Optimized Optics Solutions Always Win

What Building-to-Building Optical Interconnect
Will Enable Gigawatt Scale Training Clusters?

Th3B.5 / OFC 2025

Chris Cole / Lucidean, Inc.

OFC50

Optimized Inter-building Optical Link Requirements

- AI compute clusters spread across multiple buildings
  - Synchronous operation and data sharing across GPUs
  - Dedicated communication fabric between GPUs
- Large radix: ≤1.6T/port in 100T switch
- Reach: ≥10 km
- Fungibility: mix long (≥10km) and short (0.5-2km) reach ports
- DWDM and/or Parallel
- Low Power
- Low Latency
- Low Cost
- Applepie

Existing Datacom Optical Interconnect & Panel Focus

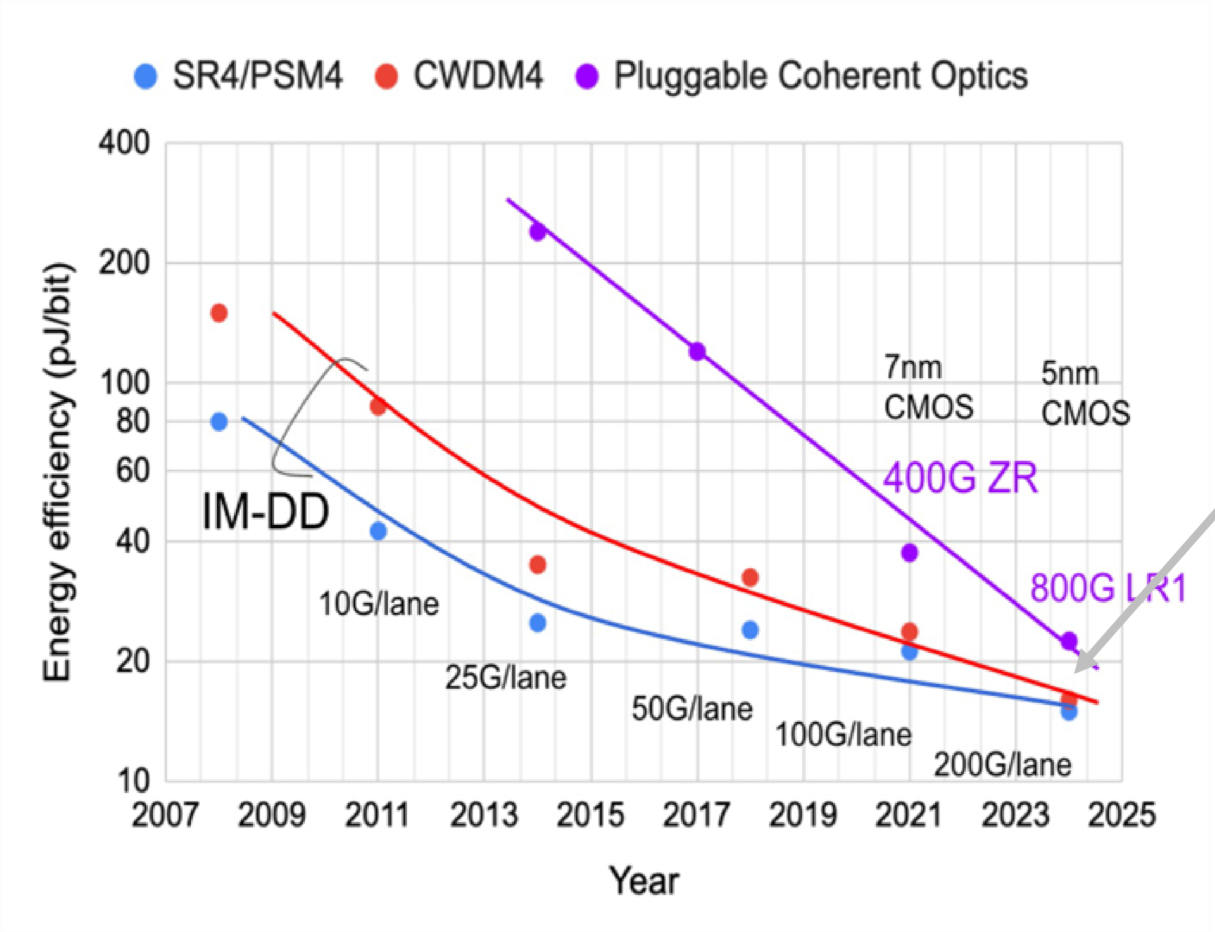
Ethernet Rate Gb/s	Reach m		Reach km			
	≤100	200-500	2	10	20-40	≥80
10	Cu	SR	VSR (ITU-T)	LR	ER	ZR
40/50	Cu, SR	PSM4	FR	LR	ER	ZR
100	Cu, SR	PSM4	CWDM4	LR, 4WDM	ER, 4WDM	Coh ZR
200	Cu, SR	DR	FR	LR	ER	Coh ZR
400	Cu, SR	DR	DR, FR	LR	ER	Coh ZR
800	Cu, SR other TBD	DR, FR	DR, FR	LR, Coh LR	Coh ER	Coh ZR
1600		DR	DR	???	???	Coh ZR

Existing & Boldly Predicted Datacom Optical Interconnect

Ethernet Rate Gb/s	Reach m		Reach km			
	≤100	200-500	2	10	20-40	≥80
10	Cu	SR	VSR (ITU-T)	LR	ER	ZR
40/50	Cu, SR	PSM4	FR	LR	ER	ZR
100	Cu, SR	PSM4	CWDM4	LR, 4WDM	ER, 4WDM	Coh ZR
200	Cu, SR	DR	FR	LR	ER	Coh ZR
400	Cu, SR	DR	DR, FR	LR	ER	Coh ZR
800	Cu, SR other TBD	DR, FR	DR, FR	LR, Coh LR	Coh ER	Coh ZR
1600	Cu, SR other TBD	DR, FR	DR, FR	**Coh LR**	**Coh ER**	Coh ZR

800G IMDD vs. Coherent Power

Xiang Zhou, Google, “IM-DD vs. Coherent in Datacenters: A Revisit in 2025”, OFC’25 M4C.1



- Power

  P_{LR1} = ~2x P_{LR4}

- Cost

  (from separate data)

  C_{LR1} = ~2x $_{LR4}$

- Are we stuck with 2x penalty for coherent inter-building links?

Coherent Power and Cost Drivers

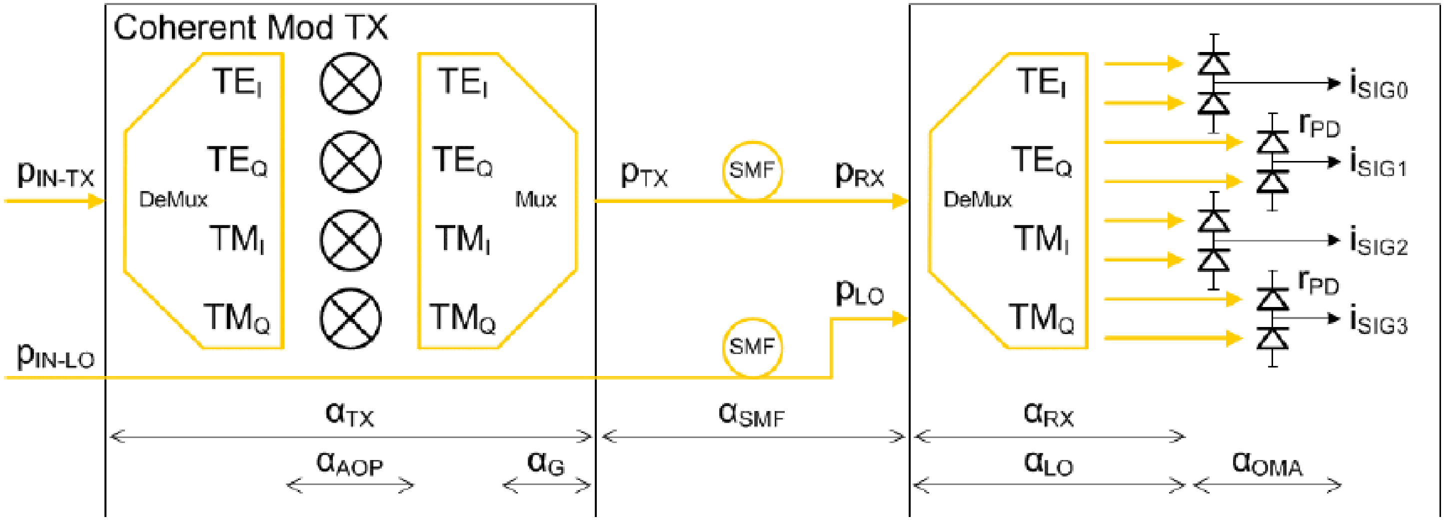
- Coherent DSP requirements
  - Long reach support
  - Phase & Frequency tracking
  - CD & PMD compensation
  - Oversampling
- Coherent Tx CW and RX LO requirements
  - Precise wavelength control
  - Cooled operation
- Can inter-building link requirements be relaxed to reduce power and cost?
  - Simplified DSP
  - Remote Oscillator (RO)

Can Coherent DSP Power Approach IM-DD ?

Xiang Zhou, Google, “IM-DD vs. Coherent in Datacenters: A Revisit in 2025”, OFC’25 M4C.1

- Remove independent CD compensation
  - Optimize toward 10km reach
  - C-band to O-band wavelength
  - |CD| <30ps/nm over 1291 to 1337 nm
- Separate polarization recovery (MIMO EQ) from bandwidth (BW) equalization
  - A single- or few-tap 4x4 real-valued MIMO for joint polarization recovery, I/Q skew correction, and partial CD/BW equalization
  - Real-valued lower-power SISO FFE as the major bandwidth equalizer
- Develop lower-power baud-rate sampling and equalization technology
- Details in Xiang Zhou et al, ‘Beyond 1 Tb/s Intra-Data Center Interconnect Technology: IM-DD OR Coherent?’ JLT 2019.

Coherent (CH) w/ same TX Signal & LO Path



Summer Topicals 2020 Virtual Conference
Tutorial TuA2.2 10:45AM – 11:30AM MDT
14 July 2020
Chris Cole

$p_{IN\text{-}TX} = 4\ \alpha_{LS}\ \alpha_{TEC}\ p_0$

$p_{TX} = \alpha_G\ \alpha_{AOP}\ \alpha_{TX}\ p_{IN\text{-}TX}$

$p_{IN\text{-}LO} = 4\ (1 - \alpha_{LS})\ \alpha_{TEC}\ p_0$

$i_{SIG} = \alpha_{OMA}\ r_{PD}\ 2\ \sqrt{(p_{PD\text{-}RX}\ p_{PD\text{-}LO})}$

$p_{RX} = \alpha_{SMF}\ \alpha_{TX}$

$p_{PD\text{-}RX} = \alpha_{RX}\ p_{RX} / 4$

$p_{PD\text{-}LO} = \alpha_{LO}\ \alpha_{SMF}\ \alpha_G\ \alpha_{AOP}\ \alpha_{TX}\ p_{IN\text{-}LO} / 4$

$i_N = \alpha_N\ i_0\ \sqrt{BW}$

Coherent (CH) RX Signal w/ same TX Signal & LO Path

Summer Topicals 2020 Virtual Conference
Tutorial TuA2.2 10:45AM – 11:30AM MDT
14 July 2020
Chris Cole

$i_{SIG} \triangleq$ RX balanced PD pair signal current

$$i_{SIG} = \alpha_{OMA}\, r_{PD}\, 2\sqrt{(p_{PD\text{-}RX}\, p_{PD\text{-}LO})}$$

$$\alpha_{LS} \triangleq ½ \qquad \alpha_{LO} \triangleq \alpha_{RX}$$

$$i_{SIG} = \alpha_{OMA}\, \alpha_{RX}\, \alpha_{SMF}\, \alpha_{G}\, \alpha_{AOP}\, \alpha_{TX}\, \alpha_{TEC}\, r_{PD}\, p_0$$

Equal DD and CH total input AOP condition:

$$p_{IN\text{-}DD\text{-}TX} \triangleq p_{IN\text{-}CH\text{-}TX} + p_{IN\text{-}CH\text{-}LO}$$

$$i_{DD\text{-}SIG} = i_{CH\text{-}SIG}$$

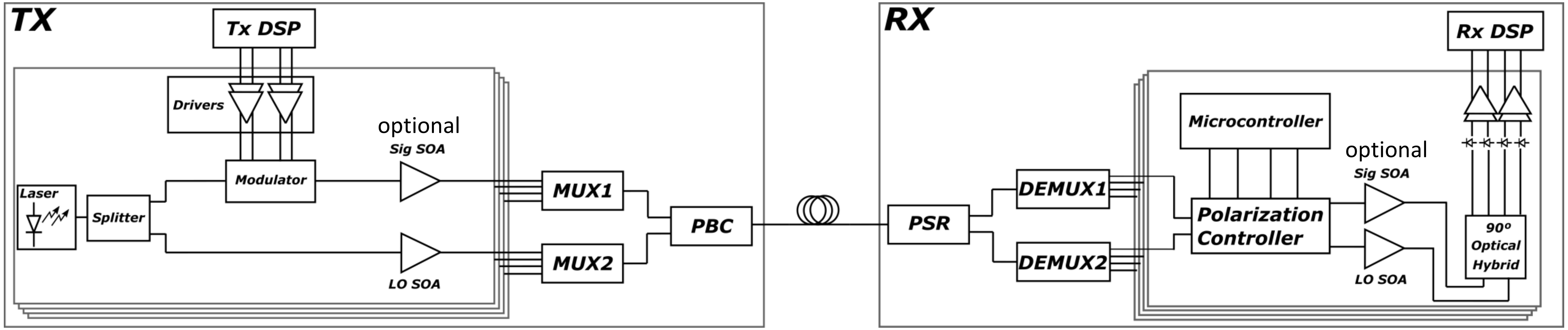
When the LO is remote, i.e. it's a RO, there is no Coherent signal gain!

Same TX Signal and LO Path analysis approach proposed by Mike Frankel, Ciena, 18 Jan 2018.

Regaining RO Coherent Gain: SOA

A. Maharry, et al., “Integrated SOAs enable energy-efficient intra-data center coherent links”, Optics Express Vol. 31, Issue 11, pp. 17480-17493 (2023)

- SOA RO amplification gives penalty-free >20 dB Coherent Gain
- Polarization Multiplexed Self-Homodyne Analog Coherent (PM-SH-ACD) Architecture for Optical Communication Links, US 11,811,499 Aaron Mahary, Hector Andrade, Clint Schow, Larry Coldren, James Buckwalter, Lucidean, Inc.



Homodyne Bi-Directional Optical Transceiver WO 2024/123683

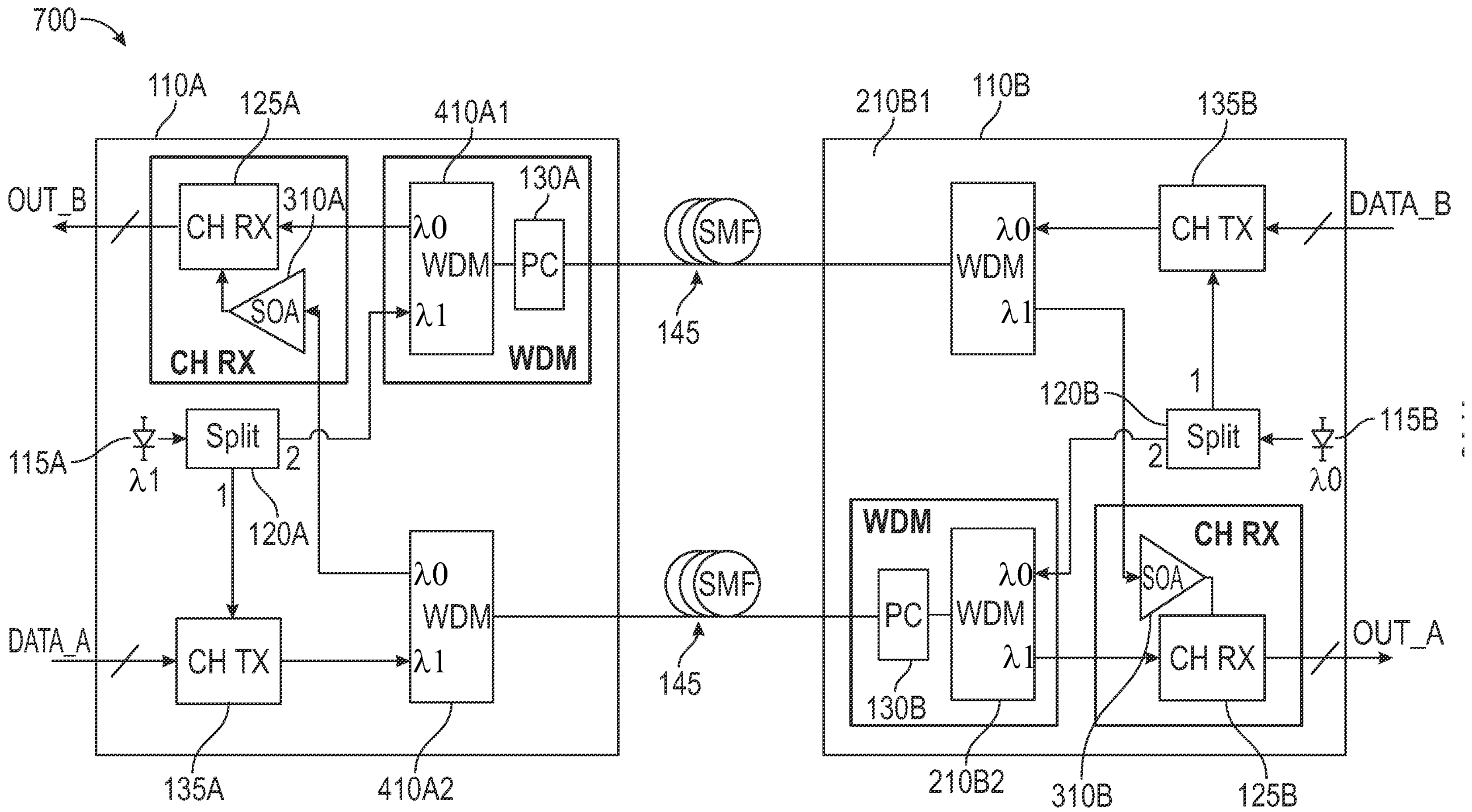


FIG. 12

Chris Cole, Aaron Mahary, Hector Andrade, Clint Schow, Larry Coldren, Lucidean, Inc.

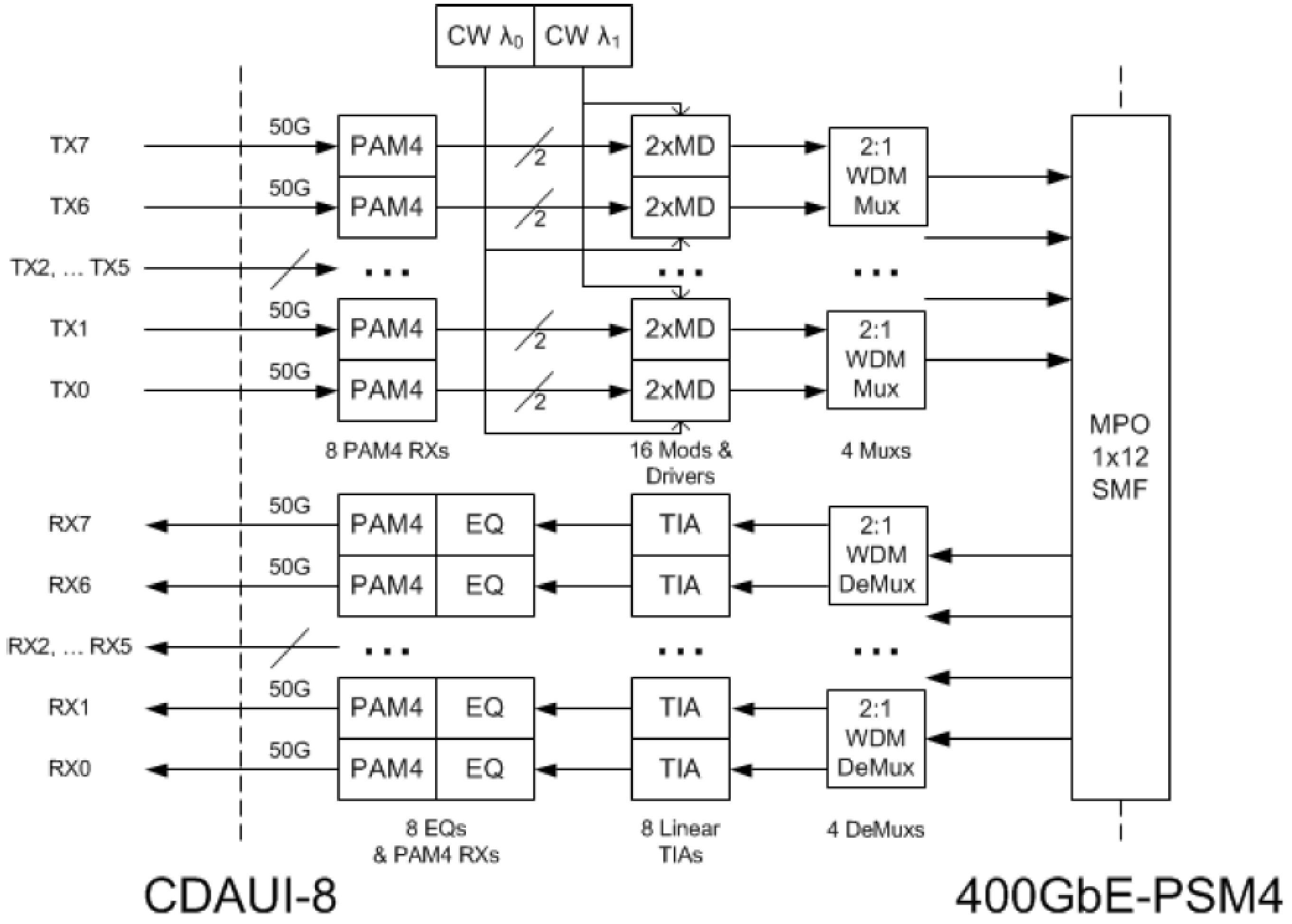
Appendix

1.6T Optimized Intra-building Optical Link

2014 Proposal

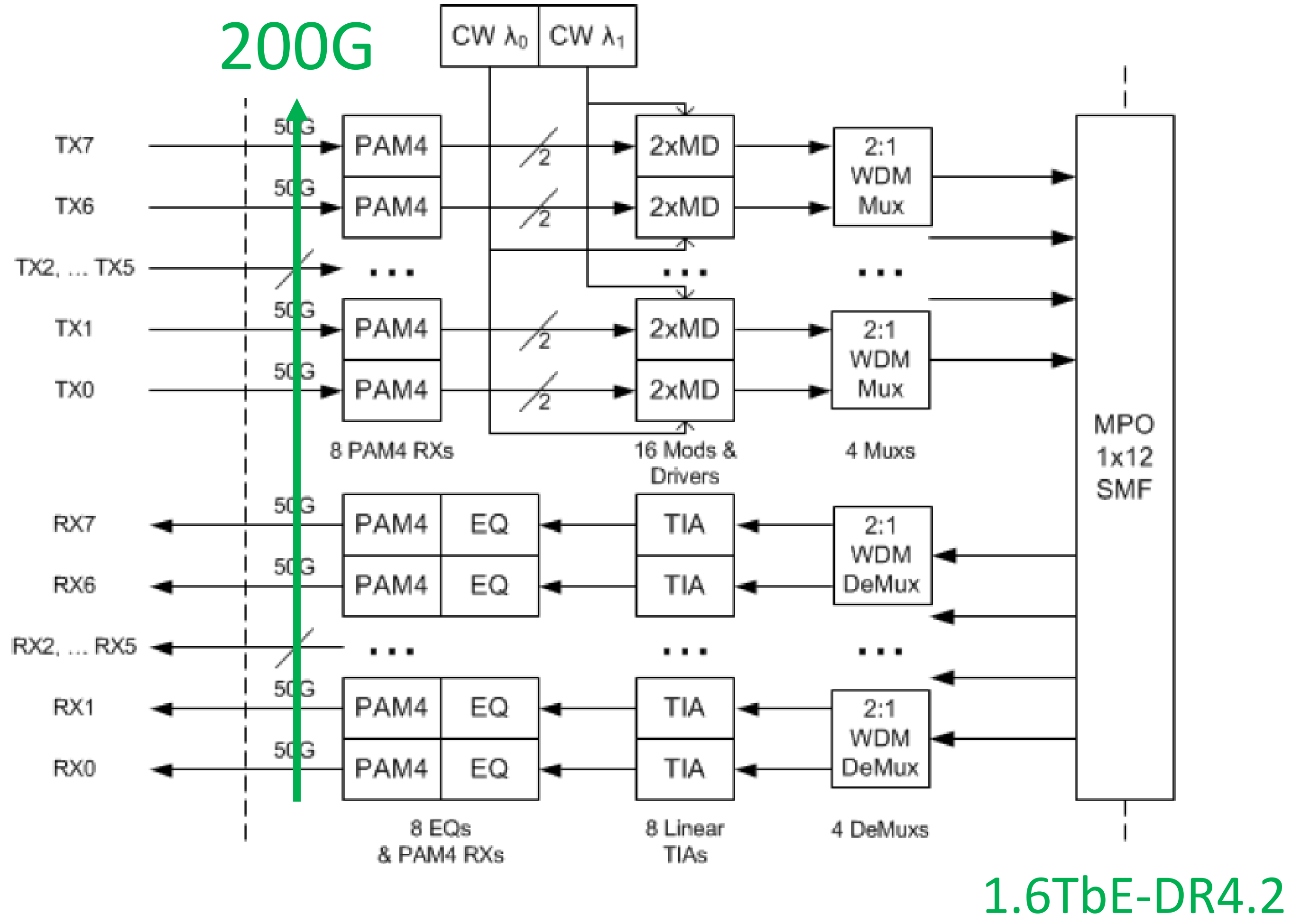
400GbE-PSM4 Alt 2: Quad 2x 50G PAM-4 λs

400Gb/s Ethernet Task Force
IEEE 802.3 Interim Meeting
Norfolk, Virginia
12-14 May 2014
Chris Cole



Finisar

2025 Proposal 1.6TbE-DR4.2 Quad 2x200G PAM-4 λs



3 April 2025 4

Optimized Optics Solutions Always Win

Thank you