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

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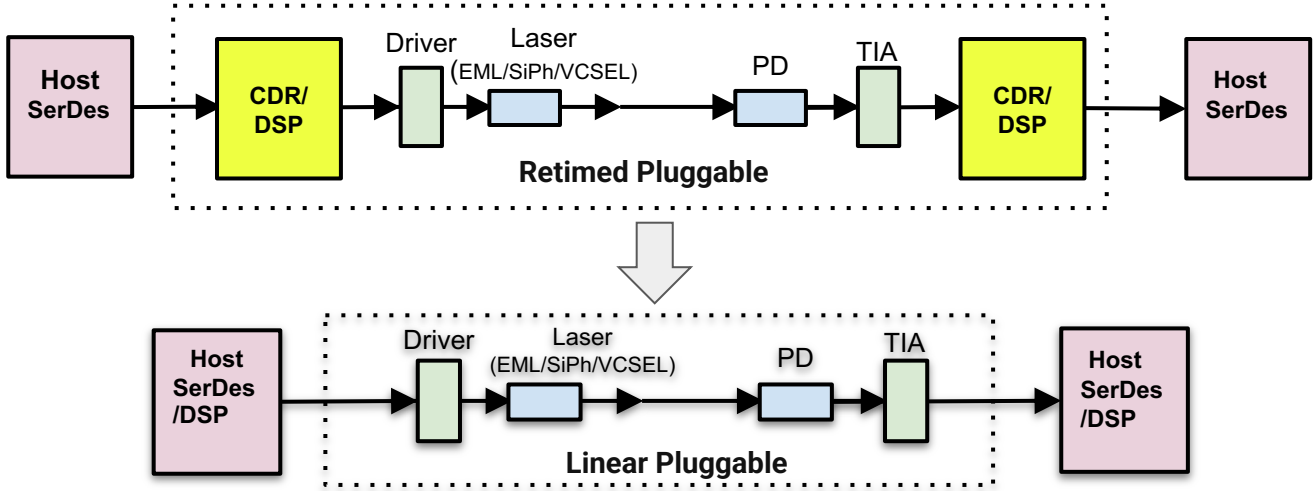
OFC'24 Workshop
Will Linear Pluggable Optics (LPO) Have a Future Beyond 112G?

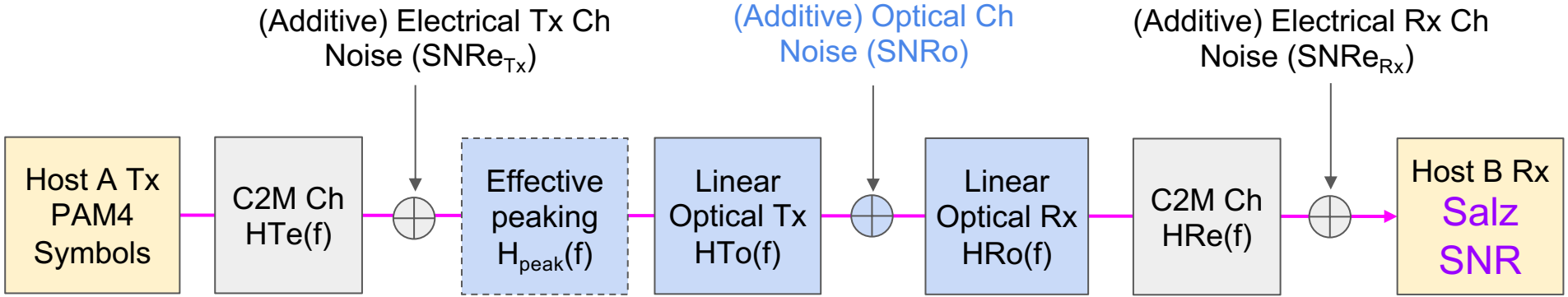
Retimed Pluggable Optics vs. Linear Pluggable Optics



- **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)



$$SNR_{Salz} = 10log_{10}e^{\frac{1}{FN}\int_{0}^{FN} Ln\left(1+\frac{S(f)}{N(f)}\right)df}$$

$$S(f) = HTe(f) \cdot H_{peak}(f) \cdot HTo(f) \cdot HRo(f) \cdot HRe(f)$$

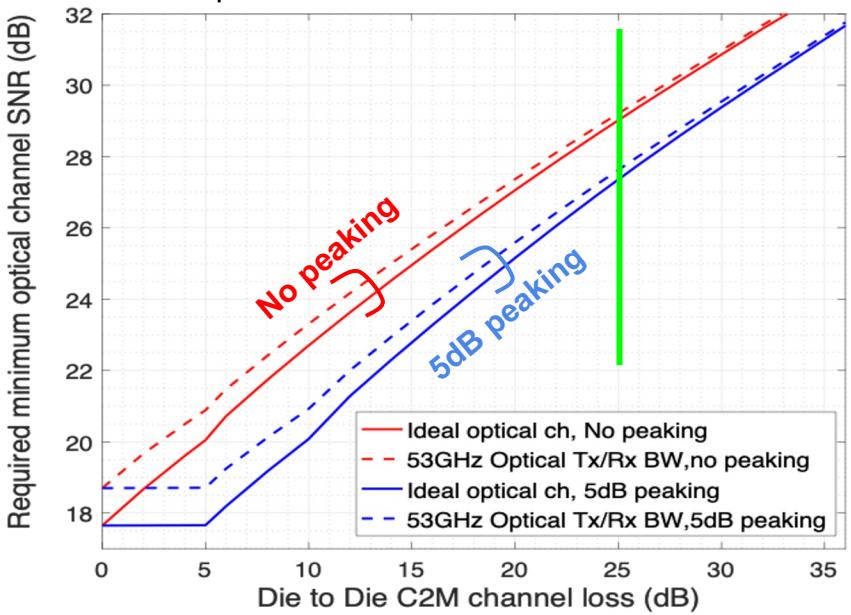
$$N(f) = \frac{H_{peak}(f) \cdot HTo(f) \cdot HRo(f) \cdot HRe(f)}{SNRe_{Tx}} + \frac{HRo(f) \cdot HRe(f)}{SNRo} + \frac{1}{SNRe_{Rx}}$$

- **$SNRe_{Tx}$ 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

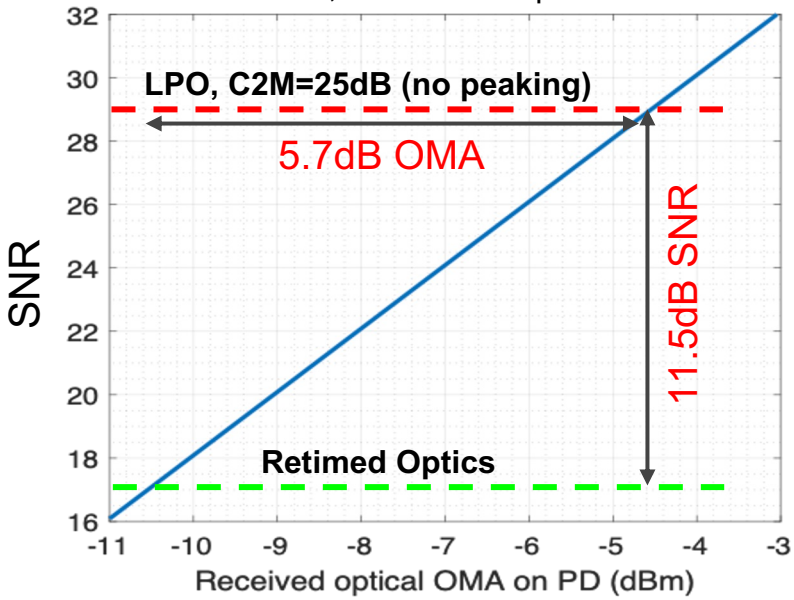
Non-Retimed LPO Not A Viable Option at 200G Lane

106.25Gbaud PAM4

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



PD R=0.9, TIA noise=18pA/√Hz

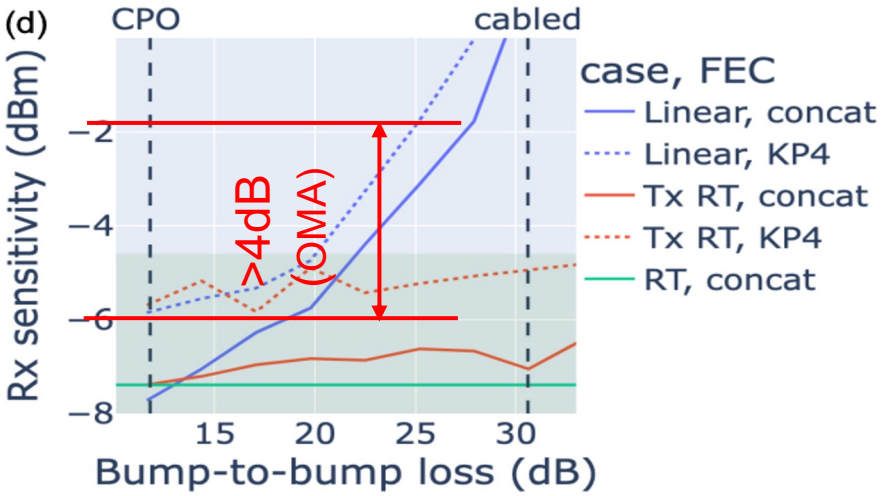


- Non-retimed LPO requires 11.5dB higher optical Ch SNR @ 25dB C2M loss
  - > 5.7dB reduction in optical link budget
  - 5dB driver peaking increases optical budget by ~ 1dB but consumes more power

Comparison to Time-Domain Model

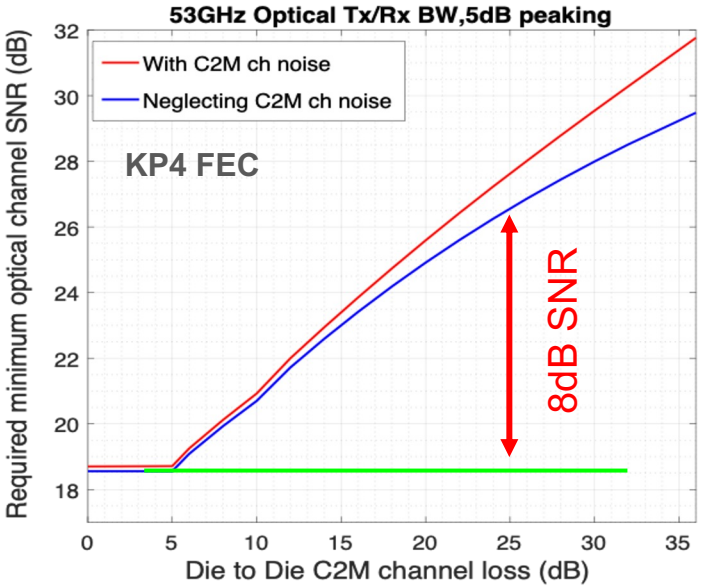
E. Chou, et al.*, "100G and 200G per Lane Linear Drive Optics for Data Center Applications", OFC 2024 W4H.3, *authors with Meta

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



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

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

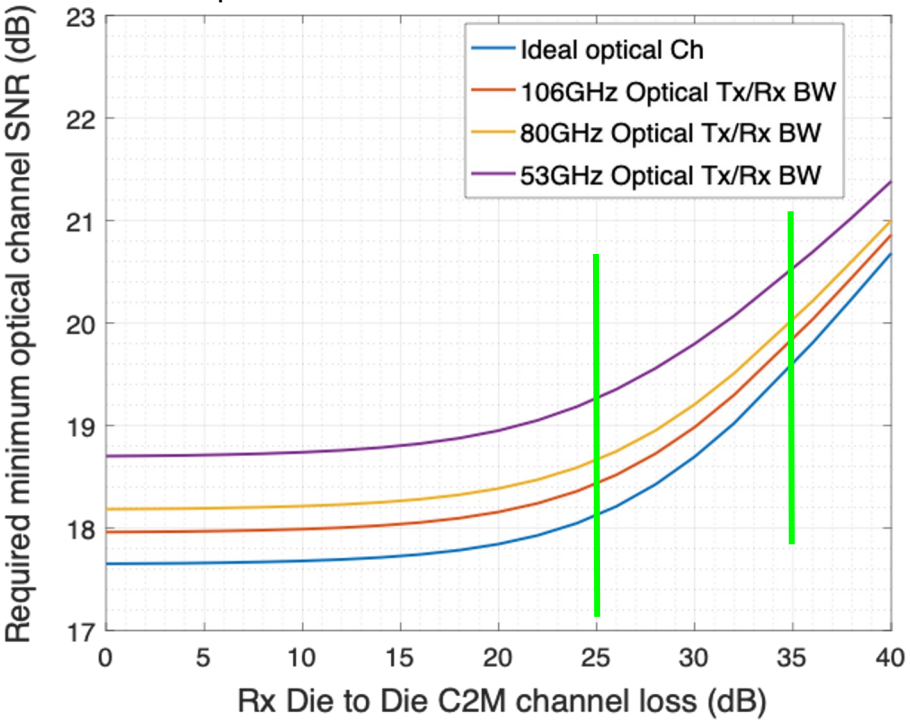


- At 25dB C2M Loss (neglecting C2M noise)
  - 8dB SNR penalty
  - 4dB OMA penalty

Tx-Retimed Optics (TRO) for Short Reach

106.25Gbaud PAM4

C2M noise density: 1.25e-8V^2/GHz (802.3dj)
TIA output: 400mVdd

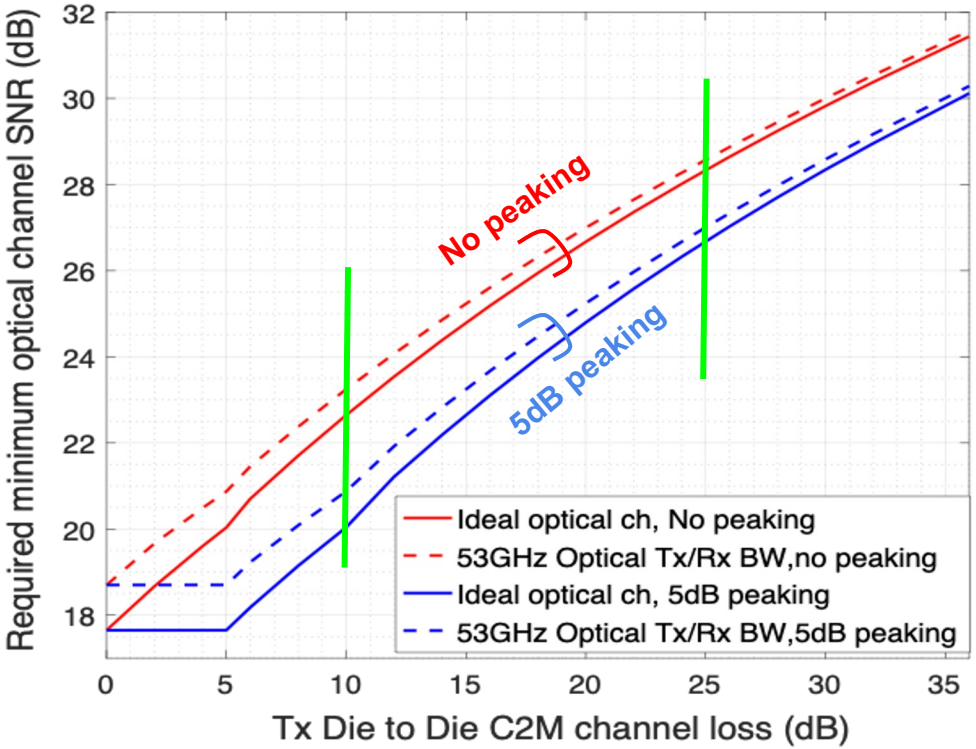


- Tx-retimed linear optics (TRO)
  - Retimed Tx, linear TIA for Rx
- TRO is effective in reducing Optical channel SNR penalty
  - <1dB @25dB C2M loss
  - ~2dB @35dB C2M loss
- Suitable for short reach links with a relatively limited optical budget
  - ToR to leaf, some ML links
- Further investigation is required to assess the impairments caused by electrical channel reflections and crosstalk

Performance Penalty of Rx-Retimed Optics (RRO)

106.25Gbaud PAM4

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



- 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

Conclusions

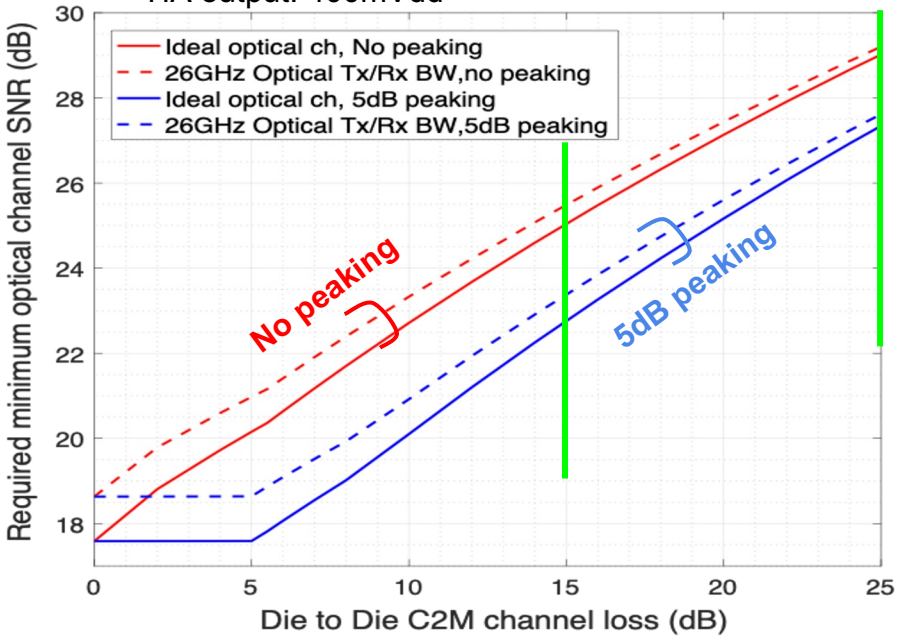
- DSP is essential for high performance optical links at 200G PAM4
  - Robust link performance with high link budget
  - Time to market with accelerated system qualification
- Non-retimed LPO is not a viable option at 200G PAM4
  - The O-SNR required is excessively high for typical 200G C2M channels
- 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

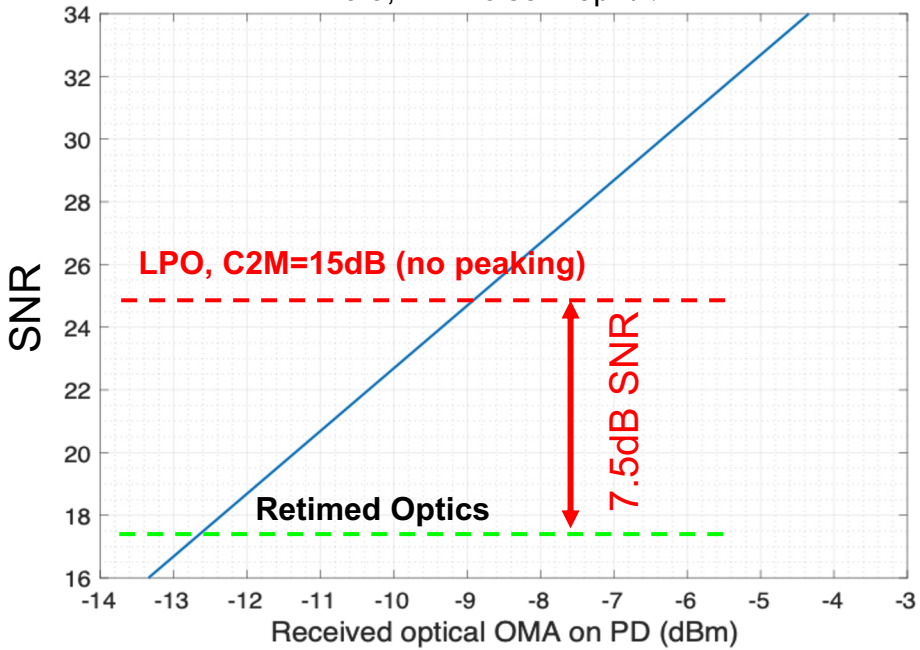
Performance Penalty of 100G lane LPO

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

53.125Gbaud PAM4

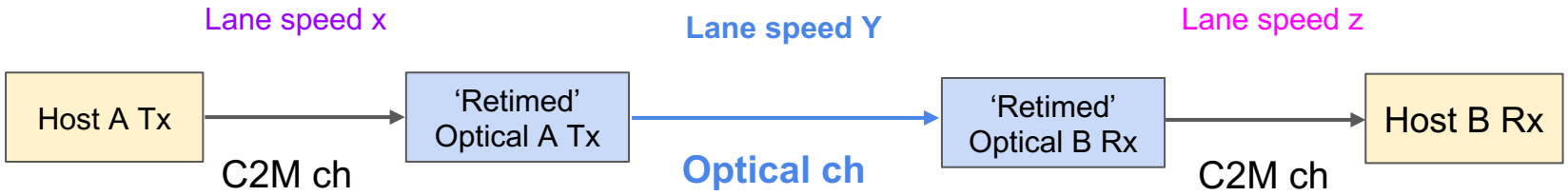


PD R=0.9, TIA noise=15pA/√Hz



- 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)

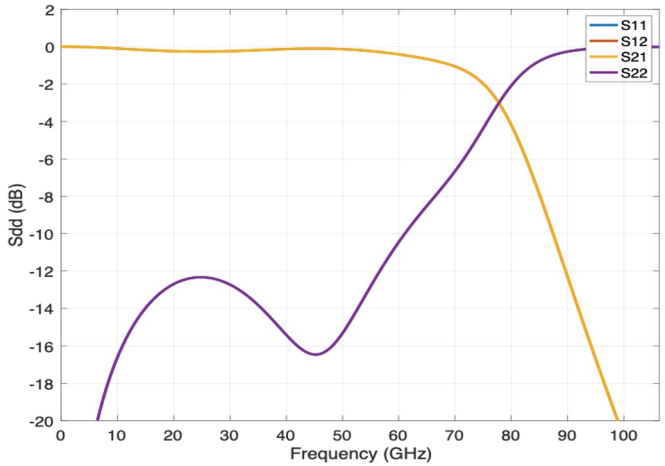
Advantage of ‘Retimed’ Pluggable Optics



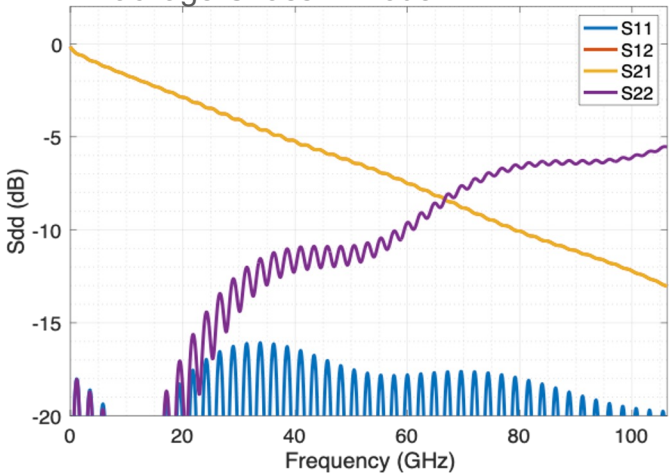
- **Support better optical performance**
  - Larger optical link budget (loss, impairment)
  - Robustness to optical component and channel variability
- **Impairment isolation of optical channel and electrical channel**
  - Higher C2M channel loss
  - Easier qualification,deployment and repair of optical 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