Understanding 4K, Ultra HD and HDR
DCI 4K
A summary of the Digital Cinema Initiative 4K format.
DCI 4K standard

Formed in 2002.
- Seven supporting studios.

Establish digital cinematography standards

DCI version 1.0 published July 2005

Version 1.1 published April 2007
- 2K (2048x1080) at 24fps or 48fps. 4K (4096x2160) at 24fps. 1.9:1 (almost 17:9).
- 12 bit per colour component (10 bits for 2K/48fps).
- CIE XYZ colour space.
- TIFF container (one per frame)
- JPEG2000 compression, at 250Mbps maximum data rate.
- Up to 16 channels of 24 bit audio in WAV container.
- Scope (2.39:1) and Flat (1.85:1) for 2K and 4K, and 3D versions also specified.
DCI 4K

The standard for movie production

- 4096x2160 pixels, 17:9 aspect ratio, exactly four times 2K.
- Used for all digital cinematography and high-end 4K productions.
DCI 4K and colour

High definition television specified by Rec 709
- Similar to SMPTE-240M.
- Quite restricted colour space, lacking green saturation.

Cinematography 4K colour specified by SMPTE231-2 & DCI P3
- More saturated green primary.
- Realised in present professional digital cinematography equipment.

ACES colour space
- Academy Color Encoding System intended as the ultimate storage container for material.
- Huge virtual colour space, with very wide gamut and dynamic range.
- 16 bit half-precision floating point samples.
- More than 25 stops of scene referred encoding, based on linear light encoding.
DCI 4K & CIE

- ACES
- SMPTE231-2 (DCI P3)
- SMPTE 240M
- Rec 709

SONY
DCI 4K variants

DCI 4K
- 4096x2160 pixels.
- 1.9:1 (@17:9 aspect ratio).

DCI Cinemascope
- 4096 x 1716 pixels.
- Vertically cropped DCI 4K.
- 2.39:1 aspect ratio.

DCI Flat
- 3996 x 2160 pixels.
- Horizontally cropped DCI 4K.
- 1.85:1 aspect ratio.
Ultra HD
Summary of the Ultra HD format
UltraHD (UHDTV)

Live broadcast and home television version of 4K
- 3840x2160 pixels, 16:9 aspect ratio, exactly four times 1920x1080 HD.
- Sometimes called Quad HD or QFHD.
- Used for consumer 4K, live production and sports 4K.
The benefits of Ultra HD

- Colour space (gamut)
- Bit depth (quantisation)
- Resolution
- Dynamic range
- Frame rate
- Audio
Ultra HD and colour

Ultra HD colour specified by ITU-R BT.2020 (Rec 2020)

- Much more saturated greens.
- Intended for all consumer Ultra HD hardware.
- Not achievable with present consumer technology.
Dynamic range
An explanation of what dynamic range is, and how it is measured.
What is dynamic range?

Dynamic range is the range of tones or brightness in a scene.
  - From the darkest areas to the brightest areas.

Low dynamic range scenes have a flat range of brightness
  - Low contrast across the scene.
  - Flat lighting with very few highlights.
  - Consistent lighting with few deep shadows.
  - These scenes are easy on the eye, but are not very exciting.

High dynamic range (HDR) scenes have a wide range of brightness
  - High contrast between dark and light areas.
  - Bright areas in the scene or sharp highlights.
  - Dark areas with deep shadows.
  - These scenes are sharper and exciting.
Low dynamic range scenes

- Softened highlights
- Muted shadows
- No bright highlights

A few highlights, but overall contrast is still quite low
High dynamic range scenes

Deep shadows and bright highlights

Sharp bright highlights and reflections

High contrast image with dark sky, and bright lights.

Remember, you are looking at this on an SDR monitor.
Dynamic range in nature

**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 5000 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.

**HD LCD televisions:** 100 nits
Most HD televisions are designed around Rec 709 that does not exceed 100 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.
Dynamic range in the human eye

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.

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

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.
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 camera to accept a far wider range of brightness levels up to about 24 stops from one scene to another.
How to squeeze the lemon

Modern image sensors are capable of very high quality
- Sensors can achieve over 14 stops of dynamic range with a wide colour gamut.

How can all this quality be retained?
- How can all this dynamic range and colour be recorded?
- How can the recording be graded and edited?
- How can this quality be displayed in the home?

RAW, gamma, and log functions retain quality
- These techniques are all designed to record as much quality as possible.

HDR standards are designed to retain higher dynamic range through to the home
- HDR standards squeeze HDR into the same signal space as SDR video.
- They allow more dynamic range to be displayed on monitors, projectors and televisions.
The problem with SDR

**Video level set low**
The high levels of brightness outside are well balanced with lots of well saturated colour. However detail in the shadows are lost.

**Video level set high**
The outside is now burnt out, but detail in the shadows are clearly visible.

Notice the black cat in the shadows.
Outside scene is clearly visible
The high level of brightness is still able to be captured because of the extended dynamic range of HDR video.

Shadow detail is clearly visible
HDR systems still have a reasonable low end dynamic range to capture and display detail in the darker areas of the scene.

Remember, you are looking at this on an SDR monitor, so this image is simulated.
Standard dynamic range cameras

Most modern camcorders and cameras can capture high dynamic range
- This dynamic range is squeezed into the video standard.

SDR cameras output or record to specific video standards
- Most HD cameras use ITU-R BT.709 (Rec 709)

SDR video standards has a limited dynamic range
- Rec 709 is limited to about 5.2 stops.
- That equates to about 100 nits brightness from the screen.
High definition colour space and dynamic range
Ultra HD colour space and dynamic range
The camera sensor

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

The native output is massive
- The 16 bit RAW output from an F65 can reach 20Gbps.
- This is not a standard and cannot be shown in the home.

Cameras need to squeeze the RAW quality
- RAW must be converted into a standard video signal.
- This can be achieved through a transfer function.
- The transfer function takes account of the human eye.
- More dynamic range is preserved for low-lights and mid-tones.
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.
- Sensors saturate suddenly as brightness increases.
- Modern sensors have a very low noise floor and high saturation.
- This gives them their characteristic high dynamic range.
Introducing 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 as much as 16 bits of linear data, depending on the camcorder. This can be used in a RAW workflow in post for supreme quality, but uses massive amounts of data, complex processing hardware and is quite impractical.

Converted output
The converted output provides a more practical recording. It takes advantage of the human eye response, and fits the sensor’s output into more workable 10 bit data, while still maintaining a high dynamic range.
The knee process
An explanation of how the knee process is used to provide an extended dynamic range for broadcast camcorders.
Purpose of knee

Broadcast camcorders have a knee control
- This is a control for maintaining a good dynamic range for the image.
- It also allows highlight to be recorded without clipping.

The knee function is a crude method of extending dynamic range
- It provides plenty of dynamic range for low lights and mid tones.
- It also provides compressed dynamic range for highlights.

The knee function crudely copies the human eye
- More dynamic range is given to low lights and mid tones.
- Less dynamic range is given to highlights.

The knee function has a hard roll-off point
- The knee is a sudden switch from normal to compressed.
The knee function

14-16 bits

Output data

Brightness 1000 nits

Sensor output

8 bits

Output data

Brightness 1000 nits

Knee function

8 bit video output
Knee adjustments

Knee On/Off
- Turns the knee function on and off.
- Turned on for high contrast scenes.

Knee Point
- Adjusts where the knee point is.

Knee Slope
- Angle of the slope above the knee.

Knee saturation (not shown)
- A colour boost control above the knee.
- This compensates for colour loss above the knee.
The effect of knee

Without knee
Highlights clip with bright areas burnt out white, and lost detail in the clouds.

With knee
White is still white but brighter areas are compressed to retain as much detail as possible.
Auto-knee or Dynamic Contrast Control

Included in some camcorders
- Auto-adjustment of the knee.
- Controls the knee point only.

DCC is intended for high contrast scenes
- Shooting against a bright window.
- Shooting in shade on a sunny day.
Cinegamma & Hypergamma
An explanation of the Sony Cine 1-4 and the Hypergamma1-4 gamma curves.
What is Cine gamma?

Cine gamma curves were introduced to some smaller camcorders

- Camcorders like the PMW-EX1 and PMW-F3.
- These camcorders have a menu selection for Standard or Cine.
- Standard is used for Rec 709 recording with extended dynamic range.

Cine1 offers extended dynamic range with a calm and quiet effect

- It smooths contrast in dark areas, accentuates changes in brighter areas and clips at 109%

Cine2 offers the same look as Cine1 at 100% clipping

Cine3 offers increased contrast compared to Cine1 and Cine2

- It accentuates graduation changed in darker areas.

Cine4 offers increased contrast compared to Cine3

- It reduces contrast in darker areas and increases it in brighter areas.
What is Hypergamma?

Hypergamma curves were introduced to some professional camcorders
- Camcorders like the F35 and PMW-400.
- These camcorders have a menu selection for Standard or Cine.

Hypergamma1 offers good low light and mid-tone representation
- It clips in highlights at 100%, so is better for darker scenes.
- Otherwise called 3250G36.

Hypergamma2 offers better dynamic range compared to Hypergamma1
- It trades off low-light and mid-tone range for extended highlights, clipping at 100%
- Otherwise called 4600G30.

Hypergamma3 and Hypergamm4 offers 109% versions
- Otherwise called 3259G40 and 4609G33 respectively.
Cine and Hypergamma similarities

Cine1 is similar to Hypergamma4

Cine2 is similar to Hypergamma2

Hypergamma labelling identifies the gamma parameters
- The first three numbers identify the dynamic range in percentage.
- The forth number identifies the clipping point, 0=100% and 9=109%.
- The “G” number specifies the waveform monitor measurement on an 20% grey card.
- Thus 4609G33 has a 460% dynamic range and a 109% clipping point.
- It also measures 33% on a waveform monitor with 20% grey card.
Sony S-Log
An explanation of the Sony S-Log1, S-Log2 and S-Log3 curves
What is S-log?

S-Log curves have been designed for digital cinematography

- They emulate the “look and feel” of film.
- They are based on mathematical log functions.
- They allow for recording in high dynamic range above 1000nits (1000%).
- This is twice the dynamic range of Cine and Hypergamma curves.

S-Log needs professional grading

- S-Log can be thought of as a digital negative
- S-Log material looks flat as it is.
- This material needs grading to produce a final look.
- The whole mood of the material can be changed during the grade.

Grading can also produce an output “tuned” to the delivery format.

- Cinema output can have a different look to a Blu-Ray output.
- A new grade can also be made specifically for UltraHD with high dynamic range.
An example of an S-log grade

Original S-Log 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-Log material can be given its final look, maybe to Rec 709. Colours are brighter and more saturated. However sacrifices may need to be made in highlights and shadows.
The various versions of S-log

S-Log1 was the original log curve
- Designed for the original range of cameras like the F35.
- About 1000% dynamic range capability.

S-Log2 introduces extended capabilities for new cameras
- Cameras like the F65 and PMW-F55.
- Similar curve to S-Log1
- About 1500% dynamic range capability.

S-Log3 offers better low end definition to S-Log2
- S-Log3 is similar to the Cineon curve.
- The curve offers more detail in shadows and low-lights.
- There is a flatter rise through mid-tones and highlights.
Comparing S-log2 and S-log3

S-Log2 and S-Log3 can be compared to each other and to Cineon

- This relative stop comparison clearly shows the benefits of each curve.

- About 1½ stops dynamic range extension for S-Log3

- More dynamic range for darker areas in S-Log3

- Slightly brighter recordings for S-Log3 at 18% grey

- Cross-over point at about +3 stops where S-Log2 and S-Log3 look the same
S-Gamut & S-Gamut.Cine
Sony wider colour spaces for use in broadcast and cinematography cameras
S-Gamut3 & S-Gamut3.Cine

S-Gamut3 colour space
- Camera’s native colour space.
- Good for an ACES colour workflow.

S-Gamut3.Cine colour space
- Similar to scanned negative film.
- Slightly wider than DCI P3.
- Easier for manual grading to P3.
S-Gamut3 & S-Gamut3.Cine

S-Gamut3

S-Gamut3.Cine

Rec 2020

SMPTE231-2 (DCI P3)

SMPTE 240M

Rec 709
HDR in the home
How to show high dynamic range material in the home
Standard dynamic range from camera to the home

Acquisition
Cameras can now capture all the dynamic range from the scene with all the shadows and highlights captured. However Rec.709 cuts the highlights when recording.

Recording, post and delivery
Using Rec.709 through post production does not allow the dynamic range of scene to be processed. In this case the scene outside has been over exposed. No grading or colour correcting can get this dynamic range back.

Home television
Broadcast televisions are designed to accept standard video signals based on 8 bit video data giving 7 stops ($10^3$) of dynamic range on the screen. Highlights burn out easily and darker areas lose definition.
Standard dynamic range with brighter televisions at home

**Acquisition**
Cameras can now capture all the dynamic range from the scene with all the shadows and highlights captured.

**Recording, post and delivery**
Using Rec.709 through post production does not allow the dynamic range of scene to be processed. In this case the scene outside has been over exposed. No grading or colour correcting can get this dynamic range back.

**Home television**
Home televisions are capable of brighter images, so the brightness can be turned up. However the bright details of the original scene has already been burned out. The result is a brighter burned out image.
Standard dynamic range with brighter televisions at home

**Acquisition**
Cameras can now capture all the dynamic range from the scene with all the shadows and highlights captured.

**Recording, post and delivery**
New high dynamic range and colour space standards retain the quality of the original scene through recording, post production and transmission into the home.

**Home television**
New high dynamic range televisions display all the dynamic range of the recorded video signal on the screen with all the dynamic range of the original scene.
Common transfer functions

Transfer functions convert RAW material to the video format

- There are a number of transfer functions used in video production.

ITU-R BT.709 is used for high definition broadcasting

- This has a standard dynamic range with a maximum brightness of 100 nits.

S-log is a Sony transfer function specifically designed for cine use

- It has a gentle roll-off maintaining the full dynamic range of the RAW material.
- It can capture brightness far beyond 1000 nits.

SMPTE ST2084 Perceptual Quantiser (PQ) curve has a sharper roll-off

- This scene-referred curve can capture brightness far beyond 1000 nits.
- Mid-tones have a sharp transition making it difficult to show on BT.709 displays.

Hybrid-Log Gamma (HLG) is a similar transfer function to S-log

- This is a practical display-referred curve with backwards compatibility to BT.709.
HDR production
How HDR is realised with equipment and productions
HDR services and productions are taking off worldwide

**Services**

- ULTRA 4K Movies & TV
- Netflix
- Amazon Instant Video

**OTT / TV Production / Cinema**

- MAD DOGS
- MARCO POLO
- The Midwinter's Eve
- Life of Pi
- Billy Lynn’s Long Halftime Walk
- Mozart in the Jungle
Why all the interest?

First HDR movies and TV shows completed

More life-like pictures

Cameras in widespread use

First live broadcast trials completed

Grading monitor is here

TVs with higher dynamic range are here

Standards for production & exchange are appearing

First post production workflows are here
Why all the interest?

- First HDR movies and TV shows completed
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Cameras are in widespread use

Feature Films

OTT

Television
Cannes Film Festival

Winner Palme d’Or 2014

Winner Palme d’Or 2015

Opening Film 2016

Woody Allen
Vittorio Storaro ASC, AIC
Cameras are in widespread use
Cameras are in widespread use

PXW-FS7
Changing the game for documentary production
Cameras are in widespread use

HDC-4300
The world’s first true 4K live system camera with HDR
Cameras are in widespread use
Why all the interest?

- First HDR movies and TV shows completed
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The ultimate master monitor for SDR / HDR

- Sony BVM-X300 30-inch TRIMASTER EL 4K™ OLED Monitor
- Full 4K / OLED/ HDR with Wide Colour Gamut
- 1,000,000:1 contrast ratio
High performance picture monitor for SDR / HDR

- Sony PVM-X550 55-inch TRIMASTER EL 4K™ OLED Monitor
- Can display Quad-view Full HD images simultaneously with independent picture settings
HDR is here

First HDR services are streaming now

More life-like pictures

Cameras in widespread use

More live broadcast trials completed

Grading and client monitors are here

More TVs & projectors with HDR are here

Post production workflows are proven

Standards for production and exchange are here
Standards are here

**ITU-R BT.2020**

*Parameter values for ultra-high definition television systems for production and international programme exchange*

**NEW**

**ITU-R BT.2100**

*Image parameter values for high dynamic range television for use in production and international programme exchange*
HDR is here

- First HDR services are streaming now
- More live broadcast trials completed
- More TVs & projectors with HDR are here
- More life-like pictures
- Cameras in widespread use
- Grading and client monitors are here
- Standards for production and exchange are here
- Post production workflows are proven
HDR workflow for optimum results

Production Domain

RAW XAVC (S-Log3) → Edit / Grading → Composite → HDR Finish → HDR

Delivery Domain

EOTF Conversion

SDR Conversion

HDR → SDR

ST 2084 (XAVC) → HDR

HLG (XAVC) → SDR

Video Gamma (XAVC)
HDR workflow for optimum results

• S-Log3 is designed to preserve the captured source light efficiently

• Similar characteristic to scanned film (“Cineon Log”)

• In widespread use in 10 bit systems

• 4000% (4000cd/m²) dynamic range

• Optimised for production, recording and future re-use (re-grade)
HDR is here

- First HDR services are streaming now
- More life-like pictures
- Cameras in widespread use
- Grading and client monitors are here
- More TVs & projectors with HDR are here
- More live broadcast trials completed
- Standards for production and exchange are here
- Post production workflows are proven
4K UHD Bravia with HDR
4K UHD Bravia with HDR
HDR is here

First HDR services are streaming now

More life-like pictures

Cameras in widespread use

More live broadcast trials completed

Grading and client monitors are here

More TVs & projectors with HDR are here

Standards for production and exchange are here

Post production workflows are proven
Live HDR trials
Live HDR trials
Live HDR trials
HDR with Sony

• How can we help customers to .....  
• Produce fantastic 4K UHD HDR images  
• Simultaneously create 4K SDR and HD SDR deliverables  
• Enable experienced shaders to rack or paint based on well known SDR techniques on HD SDR monitors and WFM's  
• With minimum impact on cost
Live Production with HDR

- 4K HDR (S-Log3/BT2020)
- OETF CONVERT
- 4K HDR (ST2084/HLG)
- 4K SDR
- Live Feed
- Computer Graphics
- UPSCALE & CONVERT
- HD SDR

Video Signal Process (OB VAN/Studio etc.)

- EOTF CONVERT
- 4K HDR (HLG/ST2084)
- 4K SDR
- CONVERT & DOWNSCALE
- HD SDR
Live Production with HDR

SR Live
for HDR
Tools for HDR Production
HDR is here

First HDR services are streaming now

More live broadcast trials completed

More TVs & projectors with HDR are here

Post production workflows are proven

More life-like pictures

Cameras in widespread use

Grading and client monitors are here

Standards for production and exchange are here
First services are streaming
Digital Motion Picture Centre Europe
Digital Motion Picture Centre Europe