KEEPIXO

by ALLEGRO DVT

High Dynamic Range Video

The Future of TV Viewing Experience

- White Paper -

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Introduction

The video industry has always worked to improve the TV viewing experience. More than a decade ago, the transition from SD to HD provided significant improvements to video quality. 3DTV was another attempt that failed to get traction and ended up with limited success. More recently, there has been much hype about 4K/Ultra-HD from the CE industry in effort to drive sales of high-end TV models with bigger screens.

On the service providers side such technological transitions have historically taken longer time as multiple elements need to fall into place. These include wide availability of new content, sufficient installed base of TV sets and reasonable cost of new equipment both on the head-end and end-customer sides.

While there is a clear push from the CE industry to adopt 4K/Ultra-HD, service providers are still struggling with the new value proposition of this new format. Various studies have shown that focusing on delivering more pixels will have limited impact on the viewing experience[1] while incurring extra cost throughout the whole content delivery value chain. On the other hand, there is a general consensus within the industry that high dynamic range (HDR) video will substantially improve the user's viewing experience and can unlock the potential of Ultra-HD. Efforts are underway to standardize HDR implementation within the end-to-end content delivery chain.

This paper outlines the key principles of HDR and reviews the remaining challenges ahead to enable mass commercial deployment of HDR video.

What is HDR?

Increased Brightness and Contrast

HDR is a technology which allows for higher contrast between the dark and the bright areas of a picture. Historically, video transmission has limited the brightness of pictures to about 100 nits[2]. This limitation was due to the physical characteristics of CRT TVs. By comparison, the dynamic range of the human eye covers up to 12 decades and can adapt to light levels ranging from approximatively 10^{-5} nit up to 10^{+7} nits.

With the advent of new TV technologies such as LCD, it is now possible to reproduce brighter pictures and lower levels of black; therefore allowing a substantial increase of the overall dynamic range or contrast ratio of the picture.

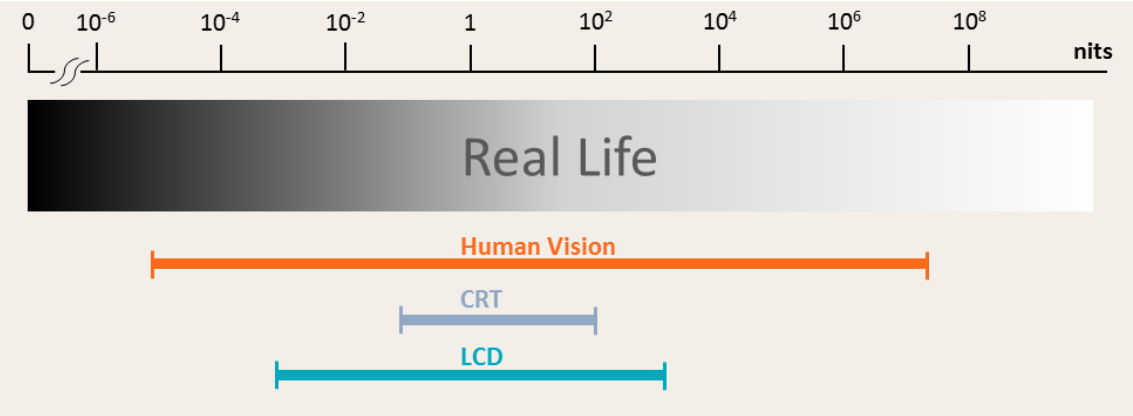

Figure 1 : Luminance Dynamic Range

[1] The benefit of Ultra-HD is more visible on big screens (>65"). Furthermore, for optimal Ultra-HD experience, it is recommended to limit the viewing distance to 1.5H (1.5x the height of the screen).
[2] Nits or candela/m² (cd/m²) is a measure of pixel brightness

Higher Bit-Depth

The advent of Ultra-HD also marked the transition to a higher bit depth. Essentially, the number of bits used to sample the pixels moved from 8-bit to 10-bit allowing the representation of 64 times more colors and more importantly providing smoother transitions between colors to reduce banding effects.

More Colors – Wide Color Gamut (WCG)

Modern TVs can produce more colors than CRT TVs and are therefore capable of rendering more realistic pictures. Up until now, the industry has used the Rec.709[3] color space throughout the video delivery chain. Video content based on Rec.709 can reproduce about 35% of all possible colors that are visible to the human eye. This limitation was due to the CRT technology which restricted the range of colors that can be rendered. The new ITU Rec.2020 which was approved in August 2012 covers of up to 75% of all visible colors. Many modern TVs have a color gamut that is close to Rec.2020.

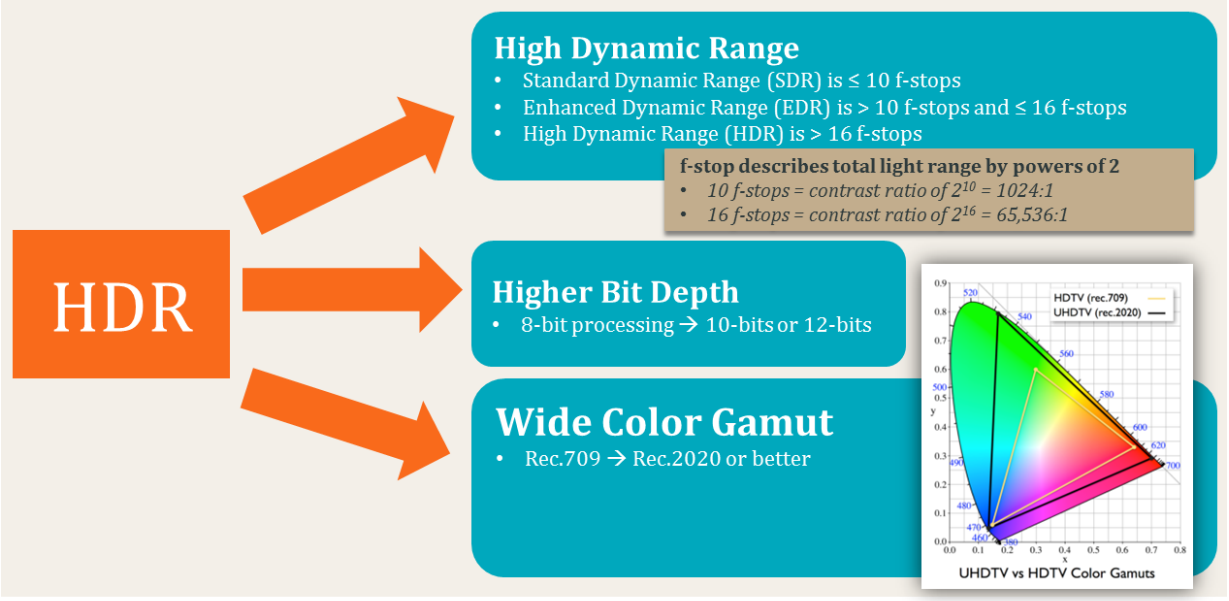

Figure 2: Components of HDR technology

The combination of higher dynamic range, wider color gamut and higher bit-depth constitutes what the industry refers to as HDR. In the following section of this paper, the term HDR refers to the combination of these three elements.

[3] ITU-R Recommandation Rec.709 - http//en.wikipedia.org/wiki/Rec._709

Implementing HDR

Transfer Functions

OETF (Optical Electrical Transfer Function) refers to the way the optical signal gets translated into voltage at the capture (camera) side. Similarly, **EOTF** (Electrical Optical Transfer Function) implements the opposite operation and is carried out within the TV to render the final image.

OETF/EOTF used for Rec.709 content have followed the so-called gamma curve up until now. The Gamma transfer function was originally introduced to compensate for the non-linear input–output characteristic of CRT displays. Rec.709 also limited the dynamic range of the luminance to 100 cd/m² (nits).

In order to increase the dynamic range of the luminance, new OETF/EOTF are needed. In 2014, SMPTE ratified ST.2084 which describes a new EOTF based on the behavior of the human visual system and allows a high luminance range capability of 0 to 10,000cd/m². The new transfer function is based on Peter G. J. Barten work and takes into account the non-linearity of the human eye sensitivity to contrast changes. The result is a new non-linear quantization law called "Perceptual Quantization (PQ)" that uses 12 bits samples to accurately represent luminance values without any contouring/banding effects. The new ST.2084 makes optimal use of sampling bits and although it requires 12 bits, 10 bit sampling remains acceptable for real-life content because of built-in noise level.

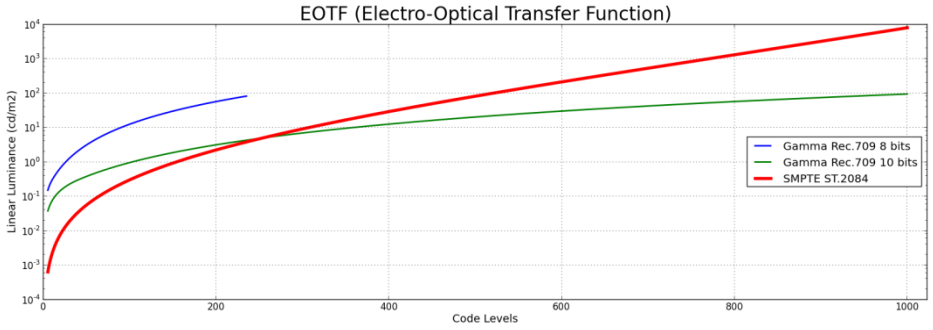

Figure 3 : EOTF examples - SMPTE ST.2084 vs. Gamma

Other EOTFs with increased dynamic range are also possible. There are proposals for modified Gamma curves (also called Hybrid Gamma) that try to stick to the traditional Gamma curve as much as possible and diverge from it to reach higher luminance values as brightness increases. The main benefit for such approaches is to maintain backward compatibility and minimize changes to existing equipment and television production process.

Color Space

HDR content can use different color spaces (Rec.709, Rec.2020…). However, in order to take advantage of the increased color gamut of modern TVs, HDR content is commonly available in Rec.2020; a color space that is much larger than Rec.709.

HDR within the delivery chain

One of the key considerations when implementing HDR is how to ensure backward compatibility with legacy SDR (Standard Dynamic Range) equipment such as STBs and TVs. Backward compatibility is important in broadcast and OTT environments as service providers need to make sure that content can be viewed on legacy SDR TVs which will continue to represent the majority of installed TVs over the foreseeable future.

A variety of backward compatible HDR solutions have been put forward by companies such as BBC, Dolby, Philips, Technicolor to name a few of them. The industry has yet to agree on one or multiple standards for end-to-end HDR content delivery.

Content production and format conversion

Today's cameras are able to capture content with high dynamic range and extended color gamut, sometimes using proprietary transfer functions and color gamut that can vary from one vendor to another.

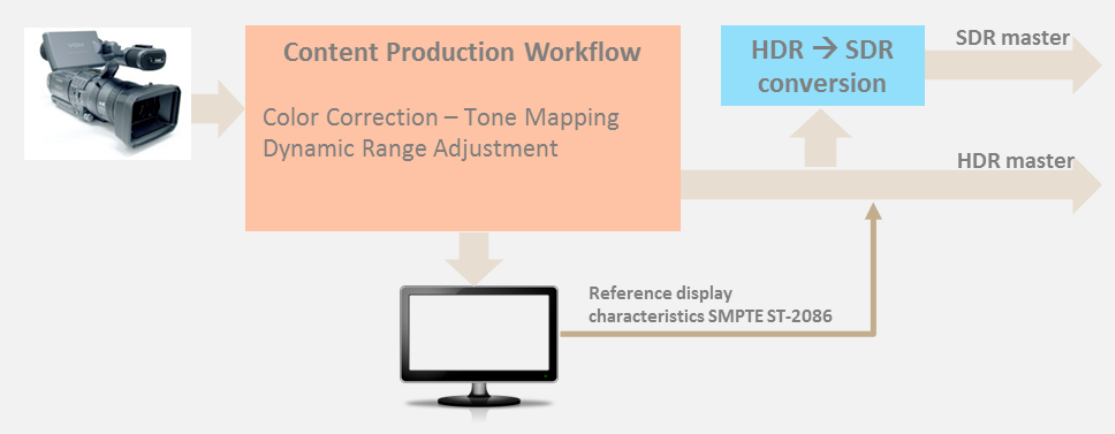

Figure 4: Content Production Workflow

Content production workflows are used to modify the colors based on the artistic intent and selected transmission formats. They also carry out dynamic range adjustment as needed. Production workflows produce the HDR master using an OETF such as ST.2084 or another OETF that was selected for content delivery. The production workflow can also include an HDR to SDR conversion to ensure backward compatibility as needed.

The characteristics of the reference display within the content production workflow can be carried as additional metadata in the HDR content. This mechanism was standardized in SMPTE ST.2086. It is used to carry information such as color primaries and luminance range of the reference display which can be fed to the HDR TV on the receive side to accurately render the content by preserving the artistic intent.

Non-backward compatible system (Blu-ray)

When the Blu-ray Association defined new 4K specifications along with HDR support, it was decided not to include backward compatibility as a new generation of 4K Blu-ray players is needed anyway. The new spec was frozen in May 2015 and includes support for 4K and HDR using SMPTE ST.2084 EOTF and Rec.2020 color space. The Blu-ray HDR technology is referred to as HDR-10 (for 10 bit content) or HDR-12 (for 12 bit content).

Backward compatible systems

Backward compatibility with SDR displays can be achieved in three ways:

1. By simulcasting both SDR and HDR content – this option is not practical in broadcast/OTT environments as it consumes extra bandwidth. However it can be envisaged for VOD or packaged content (Blu-ray discs) by selecting the proper format based on the capabilities of the TV.
2. By using a Dual Layer approach – the HDR → SDR conversion operation produces a backward compatible base layer which includes the SDR content as well as an enhancement layer that carries extra dynamic range and color information. Both layers get encoded and transmitted. On the receiver side, the base layer is decoded to retrieve an SDR compatible content that can be directly displayed on legacy TVs. The enhancement layer is decoded and combined with the base layer to produce the HDR version of the content. On average, the dual layer approach requires 15% to 30% extra bandwidth to transmit the enhancement layer. On the receiver side, an extra decoder is required as well as dedicated HW to carry out HDR signal reconstruction.
3. By using a Single Layer approach – the HDR → SDR conversion operation produces a single layer stream and a set of metadata that carries extra dynamic range and color information. The single layer includes the SDR content and gets carried throughout the delivery chain. In parallel, metadata is inserted as part of the single layer stream[4]. Legacy systems retrieve the SDR content and ignore the metadata to produce a version of content that can be displayed on SDR TVs. HDR receivers use the metadata to reconstruct the HDR content for delivery to HDR TVs. Typically, bandwidth overhead due to metadata insertion is limited to a few hundreds of kbits/s

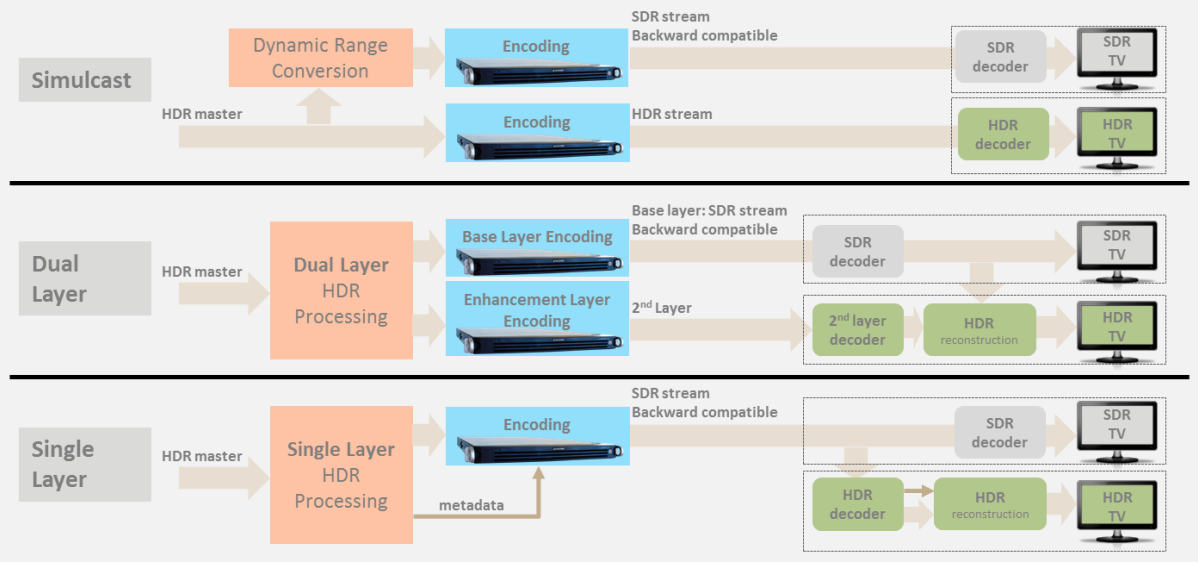

Figure 5: Backward Compatibility implementations in HDR delivery chain

In the above figure, decoder and HDR reconstruction blocks can be implemented in a standalone device such as a STB or integrated within the TV.

[4] When using H.264 or HEVC codecs, one way to insert metadata is to use Supplemental enhancement information (SEI) messages.

HDR Standardization

Efforts are underway to define new standards for delivering HDR content. Industry standards are needed to ensure interoperability between all the components of the delivery chain starting from content capture, content production, encoding, transport, decoding and finally display. However, getting the industry to agree on one across-the-board approach is proving difficult given the business implications that are on stake. The following provides an overview of standardization activities.

SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS (SMPTE)

SMPTE defined a set of new standards for HDR EOTF and signaling:

- ST.2084: High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays
- ST.2086: Mastering Display Color Volume Metadata Supporting High Luminance and Wide Color Gamut Images
- ST.2094: Content Dependent (Dynamic) Metadata for Color Volume Transformation of High Luminance and Wide Color Gamut Images. This is still work in progress and once ratified will help standardize some HDR single stream technologies.

Blu-ray

As discussed earlier in this document, Blu-ray ratified a new specification for 4K/Ultra-HD and included support for HDR based on SMPTE standards. Blu-ray did not address backward compatibility as new 4K Blu-ray players are needed anyway. The main HDR technology (HDR-10, HDR-12) is based on SMPTE ST.2084 EOTF and Rec.2020 color space and limits the dynamic range of the luminance to 1000 nits. The new specification also includes optional support for Dolby, Technicolor and Philips HDR technologies.

MPEG

MPEG included new SEI messages to support HDR signaling in the 2nd edition of the HEVC standard that was released in Oct 2014. During its 112th meeting in Warsaw, MPEG also agreed on "Fast Track" HDR standardization with a target to freeze the new spec by Oct 2016. Up to 8 different HDR solutions are currently being considered.

ATSC

ATSC has started working on ATSC3.0, a new standard for terrestrial broadcast which will include support for Ultra-HD, HDR and immersive audio. ATSC3.0 standard completion is expected in 2016. A call for proposals for HDR technologies was issued. Proposals from Ericsson, Technicolor, Sharp, BBC/NHK, Qualcomm and Dolby were received and being reviewed.

HDMI/CEA (Consumer Electronics Association)

In April 2015, the HDMI Forum released the new HDMI2.0a specification with extensions to enable transmission of HDR formats. This new version allows transmission of SMPTE-2086 static metadata based on CEA-861.3 (HDR Static Metadata Extensions published in Jan 2015).

UHD Alliance

Announced at CES-2015, the alliance was formed to establish quality requirements for best Ultra-HD experience. Another aim of the UHD Alliance is to develop branding and logos in order to distinguish products that allow consumers to view content in Ultra-HD. In August 2015, the alliance announced it is nearing completion of specifications, certification/compliance and consumer logo programs.

Ultra HD Forum

The Ultra HD Forum is focusing on developing guidelines and best practices for the implementation of end-to-end Ultra-HD systems. The forum will also facilitate interoperability tests between vendors throughout the complete delivery chain.

Conclusions

There is no doubt that HDR is a great technology which will substantially improve the user's viewing experience. It is also anticipated that HDR technology will be applied not only to Ultra-HD but also to HD content. First deployments of HDR from some online video streaming services will begin shortly and the first 4K Blu-ray players are expected to be released by end of 2015. These deployments are likely to use Blu-ray HDR-10 as it is the only standardized technology at the time this paper is written. TV vendors are starting to release new products with built-in support for HDR-10 and HDMI2.0a to enable these early deployments.

The situation on the broadcast side is different as backward compatibility is important. The current fragmentation of HDR proposals and the lack of standardization have somehow led to a standstill which we think will further delay deployment of Ultra-HD. It is important that standardization efforts converge rapidly. We expect to see progress in 2016 as newly formed organizations such UHD Alliance and UHD Forum try to focus the industry's effort towards delivering practical standards for HDR.

Keepixo as a leading provider of professional encoders and a member of the UHD Forum is following closely the progress on HDR standardization efforts. Keepixo also completed proof of concepts of some HDR technologies and demonstrated live end-to-end transmission of HDR content at IBC 2015.

About Keepixo

Keepixo, the spin-off of Allegro DVT's broadcast business, is a leading provider of software-based and cloud-ready head-end solutions for IPTV & OTT. Keepixo offers live encoders, file-based video transcoders and delivery solutions featuring advanced functions such as Catch-Up, Start-Over and nPVR. Keepixo solutions are used by more than 130 customers including 40 tier-1 operators worldwide.

For more information, visit Keepixo's website (http://www.keepixo.com) or contact us at info@keepixo.com