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Imagine Communications

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High Dynamic Range (HDR)

Making Sense of a complex topic

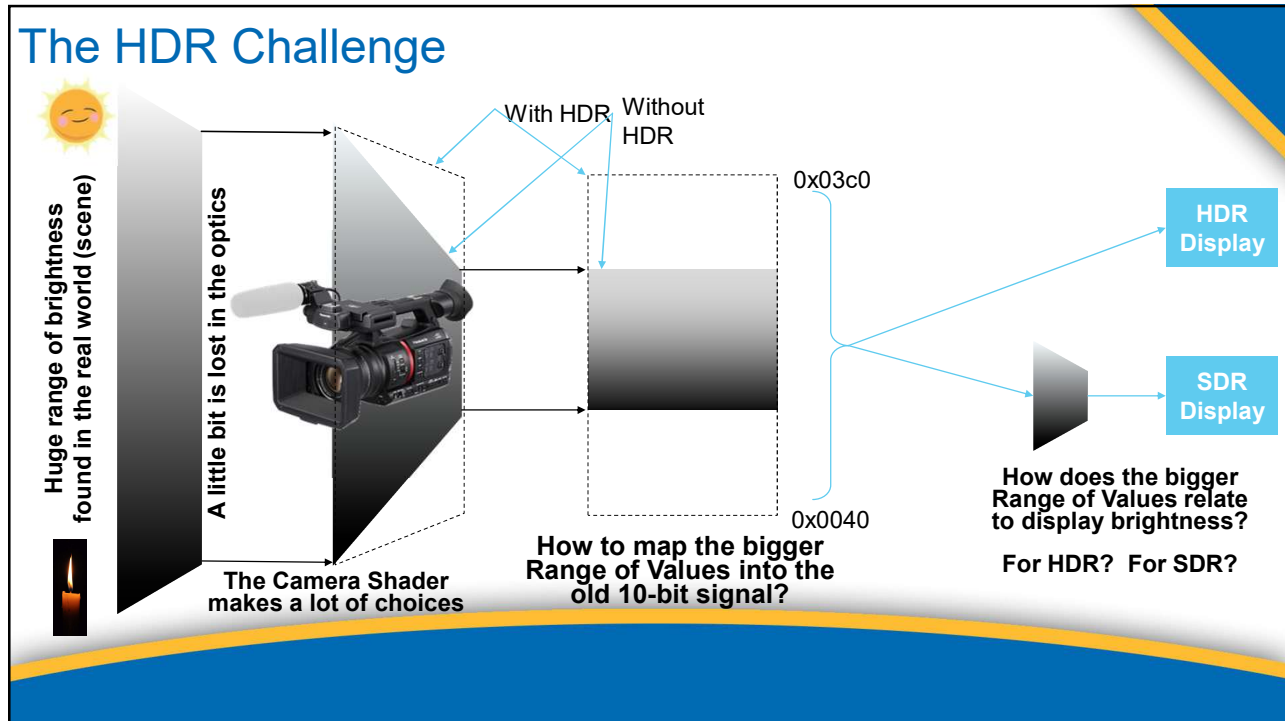
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High Dynamic Range (HDR) – What & Why ?

- Standard Dynamic Range (SDR) has about 7 “f-stops” of dynamic range between black and peak white.
- When the shader picks his aperture for a given shot, they are choosing how to apply that range against the scene in front of them. **Choosing which details to lose**
- This was OK since 1939, because CRT displays had the same limits as the tube cameras.
- The 4:2:2/10 bit infrastructure we use to produce television was designed around this range with a standard gamma curve applied



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High Dynamic Range (HDR) – What & Why ?

- But here we are in 2026: the cameras and displays are now capable of a very wide dynamic range! 14+ stops
- Everything between the camera and the display would like to stay in the 4:2:2/10-bit space for convenience. Plus the codecs are still (mostly) 8 bits
- How to “map” the HDR image data into 10 bits ?
- How to “map” the 10 bits back into an HDR display?
- How to make good-looking SDR from that HDR production for “legacy distribution”?



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Brightness, Color, Science, and Human Perception

- **HDR capable displays were developed only recently**
 - new science about human brightness perception
 - Perception of contrast is a function of the ambient light level – so ideally the display would dynamically adjust the presentation based on ambient
 - Television production is historically based on a fixed reference display
- **Well-established science about what level of quantization error humans can perceive**
 - It is a strong function of local brightness
 - Encoders leverage this trick (perceptual brightness modeling) to save bits
 - The HDR (PQ) mappings to 10-bit leverage this trick also

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Why do we care about HDR or 1080p?

- Consumers will pay more [attention, money, time] if it looks “better” (significantly better)
- HDR is a difference that consumers can actually see
- The new TV people just bought says HDR on the box
- The encoders can be more efficient when fed progressive
- The consumer TV can do better scaling when fed progressive



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Two Root Standards (plus more) for HDR

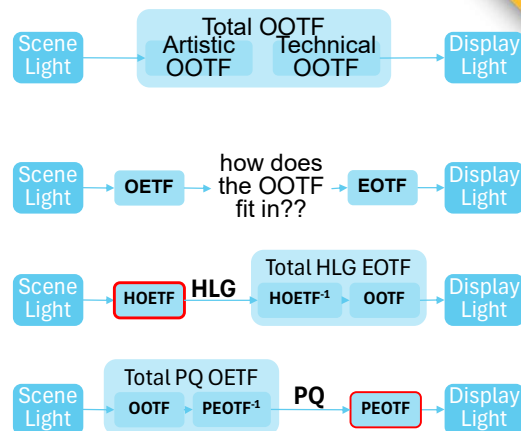


- **PQ (Perceptual Quantization) ITU BT.2100 Table 4**
 - **Display Referred** system – defined from the intensity on a reference display
 - Is an “absolute” system based on measured intensity on the ref display
 - Actual display will differ based on its capabilities and local ambient light
- **HLG (Hybrid Log-Gamma) ITU BT.2100 Table 5**
 - **Scene Referred** system – defined from the light captured by the camera
 - Is a “relative” system based on gain and aperture of the camera, etc.
 - Actual display will modulate based on its capabilities and local ambient light
- What about DolbyVision, SLOG3, HDR10, and others ?

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How do EOTF, OETF, and OOTF Fit Together?

- OOTF describes the transform between light from the scene, and what is displayed from the display. Includes both an “artistic” component (production choices) and also a “technical” component.
- Practical Systems represent the optical signals electrically (and digitally). The OETF and EOTF embody this conversion.
- In HLG, the OETF (HOETF) is the primary definition. OOTF is on the Display side
- In PQ, the EOTF (PEOTF) is the primary definition, and the OOTF is upstream



OOTF = Optical to Optical Transfer Function

OETF = Optical to Electrical Transfer Function

EOTF = Electrical to Optical Transfer Function

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What about SDR? How is that defined?



- ITU-R BT.709 defines an OETF
- In the footnote of table 1, it also says that the image “encoding” includes adjustment so that the final picture (on a standard monitor) has the “desired look”.



- ITU-R BT.2020 defines an OETF
- BT.2020 has basically the same footnote saying that the image “encoding” includes adjustments.

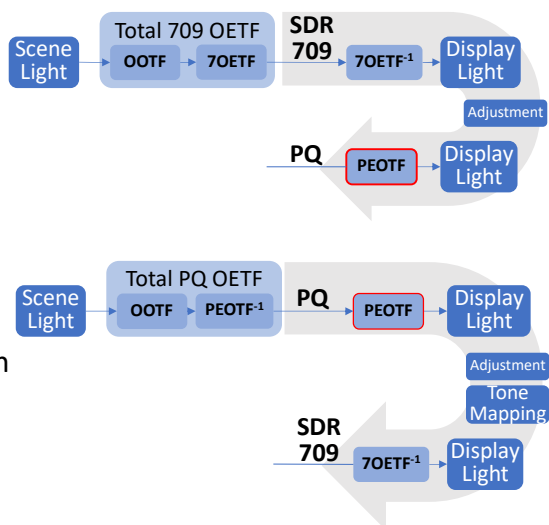


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What does this mean for converting between (PQ)?



- SDR-709 signals may incorporate artistic adjustment/intent. When converting from 709 to PQ, the default is to go from 709 to Display Light, and then apply the inverse of the PQ EOTF.
- Various optical-domain adjustments can be made to match the production intent in this conversion
- PQ-2100 signals typically already incorporate artistic adjustment/intent. The default is to go from PQ to Display Light, apply any tone-mapping or other limiting algorithms, and any other adjustments, then apply the inverse of the 709 EOTF.
- Conversion between SDR-2020 and PQ follows the same principles
- Scene-light conversion is also possible, but atypical for PQ

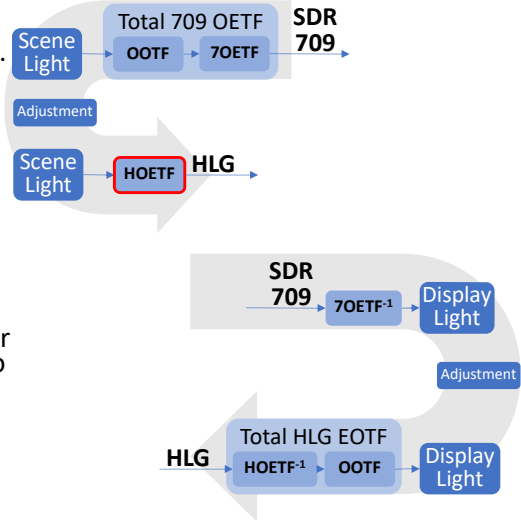


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What does this mean for converting between (HLG)?

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- When converting between SDR-709 and HLG-2100, the choice of Scene Light or Display Light conversion depends on how the signal fits into the overall production.
- In a *Scene Light* conversion, the SDR-709 signal is transformed through the inverse 709 OETF, and an OETF that models the BT.1886 display. Linear domain adjustments (if any) are applied, and then the HLG OETF applied to reach HLG.
- In a Display Light conversion, the SDR-709 signal is transformed to Display Light using the inverse of the 709 OETF, then any linear domain adjustments are applied. Then the inverse of the OETF recommended in BT.2100 for HLG, and the inverse of the HLG OETF are applied to get to HLG.
- Conversion between SDR-2020 and HLG follows the same principles but is generally done in *Scene Light*, though *Display-light* conversion is also possible
- *Scene-light* conversion is the more common case for HLG

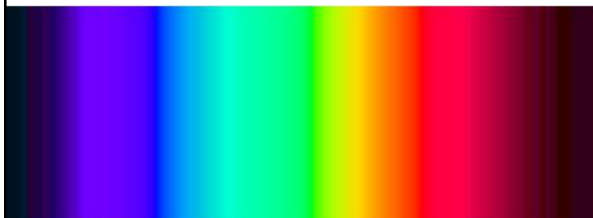


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HDR Signaling? How do I know what I'm getting?

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- **SMPTE 2110 (and also SDI and every file format and codec) use numbers to represent color values.**
- **There are thousands of ways to do this, and *dozens of them* are in use in different corners of the television industry**
- **How do we know what a given tuple of "pixel data" means?**



(1011010010, 01001011010, 1011011011)
 (0100101010, 01001101011, 1001010100)
 (1101001001, 01001011010, 1101101110)
 (1011110110, 01111101101, 0011001101)
 (0111011010, 10110101010, 1101101101)
 (1101010101, 01101101010, 1101001010)

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HDR Signaling – How does SDI do it?



- If its 525@29.97, or 625@25 then probably its ITU Rec 601
 - Typical today is 4:2:2/10 bits, but 8-bit also existed
 - 525 and 625 are slightly different R, G, B values
 - RGB 4:4:4 systems also exist

Item	Parameter	Characteristics			
		625		525	
2.6.1	Chromaticity coordinates, CIE 1931 ⁽¹⁾ Primaries Red Green Blue	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
		0.640	0.330	0.630	0.340
		0.290	0.600	0.310	0.595
		0.150	0.060	0.155	0.070
2.6.2	Assumed chromaticity for equal primary signals – Reference white <i>E_R = E_G = E_B</i>	<i>D₆₅</i>			
		<i>x</i>	<i>y</i>		
		0.3127	0.3290		
2.6.3	Opto-electronic transfer characteristics before non-linear precorrection	Assumed linear			
2.6.4	Overall opto-electronic transfer characteristic at source ³	$E = (1.099 L^{0.45} - 0.099)$ for $1.00 \geq L \geq 0.018$ $E = 4.500 L$ for $0.018 > L \geq 0$ where: L : luminance of the image $0 \leq L \leq 1$ for conventional colorimetry E : corresponding electrical signal.			


$$D'_Y = \text{INT} \left[0.299 D'_R + 0.587 D'_G + 0.114 D'_B \right]$$

$$D'_{CB} = \text{INT} \left[\frac{-0.299 D'_R - 0.587 D'_G + 0.886 D'_B}{1.772} \times \frac{224}{219} + 2^{n-1} \right]$$

$$D'_{CR} = \text{INT} \left[\frac{0.701 D'_R - 0.587 D'_G - 0.114 D'_B}{1.402} \times \frac{224}{219} + 2^{n-1} \right]$$

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HDR Signaling – how does HD-SDI do it?



- If its 1080i@29 or 1080i@25, then ITU Rec 709 applies
- If its 1080p@29 or 1080p@25, then ITU Rec 709 probably applies
- If its 1080p@59 or 1080p@50, then ITU Rec 709 *might apply*
- Typically, 4:2:2/10 bit, but 4:4:4/10 and even 4:4:4/12 also exist

1.2	Overall opto-electronic transfer characteristics at source ⁽¹⁾	$V = 1.099 L^{0.45} - 0.099$ for $1 \geq L \geq 0.018$ $V = 4.500 L$ for $0.018 > L \geq 0$ where: L : luminance of the image $0 \leq L \leq 1$ V : corresponding electrical signal	
1.3	Chromaticity coordinates (CIE, 1931) Primary – Red (R) – Green (G) – Blue (B)	<i>x</i>	<i>y</i>
		0.640	0.330
		0.300	0.600
		0.150	0.060
1.4	Assumed chromaticity for equal primary signals (Reference white) <i>E_R = E_G = E_B</i>	<i>D₆₅</i>	
		<i>x</i>	<i>y</i>
		0.3127	0.3290

$$D'_Y = \text{INT} \left[0.2126 D'_R + 0.7152 D'_G + 0.0722 D'_B \right]$$

$$D'_{CB} = \text{INT} \left[\left(-\frac{0.2126}{1.8556} D'_R - \frac{0.7152}{1.8556} D'_G + \frac{0.9278}{1.8556} D'_B \right) \cdot \frac{224}{219} + 2^{n-1} \right]$$

$$D'_{CR} = \text{INT} \left[\left(\frac{0.7874}{1.5748} D'_R - \frac{0.7152}{1.5748} D'_G - \frac{0.0722}{1.5748} D'_B \right) \cdot \frac{224}{219} + 2^{n-1} \right]$$

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What is this VPID thing anyway?

- SD-SDI was simple enough
- HD-SDI was just faster bits
- SMPTE ST 425-1 defined it first, but only for 3GSDI
- SMPTE ST 352:2013 generalized it for SD & HD
- 425-1 revised twice since
- 425-5 defines it for UHD
 - In 2014
 - Then again in 2015
 - Then perfectly in 2019

Bits	Byte 2	Byte 3	Byte 4
Bit 7	Interlaced (0) or Progressive (1) transport	Aspect ratio 16:9 (1), unknown (0)	Reserved
Bit 6	Interlaced or Progressive		
Bit 5	Transfer characteristics	Colorimetry	Luminance and color difference signal
Bit 4	SDR-TV (0h) HLG (1h) PQ (2h) Unspecified (3h)	Rec 709 ¹ (0) Color VANC Packet (1) UHDTV ² (2) Unknown (3)	YC/Cr (0) IC/Cr (1)
Bit 3	Picture Rate (Refer to SMPTE ST 352 Table 2)	Picture rate (as per Table 2 of SMPTE ST 352)	Audio - 3G-SDI Link 2 to Link 4, 3G-SDI Link 2 to Link 4 carry additional channels or audio not present (0) 3G-SDI Link 2 to Link 4 carry a copy of 3G-SDI Link 1 audio (1)
Bit 2			Bit depth
Bit 1			10-bit Full Range (0h) 10-bit (1h) 12-bit (2h) 12-bit Full Range (3h)
Bit 0			

Notes:
¹ Rec 709 indicates ITU-R BT.709 colorimetry and is equivalent to SMPTE ST 2036-1 Conventional System Colorimetry.
² UHDTV indicates SMPTE ST 2036-1 UHDTV colorimetry and is equivalent to ITU-R BT.2020 colorimetry.

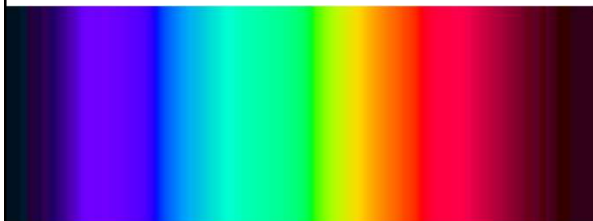
✗ Not Every Piece of Equipment gets it right – for some value of “right”

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Describing light with numbers

- Transfer Characteristic (HLG, PQ, SDR, or something else)
- Colorspace (R' G' B' → Y' Cb' Cr') (or something else)
- Sampling – 4:4:4, 4:2:2, 4:2:0, and bit depth
- We have good standards for knowing what we're getting



(1011010010, 01001011010, 1011011011)
 (0100101010, 01001101011, 1001010100)
 (1101001001, 01001011010, 1101101110)
 (1011110110, 01111101101, 0011001101)
 (0111011010, 10110101010, 1101101101)
 (1101010101, 01101101010, 1101001010)

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2110-20 developed an extensible lingo



- colorimetry = [BT601, BT709, BT2020, BT2100, ST2065-1, ST2065-3, ...]
- sampling = [YCbCr-4:2:2, YCbCr-4:4:4, RGB, XYZ, KEY, ...]
- depth = [8, 10, 12, 16, 16f]
- TCS = [SDR, HLG, PQ, LINEAR, ST2065-1, DENSITY, ...]
- RANGE = [NARROW, FULL, FULLPROTECT]

- There is a huge space of permutations of the above, with a sparse set of operating points that are used in reality
- ***This lingo for describing the signal could outlive ST2110-20 itself***
 - Also used for JPEG-XS and other emerging new format descriptions

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HDR – static metadata –vs- dynamic



- In Packaged Media, there is dynamic metadata that tells the display very exactly what to do, adapting the HDR system perfectly

- In Live Production, fixed metadata is typical – HLG or static-PQ

- After mastering, for HDR Distribution, final dynamic metadata
 - Dolby-Vision (PQ plus dynamic metadata to optimize the presentation)
 - **ATSC 3.0 (SDR video plus SL-HDR1 metadata to re-create the HDR)**

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The Important Problem – making SDR



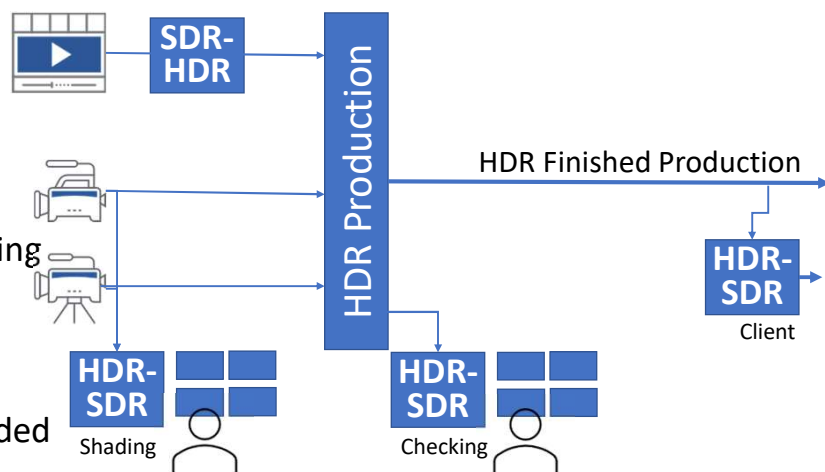
- HDR is beautiful if you can get it
- SDR is what 98% of consumers are watching today
- You only want to [Produce] one main signal
- Industry Requires common Standards & Practices for making SDR from HDR, and HDR from SDR
- [NBCU published its “single master” workflow here](#)

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Single-Stream HDR Production with SDR Checking




- SDR Contributions
SDR Clips/Archive
(up-map to HDR)
- HDR Cameras
 - Check SDR in shading
- HDR Final Show
 - Check SDR in final
 - Create SDR as needed



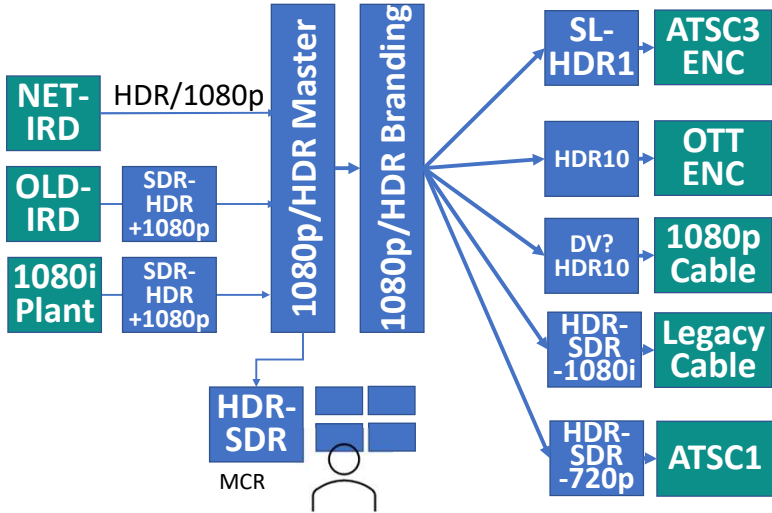
This works well in practice, as long as the SDR conversion is done the same way on both ends

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What about Downstream at Stations? How to make a great ATSC3 HDR/1080p ?




- HDR/1080p From Network
- SDR current channel
SDR Clips/Archive
(up-map to HDR & 1080p)
- Single HDR production
 - Check SDR in final
- HDR/1080p Final Channel
 - Create 1080i/SDR as needed



```

graph LR
    NET-IRD[NET-IRD] -- HDR/1080p --> Master[1080p/HDR Master]
    OLD-IRD[OLD-IRD] -- SDR-HDR +1080p --> Master
    1080iPlant[1080i Plant] -- SDR-HDR +1080p --> Master
    Master --> Branding[1080p/HDR Branding]
    Branding --> SL-HDR1[SL-HDR1]
    Branding --> HDR10[HDR10]
    Branding --> DV-HDR10[DV? HDR10]
    Branding --> HDR-SDR-1080i[HDR-SDR -1080i]
    Branding --> HDR-SDR-720p[HDR-SDR -720p]
    SL-HDR1 --> ATSC3-ENC[ATSC3 ENC]
    HDR10 --> OTT-ENC[OTT ENC]
    DV-HDR10 --> 1080p-Cable[1080p Cable]
    HDR-SDR-1080i --> Legacy-Cable[Legacy Cable]
    HDR-SDR-720p --> ATSC1[ATSC1]
    Master --> MCR[HDR-SDR MCR]
  
```

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Comments? Questions?

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