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TECHNICAL REPORT

colour inside

Power consumption of high dynamic range television sets

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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POWER CONSUMPTION OF HIGH DYNAMIC RANGE TELEVISION SETS

FOREWORD

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IEC TR 63274, which is a Technical Report, has been prepared by Technical Area 19: Environmental and energy aspects for multimedia systems and equipment, of IEC technical committee 100: Audio, video and multimedia systems and equipment.

The text of this Technical Report is based on the following documents:

DTR	Report on voting
100/3348/DTR	100/3397/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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INTRODUCTION

High dynamic range (HDR) video is emerging as a new technology that affects the entire video ecosystem from production and processing, through to distribution and presentation. HDR television sets potentially have higher peak luminance level capabilities, and HDR video signals can represent pictures with much higher luminance levels than was the case in traditional analogue and digital video systems.

Current television set power consumption measurement methods, including those standardized in the IEC 62087 series (see [1][1], [2]and [3]), consider only televisions that accept a traditional, standard dynamic range (SDR) signal. It is likely that an HDR-capable television's power consumption will differ when presented with an HDR signal versus an SDR signal.

IEC TC100 TA19 has identified a standardization opportunity related to the method of measuring the power consumption of HDR television sets, including the development of a related HDR test signal.

This document assesses the current HDR technology for the parameters relevant for TV power consumption and sets the groundwork for the subsequent development of a measurement standard for the power consumption of HDR TV sets.

[1] Numbers in square brackets refer to the Bibliography.

POWER CONSUMPTION OF HIGH DYNAMIC RANGE TELEVISION SETS

1 Scope

This document introduces high dynamic range video technology, describes current television set power consumption measurement methods, discusses the HDR TV market, analyses HDR TV power measurement challenges, and considers a path forward for HDR TV power measurement standards development.

2 Normative reference

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1 Terms and definitions

3.1.1
electro-optical transfer function
EOTF
mathematical function for transferring an electrical signal into a desired optical signal

EXAMPLE EOTFs are typically non-linear and monotonic and aim to incorporate behaviour of the human visual system, e.g. on a display device. Some are absolute, addressing luminance values directly, while others are of relative nature.

3.1.2
high dynamic range video
HDR video
capability of components in a video pipeline to capture, process, transport or display luminance levels and tone gradations that exceed capabilities of conventional SDR imaging pipelines components

Note 1 to entry: An HDR video signal typically uses a greater bit depth, luminance and colour volume than standard dynamic range (SDR) video. It also typically utilizes different tone curves such as perceptual quantizer (PQ) as specified in SMPTE ST 2084 [4] or hybrid log gamma (HLG) specified in ITU-R BT.2100 [5] instead of gamma, as used with SDR. When the HDR video signal is rendered on an HDR display, it is possible to see greater luminance ranges and wider colour gamuts

Note 2 to entry: HDR video can provide an enhanced viewer experience and can more accurately reproduce scenes that include, within the same image, dark areas and bright highlights, such as emissive light sources and reflections.

3.1.3
standard dynamic range video
SDR video
capability of components in a video pipeline to capture, process, transport or display luminance levels and tone gradations that can be characterized by the dynamic range, colour rendering and tone gradation capabilities essentially compatible with cathode ray tube (CRT) displays

EXAMPLE ITU-R BT.709 [6]/BT.1886 [7] and IEC 61966-2-1 (sRGB) [8]

Note 1 to entry: The luminance range of an SDR image is typically constrained between 0,1 cd/m^2 to 100 cd/m^2.

3.1.4
wide colour gamut
WCG
colour space that covers a larger percentage of visible colours compared to the sRGB/Rec. ITU-R BT.709 colour space

EXAMPLE ITU-R BT.2020 [9] is considered to provide WCG while BT.709 [6] does not.

3.1.5
television set
TV
equipment for the reception and display of television broadcast and similar services for terrestrial, cable, satellite and broadband network transmission of analogue and/or digital signals

Note 1 to entry: A television set can include additional functions that are not required for its basic operation.

[SOURCE: IEC 62087-3:2015, 3.1.19]

3.1.6
high definition
HD
spatial video resolution ranging from 1 280 × 720 to 1 920 × 1 080

3.1.7
ultra high definition
UHD
Ultra HD
spatial video resolution above 1 920 × 1 080

3.1.8
signal identification metadata
identifiers describing the properties of an image stream

EXAMPLE Format, resolution, colour space, chroma subsampling, bit-depth, image compression, image transport.

3.1.9
image-related metadata
identifiers describing intrinsic image properties in form of both static metadata valid throughout the content and dynamic metadata for frame-specific image parameters

EXAMPLE 1 Minimum and maximum luminance, average picture level, properties of the grading display.

EXAMPLE 2 HDR image related static metadata are MaxCLL and MaxFall as specified in CTA-861-G [10], section 6.9.1 and Appendix P, sections P.1 and P.2 for algorithms to calculate each.

EXAMPLE 3 Dynamic metadata is utilized by Dolby Vision® (SMPTE ST 2094-10 [11]) and HDR10+ (SMPTE ST 2094-40 [12]).

Note 1 to entry: They can be used as recommendations and guidance for image rendering and display.

3.1.10
average picture level
APL
average level of all the pixels of a single video signal frame in the linear luminance domain

EXAMPLE Display equipment such as television sets or computer monitors that internally use linear encoding after undoing the non-linearity of the input signal.

3.1.11
average picture level based on non-linear input signal
APL′
average level of all pixels of a single video signal frame in the non-linear luminance domain

EXAMPLE Display equipment such as television sets or computer monitor receive input signals that encode luminance in a non-linear way. Examples for such non-linear encoding are PQ or HLG EOTFs (ITU-R BT.2100-1) [5].

Note 1 to entry: APL′ is defined as a percentage of the range between reference black and reference white level.

Note 2 to entry: This is not a measure of the linear signal that might be available inside of some display equipment and delivered to the display device. The external and internal video signals are shown in Figure 1.

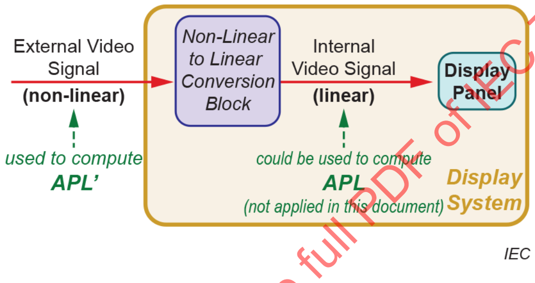

Figure 1 – Occurrence of linear and non-linear signal encodings in context of a typical display processing pipeline and how they can be used to compute APL and APL'

3.1.12
hybrid log-gamma
HLG
one set of transfer functions offering a degree of backwards compatibility by more closely matching the previously established television transfer curves

Note 1 to entry: Sets of transfer functions related to HDR signals are specified in Rec. ITU-R BT.2100-1.

[SOURCE: ISO/IEC TR 23008-15:2018, 3.4]

3.1.13
perceptual quantizer
PQ
one set of transfer functions addressing a very wide range of absolute luminance levels for a given bit depth using a non-linear transfer function that is finely tuned to match the sensitivity of the human visual system

Note 1 to entry: Sets of transfer functions related to HDR signals are specified in Rec. ITU-R BT.2100-1 [5].

[SOURCE: ISO/IEC TR 23008-15:2018, 3.8]

3.2 Abbreviated terms

ABC	automatic brightness control
ARIB	Association of Radio Industries and Businesses
ATSC	Advanced Television Systems Committee
BBC	British Broadcasting Corporation
CLASP	non-profit organisation supporting the development and implementation of policies and programs to improve the energy and environmental performance of appliances and equipment we use every day (Collaborative Labelling and Standards Program)
CLL	content light level
CRT	cathode ray tube
CTA	Consumer Technology Association (formerly Consumer Electronics Association)
FALD	full array local dimming
FALL	frame average light level
FIFA	Fédération Internationale de Football Association
FPS	frames per second
HD+ (HD-Plus)	high-definition satellite television platform for German-speaking users, owned by SES
HDMI®[2]	High Definition Multimedia Interface
HEVC	high efficiency video coding
Hz	hertz
ICDM	International Committee on Display Metrology
ICtCp	patented colour representation format specified in ITU-R BT.2100-2 [5]
ITU-R	International Telecommunication Union, Radiocommunication Sector
MDD	motion-based dynamic dimming
NC+	Polish satellite platform
NEEA	Northwest Energy Efficiency Alliance
NOS	Nederlandse Omroep Stichting (Dutch Broadcast Foundation)
OTT	over-the-top
PCL	Pacific Crest Labs
RTP	Rádio e Televisão de Portugal
SES	global satellite operator with its head office in Luxembourg
SMPTE	Society of Motion Picture and Television Engineers
sRGB	standard Red Green Blue colour space
TF1	French free-to-air television channel
TFT	thin-film transistor
TNT	American TV network operated by Turner International (originally Turner Network Television)
UGC	user generated content
YCbCr	colour space model used for digital video

2 HDMI® and HDMI® High-Definition Multimedia Interface are trademarks of HDMI Licensing Administrator, Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

4 Overview

4.1 High dynamic range video

HDR video signals are able to represent pictures that can be displayed with much higher peak luminance levels and much darker black levels compared to traditional SDR signals. HDR signals can potentially change the related power consumption of HDR-capable televisions. For more information on the history, nature, and ranges of HDR video, see IEC TR 62935:2016, Clause 4 [14].

For information on the early HDR Standards and Related Activities, see IEC TR 62935:2016, Clause 5 [14].

However, most of the standards outlined in IEC TR 62935:2016, Clause 5 [14] have been updated or superseded since its publication.

ITU-R Recommendation BT.2020-1 has been updated to BT.2020-2 [9] and now includes the higher frame rates of 100 Hz and 120/1,001 Hz. ITU-R has also now published Recommendation BT.2100-2 [5] that defines HDR formats for both HD and UHD resolutions. These formats use the same colour primaries as BT.2020-2 [9] but with two different transfer functions that may be used for HDR:

- perceptual quantizer (PQ), which was previously standardized in SMPTE ST 2084 [4];
- hybrid log-gamma (HLG), which was previously standardized as ARIB STD-B67 [15].

BT.2100-2 [5] also adds support for ICtCp constant luminance colour representations, but deprecates YCbCr from ITU-R BT.2020-2 [9].

CEA standards have now become CTA standards, with exactly the same number, as a result in the name change of the association from the Consumer Electronics Association to the Consumer Technology Association. CTA-861-F [16] has now been superseded by CTA-861-G [10], which adds support for signalling the HLG EOTF and adds the capability to support alternative dynamic HDR metadata systems SMPTE ST 2094-10 [11] (also known as Dolby Vision®[3] dynamic metadata format) and SMPTE ST 2094-40 [12] (also known as HDR10+).

In December 2016, the HDMI Forum extended its original HDMI® 2.0b specification, adding additional support for HDR video transport, in line with CTA-861-G [10], to include metadata signalling for hybrid log-gamma (HLG). The HDMI Forum included the following notice on its website:

> NOTICE: Previously, HDMI Specification Version 2.0b (HDMI 2.0b) only supported HDR (High Dynamic Range) video transport in the SMPTE ST 2084 EOTF (as applied in the media profile commonly known as HDR10), by referencing the CTA-861.3 specification. The Consumer Technology Association (CTA) has recently notified the HDMI Forum of the adoption of a new version of the CTA-861 Specification, CTA-861-G. This new version provides additional support for HDR Video transport by including (among others) an extension to the static metadata signalling to include the HLG (Hybrid Log Gamma) EOTF. The HDMI Forum has assessed the applicability of the CTA-861-G Specification to HDMI 2.0b. The HDMI Forum has confirmed that the extension of the static metadata signalling to include HLG can be utilized under the existing HDMI 2.0b Specification. This means that HLG Video Transport functionality can be implemented on HDMI 2.0b compliant devices.

3 Dolby® and Dolby Vision® are trademarks of products supplied by Dolby Laboratories, Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

In November 2017, the HDMI Forum released its HDMI® 2.1 [17] specification, which enabled even higher spatial resolutions and support for higher frame rates (10K at 120 Hz maximum) and included Dynamic HDR for specifying HDR metadata on a scene by scene basis or even a frame by frame basis.

4.2 HDR TV market

IEC TR 62935:2016, Clause 6 [4] presents an overview of the market related to HDR video content.

A small number of HDR-capable TVs were introduced to the market in 2015. In general, these televisions were able to stream HDR content from Internet-based video services. In some cases, these television sets included at least one HDMI® 2.0a interface, which enables the TV to accept HDR video from external devices such as Blu-ray™[4] discs. In early 2016, the Ultra HD Alliance announced technical requirements and a certification program for the Ultra HD Premium™[5] logo and three TV manufacturers introduced Ultra HD Premium™ television sets at the U.S. CES show in 2016. High-end TVs from the major brands supported HDR, initially just HDR10, but followed very quickly by HLG, and, by 2018, it was hard to find a 4K/UHD TV that didn't support both HDR10 and HLG. Support for other HDR formats, such as Dolby Vision®, HDR10+ and SL-HDR, varies by brand.

Various Ultra HD Blu-ray™ discs also were announced in March 2016. As more and more HDR movies are released, there will be more content available for streaming and for cable and satellite providers to eventually deliver.

ATSC published its next-generation A/341, ATSC 3.0 Standard: Video – HEVC [18], [4] in May 2017. That standard supports HDR coding using PQ or HLG transfer characteristics, and WCG ITU-R BT.2020 [9] colour space. ATSC 3.0 is now deployed in South Korea, however, until ATSC 3.0 has been widely deployed, broadcasters face the challenge of not only delivering HDR video content that was produced offline, but also should consider the challenges of live HDR production as well as backward compatibility with SDR TVs. "Over-The-Top" (OTT) 4K, WCG content is being provided by a number of streaming services such as NETFLIX[6], Hulu[7], and Amazon[8]. As HDR broadcasting emerges, high dynamic range will be applied to content types beyond pre-produced material such as movies and TV series. Examples are sports, news, daytime television, cartoons and other popular video genres.

In Europe, UHD HDR Broadcasting has started. TravelXP became Europe's first full time 4K HDR channel in December 2017, launched on Eutelsat's Hotbird satellite and on the HD+ platform in Germany over an SES satellite. TravelXP 4K, is offered in 4K resolution, 10-bit Rec ITU-R BT.2020 [9] wide colour space, 50 frames per second, with HLG HDR.

BT Sports became the first UK broadcaster to show top-flight football in HDR when it broadcast a UEFA Champions League game to mobile viewers using the BT Sport app in March 2018.

4 Blu-ray™, Blu-ray Disc™ and Ultra HD Blu-ray™ are trademarks of the Blu-ray Disc Association. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

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The match was also shown on big-screen TVs to a private audience in HDR combined with 4K Ultra HD. Eurosport launched its 4K channel in time to cover the 2018 French Open tennis tournament and included a public digital terrestrial television HDR transmission in the Paris, Nantes and Toulouse regions via France Télévisions, as well as on satellite.

In the summer of 2018, the BBC ran a series of public trials, showing the Royal Wedding, Wimbledon 2018 and FIFA World Cup matches in HDR via the BBC iPlayer. Indeed, 24 broadcasters subscribed to the FIFA World Cup UHD HDR content including RTP in Portugal, NOS in the Netherlands, TF1 in France, NC+ in Poland and Mediaset in Italy. beIN Sports in Qatar regularly broadcast UHD HDR soccer and Sky have stated that they will introduce UHD HDR broadcasts in 2019, presumably sports.

5 HDR TV power measurement challenges

5.1 Overview

The main standards related to measuring TV power consumption are IEC 62087-1 [1], IEC 62087-2 [2] and IEC 62087-3 [3]. IEC 62087-1 [4] covers general power consumption measurement aspects of AV equipment. IEC 62087-2 [2] covers the test media used in power consumption measurement, including related Blu-ray™ discs and DVDs that provide standard dynamic range video. IEC 62087-3 [3] covers the power consumption methods specific to TVs.

Since 2008, the IEC 62087 series of standards has been the primary specification for global TV power measurement, and there are many local regulations that make use of IEC 62087 as well.

Unlike the move from HD resolution to UHD resolution, which did not affect video levels, the move from SDR to HDR affects the levels of the incoming signal and with that can make meaningful use of higher peak luminance levels that are provided by modern television sets. This change enables content creators to compose, light, and expose their scenes differently and enables editors and colourists to colour and grade the final output with a different result in mind. Further, the change from standard colour gamut to wide colour gamut, as defined in ITU-R BT.2020 [9] extends the colour space of the video signal that is received an can be rendered by the television.

In addition, HDR and WCG practices will give content providers more creative options. For instance, in a scene with a couple near a candle, the colourist would be highly constrained in SDR and would need to compress the dynamic range of the image to provide clear details in faces, candle flame, and shadows. On the other hand, in HDR, the colourist can easily capture flame and shadows and would have much less creative constraint regarding the brightness of faces and other objects in the scene. Owing to these extended creative options with HDR, depending on the colour grading, the average picture level of the scene can vary much more widely in HDR than in SDR. This flexibility means that typical grading practices will evolve as colourists adapt to these new tools. HDR can support much brighter content, as well as even darker mid-tone and deeper black levels, which, along with bright highlights, can make images look much more dramatic compared to SDR. We will likely see both brighter and darker content scenarios, depending on genre.

Further, with the previous generation of CRT and early TFT and plasma-based displays, generally very little difference between the display capabilities amongst TVs was assumed and the SDR signal specifications of ITU-R BT.709 [6] and BT.1886 [7] were deemed sufficient for content delivery. In contrast, today's TVs exhibit a variety of panel display technologies and other considerations such as price point. In addition, HDR signal formats can contain signals that were created on mastering displays with varying capabilities. Technically, mapping between the source signal range and the TVs rendering capabilities are typically handled by tone mapping algorithms. Even though this approach works well from a general consumer point of view, it makes any power consumption assessments more involved.

For the above reasons, this document recommends

- assessing the power consumption of international HDR video content when displayed on current typical consumer HDR TVs (similar to the current IEC 62087-3 [3]);
- using those results to establish a new statistical power consumption target;
- creating new HDR-based content that can be used in testing the power consumption of HDR-capable televisions.

Sublause 5.2 elaborates the steps and deliverables required to assess the power consumption of HDR-capable television.

5.2 Content analysis

5.2.1 General

During the compilation of the initial test content for IEC 62087:2008 [19][9], experts in US, Europe and Australia recorded an average week of broadcast TV content (about 40 hours) and created a master APL' histogram of that content (see IEC 62087-2 [2]). The master histogram value coordinates are:

- per second averaged pre-gamma video signal voltage as demodulated from the broadcast signal expressed as a percentage of the full white signal voltage, and
- frequency of occurrence of that percentage value during the 40 hours of broadcasting.

This histogram is precisely replicated in the 10-minute dynamic TV broadcast test video sequence.

The approaches used in IEC 62087:2008 [19] for SDR content cannot be applied with HDR video content. HDR video poses several new challenges that likely have an impact on power consumption. Those challenges are listed in 5.2.2, 5.2.3 and 5.2.4.

5.2.2 Sources of HDR video content

In 2019, the vast majority of HDR video content is only available on Ultra HD Blu-ray™ discs and from online service providers. These delivery methods generally include copy protection technologies that preclude easy, legal capture of content. This means that the previous method of statistical measurement used with the broadcast content in IEC 62087:2008 [19] might not be available in the current HDR context.

Another approach to gather data for statistical purposes is to analyse protected content obtained from the content owner directly. It is possible to reach out to studios, for example, and request statistics about their content. This approach would be simple, practical, and likely statistically reliable; however, studios have not been open to providing such data.

9 IEC 62087:2008 is withdrawn and replaced by the IEC 62087 series.

5.2.3 HDR metadata

Further, PQ-based HDR video for consumer deployment generally includes metadata that can describe the peak and average luminance levels of the content. Unfortunately, these metadata are static (globally applied and constant over the full duration of the content). They therefore cannot adequately represent the statistics for the related content. Dynamic HDR metadata has recently been added to CTA-861 [10], however, the standards for some dynamic metadata technologies are not yet settled, for example, SMPTE ST 2094-40 (HDR10+) [12], and others are emerging, such as SL HDR-2 and -3. Therefore, sufficient representative content that both includes dynamic metadata and is openly accessible to the project experts is not available at this time. As noted in 6.4, project experts recognized that both HDR technologies as well as HDR video content are constantly evolving. We therefore urge to engage with further studies led by a future project team focused on the impact of dynamic metadata HDR video content on TV energy consumption.

5.2.4 Increased complexity of display technologies enabling HDR

HDR television sets often employ complex technologies in order to achieve the luminance ranges required to display HDR video content. One example is the local dimming features that are also known as "dual modulation". This technology serves the purpose of increasing the contrast of the display beyond of what would be possible with the LCD panel alone while being lit by a static backlight. These dual modulation approaches can be further separated into local approaches, where individual backlight elements such as LEDs are modulated individually (full array local dimming, FALD), or global modulation, where the whole backlight unit is dimmed or brightened up.

In general, such television sets internally compute some of the characteristics of the incoming signal in order to control the backlight system. Capturing these backlight control signals could provide insight into the statistics of the content, and therefore appear as an enticing option. However, the statistical methods and properties gathered by various manufacturers might vary, and might be based on trade secrets. Further, only the designers of these televisions would know how to access these signals. The signals are not generally captured, so this would require custom equipment that interfaces with the internal circuitry of the television sets. Such custom units would not be available to all experts and would preclude multiple-expert verification. These issues make this approach impractical.

5.3 HDR video content aspects beyond the scope of this report

Within professional content, there appears to be a large variation between subjects and genres. Horror movies are typically dark. A movie about mountain climbing could potentially be very bright. Romantic comedies are typically brighter than moody dramas. These examples show that the genre of content might also have an impact on power consumption. Therefore, a future project might consider characterizing the content genres and obtaining information about viewing preferences in order to weight the genres correctly. Another approach might be to characterize content on a more fundamental basis, such as characterizing dark, bright, and medium scenes and to weight these appropriately.

The current IEC 62087-2 [2] SDR test materials were based only on luminance characteristics. For HDR and WCG video, chroma might also affect power consumption. If chroma is found to affect power consumption, obtaining colour statistics of content could be helpful.

Many televisions now use advanced spatial image processing or modulation techniques such as local dimming technology (see 5.2.4 above) and power management that is reactive to the spatial distribution of image pixels. For this reason, it is helpful to assess spatial information as well as luminance information. For instance, if there is a single bright patch within a single lighting zone and all other pixels are black, power consumption might be quite low. On the other hand, if every lighting zone has a small number of bright pixels, such as in a star field, consumption might be quite high. Capturing spatial information could be helpful for adequately measuring the power consumption caused by today’s complex display systems, such as local dimming HDR TVs.

Another functionality of HDR display devices is the capability to re-map the tone value distribution from a source to a different target signal. This is typically implemented in displays to ensure that tone values are not clipped or crushed while still maintaining a high picture quality. Effective tone mapping is particularly beneficial if the display's hardware capabilities are significantly lower than what the HDR signal recommends. It would be beneficial to factor in the impact of any tone mapping present in the video path. However, the complexity, effectiveness and resulting imaging fidelity varies highly amongst formats, display technologies, manufacturers, models and price points. Even though desirable, it is difficult to analyse and assess the impact of tone mappers on power consumption as their implementation is typically proprietary.

In this context, it is important to note that no test materials should intentionally favour or disadvantage any given display technology. The goal of the IEC 62087-2 [2] TV test materials is to be representative of actual content encountered by a TV in consumer use.

Statistics related to the changes in luminance versus time might also be useful in creating a target profile for next-generation test material. However, the project team noted that if the requested technical content statistics are too complex or detailed, the willingness of professional content providers to release them might be low.

The situation is similar in context of content type and viewer statistics. Even though the providers might already possess information about aspects such as typical consumer viewing (e.g. news, sports, soap operas), they may see such HDR statistics about their content as proprietary information.

Therefore, experts used both analysis tools proprietary to members and a publicly available analysis tool VQPLA (http://www.videoq.com/vqpt.html), a member supported test farm of typical TVs (NEEA), and the guidance of CLASP, Dolby Laboratories, and Company 3 (a post-production firm) to focus on creating representative static metadata HDR video content for this study and document. As part of this effort, members used the analysis tools to measure the characteristics of online static metadata HDR video content hosted on YouTube and other sources, and then used those characteristics to create similar HDR video content for member experimentation.

6 Dominant aspects for HDR TV power consumption measurement

6.1 Overview

Based on the findings and lessons learned when assessing the HDR TV and content landscape, several deliverables were developed in the context of this document. To achieve this, a multitude of assessments, statistical analyses and content edits and adjustments had to be carried out. Figure 2 provides an overview of the processes employed to realize the deliverables of test content and statistical reference data used to assess power consumption. The processes and concepts leading to those deliverables are elaborated on in more detail in 6.2 to 6.9, and Clauses 7 and 8.

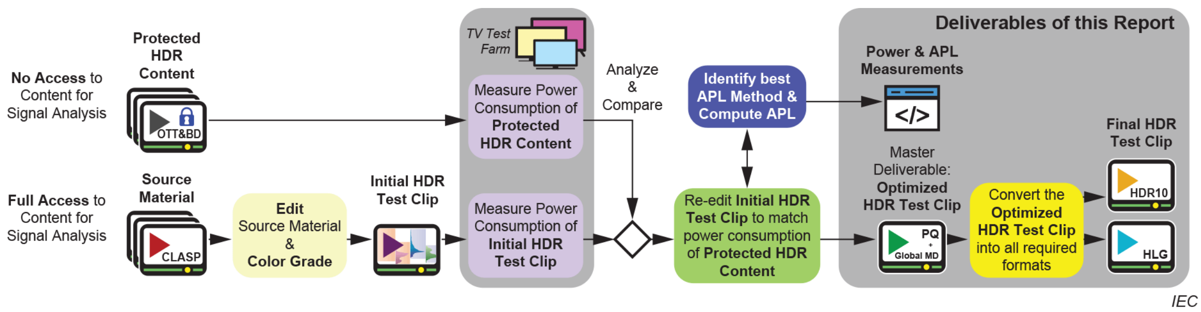


Figure 2 – Overview of how the deliverables were developed

For clarity, the following content labels are used through the remainder of this document:

'Protected HDR Video Content'

- copyright-protected HDR video content used to assess the power consumption

NOTE 1 This includes OTT (NETFLIX and Amazon) and Blu-ray™ content.

'CLASP source material'

- HDR video content provided by CLASP copyright free from which the deliverables were edited

'YouTube hosted material'

- HDR video content reviewed by project experts after first confirming that a sample CLASP clip uploaded to and then downloaded from YouTube exhibited the same average power level via the TV test farm. While YouTube hosted content cannot be considered "authoritative", there were several genres of quality content that otherwise would not have been available for comparative analysis which helped inform the experts as they developed representative HDR test content. It was noted that online user generated content (UGC), such as that on YouTube, is part of the consumer viewing experience today.

'Initial HDR Test Clip'

- initial edit and colour graded clip based on CLASP source material

NOTE 2 (see 7.2)

'Optimised HDR Test Clip'

- version of the Initial HDR Test Clip optimised to match the statistics derived from the Protected HDR Video Content

NOTE 3 This is the master deliverable from which other deployment formats can be derived.

'Final HDR Test Clip'

- final version of the project team's HDR test clip encoded from the Optimised HDR Test Clip to the formats recommended in this document

6.2 Fundamental criteria and requirements for Final HDR Test Clip deliverable

The current test media specified in IEC 62087-3:2015 [3] consist of two 1080i clips, one with 60 frames per second (fps) to be used in the U.S. and Canada, and the other with 50 fps to be used in other regions as appropriate. This content falls under the SDR category with HD resolution.

UHD and HDR have introduced a wide variety of media format resolutions, luminance ranges, colour space, EOTFs and frame rates beyond SD/HD and SDR video content. There are many approaches used to create, process, deploy and render HDR and UHD video content. Therefore, HDR video test material has the potential of adding a high degree of complexity and test burden owing to the increased number of variables involved. To alleviate this test burden, we examined variables typically encountered in HDR media formats to derive test media that does not unnecessarily increase test time, yet still provides representative power measurements. The fundamental rationale to this approach is that modern TVs can display a wide variety of media resolutions, scan types (progressive versus interlaced), and frame rates with very little or no energy consumption difference between the different formats.

The examination led to a reduction of fundamental format parameters, which are summarized in Table 1. The details of this examination are described in 6.3 to 6.6 and summarized in Table 3 and Table 6.

Table 1 – Fundamental HDR test media format summary

Progressive scan formats	Hybrid log gamma (HLG)	HDR10 mastered at 1 000 cd/m^2
HD (1 920 × 1 080 p) 25 fps	X	X
HD (1 920 × 1 080 p) 24 fps	X	X
HD (1 920 × 1 080 p) 50 fps	X	X
HD (1 920 × 1 080 p) 60 fps	X	X
UHD (3 840 × 2 160 p) 50 fps	X	X
UHD (3 840 × 2 160 p) 60 fps	X	X

Please note the above formats are provided for regional convenience from original camera raw footage shot at 25fps. Experts ascertained via empirical testing that variations from the above frame rates and formats may have little impact on TV energy consumption. Project members noted that, to ensure credibility with political and regulatory authorities, it is important that the chosen test material be as representative as possible of real world content and for the foreseeable future it is expected that this can be sufficiently met by content at 60 fps, given the test data below and current television abilities to ingest a wide variety of media resolutions. It is likely that any one regional authority would only need two resolutions for testing purposes (i.e. HD and UHD), and a revised IEC 62087-2 [2] should consider a subset of Table 1. Fractional frame rates close to these figures would have no impact on power measurements and are therefore considered unnecessary, and frame rates above 60 fps are expected to only contribute a tiny fraction of HDR material for the foreseeable future.

The data below is the result of that testing, however the workflow described in Annex B was used to create test clips in HD (1 920 × 1 080 p) 60 fps in HLG and in HDR10 (PQ) only, given the tests and analysis presented below.

6.3 HDR media formats

There are currently several HDR media formats that are available in the consumer TV landscape, which are summarized in Table 2.

Table 2 – HDR media formats available in the consumer TV landscape

Format name	Description	Metadata type
HLG	Currently the most common HDR standard for broadcast media	none
HDR10	The most common format for media for deployment via OTT (e.g. NETFLIX) or Blu-ray™ disc.	static
HDR10+	Format currently in standards revision by SMPTE	dynamic
Dolby Vision®	A common format for streaming media and Blu-ray™ applications	dynamic
SL-HDR1 & 2	Standardized format not commonly used	dynamic

6.4 Differences between HDR formats

The key difference between the HDR video formats listed in Table 2 is the type of metadata. While HLG and HDR10 either provide no or static metadata, the remaining formats all use dynamic metadata.

Dynamic metadata HDR technologies and formats extend the complexity of how images in those formats are ultimately rendered on display devices. Assessing this additional complexity was deemed out of scope of this group, leading the group to recommend further study of dynamic metadata HDR technologies and formats in the context of power consumption before creating representative test materials. Therefore, the experts only considered HLG and HDR10 for the scope of this report. This decision was further substantiated by requests from Australian, European and U.S. regulators for updated IEC 62087-1 [1], -2 [2] and -3 [3] standards to enable testing of current HDR TVs using representative content in a shorter timeframe.

Focusing on non-dynamic metadata driven HDR formats is a feasible decision, as it is expected that the vast majority of devices implementing HDR will implement both HLG and HDR10 as a minimum, thus enabling a more rigorous and meaningful comparison between devices, whereas adoption of the dynamic HDR technologies will be far from universal in the short term as previously discussed in 5.2.3 above.

In order to identify if there are significant differences between static and dynamic HDR formats in general, Pacific Crest Labs (PCL) compared video content in different HDR10 and Dolby Vision® formats. The conclusion was that movies available in both of those formats most of the time use about the same amount of power when tested. Where there is a difference, Dolby Vision® tends to use less power. This can be explained by the fact that today's TVs are typically configured to offer a darker pre-set picture setting for Dolby Vision® content than for HDR10 (which is often pre-set to brighter picture modes such as 'Cinema Home' or 'Standard' HDR). Pacific Crest Labs (PCL) tested one Dolby Vision®-capable, 2 000-cd/m^2-peak-brightness TV in its default settings, and this TV used 6% more power when displaying HDR test content[10] compared to the HDR10 equivalent mastered at 1 000 cd/m^2. Table 3 shows the results of two comparisons. First, the Dolby Vision® version of the HDR Test Content (PCL Dolby Vision® 4000 cd/m^2) versus an HDR10 version derived via direct transform from the Dolby Vision® version (PCL HDR10 1 000 cd/m^2: Dolby Vision® Transform). This was followed by a comparison of the same Dolby Vision® version compared to an HDR10 version, this time created from a new HDR10 colour grade (PCL HDR10 1 000 cd/m^2: HDR10 Grade). Annex B presents both test method and experimental clip workflow details for the analysis. On average, HDR10 versions of the HDR test content used 5 % more power than the Dolby Vision® version.

10 The HDR test content used here is: DM1 HDR10 1 000 cd/m^2 and DM1 HDR10 4 000 cd/m^2.

Table 3 – Comparison of HDR media formats on the power consumption (W) of TVs

Clip name	Res.	FPS	NEEA test farm model (W)		Avg. (W)	Increase of B over A
			C	E		
A: PCL Dolby Vision® 4 000 cd/m^2	HD	25	149,6	190,0	169,8	8,75 %
B: PCL HDR10 1 000 cd/m^2: Dolby Vision® Transform	HD	25	171,1	198,2	184,6	
A: PCL Dolby Vision® 4 000 cd/m^2	UHD	25	148,7	194,1	171,4	7,91 %
B: PCL HDR10 1 000 cd/m^2: Dolby Vision® Transform	UHD	25	171,4	198,5	185,0	
A: PCL Dolby Vision® 4 000 cd/m^2	HD	25	149,6	190,0	169,8	2,46 %
B: PCL HDR10 1 000 cd/m^2: HDR10 Grade	HD	25	151,5	196,4	174,0	
A: PCL Dolby Vision® 4 000 cd/m^2	UHD	25	148,7	194,1	171,4	1,51 %
B: PCL HDR10 1 000 cd/m^2: HDR10 Grade	UHD	25	151,4	196,6	174,0	
Average			**155,2**	**194,8**	175,0	5,16 %

6.5 Mastering display brightness

HLG assumes a 1 000 cd/m^2 mastering display. Since HLG content does not include image-related metadata (static or dynamic), the mastering display brightness of HLG content is not provided in authored content.

Most, if not all, HDR10 content is mastered at 1 000 cd/m^2 at the time of writing. There are commercially available TVs on the market that exceed 1 000 cd/m^2 brightness today, so HDR10 4 000 content can become common in the near future. This would enable brighter TVs to display image elements such as specular highlights with more than 1 000 cd/m^2. However, current test results indicate that content mastered with 4 000 cd/m^2 results in comparable power use to content mastered with 1 000 cd/m^2 when both versions are mapped by the TVs to their luminance range limits. An example for the Dolby Laboratories ‘DM1’ grade is provided in Table 4.

Table 4 – Power consumption (W) of TVs displaying the colour graded Initial HDR test clip[11]

Colour graded Initial HDR test clip	NEEA TV test farm model (W)								Avg. (W)
	A	B	C	D	E	F	G	H	
DM1 HDR10 1 000 cd/m^2	182	115	150	107	178	202	107	115	145
DM1 HDR10 4 000 cd/m^2	179	115	149	108	179	204	108	116	145

11 This data is from the PCL analysis conducted March 20, 2019, details of which are presented in Annex B.

6.6 Resolution, scan type and frame rate

A further analysis carried out by PCL[12] assessed the impact of spatial picture resolution on power consumption with the result that resolution does not significantly affect energy consumption (Table 5).

Table 5 – Power consumption (W) of TVs displaying the assessment HDR video content in different resolutions

Assessment HDR video content format	Res.	FPS	NEEA TV test farm model (W)						Avg. (W)	Increase of B over A
			A	B	C	D	E	F		
A: HDR10 1 000 cd/m^2: Dolby Vision® Transform	HD	25	109,3	148,3	171,1	115,3	198,2	179,0	153,5	0,05 %
B: HDR10 1 000cd/m^2: Dolby Vision® Transform	UHD	25	109,3	148,2	171,4	115,2	198,5	179,0	153,6	
A: HDR10 1 000cd/m^2: HDR10 Grade	HD	25	105,3	147,0	151,5	114,9	196,4	173,3	148,1	0,02 %
B: HDR10 1 000cd/m^2: HDR10 Grade	UHD	25	105,4	147,1	151,4	114,9	196,6	173,3	148,1	
A: HDR10 1 000cd/m^2: HDR10 Grade	HD	60	105,2	146,8	150,9	114,9	196,1	172,9	147,8	0,07 %
B: HDR10 1 000cd/m^2: HDR10 Grade	UHD	60	105,3	146,8	151,4	114,9	196,1	173,0	147,9	
A:SDR: HDR10 Transform	HD	25	109,5	126,4	130,5	89,6	183,6	134,3	129,0	0,16 %
B:SDR: HDR10 Transform	UHD	25	109,4	126,4	130,7	89,8	183,6	135,0	129,2	
Average			**107,3**	**142,1**	**151,1**	**108,7**	**193,6**	**164,9**	**144,6**	**0,07 %**

This power analysis of the Assessment HDR video content also indicates that frame rate has little effect on power consumption (Table 6).

Table 6 – Power consumption (W) of TVs displaying the assessment HDR video content with different frame rates

Assessment HDR video content Format	Res.	FPS	NEEA TV test farm model (W)						Avg. (W)	Increase of B over A
			A	B	C	D	E	F		
A: HDR10 1 000cd/m^2: HDR10 Grade	HD	25	105,3	147,0	151,5	114,9	196,4	173,3	148,1	−0,18 %
B: HDR10 1 000cd/m^2: HDR10 Grade	HD	60	105,2	146,8	150,9	114,9	196,1	172,9	147,8	
A: HDR10 1 000cd/m^2: HDR10 Grade	UHD	25	105,4	147,1	151,4	114,9	196,6	173,3	148,1	−0,13 %
B: HDR10 1 000cd/m^2: HDR10 Grade	UHD	60	105,3	146,8	151,4	114,9	196,1	173,0	147,9	
Average			**105,3**	**146,9**	**151,3**	**114,9**	**196,3**	**173,1**	**148,0**	**−0,16 %**

6.7 Aspect ratio

We recommend that the final HDR test content should include a combination of 16:9 with some anamorphic 2.39:1 widescreen content.

12 PCL experimental test clip analysis done on December 20, 2018.

The motivation behind this recommendation is that the Protected HDR Video Content evaluated by PCL included a random selection of movies and series streamed on NETFLIX and Amazon as well as movies available on Blu-ray™ disc[13]. About half of the titles were available in 2.39:1 widescreen format while the rest was provided in a 16:9 aspect ratio.

6.8 Picture level

The power consumption of a display device can be measured for any content rendered on the display. However, the power consumption alone does not reveal anything about the content or the display's state of operation. Therefore, the content also needs to be analysed in order to draw conclusions about the correlation between the actual content and the power consumption when displaying it. This is a feasible approach, as a display's power consumption is directly related to the signal received and shown by the display device.

Unfortunately, analysing content is challenging, as it requires access to the source data. As discussed earlier, Protected HDR Video Content such as available via OTT or Blu-ray disk cannot be used for this task as it is typically copy protected. Therefore, the final HDR test clip developed as a deliverable of this document reflects both the statistical signal level and power consumption properties of protected HDR video content.

6.9 Content signal level analysis method

In order to create such a test deliverable, the initial step was to identify the most accurate signal assessment method that is able to provide a high correlation between power consumption and signal level while being agnostic about the various fundamental display technologies in the market.

A well-established approach to correlate the complexity of an image or frame to other display system-related aspects, such as energy consumption, is to compute the average picture level (APL). In the context of HDR signals, several APL derivatives have been proposed, each leading to different results. Therefore, several APL methods have been evaluated.

This analysis was again carried out by Pacific Crest Labs (PCL) on the NEEA TV test farm[14] using the Initial HDR Test Clip using regression analysis on different APL methods and power measurements. The methods included in this test were APL (linear input), APL' (non-linear input), maxFALL (CTA-861) [10].

The result of the analysis showed that the correlation between power consumption and signal when using the APL' method was significantly higher with r^2 = 0,67 compared to the next best metric frame average light level' (FALL)[15], which resulted in r^2 = 0,32. Therefore, it was concluded that APL' is the most appropriate metric for the scope of this document.

The APL' metric is computed from the non-linear absolute PQ input signal as the weighted average of the R, G, B values of all image pixels x and y in 10 Bit PQ (nonlinear, ranging from 0 to 1 023). This is described by the following equation:

$$APL' = \frac{1}{n \times m} \sum_{x=1}^{n} \sum_{y=1}^{m} \left(0{,}2627 R'_{xy} + 0{,}678 G'_{xy} + 0{,}0593 B'_{xy} \right)$$

13 PCL evaluation presented to PT100-15 on April 26, 2018.

14 Performed by Pacific Crest Labs on 15 May 2019

15 Please note that FALL was computed as max(R, G, B), where R, G and B are the expected TV light output values in cd/m^2

Following the HDR10 specifications, the constants represent the BT.2020 [9] primaries.

7 Fundamental objectives of HDR test clip deliverable

7.1 Overview

In order to provide test scenarios that can be widely used for TV power assessments, content has to be made available that is not restricted by copyright limitations. Further, the content has to be representative of typical HDR video content. This is achieved by using the following process steps:

1) producing content that resembles real-world HDR video content that contains a wide spread of subjects and genres related to broadcast (talk shows, drama scenes, sports, commercials) and movie production (movies, trailers, TV shows). To achieve this, HDR-capable professional cameras operated by a professional film and lighting crews are used;
2) editing the wide spread of source clips in a meaningful way so that result is both useful for test purposes while still resembling real world HDR video content;
3) having professional colourists' colour-grade the content;
4) providing the content in industry-standard HDR formats.

7.2 CLASP source material

CLASP provided a ten-minute video loop prepared in HD, UHD-4K and UHD-4K with HDR10. The video was shot by professional cinematographers in and around London and included:

- street scenes around London (2 minutes);
- sports scenes from tennis and billiards matches (2 minutes);
- advertising from two info-commercials (2 minutes);
- soap opera/drama typical darkly lit scenes (2 minutes);
- news scenes from a morning TV programme (2 minutes).

The overall APL of the ten-minute original HDR CLASP clip is 34 % to match with the overall APL of the existing IEC 62087 SDR test material. This clip is currently used by Belgium, Sweden, the United Kingdom, and by NRDC and NEEA in the U.S. for comparative testing. The experts then re-edited and re-graded the original CLASP ten-minute clip to better represent the expected characteristics of real-world HDR content as described in 7.3 to 7.6 and in Clause 8.

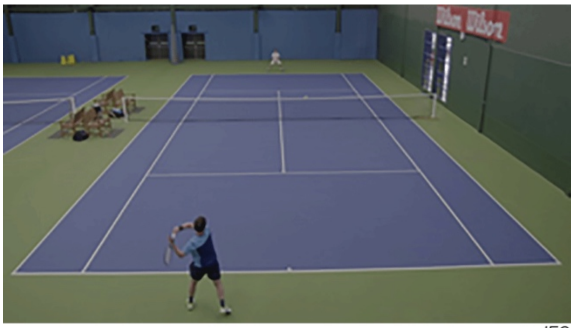
7.3 Luminance, APL and colour saturation properties

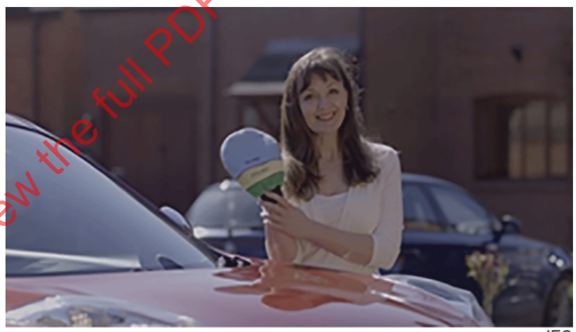
The CLASP source material was graded to reflect representative APL' level and luminance distribution levels reflecting representative of real-world HDR video content. During the preparation of this document, an initial HDR test clip with a representative APL' level, and with colour saturation that is also representative of real-world HDR video content was developed. This goal was achieved by the colour grading applied by professional colourists at Dolby Laboratories and Company 3, a post-production firm.

7.4 Order of scenes

This document recommends ordering the scenes such that darker content that best represents streaming movies/series comes first followed by content that best represents broadcast content. The proposed scene order is described in Table 7. The rationale behind this recommendation is that some TVs require a small but finite amount of time to achieve equilibrium when changing abruptly from displaying bright to darker content. Grouping the scenes as noted above tends to be more representative of real-world viewing, and permits testers interested in understanding power consumption of a device during only darker or only lighter scenes to play just those scenes during such a test. Project Team members also suggested this approach to more accurately measure TVs that have motion-based luminance processing. For a further discussion of motion-based TV response, please refer to Annex A.

Table 7 – Recommended scene order in the test clip

Name	Representative frame
1. Snooker (Half of this section is in 2.39:1 widescreen format, and the other half is 16:9)	 IEC
2. Soap opera (Half of this section is in 2.39:1 widescreen format, and the other half is 16:9)	 IEC
3. Tennis (16:9)	 IEC

Name	Representative frame
4. London streets and rivers (16:9)	 IEC
5. Fruit blender infomercial (16:9)	 IEC
6. Car washing infomercial (16:9)	 IEC
7. Talk show (16:9)	 IEC

7.5 Creating the initial HDR test clip

Figure 3 illustrates the process applied when creating the initial HDR test clip following the consideration and task described so far in this clause (any numbers and units are just for illustration). The CLASP source material was edited into a timeline, following the HDR rationale provided earlier. Then, the content was colour graded. Now, the initial test clip was ready for initial power assessments and APL’ calculations. Figure 3 illustrates the initial editing of the CLASP source material including example power measurements as well as APL’ values.

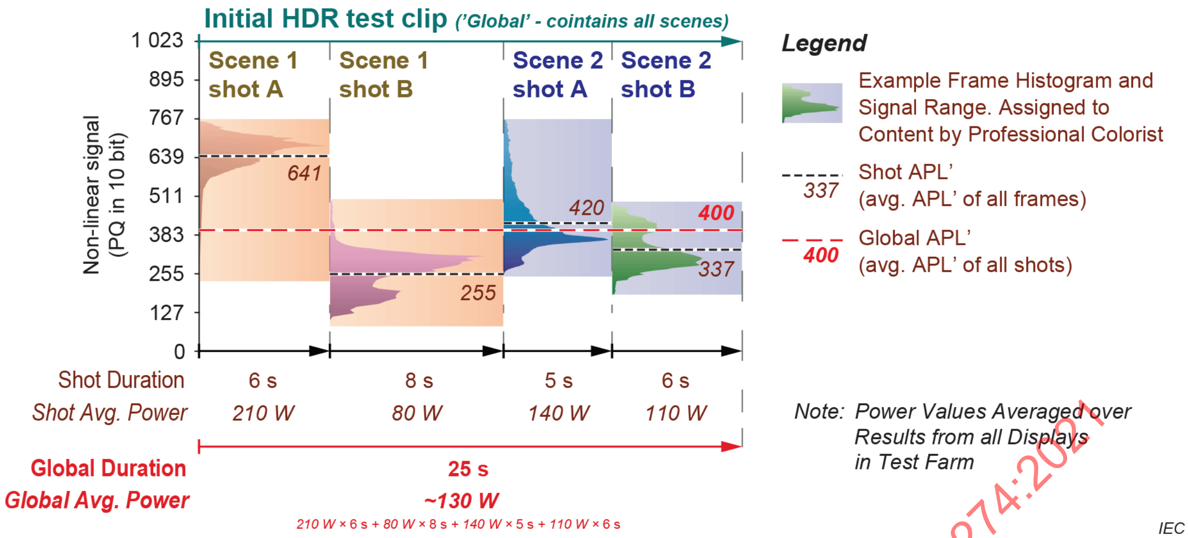


Figure 3 – Illustration on editing the initial HDR test clip from the CLASP source material

7.6 Optimization of initial HDR test clip to match power statistics

In order to optimise our initial HDR test clip, we used the NEEA TV test farm to measure the average power consumed by those TVs replaying several HDR video titles spanning different genres. The range of 126 W to 154 W of average power consumption values was selected by the project team as representative of likely future HDR content. The initial HDR test clip was then edited by modifying the lengths of bright versus dark scenes to fall approximately in the middle of that test farm power range. The range of power values extends 10 % above and 10 % below the test clip power value. As a result, we concluded that the acceptable range of APL' values is the final HDR test clip APL' (29 %) plus or minus 10 % (26 % to 32 % – 10-bit code words 266 to 327). It should be noted that the "narrow" 10-bit PQ signal range (bits 64 ~ 940) was used when calculating APL'%, making APL'% = (APL' signal − 64) / (940 − 64).

This optimization process is illustrated in Figure 4.

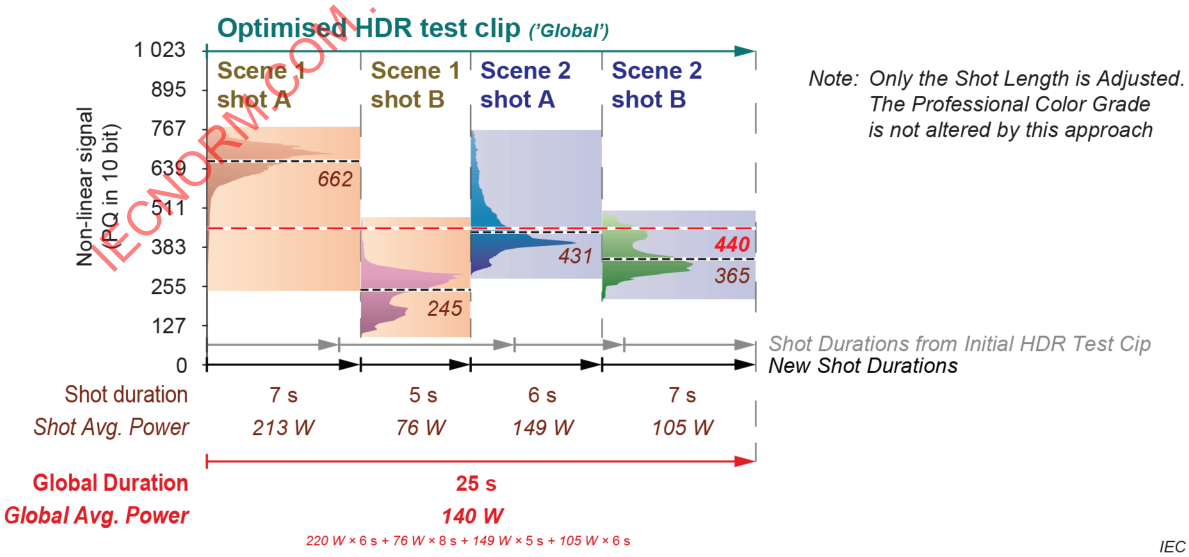


Figure 4 – Optimization of initial HDR test clip to match power statistics

Figure 5 provides the average power consumption of the optimised HDR test clip against the statistical data derived from the protected HDR video content. The shade band represents the range of power values (126 W to 154 W) that was deemed acceptable.

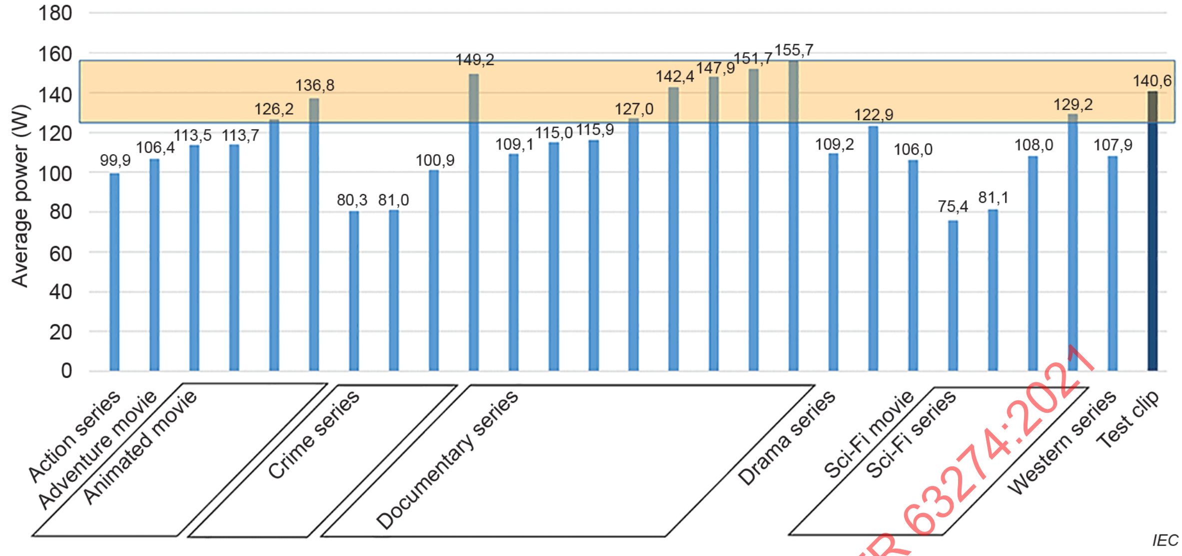


Figure 5 – Average power consumption of protected HDR content versus optimized HDR test clip

8 Generation of the final HDR test clips

8.1 HDR signal properties

8.1.1 Overview

The Optimised HDR Test Clip was created using ITU-R BT.2020 [9] primaries, SMPTE ST 2084 [4] EOTF, and a global dynamic range bracket of 0,005 cd/m^2 to 1 000 cd/m^2. In order to make the clip available in the required formats, this clip had to be converted to the respective formats and frame rates before encoding as bit-stream, ultimately leading to the final HDR test clips.

This document recommends following industry-standard signal-identification metadata to ensure interoperability of IEC's test materials with products deployed in the field.

Recommendation: this document recommends that metadata should be associated with any test clip and should include the elements as described in Annex A.

Rationale: this document strongly recommends that all test clips include signal identification metadata embedded in the test file itself to provide an easy way for testers to confirm a clip's characteristics (resolution, frame rate, colour space etc.) via open source apps such as MediaInfo [20]. The metadata embedded in the prototype test clips provided with this TR are also provided in Annex A.

8.1.2 Colour gamut

Recommendation: Apply as described in ITU-R BT.2100-2 [5].

Rationale: ITU-R standard for HDR TV.

8.1.3 Colour depth

Recommendation: ≥ 10 bit.

Rationale: ITU-R BT.2100-2 [5] defines a bit depth of either 10-bits per sample or 12-bits per sample, with either narrow range or full range colour values.

8.1.4 Chroma subsampling

Requirement: 4:2:0

Rationale: this document recommends 4:2:0 sampling as this the most commonly used chroma subsampling method for today's compressed content delivery approaches.

8.2 Converting the optimised test clip to the recommended formats

The optimised HDR test clip provided in SMPTE ST 2084 [4] (PQ) format can be converted to HDR10 and HLG formats given that several key parameters such as the display peak luminance are aligned (see Annex B). The operational approach taken by the experts of this group was to convert to HLG and HDR10 using DaVinci ResolveStudio 15 by Blackmagic[16]. In the final case, conversion from PQ to HLG was facilitated by official look-up tables (LUTs) [21] provided by the BBC (1a_PQ1000_HLG_mode-nar_in-nar_out-nar_nocomp-v1_3.cube). The processes for this conversion are also described in Annex B. For completeness, a functional form for this conversion is provided in Annex C for reference.

8.3 Additional elements

8.3.1 Countdown timer

Requirement: this document recommends a 10-second countdown timer at the beginning of the final HDR test clip. The countdown timer may be superimposed over the public domain ITU-R HDR colour bars [22].

Rationale: this allows TVs to auto-fade-out video overlay information that sometimes appears at the start of a video clip prior to commencing a power test.

8.3.2 Audio tone

Requirement: this document recommends sine-wave signals at a frequency of 1 kHz with a level of 18 dB below full scale.

Rationale: IEC 62087-2:2015 [2] has required the same specification above for audio associated with IEC 62087-3:2015 [3] for the determination of power consumption for TV sets.

9 Delivery of test media

Current IEC TV power measurement test signals are delivered on DVD and Blu-ray™ discs, however, authoring systems for Ultra HD Blu-ray™ discs are not widely available and would require a professional studio to master and replicate. At the same time, current television sets now include easy and accurate playback of file-based media e.g. via USB stick. Therefore, to allow for quicker updates reflecting fast-moving technology areas, this document strongly suggests the consideration of electronic means to distribute test media in a manner similar to how IEC standards are electronically distributed.

[16] DaVinci Resolve is a trademark of Blackmagic Design Pty. Ltd. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

10 Rating of SD and HDR power consumption

Weighting of power measurements using HDR video versus power measurements made with SDR video is not to be defined by an IEC standard. Regional policymakers, however, may wish to weight SDR and HDR results based on region and the rate of local adoption of HDR video content.

11 Summary

This document has identified and studied many aspects of static metadata HDR video content to quantify the power consumption of current HDR-capable televisions. Experts believe its experimental test clips and the data obtained from NEEA's experimental TV test farm provide useful information for the revision of IEC's existing SDR TV energy test methods to encompass HDR as well. It should be noted that, at this time, there is a limited amount of HDR video content available in genres such as sports, news, daily TV programming (soap operas, game shows, etc.). Nevertheless, the comparative analysis done by PT100-15 members using YouTube-hosted and other available content has informed PT100-15's conclusions and recommendations put forth in this document as previously noted in Clauses 6, 7, 8 and 9 above. The reader is encouraged to refer to the above clauses for details of the document's recommendations, which are briefly summarized below:

- HDR test content should include a combination of 16:9 with some anamorphic 2.39:1 widescreen content.
- Scene ordering of test clips should be such that darker content that best represents streaming movies/series comes first, followed by content that best represents broadcast content comes second.
- Test clips should follow industry standard signal identification metadata to ensure interoperability of IEC's test materials with products deployed in the field.
- Static metadata should be associated with test clips and should include the elements as described in Annex A.
- Test clips should include signal identification metadata embedded in the test file itself to provide an easy way for testers to confirm a clip's characteristics (resolution, frame rate, colour space etc.) via open source apps such as MediaInfo [20].
- Test clip colour gamut and colour depth should follow ITU-R BT.2100-2 [5].
- Test clip chroma subsampling should employ the most commonly used 4:2:0 method.
- Test clips should have a 10-second countdown timer at the beginning of each clip.
- Test clips should include a sine-wave audio signal at a frequency of 1 kHz with a level of 18 dB below full scale.
- Test clips should be distributed via electronic means in a manner similar to how IEC standards are electronically distributed.
- Further study of dynamic metadata HDR technologies and formats in the context of power consumption is needed before creating such representative test materials.

Recognizing that technology, content creation, distribution and adoption of HDR is changing quickly, this document very strongly advocates that the maintenance team responsible for TV HDR test-related standards and associated test materials act as quickly as possible to adopt this document's recommendations into revised parts of the IEC 62087 series that can be used by designers and regulators to assess the real-world energy impacts of static metadata HDR video content on TV energy use.

In addition, experts writing this document urge the responsible maintenance team to establish a short stability date for that revision that will allow IEC to revisit the HDR ecosystem and update its standards and test materials in a timelier manner.

To keep up with the fast pace of technology, experts also strongly ask for a new project team to study the energy impacts of “dynamic HDR” (e.g. SMPTE ST 2094-10 [11], SMPTE ST 2094-40 [12], SL-HDR1 and 2) and to produce a dedicated document. The need by TV designers and regulators to accurately understand the energy impacts of such dynamic metadata HDR technologies, some which are just now emerging for standardization, demands IEC’s continuous, ongoing study.

Annex A
(informative)

Other considerations for a next-generation TV power measurement standard

A.1 Overview

The television market continually evolves. New features and implementations can change the assumptions of measured power consumption versus real-world power consumption. This annex considers identified issues that need further study for any update of current measurement standards.

A.2 Visual overlays

Many regions require the availability of closed captions and subtitles. A future project team might consider if captions and subtitles affect the luminance of the display, especially for HDR signal playback. For instance, content might be rendered at different luminance distributions depending on whether graphics overlays are present or not. A TV might also incorrectly assign the luminance of overlays (such as the closed caption text) when generating it in the wrong colour space or format (e.g. SDR in Gamma) compared to the content format (e.g. HDR in PQ).

A.3 Motion-based features

In some cases, televisions change their response curves based on motion detected in the video. In fact, motion can affect measurements even for simple global dimming televisions.

Consider a television that adjusts the entire backlight (global backlight modulation) based on the content APL. If that television has a temporal delay when switching between bright and dark scenes, power consumption assessments on that TV will lead to different results than observed on TVs not exhibiting such a temporal delay.

The current SDR test loop has abrupt editing cuts every few seconds. There is some grouping of bright and dark scenes, but the grouping is limited. The development of this SDR test loop did not consider motion-based responses of television sets.

This HDR document recommends reducing motion response effects by grouping test clip scenes based on their relative brightness and to fade, rather than hard cut between scenes. This also appears to be a more accurate model of typical consumer video today. The representative HDR test clips accompanying this document use such scene grouping and scene-to-scene fades.

A.4 Standby modes and smart television set features

A.4.1 Quick start

Some TVs can take more than ten seconds to turn-on and initialize their memory, tuners, and if equipped, their network connections and other features. TV manufacturers may choose to provide a “Quick Start” menu option allowing the TV, when turned off, to keep certain functions powered such as tuners or network connections. In exchange for quicker start-up times, Quick Start generally requires additional standby power consumption. It should be noted that Quick Start energy use is being incorporated into some standby power measurement methods. It is suggested that future IEC work in this area consider if Quick Start is still in use by manufacturers or if network standby features discussed below adequately cover this topic.

A.4.2 Networked standby features

Smart TVs bring the potential for both power saving and power consuming features. Among these are standby modes such as Standby-Passive where a TV can only be turned on by a front panel or remote control button press, and Standby-Active-High where a TV may also be turned on by an external signal from, for example, another device on the TV's local Ethernet or WiFi network. This 'networked standby' feature can be very useful to provide software updates or other maintenance/housekeeping within the TV while the user is not watching the TV. In order to listen for and respond to those external signals, a TV must have a portion of its circuitry powered. The impact of those updates/housekeeping activities and the circuitry necessary to enable them needs further discussion before a suitable test method can be devised.

A.4.3 Smart TV applications

Smart TVs also often offer platforms that can be leveraged by software developers to offer new software applications that enable new capabilities and features not present when the TV was sold to a consumer. By downloading such applications, consumers can turn their televisions into set-top-box equivalents utilizing content primarily from the Internet. It is also possible that a downloaded application can increase a TV's power consumption by offering image processing or other advanced features that were not included with the original TV as purchased. Like networked standby above, the impact of smart TV applications on TV power consumption needs discussion before suitable test methods can be devised.

A.5 Audio

Some new audio codecs, such as AC-4 and MPEG-H, utilized for example in ATSC 3.0, are based on object-based audio, rather than dedicated channels. In object-based audio, the various components of an audio mix are provided with location information for each object. The audio objects are mixed when rendered for playback or for delivery over a channel-based interface. This allows a single audio stream to accommodate a variety of audio playback systems whether they are mono, stereo, 2.1, 5.1 or greater as well as systems that include sound sources above or below the intended listening positions.

It is possible that future television sets with object-based audio decoders might consume additional power in order to render the audio to the television loudspeakers or to an interface that provides the signal stream to an external audio playback system. A future project team should consider collecting data to determine if additional power is consumed for this feature and if that additional power is significant enough to be considered in a future measurement method standard.

Annex B
(informative)

Details on content assessment methods

B.1 Overview

This annex provides additional details on the assessment methods carried out by Pacific Crest Labs (PCL).

B.2 Methods for analysis done by PCL on December 20, 2018

B.2.1 General

In the second half of 2018, PCL contracted with Company 3, a Hollywood colouring and digital mastering firm, to produce professionally coloured and produced video files based on RAW video content filmed by CLASP and shared publicly in 2016. In December 2018, PCL used its TV test farm to measure the impact of the following variables on average TV power use:

- HDR Format: Dolby Vision® versus HDR10;
- frame rate;
- resolution.

The results are reflected in Table 3, Table 5 and Table 6. This clause of Annex B provides details about how Company 3 developed the test clips and how PCL conducted testing.

B.2.2 Test method

- Power measurements performed with ABC and MDD off.
- TVs otherwise in default picture setting recently except TV E, which we tested in calibrated setting.
- Test clips (except Dolby Vision® and HLG) played through Blu-ray™ player with UHD output (even for HD clips).
- Dolby Vision® and HLG clips played via TV USB port input.
- We used 6 TVs of the NEEA TV test farm as listed in Table B.1 in this research.

Table B.1 – Characteristics of TVs of the NEEA test farm used for the March 20, 2019 analysis

Unit	Size	Technology
A	55”	Edge-lit with local dimming
B	55”	Full array with local dimming
C	55”	OLED
D	55”	Edge-lit with local dimming
E	55”	Full array with local dimming
F	55”	Full array with local dimming

B.2.3 File name decoder

Table B.2 provides a reference to the actual file name in the repository and how they are referenced throughout this report.

Table B.2 – File name decoder

Clip label	Res.	FPS	File name
PCL Dolby Vision® 4 000 cd/m^2	HD	25	pcl_clasp_sept14th_25fps_DV-Profile5_12Mbps_HD.mp4
PCL Dolby Vision® 4 000 cd/m^2	UHD	25	pcl_clasp_sept14th_25fps_DV-Profile5_20Mbps_UHD.mp4
PCL HDR10 1 000 nit: Dolby Vision® Transform	HD	25	HEVC_PCL_1000Nit_Render_1080.mp4
PCL HDR10 1 000 nit: Dolby Vision® Transform	UHD	25	HEVC_PCL_1000Nit_Render_2160.mp4
PCL HDR10 1 000 nit: HDR10 Grade	HD	25	HEVC_PCL_REC2020_1080.mp4
PCL HDR10 1 000 nit: HDR10 Grade	UHD	25	HEVC_PCL_REC2020_2160.mp4
PCL HDR10 1 000 nit: HDR10 Grade	HD	60	HEVC_PCL_REC2020_5994_1080.mp4
PCL HDR10 1 000 nit: HDR10 Grade	UHD	60	HEVC_PCL_REC2020_5994_2160.mp4
PCL HLG1: from HDR10 Grade	HD	25	HEVC_PCL_1080_HG1.mp4
PCL HLG1: from HDR10 Grade	UHD	25	HEVC_PCL_10bit_HLG1_2160.mp4
PCL HLG2: from SDR	HD	25	HEVC_PCL_HLG2_1080_V2.mp4
PCL HLG2: from SDR	UHD	25	HEVC_PCL_HLG2_2160.mp4
SDR: HDR10 Transform	HD	25	HEVC_PCL_REC709_1080.mp4
SDR: HDR10 Transform	UHD	25	HEVC_PCL_REC709_2160.mp4

B.2.4 Workflow for experimental test clips

Table B.3 to Table B.7 describe the workflow used by Company 3 to create all test clips evaluated in this report with the exception of the final test clip evaluated in Figure 5, for which the workflow is described in Clause B.4.

Table B.3 – Workflow

Resolve project (.DRP)		Colour pipeline					EOTF	Colour space
		RAW colour space	Colour transform		Colourist trim	Meta-data trims		
A	Dolby Vision4000_pcl_clasp_sept14th_25fps_181015	F:55FALD Raw (S-Log 2)		P3D65	Trimmed	1000/100 nit	ST. 2084 (PQ)	P3 D65
B	Rec2020_pcl_clasp_sept14th_181015	F:55FALD Raw (S-Log 2)	P3D65	Rec. 2020	Trimmed	NA	ST. 2084 (PQ)	Rec. 2020
C	HLG1_pcl_clasp_sept14th_181015	F:55FALD Raw (S-Log 2)	Rec. 2020	Rec. 2100	Trimmed	NA	ST.2100 (HLG)	Rec. 2020
D	rec709_pcl_clasp_sept14th_181015	F:55FALD Raw (S-Log 2)	Rec. 2020	Rec. 709	Trimmed	NA	BT.1886 (Gamma 2.4)	Rec. 709
E	HLG2_pcl_clasp_sept14th_181015	F:55FALD Raw (S-Log 2)	Rec. 709	Rec. 2100	NA	NA	ST.2100 (HLG)	Rec. 2020
Colour sessions: Resolve 15.2								
Project "A" was graded 1st along with metadata trim grades for 1 000 nit and 100 nit targets. Dolby Vision® version 2.9 analysis								
Project "B" was copied from Project "A" adding the Rec.2020 transform and then graded								
Project "C" was copied from Project "B" adding the Rec.2100 transform and then graded								
Project "D" was copied from Project "B" adding the Rec.709 transform and then graded								
Project "E" was copied from Project "D" adding the Rec.2100 transform. There is no grade. This test simulates a rec 709 to HLG automatic conversion.								
All Grading was completed on a Sony x300 monitor.								
For Dolby Vision® grading a Dolby® Pulsar was also utilized for viewing purposes.								

Table B.4 – Resolve master session: PCL Dolby Vision® 4000 cd/m²

Render/ encoder	Version	Format	Reso- lution	Colour space	EOTF	Bit depth	File name	Delivery date
Resolve 15.2	4000nit / Unconstrained Render	TIFF	3 840 × 2 160	P3D65	PQ	16 bit		
Ateme TITAN File v3.9.0.0		HEVC	3 840 × 2 160	Rec. 2020	PQ	12bit	pcl_clasp_sept14th_25fps_DV-Profile5_20Mbps_UHD.mp4	12/10/2018
		HEVC	1 920 × 1 080	Rec. 2020	PQ	12bit	pcl_clasp_sept14th_25fps_DV-Profile5_12Mbps_HD.mp4	12/10/2018
Dolby® CMOffline (3.01)	1000nit Render	TIFF	3 840 × 2 160	Rec. 2020	PQ	16 Bit		
ColorFront Transkoder (2018 v.38913)	1000nit	HEVC	3 840 × 2 160	Rec. 2020	PQ	10bit	HEVC_PCL_1000Nit_Render_2160.mp4	12/7/2018
	1000nit	HEVC	1 920 × 1 080	Rec. 2020	PQ	10bit	HEVC_PCL_1000Nit_Render_1080.mp4	12/7/2018
Render Process:								
Master renders are rendered from the resolve session.								
4 000 nit TIFFs (Audio and XML Metadata) are sent to Deluxe for Dolby Vision® Encode								
To mimic the process of generating a HDR10 deliverable derived from Dolby Vision® Metadata (a process common for UHD BD)								
Using the 4000nit renders and the XML metadata a set of TIFFs are created at the 1 000 nit target level. These TIFFs become the source for a set of HEVC HD10								
Colorfront Transkoder is used to create the UHD and HD HEVC and light level reports.								

Table B.5 – Resolve master session: PCL HDR10 1000 nit: HDR10 grade

Render/ encoder	Version	Format	Reso- lution	Colour space	EOTF	Bit depth	File name	Delivery date
Resolve 15.2	1000nit HDR-10 Render	TIFF	3 840 × 2160	Rec. 2020	PQ	16 bit		
		TIFF	1 920 × 1 080	Rec. 2020	PQ	16 bit		
Autodesk Flame 2018	1000nit HDR-10 60fps	ProRes XQ	3 840 × 2 160	Rec. 2020	PQ	16 bit		
ColorFront Transkoder (2018 v.38913)	1000nit	HEVC	3 840 × 2 160	Rec. 2020	PQ	10bit	HEVC_PCL_REC2020_2160.mp4	12/3/2018
	1000nit	HEVC	1 920 × 1 080	Rec. 2020	PQ	10bit	HEVC_PCL_REC2020_1080.mp4	12/3/2018
	1000nit (60fps)	HEVC	3 840 × 2 160	Rec. 2020	PQ	10bit	HEVC_PCL_REC2020_5994_2160.mp4	12/6/2018
	1000nit (60fps)	HEVC	1 920 × 1 080	Rec. 2020	PQ	10bit	HEVC_PCL_REC2020_5994_1080.mp4	12/6/2018
Render Process:								
Master renders are rendered from the resolve session.								
To create the 60 fps conversion the TIFFs from the resolve session are converted in Flame. The ProRes XQ output is the source for the HEVC Encode.								
Colorfront Transkoder is used to create the UHD and HD HEVC and light level reports.								

Table B.6 – Resolve master session: HLG1

Render/ encoder	Version	Format	Reso-lution	Colour space	EOTF	Bit depth	File name	Delivery date
Resolve 15.2	HLG	TIFF	3 840 × 2 160	Rec. 2020	HLG	16 bit		
		TIFF	1 920 × 1 080	Rec. 2020	HLG	16 bit		
HLG1								
ColorFront Transkoder (2018 v.38913)	HLG (graded)	HEVC	3 840 × 2 160	Rec. 2020	HLG	10 bit	HEVC_PCL_10bit_HLG1_2160.mp4	12/3/2018
	HLG (graded)	HEVC	1 920 × 1 080	Rec. 2020	HLG	10 bit	HEVC_PCL_1080_HG1.mp4	12/3/2018

Table B.7 – Resolve master session: HLG2

Render/ encoder	Version	Format	Reso-lution	Colour space	EOTF	Bit depth	File name	Delivery date
Resolve 15.2	HLG	TIFF	3 840 × 2 160	Rec. 2020	HLG	16 bit		
		TIFF	1 920 × 1 080	Rec. 2020	HLG	16 bit		
HLG2								
ColorFront Transkoder (2018 v.38913)	HLG (graded)	HEVC	3 840 × 2 160	Rec. 2020	HLG	10 bit	HEVC_PCL_HLG2_2160.mp4	12/3/2018
	HLG (graded)	HEVC	1 920 × 1 080	Rec. 2020	HLG	10 bit	HEVC_PCL_HLG2_1080_V2.mp4	12/6/2018
Render Process:								
Master renders are rendered from the resolve session.								
Colorfront Transkoder is used to create the UHD and HD HEVC and light level reports.								

B.3 Methods for analysis done by PCL on March 20, 2019

In the first quarter of 2018, PCL used its TV test farm to measure the impact of the following variables on average TV power use:

- mastering display brightness.

The results are reflected in Table 4. This subclause of Annex B provides details about how PCL conducted March 20 testing.

Test method:

- power measurements performed with ABC and MDD off;
- TVs in default picture setting except TV E, which we tested in its recommended pre-set picture setting;
- test clips (except Dolby Vision® and HLG) played through Blu-ray™ player with UHD output (even for HD clips);
- Dolby Vision® and HLG clips played via TV USB port input;
- 8 TV models of the NEEA test farm as listed in Table B.8 have been used in this research. Letter assignments are different than for 20 Dec 2018 analysis results.

Table B.8 – Characteristics of TVs of the NEEA test farm used for the March 20, 2019 analysis

Unit	Size	Technology	Correlation to 20 December letter labels
A	55"	OLED	C
B	49"	Edge-lit with local dimming	D
C	55"	Quantum dot full array with local dimming	B
D	55"	Edge-lit with local dimming	A
E	55"	Full array with local dimming	F
F	55"	Full array with local dimming	E
G	55"	Full array without local dimming	-
H	55"	Edge-lit without local dimming	-

B.4 Rendering final test clip from DaVinci Resolve Studio 15

B.4.1 HDR10 workflow

Render HDR10 HD and UHD 25 fps Quicktime movies with DNxHR 444 12-bit encoding, then perform the following additional encoding using FFmpeg [23].

NOTE We used FFmpeg to convert to ProRes because the Windows version of Resolve does not support ProRes render.

```
rem HDR10 UHD
cd\
cd ffmpeg

rem Convert to ProRes
ffmpeg.exe -i "F:\071819HDR10_UHD_25fps_DNX.mov" -c:v prores_ks -profile:v 3 -
qscale:v 4 -vendor ap10 -pix_fmt yuv422p10le -y H:\071819HDR10_UHD_25fps_ProRes.mov

rem Make 59.94fps
ffmpeg -i "H:\071819HDR10_UHD_25fps_ProRes.mov" -r 60000/1001 -c:v prores_ks -
profile:v 3 -qscale:v 4 -vendor ap10 -pix_fmt yuv422p10le -c:a copy -y
F:\071819HDR10_UHD_5994fps_ProRes.mov

rem ProRes to MP4 conversion with metadata
rem GOP size = 1s (keyint=FrameRate)
rem MPEG Level = 5.1
rem HDR10 metadata set manually:
rem Color range: Limited
rem Color primaries: BT.2020
rem Transfer characteristics: PQ
rem Matrix coefficients: BT.2020 non-constant
rem Mastering display color primaries: BT.2020
rem Mastering display luminance: min: 0.0001 cd/m2, max: 1000 cd/m2
rem Maximum Content Light Level: 1000 cd/m2
rem Maximum Frame-Average Light Level: 95 cd/m2

ffmpeg -i "F:\071819HDR10_UHD_5994fps_ProRes.mov" -c:v libx265 -x265-params
"level=5.1:frame-threads=4:keyint=60:ref=1:no-open-
gop=1:weightp=0:weightb=0:cutree=0:rc-lookahead=0:bframes=0:scenecut=0:b-
adapt=0:repeat-
headers=1:range=limited:colorprim=bt2020:transfer=smpte2084:colormatrix=bt2020nc:max-
cll=1000,95:master-
display=G(8500,39850)B(6550,2300)R(35400,14600)WP(15635,16450)L(10000000,1)" -aspect
16:9 -pix_fmt yuv420p10le -b:v 40000k -bufsize -1 -movflags +faststart -c:a copy -y
H:\071819HDR10_UHD_5994fps.mp4

rem HDR10 HD

rem Convert to ProRes
ffmpeg.exe -i "F:\071819HDR10_HD_25fps_DNX.mov" -c:v prores_ks -profile:v 3 -qscale:v
4 -vendor ap10 -pix_fmt yuv422p10le -y H:\071819HDR10_HD_25fps_ProRes.mov

rem Make 59.94fps
ffmpeg -i "H:\071819HDR10_HD_25fps_ProRes.mov" -r 60000/1001 -c:v prores_ks -
profile:v 3 -qscale:v 4 -vendor ap10 -pix_fmt yuv422p10le -c:a copy -y
F:\071819HDR10_HD_5994fps_ProRes.mov

rem ProRes to MP4 conversion with metadata
rem GOP size = 1s (keyint=FrameRate)
rem MPEG Level = 5.1
rem HDR10 metadata set manually:
rem Color range: Limited
rem Color primaries: BT.2020
rem Transfer characteristic: PQ
rem Matrix coefficients: BT.2020 non-constant
rem Mastering display color primaries: BT.2020
rem Mastering display luminance: min: 0.0001 cd/m2, max: 1000 cd/m2
rem Maximum Content Light Level: 1000 cd/m2
rem Maximum Frame-Average Light Level: 95 cd/m2
```