Hybrid Log-Gamma HDR

Update for MPEG's HDR/WCG AHG Vancouver Meeting

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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

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1 Hybrid Log-Gamma (HLG) motivation

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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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- **Distribution**: single HEVC Main 10 Profile bitstream serves both HDR and SDR displays
    - NOTE, SDR HEVC Main 10 profile receivers already support BT.2020 colour!

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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

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

2 Opto-optic transfer functions

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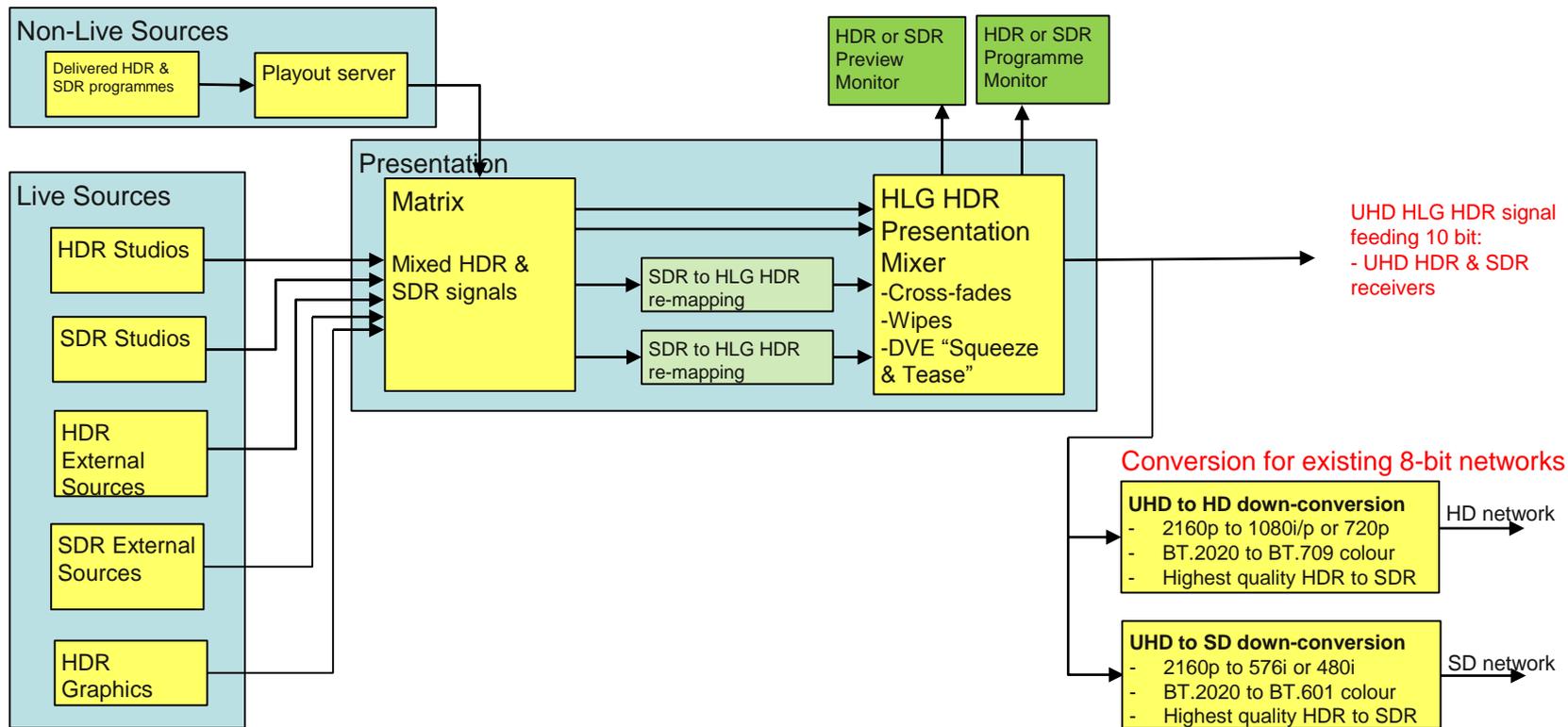
High-Level Diagram of TV Systems

Opto-Optic Transfer Function

Scene light ≠ displayed light

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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

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Reference Environments
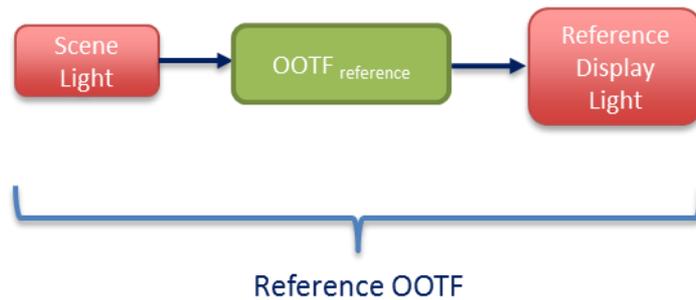
- OOTF $_{reference}$ designed to produce "natural" images on a reference display in the reference viewing environment

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Very Few TV Programmes Made in "Reference" Environments

Scene Light → OOTF mastering → Mastering Display Light
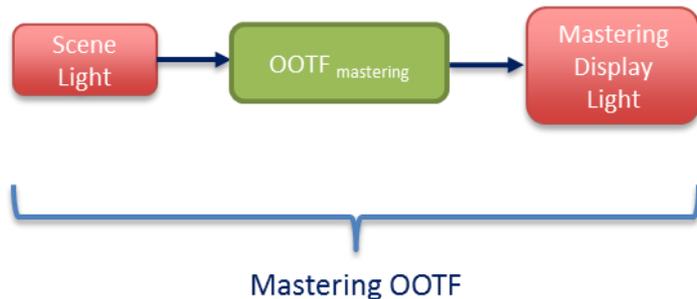
Mastering OOTF

- 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

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

Non-Reference Mastering (or Consumer) OOTF

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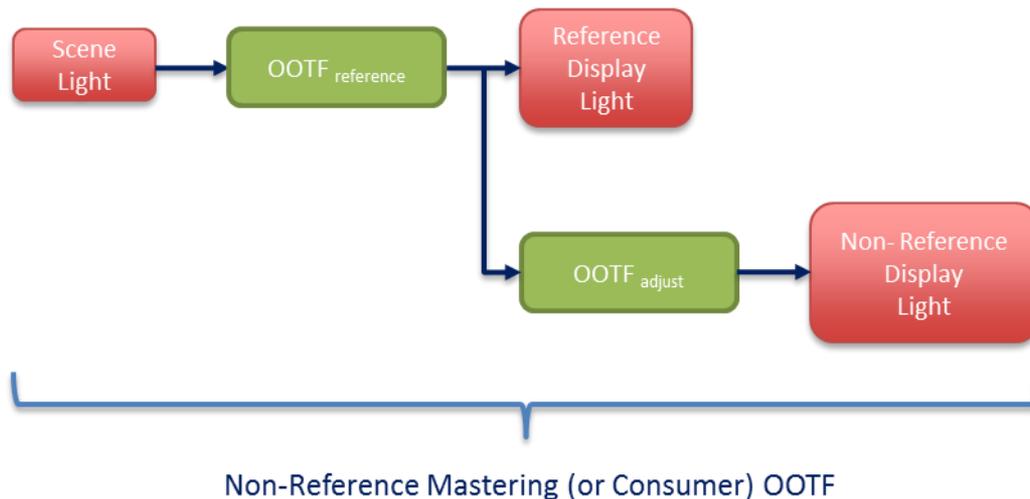
Artistic Adjustments Can be Made to Enhance the Image
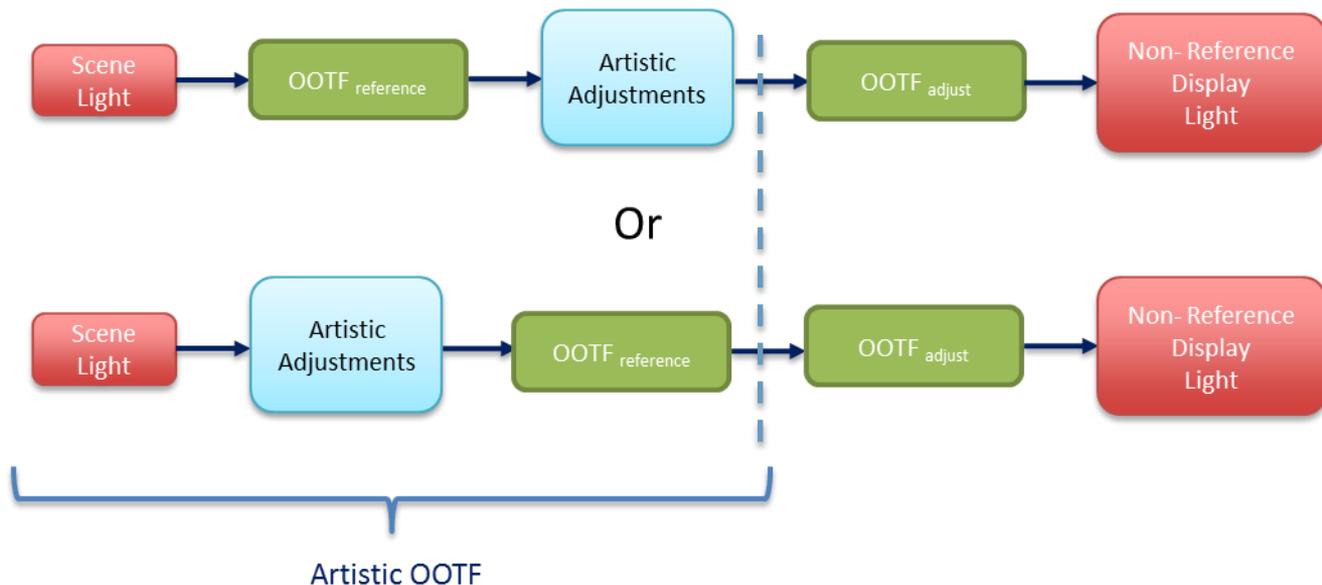
- Artistic adjustment can be applied either before or after the reference OOTF, to deliver a more pleasing image

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

3 Scene-referred & display-referred systems

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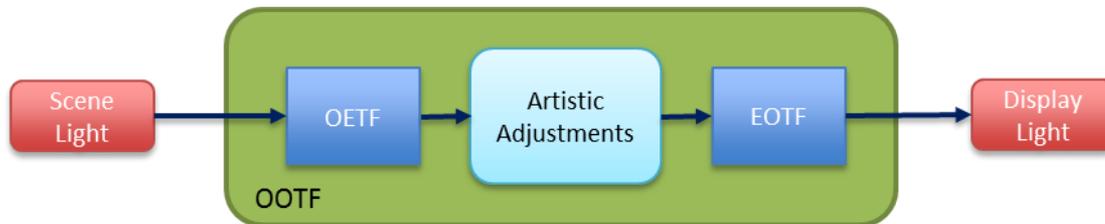
Scene-Referred Systems
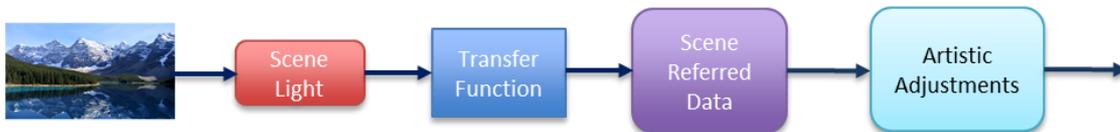
Scene-referred signals represent the light in the scene (with or without artistic adjustment)
- Existing television systems
- Signals defined by their fixed OETF
  - The EOTF may change to match the viewing environment
- Examples ITU-R BT.601, BT.709, BT.2020, ARIB STD-B67 (defines HLG signal)

Display-Referred Systems
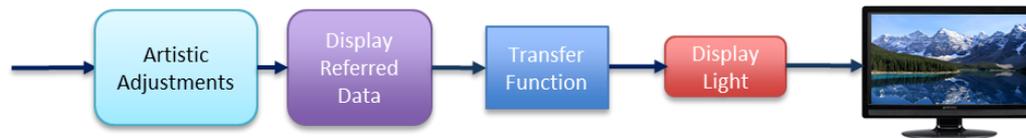
Display-referred signals represent the light emitted by the mastering display (with or without artistic adjustment)
- Defined by their fixed EOTF
- Examples SMPTE ST 2084, RP 431-2 (D-Cinema Quality - Reference Projector and Environment)

For "Scene Referred" Systems OOTF is Part of EOTF
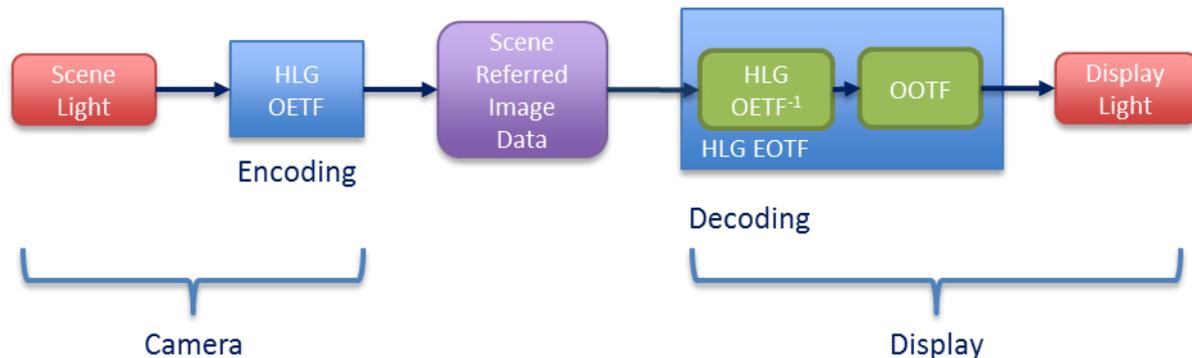
Hybrid Log-Gamma End-to-End Chain

- As OETF does not change, no metadata is necessary

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

Single function, so no metadata necessary

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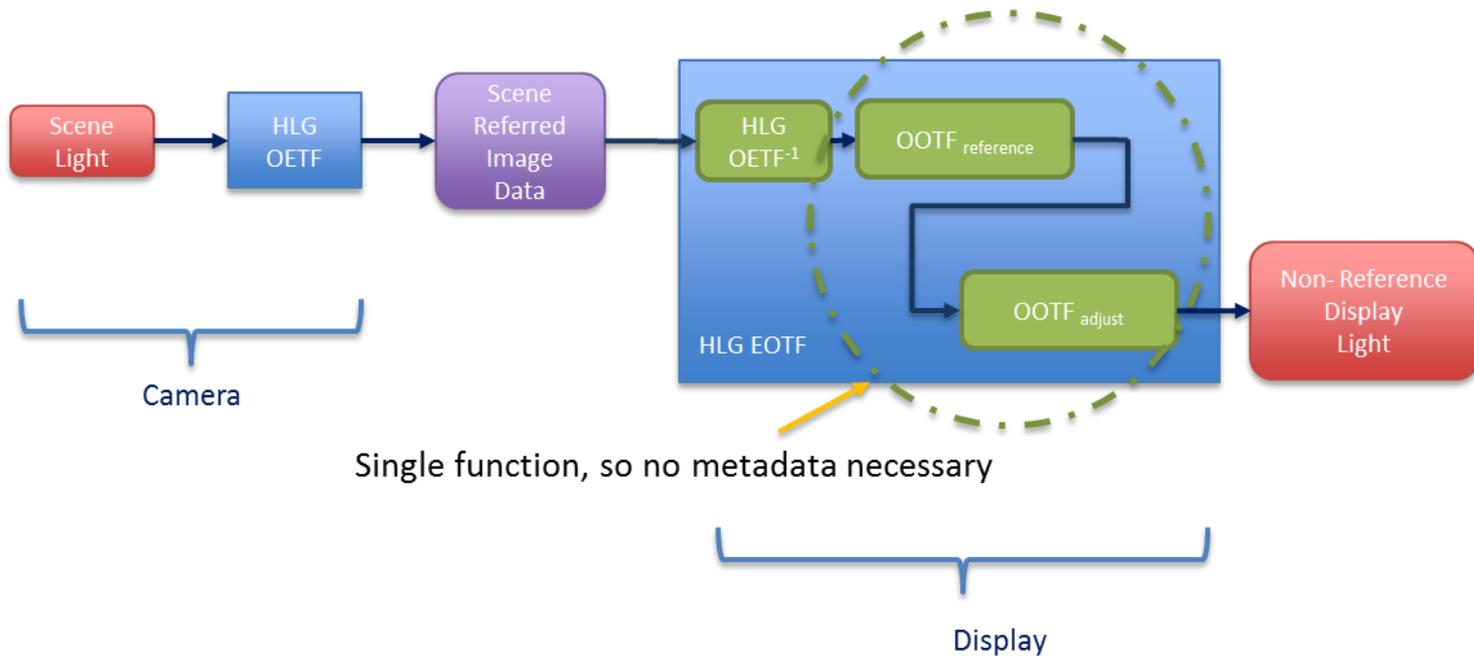
Hybrid Log-Gamma OETF Similar to SDR OETF with "Knee"
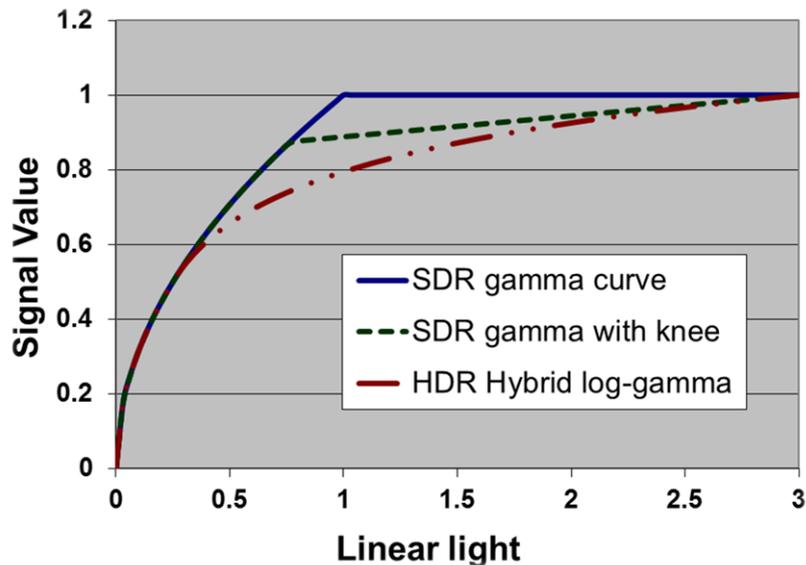
$$E' = \begin{cases} r\sqrt{E} & 0 \le E \le 1 \\ a\ln(E-b)+c & 1 < E \end{cases}$$

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

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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

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For "Display Referred" Systems (e.g. SMPTE ST 2084) OOTF is Effectively Part of the OETF
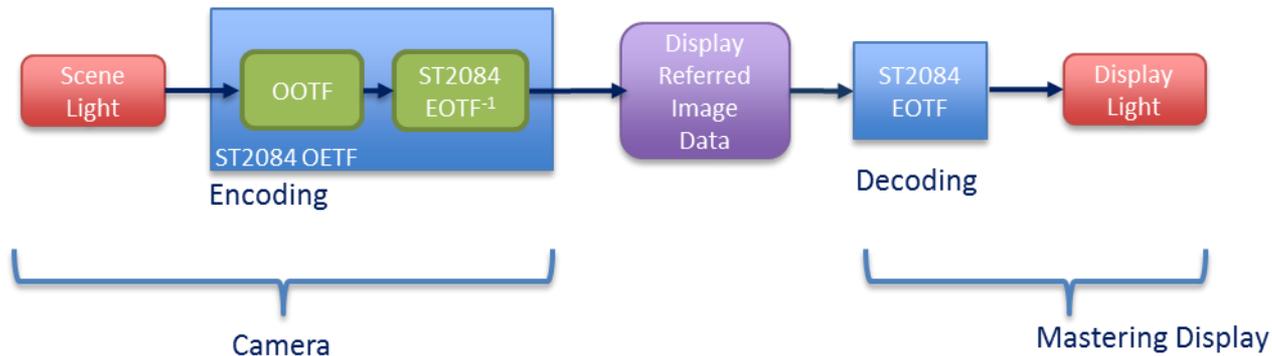
ST2084 End-to-End Chain

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

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End-to-End Both HDR Systems Identical in Reference Environment
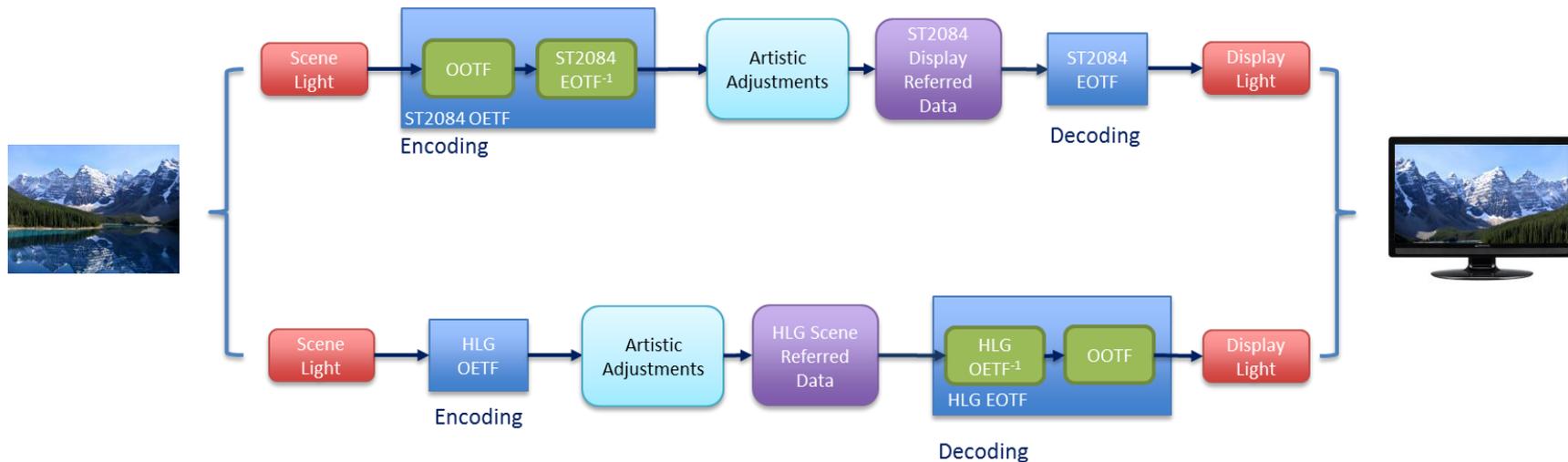
Transcoding from ST 2084 to HLG Therefore Straightforward, but BBC Believes Requires Implicit or Explicit Metadata

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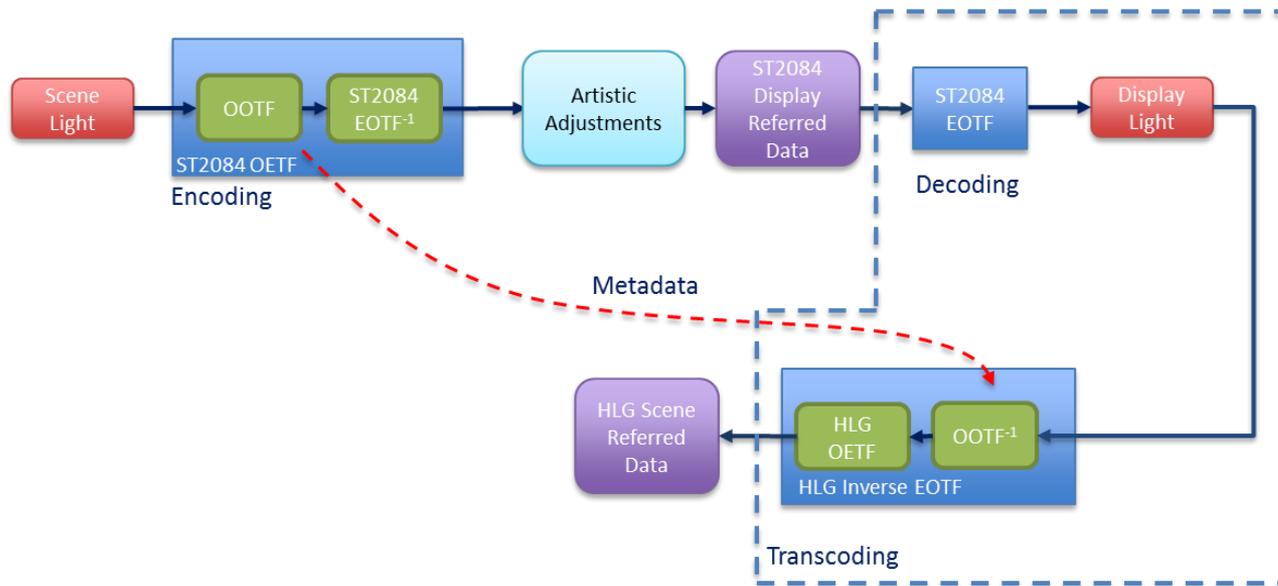
When Converting from Display- to Scene-Referred it may be Beneficial to Apply Noise Modifier

- 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

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4 Latest BBC results

HLG OOTF _{mastering} Will Impact the SDR Compatible Image
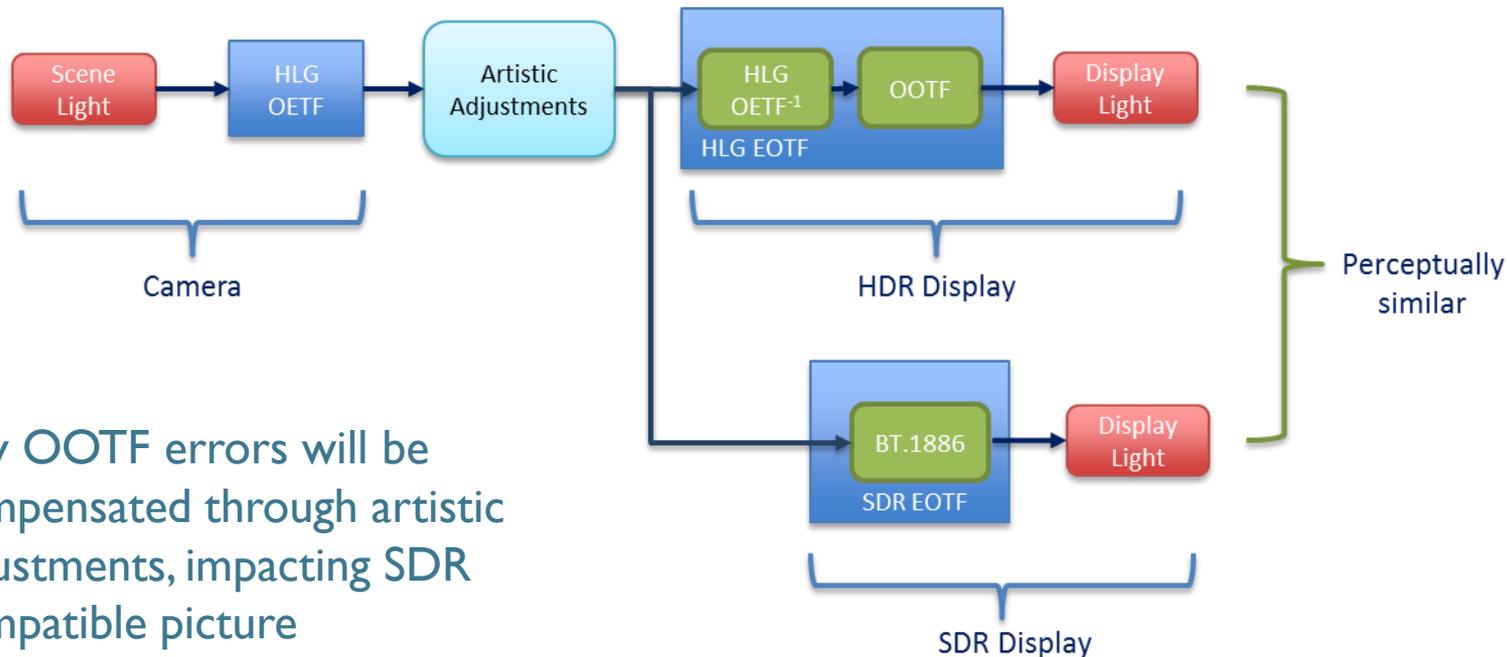
- Any OOTF errors will be compensated through artistic adjustments, impacting SDR compatible picture

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

Non-reference Screen in a Reference Environment
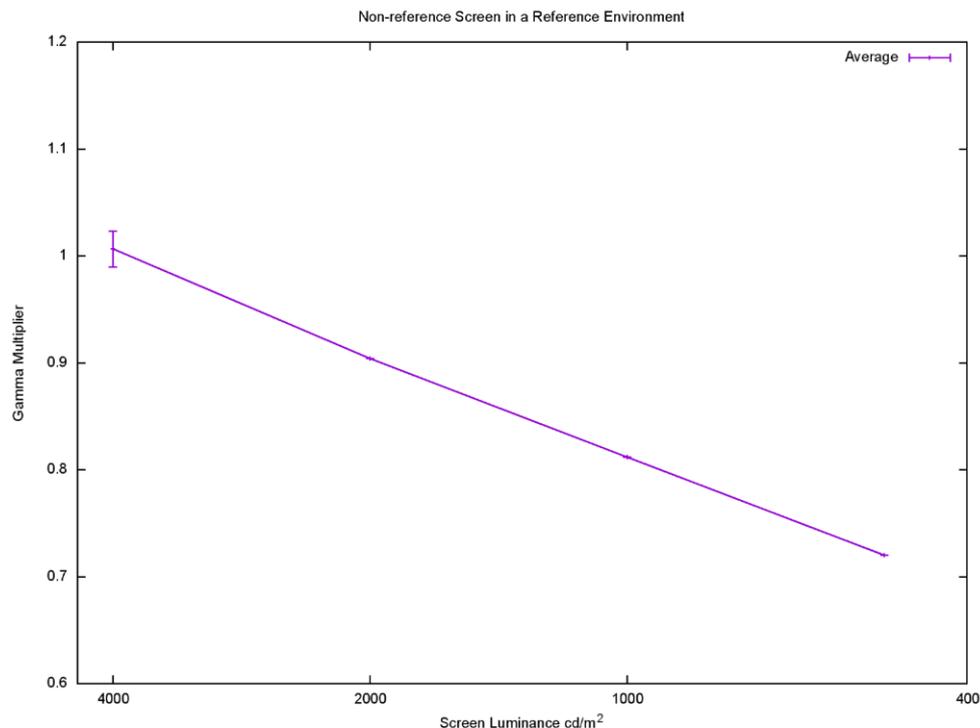
- 4000, 2000, 1000 and 500 cd/m2 on SIM2 display

- 5 cd/m^2 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

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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

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Preliminary Informal Results for OOTF to Deliver Best SDR
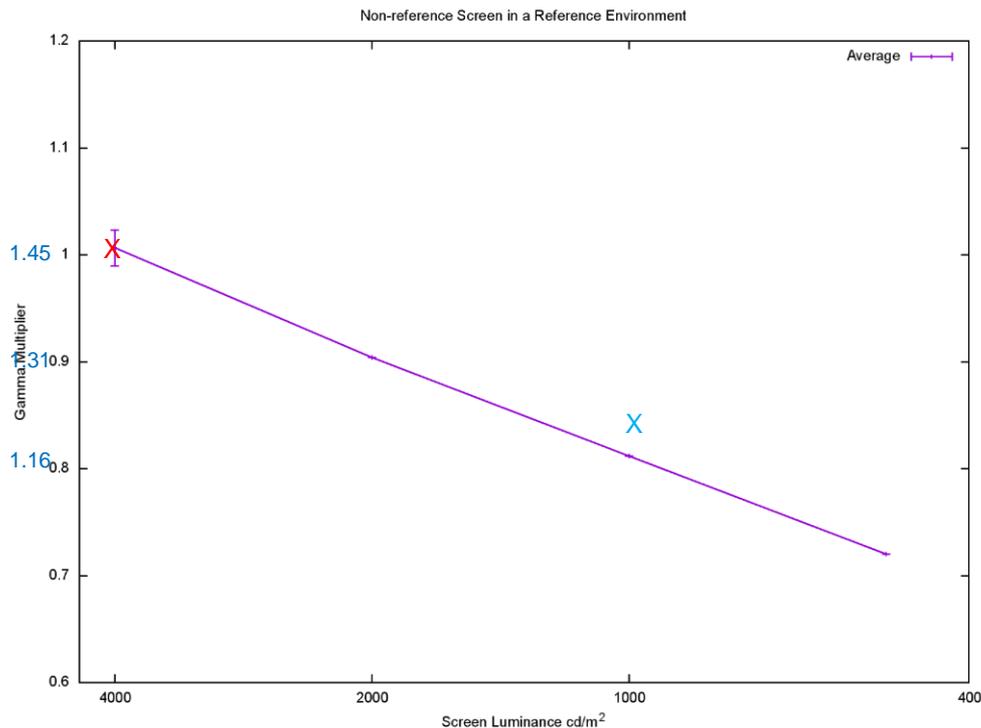
- Only 5 viewers
- Uncontrolled lighting
- Only 4 test images
  - Best SDR for 4000 cd/m2 SIM2 display, γ ≈ 1.45
  - Best SDR for 1000 cd/m2 OLED display γ ≈ 1.27

- More formal tests planned for this week

- Preliminary results consistent with earlier OOTF adjustment work

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Don't Forget Camera Iris
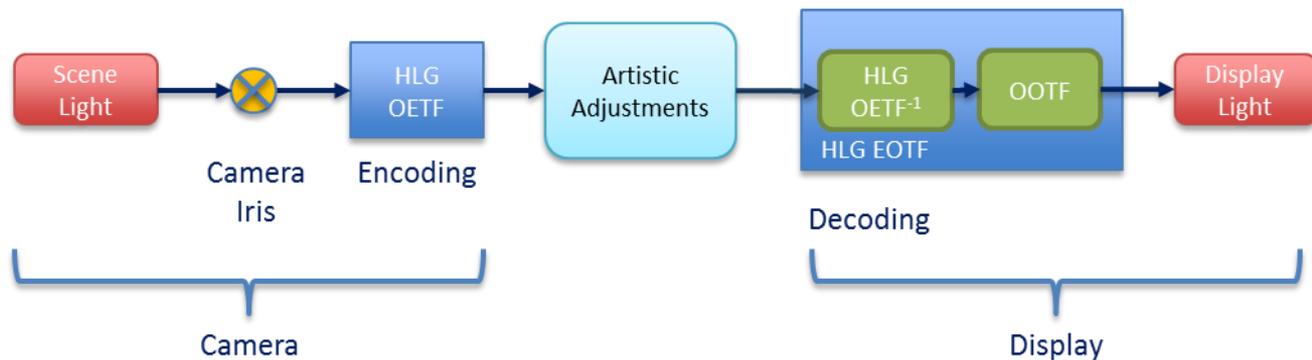
- Iris adjusts overall system gain
  - Affects clipping and reference levels (e.g. "diffuse white")

- Next phase of ITU-R work expected to address working practices (including reference levels) to ensure consist brightness of programmes (c.f. EBU R128/BS.1770 Audio Loudness)

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Different Brightness Images Require Different Gamma, Solved by Reference Levels

Average System Gamma vs Gain
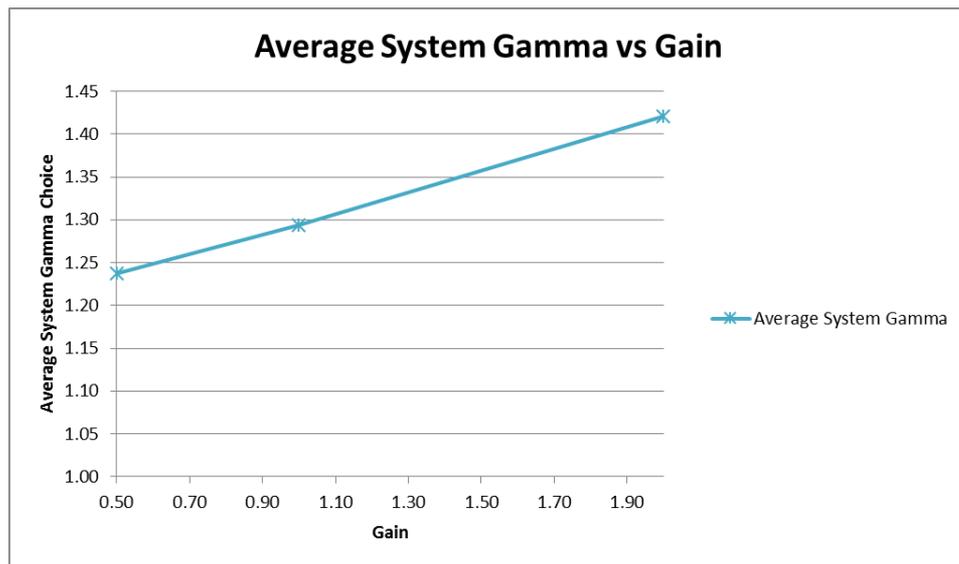
Informal Tests Results – November 2015

- BBC manually adjusted "gain" for each Mark Fairchild test image to ensure consistent brightness
- Once brightness equalised, individual's gamma preferences consistent.

- Note, no real surprise as OOTF of low-gamma/low-gain similar in low-lights and mid-tones to OOTF of high-gamma/high-gain.

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OOTF System Gamma Applied to Luminance Component within HLG EOTF
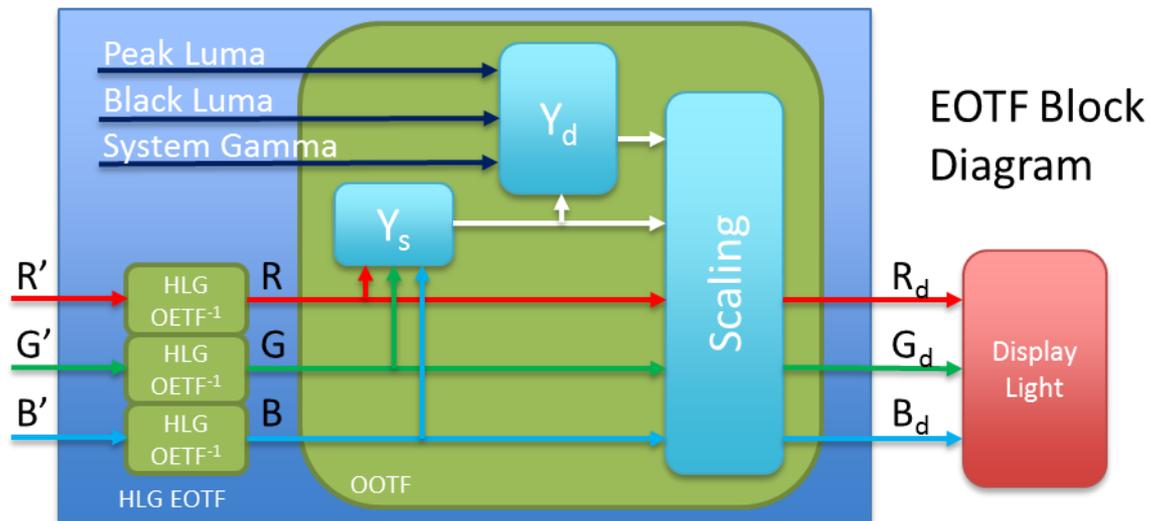
- Avoids hue and saturation distortions with different system gammas – critical in professional applications
- Mathematical equations in R&D White Paper http://www.bbc.co.uk/rd/publications/whitepaper309
- Conveniently implemented in 3D-LUT or combination of 1D-LUTs and adders

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Example HLG EOTF Implementation Using 1-D LUTs

Note: Intermediate bit depths are approximate
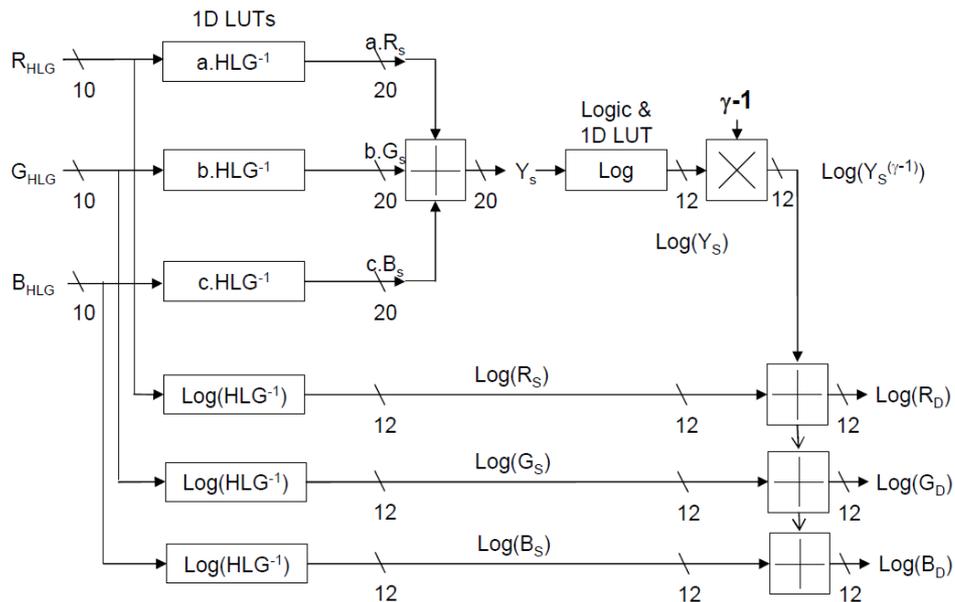
$$R_D = \alpha Y_S^{\gamma-1} R_S + \beta$$
$$G_D = \alpha Y_S^{\gamma-1} G_S + \beta$$
$$B_D = \alpha Y_S^{\gamma-1} B_S + \beta$$
$$\text{where } Y_S = aR_S + bG_S + cB_S$$

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5 Distribution of HLG signals

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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)
}	

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HLG Signalling Over HDMI (Based on CEA 861)

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

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

Table 3 Data Byte 1 - Electro-Optical Transfer Function

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6 Summary

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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

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