Feasibility Study on O-Band Coherent 800G-LR1&ER1

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IEEE 802.3dj May Interim meeting
San Antonio, Texas
May 15, 2013

Overview

802.3dj includes the following 800Gb/s objectives:

- over a single SMF in each direction with lengths up to at least 10 km (LR)
- over a single SMF in each direction with lengths up to at least 40 km (ER)

Recently, the group agreed to split the LR objective to include both 1- and 4-wavelength solutions:

- 4-wavelength solutions based on IMDD techniques
- 1-wavelength solutions based on coherent techniques

For LR applications, O-band coherent with KP4+BCH FEC is a good candidate that offers:

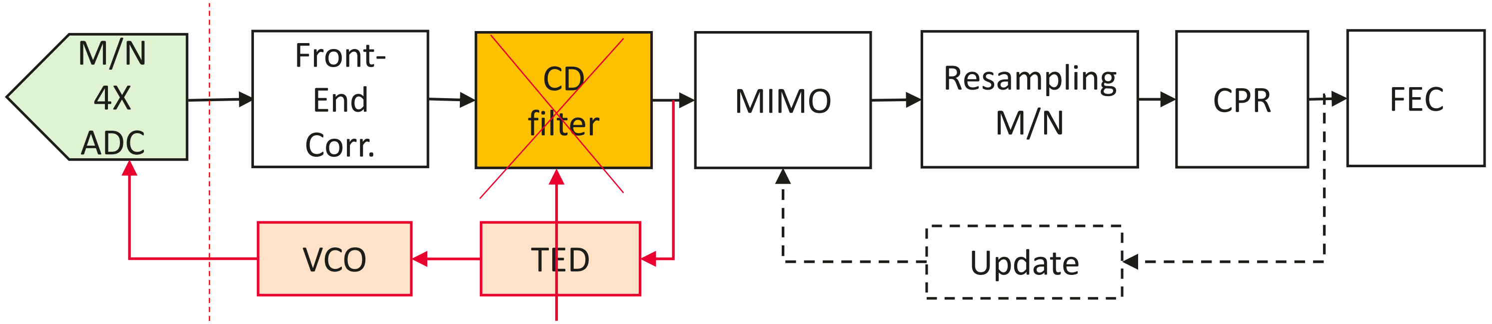
- Lower DSP complexity and power consumption: by removing CDC & allowing baud-rate sampling and equalization.
- Better future scalability: 1.6T/3.2T based on 2 or 4x 800LR with mature O-band CWDM technology

Some contributions mentioned that the interoperation between 800LR1 and 800ER1 may be useful, while O-band's higher link loss may be an issue

This contribution shows the feasibility of O-band 800LR1 & ER1 for the reference of the working group.

O-Band largely reduces the DSP power consumption

- About 50% of the power consumption of the equalization algorithm is used for CD compensation (CDC)



Mostly in Frequency domain （with FFT&IFFT）

- For O-band operation, the residual CD can be equalized in the MIMO without the CDC, thus reducing the DSP power.
- For ER application, the power saving is even more.

Modulation	Scenario	Parameter	C-band	O-band	
800G 16QAM (~124GB)	**10 km**	Total CD MAX	200ps/nm	-9ps/nm @1310nm	-60ps/nm @1270nm
		EQ Taps*	32 taps	2 taps	5 taps
	40 km	Total CD MAX	800ps/nm	-36ps/nm @1310nm	320ps/nm @1270nm
		EQ Taps*	126 taps	7 taps	26 taps

* Seiler, P.M., Georgieva, G., Winzer, G. et al. Toward coherent O-band data center interconnects. Front. Optoelectron. 14, 414–425 (2021).,

Energy-efficient transceivers in the O-Band

Fixed λ DFB laser

- Theoretically, at the same pump current, O-band laser has **~0.7dB higher power** than C band laser [1]
- O band lasers are more mature in the DCI market

DP-IQ Modulator

- Theoretically, at the same length of MZM, **V_π is lower for the O-band modulator** compared to the C-band one [2,3], thus more efficient EO effect and less power consumption in the O-band, e.g., a $V_\pi L$ value of 2.9~3.1 V·cm@C-band, and 2.0~2.3 V·cm@O-band [2]

Integrated coherent receiver

- O Band has the similar performance as C Band, the optical loss of O-band and C-band receivers are comparable; a total loss of 5dB@1310nm and 5.2dB@1550nm [4] considering the loss of grating coupler, waveguide, MMI and crossing

[1] Note that the ~0.7dB larger power in the O-band is calculated based on the photon energy difference between 1310nm and 1550nm as: 10*log(1.55/1.31)=0.7dB.
[2] F. Valdez, V. Mere, X. Wang, and S. Mookherjea, "Integrated O- and C-band silicon-lithium niobate Mach-Zehnder modulators with 100 GHz bandwidth, low voltage, and low loss," Opt. Express 31, 5273-5289 (2023)
[3] M. S. Alam et al., "Net 220 Gbps/λ IM/DD Transmssion in O-Band and C-Band With Silicon Photonic Traveling-Wave MZM," in Journal of Lightwave Technology, vol. 39, no. 13, pp. 4270-4278, July1, 2021
[4] Seiler, P.M., Georgieva, G., Winzer, G. et al. Toward coherent O-band data center interconnects. Front. Optoelectron. 14, 414–425 (2021).,

LR & ER link losses: O-band vs C-band

- According to Appendix I of Recommendation ITU-T G.695, an attenuation coefficient of 0.348~0.423dB/km @1311nm and 0.209~0.278dB/km @1551nm is considered for both LR and ER applications, and the corresponding channel loss could be calculated as:

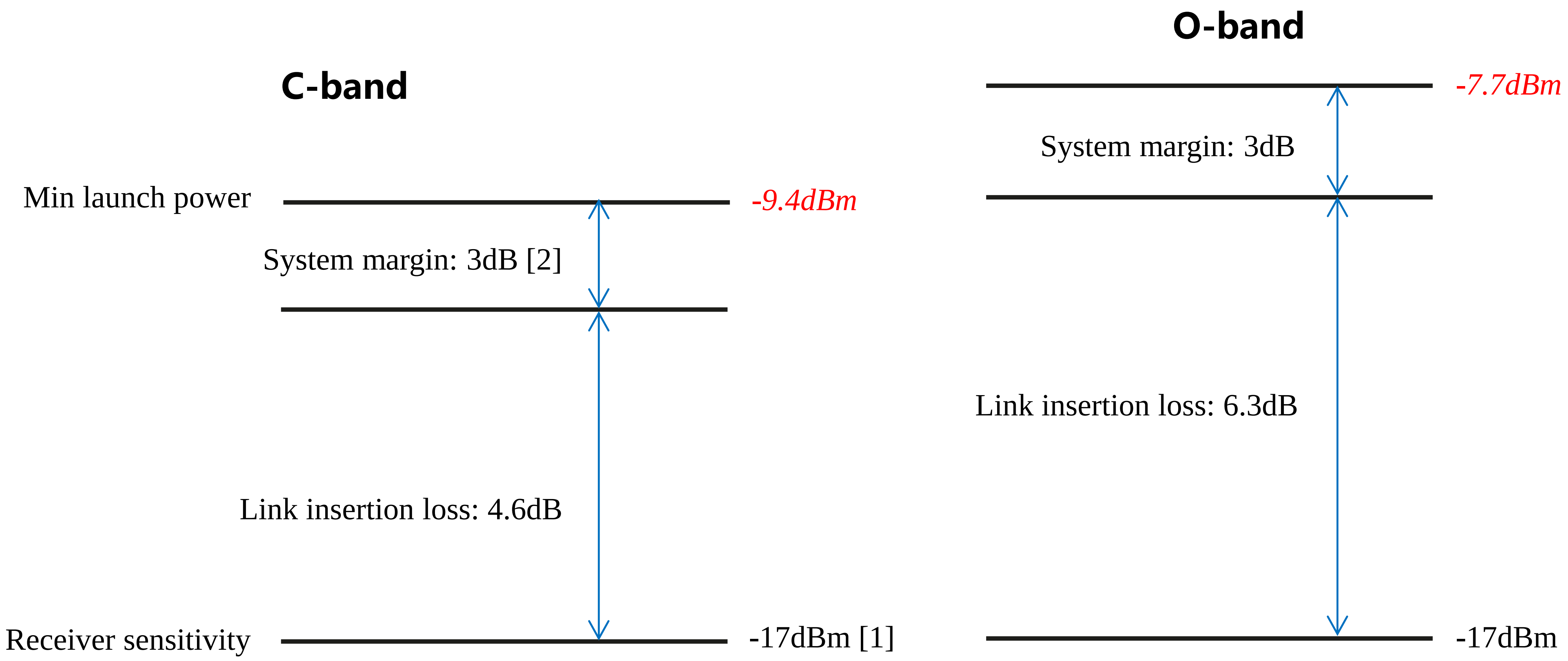
	Min attenuation Coefficient (dB/km)	Max attenuation Coefficient (dB/km)	Min channel loss (dB)		Max channel loss (dB)	
			LR (10km)	ER (40km)	LR (10km)	ER (40km)
@1311nm	0.348	0.423	3.48	13.92	4.23	16.92
@1551nm	0.209	0.278	2.09	8.36	2.78	11.12

- For 10km LR and 40km ER applications, channel insertion loss has been described as:

	C band	O band
LR 10km	4.6dB [1]	6.3dB [1, 2]
ER 40km	11dB [1], 14dB [3,4]	18dB [2,5,6]

Ref 1: P. Stassar et al., “Considerations on channel insertion loss for 10 km and 40 km 800G applications,” P802.3dj joint optics/logic ad hoc meeting, 27 April 2023
Ref 2: IEEE Std 802.3cn-2019
Ref 3: E. Maniloff et al., “Baseline proposal for 10 & 40 km 800 Gb/s objectives in 802.3dj,” Contribution maniloff_3dj_01a_2303, IEEE 802.3dj March 2023 Plenary Meeting
Ref 4: T. Williams et al., “Update to oFEC-based single lambda baseline for 10km and 40km objectives,” Contribution williams_3dj_01a_2303 a, IEEE 802.3dj March 2023 Plenary Meeting
Ref 5: 100G-LR1-20, 100G-ER1-30, 100G-ER1-40 Technical Specifications 100G Lambda MSA
Ref 6: 400G-ER4-30 Technical Specification 100G Lambda MSA Group

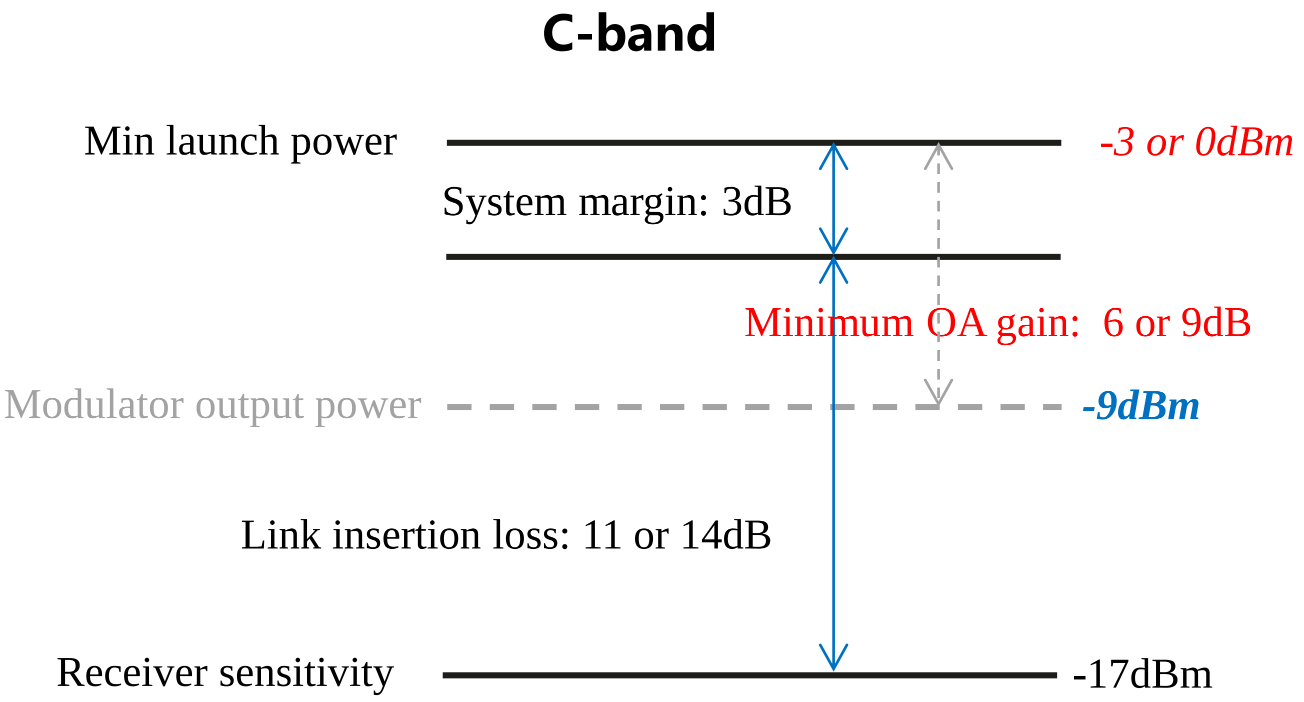
The link budget for LR1

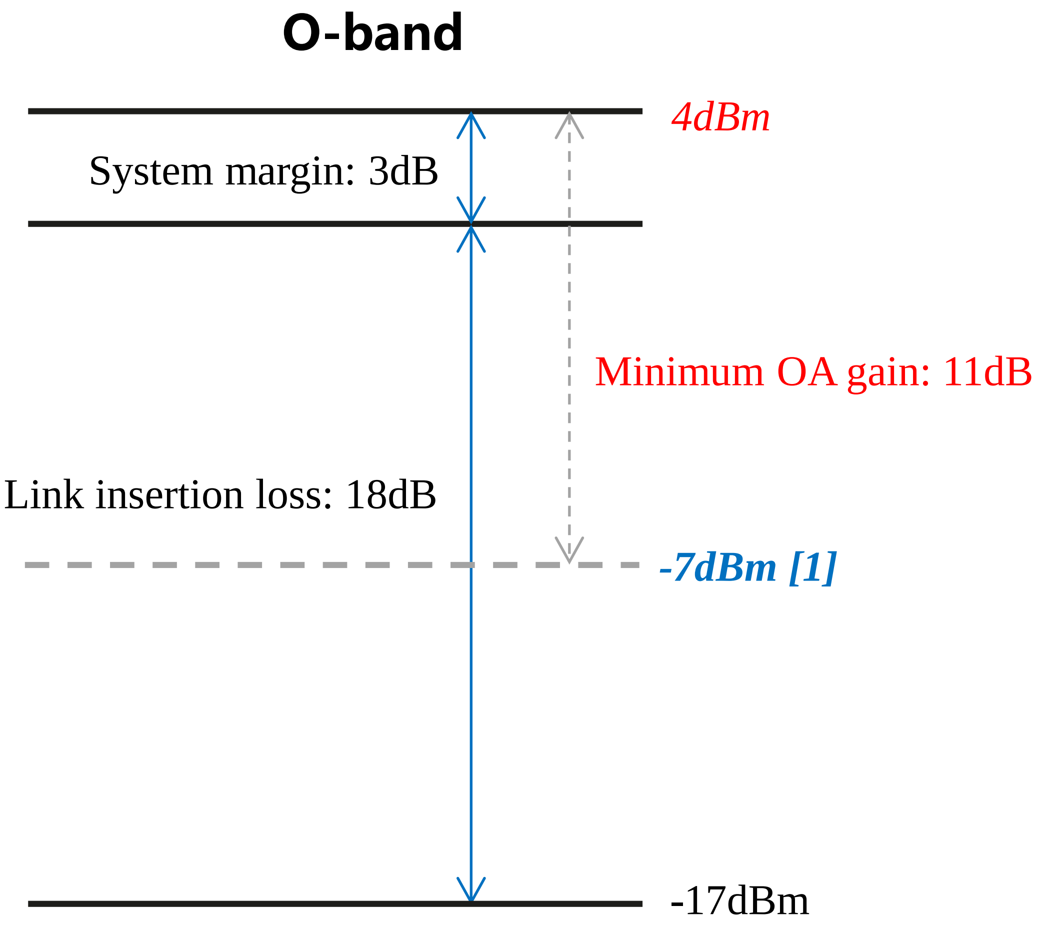


Note 1: E. Maniloff et al., “Baseline proposal for 10 & 40 km 800 Gb/s objectives in 802.3dj,” Contribution maniloff_3dj_01a_2303, IEEE 802.3dj March 2023 Plenary Meeting
Note 2: the system margin includes an allocation for connection and splice loss.

The link budget and optical amplifier requirement for ER1

	OA gain (dB)	OA output power (dBm)
O-band	11	4
C-band	6 or 9	-3 or 0



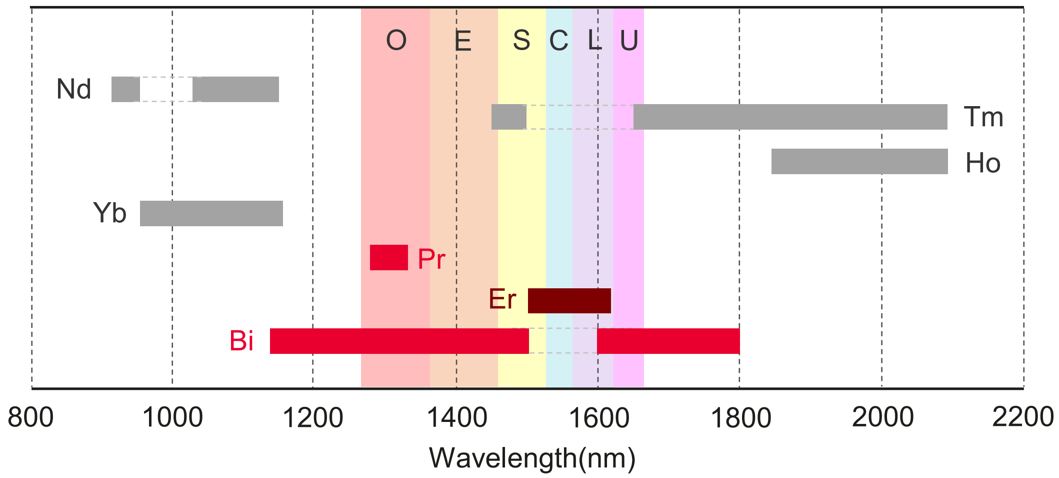


Note 1: the modulator **output power of O-band is assumed to be 2dB higher that C-band based** on the DFB laser output power difference mentioned in page 4 and the fact that the Auger effect is weaker in the shorter wavelength in the O-band (comparing with C-band).

Optical amplifiers in the O-band

Fiber-based optical amplifiers:

- Optically pumped based on active fiber with different doping elements
- For O-band: Praseodymium (Pr)-doped fiber amplifiers (PDFA) [1]and Bismuth (Bi)-doped fiber amplifiers (BDFA) [2]
- Different pump wavelength comparing with EDFA: 1020/1047nm (PDFA), ~1200nm (BDFA), 980/1480nm (EDFA)



Semiconductor optical amplifiers (SOA)

- Electrically pumped by injecting current
- Amplification wavelength determined by different composition and structure of the active region

Ref 1: Fiberlabs, Praseodymium-Doped Fiber Amplifier (PDFA).
Ref 2: Evgeny M Dianov, "Bismuth-doped optical fibers: a challenging active medium for near-IR lasers and optical amplifiers", Light: Science & Applications 1, e12, 2012.

Comparison of optical amplifiers in the O-band

<table>
<tr><th colspan="2"></th><th colspan="6">Fiber Based</th><th colspan="4">Semiconductor Based</th></tr>
<tr><th colspan="2"></th><th colspan="2">PDFA@O-band</th><th colspan="2">BDFA@O-band</th><th colspan="2">EDFA@C-band</th><th colspan="2">SOA@C-band</th><th colspan="2">SOA@O-band</th></tr>
<tr><td colspan="2">NF (dB)</td><td colspan="2">≤7 [1]</td><td colspan="2"><6 [2]</td><td colspan="2">~4</td><td colspan="2">~7 [3]</td><td colspan="2">~7 [3]</td></tr>
<tr><td>Theoretical optical to optical transfer efficiency</td><td>Pump power consumption</td><td>Medium (~78%)</td><td>Low</td><td>High (~90%)</td><td>Medium</td><td>Medium (~63%)</td><td>Low</td><td>/</td><td>Low</td><td>/</td><td>Low</td></tr>
<tr><td colspan="2">Total power consumption [4]</td><td colspan="2">Medium</td><td colspan="2">Medium</td><td colspan="2">Medium</td><td colspan="2">Low</td><td colspan="2">Low</td></tr>
<tr><td colspan="2">Cost</td><td colspan="2">High [5]</td><td colspan="2">High [5]</td><td colspan="2">Low</td><td colspan="2">Low</td><td colspan="2">Low</td></tr>
<tr><td colspan="2">Technique maturity</td><td colspan="2">Low</td><td colspan="2">Low</td><td colspan="2">High</td><td colspan="2">High</td><td colspan="2">High</td></tr>
<tr><td colspan="2">Others</td><td colspan="2">Different host glass （fluoride glass）</td><td colspan="2">Precise fiber fabrication control</td><td colspan="2">/</td><td colspan="4">Nonlinearity, polarization dependent gain</td></tr>
</table>

Ref 1: https://www.fiberlabs.com/products/product_details/o-band-pdfa-bench-top/
Ref 2: https://www.ofsoptics.com/wp-content/uploads/O-Band-Amplifier-web.pdf
Ref 3: https://www.thorlabschina.cn/newgrouppage9.cfm?objectgroup_id=3990
Note 4: The total power consumption could be calculated by the product of the optical to optical transfer efficiency and the pump power consumption.
Note 5: The current high cost of PDFA and BDFA is due to the current immaturity of these two fiber fabrication techniques and low production volumes of the pumps.

Optical amplifiers in 40km ER

- Assume the same doping concentration of active fiber and the same pumping efficiency
- Take EDFA @1550nm as an example, and add 4dB margin to accommodate manufacturing non-uniformities
- The simulated active fiber length and pump power of O-band and C-band OA requirement in ER are calculated as:

	OA requirement	Active fiber length(m)	Pump power (mW)
O-band requirement	15dB gain, 8dBm output power	4.8	62
C-band requirement	10dB gain, 1dBm output power or 13 dB gain, 4dBm output power	3.2 or 4	38 or 52

Summary

- O-band operation enables energy-efficient optical transceivers in coherent LR1&ER1 applications.
- The use of O-band optical amplifiers (such as PDFA, BDFA, SOA) helps meet the loss budget for ER1.
- The cost and power consumption of O-band (PDFA, BDFA, SOA) can become comparable with C-band (EDFA, SOA) as the O-band optical amplifier ecosystem matures.

Thank you!