SMPTE RECOMMENDED PRACTICE

Measurement and Calibration Procedure for HDTV Display Luminance Levels and Chromaticity

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Foreword

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

SMPTE RP 2080-2 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 benefits from the 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. To ensure consistent viewing conditions, periodic checks of both display and environment are necessary. It is suggested that the checks specified in this Recommended Practice be done every day the display is in use.

1 Scope

This Recommended Practice specifies methods to be used for routine measurements and calibration of absolute luminance levels and white point chromaticity produced by HDTV Displays that are intended to reproduce images conforming to the specifications of SMPTE ST 274 and SMPTE ST 296.

Some displays are designed for automated calibration using measuring devices supplied or certified by the display manufacturer for this purpose. Such automated calibration is outside the scope of this Recommended Practice. However, manufacturers implementing automated calibration are urged to consider the implications of the calibration procedures described herein, especially Sections 4.3.1 and 4.4.

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 documents contain provisions that, through reference in this text, constitute provisions of this Recommended Practice. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Recommended Practice are encouraged to investigate the possibility of applying the most recent edition of the documents listed below.

SMPTE ST 274:2008, Television — 1920 x 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 15.3:2004, Colorimetry, Third Edition

4 Measurement Procedure

4.1 Measurement Conditions

4.1.1 Operating Conditions

The display shall be allowed to stabilize thermally[1,2] before the following measurements and adjustments are made.

The lighting conditions under which the measurements shall be made shall be those used for normal operation.

4.1.2 Measurement Location on the display

Measurements shall be taken at the geometric center of the screen.

4.1.3 Location of the Measurement Device

For all measurements the measuring device shall be positioned perpendicular to and centered on the screen so that the region of the image being measured completely fills the sensing area of the measuring device. Unless certified by the manufacturer contact probes shall not be used because of potential adverse interactions between such probes and certain types of displays.

4.1.4 Photometer type

Screen luminance shall be measured with a spot photometer having the spectral luminance response of the standard observer (photopic vision), as defined in ISO/CIE 10527. The acceptance angle of the photometer shall be 2° or less. The photometer shall have an accuracy of ± 0.5 cd/m² (± 0.2 fL) or better. The photometer response to luminance variation over time shall be to properly integrate any such variation occurring at frequencies at or above 24 Hz and display the arithmetic mean value.

4.1.5 Spectroradiometer

Screen chromaticity shall be measured with a spot spectroradiometer with an acceptance angle of 2° or less. It shall report values in CIE x, y coordinates, with an accuracy of ± 0.002 or better for both x and y. As there are meters available that measure both luminous flux and chromaticity, this may physically be the same meter defined in Section 4.1.4.

4.1.6 Meter Repeatability

There can be interactions between the sampling period of a measuring device (photometer or spectroradiometer) and the display's refresh timing that can affect the accuracy of measurements. Before

[1] Depending on the type of technology used, some displays require a particular type of input signal to achieve adequate stabilization.

[2] The amount of time taken for stabilization can vary with the environment (e.g. studio versus outside broadcast) and with the circumstances (e.g. monitor measurement versus monitor operational usage).

making any display adjustments, it is necessary to determine whether such interactions are present. This should be done as follows:

- Using the Reference White Patch signal, make three or more measurements of luminance, waiting 20 to 30 seconds between measurements
- Verify that all the measurements are within the short-term repeatability tolerance of the meter, typically +/- 1%

If the measurements are not within the meter's short-term repeatability tolerance, there is an interaction between the meter's sync rate and the display's refresh rate, which shall be resolved before display calibration is attempted.

4.2 Input Signals

For measurement purposes, test patterns having the characteristics described in Annex A shall be connected to the input of the Display.

4.3 Order of Measurements and Adjustments

Black level and reference white level adjustments often interact, so they shall be repeated to ensure that both are set correctly. The measurement and adjustment procedures defined below should be performed in the following order:

- Black level set
- Reference white level set
- Black level set
- Reference white level set and measurement
- Reference white chromaticity measurement
- 20% and 50% grey level measurement

Black level, reference white level and reference white chromaticity measurements are defined in separate sections below for the sake of clarity. They may be performed simultaneously if the measuring instrument is capable of doing so, as is the case with certain spectroradiometers.

4.4 Luminance Levels

4.4.1 Black Level Set

The procedure in Table 1 shall be used to set Black Level.

Table 1 – Black Level Set Procedure

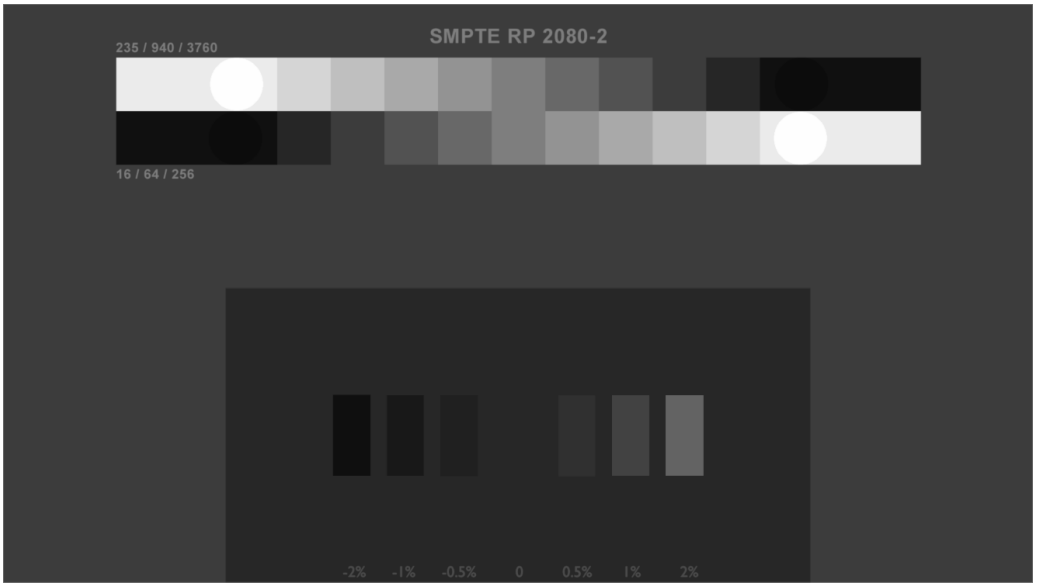
<table>
<tr><td>Test pattern:</td><td> 

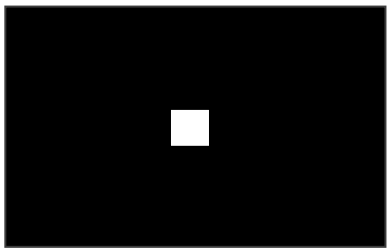
Figure 1 – Test Pattern 1, Compound PLUGE Pattern modified for demonstration
A.1 Test Pattern 1: Compound PLUGE Pattern (see Annex A). Figure 1 illustrates this pattern with the PLUGE area elevated in level to show all of the patches.</td></tr>
<tr><td rowspan="2">Adjustment procedure:</td><td>Check the black level using the PLUGE element of an appropriate test pattern, such as the Compound PLUGE Pattern specified in Annex A, and adjust it if necessary. Using this pattern, black level is correctly set when the circled three patches on the left of figure 1(-2%, -1%, -0.5%) are not visible but the circled three patches on the right of figure 1(+0.5%, +1%, 2%) are visible.</td></tr>
<tr><td> 

Figure 2 – Test Pattern 1, Compound PLUGE Pattern</td></tr>
</table>

4.4.2 Reference White Measurement and Level Set

The procedure in Table 2 shall be used to measure Reference White Level. If the measured Reference White Level is outside the tolerance specified in SMPTE ST 2080-1, it shall be adjusted to bring it within tolerance.

Table 2 – Reference White Measurement Procedure

Test pattern:	A.2 Test Pattern 2, Reference White patch (see Annex A), shown for convenience in Figure 3 below.
Measurement point:	Center of the white patch
Measurement equipment:	Spectroradiometer or luminance meter
Measurement procedure:	Measure the luminance with the spectroradiometer or luminance meter perpendicular to the center of the white patch and at a distance such that the region of the image being measured completely fills the sensing area of the measuring device. Report the luminance level.
	 **Figure 3 – A.2 Test Pattern 2, Reference White**
Measurement results:	Report the result in cd/m^2 or fL.

Note: 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 $1/\pi$ candela per square foot.

4.4.3 20% and 50% Gray Luminance Level

The procedure in Table 3 shall be used to measure 20% and 50% Gray Luminance Levels.

Table 3 – 20% and 50% Gray Level Measurement Procedure

Test pattern:	A.2 Test Pattern 2: 20% and 50% Gray Patch (see Annex A), shown for convenience in Figure 4a and 4b below.
Measurement point:	Perpendicular to the central patch
Measurement equipment:	Spectroradiometer or luminance meter
Measurement procedure:	For each gray level patch, measure the luminance with the spectroradiometer or luminance meter perpendicular to the center of the patch and at a distance such that the region of the image being measured completely fills the sensing area of the measuring device. Report the luminance level.
	 **Figure 4a – A.2 Test Pattern 2, 20% Gray**  **Figure 4b – A.2 Test Pattern, 50% Gray**
Measurement results:	Report the result in cd/m^2 or fL.

4.4.4 Example format for reporting luminance measurements (Informative)

Table 4 is an example of a format that may be used for reporting the luminance measurements performed in Sections 4.3.1, 4.3.2 and 4.3.3.

Table 4 – Example format for reporting luminance measurements

Black level	20% level	50% level	White level
Code value 16 (8 bit) 64 (10 bit) 256 (12 bit)	Code value 60 (8 bit) 240 (10 bit) 960 (12 bit)	Code value 126 (8 bit) 504 (10 bit) 2016 (12 bit)	Code value 235 (8 bit) 940 (10 bit) 3760 (12 bit)
Set with PLUGE	cd/m^2 (fL)	cd/m^2 (fL)	cd/m^2 (fL)

4.5 Reference White Chromaticity

4.5.1 Chromaticity measurement

Measurement procedures are described in the following subsections for both D65 and 9300K Reference White. The appropriate subsection should be consulted for the particular Reference White specification in operational usage.

Spectroradiometers frequently display luminance and chrominance measurements simultaneously. In this case reference white luminance and chromaticity may be measured at the same time.

4.5.2 Offsets

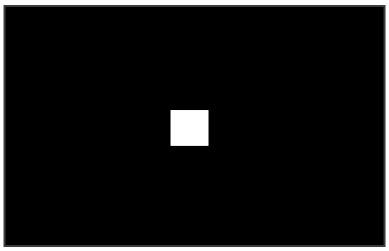
To optimize the match between objective alignment based on measured values and subjective alignment by human vision of displays employing different technologies, it is necessary to correct the measured values of the chromaticity coordinates by application of an offset. This compensates for known errors in the color matching functions of CIE 1931. See Annex C.

Some manufacturers provide an offset for specific displays. This offset should be used if provided. If not, a default offset of $\Delta x = -0.006$ and $\Delta y = -0.011$ should be used for LED-illuminated displays. Offsets are under study for other display types such as cold-cathode fluorescent-backlit LCDs. An offset is not needed and shall not be used for phosphor-based display types such as CRT and plasma.

4.5.3 Measurement Procedure

The procedure in Table 5 shall be used to measure Reference White Chromaticity. If the measured Reference White Chromaticity is outside the tolerance specified in ST 2080-1, it shall be adjusted to bring it within tolerance.

Table 5 – Reference White Chromaticity Measurement Procedure

Test pattern:	A.2 Test Pattern 2, Reference White patch (see Annex A) shown for convenience in Figure 5 below.
Measurement point:	Center of the white patch
Measurement equipment:	Spectroradiometer or luminance meter
Measurement procedure:	Measure the Reference White Patch with the spectroradiometer perpendicular to the center of the white patch and at a distance such that the region of the image being measured completely fills the sensing area of the measuring device. Record the luminance and chromaticity coordinates *Y, x* and *y*. Apply either the manufacturer-specified offset or, if none has been specified, the default offset. Convert the resulting *x, y* values to *u' v'* values using the equations for *u'* and *v'* below or the SMPTE RP-2080-2a spreadsheet.
	 **Figure 5 – A.2 Test Pattern 2, Reference White**
Measurement results:	Report the result in *u'*, *v'* (CIE 1976 uniform chromaticity scale). Determine whether the measured values are in tolerance using the inequality given below or the SMPTE RP 2080-2a spreadsheet.

The following equations shall be used to convert *x, y* values to *u' v'* values:

$$u' = \frac{4x}{-2x+12y+3}$$

$$v' = \frac{9y}{-2x+12y+3}$$

The measured values are within tolerance if

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

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
$\{u'_{ref}, v'_{ref}\}$ is {0.188765, 0.445724} for the 9300K 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 5 for D65 and for 9300K.

Note: SMPTE RP 2080-2a is an Excel spreadsheet that accepts measurements in *Y x y* form and offsets in *x y* form and calculates whether the display's white chromaticity is in tolerance using the procedures specified in this section. Both D65 and 9300K white references are supported.

4.5.4 Example format for reporting chromaticity measurements (Informative)

Table 6 is an example of a format that may be used for reporting the chromaticity measurement performed in Section 4.4.3.

Table 6 – Example format for reporting chromaticity measurements

	White Code value 235 (8 bit) 940 (10 bit) 3760 (12 bit)	
Reference white:	D65 ☐	9300K ☐
Measured value:	*x* =	*y* =
Applied Offset:	default ☐	provided by manufacturer ☐
	Δx =	Δy =
Calculated corrected value:	*x* =	*y* =
	u' =	*v'* =
Within Tolerance:	yes ☐	no ☐

Annex A Test Patterns (Normative)

A.1 General Provisions (Informative)

In the test patterns below, the 10 and 12 bit values are multiples of the 8 bit values. The percentage labels shown for each level are therefore approximate, but are in all cases well within the measurement tolerances of current equipment. Each test pattern has a one-pixel-wide border of 50% gray, which has been included so the user can ensure that the entire pattern is visible on the display.

In Figures A.2 and A.4, pixels are numbered starting with 0 but lines are numbered starting with 1. This is in accord with the provisions of SMPTE ST 274 and SMPTE ST 296.

A.2 Test Pattern 1

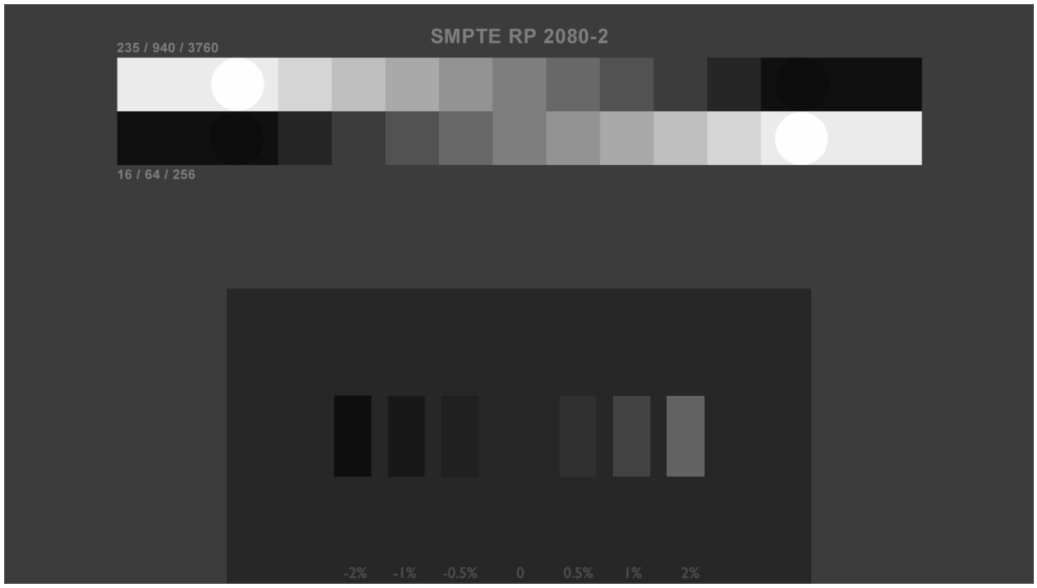


Figure A.1 – Test Pattern 1

Description:

The test pattern shall consist of a gray field with a pair of luminance staircases in the upper half and an inset black field with PLUGE in the lower half. The first and the last line and the first and last pixel of each line of the active picture shall have the code values for 50 % gray. Code values for the remainder of the test pattern shall be as specified in figure A2 and Table A.1. When assessing and setting black level, the whole picture should be visible to the observer.

Note: The image as a whole has an average picture level (APL) of 19%. This represents approximately the mid-point between SMPTE RP 219-1 (40%) and ITU-R BT.814 (1%).

Figure A.1 is an illustration of Test Pattern 1. The levels of the PLUGE within the pattern have been elevated for clarity. The figure is therefore not suitable for use as a test image and shall not be so used.

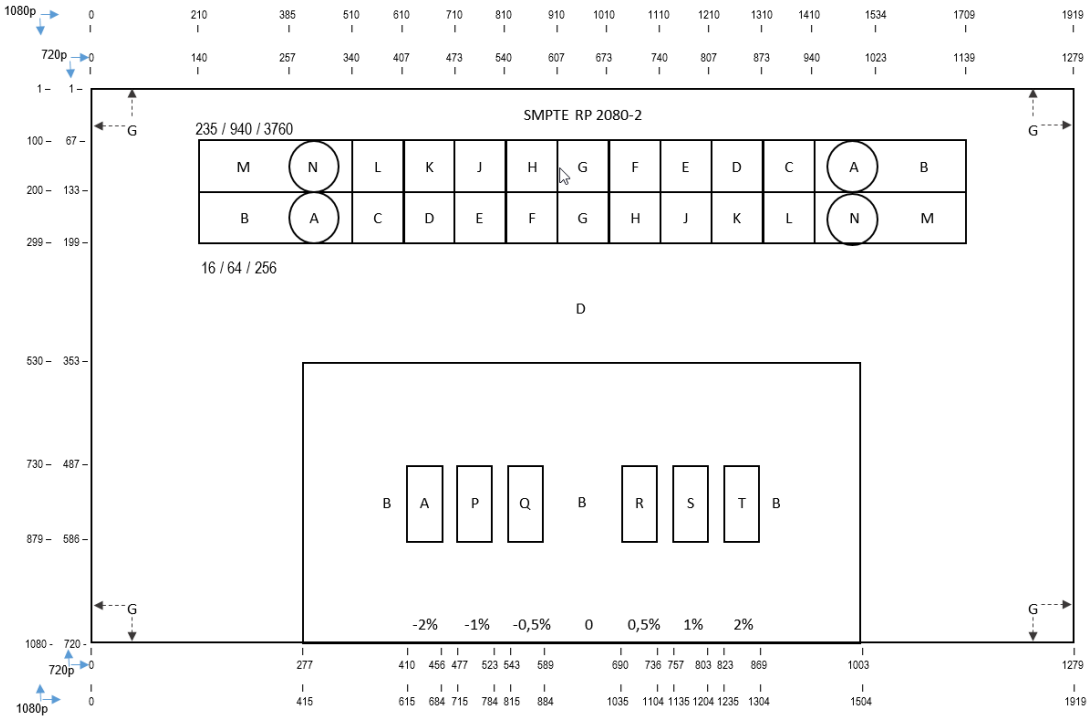


Figure A.2 – Test Pattern 1

The image shall be filtered using an appropriate anti-alias filter.

Table A.1 – Code values for test pattern 1

Image area	Level	Level (8 bit)			Level (10 bit)			Level (12 bit)		
		Y′ R′,G′,B′	C'_B	C'_R	Y′ R′,G′,B′	C'_B	C'_R	Y′ R′,G′,B′	C'_B	C'_R
A	-2%	12	128	128	48	512	512	192	2048	2048
B	0%	16	128	128	64	512	512	256	2048	2048
C	10%	38	128	128	152	512	512	608	2048	2048
D	20%	60	128	128	240	512	512	960	2048	2048
E	30%	82	128	128	328	512	512	1312	2048	2048
F	40%	104	128	128	416	512	512	1664	2048	2048
G	50%	126	128	128	504	512	512	2016	2048	2048
H	60%	147	128	128	588	512	512	2352	2048	2048
J	70%	169	128	128	676	512	512	2704	2048	2048
K	80%	191	128	128	764	512	512	3054	2048	2048
L	90%	213	128	128	852	512	512	3408	2048	2048
M	100%	235	128	128	940	512	512	3760	2048	2048
N	109%	254	128	128	1016	512	512	4064	2048	2048
P	-1%	14	128	128	56	512	512	224	2048	2048
Q	-0.5%	15	128	128	60	512	512	240	2048	2048
R	0.5%	17	128	128	68	512	512	272	2048	2048
S	1%	18	128	128	72	512	512	288	2048	2048
T	2%	20	128	128	80	512	512	320	2048	2048

Note: The percentages shown in table A.1 are approximate. Annex B provides the precise percentages produced by these code values.

A.3 Test Pattern 2

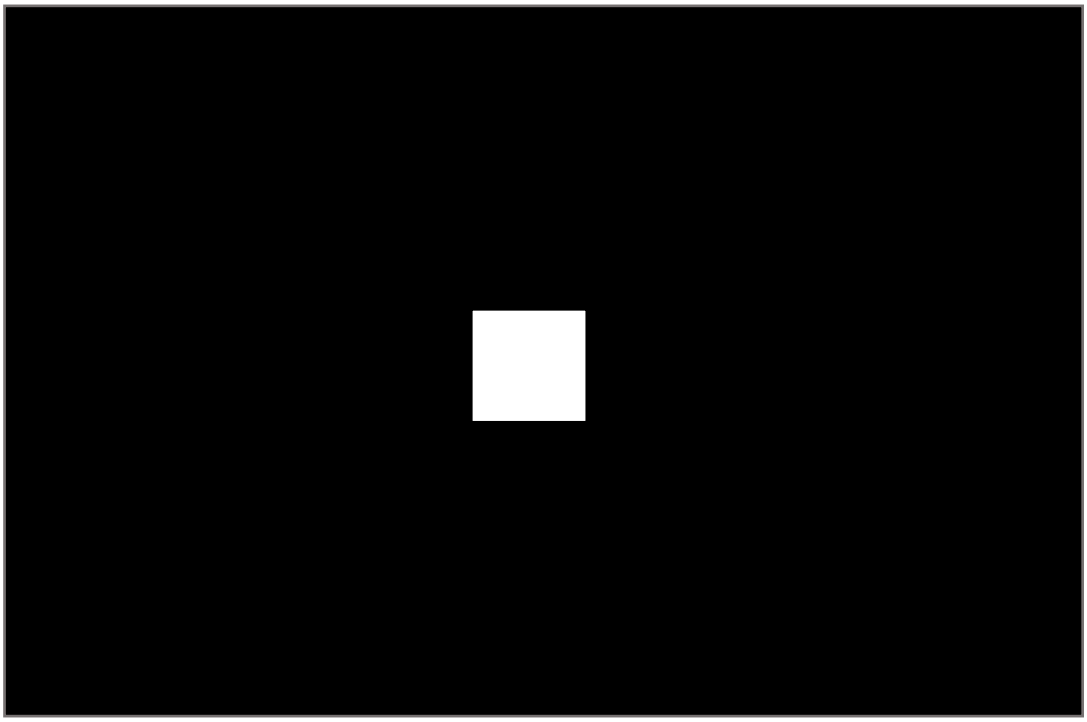


Figure A.3 – Test Pattern 2

Description:

The test pattern shall consist of a black active picture and a patch in the center of the active picture with one of the sets of code values shown in Table A.2. The first and the last line and the first and last pixel of each line of the active picture shall have the code values for 50 % gray.

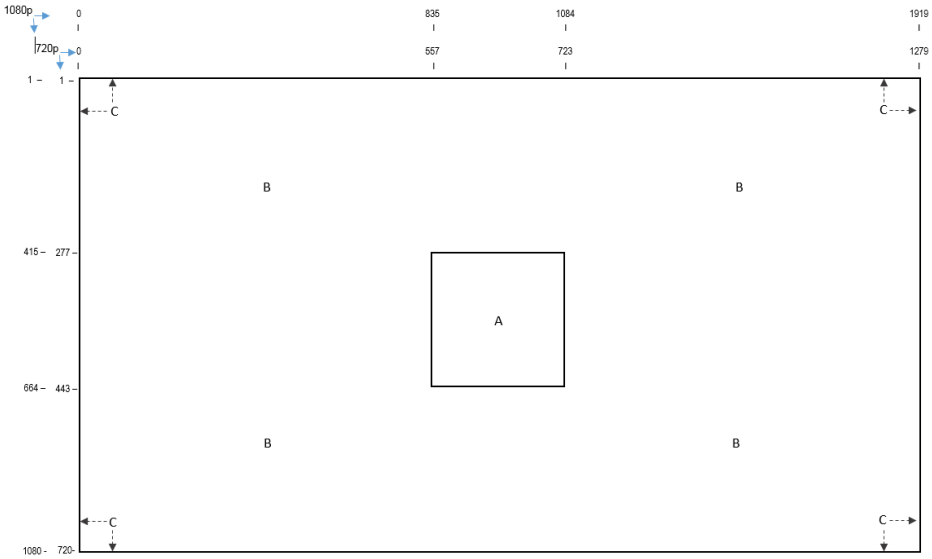


Figure A.4 – Test Pattern 2

The image shall be filtered using an appropriate anti-alias filter.

Table A.2 – Code values for test pattern 2

		Input Code Values					
		R'	***G'***	***B'***	***Y'***	$C_{R'}$	$C_{B'}$
Central Region (A) (Reference White Level Patch)	8-bit	235	235	235	235	128	128
	10-bit	940	940	940	940	512	512
	12-bit	3760	3760	3760	3760	2048	2048
Central Region (A) (50 IRE Gray Level Patch) Border (C)	8-bit	126	126	126	126	128	128
	10-bit	504	504	504	504	512	512
	12-bit	2016	2016	2016	2016	2048	2048
Central Region (A) (20 IRE Gray Level Patch)	8-bit	60	60	60	60	128	128
	10-bit	240	240	240	240	512	512
	12-bit	960	960	960	960	2048	2048
Surrounding Region (B) (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

Annex B Code Values and Associated Luminance Levels (Normative)

Table B.1 lists 8, 10 and 12-bit code values for a number of video levels, expressed as percentages of reference white level. The 10 and 12-bit code values given are integer multiples of the 8-bit values. The Signal Name column lists the nominal levels, while the Actual % Video column lists the exact level corresponding to each code value.

Table B.1 – Code Values and Associated Luminance Levels

Signal Name	Integer 8bit cv	8bit x 4 10bit cv	8bit x 16 12bit cv	Actual % Video
Reserved	0	0	0	n/a
SuperBlack	1	4	16	-6.85
-4%	7	28	112	-4.11
-2%	12	48	192	-1.83
-1%	14	56	224	-0.91
-0.5%	15	60	240	-0.46
Ref Black	16	64	256	0.00
+0.5%	17	68	272	0.46
+1%	18	72	288	0.91
+2%	20	80	320	1.83
+4%	25	100	400	4.11
5%	27	108	432	5.02
10%	38	152	608	10.05
15%	49	196	784	15.07
20%	60	240	960	20.09
25%	71	284	1136	25.11
30%	82	328	1312	30.14
35%	93	372	1488	35.16
40%	104	416	1664	40.18
45%	115	460	1840	45.21
50%	126	504	2016	50.23
55%	136	544	2176	54.79
60%	147	588	2352	59.82
65%	158	632	2528	64.84
70%	169	676	2704	69.86
75%	180	720	2880	74.89
80%	191	764	3056	79.91
85%	202	808	3232	84.93
90%	213	852	3408	89.95
95%	224	896	3584	94.98
Ref White	235	940	3760	100.00
105%	246	984	3936	105.02
SuperWhite	254	1016	4064	108.68
Max Allowed	254	1019	4079	n/a
Reserved	255	1023	4095	n/a

Annex C Correction of Chromaticity Measurement Errors (Informative)

The values specified for D65 and 9300K Reference White chromaticity in Section 4.4 follow the CIE 15 specification or the Section 4.4.2 Note 2 reference, respectively, and as such depend on the underlying CIE 1931 Color Matching Functions (CMFs) being accurately representative of human vision. All color meters and spectroradiometers currently in use for setting display chromaticity also assume that the 1931 CMFs are correct and are therefore calibrated to them.

Judd/Vos Modified CIE 1931 CMFs

Research by Judd (1951) and Vos (1978) indicates however that the CIE 1931 CMFs underestimated visual sensitivity at wavelengths below 460 nm, causing perceptual differences between displays using primary illumination sources of different spectral power distributions, e.g. OLEDs compared to CRT phosphors. If two such displays that are different in this way are adjusted for Reference White chromaticity according to the values specified in Section 4.4, it is probable that they will not match each other visually in white balance. The Judd (1951) and Judd/Vos (1978) corrections to the CIE 1931 CMFs (Figure E.1) reduce this discrepancy, as indicated below.

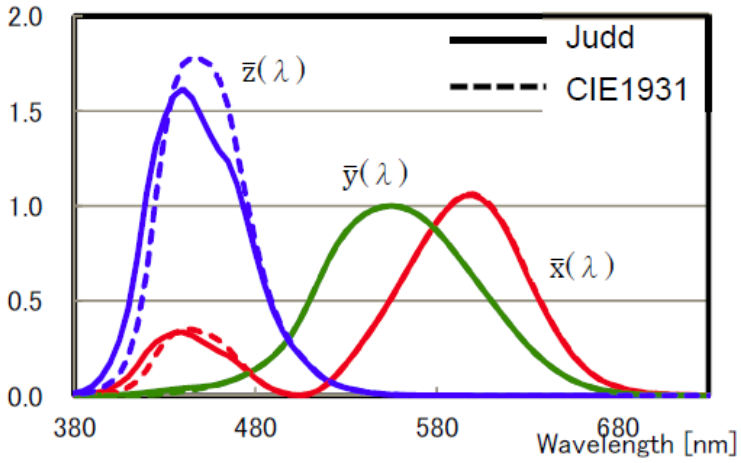


Figure C.1 - CIE 1931 and Judd-modified Color Matching Functions

Use of Judd/Vos Modified CIE 1931 CMFs

One manufacturer of OLED-based displays has published white papers showing that use of the Judd/Vos (1978) corrected version of the CIE 1931 CMFs allows better color matching between OLED and CRT reference monitors. This research determined that a normally-calibrated color meter can be used to calibrate that manufacturer's displays by adding an offset (x= -0.006; y= -0.011) to the meter reading. However, independent calculations made from the unmodified and the Judd/Vos modified CMFs support more general use of this offset in the calibration of displays of various illumination source technologies and from various suppliers.

Annex D Bibliography (Informative)

SMPTE ST 2080-1:2014, Reference White Luminance Level and Chromaticity for HDTV

SMPTE RP 219-1:2014, High-Definition, Standard-Definition Compatible Color Bar Signal

EBU Technical Publication: EBU Tech.3325, Nov 2011, Methods for the Measurement of the performance 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.