224G Electrical Link Bandwidth Considerations

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Topics discussion

• PAM 4 receiver sensitivity simulations with different channels and equalizations FFE + DFE

• Compare receiver sensitivity using PAM 4 modulation
  • Simulation of 4 different Mellitz Channels.
  • SER was analyzed for each case (Thru channel)

• The SNR required for several channels is very high (> 34 dB)

• For these channels, other modulation techniques like SE MIMO should be consider
Simulated channels

*Simulated source channels, [Contributor : Samtec (Mellitz)]*

<table>
<thead>
<tr>
<th>Source channel</th>
<th>Channel IL @ 53 GHz [dB]</th>
<th>Average Power loss (DC - 56 GHz) [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>sma_1.0mm_3.2dB_500mm_NVAC_thru</td>
<td>-19</td>
<td>-7.4</td>
</tr>
<tr>
<td>tline_termi_8dB_1000mm_NVAC_thru</td>
<td>-30</td>
<td>-12.5</td>
</tr>
<tr>
<td>Via_28mm_12dB_500mm_NVAC_thru</td>
<td>-40</td>
<td>-14.5</td>
</tr>
<tr>
<td>sma_1.0mm_12dB_1500mm_NVAC_thru</td>
<td>-41</td>
<td>-16.8</td>
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</tbody>
</table>
Rx sensitivity simulation results

SNR = 29.5 dB for BW= 28 GHZ
2 X 112 Gbps = 224 Gbps can be possible using SE MIMO modulation

Very difficult to achieve SNR higher than 34-35 dB !!!
Need to increase TX power => More system power
Rx sensitivity simulation results

SNR = 35 dB for BW= 28 GHZ
2 X 112 Gbps = 224 Gbps can be possible using SE MIMO modulation

Very difficult to achieve SNR higher than 34-35 dB !!!
Need to increase TX power => More system power
224G PAM vs SE-PAM4 signaling

Differential signaling

+V(t) \rightarrow 1 \rightarrow 2
-V(t) \rightarrow 3 \rightarrow 4

Single ended signaling

+V_p(t) \rightarrow 1 \rightarrow 2
+V_n(t) \rightarrow 3 \rightarrow 4

PG

NG

Baud Rate

112G
10G
9.6G
6.25G
5G
2.5G

Bit # per symbol

NRZ PAM4 PAM16
## 224G PAM Signaling Comparison

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Baud Rate (GHz)</th>
<th>Unit Interval (ps)</th>
<th>Nyquist Frequency (GHz)</th>
<th>** Bandwidth Requirements (GHz)</th>
<th>Bits per Symbol</th>
<th>Penalty @SER=1e-4 (Amplitude Normalized)</th>
<th>Penalty @SER=1e-4 (Power Normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>PAM4</td>
<td>112</td>
<td>8.93</td>
<td>56</td>
<td>84</td>
<td>2/1</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>PR-PAM4</td>
<td>112</td>
<td>8.93</td>
<td>28*</td>
<td>42</td>
<td>2/1</td>
<td>6.14</td>
<td>3.13</td>
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<tr>
<td>SE-PAM4</td>
<td>56</td>
<td>17.86</td>
<td>28</td>
<td>42</td>
<td>4/1</td>
<td>6.02</td>
<td>3.01</td>
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<td>6-level</td>
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<tr>
<td>CROSS-32 (PAM6)</td>
<td>89.6</td>
<td>11.16</td>
<td>44.8</td>
<td>67.2</td>
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<td>4.89</td>
<td>3.46</td>
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<tr>
<td>DSQ-32</td>
<td>89.6</td>
<td>11.16</td>
<td>44.8</td>
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<td>3.68</td>
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<td>PAM8</td>
<td>74.7</td>
<td>13.39</td>
<td>37.3</td>
<td>56</td>
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<td>7.45</td>
<td>6.32</td>
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<td>DSQ-128</td>
<td>64</td>
<td>15.63</td>
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<td>48</td>
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<td>9.78</td>
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<tr>
<td>PAM16</td>
<td>56</td>
<td>17.86</td>
<td>28</td>
<td>42</td>
<td>4/1</td>
<td>14.10</td>
<td>12.43</td>
</tr>
</tbody>
</table>

* Estimated as 1/4 of Baud Rate. ** frequency range with smooth IL or small ILD.
TRX architecture for single-ended signaling

Analog Mixed-Signal based receiver

ADC DSP based receiver

Common (Even) Mode
\[
\begin{bmatrix}
+1 & +1 \\ -1 & -1 \\
\end{bmatrix}
\]
Differential (Odd) Mode
\[
\begin{bmatrix}
+1 & +1 \\ -1 & +1 \\
\end{bmatrix}
\]

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SE-PAM4 can support PCB solutions

- **Backplane**
  - TP0 to TP5
  - ~22dB @ 26.56GHz

- **Cable**
  - Chip
  - Host Via
  - Paddle/Wire Termination

- **Orthogonal backplane**
  - TP0 to TP5
  - ~22dB @ 26.56GHz
PAM4 relies more on cable solutions

- On-board cable assembly
- Backplane cable assembly
- Fanout cable assembly

Discontinuities

- Host Via
- AC-capacitor
- Fanout cable conversion

Wire diameter conversion
Optimizations of SE-PAM4 and PAM4

SE-PAM4 requires optimization of passive channels for single-ended signaling.

PAM4 requires optimization of passive channels for 112GBd signal. Analog signal amplifier and equalizer may be the key enabling technology.
Future work

• SE-PAM4 simulation with different channels
• Add bump to ball channel
• Find optimal equalization architecture
• Investigate specific penalties related with SE
Thanks