Advances in IP Networking and HDR processing for Studio and Outside Broadcasting Production Applications

Hugo Gaggioni
Chief Technical Officer
Sony Professional Solutions Americas

IP Live: Vision

Live production environment turns to IP-base system → Facility renewal & considering migration path to “Beyond HD”
IP Live: Vision

Live production environment turns to IP-base system
→ Facility renewal & considering migration path to “Beyond HD”

Provision of not only advanced technology & migration path to 4K/8K but also total operational efficiency

Format-free & Higher-scalability
Cost-effective non-specialized IP switch can be used for synchronized low-latency AV routing to replace SDI router.
Major benefits are format agnostic, scalability and common platform with file-base operation.

Virtualization
Resource sharing over network among multi-studios or Remote production provides great operational efficiency.

Device management & Status monitoring
Accessibility to all connected devices over network is also a great benefit for system setup and maintenance/service much easier.

Remote Productions: Current Issues
VOC: Low-cost by remote production

Major League Sports
Low latency, Bi-directional, Long distance AV transmission
Use in-house studio

College Sports
Venue
Cost reduction by less equipment & staff on-site

ISSUE
Current OB truck production works for major league sports by top-tier sponsors, but it doesn’t work for college sports.
Remote Productions: Solution

Reducing OPEX by dispatching only Cams & Camera Ops on-site

Most Difficult Challenge: 4K Live Production Cabling
**4K Live Production: Interconnection Challenges**

3G SDI x 4 Tx (for 4K/422/10bit/60p x 1ch)

4K Parallel Data

3G SDI x 4 Rx (for 4K/422/10bit/60p x 1ch)

BNC Connector x 4

BNC Cable x 4

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**Explosive Increase of BNC Cable**

IP Network Solution
(4K over a single 10GbE cable)

4K Video Stream

SFP+ Optical Module

10GBASE-SR

Network LSI
(with low compression 4K Codec)

LSI

Switcher / processes

Net IF

---

4K Parallel Data
**What is SFP+?**

**Small Form-factor Pluggable Plus transceivers**

### Optical
- Suitable for long distances
- Max. distance: 300m (10GBASE-SR)
  10km (10GBASE-LR)
- Connector type: LC
- Fiber type: Multi-mode fiber (10GBASE-SR) / Single-mode fiber (10GBASE-LR)

### Twinax Cable
*(Direct-attach Copper Cable)*
- Suitable for very short distances
- Max. distance: 10m
- Copper cable with attached SFP+ connectors
- Various manufacturers offer lengths of 1, 1.5, 2, 2.5, 3, 5, 7 and 10 meters

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**Production Truck**

**SDI based 4K system**

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**8 Camera Example**

- 4K Live Camera System x8
- FSS+CA+BPU+HDCU
- 4K/60p (5G x4)
- Mon x42
- 4K Switcher
- MVS-8000X
- 4K Monitor x4
- PVM-X300
- 4K Server x5
- XAVC Server
- 4K/60p x4
- Mon x4
- 4K/60p (3G x4)
- Mon/Ret (1.5G x2)
- 4K/60p x30
- U/C & Mon (1.5G x6)
- 4K/60p x4
- Mon x42
- HD Monitoring

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Production Truck
“IP Live” based 4K system

8 Camera Example

IP Live Based
LAN: 88 pcs

SDI Based
BNC: 362 pcs

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<td>268 kg. (590 lb.) (SC2V: 74g/m)</td>
<td>40 kg. / 11kg. (89 lb. / 24 lb.) (Copper: 45g/m, Fiber: 33g/m)</td>
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Total cable weight reduced by 85%*

* Example only. Actual weight reduction will vary by situation.

IP Live Production Applications:
Standardization Status
IP A/V/D Transmission: Standardization Activities

Standards Organizations involved in IP A/V/D transmission protocols
- **SMPTE** (Society of Motion Picture & Television Engineers)
- **VSF** (Video Service Forum)
- **JT-NM** (Joint Taskforce on Networked Media) sponsored by EBU (European Broadcast Union), SMPTE and VSF

The following diagram illustrates the relationship between three:

**Correlation chart of IP format related bodies**
- **SMPTE**: Video Standard
- **AES**: Audio Standard
- **EBU**: JT-NM project
- **Sony “IP Live”:** (Sony)
- **AMWA NMI Project**: ST2022-6, AES67 (BBC, JTMN)
- **Sandbox LiveIP**: ST2022-6, AES67 (EBU, VRT)
- **AIMS**: ST2022-6, AES67, TR-03/04 (Grassvalley)
- **VSF**: Propose New IP Format to SMPTE

Imagine, Grassvalley, Lawo, Nevion, s.a.m, EVS, Cisco, Arista

Atos, Avid, BBC, Embirionix, Harmonic, InSync Technology, Melianox Technologies, Nevion, Panasonic, s.a.m, Streampunk Media and Suitcase TV

Axon, Dwsam, EVS, Genelec, Grassvalley, Lawo, LSB, Nevion, Tektronix, Trilogy
Alliance Groups for IP in Live Production

Packaging of Video Data (Single Datagram)

Bytes per IP packet

Session layer

Transport layer

Layer 3

Layer 2
### SMPTE ST. 2022: Layered Standard

<table>
<thead>
<tr>
<th>Standard</th>
<th>Scope</th>
<th>Characteristics</th>
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<tr>
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<td>&quot;Forward Error Correction for Real-Time Video/Audio Transport Over IP Networks&quot;</td>
<td>Point-To-Point IP stream transmission</td>
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<tr>
<td>ST2022-2</td>
<td>&quot;Unidirectional Transport of Constant Bit Rate MPEG-2 Transport Streams on IP Networks&quot;</td>
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<tr>
<td>ST2022-3</td>
<td>&quot;Unidirectional Transport of Variable Bit Rate MPEG-2 Transport Streams on IP Networks&quot;</td>
<td>Point-to-Point MPEG-2 Compressed Streams over IP packets with Piecewise-Constant Variable Bit Rate</td>
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<tr>
<td>ST2022-4</td>
<td>&quot;Unidirectional Transport of Non-Piecewise Constant Variable Bit Rate MPEG-2 Transport Streams on IP Networks&quot;</td>
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<tr>
<td>ST2022-5</td>
<td>&quot;Forward Error Correction for High Bit Rate Media Transport Over IP Networks&quot;</td>
<td>Point-to-Point IP Stream Transmission</td>
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<tr>
<td>ST2022-6</td>
<td>&quot;Transport of High Bit Rate Media Signals Over IP Networks&quot; (HBRMT)</td>
<td>A Point-to-Point IP transmission with a packaged mapping for uncompressed SDI signals not encapsulated in MPEG-2 TS Use of video compression not permitted</td>
</tr>
<tr>
<td>ST2022-7</td>
<td>&quot;Seamless Protection Switching of SMPTE ST 2022 IP Datagrams&quot;</td>
<td>Hitless Failover by transmission of two matching packet streams over different paths</td>
</tr>
</tbody>
</table>

### SMPTE ST. 2022-6 for HD production applications

**SMPTE ST.2022-6 SDI to IP Transport**

**HD-SDI Data Stream**
- Line Count
- Audio Samples
- Meta Data
- Video Samples
- Video Samples
- EOL

**SDI Transport**
- Active Video

**SMPTHE ST.2022-6 Formatting**
- UDP/RTP Header
- Payload Header
- Video Inf, Time stamps
- Fixed Length Payload (1376 Byte)

**IP Stream**
- IP Header
- UDP/RTP Header
- Payload

**One Multicast IP Stream**
SMPTE ST. 2022: Some Roadblocks....

Layers 5 and 6 of SMPTE 2022 present limitations for the adoption of the standard in professional production applications: modifications are required.

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<td>ST2022-5</td>
<td>FEC-based protection</td>
<td>• No frame boundary aware (a single FEC block could contain information related to two frames)</td>
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<td>SDI–IP Mapping</td>
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<td>Datagram duplication based protection</td>
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IP Live: Approach

Interoperability  Joint-working with industry leading partners

Contribution to Standardization

Expansion of Alliance Partners

Core Technology Development

LSI & FPGA IP Core
System Controller (LSM)

NMI: RDDxx
- Media Transport
LLVC: RDD34
- Video Codec
NDCP: RDD38
- Control Protocol

Adoption to Sony products

Development  System Implementation

IP Live: Network Media Interface (NMI)

Practical Approach to IP Live Production (SMPTE Journal in March, 2015)
- Essence-independent mapping, Frame boundary aware FEC, Industry Common interfaces

TECHNICAL PAPER

A Practical Approach to IP Live Production

SMPTE 2022-6: SD/HD-SDI Mapping over IP

Sony NMI: A/V/Meta Essence Independent Mapping over IP

SMPTE 2022-5: No care about Frame boundary

Sony NMI: Frame boundary aware FEC

Frame boundary
Sony’s PTP proposal has been approved as ST2059-2

Sony’s LLVC is listed as SMPTE RDD34 (Registered Disclosure Document)
- LLVC (Low-Latency Video Codec) is Wavelet base light-weight & low-latency video codec for real-time transmission and keeps HQ in multi-generation.

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**IP Live: NMI Media Transport Mapping Structure**

- Essence Independent & Frame-boundary-aware Mapping, up to 4K/8K
- Packet Protection by FEC and/or Hitless Failover

All the datagrams including Essence (video, audio and metadata) and FEC are multiplexed and transported.
Frame-Accurate, Clean Video Switching using General IP Method

Problems in Clean Video Switching using General IP Method

Using Multicast IGMP (Internet Group Management Protocol) is the accepted method to start/stop stream packets

Stream packets may start or stop in the middle of video frame as Ethernet switches do not know the video frame boundary

• This leads to a picture disruption

Also, Ethernet switches do not know the exact video frame to be switched

One video frame consists of a few thousand packets depending on the video format

IGMP leave / join
IP Live: NMI Clean Video Switching Mechanism

• Only valid method to use Regular IP switches (IGMPv3)
  – Clean Video Switching can be set to ON or OFF per Destination.

1. Stream sender puts video frame information into a network header
2. System controller issues switching requests.
3. Stream receiver issues IGMP messages.
4. Ethernet Switch joins/leaves the correspondent streams.
5. Stream receiver discards unnecessary packets.

Network Management

• Network Management Service in IP Live System Manager (LSM):
  – QoS guarantee for AV and control traffic
  – IP switch configuration
  – Bandwidth Reservation

• QoS Policy on IP network (Configured IP Switches with LSM):
  • Priority based Control
  • Access Control
Network Redundancy: ST.2022-7

General IP Technique

- A/V Stream
- IP Switch
- Failover
- e.g., LAG (link aggregation)
- IP Switch
- A/V Stream

Network failure

Picture distortion

When switching active network, data is interrupted temporarily.

Sony A/V/D Over IP Interface

- A/V Stream
- Transmitter LSI
- IP Switch
- Main
- Packet Duplication
- Receiver LSI
- IP Switch
- Backup
- Packet Selection

Network failure

Packet loss

Hitless failover

Even if one stream packet is missed, the other packet outputs seamlessly.

IP Live: Available Whitepapers

Business Whitepaper

Technical Whitepaper
IP Live Alliance: 49 Partners @NAB2016

**IP Live System Overview**

- **Remote Maintenance Tool (RMS)**
- **IP Routing Switcher**
- **IP Live System Manager**
- **Workstation**
- **Control Panel**
- **4K/HD System Camera**
- **Remote Camera**
- **XAVC Replay & Recording Server**
- **Partner Graphics System**
- **PCIe Board**
- **Network I/F LSI Built-in**
- **Partner Server**
- **FPGA IP**
- **Network I/F LSI Module**
- **Production Switcher**
- **Monitor**
- **Partner Multi-viewer**
- **IP Switch**
- **SDI-IP Converter (For SDI device)**
IP-Enabled Products

- **XVS-8000 Production Switcher**
- **XVS-7000**
- **XVS-6000**
- **HDC-4300 w/ BPU-4500**
- **HDCU-4300**
- **PWS-4500 4K/IP Production Server**
- **NXLK-IP40F SDI-IP Converter**
- **IP Live System Manager**

**IP Live: Production Components**

**Baseband Processing Unit (BPU-4500)**
- An advanced baseband processor unit with IP interfaces
- Routes 4K signals from HDC-4300 camera, PMW-F55 Live via CA-4000, or F65 Live via SKC-4065

**4K/IP Production Switcher (XVS-8000)**
- Five M/E for large production systems
- 40 inputs and 12 assignable outputs for 4K
- Eight full keyers are available per M/E

**4K/IP Production Server (PWS-4500)**
- Modular I/O and Features
- Built-in SharePlay File and Workflow Sharing
- 4K Support (Optional)
- HFR Support (Optional)
**IP Live: Products with New IP Interfaces**

**System Camera**
- Baseband Processor Unit
- BPU-4500

**Replay & Recording Server**
- Multi-port AV Storage Unit
- PWS-4500

**Production Switcher**
- Multi-format Switcher Processor
- XVS-8000

**Up to 4K x2/HD x8 HFR with HDC-4300**

**4K-4CH/HD-8CH & “Share Play” for RT file sharing among servers over 10G**

**Production Switcher**
- 4K-5M/E 40IN-12OUT
- Mixture IP/SDI capable

**Baseline Processor Unit**
- Up to 4K x2/HD x8 HFR with HDC-4300

**4K Server:**
- PWS-4500

**IP Live: New Products and Solutions**

**SONY**

**4K/IP Camera & Server**
- 4K U-HFR Camera System:
  - HDC-4800/BPU-4800
- 4K 2/3" Camera: HDC-4300/BPU-4500/HDCU-4300

**10,000 U-HFR Camera System:**
- HDC-4800/BPU-4800

**4K Server:**
- PWS-4500

**IP-based Router**
- LSM V1.1

**IP Multi-viewer**
- 4K/40IN-12OUT

**Audio Integration**
- Partner Integration

**New Products**
- 4K U-HFR Camera System: HDC-4800/BPU-4800
- Compact 4K CCU: HDCU-4300
- Mid/Small XVS Line-up: XVS-7000/6000

**Technology Demo @NAB2016**
- IP Multi-viewer, IP Audio Routing

**4K OLED Monitor**
- XVS-8000/7000/6000
- PVM-X300/PVM-X550

**IP Live: New Products and Solutions**
World’s first purpose built 4K IP OB Truck

IP Live: Worlds’s first purpose built 4K IP OB Truck
TV Globo in Brazil
**Hybrid Concept:** 4K Production over IP & HD Monitoring with SDI

**4K Matrix Size:** 69x67 (3G-SDI: 276x268)

- 3RU, 87 optical cables (double in redundant system)

**Full IP Redundancy**
- Controller, IP Switch & Cables, 2x XVS-8000 for 2x Productions or Main/Backup
IP Live: TV Globo 4K OB Truck

**Legend**
- Blue: Routing Operation
- Purple: Video Stream Control
- Orange: Setting Operation
- Black: Device Configuration

**Controller**
- Magellan
- IP Live “Live System Manager”
- Configuration
- Video Stream Control
- Video Stream Control
- Setting Operation
- Routing Control
- Routing Operation
- Setting Operation

**Device**
- Configuration
- PWS-4500
- XVS-8000
- BPU-4500
- Imagine
- SDI-IP Converter

**UI**
- Web UI
- Setting Operation
- Routing Operation
- Setting Operation

---

IP Live: TV Globo 4K OB Truck

![Image of the control panel of a TV Globo 4K OB Truck]
IP Live: Future Proof (New XVS 40GbE I/O Boards)

Sony LSI & FPGA Hybrid IP Process Design
- In order to support Multi IP Formats including Future Standard
- 40GbE makes less cabling & simple connections

Block-diagram

![Block-diagram of 40GbE Main & Backup]

Switcher Baseband Routing Backplane

IP-Live: Remote Production Demonstration

![Map showing Las Vegas Convention Center and Digital Motion Picture Center, 250 miles apart]

Las Vegas Convention Center – LVCC
Digital Motion Picture Center – DMPC
250 Miles
IP Live: Local and Remote resource sharing – NAB 2016

LVCC: Las Vegas
- Camera Corner x 4
- ICP-X7000 PNL1 (3M/E) Resource Share
- ICP-X7000 PNL2 (4M/E) Remote Production
- PWS-100NM1
- SDI (HD)
- NMI (HD) OUT x 4
- PWE+ Hub
- CNTL
- SWR1 PGM
- SWR1 MV-1
- SWR1 MV-2
- SWR2 PGM
- SWR2 MV-1
- SDI (HD)

DMPC: Los Angeles
- Juniper EX4550
- PWS-100SC1
- NXLK-IP40F (NXL-FR318)
- SDI (Ref) x 1
- NMI (Ref)
- CNTL
- SDI (Ref) – Through x 1
- SDI (Ref) – Through x n
- SWR2 MV-1
- SWR2 MV-2
- SWR2 PGM
- SWR1 PGM
- SWR1 MV-1
- SWR1 MV-2
- XVS-8000 SWR1
- XVS-8000 SWR2
- XVS-8000 SWR3
- Remote Production
- Remote Production
- LVCC: Las Vegas DMPC: Los Angeles
- 10Gbps

Provided by Level 3

Evertz ASPEN

Level 3
Evertz ASPEN

- **VSF TR-01 based HD Uncompressed Mapping**
  - Essence Independent Transport based on ST2022-2

**Diagram Description:**
- **HD-SDI (3G-SDI)**
  - D-MUX
  - Video
    - Uncompressed Video
      - RFC4175
    - MPEG-2 TS Mapping (RFC2250)
    - RTP Mapping (RFC3550)
  - Audio
    - AES3 Mapping
    - Audio: ST302
    - Auxiliary: ST2038
    - RTP Mapping (RFC3550)
  - Auxiliary
    - AES-3
    - RTP Mapping (RFC3550)

**Payload Details:**
- **TS packet:** 188B
- **TS Number per RTP packet:** 7 (1316B)

**Additional Information:**
- MPEG-2 TS Mapping (RFC2250)
- RTP Packet

**Logo:**
- AIMS (Alliance for IP Media Solutions)
VSF TR-03 (SVIP): Media Transport

- **Essence Independent Transport based on RTP**
  - Advanced format from ST2022-6
  - Currently, Uncompressed Video Only

### IP Format Prediction

- **Evertz ASPEN**
  - ESPN Only
  - HD De-Facto

- **Sony NMI**
  - Introduced Essence Independent Concept
  - 4K De-Facto
  - LLVC: 4K Codec De-Facto

- **Open Standard (HD Only)**
  - Short Life
  - 4K standardization happens later?

- **ST2022-6**
  - Short Life
  - Future Standard?

- **ST2022-xx**
  - w/ LLVC

- **TR-03**
  - w/ Codec?
Conclusions

• Replacement of SDI-based live production system with IP-based can be realized without changing the current operational practices with:
  – Generic Ethernet switches
  – Existing and emerging standards

• There are several standardization proposals to fully satisfy all the requirements such as:
  – Essence-Independent mapping
  – Frame-Boundary-Aware FEC
  – Industry Common Business Level interfaces

• There are still some issues to be improved:
  – One of the biggest advantages of adopting IT technology is that system performance can be improved as IT technologies improve

HDR (High Dynamic Range)
Technical Considerations for Production and Distribution Applications
What is HDR

Typical brightness levels

Sunlight: 500,000 nits & more
Bright sunlight can reach 100,000,000 nits. Direct sunlight is about 1,600,000,000 nits.

Lighting: 15 to 500 nits
Moody lighting can be as low as 15 nits, and normal room lighting at about 500 nits. However shop and exhibition lighting may be about 1,500 nits.

LCD televisions: 200 to 300 nits
Most televisions are designed around high definition standards that do not exceed 300 nits. Their black response is also quite poor at about 0.1 nits, which does not produce good dense blacks.

Computers: 200 nits
Most laptops will achieve 200 nits, while some of the brighter laptops can achieve 400 nits. Some desktop computer screens can achieve 500 nits or more.

Mobile phones & tablets: 200 nits
Most mobile phones and tablets will achieve 200 nits brightness, while some of the brighter devices can achieve 400 nits.

Shadows: below 1 nit
Shadows are a relative concept. In a bright room the shadows may be 10 nits. However deep shadows can be lower than 1 nit.

Nit = [cd/m²]
Human Eye Sensitivity

- **Mid-tones**: The human eye is reasonably sensitive to changes in mid-tone brightness.

- **Highlights**: The human eye is less sensitive to changes in brightness for bright areas of a scene. Not so much dynamic range is required for these areas and they can be compressed without reducing display quality.

- **Low-lights**: The human eye is more sensitive to changes in brightness in darker areas of a scene and plenty of dynamic range is needed to record these areas well.

Dynamic range of Human Eye Vision

The human eye has a native dynamic range of about 10-14 stops. This is the range of brightness we can see in one scene.
The human eye has a native dynamic range of about 10-14 stops. This is the range of brightness we can see in one scene. However, the pupil allows the human eye to accept a far wider range of brightness levels up to about 24 stops from one scene to another.

The modern digital camcorder should have a similar native dynamic range as the human eye of about 14 stops. Just like the human eye, the lens iris allows the camera to accept a far wider range of brightness levels up to about 24 stops from one scene to another.
The Camera Sensor

1. **Modern camera sensors can capture more than 14 stops**
   - These sensors have a linear response, and capture scenes with 16 bit samples.
   - This provides more than 14 stops of dynamic range.

2. **The native output data rate is massive**
   - The RAW output bitrate of the F65’s 8K sensor is 17Gbps.

3. **This amount of data is required in very high-end productions**
   - RAW workflows will use all this data to provide supreme quality in post-production.
   - However most productions do not require this level of quality.

4. **High-end production infrastructures are based on 10 bit paths**
   - Most post production can easily handle 10 bit workflows.

5. **The High Dynamic Range of the sensor needs to be carried on 10 bits**
   - This can be achieved through an *Acquisition Transfer Function*.
   - The transfer function takes account of the human eye.
   - This also emulates the action of film stock.
   - More dynamic range is preserved for low-lights and mid-tones.

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Image Sensor Sensitivity

- **Image sensor sensitivity is mostly linear**
  - Sensors have a noise floor due to background noise in the sensor.
  - It is difficult to separate dark detail from background noise.
  - Most Sensors saturate suddenly, a few with a shoulder (F65), as brightness increases.
  - Modern sensors have a very low noise floor and high saturation.
  - This gives them their characteristic High Dynamic Range.
Making High Dynamic Range fit

Many cameras and camcorders output to a specific video standard
The sensor output needs to be “squashed” to fit into the video standard.
Some broadcast camcorders use a knee response.
This retains dynamic range for shadows and mid-tones and compresses highlights.
Some cine cameras use gamma and log responses.
Shadow and mid-tone dynamic range is retained with gentle highlight compression

Introducing Acquisition Transfer Functions

The sensor
Each pixel senses light as a charge which is converted into a digital number. The higher the number the brighter the pixel. A modern sensor is able to sense the smallest change in brightness from complete darkness to very bright.

RAW output
The sensor’s native output is RAW data with 16 bits of linear data. This can be used in a RAW workflow in post for supreme quality, but uses massive amounts of data and may not be suitable for more conventional TV-based productions.

Converted output
The converted output provides a more practical recording. It takes advantage of the human eye response, and film sensitivity. It fits the sensor’s output into more workable 10 bit data, while still maintaining a high dynamic range.
Displaying Dynamic Range

Video must be edited or graded to fit into the chosen video standard

Some sacrifices may need to be made, and highlights or lowlights may be lost.

Window scene graded high
It is possible to see detail in the shadows, but the highlight areas tend to burn out

Window scene graded low
Bright areas of the scene look well balanced, but details in the shadows are difficult to see.

Vision Dynamic Range (Camera Iris)

Human Eye Vision Range
keeping $10^5$ can satisfy human eye vision system
What it should be and what it is

<table>
<thead>
<tr>
<th>Luminance Levels</th>
<th>Real World</th>
<th>Capture</th>
<th>Desirable System</th>
<th>Human Visual System</th>
</tr>
</thead>
<tbody>
<tr>
<td>[cd/m²]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;10⁻⁶</td>
<td>10⁻⁶</td>
<td>10⁻⁴</td>
<td>10⁻²</td>
<td>10⁻⁰</td>
</tr>
<tr>
<td>10⁻⁰</td>
<td>10⁻⁴</td>
<td>10⁻²</td>
<td>10⁻⁰</td>
<td>10⁰</td>
</tr>
<tr>
<td>10⁻⁴</td>
<td>10⁻⁴</td>
<td>10⁻¹</td>
<td>10⁻⁴</td>
<td>10⁰</td>
</tr>
<tr>
<td>10⁻¹</td>
<td>10⁻¹</td>
<td>10⁻⁰</td>
<td>10⁻ⁱ</td>
<td>10⁰</td>
</tr>
<tr>
<td>10⁻⁰</td>
<td>10⁻⁰</td>
<td>10⁻⁰</td>
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<td>10⁰</td>
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<tr>
<td>10⁰</td>
<td>10⁰</td>
<td>10⁰</td>
<td>10⁰</td>
<td>10⁰</td>
</tr>
</tbody>
</table>

Current System ~10³
Desirable System ~10⁵
Capture ~10⁵

What it should be and what it is

TV trend 2014: High Contrast, High Brightness

High brightness and high contrast TVs are already available in the market

The Ultimate Standard in 4K Ultra HD

There are 4K Ultra HD TVs, and television Sun’s Portable 4K Ultra HD TV with four times the clarity, color, and minute details to make you feel you’re right there in the moment. The television Sun’s Portable 4K Ultra HD TV is a true marvel of technology, providing a vivid and immersive viewing experience. The television’s exceptional detail and clarity make it an excellent choice for watching your favorite shows and movies. Whether you’re a fan of sports or movies, the television Sun’s Portable 4K Ultra HD TV is sure to impress. The television’s design is sleek and modern, with a thin bezel and a slim profile. It’s easy to set up and use, and the user interface is intuitive and easy to navigate.

High brightness and high contrast TVs are already available in the market.

Up to 3x Brightness Means the Best Contrast Ever

Sony’s new X-Reality Pro Dynamic Range PRO technology utilizes full area local dimming to produce contrast beyond comparison. Bright whites and dark blacks are controlled with fine detail. You’ll get the peak brightness that LED TVs are known for as well as deeper blacks previously only associated with Plasma TVs. Keeping the light areas bright while keeping blacks truly black is aided in stretching dynamic range. In the image shown, notice the difference in detail of the dark buildings combined with the brightness of the sky lights. The difference certainly is dramatic.
BVM-X300 HDR master monitor

BVM-X300 Master Monitor


F65/F55 4K/8K HDR Cameras

High Dynamic Range 4K, 8K cameras

### Current Standard Video Transmission

<table>
<thead>
<tr>
<th>Luminance Levels</th>
<th>[cd/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun Direct</td>
<td>$10^9$</td>
</tr>
<tr>
<td>Sun light</td>
<td>$10^8$</td>
</tr>
<tr>
<td>Indoor light</td>
<td>$10^6$</td>
</tr>
<tr>
<td>Moon light</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Star light</td>
<td>$10^2$</td>
</tr>
<tr>
<td>Night Vision</td>
<td>$10^0$</td>
</tr>
</tbody>
</table>

#### Limitation:
- 8 bits, 100 cd/m² max

- **Production**: 5 digits
- **Transmission**: 3 digits
- **Displaying**: 3 digits

**LCD (LD), OLED**

#### Compression
- **Lossy Signal Level Compression**

#### Expansion
- **Unreproducible range**

### HDR video transmission

#### Luminance Levels

<table>
<thead>
<tr>
<th>Luminance Levels</th>
<th>[cd/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun Direct</td>
<td>$10^9$</td>
</tr>
<tr>
<td>Sun light</td>
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<td>Moon light</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Star light</td>
<td>$10^2$</td>
</tr>
<tr>
<td>Night Vision</td>
<td>$10^0$</td>
</tr>
</tbody>
</table>

#### HDR standard
- **Production**: 5 digits
- **Transmission**: 5 digits or more
- **Display HDR displaying**: 5 digits

- By HDR, created image can be reproduced as it is

#### Current Standard Video Transmission

- **HDR video transmission**
- **Created image transmitted as it is**

#### Compression
- **Companding of High Signal Levels**

#### Expansion
- **display mapping**

#### OETF / EOTF

- **OETF / EOTF**

---

*5/26/2016*
**Color Volume with Wide Color Gamut & HDR**

Conventional = gamma curve (ITU BT.1886)

HDR = new display curves

**HDR requires a suitable video signal level companding curve**

---

**What is OETF/EOTF?**

- Input/output curves for transmission of HDR signals
- SMPTE standard ST.2084
- “Hybrid Log-Gamma” (HLG) developed by BBC/NHK
Transfer functions

OETF & EOTF

Opto-Electrical and Electro-Optical transfer functions

- OETF describes the action of the sensor, converting from scene brightness to data.
- EOTF describes the action of the display, converting from data to screen brightness.
**HDR Ecosystem**

**Capturing/Post-production**
- Game GFX
- Edit
- CG Comp

**Transmission**
- Broadcast IP delivery
- Physical media (BD, DVD, memory)

**Displaying**
- Panel correction

**Capturing**
- HDR camera (Sony F65/F55)
- FHD-HDR monitor (SIM2, Pulsar)
- 4K RGB-OLED monitor (Sony BVM-X300)

**Editing**
- plug-in tool (Baselight,..)
- FHD-HDR monitor (SIM2, Pulsar)

**OETF/EOTF**
- Barten model (absolute)
- SMPTE ST2084 EOTF
- Philips OETF
- Gamma base (relative)
- BBC/NHK @ITU
- Hybrid log-gamma OETF
- BT.1886 EOTF

**Transmission**
- Separate stream (MPEG regular)
- HDR/SDR
- Scalable codec
- Dolby Layered MPEG SHVC (MPEG)
- Compatible stream
- BBC/HyLG Philips Technicolor

**Signal Processing**
- Linear space convert EOTF (according to OETF)
- Display mapping HDR, WCG (disp. manufac.)
- Dolby Vision
- Proprietary system (Dynamic Meta)

**HDR panel**
- High brightness
- High power LED (Toshiba, Pana, SS)
- XDR (Sony)
- High contrast
- W-OLED (LG)
- LD algorithm (Toshiba, Pana, SS)
- XDR (Sony)

**HDR Ecosystem & Technologies**

**Optical Electrical Transfer Function**

**Transmission Technology**

**Display Mapping Technology**

**Panel correction**

**HDR**

**SDR**
**HDR Ecosystem & Technologies (open standard)**

<table>
<thead>
<tr>
<th>Capturing/Post-production</th>
<th>Transmission</th>
<th>Displaying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capturing/Editing</td>
<td>video mastering</td>
<td></td>
</tr>
<tr>
<td>Native Contents</td>
<td>Game GFX</td>
<td></td>
</tr>
<tr>
<td>Raw Data</td>
<td>Edit</td>
<td></td>
</tr>
<tr>
<td>Film scan</td>
<td>HDR master</td>
<td></td>
</tr>
<tr>
<td>Still Image</td>
<td>CG Comp</td>
<td></td>
</tr>
<tr>
<td>OETF</td>
<td>Transmission</td>
<td>Signal Processing</td>
</tr>
<tr>
<td>Single layer regular stream</td>
<td>Clip</td>
<td>HDR correction</td>
</tr>
<tr>
<td>• ST2084 EOTF</td>
<td>• Display mapping</td>
<td></td>
</tr>
</tbody>
</table>

[CTA] HDR10 Media Profile

**HDR10 Media Profile**

Video on Demand (VoD) / Over The Top (OTT) - (non-Live) content

**HDR10 Media Profile is defined as:**

- 3840x2160 picture raster
- EOTF: SMPTE ST. 2084
- Color Sub-sampling: 4:2:0 (for compressed video sources)
- Frame rates: 23.9760p / 24p / 25p / 50p / 59.94p / 60p
- Bit Depth: 10 bit
- Color Primaries: ITU-R BT.2020
- Metadata: SMPTE ST. 2086, MaxFALL, MaxCLL
- Interface between TV and STB: HDMI 2.0a utilizing CTA 861.3 for inclusion of EOTF signaling and meta-data
OTT HDR10 services <Amazon, M-Go> (Jun/'15~)

Amazon Prime's first wave of HDR videos is here

Ultra HD Blu-ray Video Characteristics

<table>
<thead>
<tr>
<th>Video Codec</th>
<th>HEVC(1)</th>
<th>AVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution</td>
<td>3840x2160</td>
<td>1920x1080</td>
</tr>
<tr>
<td>Picture Format Aspect Ratio</td>
<td>16:9</td>
<td></td>
</tr>
<tr>
<td>Bit Depth – SDR</td>
<td>10</td>
<td>8(2)</td>
</tr>
<tr>
<td>Color Space Primaries</td>
<td>BT.2020(3)</td>
<td>BT.709 (SDR only)</td>
</tr>
<tr>
<td>Color Sub sampling</td>
<td>4:2:0</td>
<td></td>
</tr>
<tr>
<td>Peak Video Bit rate(5)</td>
<td>100Mbps</td>
<td>40Mbps</td>
</tr>
<tr>
<td>Bit Depth - HDR</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>HDR EOTF</td>
<td>SMPTE ST 2084</td>
<td>N/A</td>
</tr>
<tr>
<td>Static Metadata</td>
<td>SMPTE ST2086, MaxFALL (HDR only)[6], MaxCLL (HDR only)[6]</td>
<td></td>
</tr>
</tbody>
</table>

(1) Main 10 High Tier Level 5.1. NOTE: in the mandatory part, HDR content is transmitted using a single layer codec with metadata in SEI messages.
(2) AVC 8-bit BT.709 SDR is allowed only for 1080/23.976p and 1080/24p frame rates and with a peak bit rate that is within existing BD specification
(3) BT.2020 uses the YCbCr non-constant luminance format
(4) Decoding 25Hz and 50Hz video is BD-ROM Player mandatory if a 50Hz TV system is used
(5) Peak Video Bitrate is constrained by the relevant ISO/IEC HRD conformance and by the MPEG-TS T-STD decoder buffer input rate.
# Update of HDR Standardization

<table>
<thead>
<tr>
<th>SDO</th>
<th>Transfer Function / Metadata</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMPTE</td>
<td>ST.2084 PQ EOTF</td>
<td>Dynamic Metadata (4 Applications) Dolby / Philips / Technicolor / Samsung</td>
</tr>
<tr>
<td></td>
<td>ST.2086 Display Static Metadata</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ST.2094 Master Display Color Volume Metadata</td>
<td></td>
</tr>
<tr>
<td>ITU-R</td>
<td>Application 1: ST.2084 PQ EOTF</td>
<td>ITU discussions resulted in a Draft New Recommendation (Feb. 2016)</td>
</tr>
<tr>
<td></td>
<td>Application 2: Hybrid Log-Gamma (BBC/NHK)</td>
<td></td>
</tr>
<tr>
<td>ARIB</td>
<td>ARIB STD B67 (Hybrid Log-Gamma)</td>
<td>Already published</td>
</tr>
<tr>
<td>DVB</td>
<td>Not yet defined</td>
<td>UHD1 Phase2 standardization in 2016.</td>
</tr>
<tr>
<td>ATSC</td>
<td>Not yet defined</td>
<td>Several proposals submitted for ATSC 3.0</td>
</tr>
</tbody>
</table>

*RED: Under Discussion*
SMPTE HDR Standards Activities

ST-2084: 2014 High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays
- Defines display referred EOTF curve with absolute luminance value based on human visual model. Known as Perceptual Quantizer (PQ)

- Specifies mastering display primaries, white point, and min/max luminance

Draft ST-2094. Content-Dependent Metadata for Color Volume Transformation of High Luminance and Wide Color Gamut Images
- Specifies dynamic, content-dependent metadata used in the color volume transformation of source content mastered with high dynamic range and/or wide color gamut imagery for presentation on a display having a smaller color volume


Very Recent Development!!
Two OETF/EOTF Proposal to the industry

<table>
<thead>
<tr>
<th>Absolute Value</th>
<th>Relative Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposal</td>
<td>Hybrid Log Gamma by BBC/NHK</td>
</tr>
<tr>
<td>Standardization</td>
<td>ITU-R Application 2 / ARIB STD B67</td>
</tr>
<tr>
<td>Characteristics</td>
<td></td>
</tr>
<tr>
<td>PQ by Dolby</td>
<td></td>
</tr>
<tr>
<td>SMPTE ST2084 (aka PQ)</td>
<td></td>
</tr>
<tr>
<td>PQ - Perceptual Quantization</td>
<td></td>
</tr>
<tr>
<td>• Considers human eyes perceptional characteristics of Barten Curve.</td>
<td></td>
</tr>
<tr>
<td>• Mapping 10,000cd/m² in 12 bit code values</td>
<td></td>
</tr>
<tr>
<td>• Define artistic intent in absolute luminance space</td>
<td></td>
</tr>
<tr>
<td>SDR Backward Compatibility is advantage</td>
<td></td>
</tr>
<tr>
<td>• Up to 2000%</td>
<td></td>
</tr>
<tr>
<td>• Define level of Black (0) and White (1.0) to scale relative value in the 0-1.0 range.</td>
<td></td>
</tr>
<tr>
<td>Use Case</td>
<td></td>
</tr>
<tr>
<td>Scripted Content</td>
<td>Live Production</td>
</tr>
<tr>
<td>Need well controlled environment for shooting and grading.</td>
<td>On-site painting by iris/gain control</td>
</tr>
</tbody>
</table>

![Output Absolute Value EOTF](image1)

![Output Relative Value OETF](image2)

SMPTE HDR: ST. 2084: 2014

The first 50% of the code values are from 0 to 100 nits.

The next 25% of the code values are from 100 to 1,000 nits.

The final 25% of the code values are from 1,000 to 10,000 nits.

Not all code values must be used. (The peak per program, clip, or frame may be much less than 10,000 nits.)
What is Hybrid Log-Gamma?

HDR ecosystem and technologies <open standard>
HLG Enables Easy Migration to HDR Production & Distribution

- Delivers high quality HDR pictures
  - independent of the display
  - requires no metadata

- Provides compatible pictures on SDR screens

- Production compatible with exiting 10-bit infrastructure and equipment
  - can be mixed, resized & compressed using conventional tools
  - only requires HDR cameras and HDR displays in critical monitoring areas

- Distribution: single HEVC Main 10 Profile bitstream serves both HDR and SDR displays

Hybrid Log-Gamma OETF Similar to SDR OETF with "Knee"

A hybrid gamma signal is defined as:

\[ E' = \begin{cases} r \sqrt{E} & 0 \leq E \leq 1 \\ a \ln(E - b) + c & 1 < E \end{cases} \]

Hybrid Log-Gamma OETF

Transmitting HDR Signals
What is Dolby Vision?

System of Double Layer on single stream

How to reduce data rate?
– Send Base Layer with Enhance Layer and metadata

Dolby Vision Encoder

Artistic Intent

Dolby Vision Decoder

Dolby Vision (Dual Layer) vs. Single Layer for Distribution/Display

Dual Layer: License Fee Required
(Base Layer + Enhancement Layer for HDR & SDR)

Dolby Vision Encode

Blu-Ray OTT Broadcast

Current Decode

HDR Vision Decode

HDR

SDR

Single Layer: No License Fee

HDR Master ST.2084-1 OETF

Current SDR Master

HDR Master Hybrid-Log-Gamma OETF

HDR Encode

Current Encode

HDR Decode

HDR

SDR

Blu-Ray OTT Broadcast

HDR
code

Current Decode

4K Blu-Ray OTT Broadcast

HDR

SDR

HLG considering Backward Compatibility
HDR & SDR End-to-End Production Workflows

Scope of Sony’s Professional Products

ST.2084 (PQ), HLG, Philips, etc, application area

Acquisition HDR Transfer Function

HLG, ST.2084 (PQ) application area
**Acquisition Transfer Function: What is S-Log3?**

- S-Log3 is the OETF used to derive the best performance of Sony camera’s image reproduction capability
- Preserve up to **4,000% of D-Range**
  - F65, F55, 4300 can capture up to 1,300%
- Designed based on Cineon Digital Negative
  - Close to Cineon Log
  - Optimized for Color grading
- **Most suitable for Color Grading**
  - Process under the condition of current 10-bit interface

![Graph showing S-Log3 characteristics](image)

**An example of an S-Log3 grade**

**Original S-log3 material**
There is a flat unsaturated look to the scene. However detail has been retained across the whole dynamic range, with nothing clipping badly to white.

**Final material**
With professional grading the S-log3 material can be given its final look, maybe to Rec 709. Colors are brighter and more saturated. However sacrifices may need to be made in highlights and shadows.
What is “S-Gamut3”?

A wide Color Gamut which is available with Sony F65/F55 cameras

- Comprehensive Color Gamut larger than ITU-R BT.2020
- Oncoming Laser displays was taken into consideration
- Future-proof digital negative archive

HDR & SDR Mastering
Acquisition
A digital cinematography camera can record 16 bit RAW material and 10 bit XAVC material with S-log3. This maintains the 14 stops (10^4) of Dynamic Range with a Wide Color Space.

Post production
Post-production consists of editing, grading and conforming to create both an SDR and HDR grade.

Mastering
The HDR master can be used for producing an HDR transmitted output or HDR pre-recorded media.

RAW workflow
This provides post production with the greatest creative scope, but requires huge amounts of data and powerful hardware.

S-Log3 & XAVC workflow
This provides post production with enough creative scope for most projects, requires far less data than RAW and uses conventional post-production tools.
**Metadata for HDR**

1. **Static metadata**
   - ST.2086: profile of master monitor (min/max luminance, colorimetry)
   - MaxFALL: max frame-average in the stream
   - MaxCLL: max light level of a pixel in the stream

   This metadata is generated at packaging for distribution (after the clip is completed)

2. **Dynamic metadata**
   - ST.2094: HDR to SDR tone-map (and color-space conversion)
     - Dolby-Vision, Technicolor, Phillips
     - In post-production, these metadata can be generated at HDR to SDR grading (tone-mapping) i.e. versioning
     - This metadata may be used for end-user’s CE device to create SDR from HDR stream by each vendor’s proprietary hardware or software tools

3. **HDR/SDR signal ID**
   - To identify
     - OETFs (inv)PQ, HLG or R.709
     - Color Space R.2020, P3 or R.709
     - flags are (will be) defined for:
       - SDI, HDMI (VPIID)
       - MXF, IMF (Transfer Chara)
       - AVC, HEVC (VUI, SEI)

   This metadata is generated at packaging for distribution (after the clip is completed)

**Live HDR Production & Transmission**
High Dynamic Range (HDR)

Typical use case in live sports production

World’s First: HDR Trial with Sky Germany

Production

HDC-4300 w/BPU-4000

S-Log3

BT.2020

HDR to HDR Converter

ST.2084

REC.709

BVM-X300

PWS-4400

Contribution

Encode HEVC Main 10 25Mbps

Uplink

Consumption

SDR

HDR

HLG*: Hybrid Log-Gamma (ITU-R Application 2)
Live HDR Trial

HDC-4300
4K Studio Camera

4K-HDR-Live Production System
Sony Open 2016: 4K HDR - Live Production

Video Engineer can operate with current SDR equipment. Then BPU can output LIVE-HDR picture automatically.
4K-Live HDR System – HDC-4300

**4K-HDR & 4K-SDR Simultaneous/Dual Production**

- **BPU-4000/4500**
  - HDR Processor
  - SDR Processor

- **HDC-4300**

- **Live HDR**
  - Selection of S-Log3 or HLG
  - Real-time PAINT control is available

- **Software Upgrade**
  - 4K-LIVE-HDR
    - BT.2020 / S-log3 or Hybrid Log Gamma

- **HDR Sources**
  - UHD 59p
    - S-Log3 / R2020
      - (HLG / R2020)

- **HDR Process**

- **HDR Line Out**
  - UHD 59p
    - S-Log3 / R2020
      - (HLG / R2020)

- **Res:**
  - HD → UHD

- **I/P:**
  - 59i → 59p

- **Color:**
  - R709 → R2020

- **Tone:**
  - R709 → S-Log3

- **Single Production OB for variable (HDR and SDR) distribution**

- **Cameras BPU**
  - Real-Time Camera Shading

- **HDR Sources**
  - UHD 59p
    - S-Log3 / R2020
      - (HLG / R2020)

- **HDR Process**

- **HDR Line Out**
  - UHD 59p
    - S-Log3 / R2020
      - (HLG / R2020)

- **Res:**
  - UHD → HD

- **I/P:**
  - 59p → 59i

- **Color:**
  - R2020 → R709

- **Tone:**
  - S-Log3 → PQ
    - S-Log3 → HLG
    - S-Log3 → R709

- **SDR Sources**
  - CG/Titles
    - HD 59i
    - R709 / R709

- **HDR Converter**
  - Res: HD → UHD
  - I/P: 59i → 59p
  - Color: R709 → R2020
  - Tone: R709 → S-Log3

- **HDR Converter**
  - Res: UHD → HD
  - I/P: 59p → 59i
  - Color: R2020 → R709
  - Tone: S-Log3 → PQ
    - S-Log3 → HLG
    - S-Log3 → R709
4K HDR / HD Hybrid Upgrade Capability

4K Live HDR (real time RCP operation) becomes practical with optional hardware and software

4K/HD and HDR/SDR Hybrid Converter Board
1. Requires 4K/HD Hybrid-Board for HDCUs
2. HD to 4K Up-conversion function
3. 4K HDR to 4K SDR conversion function
4. S-Log3 and Hybrid-Log-Gamma output
5. 3G-SDI output function

Camera Operating Software
1. Live HDR output from HDC-2000 series and HDC-1700
2. Expand color space from BT.709 to BT.2020

Sony’s Perspectives on OETF and EOTF
Sony’s perspectives on OETF/EOTF

HDR File-based Production

Camera OETF
- RAW 16bit
  - S-Log3 OETF
  - HLG* OETF

Grading/Paint Space
- ACES
  - Inverse ST.2084
  - S-Log3 OETF
  - HLG* OETF
  - HLG EOTF

Monitoring
- ST.2084
  - Inverse ST.2084
  - HLG* EOTF
  - HLG OETF

Transmission
- Inverse ST.2084
  - HLG* EOTF
  - HLG* OETF

CE Display (EOTF)
- ST.2084
  - HLG* EOTF

HDR Live Production

*HLG: Hybrid Log-Gamma (ITU-R Application 2)

Requirements for making the BEST HDR Images

- High Contrast
- High Luminance
- HDR
- High Resolution
- Wide Color Gamut

Already Available!

- Display: BVM-X300
  - Support HDR-EOTF
  - S-Log3, Gamma, ST.2084
  - High Contrast 1,000,000:1
  - High Luminance 1,000 cd/m2
  - Wide Color Gamut BT.2020, DCI-P3

- Capturing: F65/F55/HDC4300
  - Image Capturing with Max. D-Range
  - Wide Color Gamut
Thank You!

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