VQC – **V**ideo**Q** **C**olorator™

VideoQ **HDR** ⇔ **SDR** Converter

Software tool for on premise and cloud tasks

October 2024

www.videoq.com

HDR–SDR Conversion – Criteria for Success

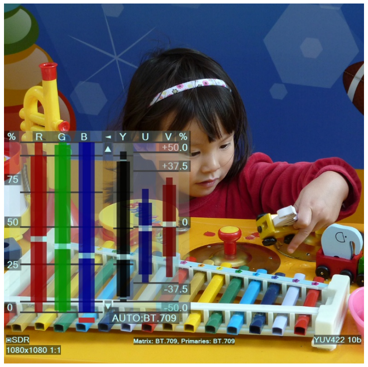
The only criteria of success is a Happy Viewer and a visual impact of wonderful video images.
Modern HDR cameras and display screens are much better than their prior-art SDR counterparts.
However the content quality and its availability is dragging behind.

Important facts are:

- **SDR content** made via **HDR to SDR down-conversion** is significantly better than regular SDR content.
- **HDR content** made via **SDR to HDR up-conversion** is nearly as good as regular HDR content, but the **production cost** is order of magnitude **lower**.

There are only **two valid questions**:

1. Are **Video Data Levels** and **Light Levels** suitable for the **distribution context**, e.g. for **streams switching** and **adverts/captions insertion**?
2. Do the converted **images** *at the workflow output* **look good** to millions of viewers?



We **should not** compare **fundamentally different** video images of ***the same object***:

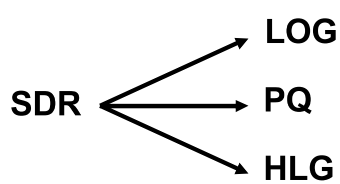
- Original HDR *(WCG)* or SDR image *(WCG UHD or NCG HD)*,
- Down-converted HDR to SDR image *(WCG UHD or NCG HD),*
- Up-converted SDR to HDR image *(WCG to WCG or NCG to WCG),*

Why? Because they belong to at least **three** quite different **workflows** and quite different **viewing conditions**.

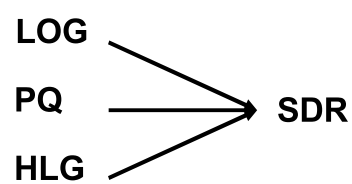
Dynamic Range Conversion – Necessity & Options

- **Mixed SDR/HDR environment** requires SW and HW engines for the up, down and cross-conversion within and/or between all formats, with additional appropriate resolution/detail management.
- This functionality is also related to the optimal choice of a mezzanine Dynamic Range format, coupled with equipment choice in a mixed SDR/HDR environment.

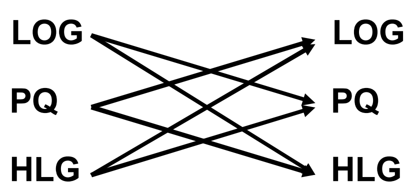
DR Up-conversion



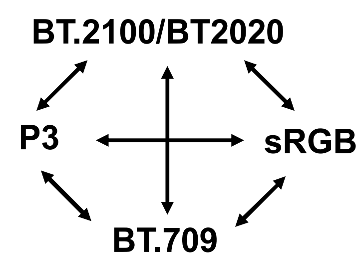
DR Down-conversion



DR Cross-conversion



And Color Space Conversion



VQC – VideoQ Dynamic Range and Color Space Converter

VQC is a **Windows/Linux CLI program** that reads a **media file** or **sequence** of **image files**, measures its video frames parameters, **converts** the content to the specified **dynamic range** and **color space** format, then creates a **Report** in **JSON** format and optionally plot the output LL profile in **PNG** format.

Supported input and output **dynamic range formats**:

- **SDR,**
- **HDR-PQ,**
- **HDR-HLG**

Supported **color primaries**:

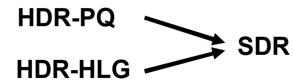
- **BT.709** *(aka NCG = Narrow Color Gamut)*,
- **BT.2020** *(aka WCG = Wide Color Gamut)*,
- **P3** (*(aka ECG = Expanded Color Gamut)*

Supported **frame sizes**:

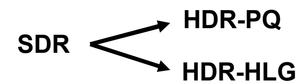
from **1920x1080** (HD)

to **8192x4096** (8K)

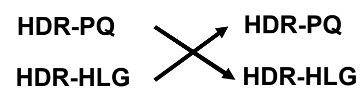
DR Down-conversion



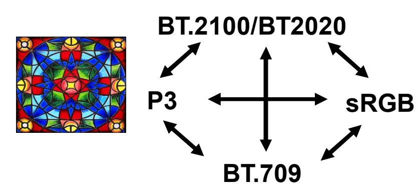
DR Up-conversion



DR Cross-conversion



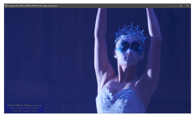
And Color Space Conversion



Learn more about **VQPT** and **VQC Colorator**™ http://www.videoq.com/vqpt.html http://www.videoq.com/vqc.html

VQC Demo Samples for Online Preview and Download

1. Example of **HDR-PQ** to **SDR** conversion:



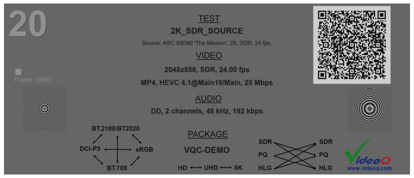
- Ø Source: UHD 16:9 120fps HDR10 BT.2020, 4 min long fragment of Netflix Open Content 'Nocturne' MP4 clip
  https://www.dropbox.com/scl/fi/ed7i39d33321sngfg1jww/VideoQ_VQC_DEMO_SOURCE_HDR10_UHD_120fps_4m20s.mp4?rlkey=0nkjfn9nw68xop0310mq4w6zz&dl=0
- Ø Output: HD 16:9 60fps, SDR BT.709, 4 min long MP4 clip
  https://www.dropbox.com/scl/fi/96focnuqwcc5ax59qt67s/VideoQ_VQC_DEMO_HDR2SDR_HD_60fps_4m20s.mp4?rlkey=obdpezro2xk5e9s7bb09jh3la&dl=0

2. Example of **SDR** to **HDR-PQ** conversion:

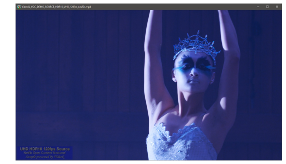
- Ø Source: 2K 2.39:1 (2028x858) 24fps SDR BT.709, 5 min long fragment of ASC StEM2 'The Mission' MP4 clip
  https://www.dropbox.com/scl/fi/iy8ckng5zz8r5vofgkf26/VideoQ_VQC_DEMO_SOURCE_SDR_2K239_24fps_5m20s.MP4?rlkey=yain9ocw1cp792ibbiipc3fgd&dl=0
- Ø Output: 2K 2.39:1 (2028x858) 24fps, HDR10 BT.2020, 5 min long MP4 clip
  https://www.dropbox.com/scl/fi/2nr6yn0si31hcumenhhr7/VideoQ_VQC_DEMO_SDR2HDR_2K239_24fps_5m20s.MP4?rlkey=wctgt8v3bhe79ouqjl4jtfmsx&dl=0

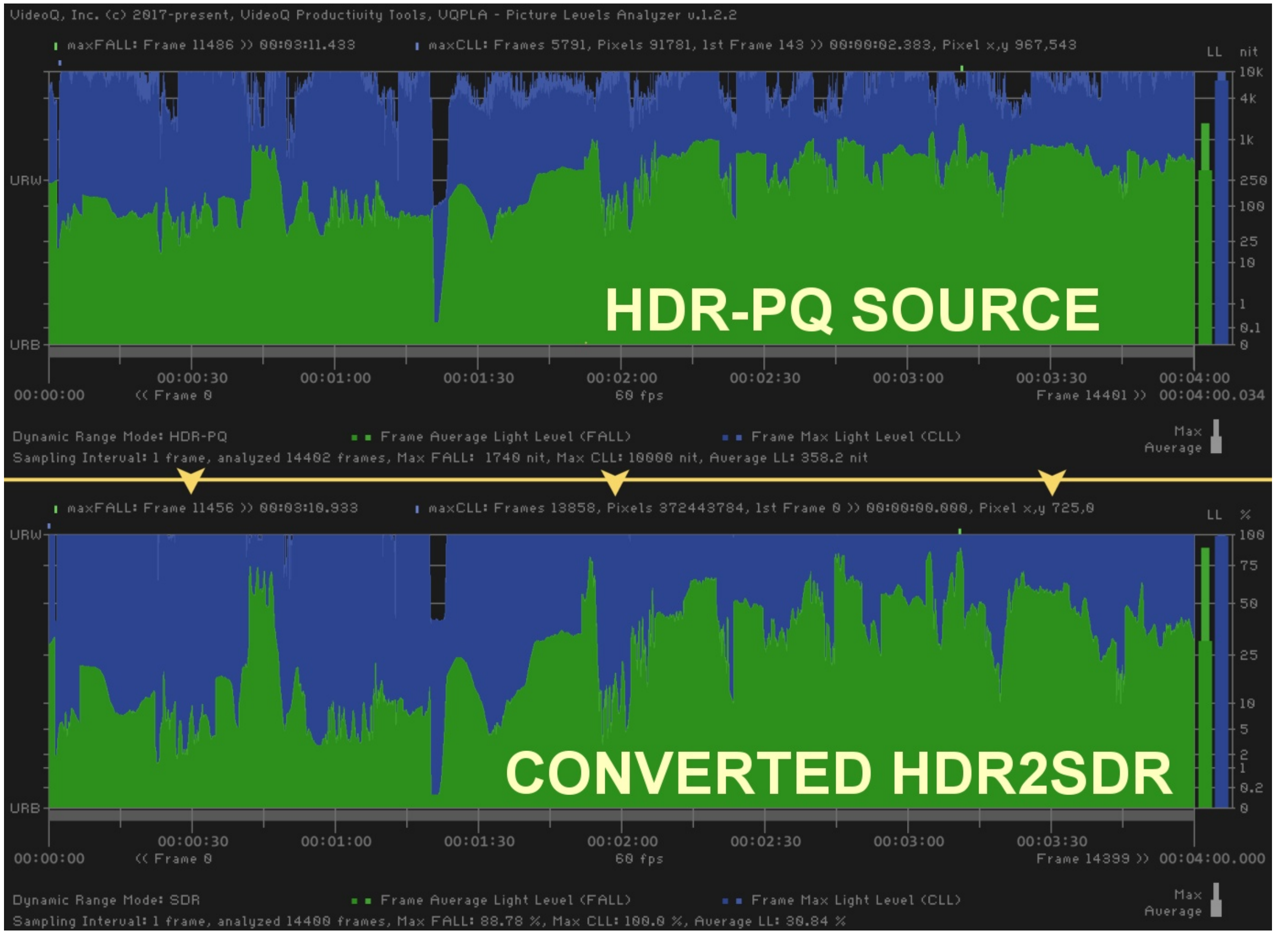
Each clip contains standard VideoQ 20s long leader, consisting of:
10s long Text Box with QR code, 8s of VQCB Test Pattern and 2s Black.

http://www.videoq.com/vqcb.html



VQC Demo Files Part 1 – From HDR to SDR





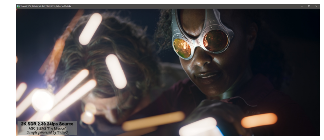
The ***top half*** of the image on the left is the **Light Levels Profile** of Netflix ‘Nocturne’ clip, UHD HRD-PQ 4 min long ***input*** fragment aka **HDR-PQ Source**.

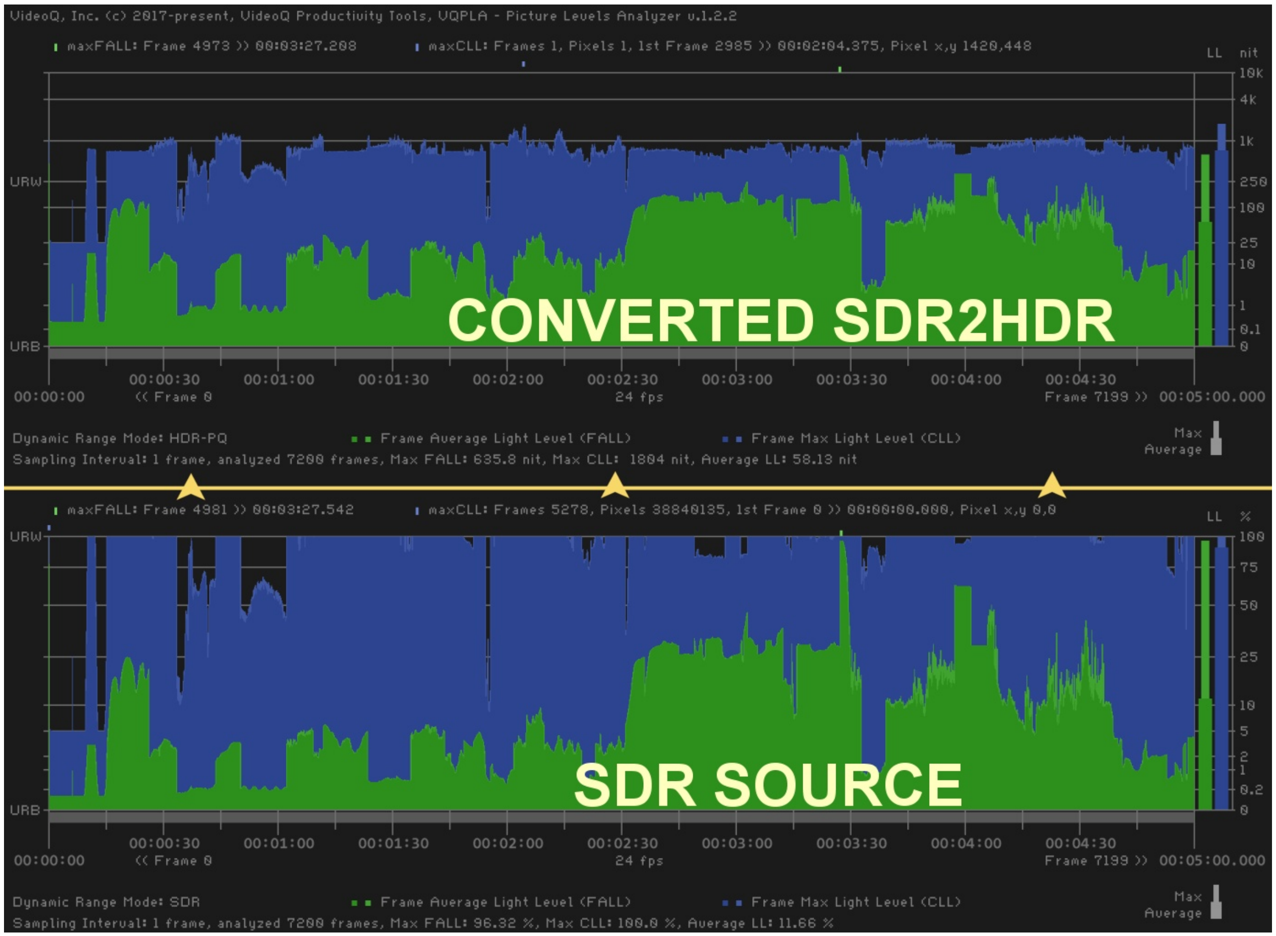
The PNG plots are created by VideoQ **VQPLA** analyzer.
- X axis is timeline,
  time code values are printed underneath
- Y axis logarithmic scale is in
  PQ LL nits (cd/sq.m) or SDR LL percents.

Light Levels are calculated frame-by-frame.
FALL values are in **Green**,
CLL values are in **Blue**.
Bars on the right show statistical Max and Average values for FALL and CLL profiles.

The ***bottom half*** of the image on the left is the **Light Levels Profile** of Netflix ‘Nocturne’ clip, HD SDR 4 min long ***output*** fragment aka **Converted HDR2SDR**.

VQC Demo Files Part 2 – From SDR to HDR





The ***top half*** of the image on the left is the **Light Levels Profile** of StEM2 'The Mission' clip, HD HRD-PQ 5 min long ***output*** fragment aka **Converted SDR2HDR**.

The PNG plots are created by VideoQ **VQPLA** analyzer.
- X axis is timeline, time code values are printed underneath
- Y axis logarithmic scale is in PQ LL nits (cd/sq.m) or SDR LL percents.

Light Levels are calculated frame-by-frame.
FALL values are in **Green**,
CLL values are in **Blue**.
Bars on the right show statistical Max and Average values for FALL and CLL profiles.

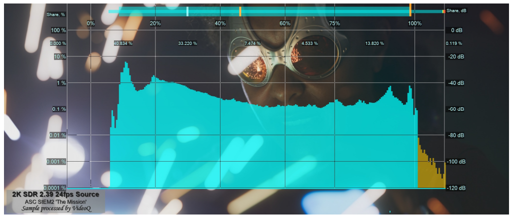
The ***bottom half*** of the image on the left is the **Light Levels Profile** of StEM2 'The Mission' clip, HD SDR 5 min long ***input*** fragment aka **SDR Source**.

VQC and Related VideoQ Tools

Other VideoQ products with HDR support:

VQV – HDR / SDR Multi-format Media Files Viewer/Player/Analyzer/Converter

http://www.videoq.com/vqv.html



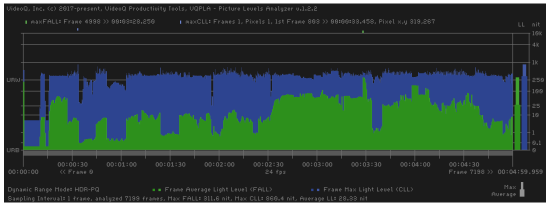
VQMP – Advanced QA/QC Media Player compatible with **VQV** Viewer-Analyzer

http://www.videoq.com/vqmp.html

VQPT – VideoQ Productivity Tools, suite of analysis and processing software modules

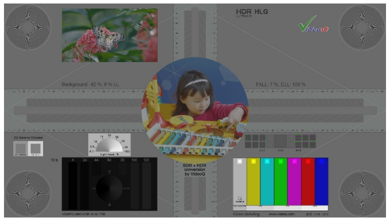
http://www.videoq.com/vqpt.html

VQPLA – Picture Levels Analyzer (**VQPT** module)



VQL – Comprehensive Library of sophisticated Test Patterns and Sequences

http://www.videoq.com/vql.html



VQC Usage Info Helper

Launching VQC executable without any parameters, or with –h flag, brings up the following help message:

Usage (see more in ReadMe):

vqc [-c configFilePath] -i inPath -o outPath

Order of flags and parameters is mandatory and cannot be changed

Other user controls and parameters are stored in the ***.INI** config file

If **[-c configFilePath]** is omitted, then VQC uses **VQC.INI** file co-sited with vqc executable

If VQC.INI file is not found, then it will be auto-created with the default control values

Path string can be path to file or folder: **Path\FileName.EXT** or **Path to folder**

If inPath is a folder, then VQC finds and opens a sequence of numbered image files

VQC can open **all common image file formats**, e.g. 0001.TIFF, 0002.TIFF, ...

VQC can also open **raw YUV/RGB video files**, e.g. 0000.RGB, 0001.RGB, ...

If **outPath is a folder**, then VQC writes a sequence of numbered rgb48le 08d.TIFF files

JSON Report file is created automatically as outPath\FileName.EXT**.vqc.json** or outPath**\vqc.json**

Optional Plot file is created automatically as outPath\FileName.EXT**.vqc.png** or outPath**vqc.png**

If Path or FileName contains spaces or special characters use double quotes

All File names, Report and Log files are in multi-lingual UTF-8 encoding format

VQC Configuration File Structure

```
;VideoQ VQC.INI file created 2023-04-20T17:39:27.937Z
;VQC: VideoQ Colorator(TM) - Dynamic Range and Color Space Converter
;User can edit or replace this file as needed, add your note here:
;
[ConfiguredBy]
ConfiguredBy=Victor Steinberg
[Source_DR_Type]
Source_DR_Type=AUTO
[Source_DR_Primaries]
Source_DR_Primaries=AUTO
[Target_DR_Type]
Target_DR_Type=PQ
[Target_DR_Primaries]
Target_DR_Primaries=P3
[SDR2PQ_RefWhite_nit]
SDR2PQ_RefWhite_nit=400
[SDR2HLG_RefWhite_pct]
SDR2HLG_RefWhite_pct=75
[PQ2SDR_Range_nit]
PQ2SDR_Range_nit=1000
[HLG2SDR_Range_pct]
HLG2SDR_Range_pct=100
[InputRawVideoFrameSize]
InputRawVideoFrameSize=1920x1080
[InputRawYUVPixelFormat]
InputRawYUVPixelFormat=yuv444p12le
[InputRawRGBPixelFormat]
InputRawRGBPixelFormat=rgb48le
[OutputFileExtension]
OutputFileExtension=MP4
[OutputFileCodec]
OutputFileCodec=h265
[OutputPixelFormat]
OutputPixelFormat=420p10le
[TimelineProfile]
TimelineProfile=YES
[PlotFileOut]
PlotFileOut=YES
```

About VideoQ

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

www.videoq.com

What’s the problem & the opportunity?

Well established workflows exist from production through final content distribution. Each discipline in the chain has come to rely upon tried, tested, and above all, unified standards. Standards that are well understood, work together and allow for free interchange of content at each juncture without technical issue and the fear of unknowns.

The advent of **HDR** and **Wide Color Gamut** technology means a change to well understood custom and practice. New workflow rules must be established and honed. The problem is that in this early adoption phase, competing standards are anything but unified. This presents the industry an opportunity to establish an agreed-upon commonality between the current, incompatible array of standards and self-interest.

The solution to harmonious, technically correct and agile content workflow from production to distribution for modern **mixed SDR/HDR** environments is being proposed, by groups of experts, in the form of an **HDR Reference White** standard.

The **SDR to HDR up-conversion** is now considered to be the easiest and fastest method of supplying the appropriate HDR content to the permanently growing number of HDR screens (and eyeballs). It requires clear definition of the HDR destination **Reference White**, as well as other control parameters, e.g., the destination **Color Primaries**.

On the other hand, the path to the fast **monetization** of growing **HDR content media assets** is via the **automated Dynamic Range down-conversion** process of HDR assets to current ubiquitous **SDR post-production/distribution formats**.

Moreover, the conversion is commonly combined with **Frame Size (spatial) conversion** and **Color Gamut Conversion.** For example, the **UHD HDR BT.2100** input is converted to **HD SDR BT.709** in widespread use, destination display devices.

The path to yield the best results for **HDR to/from SDR** conversion lies with establishing an appropriate **White Reference.**

Learn more about **Unified HDR Reference White**: http://www.videoq.com/hdr_ref_white.html

Challenges and Solutions

Why setting up the Unified HDR Reference White Level standard is so important:

Results of HDR to SDR conversion by **VideoQ VQV** and **MPV player** are noticeably different due to the **uncertainty** factor.
In absence of reliable information about the White object light levels, the slope of the tone-mapping curve **must be not so steep** to allow for a wider range of **unknown** “near White” HDR levels.
Moreover, the “soft knee” part of this curve (above the **unknown** Reference White) must be relatively large, which leads to a quite annoying effect – **darkening of all levels** – clearly visible on the corresponding slides.

VideoQ HDR to SDR down-conversion algorithm relies on **assumed and/or measured HDR Reference White Level**. The VQV tone-mapping curve has a rather **steep slope** within the relatively narrow range of light levels near the Reference White. The steep part of the conversion curve is followed by a smooth transition to “soft knee” covering levels from 200 nit to 2000 nit.
Important: In case of **non-conformant** HDR images (not compliant with the Unified Reference White) the down-conversion process must include one extra step – **auto-normalization** of HDR images prior to conversion.

By similar reason, the reliable SDR to HDR up-conversion, especially SDR to HDR-PQ conversion, is possible **only** if it is based on the **standard** (or at least, **specified**) HDR Reference White.

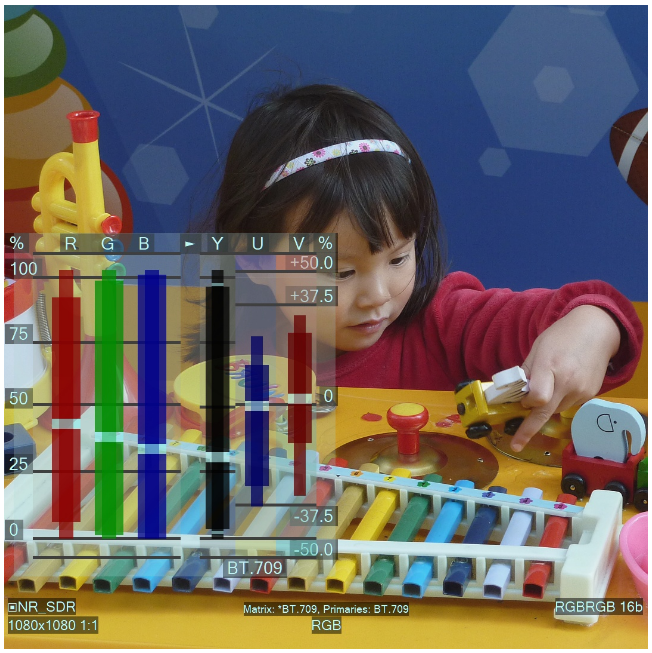
Last, but not least, **capping** the up-converted HDR White Light Level directly affects the **power consumption** of millions of displays worldwide, so it is important in terms of **energy-saving** as well.

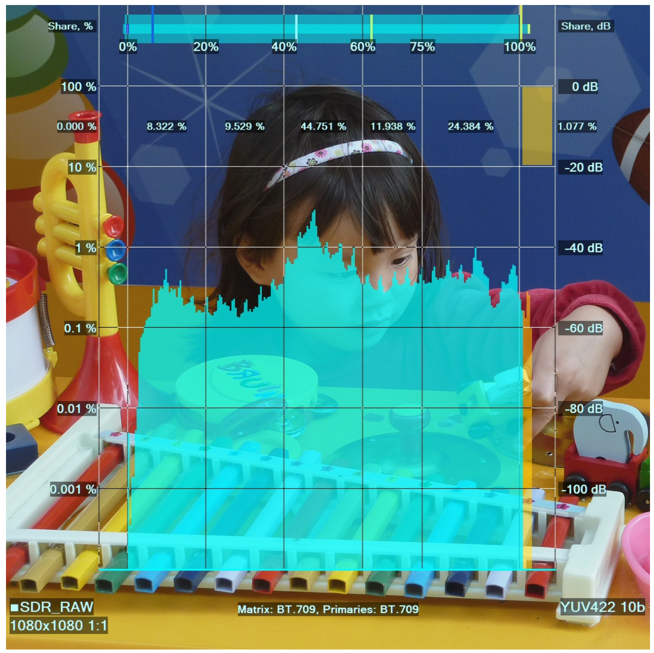
Example of the original SDR image

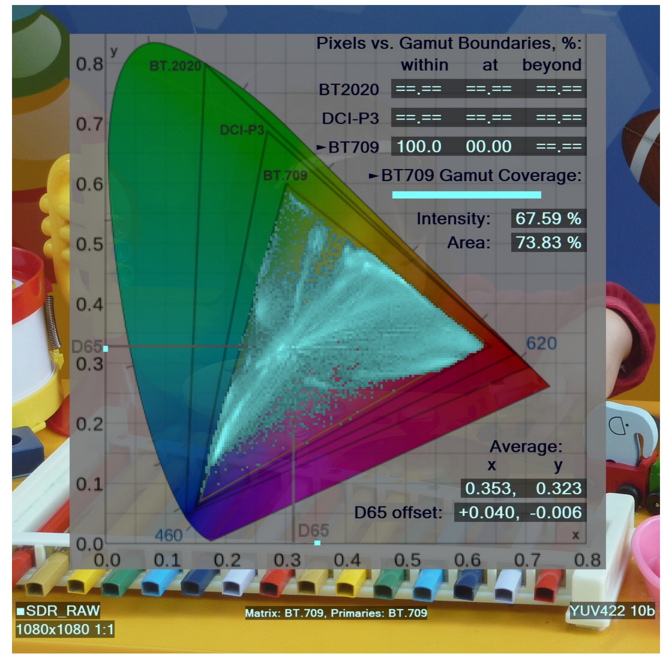
Broadcast quality, full contrast, Narrow Data Range ***SDR image***

Relatively uniform ***Light Levels Histogram***

Good BT709 color gamut coverage confirmed by ***Chromaticity Diagram***







Except specular highlights, the brightest White objects (plastic toys) ***Y level*** *is about* ***97%****, i.e. very close to the* ***SDR Reference White*** *level =* ***100%***

Examples of Conversion – HDR to/from SDR

The next slides illustrate challenges and pitfalls – why commonly accepted Unified Reference White standard is the must-be condition for the successful Dynamic Range Conversion.

All measurement results and diagrams on these slides are produced by **VideoQ VQV** analyzer tool.

SDR ⇒ HDR-PQ, BT2020 Primaries

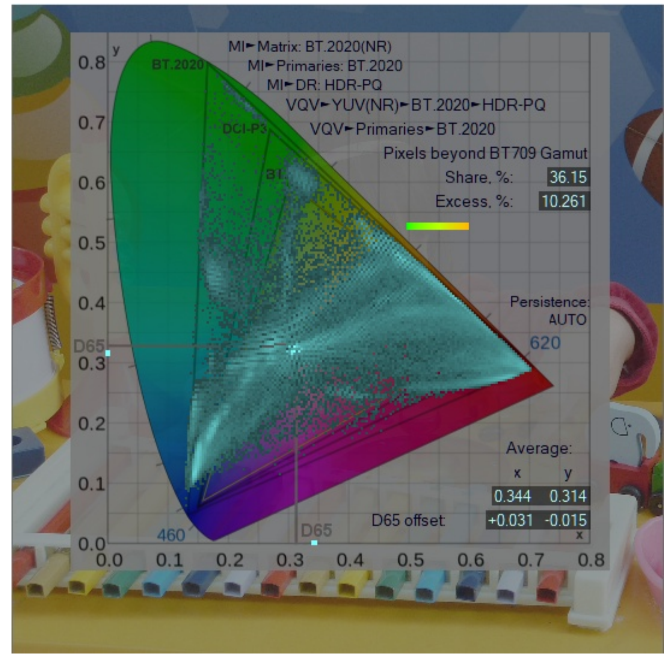
```
Video
ID                                       : 1
Format                                   : HEVC
Format/Info                              : High Efficiency Video Coding
Format profile                           : Format Range@L5.1@High
HDR format                               : SMPTE ST 2086, HDR10 compatible
Codec ID                                 : hev1
Codec ID/Info                            : High Efficiency Video Coding
Duration                                 : 10 s 10 ms
Bit rate                                 : 7 330 kb/s
Width                                    : 1 920 pixels
Height                                   : 1 080 pixels
Display aspect ratio                     : 16:9
Frame rate mode                          : Constant
Frame rate                               : 23.976 (24000/1001) FPS
Color space                              : YUV
Chroma subsampling                       : 4:2:2
Bit depth                                : 10 bits
Scan type                                : Progressive
Bits/(Pixel*Frame)                       : 0.147
Stream size                              : 8.75 MiB (100%)
Writing library                          : x265 3.5+40-0b75c44c1:[Windows][GCC 12.2.0][64 bit] 10bit
Encoding settings                        : cpuid=1111039 / frame-threads=4 / numa-pools=8 / wpp / no-
rc-pics / no-deblock / no-sao / no-sao-non-deblock / rd=3 / selective-sao=0 / early-skip / rskip / no
scenecut-bias=0.05 / hist-threshold=0.03 / no-opt-cu-delta-qp / no-aq-motion / hdr10 / no-hdr10-opt /
Color range                              : Limited
Color primaries                          : BT.2020
Transfer characteristics                 : PQ
Matrix coefficients                      : BT.2020 non-constant
Mastering display color primaries        : BT.2020
Mastering display luminance              : min: 0.0001 cd/m2, max: 1200 cd/m2
Maximum Content Light Level              : 1000 cd/m2
Maximum Frame-Average Light Level        : 80 cd/m2
Codec configuration box                  : hvcC
```

SDR ⇒ HDR-PQ, P3 Primaries

```
Video
ID                                       : 1
Format                                   : HEVC
Format/Info                              : High Efficiency Video Coding
Format profile                           : Format Range@L5.1@High
HDR format                               : SMPTE ST 2086, HDR10 compatible
Codec ID                                 : hev1
Codec ID/Info                            : High Efficiency Video Coding
Duration                                 : 10 s 10 ms
Bit rate                                 : 6 925 kb/s
Width                                    : 1 920 pixels
Height                                   : 1 080 pixels
Display aspect ratio                     : 16:9
Frame rate mode                          : Constant
Frame rate                               : 23.976 (24000/1001) FPS
Color space                              : YUV
Chroma subsampling                       : 4:2:2
Bit depth                                : 10 bits
Scan type                                : Progressive
Bits/(Pixel*Frame)                       : 0.139
Stream size                              : 8.26 MiB (100%)
Writing library                          : x265 3.5+40-0b75c44c1:[Windows][GCC 12.2.0][64 bit] 10bit
Encoding settings                        : cpuid=1111039 / frame-threads=4 / numa-pools=8 / wpp / no-
rc-pics / no-deblock / no-sao / no-sao-non-deblock / rd=3 / selective-sao=0 / early-skip / rskip / no
/ scenecut-bias=0.05 / hist-threshold=0.03 / no-opt-cu-delta-qp / no-aq-motion / hdr10 / no-hdr10-opt
Color range                              : Limited
Color primaries                          : Display P3
Transfer characteristics                 : PQ
Matrix coefficients                      : BT.2020 non-constant
Mastering display color primaries        : Display P3
Mastering display luminance              : min: 0.0001 cd/m2, max: 1200 cd/m2
Maximum Content Light Level              : 1000 cd/m2
Maximum Frame-Average Light Level        : 80 cd/m2
Codec configuration box                  : hvcC
```

SDR to HDR-PQ BT2020 Primaries (Wide Gamut) Up-conversion

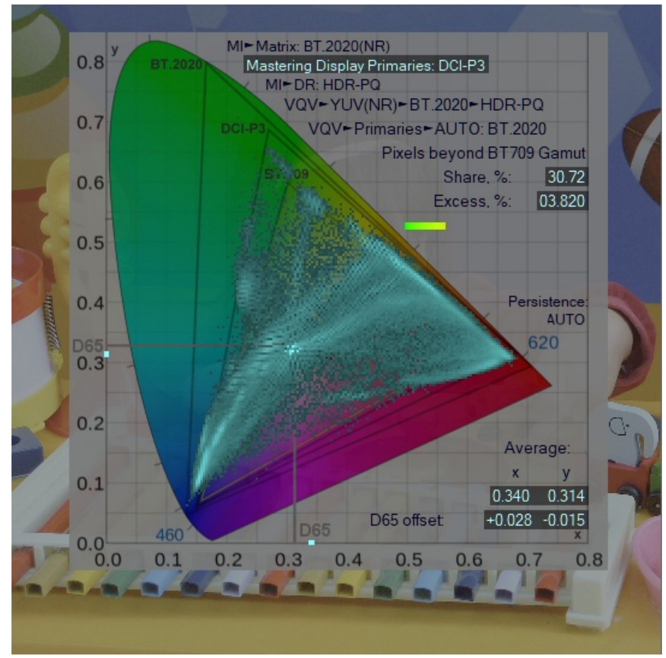
Note the relatively large extent of UV bars on the left and full coverage of BT2020 triangle on the chromaticity diagram.
On some displays with sub-optimal color processing such pictures may look over-saturated.



*Except specular highlights, the brightest White objects (plastic toys) Light Level (**LL**) is about **220 – 280 nit,** i.e. slightly above the **HDR Reference White** level = **200 nit.***
*Frame Average Light Level **(FALL)** = **72 nit** and the brightest pixel LL **(CLL)** = **1015 nit***

SDR to HDR-PQ P3 Primaries Up-conversion

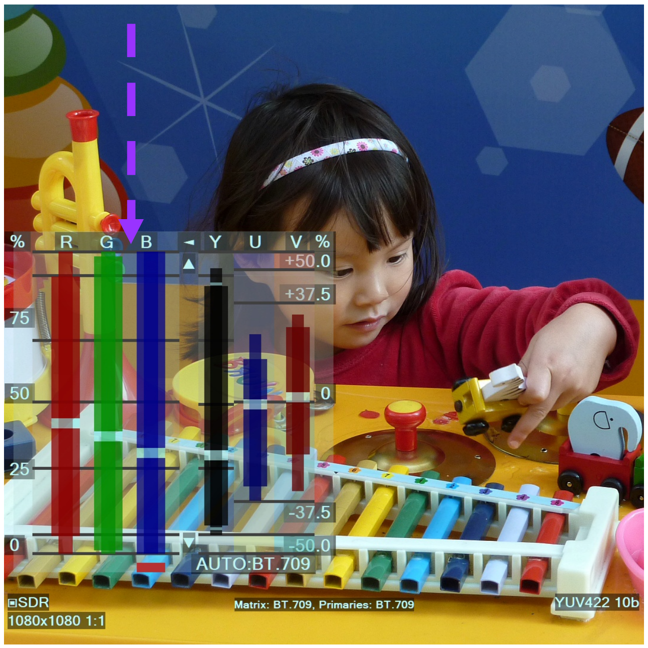
Note the smaller extent of DCI-P3 version UV bars vs. BT2020 version UV Bars on the previous slide.
This matches the smaller extent of the chromaticity diagram (DCI-P3 version Gamut vs. BT2020 version Gamut)

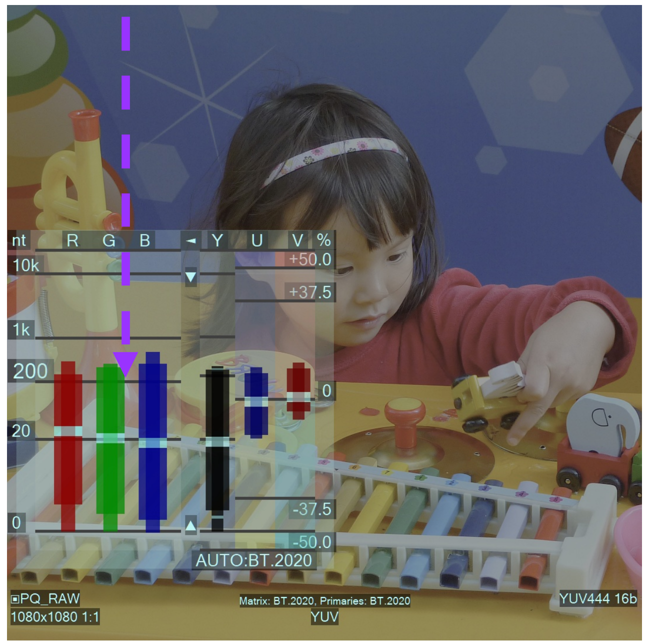


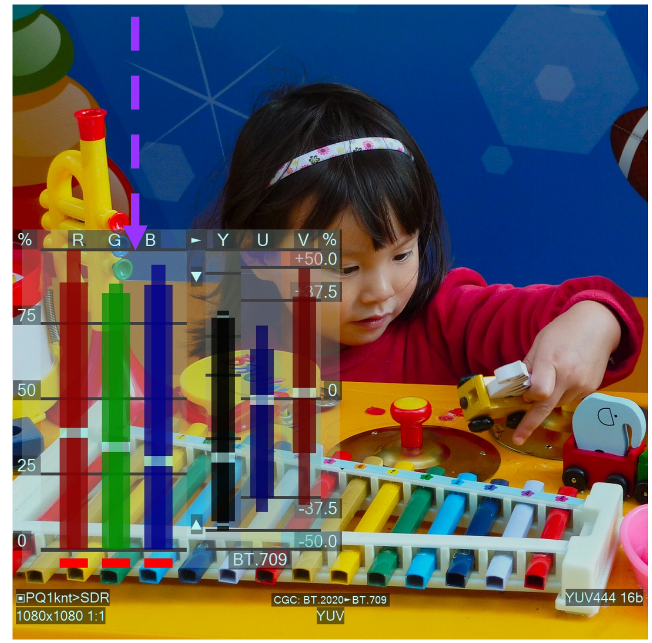
*Except specular highlights, the brightest White objects (plastic toys) Light Level (**LL**) is about **250 – 300 nit,** i.e. slightly above the **HDR Reference White** level = **200 nit.***
*Frame Average Light Level **(FALL)** = **74 nit** and the brightest pixel LL **(CLL)** = **1015 nit***

SDR to HDR-PQ to SDR Conversion by VideoQ

SDR 100% Reference White ⇒ **HDR-PQ 200 nit** Reference White ⇒ **SDR 100%** Reference White





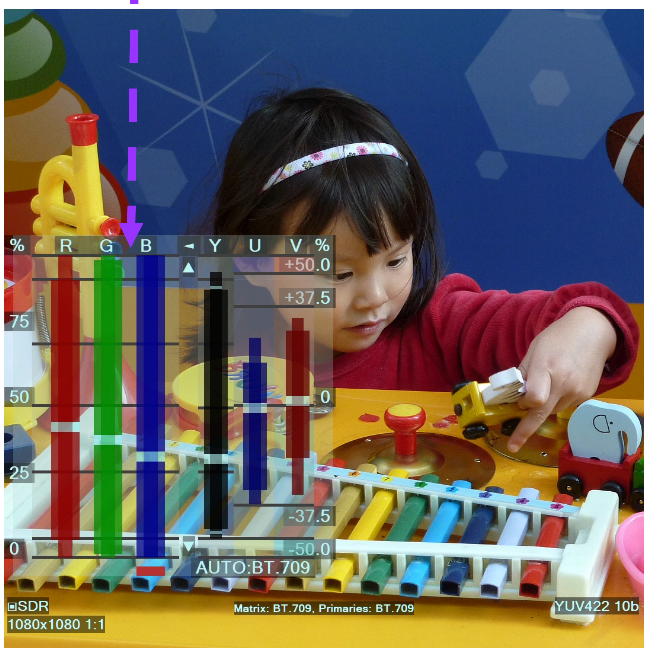


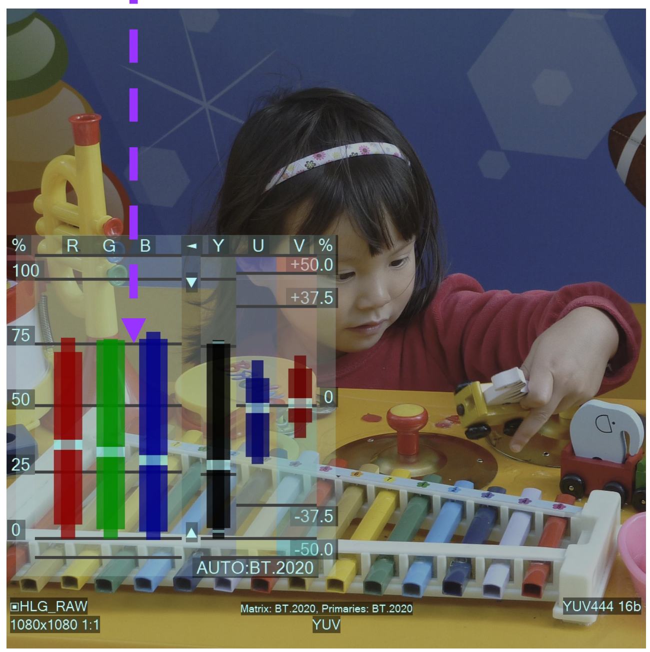
*The **reconstructed SDR** image on the right is **very similar to the original**, but it is not **the exact copy** of **original SDR** image on the left. Color saturation **increased** due to **NCG** to **WCG** to **NCG** processing. Imminent contrast **reduction** is happening because HDR-PQ to SDR converter is trying to **preserve** (to some degree) the **highlights** via the application of "soft knee" LUT.*

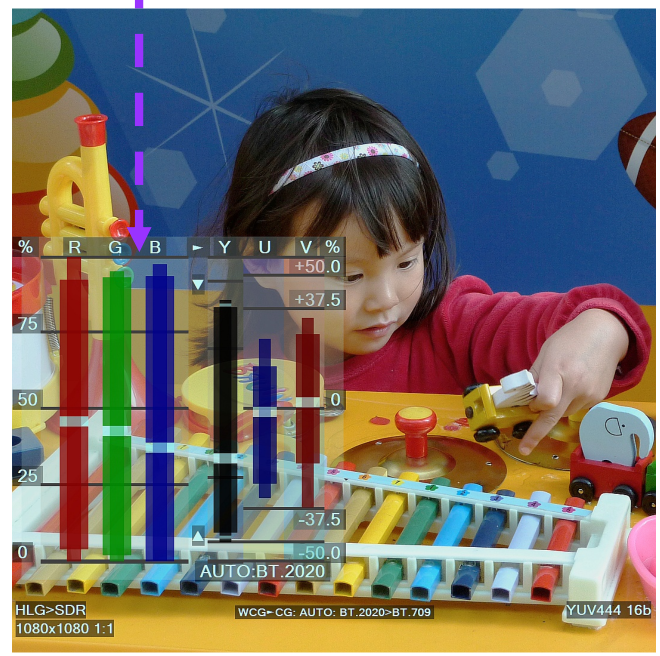
Note the steep slope of the HDR to SDR conversion curve for the levels close to the HDR-PQ Reference White.

SDR to HDR-HLG to SDR Conversion by VideoQ

SDR 100% Reference White ⇒ **HDR-HLG 75%**Reference White ⇒ **SDR 100%** Reference White







*The **reconstructed SDR** image on the right is not the **exact copy** of **original SDR** image on the left; the output image contrast is a bit lower.*
This is happening because HDR to SDR converter is trying to preserve (to some degree) the HLG highlights above HDR-HLG Reference White.

Note that for HDR-HLG to SDR conversion the slope of the curve near the Reference White point is not so steep.

UHD SDR to HD SDR vs. Direct HD SDR

Dynamic range is **just one of the parameters** affected by **down-conversion**. Let's compare two images sharing ***the same HD SDR format***:

1. Image captured by **UHD SDR BT.2020** camera and down-converted to **HD SDR BT.709** format
2. Image captured by ubiquitous **HD SDR BT.709** camera (which we consider to be of "Reference HD Camera Quality")

Parameter	**UHD ⇒ HD vs. HD Relative Quality**	**Why?**
Contrast	No difference	Both cameras use **the same** RGB / YUV digital **level mapping scheme**, i.e. both use the identical **Reference Black** and **Reference White** values.
Color Rendition	Better	**UHD** camera BT.2020 **Color Gamut** is **wider** than **HD** camera BT.709 **Color Gamut**, thus typical "visual anchor colors", such as grass, sky, flag and flesh tone after the appropriate color space mapping may look better (at least – not worse) than "direct" HD camera BT.709 colors
Signal-to-Noise Ratio	Better	Down-scaling filter limits the **spatial frequency spectrum**, thus **removing** a significant part of UHD **video noise energy**. The resultant down-converted HD image S/N ratio is usually 4…6 dB better than the "direct" HD video image S/N ratio
Sharpness	Better	For quite a wide range of contributing spatial frequencies, fine detail contrast in down-converted image is significantly higher. For example, 800 tvl frequency is **close to the limit** of the HD video spectrum, so its typical contrast is 20% ... 40% at best. However, for the UHD camera it is a "**mid-range**" frequency, so its typical contrast is somewhere between 80% and 110%.

Conclusions:

Frame size (spatial) down-conversion and Color Gamut down-conversion are well established **unattended** processes.

There are no **significant artifacts** and the resultant **image quality** is usually **better** than the "**reference quality**" of HD camera.