VESA High-performance Monitor and Display Compliance Test Specification (DisplayHDR CTS)

Revision 1.1

29 August, 2019

www.vesa.org

Purpose

The purpose of this Specification is to provide performance guidance to manufacturers of HDR PCs, including laptops, All-in-One PCs, and desktop monitors, to facilitate a DisplayHDR user-facing logo program that defines a publicly shared set of standards that are represented by a series of logos.

Summary

This Specification describes HDR, why VESA created a DisplayHDR logo program, and the compliance test specifications that are necessary for a device manufacturer to self-certify a device as meeting one or more of the VESA DisplayHDR performance tiers.

Contents

Tables

Figures

Preface

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Support for this Specification

Clarifications and application notes might exist that further support this Specification. To obtain the latest Specification and any support documentation, contact VESA.

If you have a product that incorporates the DisplayHDR logo program, ask the company that manufactured your product for assistance. If you are a manufacturer, VESA can assist you with any clarification that you might need.

Submit all comments or reported errors to support@vesa.org.

Acknowledgments

This document would not have been possible without the efforts of VESA's Display Performance Metrics (DPM) Task Group. In particular, Table 1 lists the individuals and their companies that contributed significant time and knowledge to this version of the Specification.

Table 1: Main Contributors to *DisplayHDR CTS r1.1*

Company	Name	Contribution
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Revision History

Table 2: Revision History

Date	Revision	Description

August 31, 2019	1.1	• Added new performance tier, DisplayHDR-1400 (DHDR_CTS_1400_SCR_v0.70), which included globally changing "colorimeter" to "measurement instrument"
		• Switched static contrast method with HDR focused dynamic contrast measurement method using stops
		• Finalized active dimming stops
		• Added changes made to r1.0 of this Specification through ratification of the following SCRs and related documents:
		  • *DHDR_CTS_10%_patch_screen_saver_SCR v0.9*
		  • *DHDR_CTS_Add_True_Black_Level_SCR v0.92*
		  • *DHDR_CTS_Checkerboard_SCR*
		  • *DHDR_CTS_Test_Improvements SCR v0.9*
		  • *DisplayHDR_DP_Certification_Requirement_SCR D3*
		  • *DisplayHDR_Mode_Indicator_SCR*
		  • *DP Test Certification*
		  • *Introduction of the new 500 level to the DisplayHDR CTS*
		  • *Refinement of the DPM Rise Time Performance Test*
		  • *Updates to recommended test tool location and OS versions*
		• Table 1-4 – Updated reference documents
		• Table 2-1 and Table 7-1 – Clarified Backlight Control bit depth
		• Section 3.4 – Added test tool tolerances and suggested measurement tool list
		• Section 9 – Added new Luminance and White Point Accuracy section using *Delta-ITP*
		• Appendix D – Added new Display Primary Patches appendix
		• Applied GMR feedback and editorial improvements

November 27, 2017	1.0	Initial release of the Specification.

1 Overview

1.1 Summary

This Specification describes HDR, why VESA created a DisplayHDR logo program, and the compliance test specifications that are necessary for a device manufacturer to self-certify a device as meeting one or more of the VESA DisplayHDR performance tiers.

1.2 Introduction

As of 2017, within the marketplace for televisions, there is an array of high dynamic range (HDR) logos and standards, none of which provide a complete set of technical performance specifications or fully publish their testing methodology. Thus, a user cannot easily compare one device with another.

By contrast, the PC industry has historically been far more specification-based, openly publishing performance specifications. The DPM Task Group was founded to establish a Specification that could be used for personal computer (PC) displays, both laptops and desktops, that would clearly convey a robust performance level as indicated by the specification level and associated logo for each performance level.

The DPM Task Group developed this Specification to meet the following goals:

- **Define multiple DisplayHDR performance tiers.** The initial goal was to establish this Specification with three tiers, but to also anticipate additional tiers that could be added later as display performance improves. A set of logos shall be developed that may be used by device manufactures for user products that meet each of the respective tiered performance levels.
- **Define and openly publish a set of standardized tests.** This shall enable low-cost self-certification for device manufacturers. In addition, simplified use of the test process by reviewers, retailers, and users encourages appropriate application of the DisplayHDR logo and Specification.
- **Define any necessary interface and communication protocols that may be deemed necessary to define as part of the Specification.** For example, define bit depth, color gamut, and/or other specifications that are necessary for communication between the graphics processing unit (GPU) and display, thereby leveraging existing VESA groups to drive any changes necessary within related Standards and/or Specifications.

Initially, three performance tiers were introduced in December 2017 at 400, 600, 1000. Subsequently, the 500 performance tier was added in *DisplayHDR CTS r1.1*, and the 1400 performance tier was added in September 2019. The current performance tiers and their associated label names are listed below. The test criteria for each tier are discussed throughout the remainder of this Specification.

- DisplayHDR-400
- DisplayHDR-500
- DisplayHDR-600
- DisplayHDR-1000
- DisplayHDR-1400

In addition to performance tiers, VESA defined the following new performance level in *DisplayHDR CTS r1.1* to build on each performance tier, in recognition of higher-grade HDR quality:

- DisplayHDR **True Black** (see Section 10)

1.3 Scope

Although this Specification defines device display performance, it cannot in its entirety be applied to individual display components. Specifically, many of the tests need a combination of backlighting, a display panel, timing controller (TCON), GPU, and operating system. Many of the tests might also need a scaler to evaluate performance.

The defined specifications are designed for LCD (DisplayHDR) and OLED (DisplayHDR **True Black**), but should be equally applicable to any other display technology that can pass the relevant tests.

The following features are explicitly excluded from this Specification (see Section 11 for further details):

- Resolution
- Aspect ratio
- Audio

1.4 Abbreviations and Acronyms

Table 1-1: Abbreviations and Acronyms

Term	Description
BLU	BackLight Unit. Illumination unit behind the LCD open-cell glass panel.
cd/m^2	candela per square meter (formerly referred to as “nits”).
CV	Code Value.
DisplayID	Display IDentification (VESA).
DisplayPort Alt Mode	DisplayPort Alt Mode on USB Type-C (VESA).
DP	DisplayPort (VESA)
DPM	Display Performance Metrics.
EDID	Extended Display Identification Data (VESA). Legacy VESA structure, superseded by the DisplayID structure.
E-EDID	Enhanced Extended Display Identification Data (VESA). Legacy VESA structure, superseded by the DisplayID structure.
EOTF	Electro-Optical Transfer Function.
FPS	Frames Per Second.
FRC	Frame Rate Converter.
GPU	Graphics Processing Unit.
HDR	High Dynamic Range.
HLG	Hybrid Log Gamma.
MaxCLL	Maximum Content Light Level.
mDP	mini DisplayPort (VESA).
OLED	Organic Light-Emitting Diode.
OSD	On-Screen Display.
PC	Personal Computer.
PQ	Perceptual Quantizer (*SMPTE ST 2084*).
SCE	Specular Component Excluded.
SCI	Specular Component Included.
SDR	Standard Dynamic Range.
TCON	Timing Controller.

1.5 Glossary

Table 1-2: Glossary of Terms

Term	Description
chromaticity	Typically refers to the color gamut that is being used (e.g., *ITU-R BT.709* or *ITU-R BT.2124*).
CTA-861	References to *CTA-861* refer to either *CTA-861.3* or *CTA-861-G*.
DisplayPort	VESA open digital communications interface for use in both internal connections (e.g., interfaces within a PC and/or monitor), and external display connections. Suitable external display connection interfaces, such as between the following devices: • PC and monitor or projector • PC and TV • DVD player and TV display
HDR	High Dynamic Range. References displays that have the ability to show a greater contrast ratio than what is typically considered SDR. ***Note:*** *There is no definition of the minimum ratio of HDR in general. In this Specification, the first tier evaluates to a ratio of 4000:1. For the purposes of this Specification, this ratio could therefore be considered as the HDR starting point.*
MasteringDisplay Luminance	Peak 10% patch sustainable luminance of the display that is used to master and grade video content.
MaxCLL	Maximum Content Light Level. Maximum luminance level of the entire content clip (e.g., in a movie, it is the maximum luminance pixel within the entire movie). Contained with an HDR file as metadata.
MaxFALL	Maximum Frame Average Luminance Level. Peak average luminance that is either achieved in a video sequence, –or– if in the context of hardware, the peak sustainable average full-screen luminance level.
MaxLuminance	Generically used to mean either of the following DisplayID or legacy EDID variables: • ***DisplayID Standard*** – NativeMaximumLuminance • **EDID r1.3 (and higher) with the *CTA-861* block** – DesiredContentMaxLuminance In both cases, the value represents the maximum peak luminance that the display device can achieve with a 10% **white** patch at the screen's center for a period of at least 30 minutes.
rise time	Length of time that the display takes to transition from **black** to **white**.
SCE	Specular Component Excluded; with reference to a reflectivity measurement.
SCI	Specular Component Included; with reference to a reflectivity measurement.
SDR	Standard Dynamic Range. Represented by a contrast ratio from **black** to **white**, typical panels range from 500:1 to approximately 1500:1.

1.6 Conventions

1.6.1 Precedence

If there is a conflict between text, figures, and tables, the precedence shall be tables, figures, and then text.

1.6.2 Keywords

Table 1-3 lists keywords that differentiate between the levels of specifications and options within this Specification.

Table 1-3: Keywords

Keyword	Definition
Informative	Describes information that discusses and clarifies features and mandatory specifications as opposed to mandating them.
May	Indicates a choice with no implied preference.
N/A	Indicates that a field or value is **not** applicable and has no defined value, and shall **not** be checked or used by the recipient.
Normative	Describes features that are specified by this Specification.
Optional	Describes features that are **not** specified by this Specification. However, if an **optional** feature is implemented, the feature shall be implemented as defined by this Specification (**optional** normative).
Shall	Indicates a mandatory specification. Designers are to implement all such specifications to ensure interoperability with other compliant devices.
Should	Indicates flexibility of choice with a preferred alternative. Equivalent to the phrase “it is recommended that.”

1.7 Reference Documents

Table 1-4 lists the various reference documents that are used within this Specification. Users of this Specification are advised to ensure that they have the latest versions/revisions of reference Standards/Specifications and documents.

Table 1-4: Reference Documents

Document	Version/ Revision[a]	Publication Date	Referenced As
Adobe® RGB (1998) Color Image Encoding	Version 2005-05	May 2005	*Adobe RGB*
Recommendation ITU-R BT.709, Parameter values for the HDTV standards for production and international programme exchange[b]	Version 6	June 2015	*ITU-R BT.709*
Recommendation ITU-R BT.1886, Reference electro-optical transfer function for flat panel displays used in HDTV studio production[b]		March 2011	*ITU-R BT.1886*
Recommendation ITU-R BT.2020, Parameter values for ultra-high definition television systems for production and international programme exchange[b]	Version 2	October 2015	*ITU-R BT.2020*
Recommendation ITU-R BT.2124, Objective metric for the assessment of the potential visibility of colour differences in television[c]	BT.2124-0	January 2019	*Delta-ITP*
CIE 15, Technical Report – Colorimetry	4th Edition	2018	*CIE 15*
CIE 1931, x, y Chromaticity Diagram	1931	1931	*CIE 1931*
CIE Illuminant D65	1964	1964	*CIE D65*
*CIE ISO 11664-5, Colorimetry – Part 5: CIE 1976 L*u*v* colour space and u', v' uniform chromaticity scale diagram*	2016	2016	*CIE 1976 L*u*v and u', v'*
CTA-861, A DTV Profile for Uncompressed High Speed Digital Interfaces (Formerly known as *CEA-861*)[d]	G	November 2, 2017	*CTA-861*
CTA-861.3, HDR Static Metadata Extension – (formerly known as *CEA-861.3*)[d]	Version 3A	July 1, 2016	*CTA-861.3*
High-Definition Multimedia Interface (HDMI) Specification[e]	Version 1.4b Version 2.0b	October 11, 2011 March 3, 2016	*HDMI v1.4b* *HDMI v2.0b* *HDMI Specification*
IEC 61966-2-1, Multimedia systems and equipment – Colour measurement and management – Part 2-1: Colour management – Default RGB colour space - sRGB[f]	1999	October 18, 1999 and updates through January 2014	*IEC 61966-2-1*
IEC-62341-6-1, Organic light emitting diode (OLED) displays – Part 6-1: Measuring methods of optical and electro-optical parameters[f]	2nd Edition	January 24, 2017	*IEC 62341-6-1*

Table 1-4: Reference Documents (Continued)

Document	Version/ Revision[a]	Publication Date	Referenced As
Information Display Measurements Standard[g]	Version 1.03	June 1, 2012	*IDMS v1.03*
SMPTE RP 431-2, D-Cinema Quality – Reference Projector and Environment[h]	2011	April 6, 2011	*SMPTE RP 431-2*
SMPTE ST 2084, High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays[h]	2014	August 16, 2014	*SMPTE ST 2084*
VESA DisplayID Standard[k]	Version 2.0	September 11, 2017	*DisplayID Standard*
VESA DisplayPort Alt Mode on USB Type-C Standard (DisplayPort Alt Mode)[k]	Version 1.0b	November 3, 2017	*DisplayPort Alt Mode Standard*
VESA DisplayPort (DP) Standard[k]	Version 2.0[i]	June 26, 2019	*DP Standard*
VESA Enhanced Extended Display Identification Data (E-EDID) Standard[j]	Version A.2	September 25, 2006	*E-EDID Standard*
VESA Glossary of Terms and Acronyms Specification[k]	Current	Current	
VESA Mini DisplayPort Connector (mDP) Standard[k]	Version 1	October 2009	*mDP Standard*

a. *All references include subsequently published errata, specification change notices or engineering change notices, etc.*
b. *Published by the International Telecommunication Union (ITU). See www.itu.int.*
c. *Published by the ITU. See www.itu.int/dms_pubrec/itu-r/rec/bt/R-REC-BT.2124-0-201901-I!!PDF-E.pdf.*
d. *Published by the American National Standard Institute's (ANSI) Accredited Standards Developers and the Consumer Technology Association (ANSI/CTA). See global.ihs.com.*
e. *See www.hdmi.org.*
f. *See global.ihs.com.*
g. *Published by the International Committee for Display Metrology (ICDM) and the Society for Information Display (SID). See www.icdm-sid.org.*
h. *Published by the Society of Motion Picture and Television Engineers (SMPTE). See www.smpte.org/digital-library.*
i. *This version of the referenced Standard is correct at the time of publication of this Specification. If a later version of the referenced Standard is published, reference should be made to the latest published version.*
j. *Included as legacy support for users that have PC devices that include E-EDID (or EDID). Superseded by DisplayID Standard.*
k. *See www.vesa.org/vesa-member/downloads/.*

2 DisplayHDR Specification Summary

Table 2-1 summarizes the high-level specifications documented by this Specification. The sections that follow further detail how each of these display performance features are measured.

Table 2-1: DisplayHDR Test Performance Tier Summary

Test/Specification		DisplayHDR Performance Tier[a]				
		400	**500**	**600**	**1000**	**1400**
Minimum-white Luminance – 10% Center Patch Test[b]	Minimum Luminance Level (cd/m^2)	400	500	600	1000	1400
Minimum-white Luminance – Full-screen Flash Test[b]	Minimum Luminance Level (cd/m^2)	400	500	600	1000	1400
Minimum-white Luminance – Full-screen Long-duration Test[b]	Minimum Luminance Level (cd/m^2)	320	320	350	600	900
Dual Corner Box Test – Black-level Test[c]	Screen Center, Maximum Luminance Level (cd/m^2)	0.40	0.10	0.10	0.05	0.02
	Both White Corners, Minimum Luminance Level (cd/m^2)	300	375	450	750	1050
Active Dimming	Ratio of maximum **white** to **black** of a 50cd/m^2 checkerboard (stops)	11	11.6	12	13	13.5
	Ratio of maximum **white** to **black** of a 5cd/m^2 checkerboard (stops)	12	12.6	13	14	14.5
Color Gamut and Minimum Luminance Specifications[d]	*ITU-R BT.709* Coverage for Both 10% and Full-screen Color Patches	95%	99%	99%	99%	99%
	DCI-P3 *CIE D65*[e] Coverage for Both 10% and Full-screen Color Patches	N/A	90%	90%	90%	95%
	Combined Color Luminance (Lr + Lg + Lb) 10% Color Patch Test (cd/m^2)	400	500	600	1000	1400
	Combined Color Luminance (Lr + Lg + Lb) Full-screen Color Test (cd/m^2)	320	320	350	600	900
Minimum Bit-depth Specifications[f]	10-bit Video Signal, per Channel	✔	✔	✔	✔	✔
	Temporal or Spatial Dithering	8b	8b + 2b FRC	8b + 2b FRC	8b + 2b FRC	8b + 2b FRC
	Minimum 8-bit Digital-to-analog Conversion	✔	✔	✔	✔	✔
	Backlight Control 8-bit Accuracy	✔	✔	✔	✔	✔

Table 2-1: DisplayHDR Test Performance Tier Summary (Continued)

Test/Specification		DisplayHDR Performance Tier[a]				
		400	500	600	1000	1400
DisplayHDR Rise-time Specifications[g]	Shall be 8 frames or less when measured at 60Hz	✔	✔	✔	✔	✔
	Should be 8 frames or less (measured from 10 to 90% luminance) at all supported frame rates	✔	✔	✔	✔	✔
Luminance and White Point Accuracy[h]	Permitted Maximum *Delta-ITP* error for tests up to and including approximately 15cd/m^2	20	20	20	20	20
	Permitted Maximum *Delta-ITP* error for tests at and above approximately 50cd/m^2	15	15	15	15	15

a. *See Section 10 for DisplayHDR* ***True Black*** *performance level specifications.*
b. *See Section 5.1 for further details. All specifications are expressed in* CIE 1931 *x, y chromaticity coordinates.*
c. *See Section 5.2 for further details. All specifications are expressed in* CIE 1931 *x, y chromaticity coordinates.*
d. *See Section 6 for further details. All specifications are expressed in* CIE 1976 *u', v' chromaticity coordinates.*
e. *Defined in SMPTE RP 431-2.*
f. *See Section 7.1 for further details.*
g. *See Section 8.3 for further details.*
h. *See Section 9 for further details.*

3 Test Environment

3.1 Ambient Temperature

The expectation of a User-Facing Logo program is that users can duplicate the tests at home and achieve results that indicate compliance with the DisplayHDR performance tier's specification. As such, a fairly wide range of usage environments should be considered to be "within range," and testing the devices in ambient temperatures within this range should have successful results.

An ambient temperature range of 15 through 30°C (59 through 86°F) shall be supported. Manufacturers should test their devices at 21°C (70°F).

3.2 Measurement Instrument/Sensor Usage

It should be anticipated that users and/or reviewers will use measurement instruments of two predominant form factors:

- Those that hang on a USB cable over the top of the display, and rest against the screen, –or–
- Those that are handheld and touched to the screen with a soft surrounding

In both cases, it should be assumed that:

- No significant source of ambient light leaks around the sensor's edge and into the measuring device
- Sensors are effectively flush against the screen and baffled to prevent light leakage from the sides

Additionally, a darkened room should be used for testing, thereby minimizing direct light from reflecting onto the screen.

Except where noted, the sensor shall be placed at the screen's center for all tests.

While pushing the sensor flush to the screen, take care to ensure that the panel is not being deformed because deformation will impact test performance.

3.3 System Warm-up Time

The device under test should be provided a 30-minutes warm-up time. In addition, the device's screen savers should be disabled at this time so that the display is active for 30 minutes prior to testing. To ensure testing consistency, the display should be warmed up using a **white** screen at 180cd/m^2 for this 30-minute warm-up period.

3.4 Measurement Instrument Specifications

The measurement instrument's quality and capabilities may limit the user's ability to accurately test HDR displays. It is necessary that the measurement instrument be able to reliably measure and report luminance that exceeds the limit being tested. Ideally, the measurement instrument should be able to record levels that are higher than 1400cd/m^2 because some panels with the DisplayHDR-1400 Performance Tier specification naturally perform above 1400cd/m^2.

Furthermore, the measurement instrument and associated gamut calculation method need to be able to operate in the *CIE 1976* u', v' coordinate system, resulting in u', v' chromaticity coordinates and providing a calculation of color gamut coverage in both *ITU-R BT.709* and DCI-P3 *CIE D65* (*SMPTE RP 431-2*). It is possible to use a measurement instrument to measure within the *CIE 1931* coordinate system, using x, y chromaticity coordinates, and then mathematically convert the *CIE 1931* x, y chromaticity coordinates into *CIE 1976* u', v' chromaticity coordinates.

Depending on the performance level of the display under test, there are different mandatory minimum luminance tests. Thus, when testing hardware at the baseline performance level, the measuring hardware shall be capable of accurately measuring down to 0.05cd/m^2. To measure displays at the DisplayHDR **True Black** performance level (see Section 10), however, the measuring hardware shall be capable of accurately measuring down to 0.0005cd/m^2 or less.

For official certification, the following mandates are placed on the measurement tools:

- For DisplayHDR certification:
  - **Black Level Luminance Range 0.05 – 4cd/m^2** – ±4%
  - **White Level Luminance Range 400 – 1000+cd/m^2** – ±2%
  - **Color accuracy** – 0.003 x, y
- For DisplayHDR TrueBlack certification:
  - **Black Level Luminance Range 0.0005 – 4cd/m^2** – ±4%
  - **White Level Luminance Range 400 – 1000+cd/m^2** – ±2%
  - **Color accuracy** – 0.003 x, y

The following is a non-exhaustive, non-exclusive, list of recommended measurement tools that meet the above mandates:

- For DisplayHDR certification:
  - Konica Minolta™ CA-310, CA-410, and CS-2000
  - Photo Research PR-670, PR-680
  - Gamma Scientific GS-1220
  - Topcon TechnoHouse SR-UL1R

Note: *The Konica Minolta CA-310 is limited to 1000cd/m^2, and thus cannot be used for DisplayHDR-1400 certification.*

- For DisplayHDR TrueBlack certification:
  - Konica Minolta CS-2000A
  - Photo Research PR-680L, PR-740/745, PR-788

3.5 Hardware and Software for Semi-automated Testing

Testing products to determine compliance to this Specification may use a hardware pattern generator or other means to apply patterns as specified in later sections. In addition, the DisplayHDR Test Tool is available for free from the Microsoft® Store that operates on a Windows-based PC with appropriate HDR10-capable source hardware. Section 4.1 contains HDR10 Source and Sink mandates.

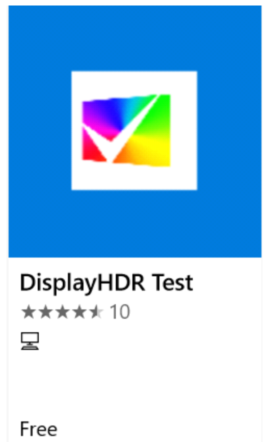

Figure 3-1: Microsoft Store User Interface for DisplayHDR Test Tool

The DisplayHDR Test Tool is **not** integrated with measurement instrument input and monitoring; thus, a second computer needs to be connected to the measurement instrument to record the instrument's data.

Graphics hardware that supports HDR10 is needed. The following suggested options are known to work with Windows®:

- AMD® Radeon Rx 5xx series and Radeon Rx Vega or later
- Intel® 7th Generation Core™ processors or later, with 620 graphics or higher
- NVIDIA® GeForce GTX 10-Series graphics cards or later

For testing of HDR monitors, Microsoft Windows 10, updated to the April 2018 Update (v1803) or later should be used.

For testing of HDR integrated panels, such as those found in laptops and AIO PCs, Microsoft Windows 10, updated to the April 2019 Update (v1903) or later should be used.

3.6 Test Suite and Test Files

Section 5 through Section 10 describe the tests that are necessary to be performed to evaluate which performance tier a display device supports. Appendix B provides the specifications for each test image. Appendix C illustrates a variety of sample DisplayIDs.

3.7 DisplayHDR True Black Performance Level Testing Methodology

Note: *See Section 10 for further details to calibrate DisplayHDR **True Black** performance level measurements.*

Test implementers should follow the *Dark Room Environment for Measurement Procedure* described in *IEC 62341-6-1*, which states:

> *"The luminance contribution from unwanted background illumination reflected off the test display shall be less than 1/20 of the display's black state luminance."*

A measurement instrument should be positioned such that a soft frustum prevents ambient light from entering the test area. If the DisplayHDR **True Black** performance level test results meet performance tier specifications, no further preparation is needed.

3.8 Quantization Ranges

All HDR monitors and, it is assumed, all HDR TVs support Full Range. However, there is a problem in that a third quantization option. Default Range. is the traditional default option for GPU vendors – the interpretation of Default Range is **not** always the same between GPUs and monitors, which can lead to unpredictable, incorrect, and reduced dynamic range.

A DisplayHDR-compliant Sink device shall expose full-range support for both CTA and non-CTA by exposing the correct DisplayID (or legacy EDID) capability fields. Thus, when a GPU GUI presents the quantization range option, the simple solution is to always select Full Range. Therefore, for CTS compliance, when the Default, Limited, and Full quantization range options (or a subset thereof) are available, Full Range shall be used for testing.

Note: *Often, when using DisplayPort, no options will be provided, in which case configuration is **not** needed.*

3.9 DisplayHDR OSD Mode Indication Specification

Effective October 1, 2019, this specification shall need to be met for DisplayHDR certification of discrete displays. This specification does **not** apply to integrated displays (e.g., those used in laptops and All-in-One PCs) unless they provide on-screen displays (OSDs) for adjusting the display modes.

Most displays include more than one mode setting that allows users to optimize the display's settings, by way of the OSD menu system, for a particular use case (e.g., Game mode).

To ensure that certified DisplayHDR displays can be easily configured to operate in DisplayHDR mode, it is important to provide testers and users with unambiguous display settings to enable DisplayHDR.

Certified DisplayHDR displays shall include a profile or mode, available through the OSD menu system, that clearly indicates which mode(s) conform to DisplayHDR performance (e.g., DisplayHDR mode).

If all modes (including if only one mode exists) support DisplayHDR, mode indication is **optional**.

3.10 DisplayPort Certification Specification

Effective October 1, 2019, all standard input connectors that meet the criteria listed below shall be VESA DisplayPort-certified, per the appropriate VESA licensing policy, to qualify for DisplayHDR certification:

- Claim support for the tests in this Specification, and
- Are either DisplayPort –or– DisplayPort Alt Mode on USB Type-C (DisplayPort Alt Mode) inputs

Standard input connectors that may be subject to the above VESA DisplayPort certification are:

- DisplayPort Alt Mode inputs
- Standard DisplayPort input(s)
- Mini DisplayPort (mDP) input(s)

See the appropriate VESA licensing documents to determine the compliance rules and relevant, in-force Standards and/or Specifications that guide VESA DisplayPort certification specifications.

4 Video Signal Input Processing

4.1 HDR10

HDR video on the PC uses the HDR10 format; thus, the minimum specification for a device to be considered HDR-compliant is that the device needs to be able to process HDR10 video.

For monitors, this means that a scaler needs to be used to be able to accept HDR10 input, including a 10-bit signal, EOTF *SMPTE ST 2084*, and *ITU-R BT.2020* color gamut. What happens between the scaler and TCON, and between the TCON and Driver IC, is undefined, other than the driver IC's bit-depth resolution, which is defined as part of this Specification.

For laptops, because their panel and GPU are tightly integrated, HDR10 video processing can be handled anywhere within the display pipeline. Therefore, the HDR10, *ITU-R BT.2020*, and EOTF signals do **not** need to go beyond the GPU. Again, as with monitors, the Driver IC's bit-depth resolution is defined as part of this Specification.

Note: *Although this Specification provides flexibility with regard to where a laptop decodes HDR10 (e.g., in the GPU, the TCON, or possibly in a scaler or similar chip), MovieLabs (movielabs.com) has defined robust security specifications for 4K playback, HDR, and protected movie content. Because of this, it is not been confirmed whether the necessary histogram analysis that is needed for local dimming can be done in the GPU while meeting the MovieLabs security specifications that are necessary for protected movie playback.*

For DisplayHDR-certified displays (both integrated panels and discrete monitors), the operating system and HDR applications shall be capable of obtaining the MaxLuminance and primary color values of the attached display. All metadata references to chromaticity are expressed in *CIE 1931* x, y chromaticity coordinates.

For external displays, the MaxLuminance and primary colors (RGB) shall be populated in the DisplayID (or legacy EDID). For an integrated panel (e.g., laptop or All-in-One PC), there are additional alternatives in which this data can be stored (e.g., in the video BIOS, .inf files, registry, and/or other operating system-supported mechanisms). However, the fundamental specification is that the MaxLuminance, primary colors, and necessary HDR flags shall be available to the HDR applications and operating systems.

The MaxLuminance value that is provided to the Source device by the display, or the alternative source mechanisms supported by internal panels, is (are) specified to be at least as much as that indicated by the DisplayHDR performance tier for which the display is certified. For example, a display that is certified for DisplayHDR-600 shall have a MaxLuminance value of at least 600.

Manufacturers should populate these values as accurately as possible to the display's true performance level, and not merely use the value of the logo achieved by the display. For example, if a display successfully passes DisplayHDR-600 logo certification, the manufacturer is advised to **not** simply use 600cd/m^2 as the MaxLuminance and 90% DCI-P3 *CIE D65* as the primary colors. Rather, the manufacturer should use the actual 10% luminance test result value and color gamut coordinates, thereby potentially yielding a device with an DisplayID (or legacy EDID) performance of, for example, 650cd/m^2 and 93% DCI-P3 *CIE D65*. The more accurate the DisplayID (or legacy EDID), the higher the image performance and quality that Source devices (e.g., Windows PCs) will be able to render to the display.

Display devices shall provide accurate MaxLuminance data to the operating system, thereby enabling sources (e.g., Microsoft Windows and/or the VESA DisplayHDR Test Tool) to optimize to the display's performance characteristics. Mandatory data that needs to be included within the static data block is as follows:

- Indicate support for *SMPTE ST 2084* = Yes.
- Indicate support for *Static Metadata Type 1* = Yes.
- Provide an accurate *Desired Content Max Luminance data* value. Based on the display's ability to display a 10% test patch, this shall also meet or exceed the DisplayHDR performance tier specification for the Minimum-white Luminance – 10% Center Patch Test (see Section 5.1.1).
- Provide accurate *primary colors* (located within the DisplayID (or legacy EDID), **not** the CTA block).

Further, displays should also provide the following data:

- *Desired Content Max Frame-average Luminance data*. Based on the display's ability to display a **white** screen for 30 minutes, this would normally be expected to meet or exceed the DisplayHDR Performance Tier specification for the Minimum-white Luminance – Full-screen Long-duration Test (see Section 5.1.3).
- *Desired Content Min Luminance data*. This value should be populated with the lowest value that is measured for **black** in the Dual Corner Box Test – Black-level Test and/or Checkerboard Tests – Black-level Test (see Section 5.2).

Notes: *All metadata names indicated above (except primary colors) are from the CTA-861 HDR Static Metadata data block. The variable names in DisplayID (or legacy EDID) are slightly different; however, the specified and recommended data inputs remain the same.*

Source devices shall read or validate that they have the relevant data from the DisplayID (or legacy EDID) block at boot up, -or- on a monitor reconnect event. The challenge with caching the data and only checking the device serial number is that OSD menu option changes may change the display behavior, and thus the DisplayID (or legacy EDID) values, while maintaining the same device model and serial number. Checking the device serial number would thus be inadequate, and either a re-read of the data block or verification of the checksum is needed.

4.2 HLG

Hybrid Log Gamma (HLG), rather than EOTF *SMPTE ST 2084*, was deemed **optional** and therefore not included as part of this Specification. This is because no operating system vendors have indicated plans to output HLG from the operating system (by way of the GPU) to the display.

This is not to say that PCs do not support HLG – there are websites with HLG content that can be played on the PC; however, the video signal that is sent from the GPU to the display is converted to EOTF *SMPTE ST 2084*.

4.3 White Point

Throughout this Specification, all references to "**white**" in the DCI-P3 *CIE D65* (*SMPTE RP 431-2*) color space assume the *CIE D65* definition. *CIE D65* is intended to represent average daylight and has a correlated color temperature of approximately 6500K. *CIE D65* should be used in all colorimetric calculations that need representative daylight, unless there are specific reasons for using a different illuminant.

4.4 Test Pattern Recognition Is Prohibited

Pattern recognition merely for the purpose of yielding different results during testing than would be achieved with similar patterns outside the test suite in normal usage is prohibited. Devices found to have used test-based pattern recognition to achieve device certification shall be stripped of their certification.

The fundamental purpose of this test suite is to help manufacturers validate that their hardware meets certain performance characteristics that are expected to be exhibited in typical user usage models. If test pattern recognition is used to achieve different results only when being tested, this would invalidate the purpose of the test suite and is thus prohibited.

Note: *The definition of "pattern recognition" extends beyond merely the images being used in the test program, and to particular metadata combinations that could be used to detect a testing scenario.*

5 DisplayHDR Luminance Specifications

5.1 Minimum-white Luminance Level Specifications

Table 5-1 lists the three kinds of minimum-white luminance level tests, each of which is designed to ensure performance levels as a proxy for various typical PC usages, and is further described in the sections that follow.

Table 5-1: Minimum-white Luminance Level Specifications

Minimum-white Luminance Level Test	Description	Defined In
Minimum-white Luminance – 10% Center Patch Test	Tests that the display can deliver a minimum luminance level for 10% of the screen for a long duration. This is used as a proxy for long-term static images that have a high brightness level (e.g., photo editing of an HDR image that has the sun located within the image).	Section 5.1.1
Minimum-white Luminance – Full-screen Flash Test	In gaming, there are many cases in which the game author's creative intent is to stun the user (e.g., an explosion within a game). While the duration may be brief, the display needs to be able to drive full power across a **white** screen for 2 seconds. It should also be noted that many movies also contain brief scenes of exceptionally high power levels. Today, most TVs fail to deliver the original creative intent of the movie. By specifying the delivery of full power across a **white** screen for 2 seconds, it should be possible to deliver most games and movies to their expected performance levels.	Section 5.1.2
Minimum-white Luminance – Full-screen Long-duration Test	Although the usage is mostly applicable to laptops that are used outside, this test applies to all PC device types. This test is mostly the non-HDR usage model of processing email outside, in bright lighting. For example, although it is not being used for HDR video playback, a user that has purchased an HDR display will typically expect the display to perform better outside than a laptop that has a standard dynamic range (SDR) display. Thus, the minimum brightness that is needed of a **white** screen under long duration is defined.	Section 5.1.3

In the two cases above where "long duration" is defined, the intent and expectation is that this could be an all-day usage scenario, and that the display needs to be designed to not only meet these specifications, but to also work after being delivered to a user who may apply these types of uses for many hours per day. To save time while testing, however, the test is applied for only 30 minutes as a proxy for "all day" as a steady state for power delivery because thermal impact is assumed to be achieved within 30 minutes.

Note: *The code values mentioned throughout this section are the EOTF* SMPTE ST 2084 *lookup values. See Appendix A for a complete list of code values as they relate to luminance levels. For ease of reference, the values in this section are hyperlinked to the lookup table values listed in Appendix A.*

5.1.1 Minimum-white Luminance – 10% Center Patch Test

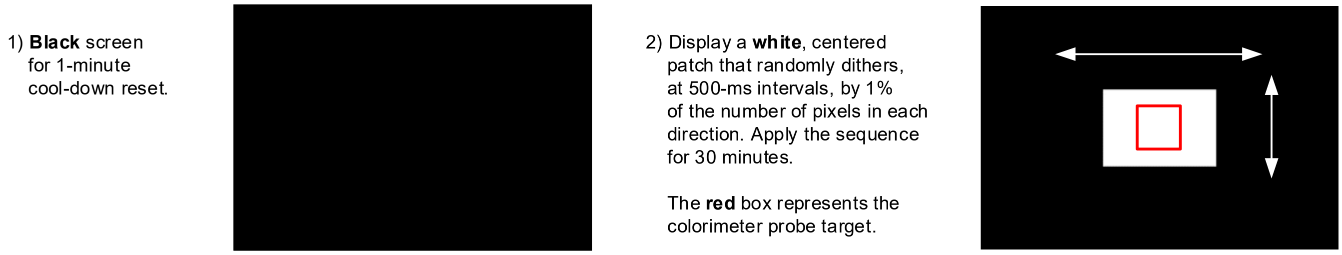

Figure 5-1: 10% Center Patch Test Sequence

- **Black** screen for a 1-minute cool-down reset, code value 0. Actual backlight power would thus be determined by the scaler/TCON/GPU.
- Sequence of bright **white**, the applied code value of which shall equal the MaxLuminance for 10% patches. The patch location shall be static for 500ms, and then randomly shift in and around the center with a uniform, pseudorandom value. A constant random seed shall be used to obtain the same random sequence whenever the pattern starts.
- Metadata included with the video signal shall be set as follows (see Section B.1 for the actual codes used for the motion path):
  - MaxCLL = MaxLuminance value
  - MasteringDisplayLuminance = MaxLuminance value
  - MaxFALL = 0.1 × MaxLuminance value
  - Chromaticity = RGB primary colors from the DisplayID (or legacy EDID)
- Luminance is measured at the screen's center once per minute for 30 minutes, using the same panel. The first measurement should be obtained within 5 seconds of when the **white** patch begins to display. The **red** box indicated in Figure 5-1 is provided for illustrative purposes only.
- All 30 measurements shall be measured at a level that is higher than the Minimum Luminance Level specified in Table 5-2.

Table 5-2: 10% Center Patch Test Performance Specifications

DisplayHDR Performance Tier	Minimum Luminance Level (cd/m^2)
400	400
500	500
600	600
1000	1000
1400	1400

- Luminance delta between the highest and lowest of the 30 measurements shall be less than 10%. The highest measurement divided by the lowest measurement shall have a ratio less than 1.1:1.

5.1.2 Minimum-white Luminance – Full-screen Flash Test

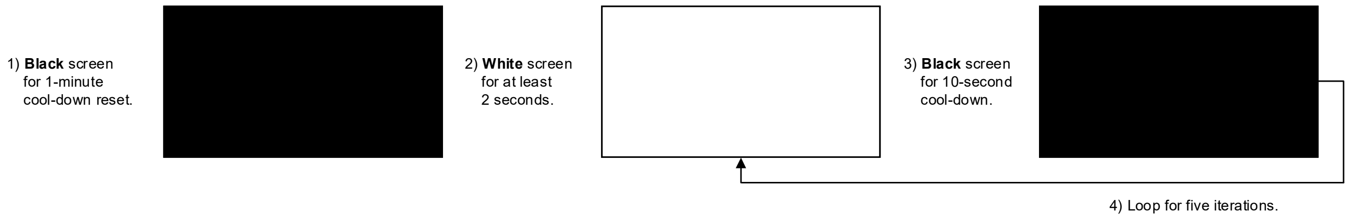

Figure 5-2: Full-screen Flash Sequence

- **Black** screen for a 1-minute cool-down reset, code value 0. Actual backlight power would thus be determined by the scaler/TCON/GPU.
- **White** screen, the applied code value shall equal the MaxLuminance. Displays for 2 seconds.
- Metadata included with the video signal shall be set as follows (see Section B.2 for the actual codes used):
  - MaxCLL = MaxLuminance value
  - MasteringDisplayLuminance = MaxLuminance value
  - MaxFALL = MaxLuminance value
  - Chromaticity = RGB primary colors from the DisplayID (or legacy EDID)

Note: *If your measuring tools are unable to respond within 2 seconds, you can display a* ***white*** *screen for a length of time that is sufficient for your tools to respond. However, this makes the test more difficult from a power delivery and thermal perspective; only 2 seconds are needed to meet this Specification.*

- Luminance is measured at the screen's center once per iteration, for five iterations on the same panel.
- All five measurements shall be measured at a level that is higher than the Minimum Luminance Level specified in Table 5-3.

Table 5-3: Full-screen Flash Test Performance Specifications

DisplayHDR Performance Tier	Minimum Luminance Level (cd/m^2)
400	400
500	500
600	600
1000	1000
1400	1400

- Due to the inability to reliably ensure that user tools are capable of measuring at the same point during the 2 seconds, this Specification does **not** define specifications with respect to luminance variance between the five measurements.

5.1.3 Minimum-white Luminance – Full-screen Long-duration Test

Figure 5-3: Full-screen Long-duration Sequence

- **Black** screen for a 1-minute cool-down reset, code value 0. Actual backlight power would thus be determined by the scaler/TCON/GPU.
- Full-screen long-duration sequence displays a full screen, the applied code value shall equal the MaxLuminance. This is expected to briefly run at maximum luminance, become either power-limited or thermally limited, and then progressively drop the luminance level.
- Metadata included with the video signal shall be set as follows (see Section B.3 for the actual codes used):
    - MaxCLL = MaxLuminance value
    - MasteringDisplayLuminance = MaxLuminance value
    - MaxFALL = MaxLuminance value
    - Chromaticity = RGB primary colors from the DisplayID (or legacy EDID)
- Luminance is measured at the screen's center once per minute for 30 minutes, using the same panel. The first measurement should be obtained within 5 seconds of when the **white** screen begins to display.
- All 30 measurements shall be measured at a level that is higher than the Minimum Luminance Level specified in Table 5-4.

Table 5-4: Full-screen Long-duration Test Performance Specifications

DisplayHDR Performance Tier	Minimum Luminance Level (cd/m^2)
400	320
500	320
600	350
1000	600
1400	900

- Display brightness is expected to decline during the 30-minute test; therefore, this Specification does **not** define specifications with respect to luminance delta.

5.2 Maximum Black-level Test Specifications

Table 5-5 lists the two kinds of **black**-level tests, each of which tests for different display performance features. Both are described in the sections that follow.

Table 5-5: Maximum Black-level Test Specifications

Test	Description		Defined In
Dual Corner Box	**Black** screen, code value 0, with two **white** square patches, each 5% of the screen area. These square patches are positioned at diagonally opposite corners (lower left, upper right). The video signal for the **white** patches is the MaxLuminance value in the DisplayID (or legacy EDID).		Section 5.2.1
Checkerboard Active Contrast Ratio[a]	Active Dimming at $50cd/m^2$	Measures stops between the average of the Maximum White 10% Center Patch test (from Section 5.1.1) over 30 minutes and the checkerboard's **black** level when the checkerboard's **white** level is at $50cd/m^2$.	Section 5.2.2
	Active Dimming at $5cd/m^2$	Measures stops between the average of the Maximum White 10% Center Patch test (from Section 5.1.1) over 30 minutes and the checkerboard's **black** level when the checkerboard's **white** level is at $5cd/m^2$.	

a. *In both tests, a simple 6x4 checkerboard is used, as illustrated in Figure 5-5 and Figure 5-6.*

5.2.1 Dual Corner Box Test – Black-level Test

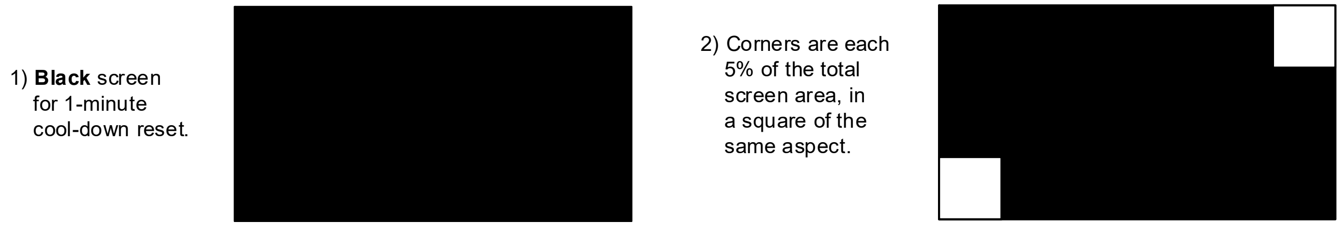

Figure 5-4: Dual Corner Box Test – Black-level Test Sequence

- **Black** screen for a 1-minute cool-down reset, code value 0. Actual backlight power would thus be determined by the scaler/TCON/GPU.
- Dual **white** corners, each 5% of the total screen area and square in shape, are placed in the lower left and upper right corners. The **white** corners use the MaxLuminance value for their video signal, as illustrated in Figure 5-4.
- Metadata included with the video signal shall be set as follows (see Section B.4 for the actual codes used):
  - MaxCLL = MaxLuminance value
  - MasteringDisplayLuminance = MaxLuminance value
  - MaxFALL = 0.1 × MaxLuminance value
  - Chromaticity = RGB primary colors from the DisplayID (or legacy EDID)
- Screen center and both **white** corners are measured after allowing the display sufficient time to stabilize
  - Screen center luminance shall be at a level that is lower than the Maximum Luminance Level specified in Table 5-6
  - Measured white level of both corners shall be higher than 75% of the Minimum Luminance Level specified in Table 5-6

Table 5-6: Dual Corner Box Test File Specifications

DisplayHDR Performance Tier	Screen Center, Maximum Luminance Level (cd/m^2)	Both White Corners, Minimum Luminance Level (cd/m^2)
400	0.40	300
500	0.10	375
600	0.10	450
1000	0.05	750
1400	0.02	1050

5.2.2 Checkerboard Tests – Black-level Test

Table 5-7 defines the two mandatory Checkerboard tests.

Table 5-7: Checkerboard Tests – Black-level Test

Test	Description	Illustrated In
Active Dimming at 50cd/m^2	Measures the scaler/TCON/other dimming driving capability. Without changing the Checkerboard Contrast Ratio test's metadata, this test changes the peak video luminance and expects that the dimming logic shall reduce the backlight and thus improve the **black** level.	Figure 5-6
Active Dimming at 5cd/m^2	Measures the scaler/TCON/other dimming driving capability. Similar to the Active Dimming at 50cd/m^2 test, but with the checkerboard's **white** patches at 5cd/m^2.	

In both tests, a simple 6x4 checkerboard is used, as illustrated in Figure 5-5 and Figure 5-6. The 6x4 checkerboard design was chosen for the following reasons:

- Simplest pattern that defeats edge-based dimming (one, two, three and/or four sides) from affecting the native panel contrast ratio test
- Provides the largest test patches for measurement probes
- Ensures that none of the test patches touch the screen's edge, thereby avoiding light fall-off at the edges
- Size of each checkerboard box varies by display size and aspect ratio so that exactly four rows and six columns are visible

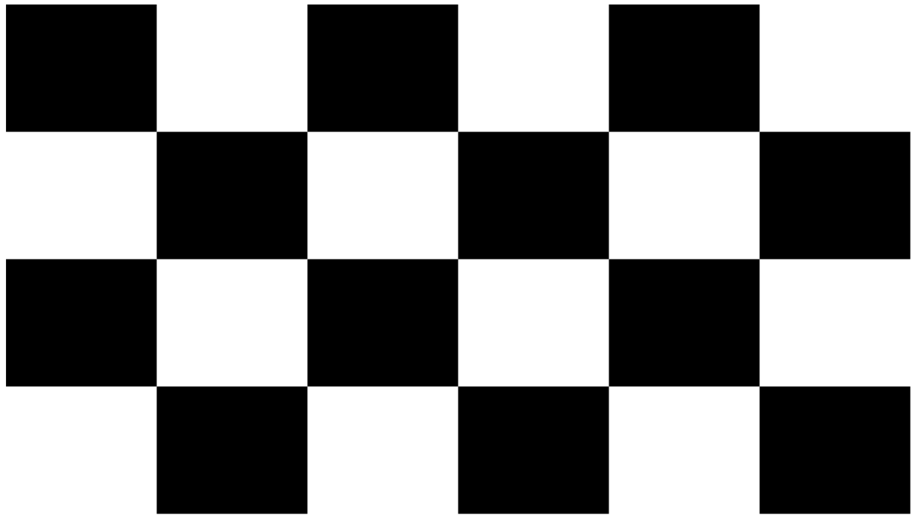

Figure 5-5: Checkerboard Contrast Ratio Checkerboard Test – Shown Full Screen without Hints

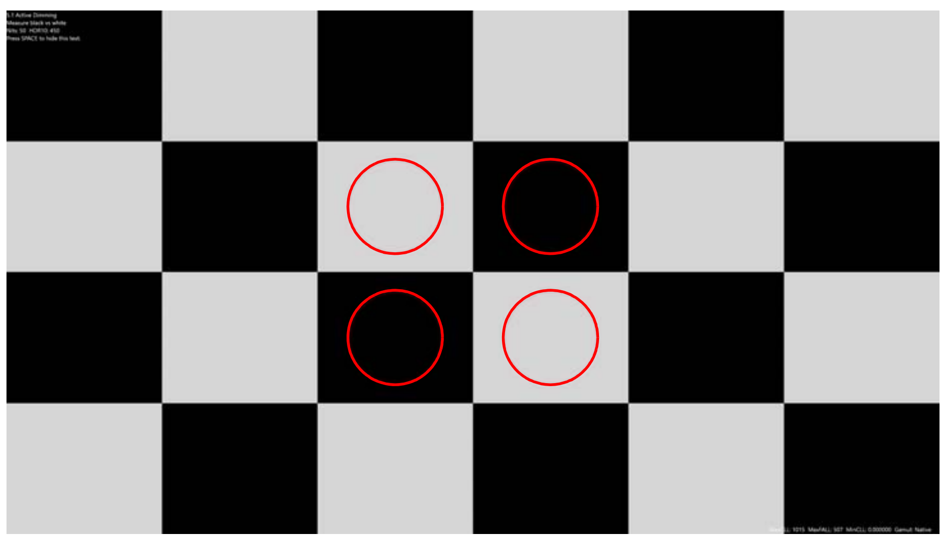

Figure 5-6: Active Dimming Checkerboard Tests – Shown with Red Circle Guide Targets and Hints

Note: *Measurement shall be made in full-screen mode, without the circles and hints visible.*

The metadata for all checkerboard versions is the same; only the video pixel luminance **white** values within the checkerboard is different between each test (see Table 5-8). The metadata is kept the same for both checkerboards to create a set of tests that represent real-world usage. During movie/video playback, game play, or even when launching SDR applications while the operating system is in HDR mode, the metadata from Windows signaling MaxCLL and the MasteringDisplayLuminance will almost always remain the same (i.e., that which matches the MaxLuminance). However, because the content's peak luminance changes dynamically, often well below the MaxCLL value that the backlight should adjust, several goals are achieved:

- Improved **black** level
- Reduced power consumption
- Lower thermal impact
- Potentially longer panel lifetime

This nature of HDR, with its increased dynamic range created by active dimming, is focused on by testing the improved **black** levels that are achieved in this test when the peak luminance is reduced to 50 and 5cd/m^2.

Table 5-8: Checkerboard Test Metadata

Test	Black Luminance	White Luminance	MaxCLL and MasteringDisplay Luminance	MaxFALL
Checkerboard at Full Luminance	0	MaxLuminance value	MaxLuminance value	0.5 × MaxLuminance value
Active Dimming at 50cd/m^2	0	EOTF *SMPTE ST 2084*, code value 450[a]	MaxLuminance value	0.5 × MaxLuminance value
Active Dimming at 5cd/m^2	0	EOTF *SMPTE ST 2084*, code value 253[a]	MaxLuminance value	0.5 × MaxLuminance value

a. 10-bit value.

5.2.2.1 Checkerboard Test Measurement

In the complete checkerboard test procedure includes 12 luminance measurements. Table 5-9 defines each of the 12 measurements.

Table 5-9: Checkerboard Test Measurements

Test	Description	Measurement
Maximum White Luminance	Determine the system's maximum **white** level, using the test described in Section 5.1.1.	Maximum **white** is determined as the average of the 30 measurements taken during the 10% Center Patch test described in Section 5.1.1.
Active Dimming at 50cd/m^2	Adjust the test's EOTF *SMPTE ST 2084* input video signal values (code values) until the average of the two center **white** patches is greater than 50cd/m^2 most closely to the 50cd/m^2 target.	Continue to adjust the input code values until the average of the **white** patches greater than or equal to 50cd/m^2.
	Maintaining the same code value as determined in the test above, measure the average of the two center **black** patches.	50.Black1 50.Black2
Active Dimming at 5cd/m^2	Adjust the test's EOTF *SMPTE ST 2084* input video signal values (code values) until the average of the two center **white** patches is greater than 5cd/m^2 most closely to the 5cd/m^2 target.	Continue to adjust the input code values until the average of the **white** patches greater than or equal to 5cd/m^2.
	Maintaining the same code value as determined in the test above, measure the average of the two center **black** patches.	5.Black1 5.Black2

5.2.2.2 Checkerboard Test Calculations

MaximumWhite = Average of the 30 luminance samples of the Maximum White 10% Center Patch test defined in Section 5.1.1.

- Active Dimming Stops at 50cd/m^2 is calculated as follows:

  Active Dimming Stops $= Log_{10}$ *(MaximumWhite / average (50.Black1, 50.Black2)) /* Log_{10} *(2)*

- Active Dimming Stops at 5cd/m^2 is calculated as follows:

  Active Dimming Stops $= Log_{10}$ *(MaximumWhite / average (5.Black1, 5.Black2)) /* Log_{10} *(2)*

5.2.2.3 Checkerboard Test Specifications

Table 5-10 defines the Checkerboard test specifications for each DisplayHDR performance tier.

Table 5-10: Checkerboard Test Specifications

DisplayHDR Performance Tier	Active Dimming Minimum Stops at $50cd/m^2$	Active Dimming Minimum Stops at $5cd/m^2$
400	> 11	> 12
500	> 11.6	> 12.6
600	> 12	> 13
1000	> 13	> 14
1400	> 13.5	> 14.5

6 DisplayHDR Color Gamut Specifications

This section provides specifications for the screen Checking Chromaticity Point tests. All specifications are stated in *CIE 1976* u', v' chromaticity coordinates (see Table 6-1) because this provides for a perceptually more-linear color space than *CIE 1931* x, y chromaticity coordinates.

Note: *See Appendix D for a description of the DisplayHDR Test Tool and the algorithm that is used to generate the patterns in these tests.*

All specifications defined within this section also speak to actual coverage as a percentage of the specified color gamut, and not merely a proportional adjacent color gamut area.

Table 6-1: Color Gamut and Minimum Luminance Specifications[a]

DisplayHDR Performance Tier	*ITU-R BT.709* Coverage (*CIE 1976* u', v' Chromaticity Coordinates) for Both 10% and Full-screen Color Patches	DCI-P3 *CIE D65*[b] Coverage (*CIE 1976* u', v' Chromaticity Coordinates) for Both 10% and Full-screen Color Patches	Combined Color Luminance (Lr + Lg + Lb)	
			10% Color Patch Test (cd/m^2)	Full-screen Color Test (cd/m^2)
400	95%	N/A	400	320
500	99%	90%	500	320
600	99%	90%	600	350
1000	99%	90%	1000	600
1400	99%	95%	1400	900

*a. See Section 10 for DisplayHDR **True Black** performance level specifications.*
b. Defined in SMPTE RP 431-2.

Testing for color gamut shall be performed using six separate tests, three full-screen images of **Red**, **Green**, and **Blue**, and three 10% patches of **Red**, **Green**, and **Blue**, as illustrated in Figure 6-1.

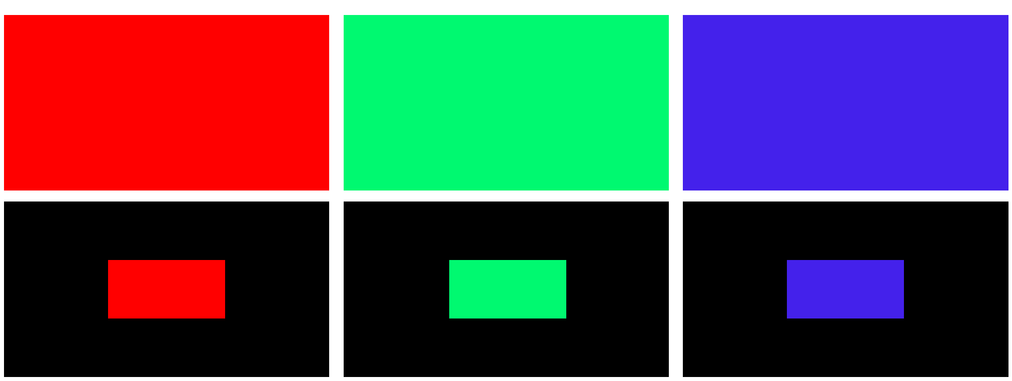

Figure 6-1: RGB Color Gamut Test

- MaxLuminance and RGB primary color values in the DisplayID (or EDID) shall be used to drive each **Red**, **Green**, and **Blue** 10% color patch and full-screen sample at the display's maximum-stated luminance and primary color values, respectively.
- As defined in Table 6-1, the **Red**, **Green**, and **Blue** luminance sum for each 10% color patch and full-screen test shall meet or exceed the **white**-level luminance specifications of the respective performance tier, for both the 10% and full-screen long-duration **white** levels for the respective performance tier.
- Color gamut shall be calculated for actual coverage of the target gamut, **not** merely gamut size.
- *CIE 1976* u', v' chromaticity coordinates for **Red**, **Green**, and **Blue** shall be obtained from the screen's center.

In Figure 6-2, the **black** line illustrates the DCI-P3 *CIE D65* (*SMPTE RP 431-2*) gamut, and the **yellow** line is an illustrative example of a potential screen's gamut. The example illustrates a screen with good, but skewed, **green** coverage, and relatively poor **red** and **blue** coverage. In this particular case, Figure 6-2 illustrates a panel that may have been optimized for *Adobe RGB*, which yields more **green** than DCI-P3 *CIE D65*, but less **red** and **blue**.

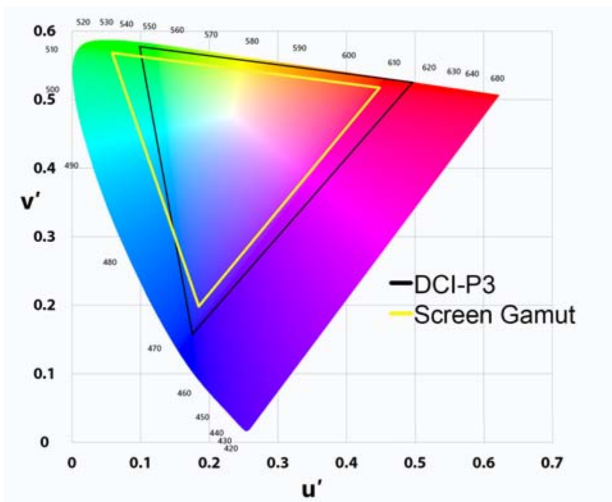

Figure 6-2: Comparison between Target DCI-P3 *CIE D65* Gamut and Example Screen's Gamut

In Figure 6-3, the **black** triangle represents the full area of the DCI-P3 *CIE D65* color gamut. In this example, DCI-P3 *CIE D65* is the target gamut, and the area of this triangle is used when comparing the screen's gamut that lies within the target compared to the area of the target gamut.

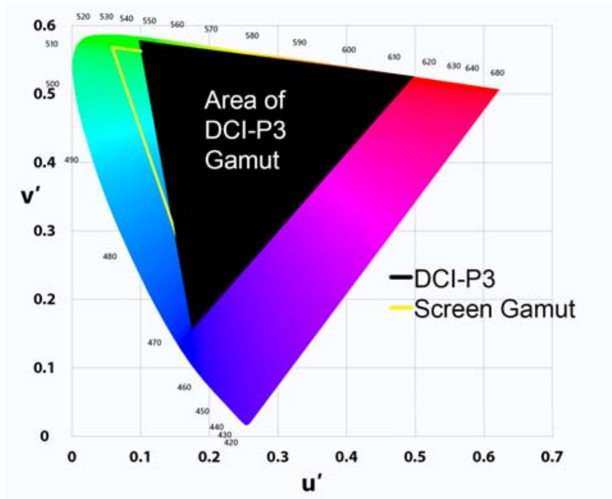

Figure 6-3: Gamut Area Represented by DCI-P3 *CIE D65* Color Gamut (Shown in Black)

In Figure 6-4, the **white** polygon represents the area of the example screen's gamut that is contained **within** the target gamut (i.e., DCI-P3 *CIE D65* in the figure). Note that much of the extended **green** area beyond that of DCI-P3 *CIE D65* is excluded from the gamut coverage area calculation because only the screen's gamut within the target gamut is included.

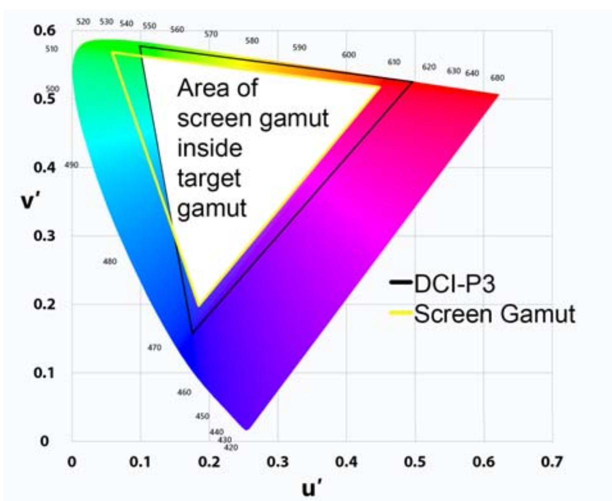

Figure 6-4: Example of Screen's Gamut Contained within Target Gamut (Shown in White)

In Figure 6-5, the relative size of the **white** polygon, which represents the target screen's gamut area that is within DCI-P3 *CIE D65*, compared to the size of the **black** triangle, the full DCI-P3 *CIE D65* gamut area, is the percentage of coverage that is used by this Specification.

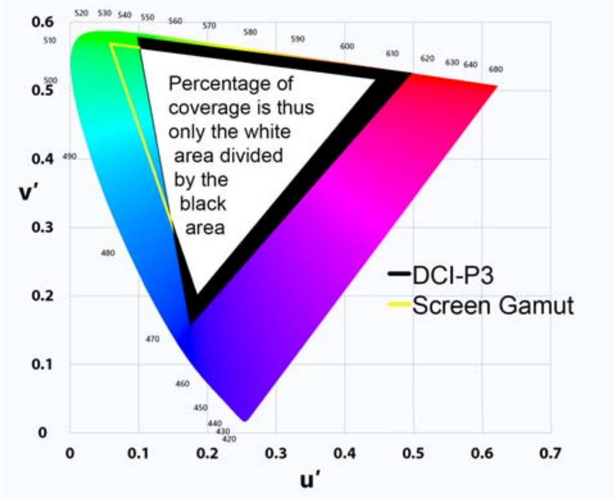

Figure 6-5: Example of Included Gamut (Shown in White) Ratio Compared to Target Gamut (Shown in Black)

7 DisplayHDR Bit Depth

7.1 Bit-depth Specification

Table 7-1 lists the minimum specifications that are necessary to ensure a minimum level of quality for both video processing and final video output. Internal processing in the scaler, GPU, TCON, or alternative chip is intentionally undefined. Vendors are recommended to select a sufficiently high bit depth to prevent visual banding.

Table 7-1: Minimum Bit-depth Specifications

Minimum Specification	Description	DisplayHDR Performance Tier[a]	
		400	500 600 1000 1400
10-bit Video Signal, per Channel	Mandatory for HDR10 and as the input video signal to the local or global dimming processing unit. Depending on the system design, this may be the scaler, GPU, TCON, or alternative chip; however, the unit that is calculating the histogram and corresponding video transparency needs the 10-bit input.	✔	✔
Temporal or Spatial Dithering	Ideally, the display pipeline can operate at true 10 bits throughout the entire pipeline; however, for cost saving, this tier permits conversion down to a minimum of 8 bits, but **not** 6b + 2b FRC. Video data shall be maintained at a minimum of 8 bits through the scaler (if present), TCON, and driver IC.	✔	
	Ideally, the display pipeline can operate at true 10 bits throughout the entire pipeline; however, for cost saving, these tiers permit simulated 10 bits using a minimum of 8 bits plus dithering, typically referred to as “8b + 2b FRC,” which simulates an additional 2-bit resolution within the display pipeline. Typically, the 8b + 2b FRC shall be implemented in the TCON for display pipelines that do not have a scaler, or the dithering could be done by the GPU outputting 8 bits to the TCON. However, for display pipelines that have a scaler, 8b + 2b FRC shall typically be implemented in the scaler; the TCON and driver IC could operate at 8 bits.		✔
Minimum 8-bit Digital-to-analog Conversion	The driver IC, which is responsible for converting the digital video signal to an analog voltage to drive the liquid crystal, is needed to operate at a minimum 8-bit resolution, with 256 discrete values, represented at sufficient voltage accuracy to record each unique value.	✔	✔
Backlight Control 8-bit Accuracy	To eliminate checkerboard patterning that may occur on segmented local dimming panels, backlight control needs be driven to an 8-bit accuracy level, but does **not** necessarily need to implement all 256 potential dimming levels. This high level of backlight power control accuracy is **not** needed for panels without segmented backlights.	✔	✔

a. *See Section 10 for DisplayHDR **True Black** performance level specifications.*

7.2 Bit-depth Testing

Bit-depth testing does **not** use a measurement instrument. Rather, the testing is performed by the user, observing test patterns as the test patterns appear on the screen.

7.2.1 Simulated Bit-depth Test

This test enables a user to distinguish between 6-, 8-, and 10-bit depths. A static image with five gradient ramp bars from left to right (see Figure 7-1) enables a user to identify the screen's bit-depth performance level.

Figure 7-1: Gradient Ramp Bars to Illustrate Simulated Bit Depth

Note: *The screen capture shown in Figure 7-1 has been brightened for illustrative purposes to make it easier to see the gradient steps in this Specification. The actual image in the test tool uses darker gray tones.*

The static image is structured from top to bottom with the following ramp bars:

- 6-bit quantization
- Display-native
- 8-bit quantization
- Display-native
- 10-bit quantization

For displays that use dithering, it is anticipated that the user should be able to identify "shimmer" and movement that closely, but not identically, matches the true bit-depth level-stepped ramp bars.

8 DisplayHDR Rise-time Specifications

8.1 Explaining the User Need for Rise-time Specifications

It is important for displays that include local or global dimming to be able to quickly respond to changes in brightness. The rise-time specification provides tests that ensure a minimum level of performance with regard to display responsiveness to changes of brightness from full OFF to full ON.

Intentional hysteresis, and thus delay, may be introduced to the speed at which the BLU changes its brightness level to eliminate visible flicker. It is assumed that this will typically be the largest contributor to rise-time delay.

Table 8-1 describes two simple usage scenarios that highlight the need for a quick rise-time.

Table 8-1: Rise-time Usage Scenarios

Scenario	Description
Local dimming panel, **black** desktop background, mouse pointer being moved in a large circle	The screen is broken into multiple 2D local dimming segments that are not illuminated until the mouse pointer moves into the zone, after which there is a time delay before the zone illuminates that the mouse pointer has already left that zone. In this scenario, only the mouse pointer, while circling around the screen, is illuminated by light leakage from adjacent zones. In a well-baffled screen, this could cause the mouse pointer to entirely disappear.
Movie with fireworks at night in an otherwise clear **black** sky	The fireworks may enter the scene and quickly explode to full luminance level, and then fade so quickly afterward that the backlight never reaches full luminance level before the fireworks are gone. The sparkle and benefit of HDR fireworks is thus detrimentally affected and the benefit of HDR is lost. In fact, in a worst-case scenario, HDR fireworks could look worse on an HDR display than on an SDR display.

8.2 Rise-time Definition

For the purposes of this Specification, “rise time” is the length of time that the display takes to transition from **black** to **white**. More specifically, it is the length of time that the display takes to transition from 10% to 90% peak-**white** luminance, where peak-**white** is the luminance level achieved in the display’s 10% center patch test.

There are multiple contributors to rise-time latency – processing by the scaler, GPU, TCON, LED power driver ramp, and LED warm-up time. However, the largest contributor of rise-time latency is usually any algorithmic application of hysteresis, which is typically used for reducing display flicker.

Because the flicker-reduction algorithm, and consequential hysteresis, is expected to be a frame-based algorithm, the rise-time test specification is defined as a maximum number of frames, rather than as a fixed-time duration.

Figure 8-1 illustrates the duration, in frames, that are counted as rise time:

- **Red line** – Shows the GPU signal transitioning from **black** to **white** on the fourth video frame within Figure 8-1.
- **Green line** – Shows a two-frame processing delay (referred to as "display latency" (DL)). The actual latency is not of consideration for this test; however, it is included in Figure 8-1 to clearly distinguish between display latency and rise time. Rise time is measured as the time from when the **green** line starts to transition from **black** to **white**, and ends when it has achieved the panel's maximum luminance. In Figure 8-1, the rise time (RT) is 4.5 frames.

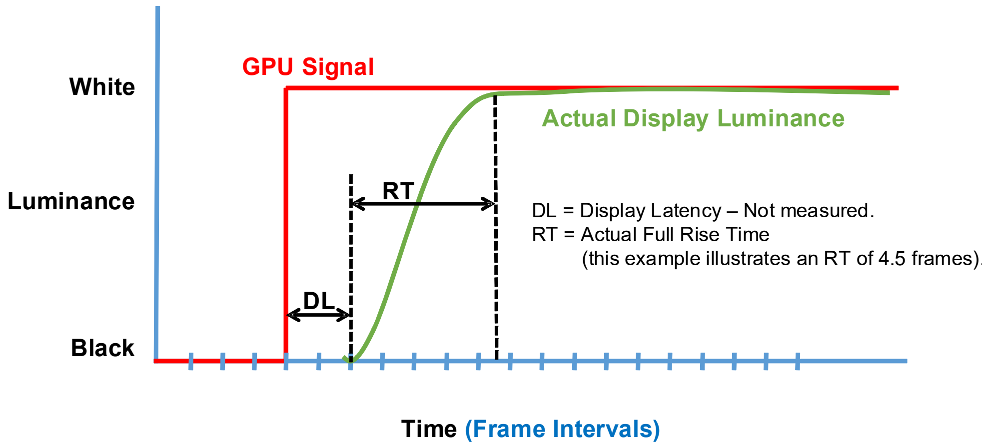

Figure 8-1: Example Actual Full Rise-time Duration

Although Figure 8-1 illustrates the full duration of the actual rise time, there are complexities with determining exactly where the signal starts rising from 0, and when the signal finally achieves 100%. Some backlight designs use a strobing/pulsing illumination, and there may be long tails getting to 100% that are not visibly noticeable, but would significantly change the rise-time measurement results. Therefore, the industry-standard method for measuring rise time is to measure from the 10 to 90% luminance levels and consider that the measured rise time. This Specification uses this methodology, and defines the measured rise time as illustrated in Figure 8-2.

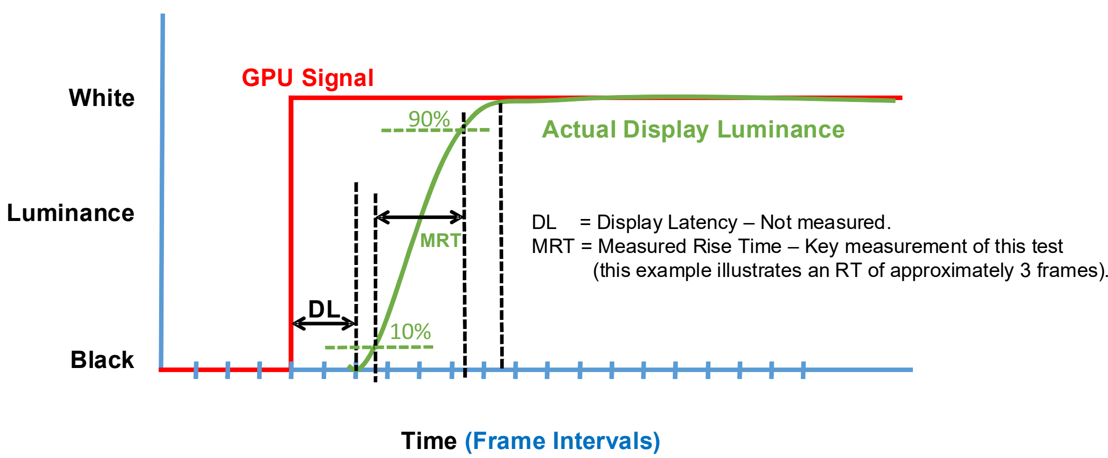

Figure 8-2: Measured Rise-time Illustration

8.3 Rise-time Specifications

The measured rise time (i.e., time from 10 to 90%) should be a maximum of 8 frames for all frame rates that the display supports.

Testing shall be performed at 60Hz, thereby mandating that the maximum rise time at a 60-Hz display refresh shall be a maximum of 8 frames, and thus a maximum of 133ms.

Table 8-2: Maximum Rise Time Examples for a Sampling of Panel Refresh Rates[a]

Display Refresh Rate (Hz)	Maximum Number of Frames for Rise from Black to Maximum Luminance		Time (ms)	
24	8	Recommended	333	Recommended
60	8	Mandatory	133	Mandatory
144	8	Recommended	56	Recommended
200	8	Recommended	40	Recommended

a. See *Section 10* *for DisplayHDR* ***True Black*** *performance level specifications.*

8.4 Measuring Rise Time

This section discusses the highly accurate and official method for rise-time measurement, and an **optional** (non-binding) approximation test that can be used with low-cost hardware.

8.4.1 High-precision Rise-time Measurement

To obtain a high-precision rise-time measurement, a photo diode or photosensor amplifier (e.g., Hamamatsu® C6386-01) can be used by sampling the voltage at 1-ms intervals. By sampling the voltage and then pre-testing the voltage for **10% (dark gray)** and **90% (light gray)**, an oscilloscope can be used to determine how many milliseconds the rise time takes to achieve the known voltage swing from 10 to 90% luminance levels.

8.4.2 Low-cost Rise-time Measurement (Low Accuracy)

This section defines an **optional**, non-binding, low-cost test that can be used to approximate rise-time measurement.

The user should record the screen with a video camera that is set to the same frame rate as the screen (e.g., 60Hz), along with a manually adjustable video shutter speed that matches the frame rate's reciprocal (i.e., 1/60th second for 60Hz). (In cinematographic terms, this is referred to as a "360-degree shutter.")

Example hardware includes the GoPro® HERO5 and most consumer camcorders that provide options for manual shutter-speed settings and recording at 60Hz. It is important that the shutter, aperture, and ISO speed be manually set and **not** in Auto mode to thus defeat any auto-exposure image processing that would invalidate the test. The user can record the display illumination, and then step through the recorded video to observe how many frames it takes to rise from **black** to full **white**. The user shall need to approximate which frame appears to reach "maximum luminance" so that there is some variability.

Furthermore, it will be nearly impossible for a consumer to visually determine the 10 and 90% points. Therefore, the rise time that this test yields is likely to be from the 0 to 100% points, which is longer than the 10 to 90% range that is defined by this Specification. This low-cost test can be used only as an approximation and **cannot** be used to determine whether a panel meets or does not meet compliance specifications.

8.5 Rise-time Video Test Sequence

This section discusses the video sequence that is used to validate rise time. In this test, the video transitions from a **black** screen to the 10% color patch test image, and then loops back to a **black** screen. This sequence then repeats and is measured five times. All five measurements shall meet the performance specifications defined in Section 8.3.

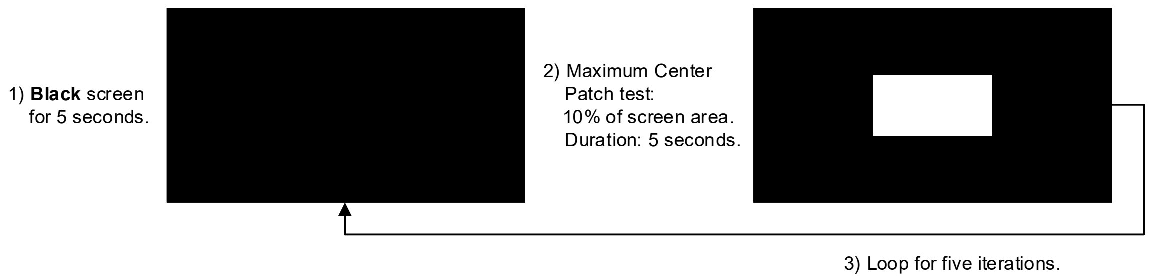

Figure 8-3: Rise-time Sequence

The 10% center patch test uses the same values as stated in Test B.1a, using MaxLuminance for the maximum **white** 10% center patch test, metadata, and video pixel values.

9 Luminance and White Point Accuracy

9.1 Luminance and White Point Accuracy

For HDR displays that use Perceptual Quantizer (PQ) input, it is critically important for the display to be able to accurately represent the PQ luminance curve as intended. This enables a content creator that edits photos, videos, and/or drawings to know how their images will look on other displays that are also correctly following the PQ luminance curve. Similarly, for consumers shopping, or gamers playing games that are designed using the PQ luminance curve, the displayed results will most closely match the original intent if the PQ tracking is accurate.

Errors in the **white** point at various luminance levels can be noticeable by users. This section describes the tests that ensure certified displays meet a particular level of *CIE D65* **white** point and PQ tracking accuracy for several luminance levels.

9.2 Measurement Methodology

Similar to the 10% Center Patch luminance test described in Section 5.1.1, these test patches use code values to represent particular PQ luminance targets. These test patches use a 10% box at the screen's center in the screen's aspect ratio, with a **black** background for the remainder of the screen. Measurement is performed at the screen's center. The PQ code values that are used for the test are chosen to be divisible by 4, thus enabling 8-bit signal generators to be used, if necessary.

Delta-ITP is used as the measurement system for simultaneously calculating both the combined luminance tracking error and **white** point error for each test sample.

9.3 Accuracy Mandates

Delta-ITP errors are calculated from a target *CIE D65* **white** at the luminance levels listed in Table 9-1. Table 9-1 also defines the maximum allowable error. For each DisplayHDR performance tier, tests are performed at approximately 5, 15, 50, 100, and 200cd/m^2. For DisplayHDR performance tier levels that are higher than 400, tests are also performed at 50% of the maximum tier level (the value indicated by the logo, rather than by the MaxLuminance).

Note: *The actual target values are those whose PQ code value is both divisible by 4 and closest to the intended target.*

Table 9-1: *CIE D65* White Point Accuracy and Maximum-permitted *Delta-ITP* Error

10% Test Patch Luminance Target	EOTF *SMPTE ST 2084* 10-bit PQ Code Value[a]	Maximum-permitted *Delta-ITP* Error
5.172cd/m^2	256	20
14.958cd/m^2	340	20
50.825cd/m^2	452	15
100.23cd/m^2	520	15
199.15cd/m^2	592	15
50% of Tier Level Maximum:		15
• DisplayHDR-500 = 249.03cd/m^2	616	
• DisplayHDR-600 = 299.55cd/m^2	636	
• DisplayHDR-1000 = 499.33cd/m^2	692	
• DisplayHDR-1400 = 691.16cd/m^2	728	

a. *Example shows 10b, Full Range values.*

10 DisplayHDR True Black Performance Level

10.1 DisplayHDR True Black Performance Level Usage

This section specifies the performance levels that are necessary for a product to be designated DisplayHDR **True Black**. All tests specified in Table 2-1 are mandatory, unless waived or modified by new limits defined in Table 10-1 and Table 10-2. Table 10-1 and Table 10-2 reflect mandates that have been loosened or tightened, respectively, for DisplayHDR **True Black** vs. the original DisplayHDR specifications.

Table 10-1: DisplayHDR True Black Performance Level Usage (Normative)

Test	DisplayHDR True Black Performance Tier (cd/m^2)				Applicable Test Method Is Specified In
	400	500	600	1000, 1400, and Future Higher	
Minimum-white Luminance – Full-screen Flash Test	250	300	350	See Footnote a	Section 5.1.2
Minimum-white Luminance – Full-screen Long-duration Test	250	300	350[a]		Section 5.1.3
Combined Color Luminance (Lr + Lg + Lb) – 10% Color Patch Test (cd/m^2)	400	500	600		Section 6
Combined Color Luminance (Lr + Lg + Lb) – Full-screen Color Test (cd/m^2)	250	300	350		

a. *Per Table 2-1.*

Table 10-2: DisplayHDR True Black Performance Level Test Limits (Normative)

Test	Minimum	Maximum	Applicable Test Method Is Specified In
Dual Corner Box Test – Black-level Test		0.0005cd/m^2	Section 5.2.1
Checkerboard at Full-luminance Test – Black-level Test		0.0005cd/m^2	Section 5.2.2
Color Gamut *ITU-R BT.709* Coverage for Both 10% and Full-screen Color Patches	99%		Section 6
Color Gamut DCI-P3 *CIE D65*[a] Coverage for Both 10% and Full-screen Color Patches	90%		Section 6
Simulated Bit-depth Test	8b + 2b FRC		Section 7.2.1
Rise time		Two frames at 60Hz (33ms)	Section 8.2 Section 8.4

a. *Defined in SMPTE RP 431-2.*

Follow the *Dark Room Environment for Measurement Procedure* described in *IEC 62341-6-1* to ensure acceptably low unwanted incident light on the display under test. After the test begins, record 10 measurements with a minimum of time between measurements, as determined by hardware and practical execution. Average the 10 readings and report this as the measured black luminance after accommodation for the room environment, as needed.

11 Undefined Features

Table 11-1 lists features that are explicitly excluded from this Specification, which enables manufacturers and designers to have complete freedom of choice in each of these areas.

Table 11-1: Undefined Features

Undefined Feature	Reason for Not Defining
Resolution	Recognizing the vast range of how PCs are used, the VESA Display Performance Metrics Task Group acknowledges that resolution is an entirely independent metric from HDR performance, and has therefore chosen to not include resolution as part of this Specification.
Aspect Ratio	The PC ecosystem continues to show an impressive range of aspect ratios, with widescreen monitors used in vertical orientation showing 9x16, all the way to ultra-wide horizontal displays showing up to 32x9. Thus, the task group saw no benefit in including aspect ratios as part of this Specification.
Audio	Unrelated, so therefore undefined.

12 Product Families and Re-certification

To speed products to market and reduce certification costs, products that use the same hardware are considered to belong to the same product family. Only one certification is needed per family, thus saving manufacturers the cost and effort involved in re-certifying effectively the same hardware when a minor cosmetic change is made that differentiates the product.

A new device is considered to be within the same product family, and thus automatically included in the certification, if the new device and the previously certified device do **not** differ in any of the following aspects:

- Panel
- Backlight
- Backlight LED power driver board changes that affect LED performance
- TCON and scaler Silicon
- TCON and scaler Firmware that affects HDR image processing
- Power supply output voltage –or– output power (wattage rating) is reduced
- Changes to filters and/or layers that are located above or below the cell (e.g., touch layers, privacy layers, or dual brightness enhancement films)

TCON or scaler firmware changes that do **not** affect HDR performance (e.g., menu or language changes) are acceptable.

With respect to the power supply, the concern is that if output voltage and/or power supplied from the power supply to the display device is reduced (i.e., power to the LEDs), shall need to be re-certified. The following power changes, however, do **not** need to be re-certified because they are considered to be within the same product family:

- Power supply input voltage changes to accommodate different geographic regions
- Power supply was increased in power to start supplying additional USB Type-C ports with power

Changes related to touch layers, or privacy, or many other filters may reduce the light output, and thus need to be re-certified.

A EOTF *SMPTE ST 2084* PQ Code to Luminance Level Lookup Table (Informative)

Table A-1: EOTF *SMPTE ST 2084* PQ Code to Luminance Level Lookup Table (Informative)

EOTF *SMPTE ST 2084* 10-bit PQ Code Value	Luminance Level[a] (cd/m^2)	EOTF *SMPTE ST 2084* 10-bit PQ Code Value	Luminance Level[a] (cd/m^2)
0	0	450	49.79
8	0.0015	452	50.83
16	0.0054	515	95.50
24	0.0119	520	100.23
36	0.0277	592	199.15
48	0.0520	616	249.03
56	0.0738	636	299.55
64	0.101	668	401.51
120	0.498	692	499.33
153	0.992	712	598.33
156	1.051	728	691.16
193	2.015	768	990.02
206	2.483	769	998.93
253	4.962	807	1404
254	5.031	846	2000
256	5.172	884	2803
307	10.05	892	3013
340	14.96	924	4024
384	24.70	1023	10000

a. Also referred to as "luminous intensity."

B Test File Specification (Informative)

This appendix defines the test image specifications. In most cases, the automated VESA DisplayHDR Test Tool can be used because it includes the complete test sequence. However, if it is necessary to test the display using a fully automated manufacturing process, signal generator, and/or other non-Windows 10 signal source, the test files can be created using the specifications defined in this appendix.

The DisplayHDR Test Tool provides two versions of several of the tests. Specifically, there are two versions of each of the three **white** luminance level tests (Tests B.1, B.2, and B.3). The two versions of each **white** luminance level tests differ, as follows:

- DisplayID (or legacy EDID) values are used to tone-map and gamut adjust the tests
- Original test images and test metadata are passed through to the display for the display to perform the tone-mapping function

In each case, the DisplayHDR Test Tool indicates its output results, as follows:

- Tests B.1a, B.2a, and B.3a use the DisplayID (or legacy EDID) values
- **Optional** Tests B.1b, B.2b, and B.3b use the values specified in this appendix

For test cases in which two **white** luminance level test versions are provided, only the “a” test results are eligible for device certification. The **optional** “b” tests are provided to enable confirmation of only the expected behavior at luminance levels that are beyond those stated as supported by the DisplayID (or legacy EDID). Although it is expected that the “a” and “b” tests should yield the same results, this is **not** included as part of the certification process.

B.1 Minimum-white Luminance – 10% Center Patch Test

Test B.1a: Minimum-white Luminance – 10% Center Patch Test Specifications

Specification	Description
Image	• **Black** screen, EOTF *SMPTE ST 2084*, code value 0. • **White** rectangular box, EOTF *SMPTE ST 2084*, code value that represents the MaxLuminance value from the DisplayID (or legacy EDID), that matches the aspect ratio of the full screen, composes 10% of the screen's area, and is centered and placed on top of the **black** background. Thus, the box is 31.62% of the screen's pixel height, and 31.62% of the screen's pixel width. • **Motion** – The motion path logic is provided in Section B.1.1.
Metadata	• MaxCLL — MaxLuminance value • MasteringDisplayLuminance — MaxLuminance value • MaxFALL[a] — 0.1 × MaxLuminance value • Chromaticity — RGB primary colors from the DisplayID (or legacy EDID)

a. *MaxFALL is only 10% of MaxLuminance because the **white** rectangular box is only 10% of the screen.*

Test B.1b: Minimum-white Luminance – Optional 10% Center Patch Test Specifications

Specification	Description
Image	• **Black** screen, EOTF *SMPTE ST 2084*, code value 0. • **White** rectangular box, EOTF *SMPTE ST 2084*, code value 1023, that matches the aspect ratio of the full screen, composes 10% of the screen's area, and is centered and placed on top of the **black** background. Thus, the box is 31.62% of the screen's pixel height, and 31.62% of the screen's pixel width. • **Motion** – The motion path logic is provided in Section B.1.1.
Metadata	• MaxCLL — 10000cd/m^2 • MasteringDisplayLuminance — 10000cd/m^2 • MaxFALL[a] — 1000cd/m^2 • Chromaticity — Should be maximum *ITU-R BT.2020* values

a. *MaxFALL is only 1000cd/m^2 because the **white** rectangular box is only 10% of the screen.*

B.1.1 Minimum-white Luminance – 10% Center Patch Test Motion Path Code/Algorithm

```
    float c = nitstoCCCS(nits);
    float dpi = m_deviceResources->GetDpi();

    // create Brush to paint rectangle with
    ComPtr<ID2D1SolidColorBrush> peakBrush;
    DX::ThrowIfFailed(ctx->CreateSolidColorBrush(D2D1::ColorF(c, c, c), &peakBrush));

    // get screen dimensions in DIPS
    auto logSize = m_deviceResources->GetLogicalSize();
    float2 jitter;

#define randf()((float)rand()/(float(RAND_MAX)))   // standard posix integer rand()
    do {
            jitter.x = 10.0*(dpi/96.)*randf()*2.f - 1.f;
            jitter.y = 10.0*(dpi/96.)*randf()*2.f - 1.f;
    }
    // round off the corners
    while( (jitter.x*jitter.x + jitter.y*jitter.y) > 10.f*dpi/96.);

    // compute rectangle to draw
    D2D1_RECT_F tenPercentRect =
    {
            (logSize.right - logSize.left) * (0.5f - sqrtf(0.1) / 2.0f) + jitter.x,
            (logSize.bottom - logSize.top) * (0.5f - sqrtf(0.1) / 2.0f) + jitter.y,
            (logSize.right - logSize.left) * (0.5f + sqrtf(0.1) / 2.0f) + jitter.x,
            (logSize.bottom - logSize.top) * (0.5f + sqrtf(0.1) / 2.0f) + jitter.y
    };

    // draw the actual rectangle
    ctx->FillRectangle(&tenPercentRect, peakBrush.Get());
```

B.2 Minimum-white Luminance – Full-screen Flash Test

Test B.2a: Minimum-white Luminance – Full-screen Flash Test Specifications

Specification	Description	
Image	• **White** screen, EOTF *SMPTE ST 2084*, code value that represents the MaxLuminance value from the DisplayID (or legacy EDID)	
Metadata	• MaxCLL	MaxLuminance value
	• MasteringDisplayLuminance	MaxLuminance value
	• MaxFALL[a]	MaxLuminance value
	• Chromaticity	RGB primary colors from the DisplayID (or legacy EDID)

a. *MaxFALL is now the same because the screen is 100%* ***white****.*

Test B.2b: Minimum-white Luminance – Optional Full-screen Flash Test Specifications

Specification	Description	
Image	• **White** screen, EOTF *SMPTE ST 2084*, code value 1023	
Metadata	• MaxCLL	10000cd/m^2
	• MasteringDisplayLuminance	10000cd/m^2
	• MaxFALL[a]	10000cd/m^2
	• Chromaticity	Should be maximum *ITU-R BT.2020* values

a. *MaxFALL is now 10000cd/m^2 because the screen is 100%* ***white****.*

B.3 Minimum-white Luminance – Full-screen Long-duration Test

Test B.3a and Test B.3b use the same image as Test B.2a and Test B.2b, respectively, for the Full-screen Flash Test (see Section B.2).

B.4 Dual Corner Box Test – Black-level Test

Test B.4: Dual Corner Box Test – Black-level Test Specifications

Specification	Description
Image	• **Black** screen, EOTF *SMPTE ST 2084*, code value 0. • Dual **white** corners, each 5% of the total screen area and square in shape, are placed in the lower left and upper right corners. The **white** corners use the MaxLuminance value for the video signal, as illustrated in Figure 5-4.
Metadata	• MaxCLL — MaxLuminance value • MasteringDisplayLuminance — MaxLuminance value • MaxFALL[a] — 0.1 × MaxLuminance value • Chromaticity — RGB primary colors from the DisplayID (or legacy EDID)

a. *MaxFALL is only 10% of MaxCLL because the two* ***white*** *corners cover only 10% of the screen*

B.5 Checkerboard Tests – Black-level Test

Test B.5a: Checkerboard Contrast Ratio Specifications

Specification	Description	
Image	• 6x4 **black** and **white** checkerboard, scaled to the screen's aspect ratio	
	• Upper left corner is **black**	
	• **Black** segments, EOTF *SMPTE ST 2084*, code value 0	
	• **White** segments, EOTF *SMPTE ST 2084*, code value of MaxLuminance	
Metadata	• MaxCLL	MaxLuminance value
	• MasteringDisplayLuminance	MaxLuminance value
	• MaxFALL	0.5 × MaxLuminance value
	• Chromaticity	RGB primary colors from the DisplayID (or legacy EDID)

Test B.5b: Active Dimming at 50cd/m² Specifications

Specification	Description	
Image	• 6x4 **black** and **gray** checkerboard, scaled to the screen's aspect ratio	
	• Upper left corner is **black**	
	• **Black** segments, EOTF *SMPTE ST 2084*, code value 0	
	• **Gray** segments, EOTF *SMPTE ST 2084*, code value 450	
Metadata	• MaxCLL	MaxLuminance value
	• MasteringDisplayLuminance	MaxLuminance value
	• MaxFALL	0.5 × MaxLuminance value
	• Chromaticity	RGB primary colors from the DisplayID (or legacy EDID)

Test B.5c: Active Dimming at 5cd/m² Specifications

Specification	Description	
Image	• 6x4 **black** and **gray** checkerboard, scaled to the screen's aspect ratio	
	• Upper left corner is **black**	
	• **Black** segments, EOTF *SMPTE ST 2084*, code value 0	
	• **Gray** segments, EOTF *SMPTE ST 2084*, code value 253	
Metadata	• MaxCLL	MaxLuminance value
	• MasteringDisplayLuminance	MaxLuminance value
	• MaxFALL	0.5 × MaxLuminance value
	• Chromaticity	RGB primary colors from the DisplayID (or legacy EDID)

B.6 RGB Color Gamut Test

Test B.6a: RGB Color Gamut 10% Patch Test Specifications

Specification	Description
Image	• Three 10% color patch image files, one each for **Red**, **Green**, and **Blue**, each set to their respective primary color and MaxLuminance, as stated in the DisplayID, legacy EDID, or other metadata source that is used for integrated displays • 10% color patch location's shape, size, and location is the same as that used for Test B.1a, but without the motion path because these test images are static
Metadata	• MaxCLL — MaxLuminance value • MasteringDisplayLuminance — MaxLuminance value • MaxFALL[a] — 0.1 × MaxLuminance value • Chromaticity — RGB primary colors from the DisplayID (or legacy EDID)

a. MaxFALL is only 10% of MaxLuminance because the color patch is only 10% of the screen.

Test B.6b: RGB Color Gamut Full-screen Test Specifications

Specification	Description
Image	• Three full-screen color patch image files, one each for **Red**, **Green**, and **Blue**, each set to their respective primary color and MaxLuminance, as stated in the DisplayID, legacy EDID, or other metadata source that is used for integrated displays
Metadata	• MaxCLL — MaxLuminance value • MasteringDisplayLuminance — MaxLuminance value • MaxFALL — MaxLuminance value • Chromaticity — RGB primary colors from the DisplayID (or legacy EDID)

B.7 Gradient Ramp Bars Used for Simulated Bit-depth Test

The Gradient Ramp Bars test is a visual inspection, showing five rows across the screen, each taking the screen's full width and 20% of the screen's height. The ramp bars are dark shadow tones, ranging from dark on the left to moderately dark on the right. Table B.7 lists how each of the gradient ramp bars is displayed.

Test B.7: Gradient Ramp Bars Used for Simulated Bit-depth Test

Row	Description
1	Ramp bar is truncated to 6-bit precision.
2	Ramp bar uses native display capability.
3	Ramp bar is truncated to 8-bit precision.
4	Ramp bar uses native display capability (same as Row 2).
5	Ramp bar is truncated to 10-bit precision.

The image is created algorithmically, using the following logic:

1 Generate a linear gradient, from left (0.0) to right (1.0):

```
float c = normalizedPosition.x;
```

2 Pre-shape with gamma of 2.2:

```
c = pow(c,0.45454);
```

3 Focus on dark levels:

```
c = c*0.25;
```

4 Quantize first strip (upper 20% of screen) to 6-bit:

```
c = trunc(c*64.0f)/64.0f;
```

5 Quantize third strip (center 20% of screen) to 8-bit:

```
c = trunc(c*256.0f)/256.0f;
```

6 Quantize fifth strip (lower 20% of screen) to 10-bit:

```
c = trunc(c*1024.0f)/1024.0f;
```

7 Revert back to gamma:

```
c = pow(c,2.2f);
```

8 Replicate to all color channels to make **gray**:

```
Final color = {c, c, c, 1.0f};
```

B.8 Rise-time Test

The Rise-time test uses a patch that switches ON for 5 seconds, OFF for 5 seconds, and then loops indefinitely. The first five rise times from **black** to **white** should be recorded and used for the measured values of this test.

Test B.8: Rise-time Test Specifications

Specification	Description
Image	• **Black** screen, EOTF *SMPTE ST 2084*, code value 0. • **White** rectangular box, EOTF *SMPTE ST 2084*, code value that represents the MaxLuminance value from the DisplayID (or legacy EDID), that matches the aspect ratio of the full screen, composes 10% of the screen's area, and is centered and placed on top of the **black** background. Thus, the box is 31.62% of the screen's pixel height, and 31.62% of the screen's pixel width.
Metadata	• MaxCLL — MaxLuminance value • MasteringDisplayLuminance — MaxLuminance value • MaxFALL[a] — 0.1 × MaxLuminance value • Chromaticity — RGB primary colors from the DisplayID (or legacy EDID)

a. *MaxFALL is only 10% of MaxLuminance because the* ***white*** *rectangular box is only 10% of the screen.*

C Sample DisplayIDs (Informative)

This appendix illustrates a variety of sample DisplayIDs, with GPU processing of HDR for a local panel laptop, TCON processing of HDR for a local panel laptop, and an HDR10 monitor:

- Sample C.1 illustrates an example DisplayID block for an embedded panel with a TCON that supports 8-bit input and sRGB EOTF on the interface. The panel is natively 8 bit, has a DCI-P3 *CIE D65* (*SMPTE RP 431-2*) color space, and uses Gamma 2.2. This DisplayID would be suitable for a panel in which HDR processing occurs in an accompanying IC, such as a scaler that receives the HDR10 signaling.
- Sample C.2 illustrates an example DisplayID block for an embedded panel with a TCON that supports both 8- and 10-bit input, sRGB EOTF, *ITU-R BT.2020*, and EOTF *SMPTE ST 2084* on the interface. The panel is natively 8 bit, has a DCI-P3 *CIE D65* color space, and uses Gamma 2.2. This DisplayID would be suitable for a panel in which HDR processing is expected to occur in the TCON.
- Sample C.3 illustrates an example DisplayID block for a monitor that supports both 8- and 10-bit input, sRGB EOTF, *ITU-R BT.2020*, and EOTF *SMPTE ST 2084* on the interface. The panel is natively 8 bit, has a DCI-P3 *CIE D65* color space, and uses Gamma 2.2. This DisplayID would be suitable for a monitor in which HDR processing is expected to occur in the scaler.

C.1 Sample DisplayID for a TCON that Supports DisplayHDR-400 with GPU HDR Processing

```
[DISPLAYID RAW DATA]
    |00|01|02|03|04|05|06|07|08|09|0A|0B|0C|0D|0E|0F|
----+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
00 |20 5f 04 00 20 00 19 12 34 56 34 12 78 56 34 12
 10 |2a 11 0d 50 43 20 48 44 52 20 53 61 6d 70 6c 65
 20 |21 00 1d 1c 0c d6 06 00 0a a0 05 80 e1 ea 51 3d
 30 |a4 b0 66 52 0f fd 34 54 00 5d 40 5e 66 36 12 78
 40 |26 00 09 02 00 00 00 00 00 01 00 00 22 00 14 5d
 50 |94 03 08 ff 09 4f 00 07 80 1f 00 9f 05 28 00 00
 60 |00 07 00 34


[DISPLAYID]
  [General Info]
  Version..................: 2
  Revision.................: 0
  Section Size.............: 95
  Product type identifier...: Desktop Productivity
  Extension Count..........: 0
  Checksum.................: 0x34

  [Datablock 0: Product Identification]
  Vendor ID................: 12-34-56
  Product Code.............: 0x1234
  Serial Number............: 0x12345678
  Week of Manufacture.......: 42
  Year of Manufacture.......: 2017
  Product ID String Size....: 13
  Product ID String ........: PC HDR Sample

  [Datablock 1: Display Parameters]
  Horizontal Image Size..............: 310.0 mm
  Vertical Image Size................: 175.0 mm
  Horizontal Pixel Count.............: 2560
  Vertical Pixel Count...............: 1440
  Scan Orientation...................: Left to Right, Top to Bottom
  Luminance Information..............: Exposed as Minimum Guaranteed
  Color Information..................: CIE 1931
  Audio Integrated Into Display.......: No
  Color 1 Chromaticity...............: X: 0.680 Y: 0.320
  Color 2 Chromaticity...............: X: 0.265 Y: 0.690
  Color 3 Chromaticity...............: X: 0.150 Y: 0.060
  White Point Chromaticity...........: X: 0.312 Y: 0.329
  Full Max Luminance.................: 320.00 CD/M^2
  10 Percent Rect Max Luminance.......: 400.00
  Min Luminance......................: 0.40 CD/M^2
  Native Color Depth.................: 8 BPC
  Device Technology..................: ACTIVE MATRIX LCD
```

```
Gamma..............................: 2.20

[Datablock 2: Display Interface Features]
            | 6-bpc | 8-bpc | 10-bpc | 12-bpc | 14-bpc | 16-bpc |
            +-------+-------+--------+--------+--------+--------+
        RGB |   N       Y       N        N        N        N
YCbCr 4:4:4 |   N       N       N        N        N        N
YCbCr 4:2:2 |  n/a      N       N        N        N        N
YCbCr 4:2:0 |  n/a      N       N        N        N        N

Minimum Pixel Rate at Which YCbCr 4:2:0 Is Supported.........: 0 MP/s

Audio at 48-kHz Supported....................................: No
Audio at 44.1-kHz Supported..................................: No
Audio at 32-kHz Supported....................................: No

sRGB Color Space and EOTF Supported..........................: Yes

[Datablock 3: Type VII Timing - Detailed]
Detailed Timing 1
 2560 x 1440 Progressive, 234.59MHz
```

C.2 Sample DisplayID for a TCON that Supports DisplayHDR-400 with HDR10 Support in the TCON

```
[DISPLAYID RAW DATA]
    |00|01|02|03|04|05|06|07|08|09|0A|0B|0C|0D|0E|0F|
----+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
00 |20 5f 04 00 20 00 19 12 34 56 34 12 78 56 34 12
 10 |2a 11 0d 50 43 20 48 44 52 20 53 61 6d 70 6c 65
 20 |21 00 1d 1c 0c d6 06 00 0a a0 05 80 e1 ea 51 3d
 30 |a4 b0 66 52 0f fd 34 54 00 5d 40 5e 66 36 12 78
 40 |26 00 09 06 00 00 00 00 00 61 00 00 22 00 14 5d
 50 |94 03 08 ff 09 4f 00 07 80 1f 00 9f 05 28 00 00
 60 |00 07 00 d0


[DISPLAYID]
  [General Info]
  Version..................: 2
  Revision.................: 0
  Section Size.............: 95
  Product type identifier...: Desktop Productivity
  Extension Count..........: 0
  Checksum.................: 0xD0

  [Datablock 0: Product Identification]
  Vendor ID................: 12-34-56
  Product Code.............: 0x1234
  Serial Number............: 0x12345678
  Week of Manufacture.......: 42
  Year of Manufacture.......: 2017
  Product ID String Size....: 13
  Product ID String ........: PC HDR Sample

  [Datablock 1: Display Parameters]
  Horizontal Image Size...............: 310.0 mm
  Vertical Image Size.................: 175.0 mm
  Horizontal Pixel Count..............: 2560
  Vertical Pixel Count................: 1440
  Scan Orientation....................: Left to Right, Top to Bottom
  Luminance Information...............: Exposed as Minimum Guaranteed
  Color Information...................: CIE 1931
  Audio Integrated Into Display.......: No
  Color 1 Chromaticity................: X: 0.680 Y: 0.320
  Color 2 Chromaticity................: X: 0.265 Y: 0.690
  Color 3 Chromaticity................: X: 0.150 Y: 0.060
  White Point Chromaticity............: X: 0.312 Y: 0.329
  Full Max Luminance..................: 320.00 CD/M^2
  10 Percent Rect Max Luminance.......: 400.00
  Min Luminance.......................: 0.40 CD/M^2
  Native Color Depth..................: 8 BPC
  Device Technology...................: ACTIVE MATRIX LCD
```

```
Gamma..............................: 2.20

[Datablock 2: Display Interface Features]
             | 6-bpc | 8-bpc | 10-bpc | 12-bpc | 14-bpc | 16-bpc |
             +-------+-------+--------+--------+--------+--------+
         RGB |   N       Y       Y        N        N        N
YCbCr 4:4:4 |   N       N       N        N        N        N
YCbCr 4:2:2 |  n/a      N       N        N        N        N
YCbCr 4:2:0 |  n/a      N       N        N        N        N

Minimum Pixel Rate at Which YCbCr 4:2:0 Is Supported.........: 0 MP/s

Audio at 48-kHz Supported....................................: No
Audio at 44.1-kHz Supported..................................: No
Audio at 32-kHz Supported....................................: No

sRGB Color Space and EOTF Supported..........................: Yes
ITU-R BT.2020 Color Space and EOTF Supported.................: Yes
ITU-R BT.2020 Color Space and SMPTE ST 2084 EOTF Supported...: Yes

[Datablock 3: Type VII Timing - Detailed]
Detailed Timing 1
 2560 x 1440 Progressive, 234.59MHz
```

C.3 Sample DisplayID for a Scaler that Supports DisplayHDR-600 with HDR10 Support in the Scaler

```
[DISPLAYID RAW DATA]
    |00|01|02|03|04|05|06|07|08|09|0A|0B|0C|0D|0E|0F|
----+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
00 |20 87 04 00 20 00 19 12 34 56 34 12 78 56 34 12
 10 |2a 11 0d 50 43 20 48 44 52 20 53 61 6d 70 6c 65
 20 |21 00 1d 50 14 b8 0b 00 0f 70 08 80 e1 ea 51 3d
 30 |a4 b0 66 52 0f fd 34 54 78 5d b0 60 66 2e 12 78
 40 |26 00 09 06 06 03 04 00 e0 61 00 00 22 00 3c 5b
 50 |af 03 08 ff 09 4f 00 07 80 1f 00 9f 05 28 00 02
 60 |00 04 00 01 23 08 88 ff 0e 9f 00 2f 80 1f 00 6f
 70 |08 3d 00 02 00 04 00 03 1d 02 08 7f 07 9f 00 2f
 80 |80 1f 00 37 04 1e 00 04 00 16 00 26


[DISPLAYID]
  [General Info]
  Version..................: 2
  Revision.................: 0
  Section Size.............: 135
  Product type identifier...: Desktop Productivity
  Extension Count..........: 0
  Checksum.................: 0x26

  [Datablock 0: Product Identification]
  Vendor ID................: 12-34-56
  Product Code.............: 0x1234
  Serial Number............: 0x12345678
  Week of Manufacture.......: 42
  Year of Manufacture.......: 2017
  Product ID String Size....: 13
  Product ID String ........: PC HDR Sample

  [Datablock 1: Display Parameters]
  Horizontal Image Size...............: 520.0 mm
  Vertical Image Size.................: 300.0 mm
  Horizontal Pixel Count..............: 3840
  Vertical Pixel Count................: 2160
  Scan Orientation....................: Left to Right, Top to Bottom
  Luminance Information...............: Exposed as Minimum Guaranteed
  Color Information...................: CIE 1931
  Audio Integrated Into Display.......: No
  Color 1 Chromaticity................: X: 0.680 Y: 0.320
  Color 2 Chromaticity................: X: 0.265 Y: 0.690
  Color 3 Chromaticity................: X: 0.150 Y: 0.060
  White Point Chromaticity............: X: 0.312 Y: 0.329
  Full Max Luminance..................: 350.00 CD/M^2
  10 Percent Rect Max Luminance.......: 600.00
  Min Luminance.......................: 0.10 CD/M^2
```

```
Native Color Depth..................: 8 BPC
Device Technology...................: ACTIVE MATRIX LCD
Gamma...............................: 2.20

[Datablock 2: Display Interface Features]
            | 6-bpc | 8-bpc | 10-bpc | 12-bpc | 14-bpc | 16-bpc |
            +-------+-------+--------+--------+--------+--------+
        RGB |   N       Y       Y        N        N        N
YCbCr 4:4:4 |   N       Y       Y        N        N        N
YCbCr 4:2:2 |  n/a      Y       Y        N        N        N
YCbCr 4:2:0 |  n/a      N       N        Y        N        N

Minimum Pixel Rate at Which YCbCr 4:2:0 Is Supported.........: 0 MP/s

Audio at 48-kHz Supported....................................: Yes
Audio at 44.1-kHz Supported..................................: Yes
Audio at 32-kHz Supported....................................: Yes

sRGB Color Space and EOTF Supported..........................: Yes
ITU-R BT.2020 Color Space and EOTF Supported.................: Yes
ITU-R BT.2020 Color Space and SMPTE ST 2084 EOTF Supported...: Yes

[Datablock 3: Type VII Timing - Detailed]
Detailed Timing 1
 2560 x 1440 Progressive, 241.50MHz

Detailed Timing 2
 3840 x 2160 Progressive, Preferred, 533.25MHz

Detailed Timing 3
 1920 x 1080 Progressive, 138.50MHz
```

D Display Primary Patches

This appendix describes the DisplayHDR Test Tool and the algorithm used to generate the pattern in the screen Checking Chromaticity Point tests provided in Section 6.

The purpose of the Section 6 tests is not to determine the chromaticity values of the display. Determining actual display characteristics is known as "calibration," and should be done by a commercial color sensor and associated calibration application. The values determined by this calibration step should be provided to the OS/device using a mechanism such as DisplayID (or legacy EDID), disk file, or ICC profile.

The purpose of this test is to allow users to confirm that the chromaticity values reported to the OS by the device can actually be rendered on the display.

The algorithm herein translates the primary colors (primaries or primary, in the code provided in this appendix) specified by the display to the OS into HDR10 values for transmission to the display.

The algorithm that is used for this is as follows:

1 Convert the *CIE 1931 x, y* chromaticity coordinates into XYZ color coordinate system, assuming a standard *CIE D65* **white** point.

2 Calculate an XYZ color coordinate system-to-RGB matrix, using Y = 1.0f to achieve relative intensities.

3 Convert each color from XYZ color coordinate system at the correct intensity into HDR10 format.

D.1 Precision Notes

The DisplayHDR Test Tool renders to an intermediate image in the form of a linear (no gamma) 16-bit float image surface that is encoded in scRGB. (These are signed values vs. the *ITU-R BT.709* primary colors, but values permitted outside that triangle.) In the external monitor/TV case, this completed image surface is converted to HDR10 (*ITU-R BT.2020* primary colors and has the *SMPTE ST 2084*/PQ curve applied) before being output on the external connector (HDMI or DisplayPort). These additional color conversion steps may be responsible for precision differences of ±1 to 2 code values.

D.2 Implementation Notes

Bits of this code have been exchanged with some VESA members that are color experts; however, the code may still contain errors. At this point, on the panels that are known to be near-correct (EDID information matches the calibrated used), the colors are fairly accurate.

D.3 Algorithm

1 **Convert the panel primary from *CIE 1931 x, y* chromaticity coordinates to the XYZ color coordinate system.**

The equation for this is as follows:

$$=> \begin{bmatrix} Y_R \\ Y_G \\ Y_B \end{bmatrix} = K * inv(\text{ Panel\_Matrix\_3x3}) * \begin{bmatrix} \dfrac{W_x}{W_y} \\ 1 \\ \dfrac{1 - W_x - W_y}{W_y} \end{bmatrix}$$

The code breaks down as shown below. First, the **white** column is calculated:

```
float3 vWhiteCol =
    float3( wht_xy.x/wht_xy.y, 1.f, (1.f – wht_xy.x – wht_xy.y)/wht_xy.y );
```

where:

- $\text{Panel\_Matrix\_3x3} = \begin{bmatrix} \dfrac{R_x}{R_y} & \dfrac{G_x}{G_y} & \dfrac{B_x}{B_y} \\ 1 & 1 & 1 \\ \dfrac{(1 - Ry - Rx)}{Ry} & \dfrac{(1 - Gy - Gx)}{Gy} & \dfrac{1 - By - Bx}{By} \end{bmatrix}$
- K = TierNits / 10000

Next, a panel matrix is filled with the other colors converted into XYZ color coordinate system, from the *CIE 1931 x, y* chromaticity coordinates:

```
float3 vRedCol =
    float3( red_xy.x/red_xy.y, 1.f, (1.f – red_xy.x – red_xy.y)/red_xy.y );

float3 vGreenCol =
    float3( grn_xy.x/grn_xy.y, 1.f, (1.f – grn_xy.x – grn_xy.y)/grn_xy.y );

float3 vBlueCol =
    float3( blu_xy.x/blu_xy.y, 1.f, (1.f – blu_xy.x – blu_xy.y)/blu_xy.y );

float3x3 PanelMatrix = float3x3(
    vRedCol.x, vGreenCol.x, vBlueCol.x,
    vRedCol.y, vGreenCol.y, vBlueCol.y,
    vRedCol.z, vGreenCol.z, vBlueCol.z
);

float K = Device.MaxLuminance/10000.f;

YRow = K * inv( PanelMatrix ) * vWhiteCol;
```

2 **Calculate $R_X, R_Z, G_X, G_Z, B_X, B_Z$ with $X = Y * \frac{x}{y}$, $Z = Y * \frac{(1-x-y)}{y}$.**

```
    float3 RXYZ;
    RXYZ.y = Yrow.x;
    RXYZ.x = RXYZ.y*red_xy.x / red_xy.y;
    RXYZ.z = RXYZ.y*(1.0f - red_xy.x - red_xy.y) / red_xy.y;

    float3 GXYZ;
    GXYZ.y = Yrow.y;
    GXYZ.x = GXYZ.y*grn_xy.x / grn_xy.y;
    GXYZ.z = GXYZ.y*(1.0f - grn_xy.x - grn_xy.y) / grn_xy.y;

    float3 BXYZ;
    BXYZ.y = Yrow.z;
    BXYZ.x = BXYZ.y*blu_xy.x / blu_xy.y;
    BXYZ.z = BXYZ.y*(1.0f - blu_xy.x - blu_xy.y) / blu_xy.y;

    float3 WXYZ;
    WXYZ.y = Yrow.w;
    WXYZ.x = WXYZ.y*wht_xy.x / wht_xy.y;
    WXYZ.z = WXYZ.y*(1.0f - wht_xy.x - wht_xy.y) / wht_xy.y;
```

The XYZ color coordinate system color coordinates for the colors needed to render at the specified intensity are now known.

3 **Convert that XYZ color coordinate system color to *ITU-R BT.2020* gamut, using the following XYZ color coordinate system_to_BT2020RGBlinear matrix.**

This means apply the transform (which occurs in linear space) from the XYZ color coordinate system to the *ITU-R BT.2020* gamut.

$$\mathrm{XYZ\_to\_BT2020RGB}_{\mathrm{linear}} = \begin{bmatrix} 1.716650 & -0.3556710 & -0.2533660 \\ -0.666684 & 1.6164800 & 0.0157681 \\ 0.0176410 & -0.0427711 & 0.9421030 \end{bmatrix}$$

In code, this looks as follows:

```
const float3x3 XYZ_to_BT2020RGB = float3x3(
    1.716650, -0.3556710, -0.2533660,
   -0.666684,  1.6164800,  0.0157681,
    0.017640, -0.0427711,  0.9421030
    );

    float3 R2020 = XYZ_to_BT2020RGB*RXYZ;       // convert to 2020 gamut space
    float3 G2020 = XYZ_to_BT2020RGB*GXYZ;
    float3 B2020 = XYZ_to_BT2020RGB*BXYZ;
    float3 W2020 = XYZ_to_BT2020RGB*WhiteCol*K;
```

4 Convert linear value to nonlinear code.

The linear space colors are then converted into HDR10 protocol code values by applying the PQ curve defined by this function:

The Inverse-EOTF *SMPTE ST 2084* non-linear encoding equation shall be defined as follows:

$$N = \left(\frac{c_1 + c_2 L^{m_1}}{1 + c_3 L^{m_1}}\right)^{m_2}$$

where

L denotes a linear color value

N denotes the corresponding nonlinear color value

m_1 is the number $2610/4096 \times \frac{1}{4} = 0.1593017578125$

m_2 is the number $2523/4096 \times 128 = 78.84375$

c_1 is the number $3424/4096 = 0.8359375 = c_3 - c_2 + 1$

c_2 is the number $2413/4096 \times 32 = 18.8515625$

c_3 is the number $2392/4096 \times 32 = 18.6875$

In code, this looks like the following function:

```
// SMPTE ST 2084 profile (PQ:Perceptual Quantizer):
float Apply2084(float L)
{
    float m1 = 2610.0 / 4096.0 / 4;
    float m2 = 2523.0 / 4096.0 * 128;
    float c1 = 3424.0 / 4096.0;
    float c2 = 2413.0 / 4096.0 * 32;
    float c3 = 2392.0 / 4096.0 * 32;
    float Lp = powf(L, m1);
    return powf((c1 + c2 * Lp) / (1 + c3 * Lp), m2);
}
```

The actual codes emitted are then:

```
    float3 RHDR10 = Apply2084(R2020)*1023.f;   // apply PQ curve and scale to 10b
    float3 GHDR10 = Apply2084(G2020)*1023.f;
    float3 BHDR10 = Apply2084(B2020)*1023.f;
    float3 WHDR10 = Apply2084(W2020)*1023.f;
```

5 Test cases.

For the algorithm provided above, if starting with a device that reports primary colors that match the entire *ITU-R BT.2020* color gamut, the non-linear PQ code value of pure R, G, B pattern rendered at 300nits will be:

red *= (636, 0, 0),* ***green*** *= (0, 636, 0),* ***blue*** *= (0, 0, 636) for the three primary points*

A device with the DCI = P3 primary colors displaying at 1015nits results in the following PQ code values:

red *= (737,441,0),* ***green*** *= (591,762,354),* ***blue*** *= (445,324,767),* ***white*** *= (769,769,769)*

6 Final Source to Routine.

```
// convert EDID primaries from chromaticity coords into sRGB colors for rendering in CCCS
    float2 red_xy, grn_xy, blu_xy, wht_xy;

    wht_xy = m_outputDesc.WhitePoint;                // from EDID or INF
    red_xy = m_outputDesc.RedPrimary;
    grn_xy = m_outputDesc.GreenPrimary;
    blu_xy = m_outputDesc.BluePrimary;

    const float WhiteLevel = 1.0f;                // reference value only

    // Convert to XYZ space
    float3 WhiteCol = xytoXYZ(wht_xy, WhiteLevel);
    float3 RedCol   = xytoXYZ(red_xy, WhiteLevel);
    float3 GreenCol = xytoXYZ(grn_xy, WhiteLevel);
    float3 BlueCol  = xytoXYZ(blu_xy, WhiteLevel);

    // Compute XYZ transform matrix
    float3x3 PanelMatrix = float3x3(
        RedCol.x, GreenCol.x, BlueCol.x,
        RedCol.y, GreenCol.y, BlueCol.y,
        RedCol.z, GreenCol.z, BlueCol.z
    );

    float K = device.MaxLuminanceInNits/10000.f;

    float3 Yrow = inv(PanelMatrix)*WhiteCol*K;

    float3 RXYZ;
    RXYZ.y = Yrow.x;
    RXYZ.x = RXYZ.y*red_xy.x / red_xy.y;
    RXYZ.z = RXYZ.y*(1.0f - red_xy.x - red_xy.y) / red_xy.y;

    float3 GXYZ;
    GXYZ.y = Yrow.y;
    GXYZ.x = GXYZ.y*grn_xy.x / grn_xy.y;
    GXYZ.z = GXYZ.y*(1.0f - grn_xy.x - grn_xy.y) / grn_xy.y;

    float3 BXYZ;
    BXYZ.y = Yrow.z;
    BXYZ.x = BXYZ.y*blu_xy.x / blu_xy.y;
    BXYZ.z = BXYZ.y*(1.0f - blu_xy.x - blu_xy.y) / blu_xy.y;
```

```
float3 WXYZ;
WXYZ.y = Yrow.w;
WXYZ.x = WXYZ.y*wht_xy.x / wht_xy.y;
WXYZ.z = WXYZ.y*(1.0f - wht_xy.x - wht_xy.y) / wht_xy.y;

float3 R2020 = XYZ_to_BT2020RGB*RXYZ;       // convert to 2020 gamut space
float3 G2020 = XYZ_to_BT2020RGB*GXYZ;
float3 B2020 = XYZ_to_BT2020RGB*BXYZ;
float3 W2020 = XYZ_to_BT2020RGB*WhiteCol*K;

float3 RHDR10 = Apply2084(R2020);           // apply PQ curve
float3 GHDR10 = Apply2084(G2020);
float3 BHDR10 = Apply2084(B2020);
float3 WHDR10 = Apply2084(W2020);

// convert HDR10 to linear+709 for CCCS rendering
float3 RCCCS = HDR10ToLinear709(RHDR10);
float3 GCCCS = HDR10ToLinear709(GHDR10);
float3 BCCCS = HDR10ToLinear709(BHDR10);
float3 WCCCS = HDR10ToLinear709(WHDR10);

// create D2D brushes for each primary
CreateSolidColorBrush(D2D1::ColorF(RCCCS.r, RCCCS.g, RCCCS.b), &redBrush);
CreateSolidColorBrush(D2D1::ColorF(GCCCS.r, GCCCS.g, GCCCS.b), &greenBrush);
CreateSolidColorBrush(D2D1::ColorF(BCCCS.r, BCCCS.g, BCCCS.b), &blueBrush);
CreateSolidColorBrush(D2D1::ColorF(WCCCS.r, WCCCS.g, WCCCS.b), &whiteBrush);

switch (m_currentColor)
{
case 0:
    ctx->DrawRectangle(centerRect, redBrush.Get(),   8);    break;
case 1:
    ctx->DrawRectangle(centerRect, greenBrush.Get(), 8);    break;
case 2:
    ctx->DrawRectangle(centerRect, blueBrush.Get(),  8);    break;
case 3:
    ctx->DrawRectangle(centerRect, whiteBrush.Get(), 8);    break;
}
```

E Main Contributor History (Previous Revisions)

Table E-1: Main Contributor History (Previous Revisions)

Company	Name	Contribution	Revision
Advanced Micro Devices, Inc.	Syed A. Hussain	Technical Content	1.0
Avatar Tech Pubs	Trish McDermott	CTS Editor, Technical Writer	1.0
Dell	Stefan Peana	Technical Content	1.0
HP, Inc.	Greg Staten	Technical Content	1.0
Intel Corporation	Roland Wooster	Task Group Chair, Technical Content, CTS Author	1.0
Japan Display, Inc.	Tsutomu Harada	Technical Content	1.0
Lenovo Group	Gordon Boyack	Technical Content	1.0
LG Display	Julie Ro	Technical Content	1.0
LG Electronics	Do-Kyun Kim	Technical Content	1.0
Microsoft Corporation	Chas Boyd	Task Group Vice-chair	1.0
NVIDIA Corporation	Alex Soohoo	Technical Content	1.0
Parade Technologies, Ltd.	Craig Wiley	Technical Content	1.0
Portrait Displays	Duane Viano	Technical Content	1.0
Realtek Semiconductor Corp.	Jay Lin	Technical Content	1.0
Samsung Electronics Co., Ltd.	Kyong-sok Seo	Technical Content	1.0
	Dale Stolitzka	Technical Content	1.0
VESA	David Braun	Technical Content	1.0