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Analysis of 4x25-Gb/s 40-km 1310-nm PMD with SOA Pre-Amplifier

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Outline

- Link Configuration and Test Pattern
- Optical Component Characteristics
- BER vs Fiber Length & Eye Diagrams
- Worst-Case BER for Short & Long Fiber Links
- Conclusions

Link Configuration & Test Pattern

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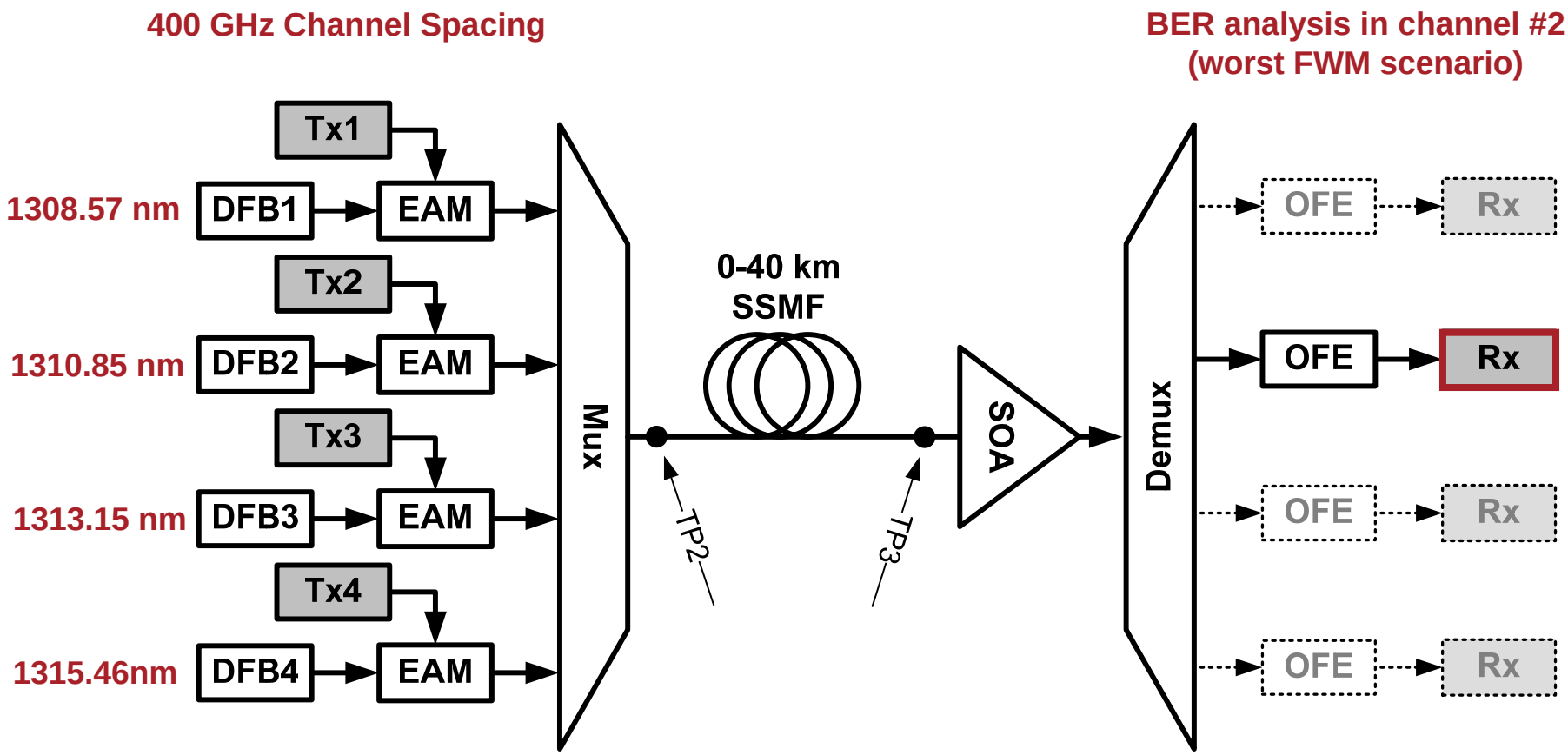
Optical Link Setup: 4x25-Gb/s EMLs & SOA Pre-Amp



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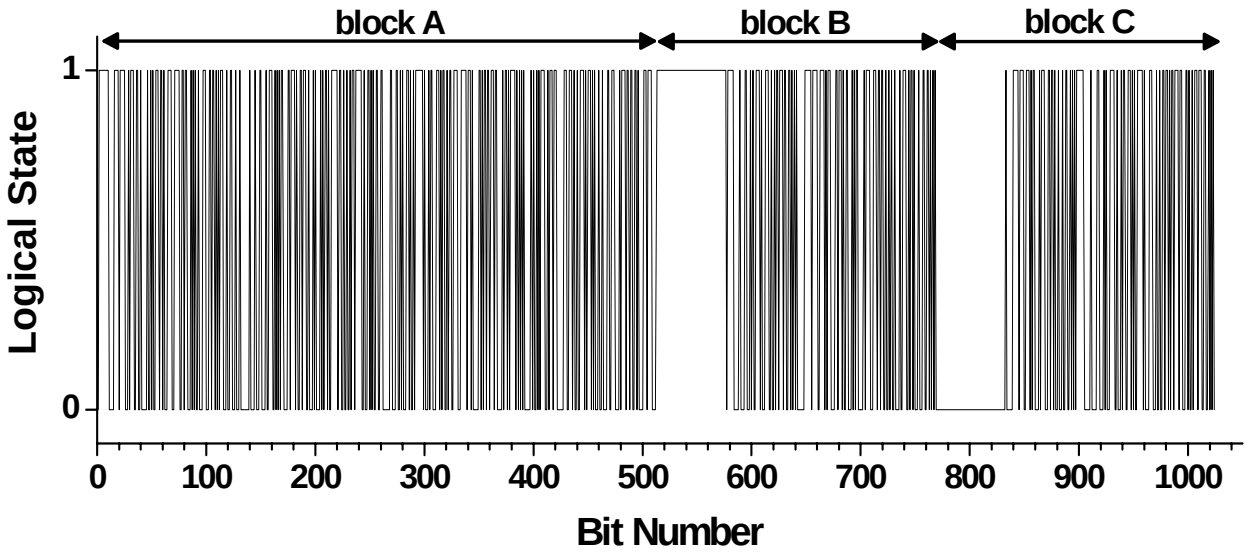
Test Pattern



- Total length = 1024 bits (2^{10})
- Block A = 512 bits, PRBS 9
- Block B = 256 bits, 64 marks + 64-bit PRBS 6 + 128-bit inverted PRBS 7
- Block C = 256 bits, inverted block B → 64 spaces
- 128-times (2^{7}) oversampling

Optical Component Characteristics

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EML Transmitters Characteristics

For the analysis we have considered:

- Four different extinction ratios = 4 dB, 6 dB, 8 dB, 10 dB
- Optical signal-to-noise ratio = 40 dB
- Three EML output powers = 0 dBm, +2 dBm, +4 dBm

EML Output Power	0 dBm	+2 dBm	+4 dBm
Total Power at TP2	+2.3 dBm	+4.3 dBm	+6.3 dBm
Min. Total Power at TP3**	-19.7 dBm	-17.7 dBm	-15.7 dBm
Min. Per-channel Power at TP3**	-25.7 dBm	-23.7 dBm	-21.7 dBm

** For a maximum link length of 40 km (22 dB span loss)

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Fiber and Optical Mux/Demux Characteristics

Optical fiber

- Dispersion coefficient @ 1310 nm, D = -0.20 ps/nm/km
- Dispersion slope @ 1310 nm, S = 0.090 ps/nm^2/km
- Fiber attenuation = 0.5 dB/km (ITU-T G.652 Attr.A)
- 2-dB additional loss from connectors & splicing
- Effective mode area = 80 μm^2
- Nonlinear index = 2.4x10^{-11}μm^2/mW

Mux/Demux

- 3rd order Gaussian bandpass filter
- 3-dB bandwidth = 175 GHz (~1.0 nm)
- Crosstalk = 25 dB
- Insertion loss MUX = 3.7 dB
- Insertion loss DEMUX = 5.2 dB

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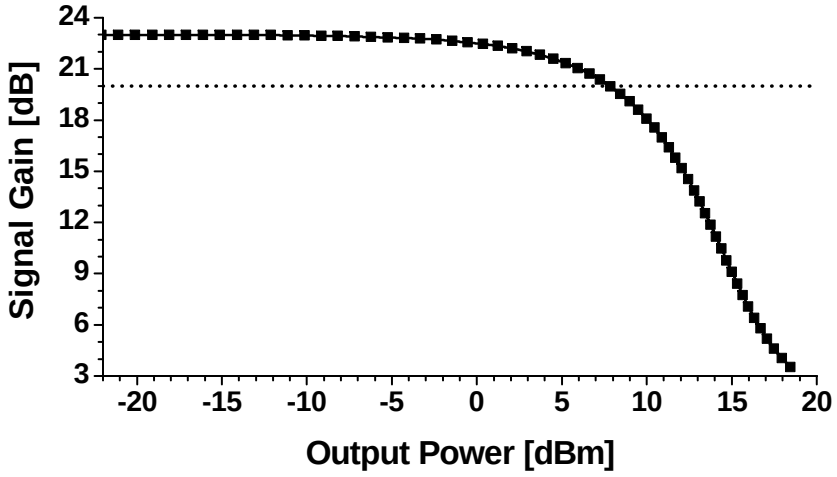
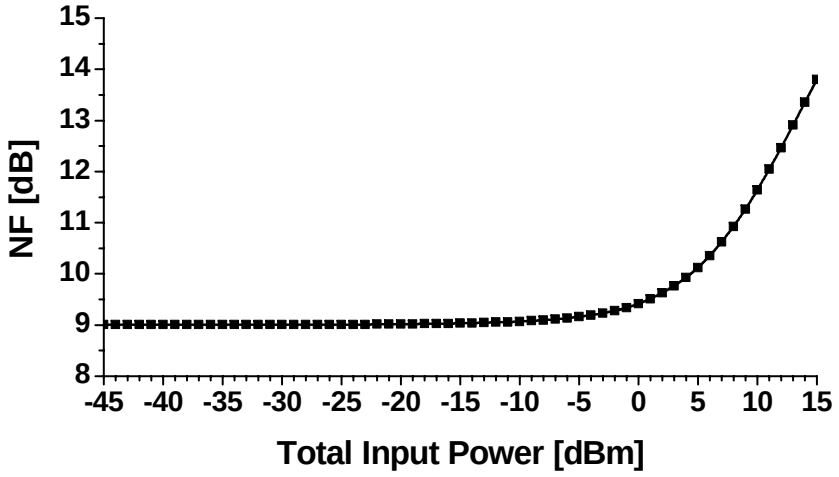
SOA Pre-Amplifier Characteristics

- Small-signal gain = 23 dB
- 3-dB compression point = +8 dBm
- Wavelength at gain peak = 1310 nm
- Carrier lifetime = 200 ps
- Noise Figure = 6.0 and 9.0 dB

DC Gain characteristics



DC Noise characteristics



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Receiver Sensitivity without SOA Pre-Amplifier (TP3)

ER	4 dB	6 dB	8 dB	10 dB
OSNR Sensitivity**	29.5 dB	26.3 dB	24.2 dB	22.9 dB
Power Sensitivity++	-10.0 dBm	-11.6 dBm	-12.6 dBm	-13.2 dBm

- BW electrical Rx = 25 GHz (RC 5th order)
- Random noise variance electrical Rx = 2.86 mV_{rms} → 40 mV_{pp} sensitivity for BER 1E-12
- BW OFE = 25 GHz (Bessel 5th order)
- TIA = 1400 Ω, 18 pA/Sqrt(Hz)
- Photodiode responsivity = 0.7 A/W

** for input power = 0 dBm
++ for input OSNR = 40 dB

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Receiver Sensitivity with SOA Pre-Amplifier (TP3)

ER	4 dB	6 dB	8 dB	10 dB
Power sensitivity^{++} for NF=6 dB	-20.8 dBm (-3.7 dBm)	-24.1 dBm (-6.6 dBm)	-26.0 dBm (-8.3 dBm)	-27.1 dBm (-9.3 dBm)
Power sensitivity^{++} for NF=9 dB	-17.4 dBm (-0.9 dBm)	-21.3 dBm (-4.0 dBm)	-23.5 dBm (-6.0 dBm)	-24.8 dBm (-7.1 dBm)

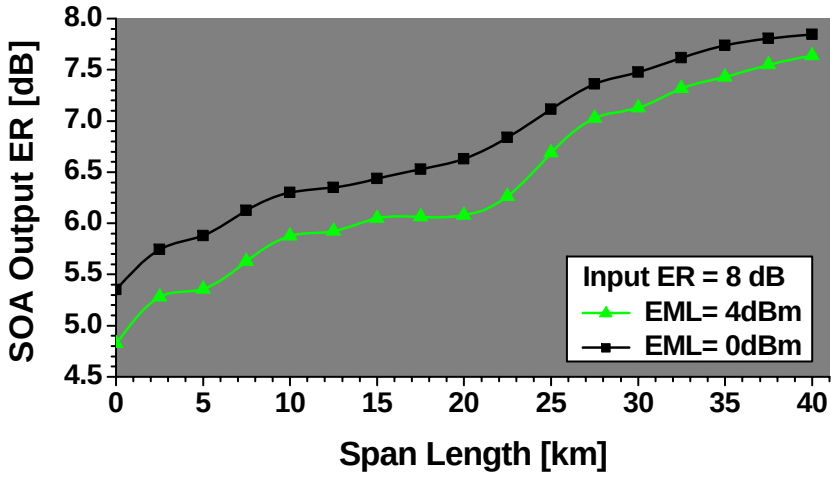
- Single-channel optical power measured at SOA input (TP3)
- Optical power @ OFE (after optical demux) in brackets
- Pre-Amplifier is necessary to meet power budget
- Power @ OFE always above power sensitivity (see previous table)
  → SOA with high small-signal gain (23 dB) is good choice

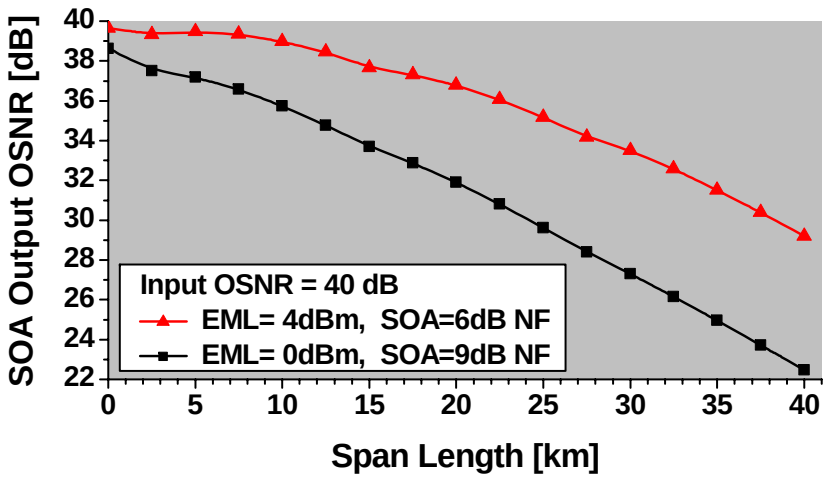
$^{++}$ for input OSNR = 40 dB

BER vs Fiber Length & Eye Diagrams

Signal Characteristics after SOA Pre-Amplifier

Signal characteristics dominated by two different phenomena:

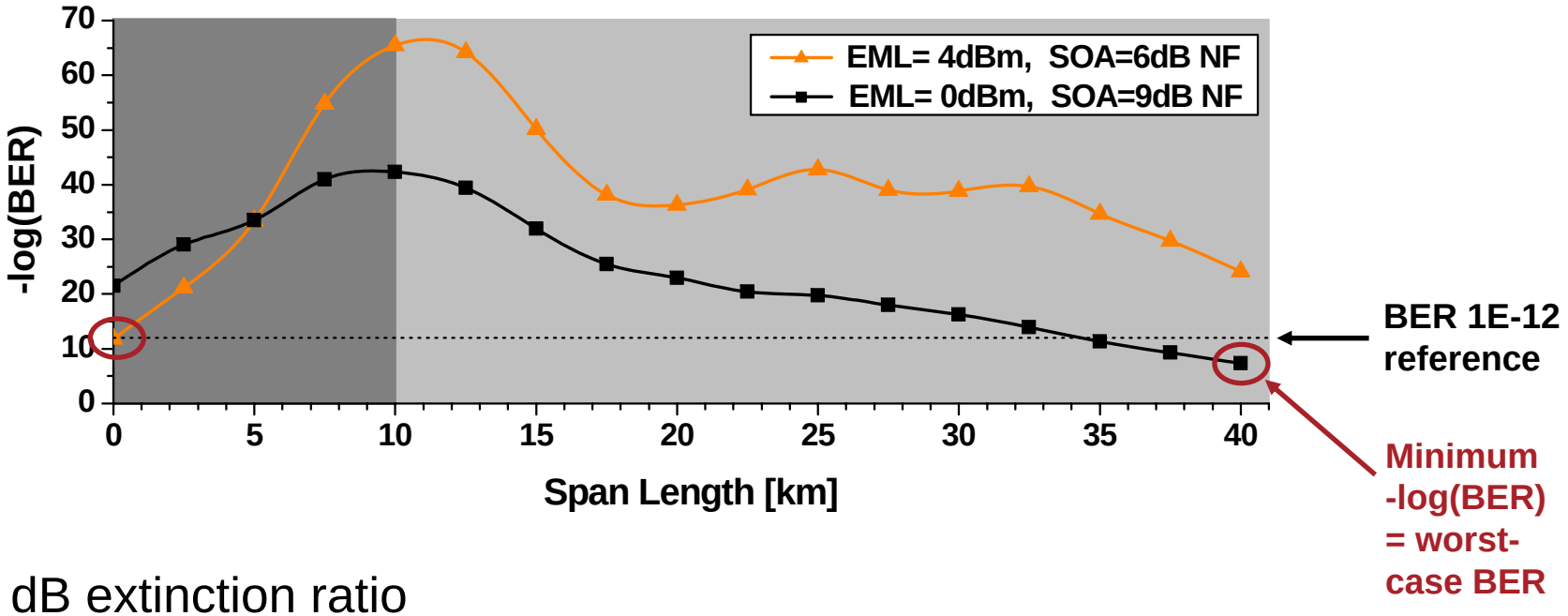




- Output ER increases with link length (fiber losses)
- For long lengths (high losses) the output ER closely matches the input ER

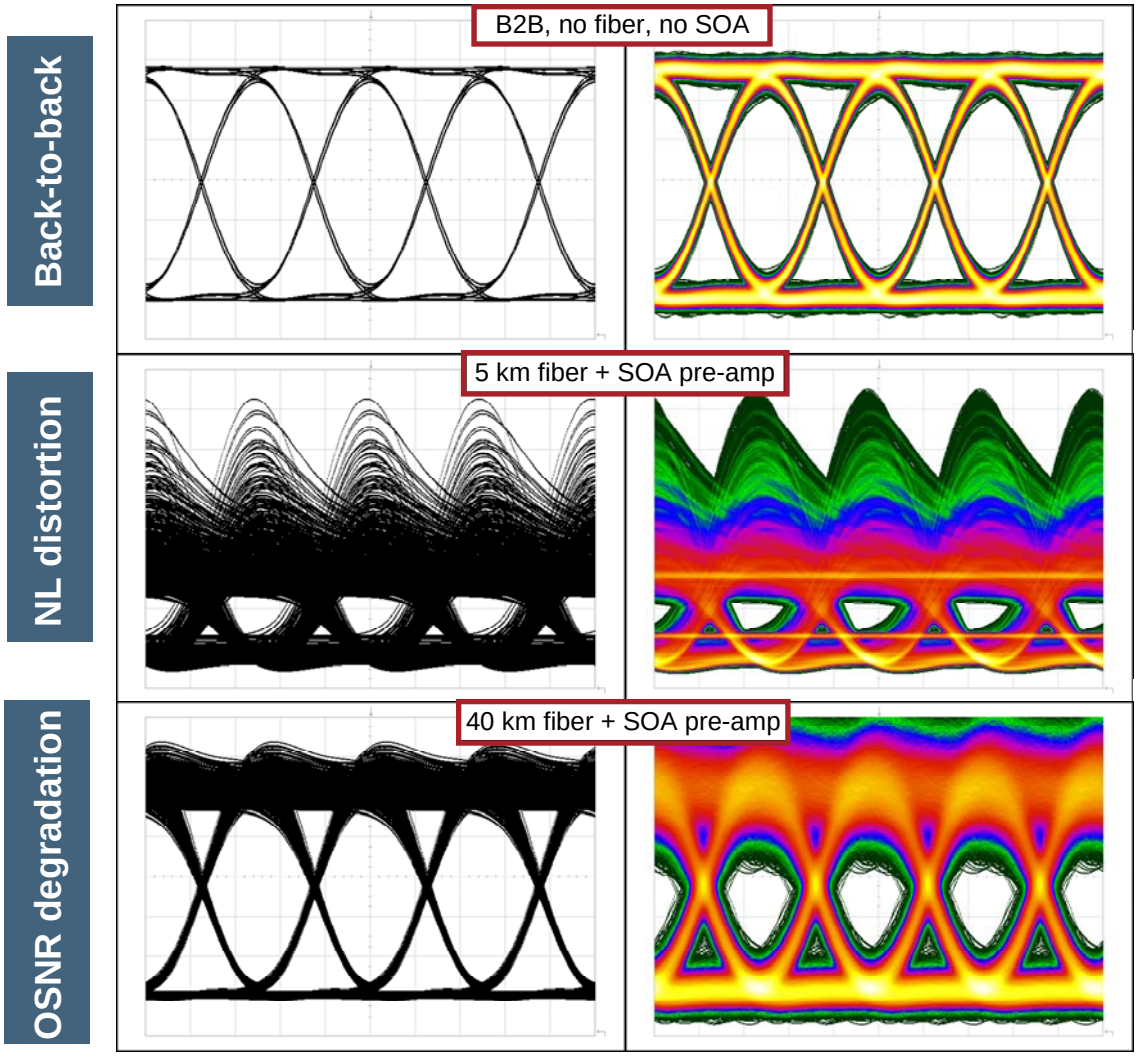
- OSNR decreases with link length (fiber losses)
- For short lengths (low losses) OSNR degradation is very small

BER Characteristics vs Fiber Length



- 8 dB extinction ratio
- Two different regimes determined by SOA physical effects:
- Short distances 0-10 km = dominated by nonlinear eye distortions
- Long distances 10-40 km = dominated by OSNR degradation

Simulated Eye Diagrams



- Left column = noise-free eye diagram = received optical waveform only, no optical or electrical noise
- Right column = "noisy" eye diagram = received optical waveform + received optical noise (ASE) + electrical noise

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Worst-Case BER for Short & Long Fiber Links

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Minimum -log(BER) for Short Fiber Links (0-10 km)

Extinction ratio of EML transmitter

	0 dBm EML output power		+2 dBm EML output power		+4 dBm EML output power	
	6 dB NF	9 dB NF	6 dB NF	9 dB NF	6 dB NF	9 dB NF
4 dB ER	—	—	—	—	—	—
6 dB ER	9.1	8.1	—	—	—	—
8 dB ER	25.1	21.4	17.8	16.0	11.8	11.0
10 dB ER	49.5	41.7	38.6	34.2	29.5	27.2

Noise figure of SOA pre-amplifier

- Minimum –log(BER) value = worst-case BER
  → obtained for shortest fiber link (~0 km = 2 dB span loss)
- Dashes mean that eyes are completely closed (BER measurement failed)
  → strong eye distortions due to nonlinear (NL) response of the SOA
- Gray-shaded areas do not meet BER 1E-12 requirement !

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Minimum -log(BER) for Long Fiber Links (10-40 km)

Extinction ratio of EML transmitter

	0 dBm EML output power		+2 dBm EML output power		+4 dBm EML output power	
	6 dB NF	9 dB NF	6 dB NF	9 dB NF	6 dB NF	9 dB NF
4 dB ER	4.6	2.9	6.5	4.1	8.8	5.5
6 dB ER	8.1	5.0	11.7	7.1	15.8	9.8
8 dB ER	11.9	7.3	17.4	10.5	24.1	14.6
10 dB ER	15.3	9.3	22.7	13.6	32.0	19.2

Noise figure of SOA pre-amplifier

- Minimum –log(BER) value = worst-case BER
  → obtained for longest fiber link (40 km = 22 dB span loss)
- Gray-shaded areas do not meet BER 1E-12 requirement !

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Conclusions

- Short fiber links (0-10 km) are dominated by nonlinear distortions in the SOA pre-amplifier
  - Minimum EML extinction ratio = 8-10 dB
  - Minimum attenuation recommendation may alleviate NL distortions
- Long fiber links (10-40 km) are dominated by OSNR degradation in the SOA pre-amplifier
  - Minimum EML extinction ratio = 8-10 dB
  - Minimum EML output power = +2 to +4 dBm
    → total power @ TP2 = +4 to +6 dBm