High Dynamic Range

PQ and HLG
- Presented by the BBC

Tim Borer & Andrew Cotton

BBC | Research & Development

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Guest Speakers

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Tim Borer   Andrew Cotton

Who Are We?

- ### Tim Borer
  - Tim Borer is a Lead Engineer at BBC Research and Development, currently focusing on aspects of UHDTV such as high dynamic range and high frame rates. Previously Tim led the video compression team at BBC R&D developing "Dirac" and the SMPTE VC-2 compression standard. Prior to the BBC he designed professional broadcasting equipment, including motion compensated standards converters and compression equipment, for both Snell and Harris. He is a co-developer of the BBC/NHK Hybrid Log-Gamma HDR solution. Tim holds degrees in video processing, electronics and physics. He is a Chartered Engineer (MIET), a senior member of the IEEE and a member of the SMPTE. He is the inventor (or co-inventor) of about 20 patents. Tim is Fellow of the SMPTE

- ### Andrew Cotton
  - Andrew Cotton is a Principal Technologist at BBC Research and Development and has a background in video compression and image processing. He coordinates the BBC's UHDTV standardisation activities and, in addition, he and his team are responsible for maintaining the technical integrity of the BBC's production, playout and IP distribution systems.
  - Andrew is a co-developer of the BBC/NHK Hybrid Log-Gamma HDR solution. He joined BBC R&D in 1987 after graduating with a BA in Engineering Science, spent 7 years in industry working for Snell and returned to the BBC in 2002. Andrew is the inventor of 7 joint patents and 3 sole patents.

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- Fundamentals of HDR

- Compare ITU-R PQ & HLG solutions

- Motivation for Hybrid Log-Gamma (HLG)

- HDR in Production

- HDR in Distribution

- HDR around the world

- Summary

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HDR Fundamentals

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Movies & Television are different media

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Movies & Television are different media

- Live versus non-live
  - Grading versus shading

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Movies & Television are different media

- Live versus non-live
- Linear Channel versus individual programmes
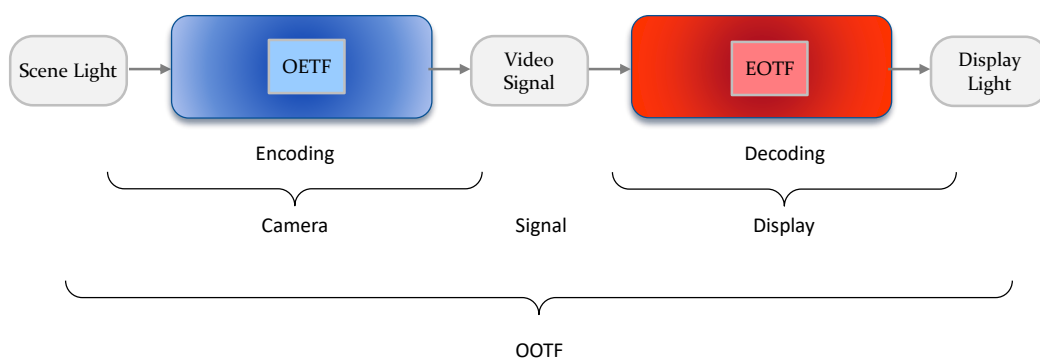
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Movies & Television are different media

- Live versus non-live

- Linear Channel versus individual programmes

- Viewing environment

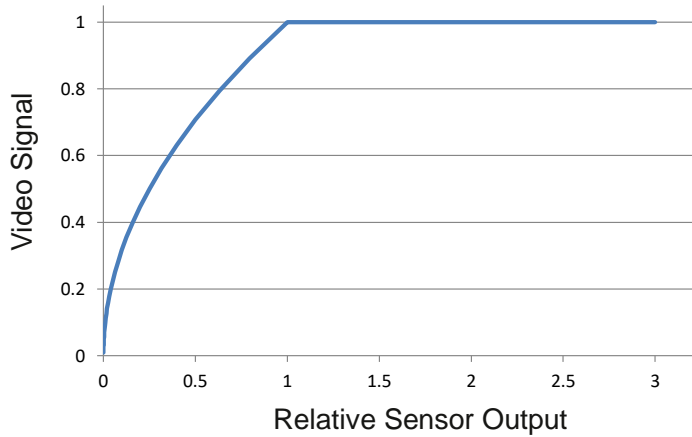PQ and HLG

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End-to-End Television Signal Chain

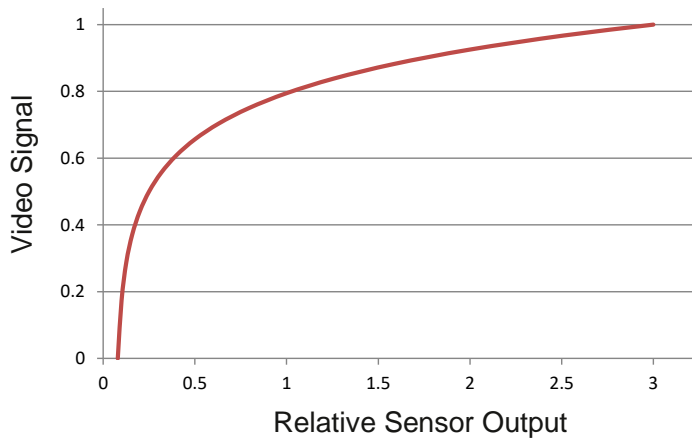PQ and HLG

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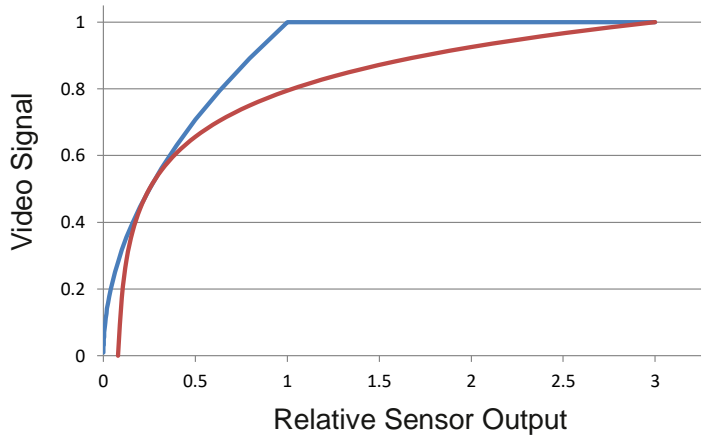## Conventional SDR Camera Curve

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Camera Log Curve

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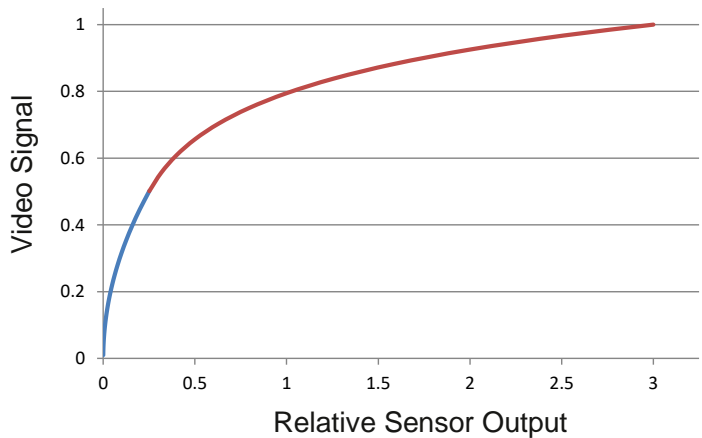
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Best of Both

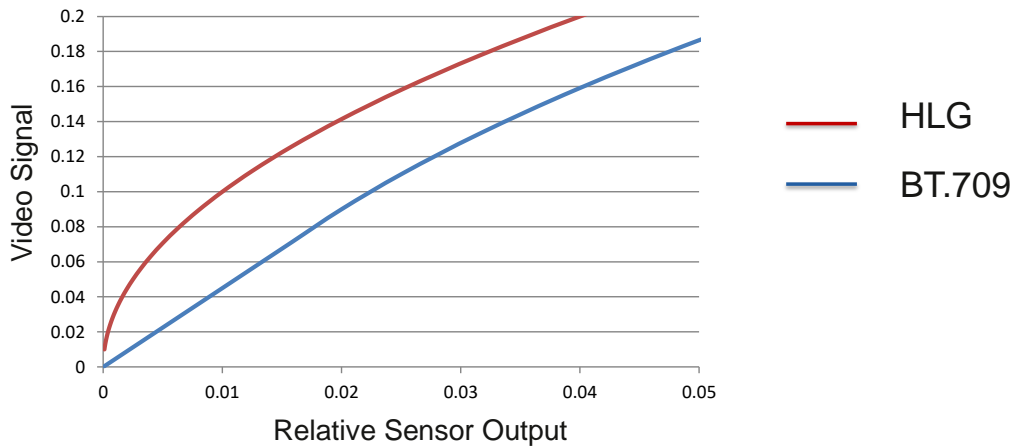PQ and HLG

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HLG HDR Camera Curve

PQ and HLG
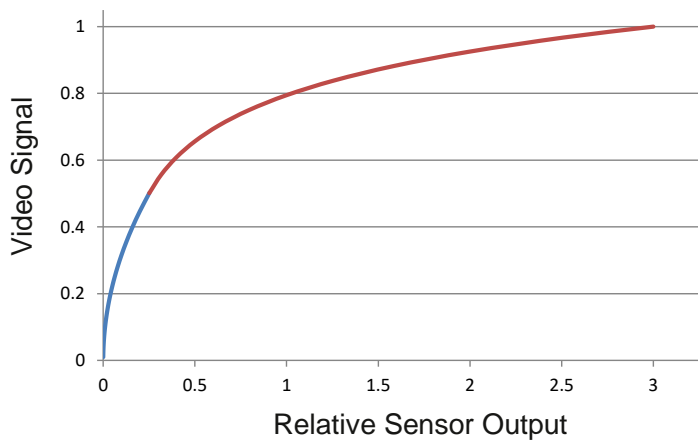
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Additional Dynamic Range in Blacks

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HLG Camera Curve Similar to SDR Camera Curve With a "Knee"

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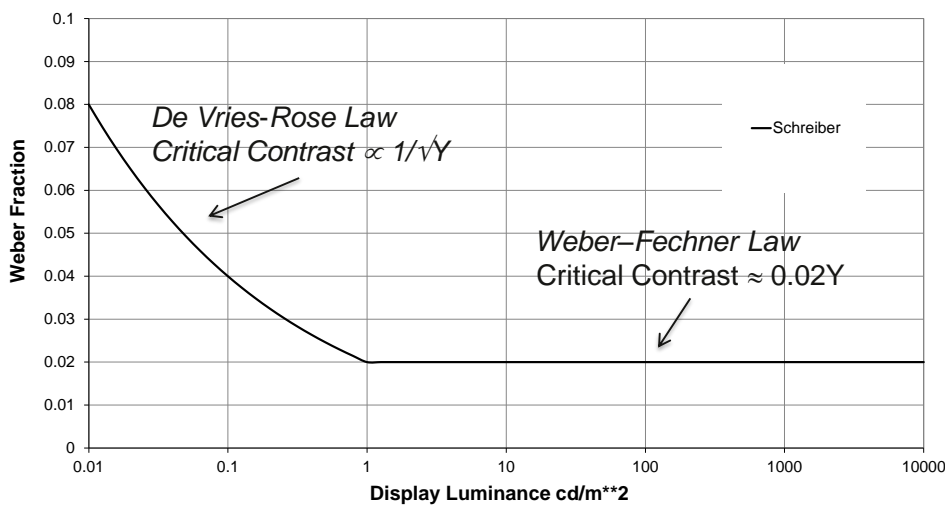**BBC** | Research & Development

Banding

Image Quantisation

Original

Extreme Banding

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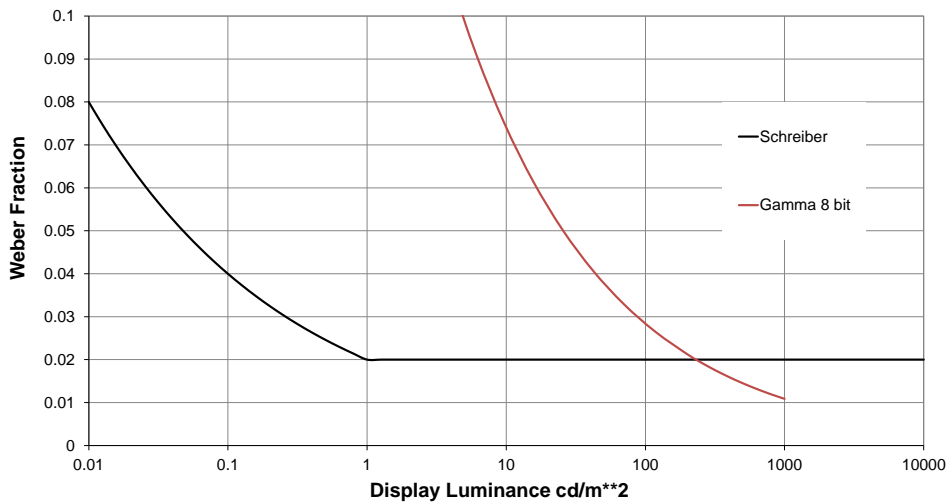**B B C** | Research & Development

Quantization Effects (Banding): The Schreiber Threshold

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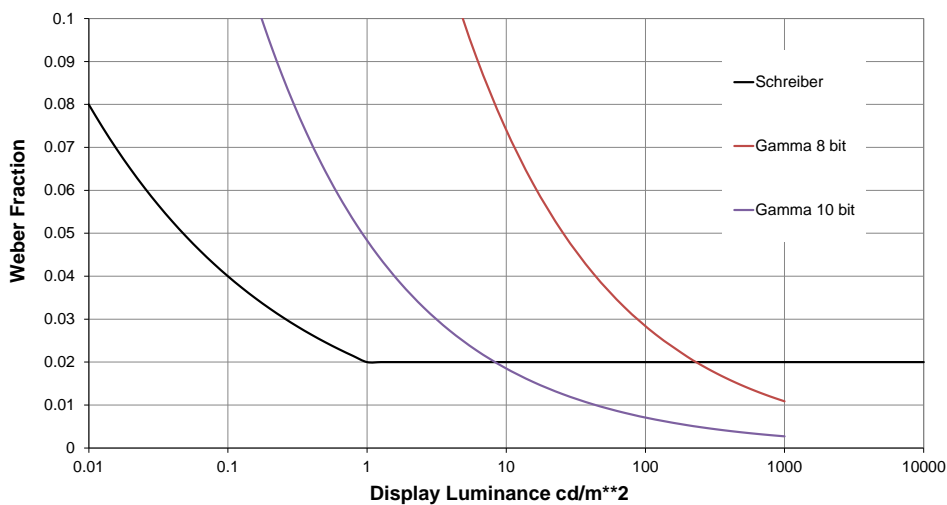**B B C** | Research & Development

Quantization Effects (Banding): Gamma Curve

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Quantization Effects (Banding): Gamma Curve

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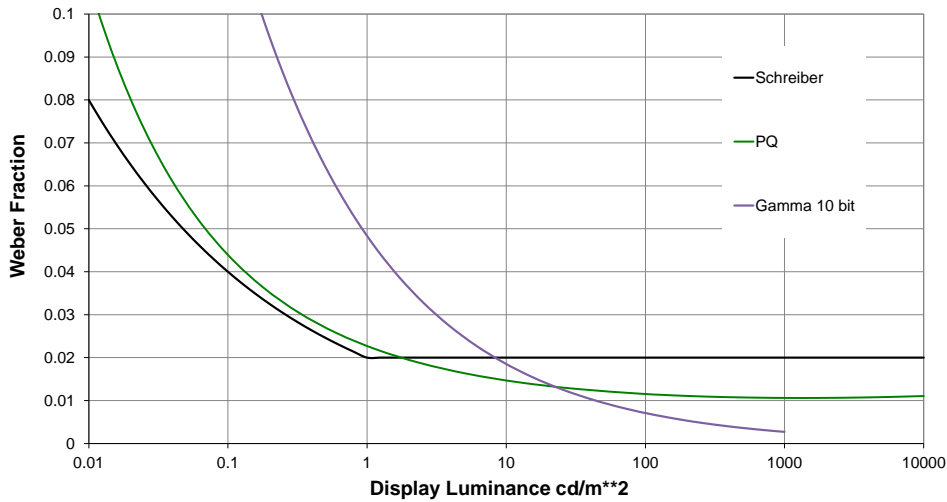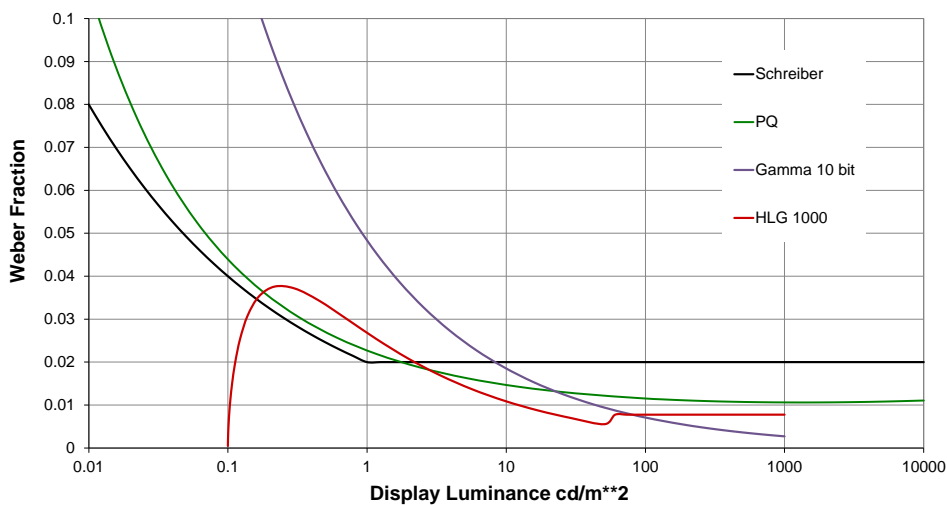**B B C** | Research & Development

Quantization Effects (Banding): PQ

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Quantization Effects (Banding): HLG

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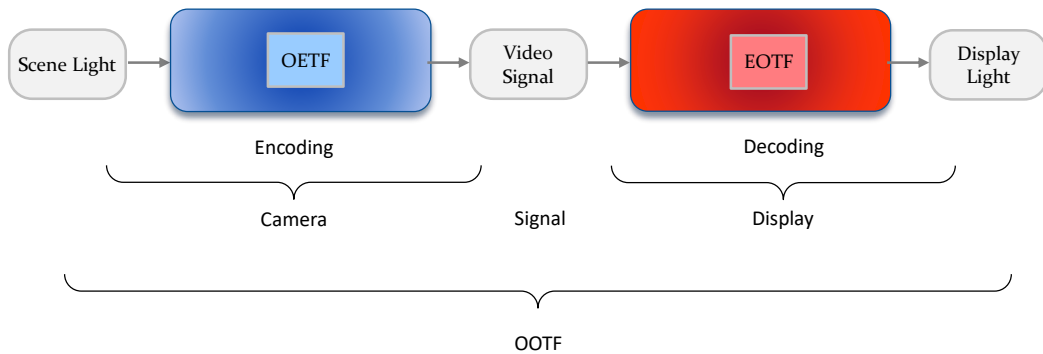
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A closer look at the Camera
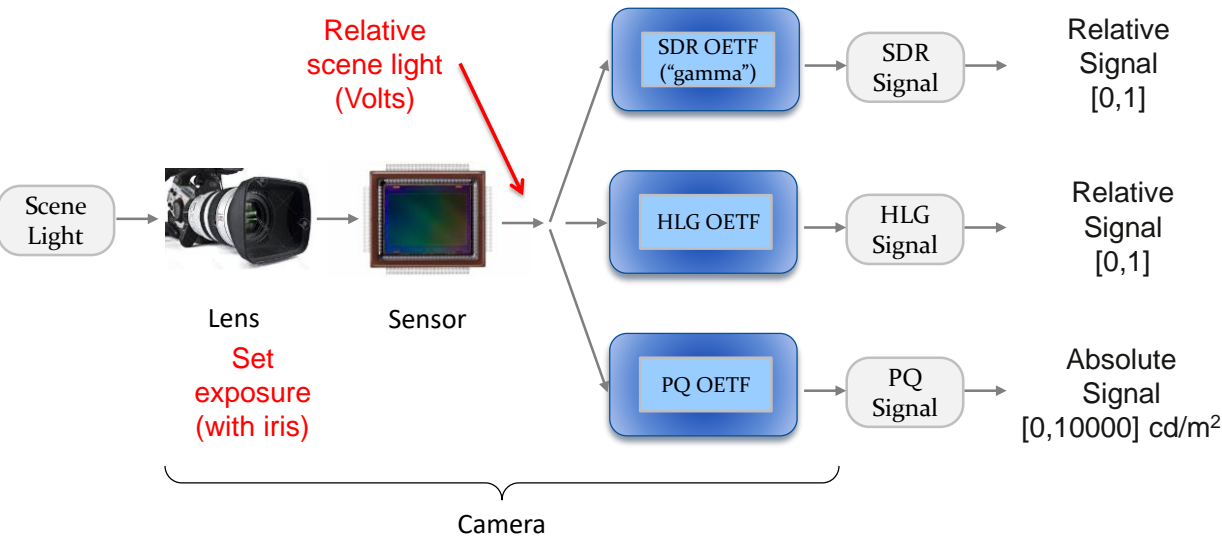
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Setting the Signal Level

Camera

Zebra Stripes

Production or Grading Suite

Waveform Monitor

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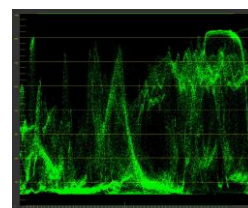
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Setting the Signal Level

- Diffuse white
  - The brightness of ideal "matte" or diffusely reflecting surface
  - Ill defined – varies with lighting
  - Not all scenes have diffuse white

- About 90% signal level for conventional SDR TV

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"Diffuse White" in HLG

- Fixed signal level
  - referred to as "reference level for graphics"
- 75% signal level (75 "IRE") proposed
- Good "compatible picture"
- ***Defines the number of stops for highlights***

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"Diffuse White" in HLG

- Defined by the camera setup
  - e.g. 18% grey card or reflectance chart
- Varies with display brightness
  - 400 cd/m^2, 75 % = 102 cd/m^2
  - 1000 cd/m^2, 75 % = 203 cd/m^2
  - 2000 cd/m^2, 75 % = 344 cd/m^2
  - 4000 cd/m^2, 75 % = 581 cd/m^2
- About 2.5 stops allocated for highlights and speculars
  - Subject to artistic choice

Levels for 1000 cd/m^2

Reflectance	Nominal Reference	
	% HLG	cd/m^2
18% Grey Card	38%	26
90% Reflectance Card	73%	176
Graphics reference	75%	203

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"Diffuse White" in PQ

|	INDOOR		OUTDOOR	
	cd/m²	% (IRE)	cd/m²	% (IRE)
18% Gray Card	17	34	57	45
Caucasian	26	38	85	49
Diffuse White	**140**	54	**425**	66

- From: Reference Level Guidelines for PQ (BT.2100), Dolby Laboratories, Aug. 9, 2016

- About 5.5 stop of linear signal range allocated to speculars and highlights

- The actual dynamic range for highlights depends on the display brightness

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Ensuring Consistent Brightness in PQ & HLG Production

- Operation practice defines reference levels
  - reference levels provide an "anchor"
  - similar to audio line-up levels

- Objective brightness measure also needed
  - similar to audio loudness, e.g. EBU R128, ATSC A/85
  - in development

- Comfort level tests underway to establish acceptable brightness range
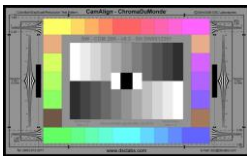
Overview of the Hybrid Log-Gamma HDR System

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Image Presentation

- HLG
  - **Brighter displays for brighter environments**
  - Image brightness changes with display brightness
  - Dynamic range of highlights **constant**
    - defined by diffuse white
  - Diffuse white important for compatibility on 4K TVs
- PQ
  - **Brighter displays for more highlights**
  - Image brightness constant with display brightness
  - Dynamic range of highlights **increases** with display brightness

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End-to-End Television Signal Chain
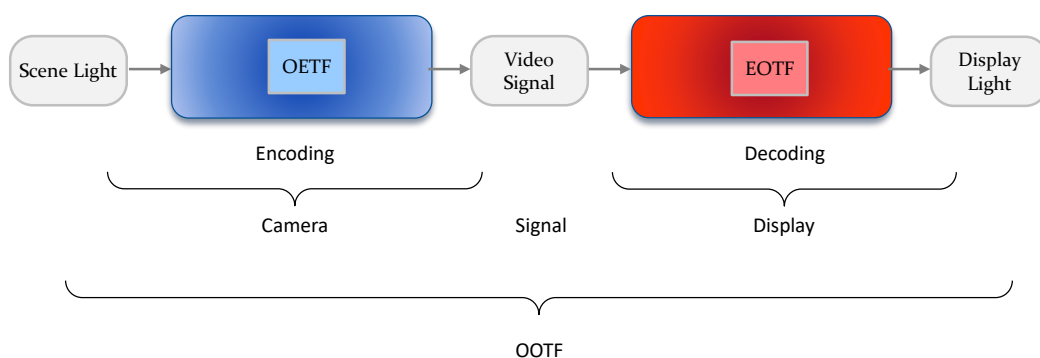
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Psychovisual Adaptation

Image plus surround

Image in dark surround

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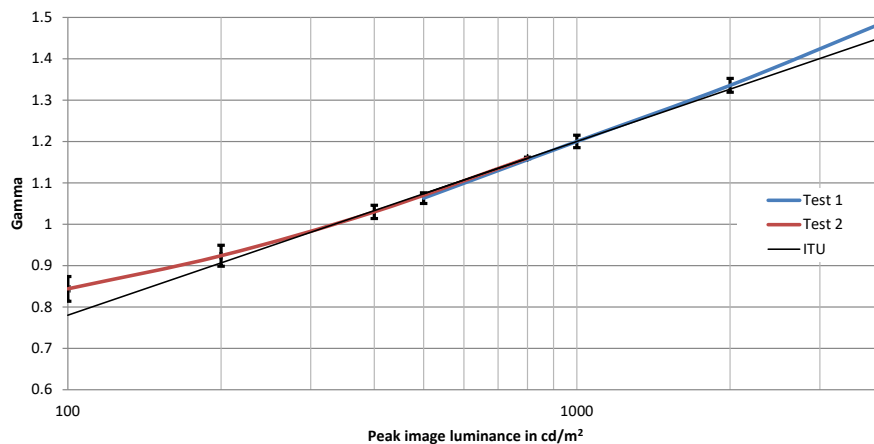## "Rendering Intent" (Display Gamma)

Gamma too low

Gamma correct

Gamma too high

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Variation of Gamma for Perceptual Match

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Artistic ("Creative") Intent

- Brighter environments need brighter pictures

- Different environments need different display gamma.

- Preserving luminance does NOT maintain creative intent

- The HLG signal, representing the camera output, remains constant.
    - HLG displays adapt to preserve artistic intent (defined in BT2100).

- The PQ signal represents the image specifically for a reference display
    - Dim environment only
    - Adaption for other brightness and environments ill-defined

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Artistic ("Creative") Intent

- Display Brightness = Production Brightness, Dim Environment
  - Both PQ and HLG maintain creative intent ☺.
- Display Brightness < Production Brightness, Dim Environment
  - HLG: Dimmer image – but maintains creative intent ☺.
  - PQ: Highlights crushed (desaturated), reduced creative intent ☹.
- Display Brightness > Production Brightness, Dim Environment
  - HLG: Brighter image ☺ – and maintains creative intent ☺
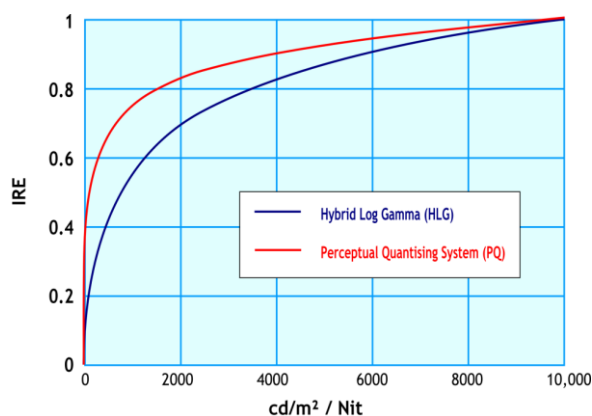 - PQ: Maintains creative intent ☺. But versioning (archive) issue ☹

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Compare ITU-R PQ & HLG solutions

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Not Just a Different Curve!

10 000 nit system

1 000 nit system

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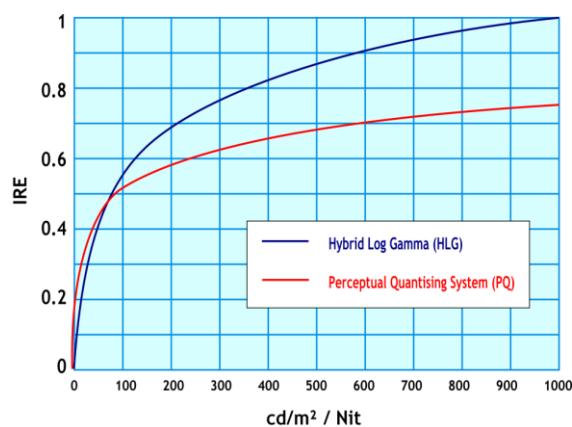
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Just like conventional TV, HLG is "Scene-Referred"

- Like BT.601, BT.709, Slog3, PanaLog etc., the HLG signal describes the **relative** light in the scene
- It is specified by the OETF (opto-electronic transfer function), the camera characteristic

PQ is display "display-referred"

- Like the digital cinema standards, the signal describes the **absolute** light output from the mastering display
- The signal is specified by the display EOTF

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PQ Represents Absolute Brightness

600 cd/m² "shading"
e.g. OB truck

e.g. Code Values 81 - 674

1000 cd/m² "shading"
e.g. studio gallery

e.g. Code Values 81 - 723

2000 cd/m² "grade"

e.g. Code Values 74 - 789

Display Re-Mapping

Display Re-Mapping

Display Re-Mapping

Display Re-mapping

e.g. 400 cd/m² home theatre
e.g. Code Values 74 – 636

e.g. 1000 cd/m² evening viewing
e.g. Code Values 81 - 728

e.g. 2000 cd/m² daytime viewing
e.g. Code Values 119 - 789

e.g. 4000 cd/m² signage display
e.g. Code Values 158 - 940

- The signal varies with mastering display.
  Display re-mapping often required.

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HLG Represents Relative Brightness

600 cd/m² "shading"
e.g. OB truck

Code Values 64 - 940

1000 cd/m² "shading"
e.g. studio gallery

Code Values 64 - 940

2000 cd/m² "grade"

Code Values 64 - 940

e.g. 400 cd/m² home theatre
Code Values 64 – 940

e.g. 1000 cd/m² evening viewing
Code Values 64 - 940

e.g. 2000 cd/m² daytime viewing
Code Values 64 - 940

e.g. 4000 cd/m² signage display
Code Values 64 - 940

- The signal constant with mastering display.
  Display adaptation inherent part of HLG EOTF

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Motivation for developing HLG

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HLG Enables Easy Migration to HDR TV Production & Distribution

Jointly developed by BBC and NHK, included in ITU-R Recommendation BT.2100

- Specifically developed for Television

- Delivers high quality HDR pictures
    - Delivery to diverse displays

- In Production
    - Requires no metadata
    - Compatible with existing 10-bit infrastructure, codecs and equipment
    - Provides compatible picture on SDR screens
    - Migration only requires HDR cameras, and HDR displays in critical monitoring areas

- Distribution
    - Supported by HEVC and HDMI 2.0b (via software upgrade)
    - Specified (alongside PQ) by DVB, ARIB and YouTube

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Metadata Free Operation Key to Unlocking Benefits

- Allows use of conventional circuits, routers, switchers and codecs

- Enables simple reliable and consistent production

- Delivers consistent results on consumer screens and devices

- Places no constraints on operational practices
    - Even simple metadata prevents, mixes, DVE and complicates graphics

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Metadata Free Operation Key to Unlocking Benefits

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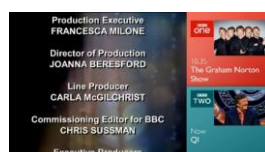

- Same issues apply in consumer equipment

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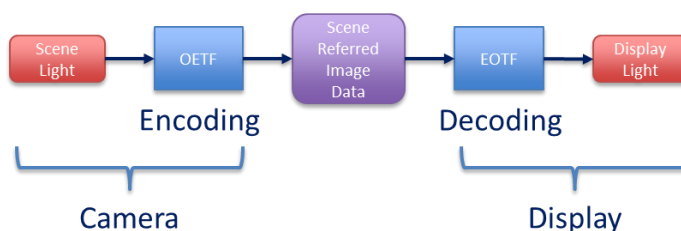
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Just like existing TV systems, HLG based on <u>Relative Brightness</u>

- Signal independent of the display
  - Utilises entire code range regardless of mastering monitor
  - Preserves the value of the archive as consumer displays get brighter

- Engineers and Craft staff read waveform monitors in the conventional way

- By design, entire image gets brighter as display brightness increases
  - Allows HDR viewing in brighter environments whilst maintain the creative intent
  - Allows consistent signals across a wide range of production environments and displays

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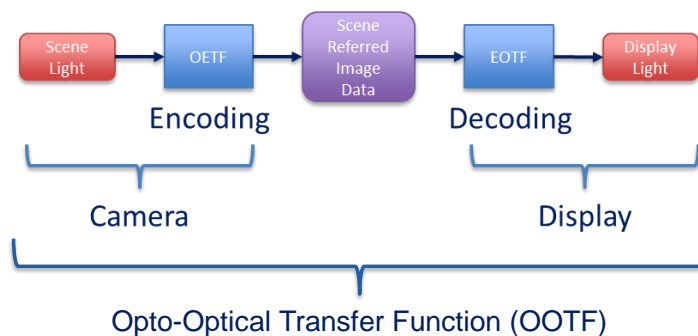## End-to-End Television Signal Chain

OETF: opto-electronic transfer function

EOTF: electro-optical transfer function

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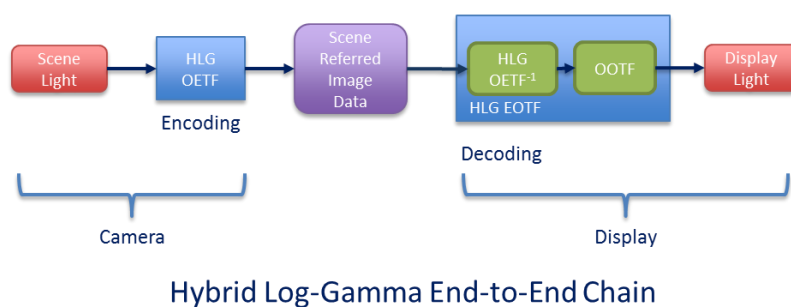## Overall Transfer Function (OOTF) Non-Linear

- OOTF varies according to viewing environment and brightness of the display
- Traditionally a "gamma" law OOTF

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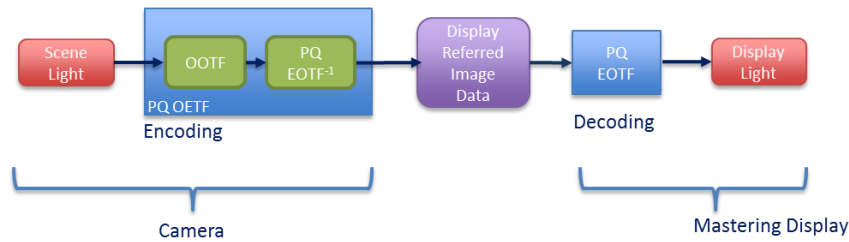## For "Scene Referred" Systems OOTF is Part of the Display

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For "Display Referred" PQ Systems OOTF is Part of the Camera

PQ End-to-End Chain

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

PQ signal chain

HLG signal chain
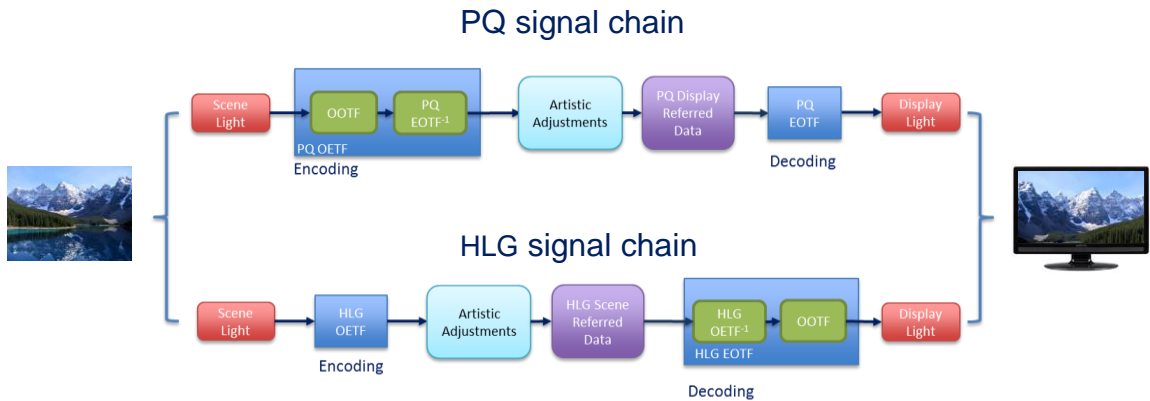
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PQ Display Rendering for Other Environments Requires Metadata for Optimal Presentation
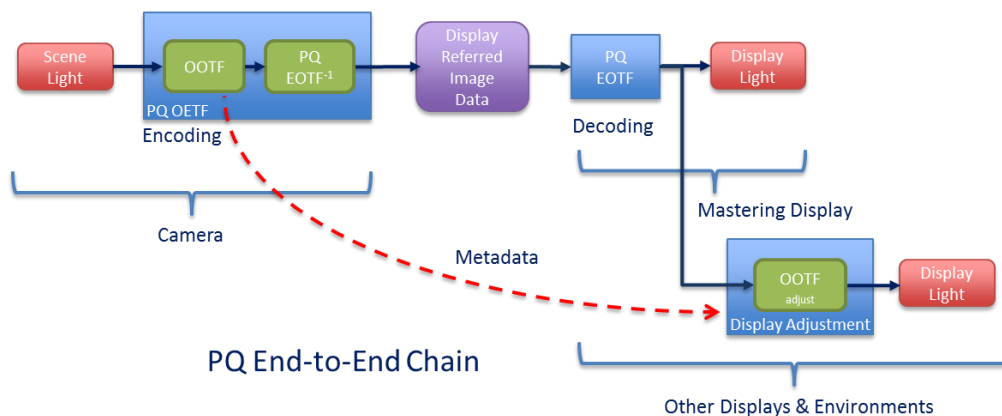
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Display Adjustments For HLG Needs No Metadata
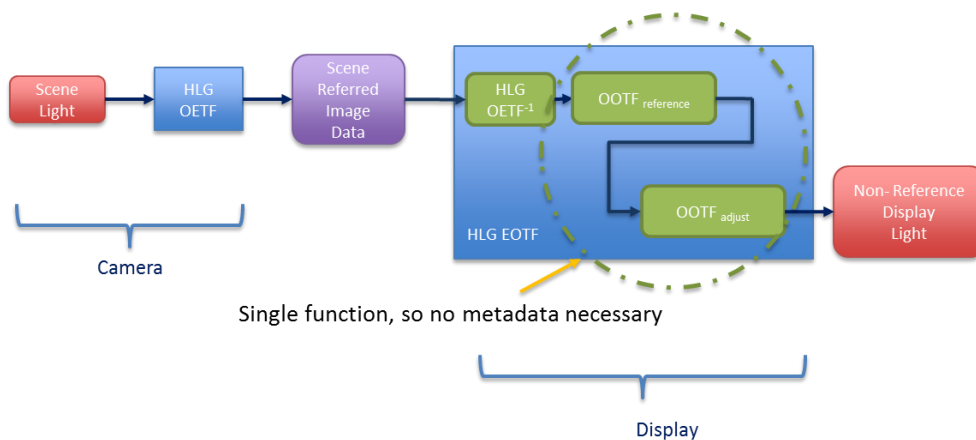
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HDR in Production

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HDR in TV Post-Production (other equipment available)

HDR (HLG & PQ) "aware" grading software
- SAM Quantel Rio
- DaVinci Resolve
- SGO Mistika
- Filmlight Baselight
- Digital Vision Nucoda
- Colorfront

HDR (HLG & PQ) displays
- Sony BVM-X300
- Canon DP-V2410, DP-V3010, DP-V2420
- Dolby PRM-4200/4220 (internal 3D-LUT for HLG)
- SIM2 (external converter)

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Landmark TV Productions already Produced in HLG
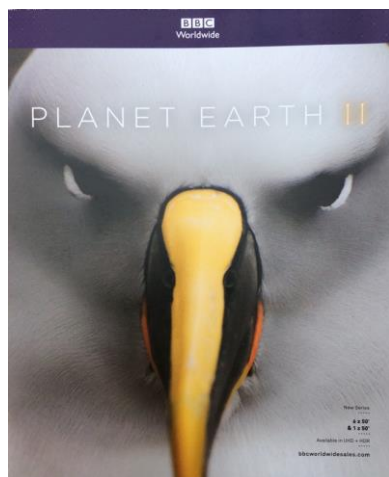
- BBC's Planet Earth II
  - UHD HLG HDR
  - Baselight grade
  - Dolby PRM4220 (with internal HLG LUT) monitor
- Around 20 programmes for Sky Perfect Japan

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Many Movies and OTT Releases in PQ

- Dolby Cinema

- HDR Blu-ray

- Streaming
  - Netflix
  - Amazon Instant Video
  - ….

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HDR Cameras

- Live HLG
    - Sony HDC-4300
    - Grass Valley LDX-86
    - Panasonic AK-UC3000
    - Ikegami UHK-430, SHK-810
- Live PQ
    - Grass Valley LDX-86
- Non-live, "Raw"
    - Sony (using sLog3)
    - Canon
    - Arri
    - Red
    - Panasonic
    - Many others …………

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Transcoding HLG to PQ
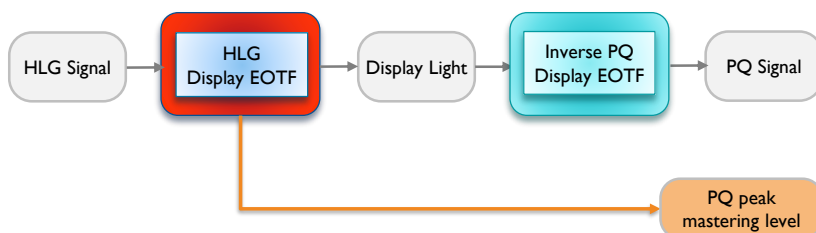

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Transcoding PQ to HLG

PQ Signal → **PQ Display EOTF** → Display Light → **Inverse HLG Display EOTF** → HLG Signal

PQ peak mastering level → (Inverse HLG Display EOTF)
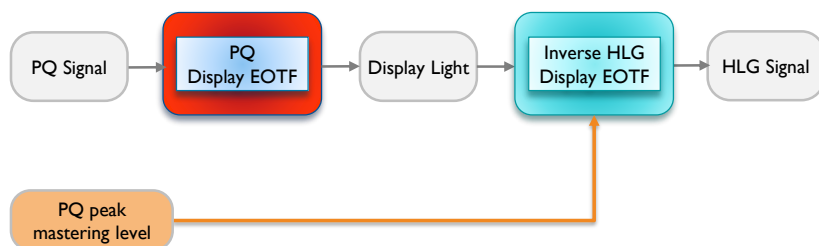
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However "Conversion" from PQ to HLG is Recommended

PQ Signal → **Tone Map to 1000 cd/m^2 "Bridge"** → PQ 1000 Signal → **Transcode to HLG** → HLG Signal →

PQ peak mastering level → (Tone Map to 1000 cd/m^2 "Bridge")

e.g. 400 cd/m^2 home theatre

e.g. 1000 cd/m^2 evening viewing

e.g. 2000 cd/m^2 daytime viewing

e.g. 4000 cd/m^2 signage display
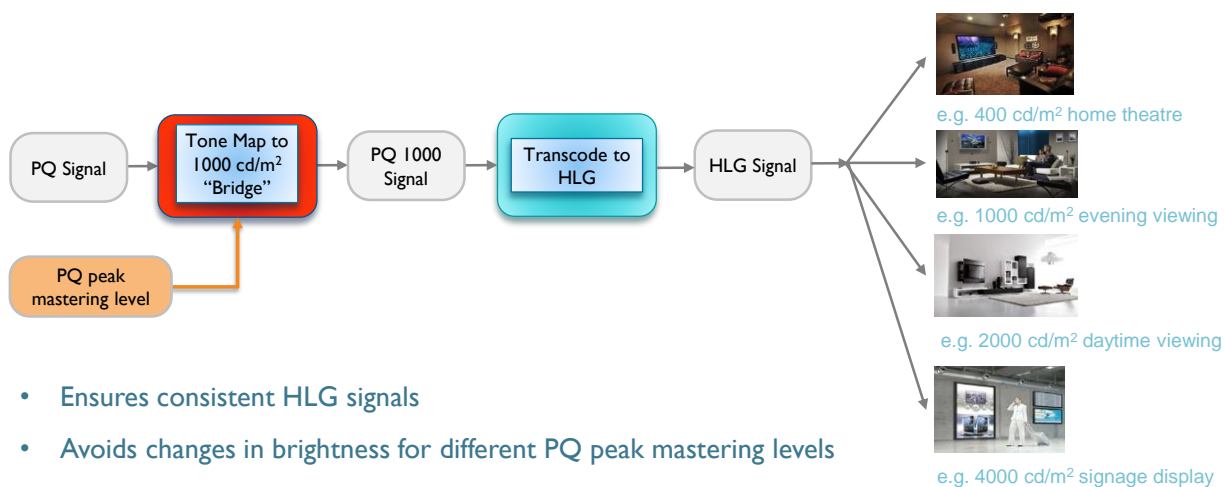
- Ensures consistent HLG signals
- Avoids changes in brightness for different PQ peak mastering levels

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PQ <-> HLG Interconversion Easily Implemented

- Already offered in grading software, distribution encoders and latest consumer silicon

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HDR in Distribution

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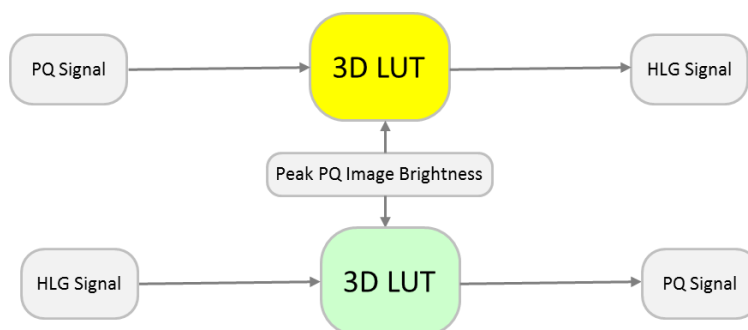
Both HLG and PQ Will be Supported in Devices in Most World Markets

HLG and PQ Included in,

- ARIB STD-B32, *Video Coding, Audio Coding And Multiplexing Specifications for Digital Broadcasting*

- DVB/ETSI TS 101 154 v2.3.1, *Specification for the use of Video and Audio Coding in Broadcasting Applications based on the MPEG-2 Transport Stream*

- Korea announced will support both HLG and PQ

- **YouTube HDR**

  https://support.google.com/youtube/answer/7126552

- HDMI 2.0b (HLG software upgrade)
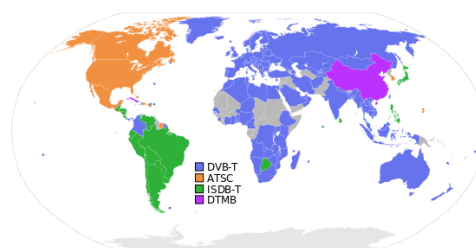
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Seven HLG TV Services Already "On-Air" Worldwide

- **HLG Commercial Services**
  - Sky Perfect Japan, launched October 2016
  - Travelxp 4K (Europe), launched January 2017

- **Current HLG Test Services**
  - SES Astra 19.2˚
    - HLG Test stream
    - NRJ (French Network) Test transmission
  - Eutelsat Hotbird 13.0˚
    - 4-Ever Project Test Channel
  - Tour Eiffel, Paris, France
    - NRJ Test transmission
- NHK Super Hi-Vision

- BBC iPlayer

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HDR in the Home

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Essential that HDR TV is suitable for <u>HOME</u> viewing environments

- Absolute brightness approach of PQ well suited to Cinema where all viewing environments the same

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4K Blu-ray vs Blu-ray Reveals HDR Is Too Dim for Daytime

By Vincent Teoh   10 April 2016, 5:35 pm BST

We've stumbled upon a truly ironic problem for the highly anticipated HDR (high dynamic range) format after watching a few Ultra HD Blu-ray movies on several 2016 4K HDR TVs we've reviewed recently. We were experimenting with introducing ambient lighting to see if we could better mask the backlight inconsistencies and local dimming issues in HDR mode on the LED LCD televisions we were testing, but invariably found ourselves asking, "Why does the HDR picture look so unimpressive? We can't make out any dark detail!"

And then it hit us.

http://www.hdtvtest.co.uk/news/4k-vs-201604104279.htm

PQ and HLG

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Essential that HDR TV is suitable for <u>HOME</u> viewing environments

- Absolute brightness approach of PQ well suited to Cinema where all viewing environments the same

- But, viewers should not have to draw curtains during the daytime to watch HDR-TV

- Relative brightness approach of HLG, well suited to diverse home TV viewing
  - To preserve details in the blacks, presentation needs to be brighter than in grading suite
  - To preserver the impact of highlights, consumer screens may need to be brighter than grading screens

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Relative Light Approach of HLG allows HDR viewing all day long

By design as HLG displays get brighter so does entire image, enabling HDR in brighter environments, e.g.,
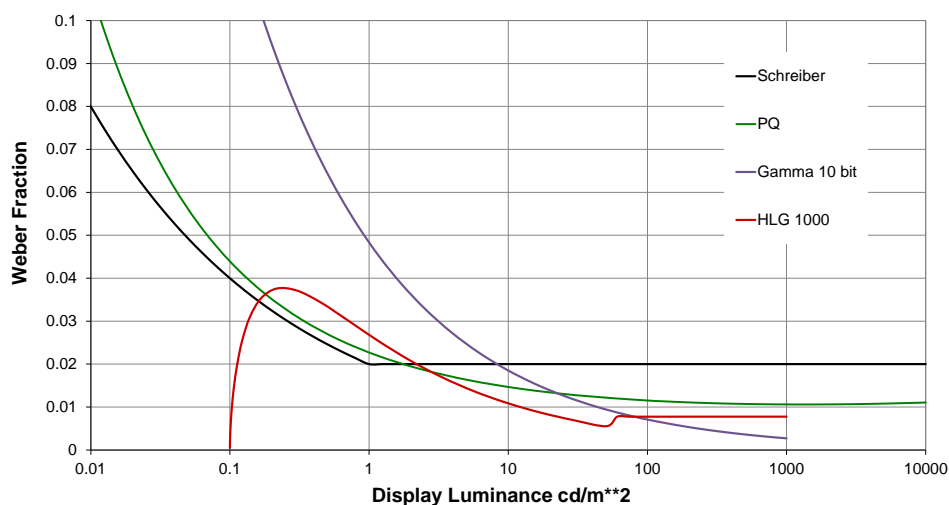
Environment   Simulated images

- Home theatre projector
  - e.g. 400 cd/m2 peak
    - graphics "ref" (75% HLG), 100 cd/m^2

- Dim evening living room
  - e.g. 1000 cd/m2 peak
    - graphics "ref" (75% HLG), 203 cd/m^2

- Bright daytime living room
  - e.g. 2000 cd/m2 peak
    - graphics "ref" (75% HLG), 344 cd/m^2

PQ and HLG
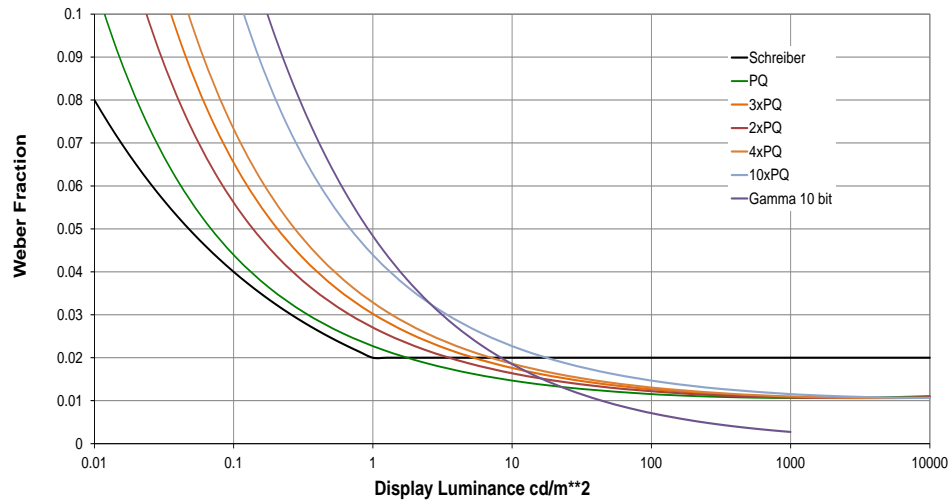
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Quantization Effects (Banding)

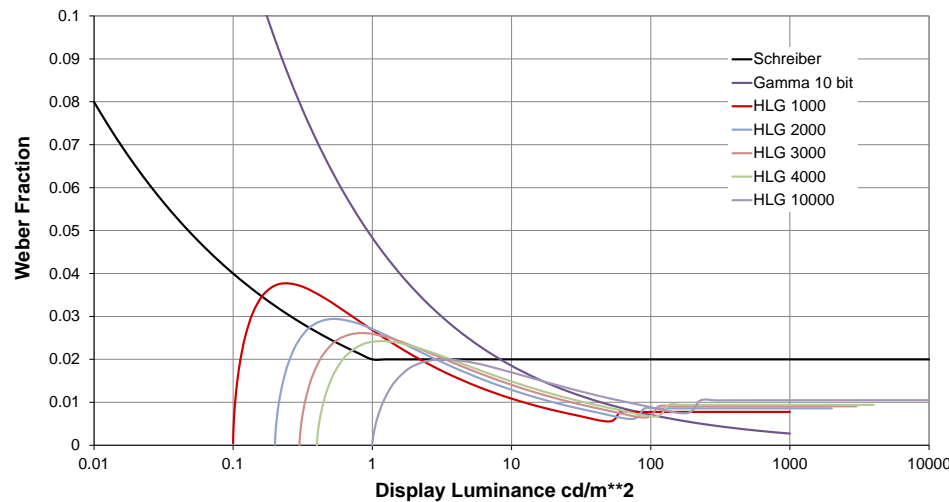
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Stretching the blacks in PQ

PQ and HLG

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Stretching the blacks in HLG

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Artistic ("Creative") Intent

- Display Brightness = Production Brightness, Dim Environment
  - Both PQ and HLG maintain creative intent ☺.
- Display Brightness < Production Brightness, Dim Environment
  - HLG: Dimmer image – but maintains creative intent ☺.
  - PQ: Highlights crushed (desaturated), reduced creative intent ☹.
- Display Brightness > Production Brightness, Dim Environment
  - HLG: Brighter image ☺ – and maintains creative intent ☺
  - PQ: Maintains creative intent ☺. But versioning (archive) issue ☹
- Brighter Environment (& Brighter Display)
  - HLG brighter image ☺, , no banding ☺, maintains creative intent ☺ .
  - PQ brighter image ☺, increased banding ☹, compromised creative intent ☹.

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HLG Appearing in Consumer Equipment

Product Announcements CES 2017

- JVC
  - DLA-X5500, X7500, X9500 projectors
- LG
  - W7, G7, E7, C7 and B7 OLED
    - Updates for 2016 E6 and C6
- Panasonic
  - EZ1000/EZ1002 OLED
  - **Lumix GH5 DSLR**
- Sony
  - Sony Bravia A1/AE1 Series OLED
    - Updates for 2016 models

- Previously shown in TVs and projectors from
  - Panasonic, Samsung & Toshiba

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PQ and HLG Summary

- HLG developed to allow straightforward migration to HDR Television
    - Supports a wide range of displays and environments
    - No need for metadata as OOTF is part of display EOTF
    - Can be displayed unprocessed on SDR screen

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- Both HLG and PQ include in DVB, ARIB and YouTube for HDR TV Distribution

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Thank you

bbc.co.uk/rd

bbc.co.uk/rd/projects/high-dynamic-range

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Q&A – Verbal Questions

Tim Borer

Andrew Cotton

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