SMPTE RP 2093:2020

SMPTE RECOMMENDED PRACTICE

Television Lighting Consistency Index (TLCI)

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Approved April 9, 2020

Foreword

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Intellectual Property

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Introduction

This section is entirely informative and does not form an integral part of this Engineering Document.

This document is a recommended practice for assessing the colorimetric quality of lighting when used in Standard Dynamic Range television production using a Television Lighting Consistency Index (TLCI) value. It was developed because the generic lighting Color Rendering Index (CRI) was never intended for use in television production. In particular, the application of white balance in TV systems renders CRI inappropriate.

Luminous efficacy can be defined as the number of lumens of light produced per watt of electrical power consumed. Since the lumen is measured using a psychovisual-weighted function of the wavelength, the highest luminous efficacies will typically be reported from those luminaires producing predominantly yellow/green light in the peak visual region of the spectrum. An extreme example of this can be experienced under sodium street lighting, but even LED sources exhibiting a "white" appearance often consist of just a narrow spectrum blue source and a secondary yellow phosphor, producing visibly poor renditions of intense colors.

Once colors have been rendered into a TV camera workflow, it could be difficult or even impossible to match pictures taken under other lighting, which can be a particular problem if mixed lighting is used.

Television or film lighting requires luminaires of good efficiency that enable acceptable color rendering, and the function of this Recommended Practice is to quantify the color performance of the luminaire. This number indicates the difficulty in color matching that will be encountered using the measured luminaire against a reference luminaire (usually daylight or tungsten lighting).

The method of RP 2093 yields the same result as EBU Tech 3355, Method for the Assessment of the colorimetric properties of Luminaires, dated March 2017.

The TLCI is optimized for Recommendation ITU-R BT.709 primaries and transfer characteristics. The results obtained are also useful for assessing lighting for use with Recommendation ITU-R BT.2020 primaries and Recommendation ITU-R BT.1886 display characteristics.

1 Scope

This Recommended Practice describes the measurement procedure and TLCI metric for assessing the colorimetric quality of lighting (luminaires), including LEDs, when used in Standard Dynamic Range television production.

2 Conformance Notation

Normative text is text that describes elements of the design that are indispensable or contains the conformance language keywords: "shall", "should", or "may". Informative text is text that is potentially helpful to the user, but not indispensable, and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

All text in this document is, by default, normative, except: the Introduction, any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:"

The keywords "shall" and "shall not" indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

The keywords "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

The keyword “reserved” indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword “forbidden” indicates “reserved” and in addition indicates that the provision will never be defined in the future.

A conformant implementation according to this document is one that includes all mandatory provisions ("shall") and, if implemented, all recommended provisions ("should") as described. A conformant implementation need not implement optional provisions ("may") and need not implement them as described.

Unless otherwise specified, the order of precedence of the types of normative information in this document shall be as follows: Normative prose shall be the authoritative definition; Tables shall be next; then formal languages; then figures; and then any other language forms.

3 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this engineering document. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this engineering document are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below.

ISO 11664-1:2007 Colorimetry – Part 1: CIE standard colorimetric observers

ISO 11664-3:2012 Colorimetry – Part 3: CIE tristimulus values

ISO 11664-4:2008 Colorimetry – Part 4: CIE 1976 L*a*b* Colour space

ISO 11664-6:2014 Colorimetry – Part 6: CIEDE2000 Colour-Difference Formula

IEEE 754-2008 - IEEE Standard for Floating-Point Arithmetic

Recommendation ITU-R BT.709-6 (06/2015), Parameter values for the HDTV standards for production and international programme exchange.

4 Terms and Definitions

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

4.1 color chart

chart containing a number of colored samples that is frequently used for testing the performance of cameras

4.2 Color Rendering Index

CRI

method of measuring and specifying colour rendering properties of light sources as defined in CIE 13.3-1995

4.3 Correlated Color Temperature

CCT

temperature of a radiator having the chromaticity nearest the chromaticity associated with the given spectral distribution on a diagram of the Planckian or daylight locus as appropriate and the test stimulus are depicted

Note: the (CIE 1931 standard observer based) *u*', 2/3*v'* coordinates are used in the calculation of CCT.

4.4 CIE 1931 standard observer

ideal observer whose color-matching properties correspond to the CIE color-matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$
[Source: ISO 11664-1:2007]

4.5 CIEDE2000

color difference formula defined in ISO 11664-6

4.6 daylight locus

locus of points in a chromaticity diagram that represents chromaticities of phases of daylight with different CCTs

4.7 daylight radiator

radiator with an spd simulating daylight with a given CCT

Note: the spd is defined in this document

4.8 mixed radiation

blend of Planckian and daylight radiation

4.9 Planckian locus

locus of points in a chromaticity diagram that represents chromaticities of the radiation of Planckian radiators at different temperatures
[Source: ISO 11664-2:2007(en), 3.11]

4.10 Planckian radiator

radiator with an spd simulating a black body radiator with a given CCT

Note: the spd is defined in this document

4.11 reference camera

camera model used in this document to calculate RGB values from spectral data

4.12 reference display

display model used in this document to calculate XYZ values

4.13 reference luminaire

luminaire with a calculated spectral power distribution such that it has a chromaticity which falls on either the Planckian or daylight locus, and it has the same Correlated Color Temperature (CCT) as the test luminaire

4.14 spectral power distribution

spd

relative distribution of the radiant power of a luminaire by wavelength

4.15 spectral reflectance

relative reflectance of an illuminated color sample by wavelength

4.16 relative spectral radiance

spectral power distribution multiplied by a spectral reflectance by wavelength

4.17 test luminaire

luminaire being tested for which the spectral power distribution is known or has been measured

4.18 Television Lighting Consistency Index

TLCI

index indicating the suitability of a luminaire for television production

4.19 XYZ

tristimulus values calculated using the CIE 1931 standard colorimetric observer

4.20 Definitions of mathematical functions

4.20.1 abs(*i*)

mathematical function that returns the absolute value of i: $-i$ if $i < 0$, i otherwise

4.20.2 arctan(*x, y*)

mathematical function that returns the arc tangent of y/x in degrees while taking into account which quadrant the point (x, y) is in

Note: The result can be in any range covering 360 degrees, such as [-180,180] or [0, 360].

4.20.3 max(*x*, *y*)

mathematical function that returns the larger of x and y

4.20.4 mod(*m, n*, *d*)

mathematical function that returns x such that $d <= x < d + n$ and $m - x$ is a multiple of n

Note: mod (a remainder after dividing m by n) is abbreviation for ‘modulo' (sometimes modulus)

4.20.5 tan(*x*)

mathematical function that returns the tangent of x where x is in units of degrees

5 Calculating the Television Lighting Consistency Index (TLCI)

5.1 Principle of the TLCI (Informative)

Rather than assess the performance of a luminaire directly, as is done in the Color Rendering Index, the TLCI mimics a complete television camera and display using only those specific features of cameras and displays which affect color performance.

The TLCI is realized in practice using software rather than real television hardware. The only hardware that is used is a spectroradiometer to measure the spectral power distribution of the test luminaire and a computer on which to run the software analysis program to perform the calculations.

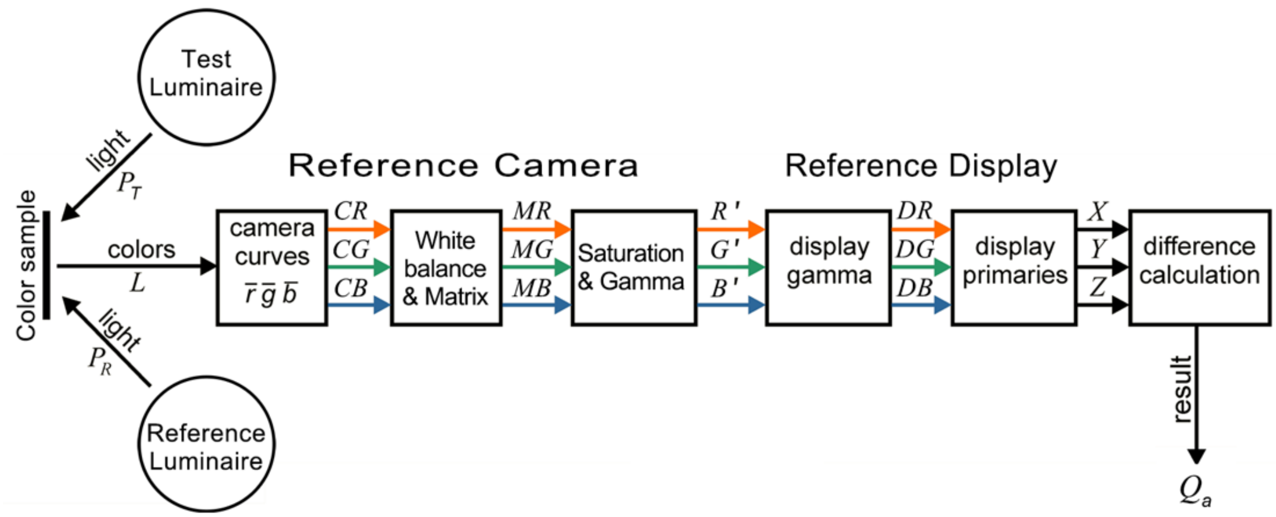

Figure 1. TLCI process diagram

A mathematically-specified set of reflective color samples is simulated as being lit by either the test luminaire or a reference luminaire. The reference camera produces linear $R_C\ G_C\ B_C$ signals which are then modified by a conventional 3x3 matrix followed by gamma-correction. The reference display has a defined electro-optic gamma function and defined primaries. The output of the display is simulated and analyzed using standard colorimetric processes to measure the difference between the performance of the test and reference luminaire for each color sample, before producing a single result value (Q_a) from all color samples.

5.2 TLCI Calculation process

The full procedure shall consist of the following steps, as described in detail in the following sub-sections. All spectral computations shall be done using data at 5 nm intervals from 380 to 760 nm. All calculations shall be performed using double precision as defined in IEEE 754.

1. Obtain the spectral power distribution (spd) of the test luminaire
2. Calculate CCT of test luminaire from the spd using the procedure in section 5.3.1
3. Determine the spd of the reference luminaire at that CCT using the procedure in section 5.3.2
4. For both test and reference luminaires, apply this common subroutine:

   a. Calculate Display XYZ values from the luminaire spd as follows:
      i. Calculate the relative spectral radiance for each color sample, using the procedure in section 5.5
      ii. Calculate reference camera output values for each color sample, using the procedure in section 5.5
      iii. Convert these values to reference display XYZ values using the procedure in section 5.6
5. Calculate Q_a value from differences between reference and test XYZ values
   a. For each color sample, calculate the CIEDE2000 value for the difference between reference and test XYZ values using the procedure in section 5.7.1
   b. Calculate Q_a value from the CIEDE2000 values using the procedure in section 5.7.2

The calculations described in this document shall use the normative data defined in the associated spreadsheet SMPTE RP 2093a, which contains the following:

Table 1: Chromaticities of the Planckian radiator.

Table 2: Chromaticities of the daylight radiator.

Table 3: Component spectra, S_0, S_1 and S_2 for calculating the spd of the daylight radiator. The values were taken from CIE Tech 15:2004 Appendix C.

Table 4: Color chart reflectivities.

Table 5: Reference camera responsivity.

5.3 Determining the spd of the Reference Luminaire

The reference luminaire has the same Correlated Color Temperature as the test luminaire, which is established as below.

5.3.1 Calculation of Correlated Color Temperature (CCT) of the Test Luminaire

After measuring the spectral power distribution of the test luminaire ($P_{T,\lambda}$), its chromaticity coordinates are obtained as follows.

The tristimulus values (X_T, Y_T, Z_T) shall be calculated from $P_{T,\lambda}$ using equation 1.

$$X_T = \sum_{\lambda=380}^{760} P_{T,\lambda}\bar{x}_\lambda$$

$$Y_T = \sum_{\lambda=380}^{760} P_{T,\lambda}\bar{y}_\lambda \qquad (1)$$

$$Z_T = \sum_{\lambda=380}^{760} P_{T,\lambda}\bar{z}_\lambda$$

where:

$\bar{x}_\lambda$, $\bar{y}_\lambda$ and $\bar{z}_\lambda$ are the CIE 1931 standard observer color-matchings functions defined in ISO 11664-1:2007 table 1, using the data at 5 nm intervals.

Note: Equation 1 is a simplified version of the standard colorimetric calculation defined in ISO 11664-1

Then the CIE 1931 chromaticity coordinates shall be derived using Equation 2 (as defined in ISO 11664-3).

$$x = \frac{X_T}{X_T+Y_T+Z_T}$$
$$y = \frac{Y_T}{X_T+Y_T+Z_T} \qquad (2)$$

The *u, v* chromaticity coordinates of the test luminaire, u_{test} and v_{test} , shall be calculated using Equation 3.

$$u_{test} = \frac{4x}{12y-2x+3}$$
$$v_{test} = \frac{6y}{12y-2x+3} \qquad (3)$$

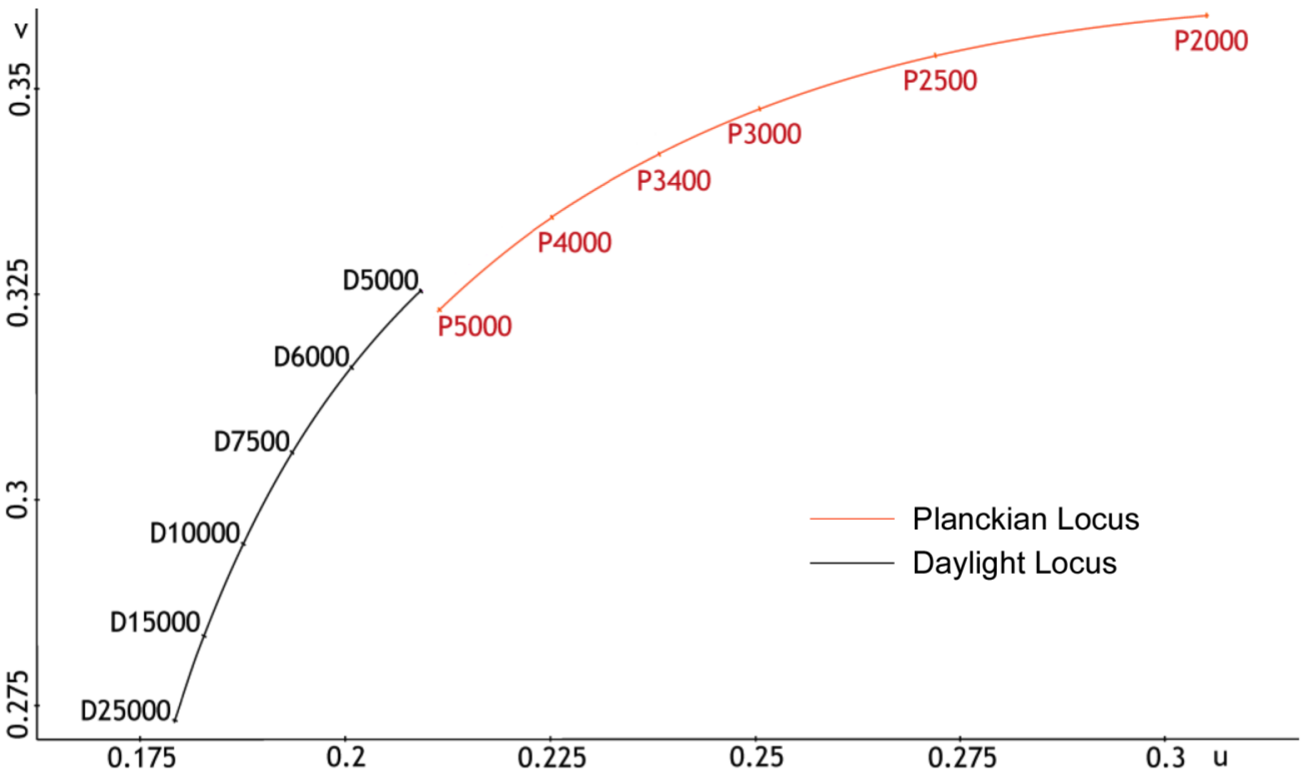

Figure 2. Chromaticity diagram, Planckian and daylight loci, CIE 1960

The data values in Tables 1 and 2 of the associated spreadsheet SMPTE RP 2093a define points on two segmented lines representing the loci, where each point specifies the chromaticity coordinate of a CCT, as shown in Figure 2.

The CCT of the test luminaire, *T*, is taken as the CCT in Kelvin of the point on the line closest to the test luminaire's chromaticity coordinate.

The applicable line segment is found by evaluating the angles between the test luminaire's chromaticity coordinate and the vertices of all line segments, and selecting a segment based on these angles.

The CCT is determined from the intersection of the line segment and its normal to the test luminaire's chromaticity coordinate.

The applicable line segment is determined as follows:

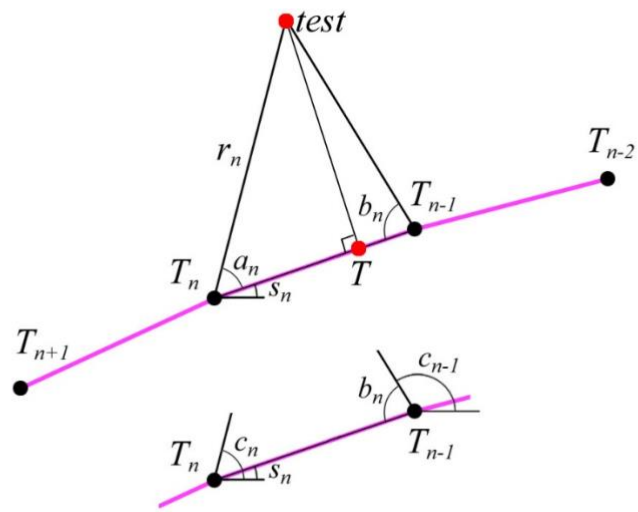

Figure 3 CCT calculation

The Planckian locus data shall be processed separately from the daylight locus data.

The line segment n is composed of the line joining pair of points, T_n and T_{n-1} , having coordinates (u_n, v_n) and (u_{n-1}, v_{n-1}), obtained from Tables 1 and 2 in the associated spreadsheet SMPTE RP 2093a, as n steps through all the adjacent data point pairs for the respective locus.

If $u_{test} = u_n$ and $v_{test} = v_n$ then T shall be T_n. Otherwise T shall be calculated as follows in Equation 4.

In the following section, all angles shall be expressed in degrees. Figure 3 illustrates the angles being used.

The angle c_n (the angle between line r_n and the u-axis) shall be calculated:

$$c_n = \arctan\left(u_{test} - u_n, v_{test} - v_n\right) \tag{4}$$

The angle s_n (the slope of the line segment n) shall be calculated:

$$s_n = \arctan\left(u_{n-1} - u_n, v_{n-1} - v_n\right) \tag{5}$$

The angle a_n (between line r_n and the line segment n) shall be calculated:

$$a_n = \mathrm{abs}(\mathrm{mod}(c_n - s_n, 360, -180)) \tag{6}$$

The angle b_n shall be calculated:

$$b_n = 180 - \text{abs}(\text{mod}(c_{n-1} - s_n, 360, -180)) \quad (7)$$

A match shall be defined as the line segment n that has the smallest max(a_n, b_n).

The CCT, T, shall be calculated as below:

$$\text{if } a_n \neq 0 \text{ then } \quad T = T_{n-1} + \frac{\tan(a_n)(T_n - T_{n-1})}{\tan(a_n) + \tan(b_n)}$$
$$\text{if } a_n = 0 \text{ then } \quad T = T_{n-1} + \frac{(u_{n-1} - u_{test})(T_n - T_{n-1})}{u_{n-1} - u_n} \quad (8)$$

Example: u_{test} = 0.199019, v_{test} = 0.313953 gives T = 6279.44

Note: This procedure is only valid for T in the range 1000 K to 25000 K.

5.3.2 Determining the spd of the Reference Luminaire

5.3.2.1 Selection of Reference Luminaire

The reference luminaire shall have the same CCT (T) as the test luminaire.

If T is less than or equal to 3400 K, then the reference luminaire shall have an spd of a Planckian radiator.

If T is greater than or equal to 5000 K, then the reference luminaire shall have an spd of a daylight radiator.

If T lies between 3400 K and 5000 K, then the reference luminaire shall have an spd of a mixed radiator, which shall be a linear interpolation between a Planckian radiator at 3400 K and a daylight radiator at 5000 K.

5.3.2.2 Planckian radiator

The spd P_λ of a Planckian radiator shall be calculated as follows:

$$P_\lambda = 100 \left(\frac{560}{\lambda}\right)^5 \frac{exp\left(\frac{1.435\times10^7}{560T}\right)-1}{exp\left(\frac{1.435\times10^7}{\lambda T}\right)-1} \quad (9)$$

where

λ = the wavelength in nanometers (nm),

T = the Correlated Color Temperature in Kelvin.

Note 1: The values are normalized such that the value at 560 nm is 100.
Note 2: The constant value 1.435 is used for compatibility with EBU Tech.3355.

5.3.2.3 Daylight radiator

The calculation of the spd of the daylight radiator shall be as described in equations 10-13.

Note: this follows the procedure of Appendix C of CIE Tech 15:2004.

x_D and y_D (the CIE 1931 chromaticity coordinates of the Correlated Color Temperature T) shall be:

$$\text{if } T < 7000\ K \text{ then} \quad x_D = -4.6070 \left(\frac{10^3}{T}\right)^3 + 2.9678 \left(\frac{10^3}{T}\right)^2 + 0.09911 \left(\frac{10^3}{T}\right) + 0.244063$$

$$\text{if } T \geq 7000\ K \text{ then} \quad x_D = -2.0064 \left(\frac{10^3}{T}\right)^3 + 1.9018 \left(\frac{10^3}{T}\right)^2 + 0.24748 \left(\frac{10^3}{T}\right) + 0.237040 \quad (10)$$

$$y_D = -3.000\, x_D{}^2 + 2.870\, x_D - 0.275 \quad (11)$$

The values M_1 and M_2 shall be derived from the chromaticity coordinates:

$$M_1 = \frac{-1.77861\, x_D + 5.90757\, y_D - 1.34674}{0.25539\, x_D - 0.73217\, y_D + 0.02387}$$

$$M_2 = \frac{-31.44464\, x_D + 30.06400\, y_D + 0.03638}{0.25539\, x_D - 0.73217\, y_D + 0.02387} \quad (12)$$

The spd, D_λ shall be:

$$D_\lambda = S_{0\lambda} + M_1 S_{1\lambda} + M_2 S_{2\lambda} \quad (13)$$

where

S_0, S_1 and S_2 are specified in Table 3 of the associated spreadsheet SMPTE RP 2093a.

Note 1: The values in table 3 are used for compatibility with EBU Tech.3355.

Note 2: The resultant spd is normalized such that the value at 560 nm is 100.

5.3.2.4 Mixed radiator

The spd of a reference luminaire for mixed radiation is calculated as follows:

$$M_\lambda = \frac{D_{5000,\lambda}(T-3400) + P_{3400,\lambda}(5000-T)}{5000-3400} \quad (14)$$

where

$D_{5000,\lambda}$ and $P_{3400,\lambda}$ are the daylight and Planckian values returned from the calculations at 5000 K and 3400 K respectively.

Figure 4 illustrates the transition between daylight and Planckian loci.

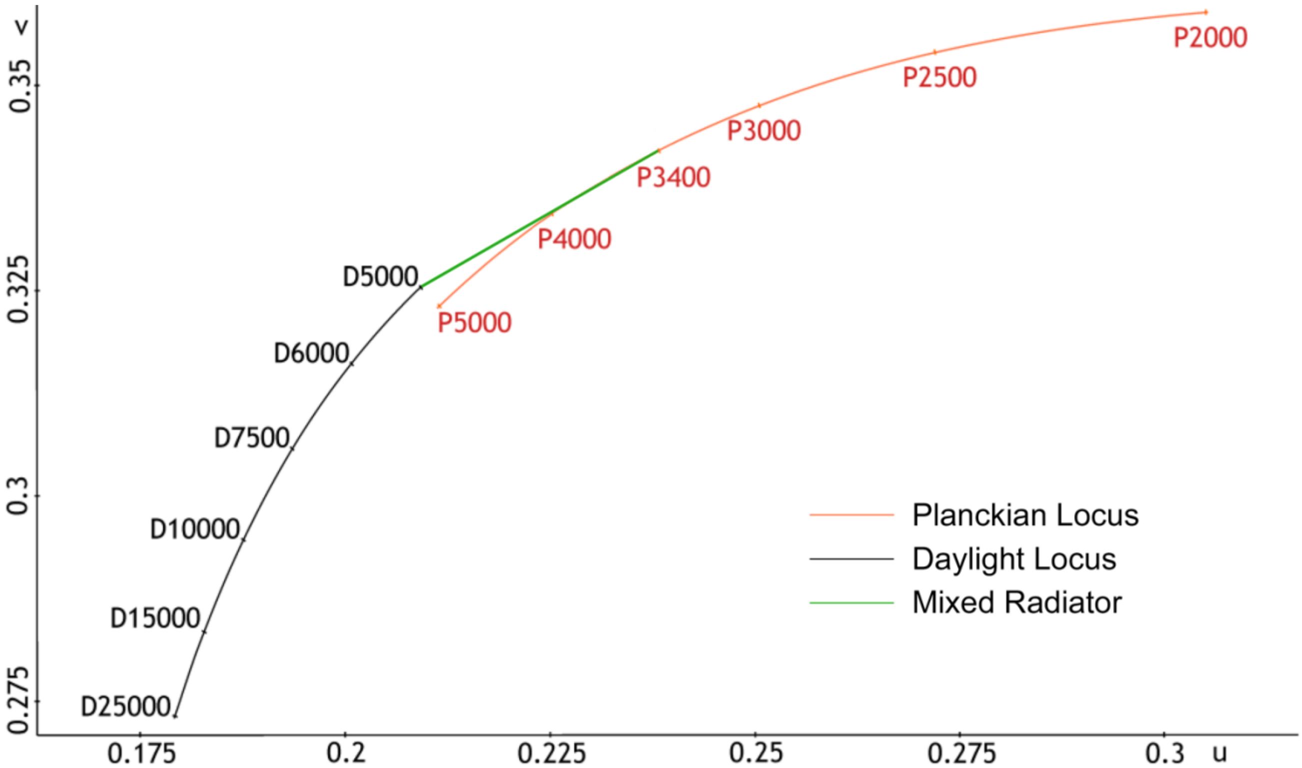

Figure 4 (informative). Planckian and daylight loci with the mixed lighting locus used for CCTs between 3400 K and 5000 K (CIE 1960 chromaticity diagram).

5.4 Color Samples

Table 4 of the associated spreadsheet SMPTE RP 2093a defines a set of spectral reflectances to be used as color samples.

The relative spectral radiance of each simulated illuminated sample, L_i shall be calculated as follows:

$$L_{i,\lambda} = SPDL_\lambda \, S_{i,\lambda} \tag{15}$$

where

λ is wavelength of light in nanometers (nm).

SPDL is the spectral power distribution for the luminaire (*P, D* or *M*, as per section 5.3.2.1) calculated for each of the test and reference luminaires in turn.

S_i is the spectral reflectance of the color sample *i* as specified in Table 4 of the associated spreadsheet SMPTE RP 2093a.

i is the index of the color sample (1-18).

Note: These color samples correspond to the 18 colored patches of a color chart, as shown in Figure 5.

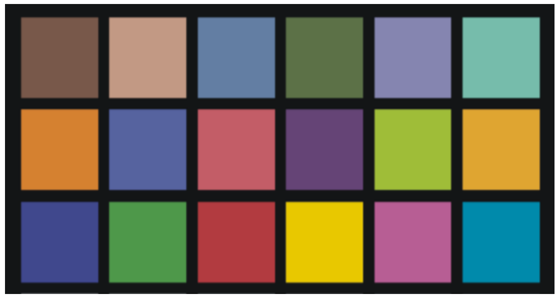

Figure 5. Color chart

5.5 Reference Camera

5.5.1 Definition of Reference Camera

The reference camera converts the relative spectral radiance, L_i, of each simulated illuminated sample, *i,* to Recommendation ITU-R BT.709 RGB video signal values. The camera processing shall consist of the following steps:

1. Applying the camera responsivity as specified in section 5.5.2,
2. Applying a white balance as specified in section 5.5.3,
3. Applying the camera matrix as specified in section 5.5.4,
4. Applying the saturation matrix as specified in section 5.5.5,
5. Applying the opto-electronic transfer function as specified in section 5.5.6.

5.5.2 Applying the responsivity of the reference camera

The signals, CR_i, CB_i, CG_i, generated by the sensors of the reference camera shall be calculated as:

$$CR_i = \sum_{\lambda=380}^{760} L_{i,\lambda}\bar{r}_\lambda$$

$$CG_i = \sum_{\lambda=380}^{760} L_{i,\lambda}\bar{g}_\lambda \qquad (16)$$

$$CB_i = \sum_{\lambda=380}^{760} L_{i,\lambda}\bar{b}_\lambda$$

where

λ is wavelength of light in nanometers (nm).

$\bar{r}_\lambda$, $\bar{g}_\lambda$ and $\bar{b}_\lambda$ are the responsivities of the reference camera sensors tabulated in Table 5 of the associated spreadsheet SMPTE RP 2093a.

L_i is the relative spectral radiance of the simulated illuminated color sample *i*

i is the index of the color sample (1-18)

CR_i, CG_i, CB_i are camera sensor RGB values of the simulated illuminated color sample *i*

5.5.3 White balance

The camera sensor RGB values shall be normalized and color balanced for each of the luminaires in turn (test and reference), as follows:

$$CR_w = \sum_{\lambda=380}^{760} P_\lambda \bar{r}_\lambda$$

$$CG_w = \sum_{\lambda=380}^{760} P_\lambda \bar{g}_\lambda \qquad (17)$$

$$CB_w = \sum_{\lambda=380}^{760} P_\lambda \bar{b}_\lambda$$

and

$$WbR_i = CR_i \,/\, CR_w$$

$$WbG_i = CG_i \,/\, CG_w \qquad (18)$$

$$WbB_i = CB_i \,/\, CB_w$$

where

λ is wavelength of light in nanometers (nm).

P is the spectral power distribution for the luminaire (which shall be one of P_T or P_R)

$\bar{r}_\lambda$, $\bar{g}_\lambda$ and $\bar{b}_\lambda$ are the responsivities of the reference camera sensors tabulated in Table 4 of the associated spreadsheet SMPTE RP 2093a.

CR_i, CG_i, CB_i are camera sensor RGB values of the simulated illuminated color sample *i*

i is the index of the color sample (1-18)

WbR_i, WbG_i, WbB_i are white balanced RGB values of the simulated illuminated color sample *i*

5.5.4 Reference Camera Matrix

The reference camera matrix operation, which converts white-balanced RGB values to Recommendation ITU-R BT.709 RGB values shall be defined as follows:

$$\begin{bmatrix} MR_i \\ MG_i \\ MB_i \end{bmatrix} = \begin{bmatrix} 1.182 & -0.209 & 0.027 \\ 0.107 & 0.890 & 0.003 \\ 0.0040 & -0.134 & 1.094 \end{bmatrix} \cdot \begin{bmatrix} WbR_i \\ WbG_i \\ WbB_i \end{bmatrix} \qquad (19)$$

where

i is the index of the color sample (1-18)

WbR_i, WbG_i, WbB_i are white balanced RGB values of the simulated illuminated color sample i

MR_i, MG_i, MB_i are post-matrix RGB values of the simulated illuminated color sample i

Note: This matrix was optimized for color performance with the given reference camera and display non-linearities.

5.5.5 Reference Camera saturation control

The reference camera includes a saturation control, which shall be applied after the camera matrix and white-balancing but before the gamma-correction. This is to prevent clipping of some colors when lit by some luminaires.

The saturation level shall be 90%, and thus the saturation matrix shall be applied as follows:

$$\begin{bmatrix} SR_i \\ SG_i \\ SB_i \end{bmatrix} = \begin{bmatrix} 0.9\dot{3} & 0.0\dot{3} & 0.0\dot{3} \\ 0.0\dot{3} & 0.9\dot{3} & 0.0\dot{3} \\ 0.0\dot{3} & 0.0\dot{3} & 0.9\dot{3} \end{bmatrix} \cdot \begin{bmatrix} MR_i \\ MG_i \\ MB_i \end{bmatrix} \qquad (20)$$

where

i is the index of the color sample (1-18)

MR_i, MG_i, MB_i are post-matrix RGB values of the simulated illuminated color sample i

SR_i, SG_i, SB_i are desaturated RGB values of the simulated illuminated color sample i

The SR_i, SG_i, SB_i values shall lie within the range 0 to 1. If there is any color sample, i, with any SR_i, SG_i, SB_i value lying outside the range 0 to 1, then the TLCI calculation and index are not valid.

5.5.6 Opto-electronic transfer characteristic

The opto-electronic transfer characteristics defined in Recommendation ITU-R BT.709 (Item 1.2: Overall opto-electronic transfer characteristics at source) shall be applied to each of the linear signals SR_i, SG_i, SB_i to calculate the “electrical signal” values R_i', G_i', B_i'.

5.6 Reference Display

5.6.1 Overview

The reference display (a mathematical model of an idealized display) shall be defined by two processes, the non-linearity or electro-optical transfer function as defined in 5.6.2, and the display synthesis matrix as defined in 5.6.3.

5.6.2 Electro-optical transfer characteristic

The electro-optical transfer characteristic of the reference display shall be applied:

$$DR_i = (R_i')^{2.4}$$

$$DG_i = (G_i')^{2.4} \qquad (21)$$

$$DB_i = (B_i')^{2.4}$$

where

DR, DG, DB are the red, green and blue components of light output from the display.

R', G', B' are the electrical signals calculated in section 5.5.6, (the display input signals).

i is the index of the color sample (1-18).

Note: The above electro-optical transfer characteristic is the same as that which is defined in Recommendation ITU-R BT.1886.

5.6.3 Display Synthesis Matrix

The display synthesis matrix shall be as defined in Equation 22.

$$\begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} = \begin{bmatrix} 0.412391 & 0.357584 & 0.180481 \\ 0.212639 & 0.715169 & 0.072192 \\ 0.019331 & 0.119195 & 0.950532 \end{bmatrix} \cdot \begin{bmatrix} \mathrm{DR_i} \\ \mathrm{DB_i} \\ \mathrm{DG_i} \end{bmatrix} \qquad (22)$$

where

X, Y, Z are the CIE 1931 tristimulus values.

DR, DG, DB are the red, green and blue components of light output from the display.

i is the index of the color sample (1-18).

Note: this synthesis matrix has been derived from the display primaries and white point of Recommendation ITU-R BT.709.

5.7 Color-difference Calculations

5.7.1 Calculation of CIEDE2000 color differences

The reference and test color $X_iY_iZ_i$ tristimulus values for each color sample, *i*, shall be converted to CIELAB L^*, a^*, b^* coordinates according to ISO 11664-4, with the X_n, Y_n, Z_n set to 0.950456, 1.0, 1.089058 (corresponding to the white point of Recommendation ITU-R BT.709).

The CIEDE2000 color difference ΔE_{00} for color sample *i*, shall be calculated according to ISO 11664-6 using the pair of CIELAB L^*, a^*, b^* coordinates calculated as above for color sample *i* under the reference and test luminaires. The parametric factors k_L, k_C and k_H, as defined in ISO 11664-6, shall be unity.

5.7.2 Calculation of the RP 2093 TLCI value, Q_a

ΔE^*_a is a power-average of the ΔE_{00} values for color sample *i*, and shall be calculated as follows:

$$\Delta E^*_a = \left(\frac{1}{n}\sum_{i=1}^{n} (\Delta E^*_i)^4\right)^{1/4} \tag{23}$$

where

n shall be 18.

ΔE^* is the CIEDE2000 color difference ΔE_{00}

The TLCI value Q_a shall be calculated using the following formula:

$$Q_a = \frac{100}{1+\left(\frac{\Delta E^*_a}{k}\right)^p} \tag{24}$$

where

k shall be 3.16

p shall be 2.4.

ΔE^*_a shall be as calculated in equation 23.

Note: The constant k was set to give a Q_a value of 50 when a daylight fluorescent tube (which was within a ΔE^*_a of 3.16 from D65) was assessed.

5.7.3 Interpretation of Q_a (Informative)

The Q_a scale can be labeled in one of two ways: using the ITU 5-point quality scale (Recommendation ITU-R BT.500), or using opinions derived from a small set of subjective tests conducted by the EBU, using five professional colorists, as shown in Figure 6.

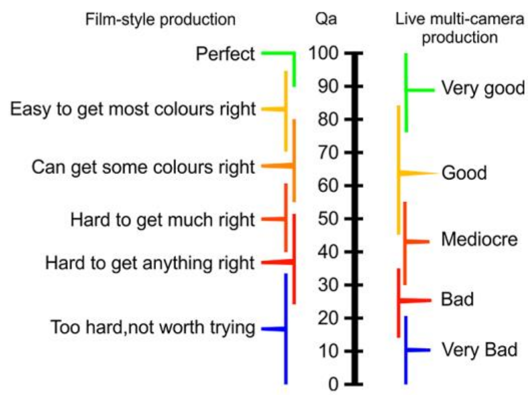

Figure 6. Subjective interpretation of Q_a values

Work in the EBU indicated that a typical daylight fluorescent tube, with a Q_a of 50, was a critical point for television colorists in that errors greater than this are difficult to correct fully, but smaller errors can usually be corrected (with varying degrees of success).

An example of how the results can be presented in greater detail is provided in EBU Recommendation 137.

Bibliography (Informative)

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ISO 11664-2 Colorimetry - Part 2: CIE standard illuminants

Recommendation ITU-R BT.500, Methodology for the subjective assessment of the quality of television pictures

Recommendation ITU-R BT.1886, Reference electro-optical transfer function for flat panel displays used in HDTV studio production

Recommendation ITU-R BT.2020, Parameter values for ultra-high definition television systems for production and international programme exchange