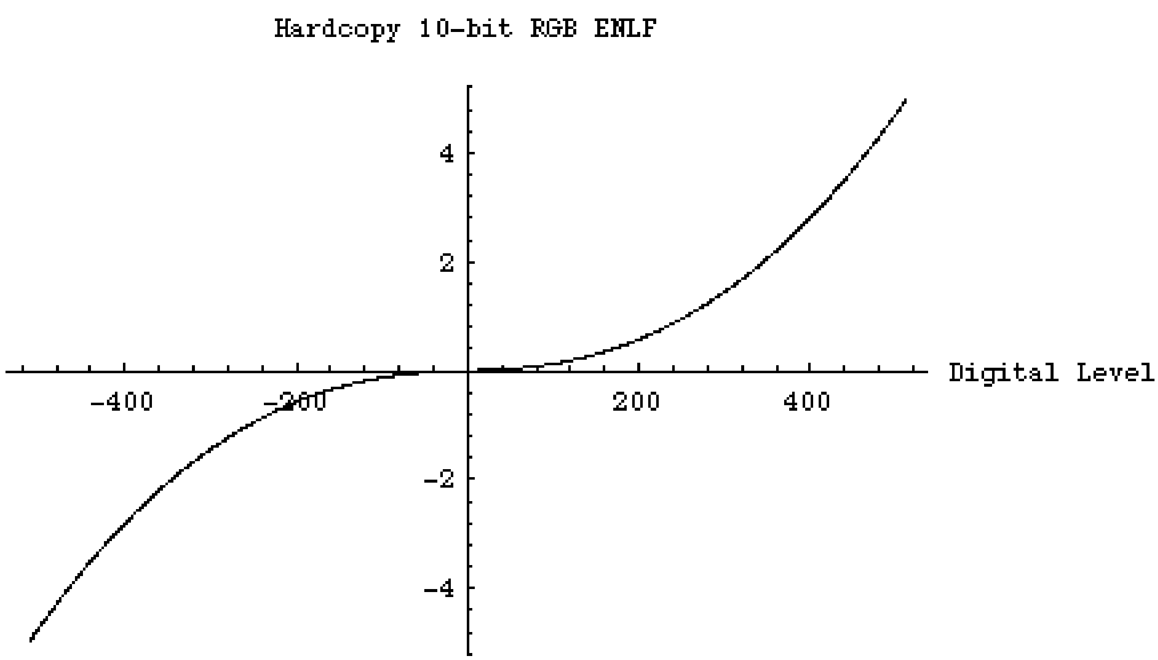

Figure 4b - 10-bit extended gamut hardcopy ENLF OECF plot.

Default ISO original RGB data is defined to be non-extended gamut 8-bit per channel data. However, interpretation of extended ISO original RGB data encoded according to the above recommendation only requires knowledge of the bit depth per channel. Also, if extended gamut data is received by a system not designed to deal with it, all negative data values can be clipped to zero, and all values larger than k can be clipped to k. Both of these operations can be performed with a minimum of computational overhead.

4.4 Transforming ISO original RGB values to CIE XYZ values ISO original RGB values can be transformed to CIE XYZ values for any reference white point as follows:

1. The linear original RGB to XYZ conversion matrix is determined based on the CIE XYZ values for the reference white point. This is accomplished by pre-multiplying the equi-energy original RGB to XYZ matrix with a diagonal matrix containing the XYZ values of the reference white point, as shown in equations 8 and 9, which are for D_{65} and D_{50} respectively.

$$\begin{bmatrix} 0,9504 & 0,0000 & 0,0000 \\ 0,0000 & 1,0000 & 0,0000 \\ 0,0000 & 0,0000 & 1,0890 \end{bmatrix}_{D65WP} \begin{bmatrix} 0,4339 & 0,3762 & 0,1899 \\ 0,2126 & 0,7152 & 0,0721 \\ 0,0177 & 0,1095 & 0,8728 \end{bmatrix}_{EqE} = \begin{bmatrix} 0,4124 & 0,3576 & 0,1805 \\ 0,2126 & 0,7152 & 0,0721 \\ 0,0193 & 0,1192 & 0,9505 \end{bmatrix}_{D65} \quad (8)$$

$$\begin{bmatrix} 0,9642 & 0,0000 & 0,0000 \\ 0,0000 & 1,0000 & 0,0000 \\ 0,0000 & 0,0000 & 0,8249 \end{bmatrix}_{D50WP} \begin{bmatrix} 0,4339 & 0,3762 & 0,1899 \\ 0,2126 & 0,7152 & 0,0721 \\ 0,0177 & 0,1095 & 0,8728 \end{bmatrix}_{EqE} = \begin{bmatrix} 0,4184 & 0,3627 & 0,1831 \\ 0,2126 & 0,7152 & 0,0721 \\ 0,0146 & 0,0903 & 0,7200 \end{bmatrix}_{D50} \quad (9)$$

2. The CIE XYZ values associated with the ISO original RGB values for the specified reference white point can then be calculated using the matrix determined above in the following equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{D65} = \begin{bmatrix} 0,4124 & 0,3576 & 0,1805 \\ 0,2126 & 0,7152 & 0,0721 \\ 0,0193 & 0,1192 & 0,9505 \end{bmatrix} \begin{bmatrix} R_{Lin} \\ G_{Lin} \\ B_{Lin} \end{bmatrix} \quad (10)$$

where R_{Lin}, G_{Lin}, and B_{Lin} are calculated by inverting equations 1, 2, 4, and 5. The conversion matrices used in equation 10 shall not be applied directly to non-linear ISO original RGB values.

It should be recognized that the CIE XYZ values calculated will be a good estimate of the scene or original colorimetry only in cases where the scene or original reference white point had the same chromaticity as the reference white point for which the conversion matrix is determined. Furthermore, the transformations defined by equations 8, 9, and 10 are not intended to be used for the analysis of ISO original RGB values from scenes, but only for the synthesis of estimated XYZ values. Methods for the analysis of ISO original RGB values from scenes are described in clause 5.

5 DSC colour characterisation methods

Three methods are specified for determining the DSC spectral space to ISO original RGB colour space transformation matrix.

5.1 Method A: spectral sensitivity based characterisation

5.1.1 Applicability Method A should be used to determine DSC characterisation transformations where no knowledge of the scene spectral correlation statistics is assumed. It will produce reasonably good scene colorimetry estimates in all conditions, but may not perform quite as well as methods B and C in situations where the scene correlation statistics are better represented by the targets used for these methods. Transformations determined using method A will produce the smallest DSC metamerism indexes.

5.1.2 Description of method With method A, the DSC relative spectral sensitivities are measured and used to determine the matrix conversion from the linearized DSC spectral space to approximations of the linear original RGB colour space. The ISO original RGB OECF is then applied.

5.1.3 Procedure for determining transformations The procedure for determining transformations using method A shall be as follows:

1. Use a monochromator to illuminate a diffuse transmitting or reflecting surface so that the illuminated area is large enough to fill the field of view of the DSC with the lens in focus. The radiance falloff shall be even, constant as the monochromator peak wavelength is changed, and circularly symmetric with the radiance at the edge no less than 70% of the radiance at the center. The integrated radiance at all wavelengths more than 10 nm. from the peak wavelength on which the monochromator is set shall be less than 1/10000 of the integrated radiance within 10 nm. of the peak radiance. Interference filters or a double monochromator may be used to meet this requirement.

2. Use a radiance meter to measure the relative radiance of the illuminated surface as a function of wavelength.

3. Capture images of the illuminated surface at wavelengths ranging from 360 nm. to 830 nm. in 10 nm. increments. The DSC shall be set up as described in ISO 14524 for alternative focal plane OECF measurements. The images shall be captured with the DSC lens and any filters used for general picture taking (such as an infrared blocking filter) in place. The data output by each colour analysis channel of the DSC shall remain independent, i.e. not be matrixed. The relative radiance of the surface shall also be recorded for each image.

4. Determine the alternative focal plane OECF of the DSC according to ISO 14524, except that the measurement may be performed at the peak sensitivity wavelength for each colour analysis channel.

5. Average a 64x64 pixel block at the center of each image to determine the raw DSC response at each wavelength.

6. Use the inverse alternative focal plane OECF to linearize the raw DSC responses at each wavelength.

7. Calculate the relative spectral sensitivities at each wavelength for each colour analysis channel by dividing the linearized DSC response by the relative surface radiance.

8. Multiply the relative spectral sensitivities for each channel by the illuminant or illumination source relative spectral power distribution to create DSC spectral response values for each channel at each wavelength. The illumination used should be as defined for Camera OECF determination in ISO 7589 and ISO 14524, except when the DSC is to be characterised for a particular illuminant or illumination source, and/or provides its own illumination. The illumination used shall be identified for each transformation determined.

9. Normalize the spectral responses for each channel by dividing by the constant necessary to make the sum of the spectral responses for each channel equal to unity.

10. Multiply the normalized spectral responses by a matrix of the form:

$$\begin{bmatrix} a & b & 1-a-b \\ c & d & 1-c-d \\ e & f & 1-e-f \end{bmatrix} \qquad (11)$$

11. Apply the 10-bit extended ISO original RGB OECF to the transformed spectral responses to produce DSC 10-bit extended ISO original RGB digital code values for the spectral colours.

12. Multiply the ISO original RGB colour matching function values for each channel by the illuminant or illumination source relative spectral power distribution to create aim spectral response values for each channel at each wavelength.

13. Apply the 10-bit extended ISO original RGB OECF to the aim spectral response values to produce aim 10-bit extended ISO original RGB digital code values for the spectral colours.

14. Choose the coefficients a, b, c, d, e, and f so the sum of the squared differences between the aim and transformed 10-bit ISO original RGB digital code values is a minimum.

Editor's Note: A comment has been received that the following step should be eliminated.
15. Construct a flare model to estimate DSC flare under different picture taking conditions. This model should allow image specific DSC OECFs to be determined based on the focal plane or alternative focal plane OECF.

Editor's Note: A comment has been received that the following subclause should be eliminated.
5.1.4 Applying the transformation to raw DSC data The transformation determined is applied as follows:

1. Linearize the DSC colour analysis channel data with respect to scene radiance by applying the image specific inverse DSC OECF as determined using the flare model.

2. Transform the channel data to linear original RGB by applying the matrix (11), as determined in 5.1.3, step 9.

3. Apply the ISO original RGB OECF as specified in equations 1, 2, 4, and 5.

5.2 Method B: standard ISO DSC colour target based characterisation
Note: The standard ISO DSC colour target is described in Annex A.

5.2.1 Applicability Method B should be used to determine DSC characterisation transformations where the scene or original spectral correlation statistics are assumed to be represented by those of the standard ISO DSC colour target.

5.2.2 Description of method Method B is similar to method C, except for the colour target used and the robustness of the transformations obtained. Since the colorants in the scene or original are assumed to be unknown, or the number of spectral basis functions required to span them is larger than the number of DSC spectral channels, it is impossible to obtain transformations that will always produce colorimetrically accurate output values (unless the DSC spectral sensitivities are colour matching functions). With method B, the goal is to determine transformations that allow pictorially pleasing results to be produced.

The transformations determined using method B do not produce preferred reproduction themselves, but rather transform the DSC data into scene or original colorimetry estimates in a standard colour space, so that preferred reproduction algorithms can be applied. The output spectral space is frequently chosen so that the reproduction of memory colours is most correct, with other colours being reproduced acceptably.

5.2.3 Illumination The illumination used should be as defined for Camera OECF determination in ISO 7589 and ISO 14524, except when the DSC is to be characterised for a particular illumination source, and/or provides its own illumination. The illumination source used shall be identified for each transformation determined.

In qualifying the illumination source, particular attention should be paid to the rolloff in red response. The spectral distribution index (SDI) described in ISO 7589 assumes a rolloff in red response which is normal with silver halide films, but does not naturally occur with typical DSC sensors. If a DSC has a long wavelength red response that is significantly different from that assumed in ISO 7589, the SDI criterion may not be sufficient for qualifying the illumination source. Annex B of ISO 14524 also contains information about the relevancy of SDI calculations to the qualification of illumination sources for DSCs. If there is some question about the relevancy of the SDI, the illumination source used should be chosen so that its spectral power distribution matches that of the desired source as closely as possible, in addition to meeting the SDI criterion.

5.2.4 Test conditions The test conditions shall be as defined for Camera OECF determination as described in ISO 14524 and ISO 554, except as follows:

5.2.4.1 White balance The transformations determined using this method will include a neutral balance, so it is generally desirable to disable any digital white balancing that the DSC may be performing. It is also necessary that any analog white balancing be fixed, so that variations in the analog white balance do not confound the digital white balance built into the transformation.

5.2.4.2 Infrared (IR) blocking filter If it is determined that an IR blocking filter is required for OECF determination according to ISO 14524, the long wavelength red and infrared response of the DSC should be checked to determine if the response is being appropriately dealt with by DSC filters. If the DSC shows abnormally high long wavelength red response (see the standard red rolloff in ISO 7589), or significant infrared response, additional filters should be used with the DSC at all times. If the DSC response appears normal, the illumination source may be emitting excessive amounts of infrared radiation, in which case the IR blocking filter should be placed on the source, and the source re-qualified.

5.2.5 Procedure for determining transformations The procedure for determining transformations using method B shall be as follows:

1. A colour target as specified in Annex A should be illuminated using a photographic daylight or tungsten source qualified according to ISO 7589, as extended by ISO 14524 for exposures through the DSC lens. Other standard sources, or a specific source designed for the particular DSC to be characterised, may also be used. The illumination source used shall be noted, and the spectral power distribution measured.

2. The spectral radiances for each patch of the colour target should be measured from the DSC position. When performing these measurements, all patches except for the patch being measured, and any other surfaces in the vicinity of the colour target, shall be covered by a mask with a reflectance of less than 2.5%, and stray light should be prevented from entering the aperture of the measuring instrument. Alternately, the illumination source spectral power distribution may be measured and the spectral radiances calculated based on spectral reflectances provided by the chart manufacturer. If this measurement approach is chosen, it is imperative that the geometric conditions present when originals are captured be duplicated by the spectral densitometer. ISO 5/1 specifies terms, symbols, and notations for density measurement, and ISO 5/2 and ISO 5/4 specify standard geometric conditions for transmission and reflection density measurement. The best results will be obtained from originals with surface and diffuse reflection geometrical characteristics similar to those of traditional photographic media if the standard geometric conditions are used in both the capture setup, and for patch measurement. It is recommended that even when measurements of the target are made, that they be compared to the manufacturer provided measurements. If significant discrepancies are found, the causes should be identified and corrected. Common causes are glare, reflections, and other illumination irregularities, measuring instrument inaccuracies, and dirt on the target.

3. Raw linear original RGB values shall be calculated for each patch of the colour target by taking the sum of the products of the spectral radiance and the ISO original RGB colour matching functions at each wavelength.

4. The raw linear original RGB values shall be normalized to produce linear original RGB aim values by dividing the raw value in each channel for each patch by the value produced by the Halon reference white patch on the target.

5. The 10-bit extended ISO original RGB OECF shall then be applied to the linear original RGB aim values to produce 10-bit extended ISO original RGB aim values.

6. The DSC shall be used to capture an image of the colour target.

7. The image data shall be linearized and normalized using the inverse Camera OECF as determined using the Halon patch and gray scale on the target. If the Camera OECF was determined correctly, applying the inverse to each channel will transform the DSC digital code values to the aim values for the neutral patches of the target.

Note: With most DSC systems, it is necessary to consider flare light in determining the Camera OECF. When the neutral scale on the target is used to determine the Camera OECF, the flare present when the target is imaged will be considered, which is appropriate for determining the transformation matrix. However, if the Camera OECF determined in this fashion is then assumed to be constant for all scenes, the data from scenes which produce different flare characteristics will not be linearized correctly, and the results produced by the entire transformation will be incorrect, even though the correct matrix is used.

8. A matrix of the form shown in (11) shall be determined, with the coefficients selected to produce the minimum mean square error between the 10-bit extended ISO original RGB aim values and 10-bit extended ISO original RGB values produced from the linearized DSC data, when the matrix is applied to the linearized DSC data. In determining the minimum mean square error, selected patches may be weighted more heavily than others if the patch weights are reported.

Editor's Note: A comment has been received that the following subclause should be eliminated.

5.2.6 Applying the transformation to raw DSC data The transformation determined shall be applied as specified in 5.1.4, except the matrix used shall be as determined in 5.2.5, step 8.

Editor's Note: A comment has been received that the following subclause should be eliminated.

5.2.7 Why matrices of look-up-tables (LUTs) are not allowed with method B A difference between methods B and C is that the determination of transformations using matrices of LUTs is considerably more difficult in the cases where method B is applicable, as opposed to method C. When the colorants are known and spanned, as is the case when method C is applicable, there exists a single transformation that produces optimal results for each illuminant and output space. When this is not the case and method B is applicable, there is no precisely correct transformation, but multitudes of possible transformations, and it is important to have many more patches than degrees of freedom in determining the best transformation. Since it is difficult to make patches with arbitrary spectral radiances, it is therefore not practical to determine matrices of LUTs using method B.

Another difficulty that can arise when using matrices of LUTs is with DSCs that feed the output of the transformation into preferred reproduction algorithms. Say a transformation is designed to optimize the reproduction of foliage in the darker areas of a scene, and the reproduction of flesh tones in the lighter areas. If a digital image is underexposed, the transformation may assume that the entire scene is dark and not optimize flesh tones anywhere. It is better to use a matrix of coefficients to transform the DSC data to an estimate of scene colorimetry, and implement tweaking in the preferred reproduction algorithm.

5.3 Method C: ISO 12641 target based characterisation

5.3.1 Applicability Method C should be used if the colorants used in the scene or original are known, and are spanned by a set of spectral basis functions whose dimensionality is not greater than the number of independent DSC spectral channels.

Examples: Three channel capture of known CMY or CMYK pigments, dyes, or inks.
Seven channel capture of artwork, in which the colorants used are spanned by seven spectral basis functions.

5.3.2 Outline of method Method C is the same as method B, except the colour targets used shall be as specified in ISO 12641, and are for scenes or originals containing a known and limited number of colorants. Also, matrices of LUTs are allowed.

5.3.3 Determination of a matrix of LUTs In some cases, non-linearities in the colour reproduction process (such as surface reflections and dye spectral characteristics that change with density) may result in somewhat better results being achieved in the capture of hardcopy originals if a matrix of LUTs is used (instead of a matrix of constant coefficients) to transform the captured data into the ISO original RGB colour space. Unfortunately, the introduction of so many additional degrees of freedom makes it somewhat difficult to separate noise from real effects. This standard allows matrices of LUTs to be used for transformations determined according to method C, as long as the neutral scale is preserved, and the MSEs produced using the matrix of LUTs are smaller than the MSEs obtained using a constant coefficient transformation matrix.

6 ISO DSC metamerism index

The ISO DSC metamerism index shall be equal to the root mean square difference between the aim 10-bit extended ISO original RGB digital code values and the 10-bit extended ISO original RGB digital code values that will be produced by the DSC for spectral colors from 360 to 830 nm. in wavelength. The matrix actually used in practice to transform the linearized DSC values to linear original RGB values shall be used to produce the spectral values from which the metamerism index is determined. Metamerism indexes may be reported for each channel of the DSC, in which case an overall value shall also be reported. The illumination on which the ISO DSC metamerism index is based shall be reported, and reported values shall be rounded to the nearest integer.

Annex A
(Normative)

Standard ISO DSC colour target specifications

The approach employed with method B is to determine transformations that produce the best results with a selected group of test patches. It is therefore important that these test patches be representative of a wide range of scene colorants, and include any spectral radiance distributions of particular importance, such as skin tones, foliage, blue sky, primary colours, and other natural object colours. Also, the test patches must duplicate spectral radiances. Duplication of tristimulus values is not meaningful for patches to be imaged by DSCs whose spectral sensitivities are not colour matching functions. Finally, for the prescribed normalization to be achieved, a Halon test patch must be included.

A colour target of this general type with only 24 patches is described McCamy, et.al. A comparison of this target with other targets containing larger sets of coloured patches is presented by Finlayson and Drew. The conclusion reached is that the target described by McCamy does a reasonable job of representing much larger sets of patches. This target is available commercially as the Macbeth Color Checker. Unfortunately, almost all research in this area deals with surface colours produced using available colorants, so the gamut of spectral radiance distributions spanned by these patches is much smaller than the gamut of all possibilities. However, it is reasonable to assume that many natural colours are represented by these patches.

The minimum required colour target for method B is therefore the Macbeth Color Checker plus a Halon patch. Early implementers of this method should also consider adding other additional patches, and varying the weights assigned to patches which they feel are reproduced unacceptably. However, the transformations obtained must operate on linearized DSC data, and be constrained to maintain the neutral scale.

Editor’s notes: The specification of the colour target is TBD. ISO 12641 targets are appropriate for method C, but are not acceptable for method B because of the limited number of colorants used. While the Macbeth Color Checker is a step in the right direction, it causes problems when used for DSC characterisation because the spectral reflectances are not sufficiently close to those of critical natural objects like foliage and skin, and because of poor surface characteristics. Other targets are available but have yet to be fully investigated. David Corley of DSC Laboratories in Toronto feels that transmission targets would be best. Klaus Witt from Germany presented information at the March 1996 CIE Colour Experts Meeting in Vienna on a reflection target for commercial television that may be adequate.

Annex B
(Informative)

Comments on the ISO original RGB colour space and DSC metamerism indexes

Editor's Note: A comment has been received that this annex should be clarified and shortened. Another comment requested that the derivation of the ISO original RGB colour matching functions be included. Only the latter comment has been accommodated for now. If it turns out that some of the material in this annex can be better edited for clarity, or removed because it is commonly known, these changes can be made in later drafts.
Editor's note: Check out Bill Thornton's work in CIE R1-17 as it relates to the issues discussed in this annex.

The ISO original RGB colour space defined in this International Standard was chosen because recent research indicates that chromatic adaptation transforms perform best when based on RGB colour matching functions. Several different sets of RGB colour matching functions are used, such as those specified in CIECAM97, in the Sharp chromatic adaptation transform described in papers by Finlayson, Drew, Funt, and Hubel, and in ITU-R BT.709. In the latter case, RGB display primary chromaticities are specified as opposed to colour matching functions, but in effect chromatic adaptation transforms are performed using these primaries. White balancing is accomplished by adjusting RGB channel gains, and RGB digital data is sent to displays set at different white points without adjustment. The only requirement is that equal RGB triplets appear neutral when viewed on the display.

A set of colour matching functions can be derived from the 709 primaries. If one does this and compares the functions obtained with those from the Sharp transformation and CIECAM97, some remarkable similarities become apparent. In all three cases, the blue and green colour matching functions are almost identical. The 709 and Sharp red colour matching functions are also almost identical. Also, if the 709, Sharp, or CIECAM97 colour matching functions are compared to a set of functions generated by ratioing cone responses, very good alignment is obtained on the peaks of the blue and green functions. The red peak, however, cannot be made to align well with that of the $V(\lambda)$ windowed rho/beta function. Either the peak is at too short a wavelength, as is the case with the CIECAM97 red, or the slope of the short wavelength side of the peak is too steep and goes too negative, as with the Sharp and 709 reds. Another observation is that the cone responses generated from the CIE 2° observer tristimulus functions do not exactly match those obtained from other cone response measurements, such as those of Smith and Pokorny or Stiles and Esteves, particularly in the red. It can therefore be hypothesized that there is some difficulty in obtaining the ideal red chromatic adaptation colour matching function from the CIE tristimulus functions. In this International Standard, the equi-energy derivative of the 709 red is used partly because it is similar to the Sharp red, but primarily because it is easily realizable and more compatible with standard reproduction description colour spaces such as sRGB.

The derivation of the ISO original RGB colour matching functions is as follows:

The matrix that transforms CIE XYZ to ITU-R BT.709 RGB is:

$$\begin{bmatrix} 3,2410 & -1,5374 & -0,4986 \\ -0,9692 & 1,8760 & 0,0416 \\ 0,0556 & -0,2040 & 1,0570 \end{bmatrix} \quad \text{(B1)}$$

However, the row sums of this matrix are not all equal to unity. This means the matrix is not white point preserving. If it is applied directly to the CIE $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ colour matching functions, it will not produce appropriately normalized RGB colour matching functions. (Colour matching functions are by definition equi-energy.) It is necessary to create a white point preserving transformation from CIE XYZ to the desired RGB colour matching functions.

There are two ways to do this. The first is to divide each coefficient in matrix B1 by the row sum. The second is to invert matrix B1, divide each coefficient of the inverted matrix by its row sum, and then invert to produce the white point preserving XYZ to RGB matrix. In this International Standard, the second approach has been chosen. Since chromatic adaptation is better performed in RGB space, it is more appropriate to perform the row normalization on the matrix that transforms from RGB to XYZ. This is consistent with the concept of white point independent RGB values. This approach also makes it possible to easily determine transformation matrices from RGB to XYZ for any white point, as described in subclause 4.4. The chromaticities of several primary sets associated with different white points are provided in table B1.

Table B1 - Several white point primary set chromaticities.

White Point	White *x*	White *y*	Red *x*	Red *y*	Green *x*	Green *y*	Blue *x*	Blue *y*
Equi-energy	0,3333	0,3333	0,6533	0,3201	0,3133	0,5956	0,1673	0,0635
D65	0,3127	0,3290	0,6400	0,3300	0,3000	0,6000	0,1500	0,0600
D55	0,3325	0,3475	0,6446	0,3301	0,3061	0,6082	0,1718	0,0682
D50	0,3457	0,3585	0,6481	0,3293	0,3105	0,6122	0,1878	0,0739
Illuminant A	0,4476	0,4075	0,6852	0,3057	0,3540	0,6127	0,3529	0,1220

The meaning of the ISO DSC metamerism indexes defined in this International Standard is also impacted to some extent by the differences between cone responses as transformed from the CIE colour matching functions, and those obtained from other measurements. In the past, errors in the CIE functions were assumed to be overshadowed by observer variability. While the von Kries transform remained the primary chromatic adaptation transform, this assumption held sufficiently well. The RGB based chromatic adaptation transforms, however, are beginning to highlight errors that may be consistent between observers. Since the ISO DSC metamerism index is based in a CIE colour space representation, there is some question about whether the lowest metamerism index will always produce the most accurate colour reproduction.

It is the hope of those involved with the development of this standard that work will continue in the CIE and elsewhere to determine the ideal chromatic adaptation transform (which may be non-linear) and the associated colour matching functions. At this time, we feel it is necessary to base the ISO original RGB colour matching functions on the CIE 2° observer, which has been proven to facilitate excellent colour reproduction over many years in a variety of applications.

Annex C
(Informative)

White point preserving maximum ignorance matrix and DSC metamerism index calculation examples

The following is an example of a white point preserving maximum ignorance matrix calculation:

1. The spectral sensitivities for each channel of the DSC (the combination of the sensor, lens, and any filters) are measured using a monochromator. The measured values are then multiplied by the corresponding relative spectral radiant power values for CIE Illuminant D_{55} to create relative spectral response values. These values are normalized so that the sum of the sensitivities for each channel is unity. (The normalization factors should correlate with the inverse OECFs used to linearize and white balance the DSC data in each channel prior to applying the spectral to colour space conversion matrix.) Table C1 lists the values that will be used in this example, which are also plotted in figures C1 and C2.

Table C1 - Example DSC spectral sensitivity and CIE Illuminant D_{55} response.

Wavelength (nm.)	Channel 1 Spectral Sensitivity	Channel 2 Spectral Sensitivity	Channel 3 Spectral Sensitivity	CIE Illuminant D_{55}	Normalized Channel 1 Response	Normalized Channel 2 Response	Normalized Channel 3 Response
360	0,00003261	0,00013975	0,00003913	30,5985	0,00001506	0,00004313	0,00001482
370	0,00003461	0,00021479	0,00004059	34,2841	0,00001791	0,00007427	0,00001723
380	0,00004644	0,00029396	0,00004955	32,5540	0,00002282	0,00009651	0,00001997
390	0,00001366	0,00089245	0,00057289	38,0560	0,00007844	0,00034254	0,00026992
400	0,00025660	0,00178245	0,00715703	60,9021	0,00023589	0,00109484	0,00539645
410	0,00047009	0,00345597	0,01816833	68,5057	0,00048611	0,00238780	0,01540940
420	0,00097895	0,00486659	0,03795726	71,5311	0,00105702	0,00351093	0,03361500
430	0,00128915	0,00597558	0,04831944	67,8734	0,00132078	0,00409055	0,04060360
440	0,00359573	0,00712640	0,06238592	85,5608	0,00464398	0,00614960	0,06608520
450	0,00420242	0,00890166	0,07353869	97,9481	0,00621332	0,00879365	0,08917740
460	0,00480050	0,01189810	0,08238498	100,4224	0,00727689	0,01205060	0,10242900
470	0,00516968	0,01743150	0,08593415	99,8776	0,00779400	0,01755920	0,10626200
480	0,00510104	0,02635610	0,08208442	102,7072	0,00790839	0,02730130	0,10437700
490	0,00503218	0,04066710	0,07760526	98,0524	0,00744806	0,04021640	0,09420900
500	0,00510768	0,05918850	0,07066773	100,6593	0,00776079	0,06008880	0,08806800
510	0,00583563	0,08051200	0,06269107	100,6783	0,00886854	0,08175200	0,07814200
520	0,00723695	0,09787800	0,05151043	99,9744	0,01092130	0,0986906	0,06375690
530	0,00903686	0,10513900	0,03728347	104,2004	0,01421400	0,11049300	0,04809820
540	0,01173669	0,10392800	0,02278527	102,0963	0,01808770	0,10701500	0,02880100
550	0,01774710	0,09617200	0,01166090	102,9651	0,02758330	0,09987130	0,01486500
560	0,03110849	0,08500250	0,00545767	100,0000	0,04695780	0,08573020	0,00675694
570	0,05188715	0,07168400	0,00273176	97,2186	0,07614440	0,07028680	0,00328802
580	0,07099540	0,05636800	0,00170658	97,7535	0,10475900	0,05557340	0,00206539
590	0,07901180	0,04070160	0,00133314	91,4415	0,10906000	0,03753680	0,00150925
600	0,07710010	0,02716290	0,00111241	94,4348	0,10990500	0,02587080	0,00130059
610	0,07033670	0,01766550	0,00094357	95,1597	0,10103300	0,01695430	0,00111166
620	0,06096258	0,0112442	0,00080327	94,2431	0,08672440	0,01068760	0,00093725
630	0,05098436	0,00670885	0,00068725	90,4725	0,06962770	0,00612162	0,00076979
640	0,04069415	0,00358846	0,00059009	92,3609	0,05673470	0,00334271	0,00067476
650	0,03065265	0,00192203	0,00049650	88,8867	0,04112760	0,00172305	0,00054639
660	0,02135266	0,00127913	0,00041089	90,3550	0,02912280	0,00116565	0,00045964
670	0,01388296	0,00112407	0,00035637	93,9930	0,01969730	0,00106559	0,00041471

680	0,00797944	0,00110539	0,00021903	90,0006	0,01084040	0,00100337	0,00024406
690	0,00372400	0,00092517	0,00014098	79,7135	0,00448095	0,00074380	0,00013913
700	0,00109441	0,00044282	0,00007053	82,8818	0,00136920	0,00037016	0,00007238
710	0,00023470	0,00013449	0,00002617	84,8819	0,00030072	0,00011514	0,00002750
720	0,00005639	0,00003951	0,00001035	70,2666	0,00005981	0,00002800	0,00000901
730	0,00001972	0,00001551	0,00000560	79,3356	0,00002361	0,00001241	0,00000550
740	0,00001011	0,00000871	0,00000410	85,0292	0,00001298	0,00000747	0,00000431
750	0,00000742	0,00000675	0,00000365	71,9107	0,00000805	0,00000490	0,00000325
760	0,00000513	0,00000496	0,00000304	52,8168	0,00000409	0,00000264	0,00000199
770	0,00000571	0,00000565	0,00000406	75,9602	0,00000654	0,00000433	0,00000382
780	0,00000561	0,00000571	0,00000478	71,8484	0,00000608	0,00000413	0,00000425
790	0,00000748	0,00000767	0,00000694	72,9666	0,00000824	0,00000565	0,00000627
800	0,00000841	0,00000871	0,00000854	67,3762	0,00000855	0,00000592	0,00000712
810	0,00000894	0,00000931	0,00000927	58,7513	0,00000792	0,00000552	0,00000674
820	0,00000852	0,00000893	0,00000905	65,0203	0,00000836	0,00000585	0,00000728
830	0,00000732	0,00000769	0,00000784	68,3353	0,00000755	0,00000530	0,00000664
		Equi-energy Normalization Coefficients:			1,42857143	1,0000000	1,17647059
		D_{55} Normalization Coefficients:			1,49667159	1,0000000	1,22755484

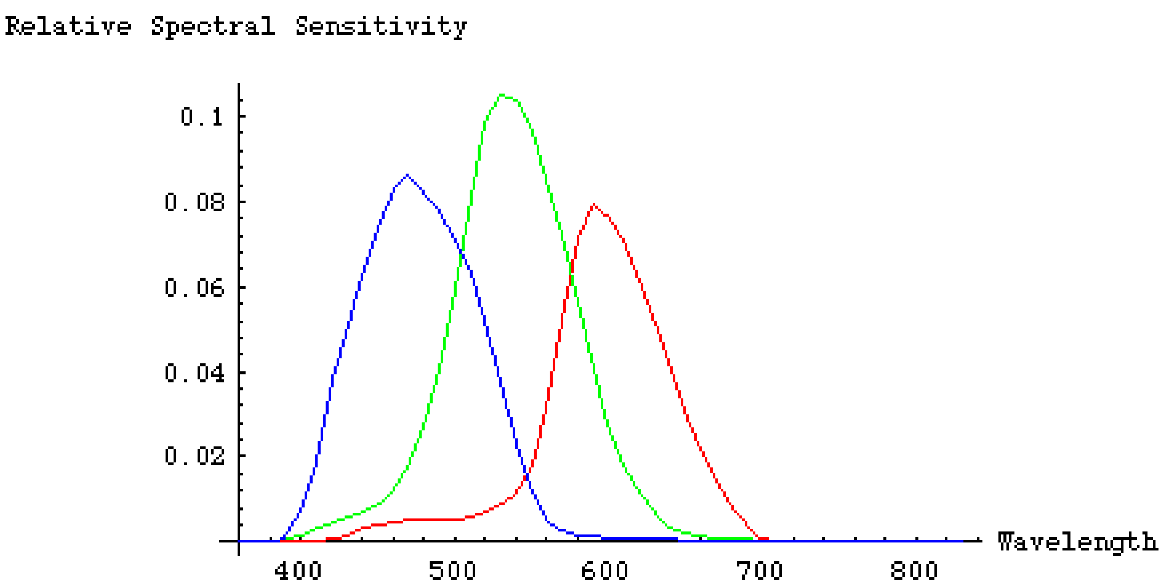

Figure C1 - Example DSC spectral sensitivities.

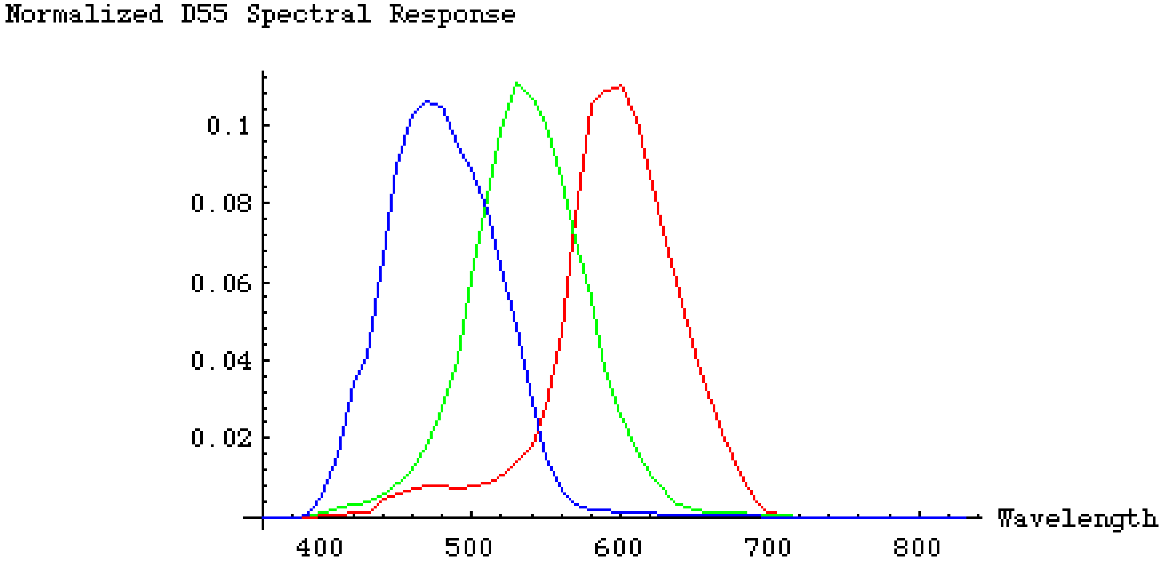

Figure C2 - Example DSC spectral responses to CIE Illuminant D_{55}.

2. The matrix in equation C1, when applied to the D_{55} spectral responses listed in the three right hand columns of table C1, produces the best white point preserving match to the aim D_{55} spectral responses. In determining this matrix, the best match is defined to be the one that produces the smallest mean square difference between the 10-bit extended ISO original RGB digital code values for the aim D_{55} spectral responses, and the 10-bit extended ISO original RGB digital code values for the transformed D_{55} spectral responses. The matrix is applied to the linear values, but the mean square error is minimised between the aim and transformed spectral responses after applying the 10-bit extended ISO original RGB OECF. Plots of the aim and transformed D_{55} spectral responses are shown in figures C3 and C4. The aim and transformed D_{55} 10-bit extended ISO original RGB digital code values are listed in table C2.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{LinearOriginalRGB} = \begin{bmatrix} 1{,}8783 & -0{,}8065 & -0{,}0718 \\ -0{,}2158 & 1{,}4462 & -0{,}2304 \\ 0{,}0842 & -0{,}7817 & 1{,}6975 \end{bmatrix} \begin{bmatrix} Ch1 \\ Ch2 \\ Ch3 \end{bmatrix}_{LinearCameraData} \quad \text{(C1)}$$

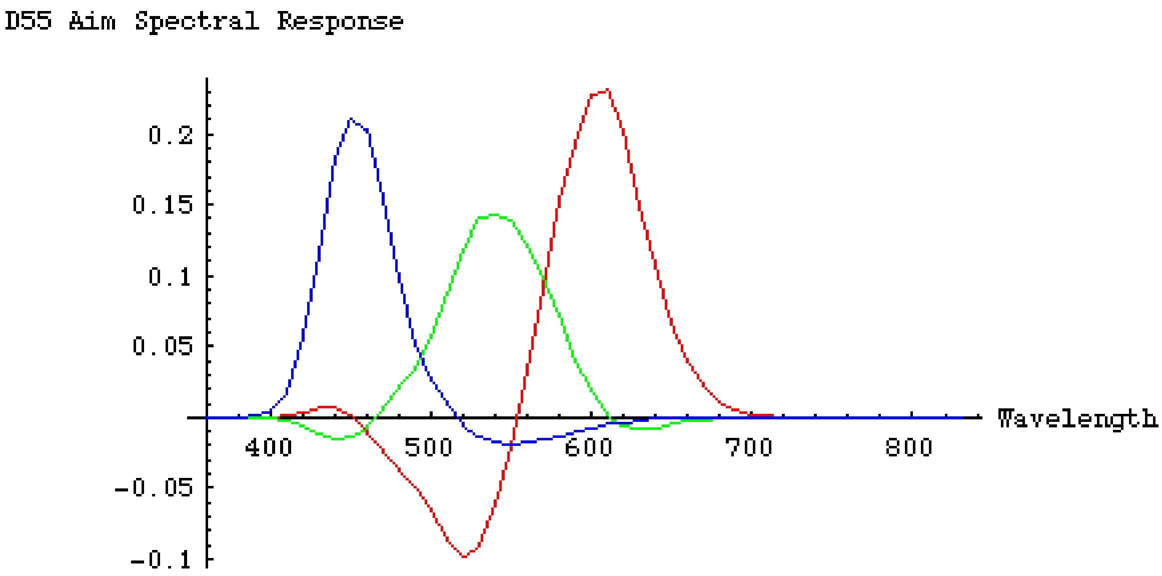

Figure C3 - Aim spectral responses to CIE Illuminant D_{55}.

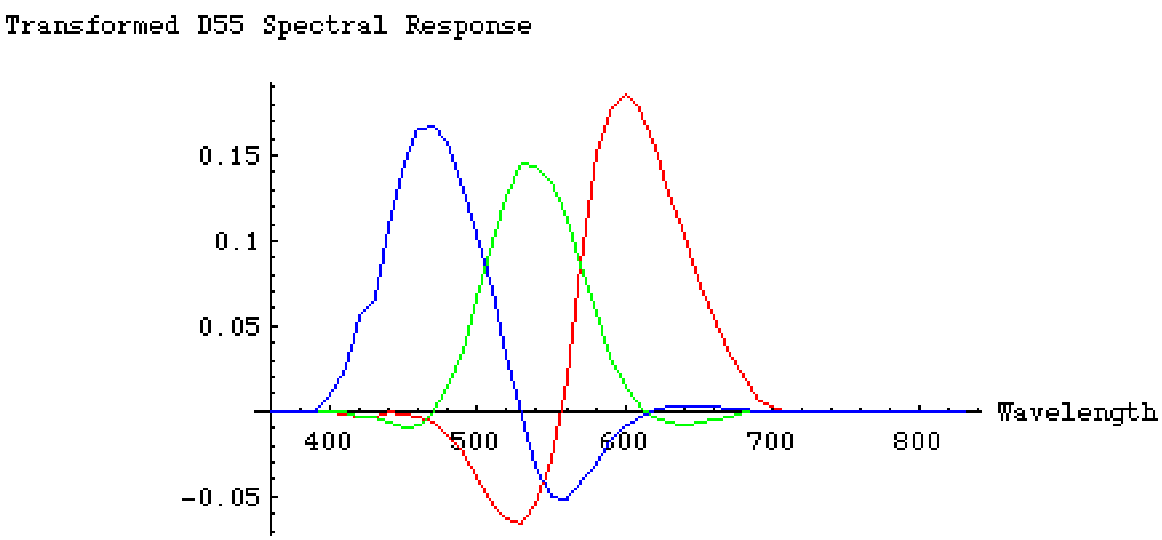

Figure C4 - Example transformed spectral responses to CIE Illuminant D_{55}.

Table C2 - D_{55} aim and transformed DSC 10-bit extended ISO original RGB digital code values.

Wavelength (nm.)	Aim Red Digital Code Values	Aim Green Digital Code Values	Aim Blue Digital Code Values	Transformed Red Digital Code Values	Transformed Green Digital Code Values	Transformed Blue Digital Code Values
360	0	0	0	0	0	0
370	0	0	0	0	0	0
380	0	0	1	0	0	0
390	0	0	3	0	1	1
400	1	-2	16	-3	1	23
410	5	-6	36	-7	-1	43
420	14	-17	67	-11	-10	66
430	21	-27	95	-12	-12	73
440	22	-33	118	-3	-21	92
450	5	-32	127	-6	-24	106
460	-27	-21	124	-11	-21	113
470	-44	14	110	-20	-3	114
480	-55	38	88	-32	31	110
490	-62	52	64	-44	52	101
500	-73	67	45	-56	72	90
510	-83	83	23	-66	88	75
520	-88	96	-17	-71	99	50
530	-85	105	-30	-73	107	-12
540	-71	106	-35	-66	106	-51
550	-40	104	-37	-48	103	-64
560	50	98	-36	37	94	-64
570	85	88	-33	83	82	-58
580	109	75	-30	109	68	-49
590	121	56	-25	116	49	-36
600	131	36	-20	119	31	-23
610	132	6	-15	116	8	-9
620	124	-18	-10	109	-11	2
630	108	-22	-6	99	-19	8
640	92	-20	-4	91	-21	11
650	73	-15	-2	78	-19	10
660	56	-10	-1	66	-15	8
670	40	-6	-1	53	-9	5
680	27	-3	0	38	-3	2
690	15	-1	0	22	0	0
700	8	-1	0	7	0	0
710	4	0	0	2	0	0
720	2	0	0	0	0	0
730	1	0	0	0	0	0
740	1	0	0	0	0	0
750	0	0	0	0	0	0
760	0	0	0	0	0	0
770	0	0	0	0	0	0
780	0	0	0	0	0	0
790	0	0	0	0	0	0
800	0	0	0	0	0	0
810	0	0	0	0	0	0
820	0	0	0	0	0	0
830	0	0	0	0	0	0
			RMS Difference:	12	5	19

3. The RMS differences listed at the bottom of table C2 are the ISO DSC metamerism indexes for the three channels. The overall metamerism index (RMS difference) for this example is 13. These values are rounded to the nearest integer so that the accuracy of the values is not assumed to be greater than is meaningful. In addition to the uncertainties in the accuracy of the colour matching functions mentioned in annex B, and variation between different observers, there are always uncertainties in the measurement of DSC spectral sensitivities. It is possible for small changes in spectral sensitivity to produce moderate changes in the transformation matrix. Fortunately such changes tend to result in small changes in the metamerism index.

4. The criterion used for determining the matrix in equation C1 results in this matrix producing the smallest metamerism index consistent with white point preservation for the specified spectral sensitivities. This matrix will generally produce good results, but in some cases it may be desirable to use a different transformation matrix. Method B may be used to determine the matrix, or an analogue of method A with some other criterion for minimisation. For example, if the criterion used is to produce the smallest white point preserving mean square difference between the ISO original RGB colour matching functions and the measured spectral sensitivities, the matrix in equation C2 is obtained.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{LinearOriginalRGB} = \begin{bmatrix} 2{,}0727 & -0{,}9164 & -0{,}1562 \\ -0{,}1836 & 1{,}4877 & -0{,}3042 \\ 0{,}2205 & -0{,}8049 & 1{,}5844 \end{bmatrix} \begin{bmatrix} Ch1 \\ Ch2 \\ Ch3 \end{bmatrix}_{LinearCameraData} \qquad (C2)$$

This matrix is somewhat different from the one in equation C1 because the minimisation is performed in linear, equi-energy space. If it is used, the metamerism indexes increase slightly, with red = 12, green = 7, blue = 21, and the overall metamerism index = 15.

Annex D
(Informative)

The place of ISO original RGB data in an image processing/rendering pipeline

ISO original RGB data represents a DSC's best attempt to colorimetrically analyse a captured scene or original. It is not an attempt to in any way describe a reproduction. In many cases, particularly with pictorial imaging or photography, the preferred reproduction will have colorimetry that is quite different from that of the scene or original. This may be because of different assumed viewing conditions for the reproduction, because of dynamic range and gamut limitations of the reproduction medium, and/or because the most pleasing reproduction for a particular application may have colours that are different from those in the scene or original. Also, a reproduction produced for one purpose may have colours that are different from those produced for another purpose, even on the same medium. Appearance models attempt to account for differences in viewing conditions, but do not deal with these other factors. Current appearance models are also considered by many to be incomplete for complex images because they do not deal with local contrast effects, such as are considered by Retinex type approaches. Additionally, experience with reproduction and preferred reproduction models indicates that optimal dynamic range and gamut mapping, and preferred reproduction processing, are image dependent.

Because of these considerations, it is not practical to standardize processing that takes a colorimetric or appearance description of a scene or original and produces a reproduction description appropriate for any medium and any purpose. In order to communicate colour information digitally, it is therefore necessary to standardize data forms that describe both scenes or originals, and reproductions, and to explicitly differentiate between these two types of descriptions. This International Standard specifies a standard form for data describing the colorimetry of a scene or original. It does it in a way that has the additional advantage of being colour constant. IEC 61966-2-1, sRGB, specifies a standard form for data describing the colorimetry of a reproduction. Special care has been taken to ensure that this International Standard and sRGB are complementary to each other. For example, if the white point chromaticity for ISO original RGB is selected to be that of CIE illuminant D_{65}, the primaries on which the ISO colour matching functions are based become equivalent to those used for sRGB. These two standards are also aligned with ITU-R BT.709, which uses the same primaries as sRGB, and specifies an OECF that results in video type rendering when the captured data values are displayed on an sRGB standard display. The product of the 709 OECF and the sRGB EOCF is the standard video rendering processing. However, for the reasons stated in the preceding paragraph, standard video rendering is not optimal for most still images, hence the need to standardize original and reproduction descriptions as opposed to the rendering processing.

At present, most consumer type DSCs process the image data to a reproduction description. This allows lossy compression to be used with less possibility of artifacts being made visible by subsequent processing. It also allows displays and other output devices to be less intelligent in producing the reproduction. Since the images produced by these DSCs are a description of a reproduction which should be close to that of the actual reproduction in dynamic range and gamut, the transforms to produce the actual reproduction from the reproduction description tend to be mild and work well for all images. The default reproduction description is sRGB, which describes a display viewed in specific conditions appropriate for viewing images. The dynamic range and gamut of an sRGB display are also reasonably similar to those of most types of reflection hardcopy.

This International Standard does not specify how to determine transformations to sRGB. It specifies how to determine transformations that estimate scene colorimetry, which must then be processed to a reproduction description such as sRGB. Even if the goal is to produce the scene colorimetry on an sRGB display, a transformation must be used for critical work because of the sRGB veiling glare. However, the common D_{65} primaries chosen for both standards allow rendering to be accomplished in a simple manner, sometimes as simple as a single one-dimensional look-up-table applied to each of the RGB channels. In some cases, image data encoded as ISO original RGB will even produce an acceptable appearance when displayed directly using the sRGB standard display and viewing conditions. Table D1 lists the attributes of ISO RGB and sRGB.

Table D1 - Attributes of RGB colour spaces described in this International Standard and in IEC 61966-2-1.

Image data form	linear or perceptually compact	integer or floating point	signed or limited gamut	specified dynamic range and viewing conditions	fixed or floating white point and primaries	scene/ original or reproduction description
linear original RGB	linear	floating point	signed	no	floating	scene/ original
ISO original RGB	perceptually compact	8-bit integer	limited gamut	no	floating	scene/ original
extended ISO original RGB	perceptually compact	10- to 16-bit integer	signed	no	floating	scene/ original
sRGB	perceptually compact	8-bit integer	limited gamut	yes, DR = 100:1	fixed; D_{65} wp, 709 primaries	reproduction

Since most consumer DSCs produce reproduction descriptions, the utility of this International Standard as applied to these DSCs is largely to allow manufacturers to take advantage of scene colorimetry based appearance, reproduction, and preferred reproduction models to process image data to standard reproduction descriptions, and to provide a context for the evaluation of DSC scene analysis performance while recognizing that further processing is typically required. Such processing may be proprietary. Consequently, this International Standard does not require that production models of a DSC be able to output ISO original RGB data for this standard to be applied.

Annex E
(Informative)

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Informative references relevant to the development of this standard are listed below.

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