Study of DDR Asymmetric Rt/Ft in Existing IBIS-AMI Flow

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Agenda:

- Motivation
- Background
- Asymmetric Rt/Ft
- AMI_Init
- AMI_GetWave
- Summary
- Q & A

Motivation

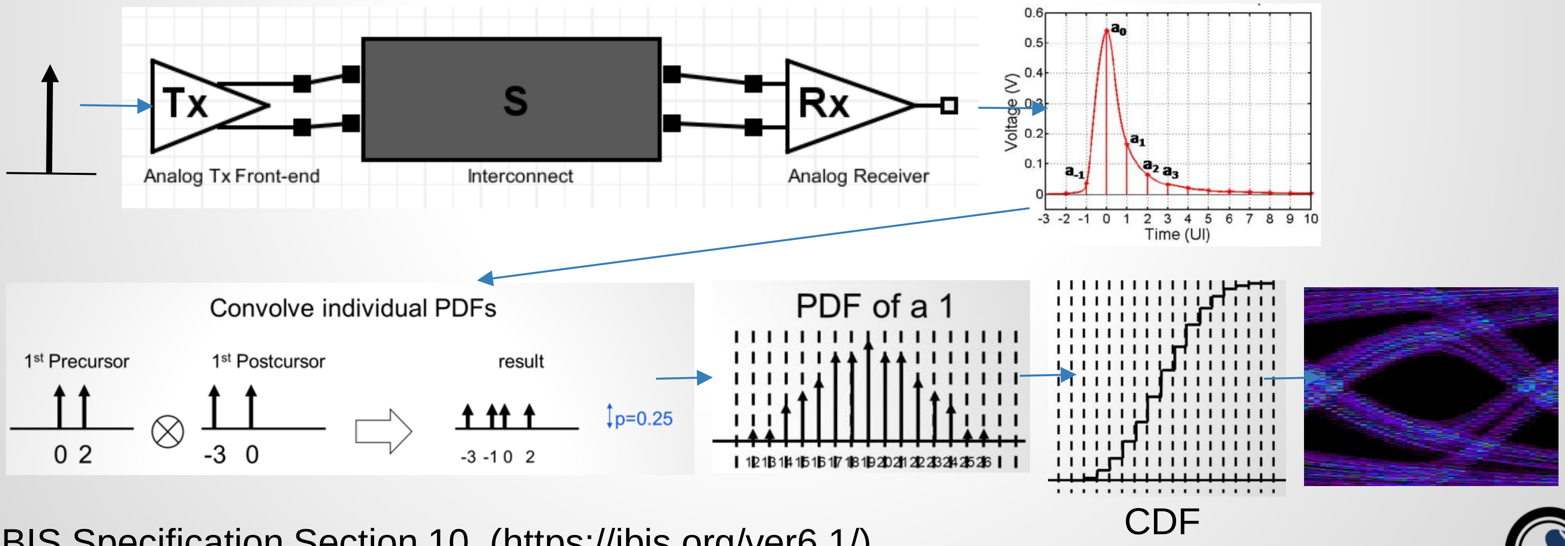
- IBIS-AMI analysis flows:
  - Statistical: use impulse response and AMI_Init
  - Time-domain: use convolution and mainly AMI_GetWave

- Existing applications focused on SERDES
  - Differential, centered around V = 0.0
  - Symmetric rise-time (Rt) /fall-time (Ft)

- How DDR may work in existing AMI flow?
  - Single-ended e.g. DQ
  - Asymmetric Rt/Ft

Background 1/2

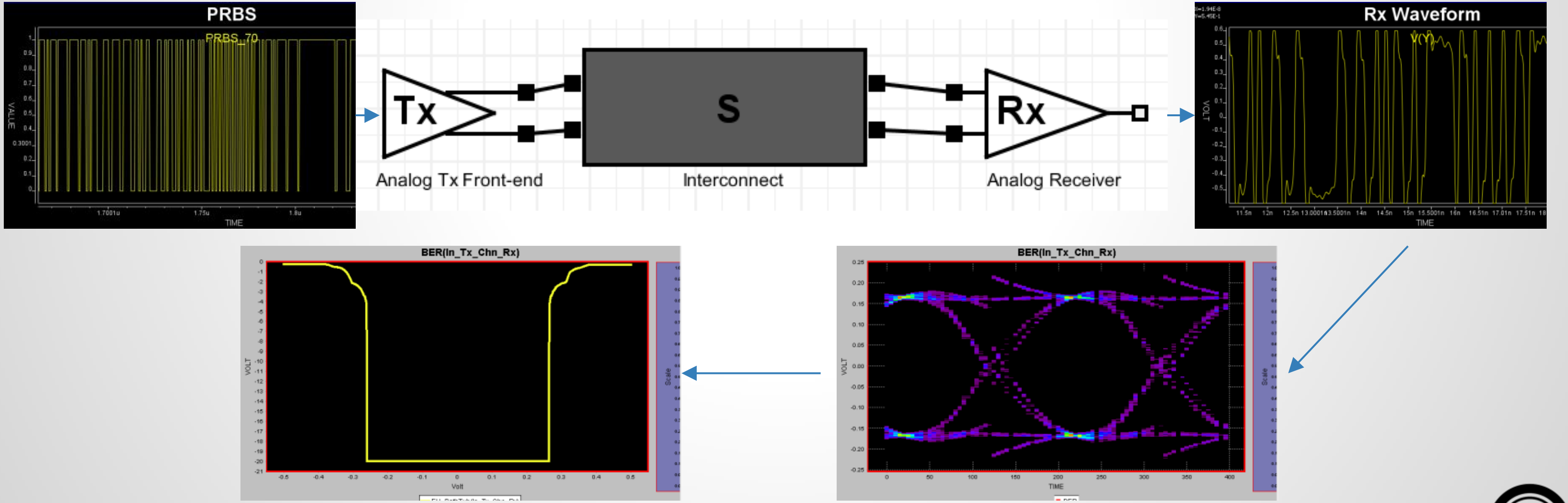
- Statistical AMI flow: [*]
  - Impulse Response for analog + channel (Linear Time Invariant, LTI)
  - Samples -> PDF -> CDF -> BER/Eye



[*] IBIS Specification Section 10. (https://ibis.org/ver6.1/)

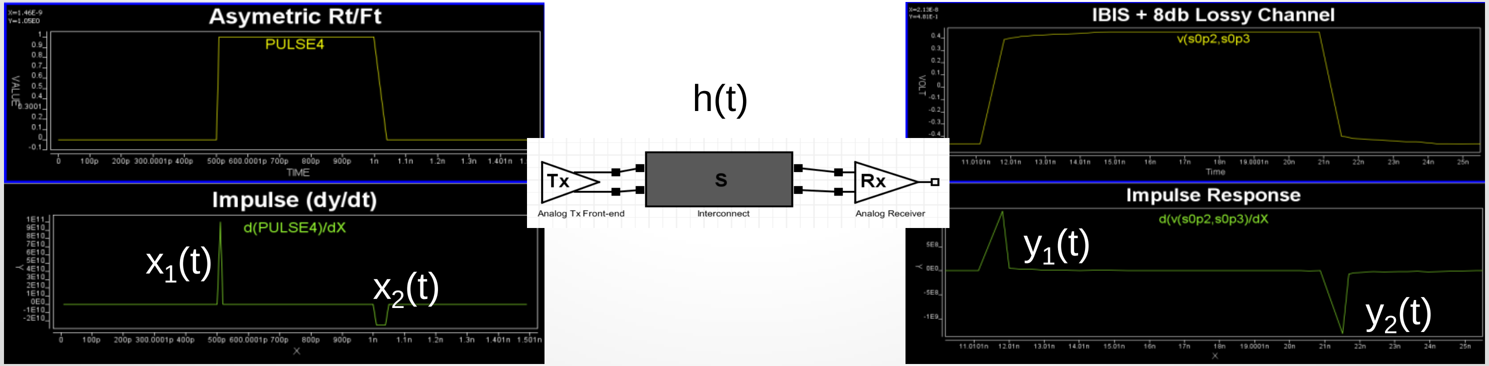
Background 2/2

- Time-domain AMI flow:
  - Analog + channel's responses to one block of bit-sequence
  - Convolve with Tx/Rx's AMI_GetWave respectively



Asymmetric Rt/Ft to Impulse:

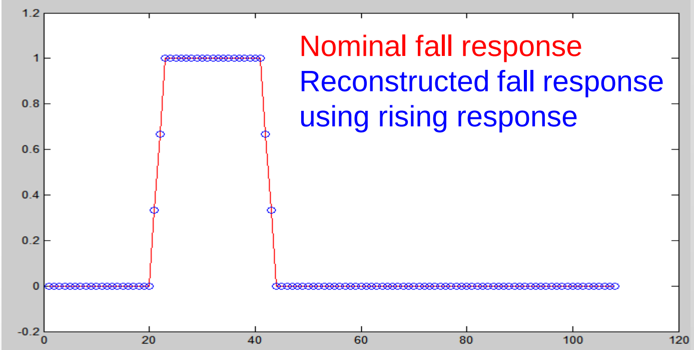
- Linear transform between Rt/Ft:
  - Rise: $y_1(t) = x_1(t) * h(t)$ Fall: $y_2(t) = x_2(t) * h(t)$
  - Fall: $x_2(t) = x_1(t) * Xform(t)$ => $y_2(t) = y_1(t) * Xform(t)$
  - Simulator knows y_1& y_2 , thus $Xform(t)$. It can then reconstruct either y_1 or y_2 from y_2 or y_1 used in AMI_Init
  - DC info disappeared during differentiation (to get impulse response). Has gap! Need specification change or new parameter to convert to single-ended.



Example:

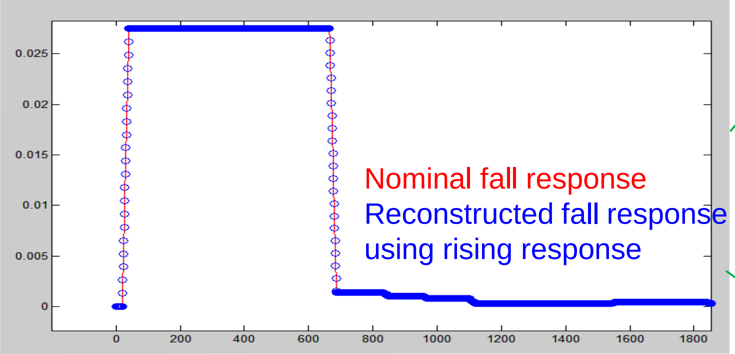
- Matlab/Octave pseudo-code:

```
% Generate rise and fall ramp of different slew rates
clc;
clear;
time1 = (-1:1:5)';
ustp1 = time1>=0;
xstp = time1.*ustp1;

time = (-1:1:2)';
ustp = time>=0;
ystp = time.*ustp;

mlen = 10;
rstp = ones(mlen, 1);
rstp(1:size(xstp,1), 1) = xstp / 5;

fstp = ones(mlen, 1);
fstp(1:size(ystp,1), 1) = ystp / 3;


% Convert to impulse
rimp = diff(rstp);
fimp = diff(fstp);

% Nominal rise and fall pulse response
pulse=zeros(100,1);
pulse(20:40,1)=1;
rpuls=conv(rimp, pulse);
fpuls=conv(fimp, pulse);

% Reconstruct fall pulse using XForm
plen =size(rpuls, 1);
xpuls=real(ifft(fft(fimp, plen) ./ fft(rimp, plen) .* fft(rpuls)));

% Plot them together
time=[1:plen];
plot(time, fpuls, 'r-', time, xpuls, 'bo');
```

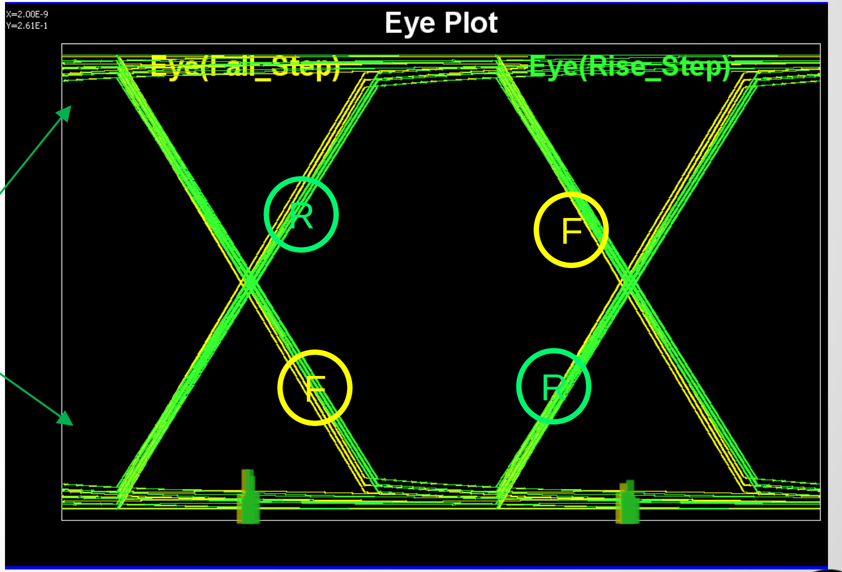


Asymmetric Rt/Ft to Eye:

- Construct different eyes portions using eyes generated by rise response and fall response (different slew rate)
  - Eye will be asymmetric as well.



Real case: (IBIS + Lossy Channel)



ISI Eye Construction with a Tree Structure

3	2	1	Cursor (0)	-1
0	0	0	1	0
1				
0	1			
1				
0	0	1		1
1				
0	1			
1				

Let $V_n(ab)$ be the contribution of ISI from the $n$thpre−cursor edge when the nth pre−cursor=a and (n−1)th pre−cursor=b, i.e. the nth pre−cursor edge is an $a \rightarrow b$ transition

When 2nd pre−cursor logic value = 0, cursor logic value =1, all possible values for the accumulated ISI from 2nd and 1st pre−cursors can be put into a row vector : $[V_2(00) + V_1(01), V_2(01) + V_1(11)]$. There are two elements in the vector due to two possible values of the 1st pre-cursor

Extending to the 3rd pre-cursor: When 3rd pre-cursor =0, there are 4 possible accumulated ISI values
$[V_3(00) + V_2(00) + V_1(01), V_3(00) + V_2(01) + V_1(11)]$ and $[V_3(01) + V_2(10) + V_1(01), V_3(01) + V_2(11) + V_1(1$

Recursive Algorithm for ISI Eye Construction

n	n-1	1 … n-2	Cursor (0)		
0	0	xxxxxxxxx	1		
1					
0	1				
1					

$W_n(ab)$: row vector consisting all possible values of the accumulated ISI from the nth pre−cursor to cursor when logic value of the nth pre−cursor is a and logic value at cursor is b

$$W_1(01) = [V_1(01)]$$
$$W_1(11) = [V_1(11)]$$
$$W_2(01) = [V_2(00) + V_1(01), V_2(01) + V_1(11)]$$
$$W_2(11) = [V_2(10) + V_1(01), V_2(11) + V_1(11)]$$
$$\ldots\ldots\ldots.$$
$$W_n(01) = [V_n(00) + W_{n-1}(01), V_n(01) + W_{n-1}(11)]$$
$$W_n(11) = [V_n(10) + W_{n-1}(01), V_n(01) + W_{n-1}(11)]$$

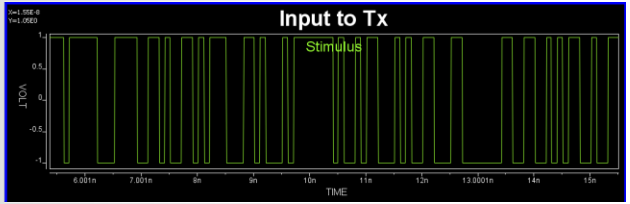
PDF Computation for ISI Eye

Waveform value	PDF of the waveform value	Notes
$V_n(ab)$	$P_{V_n(ab)}(V) = \delta\big(V - V_n(ab)\big)$	
$W_1(01)$	$P_{W_1(01)} = P_{V_1(01)} \quad P_{W_1(11)} = P_{V_1(11)}$	
$W_n(01)$	$P_{W_n(01)} = \frac{1}{2} P_{W_{n-1}(01)} \otimes P_{V_n(00)}(V) + \frac{1}{2} P_{W_{n-1}(11)} \otimes P_{V_n(01)}$	
$W_n(11)$	$P_{W_n(11)} = \frac{1}{2} P_{W_{n-1}(01)} \otimes P_{V_n(10)}(V) + \frac{1}{2} P_{W_{n-1}(11)} \otimes P_{V_n(11)}$	

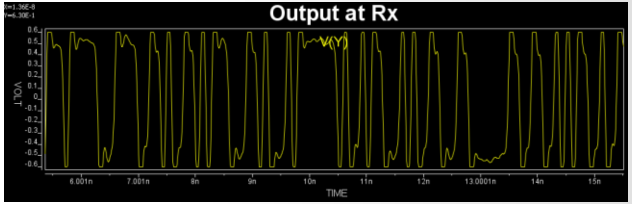
This is a Dirac delta when there is no jitter (ISI takes discrete value without jitter)
With jitter the Dirac delta will spread out into a continuous distribution. But the recursive relation remains same

Asymmetric Rt/Ft to GetWave:

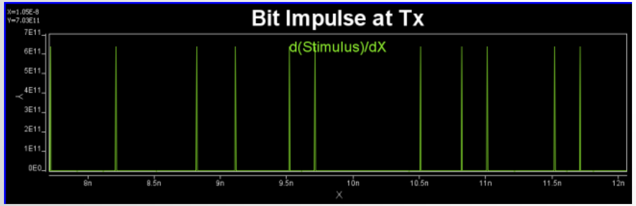
- Result will be OK if:
  - Bit-sequence waveform at Rx is simulated result from bit-sequence input at Tx
  - This may not be the case mostly as it takes longer to run.



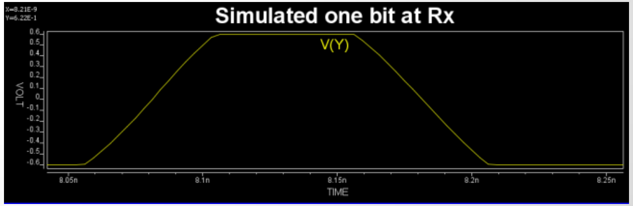
Simulated



- Result will have errors if:
  - Final waveform at Rx is from one bit simulated Rx response convolved with bit-sequence impulse at Tx

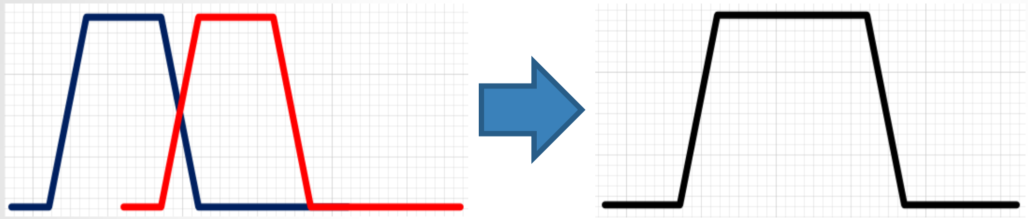


Convolve with

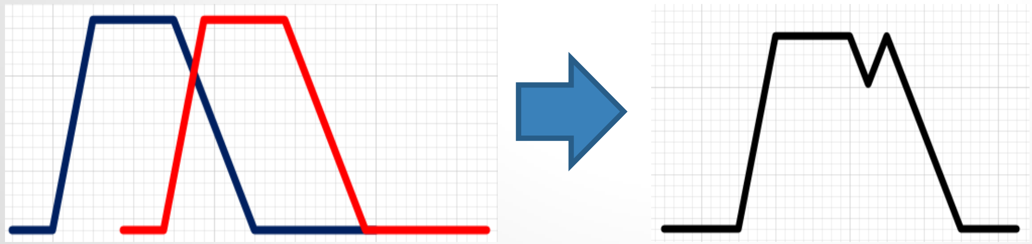


Asymmetric Rt/Ft to GetWave:

- Bit 011 using convolution with symmetric Rt/Ft



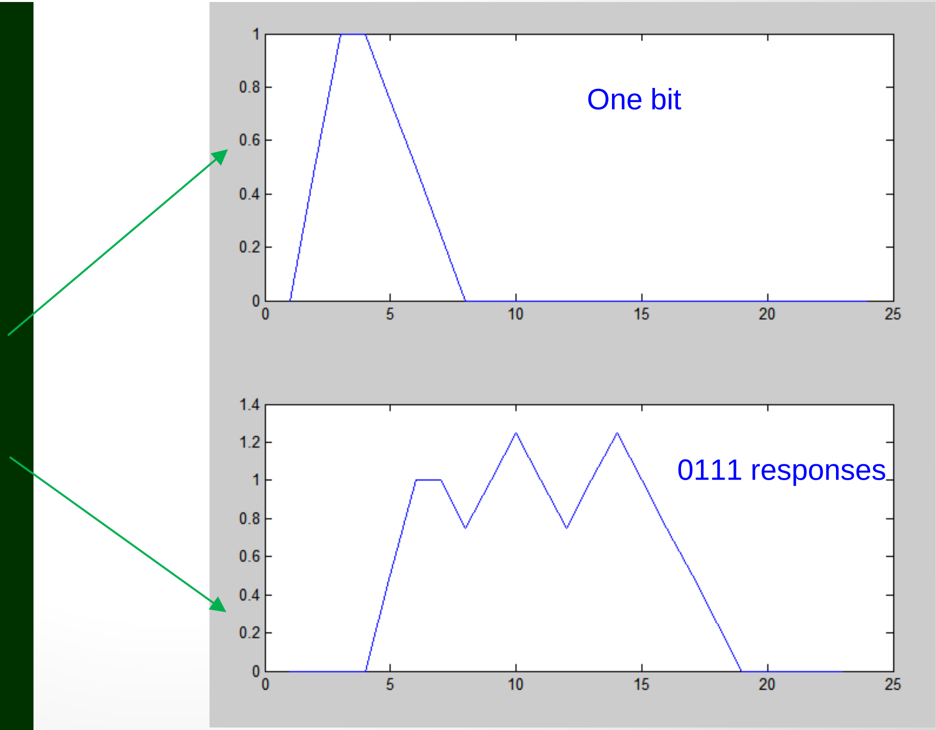
- Glitch will happen for asymmetric Rt/Ft



Asymmetric Rt/Ft to GetWave:

- Matlab/Octave pseudo-code:

```
% Generate one-bit pulse of different Rt/Ft
clc;
clear;
time = (0:1:2)';
ustp = time>=0;
xstp = time.*ustp;

time1 = (0:1:4)';
ustp1 = time1>=0;
ystp = time1.*ustp1;

xlen = size(xstp, 1);
ylen = size(ystp, 1);
mlen = xlen + ylen;
bit1 = ones(mlen, 1);
bit1(1:xlen, 1) = xstp / 2;
bit1(xlen + 1:xlen + ylen, 1) = 1 - ystp / 4;


% Bit sequence 0111
ui   = size(bit1, 1) / 2;
blen = 4 * ui;
bseq = zeros(blen, 1);
bseq(1 * ui) = 1;
bseq(2 * ui) = 1;
bseq(3 * ui) = 1;

% Form responses using convolution
resp = conv(bit1, bseq);

% Plot them together
subplot(2,1,1);
plot(padarray(bit1, blen, 'post'));
subplot(2,1,2);
plot(resp);
```



Summary:

- Existing IBIS-AMI flow:
    - Can be used for driver with asymmetric Rt/Ft.
    - Asymmetric effects can be handled within EDA tools/Simulator.
        - Assuming AMI model does not behave differently to rise/fall responses.

- Statistical flow:
    - Linear transform between rise/fall can be applied to model’s response.
    - Use rise and fall response to construct eye.
    - Tree/sequence based superposition will eliminate these glitches.

- Time-domain flow:
    - Convolution using one bit pulse will have errors.
    - Using step reponse based superposition may avoid such errors.

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