Unified HDR Reference White

VideoQ Proposal

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URW VideoQ Proposal

videoq.com

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1. HDR/SDR Open Workflow – Executive Summary

What is the challenge and the opportunity?

Well-established workflows exist across the industry – from production to packaging, through to presentation and final content distribution. These workflows rely on tried and tested rules and guidelines, that should also now become **simple** and **unified**.

The rules need to be well understood, to work together and thus allow for free interchange of content at each juncture without technical risks and the fear of the unknown.

The advent of **HDR** and **Wide Color Gamut** technologies demands changes to customs and practices. New workflow rules must also be established and honed. The problem is that in this early adoption phase, competing standards are anything but unified.

This presents the industry with an ***opportunity*** *to establish an agreed upon* ***commonality*** *between the current incompatible array of standards and self interest.*

The solution to this issue is harmonious, technically correct and agile content production and distribution, proposed here in the form of a **Target Display Agnostic HDR Workflow**, plus Video and Audio Levels Mapping, **adaptive to viewing/listening conditions**, and in addition a **Unified HDR Reference White** approach. Please read on…

2. General Considerations

Why it is so important:

Mixing, compositing, routing, transcoding, re-versioning, re-purposing, ad and text insertion – all these operations require a concept of unified signal range and unified **Reference White**. Thus, such a Reference White, by default, should be **independent** of the Mastering Display and Target Display parameters.

Simple and repeatable QA / QC procedures should be based on the implementation of the same Reference White.

Such unification and normalization should not affect or restrict any of the creative intent by the content originators, e.g. camera levels, gamma trims, associated metadata instructions, or a display manufacturer’s efforts on enhanced HDR / SDR image rendition.

HDR & SDR, PQ & HLG:

Long Live Mutually Beneficial & Peaceful Coexistence!

Dynamic Range Conversion – Necessity & Options:

Mixed HDR / SDR environments require software and hardware engines for verification, optional manual and / or automated enhancement, up, down, and cross-conversion within and/or between all HDR / SDR formats and color spaces.

A commonly accepted Reference White standard is needed for content production, post-production, distribution and product verification.

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3. SDR Reference White

The **Reference White** (***Nominal White***) concept and the term itself was originally related to the **monochrome TV** analog signal value of **100%.** The 100% level was set to **700mV** (**100IRE** in the **USA**).

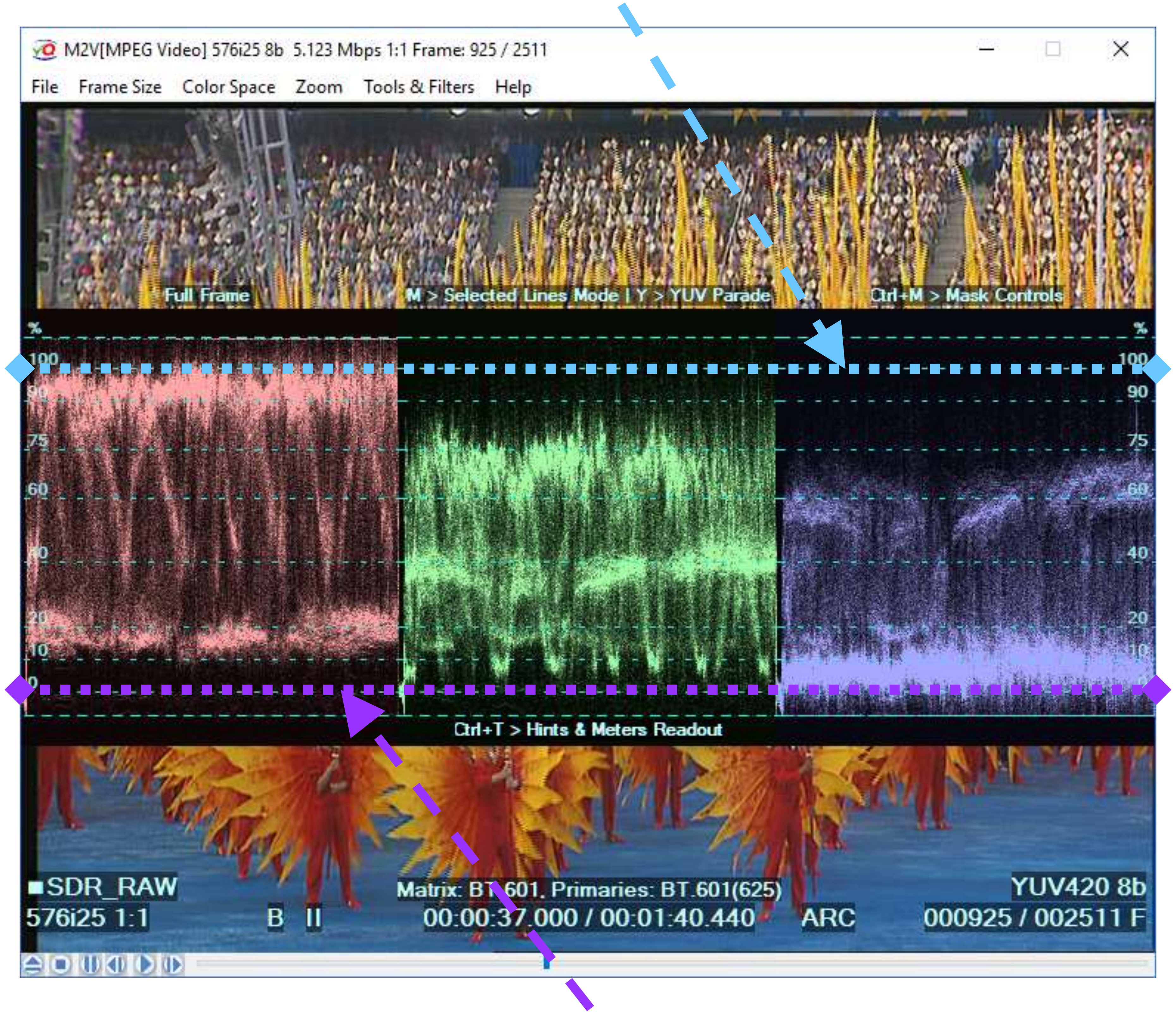
Analog color TV camera control engineers and camera operators needed tools to produce the best video images. Waveform monitors with R, G and B components parade where used in a way to see that **at least one** of the R, G and B color components should exhibit max possible signal swing, **but none of them** should go much above 100%.

Thus, video engineers used an implicit version of the **max(R, G, B)** aka **MaxRGB** envelop for **QA / QC** purposes long before the arrival of modern digital SDR / HDR systems.

The famous **ITU-R BT.601 Recommendation** and numerous following national and international standards applied this simple and very important concept to the **digital components**: Y, R, G and B.

To handle possible alignment errors and signal overshoots, the BT.601 standard allocated extra levels below **0% Reference Black** (8 bit 1-15) and above **100% Reference White** (8 bit 236-254).

SDR Reference White: 100% = 8 bit 235



SDR Reference Black: 0% = 8bit 16

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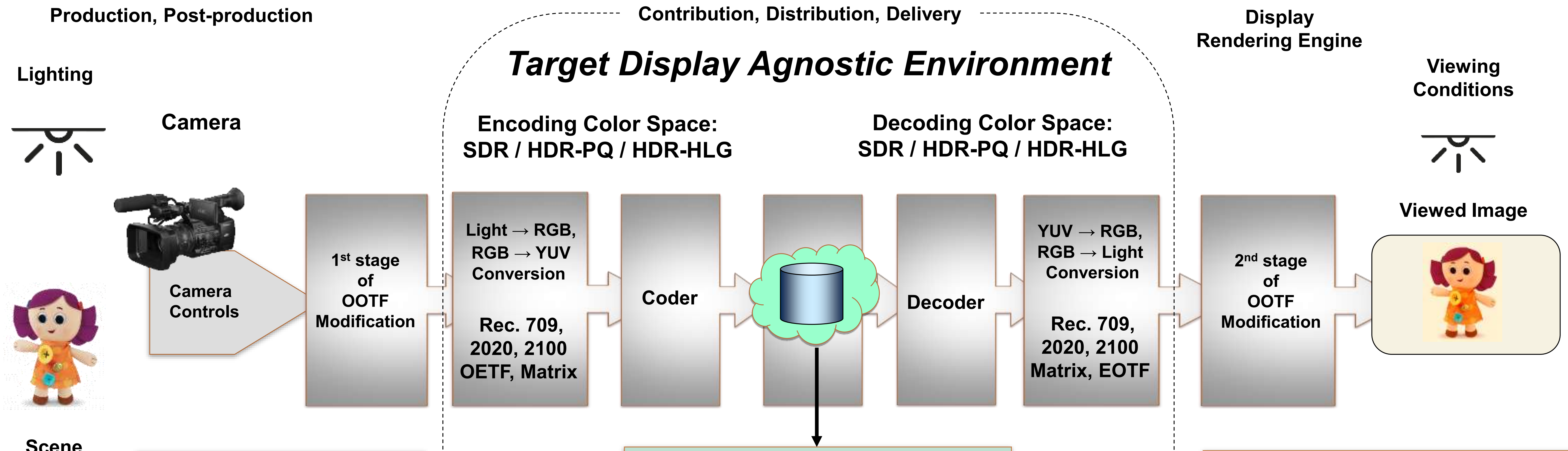
4. Big Picture – Overall System View



Engineering Controls,
***Optional* Color Grading,**
Optional creation of
Rendering Instructions
Dynamic Metadata
for the specified **array** of
Target Displays

Content Levels Metering and QA/QC,
Content Levels Alignment,
Routing & Secondary Compositing,
Ad & Graphics Insertion,
Up, Down and Cross-conversion,
Transcoding & Distribution,
Insertion & Checking of Test Patterns

Normalized HDR content data *and* ***light levels***
are ***highly desirable*** *at this stage,*
especially for ***routing****,* ***compositing*** *and* ***adverts insertion***

Display Designer Decisions:
Display Parameters/Capabilities,
Color Gamut & **Light Levels Mapping**,
Execution of **Rendering Instructions**
(driven by ***optional*** **Content Metadata**)
Viewer Controls:
Brightness, Gamma, Saturation, etc.

OOTF stands for Opto-Optical Transfer Function.

OOTF is the composition of the OETF (opto-electronic transfer function) and the EOTF (electro-optic transfer function).

5. HDR Flavors and Metadata Issues

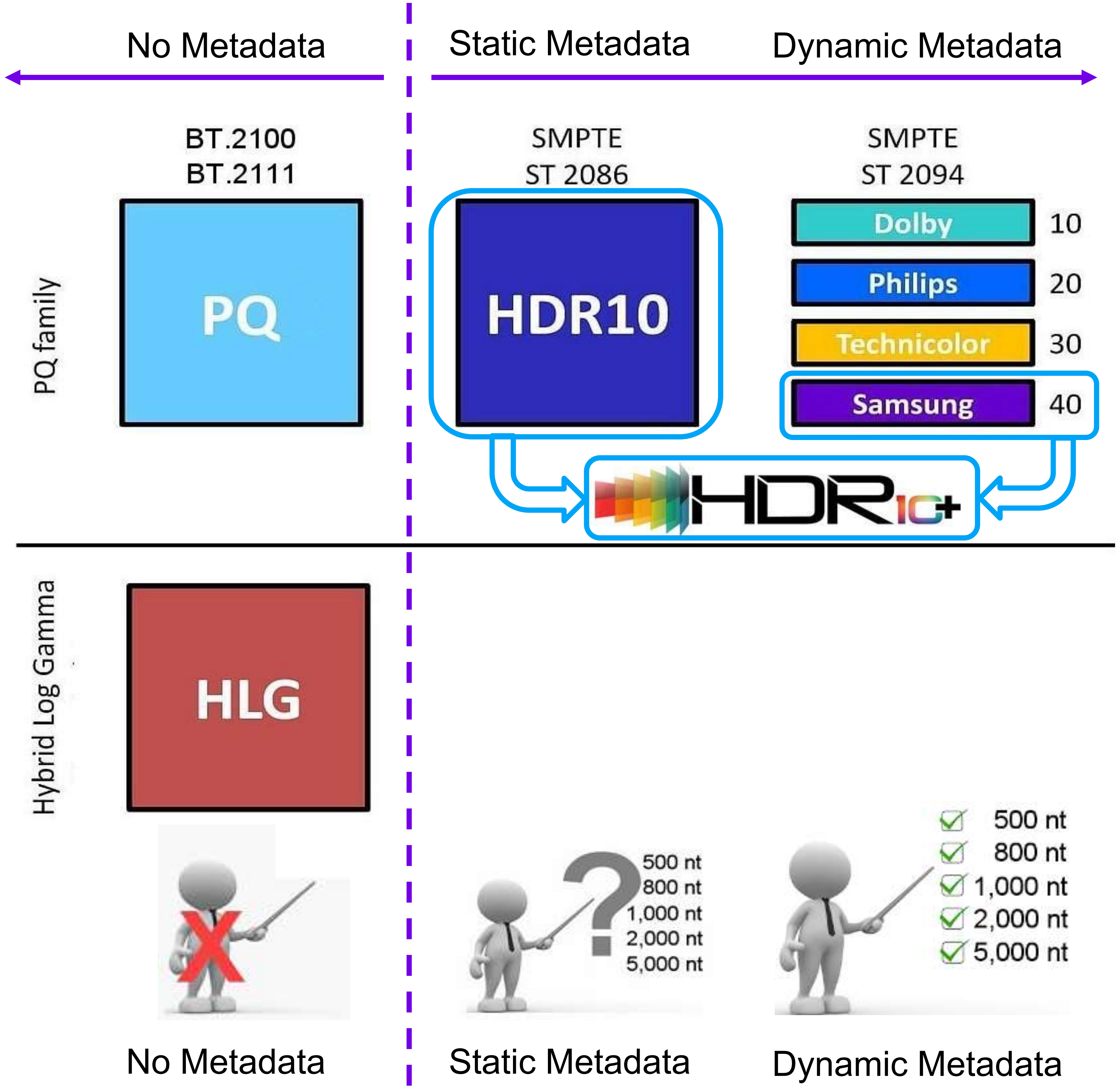
Do HDR systems need metadata?

The **no-metadata HDR** systems are based on the concept of “**the Hypothetical Reference Display**”.

‘Plain’ no-metadata HDR-PQ and HDR-HLG formats **allow** all kinds of derivations from this base **without** restricting content re-purposing and display rendering options.

These formats require only one simple **PQ/HLG switch** in the stream header.

For example, it is possible to use a custom tone mapping for different environments to accurately reproduce details so they remain easily visible in **any lighting condition**.



The **metadata-driven HDR-PQ** systems are based on the concept of a pre-defined list of “**Target Displays**”.

This **prevents** any deviation from this base and limits the number of content re-purposing and display rendering options.

Static and dynamic metadata presumably serve for the preservation of a content originator’s “creative intent” and related “authoring rights”.

This concept is **applicable** to ***controlled environments***, such as digital cinema or home theater, but it is **not applicable** to ***open***, thus ***not controlled***, consumer, prosumer, broadcasting and web-casting environments.

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6. Unified HDR Reference White – VideoQ Proposal

For PQ & HLG, optical and graphics cases VideoQ proposes practically useful ‘easy’ round figures.

Thus, **HDR Reference White Video Data Levels** are**: 75%** of **HLG Data Range**, and **58%** of **PQ Data Range**.

For the **HLG 1000nit device case** both values correspond to the same **200nit Video Content Light Level**.

Very important: The same **75%** and **58%** values are also specified in **BT.2111** standard for **HDR Color Bars Test Patterns**.

Benefits and advantages of the proposed solution

The HLG output Light Level **20%** corresponds to the signal level of **74.7%**, which is conveniently positioned between two widely used reference values of 75% (so called “CG White”) and 73% (so called “Diffuse White”), thus, this single level can be used for all cases.

In practice, the **HLG** Y,R,G,B Narrow Range data relative level **74.7%** can be rounded to **75%** (10bit value **721)**.

For the **PQ** format the **Light Level 200nit** corresponds to **58%** of Y,R,G,B Narrow Range data and 10bit value **572.**

A 200nit level is close to the middle point of the typical White Levels range currently used in PQ production; this range is reported to be about **145nit ... 250nit**.

A 200nit level is safely below **300nit**, often quoted as a typical White Level of **SDR** content displayed by consumer grade HDR displays, and effective peak level of typical computer monitors and smartphones.

The proposed HLG & PQ Reference White does not rely on any particular display type or display gamma.

The 1000nit value is used only for HLG level scaling purposes, **NOT** as a target HLG device specification.

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7. Key Values of the Unified HDR Reference White

Parameter	Measurement Unit	PQ	HLG
Relative Video Data Level [1)]	%	**58**	**75**
10bit Narrow Range Video Data Level	integer	**572**	**721**
Relative Video Content Light Level [2)]	%	**2.0**	**20**
Video Content Light Level [3)]	nit	**200**	**200** [4)]

[1)] Data level corresponding to Reference White (D65) diffuse color object in the domain of RGB or Y (of YC_bC_r) video data.
This data level should be calculated as max(R,G,B) value derived from the encoded YC_bC_r or RGB video data.

[2)] Inverse OETF output derived from Relative Video Data Level.

[3)] Full name of the unit: Video Content Nit, short form: VCNT. In unambiguously clear application cases it can be abbreviated to nit or nt.
This unit should be used ***only*** *for the Video Content Light Level values; not to be confused with* ***photometric luminance unit of cd/m²***.

[4)] Exemplary value for the ideal model 1000nit HLG display implementing the inverse OETF transfer function with additional OOTF nonlinearity (overall gamma 1.2).

Depending on the display type and parameters, the actual rendered image photometric luminance in cd/m² may significantly differ from the Reference White Level.

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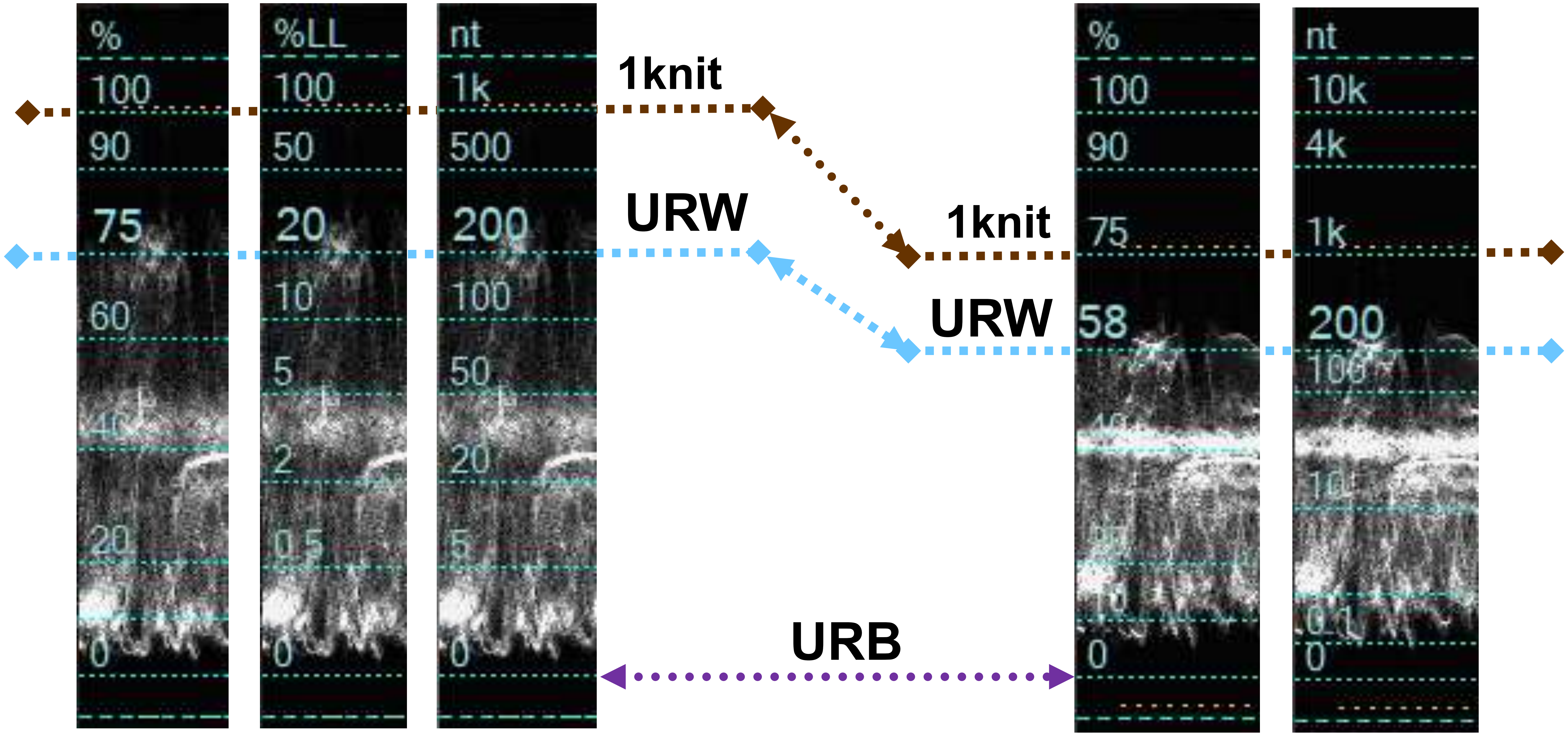
8. Unified HDR Reference White – Percent and Nit Values

HLG Reference White: URW VideoQ Proposal

- Signal Level **75%**
- Light Level **20%**
- *Derived Light Level 200nit (for 1knit device)*

PQ Reference White:

- Signal Level **58%**
- Light Level **200nit**
- *Derived Light Level 2.0% (for 10knit device)*



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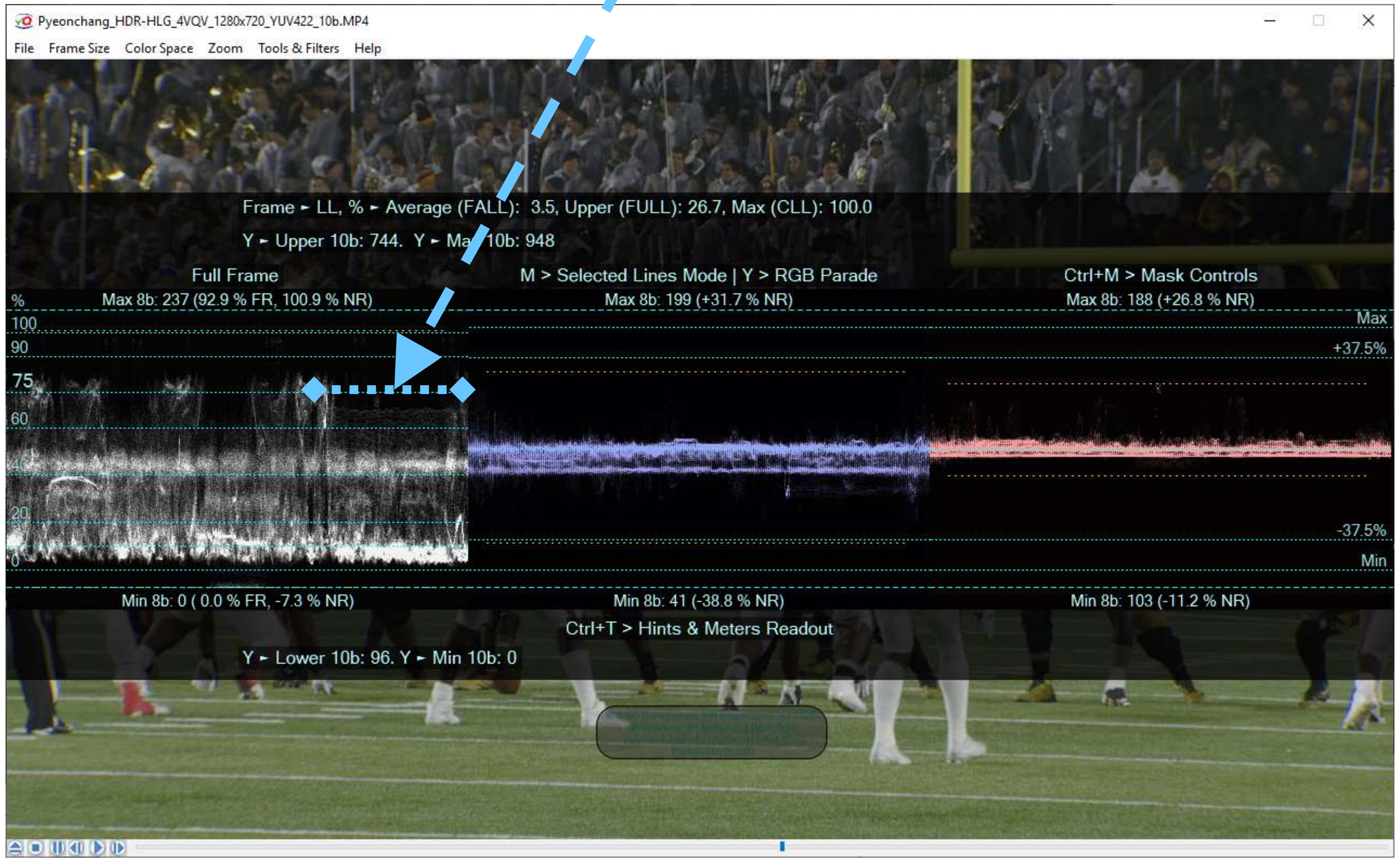
9. Unified HDR Reference White – Live Video

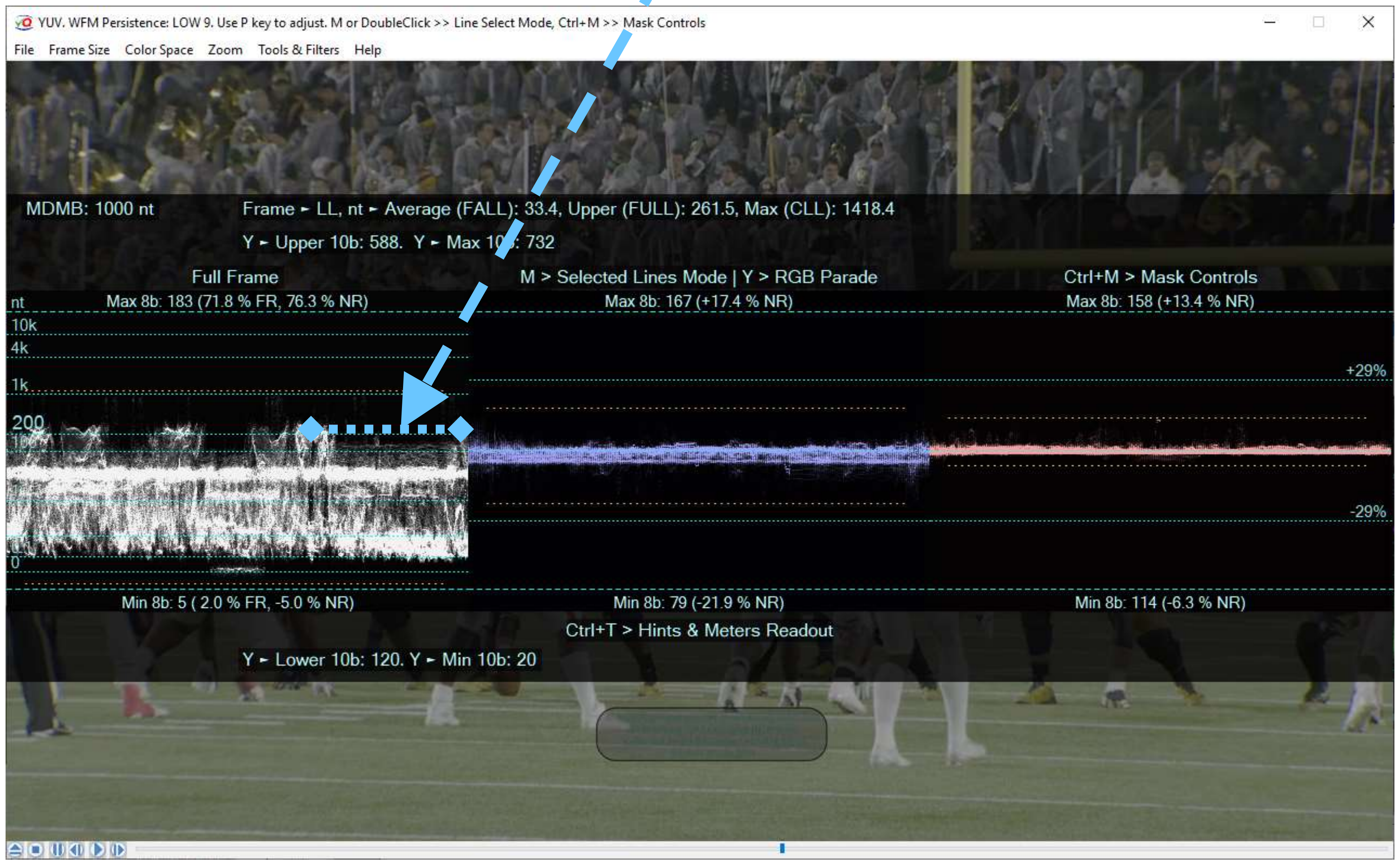
Original HLG content analyzed by **VideoQ VQV tool**

Reference White: **L**ight **L**evel **20%**, **S**ignal **L**evel **75%**



Original HLG content **converted** to **PQ**, then analyzed by **VQV**

Reference White: **L**ight **L**evel **200nit**, **S**ignal **L**evel **58%**



Unified Reference White is especially useful for live sporting event coverage

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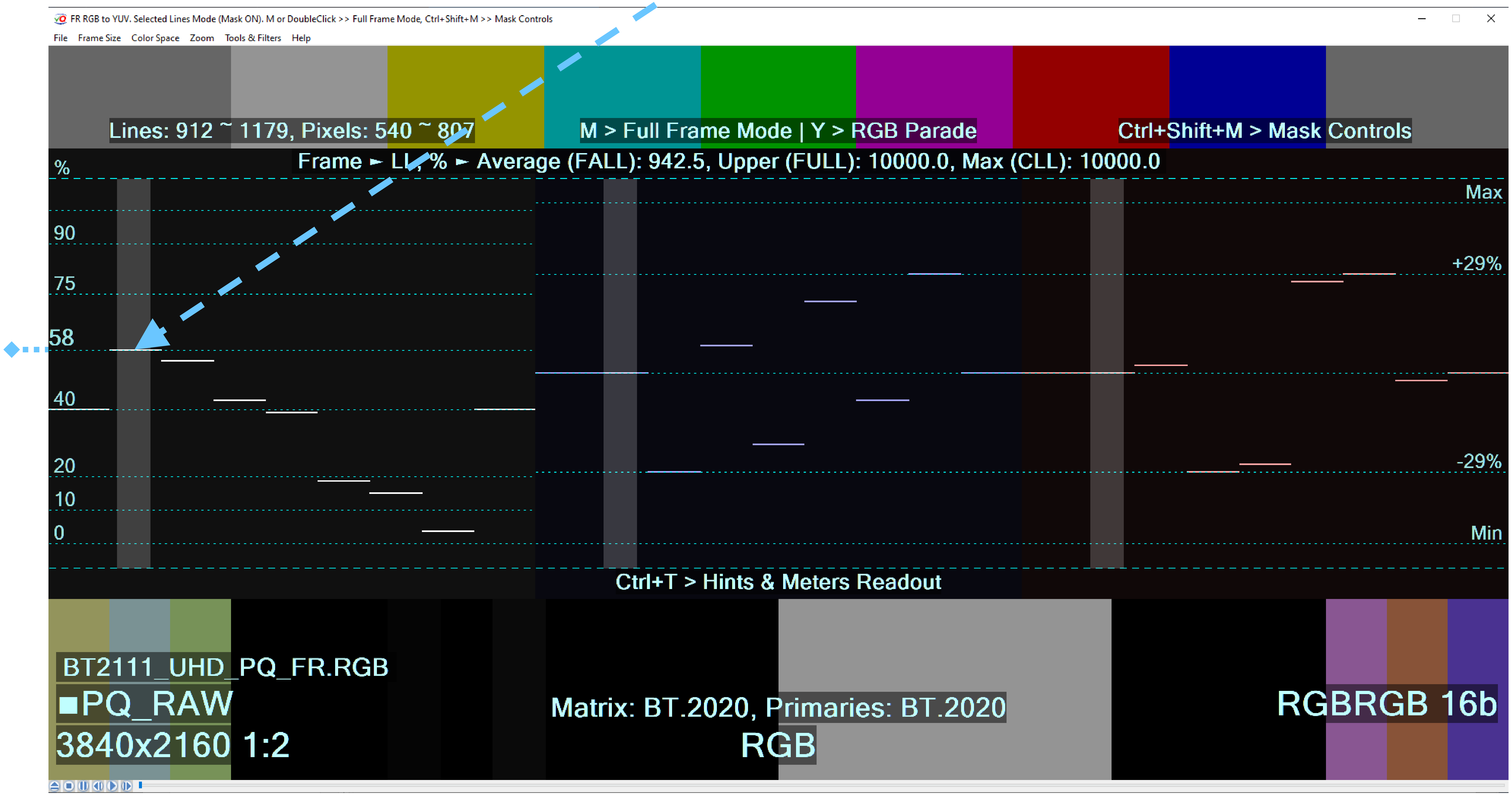
10. Unified Reference White – HDR-PQ Test Pattern

Reference White: Light Level **200nit**, Signal Level **58%** **BT.2111 HDR-PQ Color Bars** analyzed by **VQV**



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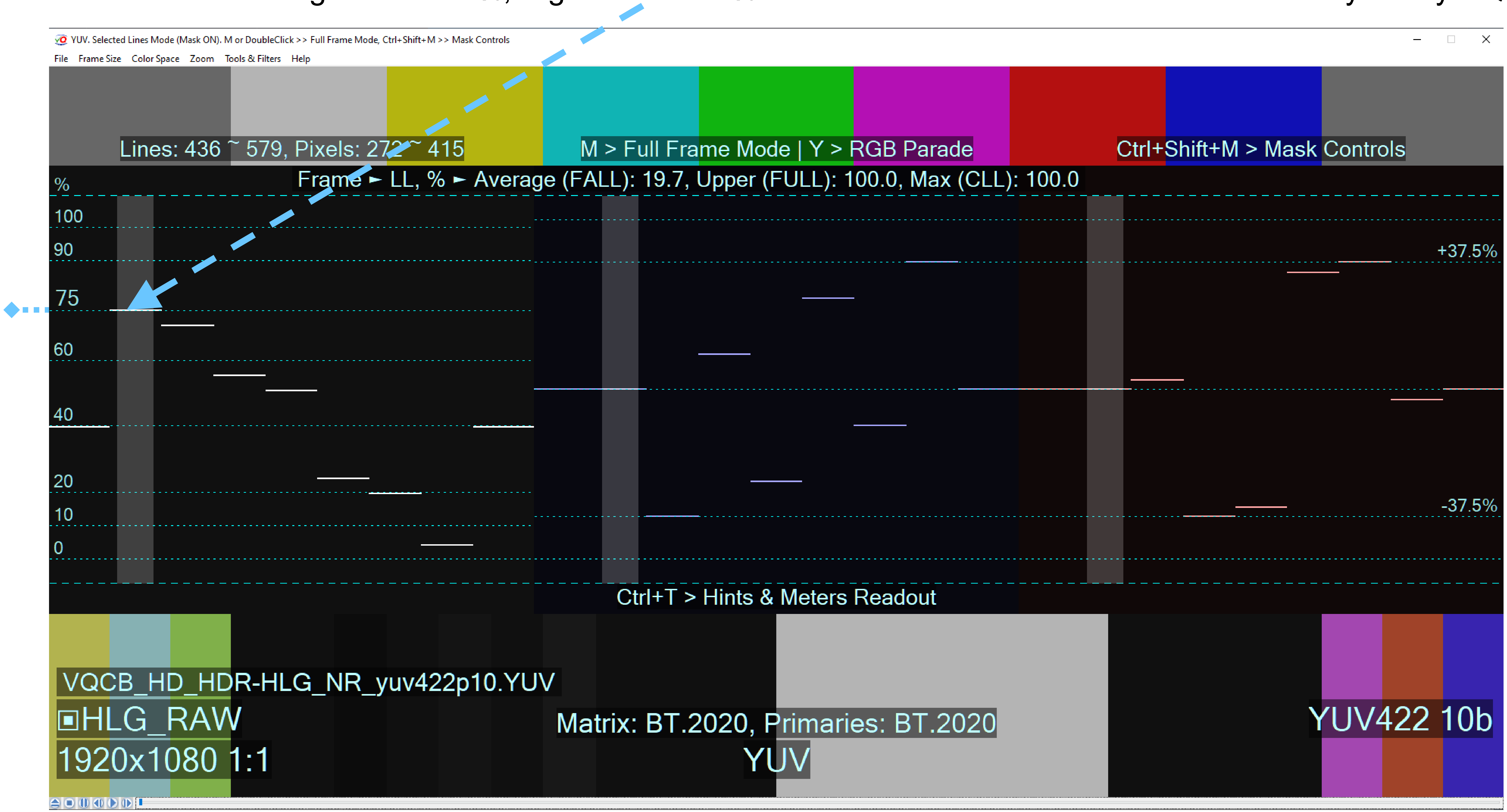
11. Unified Reference White – HDR-HLG Test Pattern

Reference White: Light Level **20%**, Signal Level **75%** **BT.2111 HDR-HLG Color Bars** analyzed by **VQV**



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12. About VideoQ, Inc.

Customers & Partners

Company History

- Founded in 2005
- Formed by an Engineering Awards winning team sharing between them decades of global video technology.
- VideoQ is a renown player in calibration and benchmarking of Video Processors, Transcoders and Displays, providing tools and technologies instantly revealing artifacts, problems and deficiencies, thus raising the bar in productivity and video quality experience.
- VideoQ products and services cover all aspects of video processing and quality assurance - from visual picture quality estimation and quality control to fully automated processing, utilizing advanced VideoQ algorithms and robotic video quality analyzers, including latest UHD and HDR developments.

Operations

- Headquarters in CA, USA
- Software developers in Silicon Valley and worldwide
- Distributors and partners in several countries
- Sales & support offices in USA, UK

13. Supporters & Contributors

Dr. Victor Steinberg, cofounder and president of VideoQ, technical awards winner

Roderick Snell, cofounder of Snell & Wilcox and winner of several Technical Emmys and Queen's Awards

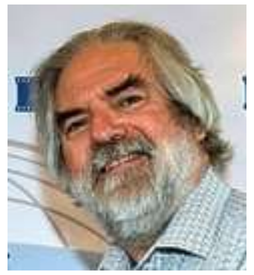
Florian Friedrich, CEO and CTO of FF Pictures GmbH

Josef Marc, a member of SMPTE's HDR committee

Maxim Levkov, industry expert, system architect

David Tasker, global industry expert, engineer, trainer & technical awards winner

Peter Wilson, founder of High Definition & Digital Cinema Ltd, technical awards winner



A1. Appendix – Background Information

This section provides useful reference and background information related to HDR flavors, digital signal data and light levels.

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A2. References

1. ITU-R Recommendation BT.2100-3 (02/2025) Image parameter values for high dynamic range television for use in production and international programme exchange
2. ITU-R Recommendation BT.2111-3 (05/2025) Specification of colour bar test pattern for high dynamic range television systems
3. ITU-R Report BT.2408-8 (11/2024) Guidance for operational practices in HDR television production
4. ITU-R Report BT.2390-11 (03/2023, *superseded*) High dynamic range television for production and international programme exchange
5. SMPTE ST.2084:2014 High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays
6. SMPTE ST. 2094-1:2016 Dynamic Metadata for Color Volume Transform – Core Components
7. ARIB STD-B67 v2.0 (01/2018) Parameter Values for the Hybrid Log-Gamma (HLG) High Dynamic Range Television (HDR-TV) System for Programme Production

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A3. General Information

Standardization bodies:

BT.2100 [1] Recommendation specifies the parameters of PQ and HLG transfer functions. It does specify **HLG Reference White Signal Level** as 75% of the signal range. The recommendation ***does not*** specify **PQ Reference White**, and it ***does not*** specify **HLG Reference White Light Level**.

BT.2111 [2] Recommendation specifies the parameters of **color bars test pattern** for HDR-PQ and HDR-HLG systems and it ***does*** specify **PQ and HLG Reference White Signal Levels**.

BT.2408 [3] Report highlights the need for the **Unified Reference White Level** which is suitable for both HDR systems (HLG & PQ) and provides examples of such values. Moreover, it stipulates that due to the distinctive large headroom in HDR systems there should only be a **single** Reference White Level, not **two** separate ones for Diffuse White and Computer Graphics.

BT.2390 [4] Report contains mostly **discussion** and **experimental results** on **tone-mapping** between various HDR / SDR systems.

Industry Experts:

Due to fundamentally different approaches, **very different transfer curves**, etc., some experts express the opinion that it is **nearly impossible** to find **common ground**.

In the daily practice of live event coverage and similar challenging production situations, engineers have already **found good solutions** and even established **de-facto standards** allowing them to work efficiently in such **multi-format environments**.

Defining HDR video content levels as linear light levels \`nits\`, as opposed to 10bit values or percentages of the signal can be considered a current trend. Linear Light values deliver “straightforward” numbers. Technical details about the differences between content light level in nits, measured candelas per square meter and perceived brightness will follow in the next slides.

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A4. HLG Reference White Level Confusion

BT.2100 gives an example of **HLG OOTF** dependent on **Target Display Max Brightness** (aka **TDMB** or **Nominal Peak Luminance**):
For the 1000 nit TDMB HLG display the "appropriate" (backward compatible with the legacy CRT displays) **gamma** value of **1.2** is recommended.
BT.2100 also states that "optimal" gamma depends on TDMB value and provides a formula for optimal HLG Display Gamma = 1.2 + 0.4 x log10(TDMB/1000).

BT.2408 Report **Table 1** shows example of **203 nit** level as a candidate for common PQ / HLG Reference White (*common for Diffuse White and Graphics White*).

TABLE 1

Nominal signal levels for PQ and HLG production

Reflectance Object or Reference (Luminance Factor, %)[3]	Nominal Luminance, cd/m^2 (PQ & 1000 cd/m^2 HLG)	Nominal Signal Level	
		%PQ	%HLG
Grey Card (18%)	26	38	38
Greyscale Chart Max (83%)	162	56	71
Greyscale Chart Max (90%)	179	57	73
Reference Level: HDR Reference White (100%) also diffuse white and Graphics White	203	58	75

BT.2408 Report **Tables 3 & 5** show a wide range of so called "optimal" gamma values from **1.03** to **1.33** and corresponding HDR Reference White values.

TABLE 3

Nominal Peak Luminance (cd/m^2)	Display Gamma
400	1.03
600	1.11
800	1.16
1 000	1.20
1 500	1.27
2 000	1.33

TABLE 5

Nominal Peak Luminance (cd/m^2)	HDR Reference White (cd/m^2)
400	101
600	138
800	172
1 000	203
1 500	276
2 000	343

The 203nit level was calculated by applying additional component (gamma 1.2), i.e. modifying the original 265 nit value of the ideal TDMB•EOTF(OETF) model:

$$\text{TDMB}\cdot\text{V2L}(0.75)^{1.2} = 203.1521454$$

BT.2111 standard specifies HLG and PQ Color Bars Test Patterns. In this standard **PQ Reference White Signal Level** of **58%** is calculated by mapping the 203nit light level of **HLG Reference White** via the **PQ OETF** function.

Note that 203nit value is only one of many candidates shown in **Table 5**; values are ranging from **101 nit** to **343 nit**.
Such **plurality** of reference levels makes practical use of this approach **extremely difficult**.

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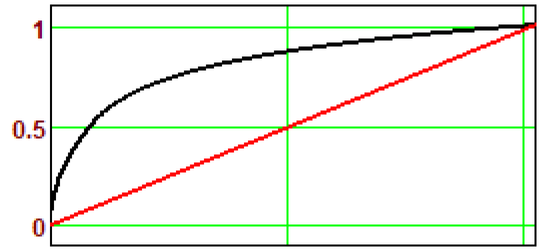
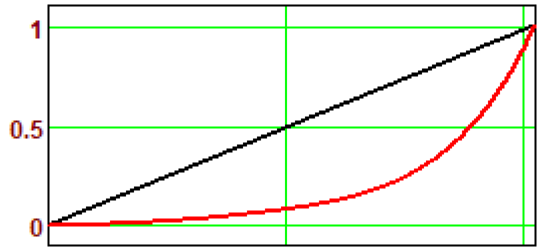
A5. A bit of HDR Terminology and Math, HLG Case

OETF: Opto-Electronic Transfer Function, i.e. L2V(L) function,
L = Normalized light value from 0 to 1,
V = Normalized R,G, or B signal value from 0 to 1.



$$L2V(L) \equiv \text{if}\left[L > \frac{1}{12}, a \cdot \ln(12 \cdot L - b) + c, \sqrt{3} \cdot (L)^{0.5}\right]$$

EOTF: Electro-Optical Transfer Function = inverse OETF, i.e. V2L(V) function,
V = Normalized R,G, or B signal value from 0 to 1,
L = Normalized light value from 0 to 1.



$$V2L(V) \equiv \text{if}\left[V < 0.5, \frac{(V)^2}{3}, \frac{1}{12} \cdot b + \frac{1}{12} \cdot \exp\left(\frac{V - c}{a}\right)\right]$$

a = 0.17883277 **b** = 0.28466892 **c** = 0.55991073

Opto-Optical Transfer Function (**OOTF**) maps relative scene linear light to display linear light.
The BT.2100 ***HLG system*** model is based on the so-called **Reference OOTF** = pow(V2L(L2V(L)),1.2), i.e. **relative light level output** is ***not equal*** to input.

BT.2100 standard defines **HLG Reference White Y, R, G, B Signals Level** = **75%** of the signal range.
A 75% signal level translates to relative light level: V2L(0.75) = **0.2649626**. After 1.2 display gamma non-linearity it comes out as **0.203152**
On widely used **1000nit** display it means **203 nit,** often rounded to **200 nit**.

Diffuse White Reference **73%** signal level, commonly used for practical HLG cameras setup [5], relies on **90% Reflectance Optical Test Chart**.
Camera output signal level, e.g. viewed on a waveform monitor, is adjusted to be a bit below the 75% Reference White.
Mapping an input 90% light level to RGB signal and then to light level via cascaded V2L, L2V and pow(L, 1.2) functions results in the **179nit** value:

Thus, it may look that we have two candidates for the HLG **Reference White Light Level**:
a) Computer Graphics Reference = **203nit** *(rounded),*
b) Diffuse White Reference = **179nit** *(rounded).*

However, it is highly undesirable to use **two** references, and there is also much better way to specify Reference White **Light Level** as the brightness level of a **typical 1knit** display screen rendering **reference 75% signal**, i.e **200nit**.

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A6. LOG Format Reference Levels – Success Story

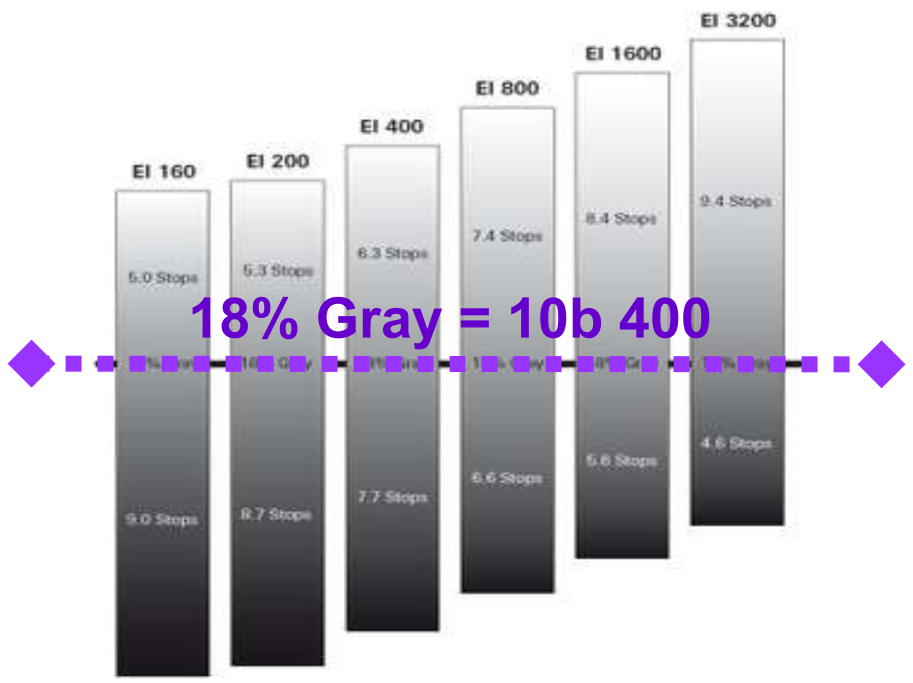
Camera LOG (aka LOG-RAW) is used in post-production workflows supplying **Digital Cinema, HDR** and / or **SDR** video deliverables.

Using the embedded metadata and reference to **18% Gray** LOG video data 'maps' to **relative L**ight **L**evels (%) and **absolute L**ight **L**evels (nit). Camera LOG formats are specific to camera manufacturers with some discrepancies in the metadata formatting and in the LOG curve shapes.

For a given LOG transfer curve parameter and 18% Gray anchor value it is possible to calculate the corresponding 90% **Reference White** values as shown in the Table below. If necessary, 100% level can be calculated as well.
Which begs to be considered as an example to follow for establishing the **HDR-PQ / HDR-HLG Reference White**.

An important advantage of LOG format is that it includes useful metadata about **absolute** Light Levels (via **EI = Exposure Index**), but it is **independent** of mastering display or target display parameters, which makes it equally suitable for SDR, HDR-PQ and HDR-HLG systems.

Log C dynamic range for various EI values



LOG C Reference Gray

LOG Format	0% Black 10 bit value	18% Gray 10 bit value	90% White 10 bit value
Sony S-Log	90	394	636
Sony S-Log2	90	347	582
Sony S-Log3	95	420	598
Arri Log C	96	400	580
Canon C-Log	128	351	614
Panasonic V-Log	128	433	602

A7. Video Content Nits vs. CIE Luminance in cd/m2

The **subjective perception** of color video image light levels (typically called simply **Brightness**) may differ significantly from the **photometric Luminance** *(relative luminance intensity)* in **cd/m^2** defined in **CIE 1931** standard, which is often used *as a measure* of video display brightness.

CIE 1931 (gamut dependent!) formula in the case of BT.709 color space: **photometric luminance Y = 0.222*R + 0.707*G + 0.071*B**
In this formula R, G and B are linear light levels (CIE R,G,B filter outputs derived from XYZ filter values), and Y is the resulting luminance value.
Note that for other color spaces e.g. for WCG UHD BT.2020, the coefficients used for Y value calculation are significantly different.

A typical response to the question "Which bar in the color bars test pattern is the brightest?" is ''All bars, except black, are **equally** bright".
This is the basis for the widely used *de-facto* formula of perceived **L**ight **L**evel: **LL** = **max(R,G,B),** in nits or percent.
To avoid confusion with the CIE Brightness in cd/m^2, video engineers often use terms like 'MaxRGB', 'video content nits value', or just 'nit value'.

Note that:
*1. **Brightness** is perceptual, **luminance** is measurable.*
2.The cd/m^2 unit is traditionally used to specify the "Brightness" (in fact – light output) of a display device.
*3. CIE Luminance numerical value in **cd/m^2** is **equal** to **video content nits** value **only** for shades of **Gray** from Black to White.*

COLOR	CIE 1931 *RELATIVE LUMINANCE, %*	PERCEIVED *RELATIVE LIGHT LEVEL, %*
WHITE	100	100
YELLOW	92.9	100
CYAN	77.8	100
GREEN	70.7	100
MAGENTA	29.3	100
RED	22.2	100
BLUE	7.1	100
BLACK	0	0

*Use of cd/m^2 units is suitable for the **HDR display peak brightness** measurement related to shades of **Gray**.*
*However, in the case of measurement of the **HDR video content Light Levels** the use of cd/m^2 should be avoided; instead, we should use different units – 'video content nits'.*