Creating 4K/UHD Content

Colorimetry

The television color specification is based on standards defined by the CIE (Commission Internationale de L'Éclairage) in 1931. The CIE specified an idealized set of primary XYZ tristimulus values. This set is a group of all-positive values converted from R'G'B' where Y is proportional to the luminance of the additive mix. This specification is used as the basis for color within 4K/UHDTV1 that supports both ITU-R BT.709 and BT2020.

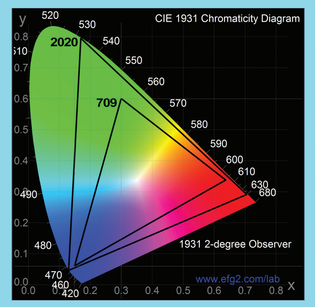


Figure A1: CIE xy diagram with color coordinates used by ITU-R BT 709 and 2020 color spaces.

White Point

The white point of the system within each format is defined by the addition of red, green, and blue in equal quantities. The CIE defined several standard sources in Table A1.

Color Gamut

A color gamut is the complete range of colors allowed for a specific color space. This range is bounded by the xy coordinates of the primary red, green, and blue colors within the color space. The xy coordinates for these primary colors is given for several different gamuts in Table A3.

Table A1: Illuminant (Ill.) Value

Source	X / Y
Illuminant A: Tungsten Filament Lamp, 2854°K	x = 0.4476 y = 0.4075
Illuminant B: Model of Noon Sunlight, 4800°K	x = 0.3484 y = 0.3516
Illuminant C: Model of Average Daylight, 6504°K	x = 0.3101 y = 0.3162
Illuminant D65: Daylight D Series, 6504°K	x = 0.3127 y = 0.3290
Illuminant (SMPTE431-2 DCI P3)	x = 0.3140 y = 0.3510

Table A2: Definition of Luma and Color Difference Values

	Rec 601	Rec 709	Rec 2020
Y'	0.299 R' + 0.587 G' + 0.114 B'	0.2126 R' + 0.7152 G' + 0.0722 B'	0.2627 R' + 0.6780G' + 0.0593B'
P'b	(B' – Y') / 1.772	(B' – Y') / 1.8556	(B' – Y') / 1.8814
P'r	(R' – Y') / 1.402	(R' – Y') / 1.5748	(R' – Y') / 1.4746

Table A3: CIE XY Coordinates for Various Color Gamuts

Gamut	Ill.	Red	Green	Blue
ITU-R BT. 2020	D_{65}	x = 0.708 y = 0.292	x = 0.170 y = 0.797	x = 0.131 y = 0.046
ITU-R BT. 709	D_{65}	x = 0.640 y = 0.330	x = 0.300 y = 0.600	x = 0.150 y = 0.060
SMPTE 431-2 (DCI-P3) XYZ		x = 0.680 y = 0.320	x = 0.265 y = 0.690	x = 0.150 y = 0.060
SMPTE	D_{65}	x = 0.630 y = 0.340	x = 0.310 y = 0.595	x = 0.155 y = 0.070
PAL/SECAM	D_{65}	x = 0.640 y = 0.330	x = 0.290 y = 0.600	x = 0.150 y = 0.060
NTSC (1953)	C	x = 0.670 y = 0.330	x = 0.210 y = 0.710	x = 0.140 y = 0.080

Figure A2. Using a 100% color bar signal to show conversion of RGB levels from 700 mv (100%) to 0mv (0%) for each color component with a color bar split field BT.2020 and BT.709 test signal. The WFM8300 was configured for BT.709 colorimetry as shown in the video session display.

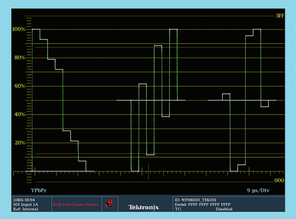


Figure A3. HD YPbPr paraded waveform display with 100% color bar test signal, using BT.709 colorimetry.

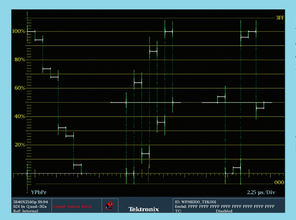


Figure A4. UHDTV1 YPbPr paraded waveform display with 100% color bar test signal, using BT.2020 colorimetry. Notice the difference in the levels between BT.709 and BT.2020 colorimetry shown in Figure A3 and A4.

Image Format / SMPTE Standards

Square Division separates the image into quad links for distribution.

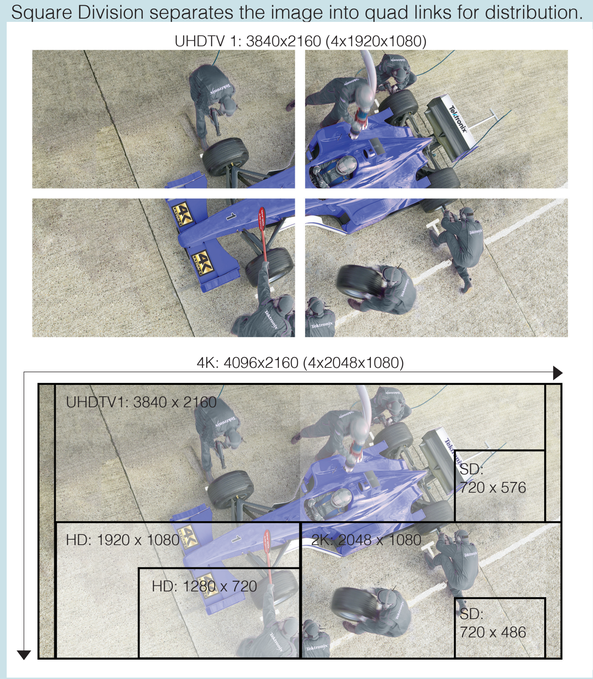


Table B1: SMPTE Standards

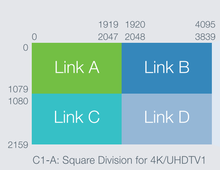
SMPTE	Standards
ST 125	SDTV Component Video Signal Coding for 4:4:4 and 4:2:2 for 13.5 MHz and 18 MHz Systems
ST 240	Television – 1125-Line High-Definition Production Systems – Signal Parameters
ST 259	Television – SDTV Digital Signal/Data – Serial Digital Interface
ST 272	Television – Formatting AES/EBU Audio and Auxiliary Data into Digital Video Ancillary Data Space
ST 274	Television – 1920 x 1080 Image Sample Structure, Digital Representation and Digital Timing Reference Sequences for Multiple Picture Rates
ST 296	1280 x 720 Progressive Image 4:2:2 and 4:4:4 Sample Structure – Analog & Digital Representation & Analog Interface
ST 299-0/1/2	24-Bit Digital Audio Format for SMPTE Bit-Serial Interfaces at 1.5 Gb/s and 3 Gb/s – Document Suite
ST 352	Payload Identification Codes for Serial Digital Interfaces
ST 372	Dual Link 1.5 Gb/s Digital Interface for 1920 x 1080 and 2048 x 1080 Picture Formats
ST 424	3 Gb/s Signal/Data Serial Interface
ST 425-0	(Revision of SMPTE 425-0:2012-06) SMPTE Bit-Serial Interfaces at 3 Gb/s – Roadmap for the 425 Document Suite
ST 425-1	Source Image Format and Ancillary Data Mapping for the 3 Gb/s Serial Interface
ST 425-2	Source Image Format & Ancillary Data Mapping for Stereoscopic Image Formats on a Single-Link 3 Gb/s Serial Interface
ST 425-3	Image Format and Ancillary Data Mapping for the Dual Link 3 Gb/s Serial Interface
ST 425-4	Dual 3 Gb/s Serial Digital Interface for Stereoscopic Image Transport
ST 425-5	Image Format and Ancillary Data Mapping for the Quad Link 3 Gb/s Serial Interface
ST 425-6	Quad 3 Gb/s Serial Digital Interface for Stereoscopic Image Transport
ST 431-1	D-Cinema Quality – Screen Luminance Level, Chromaticity and Uniformity
ST 435-0	10 Gb/s Serial Signal/Data Interface – Roadmap
ST 435-1	10 Gb/s Serial Signal/Data Interface – Part 1: Basic Stream Derivation
ST 435-2	10 Gb/s Serial Signal/Data Interface – Part 2: 10.692 Gb/s Stream – Basic Stream Mapping
ST 435-3	10 Gb/s Serial Signal/Data Interface – Part 3: 10.692 Gb/s Optical Fiber Interface
ST 2036-0	Ultra High Definition Television – Overview for the SMPTE ST 2036 Document Suite
ST 2036-1	Ultra High Definition Television – Image Parameter Values for Program Production
ST 2036-2	Ultra High Definition Television – Audio Characteristics & Audio Channel Mapping for Program Production
ST 2036-3	Ultra High Definition Television – Mapping into Single-link or Multi-link 10 Gb/s Serial Signal/Data Interface
ST 2081-0	SMPTE Bit-Serial Interfaces at 6 Gb/s – Overview for the SMPTE ST 2081 Document Suite
ST 2081-1	6 Gb/s Signal/Data Serial Interface – Electrical
ST 2081-10	2160-Line and 1080-Line Source Image and Ancillary Data Mapping for Single-Link 6G-SDI
ST 2082-0	12G-SDI Bit-Serial Interfaces – Overview for the SMPTE ST 2082 Document Suite
ST 2082-1	12 Gb/s Signal/Data Serial Interface – Electrical
ST 2082-10	2160-Line Source Image and Ancillary Data Mapping for 12G-SDI

Transport / Timing

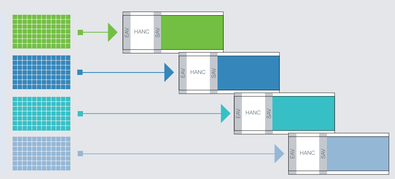
4K/UHDTV1 Quad Link requires that the image be segmented into two or four links depending on the frame rate of the video. In Quad Link there are two processes for segmenting the picture using either square division or two-sample interleave.

Square Division (Tile Mode)

In this process the image is divided into four quadrants and then sent on four separate SDI cables, see Figure C1-A. This process is the simplest method for segmenting the image but requires more memory to store each of the quadrants before assembling the complete image and is commonly used by a variety of post-production equipment.



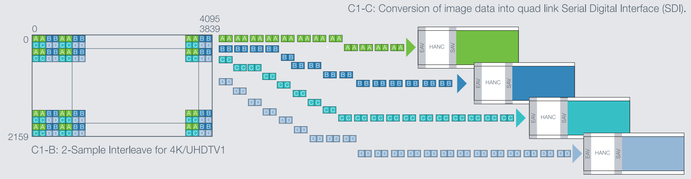
C1-A: Square Division for 4K/UHDTV1



C1-C: Conversion of image data into quad link Serial Digital Interface (SDI).

2-Sample Interleave

In this process groups of two pixels are separated from the image and sent on four different links as shown in Figure C1-B. This method requires less memory to be used and allows groups of pixels to be processed more quickly. However this process requires multiplexing of the data into four separate SDI streams. 2-Sample Interleaving has applications within the transmission process.



C1-B: 2-Sample Interleave for 4K/UHDTV1

Timing

Within Quad link SDI distribution for 4K/UHDTV1 each link will be routed differently within the network. Therefore care should be taken to ensure that each link is received at the device within certain tolerances. SMPTE standards define the timing difference between EAV (End of Active Video) / SAV (Start of Active Video) (see Figure C1-C) of Link A to Link D shall not exceed 400ns at the source. No specification is given for the receiving device and will depend up on the equipment as to how much timing difference the unit can tolerate.

The Tektronix 8000 Series Waveform Monitor and Rasterizers allow for 1024 clocks of timing difference between the inputs and will provide measurement of the timing difference between the inputs (Figure C2).

Table C1: Frame Rate Timing

Ensuring the correct frame delay is critical within these video systems and Table C1 shows the duration in milliseconds for each progressive frames rate.

Frame Rate (Hz)	23.98	24.00	25.00	29.97	30.00	47.95	48.00	50.00	59.94	60.00
Duration (ms)	41.71	41.67	40.00	33.37	33.33	20.86	20.83	20.00	16.68	16.67

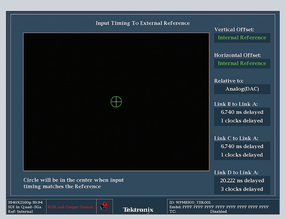


Figure C2. Input timing to external reference shown on the Tektronix WFM/WVR8000 Series Waveform Monitor.

Video Payload Identifier

The SMPTE ST 352 Video Payload Identifier (VPID) is carried within the Ancillary data space to assist a device in quickly decoding the video signal.

The 8000 Series Waveform Monitors and Rasterizers can show the VPID within the video session display and the data values can be found in the Ancillary Data Display or Datalist displays.

The VPID conforms to the SMPTE 291 Ancillary Data Packet and Space Formatting standard and contains the Ancillary Data Flag (ADF), Data Identifier (DID), Secondary Data Identifier (SDID), Data Count (DC), User Data Words (UDW 1-4) and Checksum as shown in Table D1.

Note: There is no specific value to determine 2-Sample Interleave or Square Division. Therefore if the VPID is consistent with ST 425-3 or ST 425-5 we assume sample interleave. If the VPID is standard HD ST 292 or ST 425-1 (3G) the format is consider Square Division. The user can also manually configure this within the instrument.

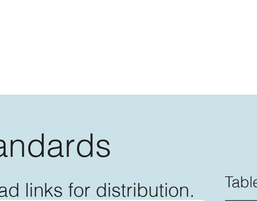


Figure D1. WFM8300 quad link Datalist display show the VPID ANC data for each link.

Table D1. Video Payload Identifier Ancillary Data Packet

Note: Please refer to latest standard for complete details of VPID information.

	Hex	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
ADF	000	0	0	0	0	0	0	0	0	0	0
	3FF	1	1	1	1	1	1	1	1	1	1
	3FF	1	1	1	1	1	1	1	1	1	1
DID	241	not b8	EP	0	1	0	0	0	0	0	1
SDID	101	not b8	EP	0	0	0	0	0	0	0	1
DC	104	not b8	EP	0	0	0	0	0	1	0	0
UDW 1	XXX	not b8	EP	Version ID	Payload Identifier (See Table D2)						
UDW 2	XXX	not b8	EP	Reserved 0 Transport Interface (0) Progressive (1)	Picture Interface (0) Progressive (1)	B5 Reserved 0 B4 Reserved 0, Transfer Characteristics[2] SDR-TV (0) HLG (1) PQ (2) Unspecified (3)		Picture Rate (See Table D3)			
UDW 3	XXX	not b8	EP	Reserved 0 Aspect Ratio 4:3 (0) 16:9 (1) Unknown (2)[1] Colorimetry[3]	Reserved 0 Horz. Sampling Unknown (0)[1] 1920 (0)[1] 2048(1)[1] 720 (0)[1] 960 (1)[1]	B5 Reserved 0 B4 Reserved 0 Colorimetry[2] Rec 709 (0) Color VANC Packet (1) UHDTV (2) Unknown (3) B5 Aspect Ratio[6] 16:9 (1) Unknown (0) B4 Reserved 0 Aspect Ratio[4] Colorimetry[3] 10G Link Assign[7]		Sampling (See Table D4)			
UDW 4	XXX	not b8	EP	B7, B6, B5 Reserved 0 Channel Assignment B7, B6, B5 Single / Link 1 Assignment (0)[5] Link 2 Assignment (1)[7] Link 3 Assignment (2)[7] Link 4 Assignment (3)[7] Link 5 Assignment (4) Link 6 Assignment (5) Link 7 Assignment (6) Link 8 Assignment (7) B5[3] Link A (0) Link B (1)		Reserved 0 Color Format[2] YCbCr (0) ICtCp (1) Colorimetry[2] ITU-R 709 (0) ITU-R 2020 (1)		Reserved 0	Reserved 0 Audio Copy Status[2] Additional CH (0) Copied CH (1) Color Format[2] YCbCr (0) ICtCp (1)	Bit Depth B1 Reserved 0 B0 8-bit (0) 10-bit(1)[2] B1-B0 8-bit (0) 10-bit (1) 12-bit (2) Reserved (3) 10-bit Full range[2] (0) 10-bit[2] (1) 12-bit[2] (2) 12-Bit Full Range[2] (3)	
Checksum	XXX	not b8	EP	Sum of B0-B8 of DID to Payload Byte 4							

[1] Defined in ST 2082

[2] Defined in ST372, ST425, ST 2081 & ST 2082

[3] Defined in ST 372 Colorimetry values UDW B7 & B4 are defined Rec 709 (0) UHDTV (2) Unknown (3), UDW 4 B7-B5 Link Assignment Link A (0) Link B (1)

[4] Defined in ST 2082-1 for Colorimetry UDW 4 B4, 10G Link Assignment UDW 3 B4 Link 1 (0) Link 2(1), Color Format UDW 4 B2 YCbCr (0) ICtCp

[5] Defined in ST 352 for 483/576 lines

[6] Defined in ST 425-1 for Aspect Ratio UDW 3 B5 Unknown (0) 16:9 (1)
Note: For ST296 values UDW 2 B7-B4 UDW 3 B7-B4 and UDW4 B7-B0 should be set to Reserved (0)
Note: UDW 3 B5 used for Aspect Ratio in ST 292, 372, 435-1. 425-5 3G level B
Note: UDW 3 B7 used for Aspect Ratio in ST 425-1, 425-3 3G level A, 425-5 Quad Link 3G level A, 2081-10, 2082-10

[7] Defined in ST 2082 & ST 2082

Table D2: SMPTE 352 Video Payload Identifier UDW 1

Decimal Value	Hex	SMPTE Standard	Description
129	81h	ST 259	SD-SDI
132	84h	ST 292-1	(720p)
133	85h	ST 292-1	(1080i)
135	87h	ST 372	(Dual Link)
136	88h	ST 425-1	(2x720) 3G Lvl B
137	89h	ST 425-1	3G Lvl A
138	8Ah	ST 425-1	3G Lvl B
139	8Bh	ST 425-1	(2x 720) 3G Lvl B
140	8Ch	ST 425-1	(2x 1080) 3G Lvl B
141	8Dh	ST 425-1	(2x 483/576) 3G Lvl B
142	8Eh	ST 425-2	3D (720)
143	8Fh	ST 425-2	3D (1080)
144	90h	ST 435-1	10Gb
145	91h	ST 425-4	3D (720) 3G Lvl A
146	92h	ST 425-4	3D (1080) 3G Lvl A
147	93h	ST 425-4	3D (1080) 3G Lvl B Dual Link
148	94h	ST 425-3	(1080) 3G Lvl A
149	95h	ST 425-3	(1080) 3G Lvl B Dual Link
150	96h	ST 425-3	(1080) 3G Lvl B Dual Stream
151	97h	ST 425-5	(2160) Quad 3G Lvl A
152	98h	ST 425-5	(2160) Quad 3G Lvl B Dual Link
153	99h	ST 425-6	3D (1080) 3G Lvl A
154	9Ah	ST 425-6	3D (1080) 3G Lvl B Dual Link
155	9Bh	ST 425-6	3D (1080) 3G Lvl B Dual Stream
160	A0h	ST 435-1	Octa-link 2160 10G
161	A1h	ST 2036-3	UHDTV1 single/multi 10G
162	A2h	ST 2036-3	UHDTV2 multi 10G
165	A5h	ST2036-4	UHDTV1 (4k) multi 10G
166	A6h	ST2036-4	UHDTV2 (8k) multi 10G
176	B0h	ST 2047-2	VC-2 1.5G SDI
177	B1h	ST 292-2	3D (1080/720) 1.5G Dual Link
178	B2h	ST 2047-4	VC-2 Lvl6S SD-SDI
179	B3h	ST 2048-3	4096x2160 Multi 10G
180	B4h	SMPTE RDD 22	(2048x1556) 1.5G Dual Link
181	B5h	SMPTE RDD 22	(2048x1556) 3G
192	C0h	ST 2081-10	(2160) 6G Mode1
193	C1h	ST 2081-10	(1080) 6G Mode 2
206	CEh	ST 2082-10	(2160) 12G Mode 1
207	CFh	ST 2082-10	(1080) 12G Mode 2

Table D3. Picture Rate

Value	Picture Rate	
0h	No Defined Value	
1h	Reserved	96/1.001[1]
2h	24/1.001	
3h	24	
4h	48/1.001	
5h	25	
6h	30/1.001	
7h	30	
8h	48	
9h	50	
Ah	60/1.001	
Bh	60	
Ch	Reserved	96[1]
Dh	Reserved	100[1]
Eh	Reserved	120/1.001[1]
Fh	Reserved	120[1]

[1]Defined in ST 2082, 2081

Table D4. Sampling Structure

Value	Sampling Structure	
0h	4:2:2 (YCbCr)	4:2:2 (ICtCp)
1h	4:4:4 (YCbCr)	4:4:4 (ICtCp)
2h	4:4:4 (G/B/R)	
3h	4:2:0	4:2:0 (ICtCp)
4h	4:2:2:4 (YCbCrA)	4:2:2:4 (ICtCp+A)
5h	4:4:4:4 (YCbCrA)	4:4:4:4 (ICtCp+A)
6h	4:4:4:4 (G/B/R/A)	
7h	SMPTE ST 2048-2 F-S	
8h	4:2:2:4 (YCbCrD)	4:2:2:4 (ICtCp+D)
9h	4:4:4:4 (YCbCrD)	4:4:4:4 (ICtCp+D)
Ah	4:4:4:4 (G/B/R/D)	
Bh	Reserved	
Ch	Reserved	
Dh	Reserved	
Eh	4:4:4 (X/Y/Z)	
Fh	Reserved	

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