**HDR-TV Image Formats and Standardization Process at ITU-R**

Yuichi Kusakabe

NHK Super Hi-Vision (UHDTV) 4K/8K test satellite broadcasting was launched on August 1, 2016. Some of the programs in this test broadcasting are provided with high dynamic range (HDR) technology. By capturing images with a wide dynamic range (from bright to dark) and reproducing these images on displays with wide dynamic range, HDR technology can reproduce scenes with a significant brightness/darkness difference (for example, simultaneous reproduction of shade and sunlit areas) and specular highlights, which had been difficult to achieve in conventional television systems. Combined with high resolution and a wide color gamut, this results in a high sense of presence for the viewer. Hybrid Log-Gamma (HLG) and Perceptual Quantization (PQ) are two image formats for high dynamic range television (HDR-TV) specified in Recommendation ITU-R BT.2100. In Japan, the HLG format is incorporated in the UHDTV test broadcasting system as the HDR-TV. In this article, we describe the features and underlying concept of each of these two HDR-TV image formats and outline the standardization process in HDR-TV at ITU-R.

1. Introduction

We have been researching and developing “full-featured” 8K Super Hi-Vision, which is an ultrahigh-definition television (UHDTV) system featuring ultrahigh-definition images consisting of 7,680 × 4,320 pixels and 22.2 multichannel sound with a frame rate of 120 Hz, a wide color gamut, a high dynamic range (HDR), and a high dynamic range television (HDR-TV) specified in Recommendation ITU-R BT.2100. In Japan, the HLG format is incorporated in the UHDTV test broadcasting system as the HDR-TV. In this article, we describe the features and underlying concept of each of these two HDR-TV image formats and outline the standardization process in HDR-TV at ITU-R.

2. HDR-TV image formats

2.1 HDR-TV background

The luminance range of an actual scene that can be perceived by human eyes exceeds 10⁹, from the luminance of moonlight at night (about 10⁻³ cd/m²) to that of direct sunlight (about 10⁶ cd/m²), owing to the adjustable aperture of the human eyes. Without this characteristic, the simultaneous luminance range is said to be about 10⁵. In contrast, the luminance range of displays such as cathode ray tubes (CRTs) and liquid crystal displays (LCDs) used for high-definition television (HDTV) programs has so far ranged from a peak luminance of 10⁰ cd/m² to a black luminance of 0.1 cd/m², giving a dynamic range on the order of 10³. For this reason, it has been necessary, in video production, to compress the high-luminance portion of an actual scene in accordance with the characteristics of the display being used; this results in a loss of tone. However, recent progress in display technology, namely, local dimming using light-emitting diodes (LEDs) in LCD backlight and self-luminous devices using, for example, organic electroluminescence (EL), has made it possible to push the black luminance to under 0.01 cd/m² and the peak luminance to

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1. cd/m² is a unit indicating the amount of light per unit area.
2. A method of individually controlling the output of a backlight in each area in accordance with the luminance distribution of the displayed image.
above 1,000 cd/m². As a result, displays with a dynamic range greater than 100,000 to 1 have now become available. At the same time, the development of HDR cameras has been progressing as image sensors achieve higher levels of sensitivity.

Against this background came the development of HDR-TV image formats. The benefits of HDR-TV lie in its capability to capture a wide range of brightness/darkness levels closer to that of an actual scene and to reproduce that range on displays. This makes it possible to reproduce scenes with a large brightness/darkness difference and a tonal gradation of specular highlights, which have been difficult to reproduce in the past. To give an example, Figure 1 shows the rendering of a stadium scene with a large brightness/darkness difference between sunlit areas and shade by a standard dynamic range television (SDR-TV) and an HDR-TV. When the point of attention, such as a player or the ball, is situated in the shade, the camera iris (aperture) is adjusted to correctly obtain images of the player or the ball in the shade. In the case of SDR-TV, however, this results in blown-out highlights in the sunlit areas of the image such as the spectators’ seats and the sky. When using HDR-TV, however, both shade and sunlit areas of the image can be simultaneously reproduced because of its wide dynamic range. In this way, HDR-TV image formats enable the high-peak-luminance and high-dynamic-range performance of new displays to be put to full use.

### 2.2 HDR-TV image formats

HDR-TV image formats are based on two key concepts: scene-referred and display-referred. The scene-referred concept is shown in Fig. 2 and the display-referred concept in Fig. 3. The scene-referred system is based on the concept that video signals are specified by an opto-electronic transfer function (OETF) that converts the light of an actual scene captured on a camera into a video signal, the same as in the SDR-TV specification in the current HDTV. The display-referred system, on the other hand, is based on the concept that video signals are specified by an electro-optical transfer function (EOTF) that converts a video signal into display light. The Hybrid Log-Gamma (HLG) format corresponds to the former concept and the Perceptual Quantization (PQ) format to the latter.

In addition to the OETF and EOTF, there is also an opto-optical transfer function (OOTF) that indicates the relationship between the optical intensity of the actual scene on the image sensor and the optical intensity reproduced on the display. It represents compensation for difference look
due to brightness differences between the camera environment and the display environment and the adjustments to be made on the basis of the production intent. In the case of HDTV, the OOTF was not explicitly specified, but total characteristics calculated as the product of the OETF specified in Rec. ITU-R BT.709 and the EOTF specified in Rec. ITU-R BT.1886 can be approximated by a power function with a power of approximately 1.2. This corresponds to the OOTF of HDTV. For the scene-referred system, the OOTF is included in the display side and the EOTF is specified as the product of the inverse function of the OETF (inverse OETF) and OOTF (Fig. 2). For the display-referred system, the OOTF is included in the camera side and the EOTF is specified as the product of the OOTF and the inverse function of the EOTF (inverse EOTF) (Fig. 3). The formulas defining the OETF of the HLG format and the EOTF of the PQ format are listed in Table 1.

The HLG format is a joint development of NHK and the British Broadcasting Corporation (BBC). It is a relative luminance format for handling luminance values in a relative manner, the same as in HDTV, and it represents all the luminance values from the “peak” video signal value to the “black” video signal value regardless of the peak luminance value of the display. The OETF of the HLG format has the same function as the HDTV OETF (gamma correction function) up to a video signal level of \( E' = 0.5 \) (relative luminance \( E = 1/12 \)), along with highlight-compression characteristics in the form of a logarithmic function for video signal levels above 0.5. These characteristics enable HDR production while maintaining compatibility with SDR signals and SDR displays. The OETF of the HLG was specified in the Association of Radio Industries and Businesses (ARIB) Standard STD-B67 in 2015.

The PQ format handles display luminance values up to a maximum of 10,000 cd/m² as absolute values. It introduces a new transfer function considering efficient bit allocation on the basis of human visual characteristics that cover a wide luminance range. As an absolute luminance format, video signals have a unique correspondence with luminance values reproduced on the display, which means that the range of video signals that can be displayed depends on the peak luminance of the display. The EOTF of

<table>
<thead>
<tr>
<th>OETF of HLG format</th>
<th>EOTF of PQ format</th>
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<tbody>
<tr>
<td>( E' = \begin{cases} \frac{\sqrt{3}E}{a \cdot \ln(12E-b)+c} &amp; 1 \leq E \leq \frac{1}{12} \ \frac{1}{12} &lt; E \leq 1 \end{cases} )</td>
<td>( Y = \max \left[ \left( E'^{1/\gamma} - c_1 \right), 0 \right]^{1/\gamma} )</td>
</tr>
<tr>
<td>( E ): Scene linear light normalized to the range ([0:1])</td>
<td>( Y ): Display luminance ([0:1])</td>
</tr>
<tr>
<td>( E' ): Video level</td>
<td>( Y = 1 ) corresponds to 10,000 cd/m²</td>
</tr>
<tr>
<td>( a = 0.17883277 )</td>
<td>( m_1 = 2.610/16.384 )</td>
</tr>
<tr>
<td>( b = 1 - 4a )</td>
<td>( m_2 = 2.523/4.096 \times 128 )</td>
</tr>
<tr>
<td>( c = 0.5 - a \ln(4a) )</td>
<td>( c_1 = 3.424/4.096 )</td>
</tr>
<tr>
<td></td>
<td>( c_2 = 2.413/4.096 \times 32 )</td>
</tr>
<tr>
<td></td>
<td>( c_3 = 2.392/4.096 \times 32 )</td>
</tr>
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Table 1: Definitions of HLG OETF and PQ EOTF
this format was specified in ST 2084\(^{(12)}\) of the Society of Motion Picture and Television Engineers (SMPTE) in 2014 as a reference display standard for use in HDR production.

The features of these two formats are listed in Table 2. Additionally, to compare the transfer function of the two formats on the same set of axes, the graph in Fig. 4 shows plots of the OETF of the HLG format and the inverse EOTF of the PQ format. From the figure, we can see that the PQ format is highly nonlinear in comparison with the HLG format, allocates many video signals in dark areas, and performs much compression in bright areas. The video signals of the HLG and PQ formats can be mutually converted. A framework for the conversion is described in Report ITU-R BT.2390\(^{(13)}\).

NHK developed an 8K HDR LCD capable of displaying the HLG format in cooperation with Sharp Corporation. Its external view is shown in Fig. 5 and its specifications are listed in Table 3\(^{(14)}\). This LCD has been installed at NHK broadcast stations as a receiver for 4K/8K Super Hi-Vision test satellite broadcasting for the purpose of reception demonstrations.

### 3. HDR-TV standardization process at ITU-R

#### 3.1 Activities of Rec. ITU-R BT.2100

Discussions on HDR-TV at ITU-R were conducted by Working Party 6C (WP 6C: Programme production and quality assessment) under Study Group 6 (SG 6: Broadcasting service). These HDR-TV discussions go back to 2012 when standardization work on UHDTV image parameter values (now Rec. ITU-R BT.2020) had already progressed. In that year, the United States proposed a new transfer function for handling a high dynamic range. This proposal

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**Table 2: Comparison between HLG and PQ formats**

<table>
<thead>
<tr>
<th>Concept</th>
<th>HLG format</th>
<th>PQ format</th>
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<tbody>
<tr>
<td>-Handles relative luminance, as in the conventional concept</td>
<td>-Handles absolute luminance up to 10,000 cd/m(^2) on display</td>
<td></td>
</tr>
<tr>
<td>-Compatible transfer function with current TV</td>
<td>-New transfer function based on human visual characteristics</td>
<td></td>
</tr>
<tr>
<td>Video signal</td>
<td>-Relative representation between “black” and “peak” (Example: 10-bit code 64 represents “black” and 10-bit code 940 represents “peak”)</td>
<td>-A code value represents a unique absolute luminance (Example: 10-bit code 64 represents 0 cd/m(^2) and 10-bit code 940 represents 10,000 cd/m(^2))</td>
</tr>
<tr>
<td>Signal specification</td>
<td>OETF side (camera)</td>
<td>EOTF side (display)</td>
</tr>
<tr>
<td>Relationship with peak luminance of display</td>
<td>Displays reproduce the complete range from “black” to “peak” regardless of peak luminance</td>
<td>Displays reproduce actual range of luminance supported by displays</td>
</tr>
</tbody>
</table>

**Figure 4: HLG and PQ transfer functions**

**Figure 5: 8K HDR LCD**

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**Table 3: Specifications of 8K HDR LCD**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Screen size</td>
<td>85 inch</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>7,680×4,320</td>
</tr>
<tr>
<td>Frame frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Bit depth</td>
<td>12-bit equivalent</td>
</tr>
<tr>
<td>Maximum luminance</td>
<td>Greater than 1,000 cd/m(^2)</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>200,000 : 1 (measured value)</td>
</tr>
<tr>
<td>Coverage of color space (BT.2020 color)</td>
<td>77 %</td>
</tr>
</tbody>
</table>
claimed that video signals should represent absolute values of the luminance of an actual scene of up to 10,000 cd/m², but dissenting opinions that such a proposal could not be accepted in terms of its applicability to a television system prevailed. This proposal from the United States was later revised such that the video signals should represent absolute luminance values on displays instead of those of an actual scene. Subsequently, as experimental results were accumulated and demonstrations were held, studies began on a television system with such an extended dynamic range of images.

However, the PQ format proposed by the United States differed from the ideas underlying the current television system in which video signals representing relative luminance are specified on the camera side. For this reason as well as concerns regarding the applicability of this format to live production, NHK believed that an HDR format with high compatibility with the SDR format was needed. The BBC had similar beliefs and joined up with NHK to develop the HLG format and propose it to ITU-R. At the same time, the United States argued for the adoption of the PQ format specifying the EOTF, citing the need to specify a standard display for the purpose of mastering*3 in HDR production. Advocates of both sides held demonstrations, each stressing the superiority of either the HLG or PQ format.

Given the difficulty of integrating the two formats that differ in concepts and transfer functions into a single format, agreement was finally reached at a meeting held in July 2015 on achieving the goal of handling the two formats uniformly by specifying a common OOTF. However, achieving a common OOTF was not an easy task, so an agreement was reached at a meeting in January 2016 on a new recommendation specifying an OETF/EOTF/OOTF set for each of the two formats. Then, after running this recommendation through an adoption and approval procedure by ITU-R member states, Rec. ITU-R BT.2100 was established in July 2016. This result was achieved after about four years of discussions following the original proposal by the United States.

3.2 Image parameters of Rec. ITU-R BT.2100

Rec. ITU-R BT.2100, which specifies HDR-TV system parameters, adopts UHDTV Rec. ITU-R BT.2020 with regard to main image parameters; the frame frequency, three primary colors and reference white, pixel structure, and bit depths are the same as those of BT.2020.

The PQ and HLG formats each specify its own OETF, EOTF, and OOTF. In the PQ format, the EOTF is equivalent to that of the SMPTE ST2084 standard, whereas the OOTF scales the total characteristics obtained from the product of the OETF specified in Rec. ITU-R BT.709 and the EOTF specified in Rec. ITU-R BT.1886 for HDR use. In the HLG format, the OETF is equivalent to that of ARIB STD-B67 and the OOTF applies a power function with a power of 1.2 (system gamma) to the luminance component for a display peak luminance of 1,000 cd/m². The reason for applying the system gamma to the luminance component is to prevent the color components (saturation and hue) of the captured actual scene from changing at the display side. In addition, the system gamma value is adjusted according to the peak luminance of the display. The purpose of this adjustment is to reproduce the same look in terms of perception regardless of the display peak luminance when displaying video signals, and to this end, the formula used for calculating the system gamma value is based on experimental results10) 15).

In addition to 4K/8K for the number of pixels, Rec. ITU-R BT.2100 specifies 2K (progressive scan only), the same as for HDTV. For luminance and color-difference signals, it specifies a new signal format of constant intensity (ICTCP) in addition to the conventional Y’C’B’C’R signal formats16).

Next, in addition to the conventional narrow-range digital representation of video signals (in which the code value14 of 64 corresponds to black and 940 to the peak for a 10-bit representation), BT.2100 specifies a full-range representation (in which code values of 0 and 1,023 correspond to black and the peak, respectively, for a 10-bit representation). Finally, it specifies a reference viewing environment for critical viewing of HDR program material, which describes the peak and minimum luminance of the display as 1,000 cd/m² or greater and 0.005 cd/m² or less, respectively.

3.3 Future issues

The recommendation on HDR-TV image parameter values has been completed, but HDR-TV program production and broadcasting have only just begun. Much more experi-

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*3 The process of creating a content master.

*4 10 bits (binary) each with a value of 1 corresponds to a code value (decimal) of 1,023.
ence is needed to move forward and establish appropriate program production techniques. Moreover, while an even greater variety of image production is now possible with the expansion of the luminance range that can be reproduced, care must be taken so as not to make viewers uncomfortable as a result of the brightness shift between programs and broadcasting stations. It will also be necessary to use the massive amount of past SDR material effectively within HDR programs. In this regard, research on operation practices, for example, specifying a reference level for maintaining consistency in brightness between programs to ensure comfortable viewing and specifying methods for mapping SDR signals into HDR signals, has begun at ITU-R.

4. Conclusion

In this article, HDR-TV image formats and the standardization process at ITU-R have been described. HDR-TV technology expands the range of luminance that can be reproduced, enabling a more realistic image to be displayed and producing an immense improvement in quality. In moving forward, we anticipate the need to research the influence of HDR-TV, such as visual fatigue due to the expansion of the luminance range and consistency of brightness among programs, on the basis of human perceptual characteristics.

NHK began 4K/8K test satellite broadcasting on August 1, 2016 and the regular service is scheduled to launch in 2018 with an eye to full-scale deployment in 2020, the year of the Tokyo Olympic and Paralympic Games. At NHK, we are committed to further research on 8K UHDTV broadcasting to provide viewers with an even higher sense of presence by making full use of HDR characteristics.

References