4K imaging technologies, in a changing context
In this presentation

- Context items
- Who is “pushing” Ultra HD?
- Ultra HD technologies
- Equipment characteristics
- Metrics and measurements
- Beyond 4K
- In concluding

4K imaging technologies, in a changing context

Views and opinions expressed during this SMPTE presentation are only mine and do not necessarily reflect those of the SMPTE, my employer, our host tonight, my wife ... Any reference to specific companies or products does not represent promotion, recommendation, or endorsement ...
Ultra HD TV

Broadcasting is all about CONTENT

What the media are talking about?

Approx. one in every eight North American homes should own an Ultra HD TV (by the end of 2016)

By 2020, almost half of all North American homes will own at least one Ultra HD TV

Recent research by Strategy Analytics

Newer “high-end” models:

Image Resolution: 3840x2160 pixels
Bit Depth: (from 8 bit to) 10-bit
Interface: HDMI 2.0a
Wider Color Gamut: More than 90% of (DCI) P3 color space
Higher Dynamic Range: 0.05 (black level) to 1000 nits peak or 0.0005 (black level) to 540 nits peak
Because of the new media market paradigms
AT THE SAME TIME, WE HAVE TO ...

Simplify infrastructure:
- Rationalize and downsize while offering the best quality possible

Adopt new technologies when relevant.
Criteria:
- Consumer market and concurrence (traditional broadcasters and CDNs)
- Affordability, reliability and inter-vendors compliancy
Thoughts

Chaos (Kā,āś)

GETTING READY FOR CHANGE

Context and Technology

Media ecosystem

Rapid on-going change

“All great changes are preceded by chaos.”

Deepak Chopra

Some “iconic” companies founded economic recessions: Disney, Microsoft, Apple, 20th Century Fox, Autodesk, Adobe ...

“In the middle of difficulty, lies opportunities.”

Albert Einstein

My goal is to identify and thwart my potential enemies to ensure survivorship.
Was 3D TV a mistake preventing us to go further?

A person who never made a mistake never tried anything new

Albert Einstein

We are not alone, anymore...
A first since the advent of television ...

Technical quality

- Ultra HD / UHD
- HD Prosumer and Pro AV
- Blu-ray Disc
- TV Broadcast

In the near future, will we be able to offer more than 1080i/720p, 4:2:0, 8 bits MPEG2 @ 19 Mbps (100 nits)?

Consumer confusion

- Which Set-up box?
- Which Smart TV OS?
- Ultra HD, UHD, 4K?
- Screen size vs. viewing distance?
- Decoder issue (H.265 compliance)?
- Available content? (and from whom?)
- What refresh rate?
- Max. frame rate?
- Standard or high dynamic range?
- Which dynamic range standard?
- TV speakers or external sound system?
- Stereo, 5.1 surround, 7.1 surround or 7.2.4 Atmos™ sound?
- Which HDMI input connector? (version 1.4b, 2.0 ...)
The “Babel Tower” Syndrome

Example

Too many “standards”
Too many technologies evolving too rapidly
Compliancy and reliability issues
Discrepancies between CDNs, broadcasters and vendors
Non consistent vocabulary

25￠ ou
30 sous?

Threat: Not understanding each other anymore

Fear of the “Plate Spinning Syndrome”

Perpetual “potential crisis” management
One unit fails = everything falls apart
MONTRÉAL January 31 2017

Fear: reliability of IT centric IP based devices

If this is the first time you've seen this error screen, restart your computer. If this screen appears again, follow these steps:

Check to make sure your boot volume is not sized too small. If this is a new computer or one that was created for a Windows manufacturer, you may need to contact them for information.

If problems continue, contact your local computer repair shop or software provider. Do not continue working. If you need to, restart your computer, select Safe Mode and then try again.

Technical Information:
*** STOP: 0x000000ED (0x80F128D0, 0xc000009c, 0x00000000, 0x00000000)

Our requirement: Same reliability requirements as for hardware specific devices

MONTRÉAL January 31 2017

Almost impossible for private producers?

Example: Alister Chapman demo of Ultra HD + HDR for “small producing firms”
External recorder with waveform, histogram and parade (incl. LUT)

Camera with SLog3, XAVC and RAW output, 4:1 compression

Computer with NLE and color correction (HLG render option)

To monitor Log content

SLog3 without LUT on a BT 709 SDR display

SLog3 with LUT on a BT 709 SDR display
Who are “pushing” this Ultra HD technology?

“Closing the loop” for UHD implementation success

Consumer Electronics
(Ultra HD TV sets)

Who are the 3 stakeholders needed to enable Ultra HD services @ homes?
Are traditional broadcasters part of the initial steps?

The new players in the TV ecosystem

CDNs or Content Delivery Networks
(VOD via the Internet)

”Scripted Content”
Film/TV Producers
(File based)
A forum is bringing together market leaders from every part of the industry to accelerate Ultra HD deployment.

**UHD Phase A Definition**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial Resolution</strong></td>
<td>2160p or 1080p if includes WCG and HDR</td>
</tr>
<tr>
<td><strong>Color Gamut</strong></td>
<td>BT.709, BT.2020</td>
</tr>
<tr>
<td><strong>Bit Depth</strong></td>
<td>10-bit</td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>SDR, PQ, HLG</td>
</tr>
<tr>
<td><strong>Frame Rate</strong></td>
<td>24, 25, 30, 50, 60 (may include fractional – not preferred)</td>
</tr>
<tr>
<td><strong>Video Codec</strong></td>
<td>HEVC, Main 10, Level 5.1</td>
</tr>
<tr>
<td><strong>Audio Channels</strong></td>
<td>Stereo or 5.1 multi-channel audio</td>
</tr>
<tr>
<td><strong>Audio Codec</strong></td>
<td>AC-3, EAC-3, HE-ACC, AAC-LC</td>
</tr>
<tr>
<td><strong>Captions/Subs Coding</strong></td>
<td>CTA-608/708, ETSI 300 743, ETSI 300 472, SCTE-27, IMSC1</td>
</tr>
</tbody>
</table>
Are CDNs real competition for TV broadcasters?
In HD (1080p) and Ultra HD (2160p)

Netflix won Best Series win for drama: The Crown, at the Golden Globe Awards 2017

What are the “usable” Ultra HD technologies?
N: 4096 X 2160p (1.90:1)
S: 4096 X 1716p (2.39:1)
F: 3996 X 2160p (1.85:1)
JPEG 2000 DCI P3 24 fps
3.0 to surround audio

A format for “theatrical” cinematography, only

Advocacy for 4K Theatrical Projection
A “Newcomer” in the Media Ecosystem

- UHD<sub>1</sub> and UHD<sub>2</sub> Standard ST 2036 for TV
- UHD<sub>1</sub> 3840 x 2160 pixels (16:9 / 1.78:1)
  UHD<sub>2</sub> 7680 x 4320 pixels (16:9 / 1.78:1)
- 23.98, 24, 25, 29.97, 30, 50, 59.94, 60, 100, 119.88, 120 fps
- ITU-R BT. 2020 / 2100 color spaces
  12/10-bit, 4:2:2/4:2:0
- Audio mapping: 22.2 channels
  16, 20, 24 bits – ITU-R BS. 2159-4

MONTRÉAL
January 31 2017

UHD TV Quality Factors

Spatial Resolution (Pixels)
HD, FHD, UHD<sub>1</sub>, UHD<sub>2</sub>

Quantization (Bit Depth)
8 bits, 10 bits, 12 bits ...

Temporal Resolution (Frame rate)
24fps, 30fps, 60fps, 120fps ...

Color Space (Gamut)
From BT 709 to Rec. 2020

Dynamic Range (Contrast)
From 100 nits to HDR

UHD TV Radar Chart by Dr. Nomoto
Total QoE = F(Q1, Q2, Q3, ... Qn)

Q1 Spatial resolution
Q2 Temporal resolution
Q3 Dynamic range
Q4 Color space
Q5 Component coding (incl. quantization)
Q6 Compression artifacts
Q7 Sound systems (and artifacts)

UHD TV Not only more pixels, but better pixels

Broadcast HD
1280 X 720p
(921 600 pixels)

“Full” HD
1920 X 1080p
(2 073 600 pixels)

UHD 1/ Ultra HD
3840 X 2160p
(8 294 400 pixels)
Temporal Resolution (Q2)

- 23.98 fps
- 29.97 fps
- 59.94 fps
- 119.88 fps
- 24/25 fps
- 30 fps
- 50/60 fps
- 100/120 fps

Dynamic Range (Q3)

OETF, OETF, OOTF and LOG curves

OETF: the opto-electronic transfer function, which converts linear scene light into the video signal, typically within a camera.

EOTF: electro-optical transfer function, which converts the video signal into the linear light output of the display.

OOTF: opto-optical transfer function, which has the role of applying the “rendering intent”.
### Dynamic Range (Q3)

<table>
<thead>
<tr>
<th>SMPTE 2084 (PQ*)</th>
<th>ARIB STD-B67</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards</td>
<td>HDR 10</td>
</tr>
<tr>
<td>EOTF *</td>
<td>From ST 2084</td>
</tr>
<tr>
<td>Components</td>
<td>YCbCr</td>
</tr>
<tr>
<td>Metadata</td>
<td>In HEVC codec</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>10 000 nits** peak</td>
</tr>
<tr>
<td>SDR compliancy</td>
<td>Needs conversion</td>
</tr>
<tr>
<td>Interface</td>
<td>HDMI 2.0a</td>
</tr>
<tr>
<td></td>
<td>ARIB STD-B67</td>
</tr>
<tr>
<td></td>
<td>Dolby Vision</td>
</tr>
<tr>
<td></td>
<td>From ST 2084</td>
</tr>
<tr>
<td></td>
<td>YCbCr or IC_p</td>
</tr>
<tr>
<td></td>
<td>In HEVC codec</td>
</tr>
<tr>
<td></td>
<td>10 000 nits** peak</td>
</tr>
<tr>
<td></td>
<td>Needs conversion</td>
</tr>
<tr>
<td></td>
<td>HDMI 1.4</td>
</tr>
</tbody>
</table>

* PQ: Perceptual Quantizer/ Quantization (curve)

** 1 nits = 1 candela/meter² (luminance)

Note: Ultra HD Alliance Premium Certification only recognize SMPTE 2084 base HDR

---

### Dynamic Range (Q3)

**Quantization (Bit Depth)**

With a “Big Screen” UHD TV @ 1.5 H

- **12 bits**
  - 4096 colors
- **10 bits**
  - 1024 colors
- **8 bits**
  - 256 colors
Dynamic Range (Q3)

Simulation

MONTRÉAL January 31 2017

Dynamic Range (Q3)

SDR Contrast

MONTRÉAL January 31 2017

Luminance Levels

10⁸ cd/m²

~ 10⁸ cd/m² SDR system

~ 10⁵ cd/m² w/o adjustments

10⁵ cd/m²

10⁶ cd/m²
Dynamic Range (Q3)

SMPTE-2084 Electro-Optical Transfer Function

HDR Contrast

Luminance Levels

~ $10^5 \text{ cd/m}^2$ ~ $10^5 \text{ cd/m}^2$

"Full" HDR system

~ $10^6 \text{ cd/m}^2$

w/o adjustments

10$^9 \text{ cd/m}^2$

10$^6 \text{ cd/m}^2$

MONTRÉAL January 31 2017

Luminance (Luminous power)
in candela per square meter (cd/m$^2$) also called "Nits"
equal to: 0.292 foot-lamberts

Light Intensity Example

133,000 nits
0.25 nits
15 nits
300 nits
171,000 nits
15 nits
185 nits
300,000 nits
6000 nits
150,000 nits
10,000 nits
Dynamic Range (Q3)

Issue of conversion ...

What about me?

- SDR
- And me?
  - ACES

Color Space (Q4)

I. Ultra HD
   REC. 709 (35.9 %)

II. Ultra HD Premium
    90% of P3 (48.2 %) ?
    100% of P3 (53.6 %) ?

III. UHD₁
    REC. 2020 (75.8 %) ?
Parameters for HD, Ultra HD and UHD\textsubscript{1} Television

<table>
<thead>
<tr>
<th>HD, Ultra HD Color Space</th>
<th>White point</th>
<th>Primary colors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X_w$</td>
<td>$Y_w$</td>
</tr>
<tr>
<td>BT. 709</td>
<td>0.3127</td>
<td>0.3290</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UHD\textsubscript{1} Color Space</th>
<th>White point</th>
<th>Primary colors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X_w$</td>
<td>$Y_w$</td>
</tr>
<tr>
<td>Rec. 2020</td>
<td>0.3127</td>
<td>0.3290</td>
</tr>
</tbody>
</table>

Component coding (Q5)

SDR, HDR: HLG and HDR 10

\[
\begin{align*}
Y' &= 16 + (65.481 \cdot R' + 128.553 \cdot G' + 24.966 \cdot B') \\
C_B &= 128 + (-37.797 \cdot R' - 74.203 \cdot G' + 112.0 \cdot B') \\
C_R &= 128 + (112.0 \cdot R' - 93.786 \cdot G' - 18.214 \cdot B')
\end{align*}
\]
**Component coding (Q5)**

*Intended as a replacement for Y' C_b C_r with Dolby Vision HDR*

\[
\begin{align*}
L &= \frac{(1688R + 2146G + 262B)}{4096} \\
M &= \frac{(683R + 2951G + 462B)}{4096} \\
S &= \frac{(99R + 309G + 3688B)}{4096}
\end{align*}
\]

\[
\begin{align*}
I &= 0.5L' + 0.5M' \\
C_T &= \frac{(6610L' - 13813M' + 7003S')}{4096} \\
C_B &= \frac{(17933L' - 17390M' - 543S')}{4096}
\end{align*}
\]
Q6 - Compression artifacts (EBU 3363 – QC)

- Flashing Video
- Dropouts
- Blanking Error
- Gamut violation
- Saturation (clipping)
- Illegal luminance
- Illegal chrominance
- Freeze
- Noise
- Bluriness
- Hue
- Cadence
- Black level
- Chroma level
- Macroblocking

Sound systems (Q7)

- IS (Immersive Sound)
- NGA (Next Generation Audio)

- Not any 22.2 system available
- Dolby Atmos™ 7.2.4
Sound systems (Q7)

Multi-channels issues (@ home)

Realism?

Television

Front/Screen channel

Lens and sensor

Some characteristics to look at
MONTRÉAL January 31 2017

APPLE
5.5” iPhone 6+ Retina HD (1920 x 1080) 401 PPI
27” iMac Retina 5K (5120 x 2880) 218 PPI
13” MacBook Pro Retina (2560 x 1600) 227 PPI
15” MacBook Pro Retina (2880 x 1800) 220 PPI

Ultra HD (3840 x x2160)
10” Display 415 PPI
13” Display 331 PPI
15” Display 286 PPI
27” Display 163 PPI
50” Display 88 PPI
65” Display 68 PPI

Retina Display HiDPI (High Dots Per Inch)

Lenses for 4K/Ultra HD Cameras

Crop factor
2/3”
Super 16 mm
1”
MFT
APS-C
Super 35 mm
“Full Frame”

BOKEH effect
Stops, F-stops (photo/video) and T-stops (cinema)

\[
T-\text{Stop} = \frac{F-\text{Stop}}{\text{Lens transmittance (\%)}}
\]

NOTES: Stops are a function of F-stops, sensibility and frame rate
\(\pm 15\) stops are needed for HDR

Required:
- Super 35 mm sensor, 80 LP/mm
- 2/3 inch sensor, 200 LP/mm

Some factors:
- MTF (Modulation Transfer Function): “resolution behaviour” (for the total focal range), object distance, spatial zones ...

From: Edmund Optics™
Another factor: Lenses are not uniformly sharp at every aperture (F-stop)

Some artifacts: astigmatism, coma, curvature of field, color fringing, defocusing distortion ...
Dead and Stuck Pixels on a “Bayer Pattern” Sensor

Stuck Pixel  Dead Pixel

Rolling, Total and Mechanical Shutter

Rolling Shutter  Total Shutter  Mechanical Shutter

A Total (or Global) Shutter usually offers less dynamic range
Experience with 4K/Ultra HD – CMOS Sensors

theatrical release
broadcast and CDN release
home entertainment

- Does a CFA (Color Filter Array) Sensors offer 4K for each of the 3 primary colors?
- Which artifacts will result of the “demosaicing” algorithm?
- Can color filtering reduce the overall resolution?

“Q67” 4K Sensors (Imager) Technology

Easier debayering artifacts and true 4K (more resolution)

“Rotated Bayer” Scheme
4K Imager
Uncompressed RAW Mezzanine

Compression
DNxHR
ProRes
XAVC
MXF

Disk and/or Data tape throughput
“Ultra HD ready” NAS
Real-time
File based
On-line
Near-line
Archives

Storage – To be assessed

UHD TV on disks and tapes Much more space and throughput needed!

Uncompressed Over IP

There are still many challenges to be met ...

La question qui tue

Essence independent frames

Ça marche tu?
Database managed content on virtual machines, in the cloud, accessible via IP

Concerns:
- Security
- Reliability
- 24/7 Availability
- Foreseeable Opex
- Relocatable
- Cost efficient

Lighting ... from NTSC to Ultra HD / UHD₁
More details (pixels), more contrast (dynamic range) and more colors (gamut)

TLCI supersedes CRI (for Film and TV)
Metrics and Measurements

To validate conformity and reliability

- Does my camera offer UHD resolution in the 3 primary colors?
- Does the lens present any aberrations?
- Does my monitor show the “full” HDR signal?
- Do I really produce in a wider color Gamut than BT.709? (If yes, what is it?)
- And ...

Trying a device IS NOT testing it!
A “practical” case study in Ultra HD implementation

For which specific services, genres and platforms?
CONCEPT FOR DISCUSSION PURPOSE ONLY
ACADEMIC BUT PRACTICAL CASE STUDY

PROJECT ASSUMPTIONS

- There is a market for a French "High-Rez" VOD service via the Internet
- This service should be accessed with computers as well as with TVs (OSs: Android, Tizen and WebOS)
- Additional feature on existing service
- No upscaling allowed
- APPs for (almost) all intelligent TVs
AN EXAMPLE (to learn from)

ACADEMIC CASE STUDY (PM)

CONCEPT FOR DISCUSSION PURPOSE ONLY

OBSERVATIONS:

Acquisition requirements
Ingest, MAM, QC and storage
Workflow from the external producer to our “ready to VOD” package (minimal processing)
Transfert to CDN service
“Fast FTP” process and validation
Online offer of content
Add to list of VOD content, Including promo this new content and viewing statistics

ACQUISITION REQUIREMENTS

Source material standards (evolutionary)

Workflow from the external producer to our “ready to VOD” package (minimal processing)

Transfert to CDN service

“Fast FTP” process and validation

Online offer of content

Add to list of VOD content, including promo this new content and viewing statistics

Acceptable Delivery Resolutions:
- 4K DCI: 4096 x 2160
- UHD: 3840 x 2160
- Camera acquisition higher than 4K is acceptable (i.e. 5K or 6K)
- Framing aspect ratio (i.e. Full 1.78, Flat 1.85, Scope 2.39) is a creative decision and should be maintained within the final delivery resolution.
Beyond 4K, from 4.6K to 8K ... *How relevant?*

- **8K and 6K digital cinema cameras**
  - 8192 X 4320 p
  - Up to 60 fps

- **Mobile (on set) workstation**
  - 6144 X 3160 p
  - 23.98 to 60 fps
A 4K camera with an 8K imager

4K Cinema  4096 x 2160 p
QFHD TV  3840 x 2160 p

Wide color gamut
16 bits recording
1 to 120 fps

In concluding ... one of the key factors for success ...
In addition to factors such as leadership and teamwork ...

**Needed Curriculum**

Broadcast specific:
FHD / UHD and related quality factors …

IT Centric:
VM, Cloud, hardware, Video over IP …

**Education is a foundational role of the SMPTE**

**THANK YOU !**

Success is not final, failure is not fatal: it is the courage to continue that counts.

*Winston Churchill*

The END?