Optical modeling of 100 GBd PAM4 with relevance to single-wavelength 200 Gb/s per lane PMDs

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Introduction

• Initial 100 GBd PAM4 optical modeling
  • Gaussian-filtered Tx pulse shape
  • Single wavelength
  • SMF chromatic dispersion (up to 2 km fiber length)
  • TDECQ reference receiver

• Investigation of TDECQ dependency on TP2 transition time, RIN and TDECQ reference equalizer length

• Aim is to begin to better understand sensitivity of link performance to key parameters
<table>
<thead>
<tr>
<th>Ethernet Rate</th>
<th>Assumed Signaling Rate</th>
<th>AUI</th>
<th>BP</th>
<th>Cu Cable</th>
<th>MMF 50m</th>
<th>MMF 100m</th>
<th>SMF 500m</th>
<th>SMF 2km</th>
<th>SMF 10km</th>
<th>SMF 40km</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 Gb/s</td>
<td>200 Gb/s</td>
<td>Over 1 lane</td>
<td>Over 1 pair</td>
<td>Over 1 Pair</td>
<td>Over 1 Pair</td>
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<tr>
<td>400 Gb/s</td>
<td>100 Gb/s</td>
<td>Over 2 lanes</td>
<td>Over 2 Pair</td>
<td>Over 2 Pair</td>
<td>Over 4 Pair</td>
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<tr>
<td>800 Gb/s</td>
<td>100 Gb/s</td>
<td>Over 8 lanes</td>
<td>Over 4 pairs</td>
<td>Over 4 pairs 1) Over 4 pairs 2) Over 4 2’s</td>
<td>Over 8 pairs TBD</td>
<td>Over 8 pairs TBD</td>
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<tr>
<td>1.6 Tb/s</td>
<td>100 Gb/s</td>
<td>Over 16 lanes</td>
<td>Over 8 pairs</td>
<td>Over 8 pairs 1.6TBASE-CR8</td>
<td>Over 8 pairs</td>
<td>Over 8 pairs</td>
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</table>

More work required

Depends on the modulation scheme & More work required

Over single SMF in each direction

Over single SMF in each direction
A simple model is best to take into account major trends for performance at the system level.
Simulation parameters

**Tx**
Modulation format: PAM4
Symbol rate: 106.25 GBd
Pattern: PRBS13Q
Pulse shape at TP2: Baud-rate rectangular pulse convolved with Gaussian filter. Variable transition time (20% - 80%) in the filter step response
Center wavelength: 1304.5 nm (for worst-case dispersion)
RIN: variable
Chirp factor: 0
ER: 3.5 dB

**SMF**
Length: 2000 m
Zero-dispersion wavelength: 1324 nm
Zero-dispersion slope: 0.093 ps/(nm² km)

**Rx**
TDECQ reference LPF: 4th-order Bessel-Thomson with −3 dBe at 53.125 GHz
TDECQ reference FFE: T-spaced with variable number of taps
TDECQ target SER: 4.8 x 10⁻⁴
Noise-free eye diagrams at TP2

TP2 transition time: 3 ps

TP2 transition time: 5 ps

TP2 transition time: 7 ps
Noise-free eye diagrams after TDECQ reference receiver

TP2 transition time: 3 ps

TP2 transition time: 5 ps

TP2 transition time: 7 ps

TDECQ reference FFE: 5 tap
TDECQ vs TP2 transition time

Simulation specific parameters:
TDECQ reference FFE: 5 tap
Red: RIN = –140 dB/Hz
     (–131.7 dB/Hz RIN OMA)
Green: RIN = –150 dB/Hz
      (–141.7 dB RIN OMA)
*Equivalent aggregate Tx bandwidth

- For equivalent aggregate Tx bandwidth of 45 to 55 GHz, RIN variation from –140 dB/Hz to –150 dB/Hz causes significant TDECQ variation
- Even at RIN of –150 dB/Hz, TP2 transition time must be lower than ≈6 ps for acceptable TDECQ
**TDECQ vs RIN**

- Dependency of TDECQ on RIN becomes stronger with increasing TP2 transition time

Simulation specific parameters:
- TDECQ reference FFE: 5 tap
- Red: TP2 transition time = 6 ps
- Green: TP2 transition time = 3 ps

100GBASE-DR limit (3.4 dB)
TDECQ vs reference FFE length

Simulation specific parameters:
TDECQ reference FFE: 5 tap
RIN: --150 dB/Hz
Red: TP2 transition time = 6 ps
Green: TP2 transition time = 3 ps

• Even for the limiting case of a TP2 transition time of 6 ps, there is no benefit from more than 5 FFE taps
• No justification to increase TDECQ reference equalizer length from 5 taps
Conclusions

• For single-wavelength 200 Gb/s per lane PMDs using 100 GBd PAM4:
  • Currently we do not expect need to change TDECQ reference equalizer from 5-tap FFE
  • Currently there is no evidence that DFE is required in the reference equalizer
  • Currently there is evidence that a tighter RIN OMA specification (compared with 50 GBd PAM4 PMDs) is helpful
Next steps

• Investigate other Tx models, including chirp
• Investigate effect of stronger FEC (higher symbol rate and higher pre-FEC BER threshold)
• Include a wider set of industry parameters to the simulation sets

Call for contributions

• Tx performance guidance from Task Force is welcome
• We can compute expected curves given the following:
  • Bandwidth or frequency response ($S_{21}$)
  • RIN
  • Chirp factor