Understanding 3G-SDI

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Agenda

- Need for 3G-SDI
  - Applications
  - Sampling structures
  - Color spaces
- SMPTE 424M
  - 3 Gb/s Serial Digital Interface
- SMPTE 425 formats
  - Mapping structure descriptions
  - Comparison of Level A and Level B
- Ancillary data considerations
  - Video Payload Identifier
  - Embedded Audio
- SDI Pathological Pattern for 3G-SDI
- Physical Layer Measurements
- Future SMPTE 425 formats

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HD-SDI Encoding (SMPTE 274M, 296M)

- 4:2:2 YCbCr 10 bit sampling structure
  - Uses color-difference encoding so fewer bits are required for the tristimulus values of each sample
  - Luma sampled per pixel; chroma sampled every other pixel
- 1125 line systems – 1920×1080 active picture

Bits/sample	20	20	20
× Samples/line	2200	2640	2750
× Lines/frame	1125	1125	1125
× Frames/sec	30	25	24
= Bits/sec	1.485×10^9	1.485×10^9	1.485×10^9

- 750 line systems – 1280×720 active picture

Bits/sample	20	20
× Samples/line	1650	1980
× Lines/frame	750	750
× Frames/sec	60	50
= Bits/sec	1.485×10^9	1.485×10^9

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What can we do with 3 Gb/s?

- By doubling the bit rate, we can double the frame rate (i.e. 1080p)

Bits/sample	20	20	20
× Samples/line	2200	2640	2750
× Lines/frame	1125	1125	1125
× Frames/sec	60	50	48
= Bits/sec	2.97×10^9	2.97×10^9	2.97×10^9

- Or we can double the sample size (i.e. 4:4:4 and/or 12-bit)

Bits/sample	40	40	40
× Samples/line	2200	2640	2750
× Lines/frame	1125	1125	1125
× Frames/sec	30	25	24
= Bits/sec	2.97×10^9	2.97×10^9	2.97×10^9

- But not both at the same time (i.e. can't do 4:4:4 @ 1080p)
  - But 4:4:4 @ 720p is now possible

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Higher Resolution Sampling

- Several options with 40 available bits per sample:
- 4:4:4 YCbCr 10 bits
  - Full chroma sampling
  - 3×10 bit channels means 10 bits unused
- 4:4:4:4 YCbCrA 10 bits
  - Use fourth channel as “Alpha channel” (e.g. luma key or metadata)
- 4:4:4(:4) RGB(A) 10 bits
  - With equal luma and chroma sampling, no need for color-difference encoding.
- 4:4:4 YCbCr or RGB 12 bits
  - 3×12 bit channels means 4 bits unused
  - Underlying transport interface is always 10 bits, so there are different methods to pack three 12 bit samples into four 10 bit channels

Applications for 3G

- 1080p “fast progressive”
  - Ideal for new facility infrastructure build-outs
  - Easier to re-purpose 1080p library content for either 1080i or 720p broadcast than to transcode between 1080i↔720p
- 4:4:4 RGB workflows
  - Cameras are increasingly using RGB output
  - Easier in production to integrate computer-generated content in the RGB domain
- Digital Cinema
  - 12 bit resolution, XYZ color space supported in 3G standards
- 3D Television
  - Right eye & left eye content transported on single 3G link with 2× SMPTE 292 formats

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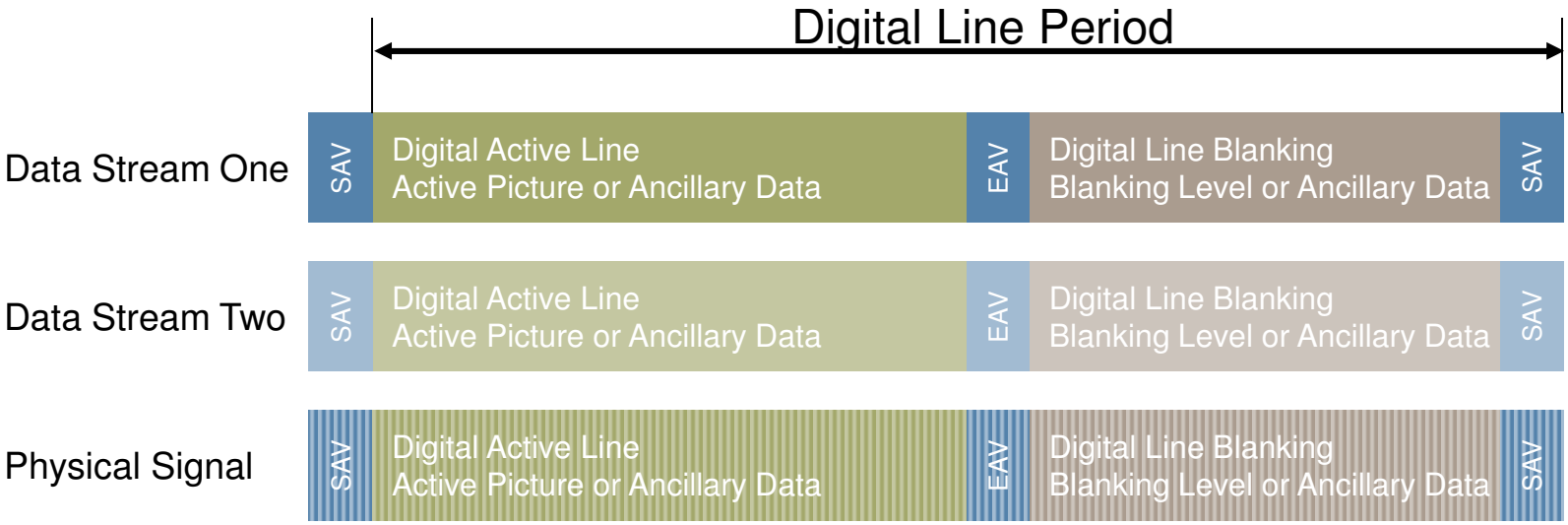
SMPTE 424M Signal/Data Serial Interface

- Defines the transport of bit-serial data structure for 2.97 Gb/s
- Mapped into two virtual interfaces
  - 10 bit parallel data streams: Data Stream One & Data Stream Two
- Physical signal is created by multiplexing the two virtual interfaces, alternating 10 bit words from the two data streams



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SMPTE 425 Signal/Data Serial Interface Source Image Format (Level A)

Mapping Structure	Reference SMPTE Standard	Picture Format	Signal Format Sampling Structure/Pixel Depth	Frame/Field Rates
1	274M	1920 × 1080	4:2:2 ($Y'C'_BC'_R$)/10-bit	60, 60/1.001 and 50 Frames Progressive
2	296M	1280 × 720	4:4:4 (R'G'B'), 4:4:4:4 (R'G'B' +A)/10-bit	60, 60/1.001 and 50 Frames Progressive 30, 30/1.001, 25, 24 and 24/1.001 Frames Progressive
			4:4:4 ($Y'C'_BC'_R$), 4:4:4:4 ($Y'C'_BC'_R$+A)/10-bit	
	274M	1920 × 1080	4:4:4 (R'G'B'), 4:4:4:4 (R'G'B' +A)/10-bit	60, 60/1.001 and 50 Fields Interlaced 30, 30/1.001, 25, 24 and 24/1.001 Frames Progressive, PsF
			4:4:4 ($Y'C'_BC'_R$), 4:4:4:4 ($Y'C'_BC'_R$+A)/10-bit	
3	274M	1920 × 1080	4:4:4 (R'G'B')/12-bit	60, 60/1.001 and 50 Fields Interlaced 30, 30/1.001, 25, 24 and 24/1.001 Frames Progressive
			4:4:4 ($Y'C'_BC'_R$)/12-bit	
	428-9	2048 × 1080	4:4:4 (X'Y'Z')/12-bit	24 Frames Progressive, PsF
4	274M	1920 × 1080	4:2:2 ($Y'C'_BC'_R$)/12-bit	30, 30/1.001, 25, 24 and 24/1.001 Frames Progressive, PsF 60, 60/1.001 and 50 Fields Interlaced

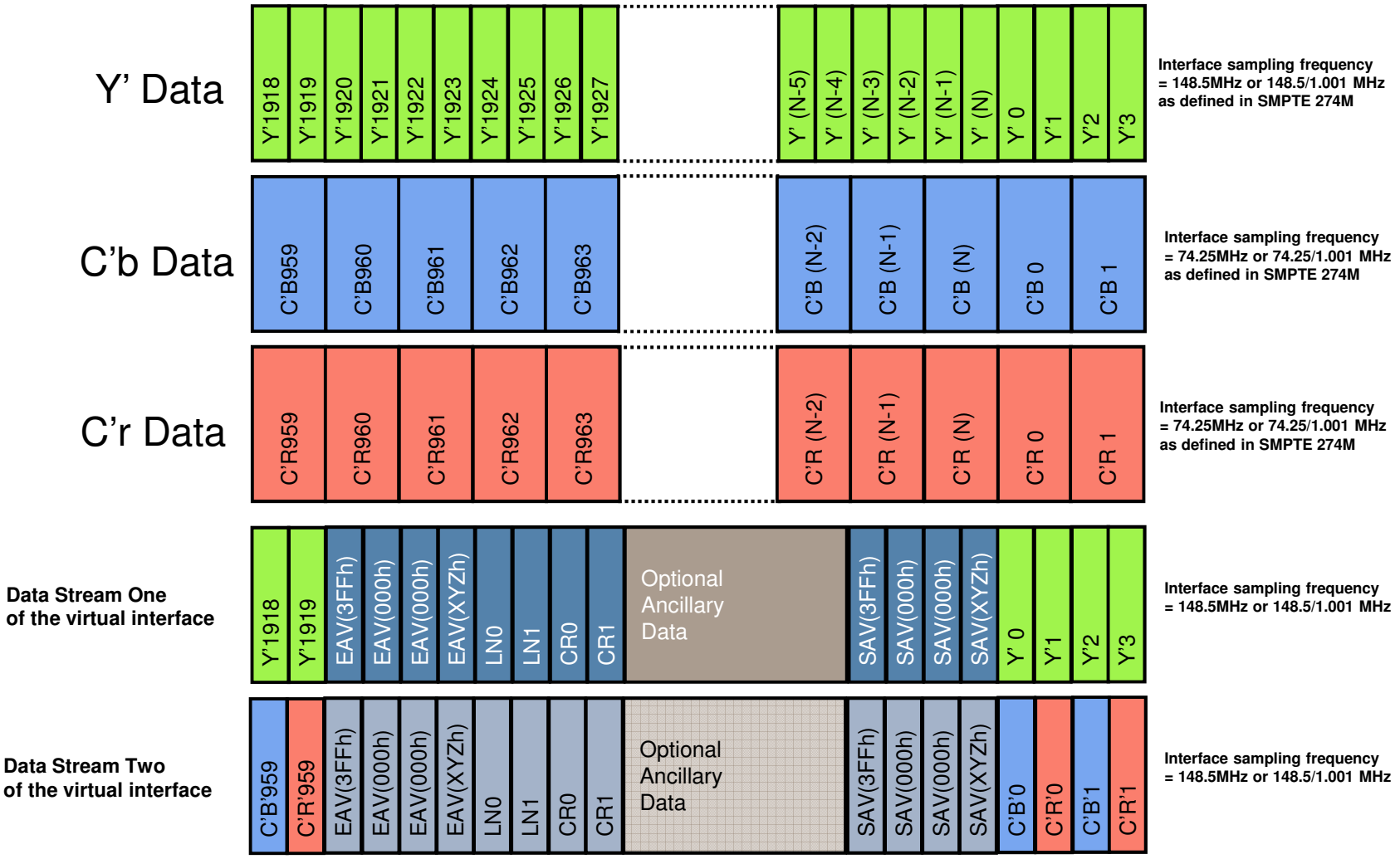
SMPTE 425 Signal/Data Serial Interface Source Image Format (Level B)

- SMPTE 372M (Dual link) already supports fast progressive and 4:4:4 and/or 12-bit formats for 1080 lines
- Therefore SMPTE 425 Level B usually refers to dual link formats mapped to a single 3G-SDI link
  - Data Stream 1 = Link A
  - Data Stream 2 = Link B
- Level B formats are also used for two SMPTE 292 data streams multiplexed together (e.g. 2×1080i or 2×720p)
  - Can be used for 3D television applications (right eye & left eye signals)

Mapping Nomenclature	SMPTE 352M VPID Byte 1
SMPTE 372M dual link payload on a 3 Gb/s serial digital interface	8Ah
2×720-line video payload on a 3 Gb/s serial digital interface	8Bh
2×1080-line video payload on a 3 Gb/s serial digital interface	8Ch
2×483/576-line video payload on a 3 Gb/s serial digital interface	8Dh

SMPTE 425 Mapping Structure 1

4:2:2 YCbCr 10-bit 60, 59.94 & 50



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Comparison of Level A vs. Level B

- 1080p 50/59.94/60
  - SMPTE 425 Mapping structure 1 – alternates Y and Cb/Cr samples, effect is similar to standard HD-SDI but at twice the rate

Stream 1	Y_0	Y_2	Y_4	…	Y_{1916}	Y_{1918}
	Y_1	Y_3	Y_5	…	Y_{1917}	Y_{1919}
Stream 2	Cb_0	Cb_1	Cb_2	…	Cb_{958}	Cb_{959}
	Cr_0	Cr_1	Cr_2	…	Cr_{959}	Cr_{959}

  - SMPTE 372M §4.1 – alternates entire lines, each with Y and Cb/Cr

Stream 1 (Line N+1)	Cb_0	Cr_0	Cb_1	…	Cb_{959}	Cr_{959}
	Y_0	Y_1	Y_2	…	Y_{1918}	Y_{1919}
Stream 2 (Line N)	Cb_0	Cr_0	Cb_1	…	Cb_{959}	Cr_{959}
	Y_0	Y_1	Y_2	…	Y_{1918}	Y_{1919}

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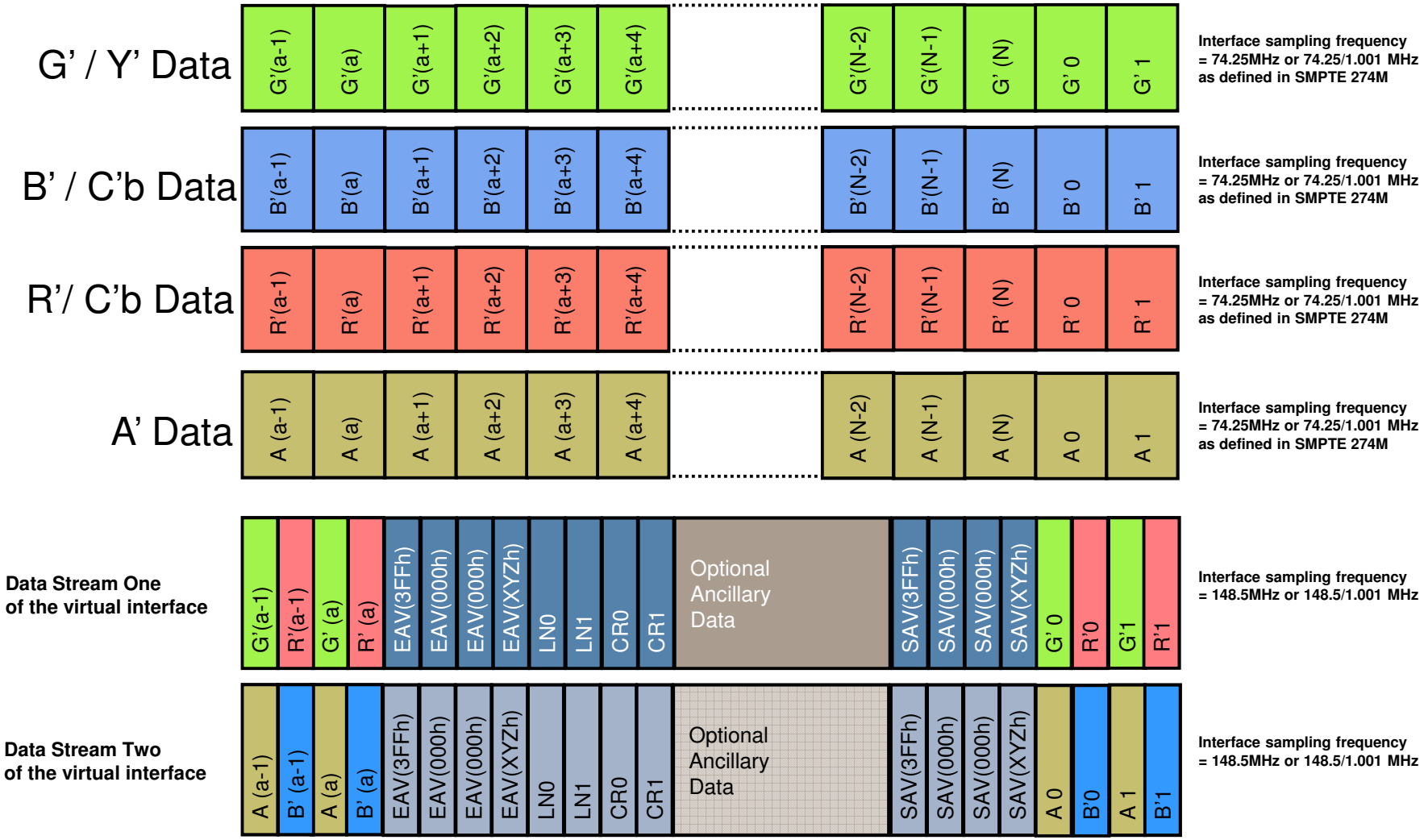
SMPTE 425 Mapping Structure 2

4:4:4:4 GBR(A) or 4:4:4:4 YCbCr(A) 10-bit



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Comparison of Level A vs. Level B

- 4:4:4(:4) 10-bit
  - SMPTE 425 Mapping structure 2 – R samples always on stream 1, B on stream 2. Alpha channel on stream 2.

Stream 1	Y_0 or G_0	Y_1 or G_1	Y_2 or G_2	…	Y/G_{1919}
	Cr_0 or R_0	Cr_1 or R_1	Cr_2 or R_2	…	Cr/R_{1919}
Stream 2	A_0	A_1	A_2	…	A_{1919}
	Cb_0 or B_0	Cb_1 or B_1	Cb_2 or B_2	…	Cb/B_{1919}

  - SMPTE 372M §4.2 – Even B+R samples on stream 1, odd B+R samples on stream 2. Alpha channel on stream 2.

Stream 1	Cb_0 or B_0	Cr_0 or R_0	Cb_2 or B_2	…	Cr/R_{1918}
	Y_0 or G_0	Y_1 or G_1	Y_2 or G_2	…	Y/G_{1919}
Stream 2	Cb_1 or B_1	Cr_1 or R_1	Cb_3 or B_3	…	Cr/R_{1919}
	A_0	A_1	A_2	…	A_{1919}

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SMPTE 425 Mapping Structure 3
4:4:4 GBR or 4:4:4 YCbCr or 4:4:4 XYZ 12-bit

- Each sample (3 channels × 12 bits) is mapped into four 10-bit words (two words per data stream)
- Each 10-bit transport word carries 3 bits from each channel, plus a check bit

	Bit Number									
Data Stream One	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
First word of sample (a) / (n)	Not b8	R'/C'r/X' [11:9]			G'/Y'/Y' [11:9]			B'/C'b/Z' [11:9]		
Second word of sample (a) / (n)	Not b8	R'/C'r/X' [5:3]			G'/Y'/Y' [5:3]			B'/C'b/Z' [5:3]		

	Bit Number									
Data Stream Two	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
First word of sample (a) / (n)	Not b8	R'/C'r/X' [8:6]			G'/Y'/Y' [8:6]			B'/C'b/Z' [8:6]		
Second word of sample (a) / (n)	Not b8	R'/C'r/X' [2:0]			G'/Y'/Y' [2:0]			B'/C'b/Z' [2:0]		

Comparison of Level A vs. Level B

- 4:4:4 12-bit
  - SMPTE 425 Mapping structure 3 – every 10 bit word includes 3 bits of each of the three channels (four words comprise complete sample)

	9	8	7	6	5	4	3	2	1	0
Stream 1	$\overline{B8}$	Cr or R [11:9]			Y or G [11:9]			Cb or B [11:9]		
	$\overline{B8}$	Cr or R [5:3]			Y or G [5:3]			Cb or B [5:3]		
Stream 2	$\overline{B8}$	Cr or R [8:6]			Y or G [8:6]			Cb or B [8:6]		
	$\overline{B8}$	Cr or R [2:0]			Y or G [2:0]			Cb or B [2:0]		

  - SMPTE 372M §4.3 and §4.4 – most significant 10 bits of the three channels appear as in §4.2 formats, and two LSBs of each channel are grouped together into a single word that displaces the A channel

Stream 1	Cb_0/B_0	Cr_0 or R_0	…	Cb/B_{1918}	Cr/R_{1918}
	Y_0 or G_0	Y_1 or G_1	…	Y/G_{1918}	Y/G_{1919}
Stream 2	Cb_1 or B_1	Cr_1 or R_1	…	Cb/B_{1919}	Cr/R_{1919}

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SMPTE 425 Mapping Structure 4
4:2:2 YCbCr 12-bit

- Data stream 1 = Luma sample components @ 74.25 Mhz
- Data stream 2 = Chroma sample components @ 37.125 MHz/channel

	Bit Number									
Data Stream One	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
First word of sample (a) / (n)	1	Reserved (000)			Y' (a) / (n) [11:6]					
Second word of sample (a) / (n)	1	Reserved (000)			Y' (a) / (n) [5:0]					

	Bit Number									
Data Stream One	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
First word of sample (a) / (n)	1	Reserved (000)			C‘b (a) / (n) [11:6]					
Second word of sample (a) / (n)	1	Reserved (000)			C‘b (a) / (n) [5:0]					
Third word of sample (a) / (n)	1	Reserved (000)			C‘r (a) / (n) [11:6]					
Fourth word of sample (a) / (n)	1	Reserved (000)			C‘r (a) / (n) [5:0]					

Comparison of Level A vs. Level B

- 4:2:2 12-bit
  - SMPTE 425 Mapping structure 4 – two 10 bit words each carry 6 bits of each of the three channels. No alpha channel is supported, despite the available space (four bits unused per word).

Stream 1		Y_0 [11:6]		Y_1 [11:6]		…		Y_{1919}
		Y_0 [5:0]		Y_1 [5:0]		…		Y_{1919}
Stream 2		Cb_0 [11:6]		Cr_0 [11:6]		…		Cr_{959}
		Cb_0 [5:0]		Cr_0 [5:0]		…		Cr_{959}

  - SMPTE 372M §4.5 – Stream 1 carries the 10 MSBs of each sample in the familiar Cb/Y/Cr/Y sequence, and stream 2 carries a word of LSBs (2 bits per channel) plus a 10 bit alpha channel.

Stream 1	Cb_0 [11:2]	Cr_0 [11:2]	…	Cb_{959} [11:2]	Cr_{959} [11:2]
	Y_0 [11:2]	Y_1 [11:2]	…	Y_{1918} [11:2]	Y_{1919} [11:2]
Stream 2	A_0	A_1	…	A_{1918}	A_{1919}

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SMPTE 352M Video Payload Identifier

- VPID is mandated by SMPTE 425
- Unlike HD-SDI, VPID is essential for determining the content format
  - Frame rate can be deduced, but sampling structure cannot

Bits	Byte 1	Byte 2	Byte 3	Byte 4
Bit 7	0x89: Level A	Transport (i=0, p=1)	0	0
Bit 6	0x8A: Level B (SMPTE 372)	Picture (i=0, p=1)	1920 (0) 2048 (1)	Link A (0) Link B (1)
Bit 5	0x8B: Level B (2×720)	0	0	0
Bit 4		0	0	Dynamic Range
Bit 3	0x8C: Level B (2×1080)	Picture Rate	Sampling Structure	
Bit 2				0
Bit 1	0x8D: Level B (2×483/576)			Bit Depth
Bit 0				

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SMPTE 352M Video Payload Identifier

- Picture Rate encoding

Value	Picture Rate	Value	Picture Rate	Value	Picture Rate	Value	Picture Rate
0_h	No defined value	1_h	Reserved	2_h	24/1.001	3_h	24
4_h	Reserved	5_h	25	6_h	30/1.001	7_h	30
8_h	Reserved	9_h	50	A_h	60/1.001	B_h	60
C_h	Reserved	D_h	Reserved	E_h	Reserved	F_h	Reserved

- Sample Structure encoding

Value	Sampling	Value	Sampling	Value	Sampling	Value	Sampling
0_h	4:2:2 YCbCr	1_h	4:4:4 YCbCr	2_h	4:4:4 GBR	3_h	4:2:0
4_h	4:2:2:4 YCbCrA	5_h	4:4:4:4 YCbCrA	6_h	4:4:4:4 GBRA	7_h	Reserved
8_h	4:2:2:4 YCbCrD	9_h	4:4:4:4 YCbCrD	A_h	4:4:4:4 GBRD	B_h	Reserved
C_h	Reserved	D_h	Reserved	E_h	4:4:4 XYZ	F_h	Reserved

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SMPTE 352M Video Payload Identifier

- Bit Depth encoding

Value	Bit Depth
0_h	8-bit
1_h	10-bit
2_h	12-bit
3_h	Reserved

- Note that specific tables in Annex A override the generalized definition
  - For example, Table A.4 describes the encoding for 750 line systems. These are always progressive transport, so you would assume bit 7 of byte 2 would be set to 1. But it is marked as “Reserved” in Table A.4 and therefore set to 0.
  - Not every manufacturer gets this correct!
- VPID ancillary packets always inserted in both data stream 1 and data stream 2 (so two copies per frame, unlike HD-SDI)

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Embedded Audio

- Audio ancillary packet location
  - Audio control packets in HANC of data stream 1 (not always Y)
  - Audio data packets in HANC of data stream 2 (not always Cb/Cr)
- Available space for twice the embedded audio content as HD-SDI
  - New standard SMPTE 299M-2 defines “extended” audio control and data packets to support up to 32 channels in Level A formats
  - (SMPTE 299M to be renamed 299M-1)

Group	Channels	Data SDID	Control SDID
5	17–20	$A7_h$	$A3_h$
6	21–24	$A6_h$	$A2_h$
7	25–28	$A5_h$	$A1_h$
8	29–32	$A4_h$	$A0_h$

- Level B formats can already carry 32 channels; each link has independent groups 1–4

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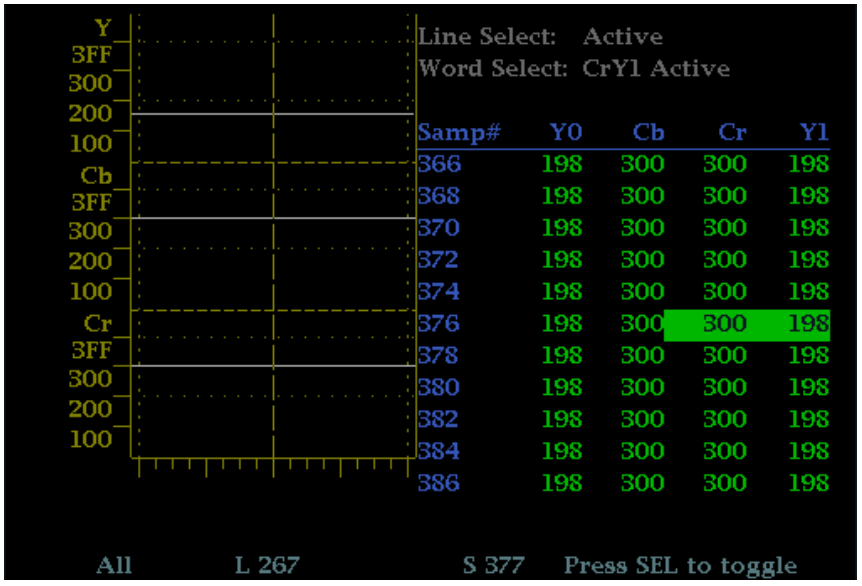
SDI Checkfield Test Pattern

- Defined in SMPTE RP 198 for HD-SDI
- Equalizer test pattern has maximum DC content
  - Uses 20 bit pattern 1100000000 0110011000 (300h 198h) input to the scrambler for the serial data stream
  - Produces output with repeated pattern of 19 consecutive high (low) states followed by 1 low (high) state
  - Corresponds to Y=198h, Cb=Cr=300h (shade of magenta) for HD-SDI



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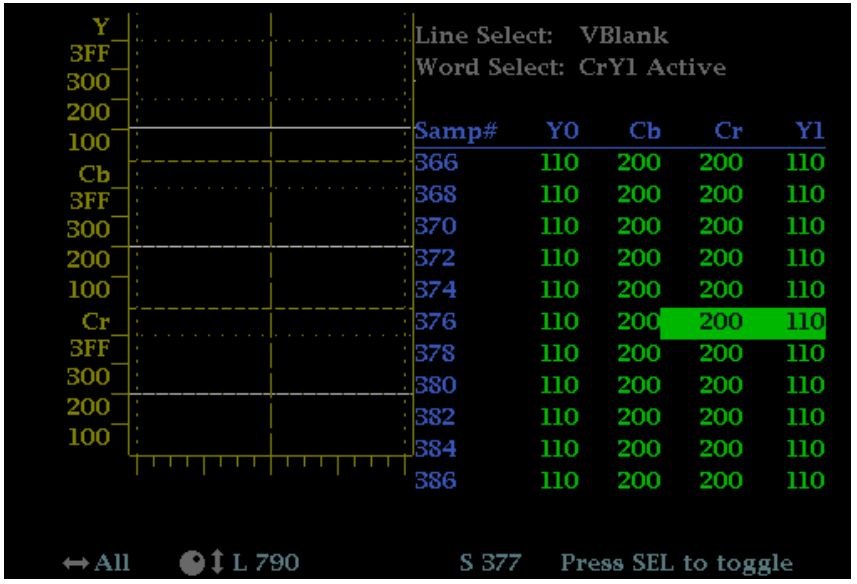
SDI Checkfield Test Pattern

- PLL test pattern has maximum low-frequency content and minimum high-frequency content
  - Uses 20 bit pattern 1000000000 0100010000 (200h 110h) input to the scrambler for the serial data stream
  - Produces output with repeated pattern of 20 consecutive high (low) states followed by 20 consecutive low (high) state
  - Corresponds to Y=110h, Cb=Cr=200h (23.74% gray) for HD-SDI



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SDI Checkfield Test Pattern for 3G-SDI

- Or, “why are the colors wrong?”
- In order to produce the same pathological patterns in the serial bit stream, the 10 bit words must be sequenced in the same order

HD-SDI	3G-SDI	Equalizer test	PLL test
Y channel	Data stream 1	198h	110h
Cb/Cr channel	Data stream 2	300h	200h

- This results in different colors from the familiar magenta/gray for various 3G mapping structures

Level A MS1 (1080p)

Data stream 1 carries the Y samples and data stream 2 carries the Cb/Cr samples, so the multiplexing is similar to HD-SDI and the pattern has the familiar colors.

Level B 1080p

In dual link, lines alternate between the two links. Therefore, in Level B, odd lines have one word for both Y and Cb/Cr samples, and even lines have the other word for both Y and Cb/Cr samples.

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SDI Checkfield Test Pattern for 3G-SDI

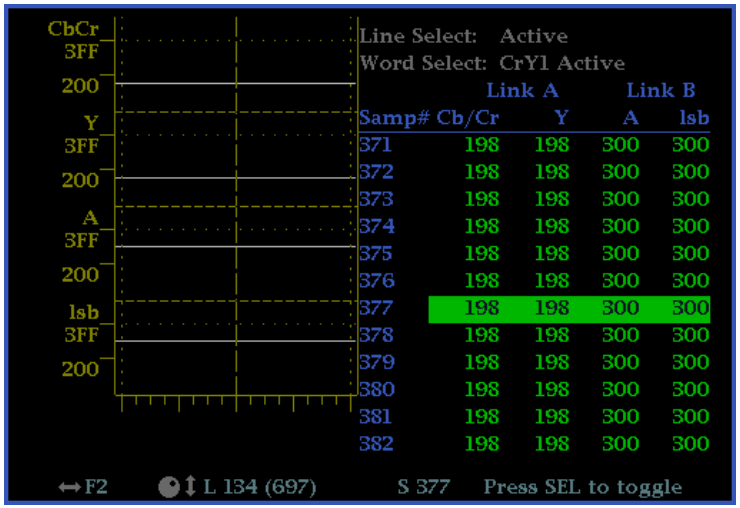
- As it appears for other Level B formats:

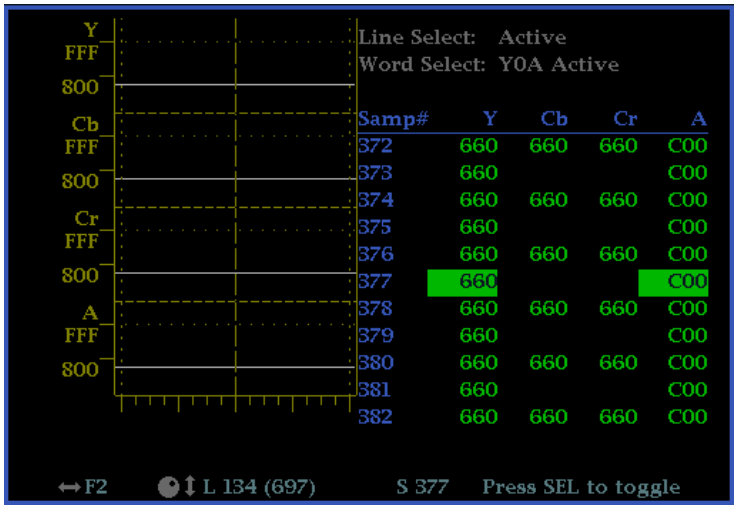
4:4:4 YCbCr 10-bit

4:4:4 GBR 12-bit

4:2:2:4 YCbCrA 12-bit

- Verify with data mode (not video mode) of data display





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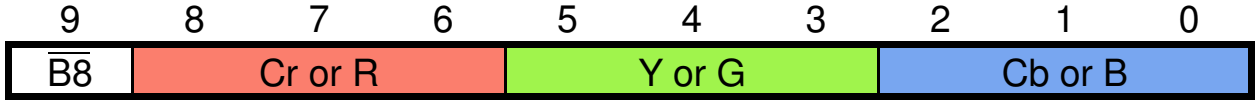
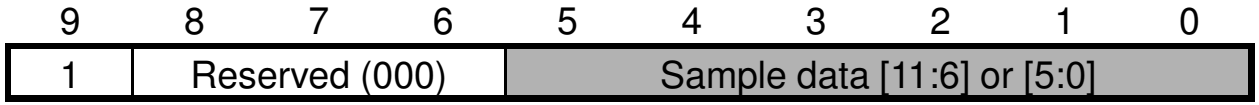
SDI Checkfield Test Pattern for 3G-SDI

- For Level A, the SDI checkfield pattern would be *illegal* for mapping structures 3 and 4, because unused bits would not be set to zero and parity bit would not be correct
  - Mapping structure 3: not possible to encode 300h for first word of equalizer test (bit 9 would not be the complement of bit 8)



  - Mapping structure 4: not possible to encode any 10 bit word other than 20Xh..23Xh



- Best solution is to simply use Level A mapping structure 1

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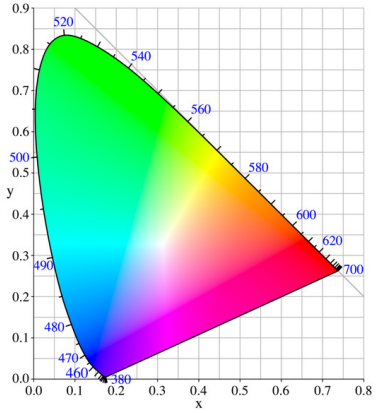
Digital Cinema 2K Formats

- 2048 samples per line (instead of 1920) leads to “2K” name
  - Increases aspect ratio from 1.78 to 1.90
    - Encompasses common 35mm widescreen size of 1.85:1
  - Allows for other aspect ratios by using fewer lines
    - e.g. 35mm anamorphic at 2.39:1 would use 2048×858 raster size
- Uses CIE 1931 (XYZ) color space to more closely match gamut of traditional film stock and human eyes
  - Not based on color difference, nor has primary colors aligned with specific channels

Color	X’	Y’	Z’
White	3794	3960	3890
Red	2901	2171	100
Green	2417	3493	1222
Blue	2014	1416	3816
Black	122	128	125



- SMPTE 428-1 defines 2K 4:4:4 XYZ 12-bit @ 24p/24PsF, and only this is included in SMPTE 425 (Mapping Structure 3)
- GBR color space also used with 2K, in post-production prior to final master in XYZ

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New Formats in Future Revision of SMPTE 425-2008

- Current work of Technology Committee 32NF, depends on two other work-in-progress standards
  - SMPTE abc-2010: 2048×1080 D-Cinema Production Image Format – 2200×1125 Signal Formatting for Serial Digital Interface
  - SMPTE xyz-2010: D-Cinema Distribution Master – Additional Frame Rates – Serial Digital Scanning

Mapping Structure	Reference SMPTE Standard	Picture Format	Signal Format Sampling Structure/Pixel Depth	Frame/Field Rates
1	abc	2048 × 1080	4:2:2 ($Y'C'_BC'_R$)/10-bit	60, 60/1.001, 50, 48 and 48/1.001 Frames Progressive
2	abc	2048 × 1080	4:4:4 (R'G'B'), 4:4:4:4 (R'G'B' +A)/10-bit	30, 30/1.001, 25, 24 and 24/1.001 Frames Progressive, PsF
			4:4:4 ($Y'C'_BC'_R$), 4:4:4:4 ($Y'C'_BC'_R$+A)/10-bit	
3	abc	2048 × 1080	4:4:4 (R'G'B')/12-bit	30, 30/1.001, 25, 24 and 24/1.001 Frames Progressive, PsF
			4:4:4 ($Y'C'_BC'_R$)/12-bit	
	xyz	2048 × 1080	4:4:4 (X'Y'Z')/12-bit	30 and 25 Frames Progressive
4	abc	2048 × 1080	4:2:2 ($Y'C'_BC'_R$)/12-bit	30, 30/1.001, 25, 24 and 24/1.001 Frames Progressive, PsF

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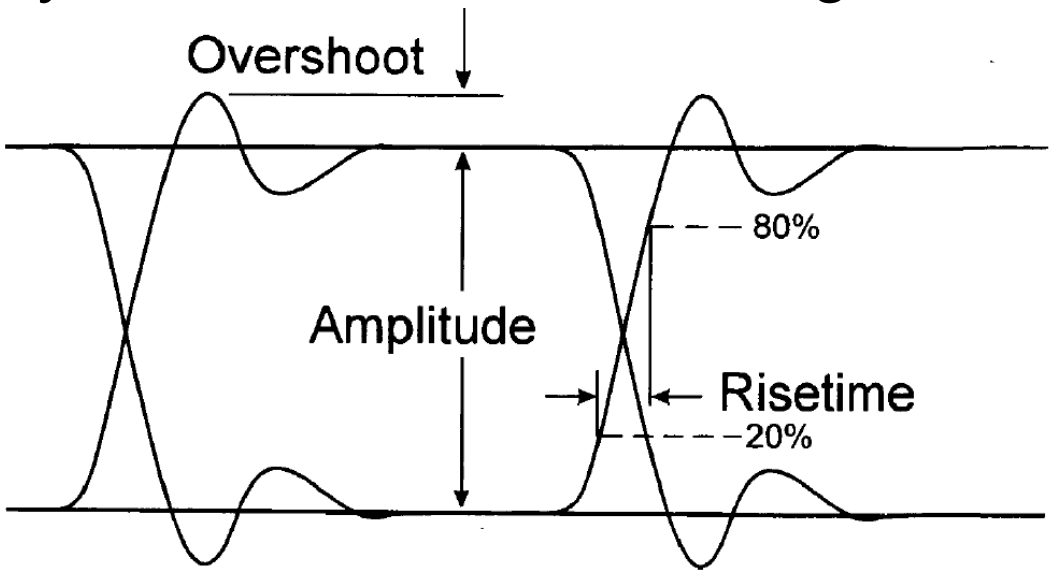
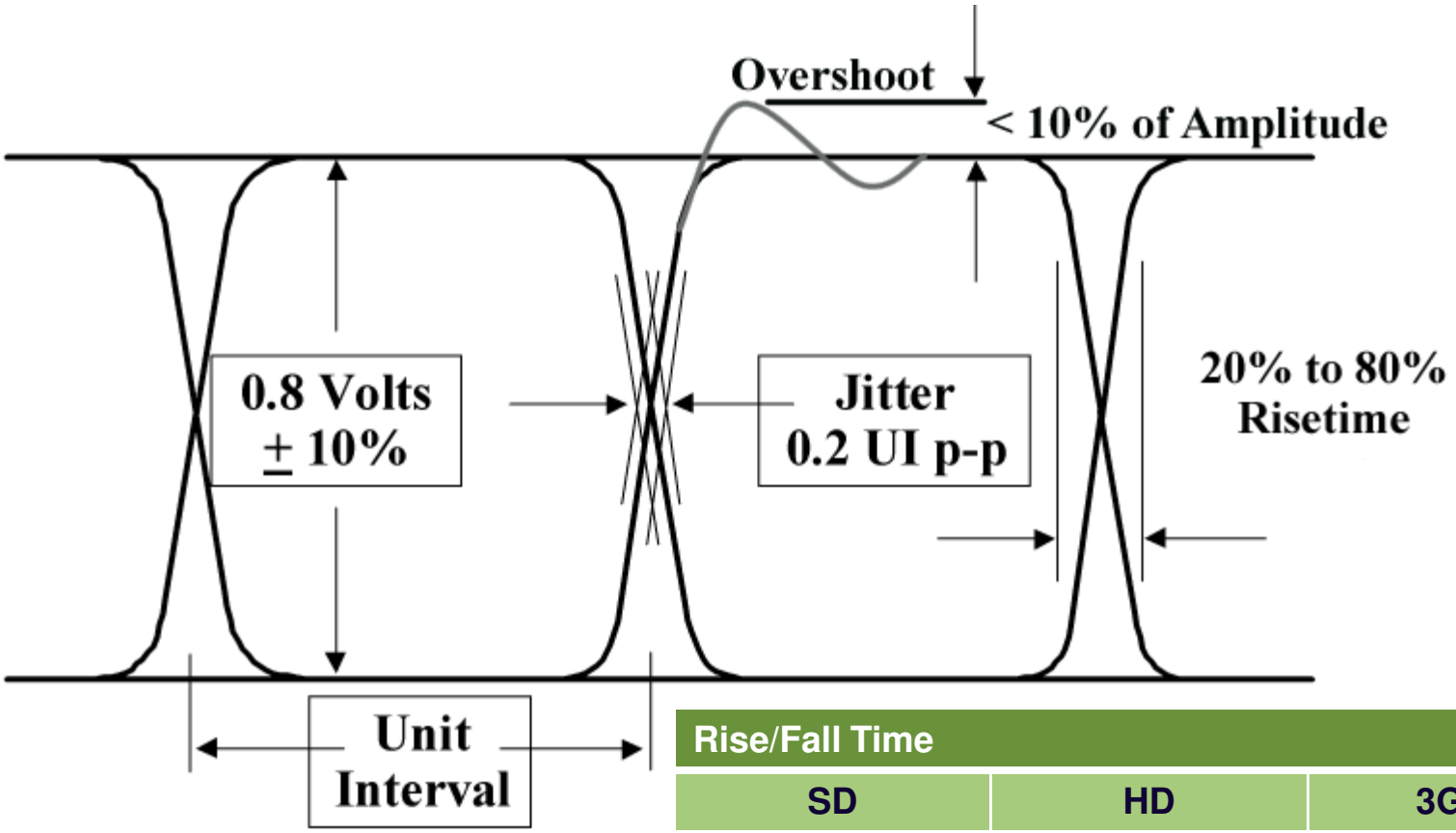
Physical Layer of the 3Gb/s Serial Digital Interface



- Pk-to-Pk Amplitude 800mV +/- 10%
- DC Offset 0.0V +/- 0.5V
- Rise/Fall Time between 20% & 80% no greater than 135ps and not differ by more than 50ps
- Overshoot rise/fall not to exceed 10% of amplitude
- Timing Jitter <= 2UI above 10Hz
- Alignment Jitter <= 0.3UI above 100kHz

Eye Specifications per SMPTE Standards



Unit Interval		
SD (259M)	HD (292M)	3Gb/s (424M)
3.7ns	673.4ps	336.7ps

Rise/Fall Time		
SD	HD	3Gb/s
Shall be no less than 0.4ns, no greater than 1.50ns, and shall not differ by more than 0.5ns	Shall be no greater than 270ps and shall not differ by more than 100ps	Shall be no greater than 135ps and shall not differ by more than 50ps

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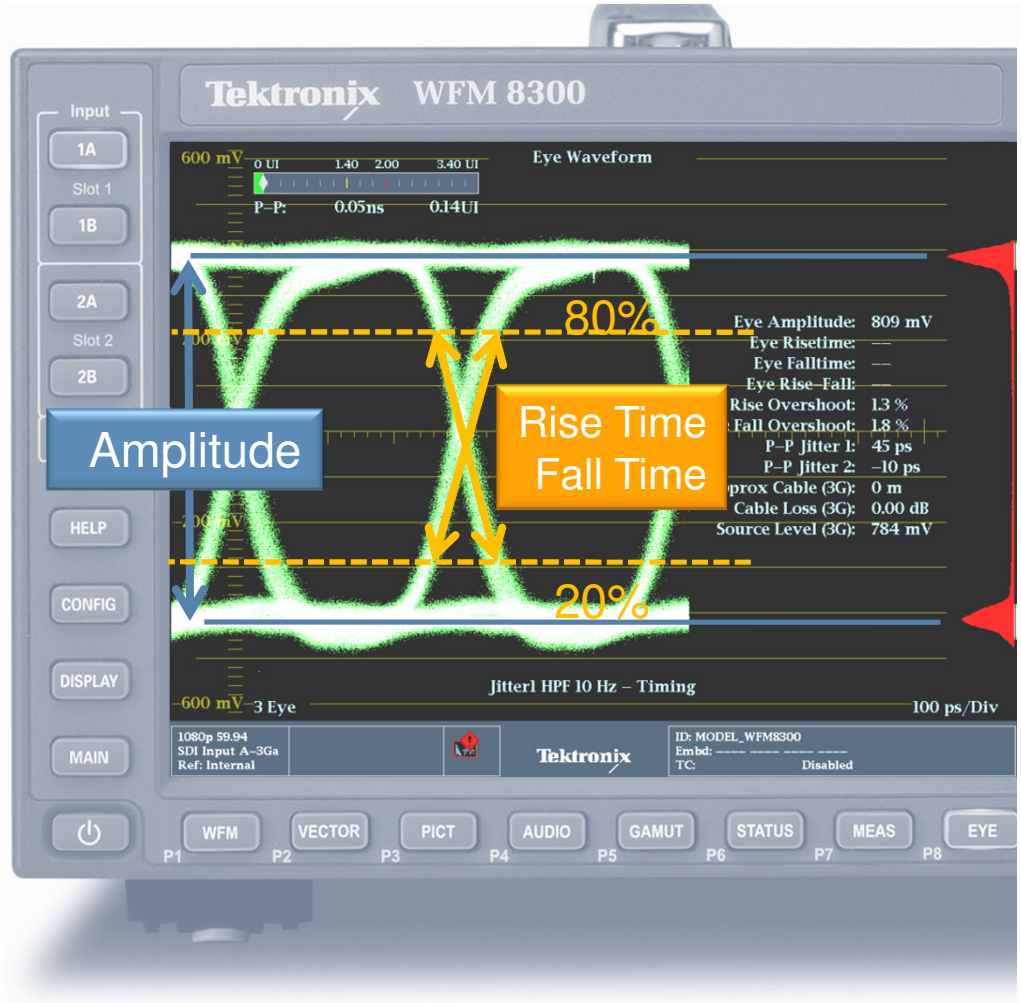
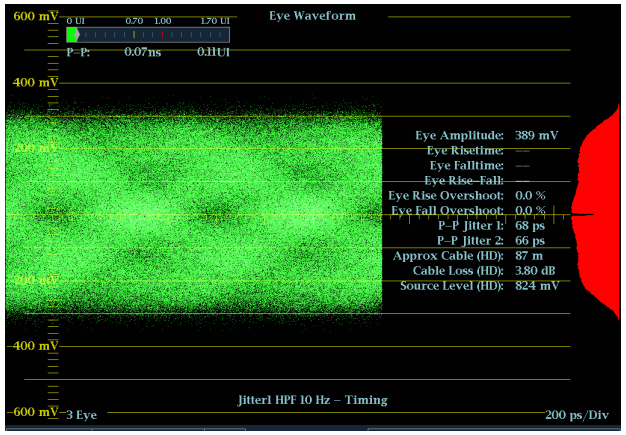
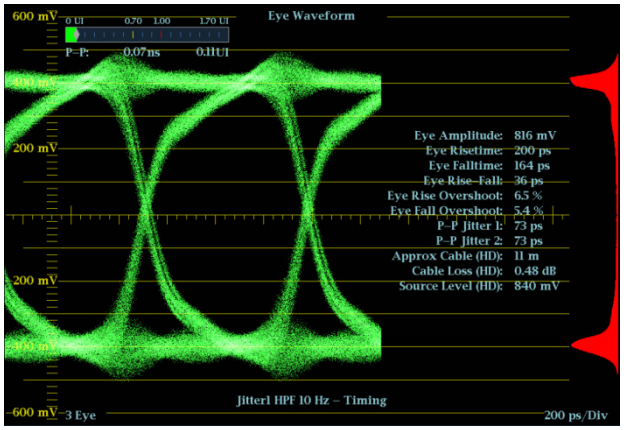
How to Make Eye Measurement

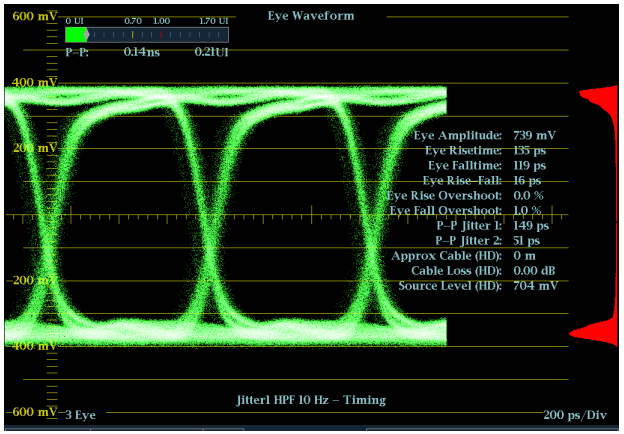


- Eye Display
- Launch Amplitude
- Short Length of Cable
- Color Bar Test Signal
- Automated Measurements
  - Available on WM8300
  - Amplitude Histogram
  - Simplifies The Task
- Infinite persistence can aid in seeing eye opening

Eye Pattern Distortions







Long cable

- Decrease in amplitude
- Decrease in Frequency response
- Eye opening narrows
- Rise/Fall time increases

Termination

- Incorrect termination causes overshoot and undershoot

Shift in Eye Crossing

- Shifts 50% point of eye opening
- Caused by unequal rise or fall time

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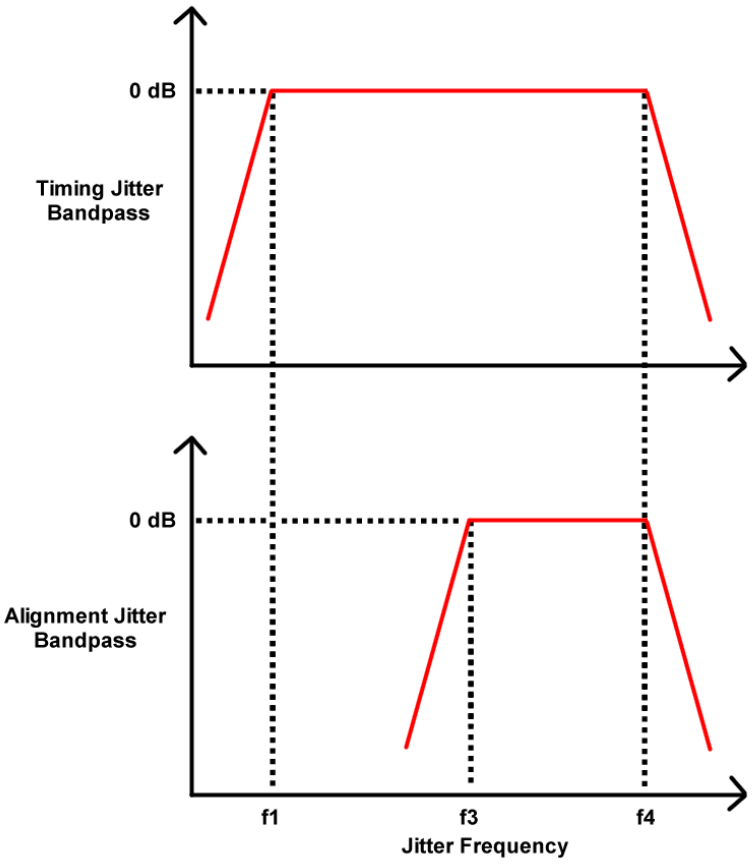
Jitter Measurements

- Timing Jitter

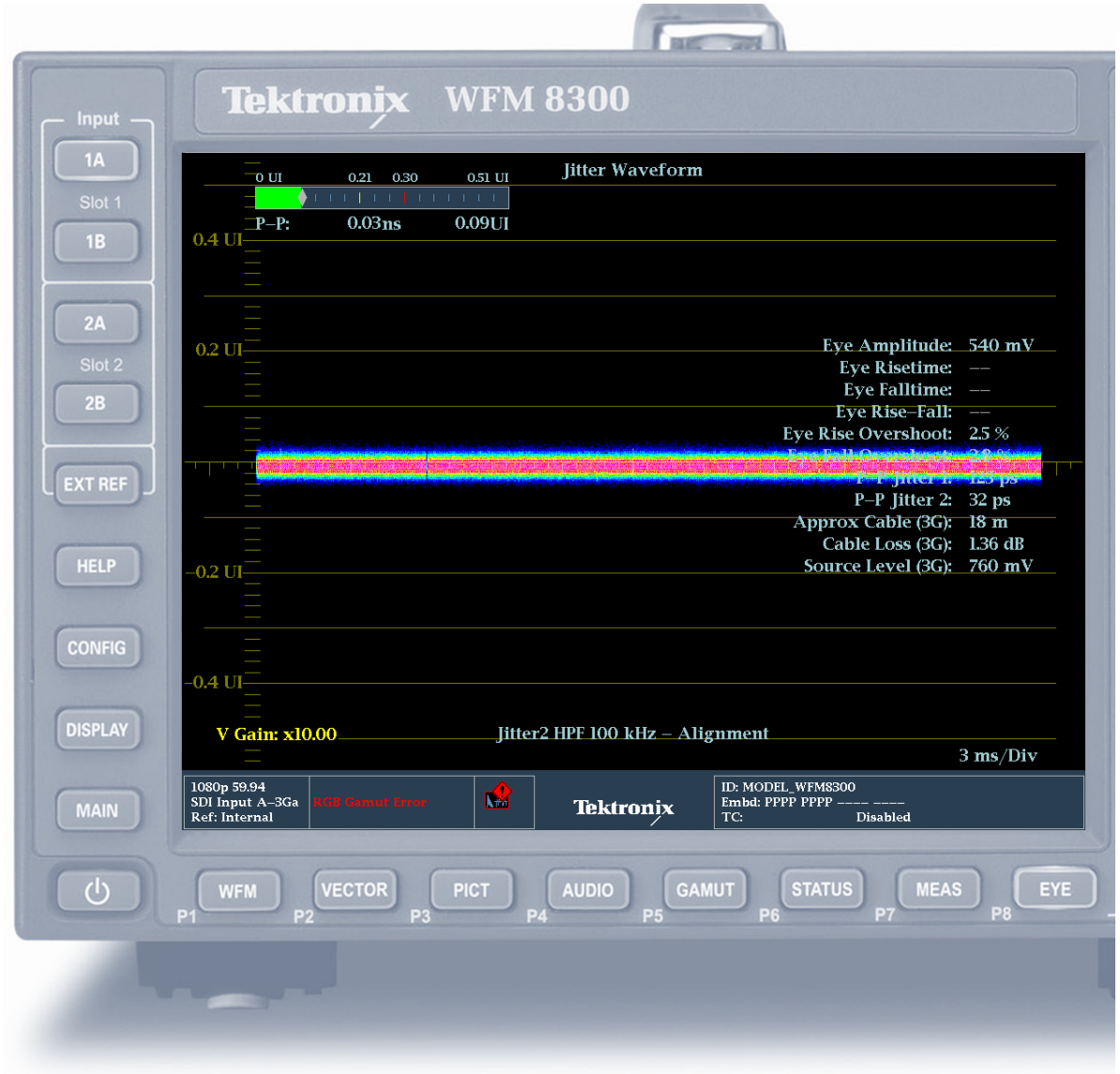
Timing Jitter (10Hz)		
SD	**HD**	**3Gb/s**
0.2UI (740ps)	1.0UI (673.4ps @ 1.485Gb/s) (674ps @ 1.4835Gb/s)	2.0UI (673.4ps @ 2.97Gb/s) (674ps @ 2.967Gb/s)

- Alignment Jitter

Alignment Jitter		
SD	HD	3Gb/s
0.2UI (740ps) @ 1kHz	0.2UI (135ps) @ 100kHz	0.3UI (101ps) @ 100kHz Maximum Preferred 0.2UI (67.3ps) @ 100kHz



How to Make Jitter Measurements



- Jitter Meter shows direct readout
- Ability to measure Timing and Alignment jitter simultaneously
- Jitter waveform show variation of signal related to line and field rate of video signal

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Thank you

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