Leader

Leader Electronics Corporation Technical Information Series Vol. 02

HDR Measurement

The content of this document is as of December 2018.

01 What Is HDR?

Overview of HDR

What Is HDR?

HDR, which stands for high dynamic range, is a technology that extends the dynamic range, which is the range of brightness expressible by video. The wider the dynamic range, the wider the range of expression from the darker parts to the lighter parts and the more it is possible to suppress overblown highlights and crushed shadows.

For example, suppose we have a scene that has a mixture of bright and dark areas on one screen.

Figure | Scene example

When this scene, which appears to the human eye as shown above, is shot with the conventional SDR (standard dynamic range) system, adjusting the exposure to the bright parts outside the windows causes the dark parts to be underexposed, and conversely, adjusting the exposure to the dark parts of the room causes the bright parts outside the windows to be overexposed. Due to the narrow dynamic range, either the tones of the bright parts or those of the dark parts must be sacrificed.

Figure | Crushed shadows

Figure | Overblown highlights

Shot this scene with HDR technology makes it possible to achieve a more realistic rendition free of overexposure and underexposure because of the wider dynamic range.

Luminance

The quality of video is considered to be determined by five factors, namely resolution, bit depth, frame rate, color gamut, and luminance. In 1990, the standard for full HD, which is the current format, was codified by ITU-R Recommendation BT.709. Later, in 2012, the standards for 4K and 8K were codified by ITU-R Recommendation BT.2020. As a result, of the five factors determining video quality, four, namely resolution, bit depth, frame rate, and color gamut evolved, but the factor of luminance remained unchanged from conventional SDR. Then, in 2016, the standard for HDR was codified by ITU-R Recommendation BT.2100. Luminance evolved from SDR to HDR.

Luminance, which has to do with the above-mentioned dynamic range, refers to the range of brightness that can be expressed by video. To what extent is the range of expressible brightness increased by switching from the SDR system to the HDR system?

First, an explanation of the unit of brightness, cd/m^2 (candela per square meter), is in order. The term candela comes from the Latin word for candle. 1 cd/m^2 is approximately equivalent to the light intensity produced by one candle to light an area of 1 m^2. Although the unit of brightness is sometimes called the "nit", which is synonymous with "cd/m^2", in this document, "cd/m^2", which is the term used by the International System of Units, is used.

The natural world under sunlight is said to have brightness ranging from 10^{-6} to 10^9 cd/m^2. The human eye is said to be able to recognize brightness on the order of 10^{14}, which is close to the brightness level found in the natural world, but this is the range that is visible by opening and closing the pupil, and the range that can be seen at once is around 10^5.

In the conventional SDR system, the maximum value is 100 cd/m^2 and the dynamic range is on the order of 10^3. As such, this system can be said to express only a narrow range compared with the humanly visible range.

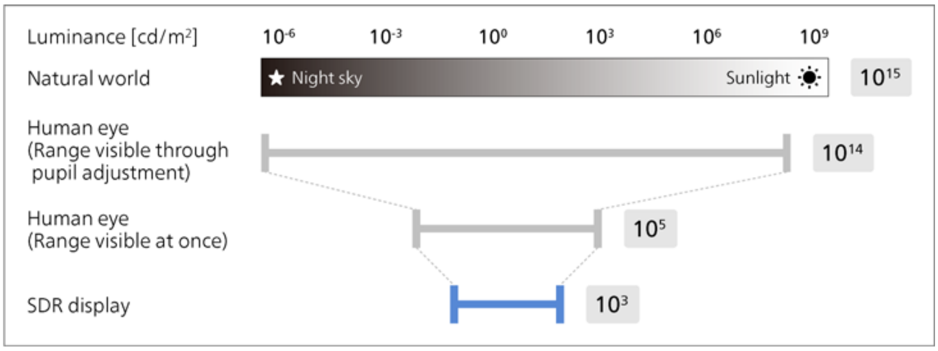


Figure | SDR System

On the other hand, with the HDR system, the maximum value is 10,000 cd/m^2 and the dynamic range is extended to 10^5, which allows for more realistic expression. However, the maximum luminance of the HDR displays currently being sold is about 1,000 cd/m^2, and displays that can produce luminance of 10,000 cd/m^2 are not commercially available.

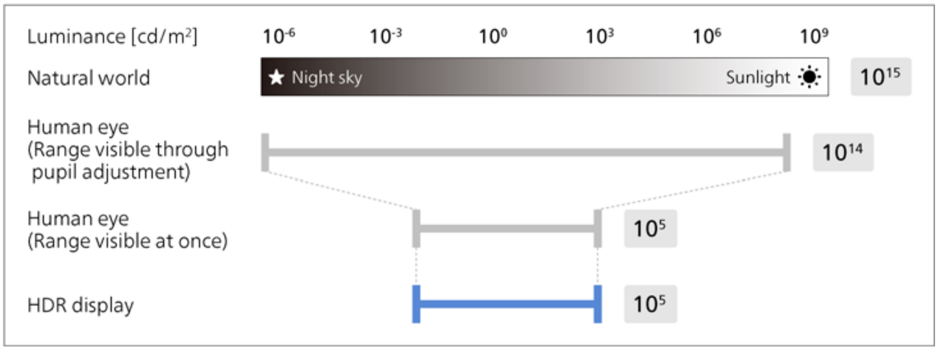


Figure | HDR System

02 What Is Gamma?

Camera gamma and display gamma

Basics of Gamma

Gamma refers to the power function “$y=x^n$”, which can be defined as follows in terms of input and output:

> Output = Input $^{\text{Gamma}}$

Let's check the characteristics of this function by varying the gamma value between 0.5, 1, and 2 and looking at what this looks like on a graph. Here, let's assume that the input and output are normalized in the range of 0 to 1.

In this figure, we can see that even for different gamma values, if the input value is 0 or 1, the output value is also 0 or 1, respectively; if the gamma value is smaller than 1, the input value is larger, and if the gamma value is larger than 1, the input value is smaller.

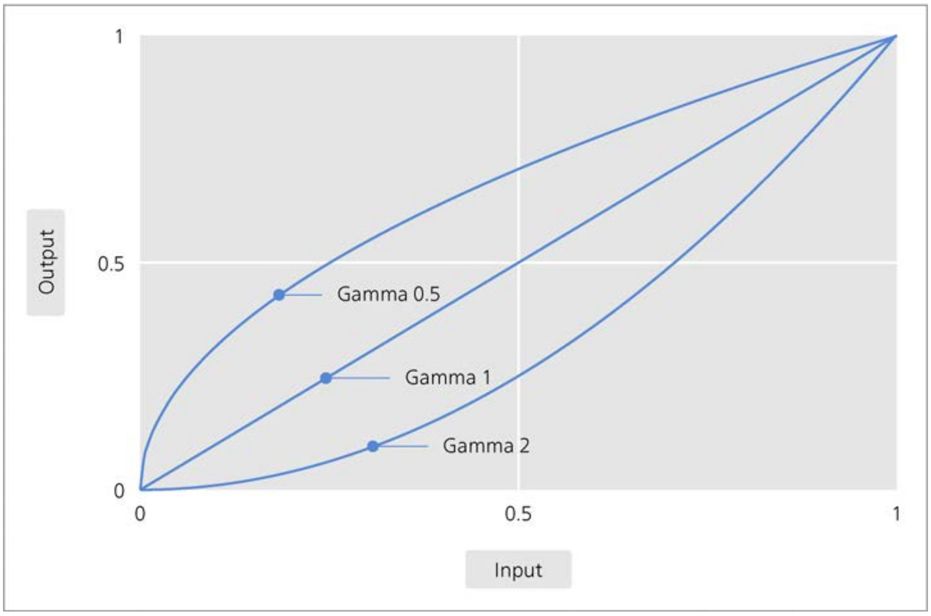


Figure | Gamma curve

From Shooting to Display

In this section, we will consider a case of a scene shot by a camera and shown on a display, from the viewpoints of the display, the camera, and the viewers.

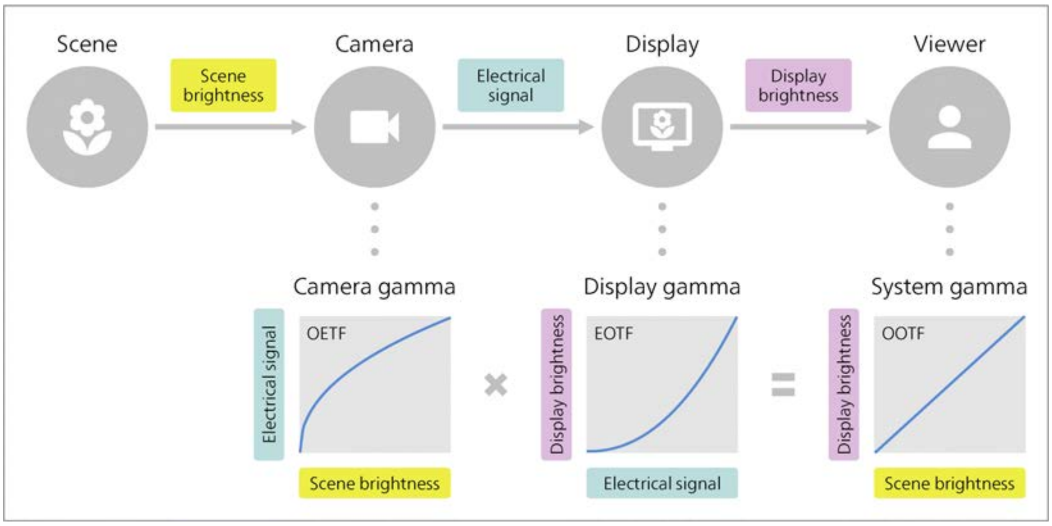


Figure | From shooting to display

Display

In the past, CRT monitors (CRTs) were used as displays. CRT monitors have the physical gamma characteristic (Gamma = 2.2) of their electron gun, which tends to display things darker compared with the input signal.

Note that on the display side, the characteristic when converting an electric signal to brightness is called display gamma, and its transfer function is called the electro-optical transfer function (EOTF).

Camera

On the display side, things are displayed darker, which can be offset by creating bright data on the camera side. Since the gamma value of a CRT monitor is 2.2, the camera side uses the gamma value with the opposite characteristics (gamma = 1/2.2 = 0.45).

On the camera side, the characteristic when converting an electric signal to brightness is called camera gamma, and its transfer function is called the opto-electronic transfer function (OETF).

Viewers

By combining camera characteristics and display characteristics, one can watch with the correct brightness. For example, if the brightness of the scene is 0.5, an electrical signal of $0.5^{0.45} = 0.73$ is input to the display via the camera. That electrical signal of 0.73 on the display side is converted to $0.73^{2.2} = 0.5$, so that the viewers see an image with 0.5 times the original brightness.

Note that the characteristic when considering camera gamma and display gamma in total is called system gamma, and its transfer function is called opto-optical transfer function (OOTF).

Effective Brightness Recording

There is another reason for gamma correction on the camera side besides canceling out the gamma characteristic of the CRT monitor. That is to record the brightness effectively.

Human vision is sensitive in dark places and insensitive in bright places. For example, if there are 100 lights in a room, one can recognize the difference in brightness between 0 lights and 1 light, and the difference in brightness between 1 light and 2 lights, but the difference in brightness between 99 lights and 100 lights is difficult to recognize.

Based on this characteristic, the brightness of a scene can be efficiently converted to an electric signal by allocating a larger amount of data (higher resolution) for darker light and a smaller amount of data (lower resolution) for brighter light.

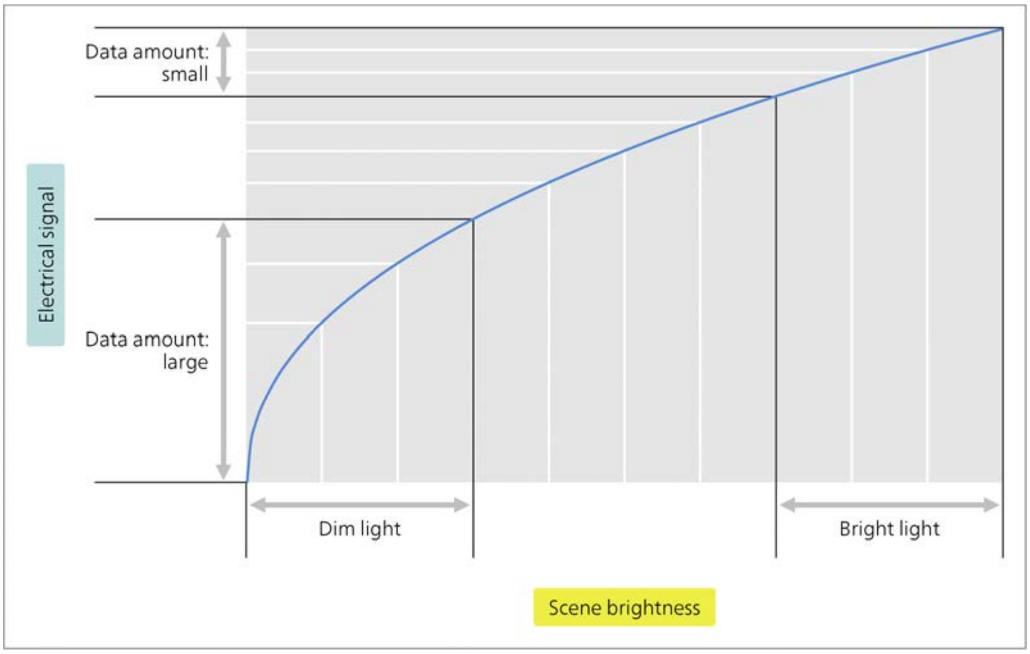


Figure | Effective brightness recording

LCD monitors have different input and output characteristics than CRT monitors, and since gamma correction on the camera side is performed in the same way as when a CRT monitor is used, the input and output characteristics of the LCD monitor are created by simulating the gamma curve of CRT monitors.

03 SDR System

Gamma curve of the conventional SDR system

Camera Gamma (OETF)

The camera gamma for SDR is defined as follows in ITU-R Recommendation BT.709.

> $V = 1.099\,L^{0.45} - 0.099 \qquad 1 \geqq L \geqq 0.018$
> $V = 4.500\,L \qquad 0.018 > L \geqq 0$
>
> L: Scene brightness (0 to 1)
> V: Electrical signal (0 to 1)
>
> (excerpted from ITU-R Recommendation BT.709-6)

Putting this in graph form, one can see that the gamma curve approximates that of the gamma value of 0.5.

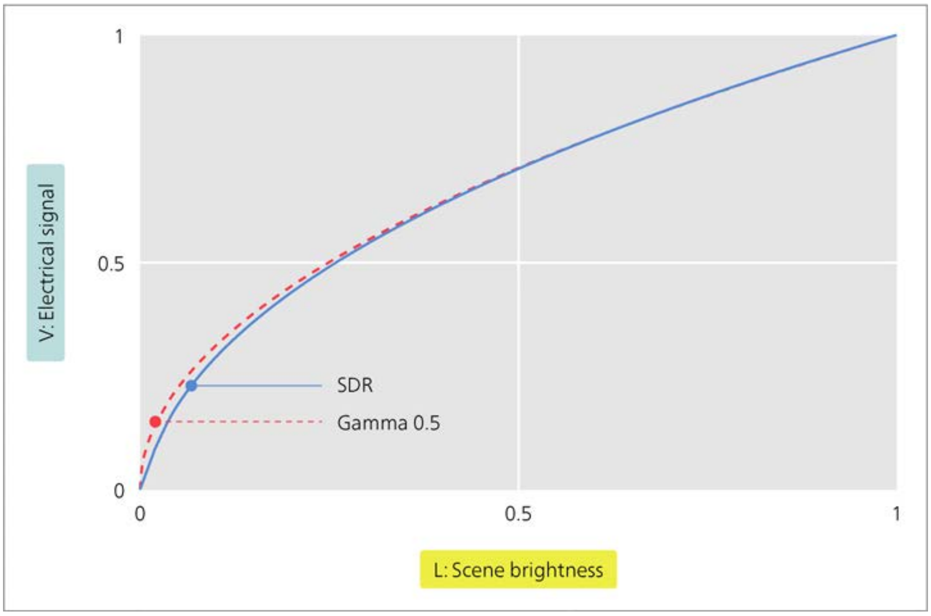


Figure | Camera gamma (OETF) for SDR

Display Gamma (EOTF)

The camera gamma for SDR is defined as follows in ITU-R Recommendation BT.1886.
The following graph shows the electric signal and display brightness normalized in the range of 0 to 1.

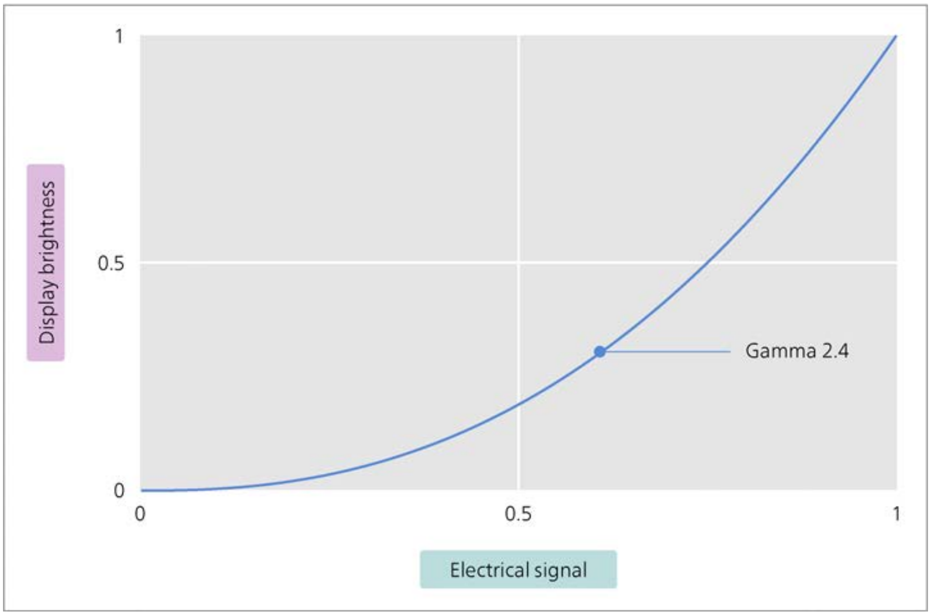


Figure | Display gamma (EOTF) for SDR

System Gamma (OOTF)

The system gamma for SDR when the camera gamma is 0.5 and the display gamma is 2.4 is 1.2.

> Display brightness
> = (electrical signal)$^{2.4}$
> = {(brightness of scene)$^{0.5}$}$^{2.4}$
> = (brightness of scene)$^{1.2}$

The following graph shows the scene brightness and display brightness normalized in the range of 0 to 1, combined with the gamma curve for the gamma value of 1.

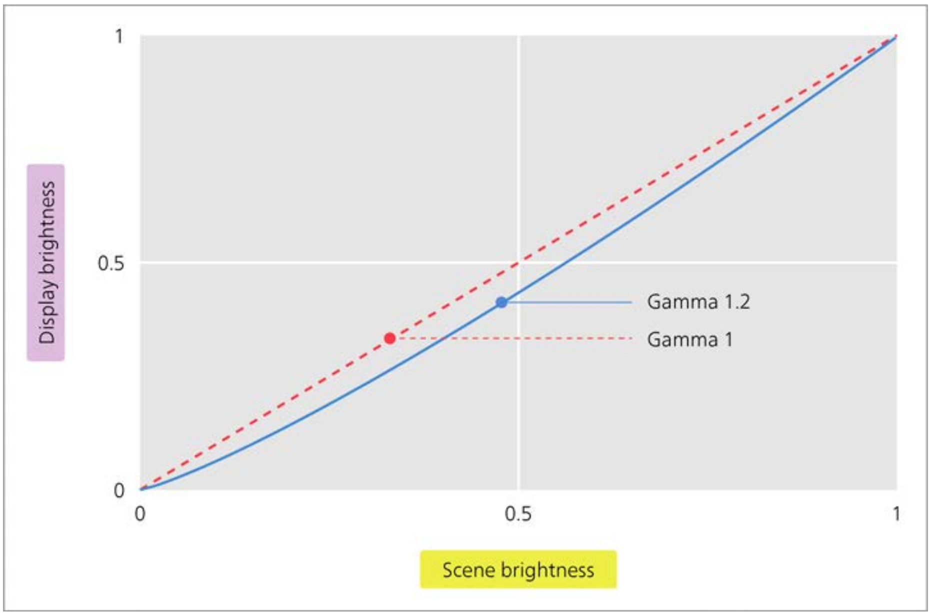


Figure | System gamma (OOTF) for SDR

Is it okay for system gamma to be a value other than 1?
As many people perceive a system gamma value between 1.1 to 1.2 as natural, the system gamma value does not necessarily have to be 1. Further, the appropriate gamma value varies according to the surrounding environment. A value of 1.1 is considered appropriate for a bright office, a value of 1.2 suitable for a dimly lit living room, and a value of 1.5 fitting for a dark movie theater.

04 HDR System

Gamma curve of the HDR system

Standards

There are two systems for HDR, namely HLG and PQ, both of which are codified as standards. The HLG system being compatible with conventional displays, it is suitable for broadcasting, and the PQ system is considered suitable for movies, a field where the emphasis is on reproducibility.

	HLG (Hybrid Log Gamma)	**PQ (Perceptual Quantization)**
Features	Like SDR, luminance is expressed as a relative value (%). Use a gamma curves compatible with SDR.	Luminance is expressed as an absolute value (cd/m^2). Uses a gamma curve that is based on human visual characteristics.
Proposed by:	NHK, BBC	Dolby
Standards	ITU-R BT.2100, ARIB STD-B67	ITU-R BT.2100, SMPTE ST 2084
Peak luminance	Varies depending on the display	10,000 cd/m^2
Transfer function	OETF	EOTF
Compatible with SDR	Yes	No

HLG System

Overview

If the range of brightness that can be recorded by SDR is considered to be in the range of 0 to 1, the brightness that can be recorded with the HLG (Hybrid Log Gamma) system is in the range of 0 to 12.

The combination of transfer functions of HLG is defined as follows in ITU-R Recommendation BT.2100. Display gamma EOTF uses the combination of the inverse function $OETF^{-1}$ of camera gamma and system gamma OOTF.

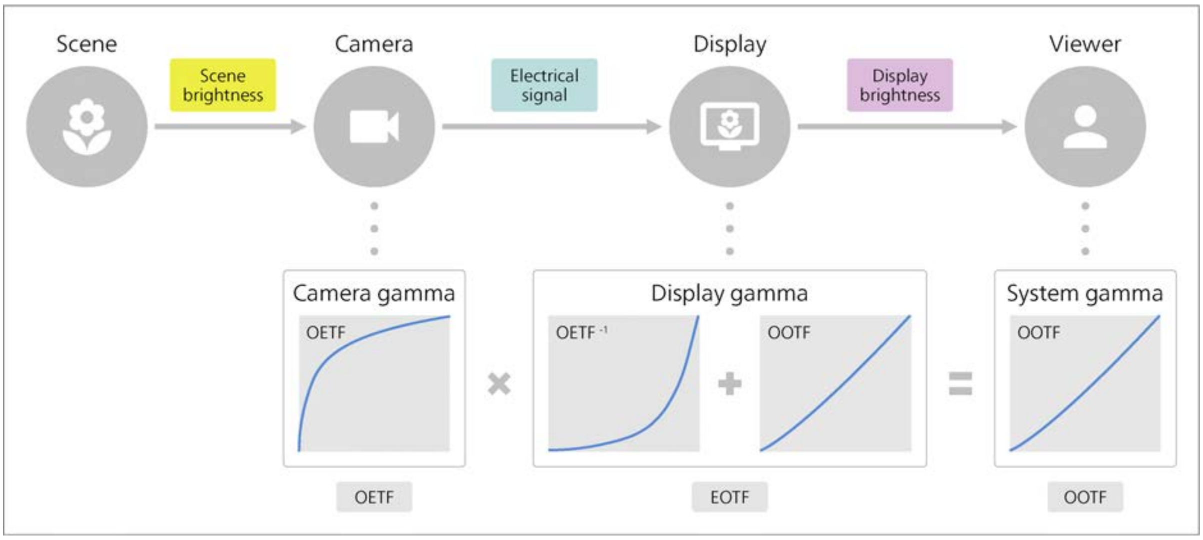


Figure | HLG system overview

Camera Gamma (OETF)

The camera gamma for HLG is defined as follows in ITU-R Recommendation BT.2100.
Per its name of "Hybrid Log Gamma", this is a hybrid (combination) of the gamma curve (SDR part) and log curve (HDR part).

> $E' = \sqrt{3E}$ $\quad 0 \leqq E \leqq 1/12$ (SDR part)
> $E' = a \cdot \ln(12E - b) + c$ $\quad 1/12 < E \leqq 1$ (HDR part)
>
> $a = 0.17883277$
> $b = 1 - 4a = 0.28466892$
> $c = 0.5 - a \cdot \ln(4a) = 0.55991073$
>
> E: Scene brightness (0 to 1)
> E': Electrical signal (0 to 1)
>
> (excerpted from ITU-R Recommendation BT.2100-1)

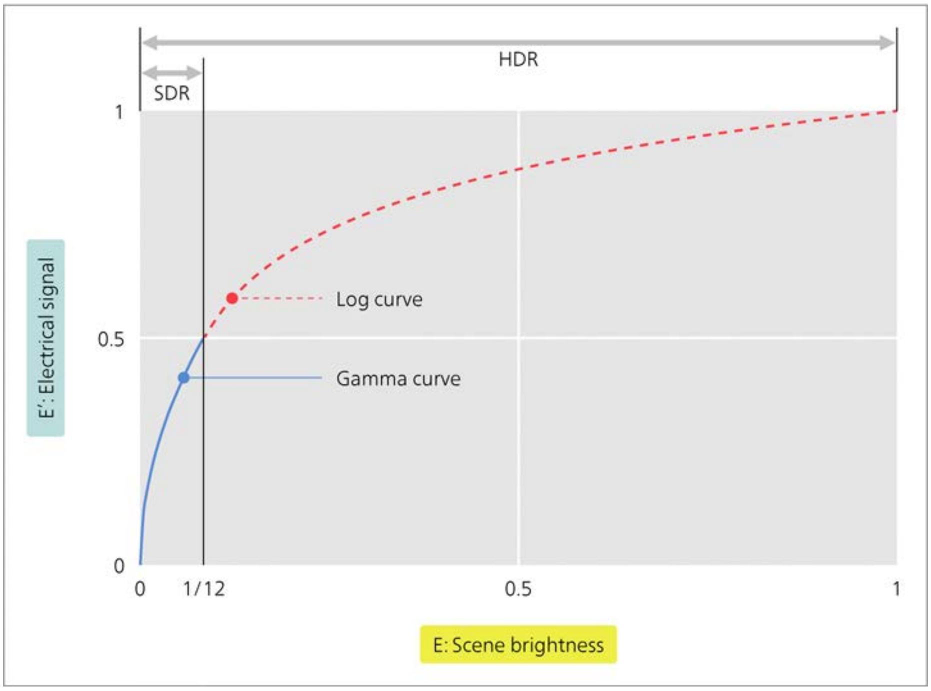


Figure | HLG camera gamma (OETF)

In the following, we compare HLG camera gamma with SDR camera gamma.

Since the SDR curve approximates the gamma 0.5 curve, it can be expressed as
$E' = (12E)^{0.5} = \sqrt{12E} = 2 \times \sqrt{3E}$

On the other hand, the HLG curve being
$E' = \sqrt{3E}$
doubling the HLG curve results in a curve that almost matches the SDR curve. The HLG system is compatible with the conventional SDR system.

Moreover, compared with SDR, HLG's electrical signal level has twice the dynamic range, allowing recording of brightness 12 times greater.

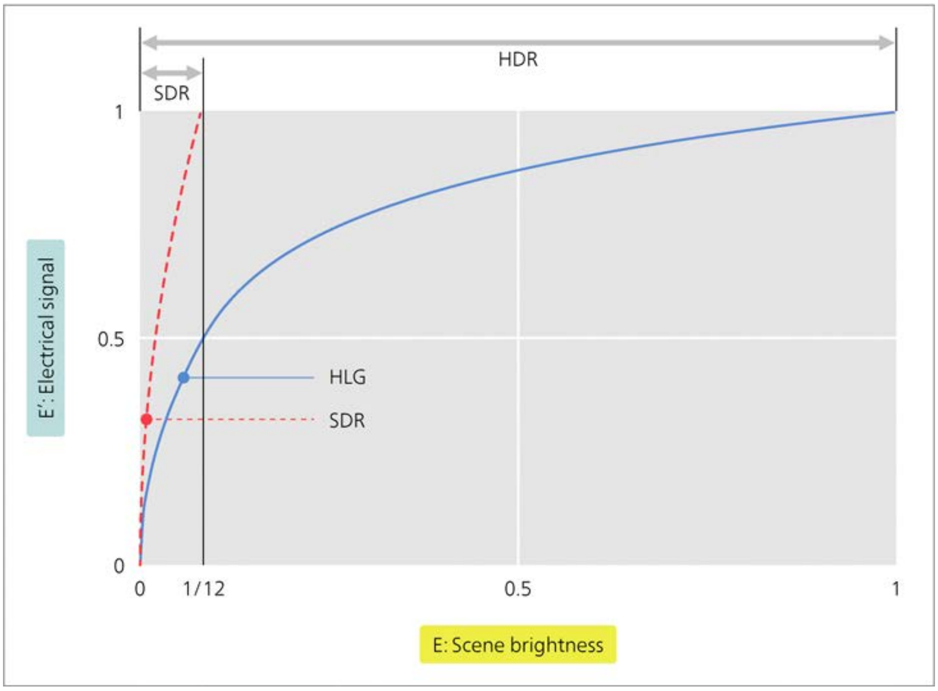


Figure | HLG and HDR camera gamma (OETF)

Display gamma (EOTF)

Display gamma of HLG uses the combination of the inverse function $OETF^{-1}$ of camera gamma and system gamma OOTF.

First, the inverse function of camera gamma is defined as follows in ITU-R Recommendation BT.2100.

$$E = E'^2/3 \qquad 0 \leqq E' \leqq 1/2$$

$$E = \{\exp((E' - c)/a) + b\}/12 \qquad 1/2 < E' \leqq 1$$

$a = 0.17883277$

$b = 1 - 4a = 0.28466892$

$c = 0.5 - a \cdot \ln(4a) = 0.55991073$

E: Display brightness (0 to 1)

E: Electrical signal (0 to 1)

(excerpted from ITU-R Recommendation BT.2100-1)

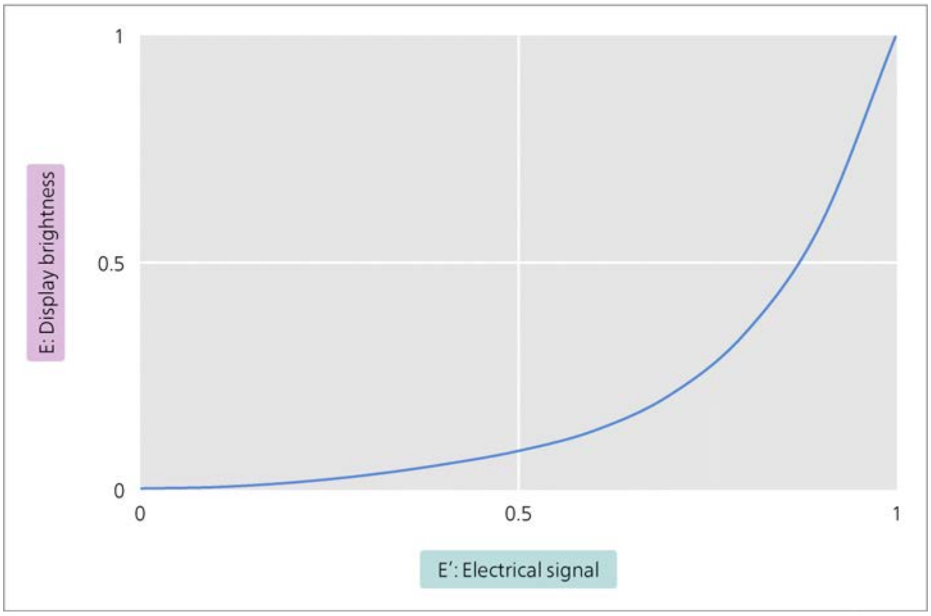


Figure | HLG $OETF^{-1}$

Next, system gamma varies depending on the peak brightness of the display, and it is defined as follows in ITU-R Recommendation BT.2100.

> $\gamma = 1.2 + 0.42\mathrm{Log}_{10}(L_W/1000)$
>
> γ : Gamma value
> L_W: Peak luminance of display (cd/m^2)
>
> (excerpted from ITU-R Recommendation BT.2100-1)

Based on the fact that peak luminance of the display is
$\gamma = 1.2$ in the case of 1,000 cd/m^2
$\gamma = 0.98$ in the case of 300 cd/m^2
$\gamma = 1.62$ in the case of 10,000 cd/m^2
the larger the peak luminance value, the larger the gamma value.

Here, the vertical axis represents display brightness [cd/m^2], peak brightness of the display is 1,000 cd/m^2 and 300 cd/m^2, and the EOTF obtained by combining the inverse function of camera gamma and system gamma is plotted.

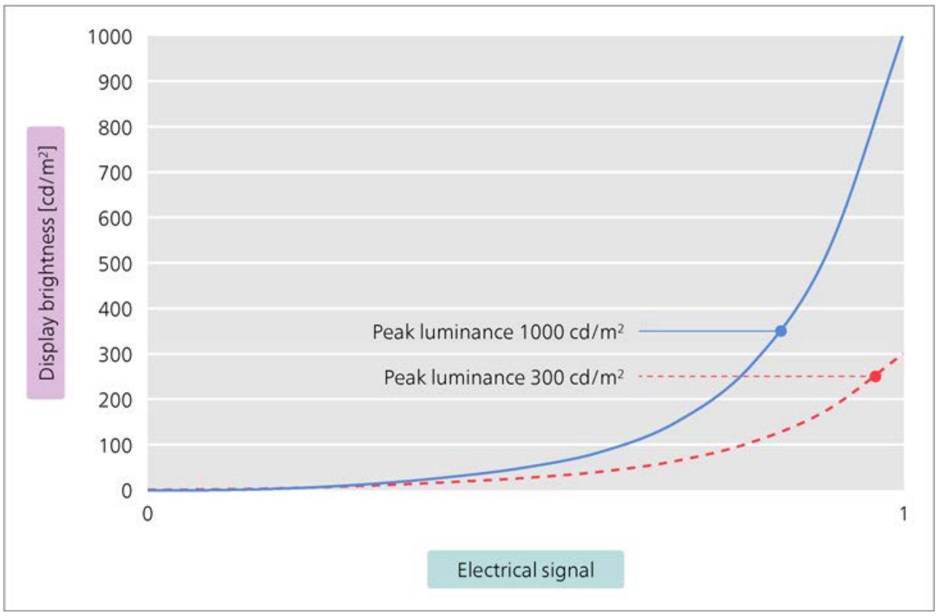


Figure | Display gamma of HLG (EOTF = OETF^{-1} + OOTF)

The HLG system is said to be a relative value display system, which means that the gamma curve changes according to the peak luminance of the display. Therefore, even if one watches HDR video on a conventional SDR TV, the video can be displayed with some compatibility.

PQ system

Overview

If the maximum brightness that can be recorded with SDR is 100 cd/m^2, the maximum brightness that can be recorded in the PQ (Perceptual Quantization) system is 100 times greater, meaning up to 10,000 cd/m^2.

The combination of transfer functions of PQ is defined as follows in ITU-R Recommendation BT.2100. Camera gamma OETF uses a combination of system gamma OOTF and inverse function EOTF^{-1} of display gamma.

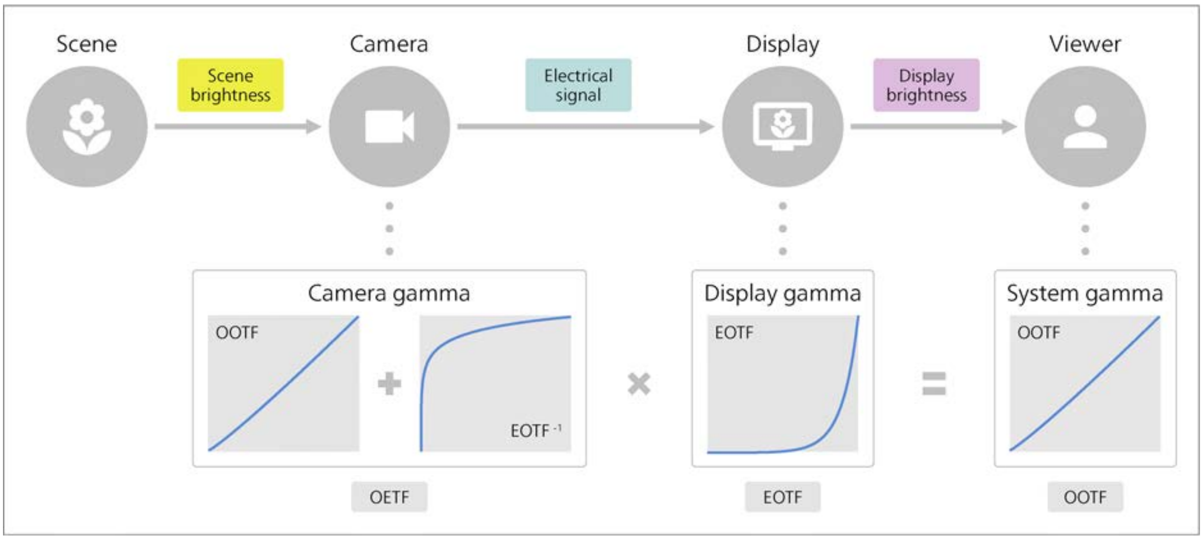


Figure | PQ system overview

Camera gamma (OETF)

Camera gamma of PQ uses a combination of system gamma OOTF and inverse function $EOTF^{-1}$ of display gamma.

First, system gamma is defined as gamma value 1.2 in ITU-R Recommendation BT.2100.
($OOTF[E] = G_{1886}[G_{709}[E]]$, $G_{1886} = 2.4$, $G_{709} \fallingdotseq 0.5$)

Next, the inverse function of display gamma is defined as follows in ITU-R Recommendation BT.2100.

$$E' = \left(\frac{c1 + c2Y^{m1}}{1 + c3Y^{m1}}\right)^{m2}$$

$Y = F_D / 10000$

m1 = 2610/16384 = 0.1593017578125
m2 = 2523/4096 × 128 = 78.84375
c1 = 3424/4096 = 0.8359375 = c3 - c2 + 1
c2 = 2413/4096 × 32 = 18.8515625
c3 = 2392/4096 × 32 = 18.6875

E: Electrical signal (0 to 1)
Y: Scene brightness (0 to 1)
F_D: Scene brightness (cd/m²)

(excerpted from ITU-R Recommendation BT.2100-1)

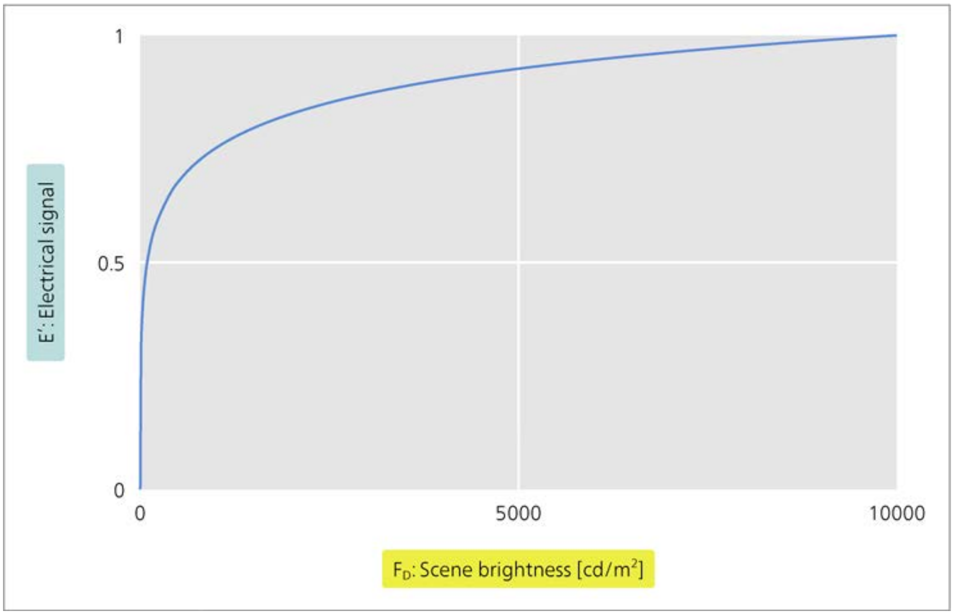
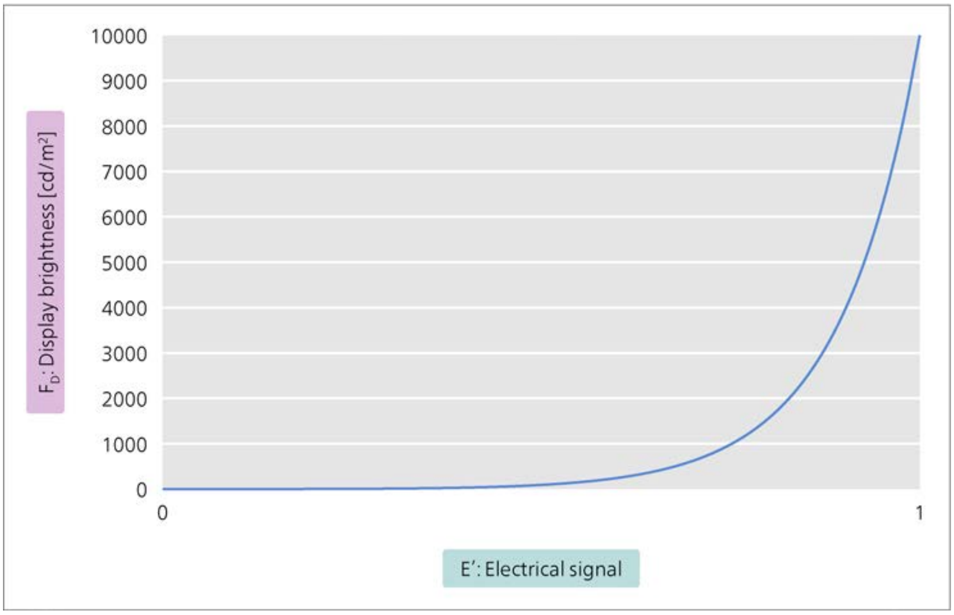


Figure | $EOTF^{-1}$ of PQ

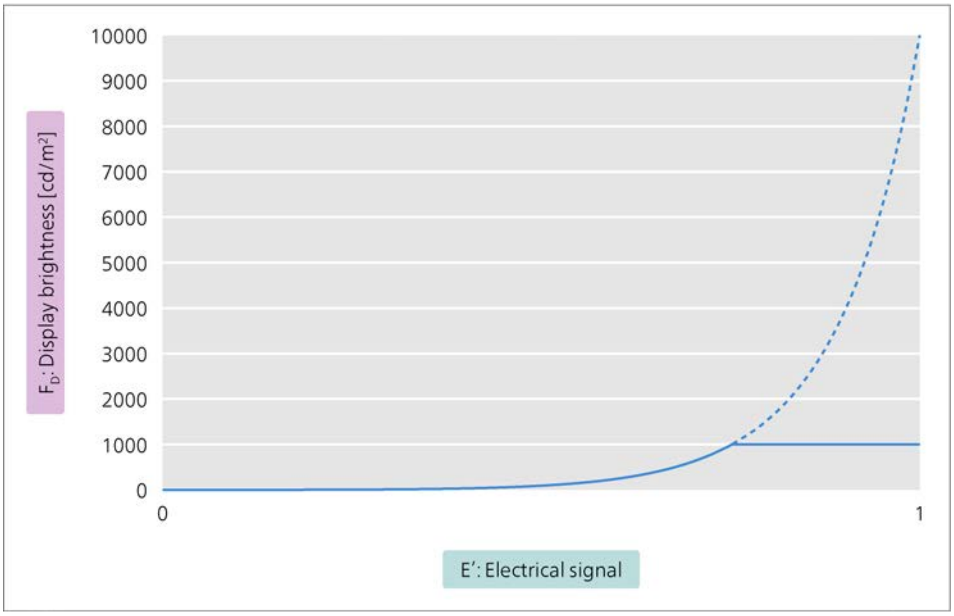
Display Gamma (EOTF)

The display gamma for PQ is defined as follows in ITU-R Recommendation BT.2100.

> $F_D = 10000Y$
>
> $$Y = \left(\frac{\max\left[\left(E'^{\frac{1}{m2}} - c1\right), 0\right]}{c2 - c3E'^{\frac{1}{m2}}} \right)^{\frac{1}{m1}}$$
>
> m1 = 2610/16384 = 0.1593017578125
> m2 = 2523/4096 × 128 = 78.84375
> c1 = 3424/4096 = 0.8359375 = c3 - c2 + 1
> c2 = 2413/4096 × 32 = 18.8515625
> c3 = 2392/4096 × 32 = 18.6875
>
> F_D: Display brightness (cd/m²)
> Y: Display brightness (0 to 1)
> E: Electrical signal (0 to 1)
>
> (excerpted from ITU-R Recommendation BT.2100-1)



The PQ system is said to be an absolute value display system, which means that the gamma curve is constant and is not affected by the peak luminance of the display. For example, if the peak brightness of the display is 1,000 cd/m^2, the part exceeding 1,000 cd/m^2 will be overexposed.



05 HDR Measurement

HDR measurement using a Leader waveform monitor

Here, as an example, the procedure for measuring the HDR signal using Leader's LV5600 waveform monitor is explained.
Measurement of HDR signals requires the LV5600-SER23 waveform monitor.

Preparations

HLG System

To measure HLG system signals, set the HDR Mode on the HDR tab to "HLG".

SYS ➡ F1 (SIGNAL IN OUT) ➡

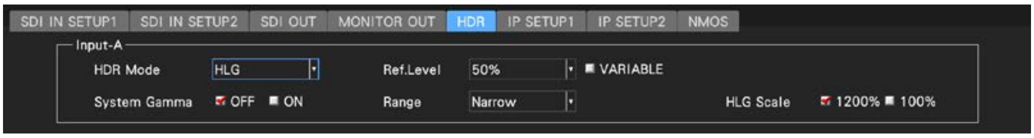


Figure | HDR tab

Also make the following additional settings.

Item	Description
Ref.Level	On the WFM display and PIC CINEZONE display, select the reference level. On the WFM display, a dash-dot line is displayed as the reference level. On the PIC CINEZONE display, this is the boundary line between SDR display and HDR display. [50% (default value) / 75%]
VARIABLE	When set to ON, the reference level can be varied with Ref.Level as the initial value. [OFF (default value) / ON]
System Gamma	When set to ON, the peak luminance of the display is 1,000 cd/m^2, and system gamma 1.2 is applied. Regardless of HLG Scale selection, the scale is displayed from 0 to 1,000 cd/m^2. [OFF (default value) / ON]
Range	Narrow: Set the range as 64 to 940 (10 bits) or 256 to 3760 (12 bits). Full: Set the range as 0 to 1023 (10 bits) or 0 to 4095 (12 bits). [Narrow (default value) / Full]

Item	Description
HLG Scale	When System Gamma is OFF, the scale is displayed from 0 to 1200% or 0 to 100%. (When System Gamma is ON, the scale is displayed from 0 to 1,000 cd/m^2 regardless of the value here.) [1200% (default value) / 100%]

PQ System

To measure PQ system signals, set the HDR Mode on the HDR tab to "PQ".

SYS ➡ F1 (SIGNAL IN OUT) ➡

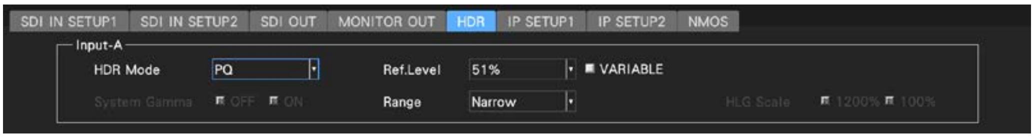


Figure | HDR tab

Also make the following additional settings.

Item	Description
Ref.Level	On the WFM display and PIC CINEZONE display, select the reference level. On the WFM display, a dash-dot line is displayed as the reference level. On the PIC cine zone display, this is the boundary line between SDR display and HDR display. [51% (default value) / 58%]
VARIABLE	When set to ON, the reference level can be varied with Ref.Level as the initial value. [OFF (default value) / ON]
Range	Narrow: Set the range as 64 to 940 (10 bits) or 256 to 3760 (12 bits). Full: Set the range as 0 to 1023 (10 bits) or 0 to 4095 (12 bits). [Narrow (default value) / Full]

Measurement

By setting the HDR Mode on the HDR tab to "HLG" or "PQ", measurements supporting HDR signals can be made with WFM display, VECT display, and PIC display.

WFM Display

Scale Display

The normal scale is displayed on the left, and the scale for HDR signals is displayed on the right. Depending on the setting of the HDR tab, the HDR scale is displayed as 0 to 1200%, 0 to 100%, or 0 to 1000 cd/m^2.

The horizontal graduation line can be switched between the one corresponding to the normal scale and the one corresponding to the HDR scale by the following procedure.

> WFM ➡ F1 (WFM INTEN/CONFIG) ➡ F5 (WFM SCALE) ➡ F3 (SCALE SETTING) ➡
> F3 (SCALE DISPLAY): OFF / MAIN / HDR / BOTH

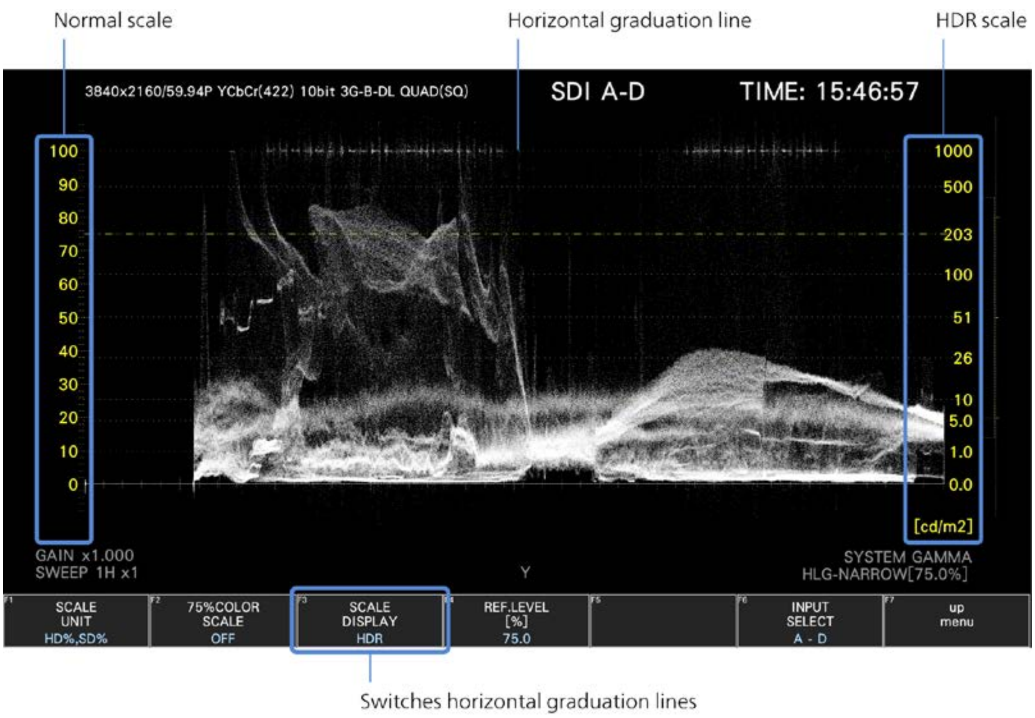


Figure | Scale display

Reference Level Display

A dash-dot chain line is displayed at the level selected for Ref.Level on the HDR tab. Also, the reference level is displayed in the lower right of the screen.

When VARIABLE is ON on the HDR tab, the reference level can be varied by the following procedure.

> WFM ➡ F1 (WFM INTEN/CONFIG) ➡ F5 (WFM SCALE) ➡ F3 (SCALE SETTING) ➡ F4 (REF.LEVEL [%]): 0.0 - 100.0

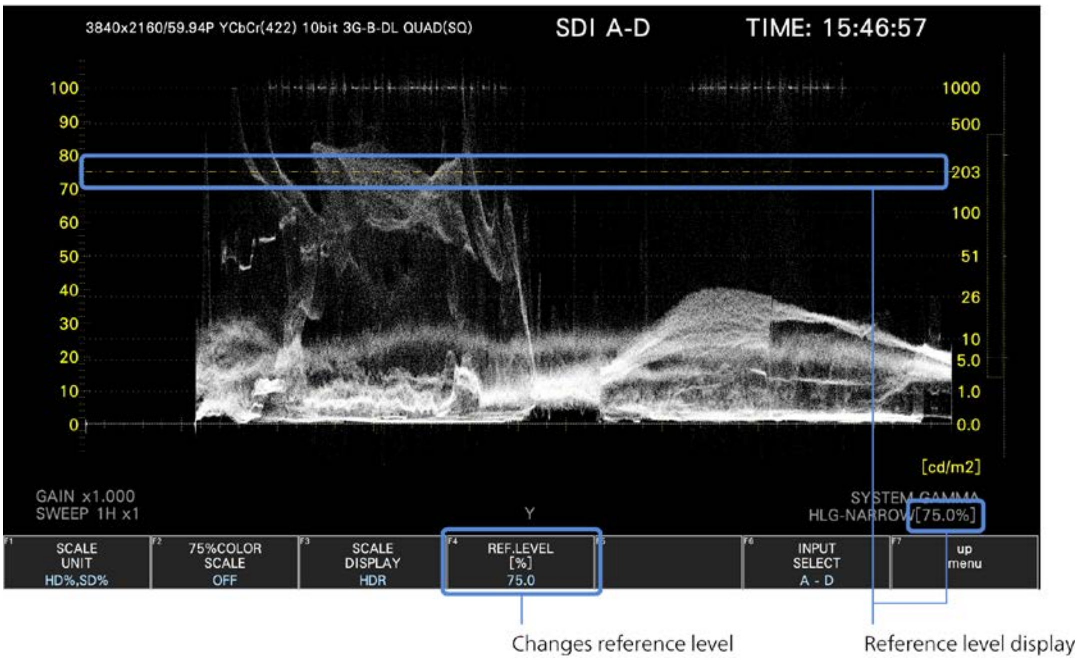


Figure | Reference level display

Cursor Display

When HDR is selected by the following procedure, the measured values corresponding to the HDR scale are displayed.

> WFM ➡ F4 (CURSOR) ➡ F3 (Y UNIT): mV / % / R% / DEC / HEX / HDR

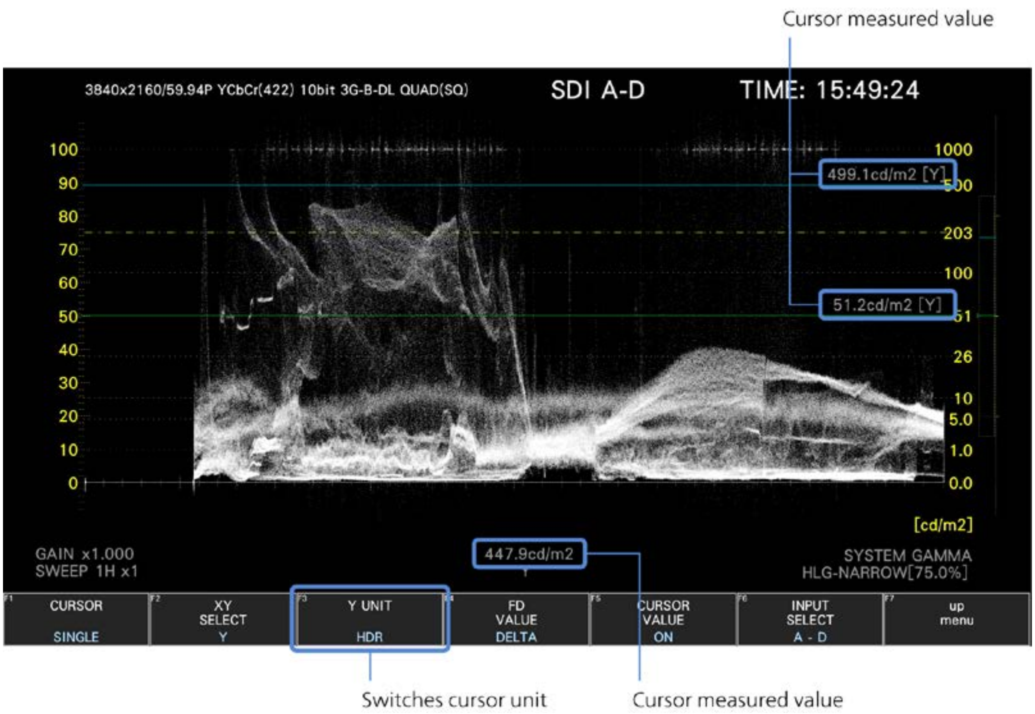


Figure | Cursor display

VECT Display

A scale for HDR signals can be displayed on the histogram display. Depending on the setting of the HDR tab, the HDR scale is displayed as 0 to 1200%, 0 to 100%, or 0 to 1000 cd/m².

To display the HDR scale, select HDR by the following procedure.

> VECT ➡ F2 (HISTGRAM SCALE): % / HDR

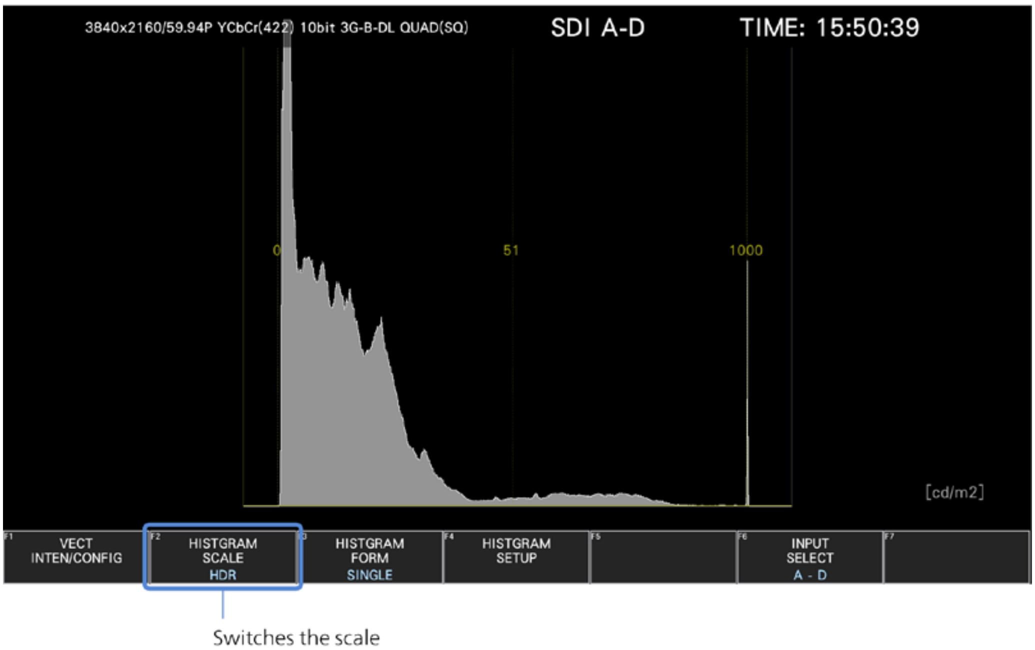


Figure | Histogram display

PIC Display

%DISPLAY Display

On CINELITE's %DISPLAY display, the measurement values for HDR signals can be displayed by selecting HDR by the following procedure. Depending on the setting of the HDR tab, the measurement values are displayed as 0 to 1200%, 0 to 100%, or 0 to 1000 cd/m2.

> PIC ➡ F2 (CINELITE/HDR) ➡ F2 (% DISP SETUP) ➡ F4 (UNIT SELECT): Y% / RGB% / RGB255 / CV / CV(DEC) / HDR

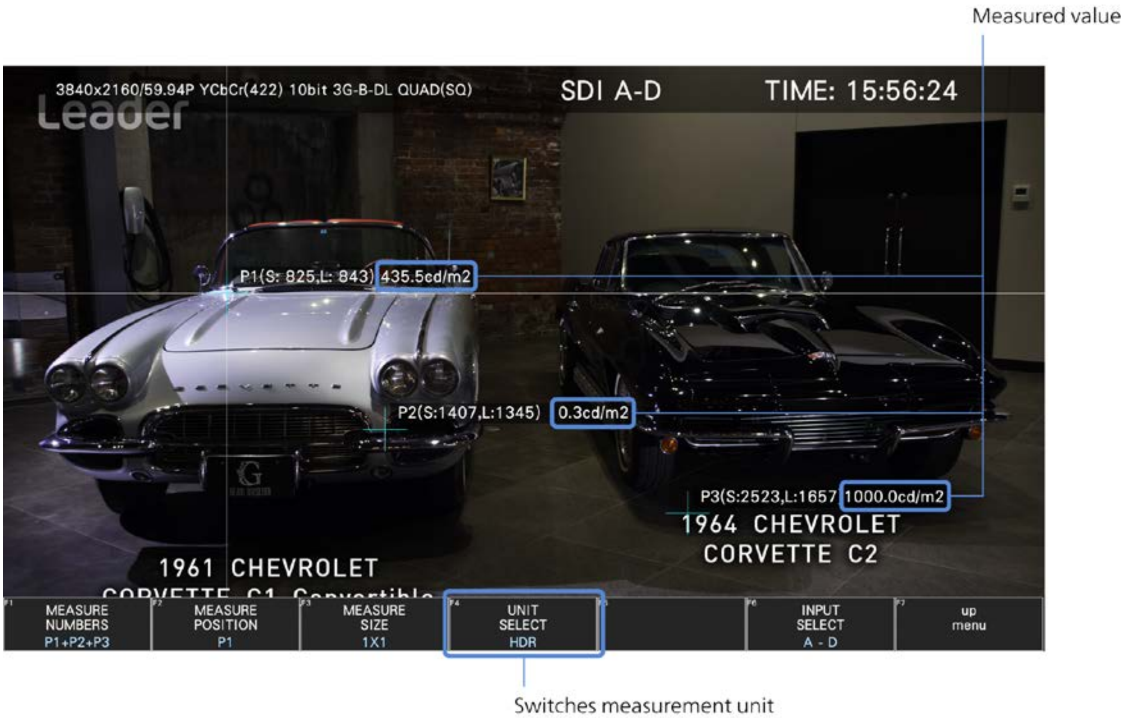


Figure | %DISPLAY display

CINEZONE Display

On the CINEZONE display, to display the SDR area in monochrome and the HDR area in color, follow the procedure below to select ON.

> PIC ➡ F2 (CINELITE/HDR) ➡ F5 (HDR ZONE): OFF / ON

Figure | CINEZONE display

When VARIABLE is ON on the HDR tab, the reference level can be varied by the following operation. The reference level is the boundary line between the SDR display and the HDR display. In the upper left of the screen, the HDR equivalent value of the value set with F2 (UPPER [%]), F3 (LOWER [%]), and F4 (REF [%]) is displayed.

> PIC ➡ F2 (CINELITE/HDR) ➡ F2 (CINEZONE SETUP) ➡ F4 (REF [%]): 0.0 - 100.0

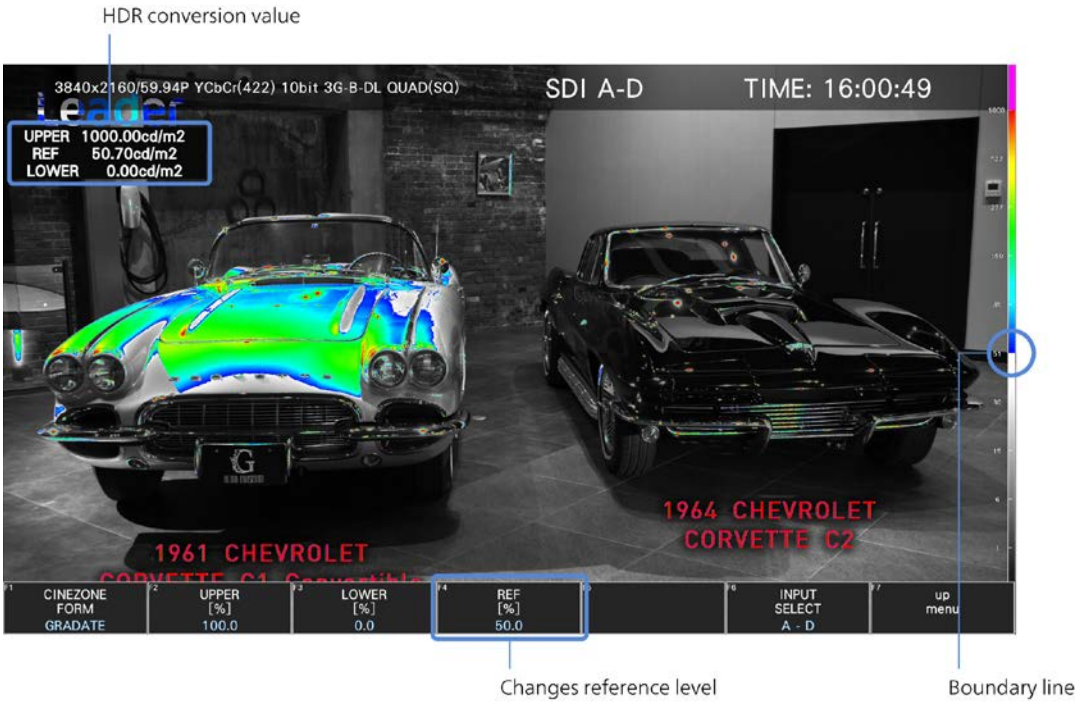


Figure | CINEZONE display

MAX FALL/CLL display

For CINELITE display, MAX FALL (Maximum Frame Average Light Level) and MAX CLL (Maximum Content Light Level) can be displayed. MAX FALL is the average maximum luminance per frame, and MAX CLL is the maximum value of the content's brightness, respectively.

To display MAX FALL/CLL, select ON by the following procedure.

> PIC ➡ F2 (CINELITE/HDR) ➡ F3 (MAX FALL/CLL) ➡ F1 (MAX FALL/CLL DISPLAY): OFF / ON

Next, set the measurement period by the following procedure. Select START to start measurement and STOP to end measurement.

> PIC ➡ F2 (CINELITE/HDR) ➡ F3 (MAX FALL/CLL) ➡ F2 (MEASURE): START / STOP

The measurement can be cleared by the following procedure. The measured value returns to 0% and F2 (MEASURE) changes to STOP.

> PIC ➡ F2 (CINELITE/HDR) ➡ F3 (MAX FALL/CLL) ➡ F3 (CLEAR)

Figure | MAX FALL/CLL display

06 Glossary

HDR-related terms

Term	Definition
EOTF	Acronym of Electro-Optical Transfer Function. Transfer function when converting an electric signal to brightness on the display side.
HDR	Acronym of High Dynamic Range. Dynamic range expanded compared with SDR, extends up to 10,000 cd/m^2.
HLG	Acronym of Hybrid Log Gamma. One of the two HDR systems. Proposed by NHK and BBC. Compatible with SDR, suitable for broadcasting.
ITU-R BT.2100	International standard for HDR.
OETF	Acronym of Opto-Electronic Transfer Function. Transfer function for converting brightness to electric signal on the camera side.
OOTF	Acronym of Opto-Optical Transfer Function. Transfer function when considering camera gamma and display gamma in total.
PQ	Acronym of Perceptual Quantization. One of the two HDR systems. Proposed by Dolby. Suitable for movies, packages, etc.
SDR	Acronym of Standard Dynamic Range. Conventional dynamic range, defined as extending up to 100 cd/m^2.
Camera gamma	Characteristic when converting brightness to electric signal on the camera side.
System gamma	Characteristic when considering camera gamma and display gamma in total.
Display gamma	Characteristic when converting an electric signal to brightness on the display side.

Leader Electronics Corporation

Address 2-6-33 Tsunashima-Higashi, Kohoku-ku, Yokohama-shi, Kanagawa Prefecture 223-8505, Japan
Phone +81-45-541-2123
Email sales@leader.co.jp
URL www.leader.co.jp/en
Published December 5, 2018 1st Edition