

Hybrid Log-Gamma HDR

Update for MPEG's
HDR/WCG AHG Vancouver
Meeting

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BBC | Research & Development



Overview

1. Hybrid Log-Gamma (HLG) motivation
2. Opto-optic transfer functions
3. Scene-referred & display-referred systems
4. Latest BBC Results
5. Distribution of HLG signals
6. Summary

I Hybrid Log-Gamma (HLG) motivation

HLG Enables Easy Migration to HDR Production & Distribution

- Delivers high quality HDR pictures
 - independent of the display
 - requires no metadata
- Provides compatible picture on SDR screens
- **Production:** compatible with existing 10-bit infrastructure and equipment
 - can be mixed, resized & compressed using conventional tools
 - only requires HDR cameras and HDR displays in critical monitoring areas
- **Distribution:** single HEVC Main 10 Profile bitstream serves both HDR and SDR displays

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 - **NOTE, SDR HEVC Main 10 profile receivers already support BT.2020 colour!**

Metadata Impractical for Complex TV Workflows

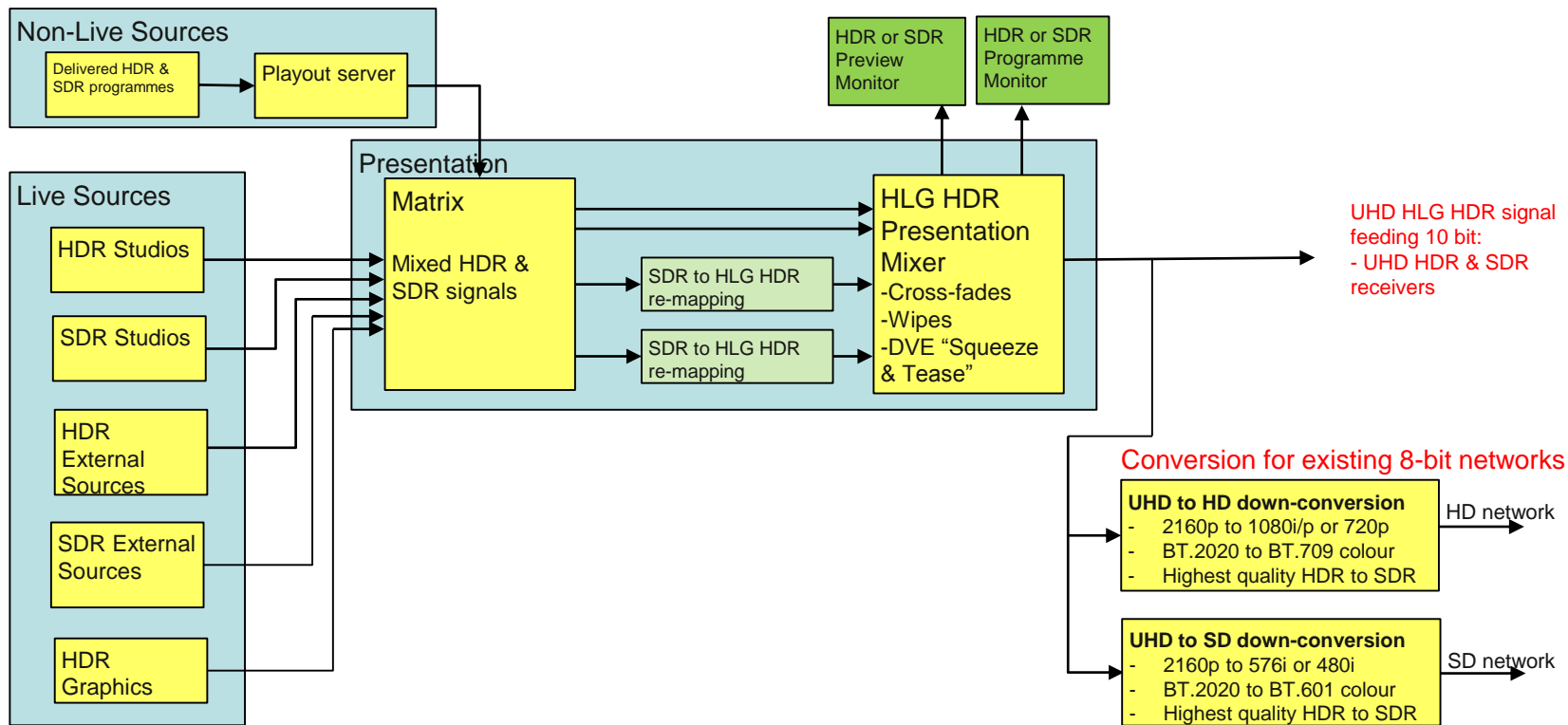


Even with just programme based metadata we can not:

- Mix between programmes
- Use a DVE (Digital Video Effects)
- Easily add graphics



Separate HDR to SDR Down-Conversion for Existing HD & SD Networks



2 Opto-optic transfer functions

High-Level Diagram of TV Systems



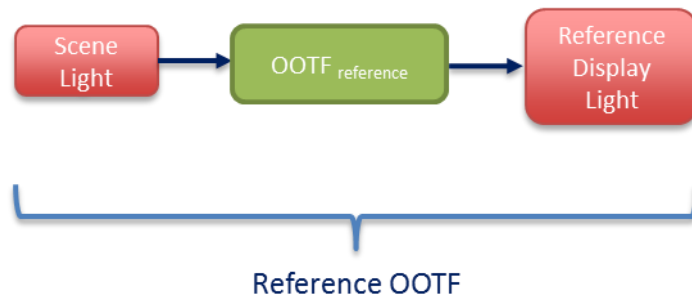
Opto-Optic Transfer Function

Scene light \neq displayed light

Role of the Opto-Optic Transfer Function (OOTF)

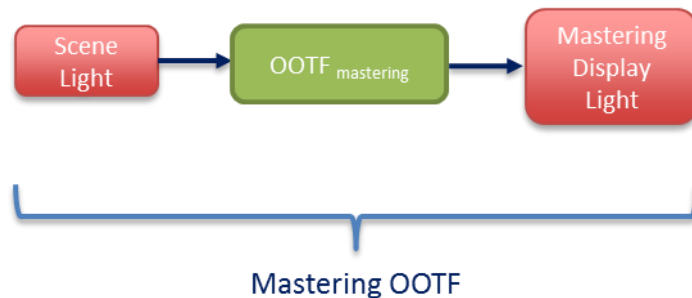
- Compensates for changes in tonal perception as the eye adapts to different environments
- Depends on,
 - brightness of the surround
 - peak brightness of the display
- Conventional “gamma law” known to work well as OOTF for both movies and TV:
 - Movies (negative/print) “gamma” 1.6 to 1.8
 - SDR TV,
 - “gamma” 1.2 in dim grading environment
 - “gamma” 1.1 in brighter domestic environment

Reference Environments



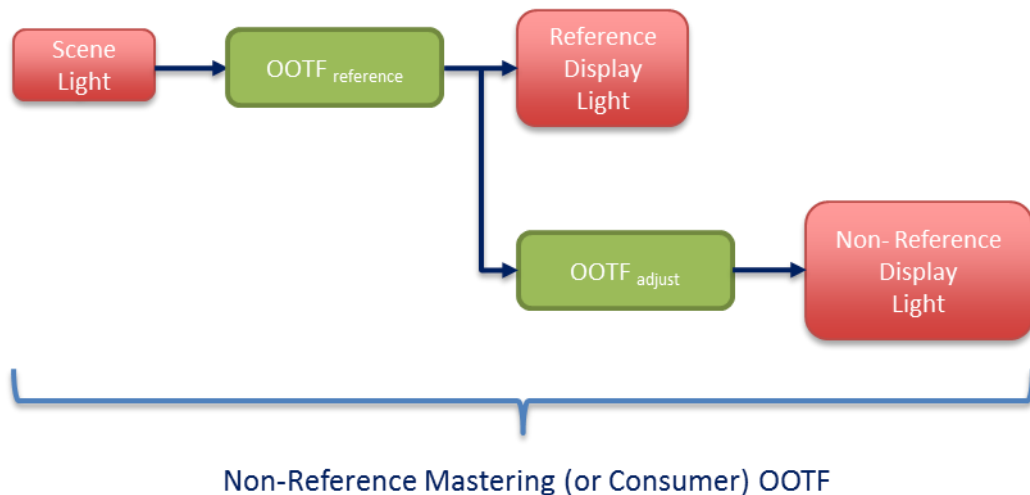
- OOTF_{reference} designed to produce “natural” images on a reference display in the reference viewing environment

Very Few TV Programmes Made in “Reference” Environments

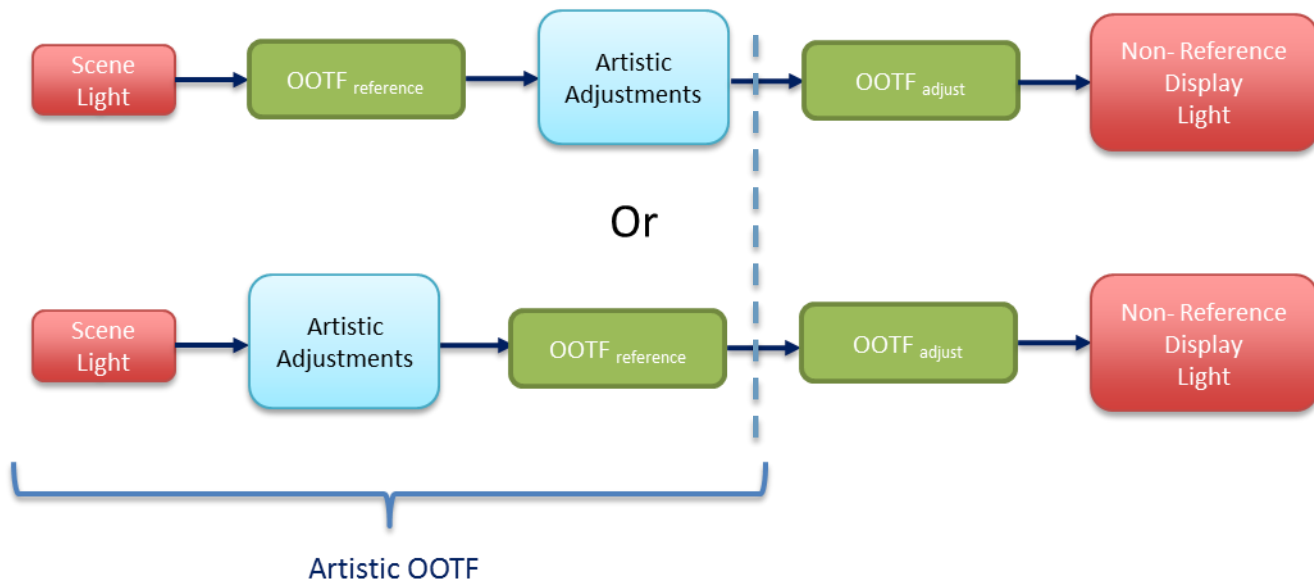


- OOTF_{mastering} designed to:
 - Produce “natural” images on the mastering display in the mastering viewing environment
 - Ensure consistent signals, across a wide range of displays and different mastering environments

$\text{OOTF}_{\text{reference}}$ Must be Adapted for Other Environments and Displays

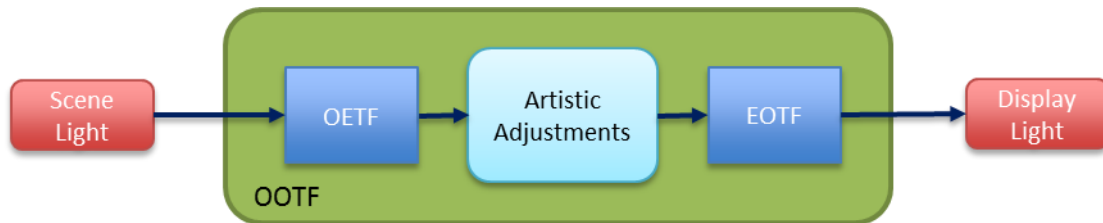


Artistic Adjustments Can be Made to Enhance the Image



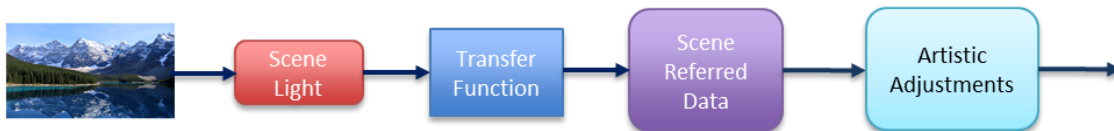
- Artistic adjustment can be applied either before or after the reference OOTF

In General OOTF is Concatenation of OETF, Artistic Adjustments and EOTF



3 Scene-referred & display-referred systems

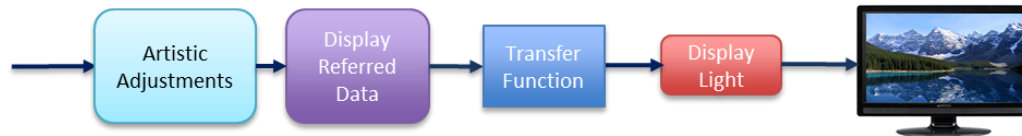
Scene-Referred Systems



Scene-referred signals represent the light in the scene (with or without artistic adjustment)

- Existing television systems
- Signals defined by their fixed OETF
 - The EOTF may change to match the viewing environment
- Examples ITU-R BT.601, BT.709, BT.2020, ARIB STD-B67 (defines HLG signal)

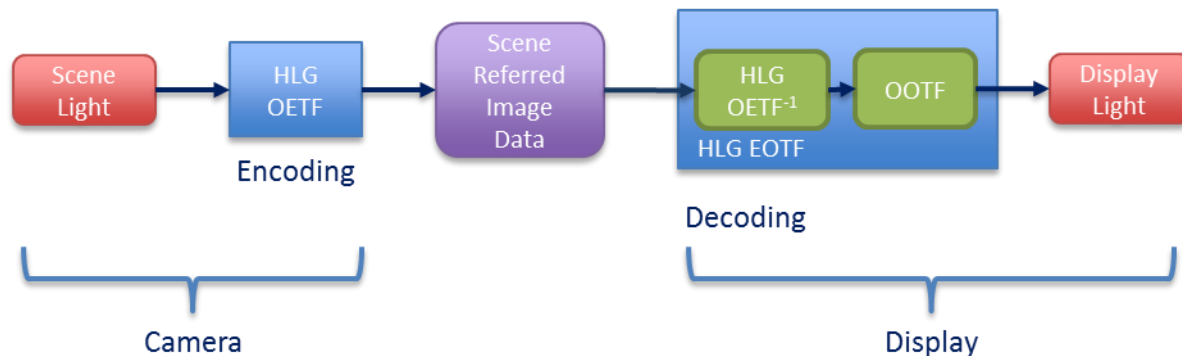
Display-Referred Systems



Display-referred signals represent the light emitted by the mastering display (with or without artistic adjustment)

- Defined by their fixed EOTF
- Examples SMPTE ST 2084, RP 431-2 (D-Cinema Quality - Reference Projector and Environment)

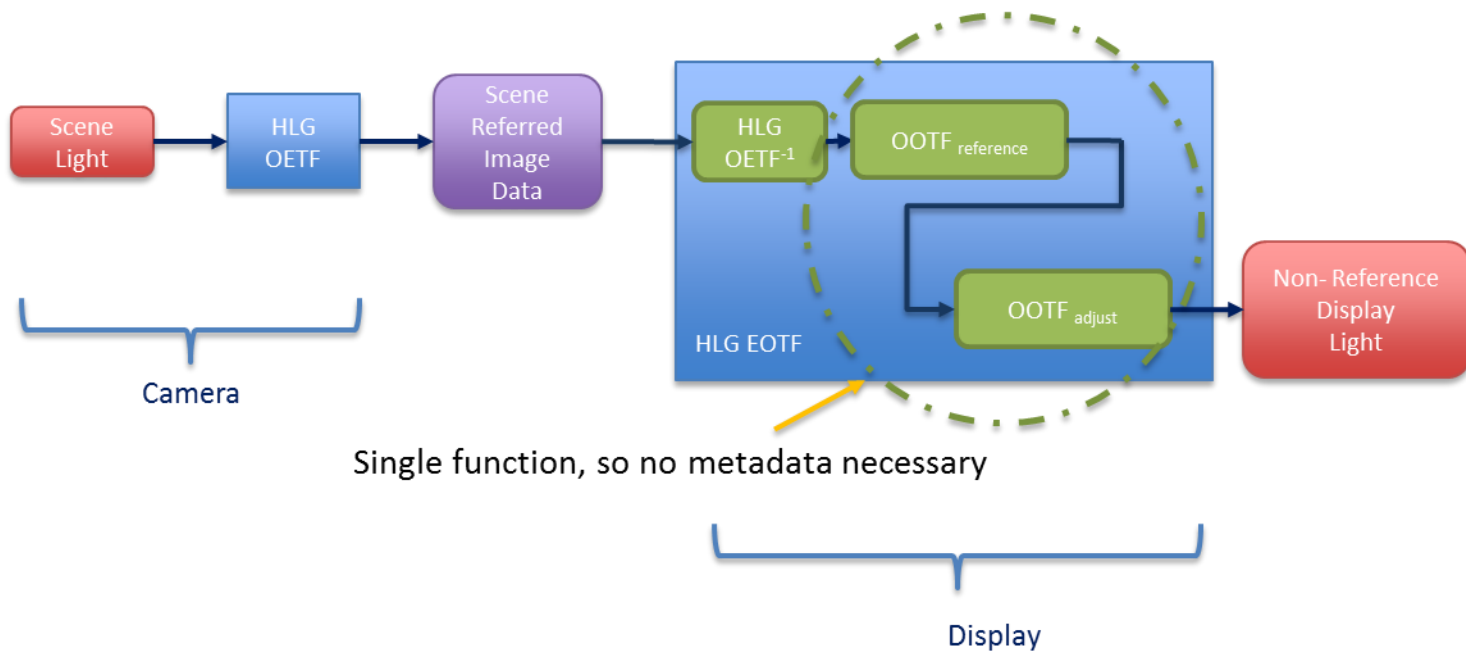
For “Scene Referred” Systems OOTF is Part of EOTF



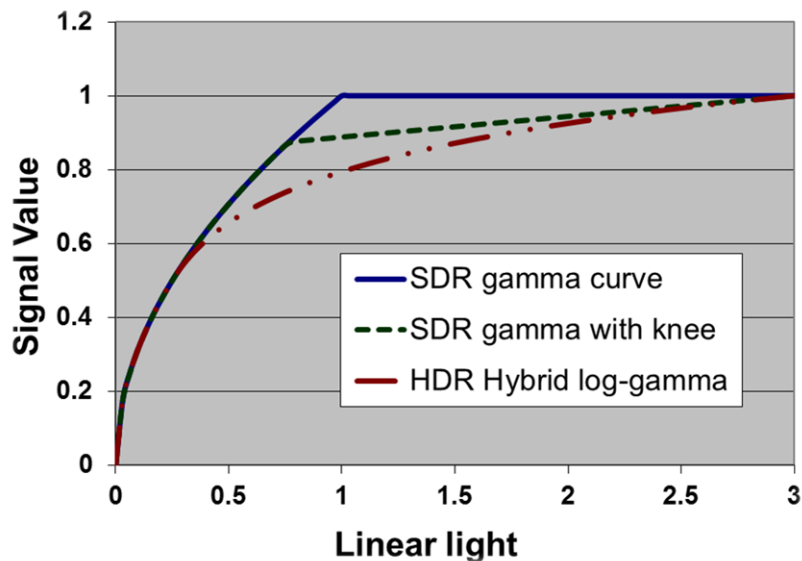
Hybrid Log-Gamma End-to-End Chain

- As OETF does not change, no metadata is necessary

For HLG, $\text{OOTF}_{\text{reference}}$ & $\text{OOTF}_{\text{adjust}}$ Combined in to a Single Function



Hybrid Log-Gamma OETF Similar to SDR OETF with "Knee"



$$E' = \begin{cases} r\sqrt{E} & 0 \leq E \leq 1 \\ a \ln(E - b) + c & 1 < E \end{cases}$$

Where,

E is proportional to light intensity

E' is the non-linear signal

r is the reference level, 0.5

$a = 0.17883277$,

$b = 0.28466892$,

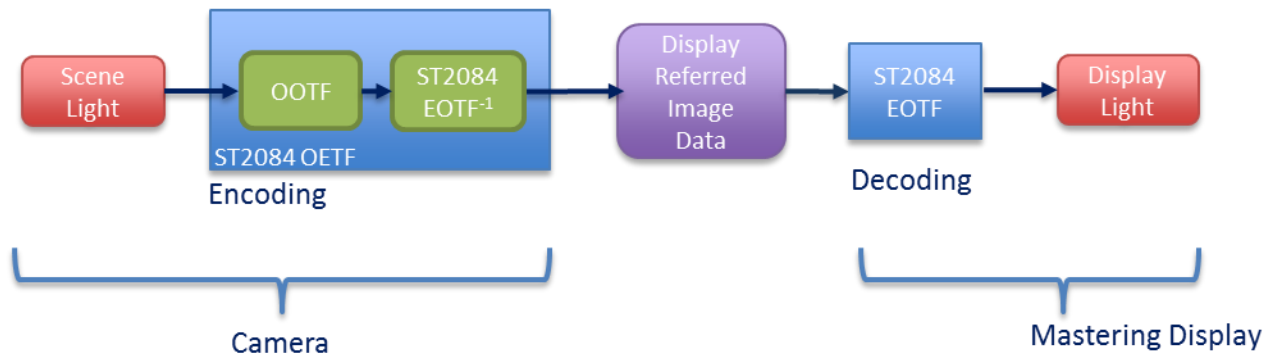
$c = 0.55991073$.

As HLG OETF so similar to SDR OETF with “knee”, compatibility achieved with SDR systems

Role of the Opto-Electronic Transfer Function (OETF)

- Originally intended to make visibility of camera and channel noise more uniform
- Today,
 - camera noise controlled by signal processing within camera
 - OETF designed to minimize visibility of “banding” artefacts
 - BBC and NHK combined their OETF approaches at ITU-R
 - HLG OETF now standardised as ARIB STD-B67

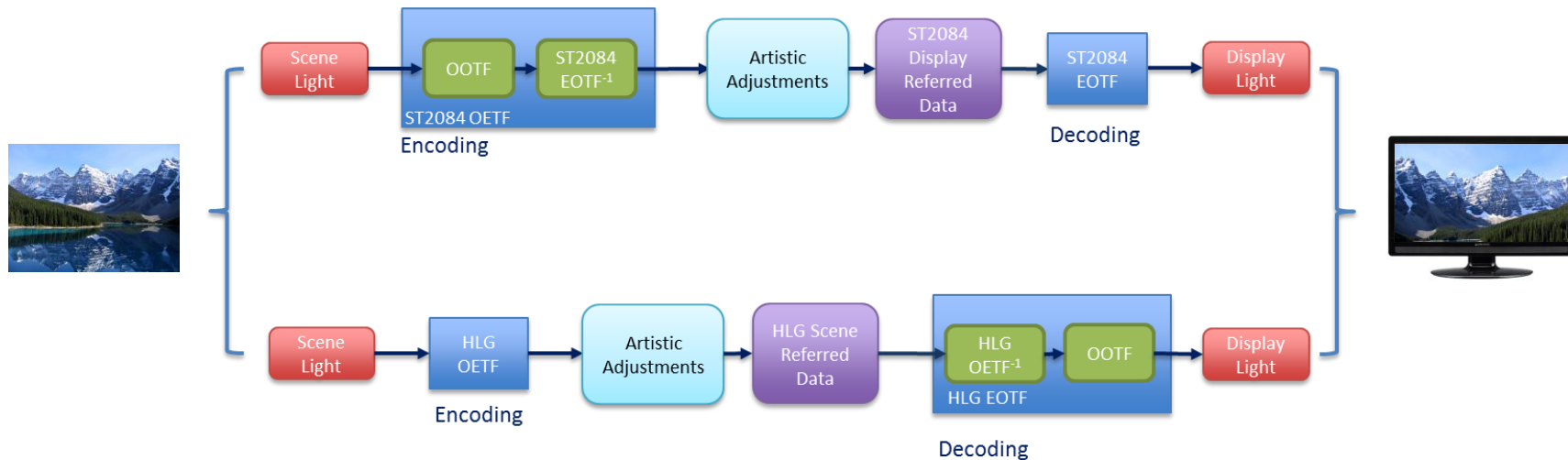
For “Display Referred” Systems (e.g. SMPTE ST 2084) OOTF is Effectively Part of the OETF



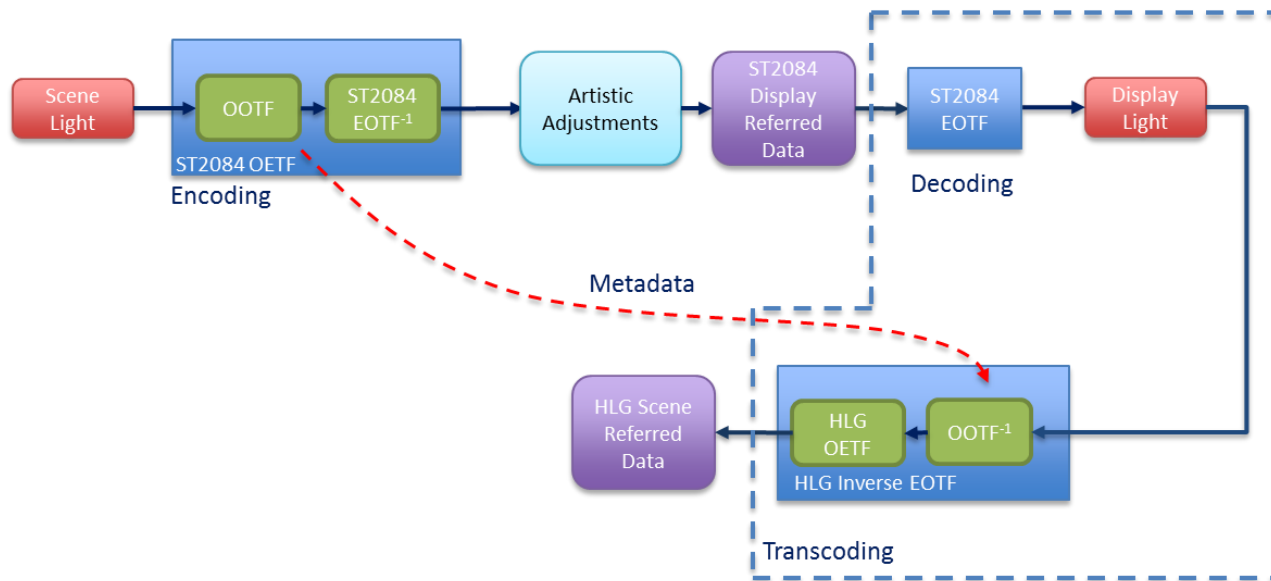
ST2084 End-to-End Chain

- A different approach
- OOTF (and hence OETF) will vary to accommodate mastering display and environment

End-to-End Both HDR Systems Identical in Reference Environment



Transcoding from ST 2084 to HLG Therefore Straightforward, but BBC Believes Requires Implicit or Explicit Metadata



When Converting from Display- to Scene-Referred it may be Beneficial to Apply Noise Modifier

- Annex 2 to ITU-R Document 6C/511-E (BT.HDR-TV PDNR), Annex 2 “Adjusting the signal to limit camera noise at low signal levels”

This annex recommends limiting the slope of the OETF, defined in table 3b-1, by applying the following function to the signal derived from a camera sensor:

$$M(E) = \frac{s^2 E^2}{(s^2 - 1)E + 1}$$

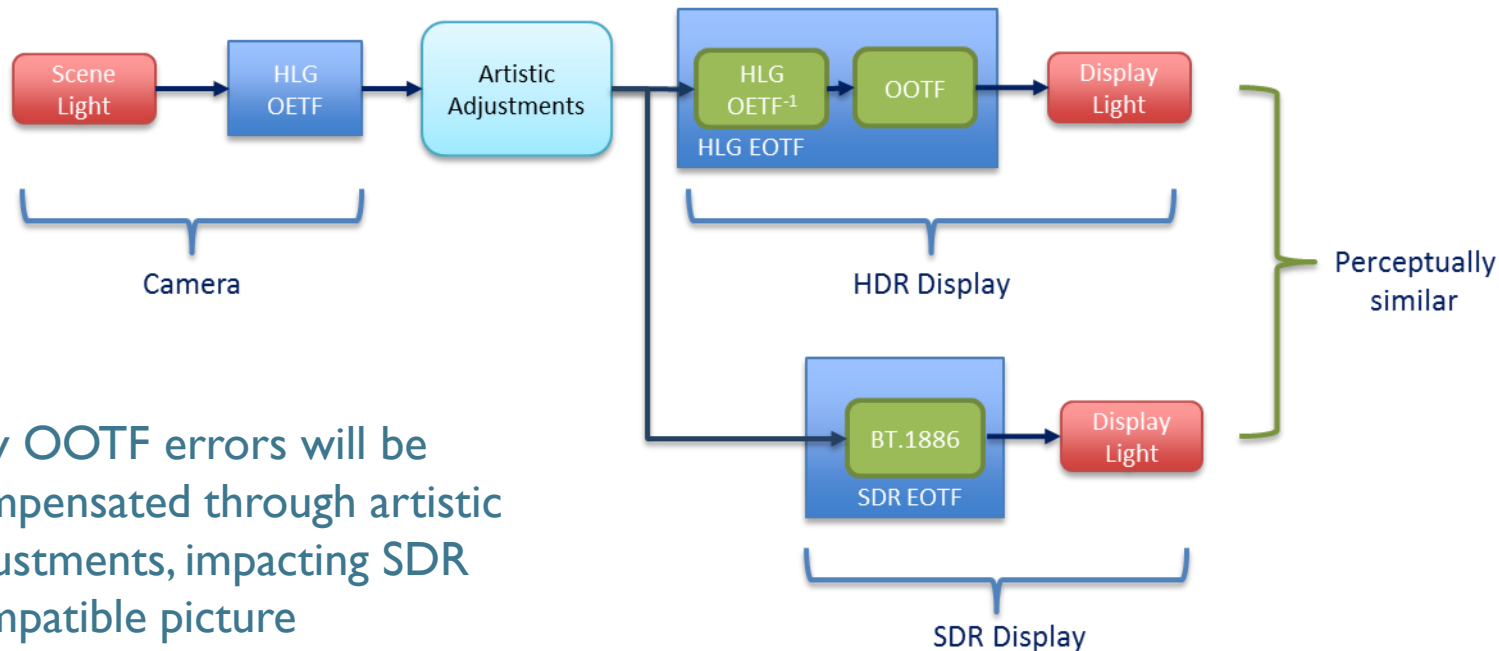
The video signal from the camera, E' , thus becomes:

$$E' = \text{OETF}(M(E))$$

This annex further recommends that the limiting parameters, s , used should have a value of $s=64$

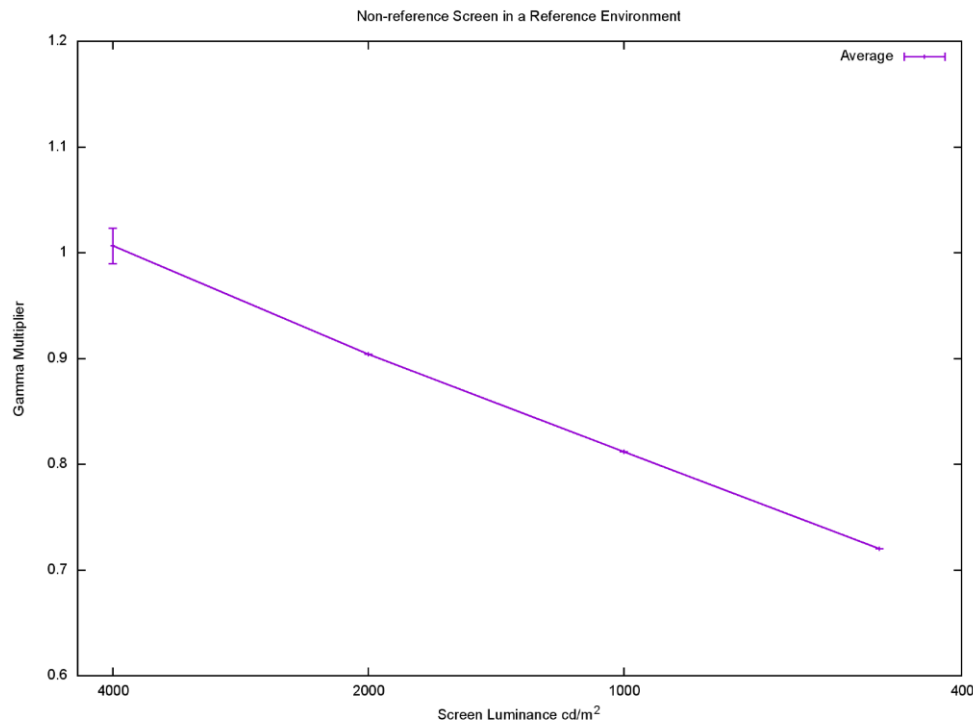
4 Latest BBC results

HLG OOTF_{mastering} Will Impact the SDR Compatible Image



- Any OOTF errors will be compensated through artistic adjustments, impacting SDR compatible picture

OOTF Adjustments for Non-Reference TV Production/Consumer Displays & Environments

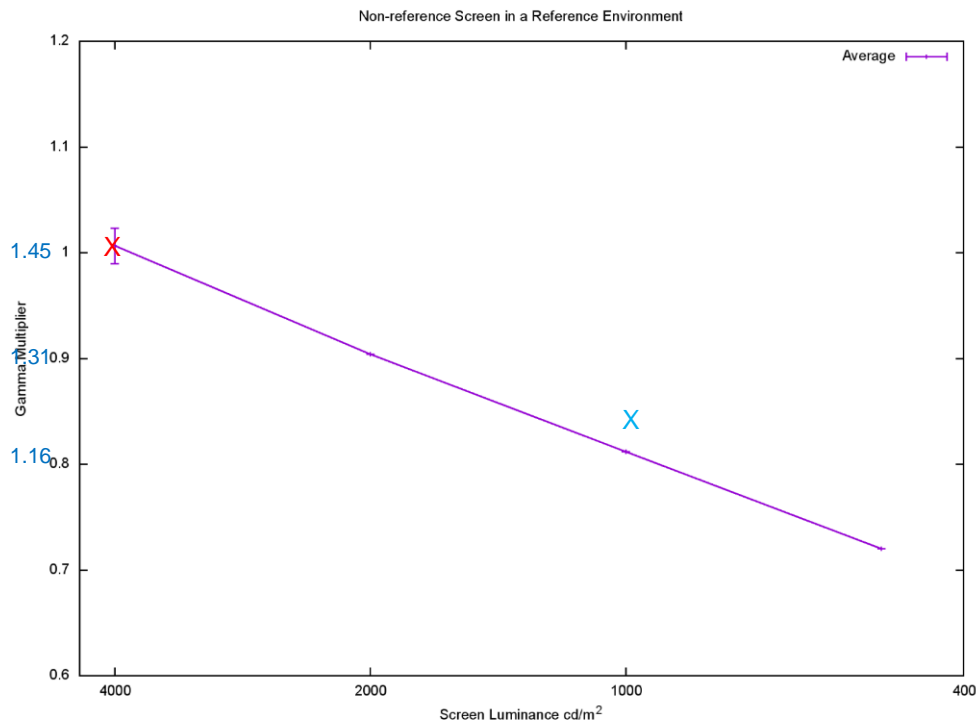


- 4000, 2000, 1000 and 500 cd/m² on SIM2 display
- 5 cd/m² background, 15 viewers
- OOTF adjustment made through changes to system gamma on luminance - preserves hue and saturation as gamma changes
- Viewers asked to match “reference” and “test” images by changing system gamma
- Peak brightness of “reference” and “test” images one stop apart to minimise eye adaption
- Consistent with results for 1000 to 500 cd/m² adjustment using OLED display
- Independent of “reference” OOTF

OOTF for “Reference” Display and Environment

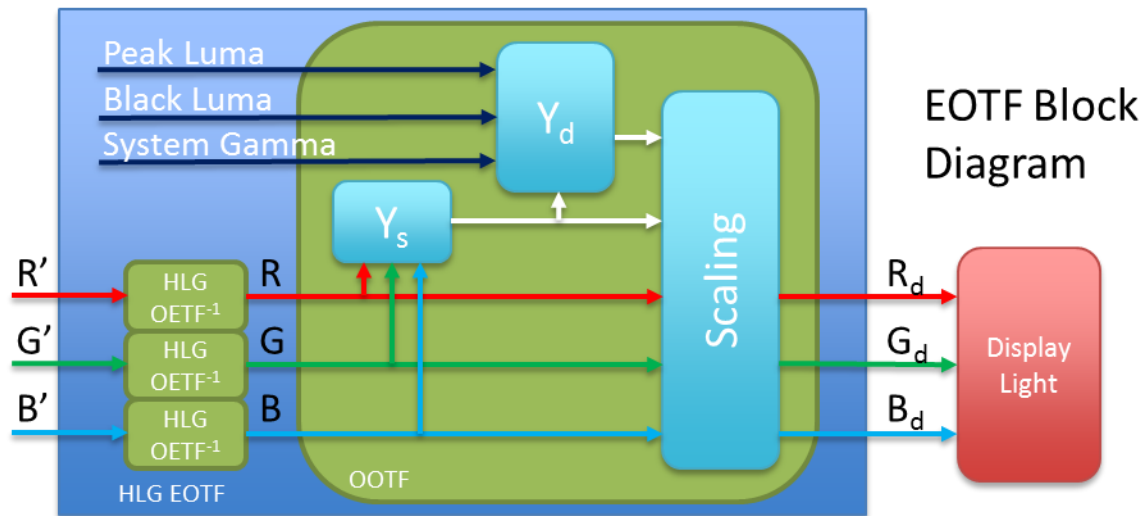
- First test set-up
 - 14 Mark Fairchild test images
 - “Gamma” function applied to luminance
 - 6 expert viewers asked to adjust gamma for most “natural” image on 4000 cd/m² SIM2 display
- Results
 - Wide variation between viewers
 - Some images very difficult to judge without a reference
 - Average across images for viewers (discarding 3 hardest images) 1.26 to 1.50
- Conclusions
 - Personal preference a large factor that is difficult to ignore
 - Most natural images may be produced with a lower gamma, but most pleasing image usually requires a higher gamma
 - Better to determine gamma for “reference” OOTF by optimising quality of SDR image

Preliminary Informal Results for OOTF to Deliver Best SDR



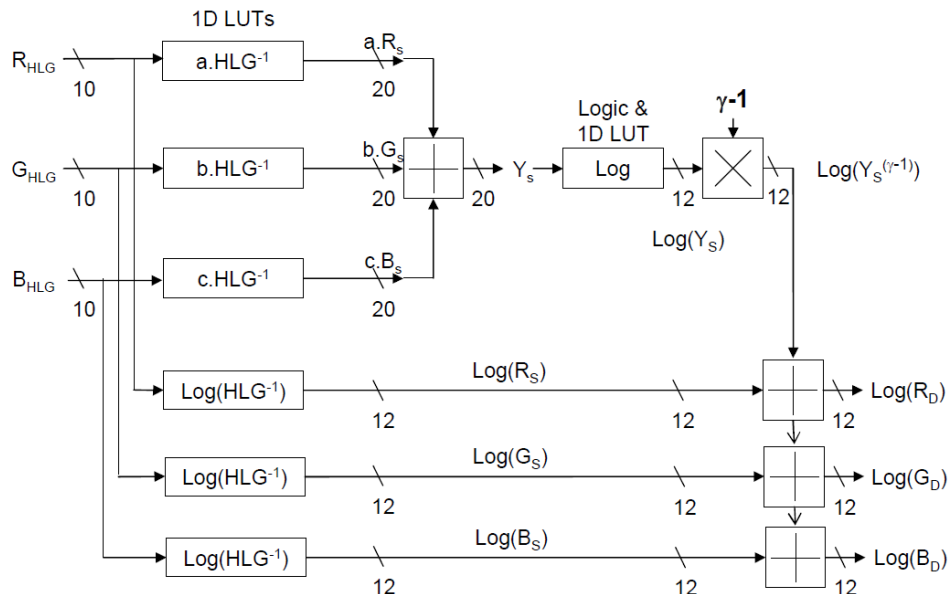
- Only 5 viewers
- Uncontrolled lighting
- Only 4 test images
 - Best SDR for 4000 cd/m^2 SIM2 display, $\gamma \approx 1.45$
 - Best SDR for 1000 cd/m^2 OLED display $\gamma \approx 1.27$
- More formal tests planned for this week
- Preliminary results consistent with earlier OOTF adjustment work

OOTF System Gamma Applied to Luminance Component within HLG EOTF



- Avoids hue and saturation distortions with different system gammas – critical in professional applications
- Mathematical equations in R&D White Paper <http://www.bbc.co.uk/rd/publications/whitepaper309>
- Conveniently implemented in 3D-LUT or combination of 1D-LUTs and adders

Example HLG EOTF Implementation Using I-D LUTs



Note: Intermediate bit depths are approximate

$$R_D = \alpha Y_s^{\gamma-1} R_s + \beta$$

$$G_D = \alpha Y_s^{\gamma-1} G_s + \beta$$

$$B_D = \alpha Y_s^{\gamma-1} B_s + \beta$$

where $Y_s = aR_s + bG_s + cB_s$

5 Distribution of HLG signals

Backwards Compatible HLG Signalling in HEVC

- Broadcasters are likely to serve SDR and HDR receivers using the same channel
- VUI Signalling
 - **transfer_characteristics = 14 (BT.2020 10-bit) to satisfy legacy SDR receivers.**
 - colour_primaries = 9 (BT.2020)
 - matrix_coeffs = 9 (BT.2020 NCL)
 - video_full_range_flag = 0 (black at code value 64)
 - *Note: HDR signals will extend below code value 64 (sub-blacks) and above code value 940 (super-whites).*
- SEI Signalling to override VUI transfer_characteristics
 - hdr_compatibility_info on IRAP
 - **hdr_transfer_characteristic_idc = 18**

D.2.38 High dynamic range compatibility information SEI message syntax

+	hdr_compatibility_info(payloadSize) {	Descriptor
	hdr_transfer_characteristics_idc	u(8)
	}	

HLG Signalling Over HDMI (Based on CEA 86I)

CEA-861.3

InfoFrame Type Code	InfoFrame Type = 0x07					
InfoFrame Version number	Version=0x01					
Length of Info Frame	Length of following HDR Metadata InfoFrame					
Data Byte 1	F17=0	F16=0	F15=0	F14=0	F13=0	EOTF (3 bits)
Data Byte 2	F27=0	F26=0	F26=0	F24=0	F23=0	Static_Metadata_Descriptor_ID (3 bits)
Data Byte 3	Static_Metadata_Descriptor					
...	...					
Data Byte n	...					

Table 2 Dynamic Range and Mastering InfoFrame

Data Byte 1 EOTF identifies the Electro-Optical Transfer Function (EOTF) used in the stream.

EOTF	EOTF of stream
0	Traditional gamma - SDR Luminance Range
1	Traditional gamma - HDR Luminance Range
2	SMPTE ST 2084 [2]
3	Future EOTF
4- 7	Reserved for future use

Table 3 Data Byte 1 - Electro-Optical Transfer Function

Needs to be revised to HLG (ARIB STD-B67)

6 Summary

Main facts on HLG

- Supports a wide range of displays and environments
- No need for metadata as OOTF part of EOTF
 - hence signal is “display independent”
- Can be displayed unprocessed on SDR screen
- 10-bit signal compatible with SDR systems
- Production can use existing SDR infrastructure and monitoring displays
 - Only critical high quality monitoring requires HDR displays
- Straightforward evolutionary migration to HDR production
- Single layer HEVC Main10 Profile distribution to both HDR and SDR displays