Asian IBIS Summit
Shanghai, P.R. China
November 14, 2014

Intra-pair skew effect analysis using IBIS-AMI simulation

Wang Jianhua , Dong Xiaoqing

www.huawei.com

HUAWEI TECHNOLOGIES CO., LTD.

HUAWEI

Agenda

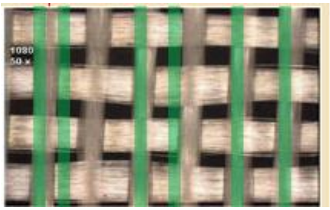
- Background: channel skew and its impairment
- AMI simulation analysis on channel skew effect
- Test analysis on channel skew effect
- Summary

Background (1)

Intra-pair skew could come from many sources in a typical high speed serial link:

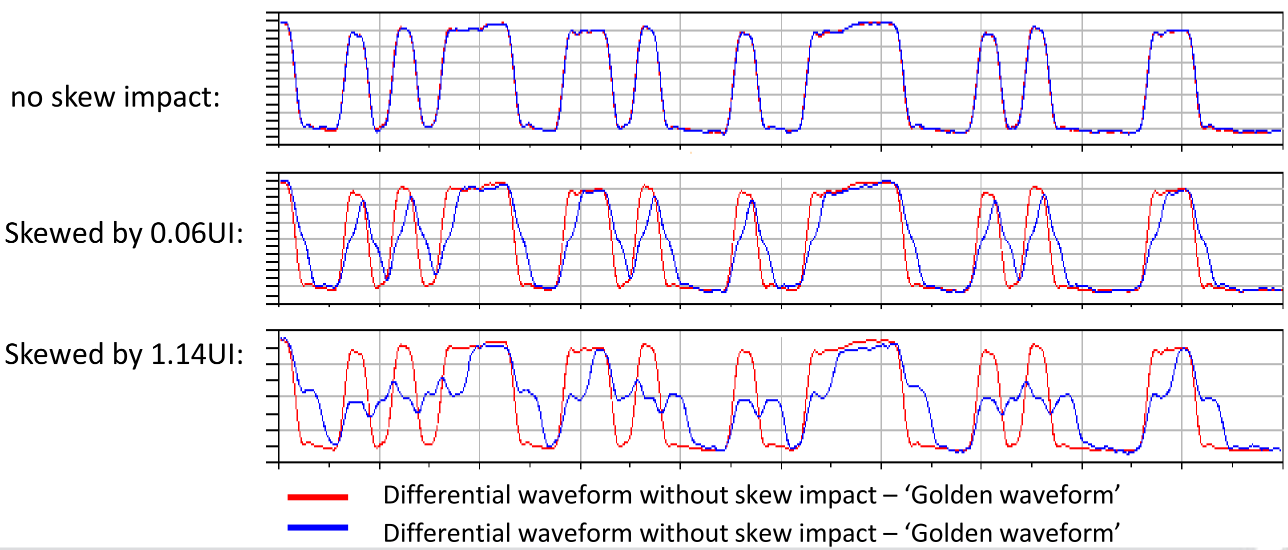
1. Deterministic sources: Different routing length, connector fan out, etc.
2. ‘Random’ sources: Fiber weave effect induced skew, etc. --- hardly to be compensated.

fibre weave effect



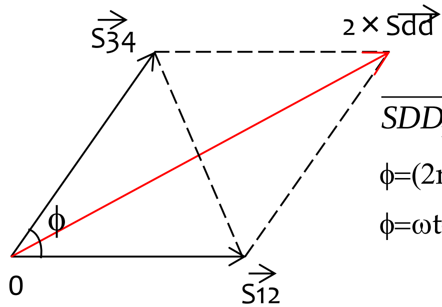
Potential skew impact in high speed serial link:

- Cause resonance and degradation to differential loss SDD21;
- Cause DCD(different arrival time between P and N signals);
- Induce common mode noise



Background (2)

Here in this presentation we focus on skew impact on differential insertion loss only:

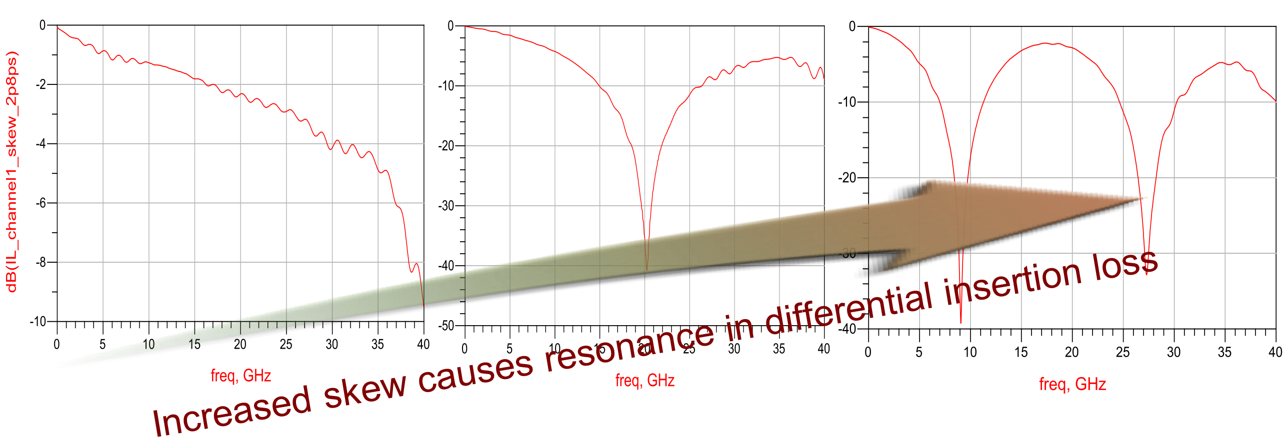


$$\overrightarrow{SDD_{12}} = \frac{1}{2}\left(\overrightarrow{S_{12}} + \overrightarrow{S_{34}} - \overrightarrow{S_{14}} - \overrightarrow{S_{32}}\right) \approx \frac{1}{2}\left(\overrightarrow{S_{12}} + \overrightarrow{S_{34}}\right)$$

$\phi = (2n+1) * 180$ degree

$\phi = \omega t = 2\pi f * skew$

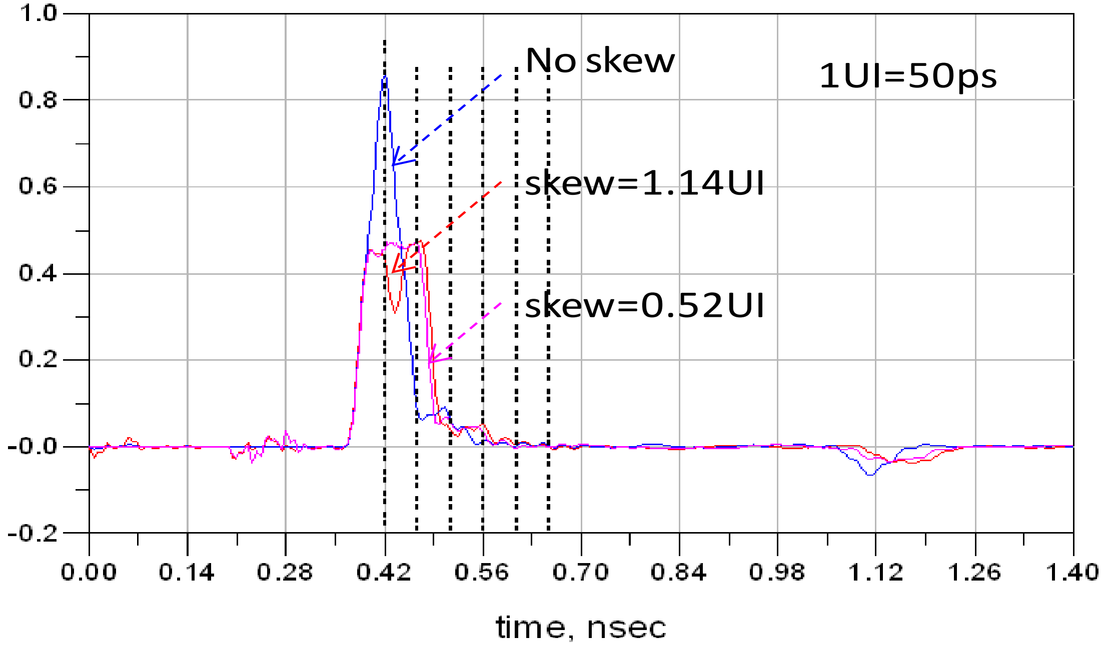
- Skew induced resonance in differential insertion loss causes SI performance degradation to signal that passes through the channel, especially when resonances occur within the Nyquist frequency.



P-N Skew(ps)	IL increment(dB) @12.5GHz
2	0.0268
8	0.4359
14	1.3847
20	3.0103
26	5.6383
32	10.2004
38	22.1071
40	∞

A quick look at skew impact on signal

- Look at the pulse response of a 20Gbps signal:

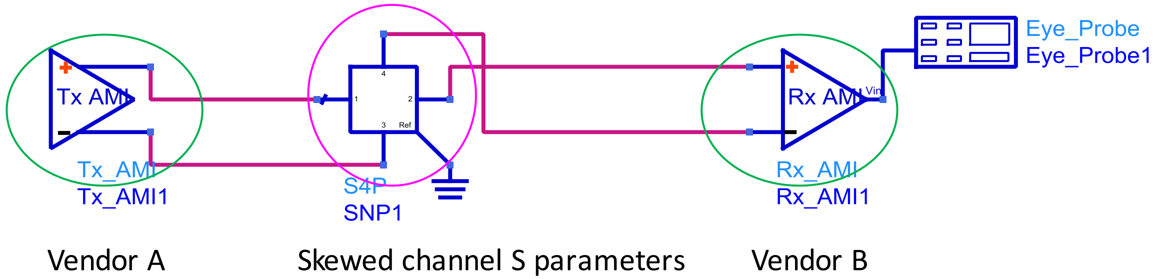


- As skew increases, pulse response amplitude decreases, and the pulse width increases.
- When intra-pair skew exceeds 1UI, apparently dual-peak response occurs.
- Skew induced pulse response distortion has the same feature as ISI induced pulse spreading. Therefore, link equalization(particularly the UI-spaced equalization) could help reduce the harm to the signal at RX detection point.

Validation through AMI link simulation

Simulation setup:

- Through channel only (to reduce the analysis matrix)
- PRBS31, 20Gbps
- TX: 3-tap FFE (vendor A)
- RX: AGC+CTLE+multi-tap DFE (vendor B)
- Target BER: 1e-15

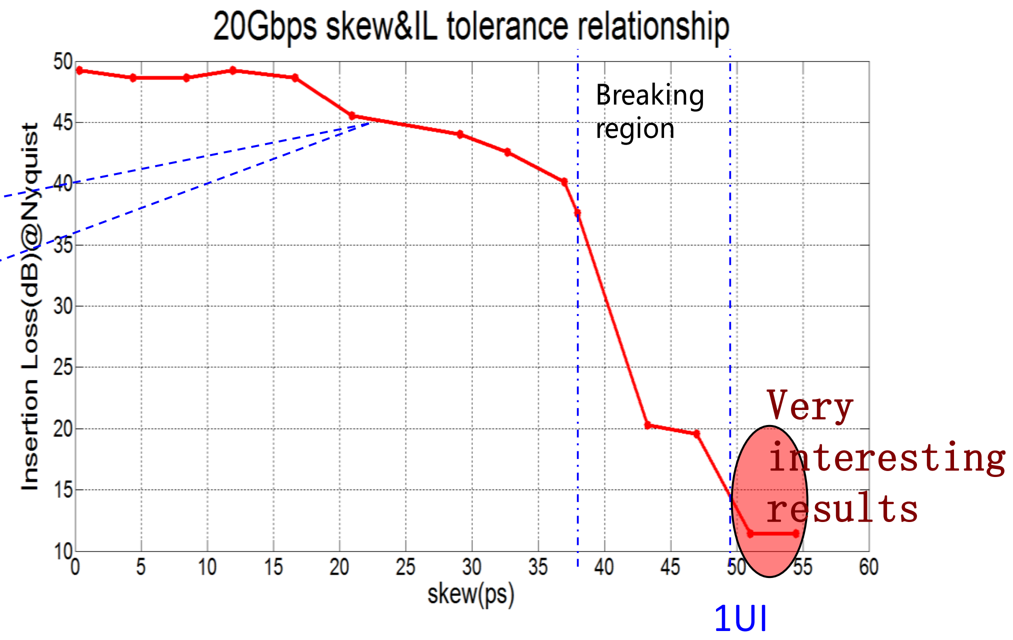


Note1: in the following simulation, TX FFE is not applied. RX AGC, CLTLE are set to be 'optimal' for each link, DFE is adapted itself through LMS criteria.

Note2: Given RX detection sensitivity (35mVppd, 0.1UI in this case), maximum link compensation capability under 1e-15 condition is summarized.

Simulation results @BER 1e-15

Skew (ps)	Max IL(dB) tolerance @10.3125GHz
0.3	49.254
4.37	48.61
8.4	48.61
11.9	49.25
16.6	48.61
20.9	45.55
29.1	44
32.68	42.56
36.95	40.15
37.95	37.6
43.26	20.26
46.98	19.54
51	11.44
54.47	11.44



- When skew is less than 0.5UI, it has very little impact on link compensation performance;
- When skew is approaching 1UI, link performance starts degrading very quickly;
- When skew exceeds 1UI, the RX still functions, but the SerDes' link compensation capability drops a lot.

A closer look at the simulation results

Since no TX FFE is applied, link equalization heavily relies on the RX.

Skew(ps)	AGC	CTLE	DFE (first four taps)
2.8	1	0	(-6 -1 -1 -0)
6.7	2	0	(-5 -1 -1 -0)
9.9	2	1	(-4 -3 -2 -1)
14.6	3	1	(1 -2 -1 -0)
18.5	3	0	(5 -2 -1 -0)
23.2	3	0	(11 -2 -1 -0)
27.5	3	0	(15 -3 -1 -0)
30.9	3	0	(22 -3 -2 -0)
32.9	3	0	(29 -4 -2 -0)
38.3	2	0	(40 -6 -1 -0)
42	1	0	(47 -7 -2 -0)
45.9	1	0	(54 -6 -1 -0)
50.3	2	0	(57 -4 -1 -0)
55.1	3	0	(57 2 -0 -1)

Skew less than 0.5UI → less impact on performance

Skew between 0.5 and 1UI → DFE coefficients increase, performance degrades quickly

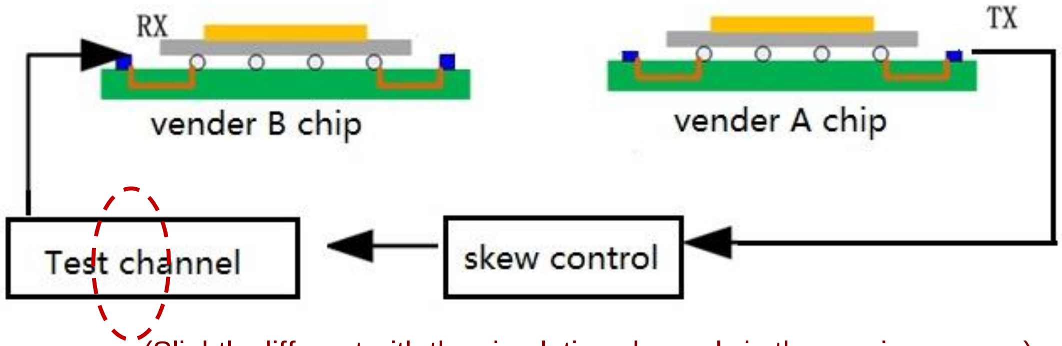
Skew exceeding 1UI → DFE strength saturates and the link performance is failing

- The coefficients trend explains the simulation curve in last page, and the 'breaking point' coefficient change between 32.9 and 38ps corresponds with the simulation curve.

Validation through lab test

Simulation setup:

- Through channel only (slightly different channels as used in simulation)
- PRBS31, 20Gbps
- TX: 3-tap FFE (vendor A SerDes)
- RX: AGC+CTLE+multi-tap DFE (vendor B SerDes)
- Target BER: 1e-14 (~2hours error free)

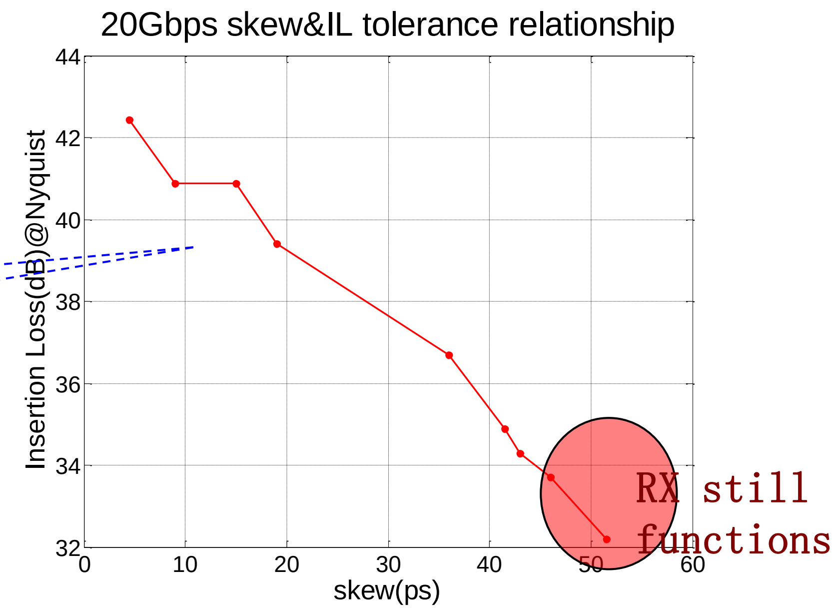


(Slightly different with the simulation channels in the previous pages)

Note: TX FFE is manually fixed to be ‘optimal’, RX is fully adaptive.

Test results @BER 1e-14

skew (ps)	Max IL(dB) tolerance @10.3125GHz
4.5	42.426
9	40.887
15	40.887
19	39.403
36	36.7
41.5	34.9
43	34.3
46	33.7
51.5	32.2



Same phenomenon as discovered through AMI simulation:

- As channel skew increases, SerDes link compensation capability decreases.
- When skew is approaching 1UI, the SerDes can still work, but the link compensation capability drops quickly into the 'dead zone' for system applications.

A closer look at the test results

TX FFE is kept the same for all the test channels. As indicated in the following table:

- AGC and CTLE parameters are relatively very stable, while DFE strength keeps increasing as channel skew increases gradually, until it get saturated.

Skew (ps)	AGC	CTLE	DFE (first four taps)
4.8	8	2	41 0 4 1
8.7	8	2	40 0 4 1
12.2	8	2	39 0 4 2
16.7	8	2	38 0 4 2
20.2	8	2	37 0 3 2
25.2	8	2	37 1 3 3
28.1	8	2	36 1 3 3
32.4	8	2	40 1 3 3
36.3	8	2	44 1 3 3
39.5	9	2	52 3 3 3
44.3	9	2	55 6 3 4
48.6	10	2	57 11 3 4
52.9	10	2	56 11 2 4

- DFE coefficients increase gradually
- Corresponds with the test curve trends, i.e., gradually degradation curve as skew increases, no abrupt change in performance.

Summary

In this slides, we focus on skew induced degradation in channel differential insertion loss, and its impact on link BER performance.

- In 20Gps+ high speed link systems, intra-pair skew has more predominant impact on link BER performance, due to decreased system link margin compared to the lower speed generations.
- Skewed channel pulse response has the same feature as ISI induced pulse distortion, and UI-spaced equalization (particularly DFE) can help in certain extent reduce the harm induced by channel skew.
- Experiments show that even when skew is approaching one UI, the link can still work under certain conditions but with much less loss compensation capability or much less margin.
- AMI model based simulation is an effective approach for system evaluation in terms of skew impact analysis.

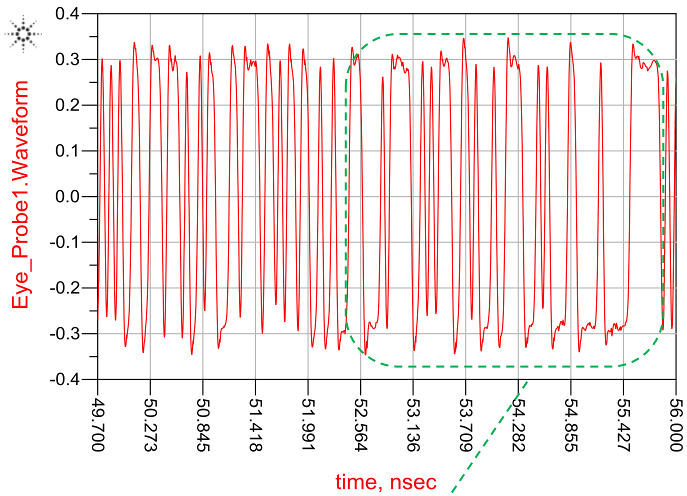
We are open to opinions and feedback on this topic, any suggestion is most welcomed!

Appendix

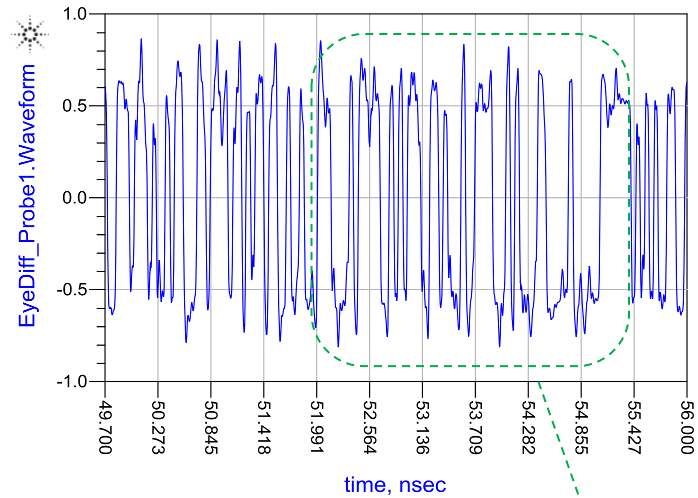
Waveform snapshot from AMI simulation

Channel skew: 0.06UI,prbs7:

waveform segment at RX detection point



waveform segment at TX



Rx bit sequence

1110000 1011111 0010101 1100110 1000100 1111000 1010000 1100000 1000000 0111111 1

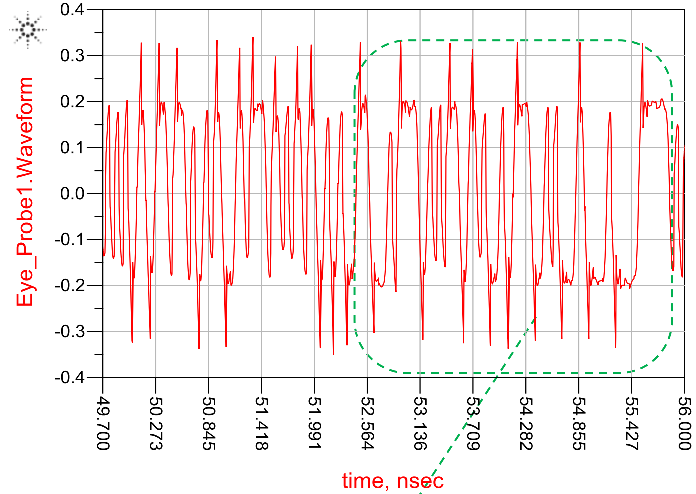
Tx bit sequence

1110000 1011111 0010101 1100110 1000100 1111000 1010000 1100000 1000000 0111111 1

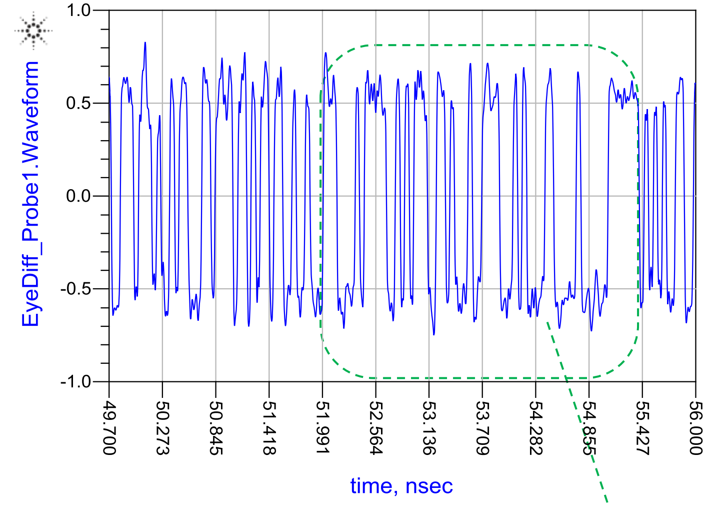
Waveform snapshot from AMI simulation

Channel skew: 0.87UI,prbs7

waveform segment at RX detection point



waveform segment at TX



Rx bit sequence

1110000 1011111 0010101 1100110 1000100 1111000 1010000 1100000 1000000 0111111 1

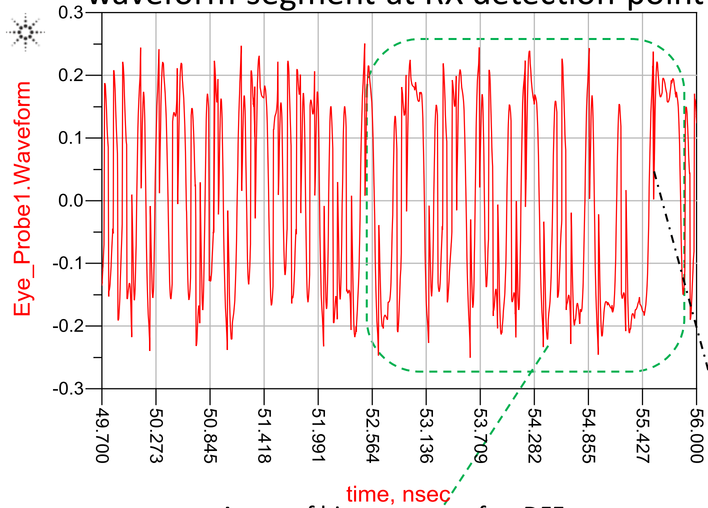
Tx bit sequence

1110000 1011111 0010101 1100110 1000100 1111000 1010000 1100000 1000000 0111111 1

Waveform snapshot from AMI simulation

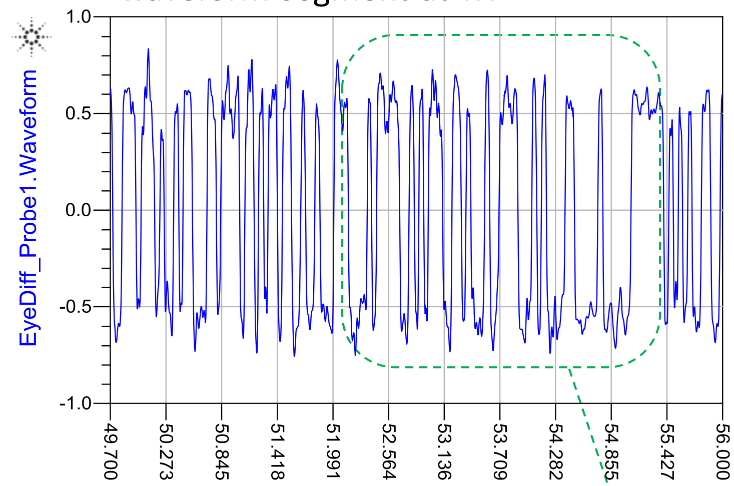
Channel skew: 1.14UI,prbs7

waveform segment at RX detection point



A part of bit sequence after DFE

waveform segment at TX



A part of bit sequence launched by Tx

Depends on RX detection sensitivity

Rx bit sequence

1110000 1011111 0010101 1100110 1000100 1111000 1010000 1100000 1000000 0111111 1

Tx bit sequence

1110000 1011111 0010101 1100110 1000100 1111000 1010000 1100000 1000000 0111111 1

Thank you

www.huawei.com