INSTITUTO
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UNAM

Technical Feasibility of 4x25 Gb/s PMD for 40km at 1310nm using SOAs

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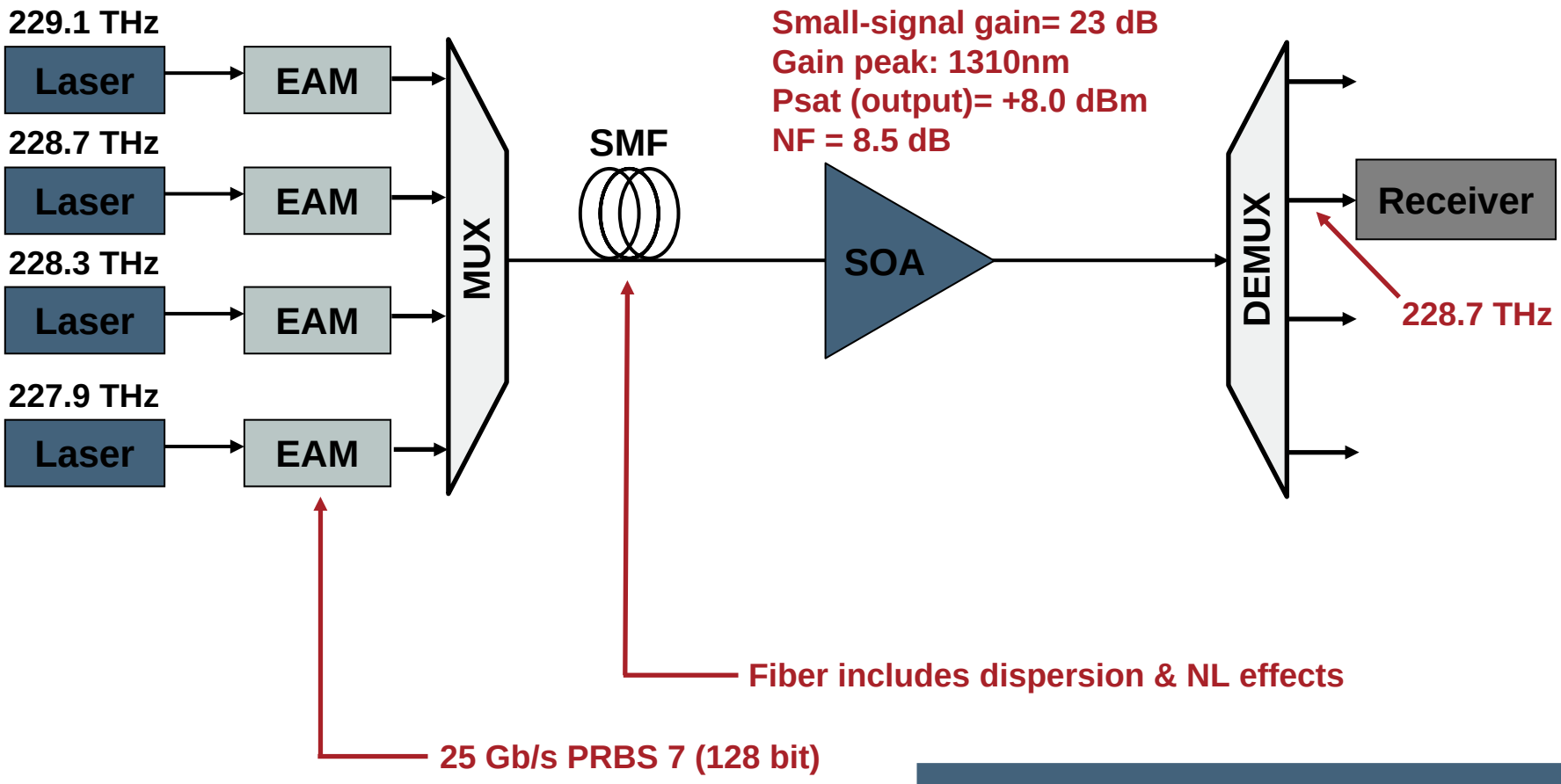
Introduction

- A transmission system simulator was used to analyze 4x25 Gb/s NRZ fiber transmission using EMLs at 1310 nm with an SOA as a pre-amplifier.
- The simulation included linear (dispersive) and nonlinear fiber transmission effects, nonlinear dynamics in the SOA and semi-analytic BER analysis using Gaussian approximation (valid for OOK).
- The analysis of the 4x25 Gb/s PMD solution for 40km standard SMF at 1310nm includes
  - Eye diagrams and extinction ratio degradation
  - Analysis of amplifier OSNR degradation
  - BER penalties due to fiber transmission and SOA amplification
  - Corresponding calculation of fiber loss and SOA gain
  - Calculation of overall power budget

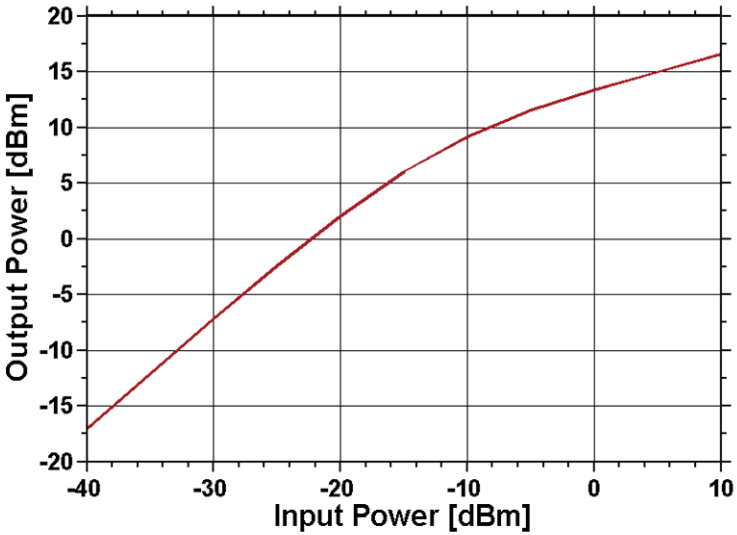
Link Setup

Link Structure and Component Characteristics

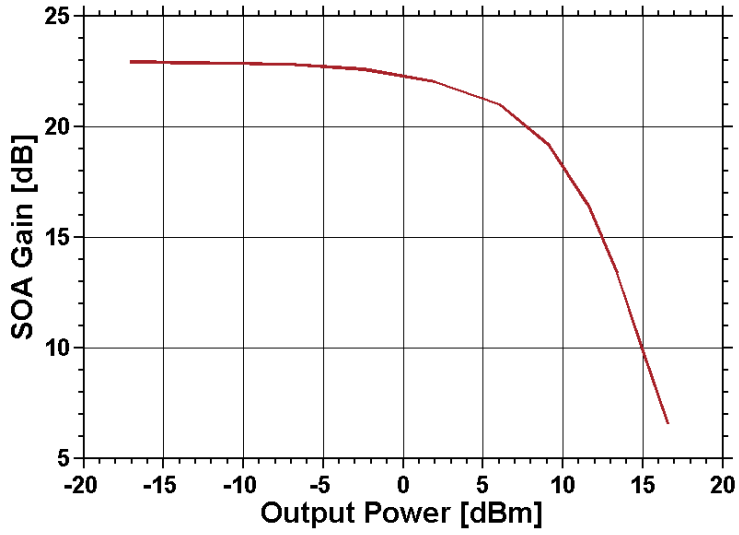


More details on components in backup …

SOA Characteristics



Pout vs Pin



G vs Pout

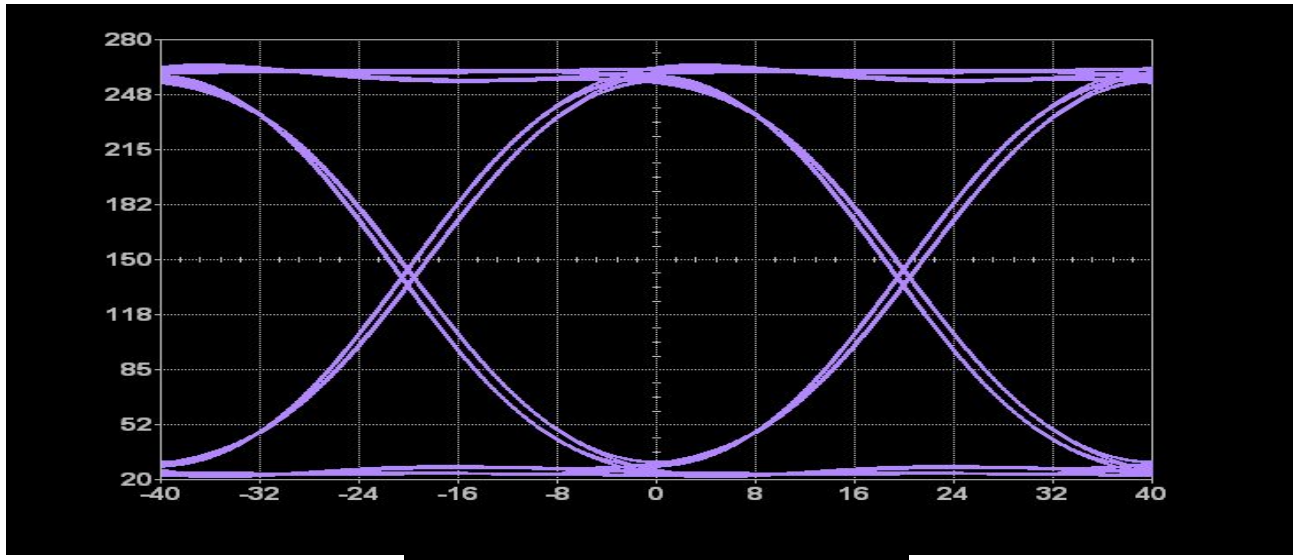
- High fiber-to-fiber gain of 23 dB
  - With a fiber coupling loss of 2.5 dB per facet this corresponds to 28 dB on chip
- Relatively high saturation output power of 8 dBm
  - The amplifier behaves linearly within a wide range of power
- Good SOA for in-line amplification

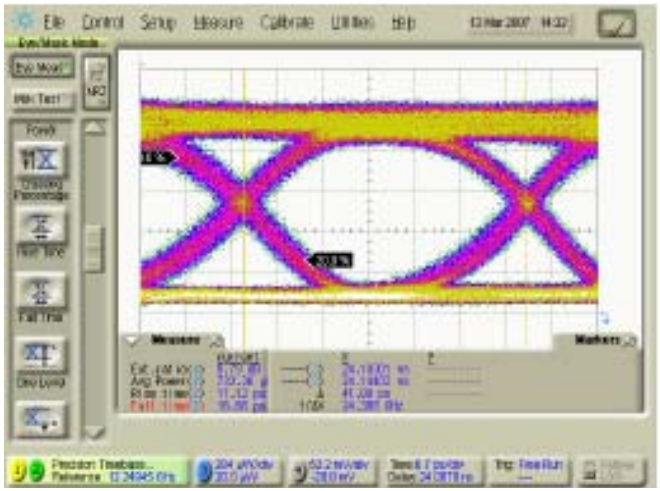
Power Budget Considerations (traverso_01_0407.pdf)

- Output from each EAM: 3.23 dBm/ch
- Loss: MUX + Splice + Aging + Accuracy: -3.7 dB
- Loss: Filter + Splice + Ag. + Acc. + Interoperability: -5.2 dB
- Loss: Fiber loss (@0.45 dB/km) plus connectors
  - 5 km fiber: 4.25 dB
  - 10 km fiber: 6.5 dB
  - 20 km fiber: 11.0 dB
  - 30 km fiber: 15.5 dB
  - 40 km fiber: 20.0 dB
- Actual SOA gain depends on input power
  - Small-signal gain 23 dB

Back-to-Back Filtered Eye

10 dB Extinction Ratio



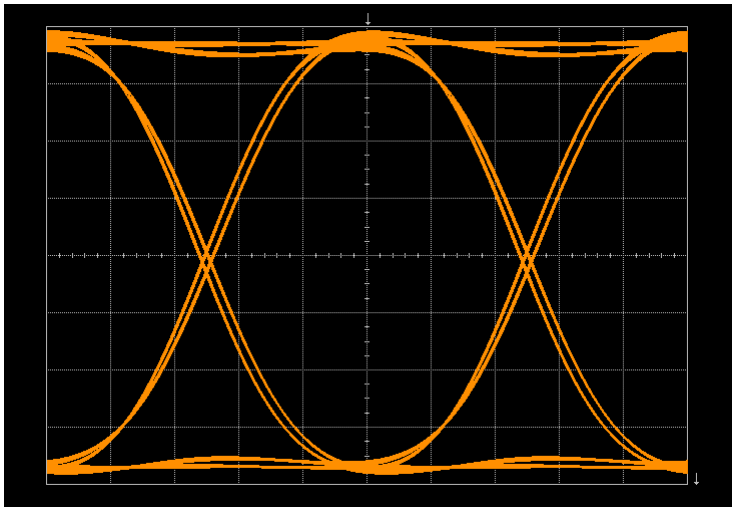


Sample eye from W. Jiang (jiang_01_0407.pdf) April presentation

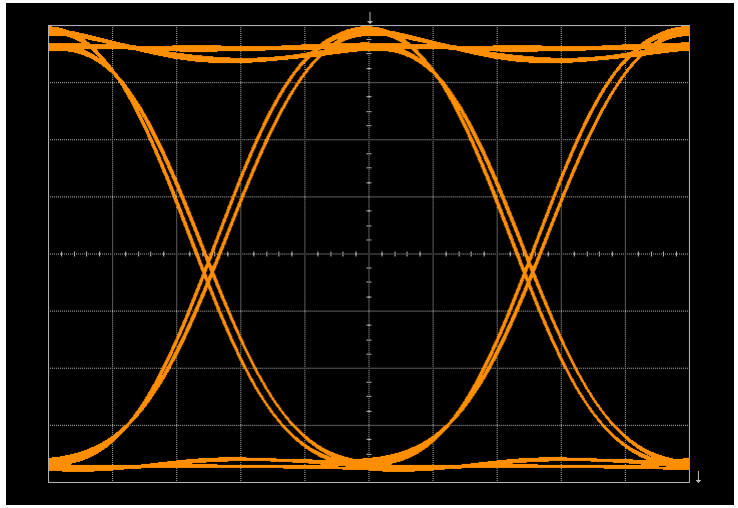
Eye Diagrams for Several Fiber Lengths

(Extinction Ratio = 10 dB,
228.7 THz = 1310.85 nm)

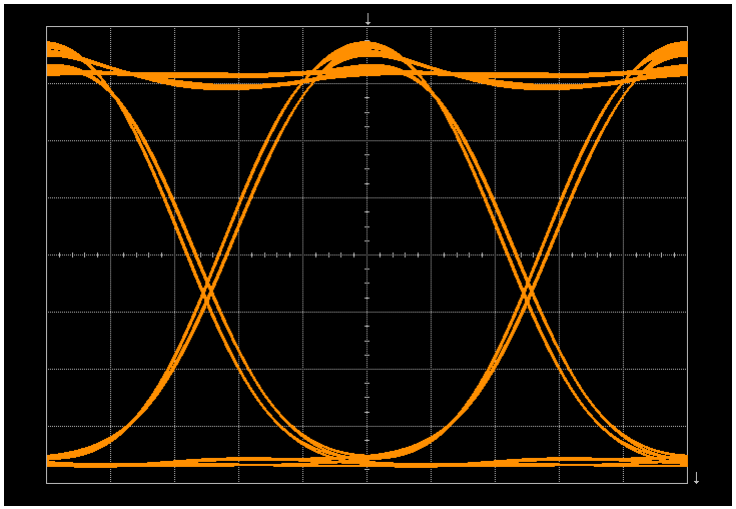
Fiber Transmission Only (10dB ER, no SOA)



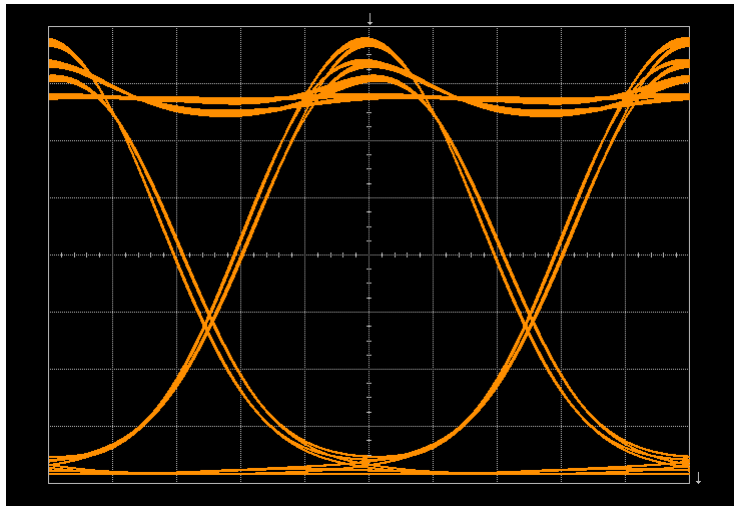
0 km fiber length



5 km

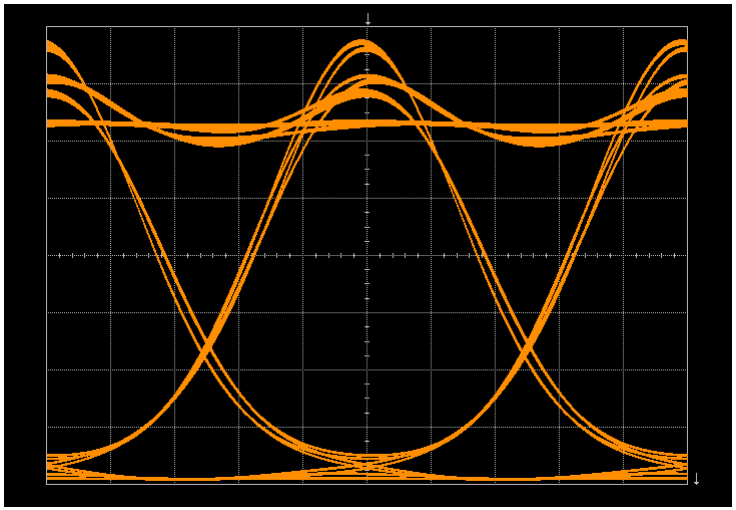


10 km

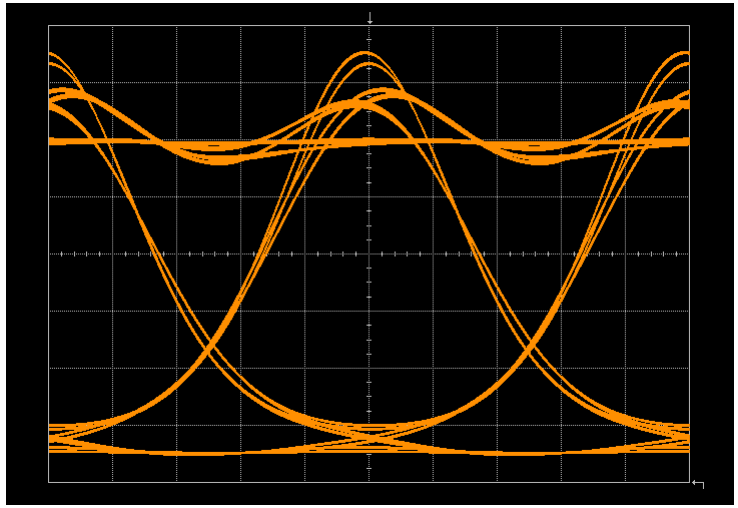


20 km

Fiber Transmission Only (10dB ER, no SOA)



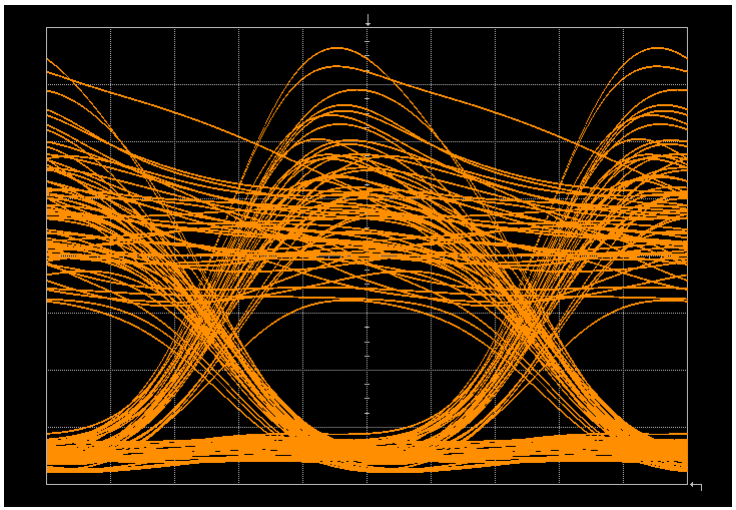
30 km



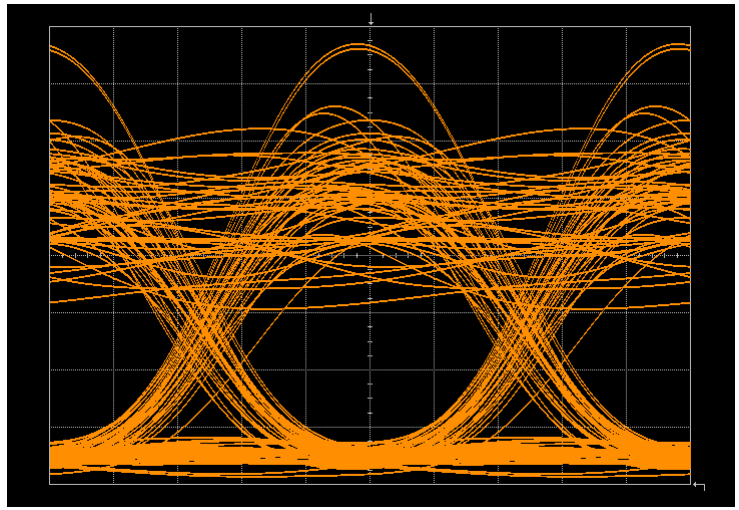
40 km

Fiber Length [km]	0	5	10	20	30	40
Extinction ratio [dB]	10	9.9	9.8	9.5	9.3	8.9

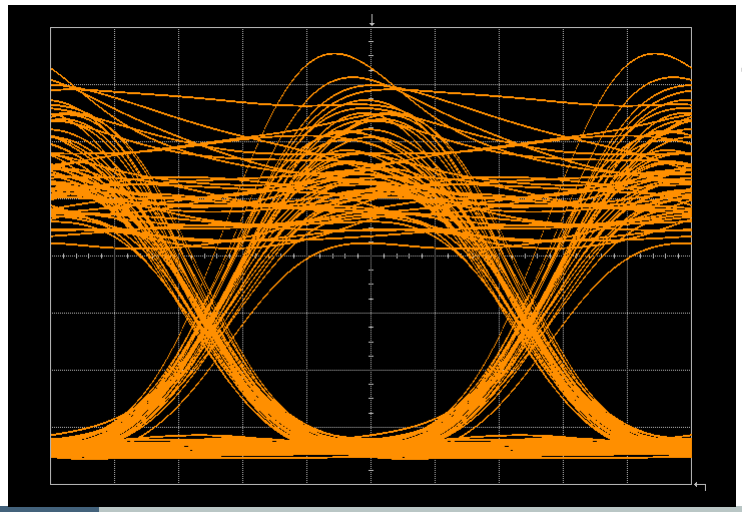
Fiber Transmission + SOA Amplification (10dB ER)



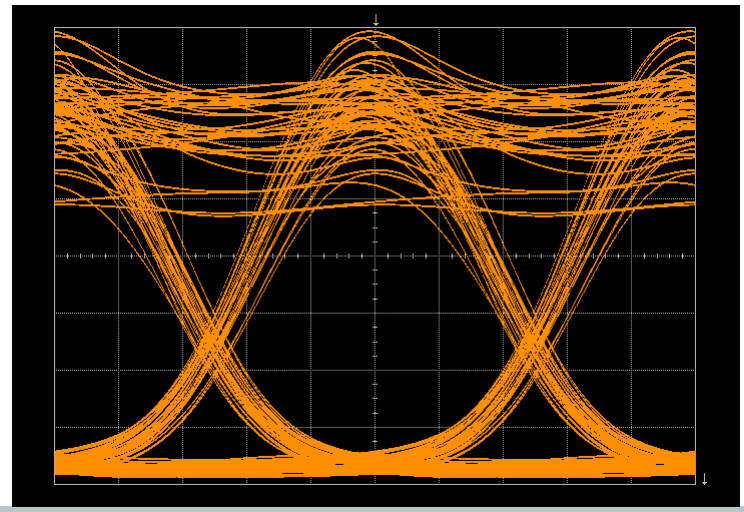
0 km fiber length



5 km

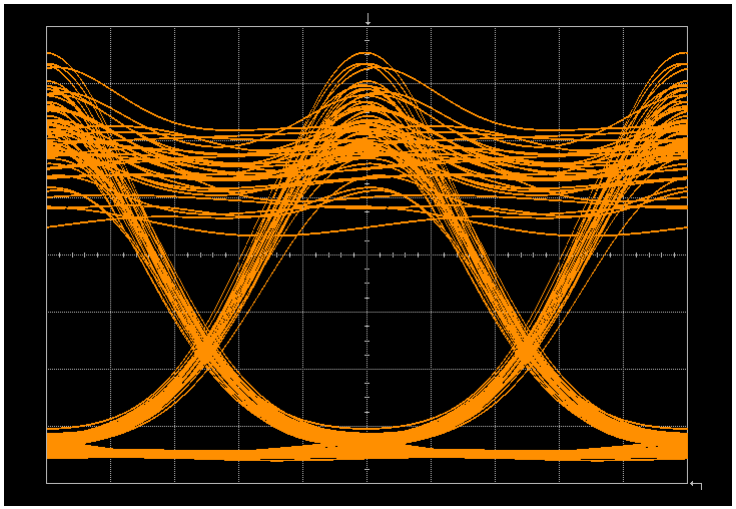


10 km

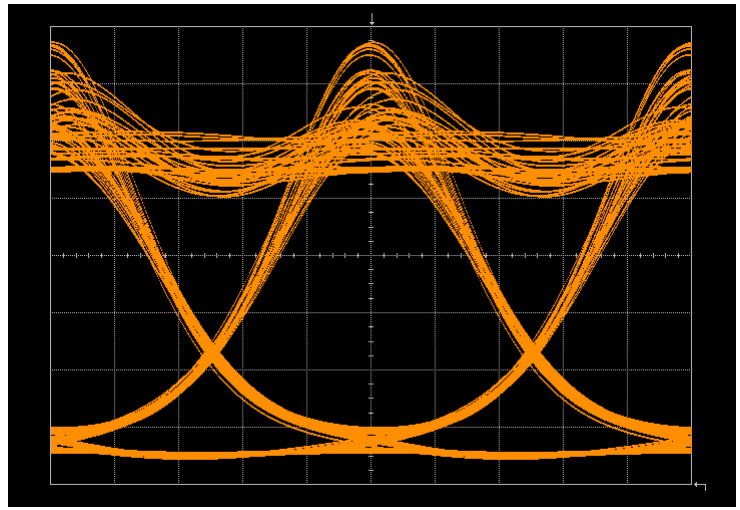


20 km

Fiber Transmission + SOA Amplification (10dB ER)



30 km



40 km

Fiber Length [km]	0	5	10	20	30	40
Extinction ratio [dB]	9.1	9.7	9.1	9.5	9.3	9.0

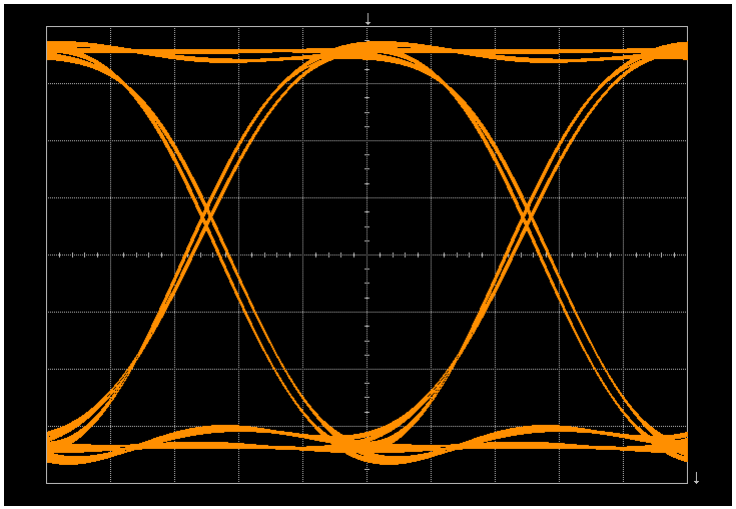
Eye Diagrams for Several Fiber Lengths

(Extinction Ratio = 5.7 dB,
228.7 THz = 1310.85 nm)

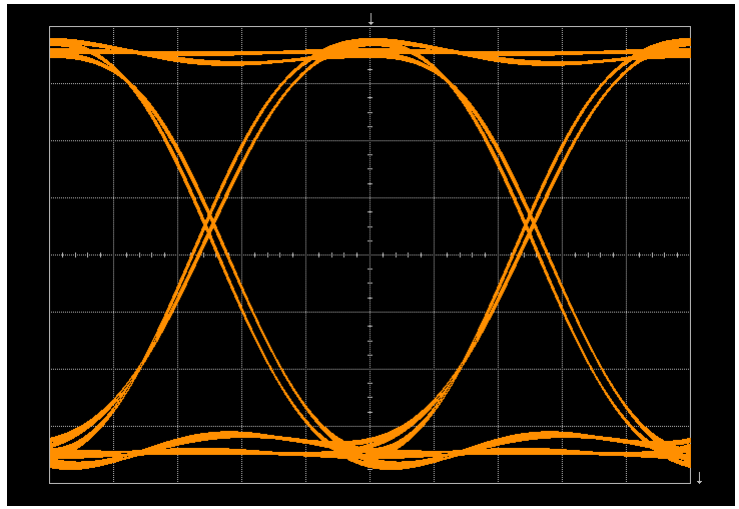
Lower Extinction Ratio

- We choose an extinction ratio of 5.7dB, which is well above the minimum extinction ratio of 3.0 dB defined in 10GBase-R, as an example that will result in a BER performance that is on the edge of the power budget …

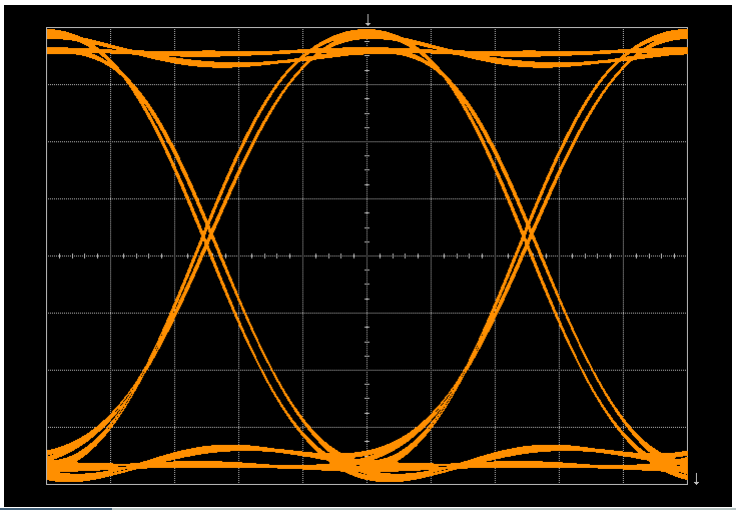
Fiber Transmission Only (5.7dB ER, no SOA)



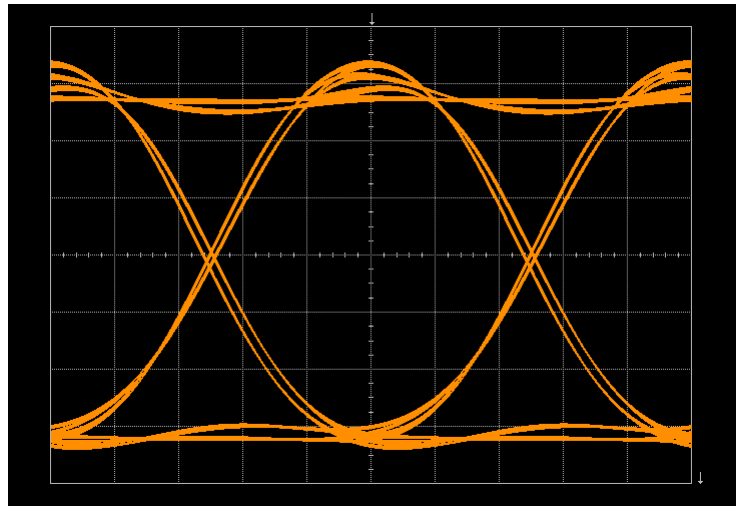
0 km fiber length



5 km

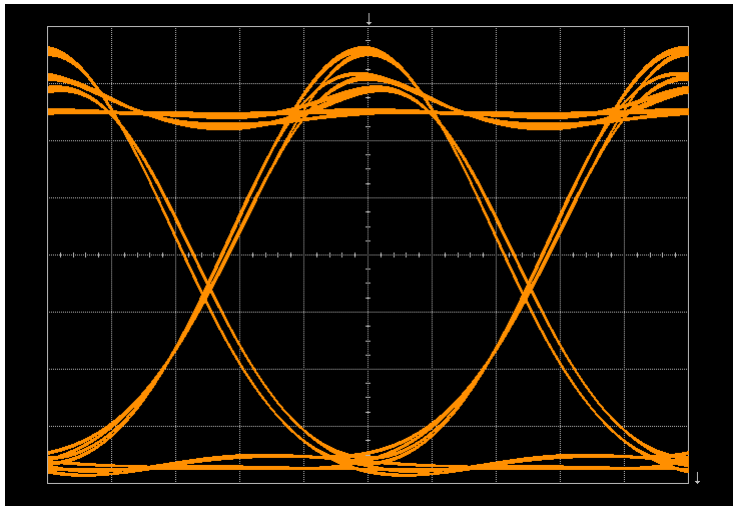


10 km

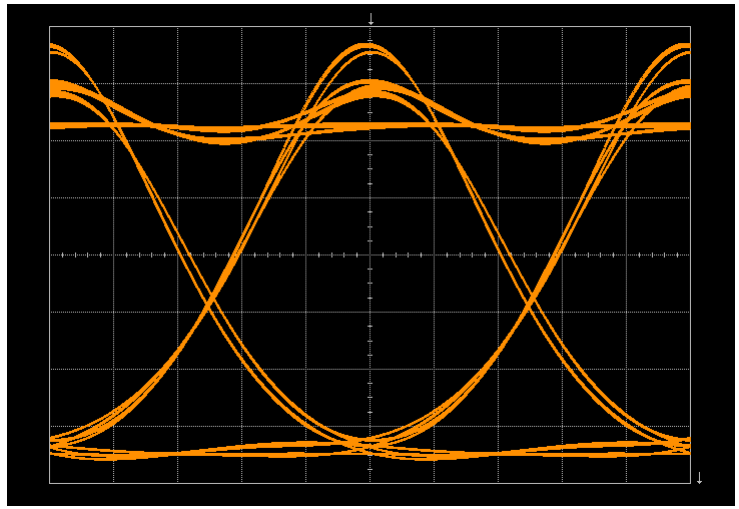


20 km

Fiber Transmission Only (5.7dB ER, no SOA)



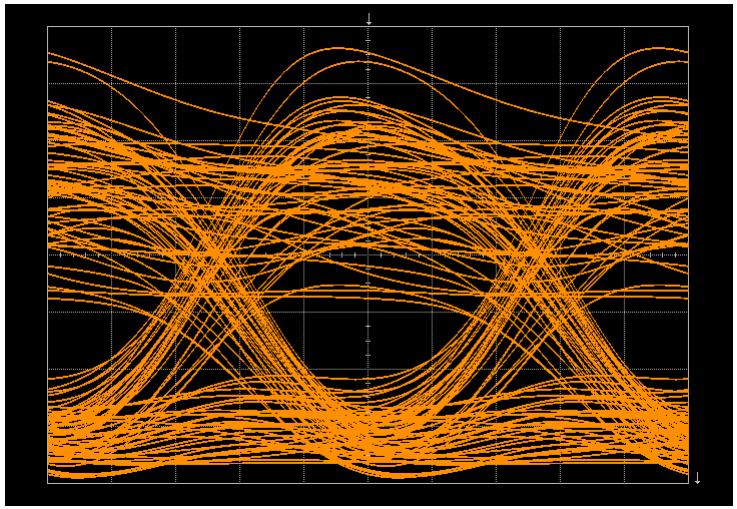
30 km



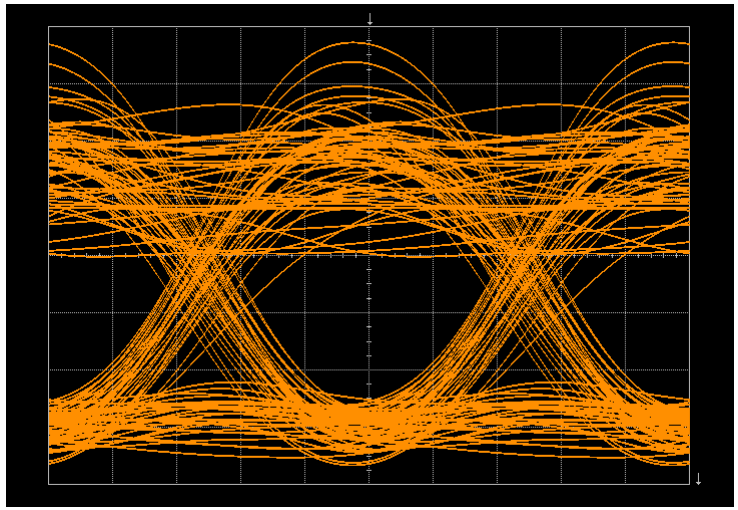
40 km

Fiber Length [km]	0	5	10	20	30	40
Extinction ratio [dB]	5.7	5.7	5.7	5.7	5.7	5.7

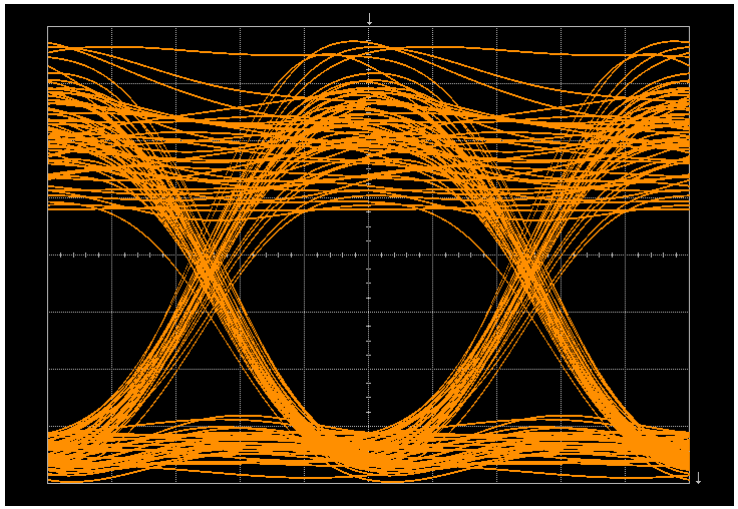
Fiber Transmission + SOA Amplification (5.7dB ER)



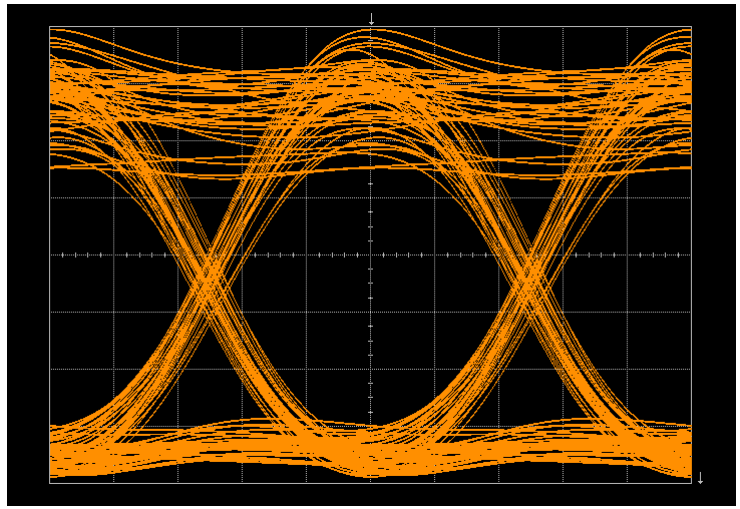
0 km fiber length



5 km

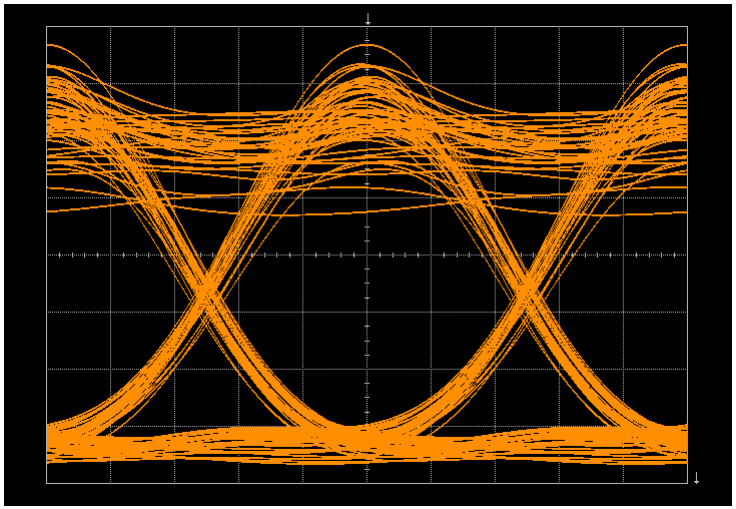


10 km

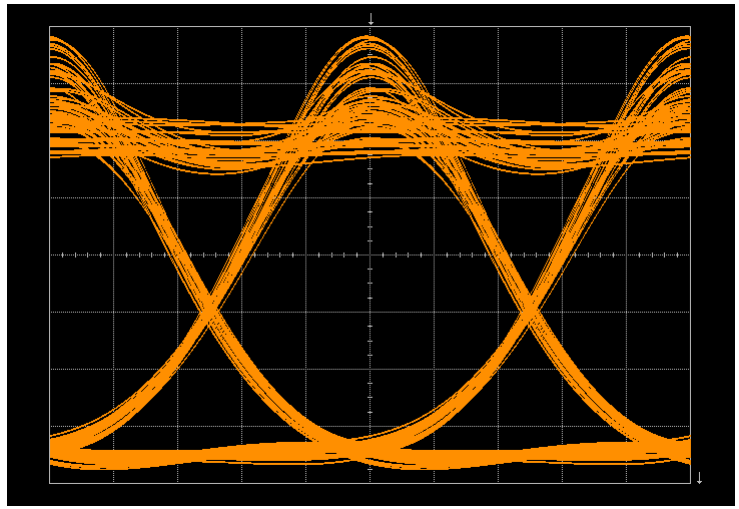


20 km

Fiber Transmission + SOA Amplification (5.7dB ER)



30 km

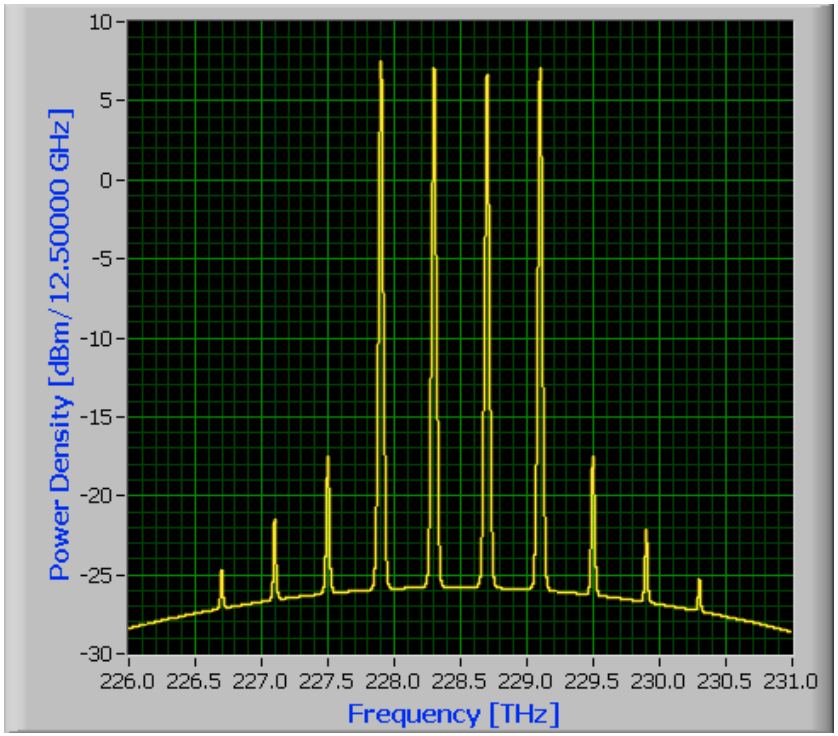


40 km

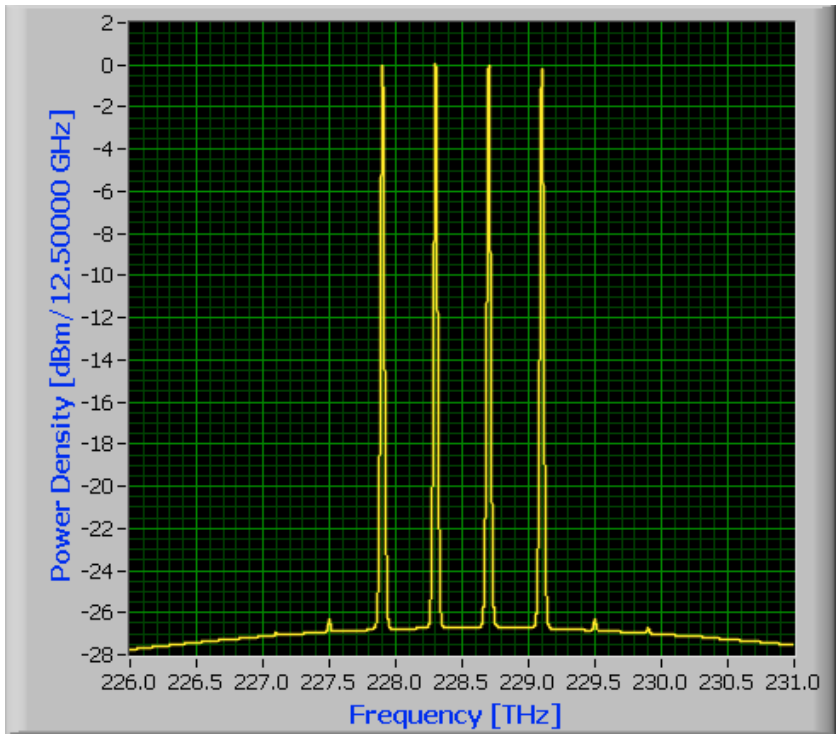
Fiber Length [km]	0	5	10	20	30	40
Extinction ratio [dB]	5.2	5.6	5.3	5.8	5.8	5.7

Output Spectra & Output OSNR from SOA

Typical Spectra at SOA Output



When using 5 km of fiber
(high input power to SOA)



When using 40 km of fiber
(low input power to SOA)

Output OSNR of SOA (Input OSNR ~34 dB)

Fiber Length [km]	0	5	10	20	30	40
OSNR [dB]	33.8	33.5	33.5	32.2	30.2	27.2

- OSNR degradation in SOA for larger span length due to lower input power into SOA
- Output OSNR independent of extinction ratio
- Assumption for transmitter:
  - EMLs with 36 dB OSNR**
  - Optical mux with 25 dB Xtalk
  - Input OSNR into SOA = 34.2 dB (within 0.1 nm)

** 10GBase-R specifies a minimum side-mode suppression ratio of 30 dB …

Output OSNR of SOA (Input OSNR ~43 dB)

Fiber Length [km]	0	5	10	20	30	40
OSNR [dB]	41.9	40.6	39.2	36	32.1	27.8

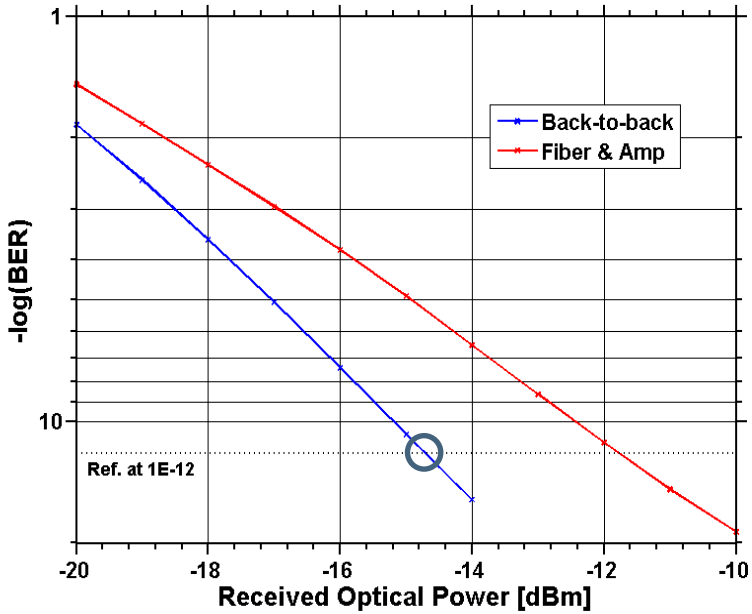
- OSNR degradation in SOA for larger span length due to lower input power into SOA
- Assumption for transmitter:
  - EMLs with 45 dB OSNR
  - Optical mux with 25 dB Xtalk
  - Input OSNR into SOA = 43.2 dB (within 0.1 nm)

The output OSNR for long fiber links is determined in the first degree by the low input power and not by the input OSNR !

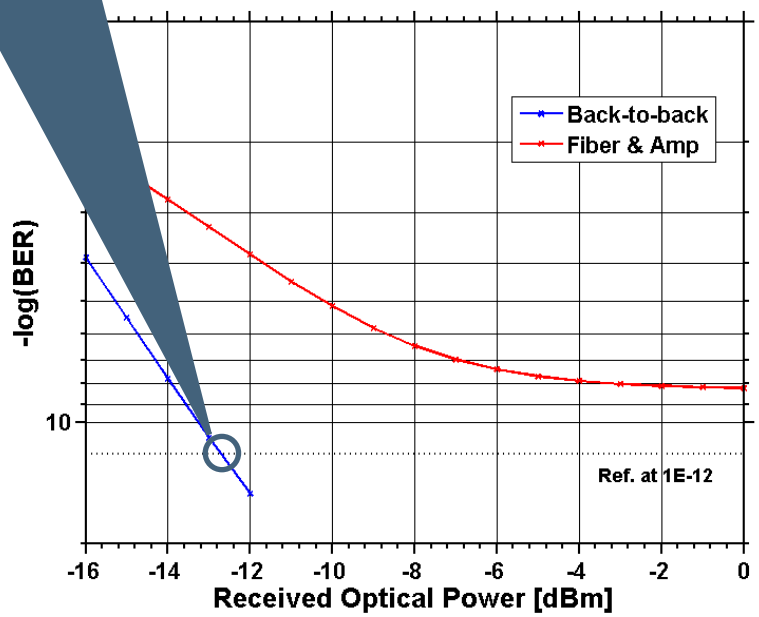
BER Analysis for Fiber Transmission & Amplification in SOA

BER Curves for 0 km Fiber Transmission

~1.9dB extra penalty (back-to-back) due to lower ER



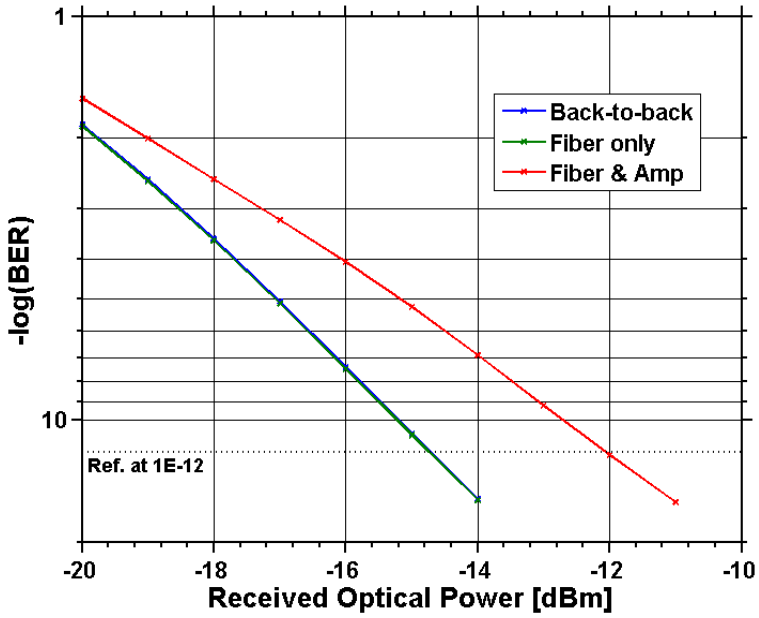
10 dB ER



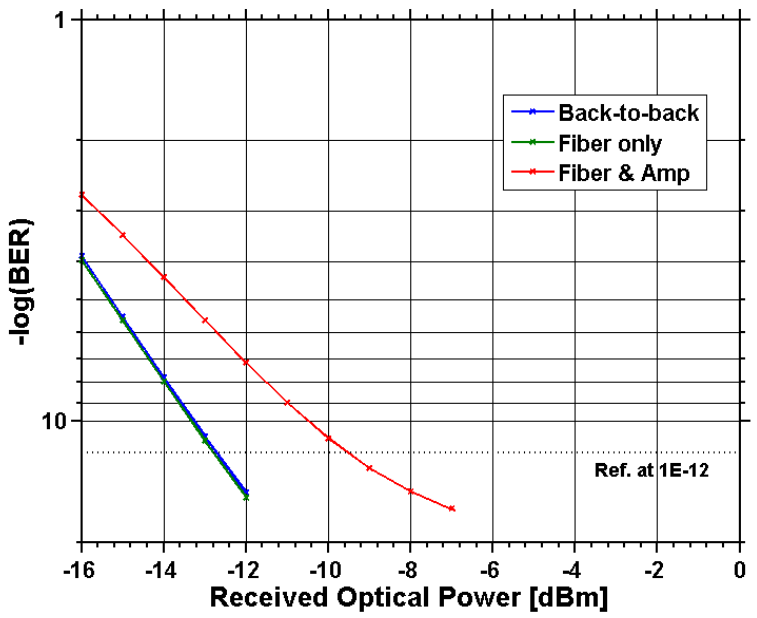
5.7 dB ER

0 km fiber length

BER Curves for 5 km Fiber Transmission



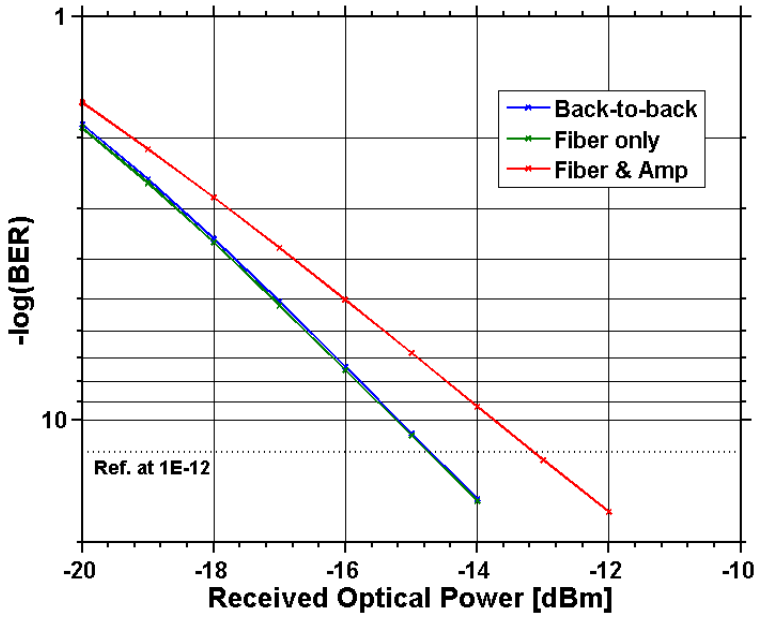
10 dB ER



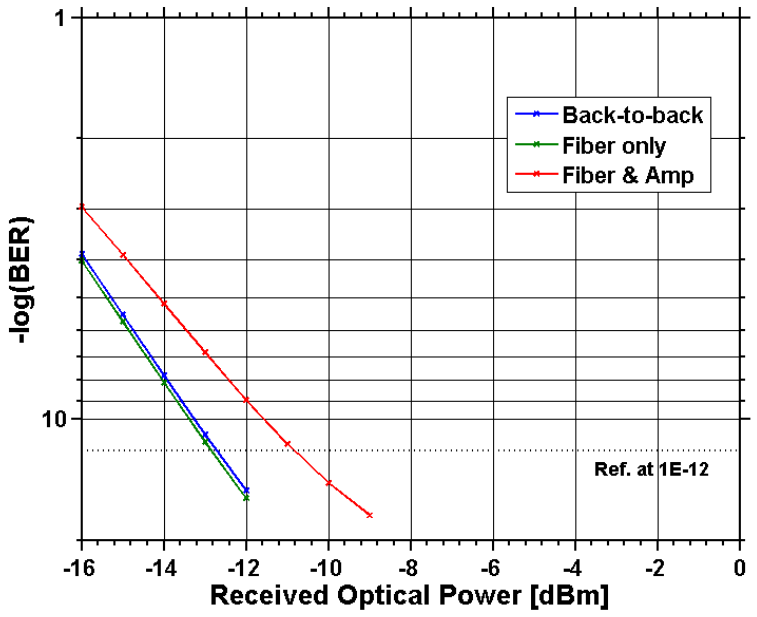
5.7 dB ER

5 km fiber length

BER Curves for 10 km Fiber Transmission



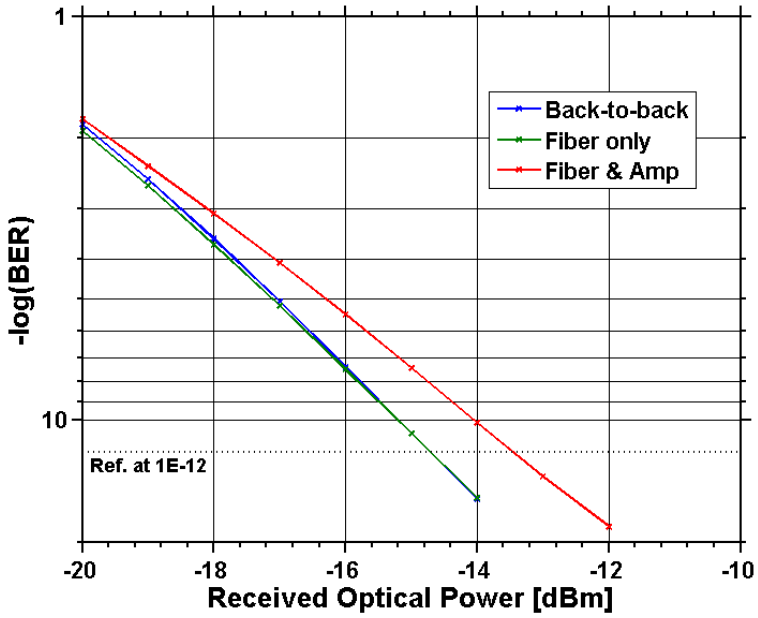
10 dB ER



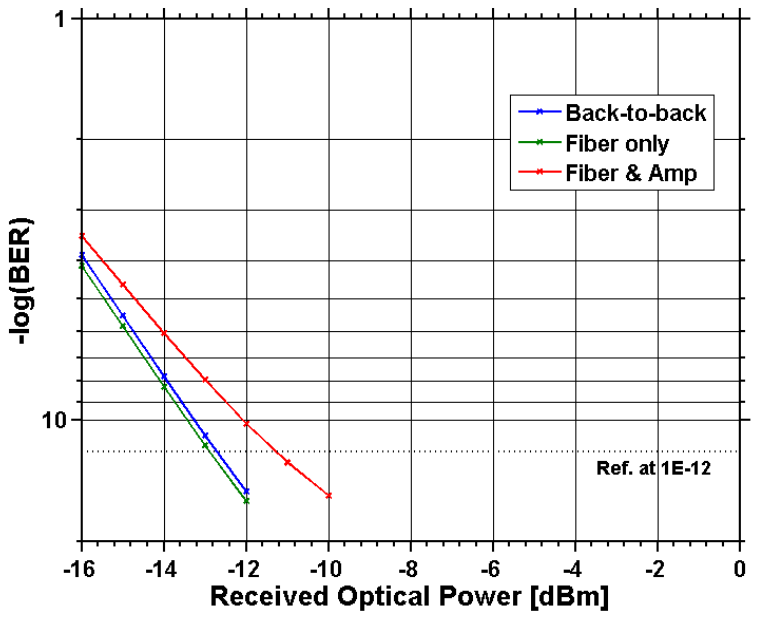
5.7 dB ER

10 km fiber length

BER Curves for 20 km Fiber Transmission



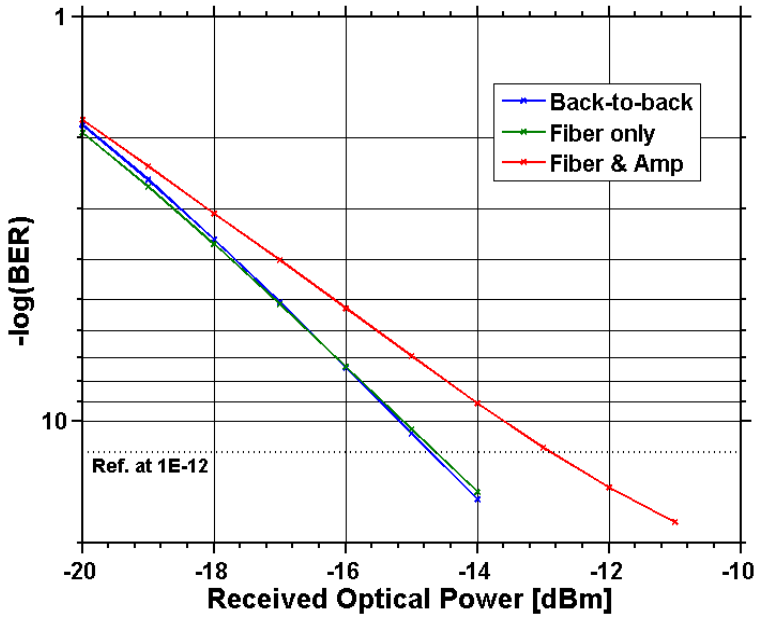
10 dB ER



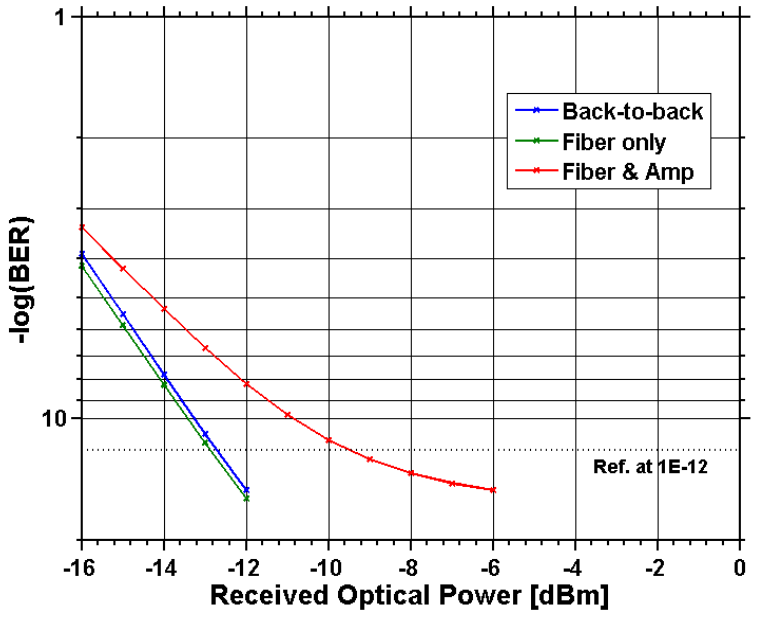
5.7 dB ER

20 km fiber length

BER Curves for 30 km Fiber Transmission



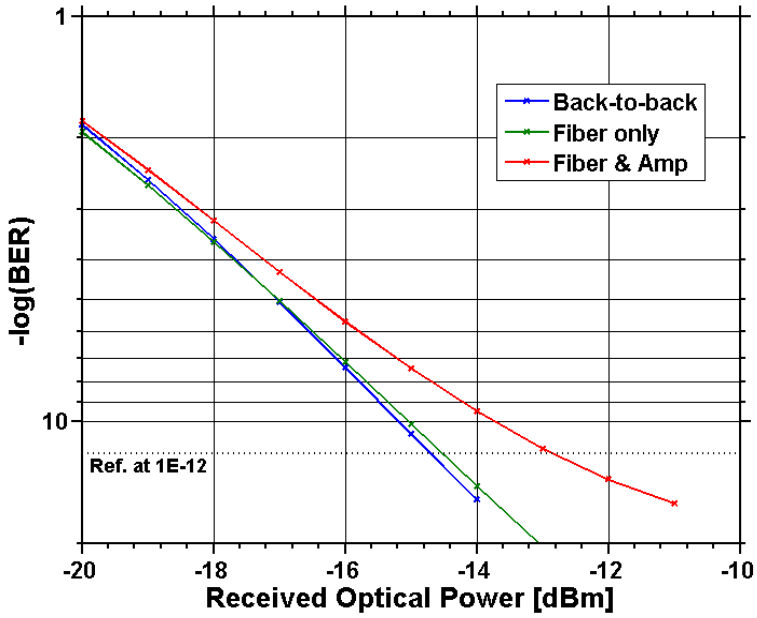
10 dB ER



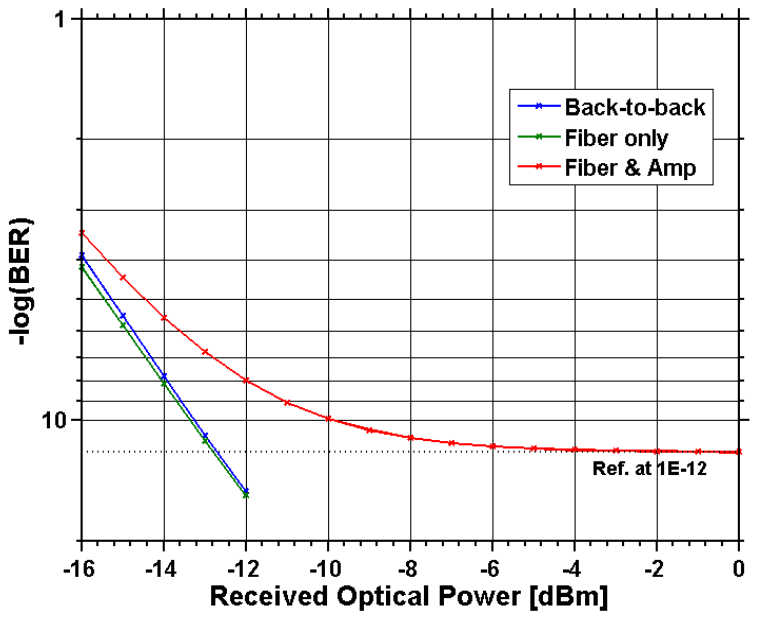
5.7 dB ER

30 km fiber length

BER Curves for 40 km Fiber Transmission



10 dB ER

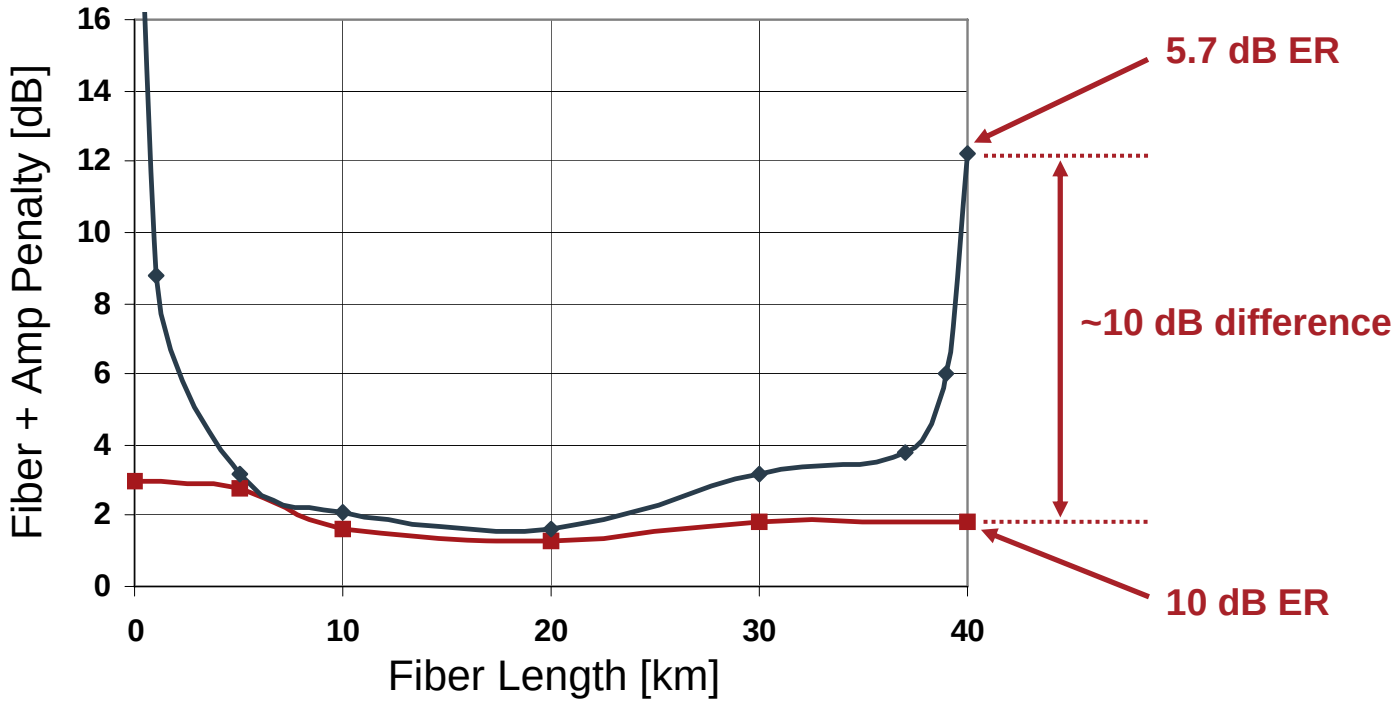


5.7 dB ER

40 km fiber length

Penalties for BER = 1E-12

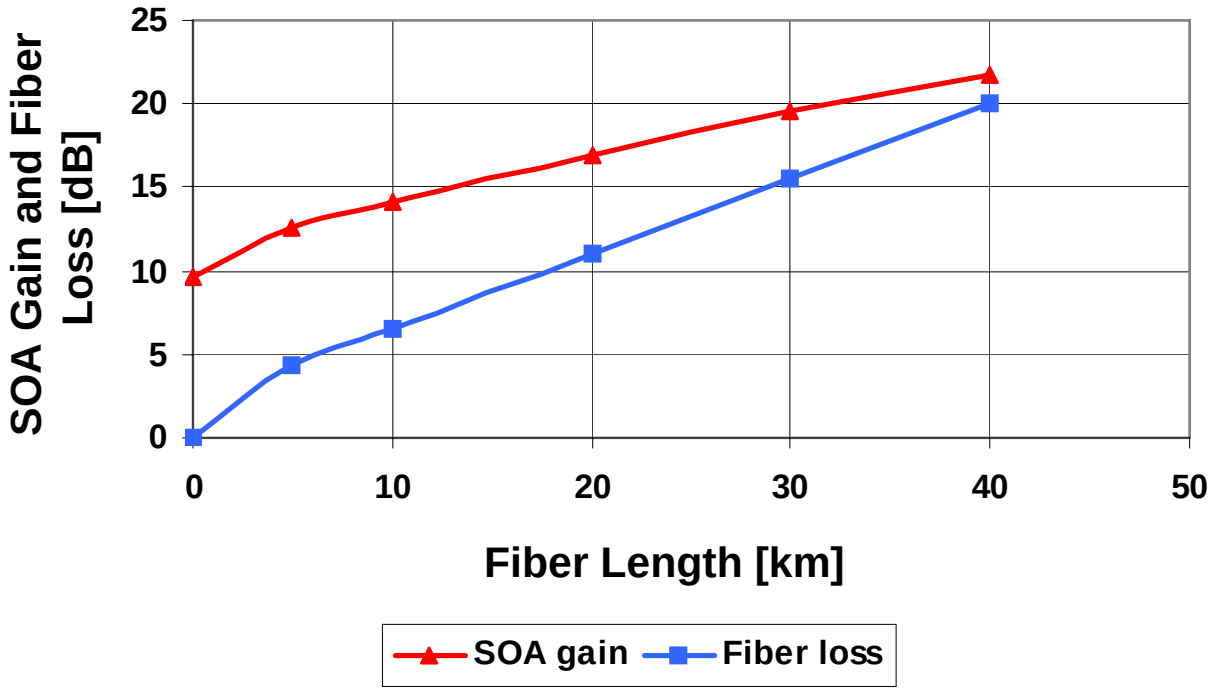
- Penalties from fiber transmission <0.3 dB (see BER graphs)
- Penalties are mainly determined by SOA amplification:
  - Penalty increase for shorter distances (NL eye distortions)
  - Penalty increase for longer distances (OSNR degradation)



Power Budget

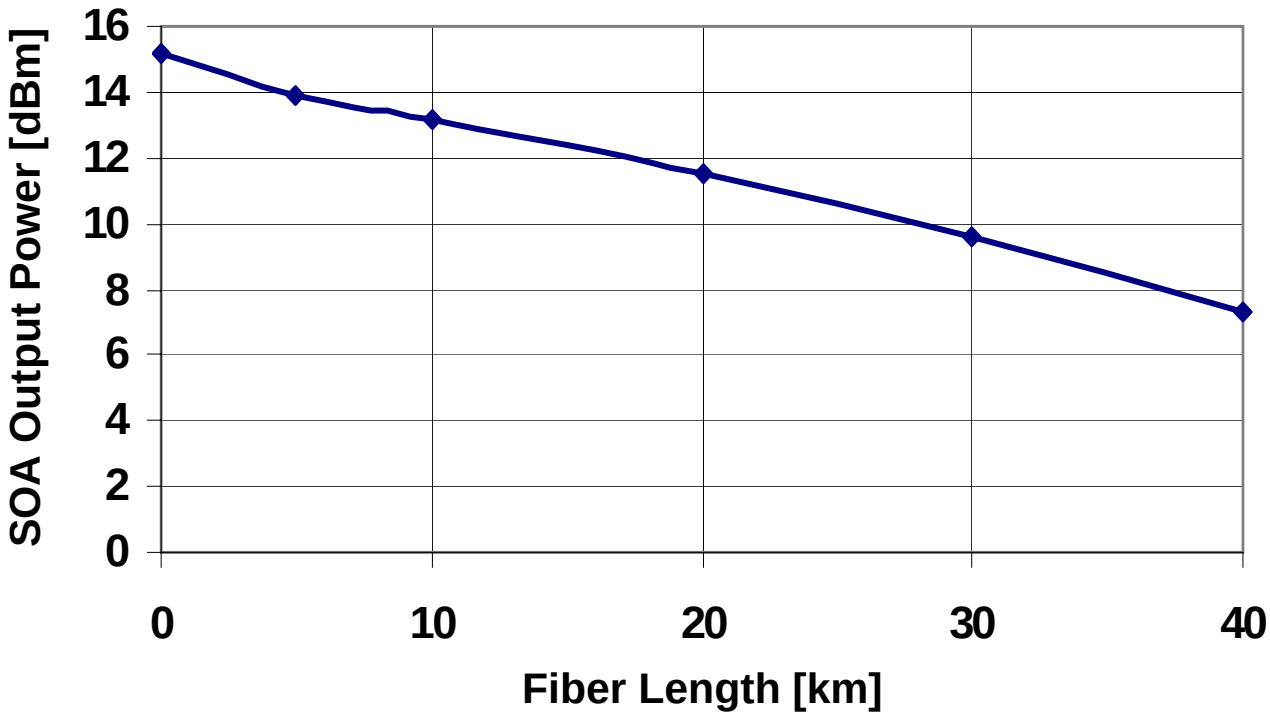
Fiber Loss and SOA Gain

- Measured (actual) SOA gain under operation
- The SOA gain always compensate for the fiber loss, even in the amplifier saturation region, for a fiber length up to 40 km



SOA Output Power

- With increasing span length the fiber loss is increasing faster than the SOA gain (which increases due to lower input power and less saturation) → SOA output power is decreasing with fiber length …

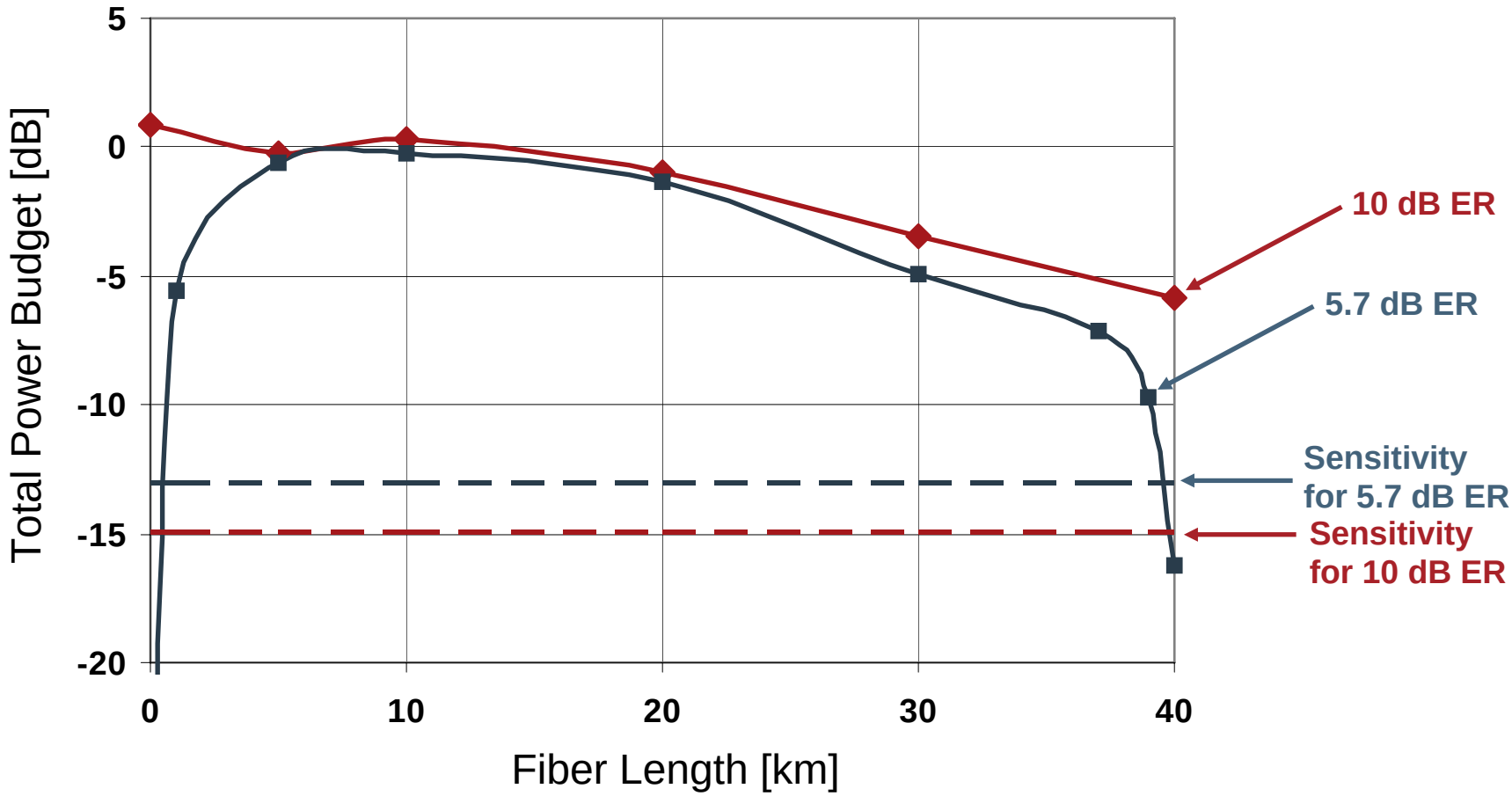


Overall Power Budget Example

- Example of power budget calculation for L= 5 km and Extinction Ratio of 10 dB.

Per lane	OMA [dBm]	LOSS [dB]
EAM OUT	3.2	
Aging+Accur.	2.2	1
MUX+splice	-0.5	2.7
Penalty fib+amp	-3.3	2.8
Fiber loss	-7.6	4.3
SOA Gain	5	-12.6
Aging+Accur.	3.5	1.5
DMUX+splice	-0.2	3.7
Total	**-0.2**	

Total Power Budget vs Fiber Length

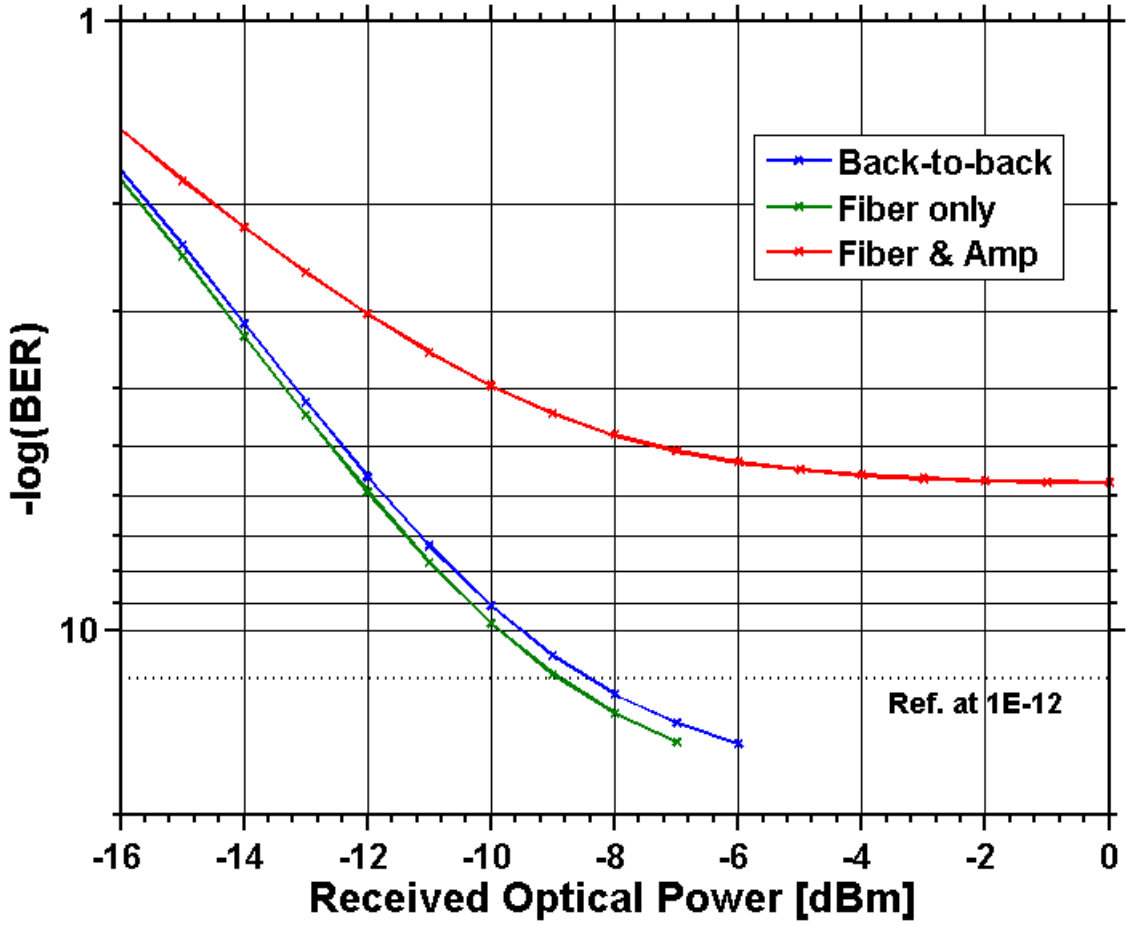


Summary

- Our simulations show that a 4x25 Gb/s PMD for 40 km at 1310 nm, with an SOA as a pre-amplifier in front of the optical demux, is feasible with EMLs having an extinction ratio of 10 dB at the transmitter
- Short links suffer from nonlinear distortions in the SOA
- Long links suffer from OSNR degradation
- For lower extinction ratios the required power at the receiver to achieve a BER of 1E-12 may exceed the available power budget !
  - For the given example a minimum extinction ratio of 6 dB was required
  - A transmit extinction ratio of 3 dB (e.g., as in 10GBase-R) resulted in error floors above the 1E-12 BER target, even for short links
  - Other data signals (e.g, PRBS 9, 64B/66B coded random data) may lead to other (e.g., higher) results regarding minimum extinction ratio
  - Other SOA characteristics may as well alter the findings

Backup

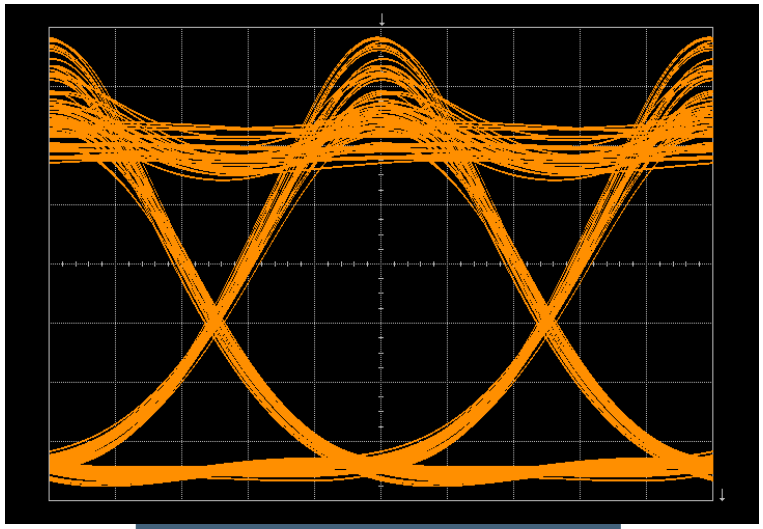
BER for 5 km Fiber Transmission with 3 dB ER



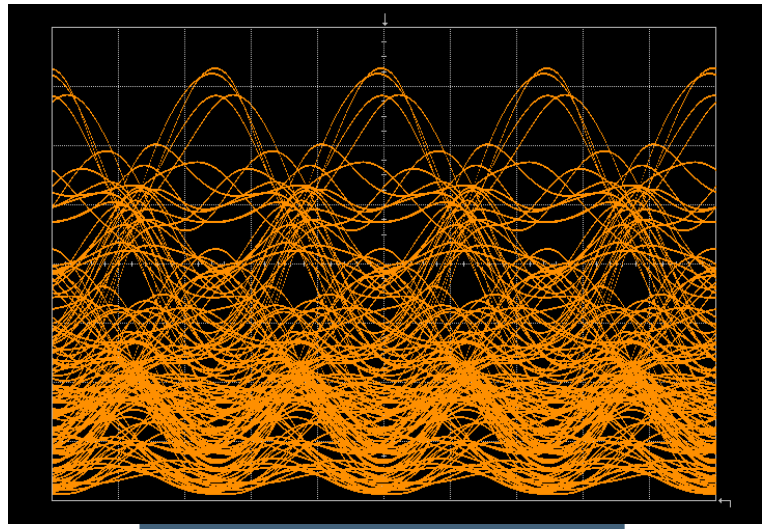
SOA before optical demux !

Floor at 5.76
Higher floors for longer fiber lengths.

25 Gb/s NRZ Transmission with EMLs



40 km @ 1310 nm



40 km @ 1550 nm

- Transmission at 1310 nm
  - Higher attenuation in the fiber (~0.45 dB/km)
  - Lower chromatic dispersion (~3 ps/nm/km @ 1310 nm)
- Transmission at 1550 nm
  - Lower attenuation in the fiber (~0.22 dB/km)
  - Higher chromatic dispersion (~17 ps/nm/km @ 1550 nm)

    → dispersion compensation definitely required for 4x25 Gb/s transmission @ 1550 nm !

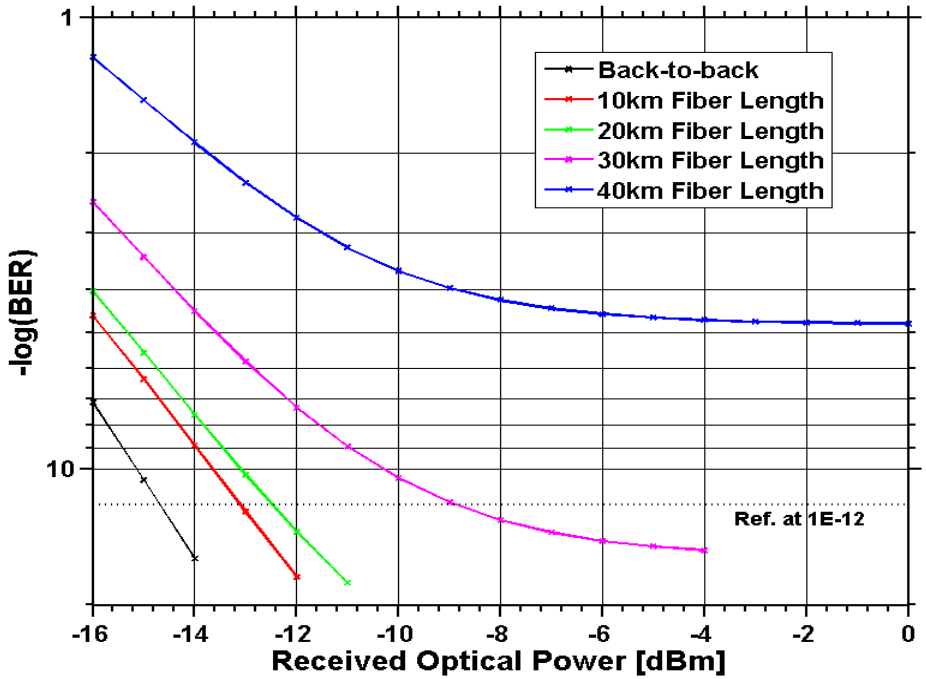
Simulation Details

- Electrical transmitter = 25.0 Gb/s PRBS 7, 25 GHz BW, 5th order Bessel
- Modulator driver = 25 GHz BW, 5th order Chebychev
- EML = +4.2 dBm output, 36 dB OSNR, EAM with 25 GHz BW
- Optical Mux/Demux = 70 GHz BW, 3rd order Gaussian, 25 dB crosstalk
- Optical Frontend = 25 GHz BW, 5th order Bessel, 0.8 A/W responsivity, 800 Ω TIA, 17 pA/Sqrt(Hz) thermal noise
- Electrical receiver = 35 GHz BW, 5th order RC filter
- SOA = Small-signal gain 23 dB, gain peak @ 1310 nm, gain BW 60 nm, saturation output power +8 dBm, noise figure 8.5 dB, spontaneous carrier lifetime 200 ps
- Optical fiber = Single mode fiber with 3.2 ps/nm/km dispersion at 1312 nm and dispersion slope of 0.058 ps/nm^2/km, attenuation 0.45 dB/km, NL index 2.4E-11 μm^2/mW, and effective area of 80 μm^2

4x25 Gb/s Reference

- J.P. Turkiewicz et al. demonstrated 4x25 Gb/s transmission at 1310 nm over 50 km SSMF using an SOA as an optical pre-amplifier (ECOC 2006, We3.P.153)
- This work was referenced as a proof for technical feasibility in cole_01_0407.pdf
- However, the paper does not specify
  - The extinction ratio at the transmitter
  - The input power into the fiber link (a booster amplifier was used @ Tx)
  - The input/output power at the SOA
  - The input/output OSNR at the SOA
  - The details of the electrical receiver
  - Power penalty of 0.6 dB is reported at BER=1E-9
  - etc.
- Hence this work does not represent a technical feasibility proof for the 40km 4x25 Gb/s PMD at 1310 nm !

SOA as a Pre-Amplifier after Optical Demux



Same SOA !
10 dB ER @ Tx

BER floor at ≈1E-5 for 40 km transmission

- BER curves for various transmission distances @ 1310nm with the SOA after the optical demux
- Lower input power into SOA due to DEMUX loss
  → Lower output OSNR after SOA
- No ASE filtering in DEMUX → higher ASE-signal & ASE-ASE beat noise
  → worse receiver performance