SMPTE STANDARD

Reference White Luminance Level and Chromaticity for HDTV

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Approved
November 24, 2014

Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally-recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Recommended Practices, and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

SMPTE Engineering Documents are drafted in accordance with the rules given in its Standards Operations Manual.

SMPTE ST 2080-1 was prepared by Technology Committee 10E.

Intellectual Property

At the time of publication no notice had been received by SMPTE claiming patent rights essential to the implementation of this Engineering Document. However, attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. SMPTE shall not be held responsible for identifying any or all such patent rights.

Introduction

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

The creation of television images that are intended to follow a standard of consistency in appearance requires definition of a reference display, of a controlled viewing environment, and of a set of measurement procedures to enable consistent calibration of both display and environment. These will be specified in a series of SMPTE Standards and Recommended Practices. This document specifies Reference White for an HDTV display.

1 Scope

This standard specifies a Reference White signal, and the absolute luminance level and chromaticity, including tolerances, that is to be produced by an HDTV display reproducing such a Reference White signal conforming to the encoding specifications of SMPTE ST 274 or SMPTE ST 296. The reference white level and chromaticity defined herein are intended for critical viewing in a controlled environment. They are not appropriate for some applications, such as displays used on a studio floor or in bright ambient light.

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; followed by formal languages; then figures; and then any other language forms.

3 Normative References

Note: All references in this document to other SMPTE documents use the current numbering style (e.g. SMPTE ST 274:2008) although, during a transitional phase, the document as published (printed or PDF) may bear an older designation (such as SMPTE 274-2008). Documents with the same root number (e.g. 274) and publication year (e.g. 2008) are functionally identical.

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

SMPTE ST 274:2008, Television — 1920 × 1080 Image Sample Structure, Digital Representation and Digital Timing Reference Sequences for Multiple Picture Rates

SMPTE ST 296:2012, 1280 × 720 Progressive Image 4:2:2 and 4:4:4 Sample Structure — Analog and Digital Representation and Analog Interface

CIE 15:2004, Colorimetry, Third Edition

4 Specifications

4.1 Reference White

The term Reference White shall be used to denote the specified upper bound of luminance level for the R', G', B' and Y' signals as they are defined in the image format documents for HDTV signals, SMPTE ST 274 and SMPTE ST 296, as set forth in Table 1 below.

4.2 Input Signal

A signal having the following characteristics shall be connected to the input of the display:

- a central region set to Reference White Level as per Table 1. The area of this region shall be between 2% and 4% of the total active pixel area,
- a surrounding region set to Black Level as per Table 1.

This signal shall be referred to as the Reference White Patch signal.

Table 1 – Code Values for Reference White Patch Signal

		Input Code Values					
		R'	**G'**	**B'**	**Y'**	**C'_R**	**C'_B**
Central Region (Reference White Level)	8-bit	235	235	235	235	128	128
	10-bit	940	940	940	940	512	512
	12-bit	3760	3760	3760	3760	2048	2048
Surrounding Region (Black Level)	8-bit	16	16	16	16	128	128
	10-bit	64	64	64	64	512	512
	12-bit	256	256	256	256	2048	2048

Note 1: An example of a suitable test signal to function as the Reference White Patch signal is that specified in SMPTE RP 2080-2.

Note 2: Some display technologies consume significantly more power when displaying high-luminance signals. displays employing these technologies sometimes use power-limiting techniques that reduce the emitted luminance level when the average picture level of the displayed image exceeds a certain threshold. The Reference White Patch signal has therefore been defined with respect to a specific input signal, as set forth above, in order to prevent such power-limiting techniques from affecting calibration of displays and consequently interfering with interoperability.

4.3 Reference White Luminance Level, center of screen

When the Reference White Patch signal is connected to the input, the display shall produce a Reference White Luminance Level of 100 cd/m^2, ±5 cd/m^2 (29.2 fL, ±1.5 fL), at the center of the screen.

Note 1: Candelas per square meter (cd/m^2) is the SI unit for measurement of reflected luminance or luminance emitted by a display. The equivalent US unit is the foot-lambert (fL). One foot-lambert equals 1/π candela per square foot.

Note 2: Some displays larger than approximately 36″ diagonal have in practice been calibrated at a lower white luminance level. Such operation is outside the scope of this standard.

4.4 Reference White Chromaticity

4.4.1 Reference White Options and Corrections

Reference White chromaticity shall be D65, as set forth in Section 4.4.2, except in those geographic regions where it is customary to use a white point of 9300K. This is set forth in Section 4.4.3.

Note 1: Color meters are designed and calibrated to the CIE1931 world wide colorimetry standard. Due to errors in CIE1931, color meters incorrectly measure displays using primaries with significant energy below 460nm, such as those incorporating LED or OLED light sources. Therefore, color meter measurements of these displays have to be corrected to account for the error, as explained in SMPTE RP 2080-2. The specification of Reference White chromaticity set forth below applies to the corrected values of the chromaticity coordinates. SMPTE RP 2080-2 provides a full explanation and technique for making the correction.

Note 2: Specification of Reference White chromaticity and chromaticity tolerance entails use of multiple color spaces. SMPTE RP 2080-2a, an element of SMPTE RP 2080, is an informative Excel spreadsheet that performs the necessary conversions among these color spaces and determines whether a measured white is within tolerance. This spreadsheet can be helpful when working with the specifications below.

4.4.2 D65 Reference White

When the display is intended to display Reference White with a color temperature known as “D65,” and when the Reference White Patch signal is connected to the input, the display shall produce a Reference White color with the following nominal *x,y* chromaticity coordinates at the center of the screen:

$x = 0.3127, y = 0.3290$

The actual color produced by the display shall lie within a tolerance of 1.3 Δu^*v^* at the specified luminance.

Note: $x = 0.3127, y = 0.3290$ converts in u', v' space to approximately $u' = 0.197830$, $v' = 0.468320$.

$u' v'$ chromaticity coordinates are defined in CIE 15:2004, clause 8.1; u^*v^* chromaticity coordinates are defined in CIE 15:2004, clause 8.2.2.

The u', v' values given above are no more accurate than the x, y values from which they are derived. They are given at a greater resolution in order to prevent roundoff errors when using the formula below.

Determination of whether a set of $u' v'$ chromaticity values are within tolerance can be made from the following formula, which is derived from CIE 15:2004, clause 8.2.2.

The measured values are within tolerances if

$$13\left(116\left(\frac{Y_m}{Y_{ref}}\right)^{1/3} - 16\right)\sqrt{(u'_m - u'_{ref})^2 + (v'_m - v'_{ref})^2} \leq t$$

where

t is the normative tolerance in u^*v^* space (in this case, t = 1.3)

$\{Y_m, u'_m, v'_m\}$ = measured and adjusted $Yu'v'$

$\{Y_{ref}, u'_{ref}, v'_{ref}\}$ = $Yu'v'$ for the reference white

Y_{ref} = 100 cd/m^2 reference white level

$\{u'_{ref}, v'_{ref}\}$ is {0.197830, 0.468320} for the D65 reference

This formula is applicable only for $Y_m > (6/29)^3 * Y_{ref}$ (approx. $0.00885645 * Y_{ref}$)

This tolerance can also be depicted graphically as a circular zone of radius 0.001 units around the nominal u',v' Reference White coordinates, as shown in Figure 1a.

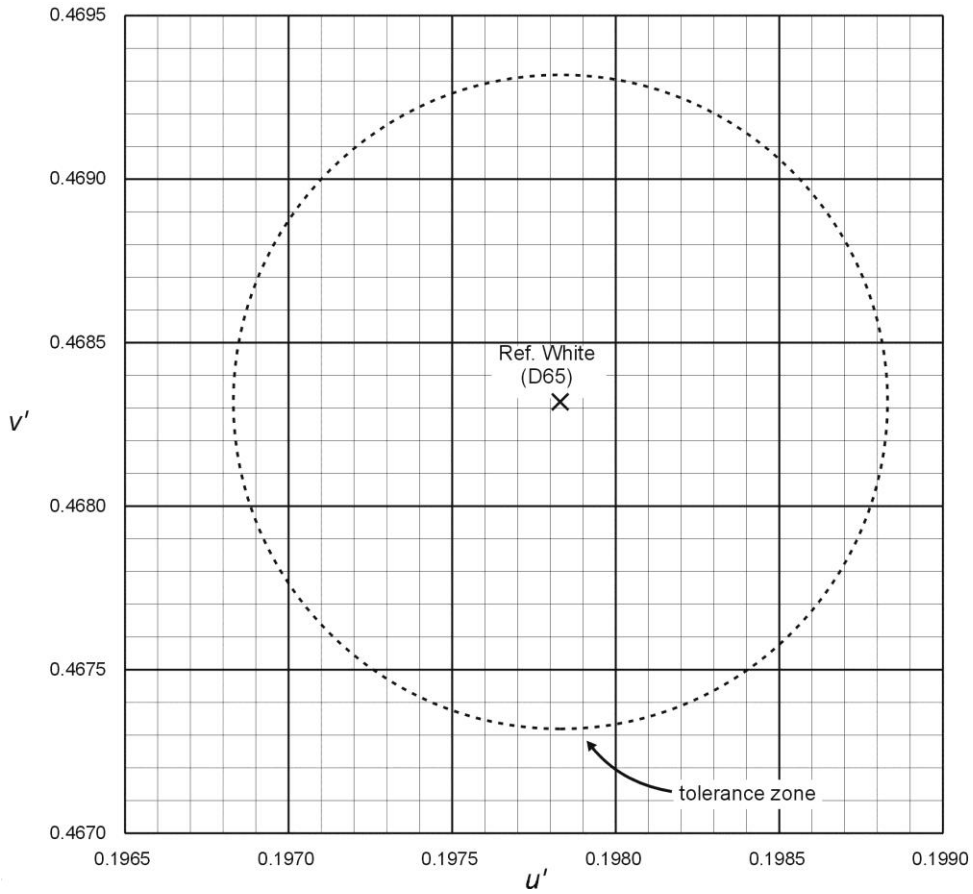

Figure 1a – Tolerance zone for D65 Reference White Chromaticity (CIE 1976 uniform chromaticity scale)

For guidance on corresponding values in CIE 1931 x,y chromaticity coordinates, see Annex A.

4.4.3 9300K Reference White

When the display is intended to display Reference White with a color temperature of 9300K, and when the Reference White Patch signal is connected to the input, the display shall produce the 9300K Reference White color with the following nominal *x, y* chromaticity coordinates, measured at the center of the screen:

$x = 0.2831, y = 0.2971$

The actual color produced by the display shall lie within a tolerance of 1.3 Δu^*v^* at the specified luminance.

Note: $x = 0.2831$, $y = 0.2971$ converts in u', v' space to approximately $u' = 0.188765$, $v' = 0.445724$

$u'v'$ chromaticity coordinates are defined in CIE 15:2004, clause 8.1; u^*v^* chromaticity coordinates are defined in CIE 15:2004, clause 8.2.2.

The *u', v'* values given above are no more accurate than the x, y values from which they are derived. They are given at a greater resolution in order to prevent roundoff errors when using the formula below.

Determination of whether a set of u',v' chromaticity values are within tolerance can be made from the following formula, which is derived from CIE 15:2004 clause 8.2.2.

The measured values are within tolerances if

$$13\left(116\left(\frac{Y_m}{Y_{ref}}\right)^{1/3} - 16\right)\sqrt{(u'_m - u'_{ref})^2 + (v'_m - v'_{ref})^2} \leq t$$

where

t is the normative tolerance in u^*v^* space (in this case, t = 1.3)

$\{Y_m, u'_m, v'_m\}$ = measured and adjusted $Yu'v'$

$\{Y_{ref}, u'_{ref}, v'_{ref}\} = Yu'v'$ for the reference white

$Y_{ref} = 100$ cd/m^2 reference white level

$\{u'_{ref}, v'_{ref}\}$ is {0.188765, 0.445724} for the 9300°K reference

This formula is applicable only for $Y_m > (6/29)^3 * Y_{ref}$ (approx. $0.00885645 * Y_{ref}$)

This tolerance can also be depicted graphically as a circular zone of radius 0.001 units around the nominal u',v' Reference White coordinates, as shown in Figure 1b.

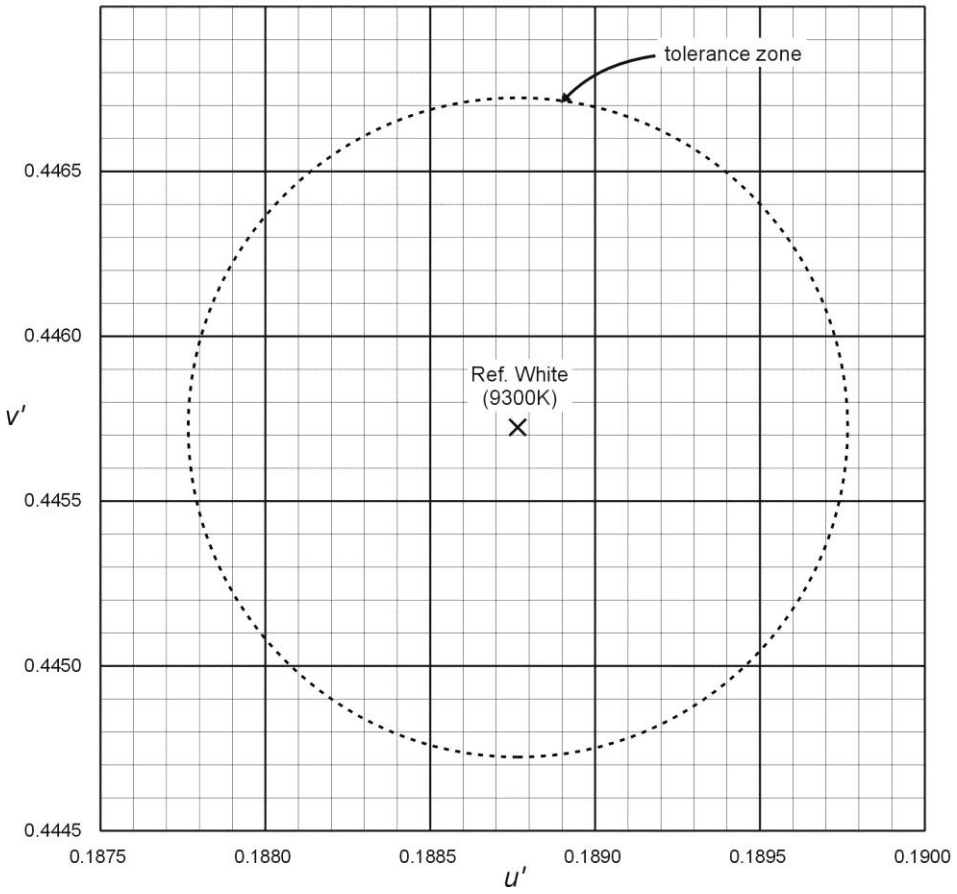

Figure 1b – Tolerance zone for 9300K Reference White Chromaticity (CIE 1976 uniform chromaticity scale)

For guidance on corresponding values in CIE 1931 *x,y* chromaticity coordinates, see Annex A.

The *u′,v′* values shown for 9300K (only) are converted from equivalent CIE 1931 *x,y* values taken from the document: "Excel Daylight Series Calculator*"* (in section: "CIE Standard Illuminant Data") at URL:

http://www.rit-mcsl.org/UsefulData/DaylightSeries.xls

Annex A Alternate Chromaticity Coordinates (Informative)

The following Annexess A.1 and A.2 provide guidance on determining compliance with the specifications of Reference White Chromaticity in Section 4.4 using measurements in the CIE 1931 *x,y* chromaticity scale instead of the CIE 1976 *u',v'* uniform chromaticity scale.

A.1 Reference White Chromaticity Tolerance Zone (D65 white), on CIE 1931 *x,y* Chromaticity Axes

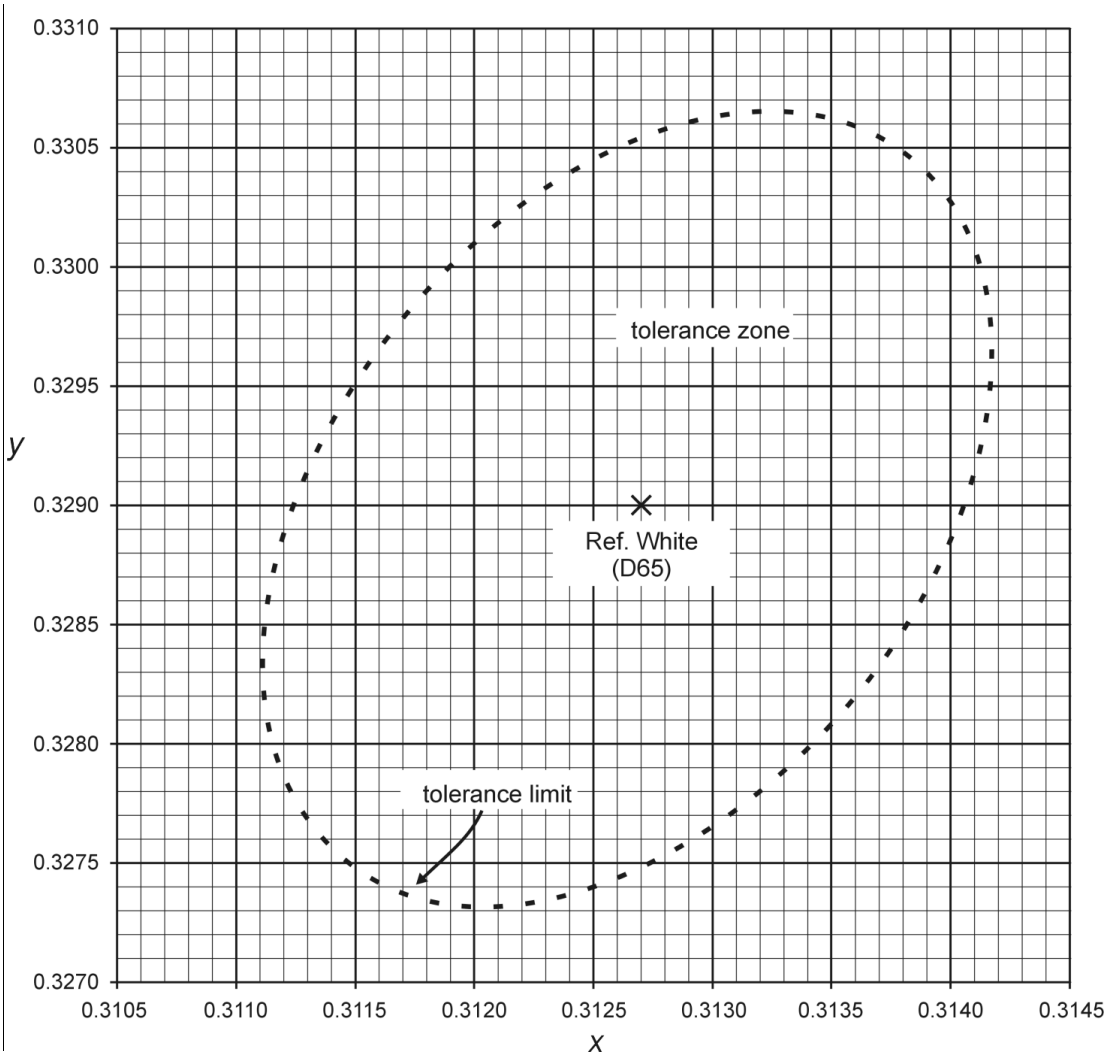

Figure A.1. Tolerance zone for D65 Reference White Chromaticity (CIE 1931 *x,y* chromaticity scale)

In Figure A.1, the dashed ellipse represents the approximate limit of the *x,y* values, measured at the screen center, that do not exceed a color difference of 1.3 delta *u*v** (CIE 1976 *L*u*v** color space differences) from a nominal D65 Reference White Chromaticity point.

The use of *x,y* units to determine approximate equivalence with the delta *u*v** tolerance value indicated is valid only if the luminance of the measured sample is the same as the luminance of the nominal D65 Reference White color specified in Section 4.3.

A.2 Reference White Chromaticity Tolerance Zone (9300K white), on CIE 1931 *x*,*y* chromaticity axes

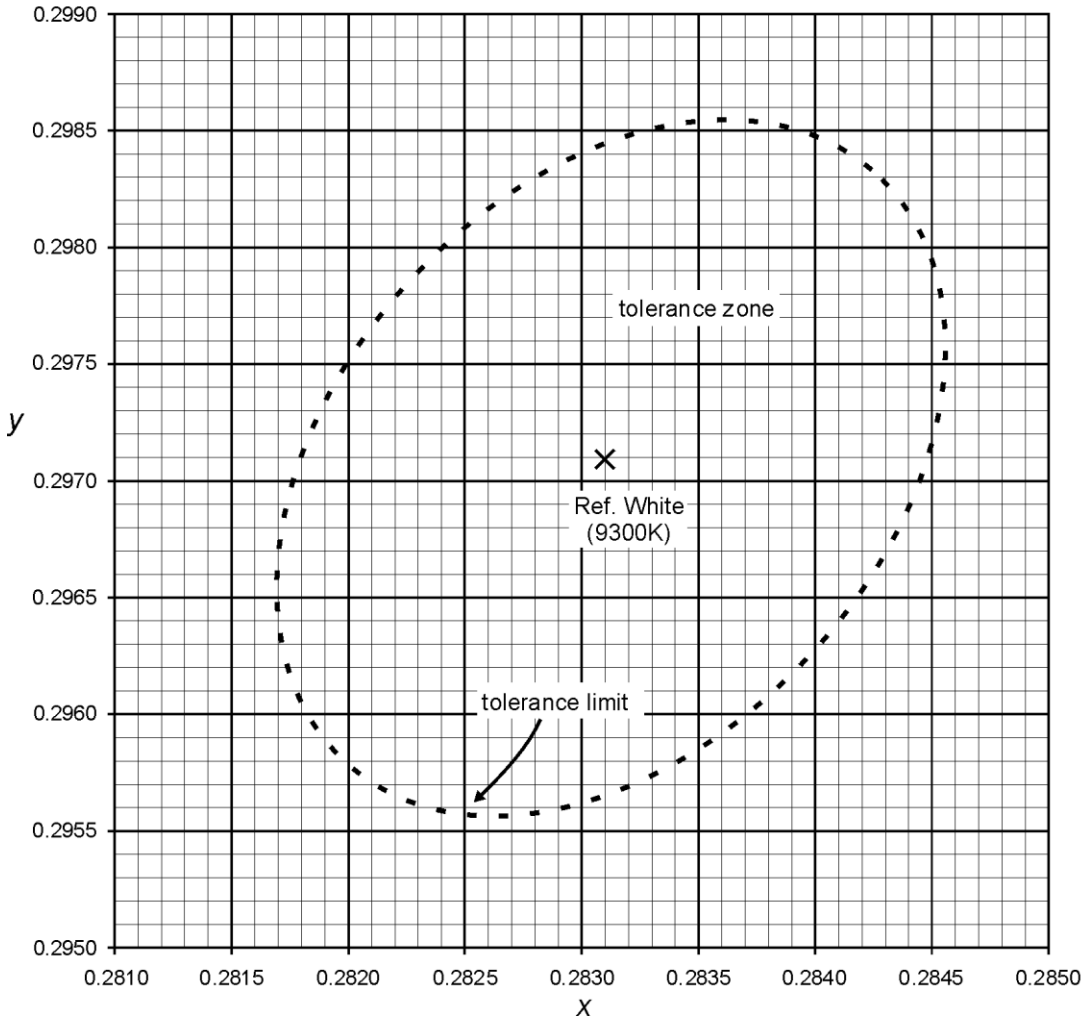

Figure A.2 – Tolerance zone for 9300K Reference White Chromaticity (CIE 1931 *x,y* chromaticity scale)

In Figure A.2, the dashed ellipse represents the approximate limit of the *x,y* values, measured at the screen center, that do not exceed a color difference of 1.3 delta *u*v** (CIE 1976 *L*u*v** color space differences) from a nominal 9300K Reference White Chromaticity point.

The use of *x,y* units to determine approximate equivalence with the delta *u*v** tolerance value indicated is valid only if the luminance of the measured sample is the same as the luminance of the nominal 9300K Reference White color specified in Section 4.3.

Annex B Bibliography (Informative)

SMPTE RP 2080-2:2014, Measurement and Calibration Procedures for HDTV Display Luminance Levels and Chromaticity

EBU Technical Publication: EBU Tech.3325 “Performance Measurement of Studio Monitors”

Recommendation ITU-R BT.814-2, Specifications and Alignment Procedures for Setting of Brightness and Contrast of Displays

“Excel Daylight Series Calculator,” in section: “CIE Standard Illuminant Data”
Author: Munsell Color Science Laboratory, Center for Imaging Science
Webpage title: “Useful Color Data”
Date published/updated: June 17, 2013.
Publisher: Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester NY 14623.
Date accessed: May 28, 2014
URL:. http://www.rit-mcsl.org/UsefulData/DaylightSeries.xls

Judd, D. B. (1951). Report of U.S. Secretariat Committee on Colorimetry and Artificial Daylight, *Proceedings of the Twelfth Session of the CIE, Stockholm* (pp. 11) Paris: Bureau Central de la CIE

Vos, J. J. (1978). Colorimetric and photometric properties of a 2-deg fundamental observer. *Color Research and Application, 3*, 125-128