EXTENDED IMAGE DYNAMIC RANGE SYSTEM FOR UHDTV BROADCASTING

Y. Kusakabe, Y. Ikeda, N. Shirai, K. Masaoka, T. Yamashita, Y. Nishida, T. Ikeda, and M. Sugawara

NHK (Japan Broadcasting Corporation), Japan

ABSTRACT

NHK has been developing 8K Super Hi-Vision (SHV), a member of ultra-high definition television (UHDTV). This can provide an increased sense of presence and realness to viewers. 8K SHV has system parameters of 7,680×4,320 pixels, 120-Hz frame frequency, and wide-colour gamut. With the addition of an extended image dynamic range feature, it is expected that 8K SHV can be further enhanced to become the true ultimate television system.

We first discuss requirements for extended image dynamic range television systems. Then, we propose the essential system parameter values based on the requirements. We introduce the specific parameter of video level corresponding to reference white to address highlights specifically. The proposed system parameters are designed with consideration of compatibility with existing workflows and infrastructure.

We conducted an experiment to examine the influence of peak display luminance level on picture production and confirmed that production practices would be substantially changed to fully exploit the display capabilities of the increased luminance levels. We also conducted experiments to determine the required conditions of black level and peak luminance level of displays in various viewing environments.

INTRODUCTION

The introduction of image systems with higher dynamic range and a wider colour gamut is a globally active topic. International standardization of these systems for broadcasting service is also underway by ITU-R, which has given these systems the name “extended image dynamic range television” (EIDRTV). Increased image dynamic range itself is not new; however, recent display technologies have made brighter television displays available without increasing the luminance of black using local-dimming technology. This has enabled high dynamic range (HDR) displays.

Ultra-high definition television (UHDTV) is the next-generation television system. This not only incorporates higher pixel numbers than high definition television (HDTV) but also higher frame frequencies and a wider colour gamut. NHK has been developing 8K Super Hi-Vision (SHV) with system parameters of 7,680×4,320 pixels, 120-Hz frame frequency, and a wide-colour gamut to provide viewers with an increased sense of presence and the sense of realness (1). Various pieces of SHV equipment such as cameras, displays, and interfaces have been developed (2,3). UHDTV test broadcasting including 8K SHV via satellite is planned to be launched in 2016 and a practical broadcasting in 2018. If UHDTV is complemented by an extended image dynamic range feature, it will be the true ultimate television system.

In this paper, we first discuss requirements for EIDRTV systems. Then, based on the requirements, we propose essential system parameter values for EIDRTV. We also present the results of experiments, which include the influence of HDR display on program production, the perceptible black levels on displays, and the preferred peak display luminance levels, to explore the implications of EIDRTV systems.

REQUIREMENTS FOR EIDRTV SYSTEMS

Before specifying the system parameters for EIDRTV systems, the requirements should be first identified. ITU-R Working Party 6C has identified the following four major requirements for EIDRTV systems:

R.1 The system should be capable of producing a “step-change” improvement in viewer experience which can substantially increase brightness and detail in highlights, increase brightness and detail for diffuse reflecting objects while providing good detail in dark areas.

R.2 The system should have, where appropriate, a degree of compatibility with existing workflows and broadcaster (legacy) infrastructure.

R.3 The system should be applicable to a range of domestic viewing environments, preferences and displays (including mobile and tablets), and be cost effective for both consumers and broadcasters.

R.4 The system should have a defined reference display and viewing environment in order that there is consistency of images that are produced.

Tone Reproduction Issues of Current Television

There are cases where the tone reproduction of the current television system is obviously not sufficient. Major examples would be the expression of specular objects, reduction of colour saturation with high brightness, and difficulties in the simultaneous presentation of differently illuminated parts in one scene (e.g., with/without sunlight). EIDRTV should be the system to resolve these issues to satisfy Requirement 1.

Relative representation of luminance

Current television signals represent the relative luminance of the images between “black” and “white”. As used in this context, “black” and “white” do not represent absolute luminance, rather relative luminance because “black” and “white” luminance varies depending on the viewing environment and display specification. This permits viewers to view the same television programmes with different and appropriate screen luminance under various circumstances including indoor/outdoor and day/night. This is a natural practice in broadcasting and should be retained in EIDRTV to satisfy Requirements 2 and 3.

Nonlinear transfer functions

Although they were originally introduced to compensate for the nonlinear transfer characteristics of cathode ray tube displays, nonlinear transfer functions in current television systems have three major roles.

The first role is to define the end-to-end transfer characteristics that significantly influence the picture appearance. Using a combination of current opt-electrical transfer function (OETF) defined in Rec. ITU-R BT.709 (4) and Rec. ITU-R BT.2020 (5), and electro-optical transfer function (EOTF) defined in Rec. ITU-R BT.1886 (6) provides an end-to-end gamma of approximately 1.2. This practice should be retained to satisfy Requirements 2 and 3.

The second role is to reduce the bit rate of the digital signals by changing the quantization steps such that the viewer minimally perceives the quantization error. This is related to Requirement 1. The required bit rate reduction depends on the dynamic range of displayed images, i.e., the range between the maximum and minimum luminance.

The third role is to ensure that the signal magnitude distribution is uniform against the perceptual luminance. The tone scale of the encoded signal with a power function is perceived as linear. This enables the encoded signals to be manipulated in a look-based manner. This practice has made the workflow of current television programme production simple and should be retained to satisfy Requirement 2.

Guideline for scene to video tone mapping

Current television programmes are exchanged among broadcasters without difficulty in terms of tone mapping, although there is no written practice for scene to video tone mapping in programme production. This is because all programme producers have similar understandings on how to map the scene from 0 to 100% video level, which is the "reference white level". This practice will not function for EIDRTV systems and a new practical guideline is required to satisfy Requirement 4. This new requirement will also be effective for ensuring consistency between the current standard dynamic range television (SDRTV) and EIDRTV.

Adjustment of display according to viewing environment

Users watch television broadcasts in different viewing environments (for example, dark, dim, or bright surroundings). It is the users' option (or, depending on the function each manufacturer provides) to adjust the white and black luminance level of the display according to each viewing environment.

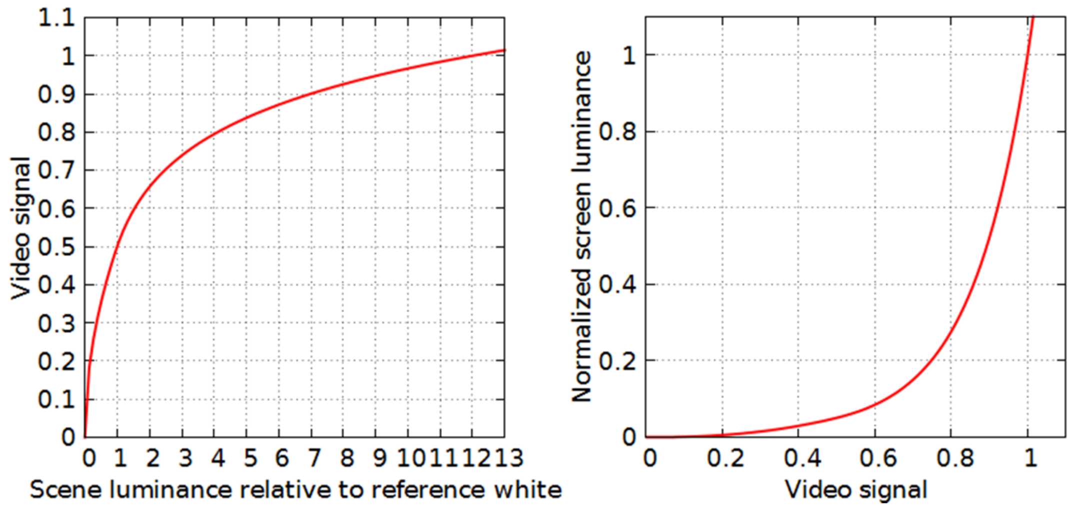
PROPOSED SYSTEM PARAMETER VALUES FOR EIDRTV

The proposed system parameter values essential to EIDRTV are presented in Table 1 and the corresponding graphs are provided in Figure 1. These values have been jointly examined by the British Broadcasting Corporation (BBC) and NHK. We anticipate that EIDRTV will be introduced as an extension of UHDTV including 4K and 8K systems. Therefore, the system parameter values for spatial and temporal characteristics and colorimetry are not provided; however, these will be the same as those specified in Rec. ITU-R BT.2020 for UHDTV. The proposed EIDRTV has the following features:

- The system can address the highlights over the reference white specifically because the highlights are assigned from 0.5 to 1.0 of the video level by assigning the video level corresponding to the reference white to 0.5.
- The reference OETF can address scene luminance 12 times higher than that of the reference white. This value corresponds to the current dynamic range of high-end image sensors for television cameras.
- The reference EOTF is based on the inverse function of OETF.

Video level corresponding to reference white, *r*	0.5
Reference OETF	$$E' = \begin{cases} r\sqrt{E} & 0 \le E \le 1 \\ a \cdot \ln(E-b) + c & 1 < E \end{cases}$$ where *E* is the voltage normalized by the reference white level and proportional to the implicit light intensity that would be detected with a reference camera colour channel R, G, B; *E'* is the resulting nonlinear signal. *a*= 0.17883277, *b*= 0.28466892, *c*= 0.55991073
Reference EOTF	Based on the inverse function of OETF associated with display adjustment functionality including system gamma, gain, and black lift. System gamma is 1.2 for reference viewing environment.
Reference viewing environment	Screen luminance level for reference white = 100 cd/m^2 in a dim surround.

Table 1 – Proposed system parameters for EIDRTV system



(a) Reference OETF (b) Reference EOTF

Figure 1 – Reference OETF and EOTF

- Both OETF and EOTF have a degree of backward compatibility to the current television system, which has the system parameters of BT.709/2020 for OETF and BT.1886 for EOTF, in the range below the reference white.
- The EOTF has display adjustment mechanisms to maintain a consistent “look” in different viewing environments.

IMPLICATIONS OF EXTENDED IMAGE DYNAMIC RANGE

We explored the implications of the EIDRTV system by conducting three experiments.

Influence of Peak Display Luminance Level on Picture Production

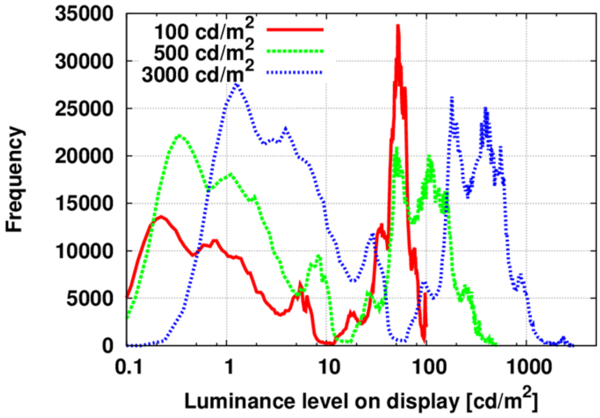
We conducted an experiment to confirm the influence of peak display luminance level on picture production by providing a display with higher peak luminance to a video engineer. Although programmes are produced using a master monitor with a peak luminance level of approximately 100 cd/m^2 in current TV program production, displays with peak luminance level of thousands of cd/m^2 have been available.

Table 2 presents the test specifications. We used a 46-inch LCD with a peak luminance level of 3,000 cd/m^2 and EOTF of gamma = 2.4. As test materials, we used images in the ".hdr" format that contains data proportional to the scene luminance. The two still images contained both dark and bright areas. We set three levels of peak luminance for the display: 100, 500, and 3,000 cd/m^2. The three adjustment parameters used for grading the pictures were gain, knee point, and knee gain. The gain adjustment is equivalent to the iris adjustment of a camera. The knee point and knee gain are equivalent to the knee compression of a camera. The video engineer was directed to adjust these parameters to grade a preferable "look" on the display with each peak luminance level.

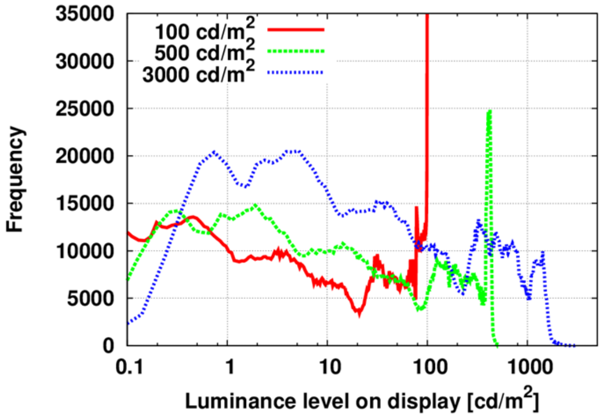
Display	DynaScan DS46LO4 (46-inch) Pixel count: 1,920x1,080 Peak luminance level: 3,000 cd/m^2 Gamma: 2.4
Peak display luminance levels	3 conditions (100, 500, and 3,000 cd/m^2)
Test materials	2 still images (.hdr format)   (a) Balloon (b) Market
Viewing environment	dim-bright (approx. 40 lx)
Viewing distance	3 H (H: picture height)

Table 2 – Test specifications for influence of peak display luminance level on picture production

The grading results of the test images are presented in Figure 2. These figures indicate that peak display luminance level substantially influences the grading. When the peak display luminance level was 100 cd/m^2, highlights were compressed and saturated as in conventional production. As the peak display luminance level was increased, compression and saturation were relaxed and highlights were more faithfully reproduced. At the peak luminance level of 3,000 cd/m^2, areas below and above the reference white were well balanced. As indicated in Figure 3, whereas highlights above the reference white were



(a) Balloon



(b) Market

Figure 2 – Results of picture luminance level distribution on the display with the peak display luminance levels of 100, 500, and 3000 cd/m^2

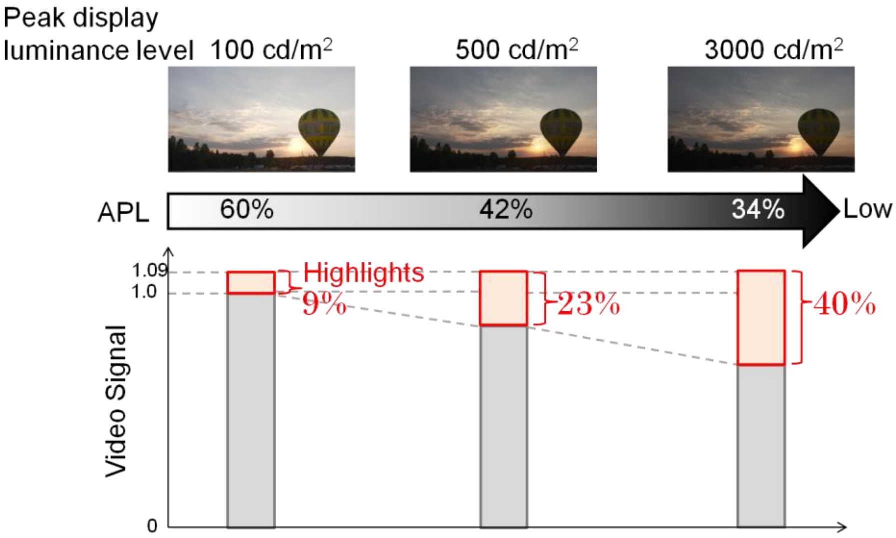


Figure 3 – APL and highlight allocation according to the peak display luminance level

allocated to 9% of the video level in the peak luminance level of 100 cd/m^2, highlights were allocated to 40% in the peak luminance level of 3,000 cd/m$^{2.}$

In this experiment, the video engineer graded the pictures based on his own production strategy cultivated by his extensive experience in production and attempted to maintain a consistent appearance below the reference white and reproduce highlights as much as possible, although this was his first experience using a brighter display for grading. Nevertheless, brighter pictures were produced on a brighter display. As discussed in the previous section, this result implies that it is essential to provide guidance or means in the specification of EIDRTV systems to ensure consistent tone reproduction.

Perceptible Black Levels on Displays

We conducted an experiment to estimate perceptible black levels for the EIDRTV system using different test signals. An EIDRTV display will have a higher peak luminance level than a conventional SDRTV display and this will inevitably influence the perceptible minimum black level owing to adaption and flare in the eyes of the human visual system.

The perceptible black level will also be influenced by the viewing environment and displayed content.

The test specifications are listed in Table 3. We used two displays, one with peak luminance level of 100 cd/m^2 and the other with 4,000 cd/m^2. Lighting conditions were controlled continuously by a special lighting system and set to five conditions, 0.01, 0.1, 1.0, 10, and 15 cd/m^2 on an 18% grey card that was set at the same position as the displays.

Four test signals, depicted in Figure 4, were used to adjust the perceptible black level. Signal A is the PLUGE pattern defined in Rec. ITU-R BT.814 (7) where the average picture level (APL) is approximately 1.0%; Signal B is similar to Signal A without the centre white patch (APL 0.0%). Signal C is a new type of PLUGE that has step patterns (APL 18.7%). Signal D includes a uniform black background and step patterns where the video level increases every two code values in a 10 bit level (APL 1.2%). Signal B was used to check the influence of the centre white patch in Signal A. Signal C and D are proposed by the BBC.

For Signals A, B, and C, each subject was requested to adjust the BRIGHTNESS such that he/she could not distinguish -2% black from 0% black; however, could distinguish +2% black from 0% black. Then the luminance level of 0% black was measured with a spectroradiometer (TOPCON SR-UL1). For Signal D, each subject was requested to indicate the darkest test block that was distinguishable from the background and the luminance level of that block was measured.

Displays	Sony BVM-E250 (25-inch) Peak luminance level: 100 cd/m^2 Gamma: 2.4 Sim2 HDR47ES4MB (47-inch) Peak luminance level : 4,000 cd/m^2 Gamma: 2.4
Test signals	4 signals (See Figure 4)
Viewing environment	5 conditions (0.01, 0.1, 1.0, 10, and 15 cd/m^2 on an 18% gray card)
Viewing Distance	1.5 H
Participants	7 participants (video researchers)

Table 3 – Test specifications for perceptible black levels

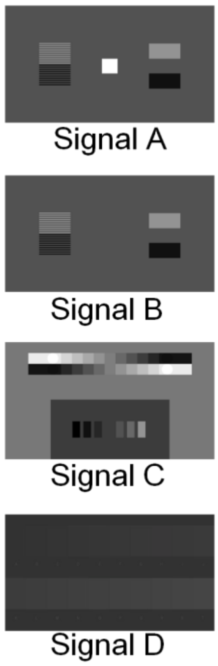
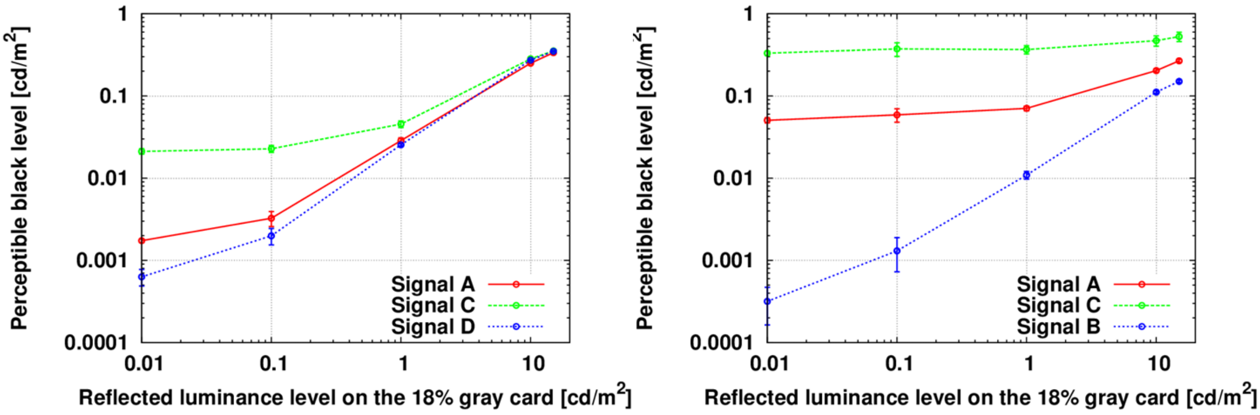


Figure 4 – Test signals

Figure 5 presents the results of perceptible black levels according to the viewing environment and test signals. These results indicate that perceptible black levels depend on the viewing environment, test patterns, and peak display luminance level. In a home environment (viewing environment is 1 to 10 cd/m^2), perceptible black level can be regarded as approximately 0.1 cd/m^2 irrespective of the test signals and peak luminance



(a) Peak luminance level of 100 cd/m^2 (b) Peak luminance level of 4000 cd/m^2

Figure 5 – Mean perceptible black levels in different viewing environment and test signals. The error bars indicate the standard deviation.

level of the display. In a production environment (viewing environment is 0.01 to 0.1 cd/m^2, dark to dim), perceptible black levels are considerably different depending on the test signals, especially on the display of high peak luminance level. Therefore, we must define an appropriate test signal to configure displays for EIDRTV. If we assume the same reference environment as HDTV production and the same reproduction below the reference white, Signal A with a modified level for the white patch could be suitable.

Preferred Peak Display Luminance Levels

We conducted an experiment to estimate the preferred peak display luminance levels when standard dynamic range (SDR) images are displayed. In current TV program production, programmes are produced using a master monitor with a peak luminance level of approximately 100 cd/m^2. However, programmes are usually displayed on brighter displays in a home environment. When EIDRTV programmes are serviced, some degree of harmonization will be required to display SDR and EIDRTV programmes on the same EIDRTV display in a home environment.

Table 4 lists the test specifications. We used four viewing environment conditions and ten SDR still images with different APLs. The participants were directed to identify their preference for the brightness of each picture using the categories “too bright” (+1 score), “appropriate” (0 score), and “too dark” (-1 score). A participant participated in tests of a certain peak luminance level with only four viewing environment conditions to avoid the contrast effect.

Figure 6 indicates that the preferred peak luminance level depends on the peak display luminance levels and viewing environment. According to the results, the preferred peak luminance level is approximately 500 cd/m^2 in a home environment, which corresponds to viewing environment of 1 to 10 cd/m^2 in this experiment. This result is consistent with the result by Daly *et al*. (8) indicating that 50% of people are satisfied with a diffuse white maximum of 600 cd/m^2.

By consolidating the experiment results and current practices, we can assume the display luminance levels for SDRTV and EIDRTV as presented in Table 5. The peak luminance level of EIDRTV requires further study considering other viewpoints such as visual fatigue and viewers’ preference. However, the proposed system offers the potential of peak luminance level of 20 times the reference white.

Display	DynaScan DS46LO4 (46-inch) Pixel count: 1,920x1,080 Peak luminance level: 3,000 cd/m^2 Gamma: 2.4
Peak display luminance levels	5 conditions (100, 250, 500, 1,000, and 2,500 cd/m^2)
Viewing environment	4 conditions (0.01, 0.1, 1.0, and 10 cd/m^2 on an 18% gray card)
Test materials	10 still images  APL: 49.1% 50.7% 47.7% 60.0% 46.8%  63.9% 34.1% 70.5% 26.8% 72.4%
Viewing Distance	3 H
Participants	120 participants (non-experts) in total 24 participants for each luminance conditions

Table 4 – Test specifications for preferred peak display luminance levels

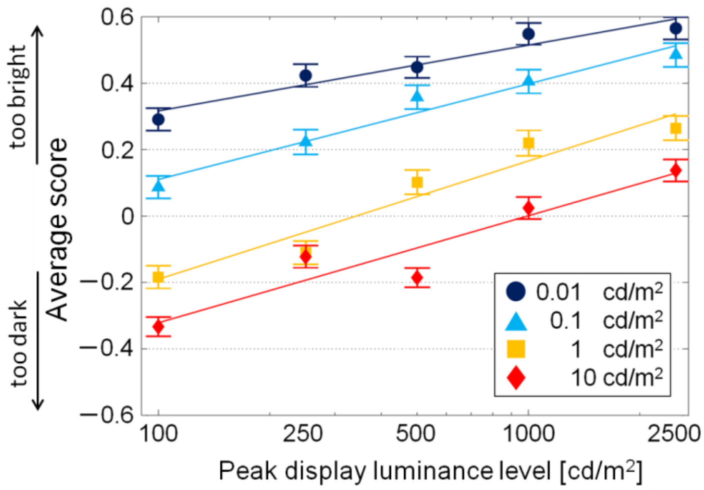


Figure 6 – Peak display luminance level and average scores

The error bars indicate the standard error.

Parameter	Home	Production
Black luminance level	0.1 cd/m^2	0.001 – 0.01 cd/m^2
Peak luminance level for SDRTV and luminance level of reference white for EIDRTV	500 cd/m^2	100 cd/m^2

Table 5 – Display luminance levels for SDRTV and EIDRTV

CONCLUSIONS

We proposed system parameters for an EIDRTV system based on the requirements. The parameters were derived from the concept of "relative" luminance approach. By introducing the parameter of video level corresponding to the reference white, the proposed EIDRTV system could specifically address the highlights over the reference white and assure consistent brightness of the pictures. The system also provides acceptable backward compatibility to existing television systems.

We explored the implications of the EIDRTV system by conducting a series of experiments. Interestingly, providing a brighter display to producers allowed them to grade differently to fully exploit the display capabilities. This implies that the simplest approach to introduce EIDRTV may be to introduce a brighter display into the production stage and change the production practice. Along these lines, it is essential to provide guidance such as the video level corresponding to the reference white in the specification of EIDRTV systems to ensure consistent tone reproduction. Nevertheless, the proposed sophisticated specifications for EIDRTV will facilitate the successful launch of EIDRTV broadcasting.

NHK plans to launch 8K SHV broadcasting with the extended image dynamic range. We expect that the extended image dynamic range 8K SHV will provide viewers with a highly enhanced visual experience.

REFERENCES

1. Nishida, Y., Masaoka, K., Sugawara, M., Ohmura, M., Emoto, M. and Nakasu, E., 2011. Super Hi-Vision System Offering Enhanced Sense of Presence and New Visual Experience. The Best of IET and IBC. Vol. 3, 2011. pp. 5 to 10.

2. Yamashita, T., Funatsu, R., Yanagi, T., Mitani, K., Nojiri, Y. and Yoshida, T., 2011. A Camera System Using Three 33-Megapixel CMOS Image Sensors for UHDTV2. SMPTE Motion Imaging Journal. November/December, 2011. pp. 24 to 30.

3. Soeno, T., Yasue, T., Kitamura, K., Masaoka, K., Kusakabe, Y., Shimamoto, H., Yamashita, T., Nishida, Y., and Sugawara, M., 2014. Development of 8K-UHDTV System with Wide-Colour Gamut and 120-Hz Frame Frequency. The Best of IET and IBC. Vol. 6, 2014. pp. 51 to 58.

4. Recommendation ITU-R BT.709-5, 2002. Parameter values for the HDTV standards for production and international programme exchange.

5. Recommendation ITU-R BT.2020-1, 2014. Parameter values for ultra-high definition television systems for production and international programme exchange.

6. Recommendation ITU-R BT.1886, 2011. Reference electro-optical transfer function for flat panel displays used in HDTV studio production.

7. Recommendation ITU-R BT.814-2, 2007. Specifications and alignment procedures for setting of brightness and contrast of displays.

8. Daly, S., Kunkel, T., and Farrell, S., 2013. Using Image Dimension Dissection to Study Viewer Preference of Luminance Range in Displayed Imagery. Proc. of IDW. 2013. pp. 1126 to 1129.