Linear Pluggable Optics Beyond 112G: Where are the use cases?

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Will Linear Pluggable Optics (LPO) Have a Future Beyond 112G?
Retimed Pluggable Optics vs. Linear Pluggable Optics

- **Lower latency and lower power consumption with the flexibility of pluggable**
- **Challenges**
  - Complex host SerDes design (die area, power, cost)
  - Lack of robustness to optical components variations
  - Requires pristine electrical channel design to minimize reflection and xtalk
  - Complex system qual and interoperability
  - Large optical channel SNR penalty
Extended Salz SNR Model for LPO

(A general upper-bound performance model assuming ideal DFE based receiver)

\[
SNR_{Salz} = 10\log_{10}e^{\frac{1}{FN}\int_0^F\ln\left(1+\frac{S(f)}{N(f)}\right)df}
\]

\[
S(f) = H_{Te}(f) \cdot H_{peak}(f) \cdot H_{To}(f) \cdot H_{Ro}(f) \cdot H_{Re}(f)
\]

\[
N(f) = H_{peak}(f) \cdot H_{To}(f) \cdot H_{Ro}(f) \cdot H_{Re}(f) + H_{Ro}(f) \cdot H_{Re}(f) + \frac{1}{SNRe_{Rx}}
\]

- **SNRe_{Tx} and SNRe_{Rx}**
  - Baseline Tx and Rx C2M SNR assuming zero C2M loss

- **SNRo**
  - Baseline optical channel SNR assuming zero C2M loss and no effective gain peaking
Non-Retimed LPO Not A Viable Option at 200G Lane

- Non-retimed LPO requires 11.5dB higher optical Ch SNR @ 25dB C2M loss
  - > 5.7dB reduction in optical link budget
  - 5dB driver peaking increases optical budget by ~1dB but consumes more power

Host Tx output: 800mVdd, 33dB SNR
C2M noise density: 1.25e-8V^2/GHz (802.3dj)
TIA output: 400mVdd

106.25Gbaud PAM4

PD R=0.9, TIA noise=18pA/√Hz

- LPO, C2M=25dB (no peaking)
- 5.7dB OMA
- 11.5dB SNR
Comparison to Time-Domain Model

E. Chou, et al.*, "100G and 200G per Lane Linear Drive Optics for Data Center Applications", OFC 2024 W4H.3, *authors with Meta

Time-domain Simulation (Meta)
5dB Peaking
C2M Ch Noise Neglected

Extended Salz Model (Google)
( A General frequency-domain model )

- At 25dB C2M Loss (neglecting C2M noise)
  - 8 to 9dB SNR Penalty
  - 4 to 4.5 dB OMA penalty

- At 25dB C2M Loss (neglecting C2M noise)
  - 8dB SNR penalty
  - 4dB OMA penalty
**Tx-Retimed Optics (TRO) for Short Reach**

C2M noise density: $1.25 \times 10^{-8} \text{V}^2/\text{GHz}$ (802.3dj)
TIA output: 400mVdd

- **Tx-retimed linear optics (TRO)**
  - Retimed Tx, linear TIA for Rx

- **TRO is effective in reducing Optical channel SNR penalty**
  - <1dB @25dB C2M loss
  - ~2dB @35dB C2M loss

- **Suitable for short reach links with a relatively limited optical budget**
  - ToR to leaf, some ML links

- **Further investigation is required to assess the impairments caused by electrical channel reflections and crosstalk**

106.25Gbaud PAM4

![Graph showing required minimum optical channel SNR vs. Rx Die to Die C2M channel loss (dB)]
Performance Penalty of **Rx-Retimed Optics (RRO)**

- **Rx-retimed linear optics (RRO)**
  - Tx linear, Rx-retimed

- Optical Ch SNR penalty is marginally better than non-retimed LPO
  - 10.7dB@25dB C2M Loss

- Limited use case for low C2M loss at one end
  - NIC to TOR AOC
  - Non-retimed Tx/Rx at NIC while retimed Tx/Rx at TOR

**Host Tx output:** 800mVdd, 33dB SNR
**C2M noise density:** $1.25 \times 10^{-8} V^2/\text{GHz}$ (802.3dj)

**106.25Gbaud PAM4**
Conclusions

- DSP is essential for high performance optical links at 200G PAM4
  - Robust link performance with high link budget
  - Time to market with accelerated system qualification

- Non-retimed LPO is not a viable option at 200G PAM4
  - The O-SNR required is excessively high for typical 200G C2M channels

- Tx-retimed TRO is highly effective in reducing optical SNR penalty
  - > 50% reduction in Rx CDR/DSP power
  - Transmitter optical specification can be well defined to ensure interoperability
  - Could be used for AOC or Short-reach interconnect with low link budget

- Standardization of interface specifications is needed to ensure robust link operation and interop
  - Host SerDes, C2M Channel, Optical Tx and Rx
Backup
Performance Penalty of 100G lane LPO

- Non-retimed LPO requires higher optical Ch SNR
  - 7.5dB @ 15dB C2M loss
  - 11.5dB @ 25dB C2M loss
- 5dB driver peaking only moderately reduces SNR penalty (~2dB @25dB C2M loss)

Host Tx output: 800mVdd, 33dB SNR
C2M noise density: 1.25e-8V²/GHz (802.3dj)
TIA output: 400mVdd

53.125Gbaud PAM4

PD R=0.9, TIA noise=15pA/√Hz

Required minimum optical channel SNR (dB)

- Ideal optical ch, No peaking
- 26GHz Optical Tx/Rx BW, no peaking
- Ideal optical ch, 5dB peaking
- 26GHz Optical Tx/Rx BW, 5dB peaking

Die to Die C2M channel loss (dB)

- No peaking
- 5dB peaking

SNR

LPO, C2M=15dB (no peaking)

Retimed Optics

7.5dB SNR
Advantage of ‘Retimed’ Pluggable Optics

- Support better optical performance
  - Larger optical link budget (loss, impairment)
  - Robustness to optical component and channel variability
- Impairment isolation of optical channel and electrical channel
  - Higher C2M channel loss
  - Easier qualification, deployment, and repair of optical modules
  - Independent optimization of electrical and optical channel technologies
  - Better interoperability between different host platforms
C2M Model (IEEE802.3dj) and Optical Ch Transfer Function Used in the Model

Device/Die Termination

Package CLass A model

Host PCB trace per inch

Optical Tx Transfer function

Optical Rx Transfer function

53GHz BW