

# Feasibility study of 1.6T FR4 PAM4 transceivers

IEEE 802.3 New Ethernet Applications Ad Hoc Ethernet for AI Assessment

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# 448Gb/s PAM4 Rx sensitivity

1.6T FR4 needs an improvement of ~2dB

## Path to 448Gb/s per lane

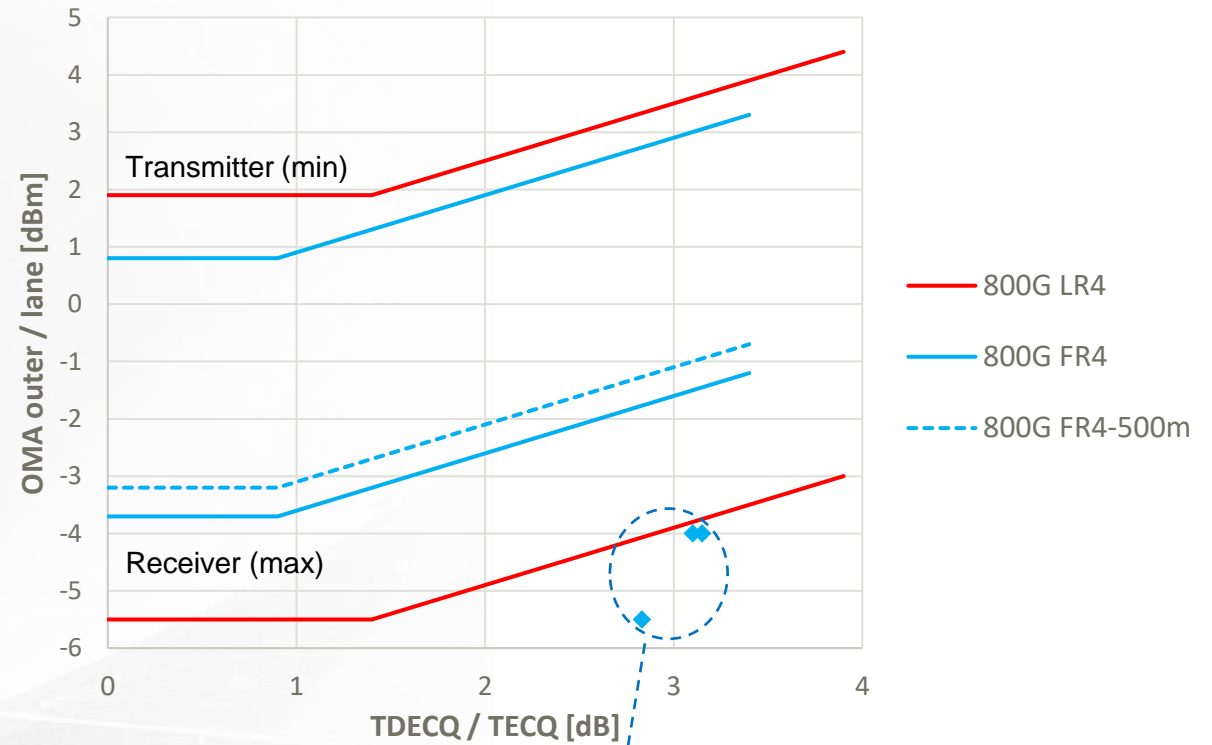
- Rx sensitivity deteriorates by ~ 2dB vs. 224Gb/s  
→ 1.5dB theory, ~0.5dB implementation penalty

## Options to increase the link budget

- Higher laser power ⇔ FWM analysis necessary
- Stronger FEC ⇔ Latency, power trade-offs
- Higher Rx sensitivity ⇔ Better PDs, Rx-SOA

## This contribution will analyze

- CD tolerance, target grid, maximum distance
- FWM tolerance of higher laser power
- Rx-SOA for higher sensitivity



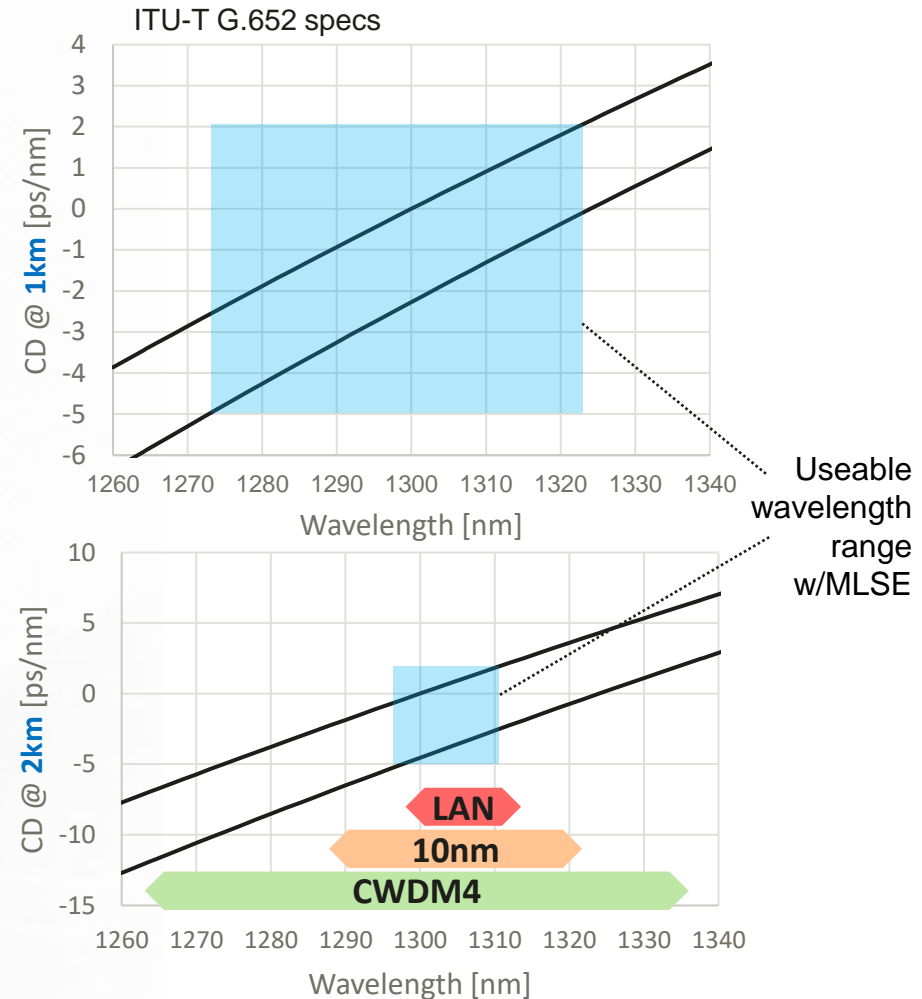
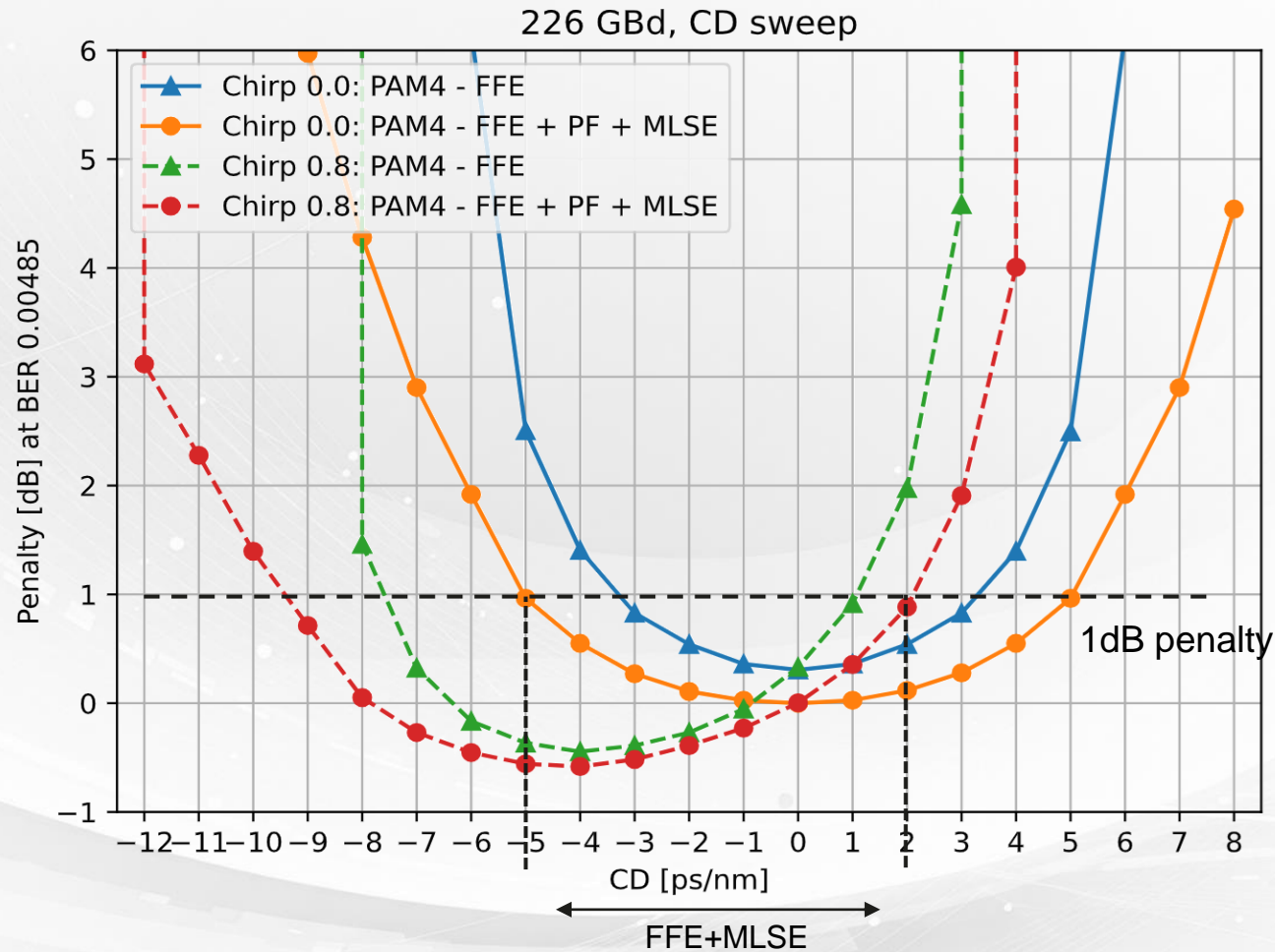
Published results of  
manufactured modules

# CD & wavelength grid



# 448Gb/s PAM4 CD tolerance & grid

FR4 1km distance possible in a 10nm grid



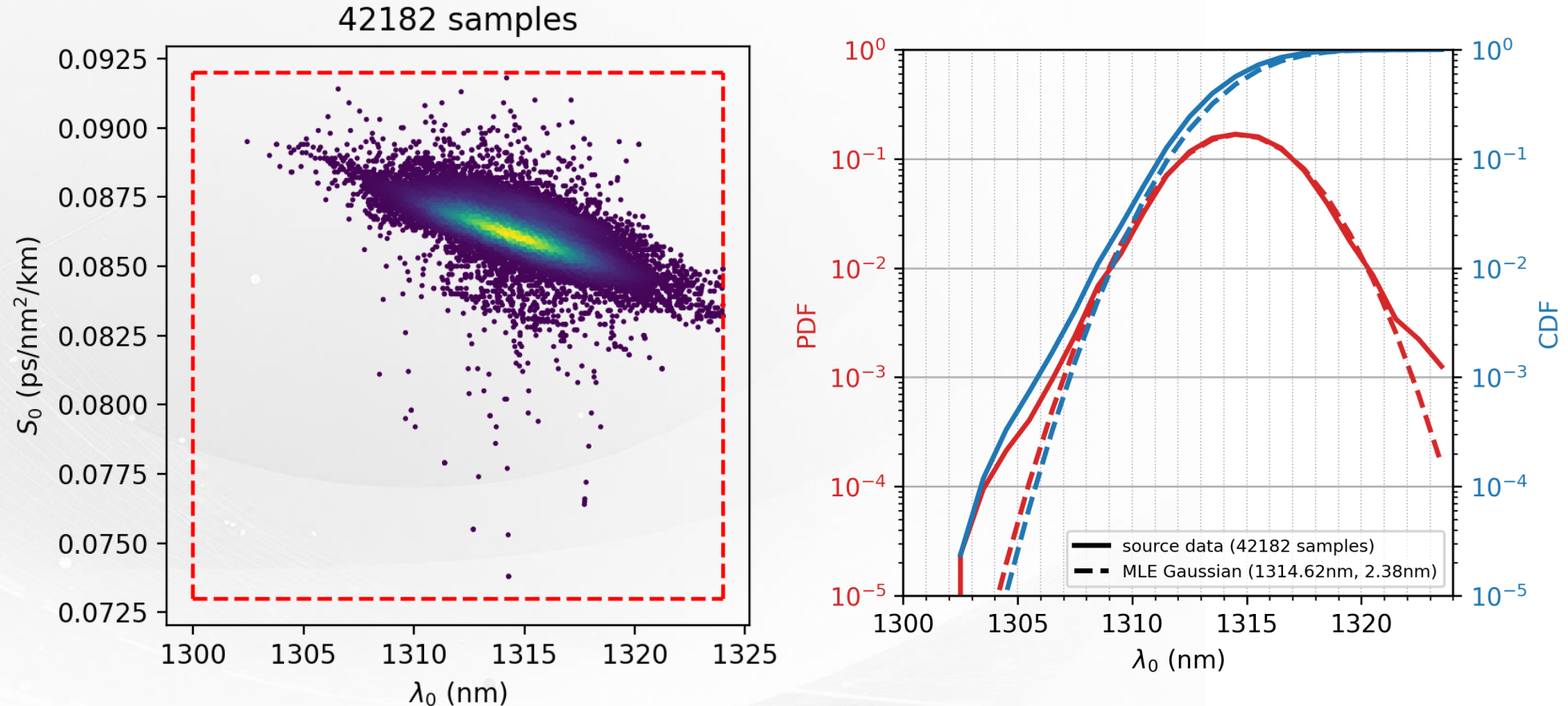
Chirp management or optical dispersion compensation can extend the reach of the FR4

**Tx: FWM tolerance**



# SSMF's ZDW Distribution

Modern (Bend-Insensitive) fiber allows more realistic modeling

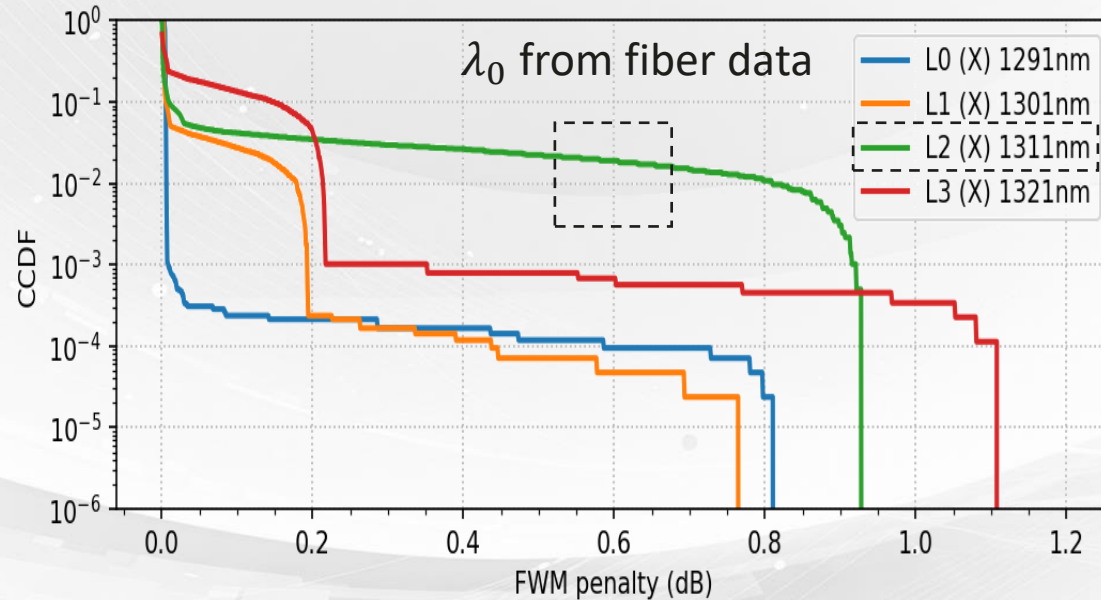


- Fiber characterization data (42K samples from single large vendor). The measured  $\lambda_0$  follows a near-Gaussian distribution centered at 1314.62 nm with a standard deviation of 2.38 nm, estimated by maximum likelihood.
- This ZDW distribution helps reduce the probability of getting the worst FWM effects.

# 1.6T FR4: FWM tolerance

FWM is limiting under worst case assumptions

- Maximum optical launch power per lane for 800G FR4 with 226G/lane: 4.9dBm
- Assessment of +1dBm / +2dBm increase per lane
- Baseline case: XXXX polarization alignment, DGD = 0ps



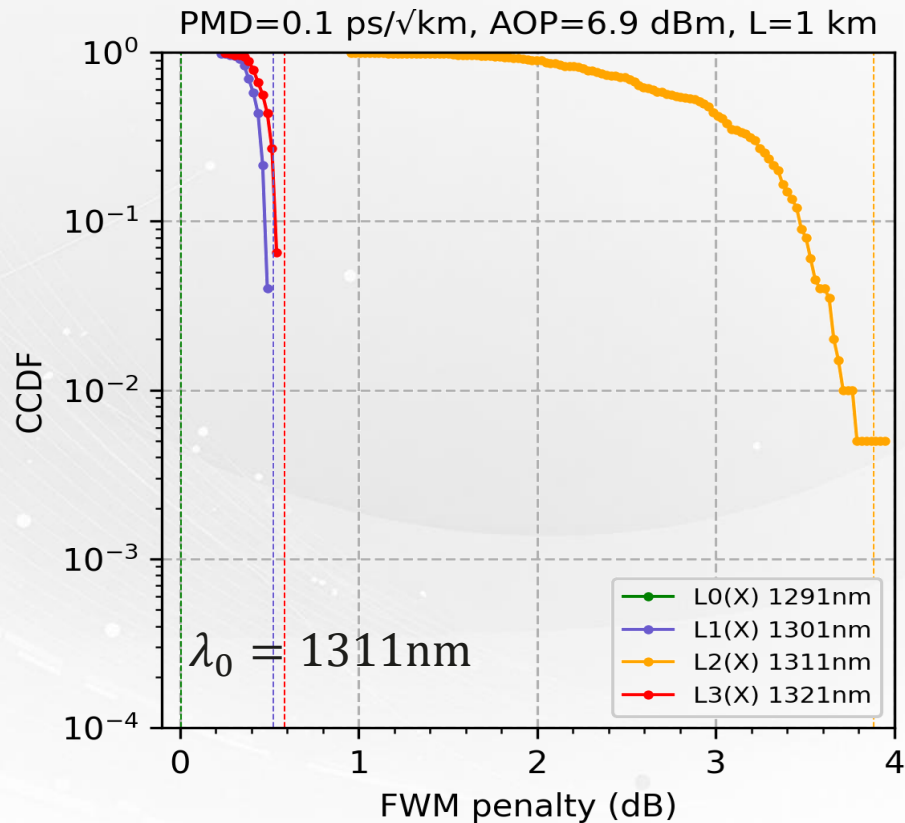
1.6Tb/s FR4 – 1km transmission

AOP [dBm]	Wavelength Lane	FWM penalty @ 1% [dB]
4.9	L0	0
	L1	0.19
	L2	<b>0.85</b>
	L3	0.22
5.9	L0	0.01
	L1	0.32
	L2	<b>1.71</b>
	L3	0.35
6.9	L0	0.01
	L1	<b>0.52</b>
	L2	<b>3.89</b>
	L3	<b>0.59</b>

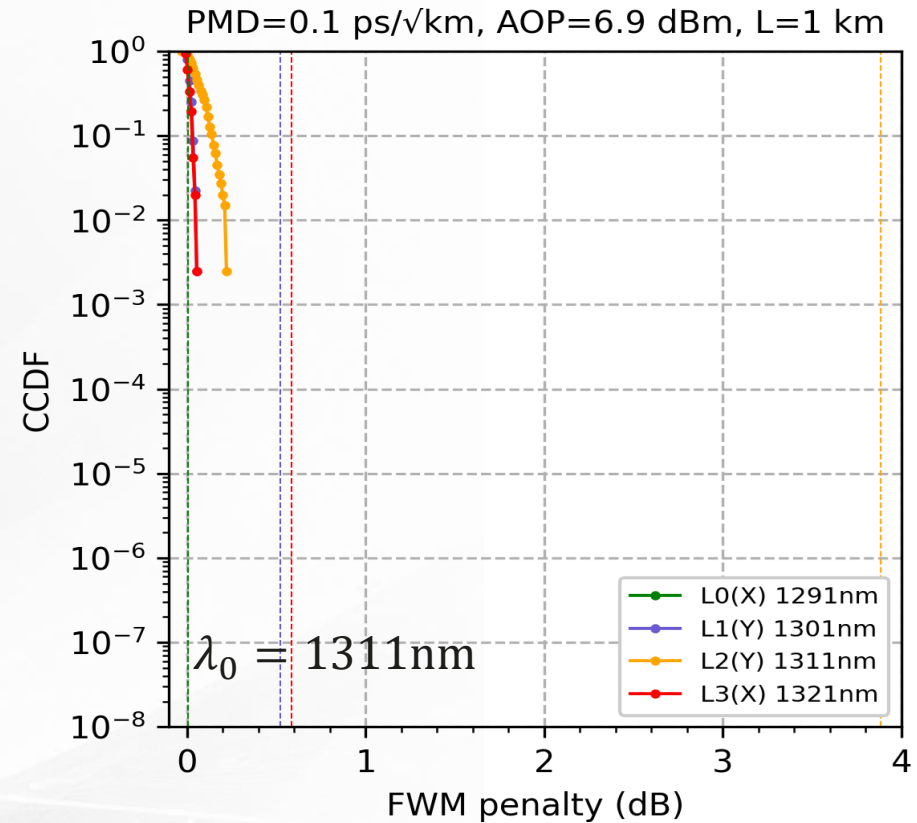
# FWM mitigation via XYYX polarization alignment

Higher laser power becomes uncritical

“XXXX” Polarization



“XYYX” Polarization



- Under moderate polarization-mode dispersion (PMD), the “XYYX” polarization arrangement reduces the FWM penalty by ~10 times as compared to the worse case of “XXXX”

# Rx sensitivity: SOA



# Rx-SOA feasibility for 1.6T FR4

SOA could address FR4-10nm targeting OCS 8dB loss use case

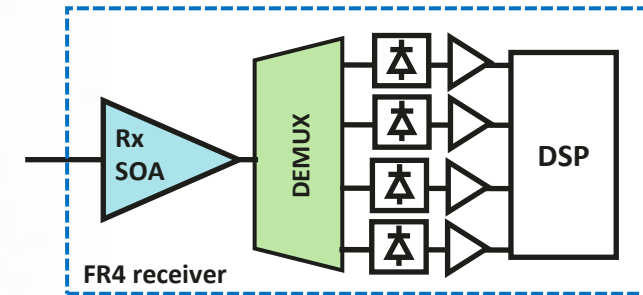
## Receiver semiconductor optical amplifier (SOA)

- Acceptable noise figure (NF) ~ 6dB
- Limited gain of ~ 10dB (relaxes saturation power requirement to operate in linear regime)
- Wider gain range for 10nm spacing
- Ability to regulate gain to avoid Rx overload and compensate PDG
- Sufficiently low polarization dependent gain (PDG) of <3dB (see penalty curve on the right)
  - 35-40nm gain bandwidth for lower PDG are feasible (10nm grid)
  - >70nm for uncooled CWDM4 are possible for single polarization amplification and would require a polarization diversity amplifier at the Rx, which is not desired

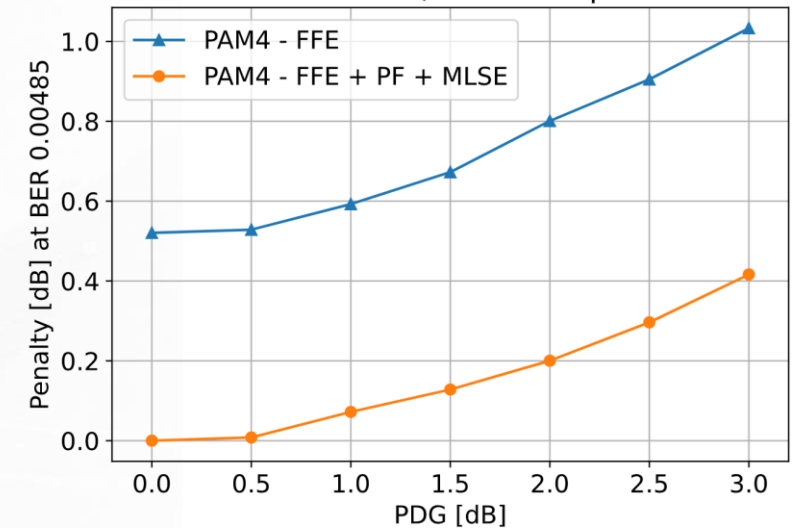
## Cost

- We believe that a Rx-SOA with the above specifications for a **FR4-10nm** use case can be a high yield component, evidenced by fabricated devices

Shared SOA for 4λ



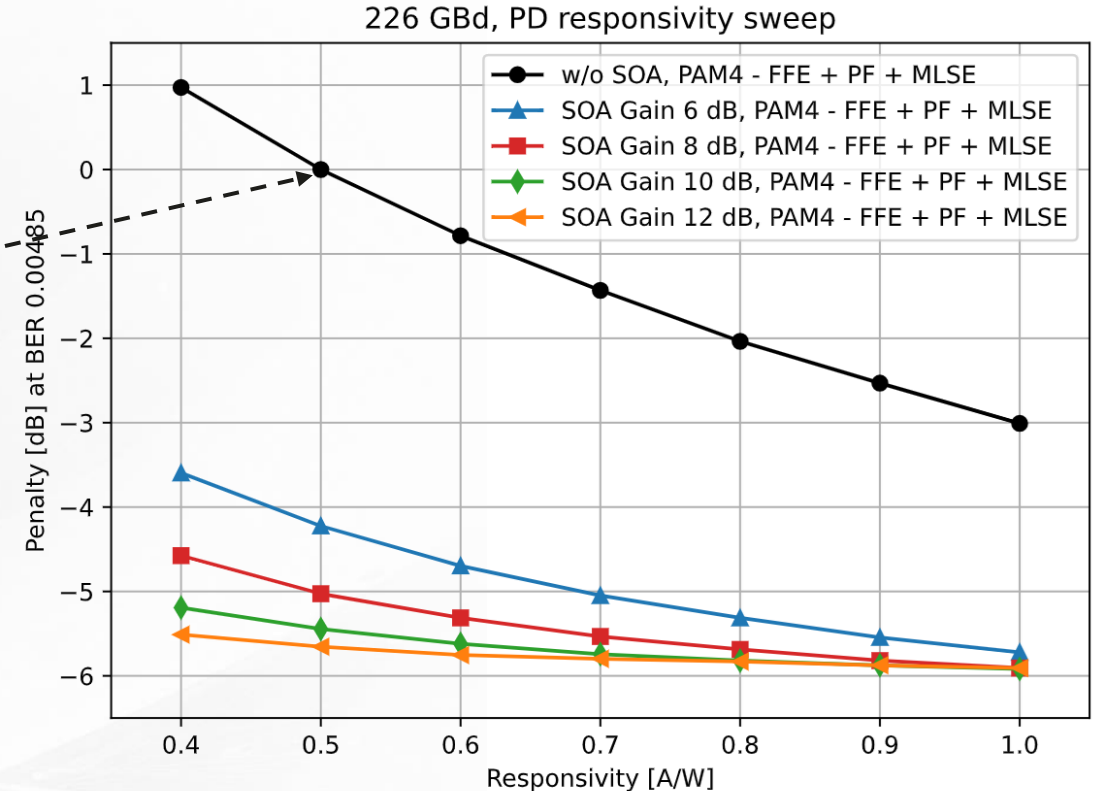
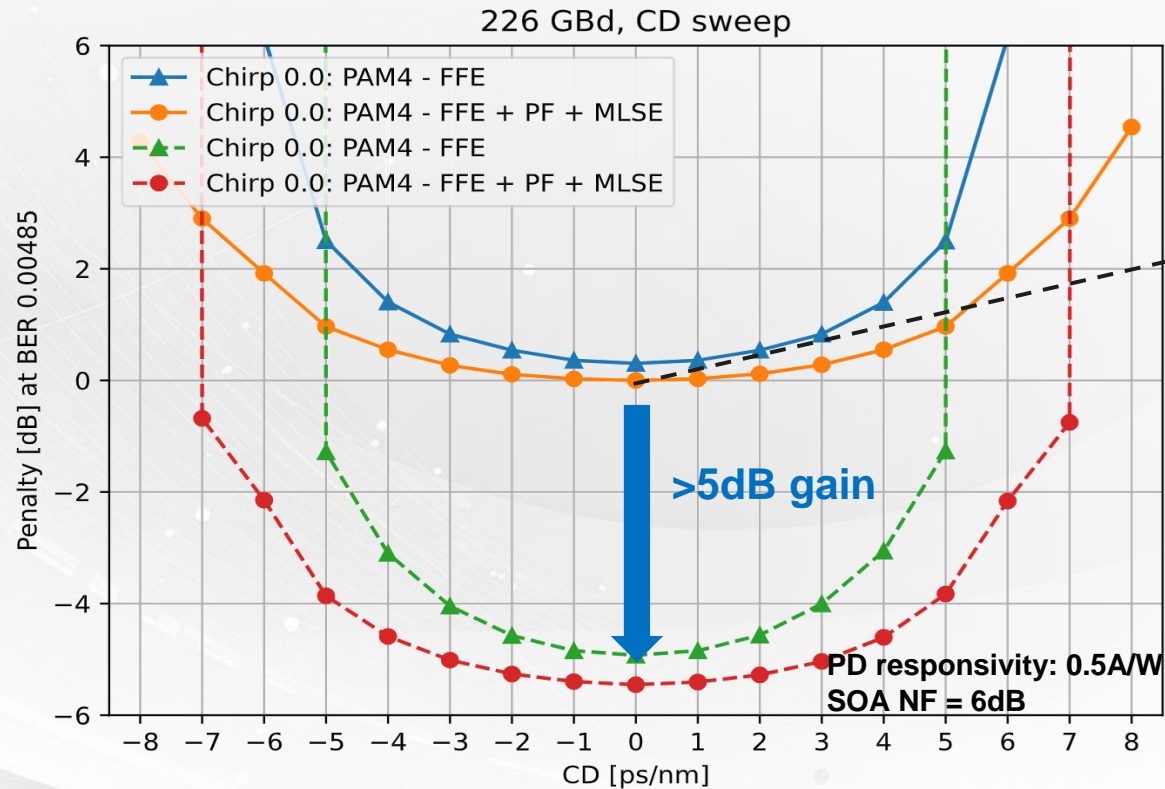
226 GBd, PDG sweep



Constant output power SOA mode

# Rx sensitivity with SOA

Cost effective alternative for 1600CL for the 8dB OCS use case



- >5dB SOA gain @ 0.5A/W PD sensitivity
- A higher PD sensitivity improves the absolute sensitivity w/SOA at a lower relative SOA gain

# Conclusions

## 1.6T FR4 can address inside data center connectivity

### Grid & Distance

- 1.6Tb/s FR4 PAM4 standard should support a wider range of material platforms (SOI, InP, TFLN, exotics) and designs (MZM, EAM, MRR)
- 1km transmission in a 10nm grid provides sufficient implementation margins with respect to CD
- 2km distance requires additional engineering (limited chirp range, optical CD compensation, etc.)

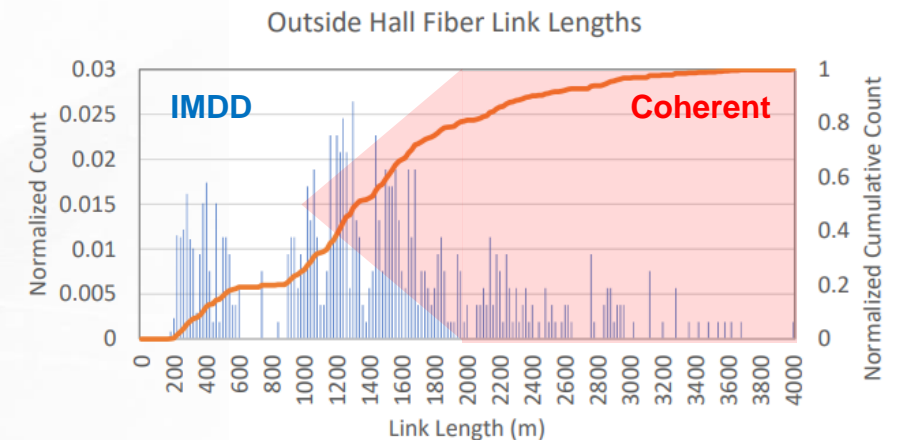
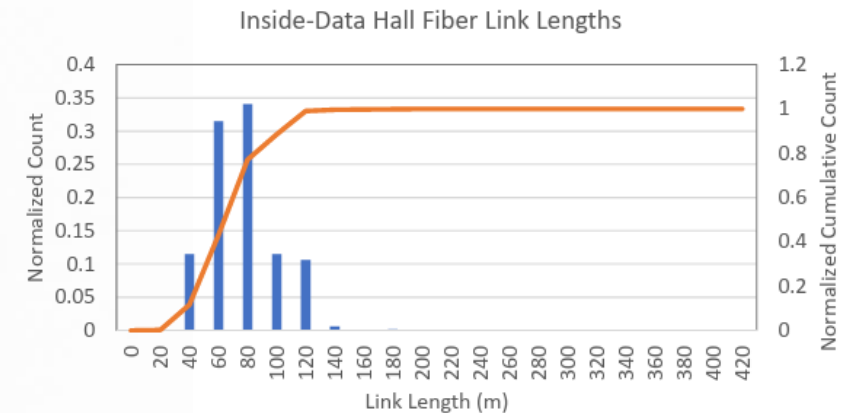
### FWM

- Increasing the laser power by 2dB shouldn't lead to noticeable FWM assuming polarization interleaving

### OCS

- 8dB OCS use case could be addressed by improved sensitivity using a Rx-SOA or improved PDs
- Required Rx-SOA specifications should allow for a cost effective implementation (1 SOA shared over  $4\lambda$ )

Reduced distance can still address all inside data hall fiber links w/OCS



[welch\\_3dj\\_02a\\_2309.pdf](#)



**Thank you**