

Analytic Estimation of MPI Penalty with supporting experimental measurements

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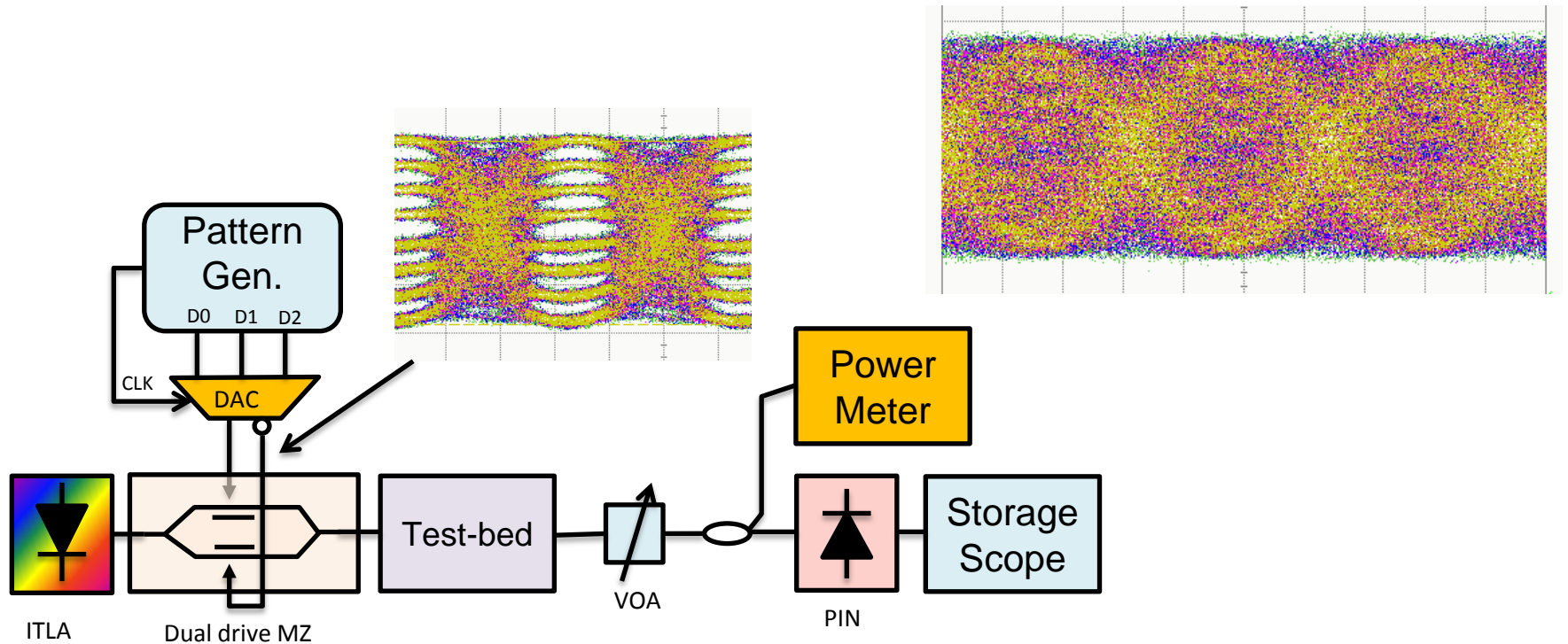
Based on Paper W1F.6, March 12th
2014, OFC 2014

Numerous presentations on MPI

- bhatt_01_0512_optx
- farhood_01_1112_optx
- Large range of MPI penalties cited
 - cole_3bs_02b_0914 suggest 1dB penalty for 2km application*
 - farhood_01_1112_optx suggests 0.65dB penalty for PAM4 based on $R_{ROSA}=R_{TOSA}=R_{Conn}=-35\text{dB}$ & 4 connectors
 - wen_3bs_01_0914 suggests high penalty for low MPI condition

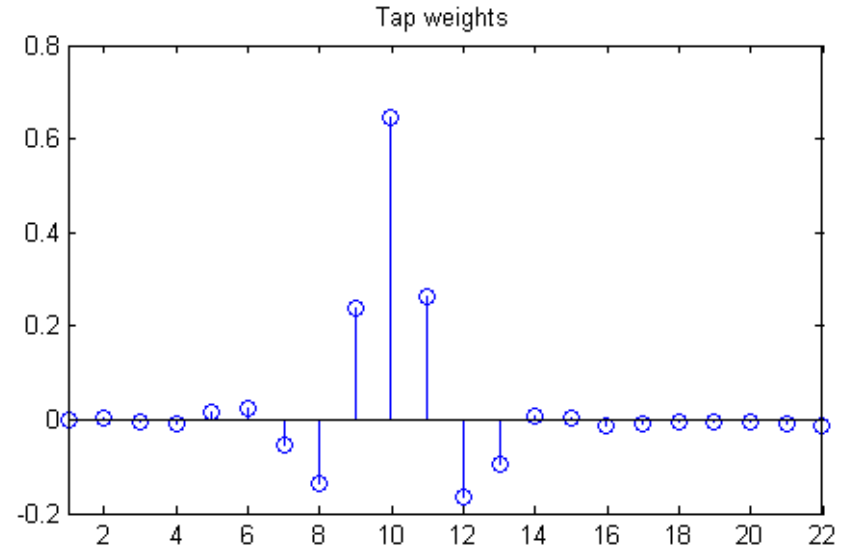
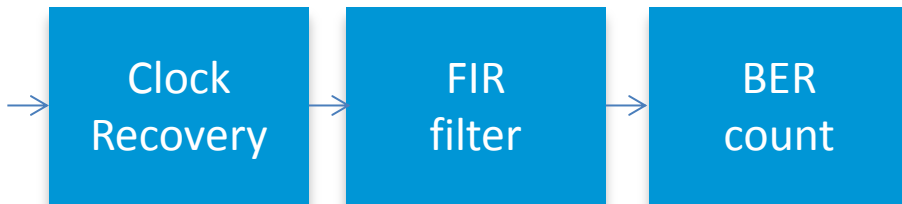
*Link reflection values not specified in presentation

Measurement Setup: PAM-8



- Optical eyes are not open
- Tx/Rx Noise / Laser RIN / Limited-bandwidth

Post-processing (Matlab)



- Clock recovery (re-sampling from oscilloscope sample rate to 2 samples/ baud) + jitter removal.
- FIR filter
 - 22 taps spaced $T/2$

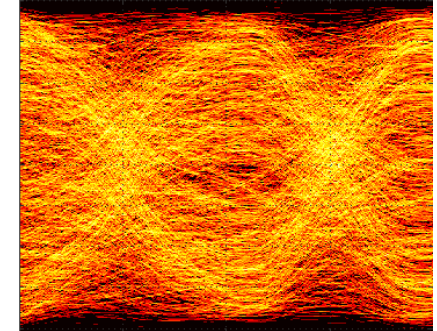
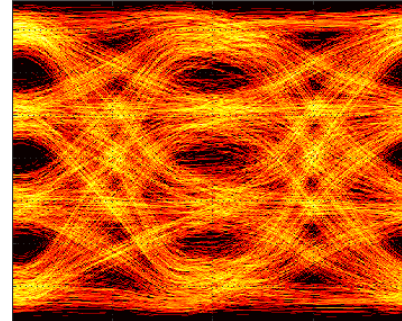
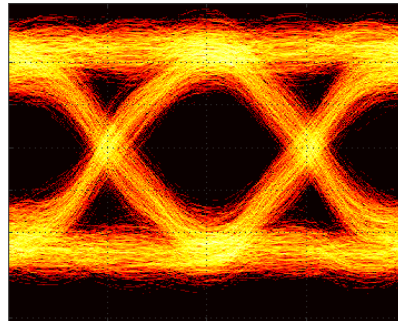
At Rx

PAM-2

PAM-4

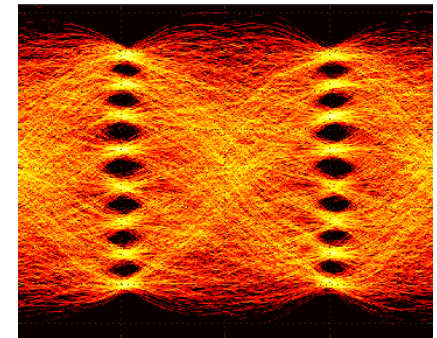
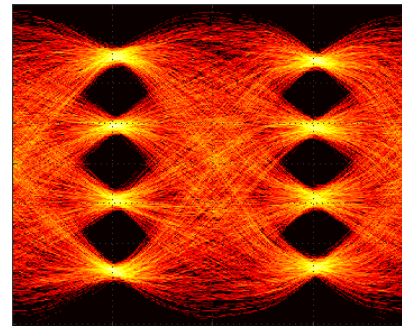
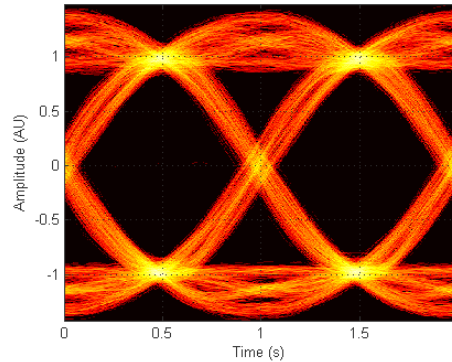
PAM-8

Before
FIR



Equalised Eye FIR only

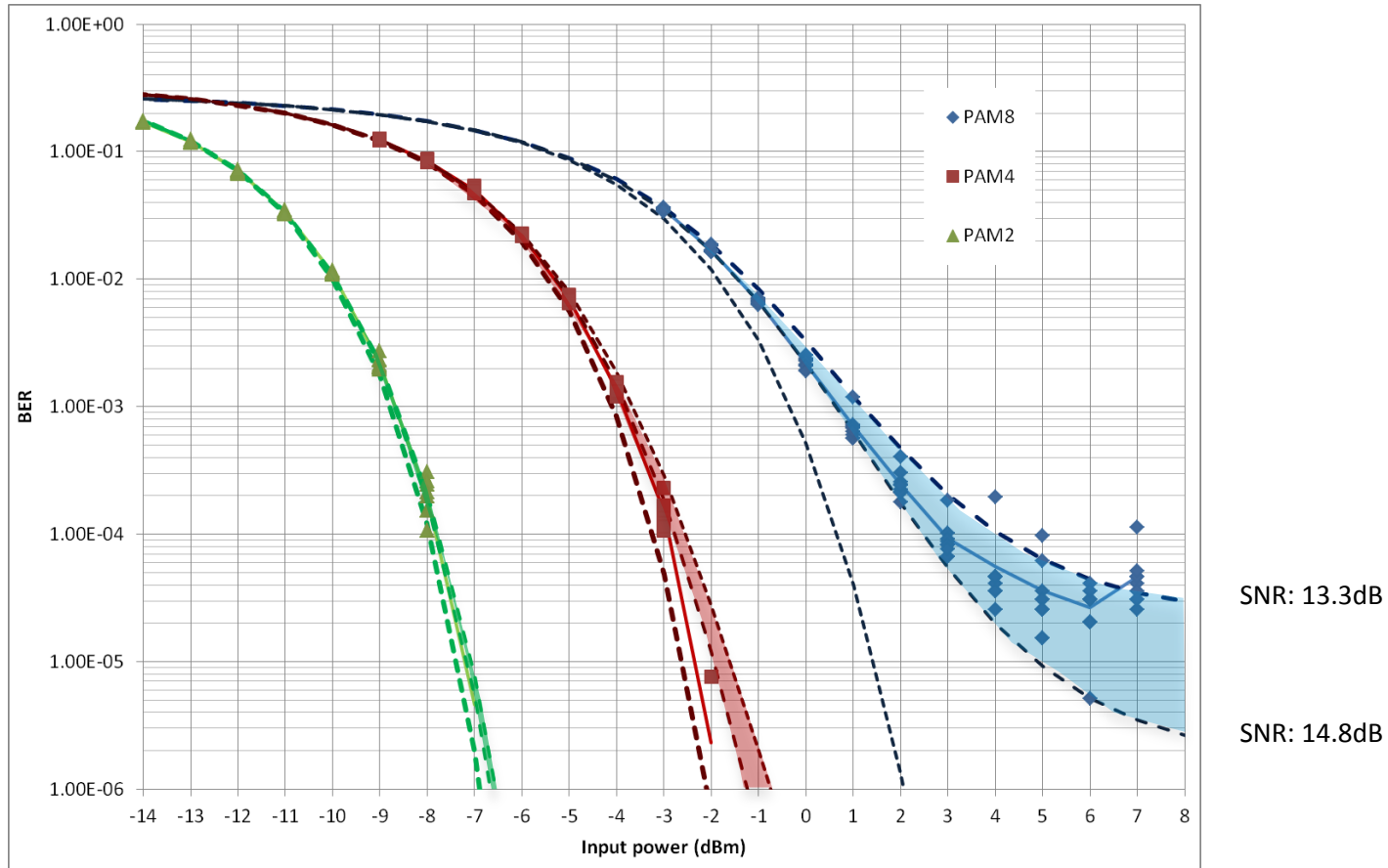
After
FIR



- FIR filter compensates for limited bandwidth and ISI

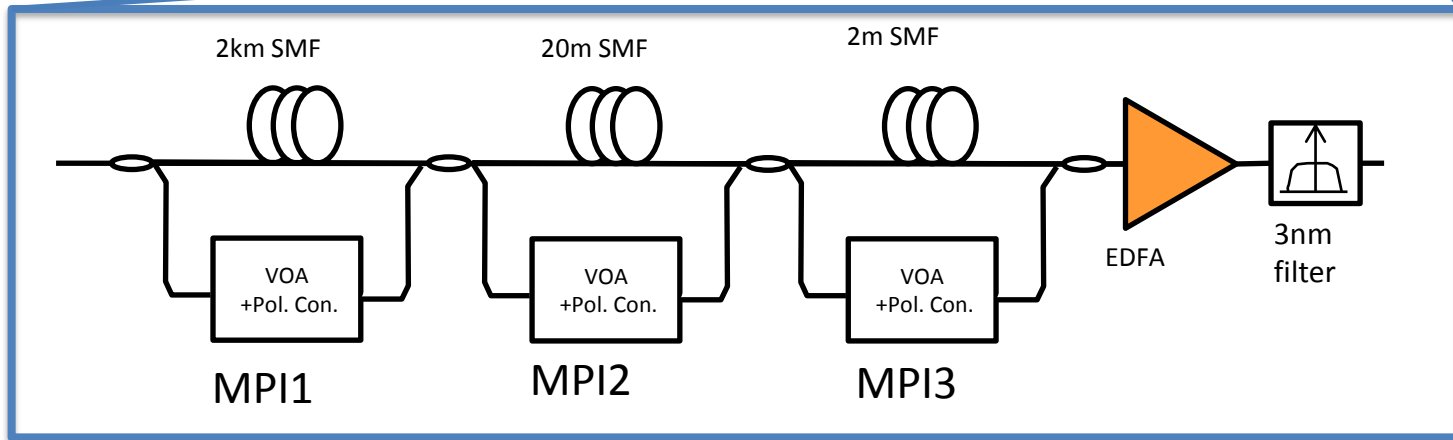
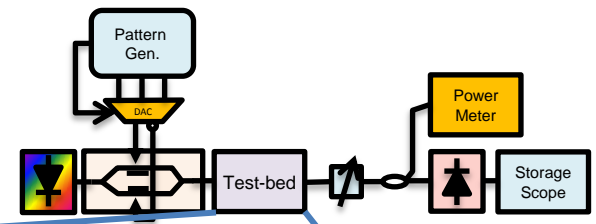
B2B Waterfall Curves

Solid lines = average of measurements
Dashed lines = Analytical simulation



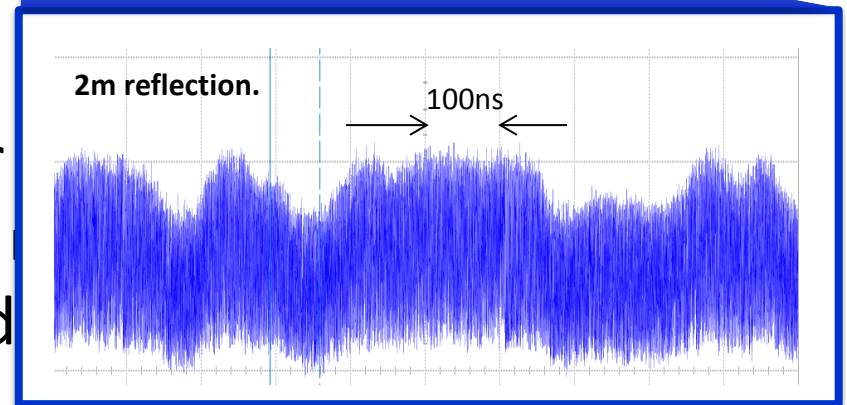
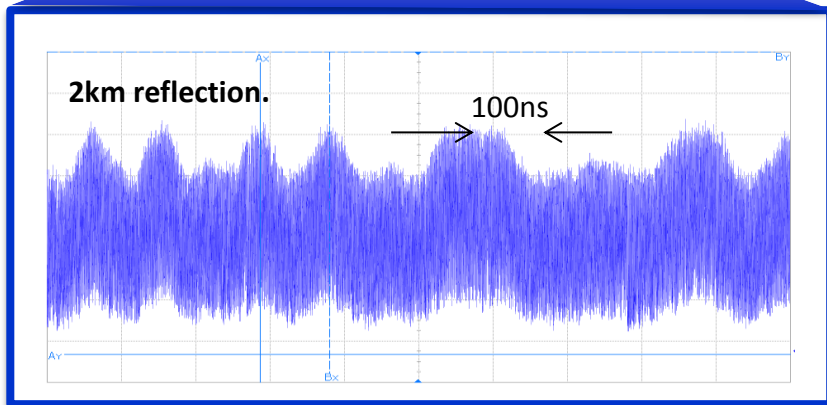
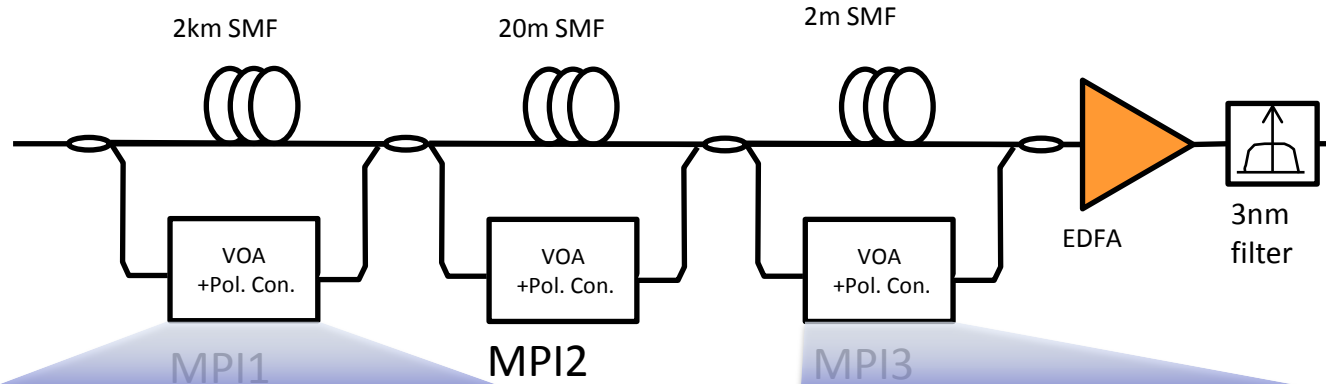
- Electrical noise at TX can limit performance
- Sensitivity can be improved by linear PIN-TIA rather than PIN diode.

Multiple interference paths



- Interferometer based – similar to [pepeljugoski 2 0301](#) setup
- EDFA to compensate power loss - no effect of signal-ASE beat noise
- Total MPI evenly distributed between interferometers
 - 2km only: $MPI1 = MPI$
 - 2km + 20m $MPI1 = MPI2 = MPI+3dB$
 - 2km + 20m + 2m: $MPI1 = MPI2 = MPI3 = MPI+4.77dB$

Multiple interference paths

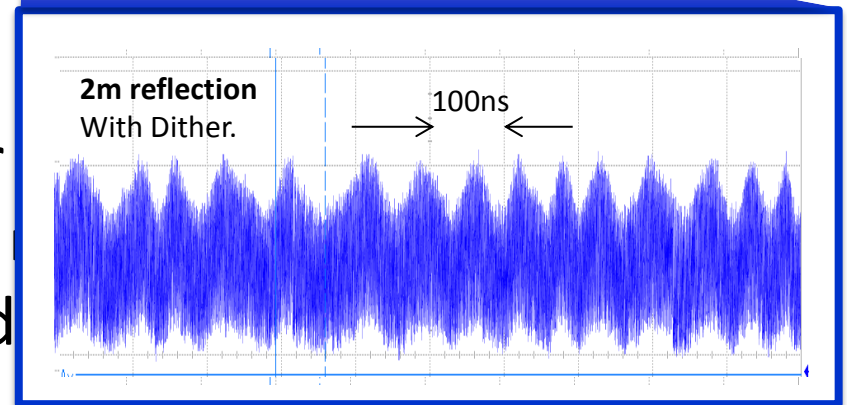
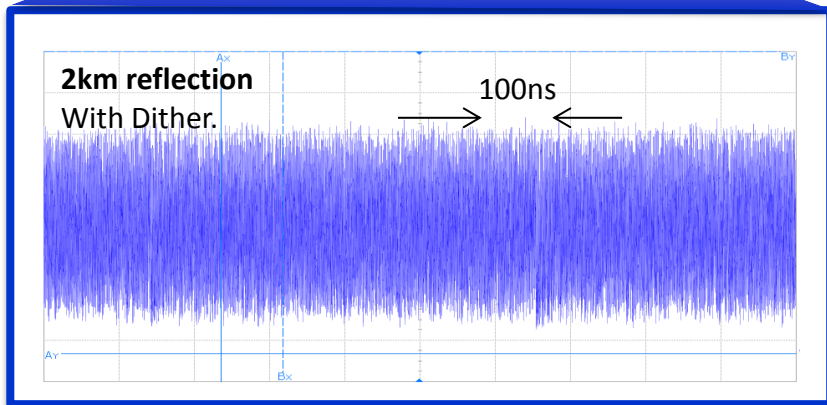
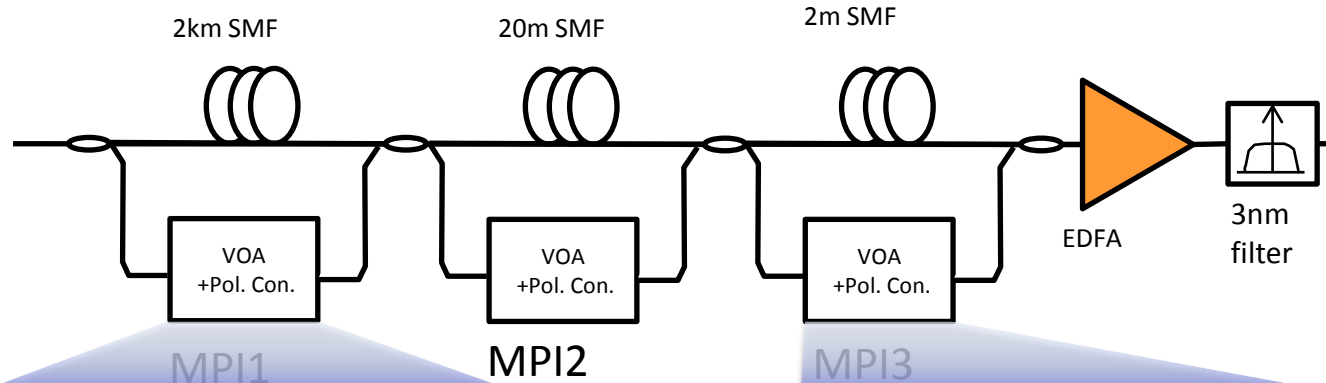


Power
beat
out

- 2km Only.
- 2km + 20m
- 2km + 20m + 2m:
MPI+4.77dB

- MPI1 = MPI2
- MPI1 = MPI2 = MPI3+3dB
- MPI1 = MPI2 = MPI3 =

Multiple interference paths

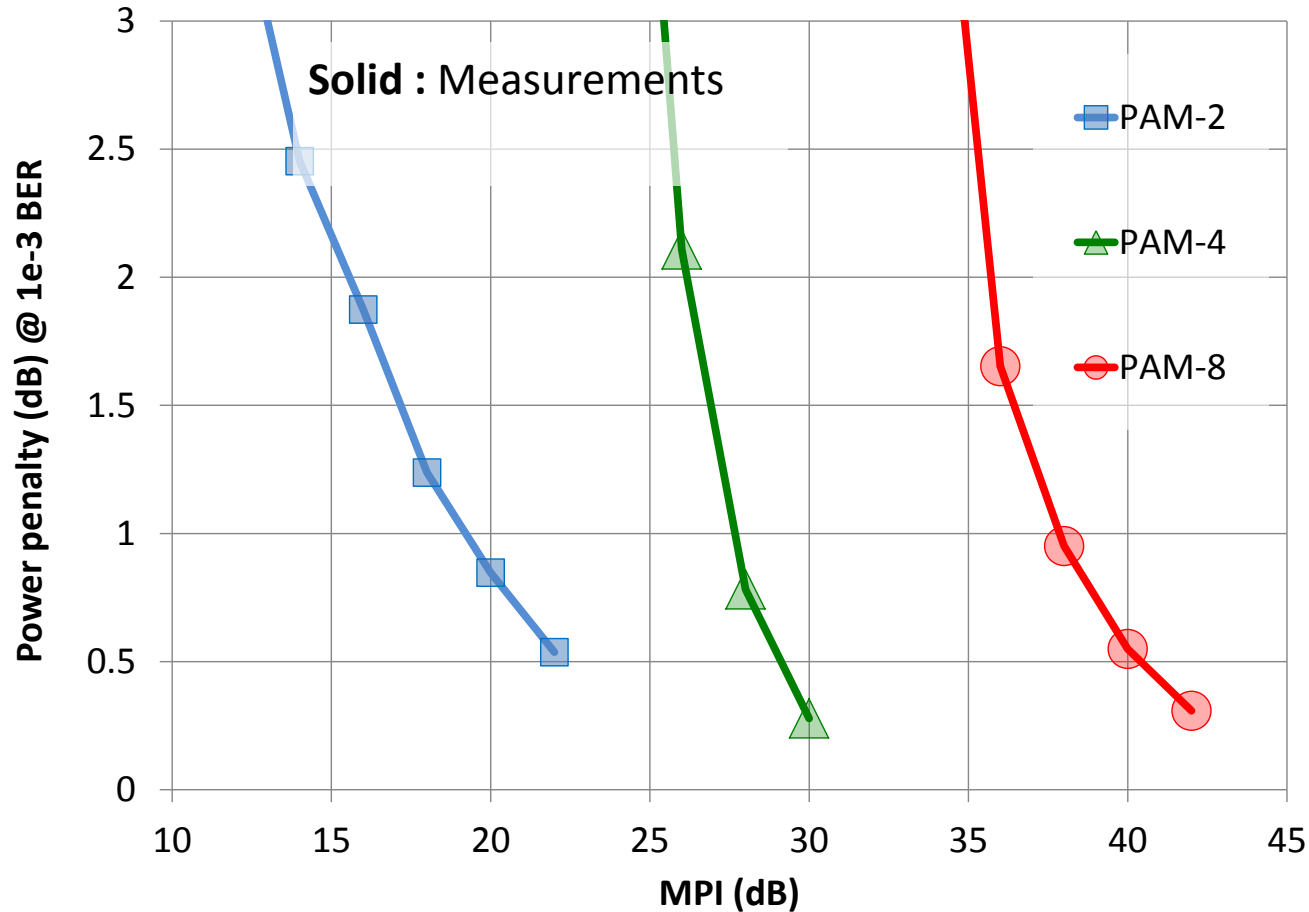


Power
beat
output

- 2km Only.
- 2km + 20m
- 2km + 20m + 2m:
MPI+4.77dB

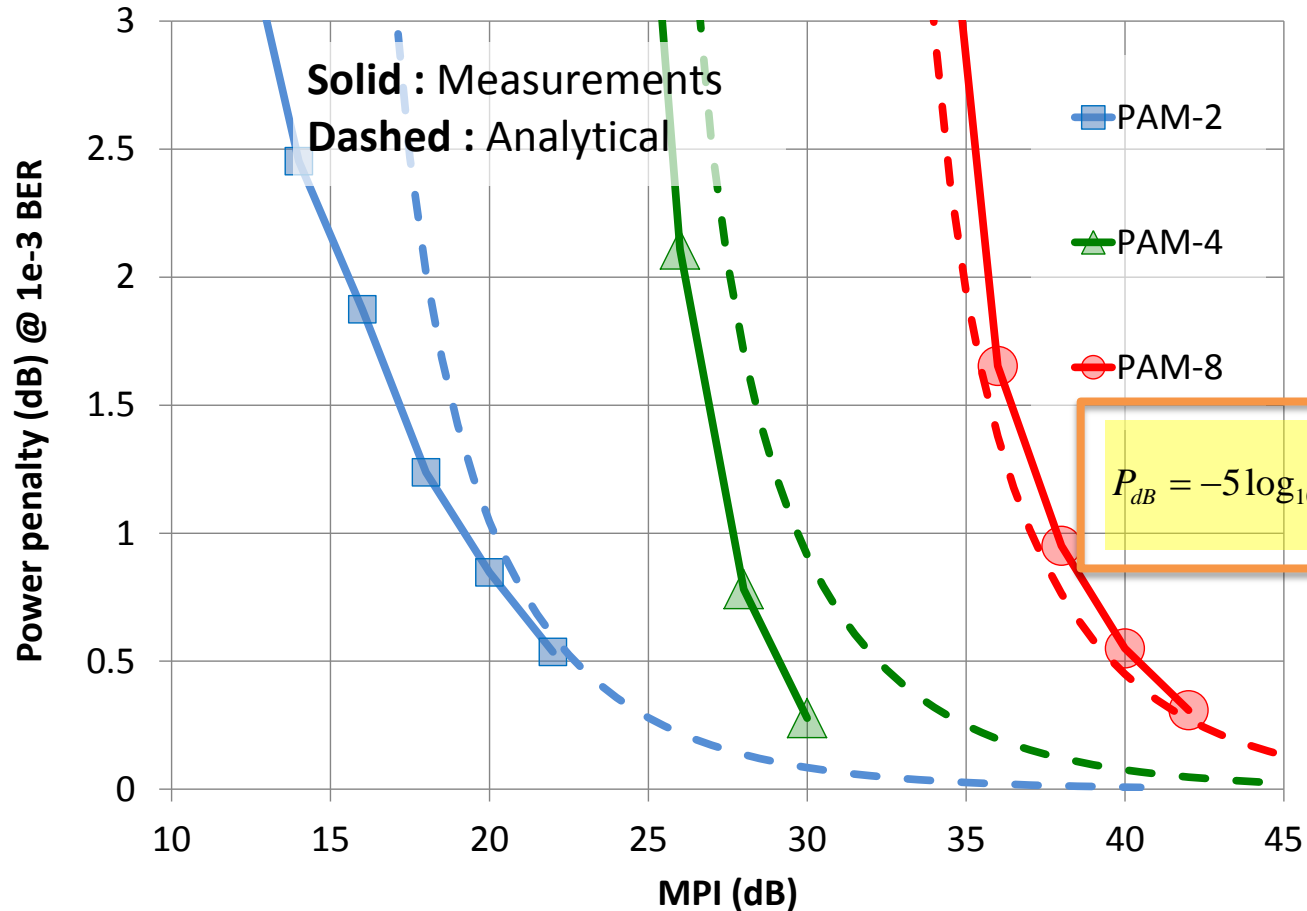
- MPI1 = MPI2
- MPI1 = MPI2 = MPI3+3dB
- MPI1 = MPI2 = MPI3 =

Multi-path interference : 2km fibre



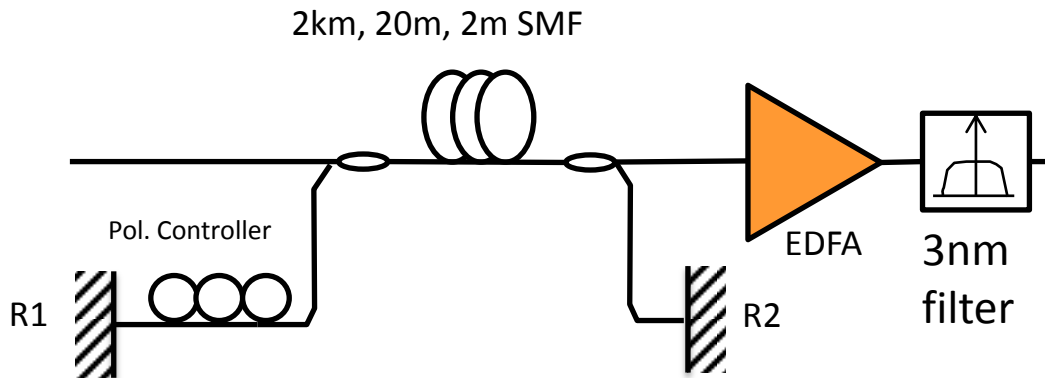
- Tolerance of PAM-4 is ~10 dB worse than PAM-2
- Tolerance of PAM-8 is ~18 dB worse than PAM-2
- Dashed lines are analytical formula assuming Gaussian interference

Multi-path interference : 2km fibre



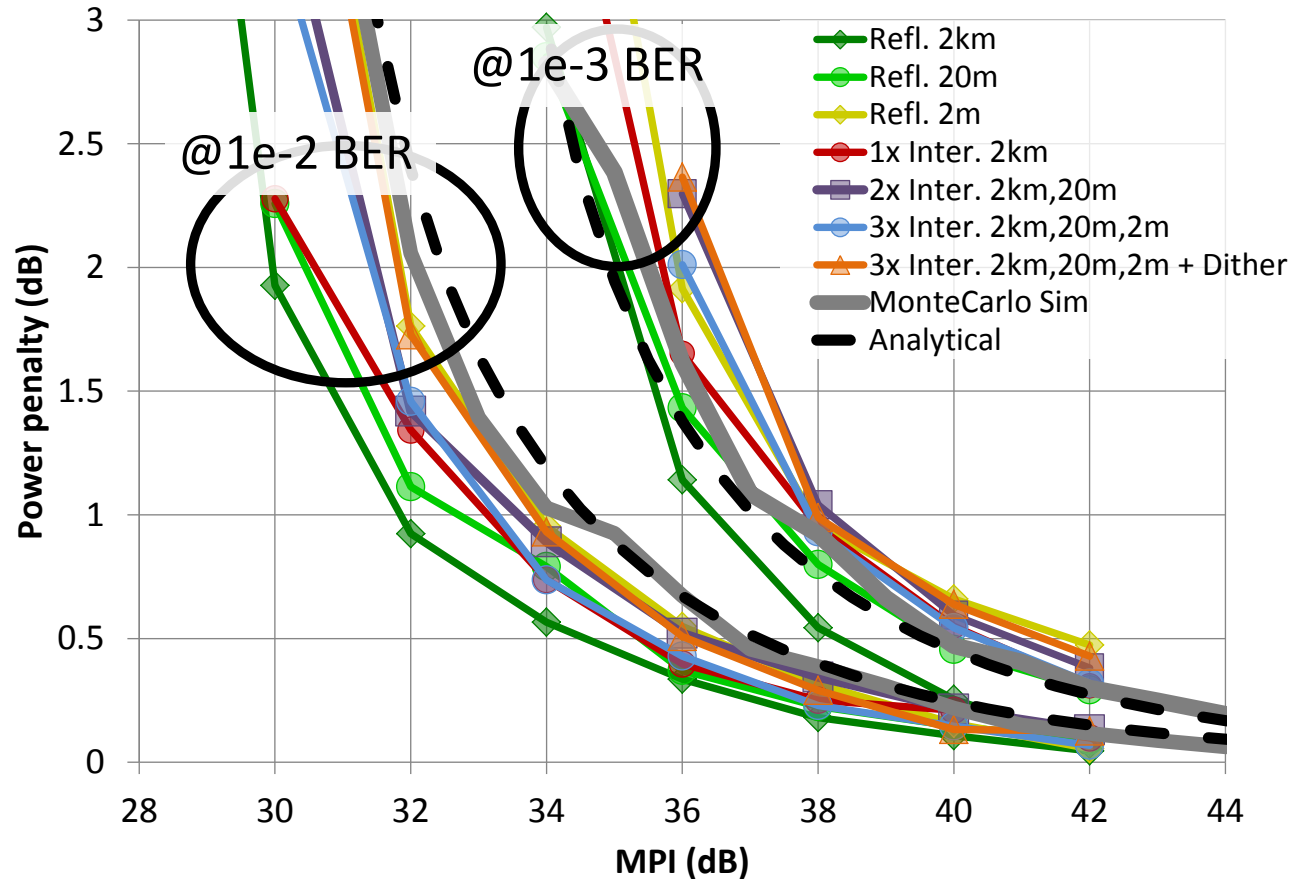
- Tolerance of PAM-4 is ~10 dB worse than PAM-2
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Single reflector pair



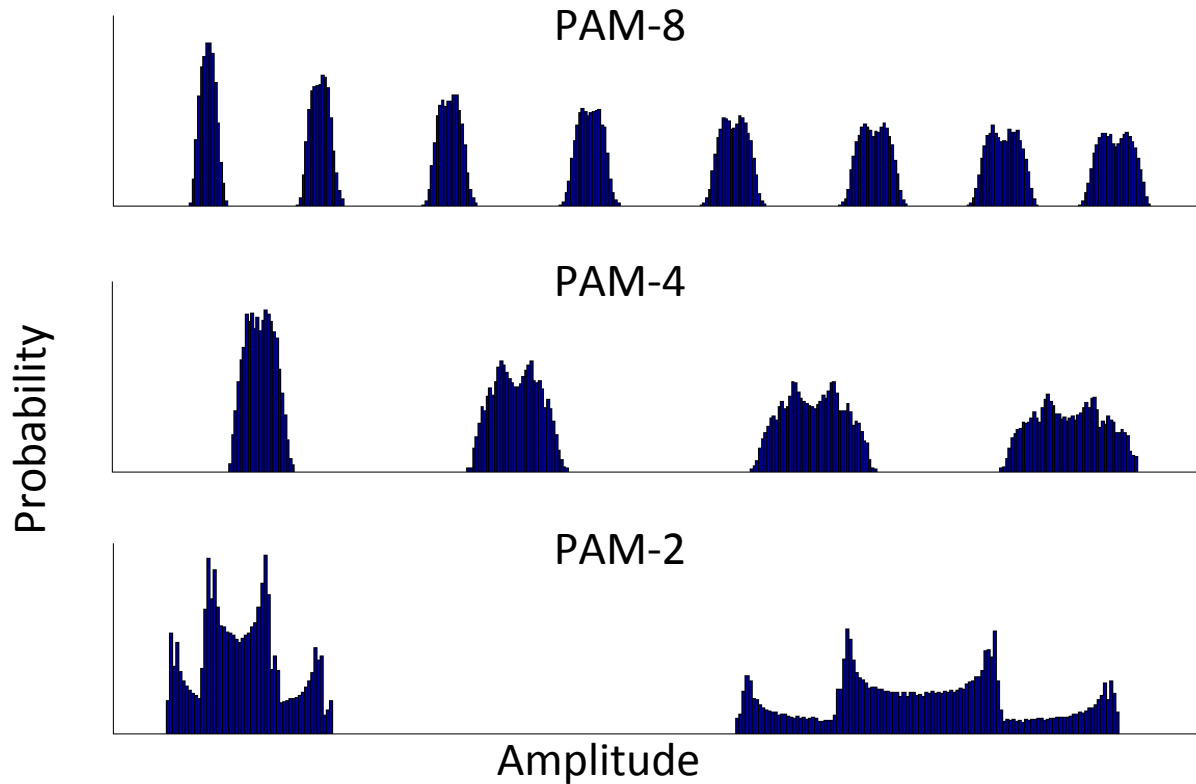
- Variable reflectors (R1,R2) were placed on either side of SMF fiber (2m, 20m, or 2km) to emulate the influence of MPI caused by a pair of poor connectors
- Polarization at R1 was varied to maximize the interference at the receiver
- MPI was defined as the sum of reflectances R1 and R2 (in dB)

MPI penalty : PAM-8



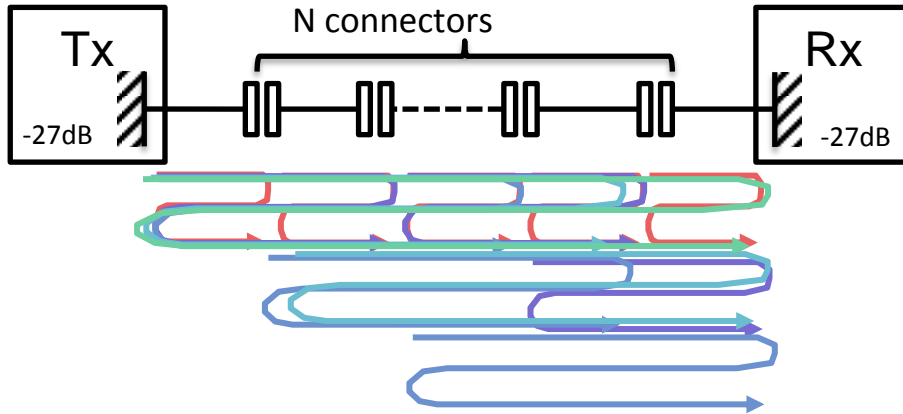
- Penalty dependent upon BER
 - Better treated as additional noise source rather than eye-closure penalty
- Good agreement with Gaussian model

Multi-path interference

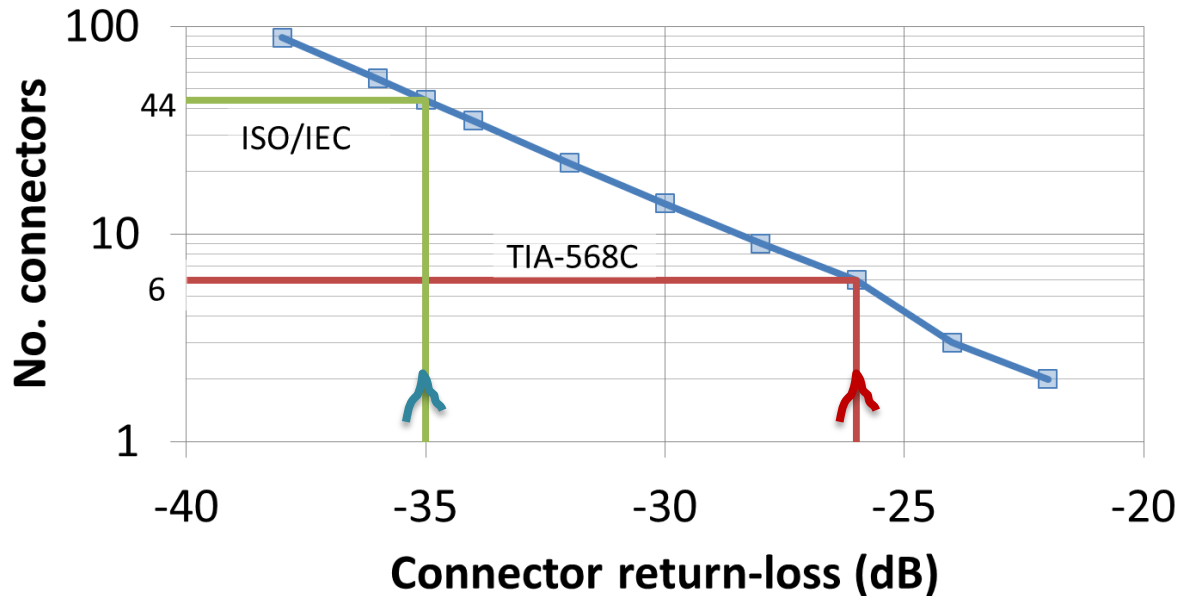


- Tendency towards Gaussian
- Extinction ratio / Multiple levels
- Convolution with thermal noise at high BER

Multi-path interference

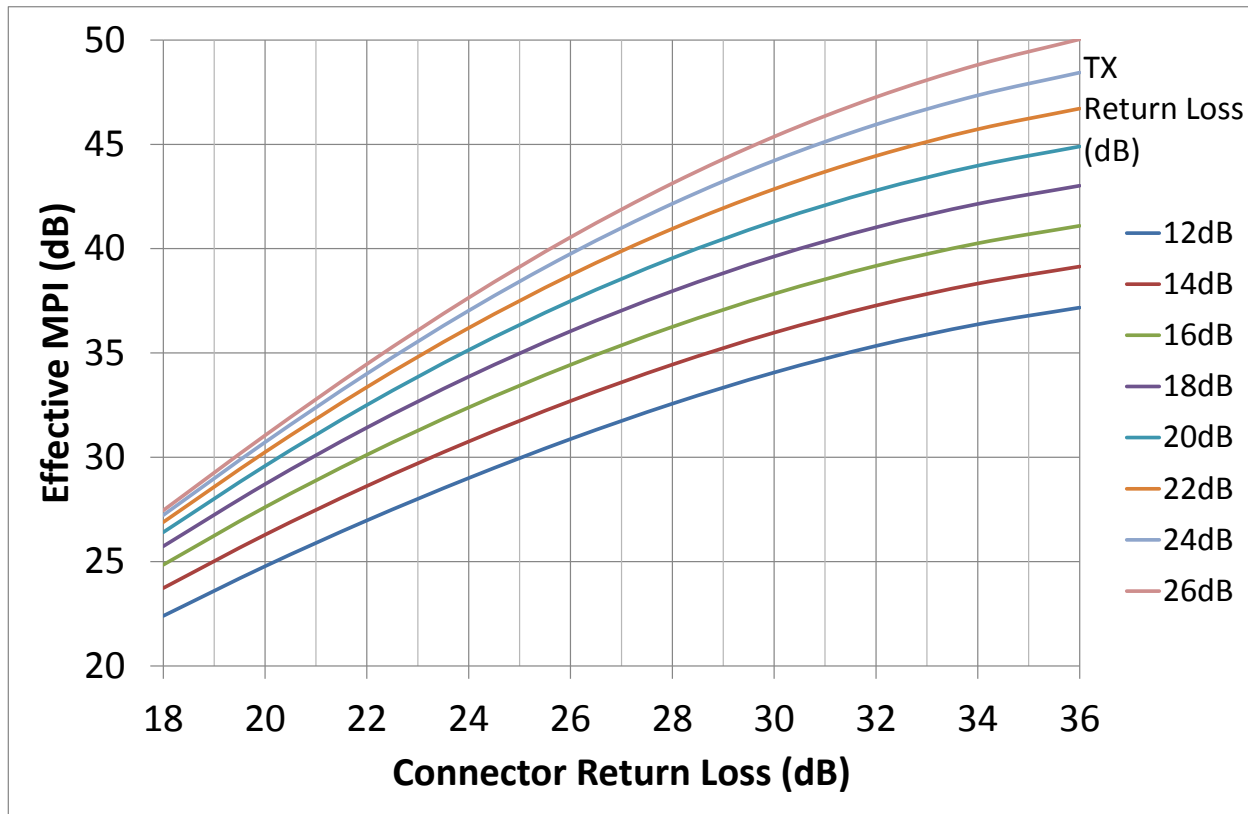
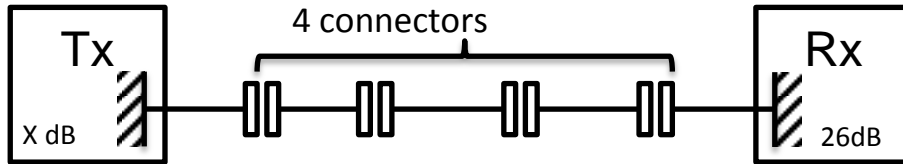


$$MPI_{Total} = \sum_{i=1}^M \sum_{j=i+1}^M R_i R_j$$



- If 1dB MPI penalty for PAM8, then 38 dB total MPI is allowed

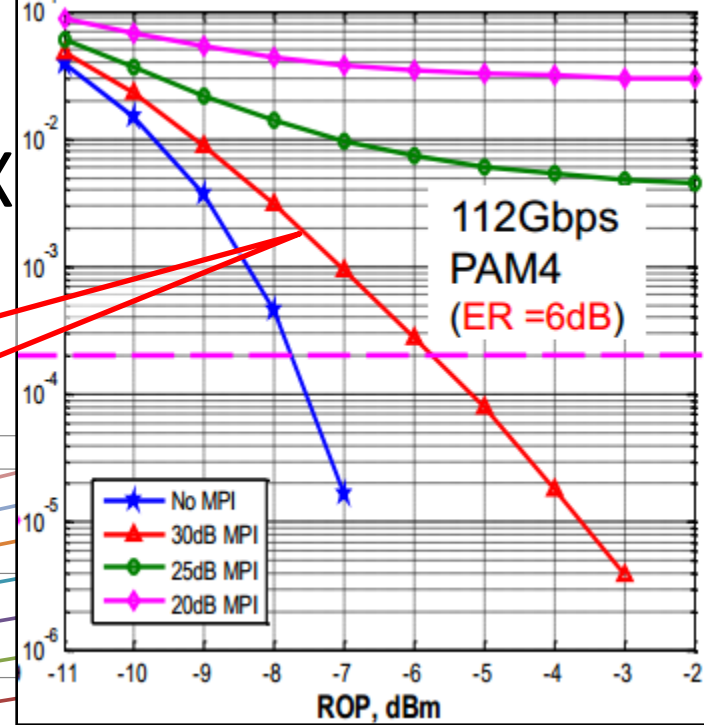
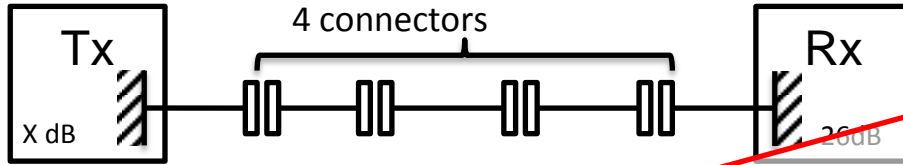
Multi-path interference : TX Return Loss



- 4 connectors w/ RX fixed at 26dB RL

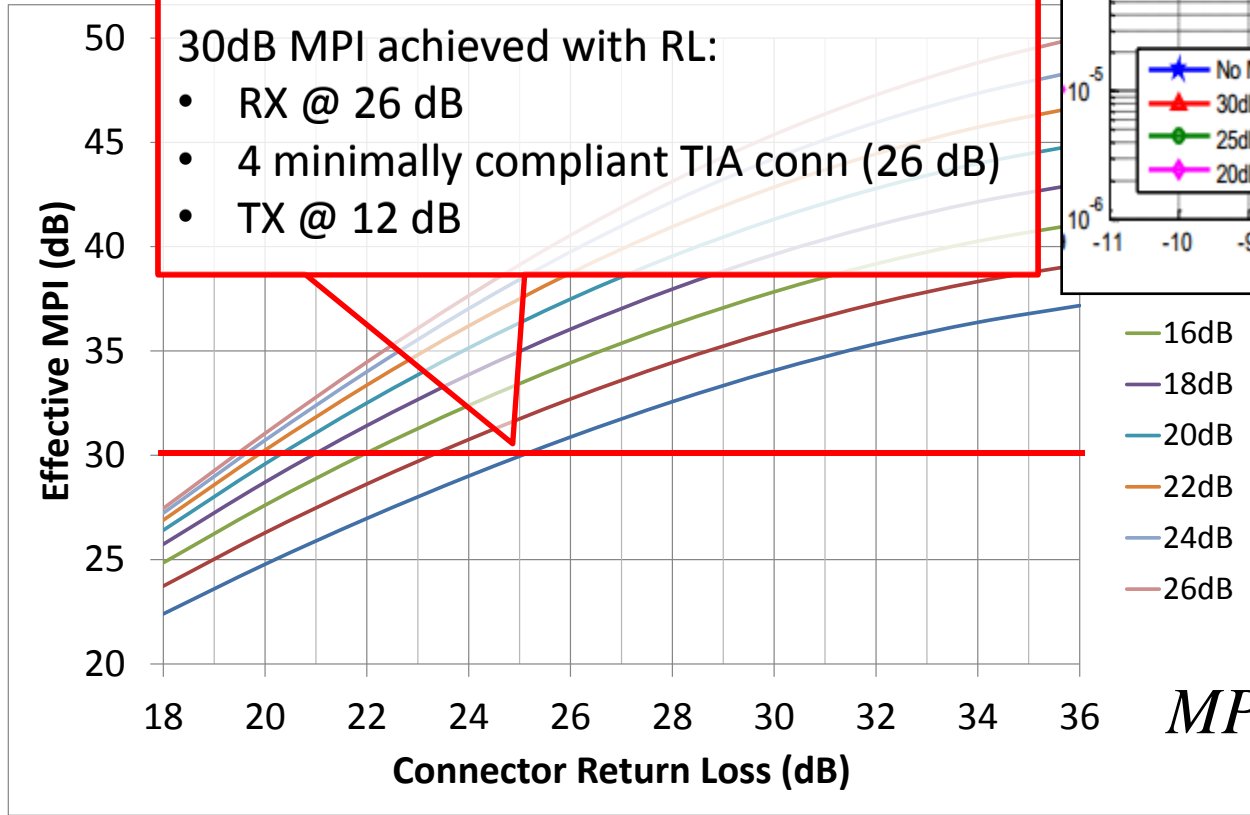
$$MPI_{Total} = \sum_{i=1}^M \sum_{j=i+1}^M R_i R_j$$

Multi-path interference : TX



30dB MPI achieved with RL:

- RX @ 26 dB
- 4 minimally compliant TIA conn (26 dB)
- TX @ 12 dB



Excerpt from
wen_3bs_01_0914

$$MPI_{Total} = \sum_{i=1}^M \sum_{j=i+1}^M R_i R_j$$

- 4 minimally TIA-568C compliant connectors w/ RX fixed at 26dB RL
- With TX RL at 20dB, MPI is ~37dB

Conclusions

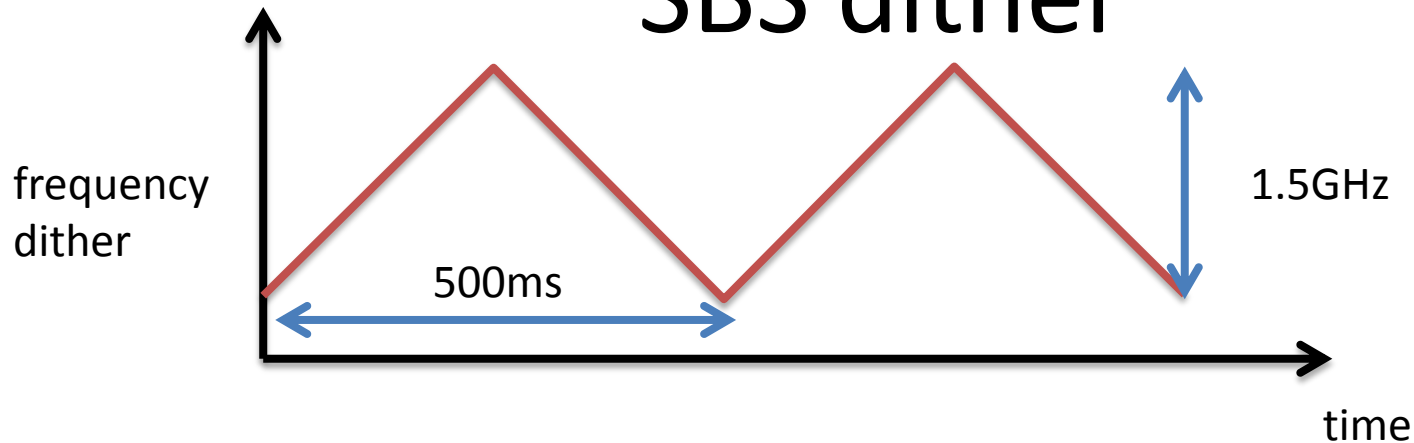
- Impact of reflection induced MPI was measured for 32Gbaud PAM-2,4,8
- In contrast to previous PAM-2 measurements at high SNR, we see good agreement with a Gaussian model at low SNR.
- 4 connector system with moderate RL specification results in MPI values >35 dB which provide low penalty

Future Work may include:

- Effect of OMA or r_e included in MPI term in analytical formula
- If 802.3bs FEC limits indicate moderate SNR, then re-evaluation of the Gaussian model may be warranted

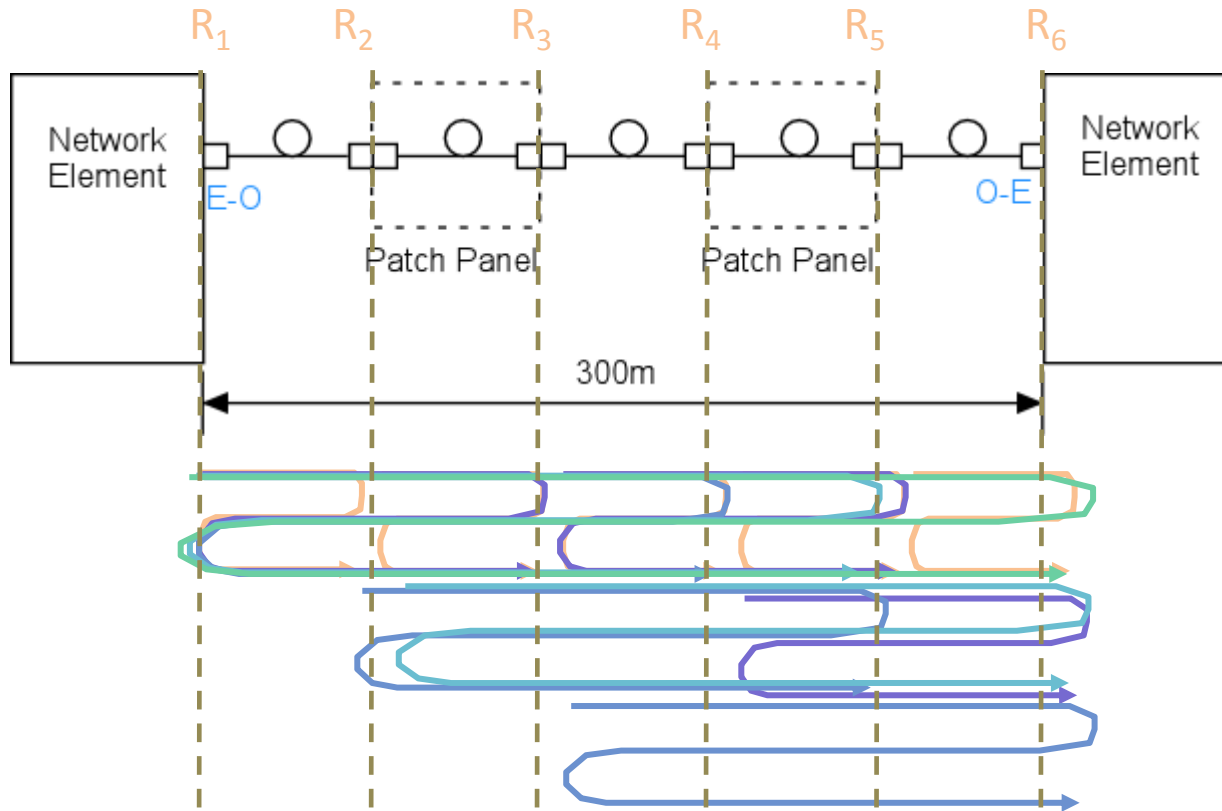
BACKUP

SBS dither



- Idea: Use SBS dither to add a frequency variation so that the phase varies continuously
- 1kHz dither @1.5GHz

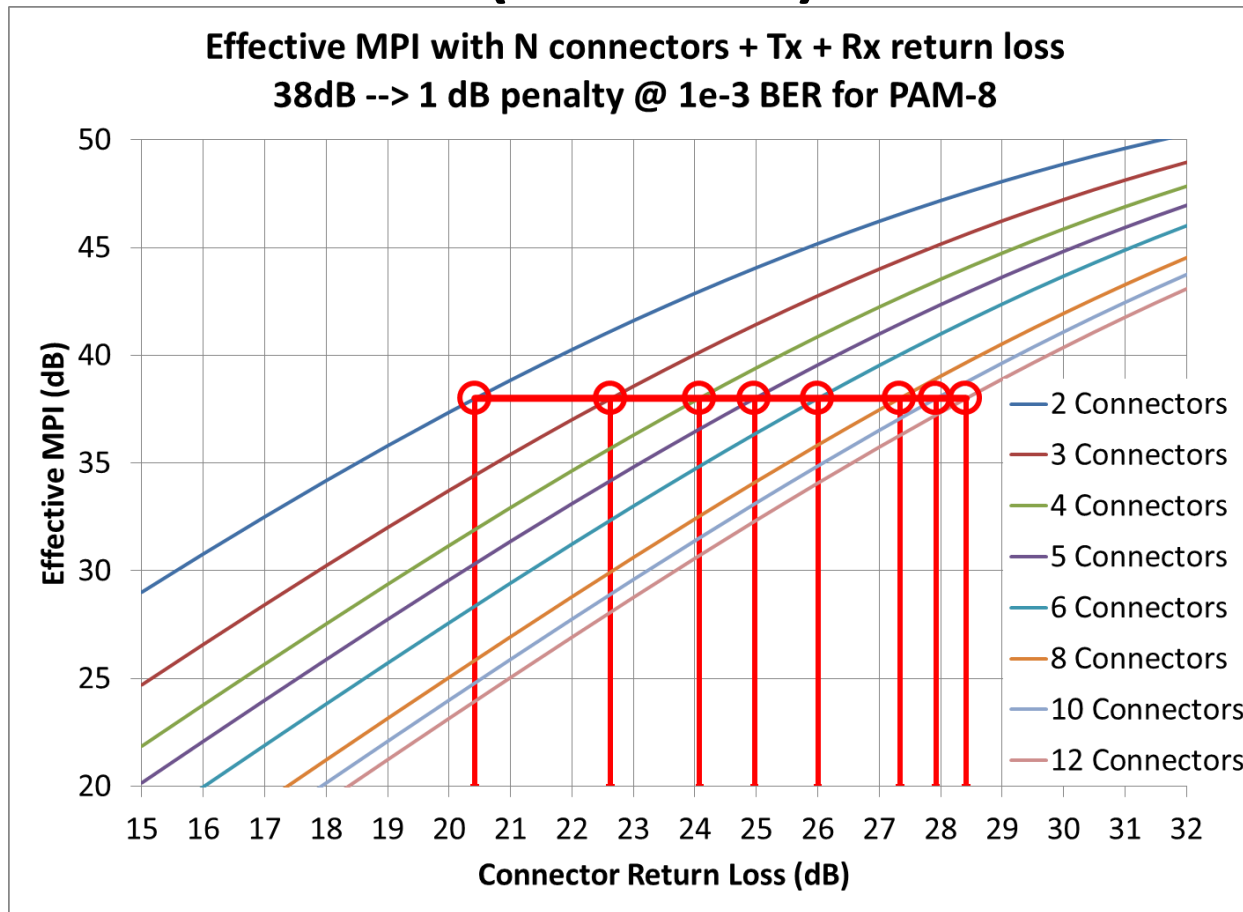
Multiple reflections



$$R_{ij} = \alpha_{ij} \sqrt{R_i R_j} \vec{p}(t) \cdot \vec{p}_{ij}(t - \tau_{ij})$$

$$\mathbf{R}_{Total} = \begin{pmatrix} 0 & R_{1,2} & R_{1,3} & \dots & R_{1,N} \\ 0 & 0 & R_{2,3} & \dots & R_{2,N} \\ 0 & 0 & 0 & \dots & \dots \\ 0 & 0 & 0 & 0 & R_{(N-1),N} \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

TX + RX (-27dB) + N connectors

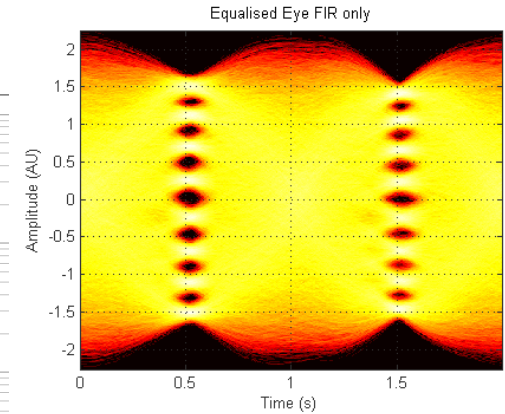
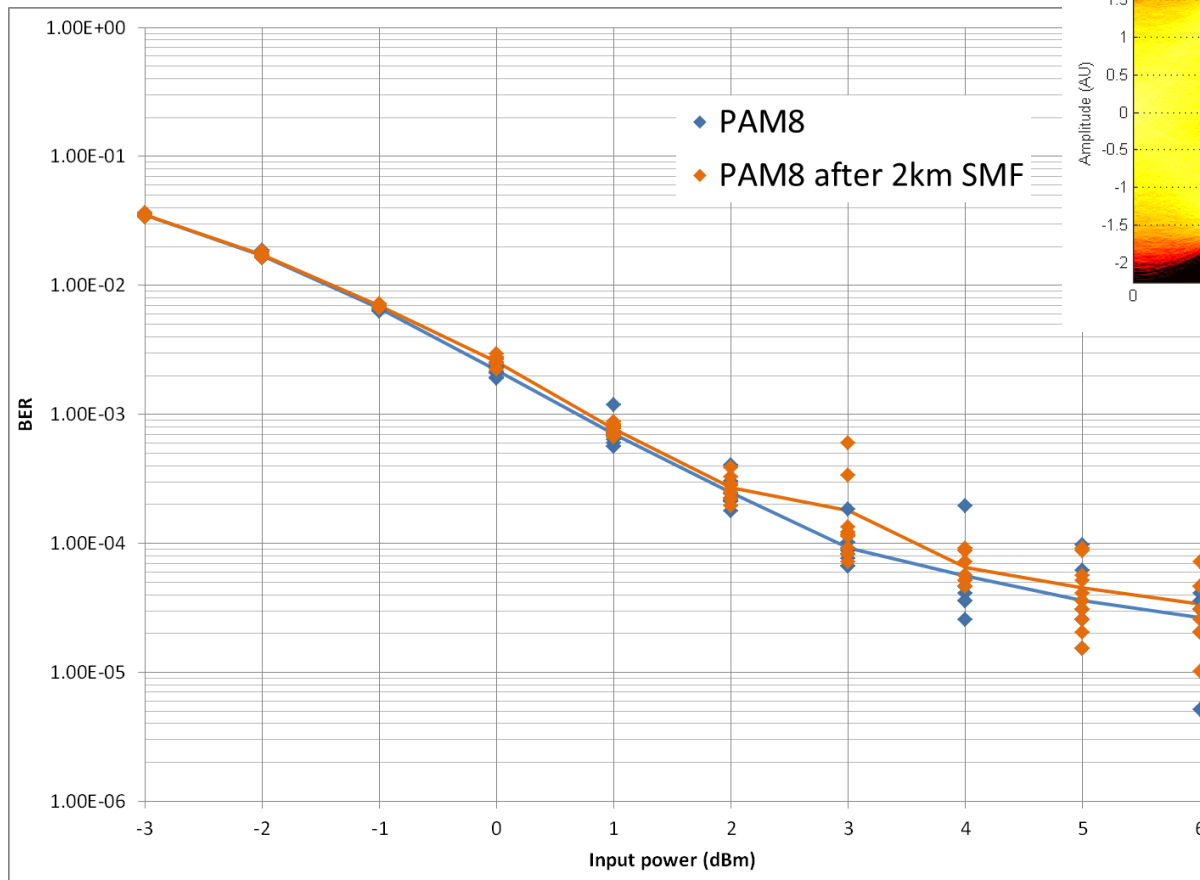


@38dB MPI:

No. Connectors	Connector return loss (dB)
2	20.42
3	22.63
4	24.08
5	24.97
6	26.00
8	27.34
10	27.92
12	28.42

- Different no. connectors. Tx and Rx return loss is fixed at -27 dB
- 38 dB MPI gives 1dB power penalty @ 1e-3 BER
- For 4 connectors + Tx + Rx → 24 dB connector return loss

After 2km SMF



Eye after 2km
(65536 symbols)

- Negligible impact of 2km SMF @1550nm
 - Only affect of chromatic dispersion
 - One would expect to see a small affect