Verification Challenges For Deep Color Mode In HDMI

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2016 DESIGN AND VERIFICATION™ DVCON CONFERENCE AND EXHIBITION EUROPE

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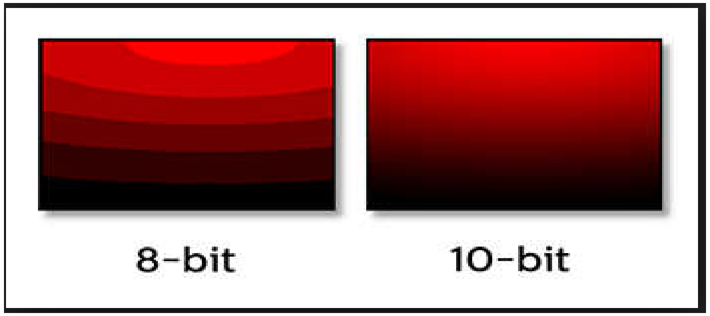
Introduction to HDMI Deep Color Mode

- Color depth or bit depth
  - the number of bits used for each color component of a single pixel
- Deep color
  - Bits per pixel higher than 24
  - For example: 30bpp, 36bpp, 48bpp



- At deeper color depths, the TMDS clock is run faster than the source pixel clock providing the extra bandwidth for the additional bits.
- The TMDS clock rate is increased by the ratio of the pixel size to 24 bits
  - 24 bit mode: TMDS clock= 1.0 x pixel clock (1:1)
  - 30 bit mode: TMDS clock= 1.25 x pixel clock (5:4)
  - 36 bit mode: TMDS clock= 1.5 x pixel clock (3:2)
  - 48 bit mode: TMDS clock= 2.0 x pixel clock (2:1)
- Pixels and fragments in modes of deep color mode
  - 24 bit mode: 1 pixel/grp, 1 fragment/grp
  - 30 bit mode: 4 pixels/grp, 5 fragments/grp
  - 36 bit mode: 2 pixels/grp, 3 fragments/grp
  - 48 bit mode: 1 pixel/grp, 2 fragments/grp

Transmission of pixels for color depth 24bpp

- Each TMDS character period (one TMDS clock) in the transmitted stream carries a single fragment of a pixel group and represents a particular packing phase of the group.

		24 BIT MODE: P=1 PIXELS; L= 1 FRAMENTS								
Fragment	Phase	Pixels	8 bit HDMI pixel data code (to encoder)							
			Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7
8P0	0	A	A0	A1	A2	A3	A4	A5	A6	A7

Transmission for color depth 36 and 48

- 36bpp

		36 BIT MODE: P=2 PIXELS; L= 3 FRAMENTS								
Fragment	Phase	Pixels	8 bit HDMI pixel data code (to encoder)							
			Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7
12P0	0	A	A0	A1	A2	A3	A4	A5	A6	A7
12P1	1	A+B	A8	A9	A10	A11	B0	B1	B2	B3
12P2	2	B	B4	B5	B6	B7	B8	B9	B10	B11

- 48bpp

		48 BIT MODE: P=1 PIXELS; L= 2 FRAMENTS								
Fragment	Phase	Pixels	8 bit HDMI pixel data code (to encoder)							
			Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7
16P0	0	A	A0	A1	A2	A3	A4	A5	A6	A7
16P1	1	A	A8	A9	A10	A11	A12	A13	A14	A15

Transmission for color depth 30

		30 BIT MODE: P=4 PIXELS; L= 5 FRAMENTS								
Fragment	Phase	Pixels	8 bit HDMI pixel data code (to encoder)							
			Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7
10P0	0	A	A0	A1	A2	A3	A4	A5	A6	A7
10P1	1	A+B	A8	A9	B0	B1	B2	B3	B4	B5
10P2	2	B+C	B6	B7	B8	B9	C0	C1	C2	C3
10P3	3	C+D	C4	C5	C6	C7	C8	C9	D0	D1
10P4	4	D	D2	D3	D4	D5	D6	D7	D8	D9

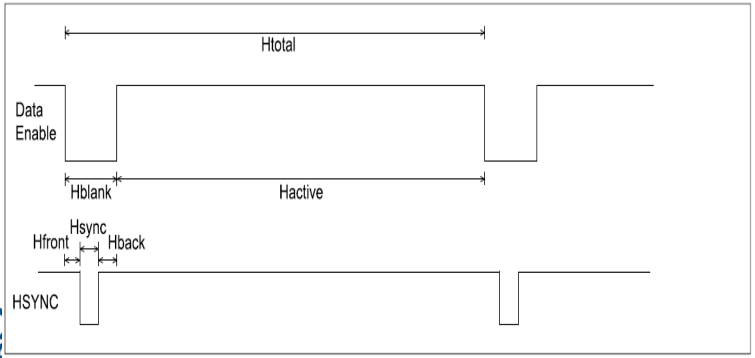
– For 30bpp, 4 pixels gets transmitted in 5 fragments when starting pixel packing phase at the start of video period is “0”.
– Situation becomes more complex when the starting pixel packing phase at the start of Video period is other than “0”.
– When transmitting 4 pixels with starting pixel packing phase as “1” in case of 30bpp, 6 fragments are required, i.e, we need one extra video fragment to transmit complete video information.
– Let’s see how we can compensate this increase in video fragment.

Verification Challenges

- To identify a way to compensate the increase in video period fragments with a decrease in fragments of blanking period keeping the total number of pixels intact, in case starting pixel packing phase at start of video period is other than PP0.
- Next set of slides discusses some use cases.

Case – 36bpp Video ID Code 2

- Hactive=720 Hfront=16 Hsync=62 Hback=60 Htotal=858
- Possible pixel packing phase at start of video period are 0, 1.
- Numbers of fragments are equal to 1.5 times the number of pixels.
- **If pixel packing phase = 0 at the start of video data then the value of fragments are as follows:**
  - *Hactive = 720 * 1.5 = 1080, Hsync = 62 * 1.5 = 93*
  - *Hback =60 * 1.5 = 90, Hfront = 16 * 1.5 = 24*
  - *Htotal = 858 * 1.5 = 1287*
  - *Htotal_1 = (Hactive+ Hback +Hsync+ Hfront) = 1080+183+24 = 1287*
  - *Htotal == Htotal_1*



- **If pixel packing phase = 1 at the start of video data then the value of fragments are as follows:**

  We need one extra fragment in video data as the first fragment of video does not contain the valid data in first 4 bits and needs to be discarded. Therefore an extra fragment is required for complete transmission of video pixels.
  - *Hactive = 720 * 1.5 = 1080 + 1 (Extra fragment to compensate loss of first 4 bits) = 1081*
  - *Hsync = 62*1.5 = 93 ; Hback =60*1.5 = 90*
  - *Hfront = 16*1.5 = 24 ; Htotal_1 = 858*1.5 = 1287*
  - *Htotal = (Hactive+ Hback +Hsync+ Hfront) = 1081+183+24 = 1288*
  - *Htotal != Htotal_1*
- Since Htotal != Htotal_1, Htotal i.e., width of frames should remain same irrespective of change in pixel packing phase.

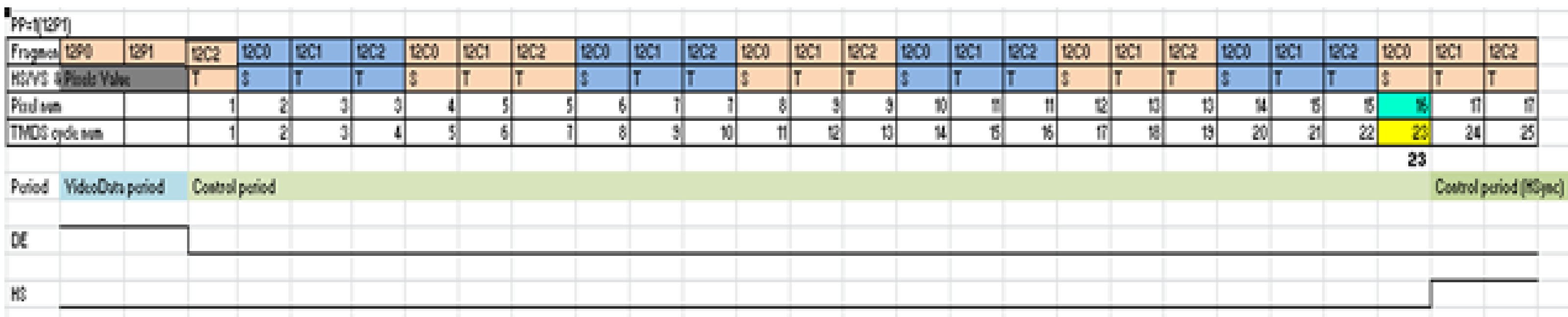
Case – 36bpp Video ID Code 2

- To resolve this problem we need to adjust the extra fragment required in Hactive by decrease in Hfront's fragment. Hence the calculations for pixel packing phase 1 are modified as:
  - *Hactive = 720 * 1.5 = 1080 + 1 = 1081*
  - *Hback+Hsync (Blank pixels) = 122(62+60) * 1.5 = 183*
  - *Hfront = 16 * 1.5 = 24 – 1 = 23 (To compensate the increase in fragment for Hactive)*
  - *Htotal_1 = 858 * 1.5 = 1287*
  - *Htotal = (Hactive+ Hback+Hsync+ Hfront) = 1081+183+23 = 1287*
  - *Now Htotal == Htotal_1*
- Even after decreasing 1 fragment in Hfront, we will still be able to transmit complete Hfront pixels.
- Fragment state transition table:

Fragment	HS/VS value
12C0	S
12C1	T
12C2	T

Table 5: Group size = 2 pixels; 3 fragments

Case – 36bpp Video ID Code 2



- Calculating the total Hfront fragments this way are: 1 (1st pixel) + 14 * 1.5 (next 14 pixels) + 1 (Last 16th pixel) = 1+21+1 = 23 fragments.
- The increase in Hactive fragment gets compensated by decrease in Hfront fragment and still we are able to transmit the complete Hfront information.

Case – 30bpp Video ID Code 2

- Possible pixel packing phase at start of video period are 0, 1, 2 & 3.
- Numbers of fragments in case of 30 bit color depth are equal to 1.25 times the number of pixels
- Calculation for horizontal fragments:
  - *Hactive = 720 * 1.25 = 900;*
  - *Hback= 60 * 1.25 = 75;*
  - *Hsync = 62 * 1.25 = 77.5*
  - *Hfront = 16 * 1.25 = 20 ;*
  - *Htotal = 858 * 1.25 = 1072.5*
- Since Hsync and Htotal are fractional, number of fragments transmitted on alternate lines are
- If PP0
  - *Htotal = (Hactive+ Hback +Hsync+ Hfront) = 900+75+77+20 = 1072*
  - *Htotal = (Hactive+ Hback +Hsync+ Hfront) = 900+75+78+20 = 1073*
- If PP1, PP2 or PP3
  - *Htotal = (Hactive+ Hback +Hsync+ Hfront) = 901+75+77+19 = 1072*
  - *Htotal = (Hactive+ Hback +Hsync+ Hfront) = 901+75+78+19 = 1073*

Case – 30bpp Video ID Code 2

- Fragment state transition table (fragments:4 groups: 5):

Fragment	HS/VS value
10C0	S
10C1	T
10C2	U
10C3	V
10C4	V

- States defined in above table are followed in normal scenario, and when pixel packing phase at the start of Hfront is 0 or 1. But when falling edge of DE occurs in mid group i.e., when pixel packing phase at start of Hfront (end of video period) is 2, 3 or 4, the states followed are shown below

Fragment	HS/VS value
10PC2	T
10PC3	U
10PC4	V

Case – 30bpp Video ID Code 2

- Transmission of Hfront fragments:

1) Pixel packing phase at start of video period is "0"

PP=0(10P4)	TMDSCLK sample																												
Fragment	10P0	10P1	10P2	10P3	10P4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3
HS/VS value						S	T	U	V	V	S	T	U	V	V	S	T	U	V	V	S	T	U	V	V	S	T	U	V
Pixel num						1	2	3	4	4	5	6	7	8	8	9	10	11	12	12	13	14	15	16	16	17	18	19	20
TMDS cycle num						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
																									20				
Period	VideoData period					Control period (Hfront)																				Control period (HSync)			
DE																													
HS																													

2) Pixel packing phase at start of video period is "1"

PP=1(10P1)																									
Fragment	10P0	10P1	***10PC2***	***10PC3***	***10PC4***	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4
HS/VS & Pixels Value			T	U	V	S	T	U	V	V	S	T	U	V	V	S	T	U	V	V	S	T	U	V	V
Pixel num			1	2	3	4	5	6	7	7	8	9	10	11	11	12	13	14	15	15	16	17	18	19	19
TMDS cycle num			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
																					19				
Period	VideoData period		Control period																			Control period (HSync)			
DE																									
HS																									

- Calculating the total Hfront fragments this way are: 3 (first 3 pixels) + 12 * 1.25 (next 12 pixels) + 1 (Last 16th pixel) = 3+15+1 = 19 fragments.

Case – 30bpp Video ID Code 2

3) Pixel packing phase at start of video period is "2".

PP=2(10P2)																									
Fragment	10P0	10P1	10P2	10PC3	10PC4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4
HS/VS & Pixels Value				U	V	S	T	U	V	V	S	T	U	V	V	S	T	U	V	V	S	T	U	V	V
Pixel num				1	2	3	4	5	6	6	7	8	9	10	10	11	12	13	14	14	15	16	17	18	18
TMDS cycle num				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
																						19			
Period	VideoData period			Control period																			Control period (HSync)		
DE																									
HS																									

Calculating the total Hfront fragments this way are: 2 (first 2 pixels) + 12 * 1.25 (next 12 pixels) + 2 (Last 2 pixels) = 2+15+2 = 19 fragments.

4) Pixel packing phase at start of video period is "3".

PP=3(10P3)																									
Fragment	10P0	10P1	10P2	10P3	10PC4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4	10C0	10C1	10C2	10C3	10C4
HS/VS & Pixels Value					V	S	T	U	V	V	S	T	U	V	V	S	T	U	V	V	S	T	U	V	V
Pixel num					1	2	3	4	5	5	6	7	8	9	9	10	11	12	13	13	14	15	16	17	17
TMDS cycle num					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
																							19		
Period	VideoData period				Control period																			Control period (H:	
DE																									
HS																									

Calculating the total Hfront fragments this way are: 1 (first pixel) + 12 * 1.25 (next 12 pixels) + 3 (Last 3 pixels) = 1+15+3 = 19 fragments.

Validation For 30bpp VIC 2

Validation with PP0

- Validation in this case is trivial as by default the transmission of video data start with pixel packing phase as “0”. This case does not require any compensation in video data. The complete video data gets transmitted in hactive * 1.25 fragments requiring no extra fragment for compensation.

Validation with PP1,PP2 and PP3

- To validate PP1 case, we should have scenarios where video data start with pixel packing phase as “1” or “2” or “3” leading to the requirement of extra fragment in transmission exercising the scenario requiring the compensation by horizontal blanking period.
- Visually, each of these periods need to be reviewed and validated. For automation and regression, scoreboard and counters are used to cover all horizontal frame regions.

Role of Protocol Checks and Functional Coverage

Protocol Checks

- There should be appropriate and sufficient number of temporal or procedural checks for all the combinations of different color depths and different pixel packing phases. They must look for all use cases for pixel compensation.
- There should be checks for ensure that the pixel packing phase is getting adjusted properly when there is a difference in the pixel packing phase of transmitter and receiver.
- Error injection is required to ensure that checks are covering all conditions correctly.
- Coverage of these protocol checks is required for determining completion.

Functional Coverage

- For the scenarios discussed in this presentation, Signal level coverage, data object and transaction class variables coverage is not sufficient for verification closure.
- There is a need for comprehensive scenario coverage for as well as cross coverage for pixel packing phase, color mode, stating phase and other contributing attributes.

Conclusion

- For deep color mode, when pixel packing phase at start of video period is other than 0, then we require an extra fragment to transmit complete video data.
- This increase in fragment count for video data is getting compensated by decrease in Hfront fragment and still able to transmit complete Hfront information.
- Assertions or protocols checks and functional coverage should be written in such a way that it exercises and checks all the complex scenario's required for verification of the implemented logic.

Questions