Tektronix

Gamma and High Dynamic Range

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Gamma and High Dynamic Range (HDR)

AGENDA

- Review of Gamma
  - What is Gamma?
  - Typical HD Video SDR Processing
  - System Gamma
- High Dynamic Range (HDR)
  - Visual Dynamic Range and Mapping into Camera F-Stops
  - HDR Standards and Comparison to SDR
  - Potential Issues with Bright HDR Displays
- Monitoring Camera RAW footage and HDR
- Summary

What is Gamma?

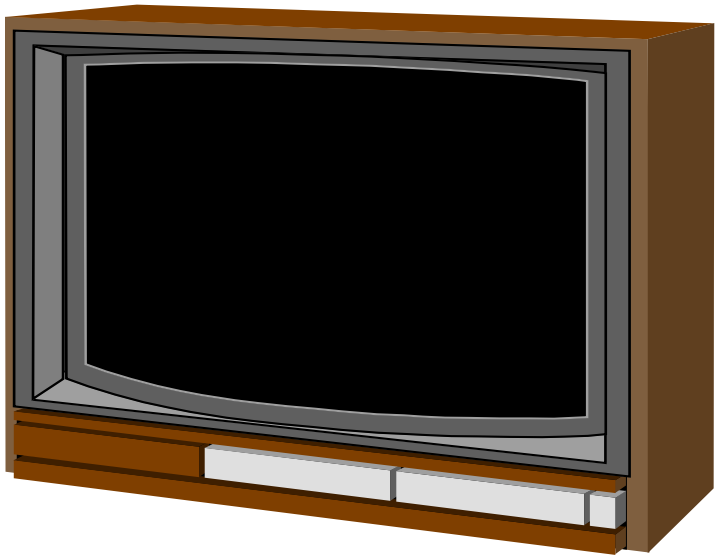
- CRT Defect?
- Needed to match Human Visual Response?
- Can I adjust gamma?
- Gamma for a CRT but what about flat panel displays?
- Why not get rid of gamma power-law?

What is Gamma?

- CRT Defect?

  It is caused by the voltage to current grid-drive of the CRT and not the phosphor.

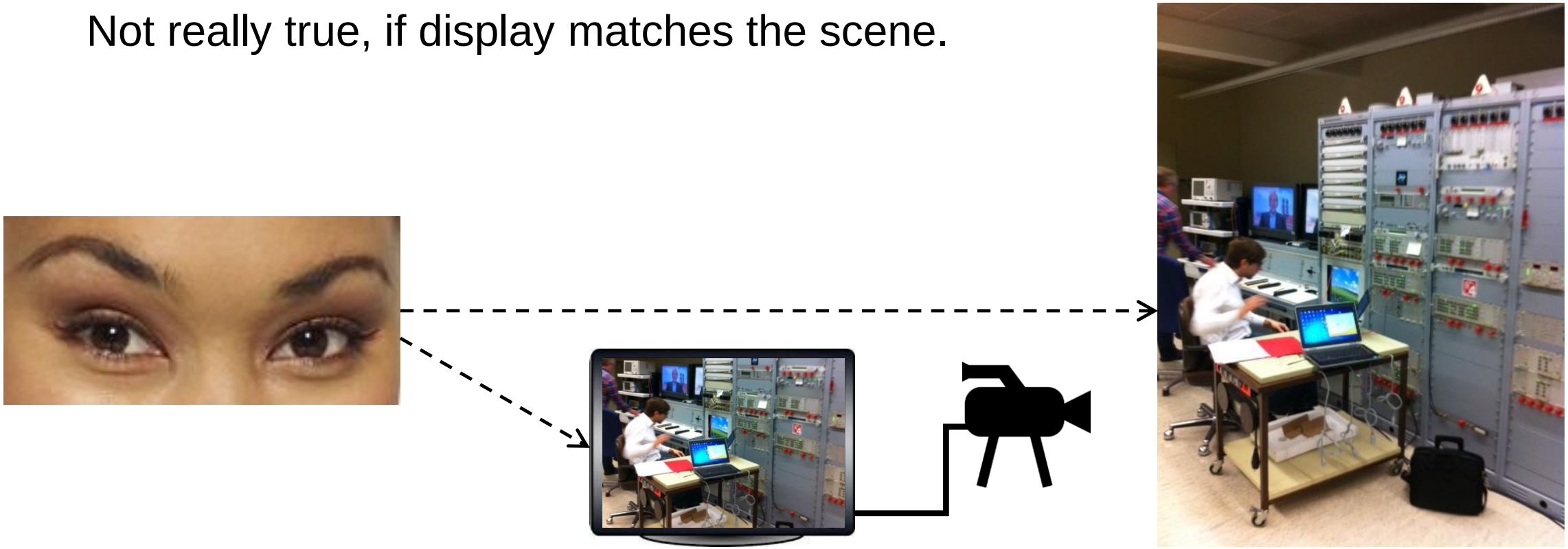
  A current-driven CRT cathode has a linear response and so we could easily remove gamma even in the days of B/W)



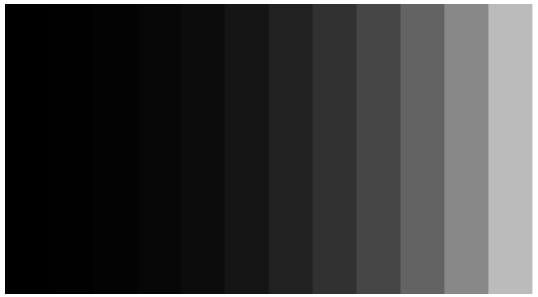
What is Gamma?

- Needed to match Human Visual Response?

  Not really true, if display matches the scene.



What is Gamma?



- Can I adjust gamma?

BT.1886 says all displays should be calibrated to 2.4 but it changes with Black-level or room lighting.

RECOMMENDATION ITU-R BT.1886

Reference electro-optical transfer function for flat panel displays[1] used in HDTV studio production

Scope (2011)

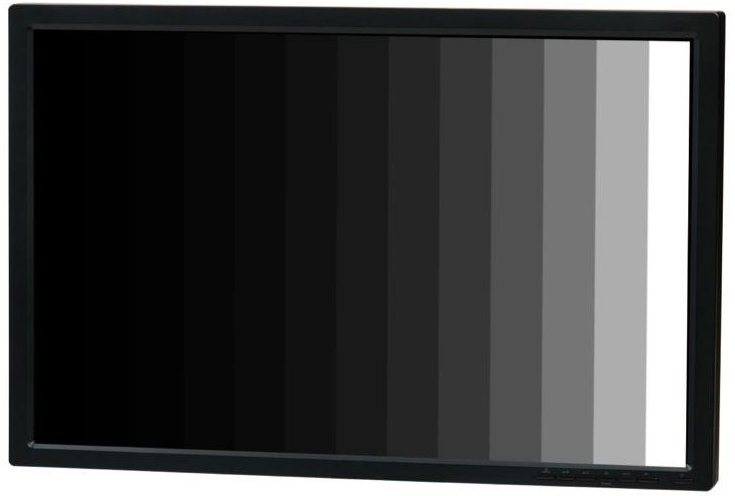
This Recommendation specifies the reference electro-optical transfer function (EOTF) that the displays used in HDTV programme production should follow in order to facilitate consistent picture presentation[2]. The reference EOTF is specified as a simple equation, with exponent function, based on measured characteristics of the Cathode Ray Tube (CRT).

Black levels can track room lighting with auto-brightness (began in early 70's) to roughly maintain gamma.

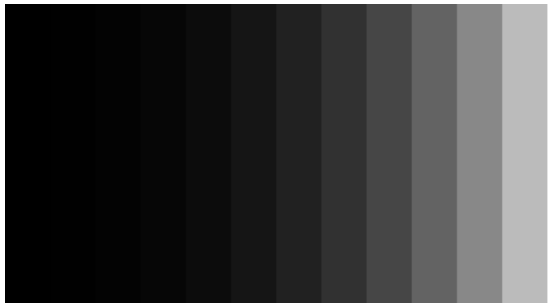
What is Gamma?

- Gamma for a CRT but what about flat panel displays?

  CRT is black-level sensitive power-law.
  Light power = $(V + \text{black-level})^{\text{gamma}}$
  The Brightness or Black-level adjustment dramatically changes gamma.



What is Gamma?



- Why not get rid of gamma power-law ?

For some time now, we have. Cameras do not need to be set for BT.709 gamma. But, for current HD SDR displays, even with BT.2020 colorimetry, BT.1886 applies.

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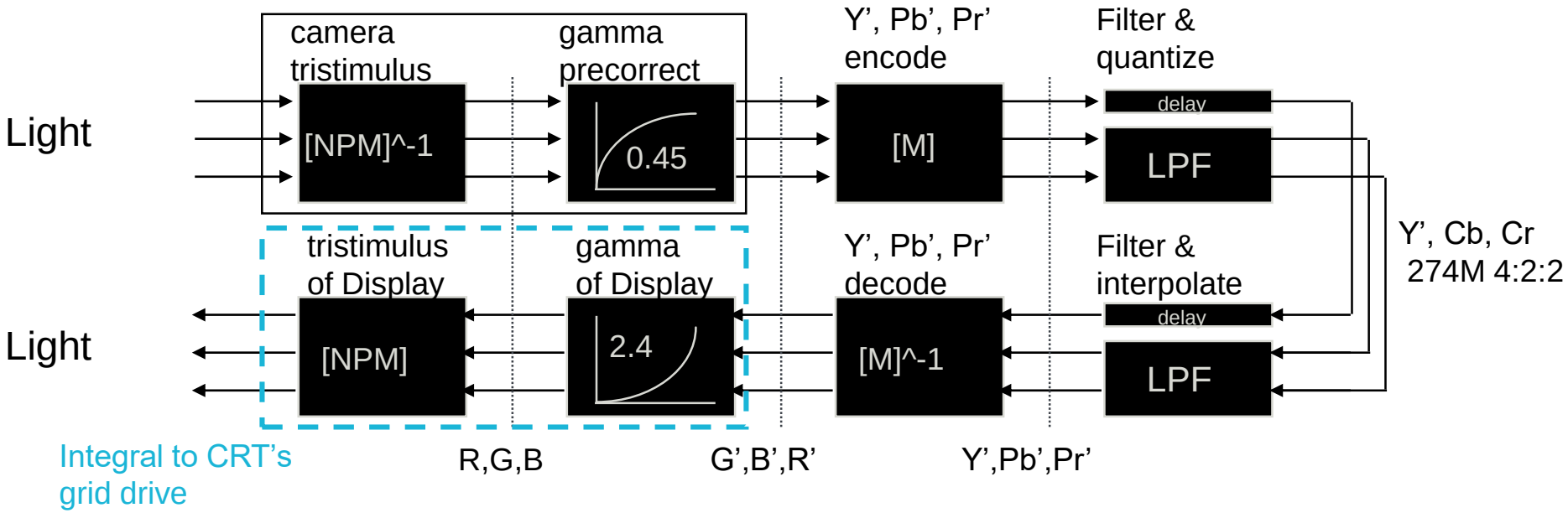
System Gamma

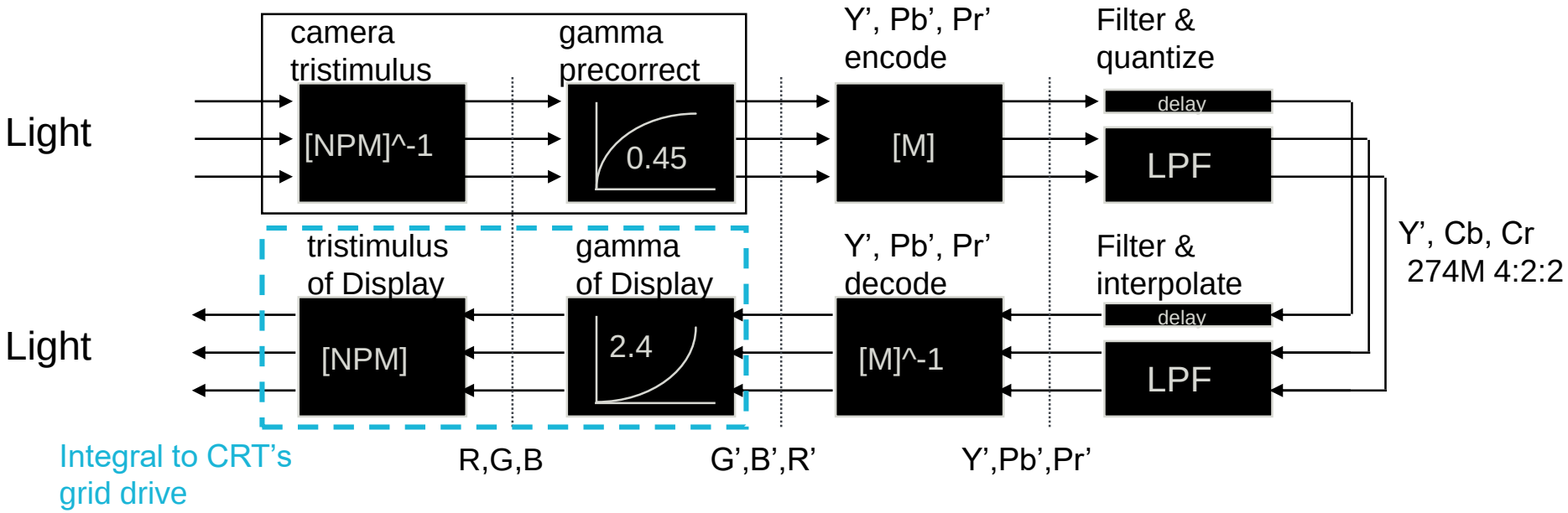
TYPICAL HD VIDEO SDR PROCESSING



- BT.709 says camera output, V, is linear to 1.8% and then proportional to (light)$^{0.45}$ above that. The lower gain in the blacks mitigates camera noise.
- BT.1886 says pix monitor displayed Light = (V + offset)$^{2.4}$ over entire range.

System Gamma

TYPICAL HD VIDEO SDR PROCESSING



- **However, note that 1/0.45 = 2.22 and not 2.4!**
  Therefore, system gamma not unity. More about it later.

System Gamma

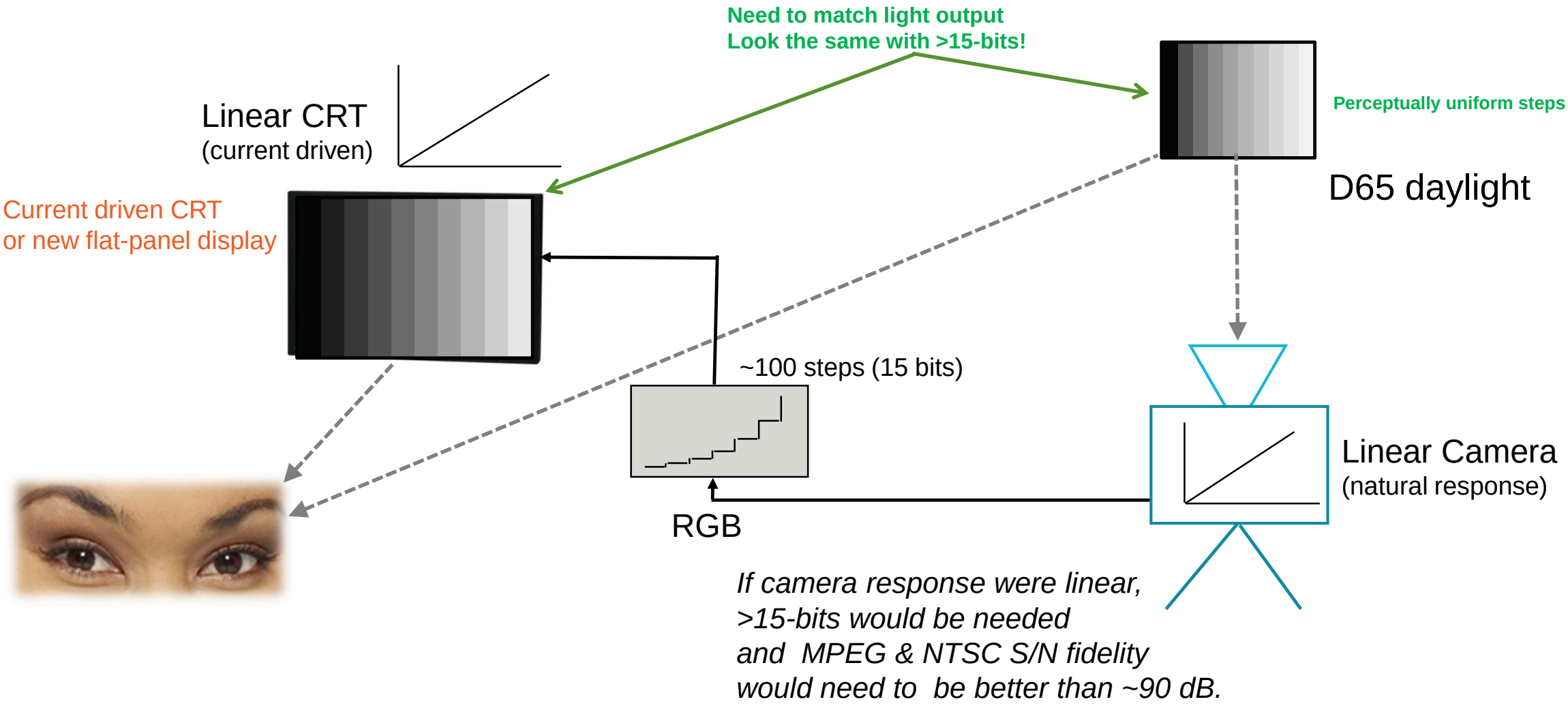
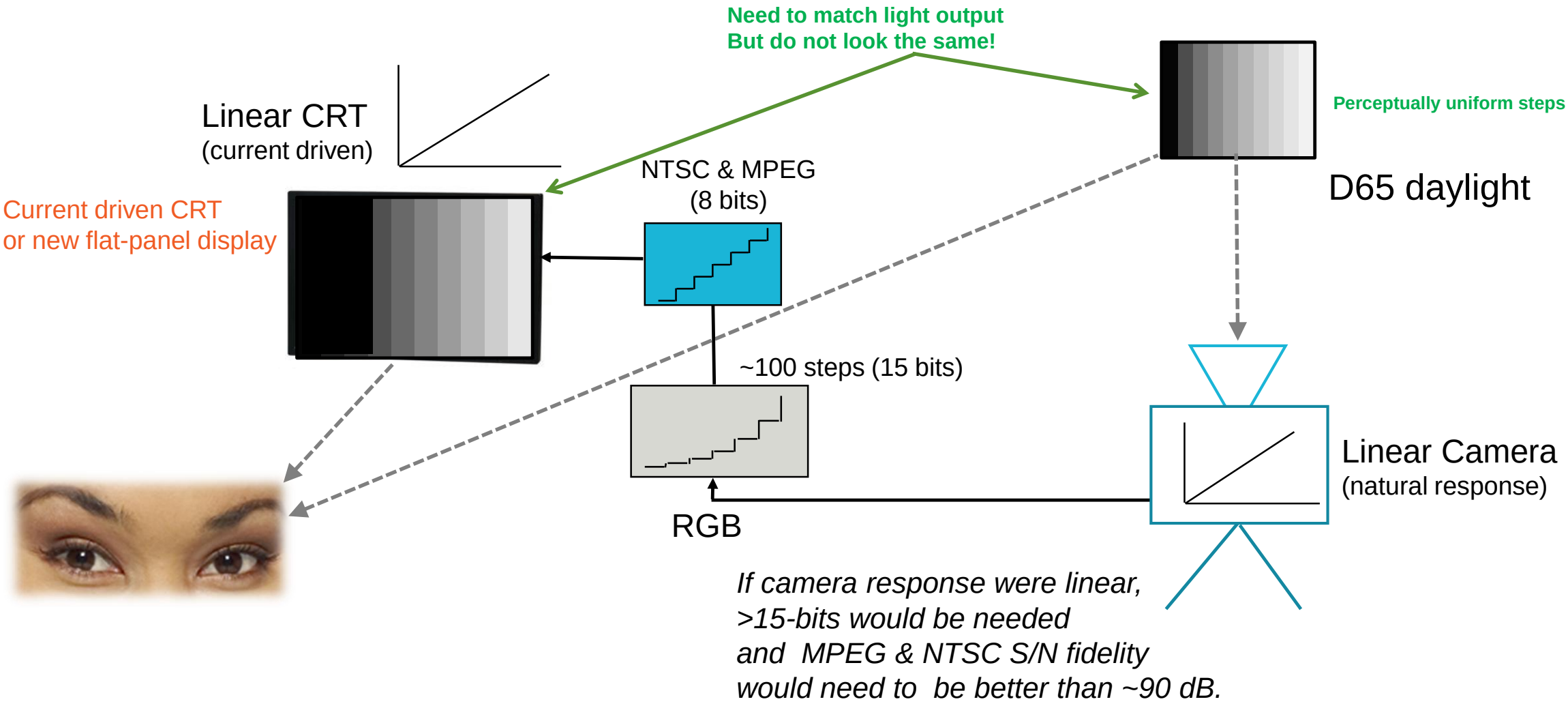


Image reproduction using video is perfect if display light pattern matches scene light pattern.

System Gamma



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System Gamma

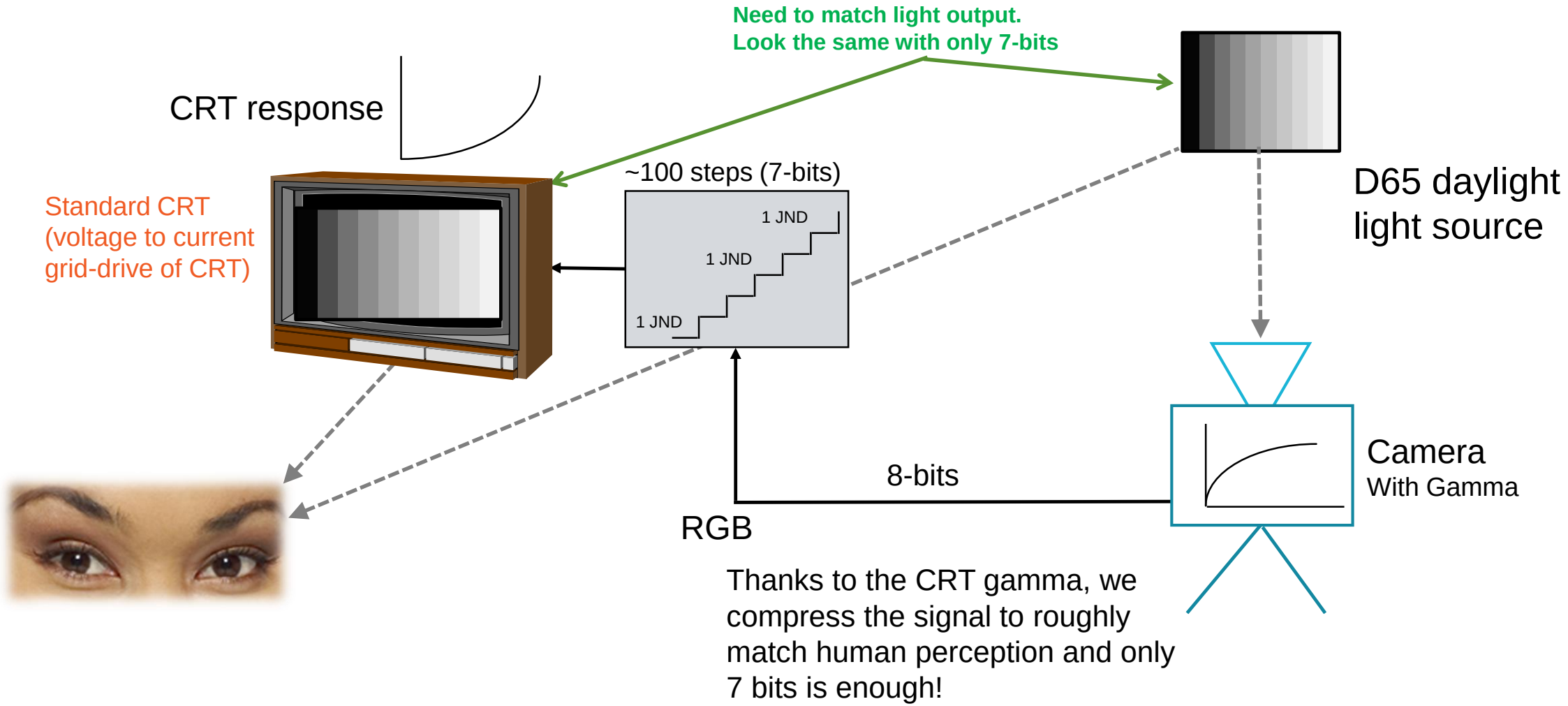


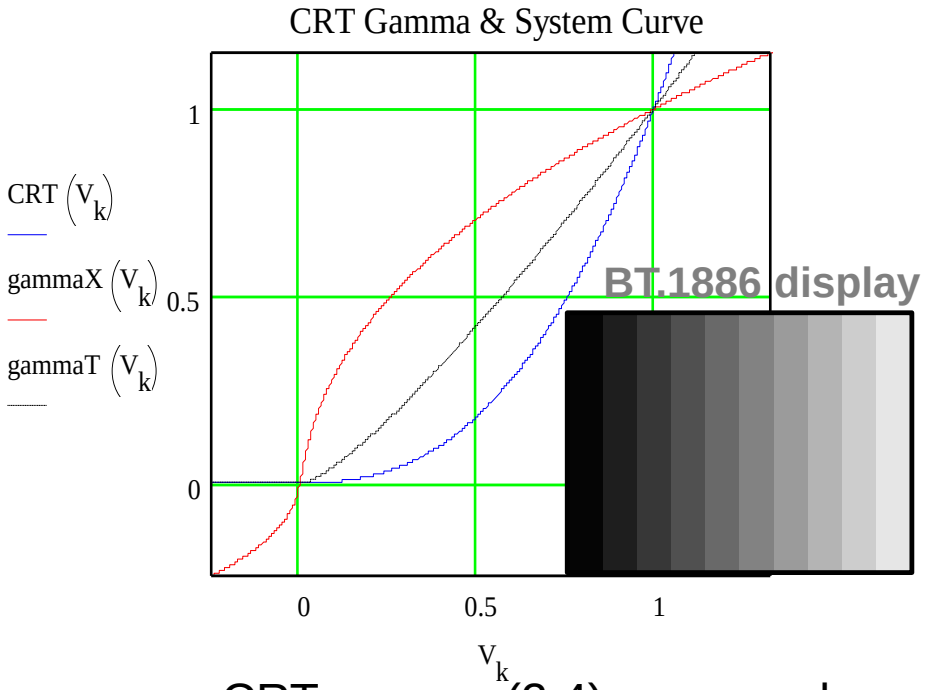
Image reproduction using video is perfect if display light pattern matches scene light pattern.

System Gamma

- System gamma is about 1.2 to compensate for dark surround viewing conditions.

- Amazing coincidence:
  CRT gamma curve (grid-drive) nearly matches human lightness response so pre-corrected camera output is close to being perceptually coded!

- **If TV's with CRT's had been designed with a linear response, the early designers would have invented gamma correction anyway and added it to all display technologies!**



CRT gamma (2.4) compared to total system gamma (1.2).

Gamma facts (review)

- CRT Defect? No!
  It is caused by the voltage to current (grid-drive) of the CRT and not the phosphor.
  The nonlinearity is roughly the inverse of human lightness perception.
- Display monitors have black-level sensitive power-law. $L = (V + \text{black-level})^{2.4}$
- Gamma exponent in TV's and sRGB flat-panels is fairly constant at about 2.4 to 2.5. Modern displays should be calibrated to 2.4 as per BT.1886.
- We see about 1% changes in luminance. If a display is a linear light transducer, it takes about 15-bits to provide a perceptually continuous lightness. A grid-drive CRT roughly pre-corrects for lightness perception requiring only 8-bits for a perceptually continuous luminance.

High Dynamic Range (HDR)

Why does HDR look better than SDR ?

- Are HDR screens brighter on average? **Answer: No.**
- Are HDR screens darker on average with blacker blacks? **Answer: No.**
- Is the average picture level (APL) unchanged? **Answer: No.**

Why does HDR look better than SDR

HDR RETAINS BRIGHT SPECULAR HIGHLIGHTS AS WELL AS DETAIL IN BLACKS WHICH CAN MAKE COLORS APPEAR MORE SATURATED.

Sky Light: >500K nits
Looking at the sun > 1 billion nits (don't look at it)

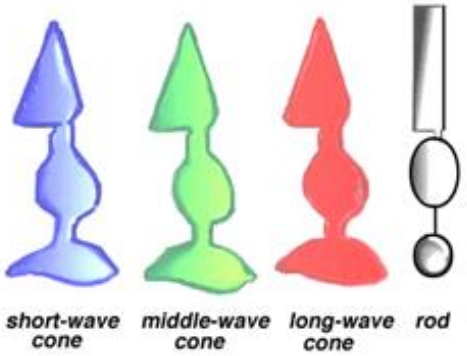
Luminance:
The amount of light in candela per square meter (cd/m^2) or nits
(Latin nitere = "to shine")

Lap top or TV: 100 to 200 nits
(hard to see in bright daylight

Shadows: .1 to 10 nits
With day adapted eye shadows can be 10 nits. In living room, less than 0.1 nits

Anatomy of the Eye's Receptors

- Rods
  - Sensitive to Blue-green light
  - Used for vision under dark-dim conditions.
- Cones
  - 3 Types of Cones
  - Sensitive to either long wavelengths of light (red light), medium wavelengths of light (green light) or short wavelengths of light (blue light).



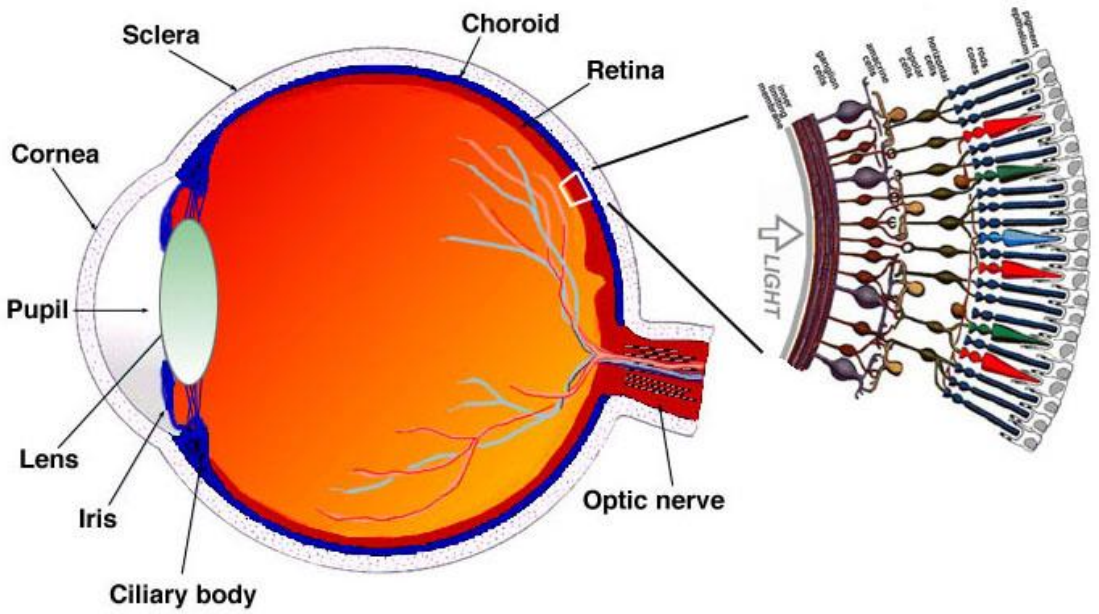


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

http://webvision.med.utah.edu/index.html

Total Visual Dynamic Range

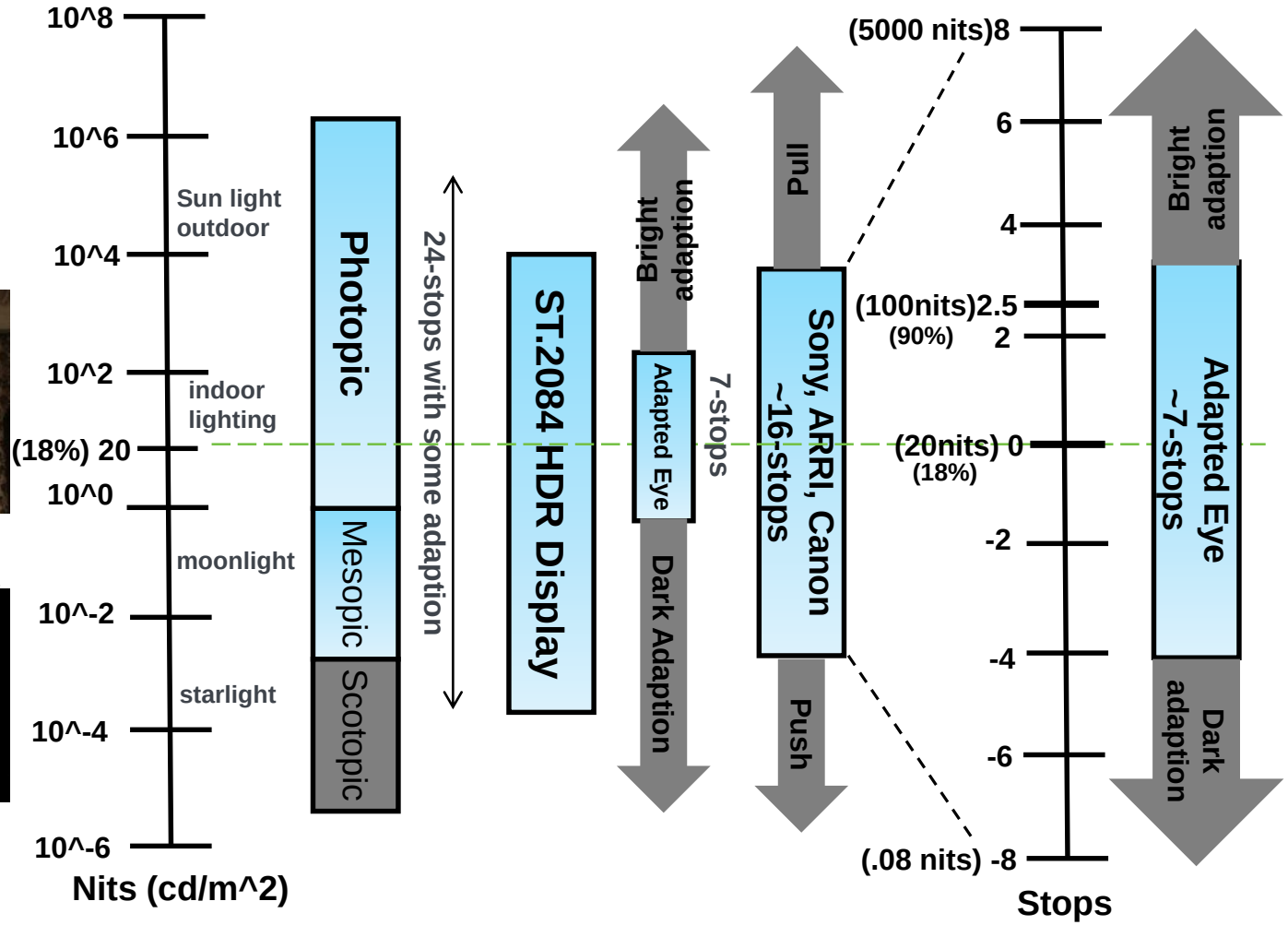
HDR MAPPING INTO CAMERA F-STOPS (0 STOP = 18% REFLECTANCE)

Sunlight outdoor

Indoor Lighting

Moonlight

Starlight



Camera Dynamic Range

- Sony (S Log 1,2,3)
  - F55
  - F5
  - HDC4300L
  - FS7K
  - FS700 (S Log 2) [13.3 Stops]

- Canon (C Log)
  - C700 [15 Stops]
  - C500
  - C300 Series

- Red
  - Weapon 8K [16.5 Stops]
  - Epic 8K
  - Scarlett 5K
  - Raven 4.5K

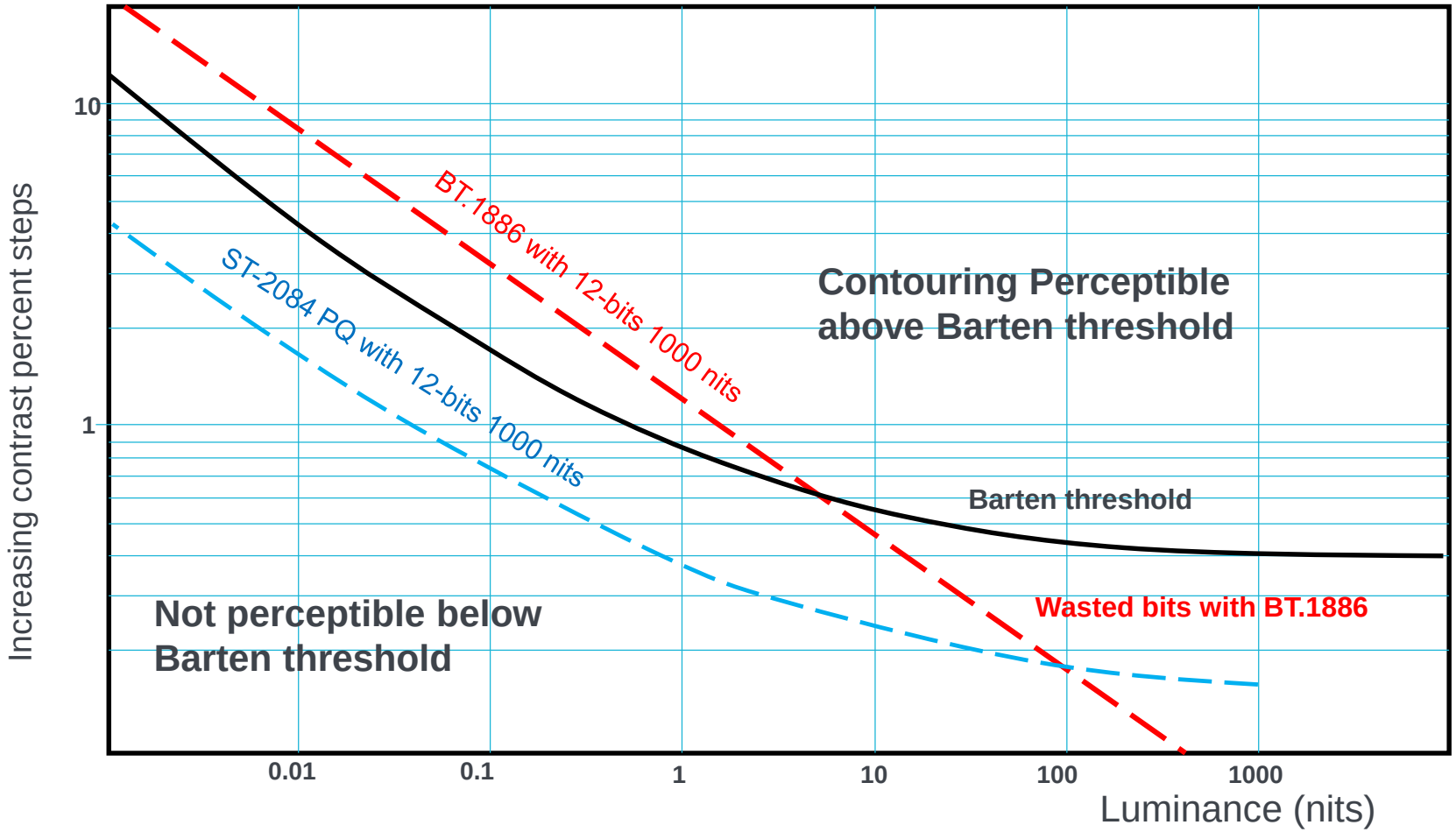
- ARRI (Log C)
  - Alexa 65 [>14 Stops]
  - Alexa SXT
  - Alexa mini
  - Amira

- Panasonic (V-Log)
  - VariCam LT
  - VariCam 35 [14+ Stops]
  - VariCam Pure

- Black Magic
  - Ursa [15 Stops]
  - Ursa mini
  - Cinema Camera

ST.2084 with Perceptual Quantizer for HDR

12-BIT PQ AND REC-1886 COMPARED WITH BARTEN THRESHOLD



SMPTE ST-2084 PQ HDR versus BT.1886 SDR

COMPARISON OF ST-2084 PERCEPTUAL QUANTIZER (PQ) TO BT.1886 POWER-LAW EOTF (Electrical to Optical Transfer Function).

maxi (x) := if (x < 0 , 0 , x)

m1 := 2610 / 4096 · 1/4 = 0.1593017578125

m2 := 2523 / 4096 · 128 = 78.84375

c1 := c3 − c2 + 1 = 0.8359375

c2 := 2413 / 4096 · 32 = 18.8515625

c3 := 2392 / 4096 · 32 = 18.6875

nits

PQ EOTF:

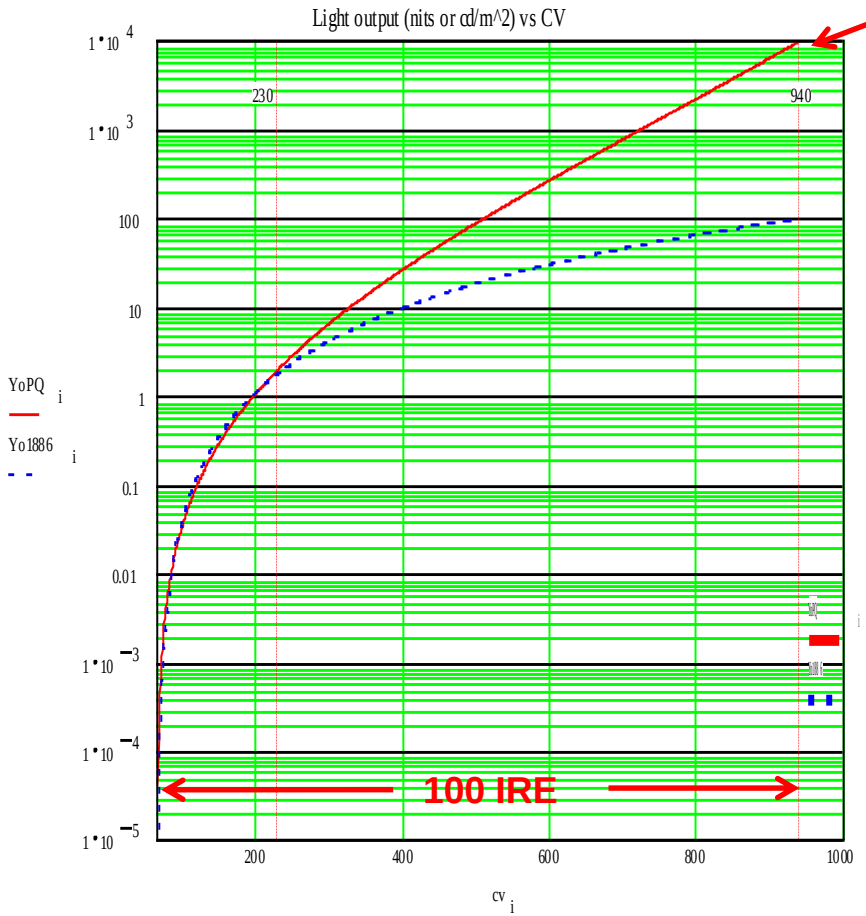
$$Y_P(V) := L_p \left[\frac{\max\left(V^{\frac{1}{m2}} - c1, 0\right)}{c2 - c3 V^{\frac{1}{m2}}} \right]^{\frac{1}{m1}}$$

BT1886 EOTF:

nits

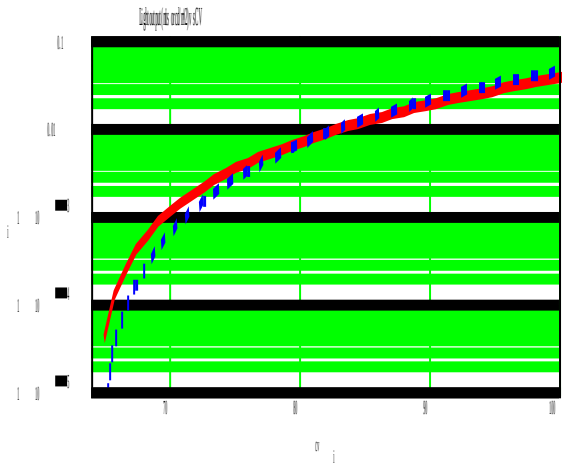
PQ OETF:

NOTE: PQ OETF is inverse of EOTF.
However, BT1886 (EOTF) is not exact inverse of BT.709 (OETF).



100X Brighter @ 100 IRE

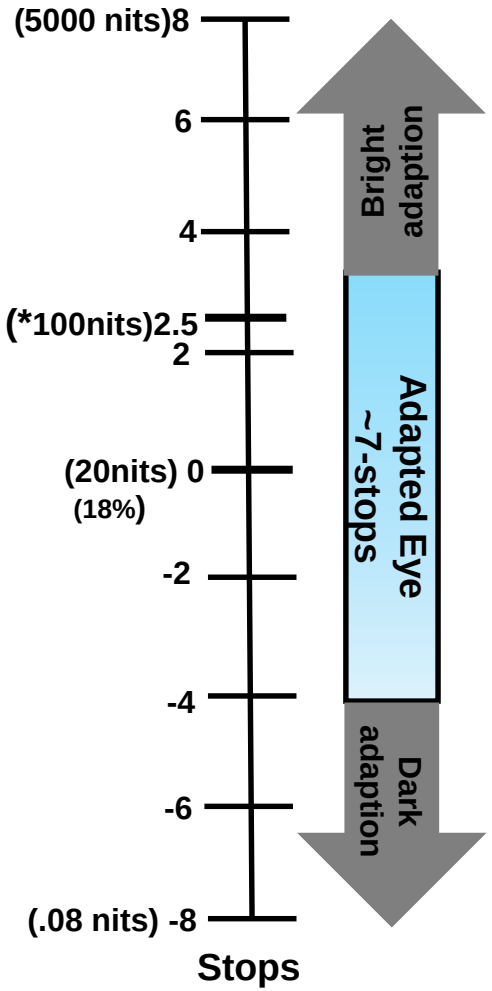
Note that ST.2084 has more gain above code value 230. This means more quantization error of bright light. However, the eye is less sensitive to changes in bright regions. Conversely, it has slightly less gain below 230 so there is less quantization error in the blacks where the eye is most sensitive.

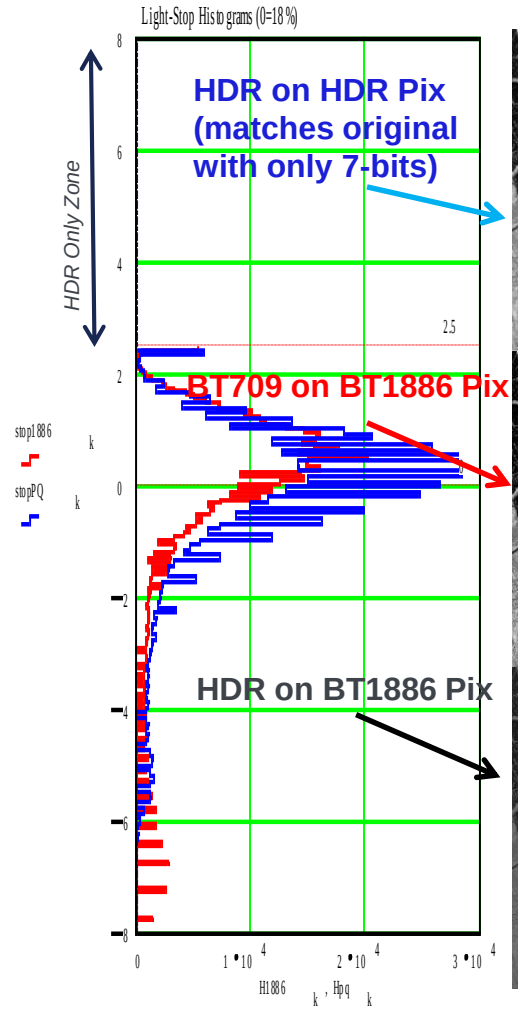


10-bit Code values

ST.2084 “PQ Gamma” Dynamic Range

HDR MAPPING INTO CAMERA F-STOPS (0 = 20 NITS, 2.5 = 100 NITS)





- HDR coding on HDR display is best match to viewing scene.
- BT.709 gamma on BT.1886 calibrated display stretches blacks and actually increases DR
- HDR coding on BT.1886 display will look washed out.
- With an HDR master, DR compression can much improve the SDR picture on a well calibrated BT.1886 display.
- <u>HDR coding does not change APL since it only provides more light in the highlights and more light-level accuracy in the blacks.</u>

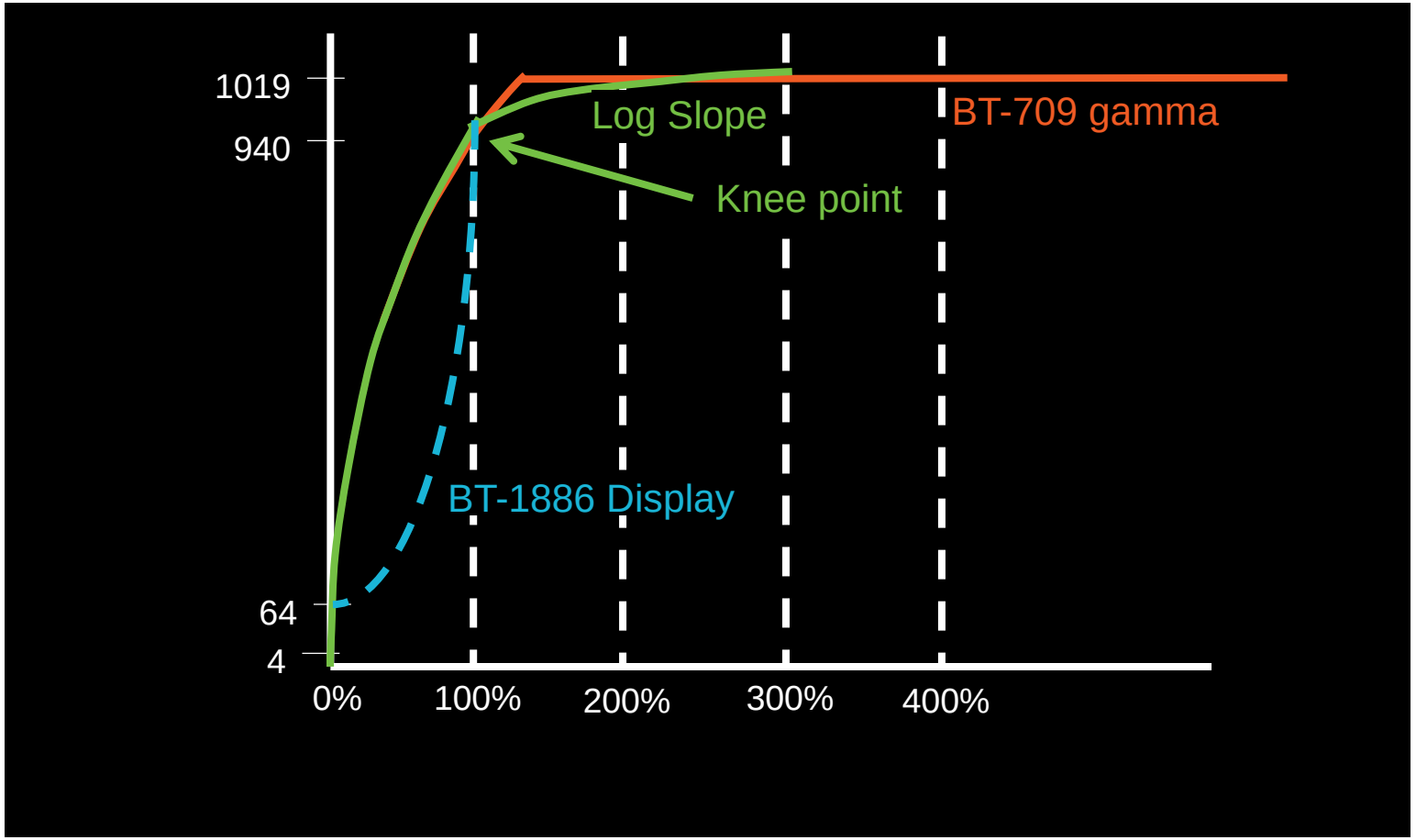
* *EBU Tech 3320 Grade-1 monitor = 100 nits*
Grade-2 monitor = 200 nits

Potential Issues with Bright HDR Displays

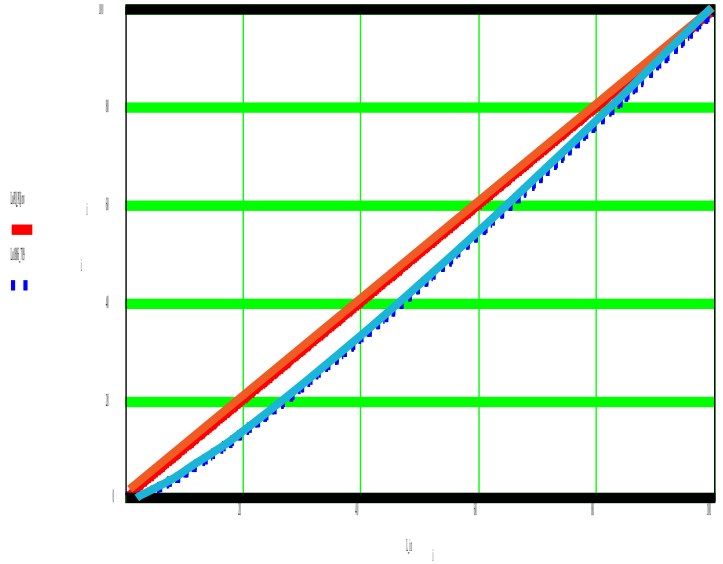
- **Color shift in the Mesopic-level adaption (dark viewing environment)**
  - As light moves below Photopic (dominated by cones) and gets closer to Scotopic (dominated by rods) color saturation will diminish.
  - This may occur in dark scenes in low-light home theater.
- **Light/Dark Adaption (bleaching process rather than pupil size)**
  - Sustained bright images cause the photo-pigment in the retina to reduce and can result in the perception of after images.
  - Dark adaption can take seconds or even minutes. Changes to dark scenes from bright scenes may take more time in dark theater as opposed to same scene in higher ambient light.
- **Viewing distance**
  - Static adaption is only about 7 to 9 stops.
  - To take full advantage of HDR (> 9 stops) via local adaption, you have to be closer than 2 screen widths
  - If you do sit this close, you may get eye strain
- **Large Area Flicker**
  - Strobing of high peak light levels may cause distress to some viewers. Perceptual flicker frequency may be increased since it is a function of retinal adaption. May contribute to PSE (BT.1702).
  - Frame rate judder may be more visible.

SDR (BT.709) Camera OETF (gamma)

CAMERAS TYPICALLY USE A KNEE (AKA SOFT CLIP) RATHER THAN HARD CLIP ABOVE 100 IRE. BT.709/BT.1886 SYSTEM GAMMA IS NOT UNITY!



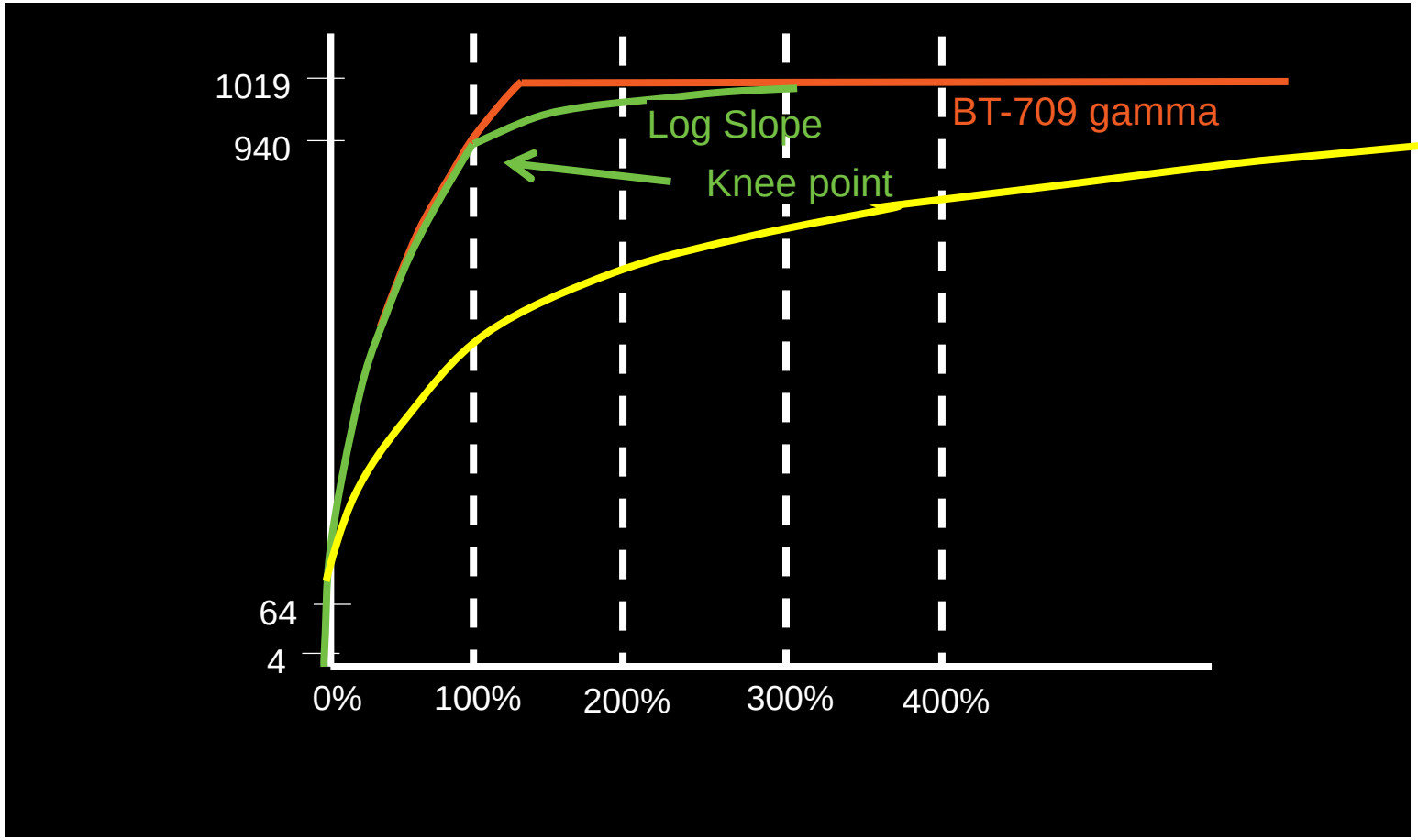
HDR vs SDR system gamma (nits-to-nits)



ST-2084 (PQ) has system gamma unity (i.e. image should look the same on pix monitor as actual scene).
BT.709/BT.1886 are not reciprocal so system gamma is not unity. *Blacks are stretched so as to increase the full D-range over that of HDR.*

HDR Hybrid log-gamma (BBC/NHK)

HYBRID LOG-GAMMA RETAINS BT.709 POWER-LAW AT LOW LIGHTS BUT SEAMLESSLY ADDS LOG COMPRESSION TO HIGH LIGHTS UP TO 3-STOPS



Hybrid Log Gamma ARIB STD-B67:

$$HLG(L) := \begin{cases} \sqrt{L}\cdot 0.5, & L \le 1 \\ a\cdot \ln(L-b)+c \end{cases}$$

EOTF Curve is modified based on ambient lighting

Proposed HDR Formats

- **SMPTE ST.2084:2014 High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays**

  “Dolby Vision”

  Perceptual Quantizer (PQ) based on Barten contour perception

  EOTF is inverse of OETF allowing .001 to 10K nits with 10-bits

  Current “Pulsar” display peaks at about 4K nits

- **Hybrid Log-Gamma, “HLG”, from BBC/NHK (ARIB STD-B67)**

  Extends log processing (de-facto in many cameras) of high brightness peaks to mitigate blown-out or clipped whites

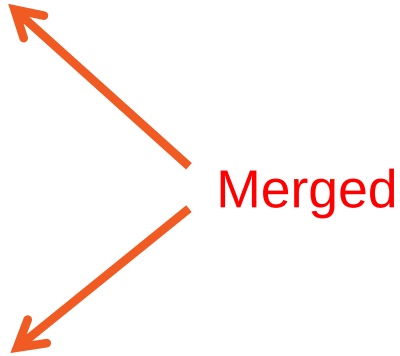
  Seamless “gamma” power-law processing in blacks as in BT.709/BT.2020 but without linear segment

  Displays can evolve to allow 400X to 800X increase in display

  Allows display EOTF to adjust system gamma to correct for surround illumination (i.e. 10 nits to 500 nits)

Proposed HDR Formats

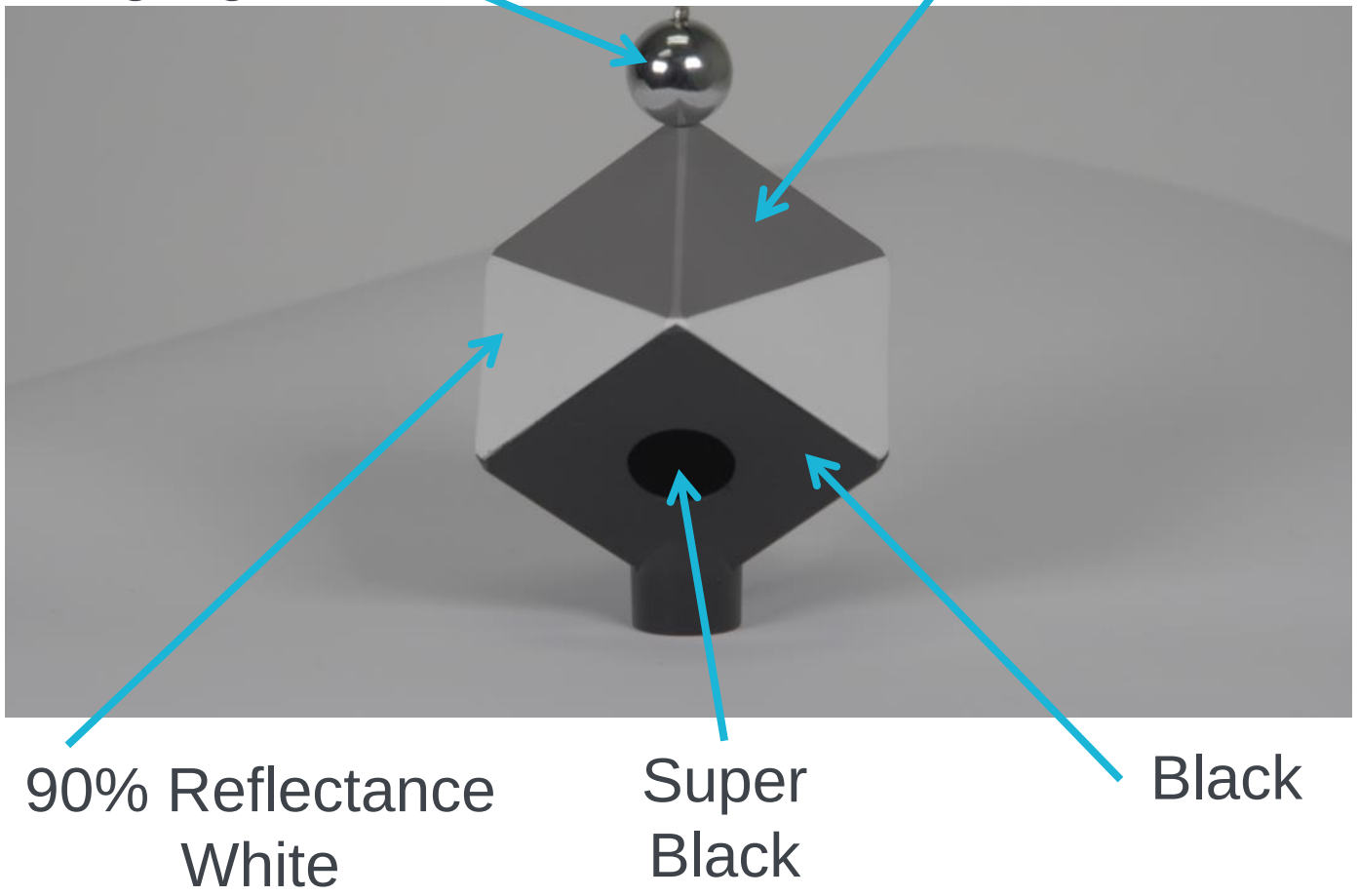
- **Philips Parameter-based from HDR master**
  - **Embed low bit-rate HDR and SDR conversion parameters into metadata**
  - **Extract parameters during decode and tune display for peak luma**
  - **Optional Y'u'v' encoding (more perceptually uniform)**
- **Technicolor Video Mastering and Distribution Workflow**
  - **Grade both an HDR and SDR master**
  - **Vital to maintain "Artistic Intent"**
- ***Academy Color Encoding System (ACES)***
  (dynamic range and wide color gamut preserving workflow, not an HDR format)
  - ***33 bit floating point***
  - ***10-bit proxy output in stops (log2).***



Monitoring Camera Raw footage and HDR

Capturing Camera RAW Footage

- Setup your test chart within the scene
- Adjust the lighting to evenly illuminate the chart
- Adjust the camera controls to set the levels
  - ISO/Gain, Iris, Shutter, White Balance



Capturing Camera RAW Footage

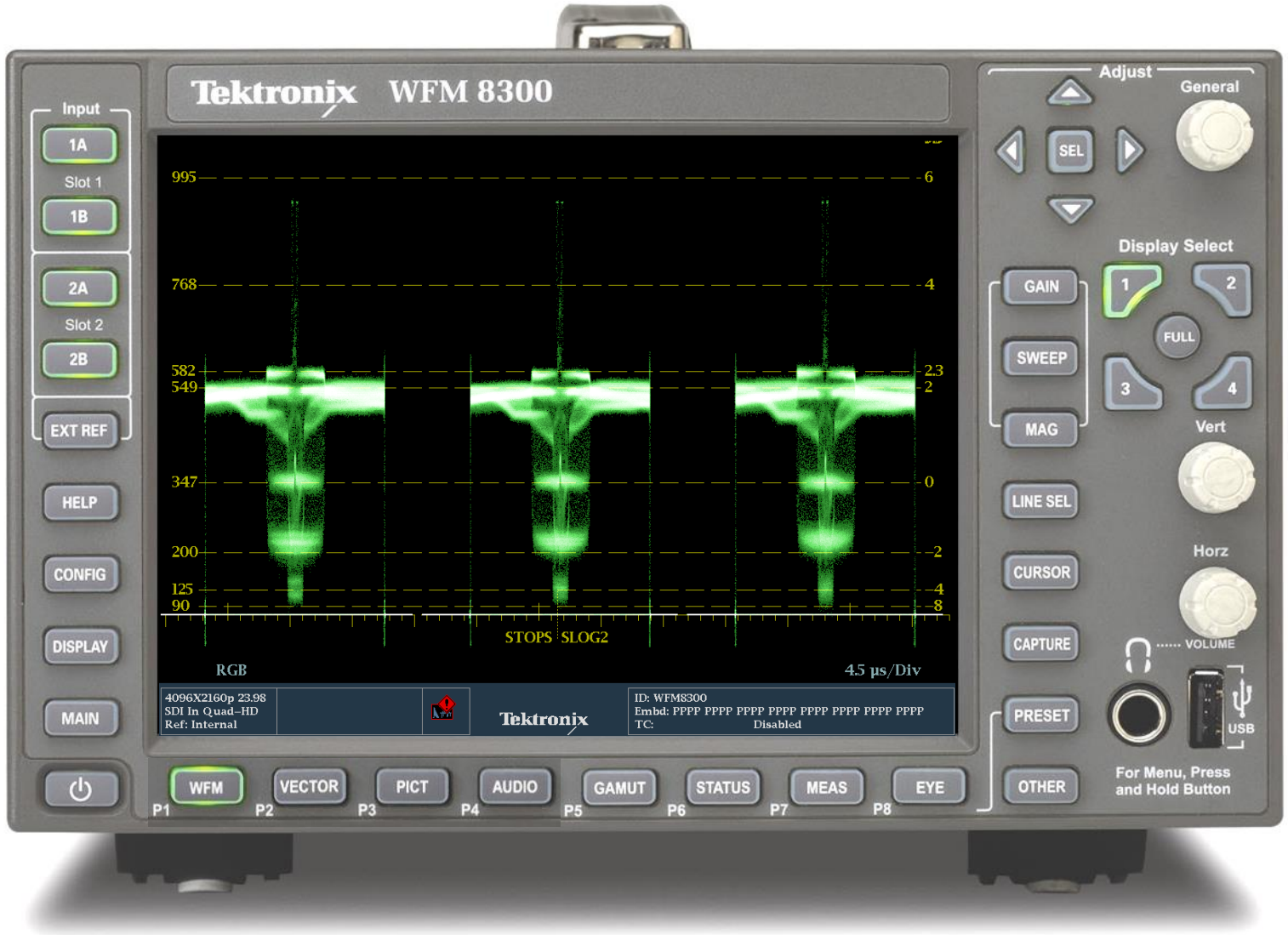
- WFM8300
  - Select Picture Display
  - RAW image
  - Low Contrast

Capturing Camera RAW Footage

Gamma	0% Black 10-bit Code-Value	%	18% Grey (20 nits illumination) 10-bit Code-Value	%	90% Reflectance 10-bit Code-Value	%
S Log 1	90	3	394	37.7	636	65
S Log 2	**90**	**3**	**347**	**32.3**	**582**	**59**
S Log 3	95	3.5	420	40.6	598	61
LogC	134	3.5	400	38.4	569	58
C-Log	128	7.3	351	32.8	614	63
ACES (proxy)	ND	ND	426	41.3	524	55
BT.709	64	0	423	41.0	940	100

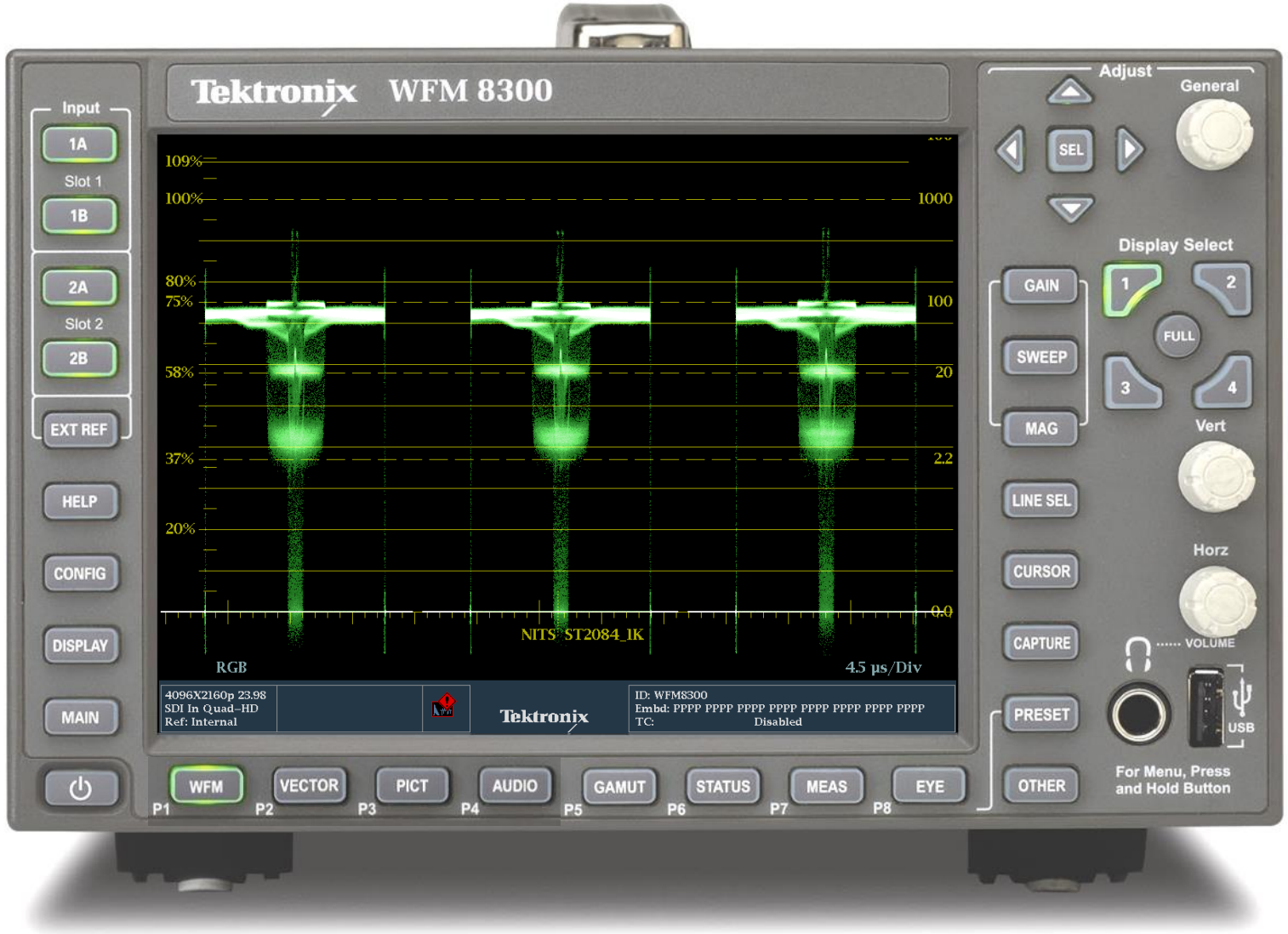
Option PROD supports HDR and Camera Log

- **Simplifies adjustment of Camera Log**
  - S Log
  - S Log2
  - S Log3
  - C Log
  - BT709
- **Setup levels to :-**
- 0 Stops for 18% grey
- 2.3 Stops for 90% Reflectance White



Option PROD supports HDR and Camera Log

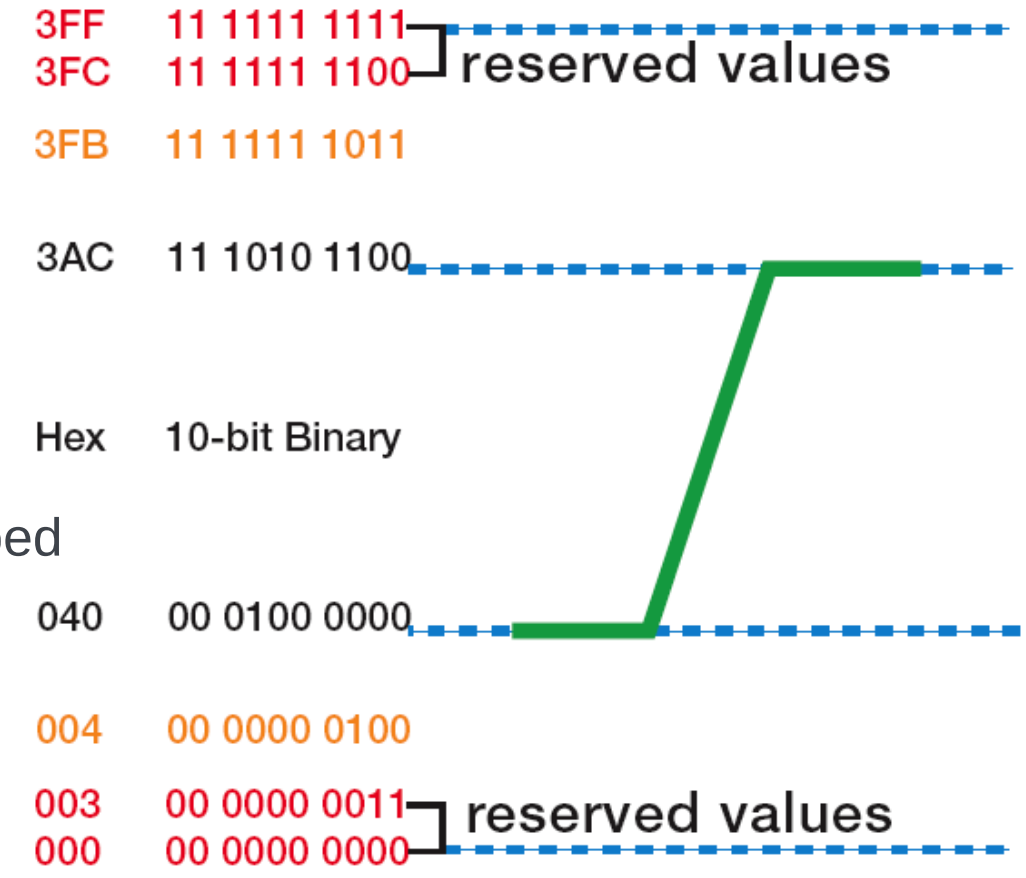
- **Simplifies adjustment of HDR**
  - HLG(1200)
  - ST2084(1K)
  - ST2084(2K)
  - ST2084(4K)
  - ST2084(5K)
  - ST2084(10K)
- **Setup levels to NITS scale**
  - 100 NITS reference white



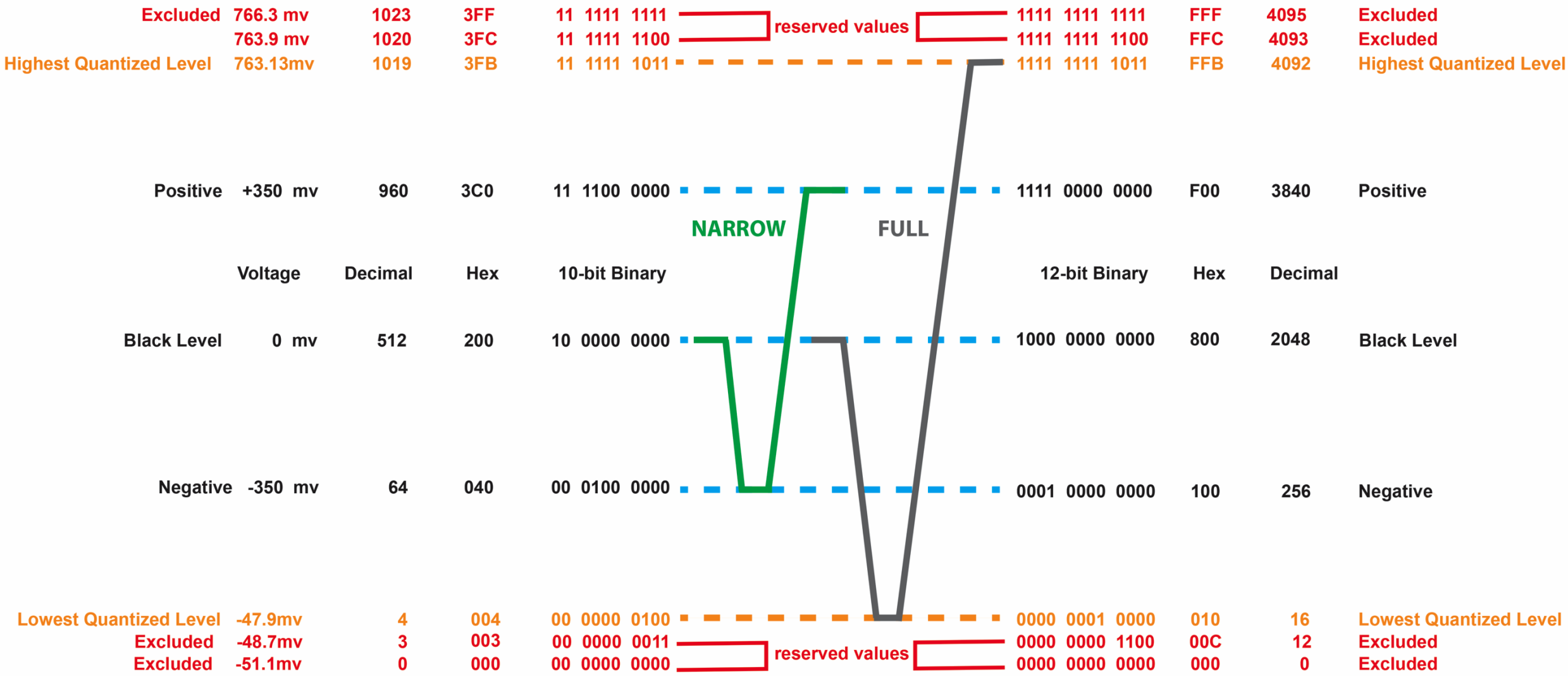
What is Narrow or Full?

- Standard ITU-R BT.2100
  - Full Defined
    - Luma Y 0d –1023d for 10-bit
    - Chroma Cb/Cr 0d –1023 for 10-bit
    - 0d – 4092d for 12-bit Luma
    - Chroma Cb/Cr 0d – 4092d for 12-bit
    - Note:- SDI codewords excluded and range clipped

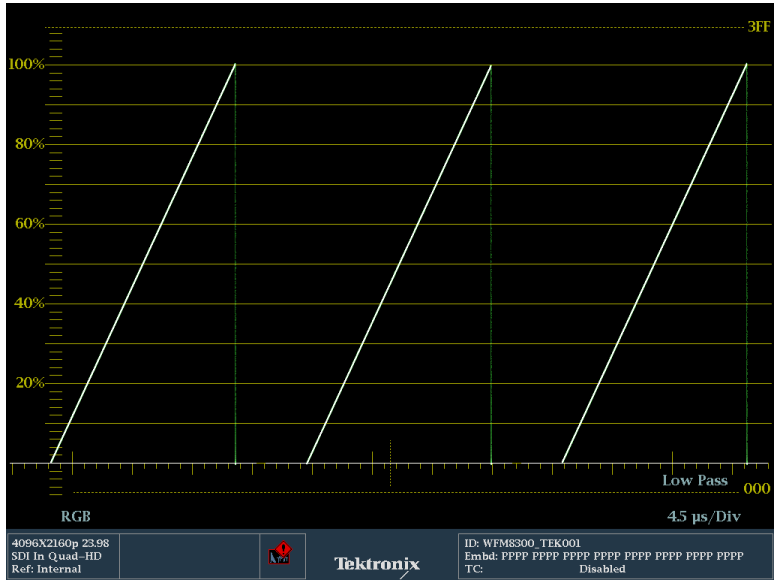
  Narrow Defined
    - Luma Y 64d –940d for 10-bit
    - Chroma Cb/Cr 64d – 960d for 10-bit
    - 256d – 3760d for 12-bit Luma
    - Chroma Cb/Cr 256d – 3840d for 12-bit



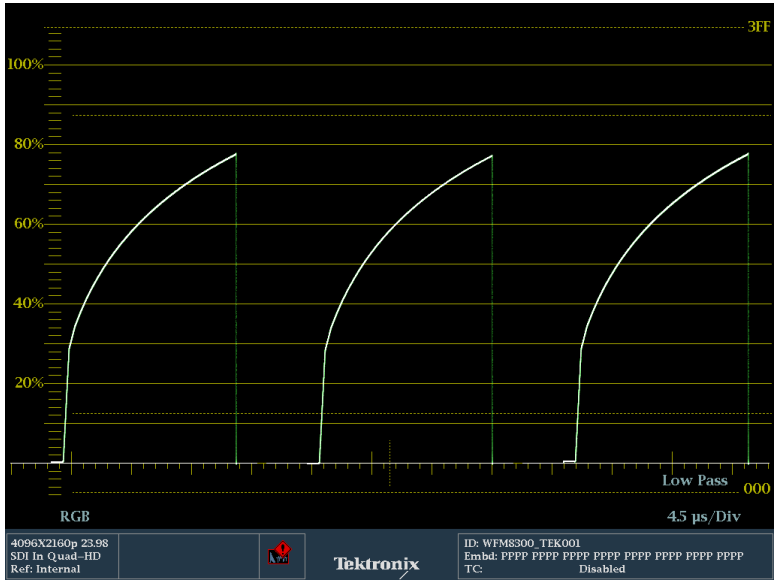
What is Narrow or Full?



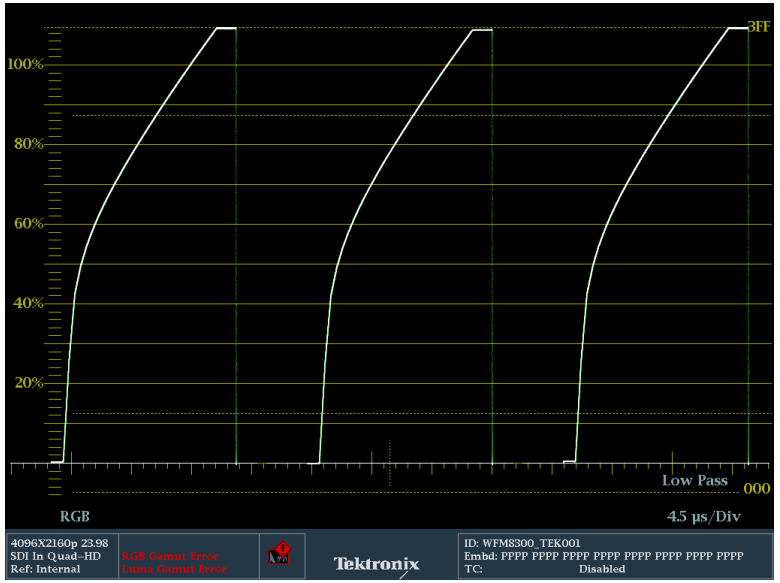
SMPTE 2084 PQ Look Up Tables



Linear Ramp Test Signal
BT.709



Look Up Table
SMPTE 2084 1000nits
Reference White 100nits



Look Up Table
SMPTE 2084 1000nits
Reference White 300nits

Summary

GAMMA AND HIGH DYNAMIC RANGE

- Camera's today are able to capture a wide dynamic range
- SDR displays typically clip or blow out the highlights of the image
- The use of non-linear processing such as S-Log 2, ST 2084 PQ and HLG use the bits more efficiently to capture the image
- Overall this allows HDR displays to utilize the bits more effectively
- White point and 18% grey levels need to be set correctly using a waveform monitor to simplify the process

Thank you.

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