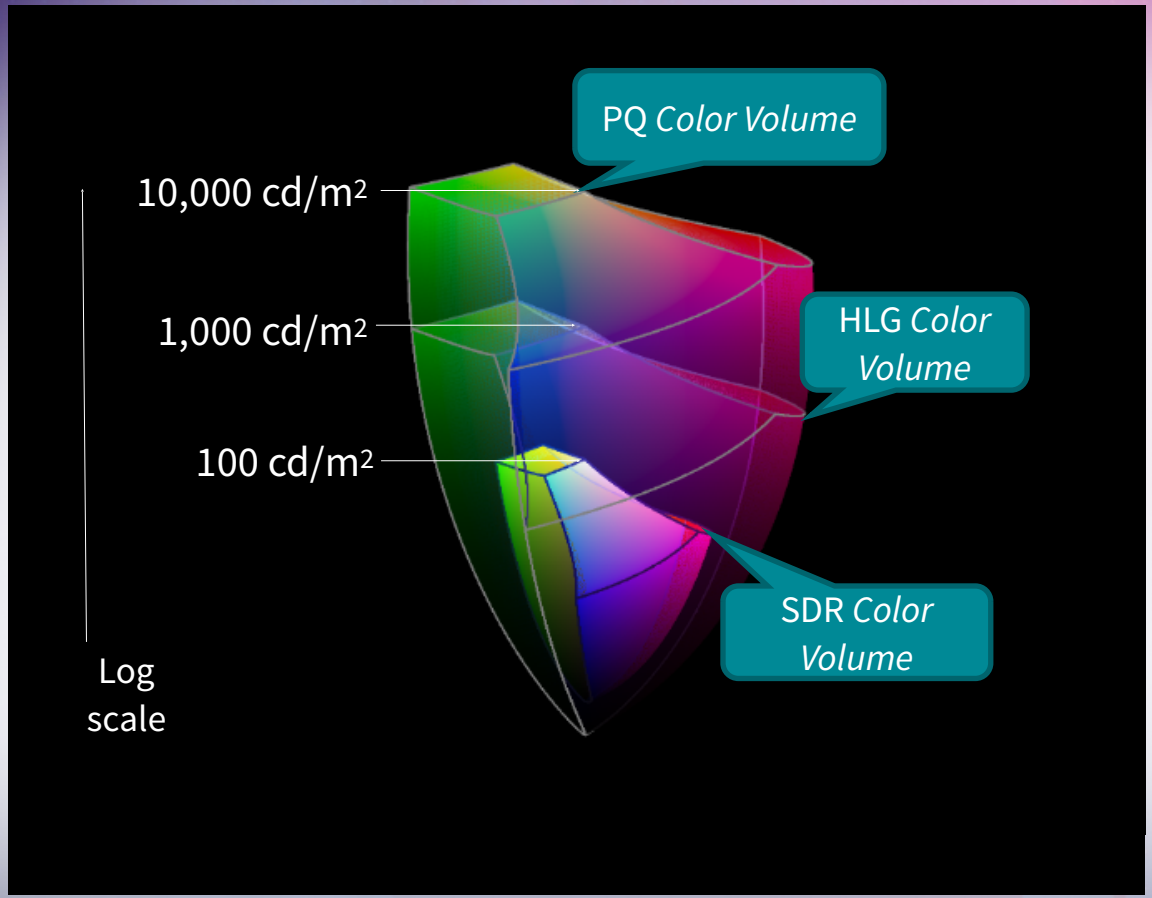
Designing LUTs for UHD Broadcasting Using Objective Color Metrics During The Tokyo Olympics

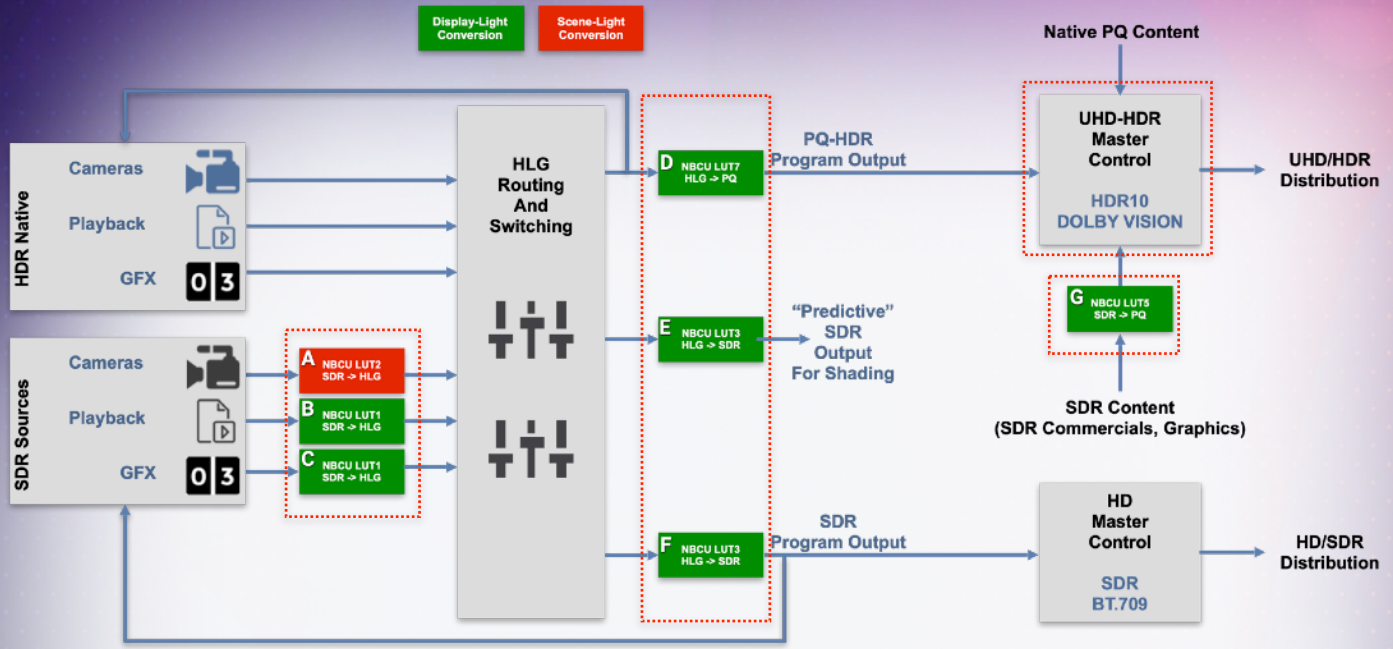
November 2021
NABShow.com

Comparing The Old and The New



* Per ITU-R, HLG reference display normalized at 1k cd/m2

Single Stream Production and Transmission



- Conversion points to test in HDR path (LUTS or Compositing)

- **Determine Conversion Points**
- **Determine conversion goals (i.e. - where is graphics white, what are the anchor points between formats**
- **Make conversions from one format to another without changing perceptual representation ("original artistic intent").**

Objective Perceptual Metrics Become More Important

For High Dynamic Range
and
Wide Color Gamut
Color Accuracy Assessments

Subjective assessments yielded inconsistent results

What are our goals?

Preserves Original Artistic Intent
During Conversion From Different Formats

Make Really Beautiful Pictures

NBCUniversal UHD HDR Experiences

Here's where we start

What signals are we converting between?

PQ, HLG, and SDR Transfer Functions

NABSHOW Where Content Comes to Life

- **PQ** - Captures absolute light levels which translate natively in a display
- **HLG** - Captures relative light levels which are converted at the display
- **SDR** - Designed for a peak luminance of 100nits which is typically scaled in a consumer display to a higher light level

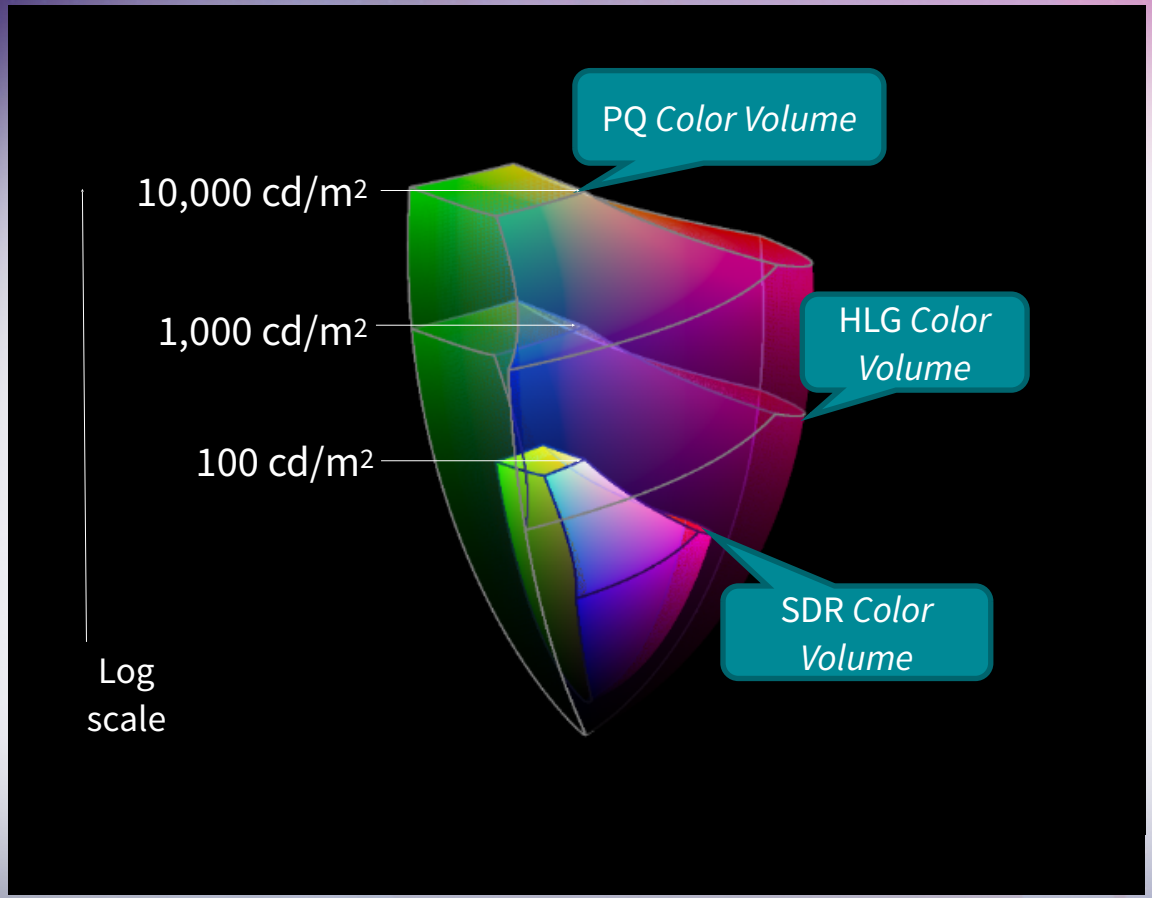
Color Spaces

- **BT.709 -** Used in conventional SDR video formats
- **BT.2020 -** Used in current HDR video formats

Color Representations

- **YCbCr -** Luma/Color difference used in conventional video formats
- **RGB -** Red/Green/Blue (mixes color primaries to create any color).
- **IC_TC_P -** Used by Dolby Vision Profile 5 and our objective metric toolset.

Comparing The Old and The New



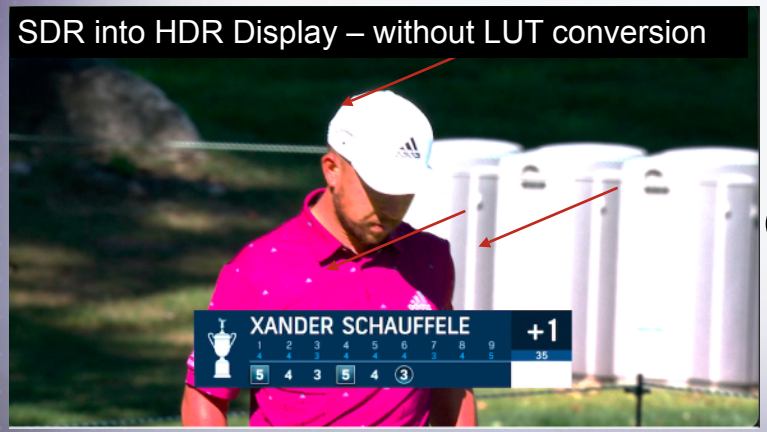
* Per ITU-R, HLG reference display normalized at 1k cd/m2

HDR and WCG have a much larger color volume
Compared to SDR

What can possible go wrong

Example: SDR Content Into HDR Without Proper Conversion

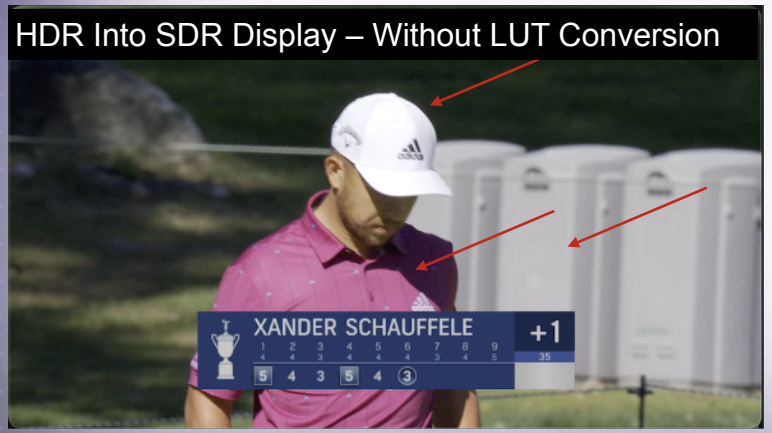
Correct



Content Clips, and over-saturated

Example: HDR Content Into SDR Without Proper Conversion

Correct

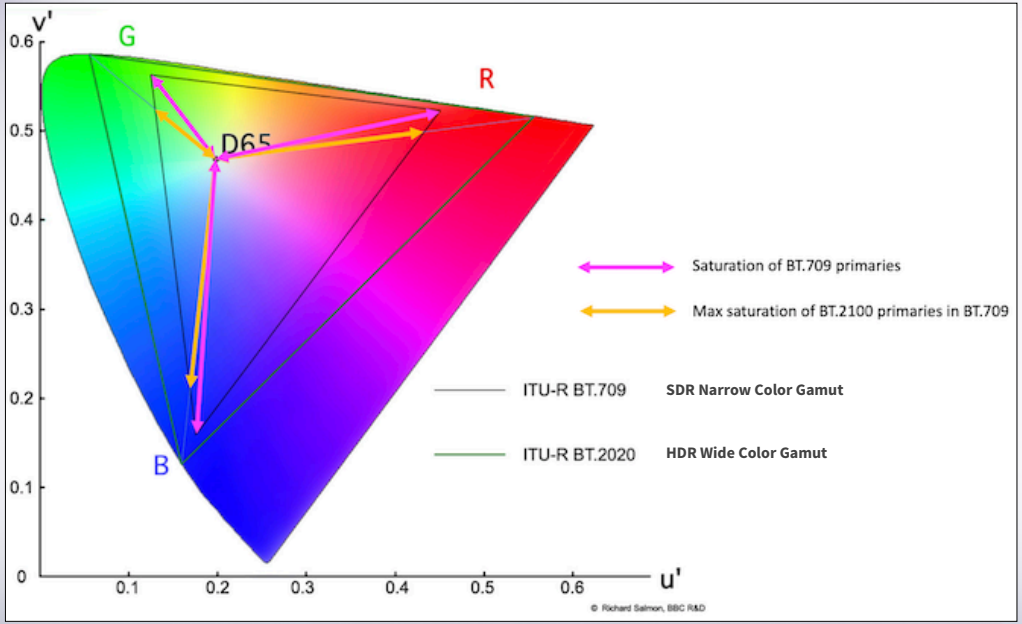


Dim and under-saturated

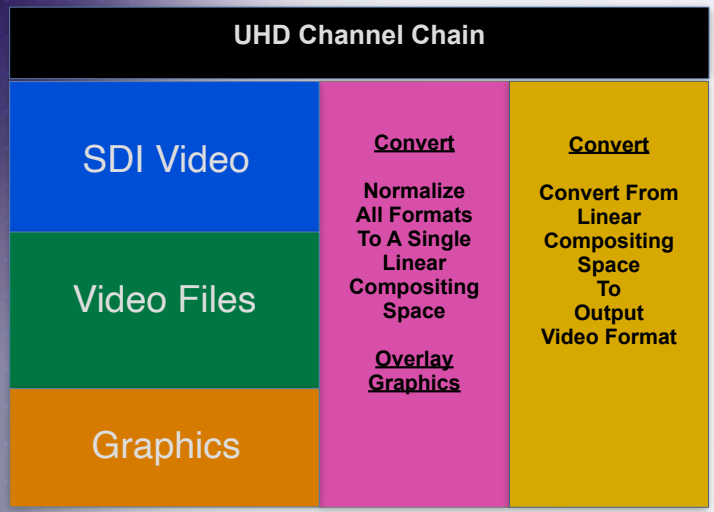
HDR to SDR Conversion - Saturation Preservation

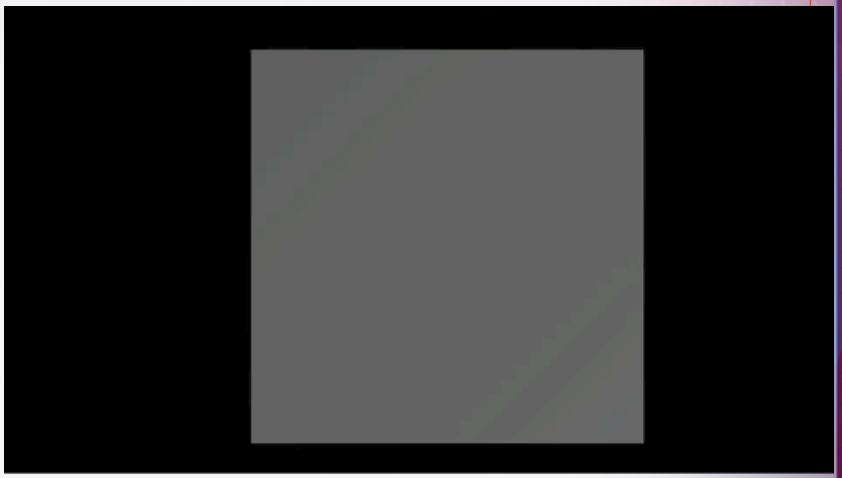
HDR to SDR Conversion - Saturation Clipping

Saturation Strategies for BT.2020 to BT.709 conversion



Compositing Requires Conversion Between Non-Linear and Linear Formats





Check YCbCr <-> RGB pipeline passthrough

Check Bit Depth of Processing Pipeline

Each Format is Composed of Light and Color Represented(Coded) In Different Ways.

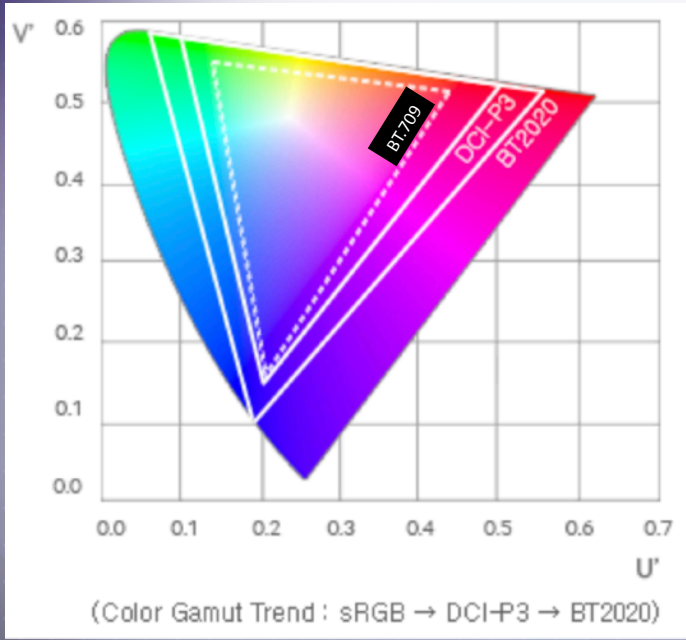
How Do We Measure Color Volume Objectively?

Familiar Color Representations

CIE 1976 (L'u'v') Color Representation

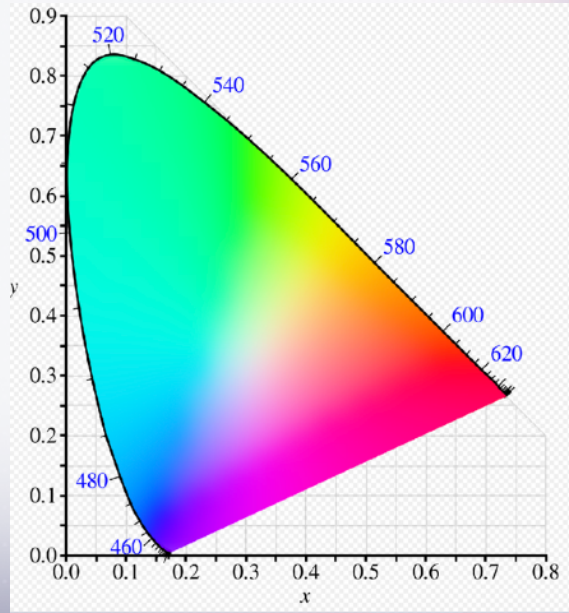
A more uniform color distribution

For Displaying Absolute Chromaticity (Color)

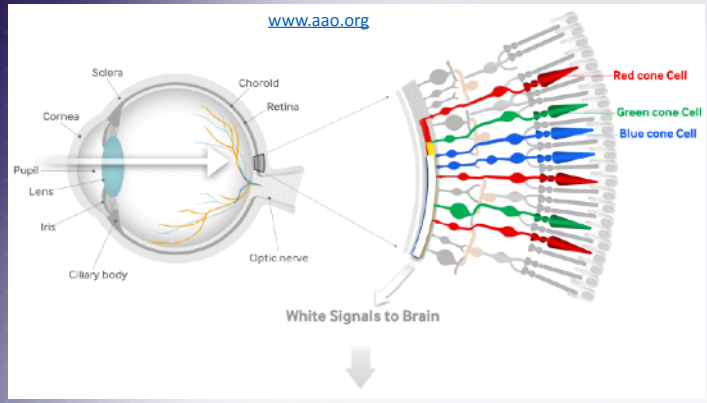


CIE 1931

A Less Uniform color distribution



A Newer Color Representation: IC_TC_P and it's sister ITP



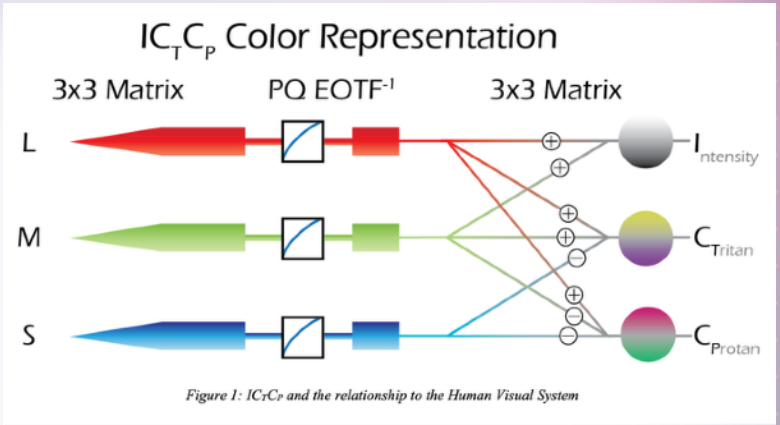


Figure 1: IC_TC_P and the relationship to the Human Visual System

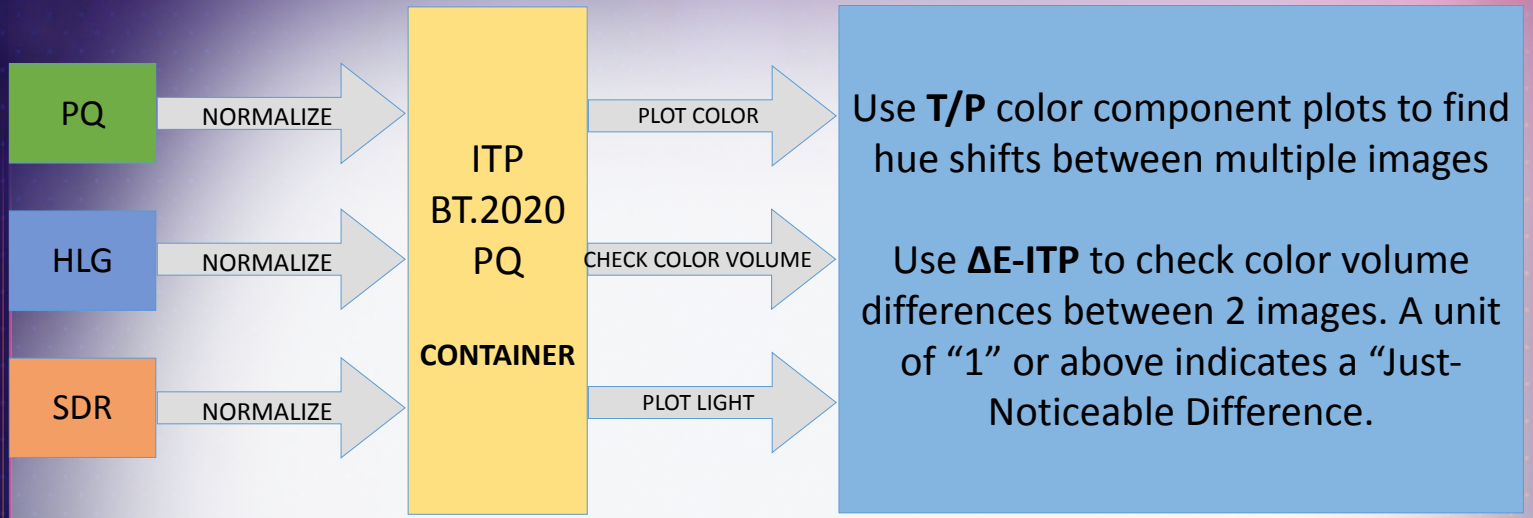
"L", "M", "S" each element captures different wavelengths representing specific color ranges

"I" represents brightness(intensity) while "T/P" represent chroma components (tritan/protan)

Getting Geeky: Why use ITP for objective perpetual measurement?

- **ITP's near-constant luminance and improved hue consistency provides better separation between the luma(intensity) and chroma(color) components.**
  - T/P Chroma components hue consistency allows us to visualize hue shifts in X/Y color plots
  - The de-correlated intensity and color components allow for improved overall "color-volume" measurements that are useful in ΔE-ITP line graphs
  - T/P's ability to mimic to some degree, perceptual effects like the Hunt Effect showing perceived saturation increases with increased luminance can be useful.
- **ITP provides a large enough color-volume "container" to normalize all current HDR and SDR formats.**
- **ΔE-ITP provides a system of comparison between multiple video sources by creating a simple unit of measure to describe "just-noticeable difference" where any number above "1" (one) represents a detectable change by the human visuals system.**

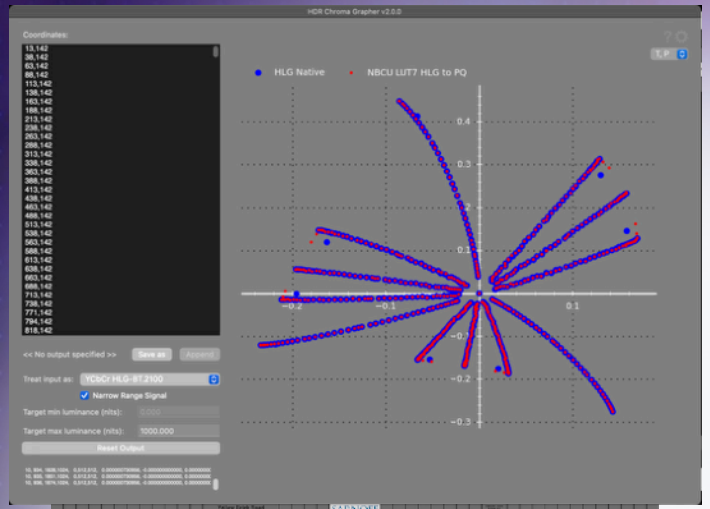
PERCEPTUAL OBJECTIVE METRICS DETERMINE ACCURATE CONVERSIONS

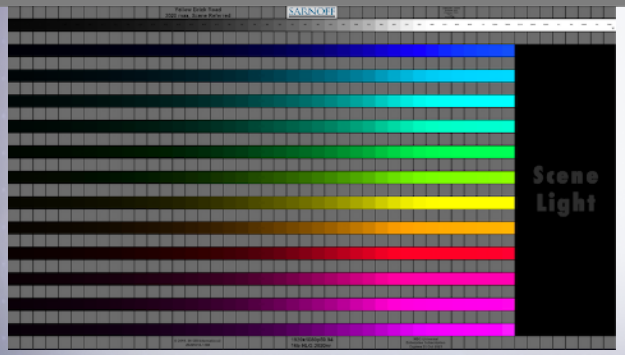


HOW DO WE USE ITP TO COMPARE DIFFERENT VIDEO FORMATS

- PQ, HLG or SDR are converted to a large enough container for all the video formats (ITP-PQ-BT.2020)
- The conversion of all formats into one is a form of "normalization"
- Normalized video colors can be compared in a 2D X/Y (or in this case T/P) plot for hue consistency.
- We can compare multiple video sources objectively for perceptual color volume (color and light) using formulas defined in BT.2124 (ΔE-ITP)

Vooya: A Tool for Color Metric Measurement & Plotting





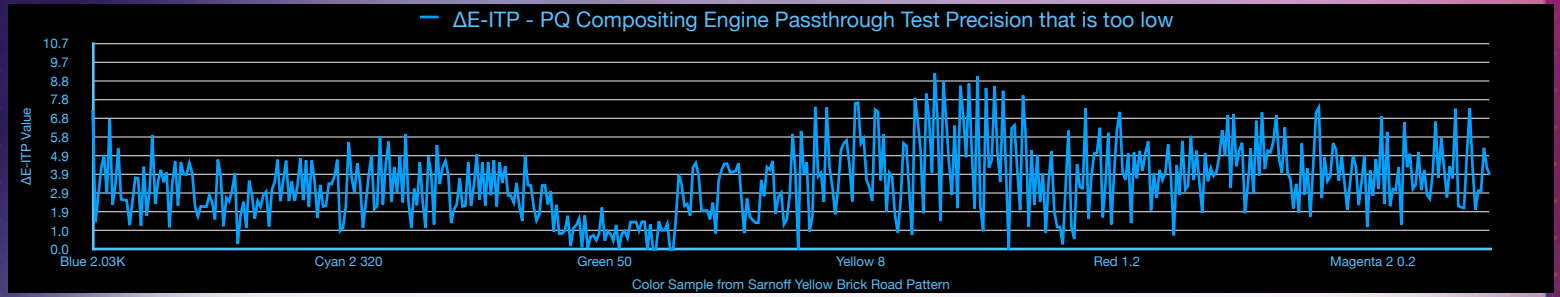
This Plot Compares Sources vs Conversion

- Source = HLG BT.2020 Reference Pattern(BLUE)
- Conversion = HLG to PQ Conversion NBCU LUT7 (RED)

Vooya Color Volume Measurement Plug-In

- NBCU commissioned a plug-in for Vooya which makes it easier to plot video within ITP
- User-supplied X/Y pixel positions allows Vooya to grab YC_BC_R code values from test patterns and convert them to “I-T-P” or “u’v’” for measurement
- Visualize hue consistency thru plots of T/P for (left) .
- Vooya can export ITP values to a text file or plot the results
- By applying a simple formula we can compare one video against another using specific test patterns.
- Compares multiple video sources against a reference

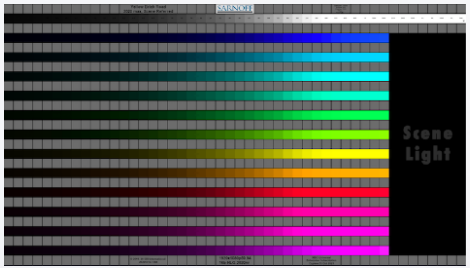
Delta-E ITP: Examining Color and Light Differences Easily



The line-graph above samples color volume changes that occur while being processed thru a compositor which converts incoming PQ Y'CbCr video to linear RGB and back to PQ Y'CbCr video for output.

This pattern has single colors with increasing luma to determine if the

Sarnoff Yellow Brick Road



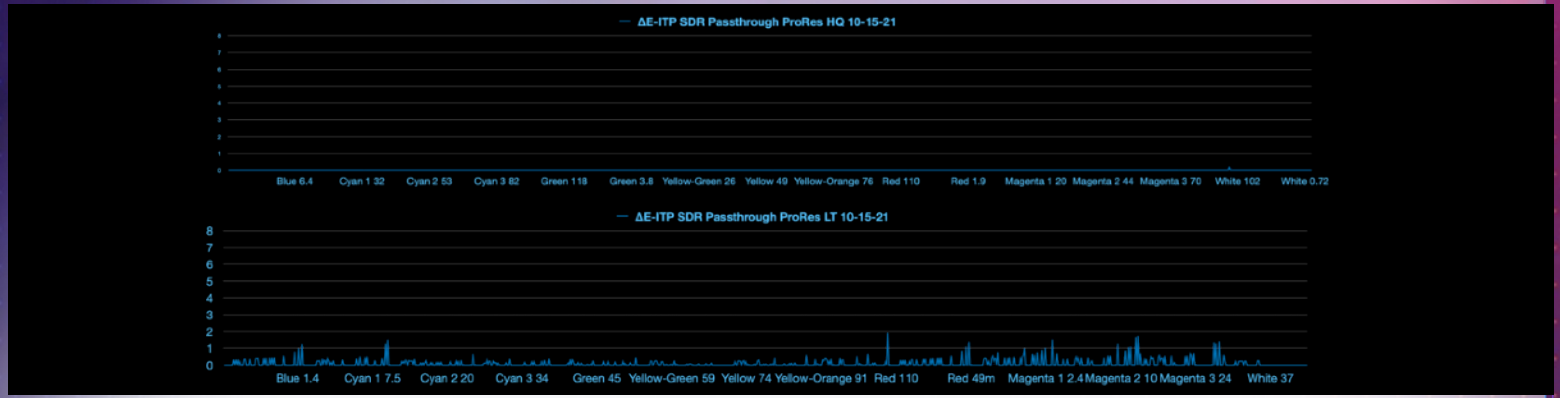
Individual color squares from a Sarnoff "Yellow Brick Road" test pattern are sampled and converted to ITP-PQ-BT.2100

Results are compared using a simple formula which presents the result in units of "Just Noticeable Difference" (JND) to the human visual system.

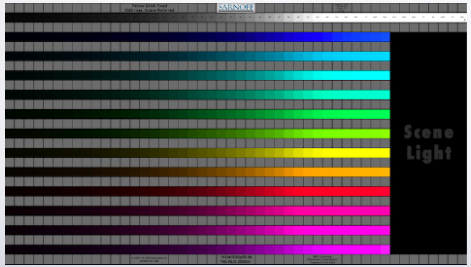
Any number above "1" will have a noticeable color difference by the human eye.

[1] During it's most sensitive state of adaption. This is to avoid under-prediction of error.

Delta-E ITP: Examining Color and Light Differences Easily



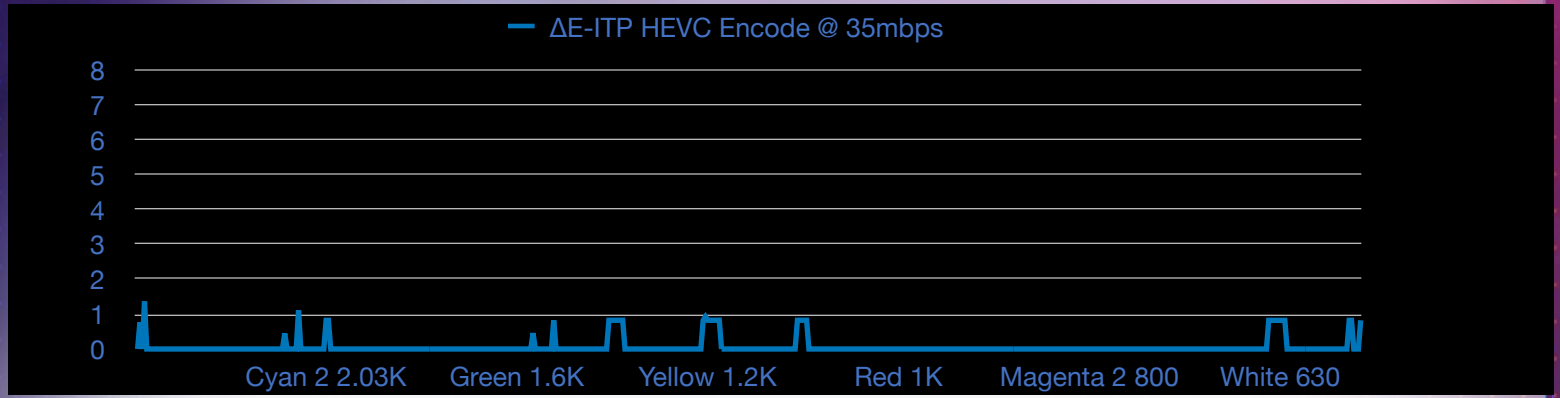
Sarnoff Yellow Brick Road



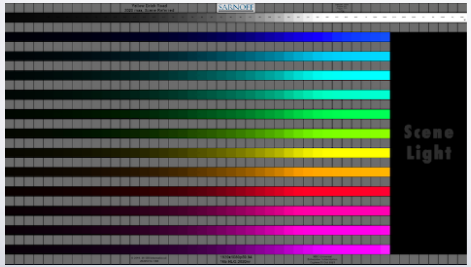
The plot above samples color volume changes that between ProRes HQ and ProRes LT

Similar tests could show inaccuracies that occur between 8 and 10bit codecs

Delta-E ITP: Examining Color and Light Differences Easily



Sarnoff Yellow Brick Road

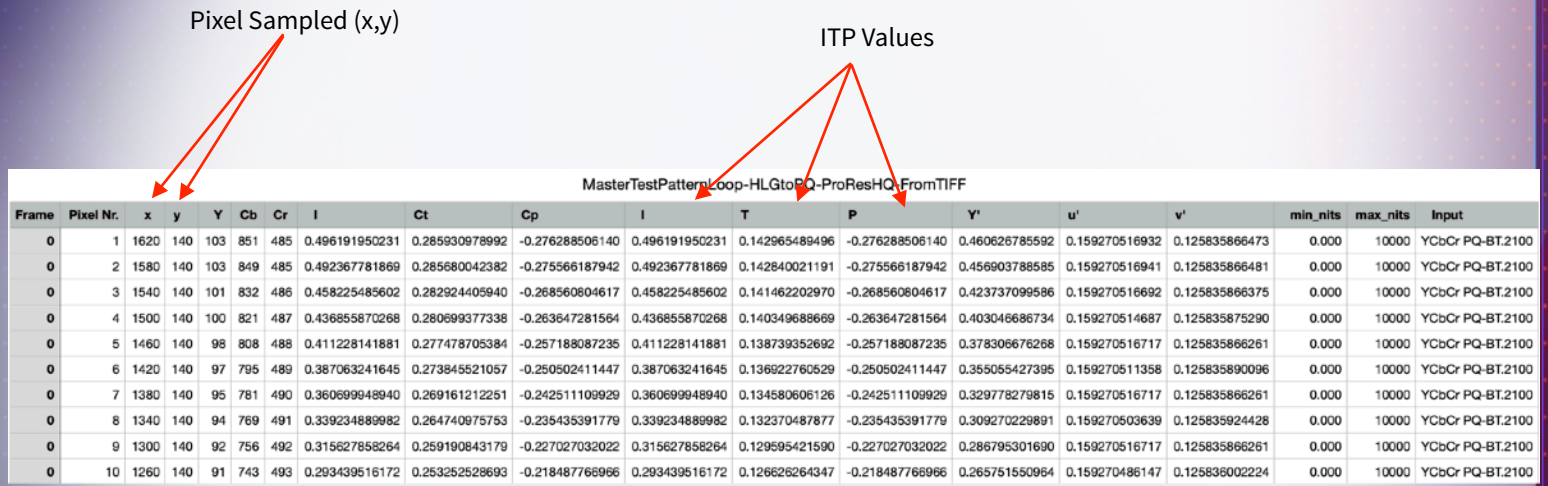


The plot above samples color volume changes that occur in an HEVC Encoder

As the majority of the values are under a value of 1, the color accuracy is very good

Vooya text output: What does it look like

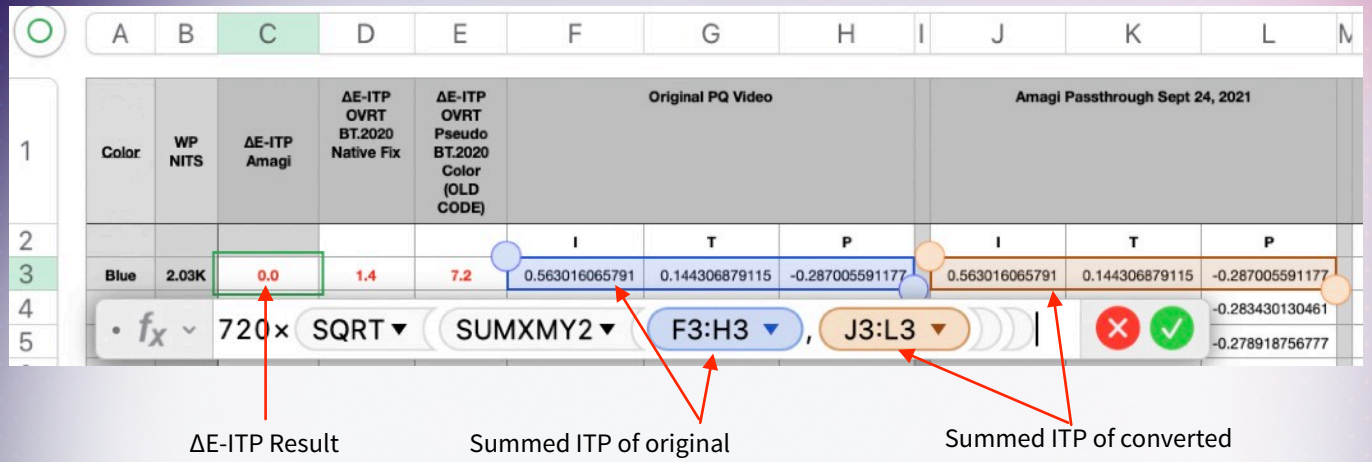
1. Open CSV ITP results (see example below) into any plotting software including Apple Numbers or MS Excel as a “line graph”.



MasterTestPatternLoop-HLGtoPQ-ProResHQ.FromTIFF

Frame	Pixel Nr.	x	y	Y	Cb	Cr	I	Ct	Cp	I	T	P	Y'	u'	v'	min_nits	max_nits	Input
0	1	1620	140	103	851	485	0.496191950231	0.285930978992	-0.276288506140	0.496191950231	0.142965489496	-0.276288506140	0.460626785592	0.159270516932	0.125835866473	0.000	10000	YCbCr PQ-BT.2100
0	2	1580	140	103	849	485	0.492367781869	0.285680042382	-0.275566187942	0.492367781869	0.142840021191	-0.275566187942	0.456903788585	0.159270516941	0.125835866481	0.000	10000	YCbCr PQ-BT.2100
0	3	1540	140	101	832	486	0.458225485602	0.282924405940	-0.268560804617	0.458225485602	0.141462202970	-0.268560804617	0.423737099586	0.159270516692	0.125835866375	0.000	10000	YCbCr PQ-BT.2100
0	4	1500	140	100	821	487	0.436855870268	0.280699377338	-0.263647281564	0.436855870268	0.140349688669	-0.263647281564	0.403046686734	0.159270514687	0.125835875290	0.000	10000	YCbCr PQ-BT.2100
0	5	1460	140	98	808	488	0.411228141881	0.277478705384	-0.257188087235	0.411228141881	0.138739352692	-0.257188087235	0.378306676268	0.159270516717	0.125835866261	0.000	10000	YCbCr PQ-BT.2100
0	6	1420	140	97	795	489	0.387063241645	0.273845521057	-0.250502411447	0.387063241645	0.136922760529	-0.250502411447	0.355055427395	0.159270511358	0.125835890096	0.000	10000	YCbCr PQ-BT.2100
0	7	1380	140	95	781	490	0.360699948940	0.269161212251	-0.242511109929	0.360699948940	0.134580606126	-0.242511109929	0.329778279815	0.159270516717	0.125835866261	0.000	10000	YCbCr PQ-BT.2100
0	8	1340	140	94	769	491	0.339234889982	0.264740975753	-0.235435391779	0.339234889982	0.132370487877	-0.235435391779	0.309270229891	0.159270503639	0.125835924428	0.000	10000	YCbCr PQ-BT.2100
0	9	1300	140	92	756	492	0.315627858264	0.259190843179	-0.227027032022	0.315627858264	0.129595421590	-0.227027032022	0.286795301690	0.159270516717	0.125835866261	0.000	10000	YCbCr PQ-BT.2100
0	10	1260	140	91	743	493	0.293439516172	0.253252528693	-0.218487766966	0.293439516172	0.126626264347	-0.218487766966	0.265751550964	0.159270486147	0.125836002224	0.000	10000	YCbCr PQ-BT.2100

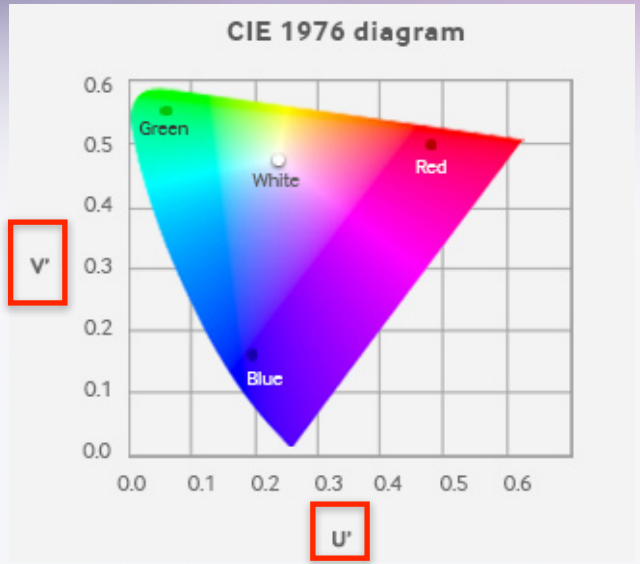
Line Plotting using Vooya ITP Output



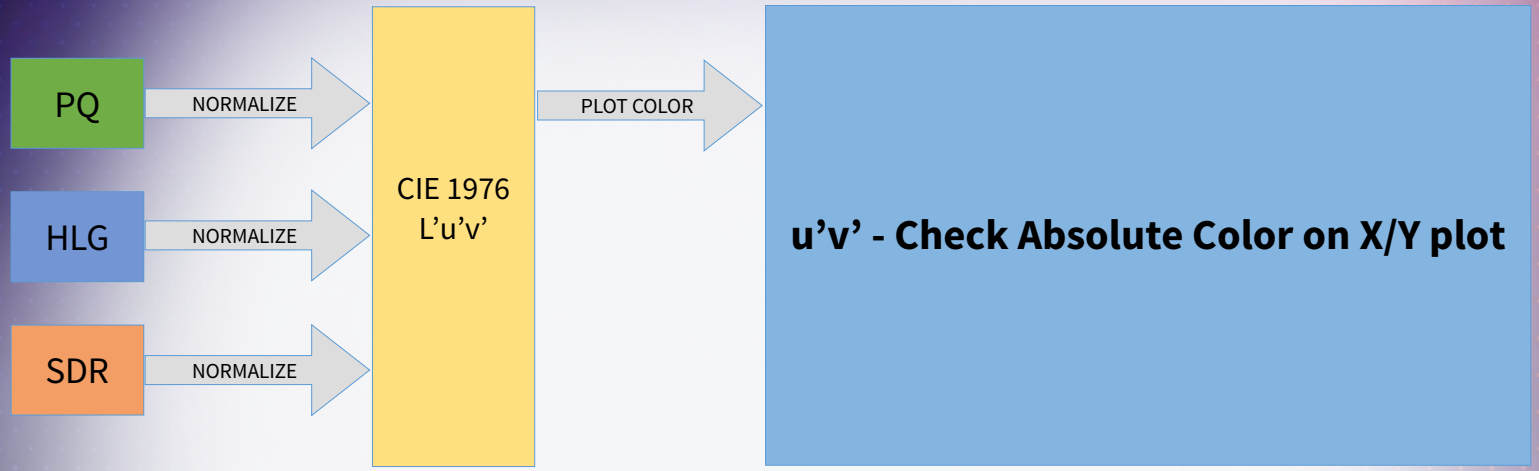
Each sampled ITP Value is multiplied by 720 times the Square Root of the sum of squares of the differences of corresponding values in two arrays

This produces each ΔE-ITP Value

Absolute Objective Color Volume Metrics



We use u'v' from CIE 1976 to plot absolute chromaticity.



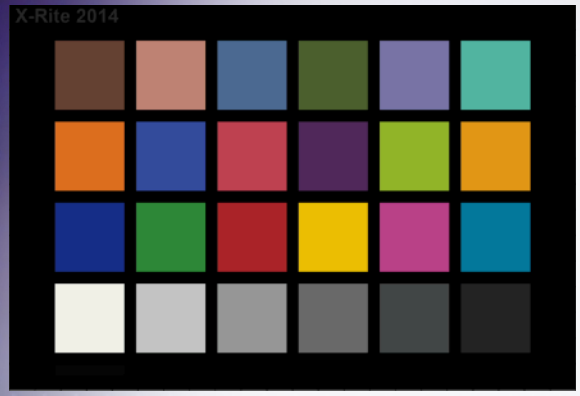
CREATE A COMMON "CONTAINER" FOR PLOTTING ABSOLUTE CHROMATICITY

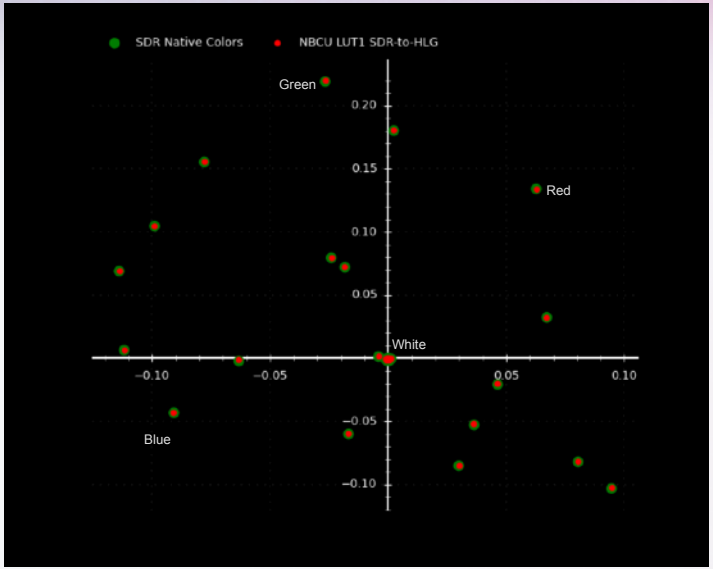
When To Use Each Metric

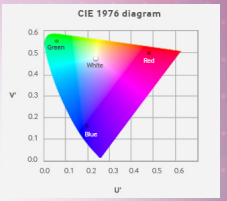
- **When to use ITP (T/P:**
  - **T/P (X/Y plots) to observe color changes:**
    - **Unwanted hue shifts or for designing hue strategy during conversion**
    - **Low precision conversions (plot will show erratic hue shifts)**
  - **ΔE-ITP (Line Plots) to observe color volume changes: Measuring a source and output color volume for Just-Noticeable-Difference (any kind of conversion or signal flow that should show no change)**
  - **FUTURE - Euclidian distance to measure degree of hue shift**

- **When to use u'v':**
  - **Δu'v' (X/Y plots) to observe:**
    - **Any undesired change in absolute chromaticity change (separate from any change in light level)**
    - **FUTURE - Euclidian distance as a measure degree of hue shift**

u’v’ Components Allow Us to Visualize Absolute Chromaticity





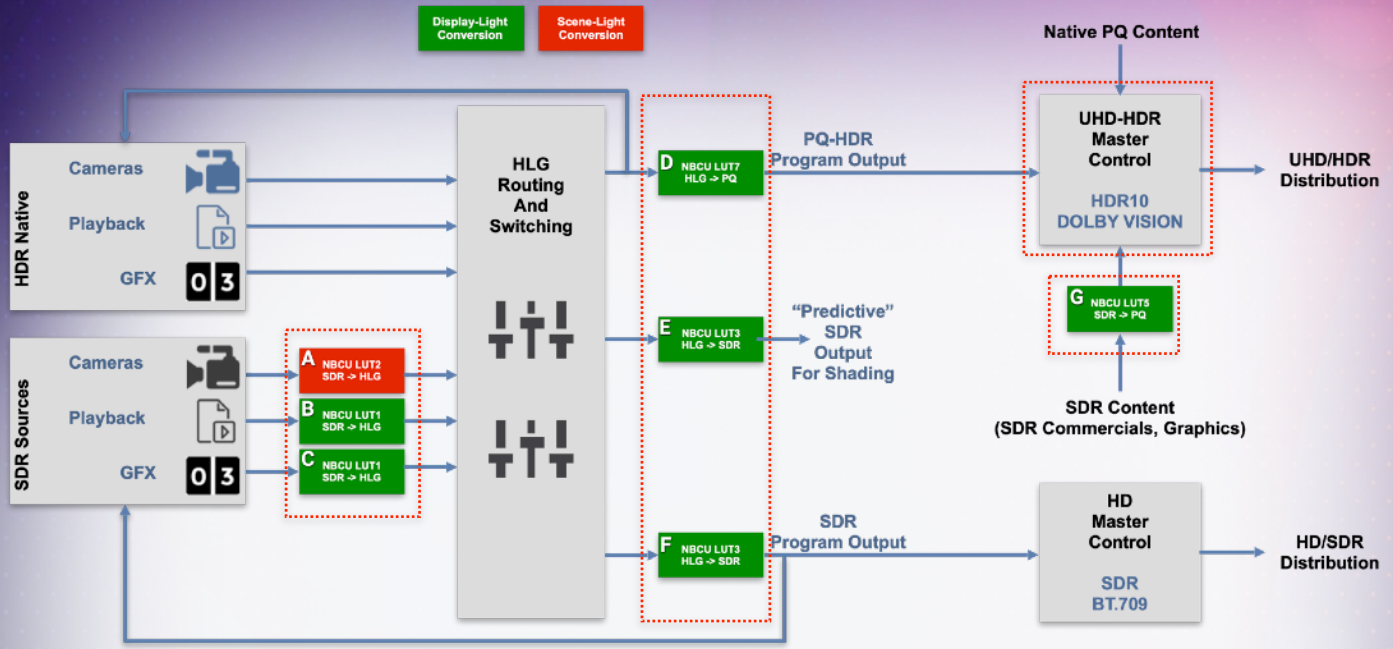


Vooya Plots of the ColorChecker 2014 Test Pattern using u’v’

- Green dots are source; Red does are conversion using NBCU LUT1 (SDR to HLG)
- Since each color overlaps the other, the plot identifies an excellent “absolute” color conversion

Another Look At Production And Distribution

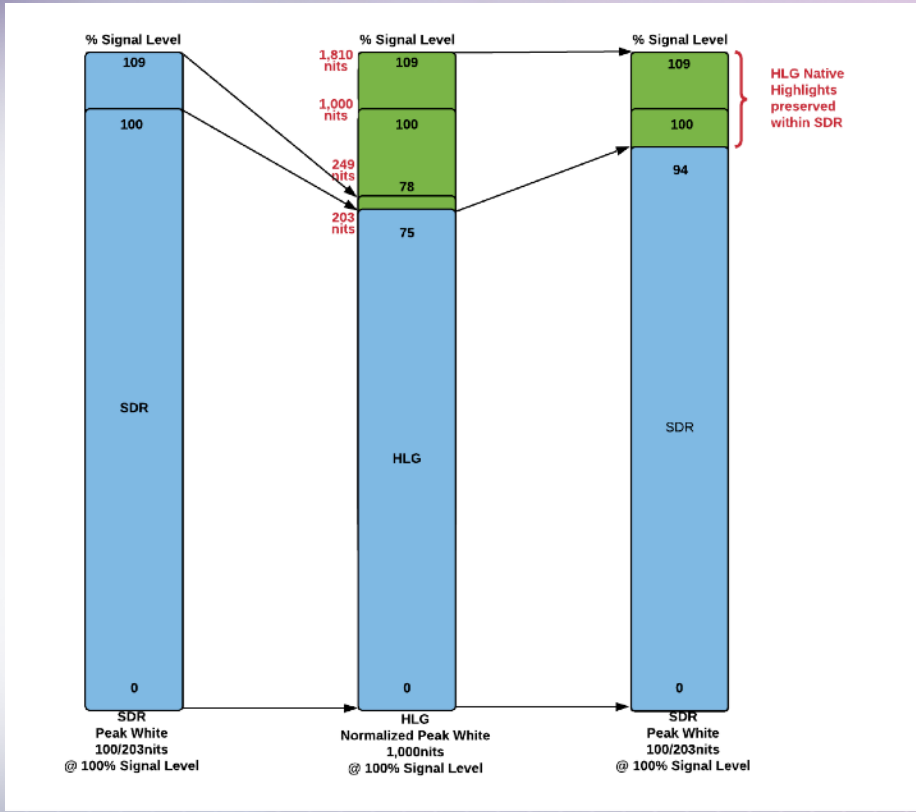
Single Stream Production and Transmission



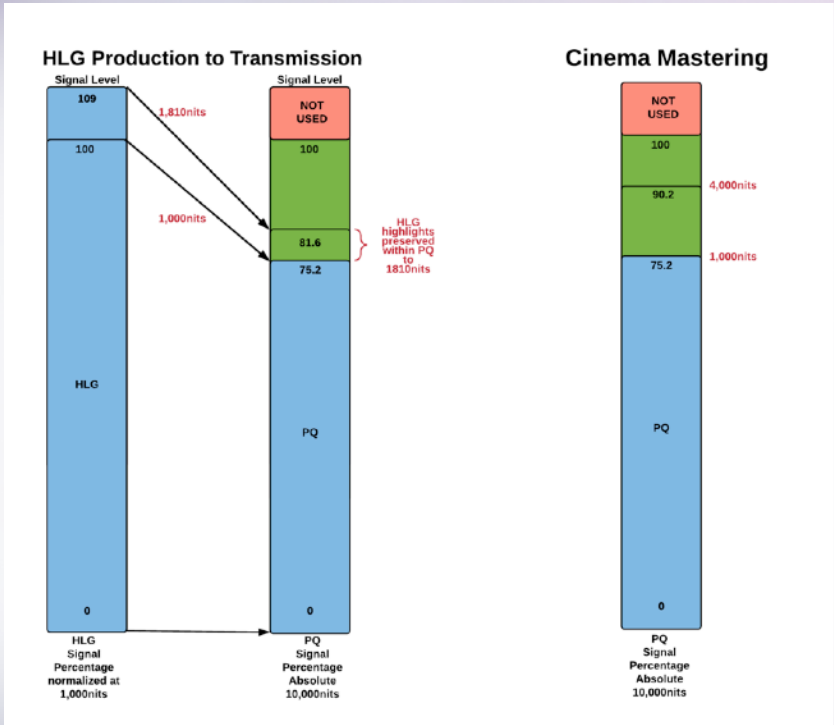
- Conversion points to test in HDR path (LUTS or Compositing)

- **Determine Conversion Points**
- **Determine conversion goals (i.e. - where is graphics white, what are the anchor points between formats**
- **Make conversions from one format to another without changing perceptual representation ("original artistic intent").**

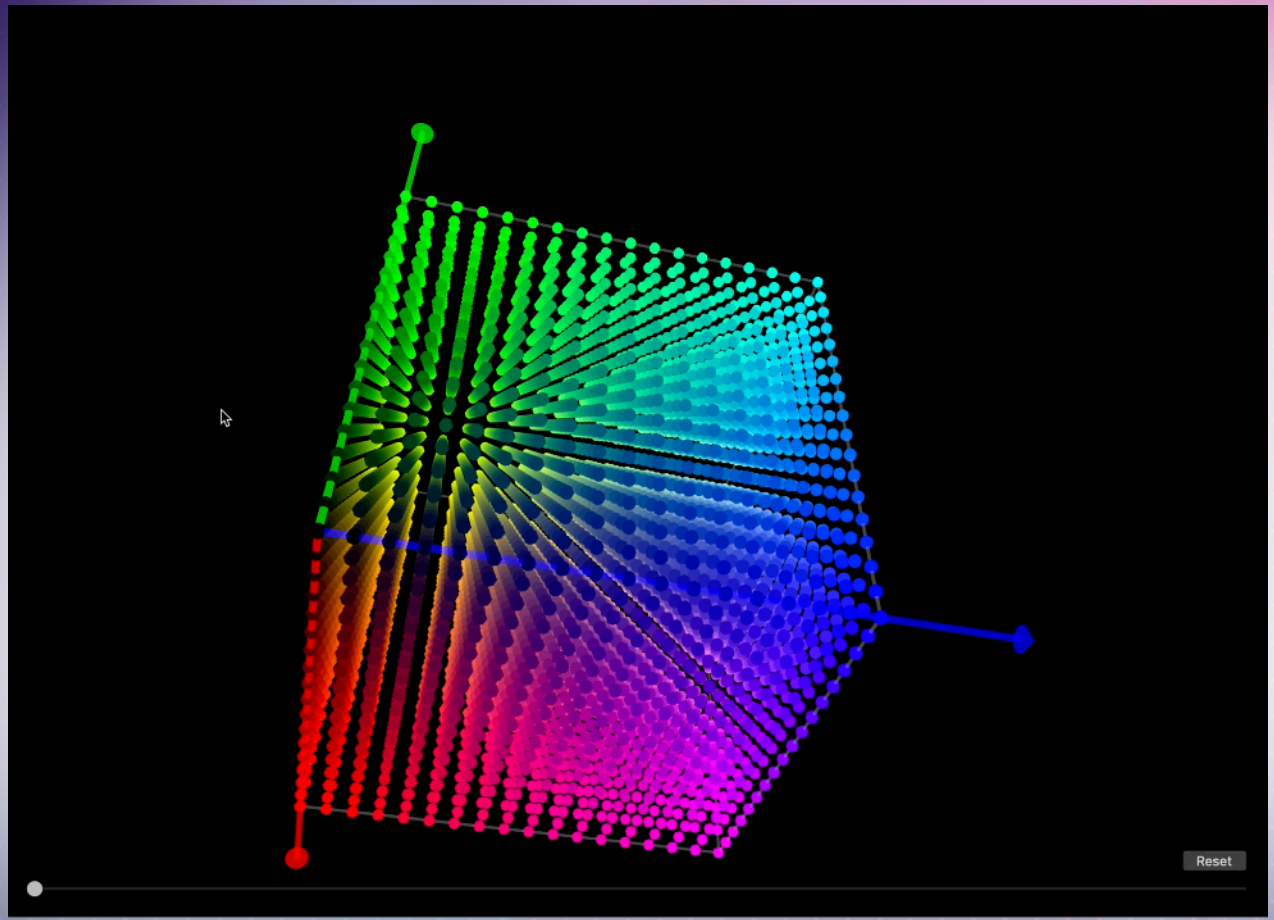
SDR->HLG->SDR (Light-Level Anchor Points)



HLG->PQ (Light-Level Anchor Points)



3D LUTS - Before and After Conversion



NBCU's Single Stream Recommendation

NBCU, in collaboration with Cromorama, and building on ITU working group discussions for HDR operational practices involving Dolby, BBC and Philips, has developed techniques to enable "single-stream" production that feeds both UHD HDR and SDR transmission simultaneously.

The NBCU LUTs developed for this workflow enable single-stream production whereby the HDR and SDR products are consistent to the point where the benefits of HDR are realized making a unified production possible. Subsequently we're sharing these efforts with the broadcast community for continued collaboration and use in production and distribution.

The NBCU LUTS include both HLG and PQ LUTs following similar HDR/SDR conversion methodology and color science.

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.
The package of NBCU LUTs with additional documentation are available at the following link:

https://www.dropbox.com/sh/kij6u62f3rr1wzf/AADBCBwv58pXmqes4kxuOSXBa?dl=0

Chris Seeger and Michael Drazin are happy to answer questions pertaining to this effort and provide further insight into workflow.

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The NBCU Recommendation and
LUTS

We ask that manufactures include an acknowledgment in their license to their customers that the LUTs were "developed by NBCUniversal Media, LLC."