COM Simulation and Analysis for 200Gbps/Lane CR

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IEEE P802.3df Task Force
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Overview

Link Budget Analysis for 200G/L PAM4 CR

Channel Feasibility: Key Challenges

SerDes Feasibility: COM Sensitivity to Key Parameters

Modulation Type for 200G/L CR: PAM4 vs PAM6

Conclusion
Motivation and Methodology

• Explore feasibility of 200G/L PAM4 CR
  – Channel & SerDes requirements?

• Analyze channel requirements – based on COM v3.70 simulation
  – All available 200G CR channels from IEEE, OIF, & OSFP (total 73x)
  – Based on baseline SerDes

• Assess SerDes feasibility – starting from COM sensitivity check with sweeping key SerDes parameters
  – Provide the directions to make good trade-off between performance & power/cost of SerDes
  – Allow the interoperability between channel & SerDes improvements

• Investigate modulation format for 200G/L CR – comparing PAM4 & PAM6 under the assumption of identical transceiver capability
Objectives

• Do
  – Leverage published channel materials to represent potential 200Gbase channel characteristics and evaluate their corresponding performance
  – Analyze 200G/L CR feasibility from the system’s point of view
  – Point out key challenges of channel: roll-off characterizing impairments, reflection, & crosstalk
  – Provide direction of next generation SerDes: COM sensitivity of key parameters
  – Provide the baseline performance for candidate modulation formats

• Don’t
  – Offer the SerDes or channel solutions
  – Draw conclusions on modulation type for 200G/L CR
CR Channel Profile

- Channel variations mainly come from
  - Host PCB length
  - Cable length, impedance, & AWG
  - Verticals (connector & BGA breakout region)
  - Crosstalk
- Total of 73 channels

<table>
<thead>
<tr>
<th>Source</th>
<th>Contributor</th>
<th>LR Channels</th>
</tr>
</thead>
</table>
| 1. OSFP 200GEL | Amphenol | • 0.5/1m 27AWG CA  
| | Amphenol | • 1”-7” PCB at each side (92 Ohm, 1.3dB/in @56GHz)  
| | Keysight | • BGA breakout: parallel/orthogonal (no skew)/orthogonal  
| | | • Crosstalk mainly comes from connector via |
| 2. mellitz_3df_01_220502 | Samtec | • 0.5/1m/1.5 27AWG CA (100Ohm target)  
| | | • 2”/5”/7.45” PCB at each side (1.6dB/in @53.125GHz)  
| | | • Termination: T-line (ideal)/SMA 1.0mm/SMA 1.85mm/via 28mm  
| | | • No crosstalk |
| 3. oif2022.194.00 | Samtec | • 1/1.5m 28AWG CA (92.5 Ohm)  
| | | • Cable backplane with connector direct to package: 100/250 mm 34 AWG (92.5 Ohm)  
| | | • Direct to package connector (Cp and Zp2 set to zero)  
| | | • Crosstalk mainly comes from connector via |

The objective is to explore diverse channels to assess LR technology feasibility
- Channel IL: 16~42 dB
- FOM_ILD: 0.93~4.23 dB
COM Simulation Consideration: 200G Baseline

- **Die model:** keep the similar IL as 100G (parameters need further investigation)
- **PKG model:** 25% trace loss improvement from 100G, follows the values proposed in oif2021.596.01 (parameters need further investigation)
- **RXEQ length/rise time/jitter/RX noise PSD** scaled with 2x baud rate
- **DER/TX swing/TX SNR/Nonlinearity/TXEQ length** kept the same as 100G
- COM version: 3.70
- Test case (TC 1) (short package): \([z_p(TX) z_p(RX)] = [12, 12]\) mm
- TC 2 (long package): \([z_p(TX) z_p(RX)] = [31, 29]\) mm
**Link Budget Analysis for 200G/L PAM4 CR**

**Whole link budget analysis**
- To allow the interoperability among channel components & point out the design challenges
  - Currently the group don’t have consensus in package model → bump-to-bump IL target is evaluated instead of ball-to-ball IL target
  - Analyze performance from the system’s point of view

**Whether 200G/L PAM4 CR works?**
- If keep the same IL target from 100G to 200G: bump-to-bump IL ~ 36.5 dB (28.5dB ball-to-ball + 8 dB PKG in 802.3ck)
- If make SerDes capability aligned from 100G to 200G

![Link Budget Analysis (wo Crosstalk)](image1)

![Link Budget Analysis (wi Crosstalk)](image2)
**Channel Feasibility: ILD**

- Resonances characterizing impairments in next generation have been discussed in noujeim_3df_01_220224
- **Vertical transition**
  - Connector footprint
  - BGA breakout region
  -> Can cause multiple reflections
  -> Need more banks of floating taps
- **Impedance mismatch**
  - Connector-BGA breakout
  - Channel-package
  -> Reflection issue have been investigated in 802.3ck
  -> Length of DFE/floattab used to compensate reflections is twice of that for 100G/L CR

*wo crosstalk*
Noise Distribution (wo Crosstalk)

- Basically, performance is limited by noise enhancement with increasing IL
- Reflection-induced residual ISI can further degrade COM

*Channels with FOM ILD wi_PKG <= 2

Bump-to-bump IL > 36.5 dB
### Channel Feasibility: Crosstalk

- **Crosstalk Impact**
  - Crosstalk can degrade COM up to ~2dB at IL of interest

\[ d\text{COM} = \text{COM (wi Xtalk)} - \text{COM (wo Xtalk)} \]

- **Insertion-loss-to-crosstalk ratio (ICR) of test channels: 10.5 dB ~ 22 dB**

- **Link budget analysis (wo crosstalk)**

- **Crosstalk limit: ICR >= 25 dB?**

A tight margin of COM (<0.5 dB) for crosstalk
Sensitivity to Transceiver Capability: $A_v$ & SNR_TX

* Baseline: $A_v$ scale factor = 1 ($A_v = 0.413$ V)

* Baseline: SNR_TX = 33 dB

- Increased $A_v$ can help to enlarge signal margin
- Concern: Linearity & power consumption

- TX noise is less significant since ISI dominates the noise budget

**Figure:**
- Sensitivity to $A_v$ (TC1)
- Sensitivity to $A_v$ (TC2)
- $A_v$ Scale Factor = 1.25

**Graphs:**
- Sensitivity to SNR_TX (TC1)
- Sensitivity to SNR_TX (TC2)
- SNR_TX = 35

**Data:**
- $A_v$: 0.413 → 0.51625
  - COM: ~0.65 dB gain
- TX SNR: 33 → 35
  - COM: ~0.18 dB gain
Sensitivity to Transceiver Capability: Jitter

* Baseline: $A_{DD} = 0.02$

* Baseline: $\Sigma_{RJ} = 0.01$
Sensitivity to Transceiver Capability: $\eta_0$ & $f_r$

* Baseline: $\eta_0$ scale factor = 0.5 ($\eta_0 = 4.1E-9$)

* Baseline: $f_r = 0.75$

• A proper design of RX filter can achieve a better tradeoff between peaking gain & noise reduction
• Higher loss channels enjoy higher performance gain as reducing $f_r$
Sensitivity to Transceiver Capability: \( b_{\text{max}}(1) \)

*Baseline: \( b_{\text{max}}(1) = 0.85 \)

- More flexible DFE coefficient range
  - Beneficial for longer channels due to less noise enhancement induced by CTLE
  - Can help near-main cursor reflections (induced by roll-off)
- Concern: error propagation

\[ b_{\text{max}}(1): 0.85 \rightarrow 1 \]
COM: \( \sim 0.45 \text{ dB gain} \)
Summary: Sensitivity to Transceiver Capability

- Average COM gain obtained by SerDes enhancement
  - Based on TC2 & target bump-to-bump IL = 36.5 dB

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Changes from Baseline</th>
<th>Improvement</th>
<th>COM Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_v$</td>
<td>0.413 → 0.51625</td>
<td>25% increased</td>
<td>0.65 dB</td>
</tr>
<tr>
<td>SNR_TX</td>
<td>33 → 35</td>
<td>25% increased</td>
<td>0.18 dB</td>
</tr>
<tr>
<td>$A_{DD}$</td>
<td>0.02 → 0.016</td>
<td>20% decreased</td>
<td>0.15 dB</td>
</tr>
<tr>
<td>Sigma_RJ</td>
<td>0.01 → 0.008</td>
<td>20% decreased</td>
<td>0.04 dB</td>
</tr>
<tr>
<td>$\eta_0$</td>
<td>4.1E-9 → 3.28E-9</td>
<td>20% decreased</td>
<td>0.30 dB</td>
</tr>
<tr>
<td>$f_r$</td>
<td>0.75 → 0.5</td>
<td></td>
<td>0.00 dB</td>
</tr>
<tr>
<td>$b_{max}$</td>
<td>0.85 → 1</td>
<td>17% increased</td>
<td>0.45 dB</td>
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- Potential ways to improve the reach of 200G/L CR
  - Increase $A_v$ → Further investigation in linearity & power consumption required
  - Increase $b_{max}$ → Advanced RX technology can help the problem of error propagation?
  - Enhance $\eta_0$ → It’s very challenging to further improve RX noise
PAM4 vs PAM6 (wo Crosstalk)

- Assumptions: Identical transceiver capability for both PAM4 & PAM6
  - Identical impairments (absolute values of rise time, jitter, & RX noise)
  - Identical equalizer length

<table>
<thead>
<tr>
<th>SNR penalty (PAM4 → PAM6)</th>
<th>1E-4</th>
<th>1E-5</th>
<th>1E-6</th>
</tr>
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<tbody>
<tr>
<td>PAM4</td>
<td>18.23</td>
<td>19.46</td>
<td>20.42</td>
</tr>
<tr>
<td>PAM6</td>
<td>21.81</td>
<td>23.06</td>
<td>24.04</td>
</tr>
<tr>
<td>SNR Penalty (dB)</td>
<td>3.58</td>
<td>3.6</td>
<td>3.62</td>
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PAM4 vs PAM6 (wo Crosstalk)

- PAM4 shows the better overall performance under:
  - Bump-to-bump IL @ 53.125 GHz <= 36.5 dB
  - Channel bandwidth is sufficient (FOM_ILD_wi_PKG <= 2)

- PAM6 outperform PAM4 when channel loss increases

- Channels with limit bandwidth enjoy higher performance gain when moving from PAM4 to PAM6

![Graph showing performance comparison between PAM4 and PAM6](image)
PAM4 vs PAM6 (wi Crosstalk)

- Crosstalk has a high-pass frequency response in general
- If signals can no longer maintain sufficient isolation, PAM6 gains a competitive advantage
- Required channel specifications as considering backward compatibility with 100G/L modulation format
  - BW/Reflection-related requirement: ILD <= 2dB?
  - Crosstalk requirement: ICR >= 25 dB?

![Graphs showing PAM4 vs PAM6 performance](image-url)
• Feasibility of 200G/L PAM4 CR requires both channel and SerDes technology enablement
  – Based on potential reach: bump2bump IL ~36.5 dB

• Channel feasibility and the potential directions for channel design were explored
  – FOM_ILD_wi_PKG <= 2dB
  – ICR >= 25 dB

• SerDes feasibility started with the sensitivity check of key parameters, and the potential solutions to achieve 200G/L PAM4 CR were observed
  – Increased TX swing under proper assessment of linearity & power consumption
  – More flexible DFE coefficient range with advanced RX technology

• Baseline performance of PAM4 & PAM6 was compared under the assumption of identical transceiver capability
  – PAM4 can outperform PAM6 under the well-qualified channel conditions
Further discussion

• Whether 36.5 dB bump-to-bump IL target can meet the 200G/L CR objective with 1 m cable reach?

• Potential approaches to extend bump-to-bump IL target
  – Further SerDes enhancement, e.g., increased $A_v$ & $b_{\text{max}}$(1)
  – Advanced RX technology, e.g., MLSD
  – PAM6
Sensitivity to Transceiver Capability

- Minor changes in performance trend and the resulting values when removing channels with FOM_ILD_wi_PKG > 2

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*Remove channels with ILD > 2*
PAM4 vs PAM6 (wo Crosstalk)
PAM4 vs PAM6 (wi Crosstalk)
THANK YOU