Impact of MPI on High-Speed PAM4 Transmission

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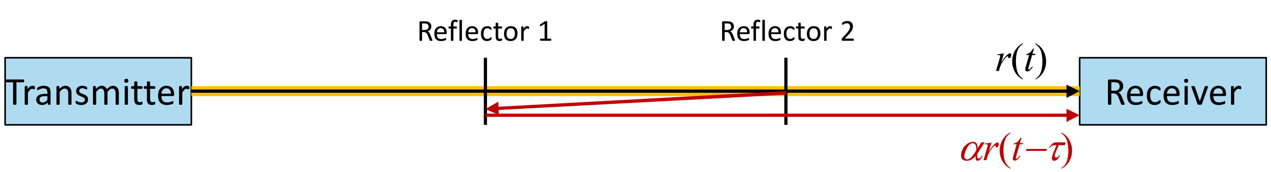
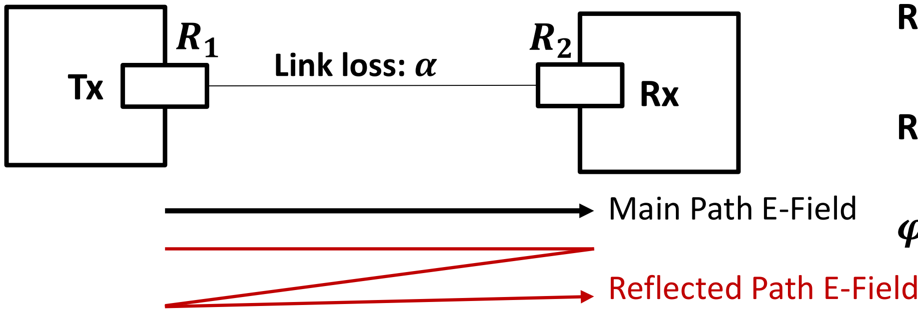
Multipath Interference

- **Multipath Interference (MPI)**
  - Optical links contain a number of fiber connectors, splices, and patch panels, which can cause significant reflections if poorly assembled;
  - Multiple reflection from fiber connectors, transmitter and receiver interfaces creates delayed copies of transmitted signal in the forward path and interfere with the transmitted signal in direct path.
  - Effect of MPI depends on return loss of the reflectors, the distance and loss between reflectors, and the linewidth (phase noise) and frequency chirp of the transmitted signal.
- **MPI Issue in deployed networks**
  - 50GBASE-LR/ER and 200GBASE-LR/ER have been widely deployed for 5G midhaul/backhaul
  - The return loss of fiber connectors degrades over time and causes significant MPI -> 10% link failure in real deployed networks!



Multipath Interference: Theoretical Analysis

Two connector case



Received signal in direct path: $\sqrt{\alpha}A(t)exp(i\omega_0 t + \varphi(t))$

Received MPI signal: $\alpha^{1.5}\sqrt{R_1 \cdot R_2}A(t-\tau)exp(i\omega_0(t-\tau) + \varphi(t-\tau))$

$\varphi(t)$ **is a random process including the phase noise of the lightsource**

$$I(t) = |mainPath + reflectedPath|^2 = \underbrace{\alpha A(t)^2}_{\text{Desired signal}} + \underbrace{2\alpha^2\sqrt{R_1 \cdot R_2}A(t)^2\Re(exp(i\omega_0\tau + \varphi(t) - \varphi(t-\tau)))}_{\text{Multipath interference}} + \underbrace{\alpha^3 R_1 R_2 A(t)^2}_{\text{Very small, negligible}}$$

With modulated signal, MPI noise spectrum is mixed with the signal spectrum. For simplicity, assume cw signal is transmitted. Then the MPI noise spectrum can be found from the Fourier transform of the autocorrelation function

$$RIN_{MPI}(f) \approx \frac{4R_e^2}{\pi} \cdot \frac{\Delta v}{f^2 + \Delta v^2}$$

where Δv: Laser linewidth $R_e = \alpha\sqrt{R_1 \cdot R_2}$

Assume worst case (polarization aligned) and $2\pi\Delta v\tau \gg 1$

MPI Noise Analysis

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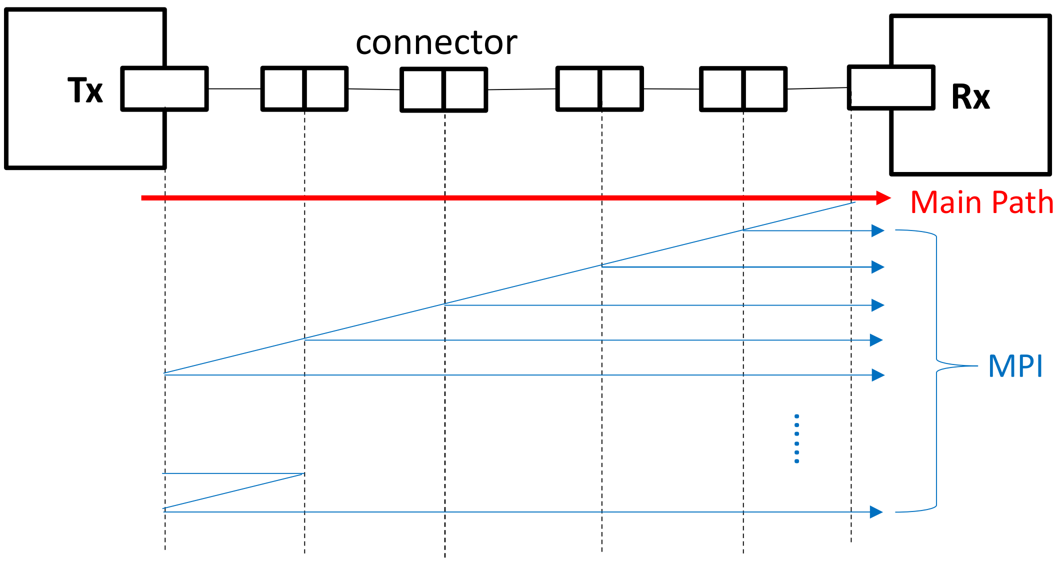


For multiple reflections in the link, the received optical signal is (assume cw signal transmitted):

$$I(t) = \alpha|A|^2\left[1 + \sum_{i=2}^{N}\sum_{j=1}^{i-1} 2R_{ij}\cos\left(\omega_0\tau_{ij} + \Delta\varphi_{ij}(\tau_{ij})\right)\right]$$

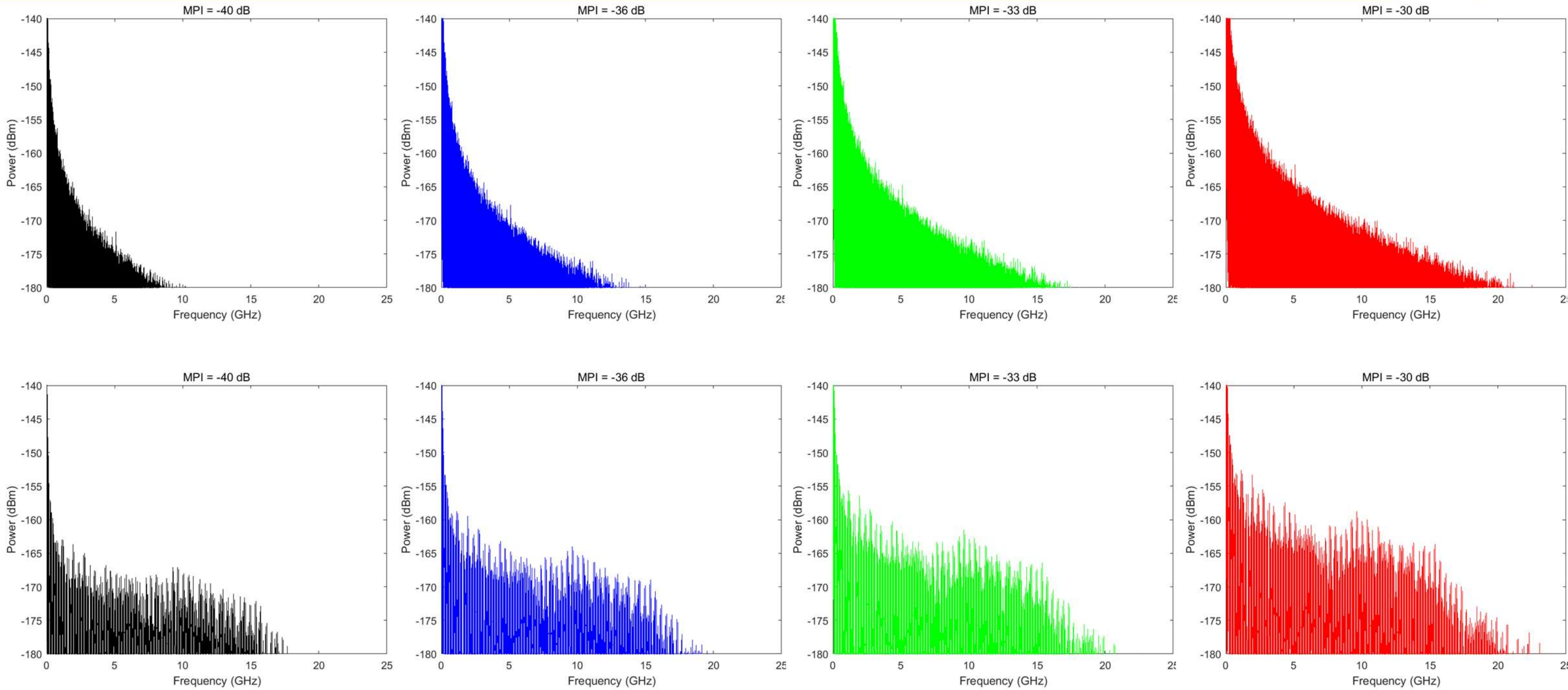
MPI noise spectrum is then given by

$$RIN_{MPI}(f) = \frac{4}{\pi}\cdot\frac{\Delta v}{f^2 + \Delta v^2}\cdot R_e^2$$

where effective MPI

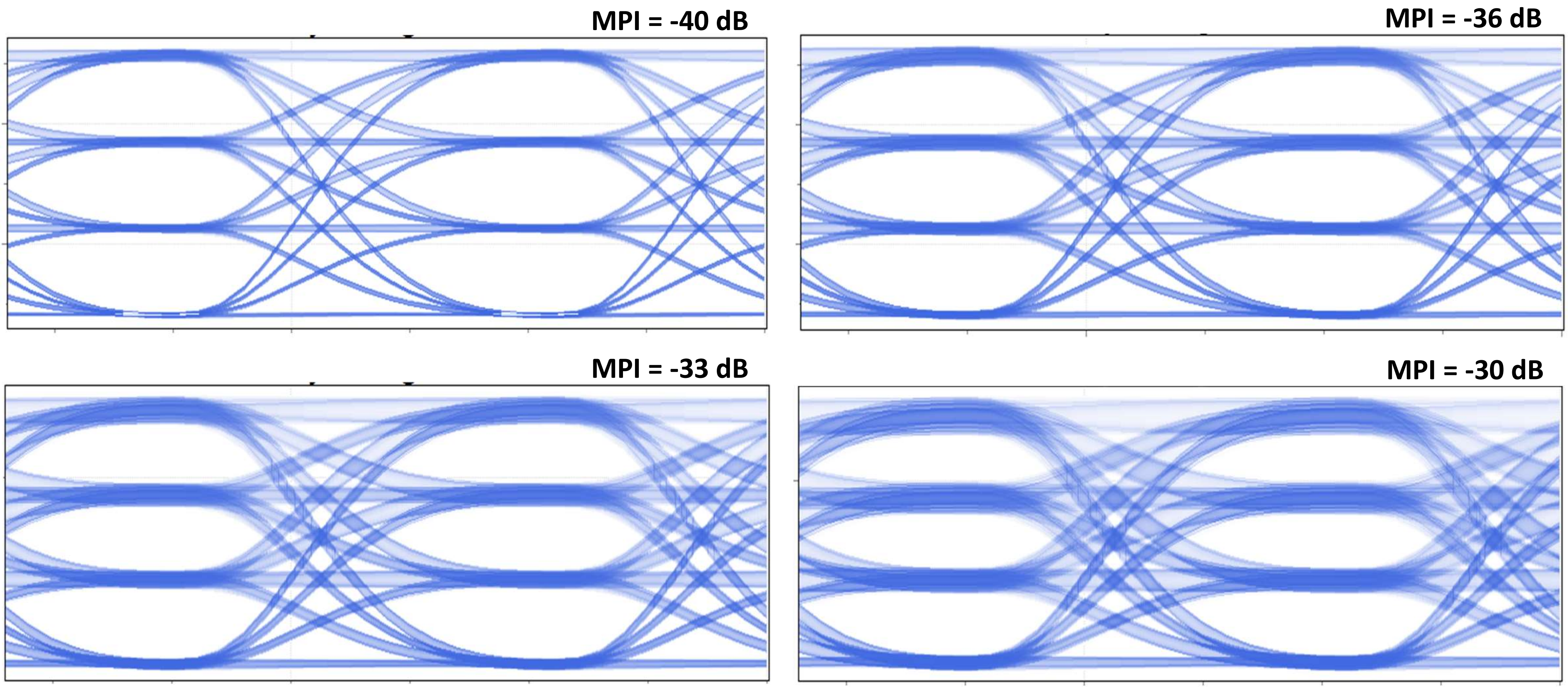
$$R_e^2 = \sum_{i=2}^{N}\sum_{j=1}^{i-1} R_{ij} = \sum_{i=2}^{N}\sum_{j=1}^{i-1} \alpha_{ij}^2 R_i R_j$$

MPI Noise Measurement

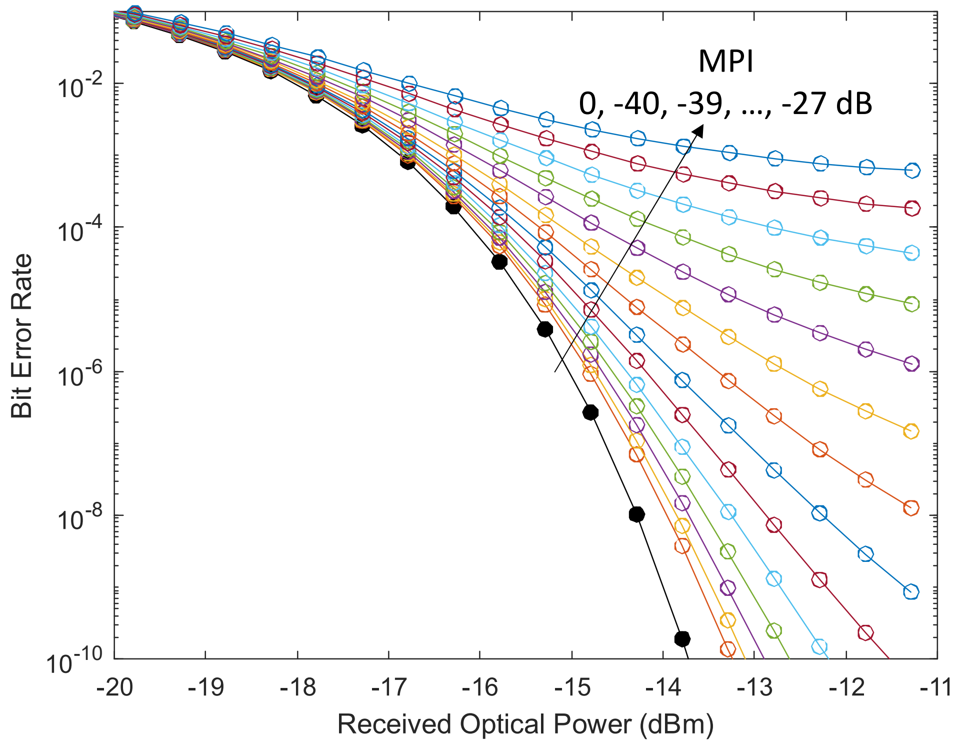


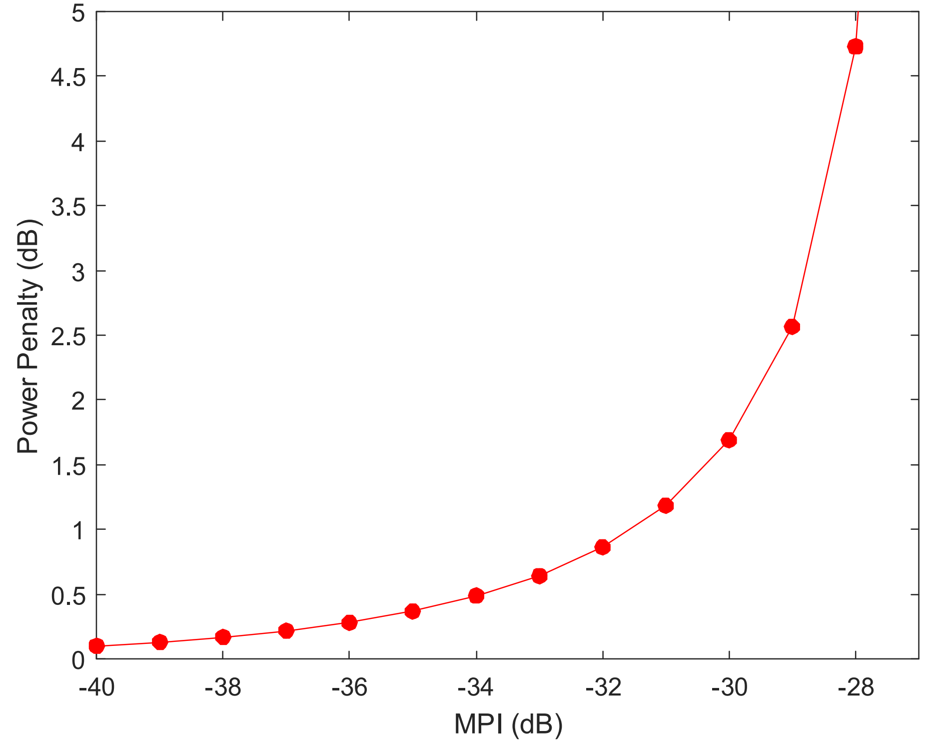
Top row: cw signal transmitted; Bottom row: PAM4 signal transmitted

Impact of MPI on 50Gb/s PAM4 Transmission

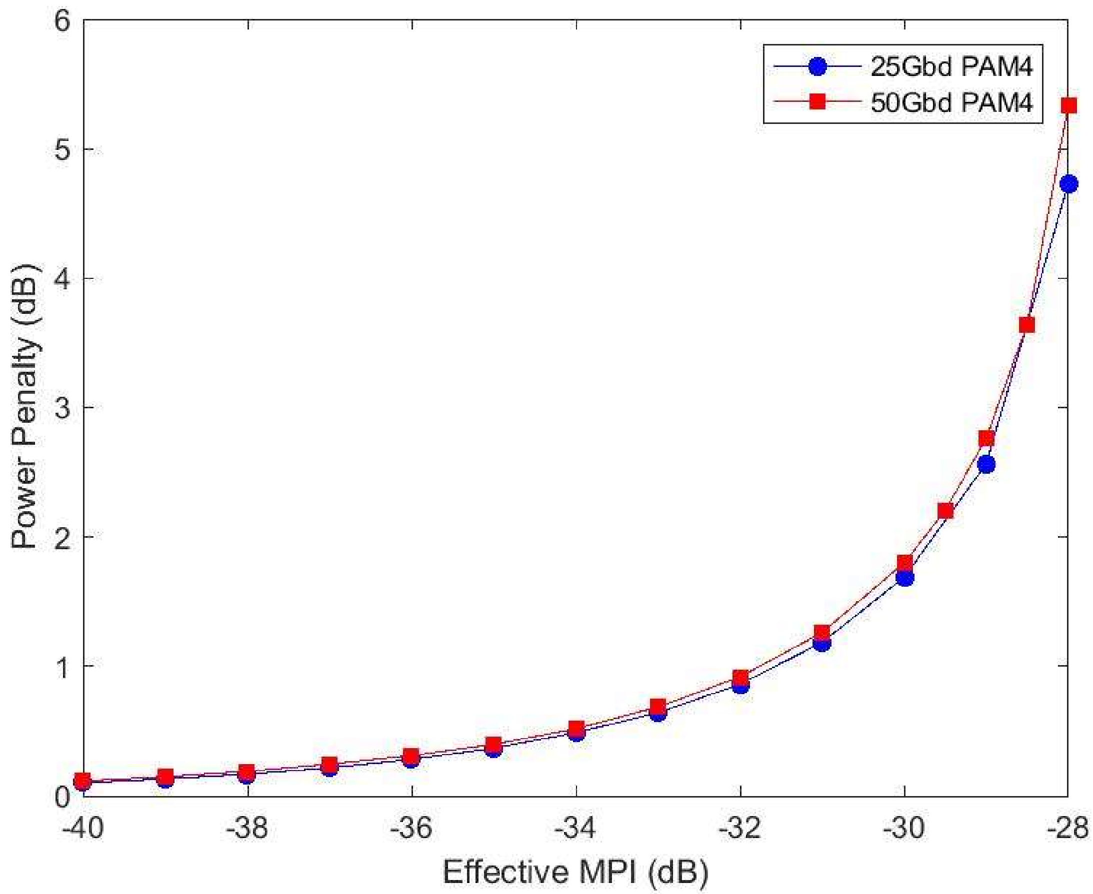


Impact of MPI on 50Gb/s PAM4 Transmission





Impact of MPI on 50Gb/s and 100Gb/s PAM4 Transmission



Conclusions and Proposal

- MPI noise spectrum is analyzed theoretically and measured experimentally
  - MPI noise spectrum exhibits lowpass behavior due to the interference among signals from the direct path and the reflected paths.
  - MPI noise spectrum spreads to higher frequencies due to large signal modulation and the frequency chirp of modulated signal.
- MPI could have significant impact on PAM4 transmission performance
  - -32dB effective MPI could lead to 1 dB power penalty
  - Effective MPI larger than -30dB is intolerable in high-speed PAM4 transmission
- It is proposed to address the MPI issue in IEEE802.3dk
  - IEEE 802.3 and 100G Lambda MSA have tightened fiber connector return loss specifications from -26 dB to -35dB. However, this can not be applied to the legacy fiber links.
  - Even if the newly deployed links meet the -35dB specification, the return loss of fiber connectors in the field could deteriorate over time due to the elements of nature.
  - Is there a way to combat MPI noise from the transmission equipment perspective?

    For example, advanced signal processing techniques to mitigate MPI noise?

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Thanks