Tech Breakfasts: High Dynamic Range for UHD/4K Television

High Dynamic Range for UHD/4K Television primer

- A bit of history
- Gamma correction and why it was needed and why it's still useful
- How this relates to colour encoding and greyscales; some reminders
- Why gamma is still useful in our HD & UHD/4k world
- Constant Luminance
- Alternate gammas for shooting – Clog/Slog
- Maintaining the HDR through to delivery (via Avid & Baselight etc)
- Hybrid Log gamma vs. DolbyPQ for broadcast deliverables
- ACES for film workflows

What is considered Hi-Def has changed over the years!

Production vs. Delivery formats

Until very recently we have always assumed that our production format largely is the same as out delivery format.

- Pre-history – the 40-line mechanical Televisor (John Logie-Baird, broadcast by the BBC late 20s/early 30s over the GPO ‘phone network!)
- 405-line television – CCIR System A; **a gamma of 2.2** and monochrome with 50i fields.
- 625-line – CCIR System B; **a gamma of 2.2** and monochrome with 50i fields
- 625-line PAL – CCIR System I; **a gamma of 2.2** and 4.43Mhz subcarrier with 50i fields – once we had digital video Rec.601 (1981) became the governing standard.
- 1080-line – Rec.709 (1992) doesn’t define the display response but an assumption of **a gamma of 2.2** has been assumed until 2011 when Rec.1886 defined it.

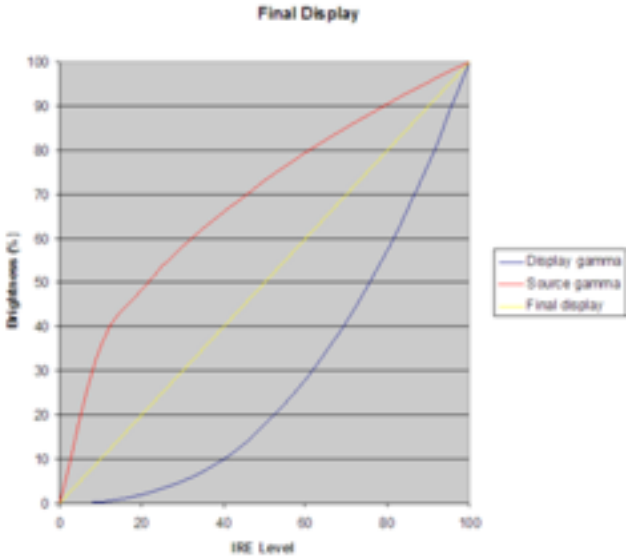
But what is so magical about 2.2 and why are we talking about it now in relation to UHD/ 4k TV?

Why a gamma response?

A cathode ray tube (CRT) converts a video signal to light in a nonlinear way, because the electron gun's intensity (brightness) as a function of applied video voltage is nonlinear. The light intensity I is related to the source voltage Vs according to;

$$I \propto V_s^{\gamma}$$

Which looks like;



Why a gamma response?

- So to achieve a linear transfer function for the whole system (camera -> TV) we need to apply the reverse gamma in the camera to make the CRT appear linear.

- **Camera**: light -> electrical signals, “OETF”
- **Display**: Electrical signal -> light “EOTF”

Colour Systems – *Just a reminder!*

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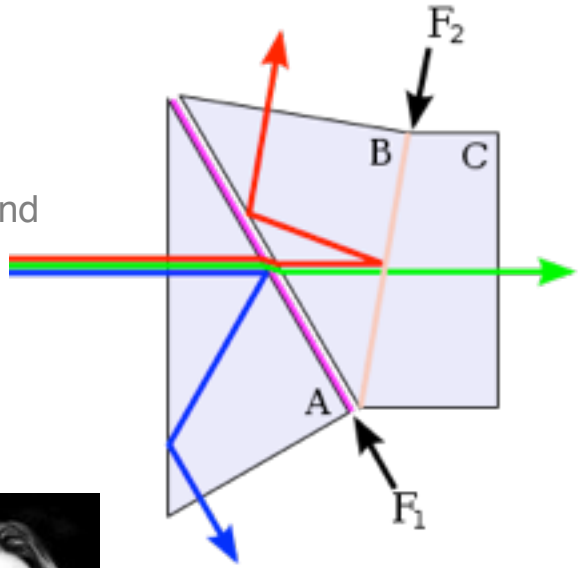
Image acquisition

- All devices that make pictures (TV camera, Telecine machine, computer graphics workstation etc) make pictures as three monochrome images; Red, Green, and Blue.
- This mimics the way the eye works, ‘tristimulus’
- In the case of a TV camera this is achieved with a specially designed glass component referred to as a ‘dichroic block’



Original image.

Image when separated into RGB components.

Colour Systems – *Just a reminder!*

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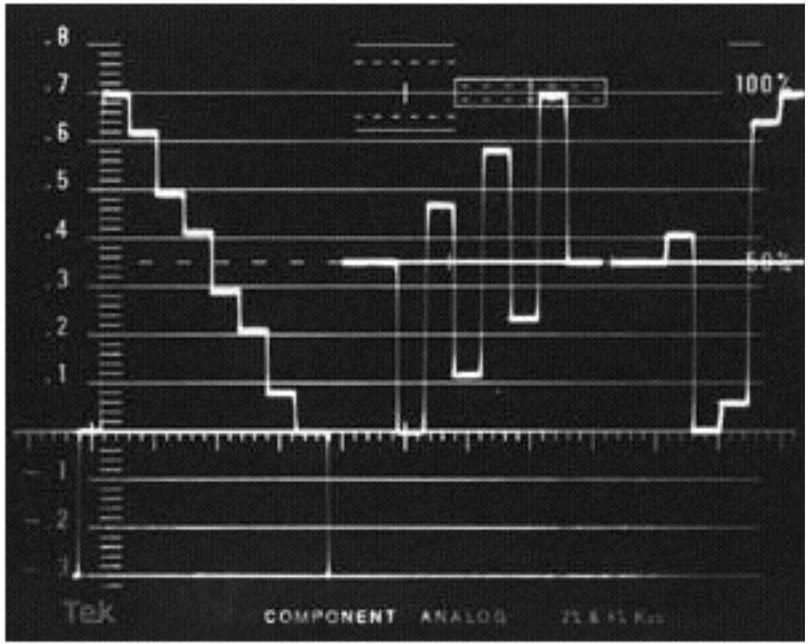
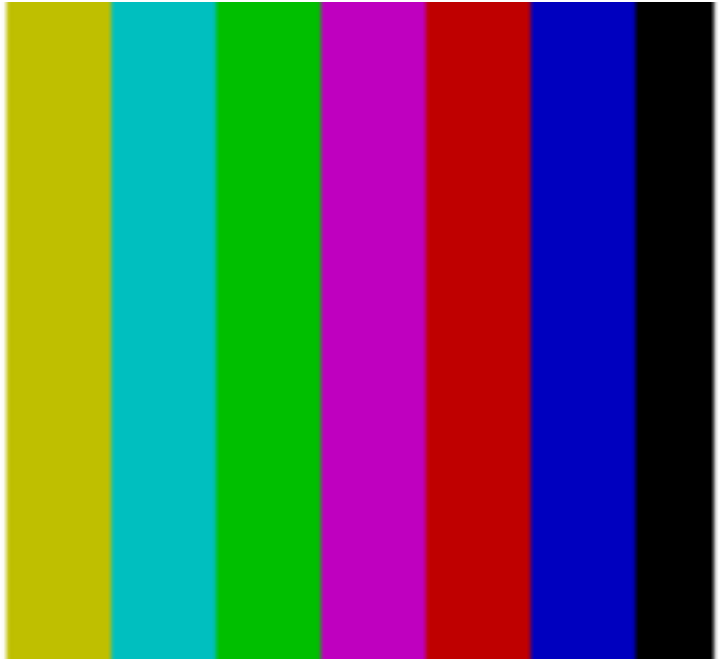
Generation of colour component signals





Count the number of bars (white through black) and match them to the colour bars on the monitor.

Colour channel linearity

Rec.709 states;

$$
\begin{aligned}
Y &= 0.213R + 0.715G + 0.072B \\
C_b &= 0.539(B-Y) + 350mV \\
C_r &= 0.635(R-Y) + 350mV
\end{aligned}
$$

So our greyscale fidelity is dependent on linearity in the luminance channel.

So far, so obvious – but;

- We're no longer using CRTs
- Every point in the chain has more than enough processing to implement whatever response we choose.
- So where does gamma come into all of this and why are we still talking about it?

Gamma is still useful

1. Our eyes do not perceive light the way cameras do. With a camera, when twice the number of photons hit the sensor, it receives twice the signal (a linear relationship). We perceive twice the light as being only a fraction brighter — and increasingly so for higher light intensities (a nonlinear relationship).
2. Gamma encoded images stores greyscale more efficiently. Since gamma encoding redistributes tonal levels closer to how our eyes perceive them, fewer bits are needed to describe a given tonal range. Otherwise, an excess of bits would be devoted to describe the brighter tones (where the camera is relatively more sensitive), and a shortage of bits would be left to describe the darker tones (where the camera is relatively less sensitive).

Gamma is still useful *cont.*

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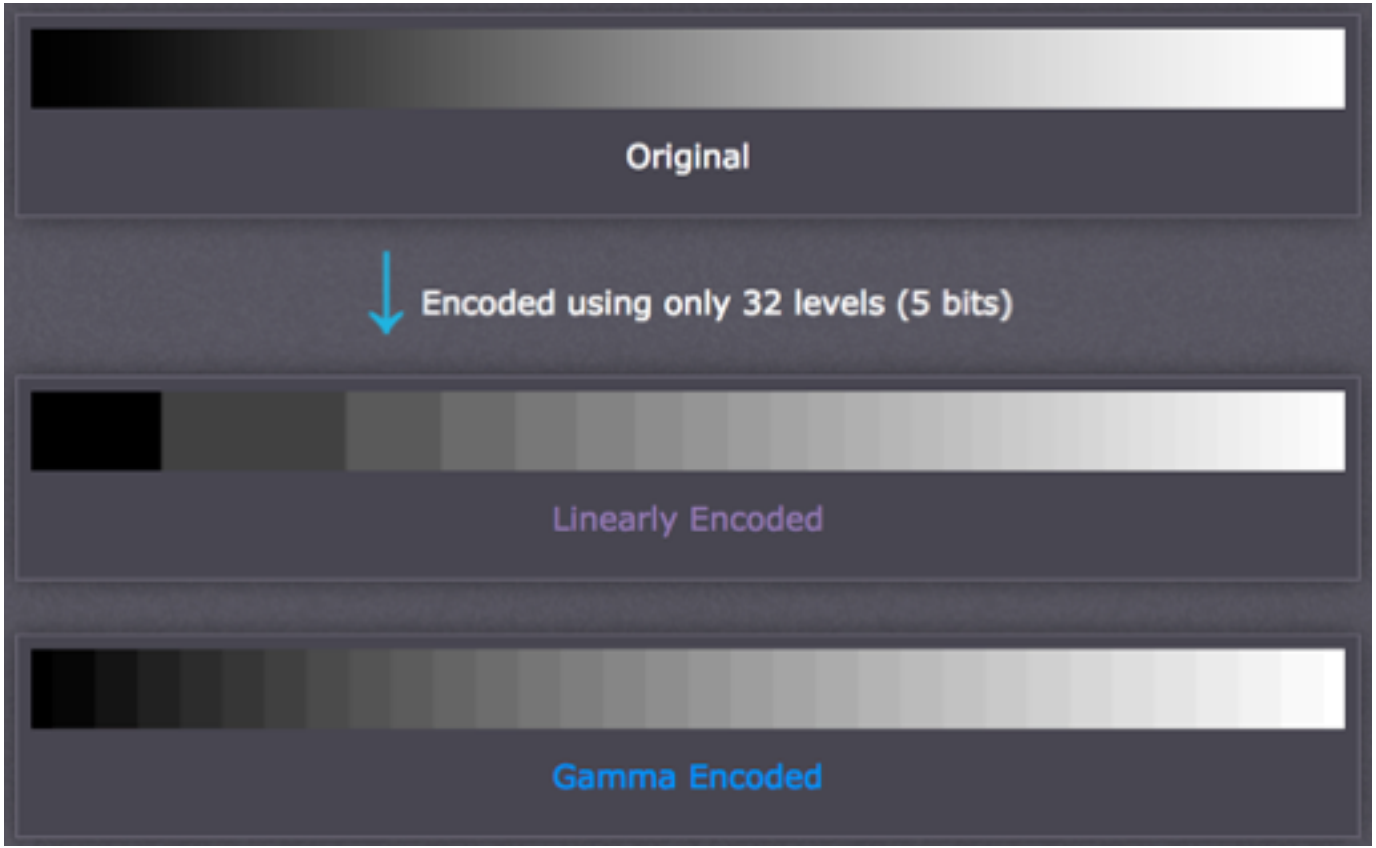

Calibrating Monitors for TV use

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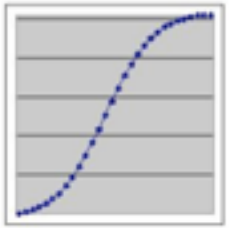
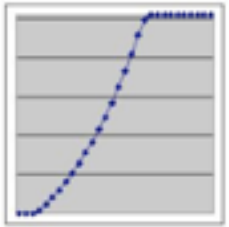
1. Set the overall black level using PLUGE so that dark areas of the picture are faithfully reproduced.
2. Set the peak-white of the monitor to around **100 Cd/m²**
3. Check the colour of the white point so that it sits as near to **6504 kelvins** as possible
4. Check the 10% grey point for the same colour; track up to peak white and ensure the colour temperature remains constant
5. Check the saturation by putting the monitor into blue-check mode and match the blue coming through the luminance path to the blue coming via the C_b channel.
6. Go back and do it all again as the controls interact somewhat.

Gamma with non-TV cameras

LUT Applied - LUT_Light_Illusion_LOG-01_CIN_to_PRINT



LUT Applied - LUT_Light_Illusion_LOG-01_CIN_to_VID



Cameras that are more aimed at digital movie production will often use other gamma curves in an effort to concentrate digital levels where most of the image's latitude is.

The upper image shows a typical Canon EOS-series response (from a C300 – Clog) and the associated gamma.

The lower image shows what LUT would bring the image into a more video-style, Rec.709 (or 1886 to be more accurate).

Alternate gammas with Avid

Notice the headlights of the taxi - you can see details inside the headlight.

exactly the same frame; notice the dark details in the trees against the night-sky.

Alternate gammas with Avid *cont.*

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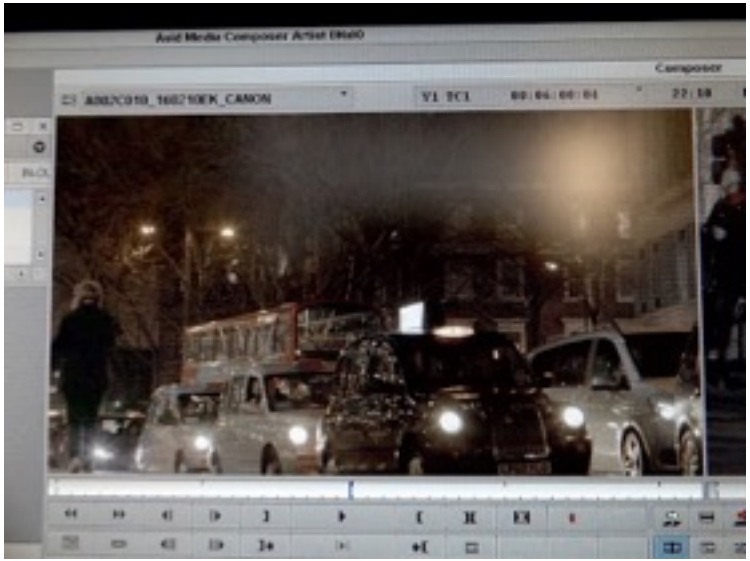
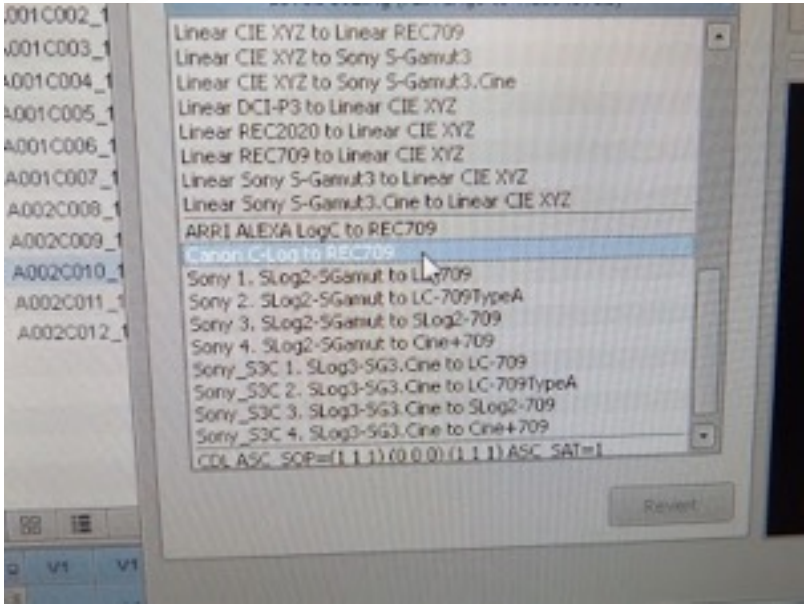
Of course on Media Composer's GUI display you get the CLog gamma rendered as if it was Rec. 709 and so it looks very washed out and lacking in detail.





You can have Avid flatten the gamma of source clips so that it looks OK on the GUI - that doesn't affect sequences that the clip has been used in.

Alternate gammas with Avid *cont.*

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So now clicking the source window and setting the monitor to regular HD gamma (Rec. 1886) shows you what the same material shot on a "regular" camera would look like; very little detail in the blacks and none in the whites.

So we have a choice of many different camera gammas for shooting; what if we could specify brighter highlights for a higher dynamic range on delivery?

High Dynamic Range Standards

HDR is still a bit of a crap-shoot as far as standardisation is concerned;

- BBC/NHK system - HLG
- Dolby Vision / DolbyPQ

The principle of using an alternate gamma so that you concentrate the bit-depth where you want the extra range is well established as we've seen. However – now we have displays that allow peak whites at much higher levels;

- **1,000** Cd/m^2 specula highlights for grading displays; Sony BVM-X300 etc.
- **10,000** Cd/m^2 possible highlights for future domestic displays; future domestic OLEDs

- But remember, **black cannot be made any blacker** with current displays!

High Dynamic Range *cont.*

The hope is that all of these manufacturers will coalesce around Rec.2100

- Supersedes Rec.2020 in defining UHD/4k/8k resolutions, WCG, HDR & HFR
- defines how you handle the specula highlights;
- those very bright parts of the picture which give a real addition to the look of the pictures. These are typically defined to be >500 Cd/m^2
- MUCH brighter than broadcast white!

The idea is that the last bit of dynamic range (10th bit - all values above 512) represent the highlights and everything up to 50% is akin to the usual video dynamic range.

You calibrate the monitor such that 50% is set at 100Cd/m^2 and just hope that the colourimetry of the highlights tracks RGB-wise!

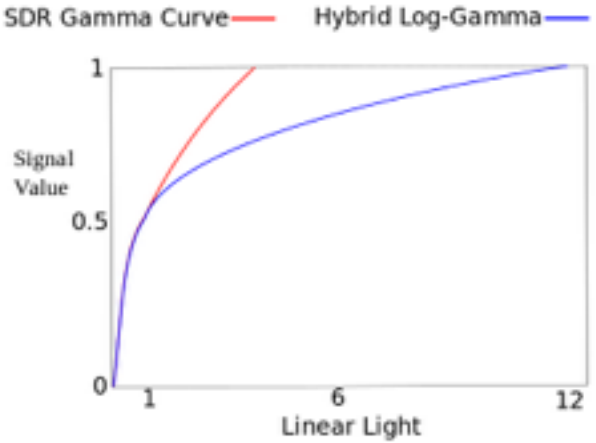
But remember, **black cannot be made any blacker** with current displays!

BBC / NHK Hybrid Log Gamma (HLG)

"HLG is a **scene-referred** system, just like conventional television. The signal represents relative light levels in the original scene, which allows pictures from a single mastering process or live production to be adapted to give the same artistic effect on brighter or darker screens at home. Only the display itself needs information about its own capabilities and environment to faithfully render the scene-referred signal, so metadata that describes the mastering display is not required. HLG also has native compatibility with standard dynamic range (SDR) television within the same colour format, which can be used for ultra-high definition (UHD) SDR displays."

Appeals to broadcasters due to general compatibility with existing 10-bit SDi production installations.

As with all video levels are considered **dimensionless**

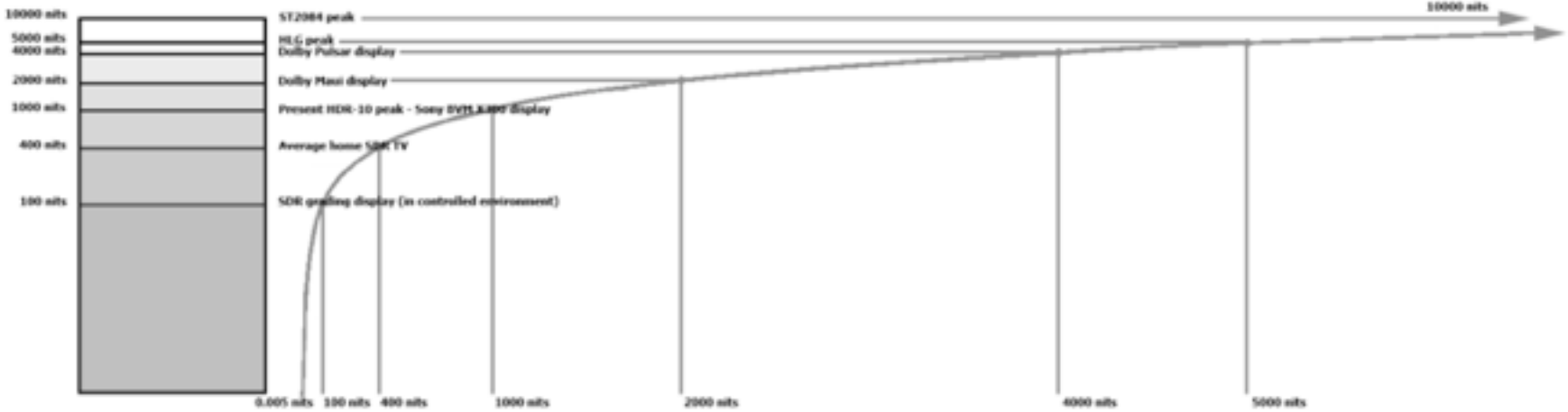


BBC / NHK Hybrid Log Gamma (HLG) *cont.*

- HLG does not need to use metadata since it is compatible with both SDR displays and HDR displays. HLG can be used with displays of different brightness in a wide range of viewing environments.
- The dynamic range that can be perceived by the human eye in a single image is around 14 stops. SDR video has a dynamic range of about 6 stops. Pro SDR video with a bit depth of 10-bits per sample has a dynamic range of about 10 stops. When HLG is displayed on a 1,000 Cd/m^2 display with a bit depth of 10-bits per sample it has a dynamic range of 200,000:1 or 17.6 stops.
- HLG also increases the dynamic range by not including the linear part of the conventional gamma curve used by Rec. 601 and Rec. 709. The linear part of the conventional gamma curve was used to limit camera noise in low light video but is no longer needed with HDR cameras.
- HLG is supported in Rec. 2100 with a nominal peak luminance of 1,000 Cd/m^2.
- HLG is supported in HEVC.

Dolby PQ (Perceptual Quantiser)

- Dolby Vision is the wider set of products that cover both digital cinema and video.
  Unlike HLG DolbyPQ is a **Display Referred** system that uses absolute dimensioned values for the light captured. The metadata that travels in the SDi payload defines what video-levels equate to light levels and how they should be reproduced at the DolbyPQ display end with a maximum of 10,000 Cd/m^2
  The display reports back to the playback device via EDID to convey its maximum



BBC/NHK HLG vs. DolbyPQ – a few thoughts

Both standards for HDR are supported by Rec.2100 and the current DVB-T specification so it seems like no standards body will get behind either!

- As TVs get brighter what happens to material that is mastered at 1,000 Cd/m^2 ?
- How can broadcasters effectively deliver to TVs and mobile devices with a sensible workflow?
- How can broadcasters predict the illumination environment of people's homes?

It seems that HLG is better suited to the badly-configured home viewing environments of video.

If you could have a controlled environment (like a movie theatre) then DolbyVision makes a lot of sense.

ACES workflow of cinema production – brief introduction

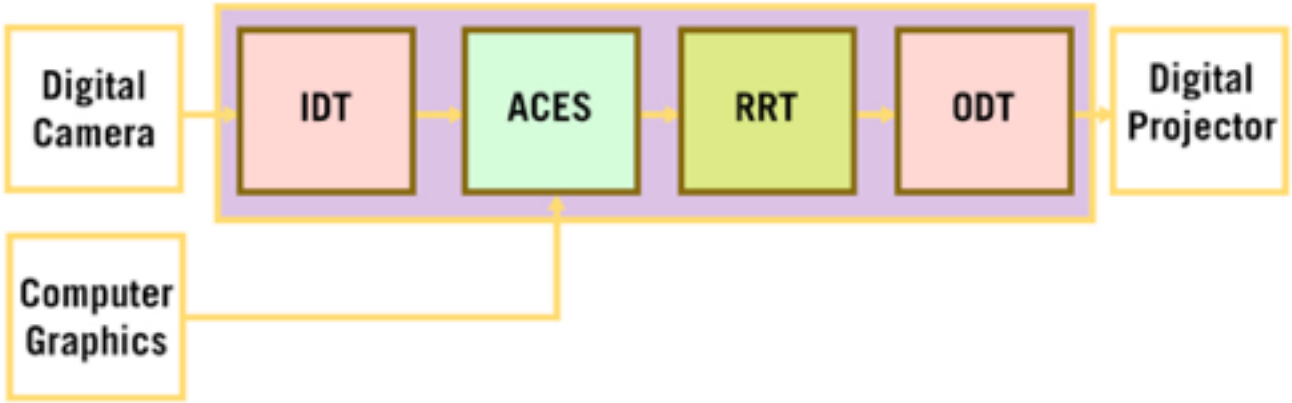
The Academy Colour Encoding System (ACES) is a colour image encoding system created by the Academy of Motion Picture Arts and Sciences that allows for a fully encompassing colour accurate workflow, with "seamless interchange of high quality motion picture images regardless of source"

Ten years of work has derived a system that standardises;

- Its own colour primaries that completely encompass the visible spectral locus as defined by the CIE xyY specification; the RGB primaries (NOT xy) are non-realisable colours.
- The white point is approximate to the CIE D60 standard illuminant (like DCI-P3, but not video!)
- ACES compliant files are encoded in 16-bit half-floats, which are valid in the range -65504.0 to +65504.0 thus allowing 33+ stops of scene-referred relative exposures.
- ACES supports both high dynamic range (HDR) and wide colour gamut (WCG)

Clearly cameras & projectors do not conform to these ideas!

Inside ACES



- Input Device Transform (IDT) – specific to the capture device
- Academy Colour Encoding Specification (ACES) – graphics are rendered straight into ACES
- Reference Rendering Transform (RRT): It has a larger gamut and dynamic range available to allow for rendering to any output device (even ones not yet in existence).
- Output Device Transform (ODT) – specific to the output device.

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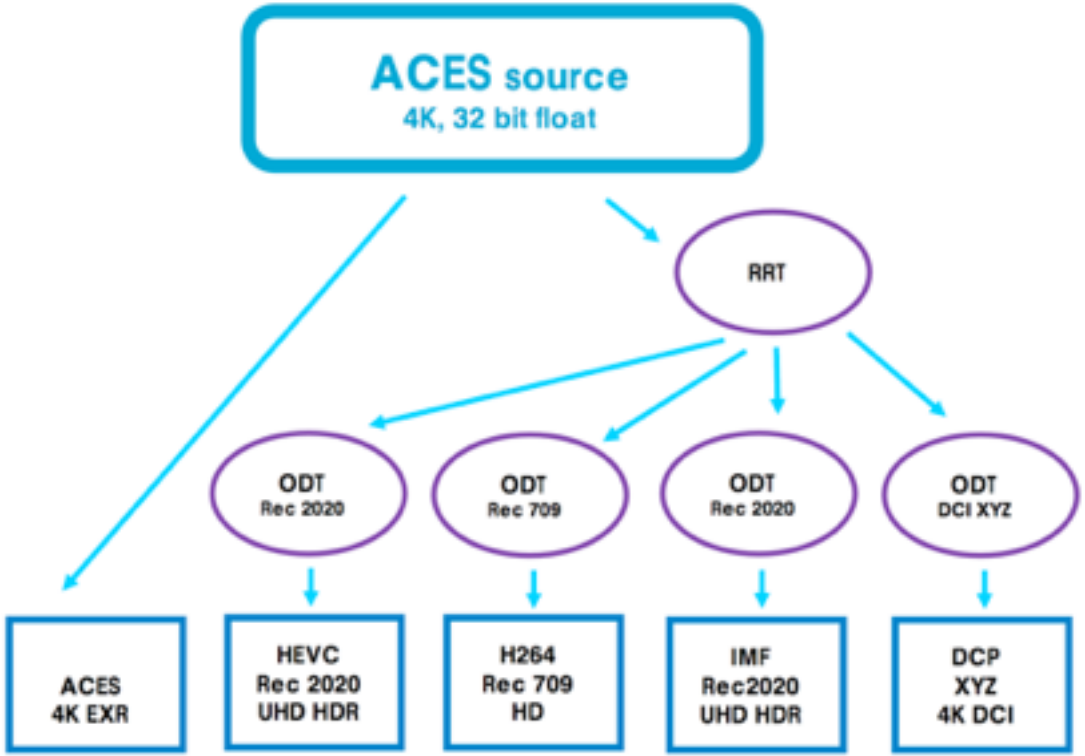
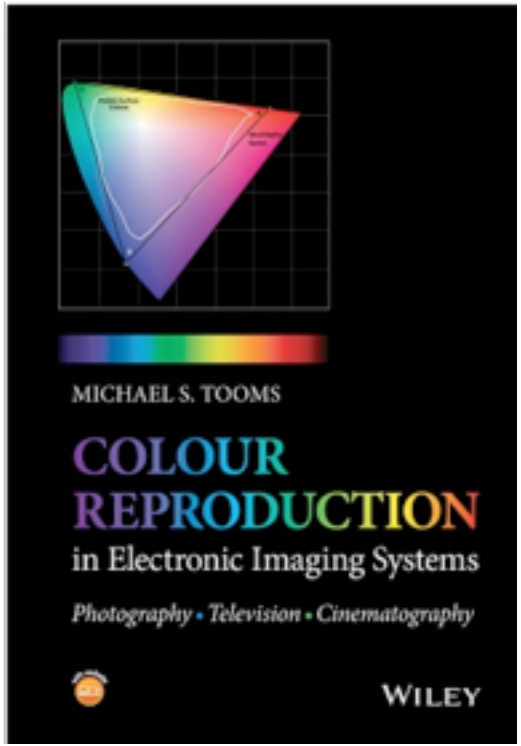
Could ACES be the one workflow to rule them all?



Resources



Michael S. Toon; Colour Reproduction in Electronic Imaging Systems: Photography, Television, Cinematography.

http://www.lightillusion.com/uhdtv.html
Steve Shaw (of LightSpace fame) – excellent article on UHD/HDR,

http://www.poynton.com/PDFs/GammaFAQ.pdf
Charles Poynton

Scott Miller; 2016 Update on HDR Television; SMPTE Motion Imagine Journal, Sept. 2016

http://www.bbc.co.uk/rd/projects/high-dynamic-range
"High Dynamic Range Television and Hybrid Log-Gamma" **Tim Borer**

http://m.broadcastnow.co.uk/5111178.article
"DVB readies for HDR delivery spec approval"

http://www.oscars.org/science-technology/aces/aces-documentation

http://www.dolby.com/us/en/technologies/dolby-vision/dolby-vision-white-paper.pdf

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