Intrapair Skew Considerations for 224Gbps/lane Electrical signaling

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Overview

• Introduction and essential Ideas
• Impact of Intrapair skew
• Types of systems and Skew considerations
• Summary
Introduction - Essential Ideas

• Most High-speed Electrical Interfaces use differential signaling for high noise immunity compared to single ended signaling, except for some ultra short reaches, where noise conditions can be better controlled.

• In differential signaling:
  • True signal and equal and complementary signal is generated by transmitter and drives the two conductors of the differential pair of the channel.
  • These signals arrives at the receiver differential amplifier after passing through channel and analog front end (AFE), where a difference signal is built cancelling the noise picked up along the way equally by these two conductors.

• Intrapair skew refers to the difference in time or phase between two signals that are supposed to be identical but complementary. This difference can occur due to factors such as variations in trace lengths, differences in propagation delays, or other physical or design-related factors. From here onwards we refer intrapair skew, simply as skew for convenience.

• The data signals are supposed to arrive at the same time for proper cancellation of common-mode noise and signal recovery. When there is a skew, the signals do not arrive exactly at the same time, which means that the noise cancellation is not perfect, leading to potential signal integrity issues, reduced noise margins and Serdes performance and thus increases the bit error rate (BER) of a system.
Skew impact – Ideal square pulse

Square Pulse:
UI: 9.4ps for 212.5 Gbps data rate.

- As the skew approaches to 0.5 UI the difference signal width reduces
- If the skew is 1 UI, the difference signal would be null signal
- Note corresponding Common mode signal profiles
Skew impact – Pulse with Rise/Fall ramps

- As the skew approaches to 0.5 UI the difference signal width reduces
- Once skew goes above 0.5 UI not only difference signal width reduces its amplitude also reduces
- If the skew is 1 UI, the difference signal would be null signal
- Note corresponding Common mode signal profiles

Pulse:
UI: 9.4ps for 212.5 Gbps data rate.
Skew impact – Rise/Fall time and skew

Pulse:
UI: 9.4ps for 212.5 Gbps data rate.

- For all cases, If the skew is 1 UI, the difference signal would be null.
- As rise/fall time increases, the skew impact on difference signal amplitude becomes more significant.
Skew impact – Time domain profiles

- Step response doesn’t reveal adequate information about the skew time domain profile. Pulse response is more useful.
Skew impact – Time domain profiles

- Skew can occur due to various factors such as
  - differences in trace length,
  - impedance mismatches,
  - temperature variations,
  - manufacturing tolerances, and propagation delays.
  - Construction elements – like fabric weave, dielectric variation in different dimensions etc.. (too many to list here)

- These factors not only impact the delay between true and complementary signals and their respective signal profiles
System construction types

• Systems constructions in broad context can be categorized in to two.
  • Rigid construction
  • Semi-rigid construction

• Rigid constructions are typically multi-layered structures where signal conductors and their reference plane are built into these layers. These multilayered structures are then assembled with various assembly processes and /or Connectors to build a final system. These are planar structures in nature. e.g., Silicon die, Chip package substrates, PCBs

• In Semi-rigid construction some or portions of rigid structures in a system are substituted by flexible cylindrical structures like copper twin-ax cables. These cables are terminated to rigid structures either directly in the assembly or with connectors.
System construction types – skew contribution

• Effective Skew compensation techniques differ to each construction type.
• In rigid structures: like PCBs
  • to most extent the skew contribution can be quantified for each sub structure and one can try to compensate for it in other sub-structures – not only for physical length match but also for electrical length matching.
  • Skew mitigation by tightly coupling the conductors in the differential is difficult as max coupling that can achieved is limited to approx. 10% in high connectivity and dense designs.
  • Some level of statistical skew coming from glass fabric weave effects, DE variations needs to be budgeted in the design as they cannot be accurately quantified per instance due to instance to instance variation
• In semi-rigid structures: like Cables
  • loss contributions are much lower compared to rigid structures
  • Much higher coupling between differential conductors can be archived to reduce skew
    But
  • It is difficult to quantify these types of substructure skew contributions as it differs per instance to instance. i.e., cable segment to cable segment, or cable to cable in the same design (or system to system).
  • Poses additional skew and other impairments under stress conditions like Bend and twist, higher temp and humidity
  • Much higher level of statistical skew contribution budget needs to be allocated into the design for the stress conditions.
  • Cable skew tend to be not linearly distributed over length of the cable (see the next slide)
System construction types – skew contribution

skew varies:
- Instance to instance of Cable segment
- Skew contribution is not linearly related to length of the cable
System construction types – Freq. Domain profiles

• Rigid structures tend to have different skew profiles compared to semi-rigid structures and each Construction type poses different types of limitations in controlling the skew.

• These differences somewhat difficult to notice or distinguish in time domain, but can be observed better in frequency domain.

• Freq. domain skew profiles exhibit 4 basic types of profiles- see next slide.

• Each channel skew profile is combinations of these basic profiles and depends on type of construction and stress conditions subjected on these structures.
Basic Freq. Domain profiles - Basic

Basic skew profiles

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Freq. Domain profiles of real channel components - measurements

Example of Rigid structure (PCB) skew profiles

Example of Semi- Rigid structure (Cables) skew profiles
Skew Impact on Serdes performance

- Bit-by-bit simulation with Jitter and Noise introduced with similar limits in the 802.3ck project
- Base lined with BER of 1e-7 as zero delta SNR (y-axis)
- Accounting for the end-to-end skew of 0.3 UI to 0.4 UI seems a reasonable starting point.
- The working group needs to agree on how much of a skew level the reference receiver must handle.

SNR degradation due to skew

PRBSQ15—pattern used for test
## Skew Impact in COM Tool – on some of contributed channels

### Intrapair Skew 0.0 UI 0.32UI 0.43 UI

<table>
<thead>
<tr>
<th>SL.NO</th>
<th>Channel File Name</th>
<th>ICN, mv</th>
<th>FOM_ILD</th>
<th>Ball_Ball Insertion Loss, dB</th>
<th>COM values, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>cbl_hst_S4_B2B_s0nl0_Ms1_9_t</td>
<td>4.32</td>
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<td>3</td>
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<td>0.19</td>
<td>10.8259/4.5344</td>
<td>11.9078/4.3038</td>
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<td>4</td>
<td>cbl_hst_S4_B2B_s0nl0_Ms13_13_t</td>
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<td>13.4754/3.9365</td>
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<td>5</td>
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<td>18.286/4.027</td>
<td>19.3681/3.8628</td>
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<td>9</td>
<td>cbl_hst_S4_B2B_s0nl0_Ms18_18_t</td>
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<td>cbl_hst_S4_B2B_s0nl0_Ml20_20_t</td>
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<td>0.16</td>
<td>19.9252/3.815</td>
<td>21.0069/2.9504</td>
</tr>
</tbody>
</table>

### Intrapair Skew in UI

<table>
<thead>
<tr>
<th>SL.NO</th>
<th>Channel File Name</th>
<th>ICN, mv</th>
<th>FOM_ILD</th>
<th>Ball_Ball Insertion Loss, dB</th>
<th>COM values, dB</th>
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<tbody>
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<td>10.7662/4.4246</td>
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<td>3.45</td>
<td>0.17</td>
<td>11.5466/4.6425</td>
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<td>pcb_hst_S4_B2B_s0nl0_Ml24_12_t</td>
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<td>0.18</td>
<td>12.061/4.651</td>
<td>12.5211/4.6043</td>
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<td>0.16</td>
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<td>pcb_hst_S4_B2B_s0nl0_Ml32_18_t</td>
<td>2.01</td>
<td>0.16</td>
<td>17.9419/4.2792</td>
<td>18.4021/4.2366</td>
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<td>pcb_hst_S4_B2B_s0nl0_Ms19_20_t</td>
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<td>20.9862/3.3626</td>
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</table>

**COM values**: Worst case values with Package types A and B with Host ASIC package traces 8mm-45mm and Module Package traces 4mm-12mm.

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Skew – Silicon (Serdes) role

• Skew can also be introduced in Silicon analog paths both in Transmitter and Receiver analog paths and circuits.

• Silicon can also help with skew compensating circuits. Some of such solutions are:
  • Tunable Delay line on one of the differential legs
  • Tunable matching filter to compensate for skew (see loss due to skew in freq. domain
  • Pre-emphasis and de emphasis can help reduce the impact of skew
  • All these solutions comes at the cost of either additional power or reduced Serdes performance and with a difficult task of tuning them for varying skew due to system stress conditions like temperature, cable bend and twist etc..
Summary

• As we address higher data rates, the Unit interval (UI) reduces, and the percentage of intrapair skew level w.r.t UI becomes higher. It impacts Highspeed Serdes performance significantly.

• Skew is contributed from every part of the serial link, i.e., Silicon, Packages, and system channel.

• Different types of skew profiles are observed from different categories of system constructions.

• Active skew compensation solutions shall be considered to reduce the skew impact, although such solutions are expected to come at a cost.

• System design must budget for a certain skew tolerance to allow manufacturing, assembly, and environmental variations.

• The working group shall determine how much a skew level the reference receiver must handle. Suggest 0.3 UI to 0.4 UI as a starting point.
Backup
### COM Configuration file with Package B

#### Table 1: COM Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
<th>Units</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_DPPC</td>
<td>10Gbps</td>
<td>GHz</td>
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<tr>
<td>f_DCM</td>
<td>3Gbps</td>
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<tr>
<td>C_d</td>
<td>[1.5, 2.5]</td>
<td>ns</td>
<td>[TX] kiloRm</td>
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<tr>
<td>C_p</td>
<td>[2.5, 6.5]</td>
<td>ns</td>
<td>[TX] kiloRm</td>
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<tr>
<td>Z_p select</td>
<td>[1.2, 3.1]</td>
<td>[TX] 12 13 15 18 20 24 30 36 41</td>
<td>[TX] kiloRm</td>
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</table>

#### Table 2: I/O Control

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
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<tr>
<td>RXD, TXD</td>
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<td>DTR</td>
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<tr>
<td>RTS</td>
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<td>logical</td>
<td></td>
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<tr>
<td>CTS</td>
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<tr>
<td>RTS_DTR</td>
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</table>

#### Table 3: Package Parameters

<table>
<thead>
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<th>Parameter</th>
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<th>Information</th>
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<tr>
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COM Configuration file with Package A