DRAFT High Dynamic Range D-Cinema Addendum

DRAFT Version 0.9

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Digital Cinema Initiatives, LLC, Member Representatives Committee

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1 Introduction

The proper presentation of a High Dynamic Range Digital Cinema Distribution Master (HDR-DCDM) requires the definition of an HDR Reference Display and controlled environment. This specification defines the HDR Reference Display and specifies the tolerances around the critical image parameters for Review Rooms and Exhibition Theaters so that consistent and repeatable color quality can be achieved.

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2 Scope

This specification defines the HDR Reference Display and its controlled environment, along with the acceptable tolerances around critical image parameters for Review Room and Exhibition Theater applications. The HDR Reference Display may be an HDR projection system, or a Cinema Direct View Display as constrained in DCI's *Direct View Display D-Cinema Addendum*.

The goal is to provide a means for achieving consistent and repeatable color image quality. The HDR Reference Display is a practical device. The nominal parameters are based on industry experience and have been demonstrated by commercially available HDR Displays in controlled environments. Two levels of tolerances are specified, a tighter tolerance for Review Rooms[1] where critical color judgments are made, and a wider tolerance for satisfactory reproduction in Exhibition Theaters used for general public exhibition.

This document shall be integrated into DCI's Digital Cinema System Specification.

3 Normative References

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

DCI Direct View Display Addendum

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

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

[1] The use of the term "Review Room" includes the mastering environment where creative color decisions are made on a displayed image.

ISO/CIE 11664-5:2016, Colorimetry -- Part 5: CIE 1976 L*u*v* colour space and u', v' uniform chromaticity scale diagram

ISO/CIE 11664-6:2014, Colorimetry -- Part 6: CIEDE2000 Colour-difference formula

SMPTE RP 431-2: 2011, Reference Projector and Environment for D-Cinema Quality

SMPTE ST 428-1:2006, D-Cinema Distribution Master (DCDM) — Image Characteristics

SMPTE ST 429-16:2014, Additional Composition Metadata and Guidelines

SMPTE ST 431-1:2006, Screen Luminance Level, Chromaticity and Uniformity for D-Cinema Quality

SMPTE ST 2084:2014, High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays

4 Terms and Definitions

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

4.1 Edit Unit

The smallest unit of D-Cinema content that can be successfully edited while maintaining the integrity of the content. The edit unit value must be an integer multiple of the duration of a single D-Cinema frame. In most cases, the edit unit value is the same as frame duration, but in certain applications, the value can be >1 (for example, stereoscopic D-Cinema requires an edit unit value twice that of the frame duration).

4.2 Minimum Active Black Level

The Minimum Active Black Level of a HDR Reference Display is the lowest luminance level above code value 0 reproduced within the specified uniformity tolerance.

5 Input Requirements

The HDR Reference Display shall support the HDR-DCDM (HDR Digital Cinema Distribution Master), with full-range 12 bit image data formatted for SMTPE ST-2084 EOTF with CIE XYZ colorimetry at 4096 x 2160 image structure and frame rates as described in Table 1.

EU/sec	2K 2D	2K 3D[2]	4K 2D
24	Required	Required	Required
48	Required	Required	
60	Required	Required	
96	Required		
120	Required		

Table 1 *Edit units per second requirements for HDR Reference Display*

5.1 Signaling HDR in DCP Packaging

Composition Playlists containing picture track files that carry HDR essence shall signal this fact using SMTPE ST 429-16 Metadata as follows:

Scope:	http://www.dcimovies.com/schemas/2018/HDR-Metadata
Name:	Image Encoding Parameters
Property Name:	EOTF
Property Value:	ST 2084

Below is an example excerpt from such a Composition:

```
<ExtensionMetadata scope="http://www.dcimovies.com/schemas/2018/HDR-Metadata">
  <Name>Image Encoding Parameters</Name>
  <PropertyList>
    <Property>
      <Name>EOTF</Name>
      <Value>ST 2084</Value>
    </Property>
  </PropertyList>
</ExtensionMetadata>
```

Devices shall display content in HDR mode when presented with a Composition Playlist containing this signal. Devices shall display content in SDR mode when presented with a Composition Playlist that does not contain this signal.

6 Standard Dynamic Range (SDR) Mode

HDR capable systems shall be capable of displaying SDR content in a manner that appropriately models the SDR environment in which the content was mastered (SDR Mode). This mode shall include a black level under which the display shall never reproduce. This value shall be 0.01 cd/m^2. In SDR mode, the luminance tracking

[2] Support for Stereoscopic 3D is optional; “Required” in this category applies only to displays in which 3D is implemented.

shall conform to SMPTE RP 431-2, with the exception that screen black level shall be displayed at luminance levels above 0.01 cd/m^2.

7 Initial Conditions

The display shall be turned on and allowed to thermally stabilize for 20 to 30 minutes prior to all measurements. The room lights shall be turned off, with the exception of the minimal lighting provided for working or safety reasons.

The display shall be calibrated to the target image parameters before final measurements are made.

8 Environment

8.1 Ambient Luminance

An HDR Reference Display can be either a projector or a Cinema Direct View Display. For projection displays, stray light reflected from the display should be minimized. Black, non-reflective finishes on all surfaces, along with recessed lighting, should be used.

With the reference HDR display device turned off, measure the luminance of the center of the screen. For Review Rooms and Exhibition Theaters, the ambient light level measured in the center of the screen should be less than or equal to 0.005 cd/m^2. Safety regulations and the placement of exit lights or access lights may result in a higher ambient light level, but it should be noted that this will reduce the contrast of the resulting image.

8.2 Reference Viewing Position for Color Grading

The reference viewing position for color grading shall be at a viewing distance of 1.5 to 3.5 screen heights (for constant height presentation), or if constant width is used for both 2.39:1 and 1.85:1 aspect ratios, then this viewing distance refers to the height of the 1.85:1 picture. Lighting on work surfaces or consoles should be masked and filtered to eliminate any spill onto the display.

9 Image Parameters

All image parameters shall be measured as light from the screen, with the measurements made from the reference viewing position in the Review Room, or from the center of the normal seating area in an Exhibition Theater.

9.1 Luminance Uniformity

The variance in measured luminance across the display shall not exceed the specified tolerances in Table A.1.

9.2 Calibration White Point and Luminance

When the HDR Reference Display is sent a full frame image with the code values 2060 X'', 2081 Y'', 2116 Z'', the chromaticity coordinates of the displayed image shall be x = 0.3127, y = 0.3291. These code values shall produce a displayed luminance of 100 cd/m².

When the HDR Reference Display is sent a full frame image with code values 2747 X'', 2770 Y'', 2808 Z'', the chromaticity coordinates of the displayed image shall be x = 0.3124, y = 0.3291. These code values shall produce a displayed luminance of 500 cd/m².

Behavior of code values representing output luminance exceeding 500 cd/m² is undefined.

9.3 Minimum Active Black Level

Minimum Active Black Level shall be 0.005 cd/m², and shall not exceed the specified tolerances in Table A.1. Behavior of code values representing output luminance below 0.005 cd/m² is undefined.

9.4 White Chromaticity Uniformity

The variance in displayed chromaticity across the display shall not exceed the specified tolerances in Table A.1.

9.5 Electro-Optical Transfer Function

9.5.1 Encoding Function

The encoding transfer function shall be defined in terms of output-referred CIE XYZ tristimulus values produced by the HDR Reference Display unit. The HDR transfer functions are specified using 12bit CIE XYZ Encoding Primaries and ST 2084 EOTF, as shown below:

$$CV_{X''} = floor\left(\frac{1}{2} + \mathrm{k}_1 \cdot \left(\frac{c_1 + c_2\left(\frac{X}{k_0}\right)^{m_1}}{1 + c_3\left(\frac{X}{k_0}\right)^{m_1}}\right)^{m_2}\right)$$

$$CV_{Y''} = floor\left(\frac{1}{2} + \mathrm{k}_1 \cdot \left(\frac{c_1 + c_2\left(\frac{Y}{k_0}\right)^{m_1}}{1 + c_3\left(\frac{Y}{k_0}\right)^{m_1}}\right)^{m_2}\right)$$

$$CV_{Z''} = floor\left(\frac{1}{2} + \mathrm{k}_1 \cdot \left(\frac{c_1 + c_2\left(\frac{Z}{k_0}\right)^{m_1}}{1 + c_3\left(\frac{Z}{k_0}\right)^{m_1}}\right)^{m_2}\right)$$

where:

$$\mathrm{k}_0 = 10{,}000 \qquad \mathrm{m}_1 = \frac{2610}{4096} \cdot \frac{1}{4} \qquad \mathrm{c}_2 = \frac{2413}{4096} \cdot 32$$

$$\mathrm{k}_1 = 4095 \qquad \mathrm{m}_2 = \frac{2523}{4096} \cdot 128 \qquad \mathrm{c}_3 = \frac{2392}{4096} \cdot 32$$

$$\mathrm{c}_1 = \mathrm{c}_3 - \mathrm{c}_2 + 1$$

The unary function $floor()$ yields the largest integer not greater than its argument.

Note: If the data is transported over SMPTE ST 372 (SDI dual link), code values 0-15 and 4080-4095 are reserved (illegal) code values and these code values will be clipped.

9.5.2 Decoding Function

The following equations can be used to compute X, Y and Z from a set of code values:

$$X = k_0 \left(\frac{max\left[\left(\frac{CV_{X''}}{k_1} \right)^{\frac{1}{m_2}} - c_1, 0 \right]}{c_2 - c_3 \left(\frac{CV_{X''}}{k_1} \right)^{\frac{1}{m_2}}} \right)^{\frac{1}{m_1}}$$

$$Y = k_0 \left(\frac{max\left[\left(\frac{CV_{Y''}}{k_1} \right)^{\frac{1}{m_2}} - c_1, 0 \right]}{c_2 - c_3 \left(\frac{CV_{Y''}}{k_1} \right)^{\frac{1}{m_2}}} \right)^{\frac{1}{m_1}}$$

$$Z = k_0 \left(\frac{max\left[\left(\frac{CV_{Z''}}{k_1} \right)^{\frac{1}{m_2}} - c_1, 0 \right]}{c_2 - c_3 \left(\frac{CV_{Z''}}{k_1} \right)^{\frac{1}{m_2}}} \right)^{\frac{1}{m_1}}$$

9.6 Color Gamut

In an additive display, the color gamut is a cuboid with vertices determined by the XYZ coordinates of the three color primaries, the white point, and the black point. The color primaries and white point in Table A.1 define the minimum gamut for an HDR Reference Display.

9.7 Color Accuracy

Within the minimum color gamut, all colors shall be accurately reproduced. Table A.1 defines tolerances that can be used to verify the color primaries of the minimum gamut. Table A.4 provides exact chromaticity and luminance values for a set of test code values that fall within these tolerances.

ANNEX A: Normative Tables

The HDR Reference Display image parameters and tolerances for the displayed image in Review Rooms and Exhibition Theaters, as measured from the display and including the room ambient light, are summarized in Table A.1. Where the nominal parameters are specified as minimums, it is understood that these parameters shall not be constrained from future improvements as the technology improves.

Tolerances for Electro-Optical Transfer Function – distortion measured as a percentage error calculated as follows:

Percentage error = 100*((measured luminance – target luminance) / target luminance)

where target luminance is derived by decoding the input code value using the decoding equation in Section 9.5.2, using the ranges and tolerances specified in Table A.1.

Table A.1 *Image Parameters and Tolerances for HDR Reference Display*

Section	Parameter	Nominal	HDR Reference Projector		HDR Cinema Direct View Display
			Review Room	Theater	
8.2	Luminance, spot (for proj) or screen average (for DVD), 100% white	500.0 cd/m^2 (146 fL)	± 10.0 cd/m2	± 10.0 cd/m2	± 10.0 cd/m2
	Luminance, sides	500.0 cd/m^2 (146 fL)	85% of center	80% to 90% of center	Per DCI Cinema Direct View Display Requirements Addendum
	Luminance, corners	500.0 cd/m^2 (146 fL)	85% of center	Not Specifed	
8.3	White chromaticity, center, 100% white	x = 0.3127 y = 0.3290	± 0.002 x ± 0.002 y	± 0.006 x ± 0.006 y	
8.4	Minimum Active Black Level	0.005 cd/m2 (0.0003 fL)	< 0.0002 cd/m²	< 0.0002 cd/m²	
8.5	White chromaticity uniformity, corners (tolerance from center)	± 0.000 x ± 0.000 y	± 0.008 x ± 0.008 y	± 0.015 x ± 0.015 y	
8.6	Electo-Optical Transfer Function	Per SMPTE ST 2084	< 0.02 cd/m^2 ± 5% 0.02 - 500 cd/m^2 ± 2%	< 0.02 cd/m^2 ± 5% 0.02 - 500 cd/m^2 ± 2%	< 0.02 cd/m^2 ± 5% 0.02 - 500 cd/m^2 ± 2%
8.7	Color Gamut	The cube in XYZ space defined by the black point and the following points expressed in Y,x,y. Representing a 500 nits P3D65 color volume Red (114.48, 0.6800, 0.3200) Green (345.8693 ,0.2650, 0.6900) Blue (39.6435 , 0.1500, 0.0600) Peak White (500, 0.3127, 0.3290)	N/A	N/A	N/A
8.8	Color Accuracy	The following points are expressed in x,y. Red (0.6800 ± .01 0.3200 ± .01) Green (0.2650 ± .02 0.6900 ± .02) Blue (0.1500 + 0.01/-0.03, 0.0600 + 0.02/-0.04)	Same	Same	Same

Table A.2 – *Black-to-white gray step-scale test pattern code values, luminance values, and chromaticity coordinates (all measurements are made in the center of the Screen)*

	Input Code Values			**Output Chromaticity Coordinates**		**Output Luminance**
Step Number	**X″**	**Y″**	**Z″**	**x**	**y**	**Y,** cd/m²
1	472	481	496	0.3126	0.3292	0.50
2	603	614	632	0.3122	0.3292	1.00
3	758	771	792	0.3121	0.3293	2.00
4	1000	1015	1040	0.3124	0.3291	5.00
5	1211	1227	1255	0.3128	0.3288	10.00
6	1444	1462	1492	0.3128	0.3291	20.00
7	1783	1803	1836	0.3126	0.3292	50.01
8	2060	2081	2116	0.3127	0.3291	100.10
9	2350	2372	2408	0.3127	0.3292	200.21
10	2747	2770	2808	0.3124	0.3291	499.30

Table A.3 – *Black-to-dark gray step-scale test pattern code values, luminance values, and chromaticity coordinates (all measurements are made in the center of the Screen)*

	Input Code Values			**Output Chromaticity Coordinates**		**Output Luminance**
Step Number	**X″**	**Y″**	**Z″**	**x**	**y**	**Y,** cd/m²
1	60	62	65	0.3095	0.3296	0.0050
2	74	76	79	0.3134	0.3302	0.0075
3	86	88	92	0.3133	0.3281	0.0100
4	105	108	112	0.3124	0.3309	0.0151
5	121	124	129	0.3129	0.3293	0.0202
6	157	161	167	0.3125	0.3300	0.0352
7	185	189	196	0.3138	0.3291	0.0501
8	221	226	234	0.3131	0.3296	0.0752
9	250	255	265	0.3129	0.3279	0.0998
10	332	339	351	0.3121	0.3289	0.1997

Table A.4 – *Color Accuracy color patch code values, luminance values, and chromaticity coordinates. The accuracy with which these colors shall be displayed are shown in Table A.1*

	Input Code Values			Output Chromaticity Coordinates		Output Luminance
Patch	**X′′**	**Y′′**	**Z′′**	**x**	**y**	**Y,** cd/m²
Red-1	2455	2136	67	0.6799	0.3201	114.37
Green-1	2198	2608	1506	0.2650	0.6898	345.41
Blue-1	2078	1715	2789	0.1505	0.0603	39.79
Cyan-1	2435	2656	2808	0.1996	0.3319	385.41
Magenta-1	2604	2261	2789	0.3363	0.1515	154.19
Yellow-1	2645	2734	1505	0.4378	0.5360	460.19
Red-2	2385	2106	1216	0.6401	0.3299	106.37
Green-2	2324	2623	1872	0.3002	0.5998	357.45
Blue-2	2039	1679	2748	0.1502	0.0602	36.19
Cyan-2	2499	2665	2800	0.2247	0.3287	393.40
Magenta-2	2541	2228	2757	0.3207	0.1544	142.57
Yellow-2	2655	2737	1931	0.4193	0.5053	463.34
White-1 D65	2747	2770	2808	0.3124	0.3291	499.30
White-2 D60	2733	2755	2759	0.3214	0.3378	482.63
White-3 D55	2716	2736	2700	0.3321	0.3476	462.29

ANNEX B: Subjective Parameters (Informative)

The following parameters are also important to picture quality, but because they are difficult to measure with today’s readily available instrumentation, they are generally assessed subjectively.

Instrumentation designers are encouraged to design and manufacture equipment that can be used to translate subjective parameters into objective performance characterization.

B.1 Grayscale Tracking

Using the black-to-white gray step-scale test pattern, the entire step-scale appears neutral without any visible color non-uniformity. The black-to-white gray step-scale test pattern is centered on the display and occupies a rectangle sized 20% of the screen height by 80% of the screen width. The background is defined by code values [1000 1015 1040], which define a luminance of 5.0 cd/m^2 and chromaticity coordinates x = 0. 0.3124 y= 0.3291. Each step is 8% of the screen width and is defined by the code values in Table A.2.

Using the black-to-dark gray step-scale test pattern, the entire step-scale appears neutral without any visible color non-uniformity. The black-to-dark gray step-scale test pattern is centered on the display and occupies a rectangle sized 20% of the screen height by 80% of the screen width. The background is defined by code values

[122 124 129], which define a luminance of 0.020 cd/m2 and chromaticity coordinates x = 0.3129 y= 0.3293. Each step is 8% of the screen width and is defined by the code values in Table A.3.

B.2 Contouring

Contouring is the appearance of steps or bands where only a continuous or smooth gradient is expected. Because contouring is a function of many variables, it is important to look at a series of test patterns with shallow gradations to simulate naturally occurring gradations in images.

Examples include horizons, particularly at sunset or sunrise, and the natural falloff around high intensity spotlights, particularly if diffused by atmosphere or lens filtration. These test pattern ramps have a step width of no less than 4 pixels with an increment of one code value per step and are placed on a background equal to the minimum value in the ramp, so that the eye is adapted for maximum sensitivity.

Since dynamic fades to black are widely used in real-world content, a dynamic test pattern that fades slowly to black is another useful approach.

Each image is viewed in the proper environment as defined in Section 7, and ought not to exhibit any contouring (step in luminance), or color deviation from the neutral gray.

ANNEX C: D65 Color Primaries, White Point and Color Conversions (Informative)

The color image encoding parameters for today's HDR Reference Displays and the corresponding color conversion steps to convert from P3D65 R'G'B' to X''Y''Z'' and from X''Y''Z'' to P3D65 RGB are shown here as an example for implementation.

C.1 Color Primaries

Table C.1 *– Chromaticity Coordinates of Primaries*

Encoding Primaries
R (x, y) = (0.6800, 0.3200)
G (x, y) = (0.2650, 0.6900)
B (x, y) = (0.1500, 0.0600)

x, y refers to the chromaticity coordinates defined by the CIE.

C.2 White Reference

Table C.2 *– Chromaticity Coordinates of White Reference*

White Reference
(x, y) = (0.3127,0.3290)

x, y refers to the chromaticity coordinates defined by the CIE.

C.3 Luminance

The Reference White Luminance is 500 cd/m^2.

C.4 Color Conversion R′G′B′ to X″Y″Z″

Color conversion from R′G′B′ to X′′Y′′Z′′ typically involves the following five-step process:

1) To the R′G′B′ code values, apply the inverse-quantization process to convert the image's integer code values to a non-linear R′G′B′ signal in the range [0.0,1.0] from the code value's integer range, 12bit full-range code values range from [0,4095] and 16 bit full-range code values range from [0,65535].

2) To the non-linear R′G′B′ signal, apply ST 2084 EOTF to convert non-linear R′G′B′ signal to linear RGB signal.

3) To the linear RGB signal, apply the RGB to XYZ primary conversion matrix to convert linear RGB to linear XYZ.

4) To the linear XYZ signal, apply the ST 2084 Inverse-EOTF to convert from linear XYZ to non-linear X′′Y′′Z′′.

5) To the non-linear X′′Y′′Z′′ signal, apply the 12 bit full-range quantization process to convert non-linear X′′Y′′Z′′ to 12 bit X′′Y′′Z′′ code values.

The transfer function of the HDR Reference Display is explicitly specified by ST 2084. The actual coefficients of the color transform matrices depend on the color primaries of the Mastering HDR Reference Display (encoding side) and the Cinema HDR Display (decoding side), and their respective white points.

The processing steps for converting 12 bit R′G′B′ code values (which range from 0 to 4095) of the color-graded master to device-independent X′′Y′′Z′′ are shown below.

This color space conversion can be implemented within the color corrector or applied in a separate batch process. The equations below combine step #1 (inverse quantization) and step #2 (ST 2084 EOTF):

$$R = k_0 \left(\frac{max\left[\left(\frac{CV_{R'}}{k_1} \right)^{\frac{1}{m_2}} - c_1, 0 \right]}{c_2 - c_3 \left(\frac{CV_{R'}}{k_1} \right)^{\frac{1}{m_2}}} \right)^{\frac{1}{m_1}}$$

$$G = k_0 \left(\frac{max\left[\left(\frac{CV_{G'}}{k_1} \right)^{\frac{1}{m_2}} - c_1, 0 \right]}{c_2 - c_3 \left(\frac{CV_{G'}}{k_1} \right)^{\frac{1}{m_2}}} \right)^{\frac{1}{m_1}}$$

$$B = k_0 \left(\frac{max\left[\left(\frac{CV_{B'}}{k_1}\right)^{\frac{1}{m_2}} - c_1, 0\right]}{c_2 - c_3\left(\frac{CV_{B'}}{k_1}\right)^{\frac{1}{m_2}}} \right)^{\frac{1}{m_1}}$$

where:

$$\mathrm{k}_0 = 10{,}000 \qquad \mathrm{m}_1 = \frac{2610}{4096} \cdot \frac{1}{4} \qquad \mathrm{c}_2 = \frac{2413}{4096} \cdot 32$$

$$\mathrm{k}_1 = 4095 \qquad \mathrm{m}_2 = \frac{2523}{4096} \cdot 128 \qquad \mathrm{c}_3 = \frac{2392}{4096} \cdot 32$$

$$\mathrm{c}_1 = \mathrm{c}_3 - \mathrm{c}_2 + 1$$

The output (RGB) of this linearization is a floating point number that ranges from 0.0 to 10000.0. The 3x3 linear matrix is then applied to this signal, resulting in a linear XYZ signal with floating point values that range from 0.0 to 10000.0. To minimize quantization errors, this matrix should be implemented as a floating point calculation. The matrix is shown here to 14 significant digits.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{pmatrix} 0.48657094864822 & 0.26566769316910 & 0.19821728523436 \\ 0.22897456406975 & 0.69173852183651 & 0.07928691409375 \\ 0 & 0.04511338185890 & 1.04394436890098 \end{pmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Finally, the X''Y''Z'' encoding transfer function is defined by the following expression which performs both step #4 (Inverse-EOTF) and step #5 (12bit Quantization). This equation does not compensate for the screen black level, so it represents an absolute encoding of the light levels independent of the screen black level.

$$CV_{X''} = floor\left(\frac{1}{2} + \mathrm{k}_1 \cdot \left(\frac{c_1 + c_2\left(\frac{X}{k_0}\right)^{m_1}}{1 + c_3\left(\frac{X}{k_0}\right)^{m_1}}\right)^{m_2}\right)$$

$$CV_{Y''} = floor\left(\frac{1}{2} + \mathrm{k}_1 \cdot \left(\frac{c_1 + c_2\left(\frac{Y}{k_0}\right)^{m_1}}{1 + c_3\left(\frac{Y}{k_0}\right)^{m_1}}\right)^{m_2}\right)$$

$$CV_{Z''} = floor\left(\frac{1}{2} + \mathrm{k}_1 \cdot \left(\frac{c_1 + c_2\left(\frac{Z}{k_0}\right)^{m_1}}{1 + c_3\left(\frac{Z}{k_0}\right)^{m_1}}\right)^{m_2}\right)$$

where:

$$\mathrm{k}_0 = 10{,}000 \qquad \mathrm{m}_1 = \frac{2610}{4096}\cdot\frac{1}{4} \qquad \mathrm{c}_2 = \frac{2413}{4096}\cdot 32$$

$$\mathrm{k}_1 = 4095 \qquad \mathrm{m}_2 = \frac{2523}{4096}\cdot 128 \qquad \mathrm{c}_3 = \frac{2392}{4096}\cdot 32$$

$$\mathrm{c}_1 = \mathrm{c}_3 - \mathrm{c}_2 + 1$$

The unary function $floor()$ yields the largest integer not greater than its argument.

C.5 Color Conversion X″Y″Z″ to P3D65 RGB

The X″Y″Z″-to-P3D65 RGB processing steps for a Cinema HDR Display with the same color primaries as the HDR Reference Display are shown below and defined by the following steps:

1) Apply Inverse Quantization to the 12 bit X″Y″Z″ code values, converting 12 bit X″Y″Z″ code values to non-linear X″Y″Z″ in the range [0.0,1.0]

2) Apply ST 2084 EOTF to non-linear X″Y″Z″ values, converting non-linear X″Y″Z″ to linear XYZ

3) Apply XYZ to RGB conversion to linear XYZ values

The equations below show step #1 (inverse quantization) and step #2 (ST 2084 EOTF) combined

$$X = k_0\left(\frac{max\left[\left(\frac{CV_{X''}}{k_1}\right)^{\frac{1}{m_2}} - c_1, 0\right]}{c_2 - c_3\left(\frac{CV_{X''}}{k_1}\right)^{\frac{1}{m_2}}}\right)^{\frac{1}{m_1}}$$

$$Y = k_0\left(\frac{max\left[\left(\frac{CV_{Y''}}{k_1}\right)^{\frac{1}{m_2}} - c_1, 0\right]}{c_2 - c_3\left(\frac{CV_{Y''}}{k_1}\right)^{\frac{1}{m_2}}}\right)^{\frac{1}{m_1}}$$

$$Z = k_0\left(\frac{max\left[\left(\frac{CV_{Z''}}{k_1}\right)^{\frac{1}{m_2}} - c_1, 0\right]}{c_2 - c_3\left(\frac{CV_{Z''}}{k_1}\right)^{\frac{1}{m_2}}}\right)^{\frac{1}{m_1}}$$

where:

$$k_0 = 10{,}000 \qquad m_1 = \frac{2610}{4096} \cdot \frac{1}{4} \qquad c_2 = \frac{2413}{4096} \cdot 32$$

$$k_1 = 4095 \qquad m_2 = \frac{2523}{4096} \cdot 128 \qquad c_3 = \frac{2392}{4096} \cdot 32$$

$$c_1 = c_3 - c_2 + 1$$

Apply XYZ to P3D65 color encoding primaries transformation:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{pmatrix} 2.49349691194142 & -0.93138361791914 & -0.40271078445070 \\ -0.82948896956157 & 1.76266406031835 & 0.02362468584193 \\ 0.03584583024378 & -0.07617238926804 & 0.95688452400768 \end{pmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

The resulting linear RGB light levels may end up being converted to other formats as the image data flows through the image/display processing operations involved in ultimately displaying the image to the viewer via the HDR display.

If other formats within the HDR display that may have a limited precision, it is important to preserve the visual fidelity/accuracy that is achievable with the 12 bit X′′Y′′Z′′ ST 2084 distribution format across the minimum gamut (luminance range and color volume) specified elsewhere in this document to ensure that additional fidelity isn’t loss.

ANNEX D: Bibliography (Informative)

SMPTE ST 372:2011, Dual Link 1.5 Gb/s Digital Interface for 1920 × 1080 and 2048 × 1080 Picture Formats

SMPTE RP 177:1993, Derivation of Basic Television Color Equations