Novel Methodology of IBIS-AMI Hardware Correlation using Trend and Distribution Analysis for high-speed SerDes System

Hong Ahn, (Xilinx)
Brian Baek, (Cisco)
Ivan Madrigal (Xilinx)
Hongtao Zhang (Xilinx), Alan Wong(Xilinx), Geoff Zhang (Xilinx), Chris Borrelli (Xilinx)
Jiali Lai (Cisco), Mike Sapozhnikov (Cisco)
Novel Methodology of IBIS-AMI Hardware Correlation using Trend and Distribution Analysis for high-speed SerDes System

Hong Ahn, (Xilinx)
Brian Baek, (Cisco)
Ivan Madrigal (Xilinx)
Hongtao Zhang (Xilinx), Alan Wong (Xilinx), Geoff Zhang (Xilinx), Chris Borrelli (Xilinx)
Jiali Lai (Cisco), Mike Sapozhnikov (Cisco)
SPEAKERS

Brian Baek
SI Technical Leader, Cisco
sebaek@cisco.com

Hong Ahn
SerDes Application Engineer, Xilinx
Hong.ahn@Xilinx.com

Ivan Madrigal
SerDes Application Engineer, Xilinx
Ivan.Madrigal@Xilinx.com
MOTIVATION

- Most of IBIS-AMI correlation is performed under specific settings and small number of silicon parts.
- This approach cannot guarantee accurate correlation throughout all other settings under distribution of real parts across PVT.
- Simulation results need to follow behavioral trends from real hardware measurements with all possible combinations of the controllable settings under reasonable tolerance.
- The results need to reflect the distribution of real measurement across PVT in order to achieve reliable simulation optimization in a mass production system.
Trend Correlation
Main purpose of IBIS-AMI simulation

- To obtain the optimized SERDES equalizer setting which has the best performance.
- To support the optimized value for the initial equalizer setting.
- To evaluate SerDes IP early stage.

- If overall simulation result doesn’t follow the measurement, the wrong SERDES setting may be the best optimum value.
- The effective methodology for correlating IBIS-AMI simulation to measurement should be needed.
Comparison for two cases of correlation

Case 1 at BER1E-10

Eye height after RX EQ (mV)

Measurement
Simulation

TX equalizer setting
[Combination of Main/Pre/Post cursor]

5mV

Case 2 at BER1E-10

Eye height after RX EQ (mV)

Measurement
Simulation

TX equalizer setting
[Combination of Main/Pre/Post cursor]

20mV
Comparison for two cases of correlation

Only few cases correlation can not represent all equalizer behavior performance!!
The trend correlation is:
- How eye opening trend after RX equalizer by TX equalizer setting.
- The plot should be acquired by a large number of TX equalizer combination.
- The optimized transceiver settings from the simulation can give a higher level of confidence with trend-matched simulation.
Requirement to do better correlation
[Internal eye monitoring circuit]

- It is difficult to measure the signal after RX equalizer.
- The latest scope has the ability of equalizer, but it is for generic function and not exactly same with ASIC’s equalizer
- The internal eye diagram should be required
Requirement to do better correlation
[Script for TX parameter sweep]

- The internal eye diagrams should be measured with many combination of TX equalizer setting.
- It is very time consuming work if there is no TX parameter sweep script which measures
- Eye height and width for each TX equalizer setting need to be measured automatically.
Measurement Set up

- Using Xilinx UltraScale GTH for 10Gbps and 16Gbps
- Using Xilinx UltraScale GTY for 28Gbps
- Eye Scan Parameters
  - Simulation eye height and eye width at BER 1E-10
  - HW Eye Scan: 1E-10 BER at each scan point
## Test Cases

<table>
<thead>
<tr>
<th>Line Rate</th>
<th>EQ mode</th>
<th>Loss of ISI Channel</th>
<th>Diff Insertion Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.375Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>23dB @ 8GHz</td>
</tr>
<tr>
<td>16.375Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>19dB @ 8GHz</td>
</tr>
<tr>
<td>10.3125Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>24dB @ 5GHz</td>
</tr>
<tr>
<td>10.3125Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>18dB @ 5GHz</td>
</tr>
<tr>
<td>28Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>28dB @ 14GHz</td>
</tr>
<tr>
<td>28Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>20dB @ 14GHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line Rate</th>
<th>EQ Mode</th>
<th>Loss</th>
<th>MainCursor</th>
<th>PostCursor</th>
<th>PreCursor</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.375Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>[B, D, E, F]</td>
<td>[00, 0E, 16, 1F]</td>
<td>[00]</td>
</tr>
<tr>
<td>16.375Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>[9, B, D, F]</td>
<td>[00, 0E, 16, 1F]</td>
<td>[00]</td>
</tr>
<tr>
<td>10.3125Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>[9, B, D, F]</td>
<td>[00, 0E, 16, 1F]</td>
<td>[00]</td>
</tr>
<tr>
<td>10.3125Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>[6, 7, 9, A]</td>
<td>[00, 0A, 12, 16]</td>
<td>[00]</td>
</tr>
<tr>
<td>28Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>[12,13,14,15]</td>
<td>[00, 0C, 12, 1B]</td>
<td>[00]</td>
</tr>
<tr>
<td>28Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>[12,13,14,15]</td>
<td>[00, 0C, 12, 1B]</td>
<td>[00]</td>
</tr>
</tbody>
</table>
Measure Channel S-parameter

- Accurate s-parameter of channel is crucial for the correlation
- Measured s-parameter up to 50GHz without extrapolation
Case 1: 10.3125 Gbps High Loss DFE Result

- Used -24dB differential insertion channel at 5GHz
- Compare the results under [No TXEQ, Small TXEQ, High TXEQ, Over TXEQ] at given amplitude
- Trends are matched well for both eye height and eye width
Case 2: 10.3125Gbps Medium Loss DFE Result

- Used -18dB differential insertion channel at 5GHz
- Compare the results under [No TXEQ, Small TXEQ, High TXEQ, Over TXEQ] at given amplitude
- Trends are matched well for both eye height and eye width
Case3: 16.3125Gbps High Loss DFE Result

- Used -23dB differential insertion channel at 8GHz
- Check the correlation under [No TXEQ, Small TXEQ, High TXEQ, Over TXEQ] at given amplitude
- Trends are matched well for both eye height and eye width
Case 4: 16.3125Gbps Medium Loss DFE Result

- Used -19dB differential insertion channel at 8GHz
- Check the correlation under [No TXEQ, Small TXEQ, High TXEQ, Over TXEQ] at given amplitude
- Trends are matched well for both eye height and eye width
Case6: 28Gbps Medium Loss DFE Mode

- Used -19dB differential insertion channel at 14GHz
- Check the correlation under [No TXEQ, Small TXEQ, High TXEQ, Over TXEQ] at given amplitude
- Trends are matched well for both eye height and eye width
Case 5: 28Gbps High Loss DFE Mode

- Used -28dB differential insertion channel at 14GHz
- Check the correlation under [No TXEQ, Small TXEQ, High TXEQ, Over TXEQ] at given amplitude
- Trends are matched well for both eye height and eye width
Distribution Correlation
The value of distribution analysis

- IBIS-AMI simulation needs to cover the variation of devices
- IBIS-AMI simulation needs to represent the worst performance by PVT variation
- Distribution Analysis shows how well IBIS-AMI Simulation represents the boundary of hardware variation
- If simulation result would be better than the worst case measurement, it cannot guarantee the link performance in mass production system
Comparison for two cases of distribution analysis

*IBIS-AMI simulation needs to represent the distribution of hardware under given condition!!*

---

**Case 1.** Simulation is better than measurement

**Case 2.** Simulation represents the distribution of measurement
The distribution of transmitter

- The distribution of transmitter is also critical to analyze the one of receiver
  - The distribution of differential amplitude
  - The distribution of de-emphasis by postCursor
  - The distribution of de-emphasis by precursor
The distribution of differential amplitude

- IBIS-AMI model represents the distribution of hardware measurement well
The distribution of de-emphasis by postCursor

- IBIS-AMI model locates at the center of hardware distribution
The distribution of de-emphasis by preCursor

- IBIS-AMI model locates at the center of hardware distribution

Xilinx UltraScale GTH at 10.3125Gbps

Xilinx UltraScale GTY at 28Gbps
Test Cases for receiver distribution analysis

<table>
<thead>
<tr>
<th>Line Rate</th>
<th>EQ mode</th>
<th>Loss of ISI Channel</th>
<th>Diff Insertion Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.375Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>23dB @ 8GHz</td>
</tr>
<tr>
<td>16.375Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>19dB @ 8GHz</td>
</tr>
<tr>
<td>10.3125Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>24dB @ 5GHz</td>
</tr>
<tr>
<td>10.3125Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>18dB @ 5GHz</td>
</tr>
<tr>
<td>28Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>28dB @ 14GHz</td>
</tr>
<tr>
<td>28Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>20dB @ 14GHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line Rate</th>
<th>EQ Mode</th>
<th>Loss</th>
<th>MainCursor</th>
<th>PostCursor</th>
<th>PreCursor</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.375Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>[B, D, E, F]</td>
<td>[00, 0E, 16, 1F]</td>
<td>[00]</td>
</tr>
<tr>
<td>16.375Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>[9, B, D, F]</td>
<td>[00, 0E, 16, 1F]</td>
<td>[00]</td>
</tr>
<tr>
<td>10.3125Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>[9, B, D, F]</td>
<td>[00, 0E, 16, 1F]</td>
<td>[00]</td>
</tr>
<tr>
<td>10.3125Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>[6, 7, 9, A]</td>
<td>[00, 0A, 12, 16]</td>
<td>[00]</td>
</tr>
<tr>
<td>28Gbps</td>
<td>DFE</td>
<td>High Loss</td>
<td>[12,13,14,15]</td>
<td>[00, 0C, 12, 1B]</td>
<td>[00]</td>
</tr>
<tr>
<td>28Gbps</td>
<td>DFE</td>
<td>Med Loss</td>
<td>[12,13,14,15]</td>
<td>[00, 0C, 12, 1B]</td>
<td>[00]</td>
</tr>
</tbody>
</table>
Measure Channel S-parameter

- Accurate s-parameter of channel is crucial for the correlation
- Measured s-parameter up to 50GHz without extrapolation
Case1: 10.3125Gbps Medium Loss DFE Result

- Used -19dB differential insertion channel at 5GHz
- The worst case of hardware distribution is above the worst result of simulation across all of TX settings
Spot Check at “Small TXEQ” at AMP = 0x09 shows the detail histogram between hardware and IBIS-AMI simulation.

There are “Conservative Outliers” which is showing the model is conservative than hardware.
Case 2: 10.3125Gbps High Loss DFE Result

- Used -24dB differential insertion channel at 5GHz
- The worst case of hardware distribution is above the worst result of simulation across all of TX settings
Spot Check at “Small TXEQ” at AMP = 0x0F shows the detail histogram between hardware and IBIS-AMI simulation

There are “Conservative Outliers” which is showing the model is conservative than hardware
Case 3: 16.325 Gbps Medium Loss DFE Result

- Used -19dB differential insertion channel at 5GHz
- The worst case of hardware distribution is above the worst result of simulation across all of TX settings
Case 3: 16.325Gbps Medium Loss DFE Result (cont.)

- Spot Check at “Small TXEQ” at AMP = 0x0F shows the detail histogram between hardware and IBIS-AMI simulation.
- There are “Conservative Outliers” which is showing the model is conservative than hardware.
Case 4: 16.325Gbps High Loss DFE Result

- Used -19dB differential insertion channel at 8GHz
- The worst case of hardware distribution is above the worst result of simulation across all of TX settings
Spot Check at “Small TXEQ” at AMP = 0x0F shows the detail histogram between hardware and IBIS-AMI simulation

There are “Conservative Outliers” which is showing the model is conservative than hardware
Case5: 28Gbps Medium Loss DFE Result

- Used -19dB differential insertion channel at 14GHz
- The worst case of hardware distribution is above the worst result of simulation across all of TX settings
Case6: 28Gbps High Loss DFE Result

- Used -28dB differential insertion channel at 14GHz
- The worst case of hardware distribution is above the worst result of simulation across all of TX settings
Conclusion

- Trend Correlation is required to optimize the setting for given channel
- Distribution Correlation is required to reduce the risk by PVT variation
- IBIS-AMI model needs to be designed carefully to cover both trend and distribution correlation
- New methodology of correlation is applied successfully to Xilinx UltraScale GTH / GTY at 10.3125Gbps, 16.325Gbps and 28Gbps
Thank you!

---

QUESTIONS?