HDR Test Patterns Suite

VQL – **V**ideo**Q** Test Patterns **L**ibrary

Training Presentation

December 2024

videoq.com/vql.html

videoq.com

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in the upper-right corner
of any slide for this global
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1. General Info

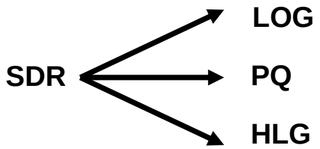
1.1 Color Spaces, Data Ranges, Conversion Options

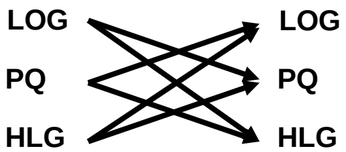
International Telecommunication Union (**ITU**) Recommendation **BT.2020** defines various aspects of ultra-high-definition television (**UHDTV**) with standard dynamic range (**SDR**) and wide color gamut (**WCG**).
It mandates the use of RGB ⇔ YUV Color Space Conversion **BT.2020 Matrices** for the frame sizes greater than HD.
Note that RGB ⇔ YUV conversion in ubiquitous **HD** format relies on significantly different **BT.709 Matrices**.

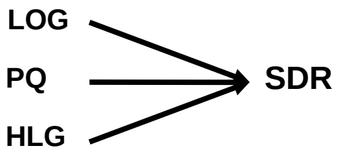
Since the introduction of **BT.601** standard YUV data are generated in **Narrow Range** format (abbreviated as **NR**).
Main advantage of the NR format is the availability of extra levels below **Reference Black** and above **Reference White**.

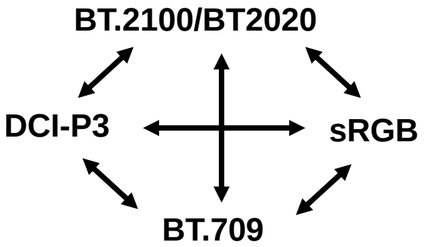
However, the RGB data traditionally used in production and post-production are defined in two formats – **Full Range** format (**FR RGB**, without reserved levels) and **Narrow Range** format (**NR RGB**, similar to NR YUV).
Thus, generic RGB ⇔ YUV conversion workflows should handle FR/NR RGB, NR YUV and BT.2020/BT.709 Matrices.

The **HDR/SDR** conversion processes are even more complicated, note the **Unified Reference White** concept:
http://www.videoq.com/hdr_ref_white.html









1.2 Color Bars Related Standards

Years ago ITU-R (United Nations agency division) issued Recommendation BT.471 “Nomenclature and Description of Color Bar Signals”, which does not address modern UHD, HDR and WCG issues.

They are mostly covered by ITU-R Recommendation **BT.2111** “Specification of colour bar test pattern for high dynamic range television systems”:

https://www.itu.int/rec/R-REC-BT.2111/en

However, the Recommendation BT.2111 specifies the reference test patterns *only* for the **High Dynamic Range** (**HDR**) television systems specified in ITU-R Recommendation **BT.2100**.

This means that currently there is no *recommended* Color Bars Test Patterns suitable for widely used **Standard Dynamic Range** (**SDR**) workflows in mixed UHD/HD and WCG formats.

VideoQ has filled this gap by developing the suite of Color Bars Test Patterns, which includes all **BT.2111 HDR** variants ***as well as*** the newly developed **SDR** variants for the **BT.2020** Color Space ***and*** traditional **BT.709** Color Space:
http://www.videoq.com/vqcb.html

The layout, data levels and appearance of the SDR variants of **VQCB** test pattern suite are similar to the HDR variants, which makes much easier the usage of the whole VQCB suite in modern mixed formats environments.

Note that widely used **SMPTE Color Bars** are for **SDR** workflows **only**; so far there is no SMPTE standard for HDR version.

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1.3 VideoQ HDR Test Patterns Applications

Picture quality control and calibration tools for general public, video installers, hardware and software developers, video development labs, production, post-production and content distribution facilities in the fields of:

- Broadcast HD & UDH TV
- Consumer Electronics and Video Games
- Video Transcoding
- Video Data Compression
- Digital Cinema
- Home Theatres
- IPTV, CDN
- Cloud video processing and transcoding

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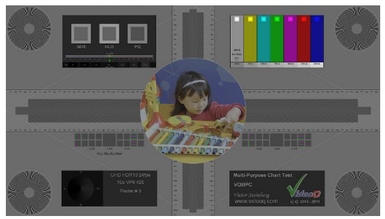
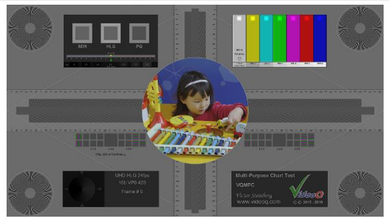
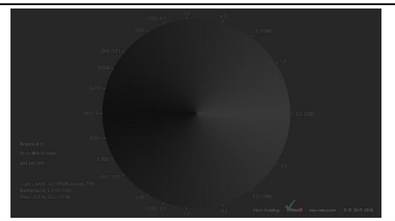
1.4 VideoQ HDR Test Patterns Suite – Entry Level Set

Codename	Description	HDR10 (PQ) version	HLG version
VQCB	**V**ideo**Q** **C**olor **B**ars specified by ITU BT.2111. Optional text box slate with QR code and text/graphics overlays within side panels show file parameters and customer/source info. Note **VQCBA** analyzer: http://www.videoq.com/vqcba.html		
VQMPC	**V**ideo**Q** **M**ulti-**P**urpose **C**hart with optional AV Sync components. A sophisticated test pattern for display setup, image quality visual assessment and processing chain performance check		
VQLA	**V**ideo**Q** **L**evels **A**lignment static test pattern for metadata handling, displayed light levels range and tone-mapping performance check		
VQSP	**V**ideo**Q** **S**uper **P**LUGE (Conical Grayscale) test pattern for the HDR-PQ displays performance check for very low light levels. The Light Level Range is 0.001 nit … 2 nit		**N/A**
VQAPL	**V**ideo**Q** **A**verage **P**icture **L**evel dynamic sequence for testing display auto-brightness control performance. Featuring a static photo on a calibrated variable light level background. FALL range is 75 nit … 6340 nit	 	**N/A**

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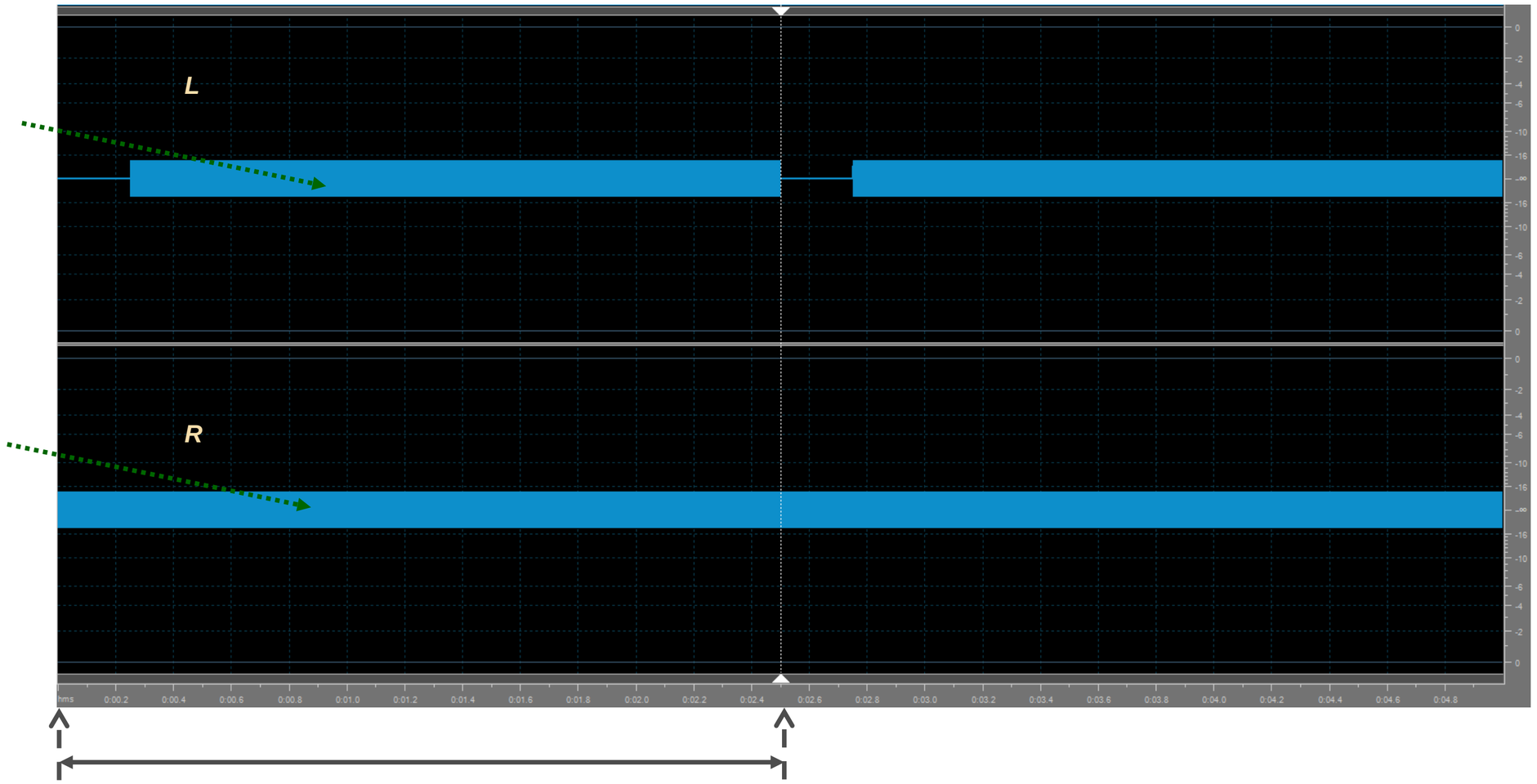
1.5 Optional Audio Component

***L channel**:*
-20 dBfs, 1 kHz tone,
periodic gaps 250 ms

***R channel**:*
-20 dBfs, 1 kHz tone



*Period = **2500 ms** (**2502.5 ms** for 23.976, 29.97 and 59.94 fps)*

This optional audio stream component can be added to any VideoQ HDR test.
It complies with the generic multichannel audio line-up tones specification in EBU Tech 3304

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1.6 VideoQ HDR Test Patterns Data Formats

Test patterns are available as media files in the following formats:

- Frame size: 3840x2160 (UHD) = default, 1920x1080 (HD) – available on request:
- Media file parameters:
  - MP4 and WEBM containers
  - HEVC, VP9, AV1 lossless codecs
  - Seamless loop duration: 40s or 400s (typical values),
  - Pixel format: 444 or 420, 10, 12 or 16 bit per component
  - IPPP… GOP size: 1s
  - HDR-PQ or HDR-HLG metadata embedded – as appropriate
- Frame rate: 24.0 fps = default, other frame rates available on request
- Optional audio streams: 2.0 stereo, AC3 for MP4, Vorbis OGG for WEBM
- Other video & audio data formats and codecs are available on request

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2. VideoQ Color Bars Set

TOC2

2.1 VQCB HDR-PQ Test Composition

Peak White
100%, 10,000 nit

100% Bars

58% Bars
for Color Calibration

40% Gray Side Panels
may contain text
messages about video
and audio parameters
plus customizable info

Reference White
58%, 200 nit

Grayscale

Full Range Ramp

BT.709 Bars
mapped to
BT.2020

BT.709 Bars
mapped to
BT.2020

0% -2% +2% +4% 0%
NR PLUGE
or
0% 0% +2% +4% 0%
FR PLUGE

Reference White
58%, 200 nit

Reference Black
0%, 0 nit

TOC2

2.2 VQCB HDR-HLG Test Composition

Peak White
1,000 nit, 100% LL

100% Bars

75% Bars
for Color Calibration

40% Gray Side Panels
may contain text
messages about video
and audio parameters
plus customizable info

Reference White:
75%, 200 nit, 20% LL

Grayscale

Full Range Ramp

BT/709 Bars
mapped to
BT.2020

BT.709 Bars
mapped to
BT.2020

0% -2% +2% +4% 0%
NR PLUGE

Reference White:
75%, 200 nit, 20% LL

Reference Black
0% LL

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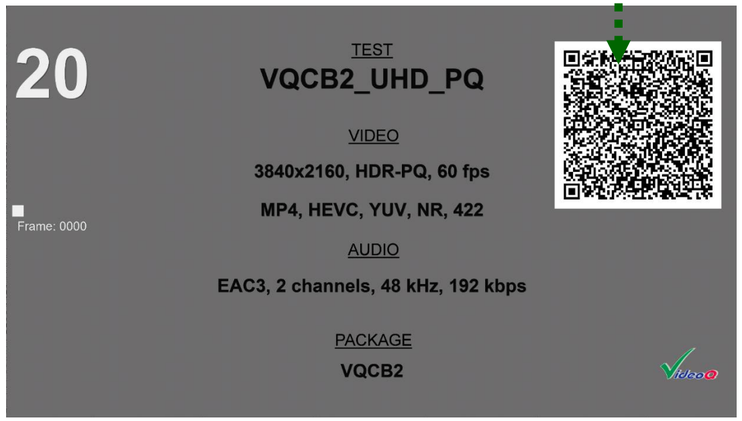
2.3 VQCB Sequence Timeline Segments

VQCB sequence is suitable for automated repetitive lab testing. The sequence consists of three segments:

- 0s~10s: **Text Box** containing all test pattern details and machine-readable QR Code,
- 10s~18s: **Color Bars** test pattern,
- 18s~20s: **Black**.

Frames Counter **QR Code**

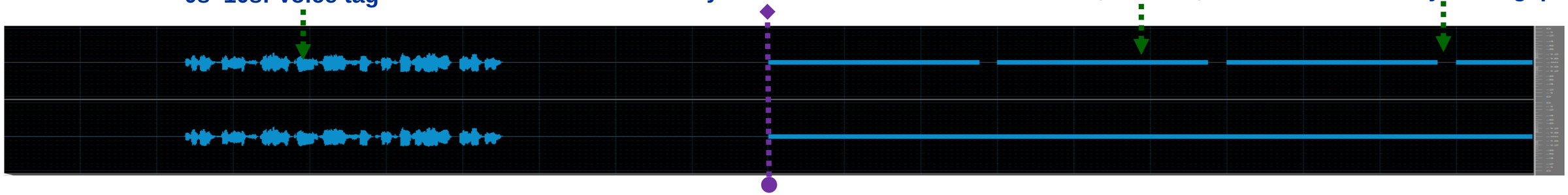


Placeholder for License Info

20s Count-down

Optional audio stream composition (LR stereo, 48kHz, PCM 24b or AC3 192kbps):

0s~10s: Voice tag **AV Sync: 0ms** **10s~20s: 1kHz tone, -23dBfs, L channel marked by 0.25s gaps**



TOC3 <— *Click on **TOC3** for the **Section 3 TOC***

3. VQMPC Test Patterns Set

3.1 VQMPC Test Features

Multi-purpose test pattern to check at glance:

- **Geometry**: Aspect Ratio, Overscan and "Ultra-wide Mode" effects of the display
- **Scaling Quality** or proof of no-scaling, especially in case of DHCP conflict in STB
- **Colors, Gradations and Light Levels**:
  - PLUGE, SPLUGE, special HDR Color Bars and Grayscales for display setup,
  - Central Photo Insert for general quality evaluation
- **2D Frequency Response**
- **Sharpness Correction** settings & controls
- **Display** setup and **Dynamic Range Mode** settings & controls
- **Frames Continuity** and **AV Sync** Errors

3.2 VQMPC Test Composition

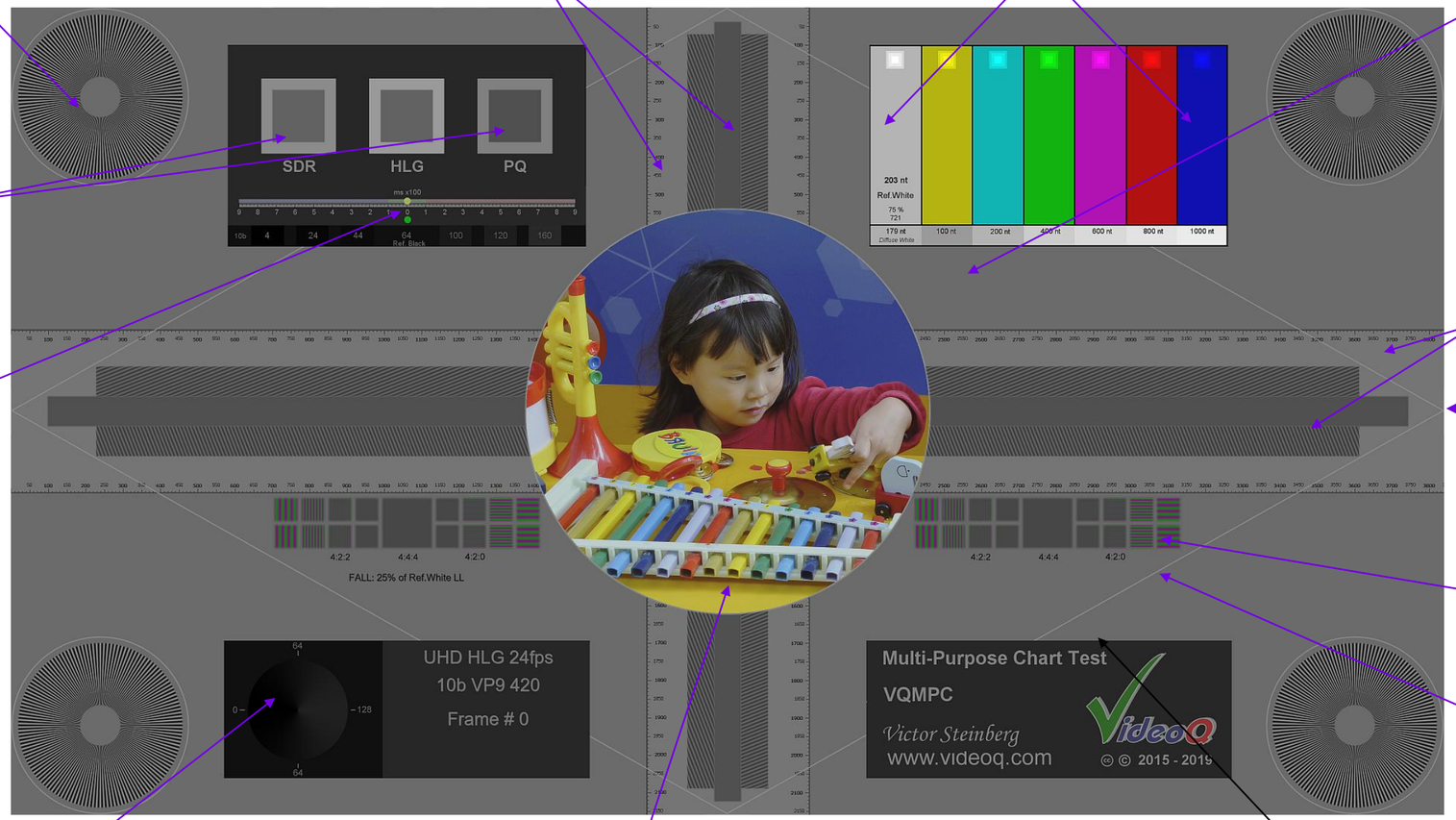
Four Corner Radial Plates
aimed at testing
Geometry & Sharpness

Vertical Ruler,
Vertical Frequency Bursts

Special **HDR Color Bars**
aimed at testing
HDR Display Light Output Profile

Mid-gray background
aimed at testing
Display Light Output Uniformity

3 OETF Curve Tests
aimed at testing
Display Tone-mapping Mode Selection



Horizontal Ruler,
Horizontal Frequency Bursts

Sliding Yellow Marker and
Flashing Green Marker
aimed at testing
Frames Continuity
and
AV Sync Errors

Four H & V
Edge Markers
White line width = 1 pixel

Chroma Sampling Test
aimed at testing
Encoded YUV Pixel Format

Diamond Lines
aimed at testing picture
Geometry

Black SPLUGE Conical Grayscale
on **Reference Black** background
aimed at testing
Display Min Brightness

Central “Katie” Photo Insert
aimed at checking **Tone-mapping** and **Color Rendition**

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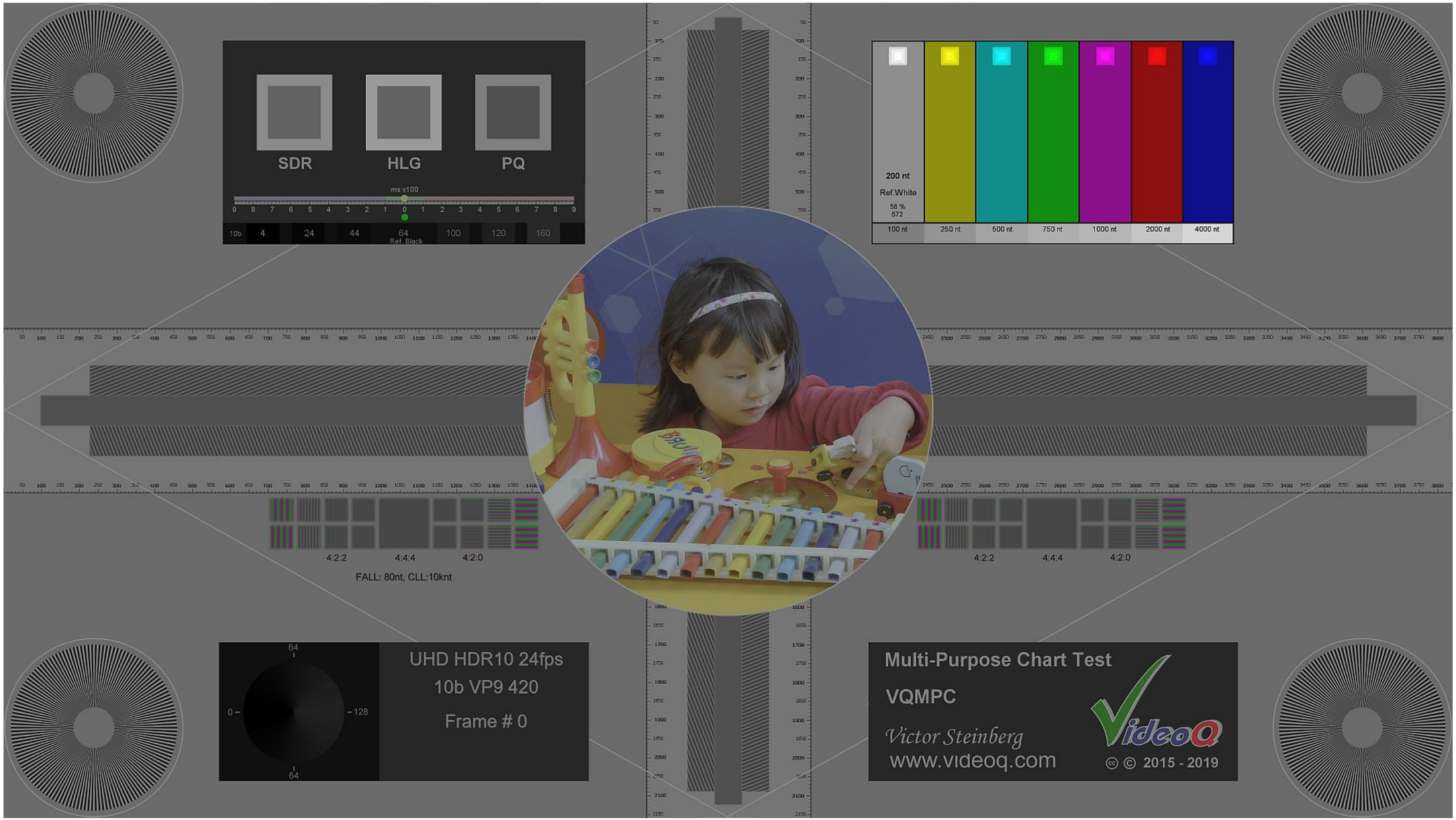
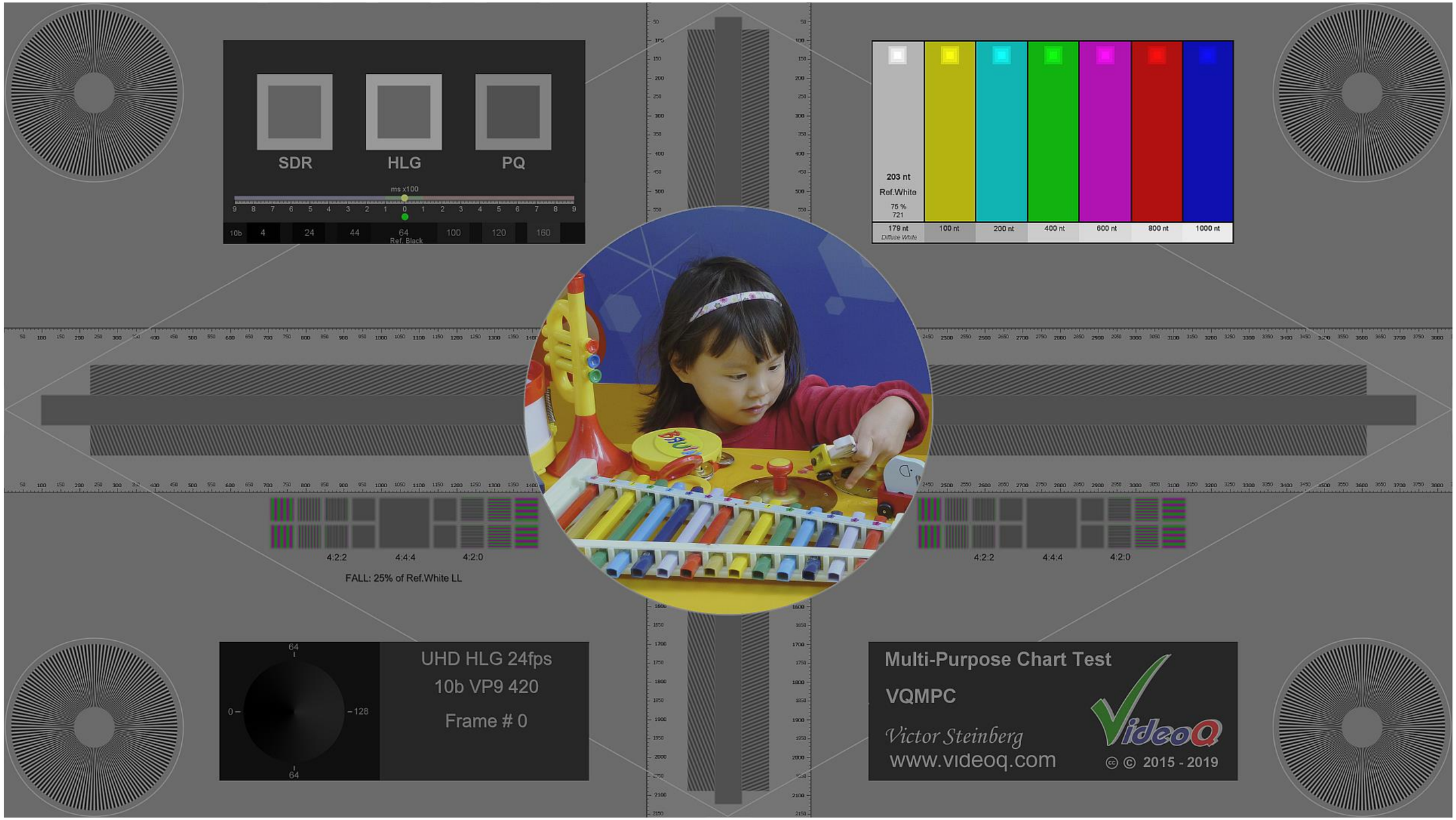
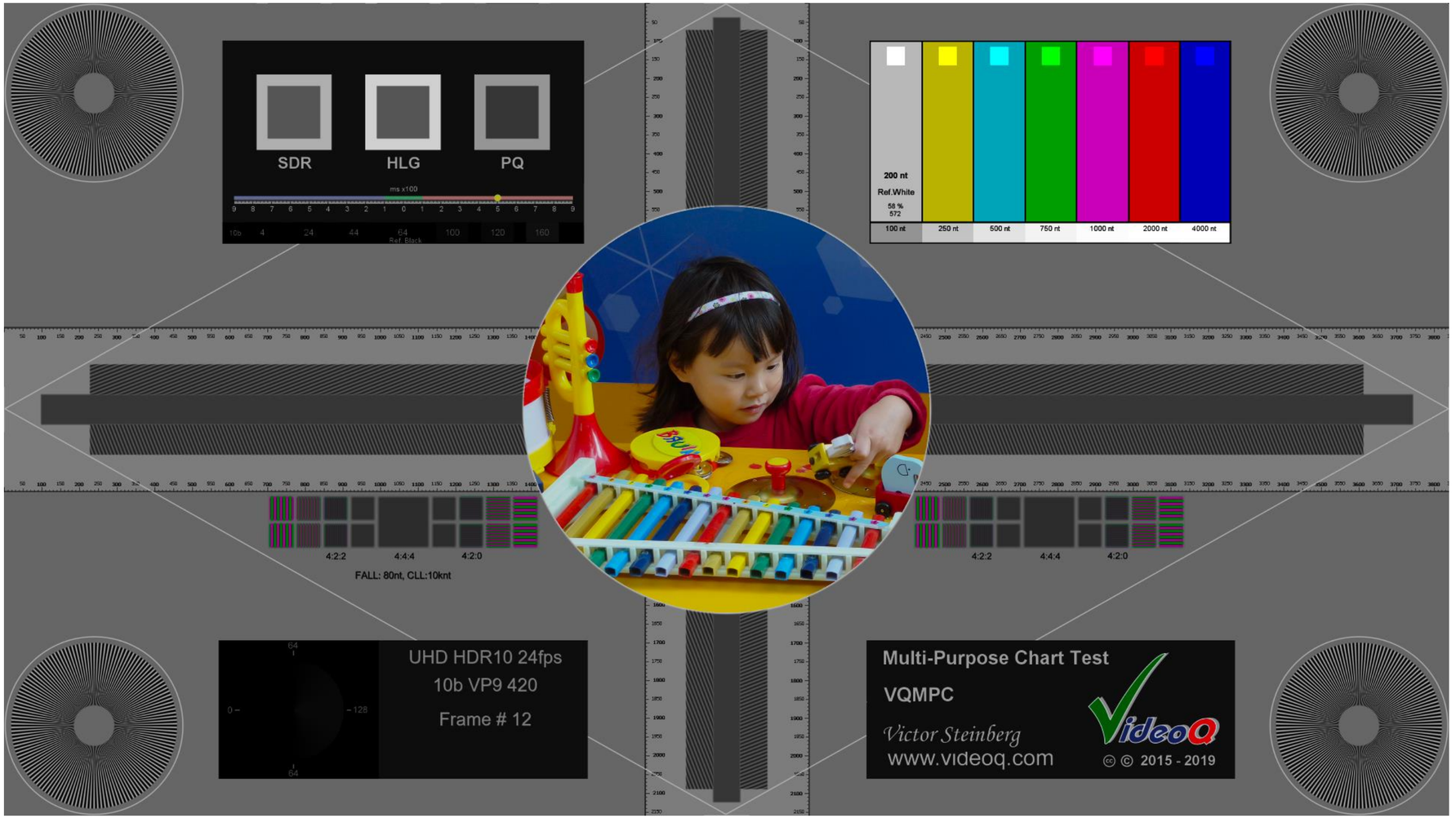
3.3 VQMPC Test HDR10 (PQ) version



3.4 VQMPC Test HLG version



3.5 VQMPC Usage Example – HDR10 to SDR Conversion



The HDR10 to SDR conversion (in this example – by **VLC** player) looks good. The most critical issues are the central photo **color rendition** and absence of noticeable **quantization artifacts** (“*banding*”) on the gradients.

3.6 VQMPC Optional AV Sync Test Audio Component

*Loop duration: **2,000 ms** (**2,002 ms** for 23.976, 29.97 and 59.94 fps)*

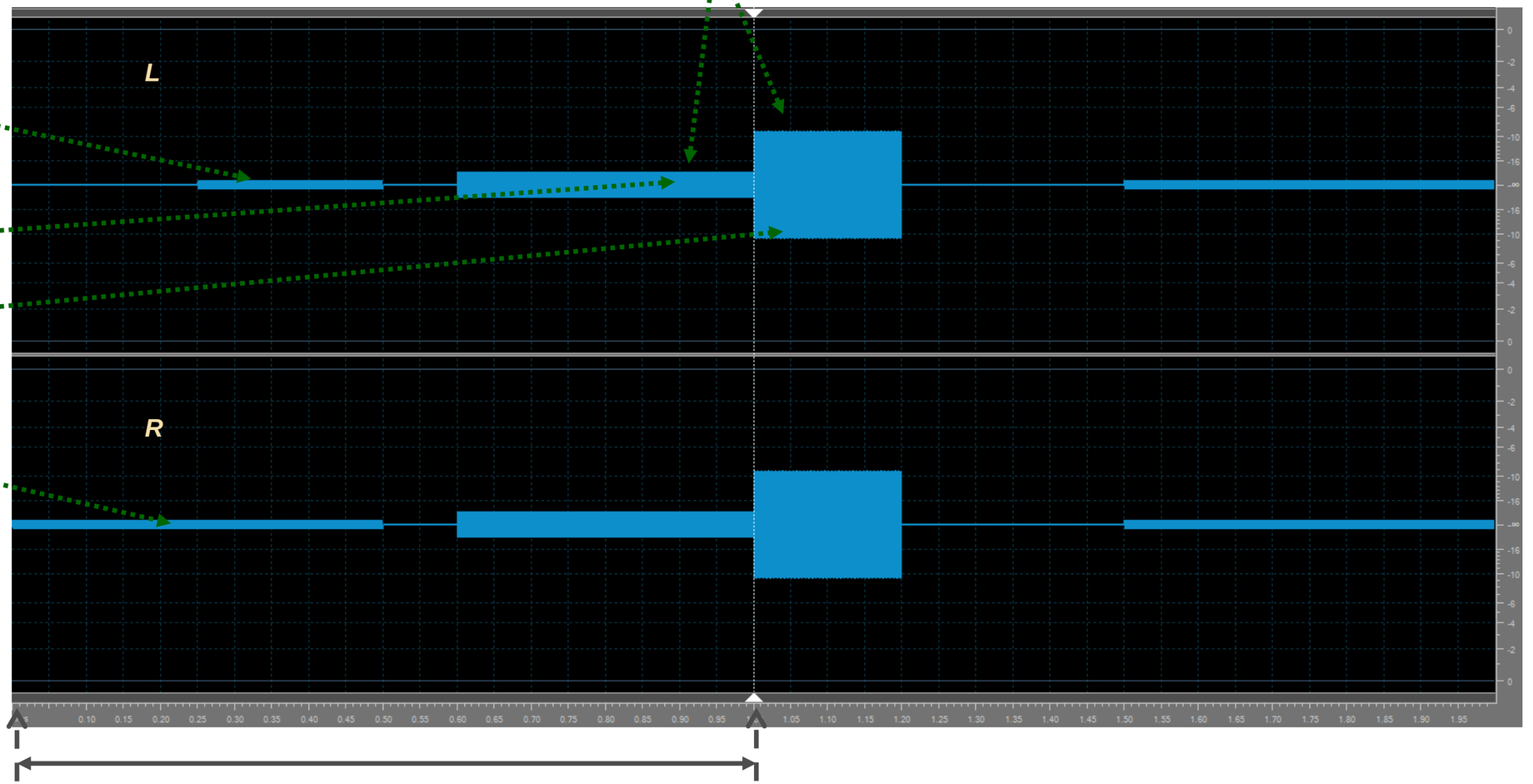
AV Sync Reference: “Beep-bop” burst

L channel
low level 1kHz
tone bursts

***Beep**:*
-20 dBfs, 1250 Hz, 400 ms

***Bop**:*
-9 dBfs, 1000 Hz, 200 ms

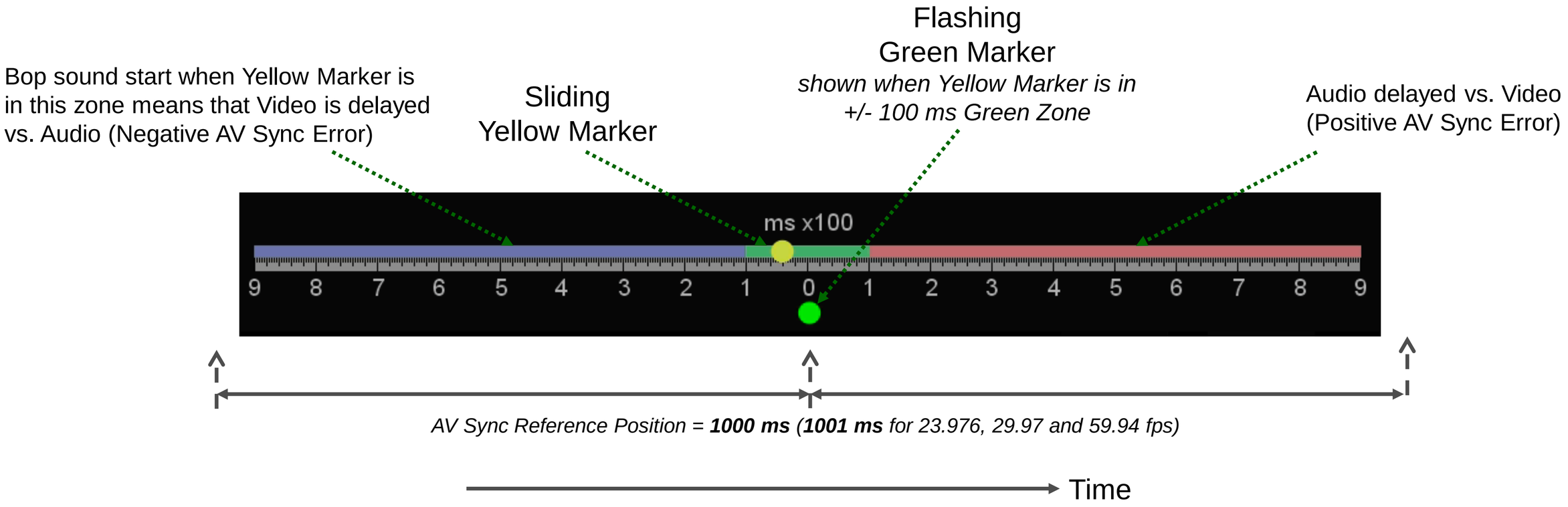
R channel
low level 1kHz
tone bursts



*AV Sync Reference Position = **1000 ms** (**1001 ms** for 23.976, 29.97 and 59.94 fps)*

3.7 VQMPC Optional AV Sync Test Video Component

AV Sync Test period is 2000ms, thus the reliably detectable AV Sync error range is +/- 900 ms.



Sliding Marker can be also used as frames continuity indicator. If the decoded video frames are skipped or frozen, normally smooth marker movement becomes jerky and erratic.

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4. VQLA Test Patterns Set

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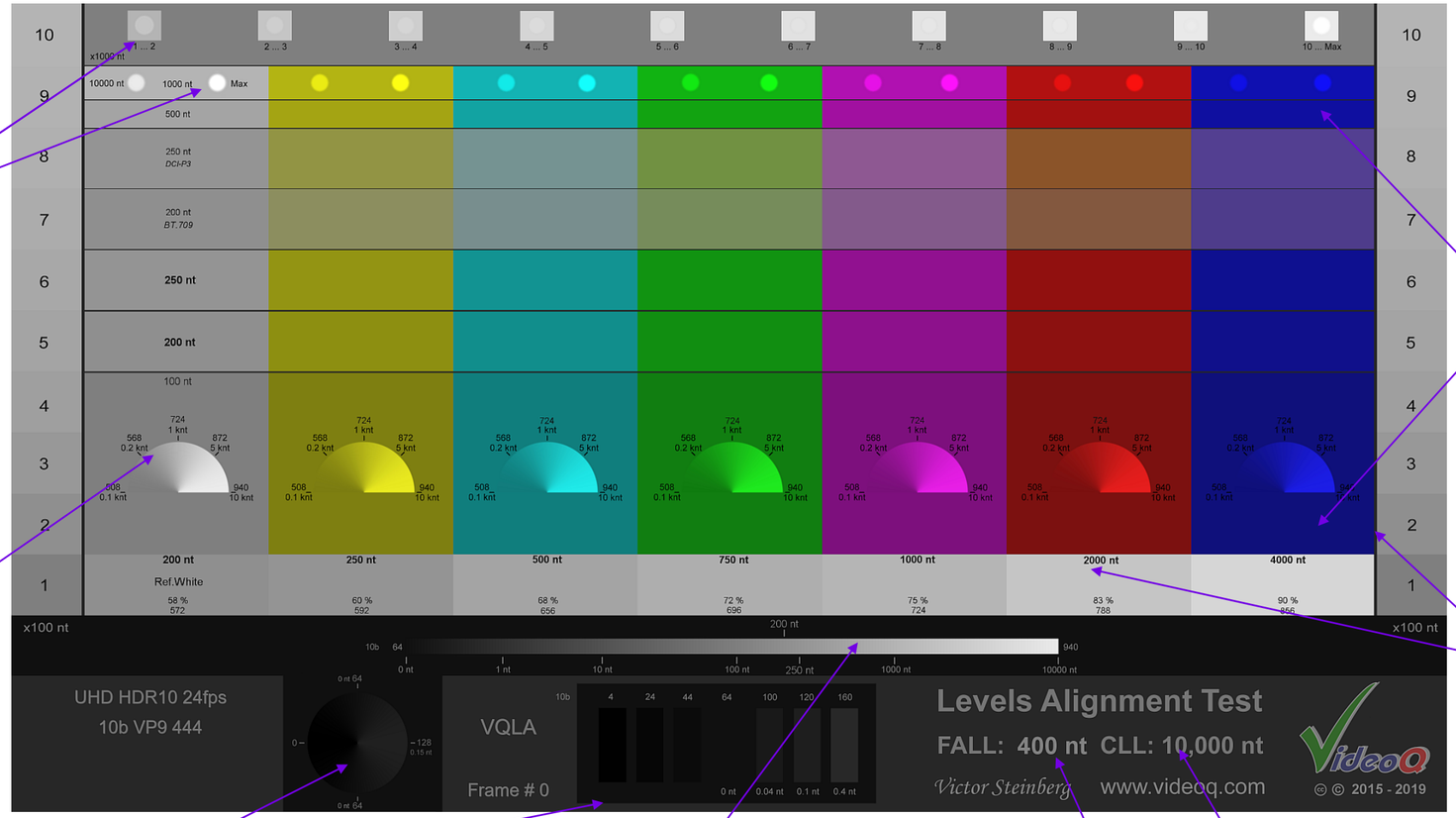
4.1 VQLA-HDR10 (PQ) version

TOC4

4.2 VQLA-HDR10 Test Composition



10 Two-tones Patches
and **14 Overload Indicators**
aimed at testing
Display Clipping Levels

7 White SPLUGE
Conical Grayscales
aimed at testing
Display Clipping Levels

Special set of **HDR Color Bars**
aimed at testing
Display Light Output Profile
and **Color Space Conversion**

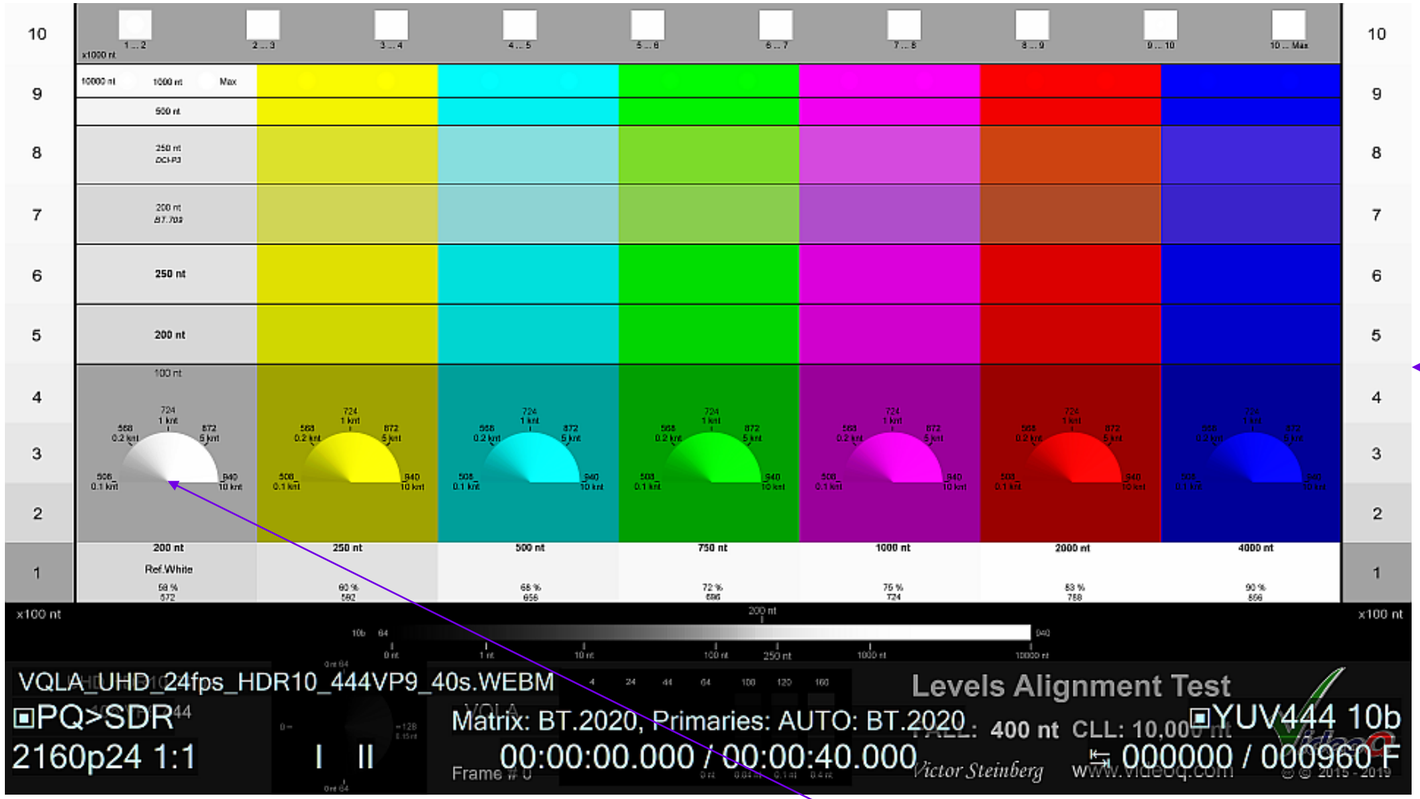
Special **HDR Grayscales**
(light and signal levels set)
aimed at testing
Display Light Output Profile
and **Clipping Levels**

Black PLUGE rectangles and
Black SPLUGE Conical Grayscale
on **Reference Black** background
aimed at testing
Display Min Brightness

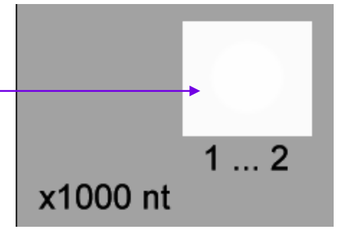
Valid Range 10 bit Linear Ramp
with critical levels markers
aimed at testing
Display Tone-mapping Uniformity
(checking the “banding” artifacts)

Precise **FALL & CLL r**eadout
aimed at calibration & testing of
Content Levels Analyzers

4.3 VQLA Usage Example: HDR10 to SDR Conversion

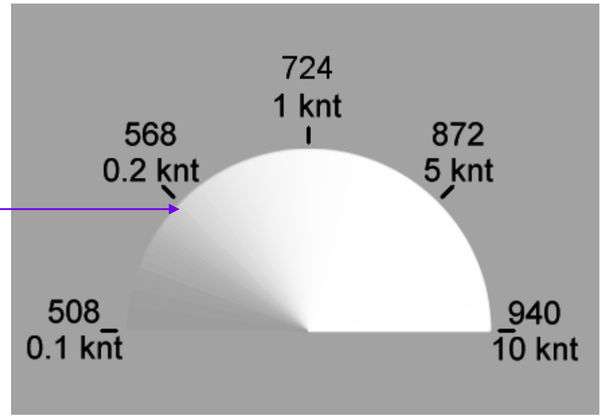


1 ... 2 knt Two-tones Patch:
2 knt Circle within 1 knt Square
is not visible, i.e. clipped at 1knt level



0 ... 1 knt Grayscale:
shows that all levels above
500 nit are clipped

0.1 ...10 knt White SPLUGE:
shows soft clipping above the
Reference White Level of 200 nit and
hard clipping above 500 nit



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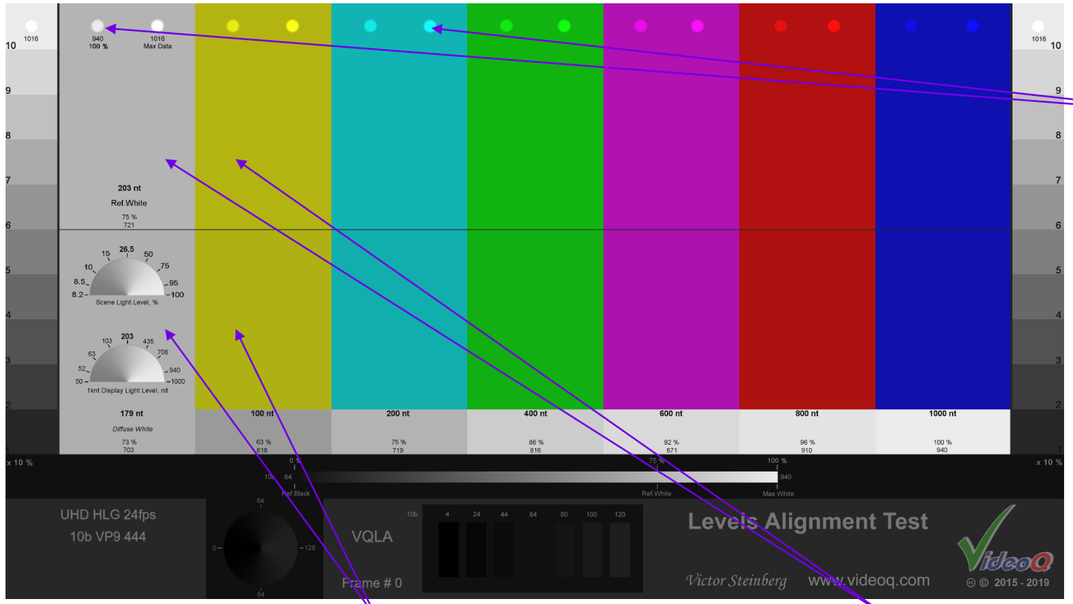
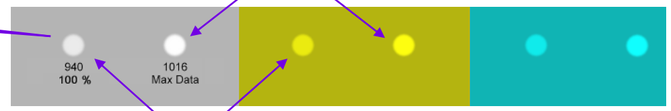
4.4 VQLA-HLG version

4.5 VQLA-HLG Test Composition



Video Data Range Upper Limit: RGB Max = 1016 (10 bit)



Maximum White: RGB Max = 940 (10 bit)

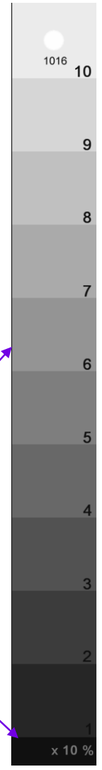
Small circles at the top of each bar represent specular highlights going beyond the legal range.
Display shall exhibit correct response:
The highlighted circles should be clipped to some level above the level of the corresponding bar, without any noticeable artifacts.

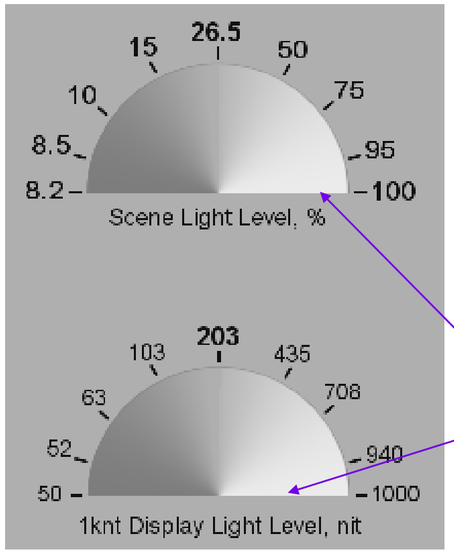
“Diffuse White” Color Bars Signal Level 73%

BT.2111 Color Bars Reference White Signal Level 75%

7 steps Grayscale aimed at testing **Display Gradations Mapping**

10 steps Grayscale aimed at testing **Signal Levels**





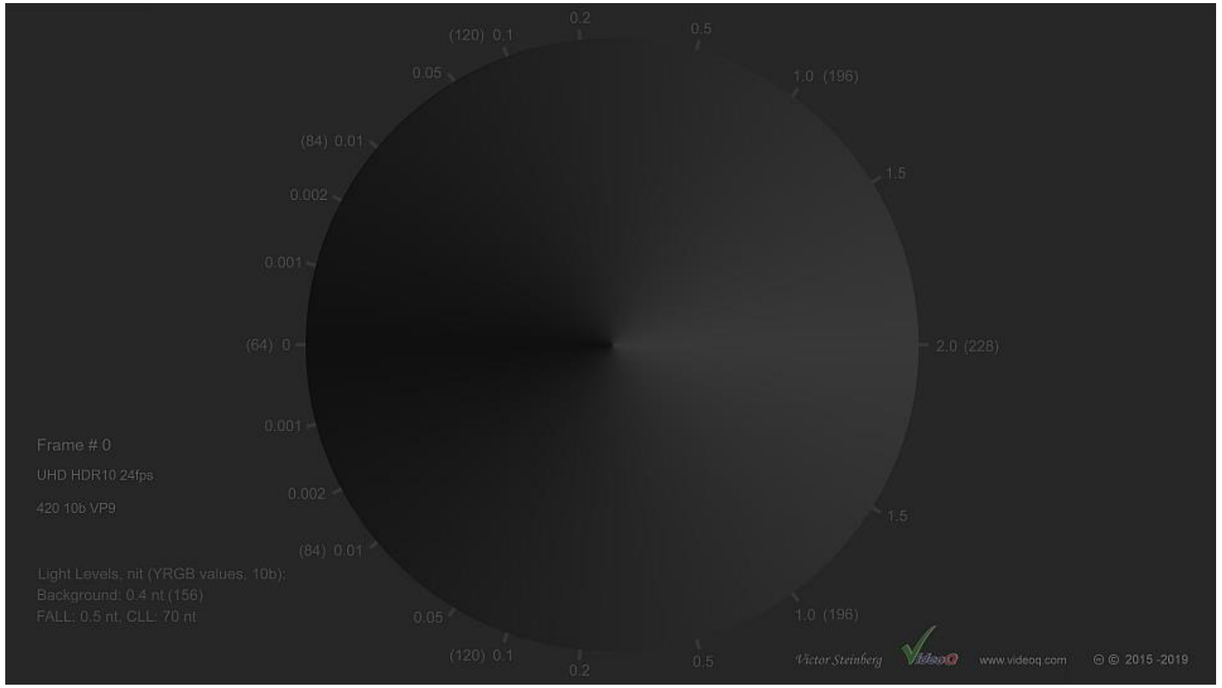
2 White SPLUGE
Conical Grayscales
aimed at testing
Display Clipping Levels

Two identical grayscales, different units:
- **Scene Light Level** in percents of max LL
- **1knt Reference Display LL values** in nits

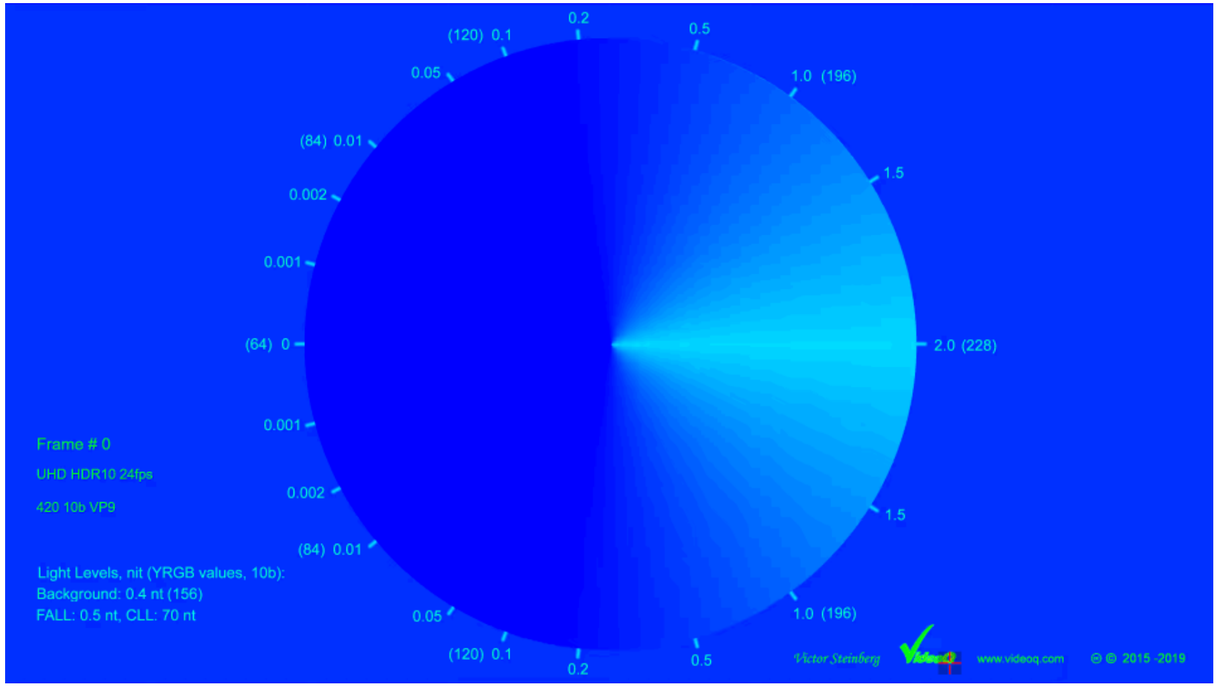
179 nt	100 nt	200 nt	400 nt	600 nt	800 nt	1000 nt
Diffuse White						
73 % 703	63 % 616	75 % 719	86 % 816	92 % 871	96 % 910	100 % 940

5. VQSP – Very Low Light Levels Test

Raw YUV Data Image



VideoQ VQV “Heat Map” Image



If the processing chain preserves the full 10 bit resolution and the display black level cut-off point setup is correct (i.e. the display under test EOTF complies with the standard PQ curve), then all the gray levels, even the very low, e.g. 0.001 nt, should be visible.

This test is for viewing in a dark room (i.e. very low ambient light levels), and the observer should be given enough time for the visual system adaptation to these conditions. Rendering of low light levels is relatively easy for not so bright displays, for brighter displays this test would be much more challenging.

6. VQAPL – Dynamic Average Light Level Test

Part 1/15 – lowest FALL value = **75nt** (Window LL = **0nt**)

Part 15/15 – highest FALL value = **6340nt** (Window LL = **10knt**)

Time

This dynamic sequence serves to test the display's auto-brightness control (ABC) and auto-brightness limiting (ABL) systems. It consists of 15 parts with different brightness levels of the large window surrounding central photo insert. Each part is displayed for 4s, total test sequence duration is 60s.

Modern HDR displays may include eye safety and power consumption protective measures, e.g. automatic reduction of the light output, when the content variable light level (FALL value) goes above some threshold.
However, such protection should not be accompanied by a significant distortion of the central insert image, and the recovery time (recovery here means full return to normal mode after FALL value drop-down) should not be too long.

7. About VideoQ

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

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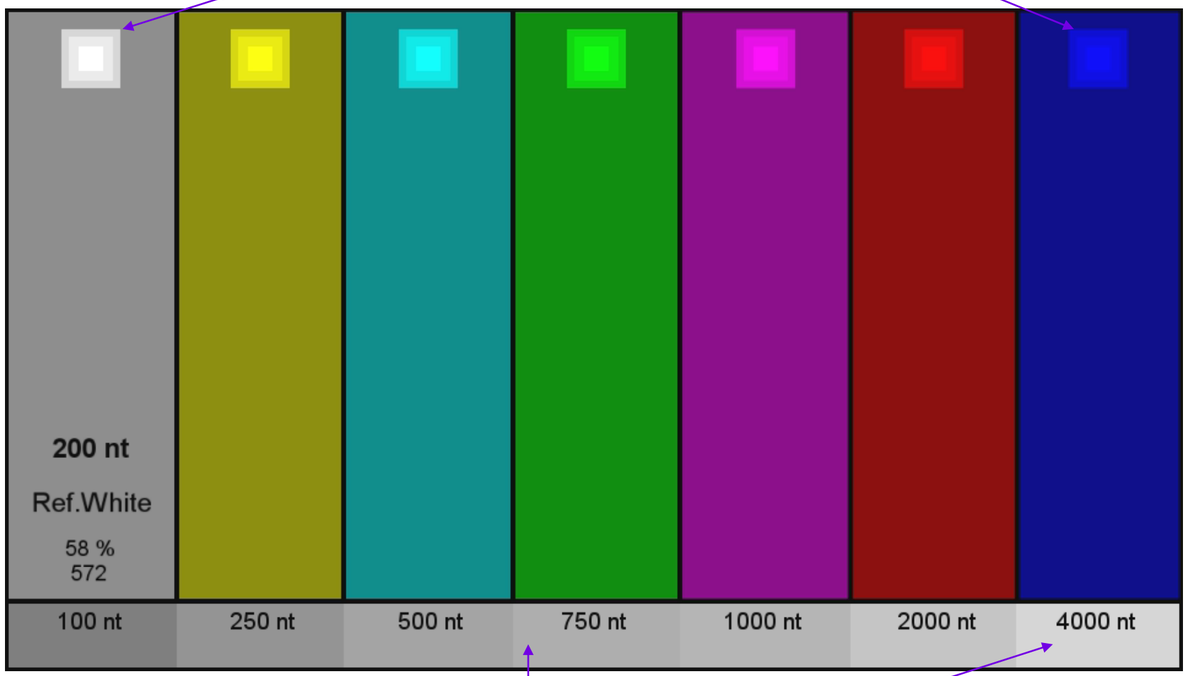
8. Appendix A: VQMPC Test Details

8.1 VQMPC: HDR Color Bars Details and Usage

7 **White PLUGE** components (nested squares)



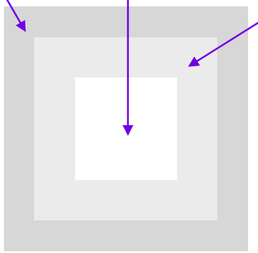
7 steps **HDR-PQ Grayscale**
features critical Light Levels up to 4000 nt

White PLUGE 10 bit levels:

860

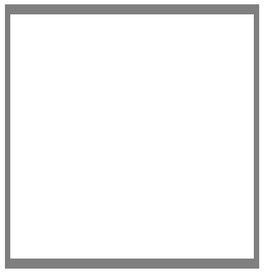
1016 = upper limit of full 10 bit video data range

940 = upper limit of valid (“Narrow”) 10 bit video data range



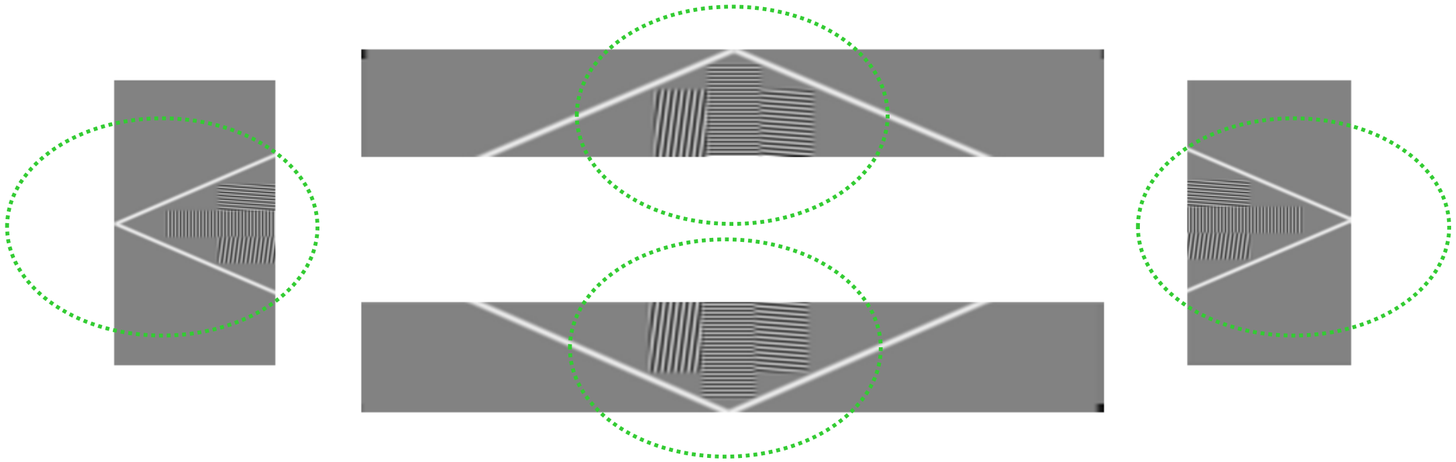
Case 1:
The HDR display renders the full 10 bit video data range **without clipping at the level 940**; this is **not allowed** by any HDR standard (PQ or HLG)

Case 2:
Clipping at 10 bit value of 940 as required by HDR standard:
- It is normal for **all HLG** displays,
- It is also normal for the **PQ displays capable of rendering the full valid range**, i.e. if **TDMB = 10,000 nit**

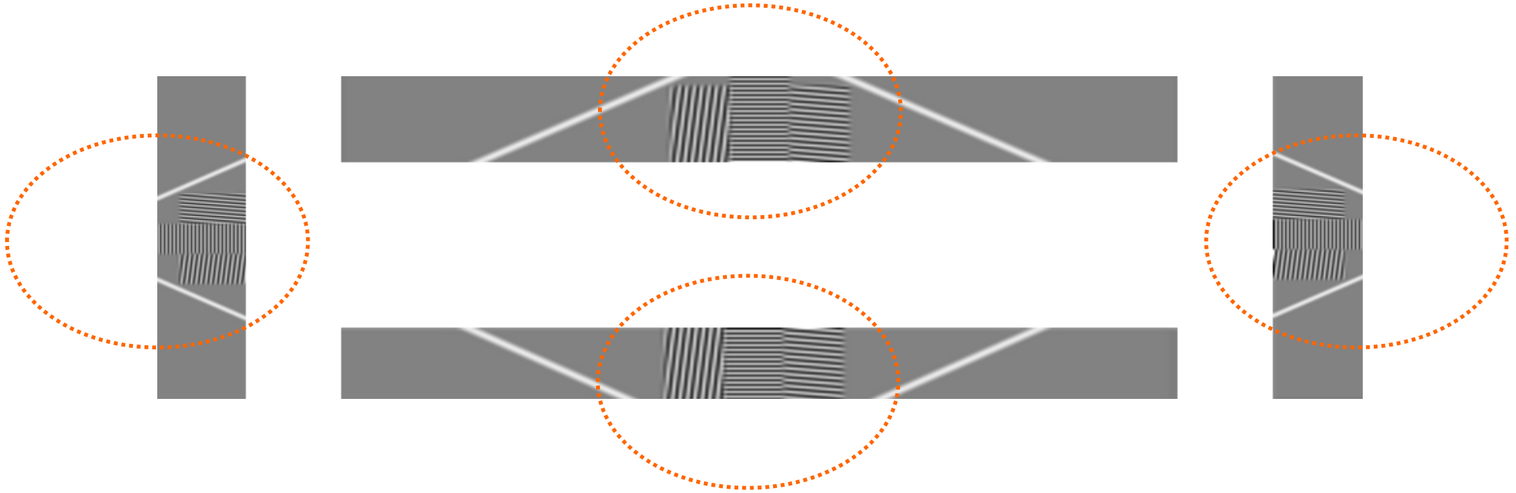


Case 3:
The display is not rendering full valid range;
the clipping is at a video level much lower than 940:
- It is **not normal** for any **HLG display**,
- It is **normal** for the **PQ displays** with a **TDMB < 10,000 nit**

8.2 VQMPC: Diamond Pattern and Crop Markers Usage

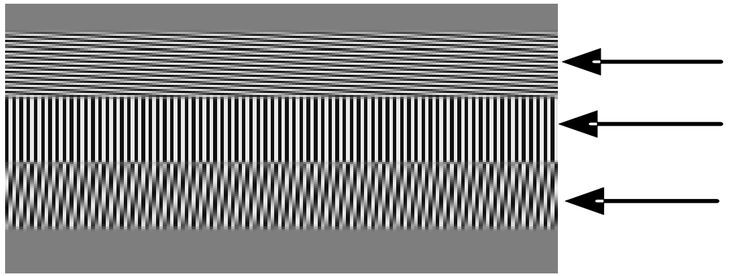


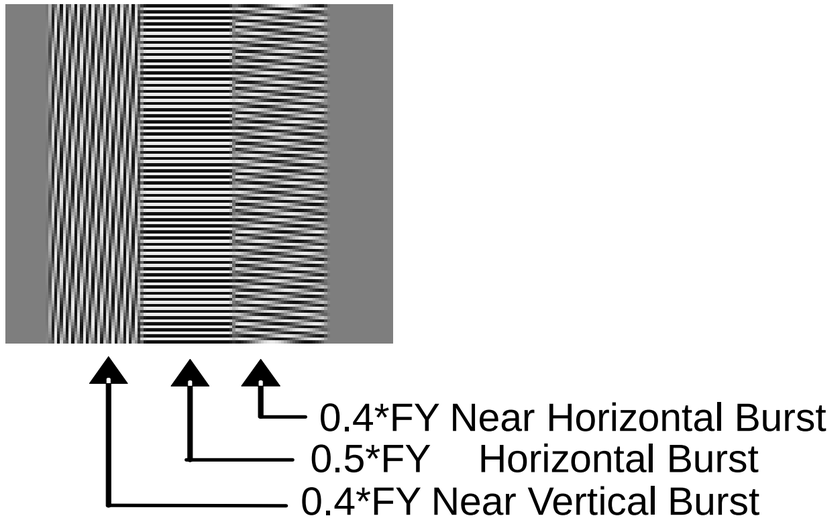
Example of correct settings (no cropping):
All picture edges are not cropped and single pixel white markers are visible



Example of incorrect settings (with cropping):
Picture edges are cropped

8.3 VQMPC: Tri-band Bursts Pattern





There are two groups of bursts with frequencies proportional to luma pixels rate **FY**:
full length horizontal bursts band and **full height vertical** bursts band.
Maximum luminance frequency burst of exactly **0.5 FY** is in the middle of each band.

Two slightly oblique bands of 0.4 FY surrounds the middle burst.

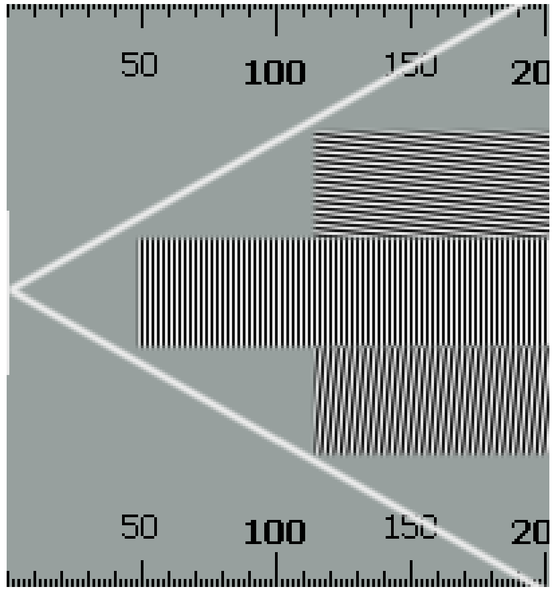
Two **central 0.5 FY sub-bands** are especially sensitive to any errors in **pixel clock**, **mapping** or **scaling**.

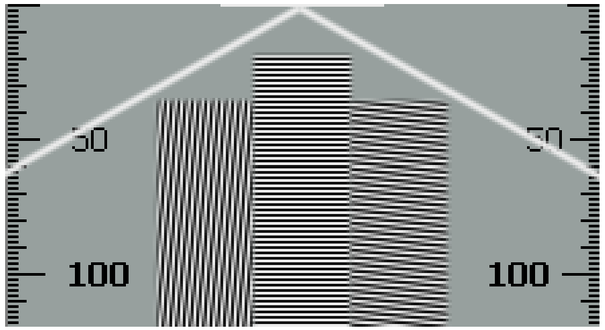
Four other sub-bands allow differentiation between horizontal and vertical distortions thru the whole picture area – from left picture edge to the right picture edge and from top to bottom.

Within the burst vertical and almost **vertical lines** test **horizontal frequencies**,
whilst horizontal and almost **horizontal lines** test **vertical frequencies**.

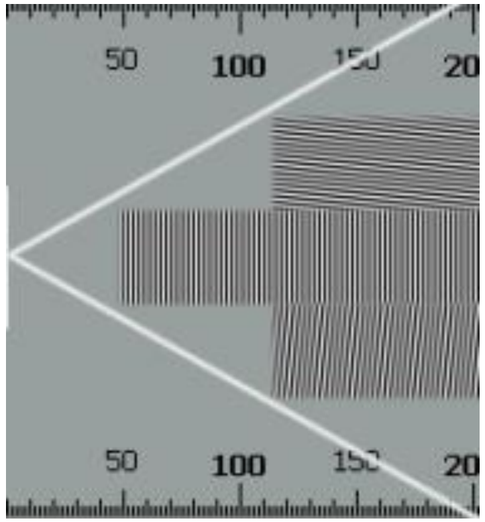
8.4 VQMPC: Tri-band Bursts Pattern Usage

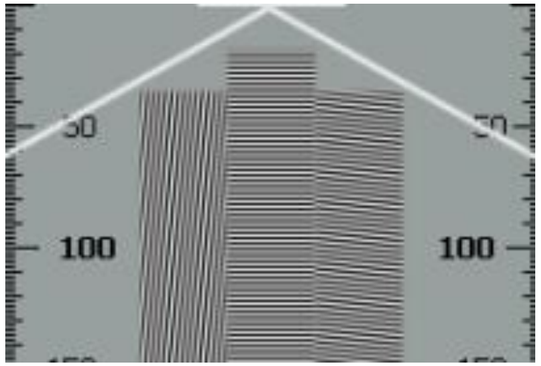
Example of correct settings (no scaling):
There are no visible beat waves on both horizontal and vertical Tri-band Patterns



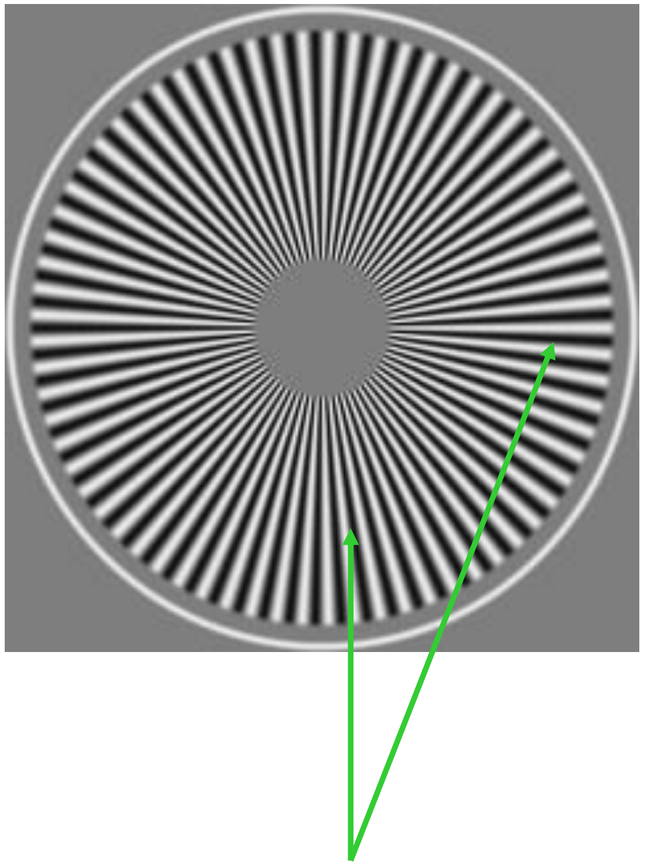


Example of scaling artifacts:
Scaling causes beat waves on both horizontal and vertical Tri-band Patterns

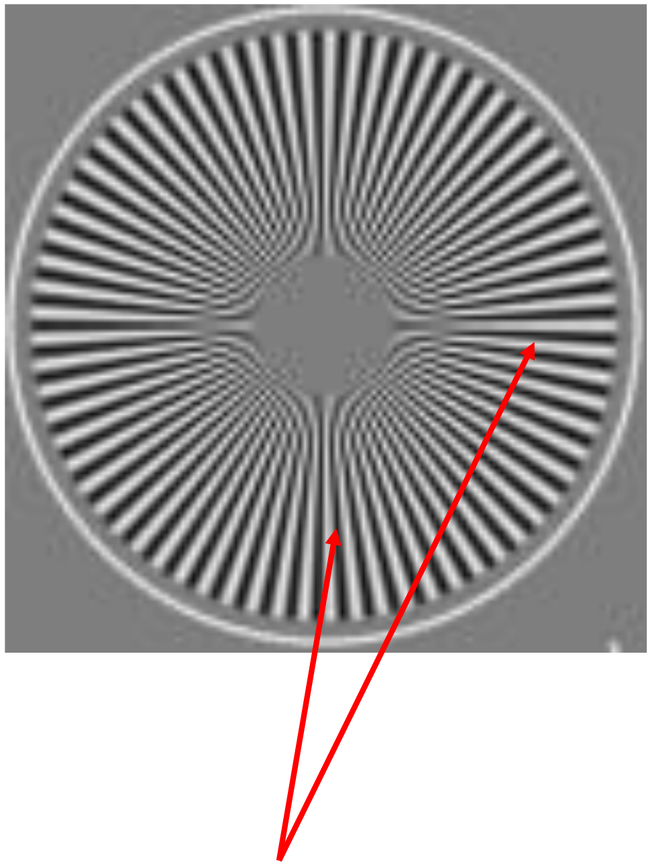




8.5 VQMPC: Radial Plates Usage



Original Size – dot-by-dot:
Full contrast of **fine details** in all directions



Scaled (Up or Down) Picture,
or **Sharpness Correction** sub-optimal settings:
Loss and/or **distortion** of **fine details**

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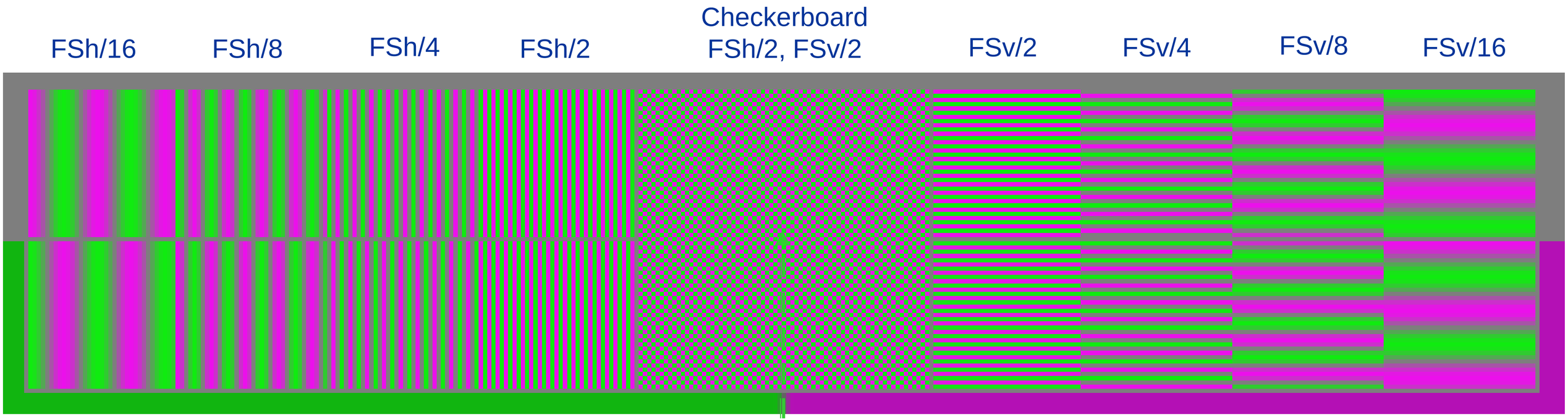
8.6 VQMPC: Chroma Sampling Test Details

FSh: Original Horizontal Sampling Rate

FSv: Original Vertical Sampling Rate



4:2:2 and 4:1:1 (UV horizontal sub-sampling) Detection Area

4:2:0 (UV vertical sub-sampling) Detection Area

H & V Scaling Detector Area looks like checkerboard only in absence of any conversion vs. pristine 4:4:4 YUV/RGB

8.7 VQMPC: Chroma Sampling Test Usage Example

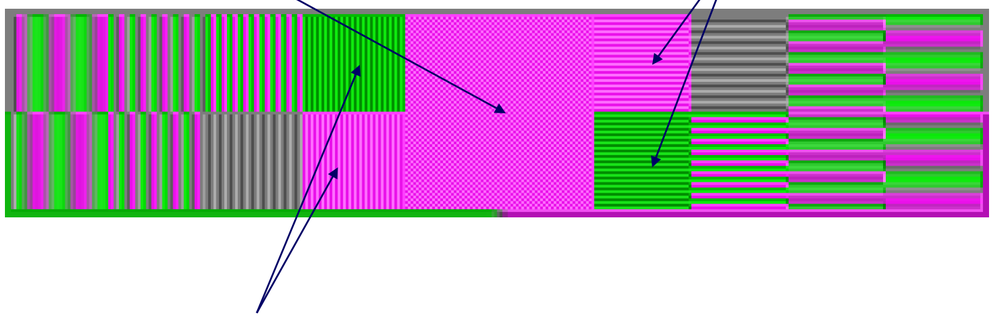
Test appearance after UV sub-sampling without pre-filtering

Case #1

Dedicated areas indicate different sub-sampling issues:

Pristine *4:4:4?* **No**

4:2:0 (UV vertical sub-sampling)? **Yes**



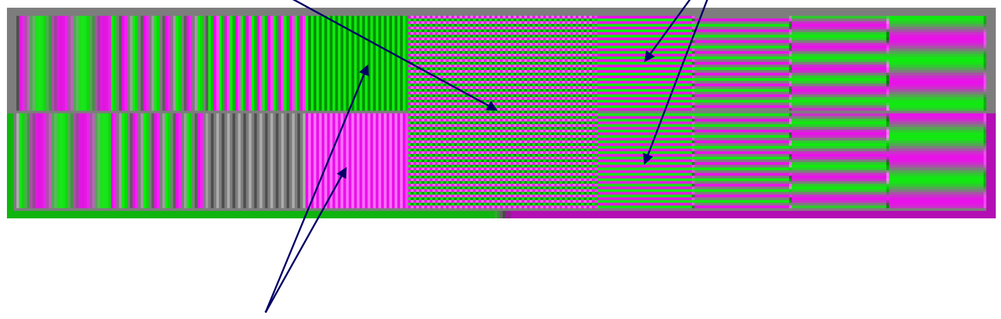
4:2:2 *or* 4:2:0 (UV horizontal sub-sampling)? **Yes**

Sampling Conversion Test Result:
4:2:0 sub-sampling mode detected

Case #2

Pristine *4:4:4?* **No**

4:2:0 (UV vertical sub-sampling)? **No**



4:2:2 *or* 4:2:0 (UV horizontal sub-sampling)? **Yes**

Sampling Conversion Test Result:
4:2:2 sub-sampling mode detected

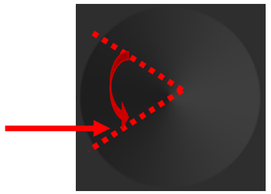
8.8 VQMPC: Black PLUGE & Black SPLUGE Usage

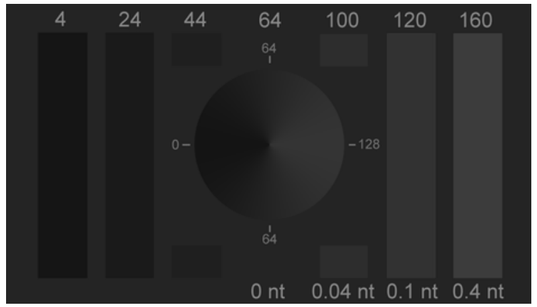
Fine Tuning (SPLUGE)

Coarse Tuning (PLUGE)

Brightness is **too high**

Clipped sector (with no shades of gray) is much less than 180 degrees

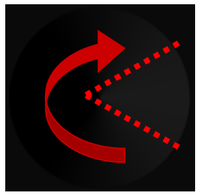


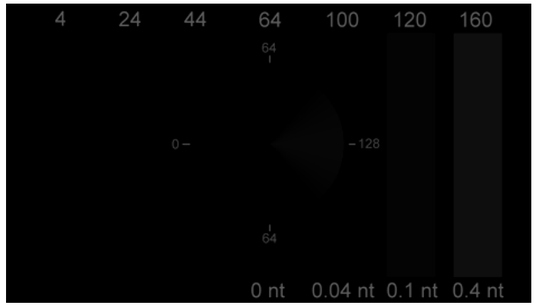


All rectangles on the right and some rectangles on the left are visible

Brightness is **too low**

Clipped sector (with no shades of gray) is much more than 180 degrees

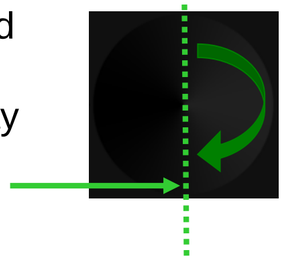


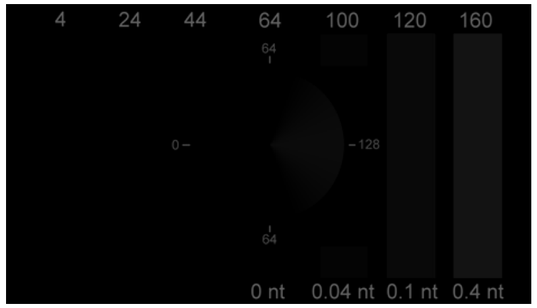


Not all rectangles on the right are visible

Brightness is **correct**

Conical grayscale is clipped exactly half-circle (180 degrees), no shades of gray on the left half





All rectangles on the right are visible and all rectangles on the left are not visible

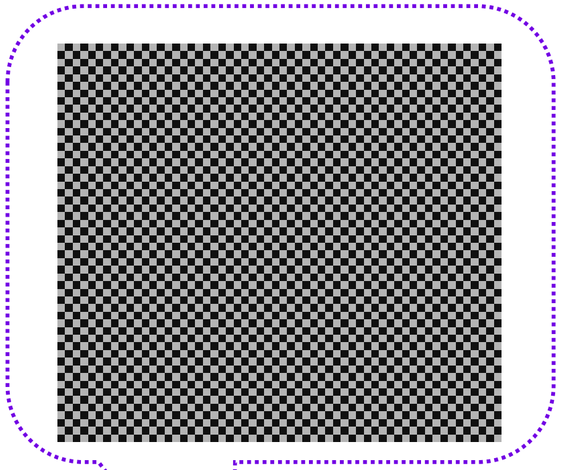
Note that some versions
do not contain PLUGE or fine tuning SPLUGE components

8.9 VQMPC: OETF Test Details and Usage Example

All 3 Checkerboards have the **sampling limit** frequencies: FSh/2, FSv/2

FSh: Original Horizontal Sampling Rate
FSv: Original Vertical Sampling Rate

*Note that this test can be used only for full **native** resolution displays and all sharpness correction and gamma curve controls should be switched **off**.*



Case #1:
Checking that the selected display mode matches the HDR10 (PQ) test file metadata.

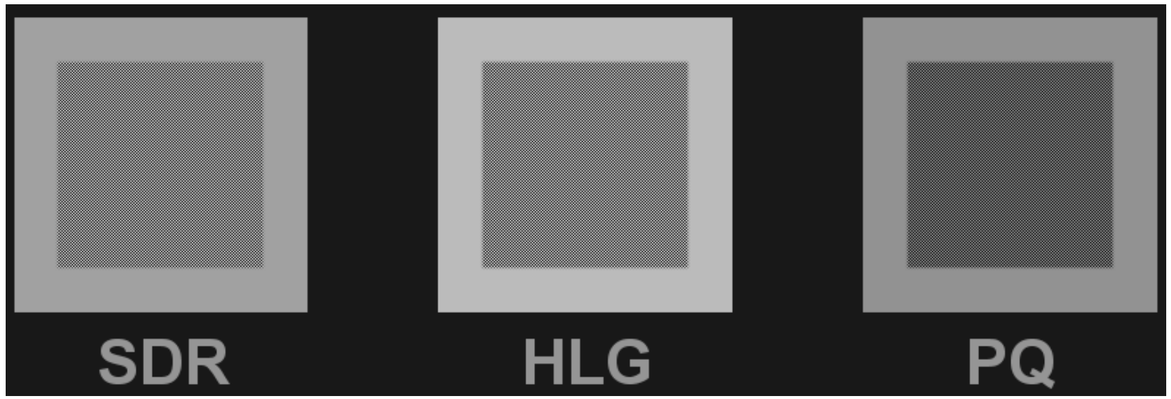
SDR and **HLG** squares show much higher contrast than the **PQ** square:

Test result: **Correct OETF Mode (PQ)**

Case #2:
PQ and **HLG** squares show much higher contrast than the **SDR** square.

Thus, the display under test is in **SDR** mode, **not matching** the **PQ** file metadata

Test result: **Wrong OETF Mode (SDR)**



For an average human observer the high frequency checkerboard textures are visible only from a very small viewing distance. From a normal viewing distance all central squares look like shades of solid gray.
If the display OETF complies with the standard curve, then the corresponding checkerboard average gray level should match the appropriate square background level, i.e. the contrast of this central square vs. the background is minimal.

TOC9 <— *Click on **TOC9** for the **Section 9 TOC***

9. Appendix B: Additional Tools

The following slides contain the description of VideoQ Test Patterns and tools recommended for pre-testing prior to the full HDR test procedures.

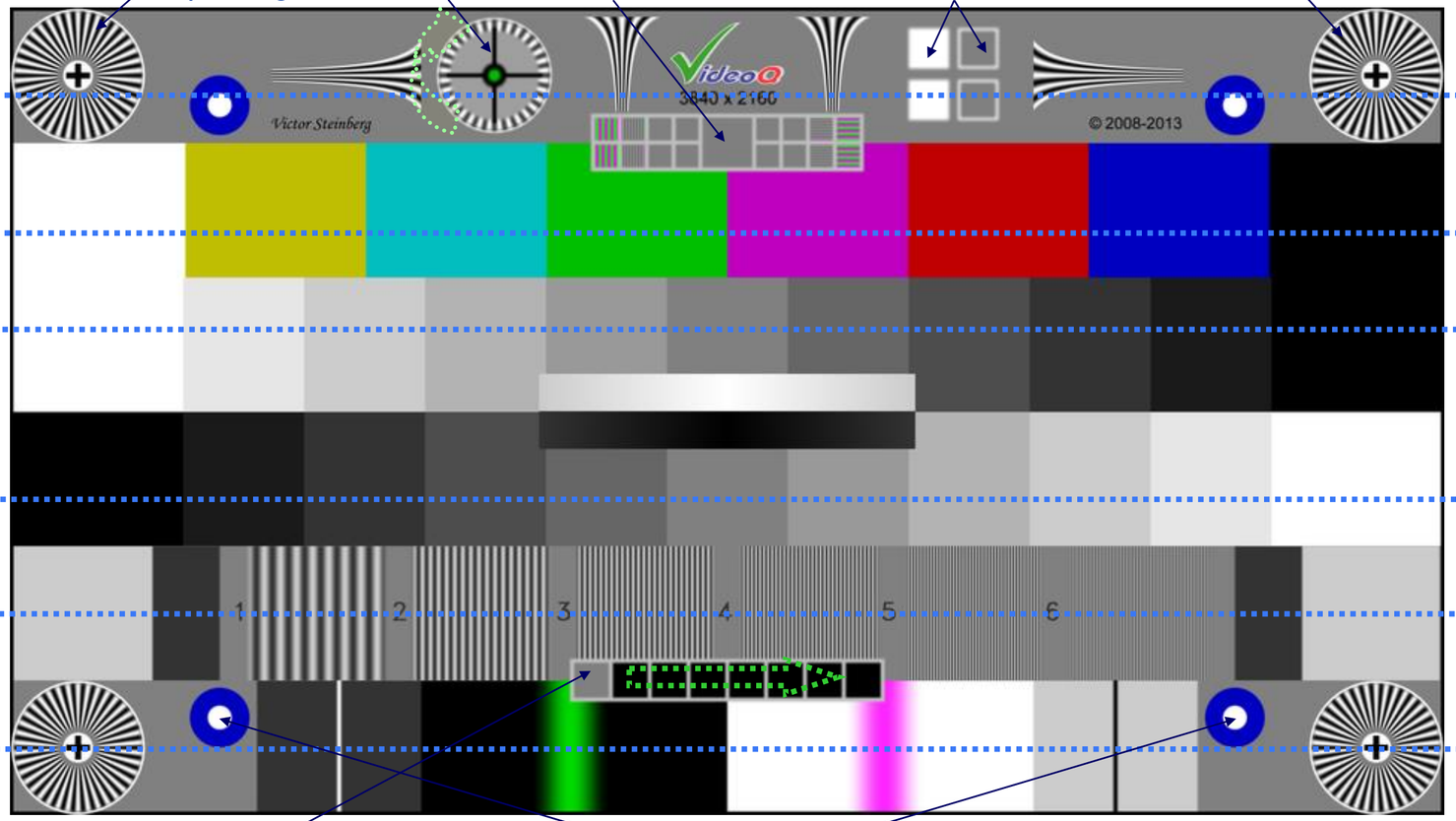
9.1 VQMA – Matrix Test Pattern for Automated Analysis

All-In-One: Single pattern allows automatic measurement of multiple video signal parameters

Radial Plates x4 for visual estimation, camera shading and sharpness measurement

Test Signals:

Parameters:



9.2 VQL, VQMA, VQV – Workflow

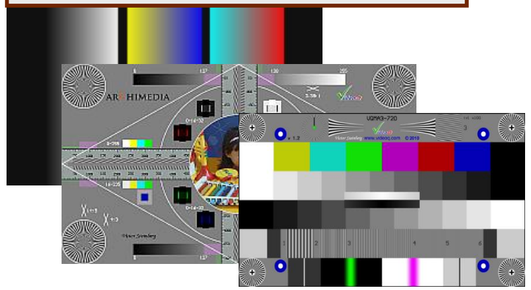
Test Setup

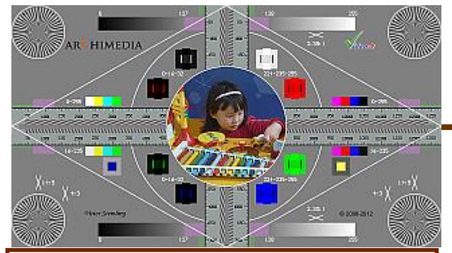
Main QC Monitor

HDMI / SDI

HDMI / SDI

Test Patterns Library





Test Pattern File
selected by User

Master Player

Devices Under Test

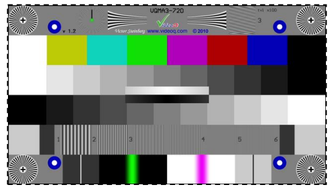
Video Player

Processor, Encoder

SW Video Encoder

Capture Card

Reference Decoder



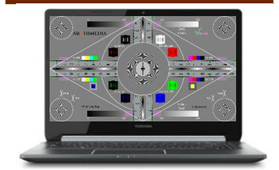
Captured YUV Data File

More QC Tools

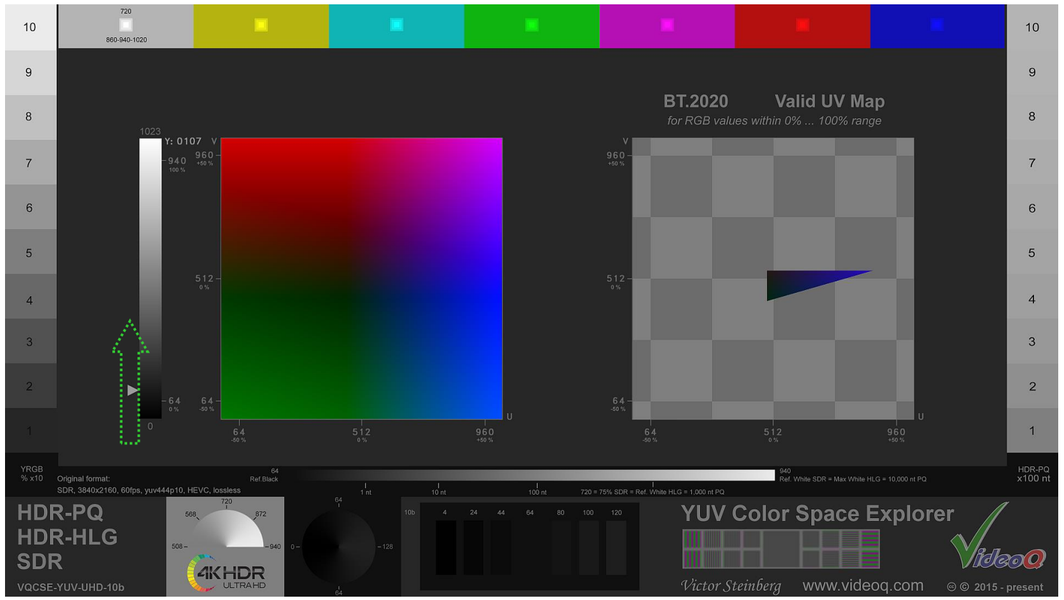
VQMA Analyzer

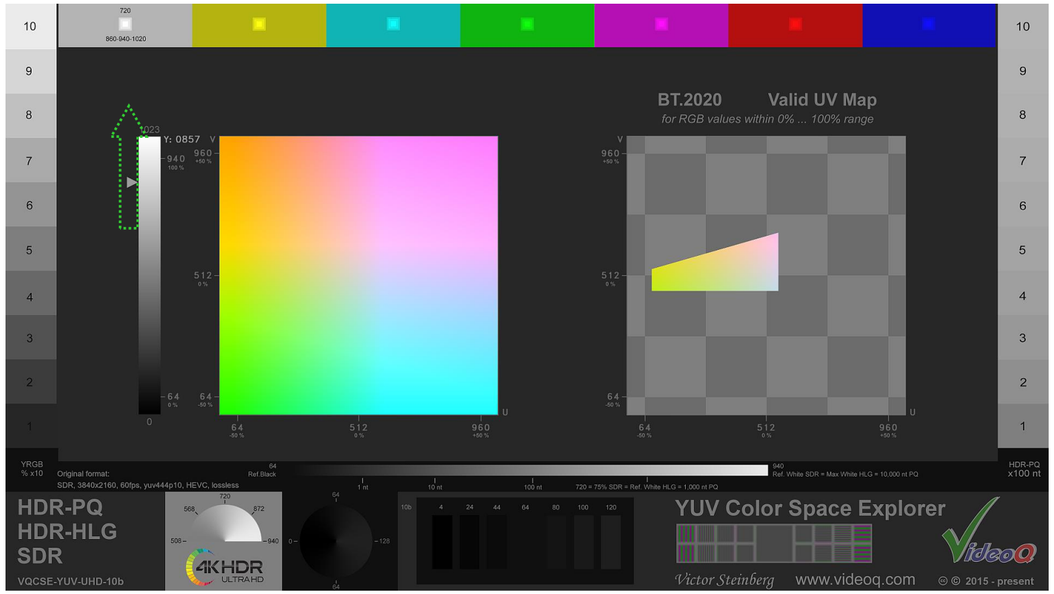
VQMA Test Reports

VQV "Visualizer"



9.3 VQCSE – Color Space Explorer Dynamic Test





Time

In few seconds this sophisticated dynamic UHD test checks more than one billion (1024^3) colors of the **10 bit YUV** or **10 bit RGB** color space. For example, the VQCSE_YUV variant covers all combinations of Y, U and V values – from 0 to 1023, including all “illegal” colors.

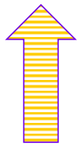
For any given Y 10b value “Valid UV Map” on the right side shows the boundaries of “legal” colors area.

VQCSE is equally suitable for **SDR**, **HDR-PQ** and **HDR-HLG** systems, checking processors, codecs and display performance.

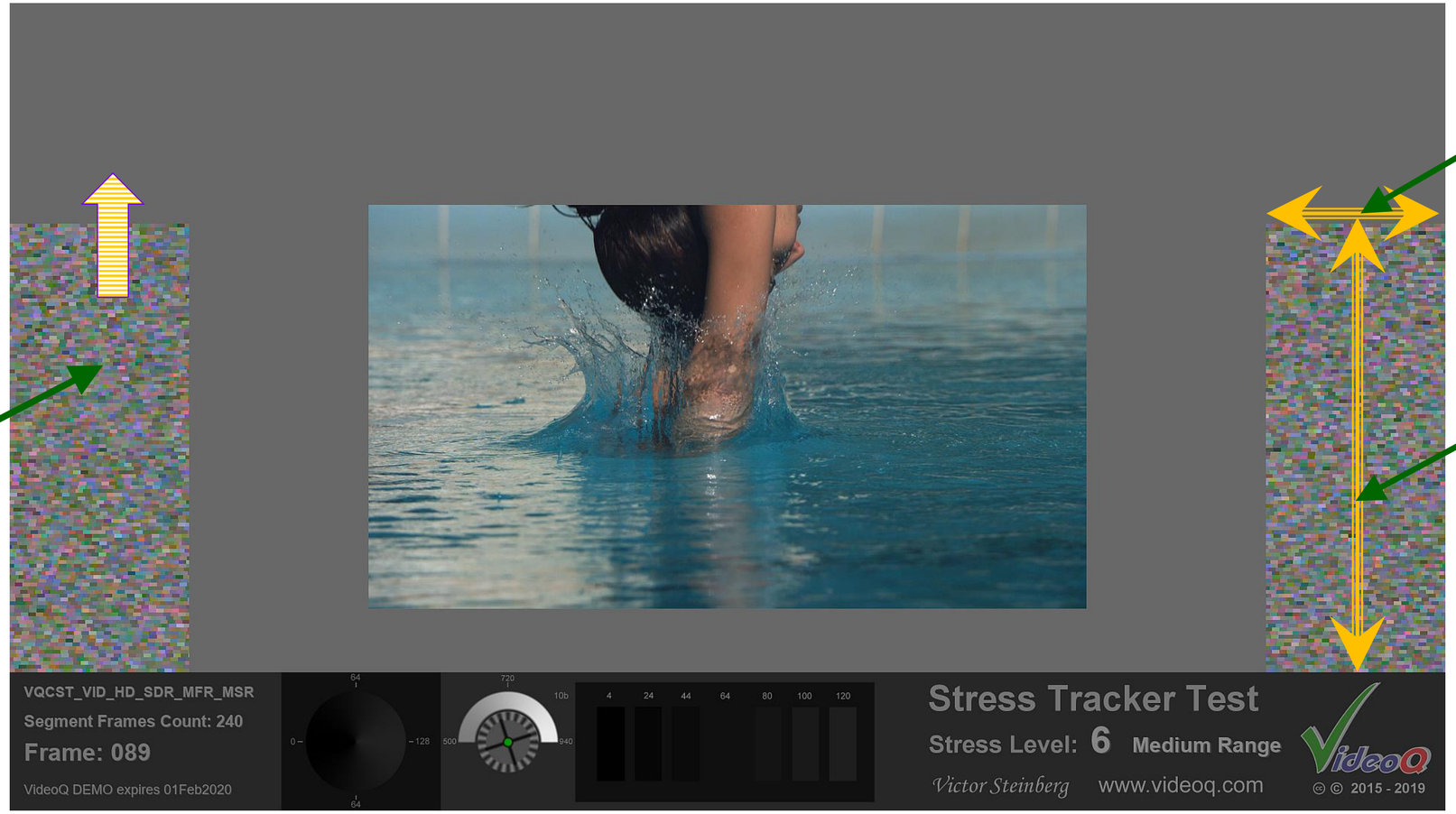
It is suitable for both visual and instrumental tests, the results are visible on regular video monitors, waveform monitors and/or vectorscopes. VQCSE is especially efficient in combination with *the VideoQ **VQV** Viewer-Analyzer tool*.

9.4 VQCST – Dynamic Test for Compression Codecs

Stress Level
rising



Pseudo-random color shapes: ***calibrated*** stress source



Switchable **Stress Ranges**: Low, Medium, High

Variable **Stress Level**: from 0 to 9

VQCST is a sequence of **10 Segments** (**10 Stress Levels**), each segment duration: 4.0, 4.8 or 5.0 seconds. Total sequence duration is 40, 48 or 50 seconds, depending on the selected frame rate.
Stress Tracker ™ test is suitable for **subjective image quality estimation** in real time and for **automated** measurement of **Stress Response Profile**.
It is possible to play infinite loop of each segment or infinite loop of the full sequence.

9.5 VQFCT – Frames Continuity and Packet Loss Test

VQFCT test features rotating wheel clock, scrolling medium frequency diagonal sinusoidal pattern and frame counter display.

This simple test provides for checking the video communication systems performance in the congested network conditions. Even intermittent or partial disruptions of the smooth timeline progress, e.g. frozen image slices due to the network packets loss, are easily noticeable. It is equally suitable for visual estimation and automated monitoring (watchdog functionality).