NBCUniversal
Single-Stream Broadcast Production and Distribution Recommendations
#NBCU-Rec-UHD-HDR-01.07

November 1st, 2021

1. Introduction

For movies and early broadcast trials, creating HDR/SDR content versions has required separate grading/shading and mastering processes. As dual live production workflows are impractical, this encouraged the development of a single-stream approach that can deliver both emerging UHD/HDR and legacy HD/SDR platforms simultaneously. The process utilizes the available technology to maximize the dynamic range and color volume in HDR, without compromising the core legacy HD/SDR broadcasts.

In collaboration with Cromorama, and building on ITU working group discussions involving Dolby, BBC and Philips, NBCU has developed single-stream production and distribution techniques. These techniques and supporting conversions have been developed using objective color science as well as traditional real-world testing.

This document provides a potential best practice for broadcast production and distribution processes including conversion. We are sharing our experiences to continue a dialog with our colleagues so that consistent creation, delivery and media exchange of HDR and SDR content is possible.

2. "Single-Stream" HDR-SDR Workflow Guide

2.1. Signal Flow from Production to Distribution

We believe that a "Single-stream" live production workflow will enable production with the highest possible quality while managing cost and taking advantage of operational efficiencies. Live HDR productions can be performed in Hybrid Log Gamma (HLG) BT.2100. For distribution, live production feeds can be converted to PQ to maintain compatibility with other content.

Amidst an evolving multi-format landscape, it is crucial to integrate accurate and consistent format conversions to ensure interoperability between HLG, PQ and SDR sources and platforms. This is especially important with the new video formats capabilities in color, dynamic range, and the subsequent conversion between them.

The single-stream production workflow recommended includes a combination of native HLG sources as well as SDR sources. In this model, SDR content is converted to HLG prior to inclusion into the HDR production environment. The final HLG production is then converted as needed for transmission. All conversions are performed through LUTs (Look Up Tables) as described in Annex 1.

Figure 1, illustrates the end-to-end signal flow for multi-format sources and conversion points (conversions are identified by letters **A-F**).

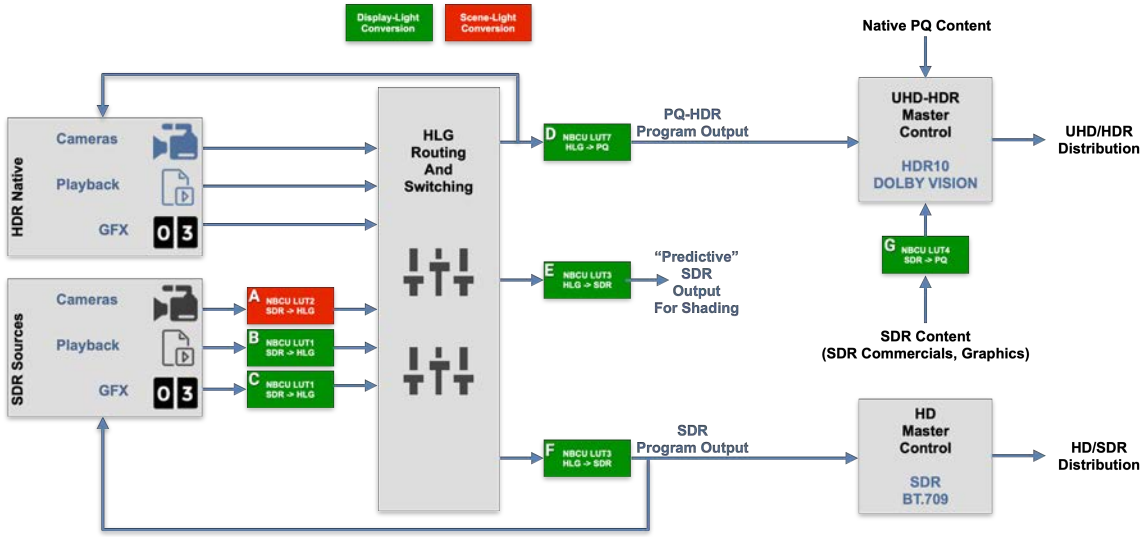


Figure 1 - Single-Stream Production and Distribution Simplified

PRODUCTION CONVERSIONS

- **All Native HLG sources:** Available on the source router and available to the video switcher without any conversion.
- **SDR Cameras Source - "A": NBCU LUT2** performs an SDR to HLG conversion using ***"scene light"*** so that SDR cameras will ***match*** a native HLG camera's "look".
- **SDR Playback Source- "B": NBCU LUT 1** performs an SDR to HLG conversion using ***"display light"*** to preserve the original artistic intent (the SDR look).
- **SDR Graphics Source - "C": NBCU LUT 1** performs an SDR to HLG conversion using ***display light"*** to preserve the original artistic intent (the SDR look).
- **HLG to SDR Predictive LUT - "E": NBCU LUT 3** converts from HDR to SDR using display light and acts as a "predictive LUT" so that a shader can preview the "look" of SDR transmission.

DISTRIBUTION CONVERSIONS

- **HLG to PQ Output - "D": NBCU LUT7** converts transparently between HLG and PQ using ***"display light"*** to preserve the original artistic intent (the HLG look).
- **HLG to SDR Production Output - "F": NBCU LUT 3** converts HLG to SDR using ***"display light"*** and a sophisticated 2-stage highlight compression knee to reduce the dynamic range and color gamut while preserving much of the artistic intent.
- **SDR to PQ Distribution Conversion - "G": NBCU LUT 4** performs an SDR to PQ conversion using ***"display light"*** to preserve the original artistic intent (the SDR look).

ANNEX 3 & 4 PROVIDE FURTHER DETAILS ON THE CONVERSION PROCESSES

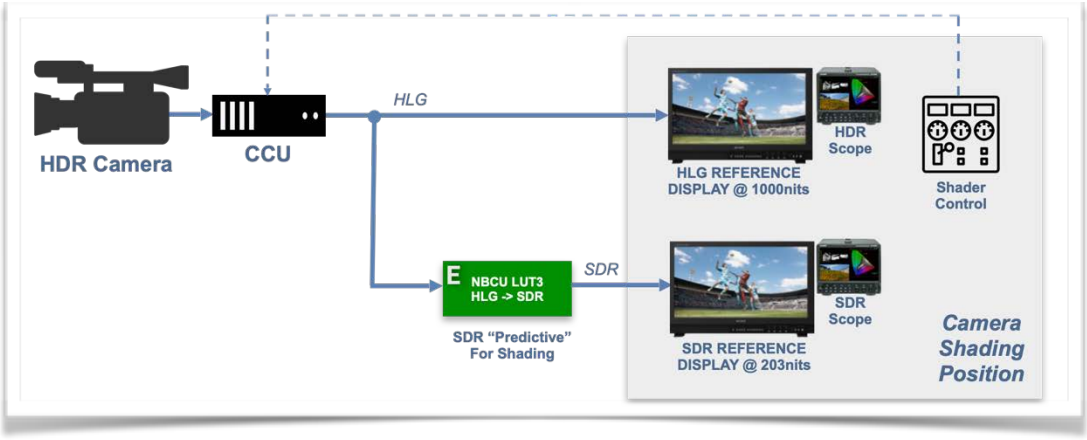
2.2. Basic Shading and Video Monitoring Practices

In the single-stream production workflow described in Figure 1, camera shading is performed in HLG BT.2100 using HLG reference displays[1]. We provide a "predictive" conversion for the video operator so that SDR created for transmission can be monitored. The NBCU HDR to SDR LUT is designed to maintain the creative intent inside of the boundaries of SDR when compressing the HDR in a consistent manner.

[1]It is possible to shade in SDR thru the predictive NBCU LUT 3, but it is preferred to use the HDR display as the primary shading display.

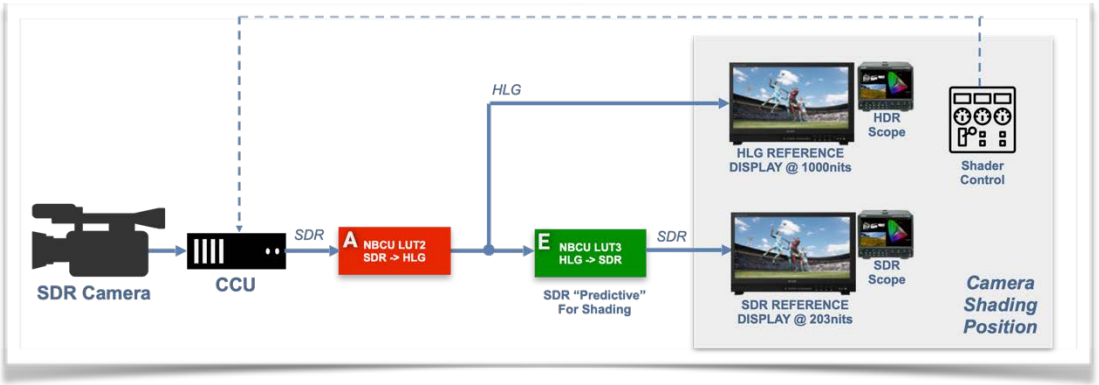
A. Shading Cameras

- Native HDR cameras are shaded on an HLG reference display.
- The camera signal is passed thru NBCU LUT3 (what we call the "Predictive LUT") to enable a shader to preview the camera's appearance as it will be seen thru legacy SDR transmission. Generally this is fed by the router and can also be switched to the program output.



HDR CAMERA SHADING

- SDR camera signals are converted to HLG using **NBCU LUT2** and shaded on an HLG reference display with **NBCU LUT3** providing a "predictive" preview of SDR.



SDR CAMERA SHADED IN HDR

PLEASE REFER TO ANNEX 3-7 FOR DETAIL ON SHADING PRACTICES AND REFERENCE LEVELS

3. NBCU HDR/SDR Conversion LUTs

NBCU has a commitment to industry collaboration and would like to encourage consistent media exchange, therefore we are willing to provide the NBCU LUTs freely. The NBCU LUTs are provided on an “as is” basis with no warranties.

Please contact: chris.seeger@nbcuni.com for a link to the NBCU single-stream LUTs package and documentation.

Both NBCU LUT3 and NBCU LUT5 use a unique “color primary tracking technique” and a sophisticated 2-stage knee for down-mapping of color and light in order to achieve an optimized preservation of the original artistic intent during conversion that reduces the dynamic range and color from HDR to SDR. Below are the LUTS for hardware devices followed by LUTS which are specific to software-based editing platforms.

A. HLG-BT.2100 (to/from SDR-BT.709)

LUT	NAME	Description
1	1-NBCU_SDR2HLG_DL_v1.cube	Up-maps legacy SDR signals into a native HLG production using display-light conversion.
2	2-NBCU_SDR2HLG_SL_v1.cube	Tonemaps and matches SDR cameras with the HLG “Look” for a native HLG production using scene-light conversion.
3	3-NBCU_HLG2SDR_DL_v1.cube	Down-maps native HLG-BT.2100 signals to SDR as a predictive LUT or for legacy SDR-BT.709 transmission.

B. PQ-BT.2100 (to/from SDR-BT.709)

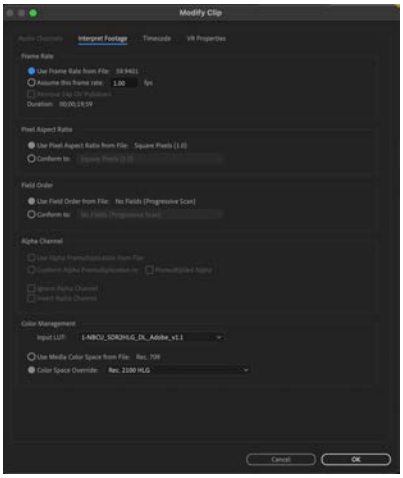
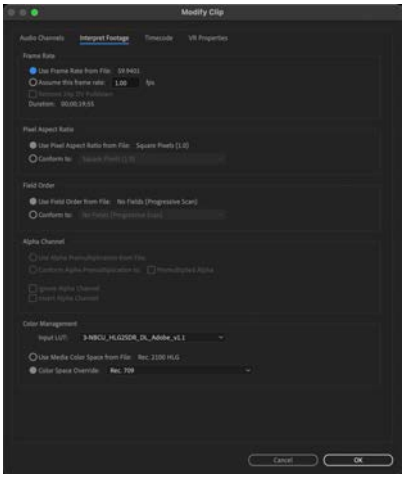
LUT	NAME	Description
4	4-NBCU_SDR2PQ_DL_v1.cube	Up-maps legacy SDR signals into a native PQ production or transmission.
5	5-NBCU_PQ2SDR_DL_v1.cube	Down-maps native PQ-BT.2100 signals to SDR-BT.709 as a predictive LUT or for legacy SDR-BT.709 transmission.

DaVinci Resolve 17

There are special application-specific cube LUTs for **DaVinci Resolve 17** that use a special video tag for use with video range projects. They are contained in a DaVinci Resolve-labeled folder.

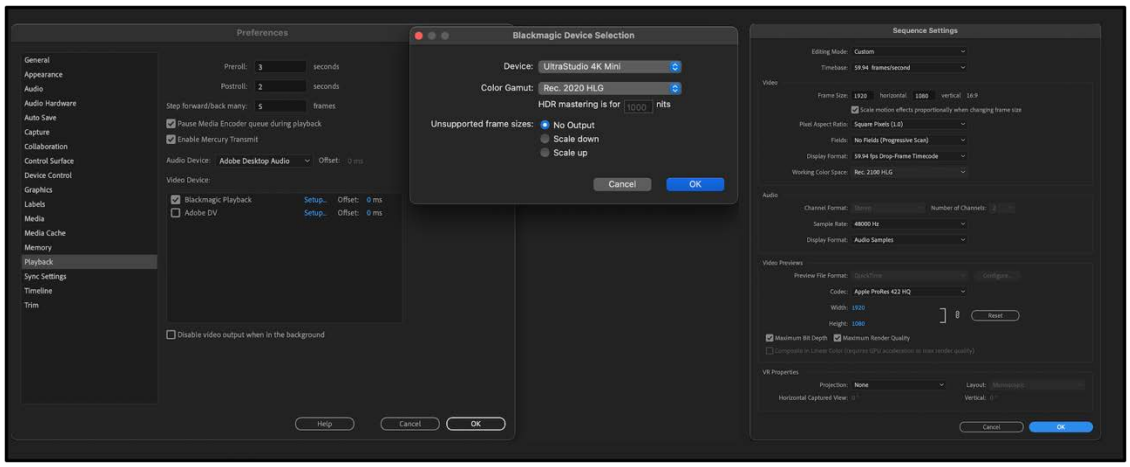
Adobe Premiere 2021

Adobe Premiere uses a slightly different cube LUT format. They are contained in an Adobe-labeled folder. A maintenance release from June 2021 is required for Tetrahedral interpolation. To apply a LUT, click on the media file and navigate using the dropdown menu to “Modify/Interpret footage”. Using the selection seen in the screen captures below, select a LUT and “Color Space Override”. The LUTS are contained in an Adobe Premiere-labeled folder.

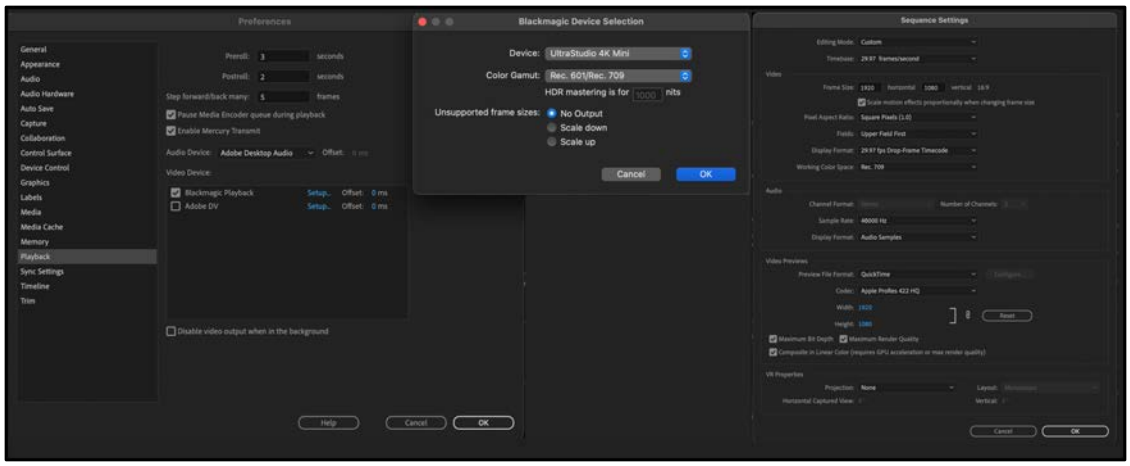
SDR to HLG Conversion in an HLG Sequence	HLG to SDR Conversion in an SDR Sequence
	

Below are Adobe Premiere preferences for HLG Video IO and sequence Settings. Each setting will determine the baseband and file-based output video formats

Adobe Premiere Video IO Preferences and Sequence Settings for HLG-BT.2020



Adobe Premiere Video IO Preferences and Sequence Settings for SDR-BT.709



Adobe Premiere HDR workflows have some LUT conversion accuracy issues which we are still studying.

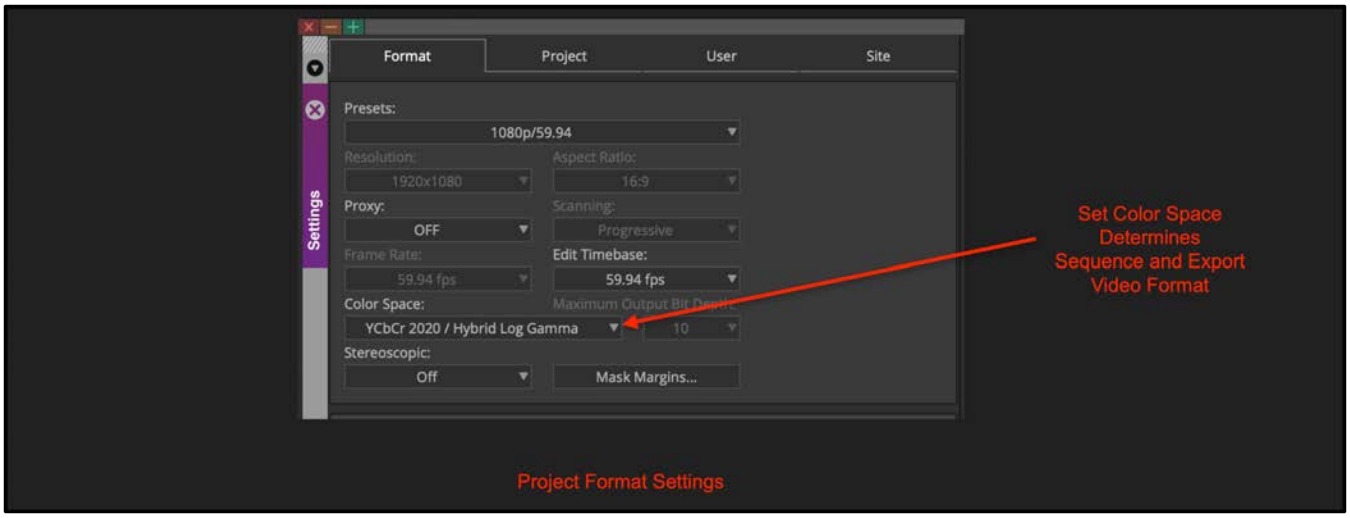
Adobe Photoshop 2021

Adobe Photoshop uses the "normal" LUT. They are located in this folder:
"3D_Type_III_Cube_LUTS_for_Hardware_Devices"

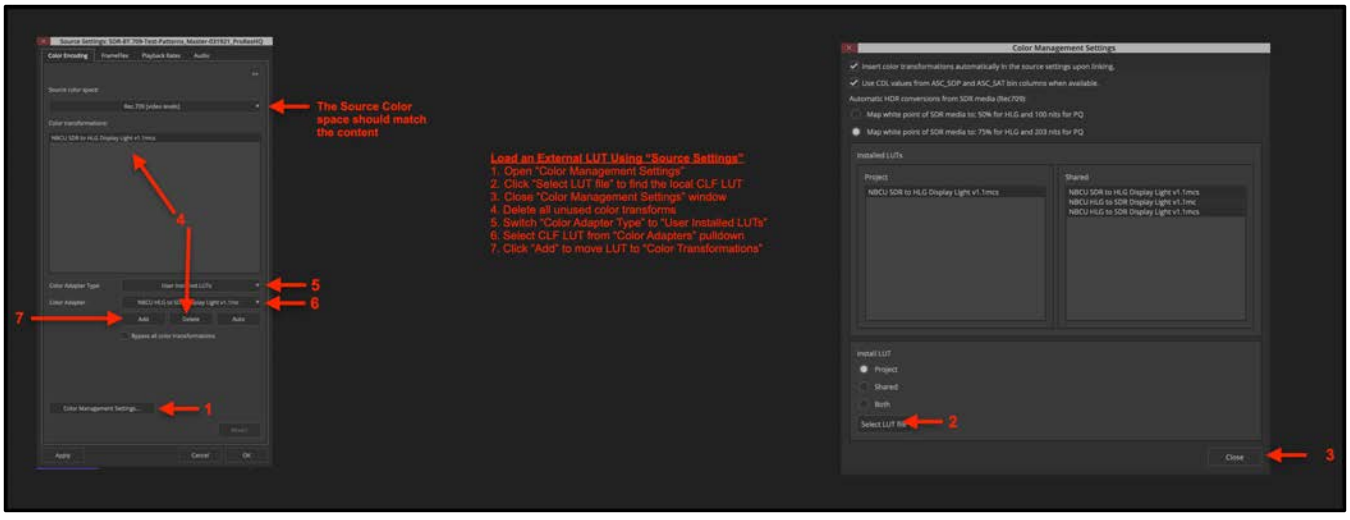
Avid Media Composer

There are special **CLF LUTS** for **Avid Media Composer** because it does not support Type III LUTS natively. In order to support sub-blacks and super-whites we use unique **CLF LUTs**. Use the "Source-Settings" dialog to add a CLF LUT. The current Avid CLF LUTs work around current issues with the conversion pipeline by scaling and unscaling full-range video into a narrow-range "container. In addition, a special matrix compensation is applied to compensate for the different scaling factors and conversion between YCbCr and RGB (the conversion occurs in a RGB color representation).

- **Avid Project Settings determine Sequence and Export video format**



- **Avid "Source Settings" determine source conversions using a CLF LUT**



4. Cross-Conversion HDR LUTs

Below is a list of HDR-to-HDR cross conversion LUTS and their purposes. The BBC LUTs are available under a license agreement by contacting transfer.rd@bbc.co.uk and the MovieLabs LUT is included with the NBU LUT package with MovieLabs permission. NBCU does not guarantee particular results or otherwise provide any warranties with respect to the BBC or MovieLabs LUTs. MovieLabs does not guarantee particular results or otherwise provide any warranties with respect to the MovieLabs LUTs.

A. HLG to PQ

Name	Version	NAME	Description
NBCU LUT-7	1	7-NBCU-HLG10002PQ.cube	BT.2100 HLG signals are converted to BT.2100 PQ at the 1,000nits "bridge" condition, so that 100% HLG maps to 1,000nits PQ. This is a transparent conversion. **This LUT is freely distributed.**
BBC 7C	1.5	7c_HLG_PQ1000_Type3_Transcode_nocomp-v1_5.cube	BT.2100 HLG signals are converted to BT.2100 PQ at the 1,000nits "bridge" condition, so that 100% HLG maps to 1,000nits PQ. This is a transparent conversion. **This requires a BBC LUT License.**

B. PQ to HLG

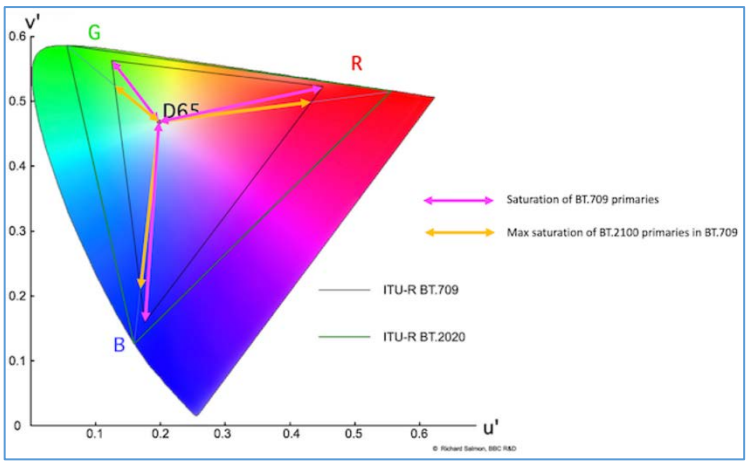
LUT	Version	NAME	Description
BBC 1E	1.5	1e_PQ1000_HLG_Type3_Transcode_nocomp-v1_5.cube	BT.2100 PQ signals are converted to BT.2100 HLG in the 1,000 nit "bridge" condition, so that 1000nit PQ maps to 100% HLG. Please refer to ITU-R report BT.2390 Section 7.2 ("Conversion concepts using a reference condition at 1,000 cd/m2"). PQ signals above 1,000nit are mapped into the HLG "super-white" signal range up to 109% signal, equivalent to 1,811 cd/m2 (PQ). There can be some minor color volume loss with this conversion.
BBC 2E	1.5	2c_PQ4000_HLG_Type2_Transcode_nocomp-v1_5.cube	4,000nit BT.2100 PQ signals are converted to BT.2100 HLG by first tone-mapping to the 1000nit "bridge" condition, and then converting to HLG. The tone-mapping is applied to the luminance component so that hue distortions are avoided; note that 4,000nit PQ maps to 100% HLG. For more information, please refer to ITU-R report BT.2390 Section 7.4 ("Handling PQ signals with greater than 1,000nit peak-luminance"). PQ signals above 4,000nit are mapped into the HLG "super-white" signal range. There will be some color volume loss with this conversion.
MovieLabs PQ-to-HLG MaxRGB	1	MovieLabs_PQ4000_to_HLG1000_MaxRGB_Narrow_with_superwhite_65Point_TypeIII.cube	PQ to HLG conversion for a 4,000nit-PQ to normalized 1,000nit-HLG workflow using MaxRGB highlight compression during normalization to HLG at 1,000nit (see citation at the end of this document). This is a mostly transparent conversion with highlight compression and improved gamut compression when superwhites in HLG are used.

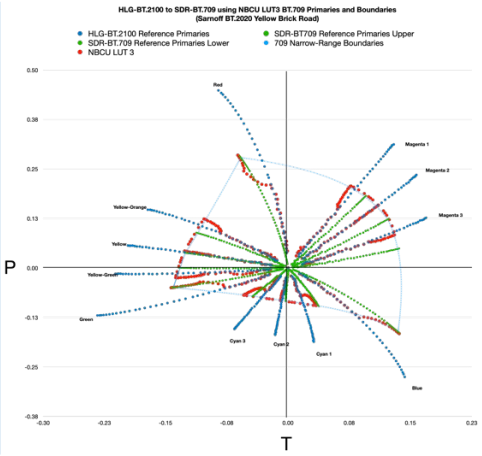
ANNEX 1: The Strategy Around NBCU LUT Conversions

The focus of the entire conversion effort is to maintain the original artistic intent such that the SDR derived from the NBCU LUT compared side-by-side is consistent with the HDR until the point where the advantages of HDR are realized even with a reduction of dynamic range in the converted SDR.

For HDR to SDR conversions there are several key characteristics that we adhere to:

- SDR BT.709 content round-tripped through HDR returns to SDR imperceptibly from how it started. The color is consistent to the original and the reduction in the luminance isn't noticeable.
- The conversion uses a knee that is natural and provides appropriate latitude for live video shading while preserving highlights in SDR workflows that don't exceed 100% signal level.
- BT.2020 colors inside the BT.709 triangle remain unchanged when mapped back to SDR.
- Content with BT.2020 colors that originate outside of the 709 boundary are mapped back into 709 in a manner that is as consistent to the original as possible. The illustration below shows that by using these techniques, we can fully saturate each color in SDR.
- Attention has been placed on the mid-tones so that they remain at consistent light levels throughout the conversion.





During the creation of these LUTs a system has been created to plot various conversions and measure their color and light-level accuracies. By utilizing this technique, in combination with a set of test patterns that encompass the range of available color and light levels, we are able to drive the development of the color science behind the LUTs.

ANNEX 2: 3D Cube Look-Up-Tables (3D-LUT)

3D-LUTS are the most common and efficient way to convert between HDR, SDR and different color spaces and transfer function curves.

In order to guarantee that the NBCU LUTS are accurate, we've collaborated with experts to develop **objective color metrics tools (using BT.2124)** that mimic the human visual systems or show absolute color values (u'v'). Both are important to quantify. The perceptual metrics differ from absolute mathematical comparisons that don't take into account how the human visual system perceives color and light.

The set of tools allow us to design and qualify conversions in hardware and software as well as detect issues that need to be fixed or optimized. ITU-R BT.2124 techniques allow us to translate perceptual characteristics of color and light into graph-able results. Perceptual effects can alter production decisions, especially when HDR and WCG are introduced.

Figure 6a is a visualization how a 3D CUBE LUT works. The input samples create perfectly equidistant points within an RGB 3D cube. A 3D CUBE represents all the points of both color and light represented by values between zero(0) and one(1). The conversion LUT(**Figure 6b**) represent those same points after they've been moved to new locations. A LUT provides the new locations for each point (the conversion).

Input
Equidistant RGB Points

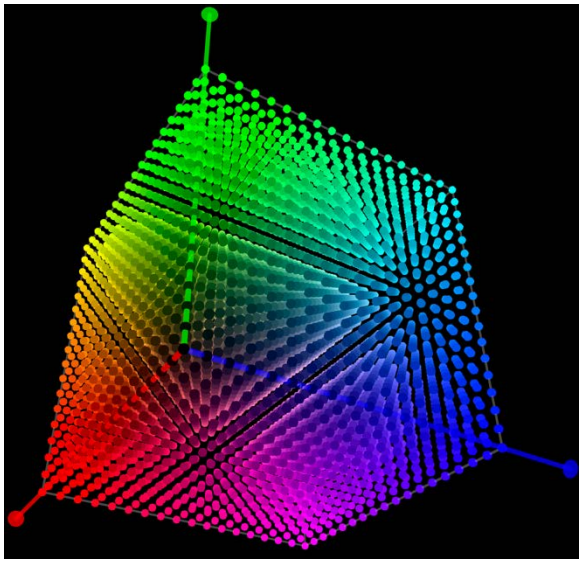


Figure 6a

Output
Changes from original position

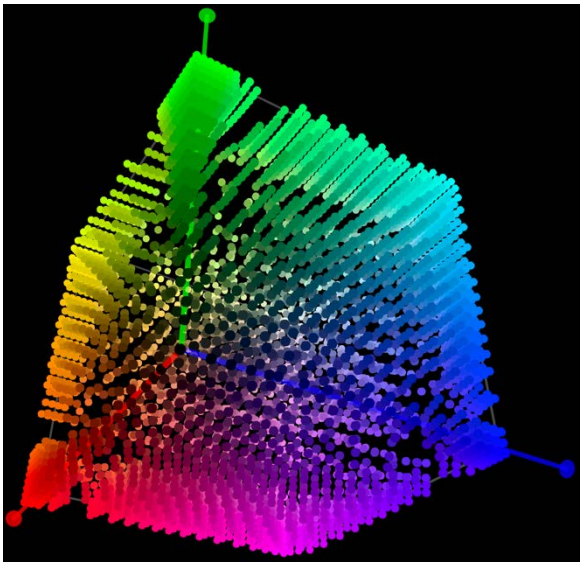
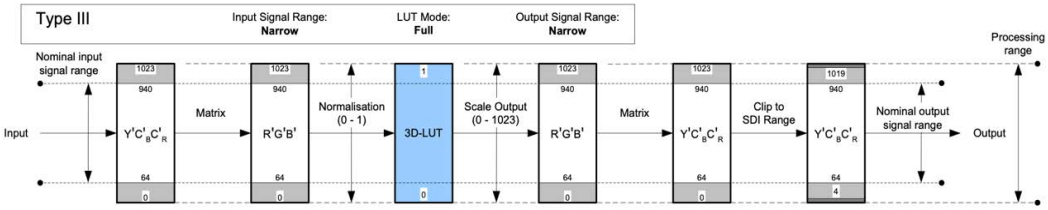


Figure 6b

Look-Up-Tables can come in several different varieties that process different signal ranges. The BBC has labeled the different LUTs as **"Type I, II, III"**. **All NBCU LUTS are "Type III"**.:

- **Type III LUTs** - Processes narrow/legal range signals with extended range support (also known as super-white or sub-black). Narrow range in the 10-bit code range define video black at 10-bit code value 64 and "nominal peak level" or "peak white" at 10-bit code value 940. The nominal levels in a narrow range signal are also represented in a video waveform (scope) as 0-100% or 0-100IRE.



GRAPHIC COMPLEMENTS OF BBC

- **Cube LUT Types** - NBCU LUTS are supplied in Adobe, DaVinci Resolve 17 and DaVinci Resolve 3D Cube LUT formats.

- EBU r103 has more information on the usage of narrow range, nominal signal levels and "excursions" above 100% signal level.

- **Caveats** - Some hardware or software require that a CUBE LUTs "TITLE" parameter be commented-out in a "Cube LUTS" text file. Add a "#" sign (without quotes) before the TITLE in order for the parameter to be ignored.

3D LUT Interpolation Modes

LUT Interpolation Modes - Hardware and software use interpolation to determine values that are in-between the conversion points defined in a CUBE LUT. Through testing we were able to determine that to support our sophisticated gamut and luma compression in the down-mapping LUTS, **Tetrahedral interpolation** must be used to avoid artifacts.

The "sawtooth" artifact in Figure 8a is produced by trilinear interpolation. This is observed in the waveform display using a simple gray ramp with "highlight knee" used in the **NBCU HDR to SDR LUT** conversion. The waveform display (Figure 8b) shows the same knee with a smooth ramp produced by tetrahedral interpolation.

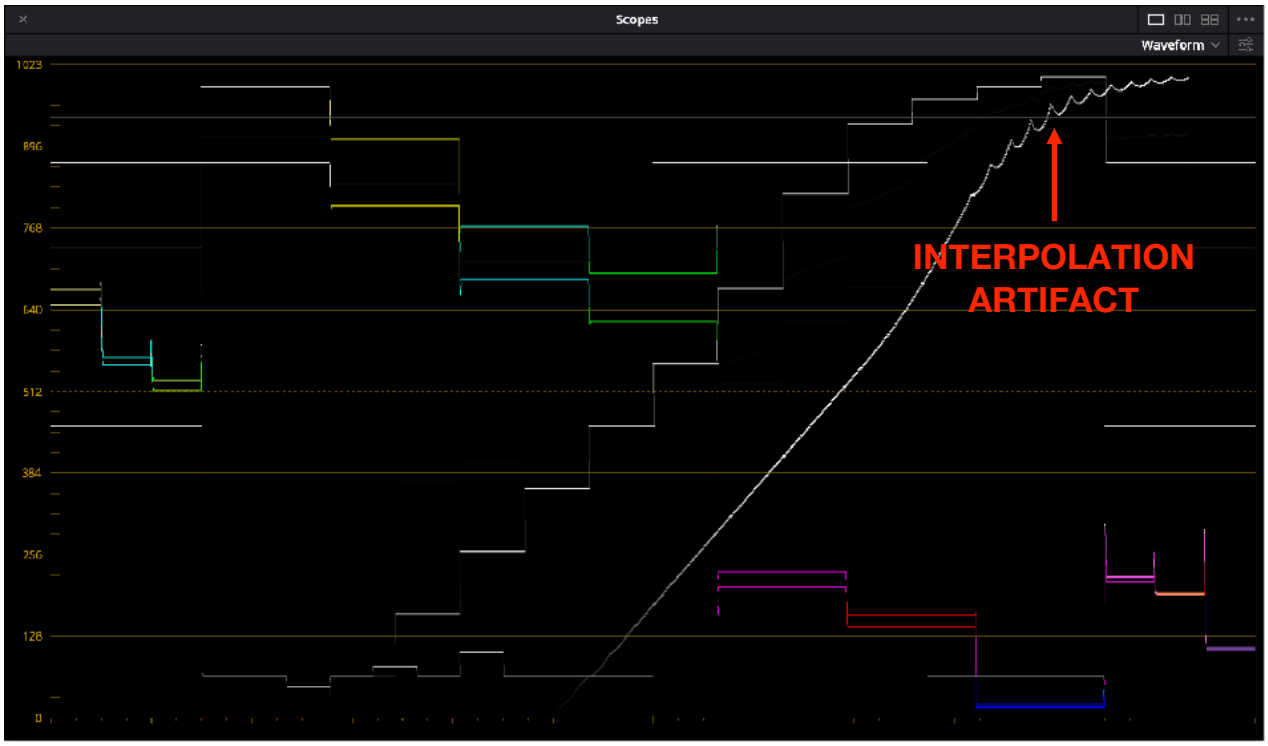


Figure 8a - Trilinear LUT Interpolation

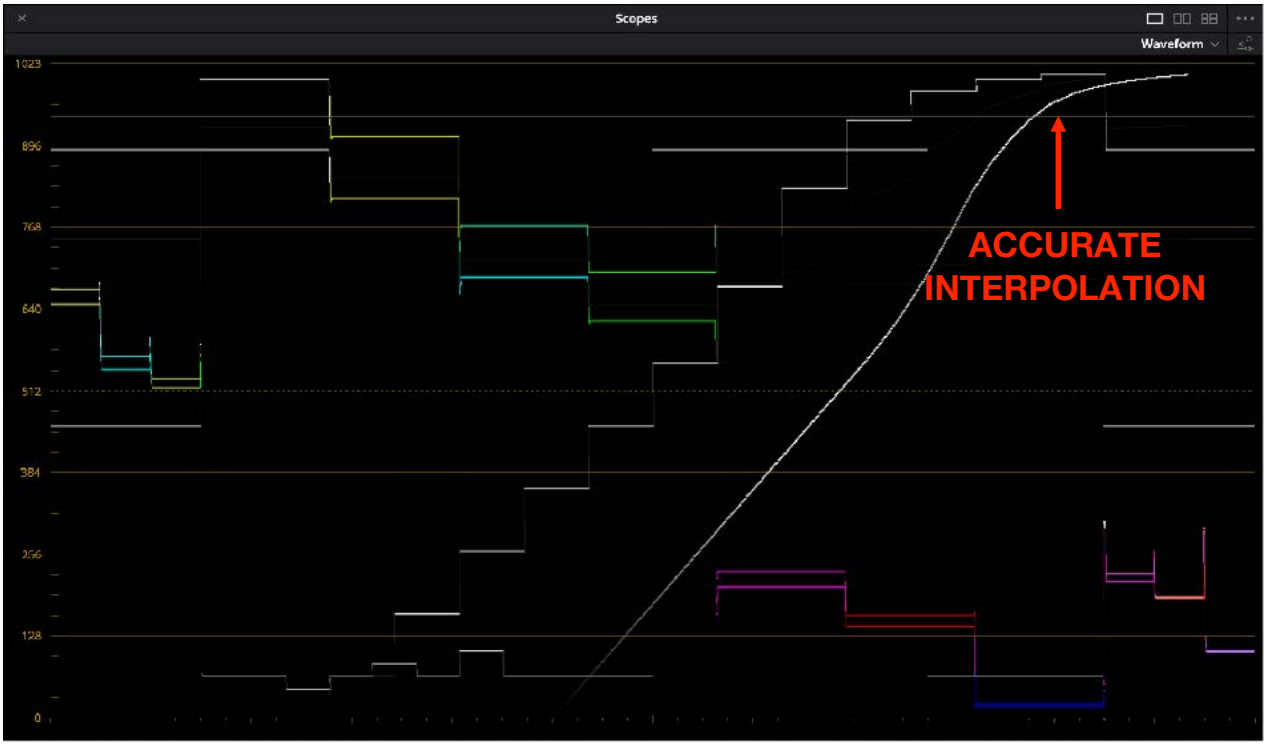


Figure 8b - Tetrahedral LUT Interpolation

ANNEX 3: Shading Detail

Single-stream HDR-SDR camera shading benefits by understanding the relationship of HLG levels in a scene. These levels have been studied are available in the ITU Recommendations of BT.2408 (see table below)

HLG Video Levels (Display @ 1,000nits)		
	nits(cd/m²)	% of HLG Signal
Grey Card (18%)	26	38
Greyscale Chart Max (90%)	179	73
Reference Levels HDR Reference White (100%) Diffuse White Graphics White	203	75
Type 1-2 Light skin tone	65-110	55-65
Type 3-4 Medium skin tone	40-85	45-60
Type 5-6 Dark skin tone4	10-40	25-45
Grass	30-65	40-55

Setup

- **HDR Camera settings**: Our suggestion is that Sony camera SDR differential gain should start around **-10**. In our model we don't utilize the SDR output of the CCU, this setting only affects the viewfinder and can be adjusted to aid the camera operator.
- **Predictive LUT:** Shaders should use **NBCU LUT3** as a "predictive LUT" for previewing SDR output to transmission.
- **HLG displays settings**: Video format should be set to HLG-BT.2100 **(which utilizes BT.2020 color space).**
- **SDR Display Settings:** When working in this environment we have found it's beneficial or the SDR monitoring to be set such that display brightness is 203nits. This provides for consistency between the 75% anchor point in HDR and the resultant SDR. For Sony reference displays, a SDR **User Preset** contrast setting can be adjusted to achieve this:

Sony Display SDR Mode Contrast Settings					
	BVM-HX310	PVM-X2400	PVM-X1800	BVM-X300	BVM-E171
Contrast Value	812	812	812	812	2030

Setting HDR Camera Levels

- **Diffuse White**: defined as a large matte-white object like a white jersey or tee-shirt.
    - In a live-linear HLG production, diffuse white should be set at around 75% signal level (203nits). This is easily identifiable in a waveform monitor.
    - **Camera Charts**: Diffuse white would be the 100% chip on a camera chart.
    - **Diffuse-White** acts as an ***"anchor point"*** around which the rest of the production images are built.
- **Highlights**: The additional dynamic range available in HDR is known as highlights. On a waveform monitor this energy is represented from 75% to 100% of the HLG signal level. The subject of the composition is generally located below the anchor point but this will change scene by scene.

Setting SDR Camera Levels

- SDR cameras are shaded thru **NBCU LUT2 (SDR-to-HLG using scene light).** Scene-Light conversion matches SDR cameras with native HLG cameras that have a slightly different "look". Once they are converted to HLG, the bulk of the energy will be contained below the 75% anchor point.

Monitoring Graphics Video Levels

- **Graphics-White**: Graphics are currently produced in SDR content with a peak at SDR-100% signal level. **NBCU LUT 1** maps graphics to the recommended HDR graphics-white level of 203nits (75% signal level or 75IRE in HLG).

Monitoring SDR Output Down-Mapped Quality

- When an HDR display is used as the primary shading display, we utilize **NBCU LUT 3 acts as a "Predictive LUT"** for monitoring the signal fed to an SDR display and SDR transmission (a legacy channel).
- Diffuse-White acts as an "**anchor-point"** for setting HDR camera levels which simultaneously produces SDR output through **NBCU LUT3**. The **"Predictive LUT" provides** the ability to determine the relationship between optimal HDR levels and the derived SDR.

ANNEX 4: Production and Distribution Video Formats

The NBCU production LUTS have been designed and tested using both objective perceptual and absolute color metrics. The goal has been to preserve the artistic intent during each stage of the conversion process. Basic concepts for signal flow:

- Every video signal entering production is normalized to HLG-BT.2100.
- Every video signal entering distribution is normalized to PQ10-BT.2100.
- HLG to PQ conversion is mathematically transparent and uses formulas defined in ITU-R BT.2390.

Why Use HLG For Production?

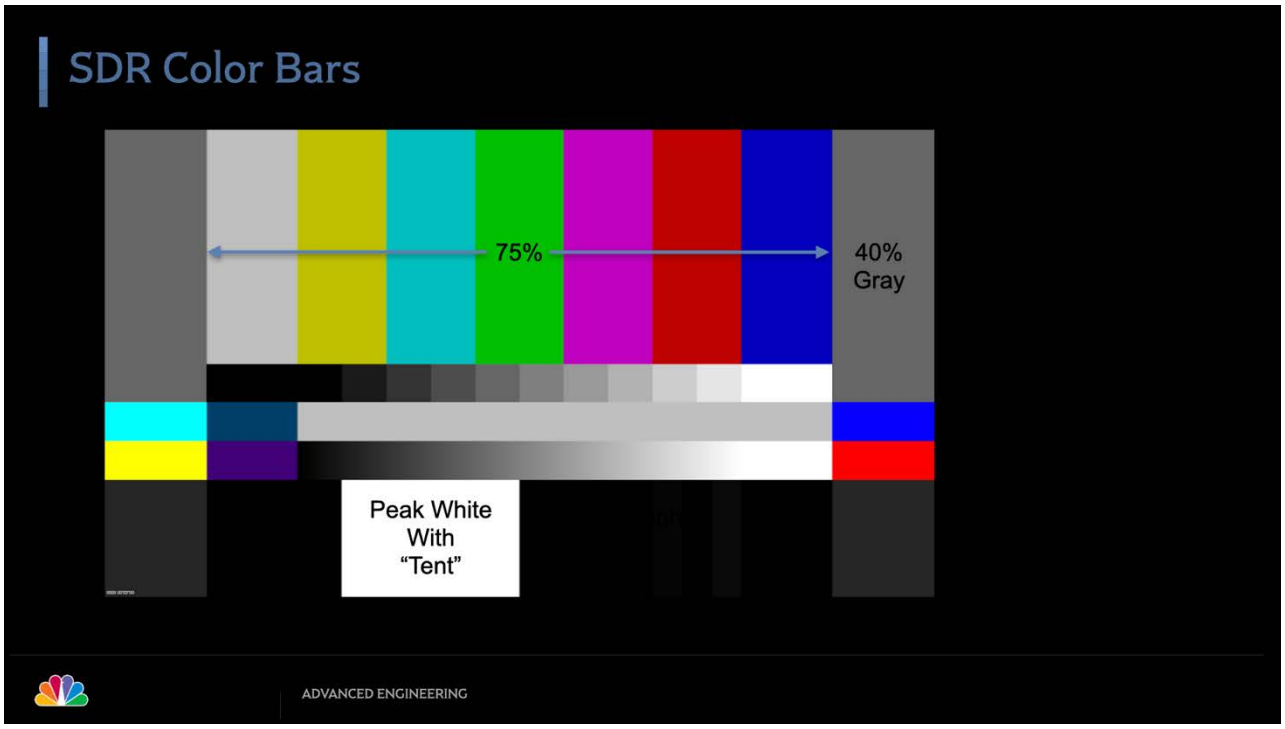
HLG is the most common native HDR format used in broadcast production. HLG is universally supported by professional native-HDR broadcast displays, switchers, software and conversion devices. HLG is capable of being viewed on existing SDR displays with some level of backwards compatibility.

Why Use PQ For Distribution?

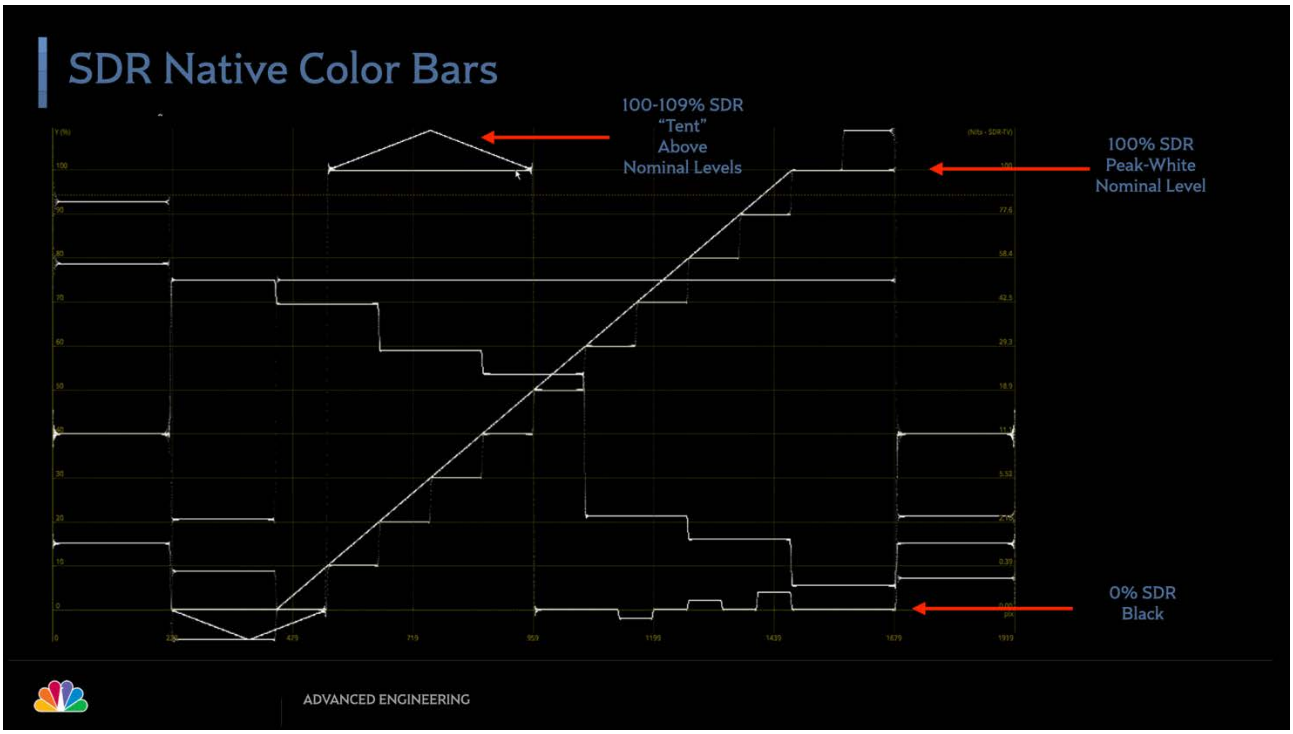
PQ preserves the capabilities of linear production which currently occurs at a peak of 1,000nits. PQ is the native HDR format used during cinema(film) mastering which can be mastered as high as 4,000nits. PQ enables both content types to be displayed on the same live-linear channel without changing the original artistic intent.

- PQ is the currently the most common format for streaming devices and services.
- PQ is the standardized HDR format for delivery to cable services in the United States (SCTE)
- PQ preserves an absolute brightness level to the consumer device which provides a more consistent method for preserving the focal point of the composition.
- PQ allows for additional saturation to be described. This is described in Section 7.5 of **ITU-R BT.2390.**
- HLG to PQ conversion is mathematically transparent so there is no quality loss when converting between linear broadcast production and distribution. This is described in Section 7.2 of **ITU-R BT.2390**.
- Converting HLG to PQ for distribution preserves HLG levels between 100-109% in PQ and therefore ensures delivery of this range to the home consumer display. HLG levels beyond 100% are often clipped in consumer displays.
- PQ can support more sophisticated tone-mapping formats such as HDR10, Dolby Vision and HDR10+ (static and dynamic methods).

ANNEX 5:
WAVEFORM MONITOR REFERENCE SCREENSHOTS

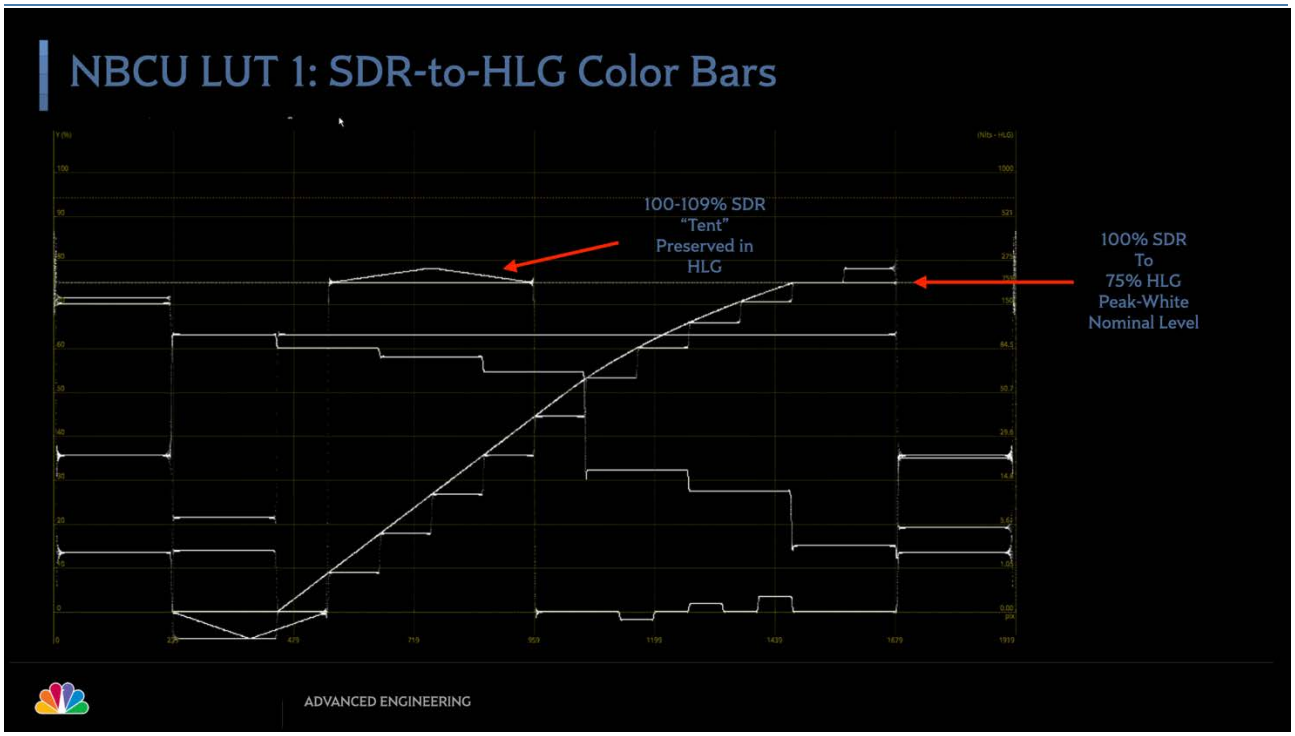


SDR Native SMPTE Bars with Gray 10% Ladder



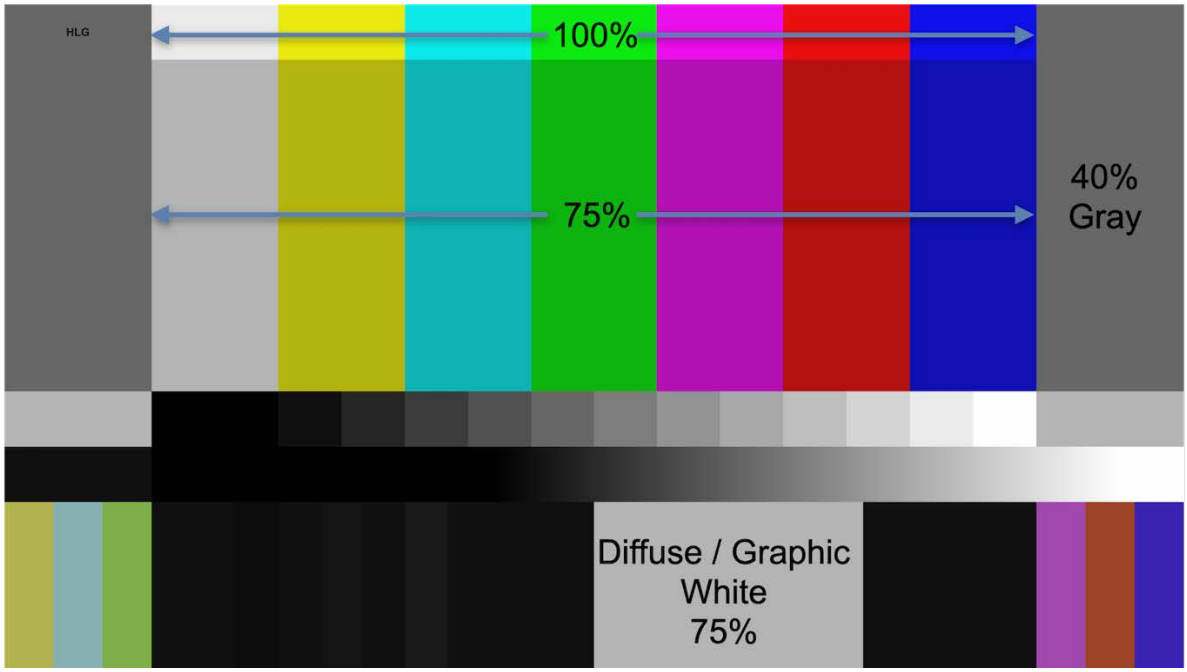
Waveform: SDR Native SMPTE Bars with Gray 10% Ladder

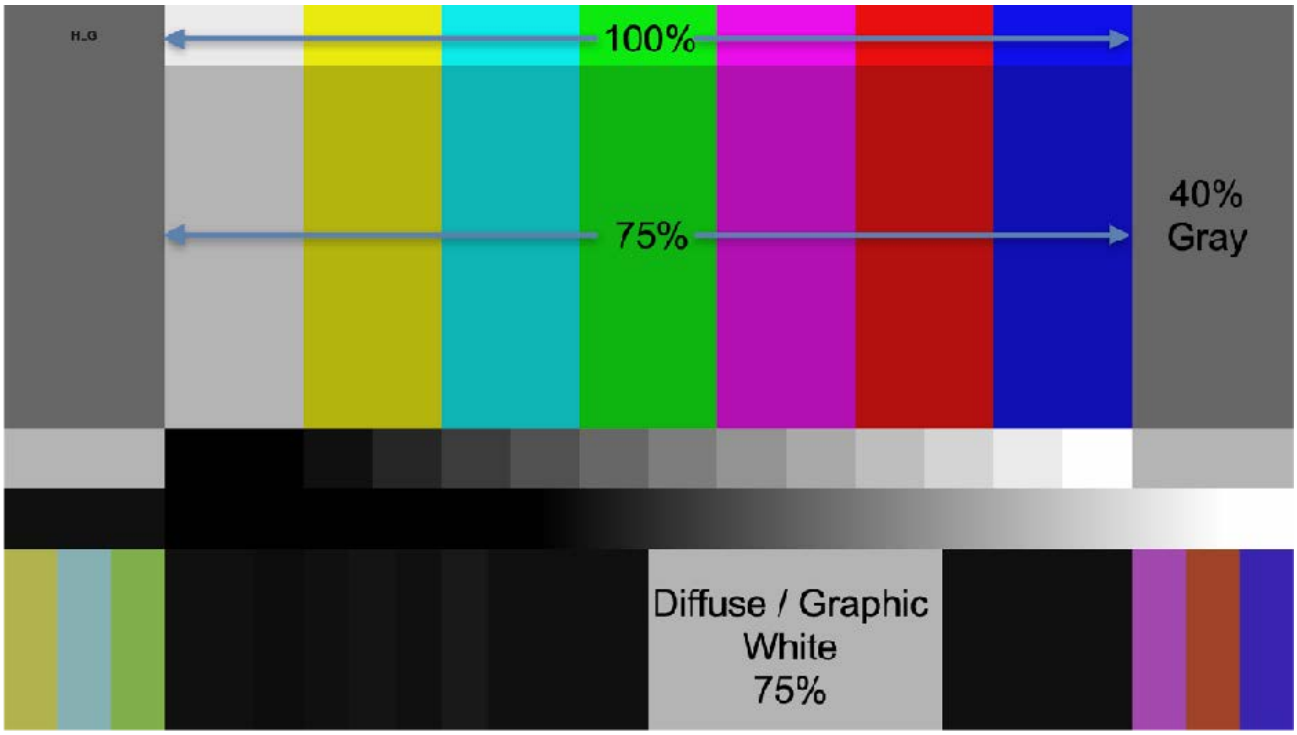
NBCU LUT1: SDR-to-HLG - SMPTE Bars with 10% Gray Steps



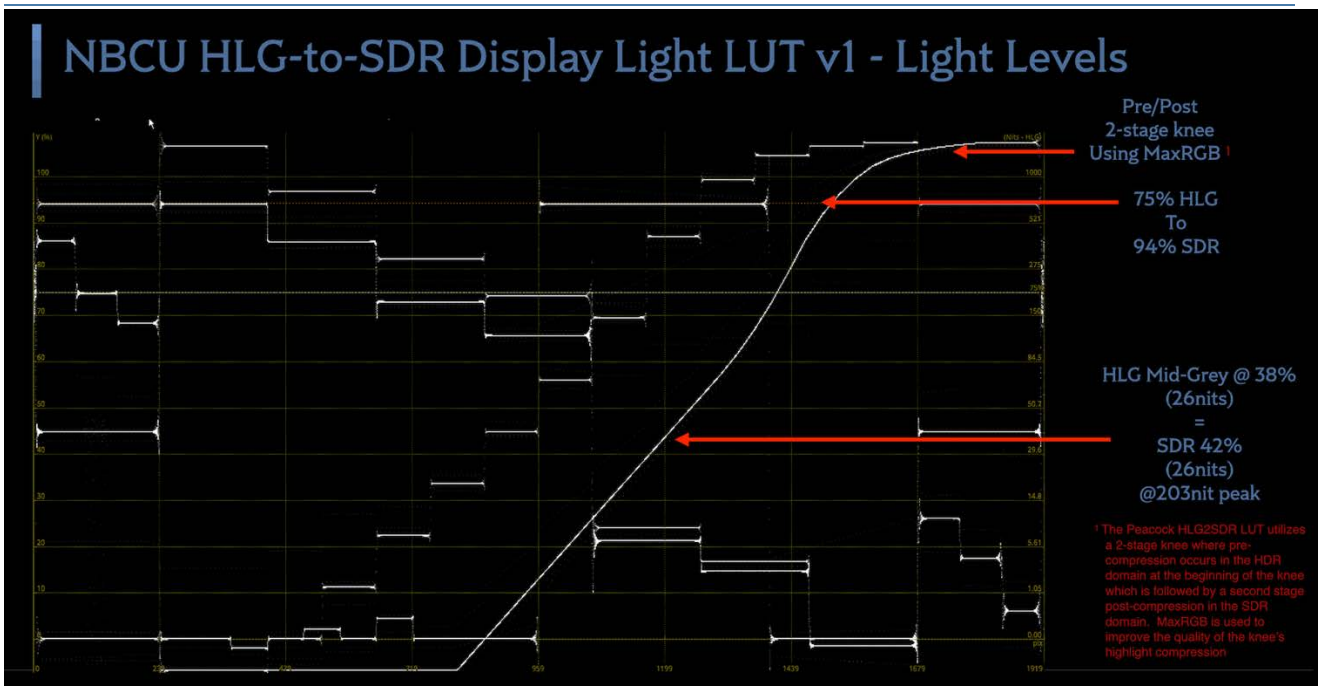
Waveform: NBCU LUT1: SDR-to-HLG - SMPTE Bars with 10% Gray Steps

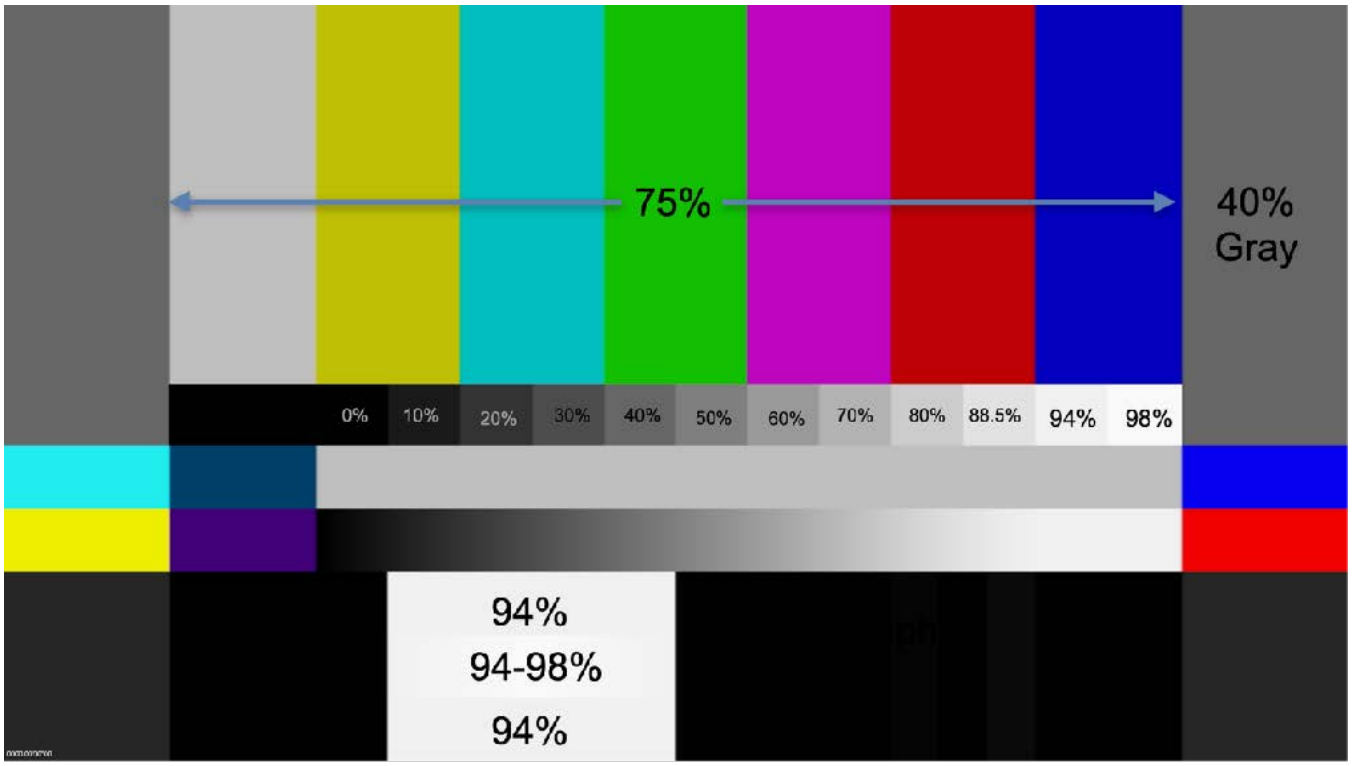
HLG Native Color Bars - Normalized at 1,000nits



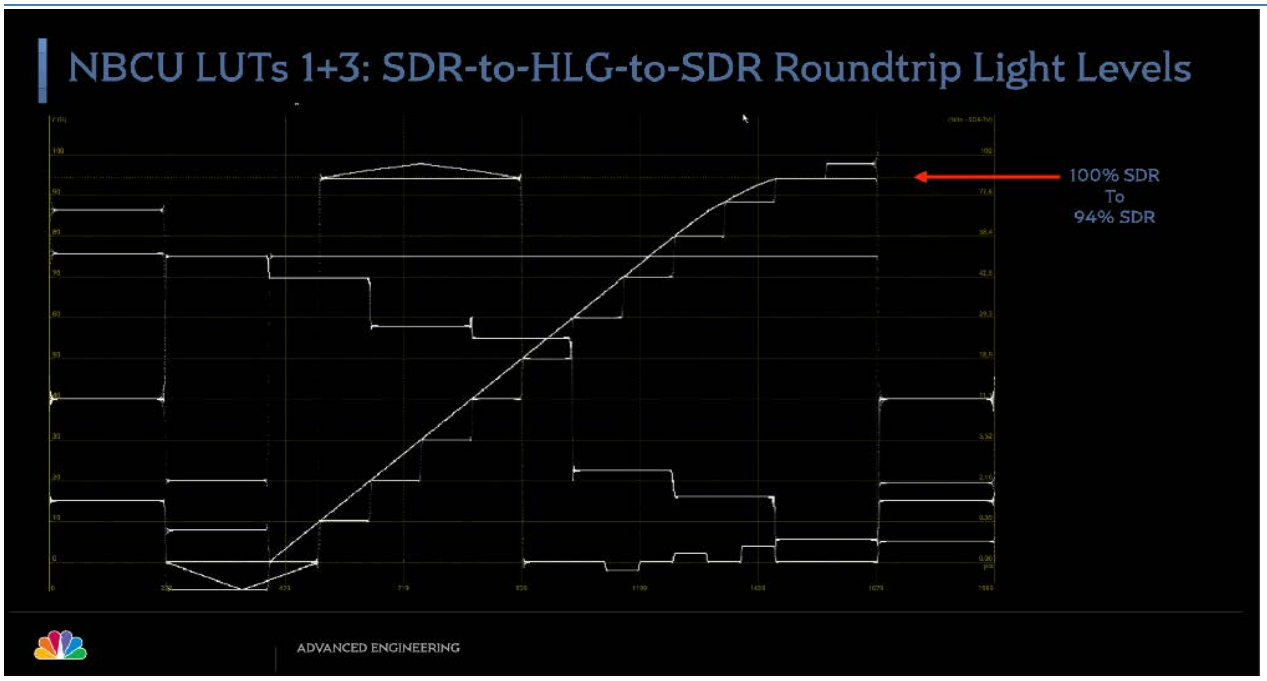


BT.2111 NBCU LUT 3 (HLG to SDR - Display Light)

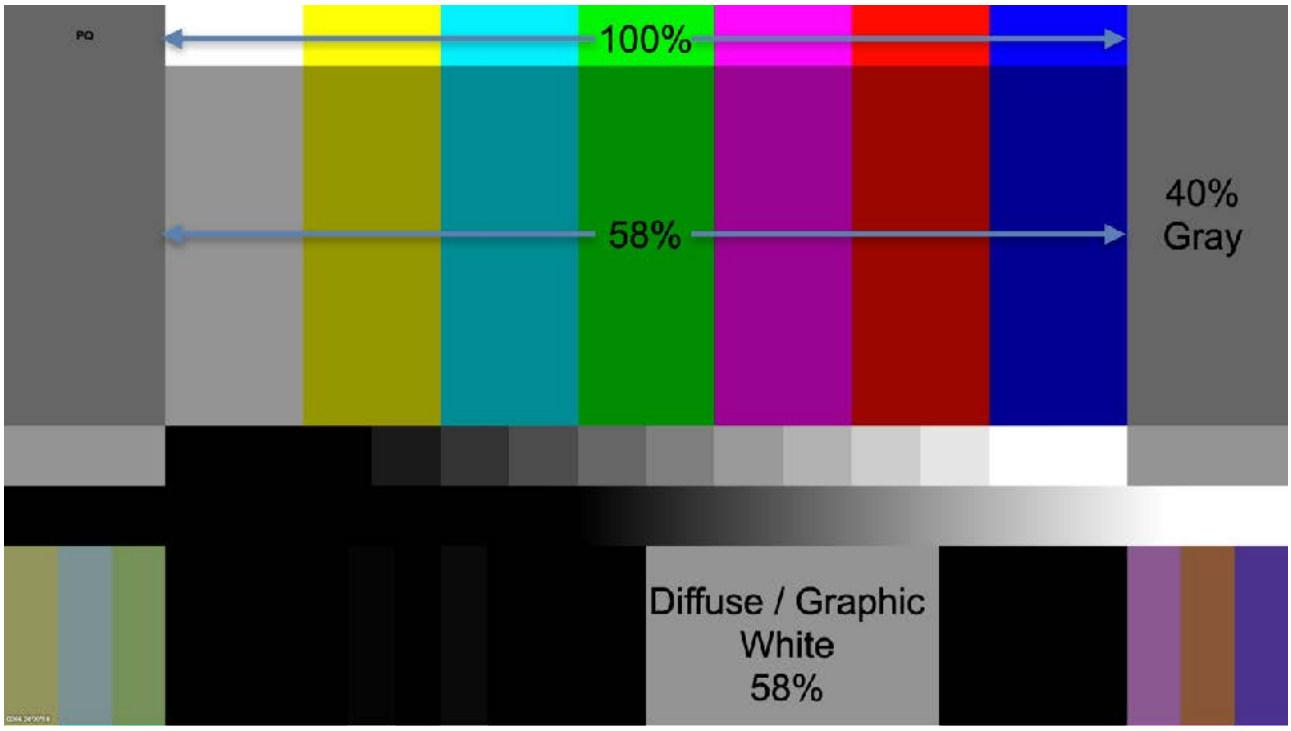




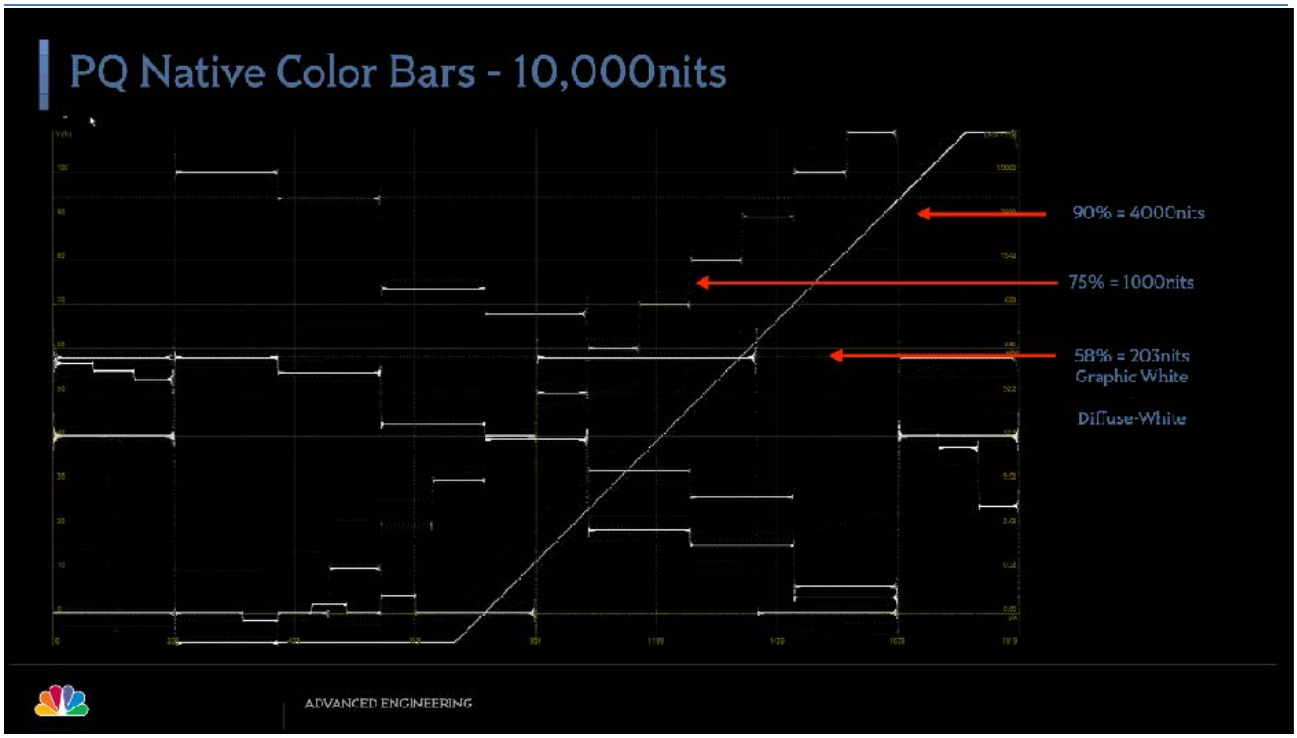
NBCU LUTS SDR-HLG-SDR Roundtrip BT.2111 Color Bars



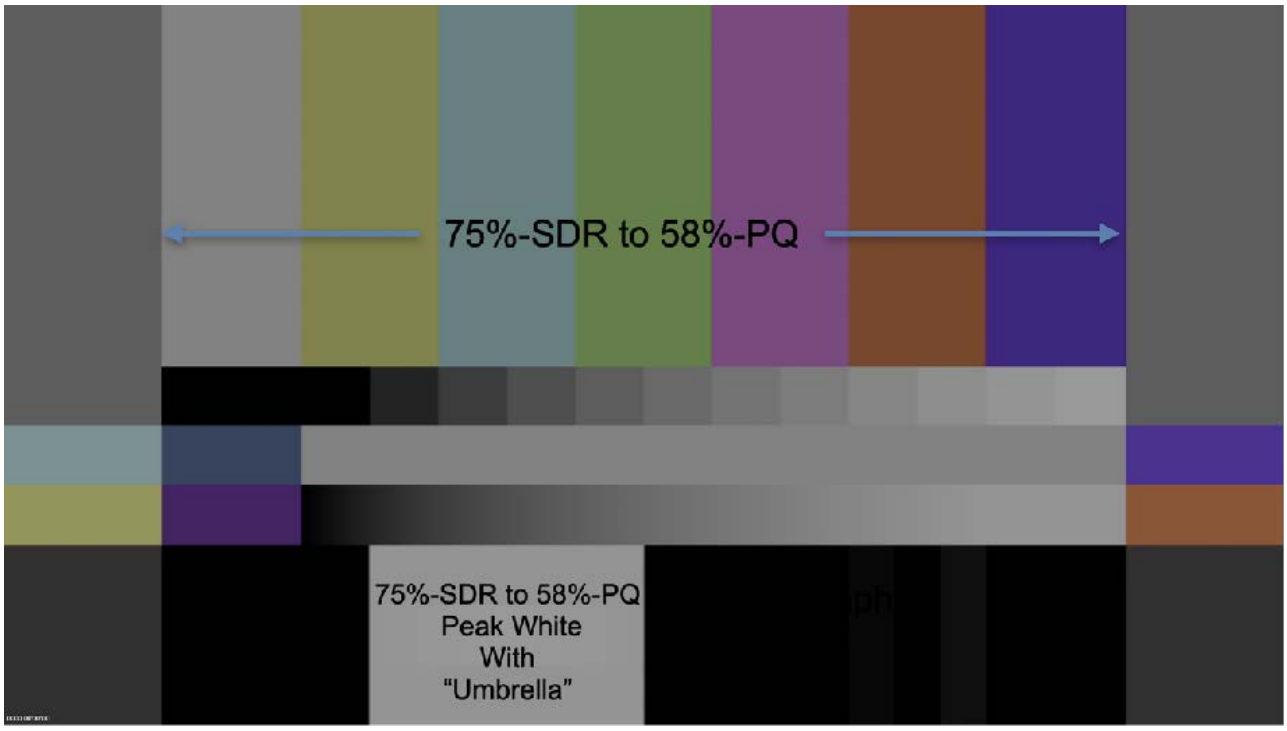
Waveform: NBCU LUTS SDR-HLG-SDR Roundtrip BT.2111 Color Bars



BT.2111 - PQ Color Bars

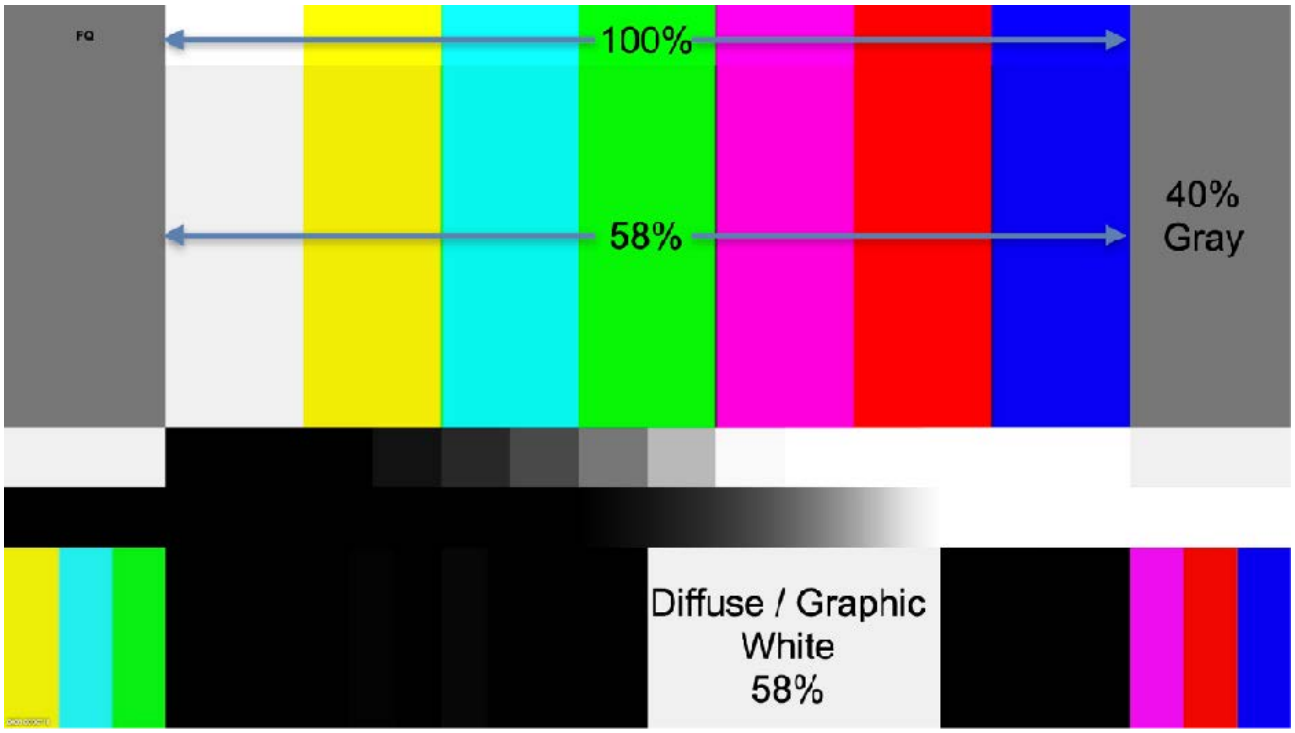


Waveform: BT.2111 PQ Color Bars

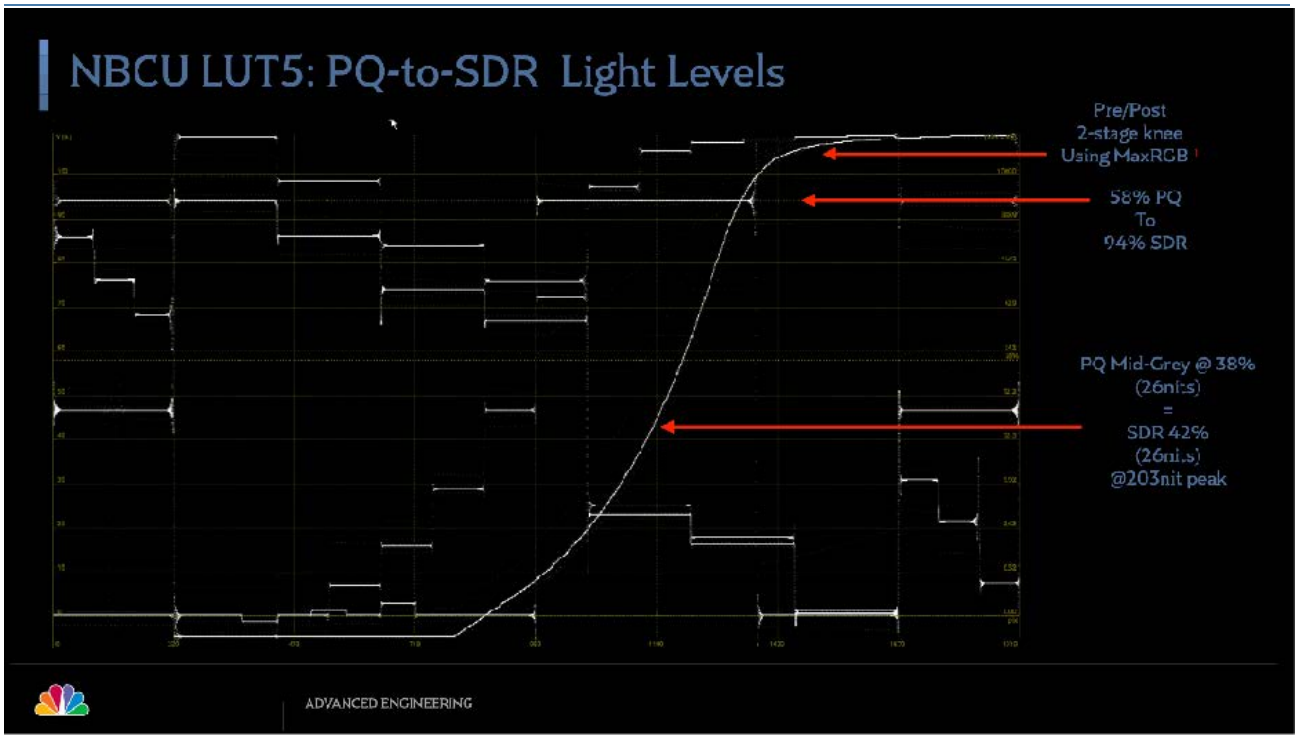


SDR to PQ - SMPTE Bars with Gray 10% Ladder

Waveform: SDR to PQ - SMPTE Bars with Gray 10% Ladder



BT.2111 NBCU LUT 5 (PQ to SDR - Display Light)

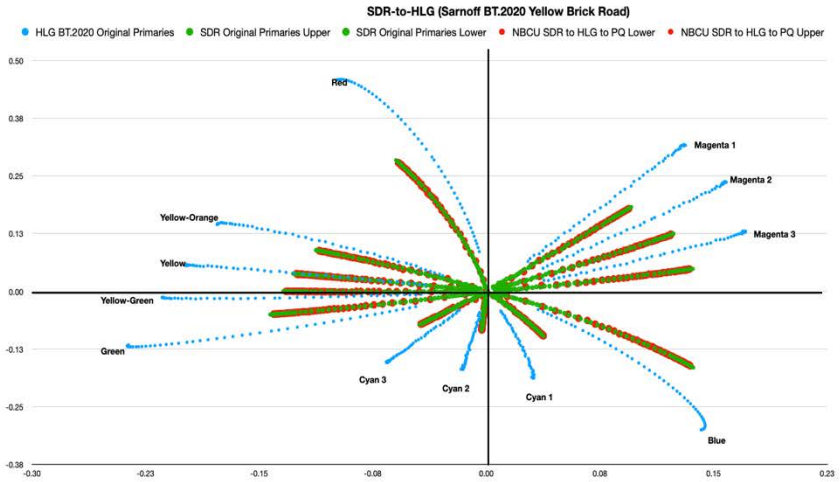


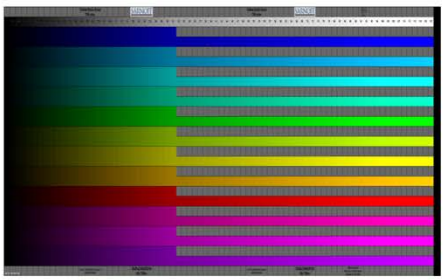
Waveform: BT.2111 NBCU LUT 5 (PQ to SDR - Display Light)

ANNEX 6: Color Conversion Accuracy Analysis

NBCU LUT 1: SDR to HDR Conversion

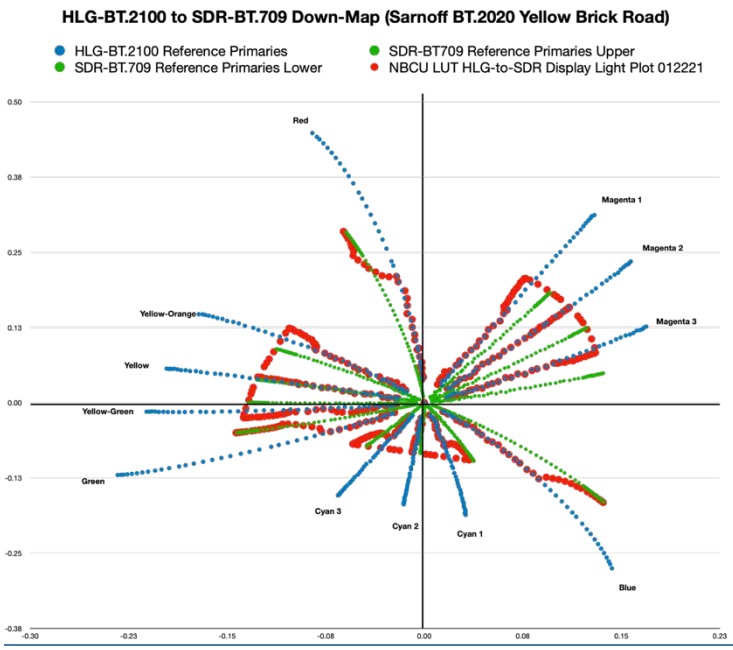
Original Colors in BT.709 are preserved into a HDR-BT.2020 container(Either HLG or PQ). There are no perceptible hue shifts.

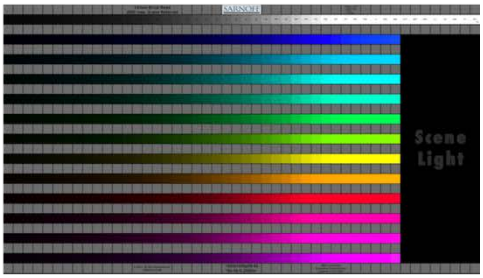




NBCU LUT 3 & 5: HDR to SDR Conversion

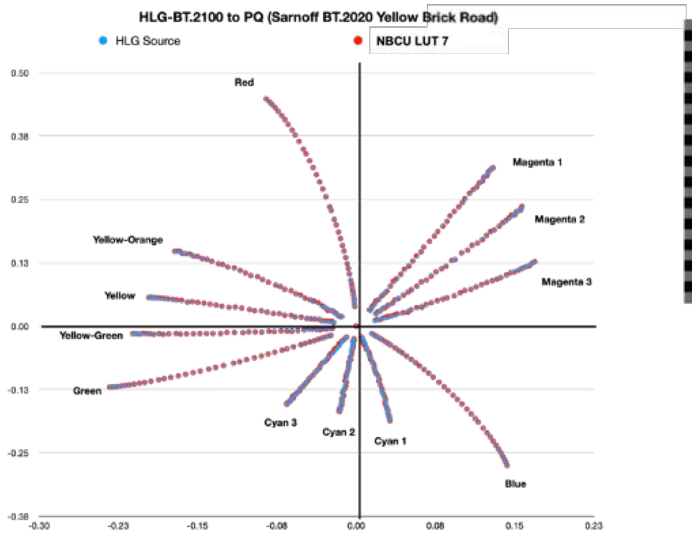
Original Colors in BT.2020 are preserved into SDR-BT.709 Container until colors are too bright or saturated. No perceptible hue shifts.

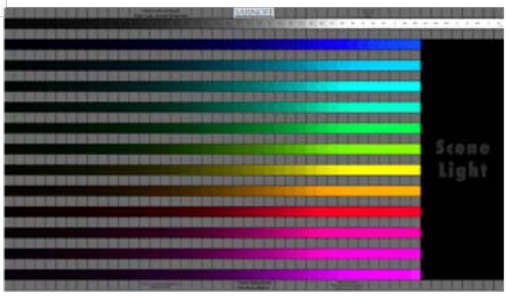




NBCU LUT 7: HLG to PQ Conversion

Mathematically transparent conversion.

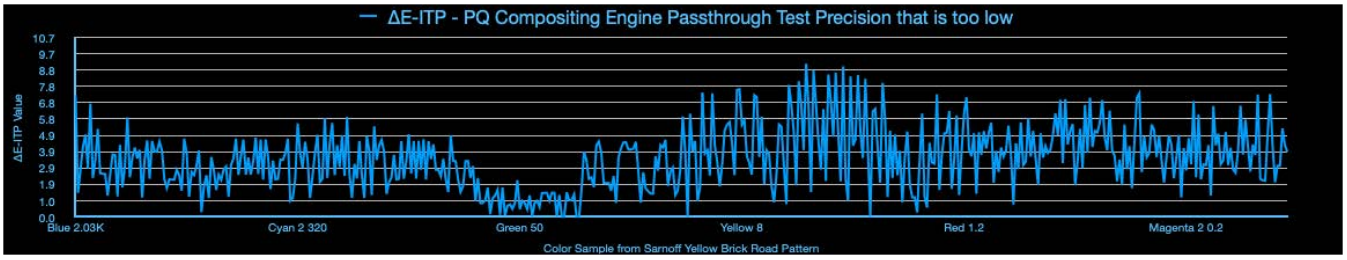




- No visible hue shifts
- Perfect hue tracking

Testing Signal Passthru using ΔE-ITP

The full ∆**E-ITP** recommendation in ITU-R BT.2124 can be plotted in a line graph (see below). This particular plot samples a **very inaccurate** video passthrough in a signal chain. Each square in the Sarnoff Yellow Brick Road pattern (over 400 points) is sampled to see if the signal path is transparent. Ideally all samples should equal zero (0), but any number above one is a "Just Noticable Difference"(JND).



ANNEX 7:

Signal Level Relationships During Conversion

Signal Level Relationships Between HDR and SDR

Single-stream live production requires that specific relationships be established between HDR and SDR levels. To create those relationships, we must define:

- **Where conversions occur between different video formats (SDR, HLG, PQ).**
- **What "Anchor Points" are used to establish a relationship between the levels of one format to another. For the purpose of this document, we will use the most common anchor point between SDR and HDR which is 203nits or 75% ire in HDR.**
- **The assumption is that HDR displays are set for peak brightness of 1000 nits and SDR displays are set for a peak brightness of 203nits at 100% signal level.**

GOALS:

- **Convert all source formats to a single, internal format within each environment (Production=HLG) (Transmission=PQ).**
- **Production shall feed both the native HDR formats and the legacy SDR formats with the eventual goal of switching transmission to accepting a single-stream deliverable as well.**

On the next few pages, we will graphically explore the relationships between HDR and SDR when using the conversion LUTs.

A. SDR->HLG->SDR ROUNDTRIP MAPPINGS:

Figure xxx demonstrates how the signal levels are remapped

- **SDR to HLG - NBCU LUT 1+2:** SDR-100% signal level is converted to HLG-75%.
- **HLG to SDR - NBCU LUT 3:** HLG-75% is converted to SDR-94% with HDR highlights compressed between SDR_94-109% using a 2-stage knee.

SDR to HLG to SDR Roundtrip Anchor Points

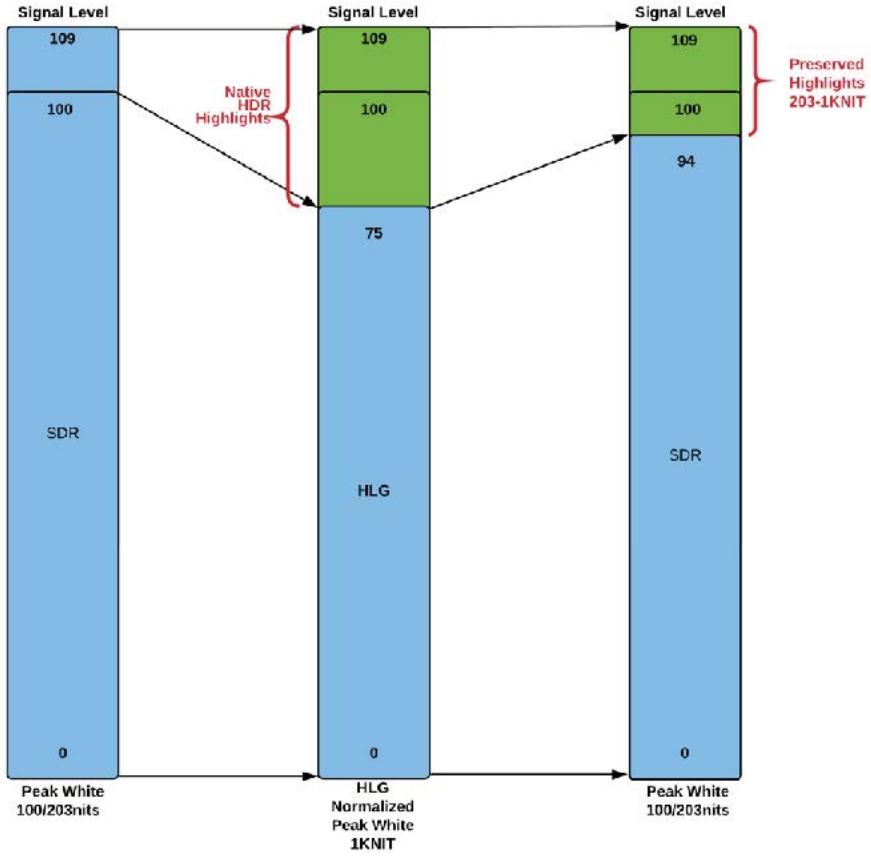


Figure 1

B. PQ MAPPINGS (SDR-PQ-SDR):

Transmission LEVELS (Roundtrip SDR-PQ-SDR):

Figure xxx demonstrates the signal levels in transmission.

- **SDR to PQ - NBCU LUT 4:** SDR-100% is converted to PQ-58%.
- **PQ to SDR - NBCU LUT 5:** PQ-58% is converted to SDR-94% with HDR highlights compressed between SDR_94-109% using a 2-stage knee.

SDR to PQ to SDR Roundtrip Anchor Points

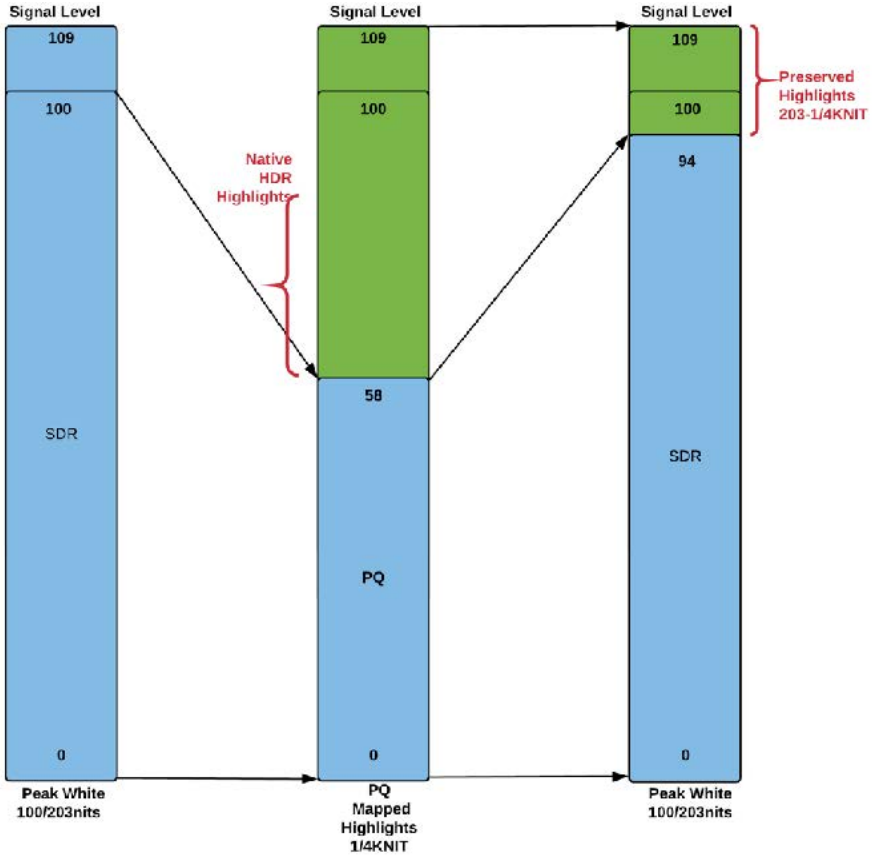


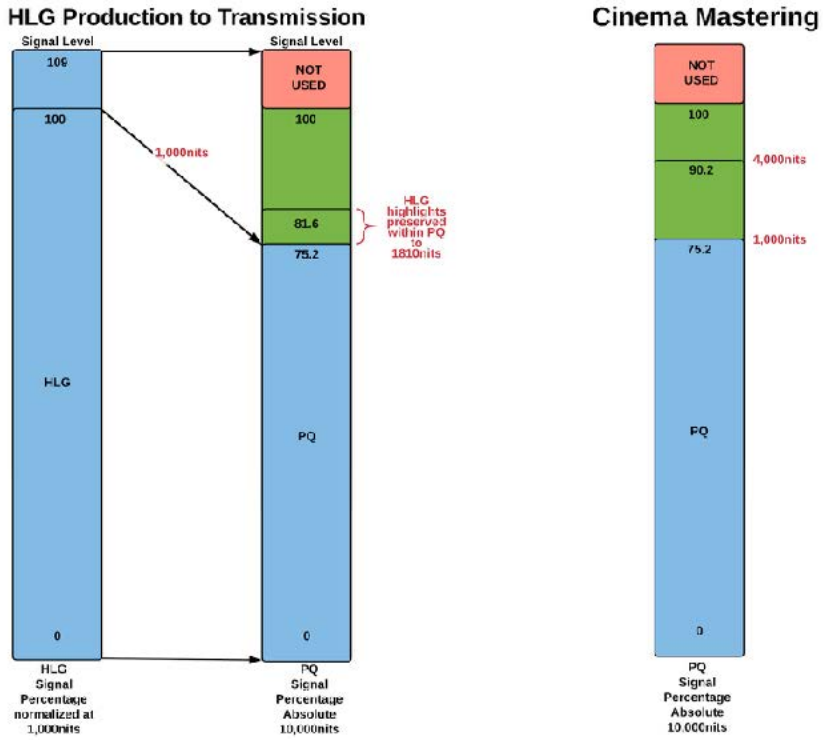
Figure 2

C. HLG -> PQ LEVEL MAPPINGS:

Native HDR Transmission LEVELS (HLG-to PQ and Cinema PQ):

To see how the signal levels are adjusted look at Figure xxx below to examine a full roundtrip thru production:

- **HLG to PQ - BBC LUT7C:** Transparent conversion from HLG to PQ preserving both the look and absolute light levels.



- Cinema mastering levels remain intact.

D. PRODUCTION LEVELS MAPPINGS:

The tables on the following pages describe the primary "anchor points" (levels) broadcasters use during shading to make sure image levels between cameras are consistent as well as conversion to SDR. Single-stream production is dependent on keeping the anchor points consistent. All tables indicate percentages of signal level and/or nits.

In these tables, SDR peak white has an "adjusted" peak white level of 203nits (instead of 100nits). HLG and PQ Peak-White is assumed to be normalized at 1000nits excursions above 100% signal level are allowed in HLG and SDR.

Here are the most important reference levels that we will identify as defined in ITU-R BT.2408:

- **Graphic White:** 203nits.
- **Mid-Grey:** 26nits
- **Peak White:** Peak white defined at 100% signal level in each format.

NBCU HDR<->SDR LUT Reference Levels

A. SDR-BT.709 to HDR-BT.2100 Display-Light

	SDR		HLG (LUT1)	PQ (LUT 4)
Graphic White	100%	=	75%=203nits	58%=203nits
Mid-Grey	43%=26nits	=	38%=26nits	38%=26nits
Peak White	Normalized at 1,000nits	=	75% = 1,000nits	
Highlights	1000-1810nits	=	75-82%	

B. SDR-BT.709 to HLG-BT.2100 Scene-Light

	SDR		HLG (LUT3)	
Graphic White	100%	=	75%=203nits	
Mid-Grey	43%=26nits	=	38%=26nits	

C. HDR-BT.2100 to SDR-BT.709 Display Light

	HLG (LUT 3)	PQ (LUT 5)		SDR 203nit Peak White (Display) @ 100% Signal Level
Mid-Grey HDR@26nits	38%	38%	=	43% = 26.16nits
Graphics / Diffuse White HDR@203nits	75%	58%	=	94% = 174nits
HDR-to-SDR Peak White HDR@289nits	81%	62%	=	100% = 203nits
Highlights HDR@1000nits	100%	75%	=	107 = 237nits

3rd party cross-conversion LUTs transform transparently from HLG-to-PQ. PQ-to-HLG down-mapping will have some color volume loss because of PQ's larger color volume. HLG is normalized at 1,000nits, because there is no associated tone-mapping metadata for HLG ITU determined this is an optimal level for conversion.

3rd Party HDR Cross-Conversion LUTS Reference Levels

1. HLG-to-PQ (BBC 7c)

	HLG		PQ
Mid-Gray	38% (26nits)	=	38% (26nits)
Graphic White	75% (203nits)	=	58%(203nits)
Peak White	Normalized at 1,000nits	=	75% = 1,000nits
Highlights	1000-1810nits	=	75-82%

2. PQ-1KNIT Peak to HLG (BBC 1e)

	PQ		HLG
Mid-Gray	38% (26nits)	=	38% (26nits)
Graphic White	58% (203nits)	=	75%(203nits)
1,000nits	75%(1000nits)	=	100%(1000nits)
Highlights	75-84%(1000-2249nits)	=	100-109%

3. PQ-4KNIT Peak to HLG (BBC 2e)

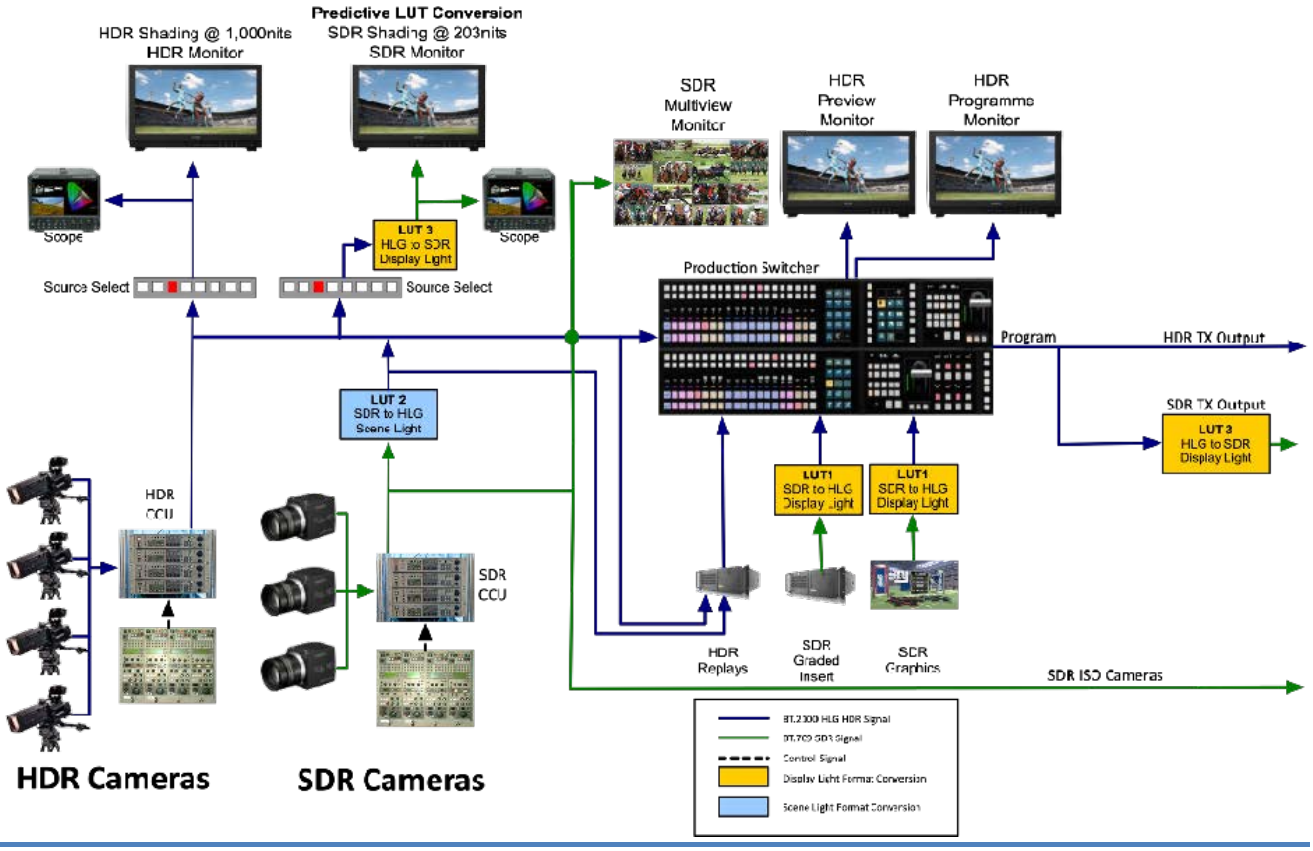
	PQ		HLG
Mid-Gray	38% (26nits)	=	38% (26nits)
Graphic White	58% (203nits)	=	75%(203nits)
1000nits	75% (1000nits)	=	91.89%
Highlights	75--90.18%(1000-3972nits)	=	92-100%
Super Highlights	90.18-100%(3972-10Knits)	=	100-106.73%

4. PQ-4KNIT Peak to HLG (BBC 2e)

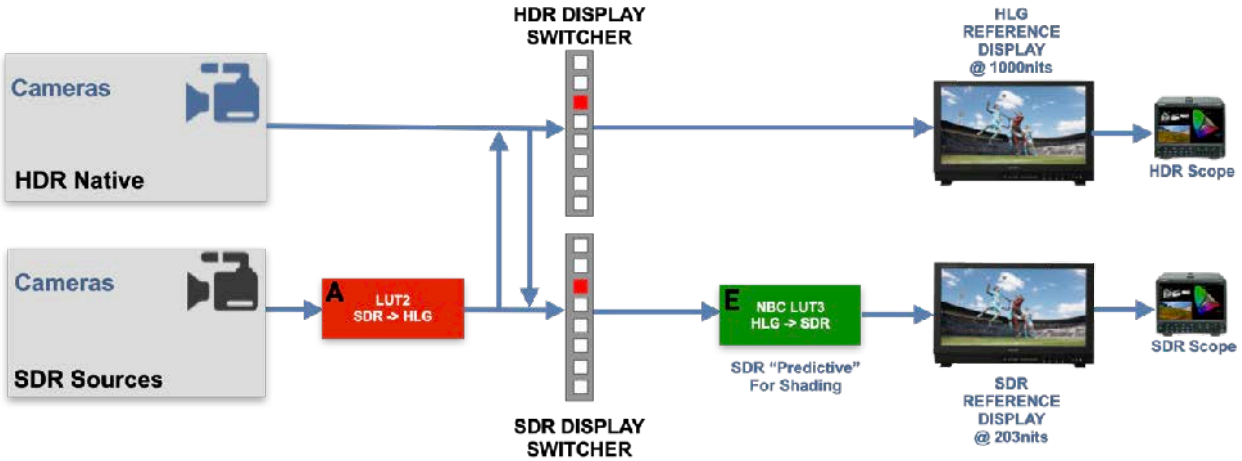
Mid-Gray	38% (26nits)	=	38%(26nits)
Graphic White	58% (203nits)	=	75%(203nits)
1000nits	75% (1000nits)	=	97%
4000nits	90% (4000nits)	=	100%

ANNEX 8: ITU-R BT.2408 Workflow Drawing – NBCU Adapted

ITU-R BT.2408 Production (Modified NBCU Workflow)



SHADING WITH HDR AND SDR CAMERA DISPLAY SWITCHING



ANNEX 9: ITU-R BT.2408 Conversion Detail

Display Light Conversion (SDR to HDR)

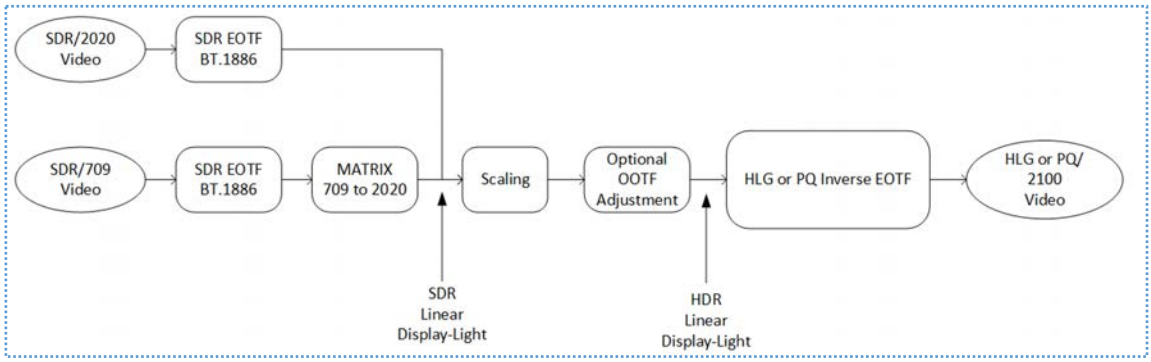


IMAGE IS COMPLEMENTS OF ITU-BT.2408

Scene Light Conversion (SDR to HDR)

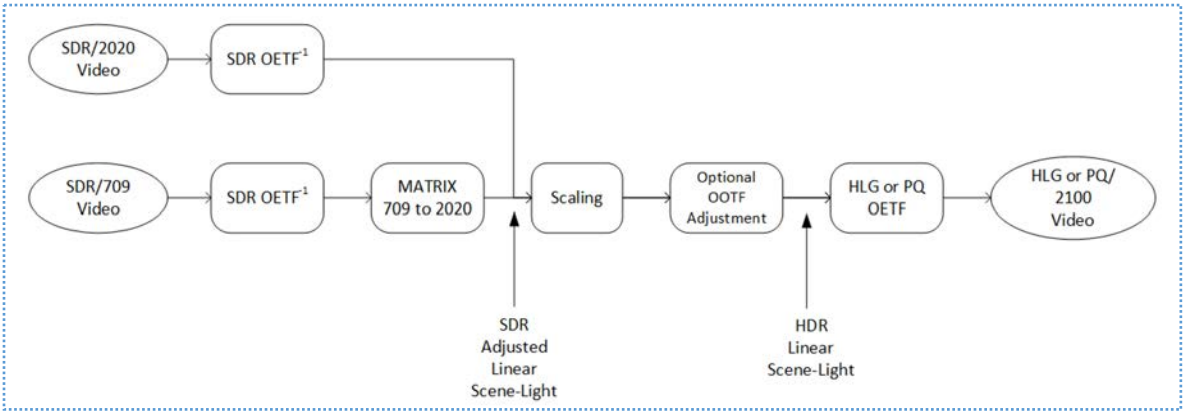
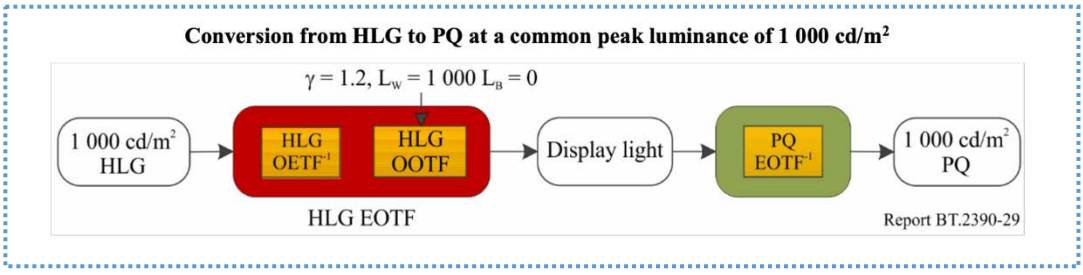


IMAGE IS COMPLEMENTS OF ITU-BT.2408

HLG to PQ Conversion (Production to Transmission)



Reference

ITU-R BT.2408	Guidance for operational practices in HDR television production
ITU-R BT.2390	High Dynamic Range Television For Production and International Programme Exchange
EBUr103	Video Signal Tolerance in digital television system
ITU-R BT.2124	Objective metric for the assessment of the potential visibility of color differences in television
ITU-R BT.2100	Defines the HLG and PQ transfer functions
ITU-R BT.2020	Objective metric for the assessment of the potential visibility of color differences in television
ITU-T H Supplement 19	Summarized list of approximately 47 standards for signaling UHD-HDR-WCG and SDR
Color Volume and Hue-Preservation in HDR Tone Mapping	A. Burke, M. D. Smith and M. Zink, in *SMPTE Motion Imaging Journal*, vol. 129, May 20th 2020.

Acronyms

3D Cube LUT	Efficient R-G-B Tables that allow remapping of both color and light.
Tetrahedral Interpolation	Interpolates points in-between values supplied in a LUT using a method that more accurately predicts a correct value based on adjacent LUT values.
High Dynamic Range (HDR)	High Dynamic Range – In the context of this discussion HDR represents a larger range of light (from dark to peak white) represented in stops where HLG can represent up to 17 stops and PQ can represent up to 28 stops compared to SDR which can only present up to 5 stops
Wide Color Gamut (WCG)	Wide Color Gamut – In the context of this presentation, WCG has a wider range of color represented by the different color primaries defined in ITU-R BT.2020.
Stop	1 stop represents a doubling of light that gets compounded at each additional stop.
Display Light Conversion	Uses the source signals display transformation “electro-optical-transfer-function”(EOTF) prior to conversion to another video format (SDR/HLG/PQ).
Scene Light Conversion	Converts to a signal that would leave a camera using a specific video format (i.e. HLG, SDR, etc) prior to the conversion to a signal for a display (OETF)
Super-Whites	Levels above 100% signal level. Despite the label this also includes color’s above 100% signal level. Only some displays will show these levels.
Tone-Mapping	Re-mapping of light levels between signals or devices with different dynamic range capabilities.
Static Metadata (For PQ HDR)	Defined in ST.2084. Static Metadata defines the mastering displays color volume capabilities. This includes the displays peak brightness, color space and white point.
Dynamic Metadata (For PQ HDR)	This includes Dolby Vision, HDR10+, CUVA all of which can define informative tone-mapping metadata on a scene or frame-based basis.

Reference Files, Tools and Test Patterns

NBCU LUTS	Download NBCU LUTs, documentation and test patterns
Vooya Video Player	Vooya Video Player Software
Color Metric Plug-In for Vooya	Objective Color Metrics plug-in for Vooya Video Player

Document History

Version #	Date	Revised by	Reason for Change
NBCU-Rec-UHD-HDR-1.01	03/23/21	Chris Seeger, Clarence Hau, Michael Drazin, Jim Starzynski	Document Creation and Editing
NBCU-Rec-UHD-HDR-1.02	04/07/21	Chris Seeger	Typo and graphics fixes
NBCU-Rec-UHD-HDR-1.03	4/11/21	Chris Seeger, Michael Drazin	Replaced degraded graphics, improved Annex 4
NBCU-Rec-UHD-HDR-1.04	4/20/21	Chris Seeger, Michael Drazin	Corrected typos in cross-conversion LUTS (Section 4)
NBCU-Rec-UHD-HDR-1.04	5/03/21	Chris Seeger, Mike Zink	• Updated Section 4 – Added cross-conversion NBCU-LUT7 (HLG to PQ) • Added link to ITU-T H Supplement 19 • Added link for free MaxRGB Article
NBCU-Rec-UHD-HDR-1.04	5/11/21	Chris Seeger	• Updated Figure 1: “SDR Commercials and Graphics”

NBCU-Rec-UHD-HDR-1.05	5/21/21	Chris Seeger	• Added usage notes for DaVinci Resolve, Adobe, Avid
NBCU-Rec-UHD-HDR-1.06	06/01/21	Chris Seeger	• Added usage notes for Avid and Adobe
NBCU-Rec-UHD-HDR-1.07	11/01/21	Chris Seeger	• Added line-graph examples of ΔE-ITP