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Evaluation of High Dynamic Range TVs using Actual HDR Content

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Abstract

High Dynamic Range (HDR) content standards such as HDR10, Dolby Vision, HLG (Hybrid Log Gamma) have been presented over a last couple of years, and these standards commonly have both wider dynamic range and color gamut than that of the legacy content. However, it is practically hard to fully satisfy the HDR content standards with the current TV technology. Although various standards for display metrology regarding HDR content standards have been released to evaluate the performance of HDR TVs, it has been controversial whether the performance obtained from measurements using artificial test patterns is well consistent with the actual performance of HDR TVs from which viewers are expecting. For this reason, we examined how the performance of HDR TVs is varied in case measurements are made using actual HDR contents instead of artificial test patterns in terms of peak luminance, black level, and Electro-Optical Transfer Function (EOTF) accuracy. Our investigation was carried out using two different types of TV, an Organic Light Emitting Diode (OLED) and a Liquid Crystal Display (LCD). As a result, while the measurements of the OLED TV were quite coincided with the measurements made from artificial test patterns, those of the LCD TV were not.

Introduction

Recently, the International Telecommunication Union (ITU) announced a new recommendation that aims for the production and international exchange of high dynamic range (HDR) television program [1]. This is remarkable because the advent of this recommendation implies HDR broadcasting for the public is just around the corner. The concept of HDR which is dealt with in the recommendation is not an unprecedented technology, however, it can be regarded as a set of very recently established technologies. Because the HDR technology stated in the new recommendation includes evolved specifications different from the former ones such as the electro-optical transfer function (EOTF), opto-electric transfer function (OETF), bit-depth, color gamut and so forth [2-5], as described in Table 1.

In terms of the technical specification, it is noteworthy that the new HDR standard allows a brighter luminance for reference monitor, 1000 cd/m^2 while the legacy imaging standard, SDR, restricts the maximum brightness of a reference monitor to 100 cd/m^2. Theoretically, HDR image format was designed to be capable of corresponding to much higher luminance, for example, 10000 cd/m^2 [4], however, it was determined owing to a few practical reasons that 10000 cd/m^2 for consumer displays is unrealistic now. Another interesting point for the new image format is that there are two EOTFs and OETFs, perceptual quantizer (PQ) [4] and hybrid log gamma (HLG) [5]. The reason why two EOTFs are important for the HDR image format is that they are intentionally designed to well reproduce a high dynamic range with brighter displays. In addition, since the PQ EOTF was deliberately built to yield an absolute luminance corresponding to an input code value unlike the legacy EOTF defined in ITU-R BT.1886, the PQ EOTF is much beneficial to keep the creative intent of content across different display devices. The increase of bit-depth for an image should not be overlooked in terms of HDR technology because it is essential to prevent or to minimize contour or banding artefacts that might be arisen by the increase of dynamic range. More importantly, it is hard to think that the three specifications of luminance, EOTF / OETF, and bit-depth, are independent features because they greatly affect each other.

Table 1. Comparison of Specifications between SDR and two HDR Standards for broadcasting [2-5].

Item	Specifications		
	SDR	HDR	
		HDR10	HLG
EOTF / OETF	BT.1886 [2] BT.709 [3]	SMPTE ST.2084 [4] (Perceptual Quantizer)	Hybrid Log Gamma ARIB STD-B67 [5]
Color gamut	BT.709	ITU-R BT.2020	
Content bit-depth	8-bit	10-bit	
Metadata	None	Required (Static)	None
Peak luminance (reference monitor)	100 cd/m^2	1000 cd/m^2	
Minimum luminance (reference monitor)	0.1 cd/m^2	0.005 or less cd/m^2	

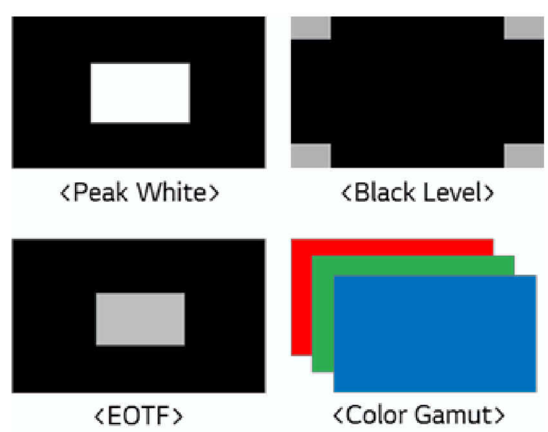

Figure 1. Artificial test patterns generally used as HDR metrology standards.

Such these stark changes of imaging standard have been motivated the work of new display metrologies. In order to develop a new metrology for HDR technology, indeed, many both commercial and non-commercial committees, such as Ultra High Definition Alliance (UHDA), International Committee for Display Metrology (ICDM), International Electrotechnical Commission (IEC), and so forth have established various workgroups related to the new imaging standards [6, 7]. However, many HDR standards to evaluate the performance of HDR display have generally suggested artificial test patterns to date which are unlikely to appear when we are watching on TV in daily life, as shown in Figure 3. Also, it is somewhat questionable whether a TV device marked a high score from the measurements with those artificial test patterns could guarantee a good performance with real HDR content or not. From this view, we examined how the performance of HDR TVs is varied in case measurements are made using actual HDR content instead of artificial test patterns in terms of peak luminance, black level, and EOTF accuracy. Our investigation was carried out using two different types of the TV, an Organic Light Emitting Diode (OLED) and a Liquid Crystal Display (LCD) TV.

Actual HDR Test Video

As mentioned above, there are various types of HDR content standards, and the most widely used HDR content standard is the HDR10 format which is currently available to watch through Ultra HD Blu-ray or streaming services such as Netflix and Amazon. For this reason, the content type which this paper deals with was confined to the HDR10 format. Total 34 HDR video clips encoded with the HDR10 format were used for our measurement which consist of several HDR movies from Hollywood studios, HDR test videos from Stuttgart Media University [8], Imagica [9]. In order to prevent from spending excessive time to measure display devices, we decided to sample the video clips. Since it is necessary to keep sampled video clips well represent the original content, a careful approach was required. For this reason, the luminance features of the actual HDR test videos were analyzed to utilize when sampling the video clips. In fact, the average picture level (APL) or the average luminance level (ALL) have been mainly employed to determine the characteristic of contents or test patterns in terms of brightness or luminance level, however, there have been concerns with respect to the ambiguity of the definition of these terminologies as well [10, 11]. In this paper, the Maximum Frame-Average Light Level (MaxFALL) devised to determine the average luminance level of HDR content was used instead of either APL or ALL. In addition, in order to investigate how high peak highlights are included in the HDR video clips, the maximum Content Light Level (MaxCLL) was also calculated. Although most broadcasting contents do not have a letterbox on it, many movie contents including Blu-ray titles tend to have a letterbox. In this sense, it was also examined how the luminance features of HDR content are varied with the existence of letterbox. As a result, two test clips (with and without letterbox), 15 minutes length, were extracted from the original 34 video clips and end up with retaining the similar distribution of MaxFALL, as shown in Figure 2. The average MaxFALL and MaxCLL of the test clips are described in Table 2.

It is noteworthy that Figure 2 plainly illustrates the average luminance levels of the frames from the HDR video clips are skewed towards lower ranges, that is, about 90% of the frames of with and without letterbox is distributed less than 100 cd/m^2 and 300 cd/m^2, respectively. Also, Table 2 represents that the overall average of MaxFALL regardless of the existence of letterbox are somewhat low, 32.47 cd/m^2 and 143.37 cd/m^2, respectively. On the other hand, the overall average of MaxCLL, which represents the average brightness of peak highlights in content, exceeds 1,000 cd/m^2 either with or without letterbox. These tendencies are clear evidence for the HDR video literally means that the video itself has a wider dynamic range but not brighter images [11]. Besides, these are well consistent with the guideline of the HDR content production of the Blu-ray Disc Association (BDA) that the MaxFALL should not exceed 400 cd/m^2, while only small-sized peak is allowed to exceed 1000 cd/m^2 [12]. Therefore, it is plausible that we used the test video clips to measure and evaluate the performance of HDR TVs.

Table 2. Overall average of MaxFALL and MaxCLL of the Test video clips.

	Test video clips	
	with Letterbox	w/o Letterbox
Average MaxFALL	32.47 cd/m^2	143.37 cd/m^2
Average MaxCLL	1688.07 cd/m^2	4717.92 cd/m^2

Measurement of OLED and LCD TV

The UHD Alliance, which consists of various companies from diverse industries, such as TV manufacturer, content provider, and instrumental maker, has nearly exclusively published a specification and measurement methods for HDR TVs so far. The commercial committee to issue the certification on HDR TVs propose plural test patterns and items, for example, peak white, black level, EOTF, color gamut, and so on [7]. Considering the pros and cons of two display technologies, OLED and LCD, criteria for evaluation between them are somewhat different, as briefly described in Table 3.

The table implies that while OLED TV is beneficial to achieve the deeper black level, LCD TV has an advantage to represent the brighter peak white. In order to figure out how the performance of two different technologies varies with actual HDR contents, we performed a series of measurements using the test clip that we made. Total three attributes were selected. Both peak and black luminance are prominently important attributes in terms of HDR TV because the difference between two attributes could be intuitively utilized to represent the dynamic range of itself. In addition, EOTF accuracy is measured to see how two technologies reproduce the PQ EOTF accurately in real HDR content.

Table 3. Comparison of UHDA device specification between OLED and LCD. Black luminance is measured with two different patterns, 4-corner and image-signal black.

	OLED	LCD
Peak Luminance (cd/m^2)	540	1000
Black Luminance (cd/m^2)	0.0005	0.1 or 0.05
Color Gamut Coverage	At least DCI.P3 90%	
Bit-depth	At least 10 bits	

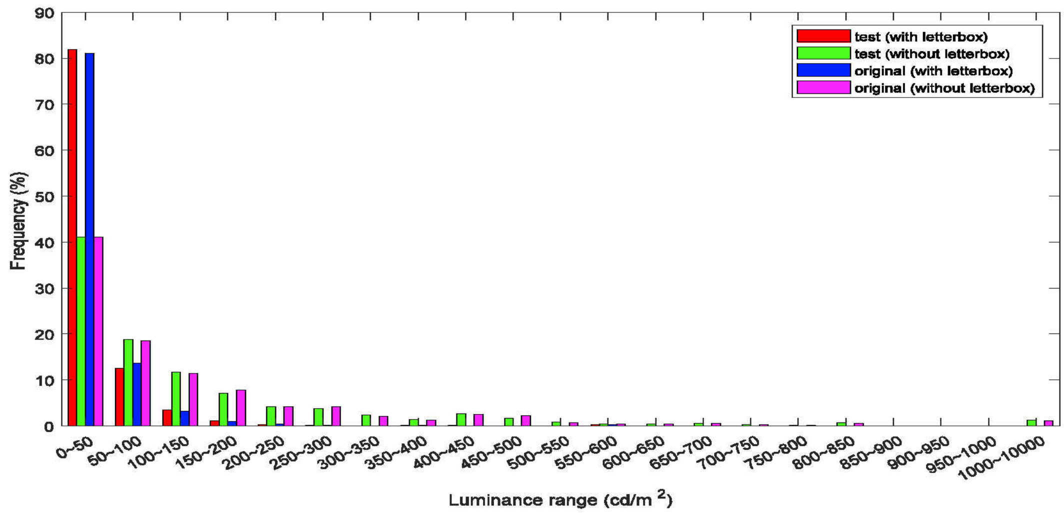

Figure 2. MaxFALL histogram of the original clips and test clips. Test clip with letterbox (red), test clip without letterbox (green), original clip with letterbox (blue), and original clip without letterbox (magenta).

Measurement Setup

We used 65" OLED TV and 65" VA LCD TV, which were released in 2017 and both two TVs were certified the premium UHD/HDR TVs by the UHD Alliance. To begin with, the curve of the peak luminance of two TVs were measured on the standard HDR mode (cinema mode) defined in the UHD Alliance standard using the white patch on the black background to concisely figure out the characteristic of them. Figure 3 where the x axis indicates the area of white patch in percentage to the size of the screen and y axis means the luminance corresponding to input patches well depicts how the characteristic of two TVs is different. Notably, the LCD TV emanates over the highest peak luminance, 1200 cd/m^2, near at 10% APL, however, its peak luminance rapidly decreases as the patch size reduces. On the other hand, the OLED TV represents over 600 cd/m^2 as its peak luminance between 0.01% and 10% APL. Thus, it can be said that the LCD TV can achieve higher peak luminance over the OLED TV in overall when measuring the artificial test pattern, white on the black.

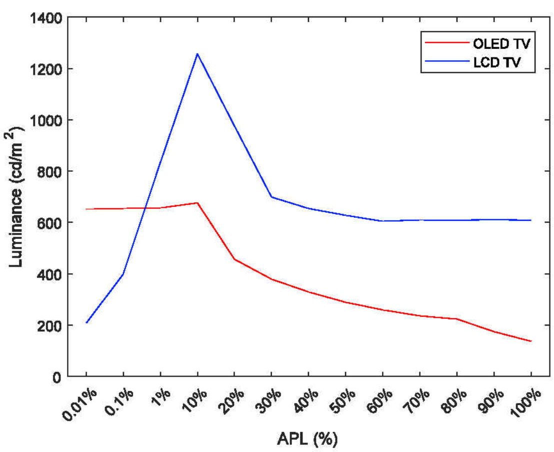

Figure 3. Plot of peak luminance curve of OLED and LCD TV.

Then, a series of measurements were made to evaluate the performance of two TVs in terms of peak luminance, black luminance, and EOTF accuracy using actual HDR test clips. Taking a broadcasting content into account, the test clip without letterbox was particularly selected for our measurements. However, since it is not only elusive to pinpoint the points to measure at every single frame but also practically impossible to measure different points at all frames, a patch was placed at the center of each frame. The patch size was determined as 0.2% size (172 by 97 pixels over 3840 by 2160 pixels) for two reasons. Firstly, the decision was plausibly made based on the work of our previous study revealed that the real size of 90% of peak highlights in real content is less than 0.2% [11]. Figure 4 is a good example to show how peak highlights (red circle), which are partially extracted from peak highlights exceeding 500 cd/m^2, in actual HDR content is small, and the center box (white rectangle) shows size of 0.2%. Secondly, in fact, as the patch size gets bigger, the average luminance level of the content can be skewed, thereby the output peak luminance of TV might be dramatically varied as shown in Figure 3. Therefore, whatever patch color is, for example, white or black, the smaller size of patch could less affect not only the average luminance of content but also the behavior of TV. From this premise, the patches for peak and black luminance were determined to have the code value 1023 at 10-bits and 0 at 10-bits, respectively. In terms of EOTF accuracy, the code value 512 at 10-bits was selected for the patch because its corresponding output luminance is 94 cd/m^2 according to the standard of the PQ EOTF that is somewhat closer to the average MaxFALL of the test video clip.

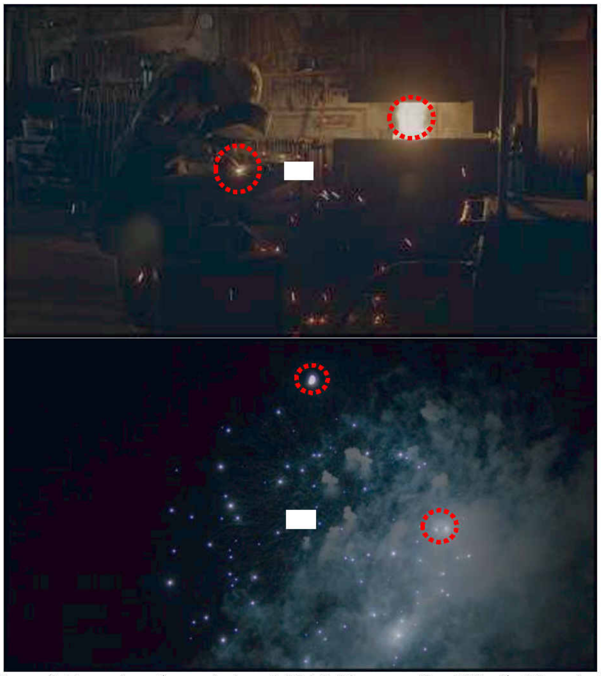

Figure 4. Examples of sampled peak highlights exceeding 500cd/m2 in actual HDR content [8].

In order to automatically make the measurements, a software where presents the image sequences for the test video clip and communicates with instruments to gather measurements was developed using C#. Because the measurement duration for each image sequence depends on what patch is given, for example, measuring black takes much longer time than white, the measurement for each attribute was taken at least an hour. The measurement for peak luminance and EOTF accuracy was made using CA-310 produced by Konica Minolta. However, due to its limit of black level in terms of accuracy, Konica Minolta CS-2000A was utilized to measure black luminance. Since our software was used for the measurement, two TVs were driven by a PC and HD Fury Integral. The latter was employed to activate HDR mode for each TV by transmitting HDR metadata manually. We confirmed that the behavior of the TVs driven by a PC and HD Fury Integral is identical to that driven by USB input and UHD Blu-ray player. The schematic concept of our measurement is illustrated in Figure 5 and our measuring condition is noted in Table 4.

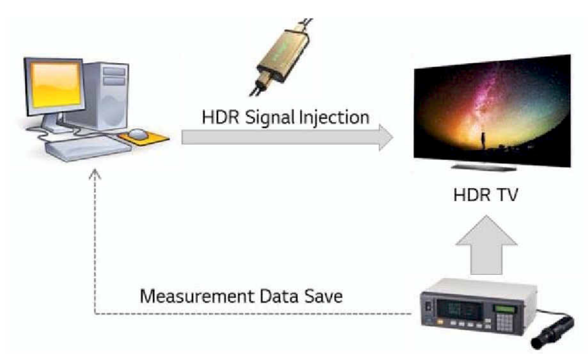

Figure 5. Schematic concept of our measurement.

Table 4 Measurement Setup.

	Conditions
Test Sample	High-End OLED, VA LCD TV
Measurement Item	Peak White (1023), Black Level (0), EOTF Accuracy (512)
TV Mode	HDR Cinema mode
Patch size	0.2%
Measuring Device	Peak White, EOTF Accuracy: CA-310 Black Level: CS-2000A
Test Image	Actual HDR test video (23260 Frames) (w/o letter-box)

Measurement Result

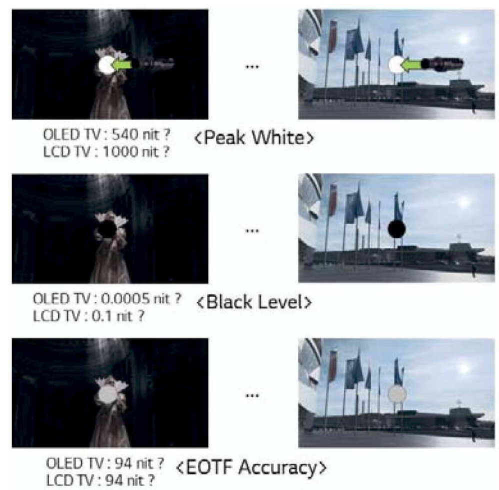

Figure 6. An example of image sequence for our measurements

In order to evaluate the performance of OLED and LCD TV on actual HDR content, a series of measurement was made based on the measurement setup described in the previous section. The patches for measurements with different gray levels were inserted in every single frame in Figure 6. A white patch with code value 1023 at 10-bits and 0.2% of size for measuring the peak white were placed in all frames to obtain the highest luminance. The peak measurements were obtained using CA-310.

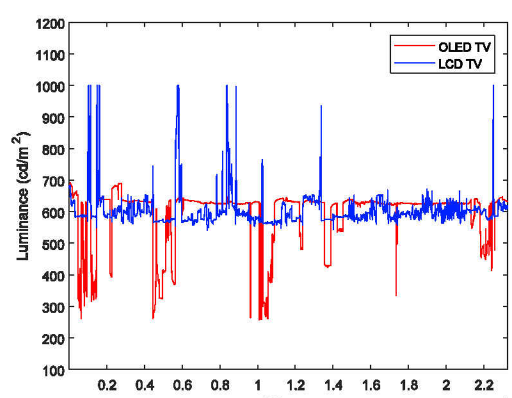

Figure 7. Measurements of peak luminance for OLED (red) and LCD (blue) TV.

As a result, our measurements indicate that the peak luminance values of OLED and LCD TV on actual HDR content are, on average, 596 cd/m^2 and 604 cd/m^2, respectively, as shown in Figure 7. Interestingly, although the LCD TV has the more higher range of peak luminance, from about 540 cd/m^2 to 1300 cd/m^2 than that of the OLED TV, from about 257 cd/m^2 to 692 cd/m^2, the average peak luminance values of the two TVs in the actual HDR content are nearly equivalent. This is remarkable because this result indicates that the average peak luminance of the OLED TV in the actual HDR content, on average, exceeds the UHDA specification for peak luminance, 540 cd/m^2, while that of the LCD TV in the same content does not fairly much reach to its UHDA specification, 1000 cd/m^2. More specifically, the OLED TV represents the higher peak luminance than its UHDA criterion in 84% of scenes in the actual HDR content, however, the LCD TV only emanates over 1000 cd/m^2 in 0.5% scenes in the same content. Another notable point from the measurements is that the peak luminance of OLED TV certainly decreases in bright scenes having relatively higher MaxFALL values, however, its peak tends to be consistent when displaying normal scenes. We found that these tendencies are attributed to the characteristics of both HDR content and OLED TV. Firstly, as depicted in Figure 3, the OLED TV can achieve its peak consistently for APLs less than 10%. Secondly, as represented in Table 2 and Figure 2, even though actual HDR content usually represents a higher dynamic range, it does not mean the content is brighter in overall. Thus, even if an HDR scene includes a very high peak region, the OLED can represent its highest peak luminance if the average brightness of the scene is not too high. On the other hand, it is presumably thought that the measured peak luminance of the LCD TV was determined by its driving method and the characteristic of peak luminance curve which is represented in Figure 3. Since LCD TVs usually achieve their peak luminance using local dimming technology, their peak luminance might not be consistent with their peak luminance curve, if the TVs do not have enough local dimming blocks which allow to control backlight individually. Therefore, it could be thought that LCD TVs can achieve a better performance in actual HDR content in terms of peak luminance, if the TVs have much more local dimming blocks.

Since we anticipated that the CA-310 is not good enough to measure a very low black level of the OLED TV, the black level measurements were made using CS-2000A. In order to minimize external factors such as ambient illumination, a mask was attached on the screens, leaving each center point of the TVs unblocked. Besides, measuring a black level generally requires a long duration per each measurement, more and less 1 minute, so it was expected to take about 400 hours to measure black levels for all 23260 frames in the test content. For this reason, we just made the measurements at about every 1 minute so that we could collect 100 black levels for each TV. Because the black level of TVs should keep lower as much as possible whatever images are displayed, our decision can make sense.

Figure 8 shows each measured black levels of the two TVs. The black luminance was determined in consideration of characteristics of each OLED and LCD. (OLED : 0.0005 cd/m^2, LCD : 0.01 cd/m^2)

The measured black levels of the OLED TV are ranging between about 0.0001 to 0.0009 cd/m^2, while those of the LCD are ranging between about 0.0005 to 0.17 cd/m^2. The average luminance values for the two TVs are 0.00045 cd/m^2 and 0.081 cd/m^2, respectively. Both OLED and LCD TV are fluctuated slightly, and OLEDs are also affected by internal reflection depending on adjacent pixels.

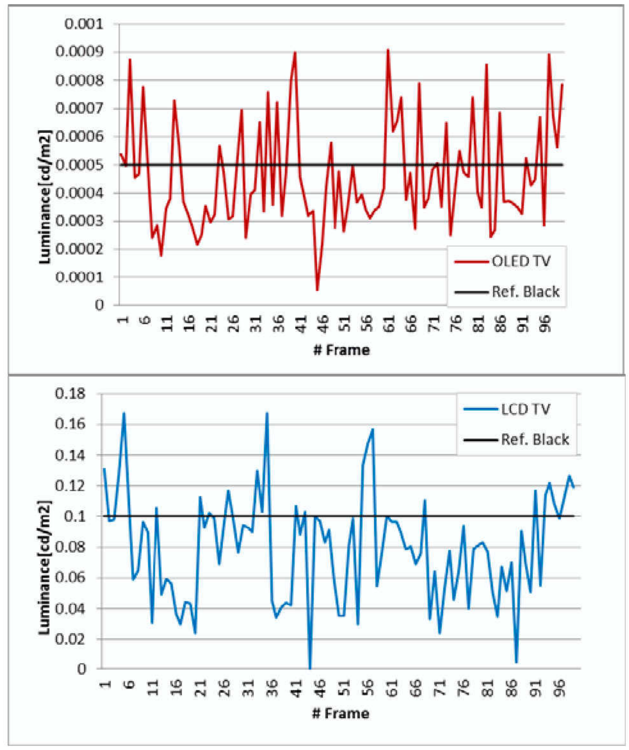

Figure 8. Measurements of black luminance for OLED (top) and LCD TV (bottom).

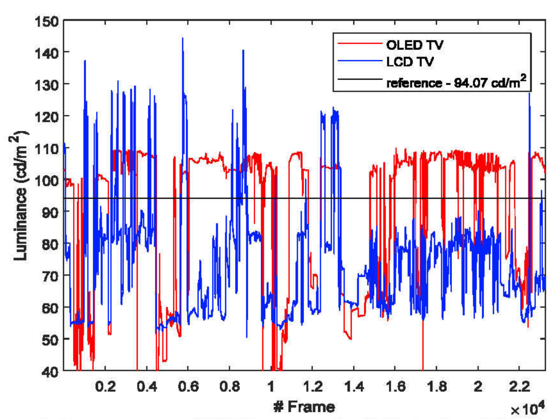

Figure 9. Measurements of EOTF accuracy for OLED (red) an LCD (blue) TV.

Standard of SMPTE ST.2084 defines an electro-optical transfer function (EOTF) with a high luminance range capability of 0 to 10,000 cd/m^2, and this EOTF is referenced to absolute luminance. The output luminance value for the input value is fixed. For 512 code value, the output luminance should be 94 cd/m^2. Average luminance of OLED and LCD TV is 91.86 cd/m^2, 73.2 cd/m^2. Although luminance value of OLED TV is closer to reference value, both OLED and LCD TV fluctuate in the Figure 9.

If tolerance of ±10% is allowed from reference value, OLED TV is 22% and LCD TV is 7%, OLED TV is slightly higher.

Conclusion

Although many HDR standards to evaluate the performance of HDR display have been developed, suggesting artificial test patterns to date which are unlikely to appear when we are watching on TV in daily life. For this reason, we presented an approach to measure the performance of HDR display using actual HDR content. Specifically, we focused on seeing how the performances of two representative TV technologies, OLED and LCD, are represented in actual HDR content. Three attributes may affect the image quality of HDR TV are selected, peak luminance, black level, and EOTF accuracy.

Firstly, 34 kinds of HDR contents were combined and investigated in terms of luminance such as MaxFALL, MaxCLL, AvgY, MaxY. The results show that the average content light levels, MaxFALL and AvgY are, 143.37 and 106.46 cd/m^2 respectively. In addition, MaxCLL and MaxY are, 4717.92 and 3637.9 cd/m^2. It means that although there are over 4000 cd/m^2 bright values in HDR content, most are very few. Therefore, in HDR TV, it is important to simultaneously represent the small area of the peak and surrounding dark area.

Secondly, Luminance of actual test HDR video in OLED, LCD TV was measured in terms of peak white, black level and EOTF accuracy. For the measurement, a 0.2% patch was inserted into the actual test HDR video and the luminance was measured in all frames. As a result, average luminance of OLED and LCD TV is about 600 cd/m^2, and comparing UHDA specification, the result of OLED TV in actual HDR content is similar, but LCD TV is lower. In order to maintain the peak luminance even in a actual HDR video of LCD TV, there is a method of improving the backlight structure and increasing the number of dimming blocks, but a side effect such as an increased power consumption can occur. The black level of OLED and LCD TV were average 0.00045 cd/m^2, 0.081 cd/m^2, respectively, satisfying the UHDA specification. In EOTF accuracy, Theoretically even if the peak luminance of the display is different, the EOTF curve shape should be maintained, so that the same luminance value should appear, but the EOTF curve shape actually seems to be changed. Therefore, it seems that the influence of the algorithm in the TV is larger than the display.

The results of the artificial test pattern for evaluating the HDR TV are different from actual HDR content, and it can be seen that OLED TV reflects closer to the artificial test pattern measurement results in the actual HDR content as well. We think that the test pattern for measuring the display will need to develop a pattern that replaces the actual viewing environment.

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