10G EDC For Extended Reach in SMF: Both Down- & Up-stream

Making next-generation networks a reality.

IEEE 802.3 Extended EPON Study Group November Plenary

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Agenda:

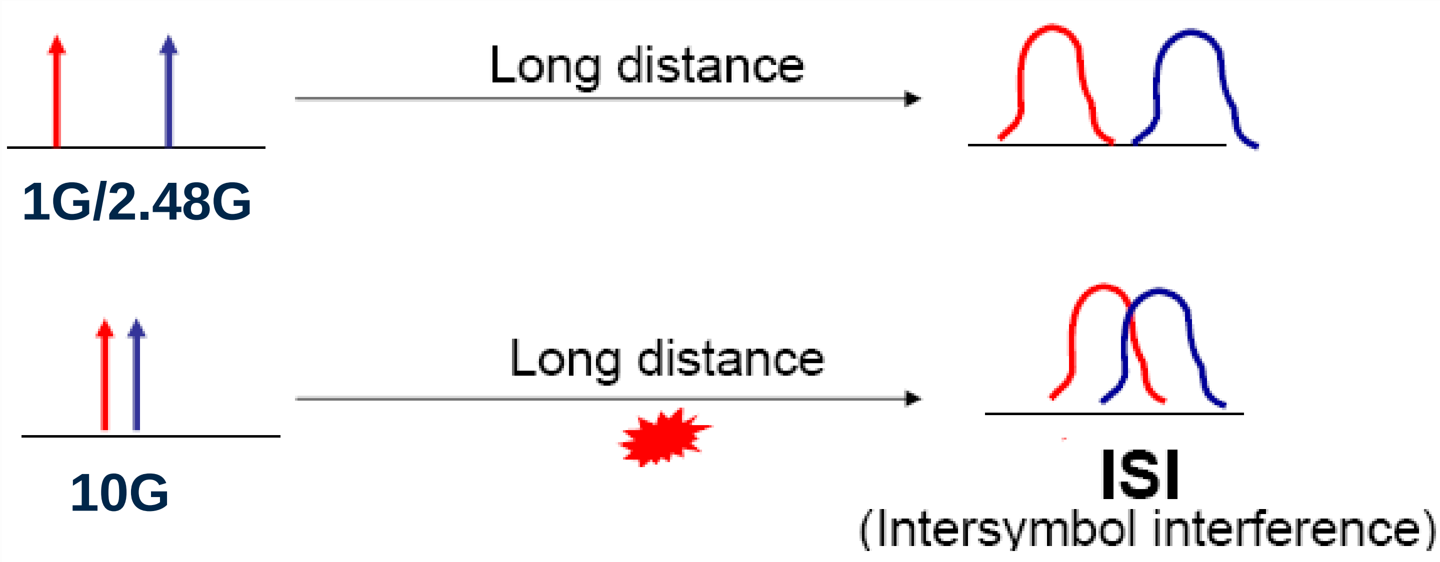
PURPOSE: ***EDC support technology feasibility for Extended EPON in higher link budget with longer fiber reach.***

- ***EDC basics & rationalness***
- ***EDC structures and standards***
- ***EDC implementation examples***
  - *Extend 10G reaches in the range from 40-120km*
  - *40G (4x10G) WDM/TDMA - PON*
  - *Additionally fast settling time with burst-mode*
  - *And many many more….*

Mature enough, EDC reach field-proven mass deployment including SMF space

EDC takes care of one of critical Challenges for Extended EPON

- **Challenge to upgrading to higher rates such as 10G - *dispersion***

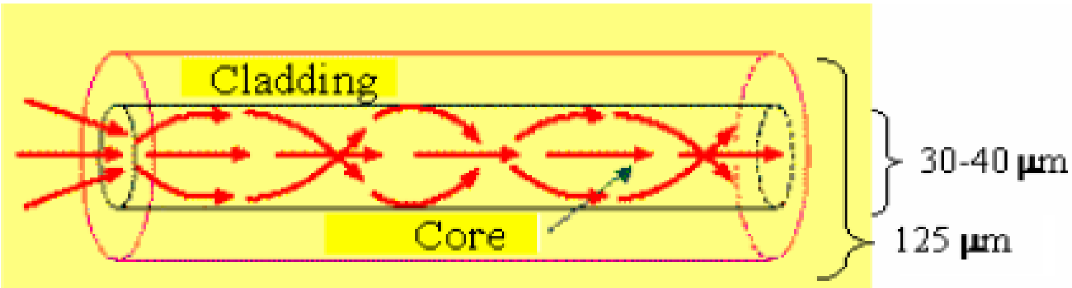


Solution: Electronic Dispersion Compensation (EDC)

- ✓ **Compensates for optical dispersion in the electrical domain by filtering and algorithmic methods**
- ✓ **Applicable to various mediums, not limited to fiber**

EDC Addresses 3 Types of Dispersions

Modal Dispersion

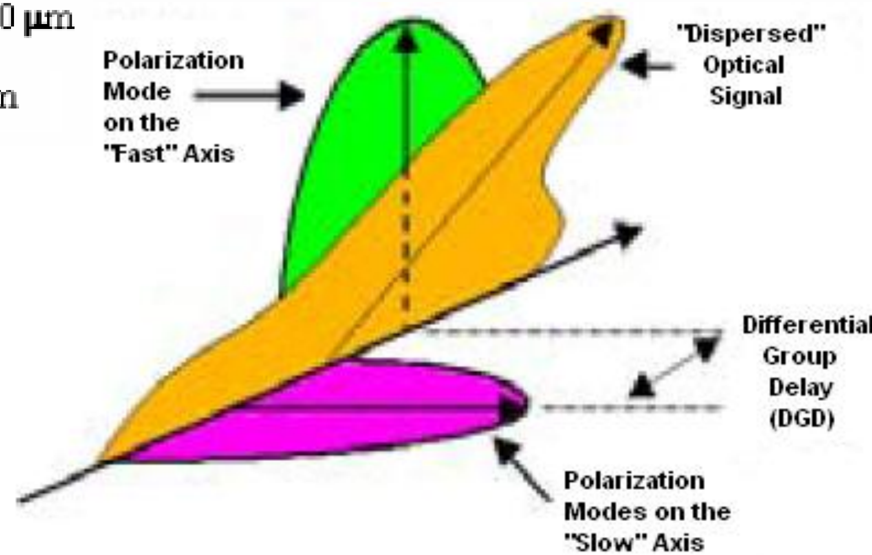


Modal Dispersion, MMF, enterprise

Chromatic Dispersion

Chromatic Dispersion
SMF, Metro

Polarization Mode Dispersion



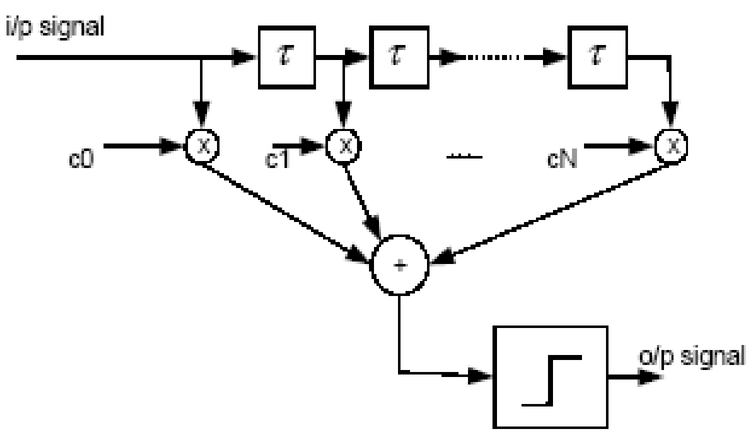
Polarization Mode Dispersion
SMF, extended Metro / LH

Source: Kirkpatrick et al., Intel Tech. J. **8**, 83 (2004)

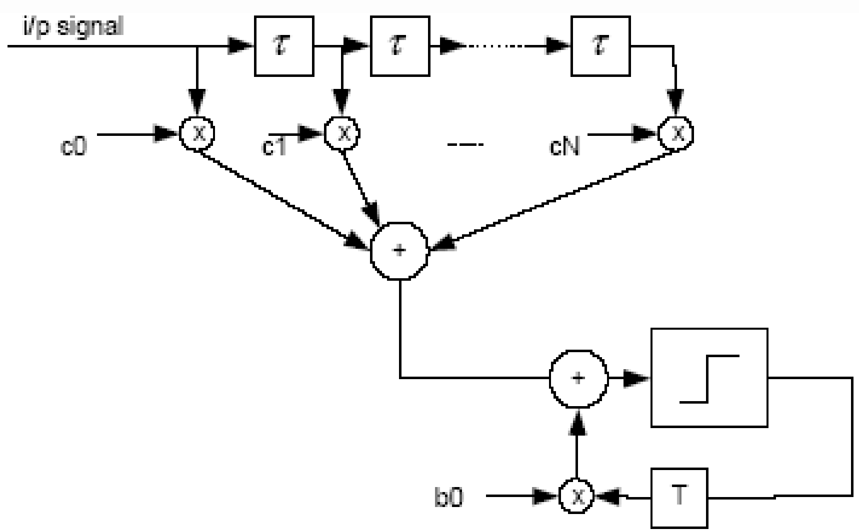
Well-known Classical EDC Implementations

Analog FFE/DFEs are current mainstream deployment

- FIR - Analog or Digital Implementation
- DFE – Analog or Digital Implementation
- MLSE - Digital Implementation is only practical
  - *MLSE = Maximum likelihood sequence estimation*
  - Relatively complex and power hungry – less usable



Linear Feedforward Equalizer (FIR)



Decision Feedback Equalizer

Underlying Reasons to deploy EDC

- *Extend fiber reach to as long as 2400ps/nm w/o optical compensation;*
- Lower the cost, and footprint;
- Low power;
- Simplify network deployment;
- Relaxes network reconfiguration;
- Allow cheaper optics and help power budgets;
- Silicon CMOS driven market economy and scaling;
- *Versatile tool works efficiently with others such as FEC*
- *Most importantly, FFE/DFE algorithm handle also burst-mode.*

One important feature for extended EPON is to achieve longer reach such as 40-100km

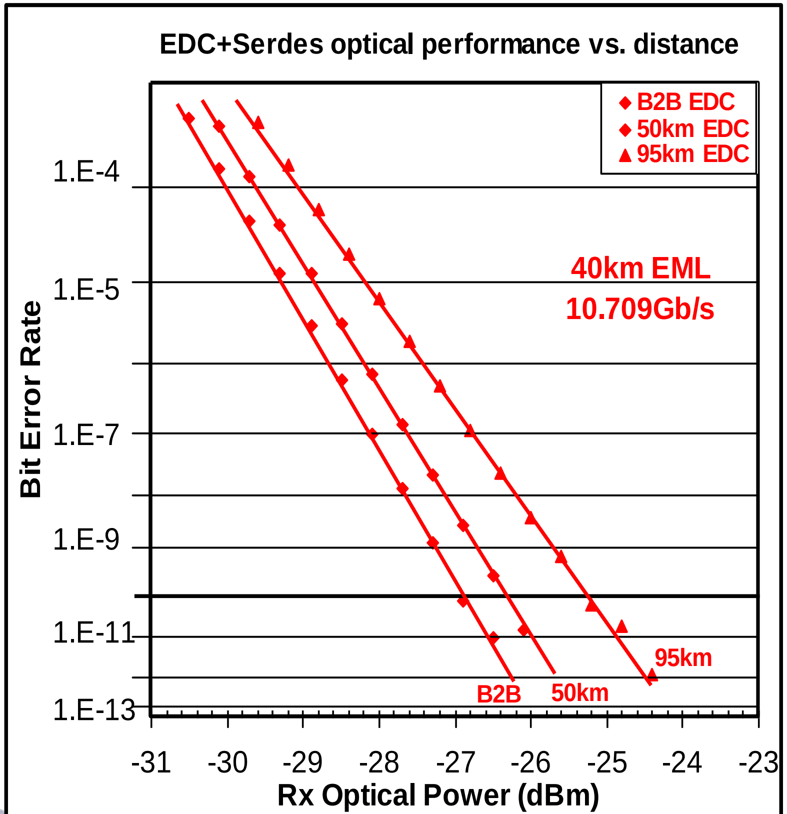
EDC as cost-efficient tool to improve dispersion tolerance for range of 40-300km

Multi-vendor interoperable 10G EDC Standards

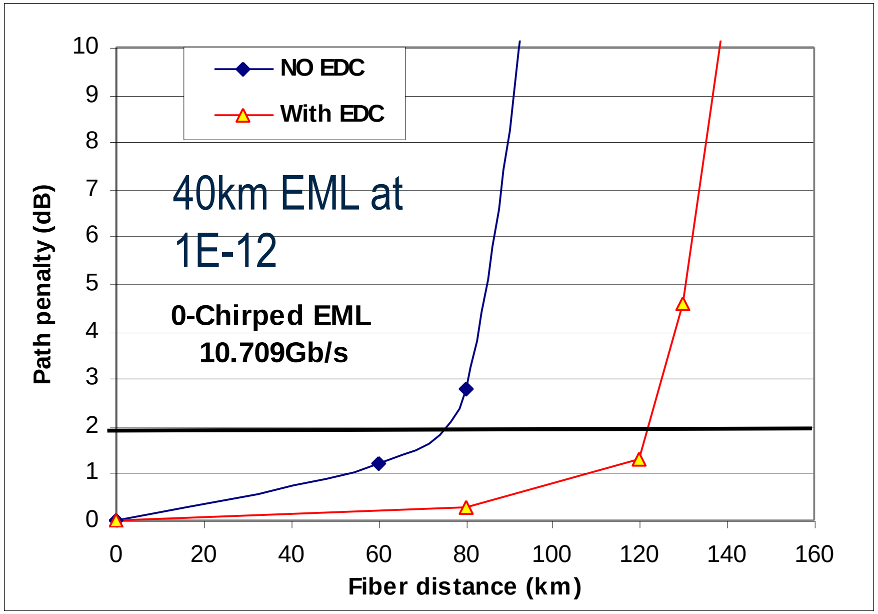
	10GbE LAN	10GbE LAN with EDC	10G SONET IR / LR	10G SONET LR/VR with EDC
Standard	IEEE 802.3ae SR	IEEE 802.3aq LRM	GR.253 LR (IR) 802.3ae ER, ZR	ITU SG15 G.959.1 VR(LR)
Max Distance	**26/33m**	**220m (300m)**	**80(40)km**	**120(80)km**
Dispersion	-	-	1600ps/nm (800ps/nm)	2400ps/nm (1600ps/nm)
Wavelength	850nm	1310nm	1550nm	1550nm
Fiber type	FDDI/OM1	FDDI/OM1	SMF-28	SMF-28
	62.5/125μm	62.5/125μm	9μm	9μm
Path Penalty	-	-	2dB	2dB
BER	10^{-12}	10^{-12}	10^{-12}	10^{-12}
Module Type	Xenpak/X2, XFP	X2, XFP, SFP+	300-pin, XFP, SFP+	300-pin, XFP, XFP-E, SFP+

EDC implementation examples:
#1: 0-Chirp EML TX (DS)

- **There are many EDC-enabled applications to achieve longer distance aimed for higher link budget.**
  - TX baseline: 0-chirped EML rated for 40km
  - Extendable to >80km



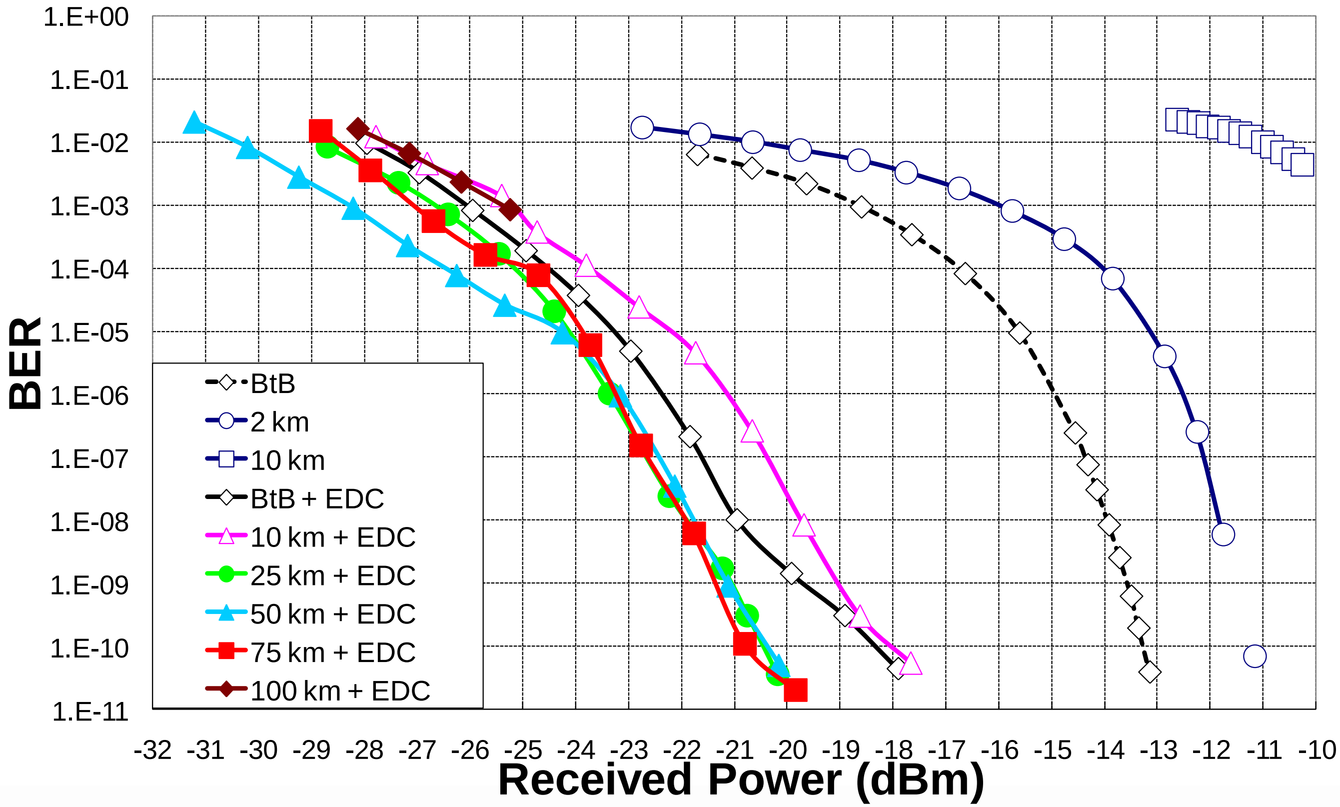
Disp. penalty with and w/o EDC



Source: Chang, OFC'07, NWA2

EDC implementation examples:
#2: Low-bandwidth TX optics (DS)

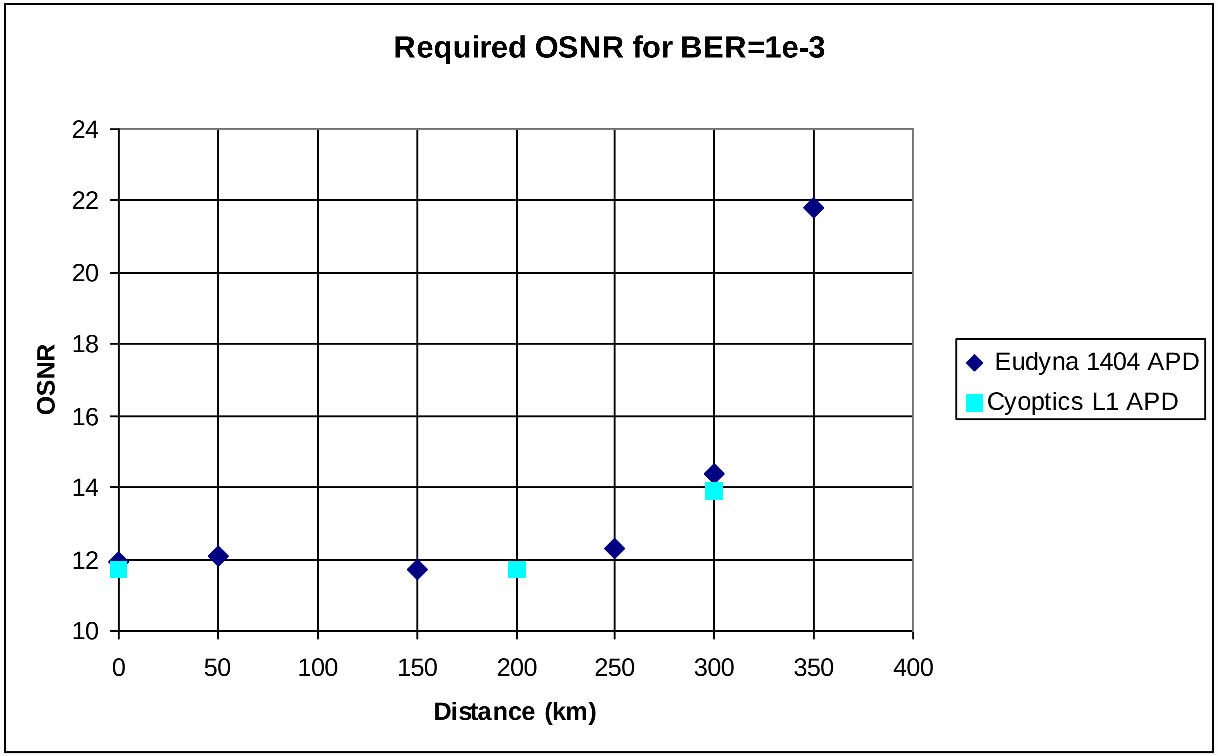
- **TX baseline: Un-cooled 1550nm DML (use less complex driver)**
  - Low bandwidth TX
  - Extendable to over 75km for pre-FEC BER of 1.1E-3.



Source: P. Chanclou, ECOC'09, Postdeadline paper

EDC implementation examples:
#3: CML TX (DS)

- **TX baseline: CML (chirp managed laser).**
  - The reference Tx is rated for 200km (~3400ps/nm)
- **Extendable to 300km (~5100ps/nm) at 15dB OSNR within 2dB OSNR penalty.** At pre-FEC BER of 1.E-3.

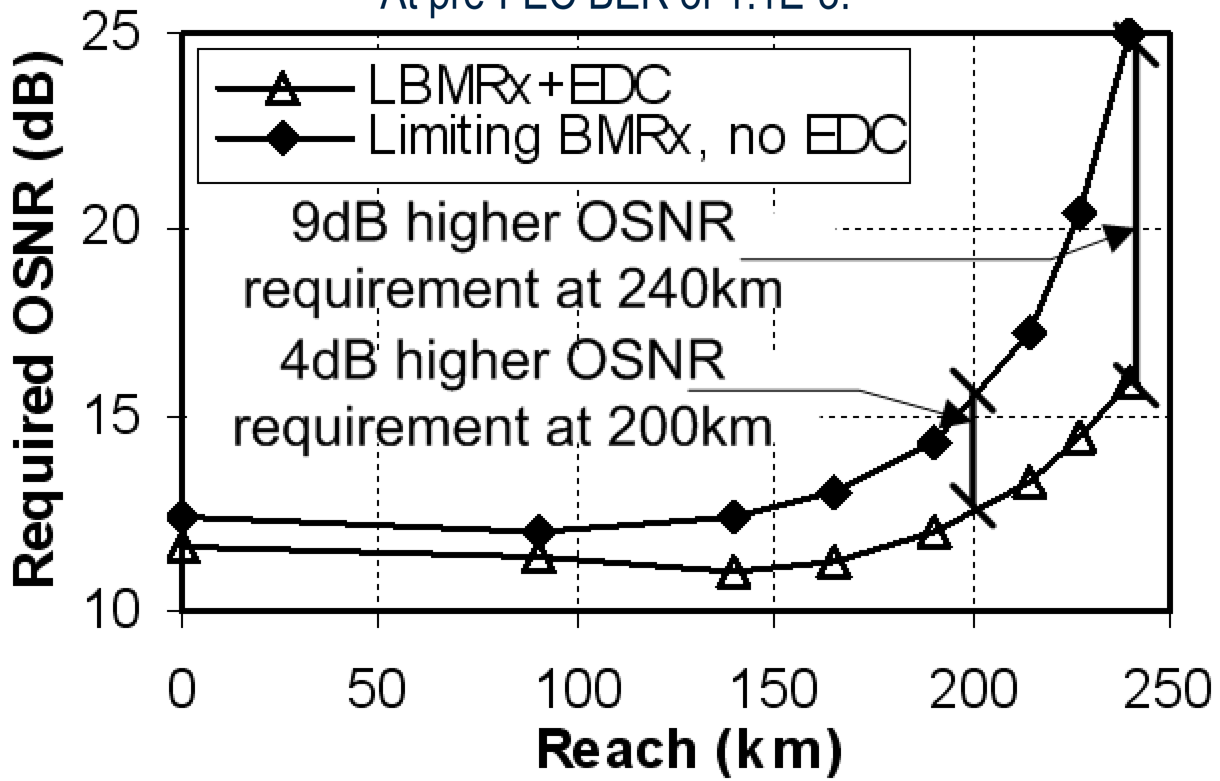


Source: Zheng, IEEE/LEOS Topical'08, paper#: TuD2.2

EDC implementation examples:
#4: Standard 1550nm EML TX (US)

- **TX baseline: standard 1550nm EML.**
  - With the aid of new linear burst-mode ROSA.
- **Extendable to 200km for 2dB OSNR penalty.**

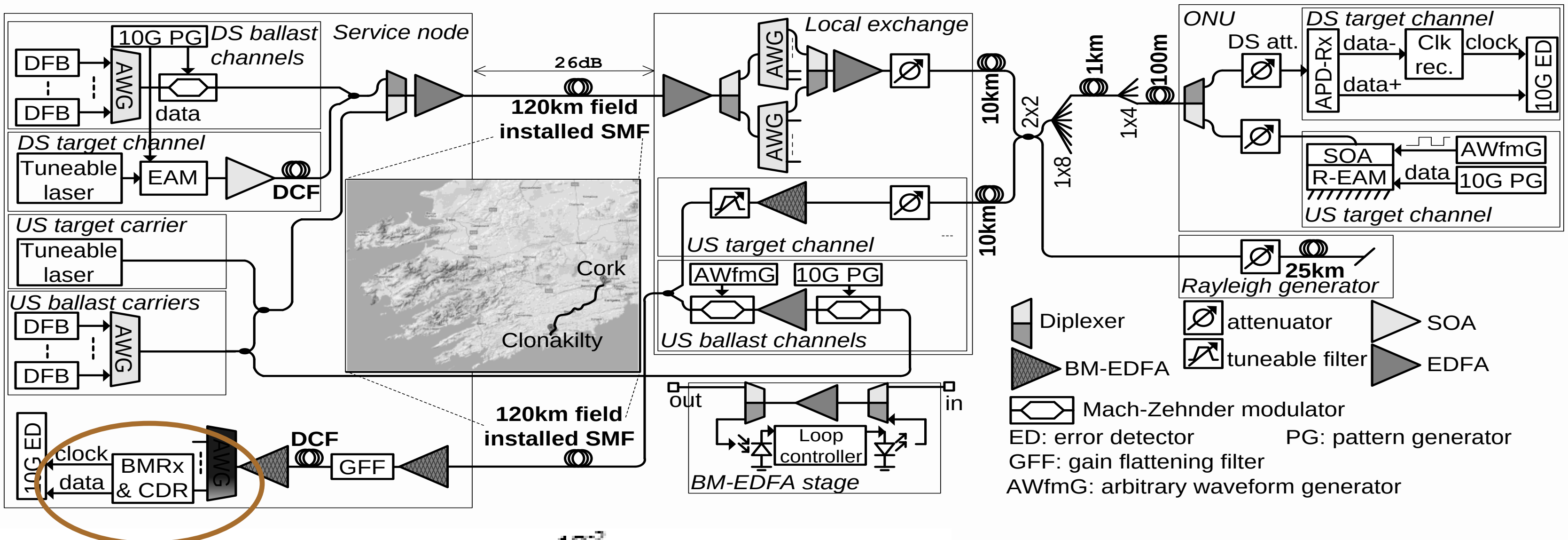
At pre-FEC BER of 1.1E-3.



Source: ECOC'2011 P Ossieur Postdeadline Paper#: Th.13.B.4

EDC implementation examples :
#5: EDC for metro access

- **EDC/FEC help achieve 32x256=8192 splits over 124km fiber for Std EML TX.**



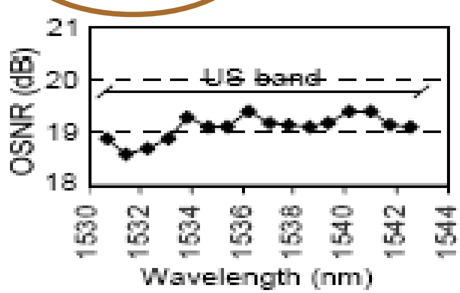


Fig. 4c Worst-case US OSNR.

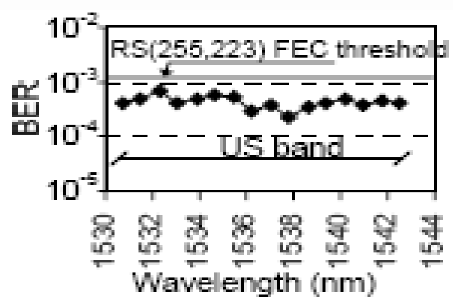


Fig. 4d Worst-case US BER.

At pre-FEC BER of 1.1E-3.

Using RS(255, 223) FEC with 1.2×10^{-3} input BER.

Source: **OFC'2010 post-deadline paper (PDPD8)**

Summary:

- **EDC are field proven cost-effective solution in mass deployment for Telecom and Datacom**
  - Target various EDC enabled reach extension applications.
- **EDC can be usable for extended EPON for both down- and upstream to support higher link budget with fiber distance beyond 20km.**
  - Target dispersion-limited links beyond 20km with either DML or EML.
- **Suggest Study Group to consider link budgets considering 40km, 60km or even 100km reaches.**

EDC support Extended EPON technology feasibility in higher link budgets for longer fiber reaches.

Further References
- Running continuous-mode for DS

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- Iannone et al.; "*Bi-directionally amplified extended reach 40Gb/s CWDM-TDM PON with burst-mode upstream transmission*"; OFC'2011, Postdeadline Paper# PDPD6: http://www.cyoptics.com/files/OFCPD2011.pdf
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- Reichmann et al.; "*A Symmetric-Rate, Extended-Reach 40Gb/s CWDM-TDMA PON with Downstream and Upstream SOA-Raman Amplification*"; Submitted to JLT.
- Yin et al.; "*Experiments on 10Gb/s Fast Settling High Sensitivity Burst-mode Receiver with On-Chip Auto-Reset for 10G-GPONs*" Submitted to OFC'12.