FROM TRANSCEIVERS TO CO-PACKAGED OPTICS

A Technology Overview

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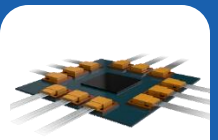
TOPICS

Markets and Applications

Transceivers



CPOs

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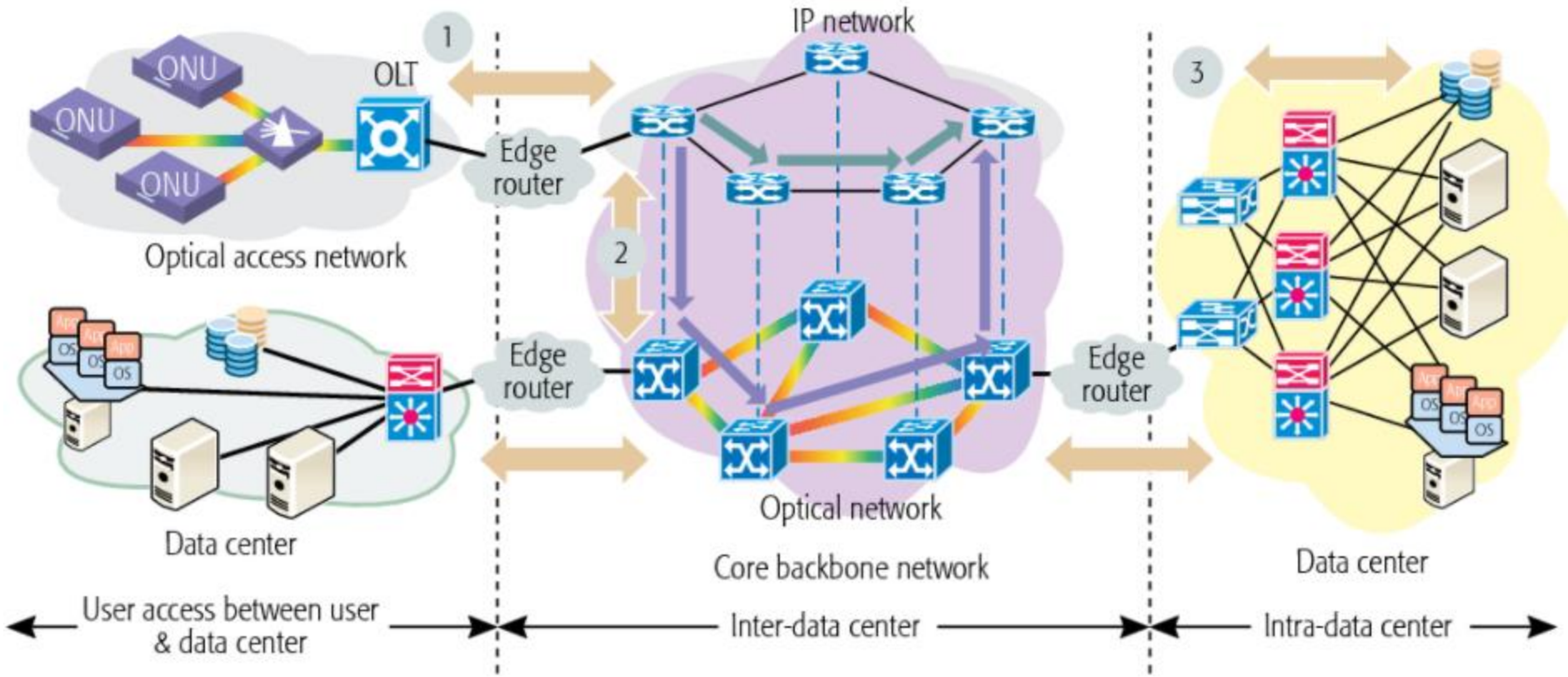
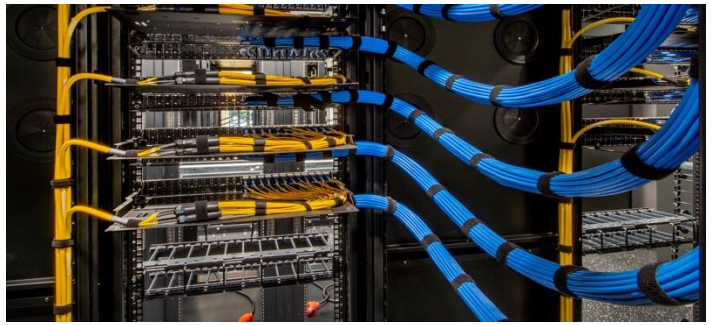
OPTICAL CONNECTIVITY FORMS THE FOUNDATION OF MODERN NETWORKS



KEY GROWTH DRIVERS: DATACENTER AND COMMUNICATIONS

AI Data Transmission



Datacenter Bandwidth Growth
10X in the next 5 years

Datacom transceivers

1.6T Transceivers in production this year

3.2T and 6.4T in development

Datacenter Interconnect

DCI Transceiver Market
Grows to $4B in 2030

Coherent transceivers

400G & 800G ZR/ZR+ ramping

1.6T ZR/ZR+ in development

Note: 10X ('25-'30) - LightCounting; OCS $2B+ and DCI $4B in 2030 - Cignal AI and internal estimates.

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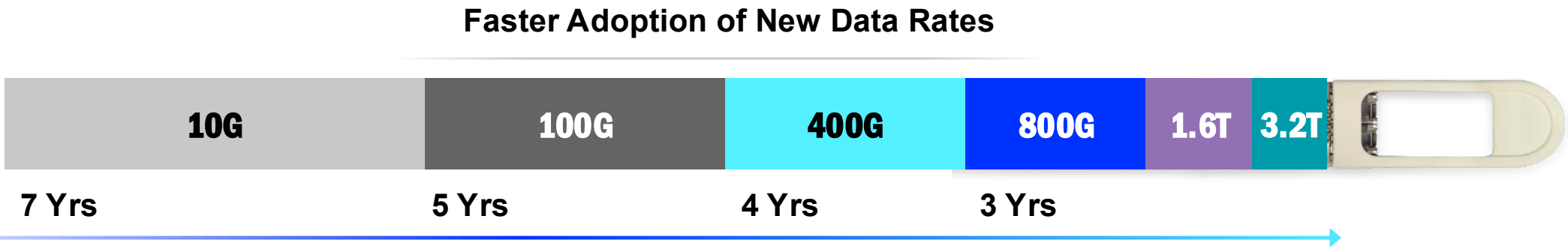
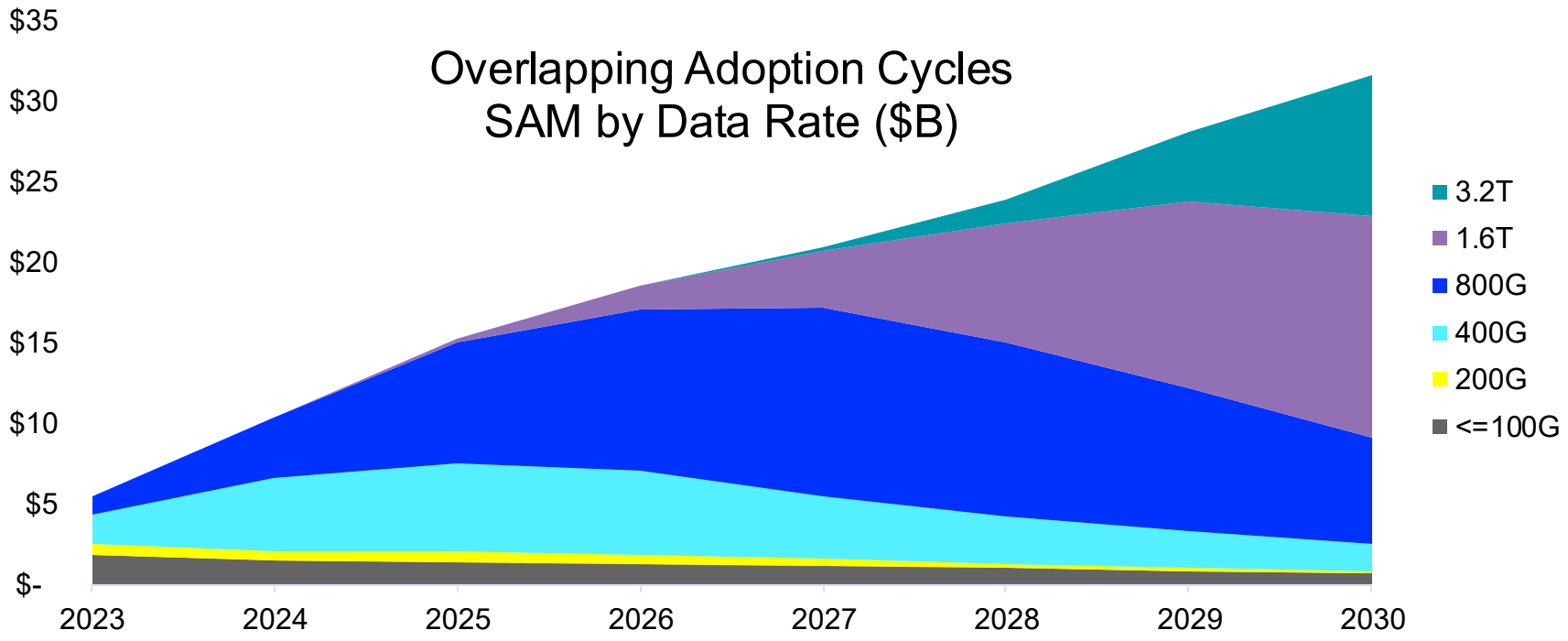
ACCELERATING ADOPTION CYCLES FAVOR TECHNOLOGY LEADERS

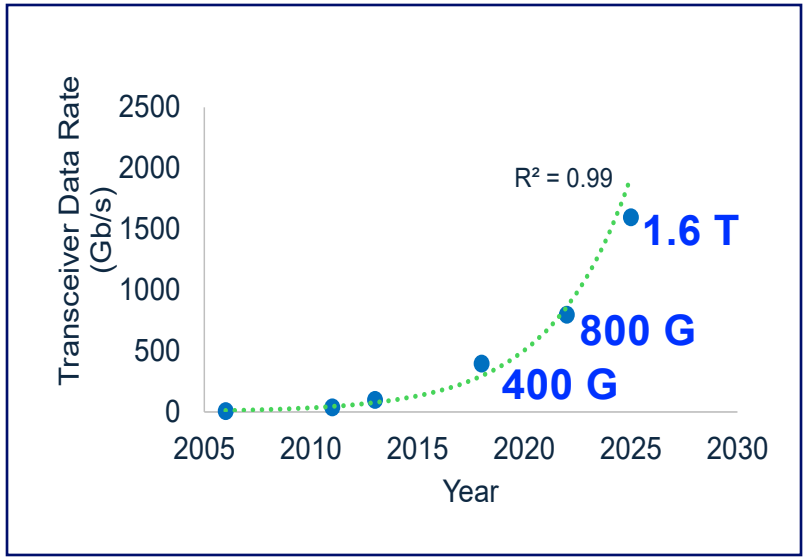




LightCounting and internal estimates

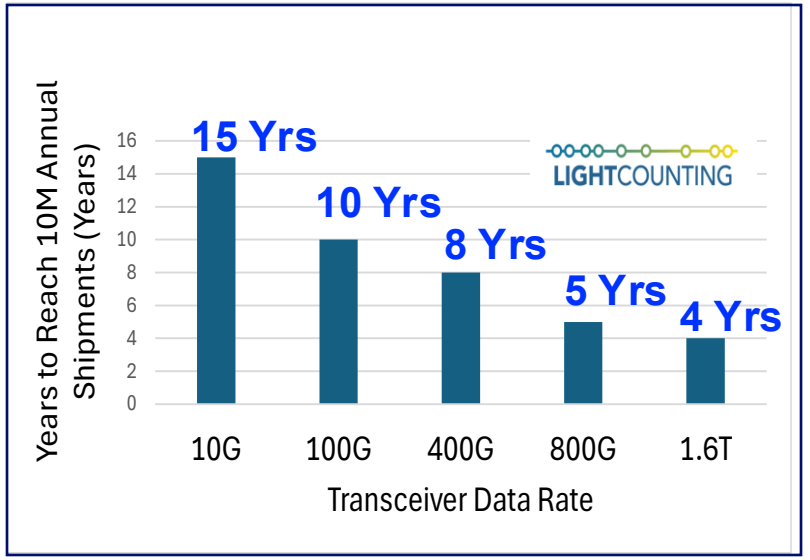
FASTER DATA RATE TRANSITIONS AND FASTER MANUFACTURING RAMPS

Transceiver Data Rate



Source: LightCounting

Years to Reach 10M units/year



Source: internal data

- Transceiver data rates are increasing at an exponential rate
- New technology needs to be developed even faster than before
- Manufacturing ramps are also happening much faster than before

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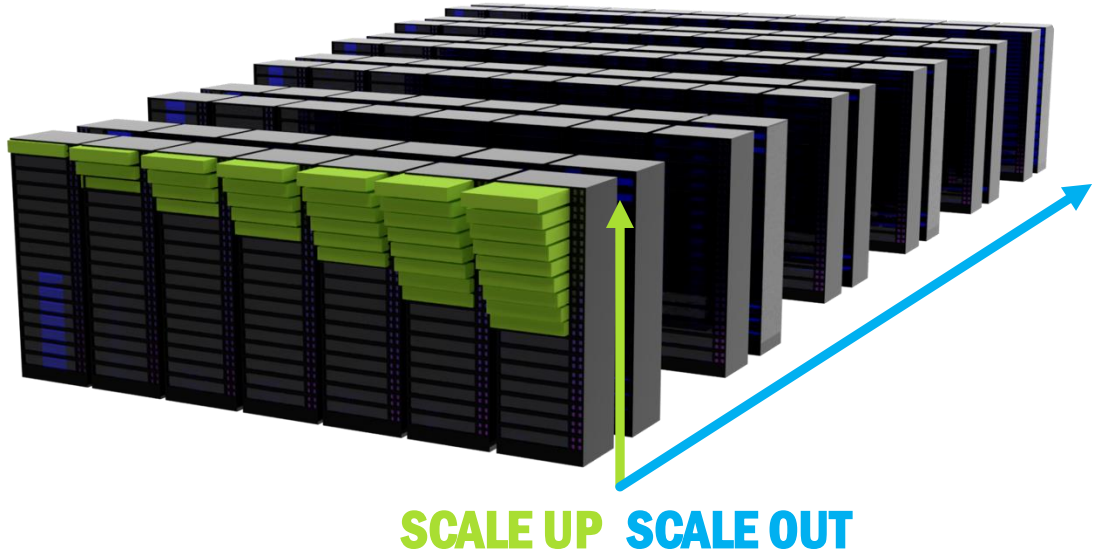
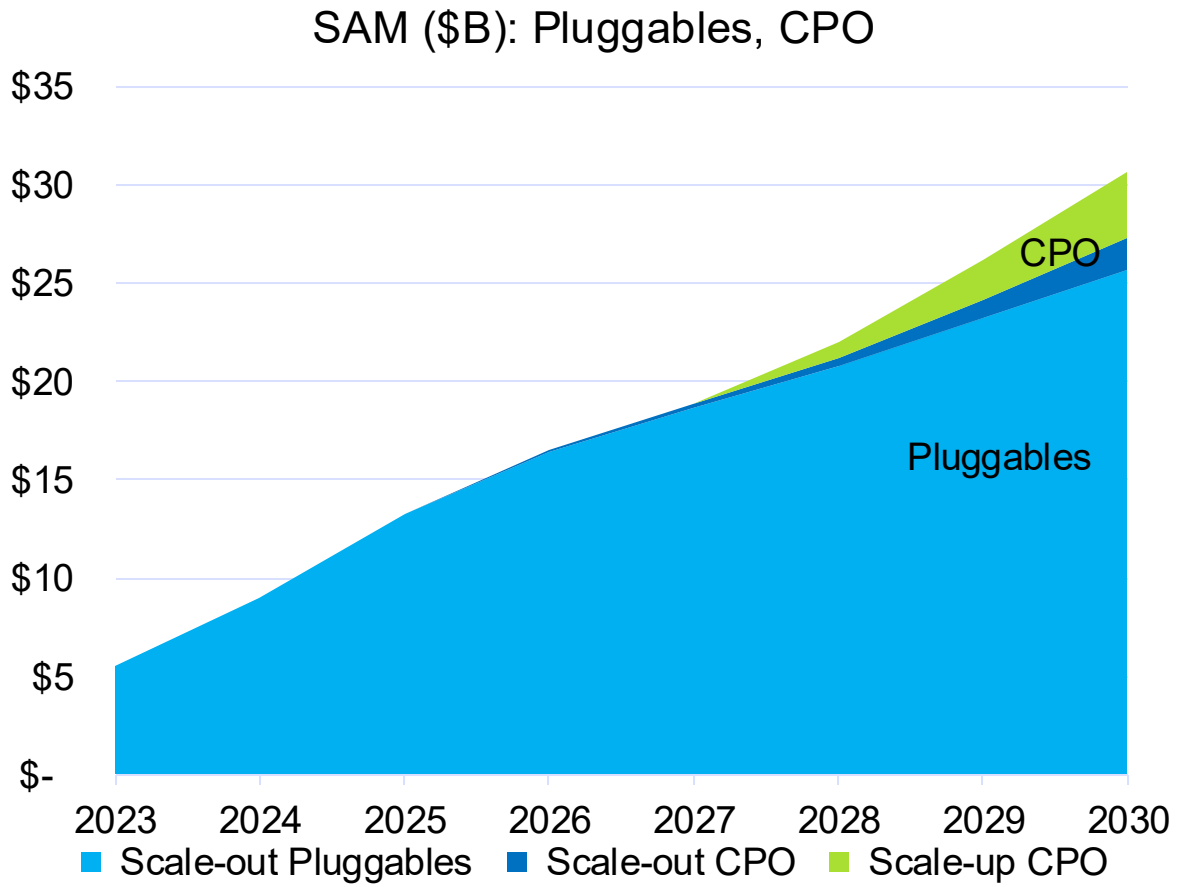
CPO IS A MARKET EXPANSION OPPORTUNITY FOR THE PHOTONICS INDUSTRY

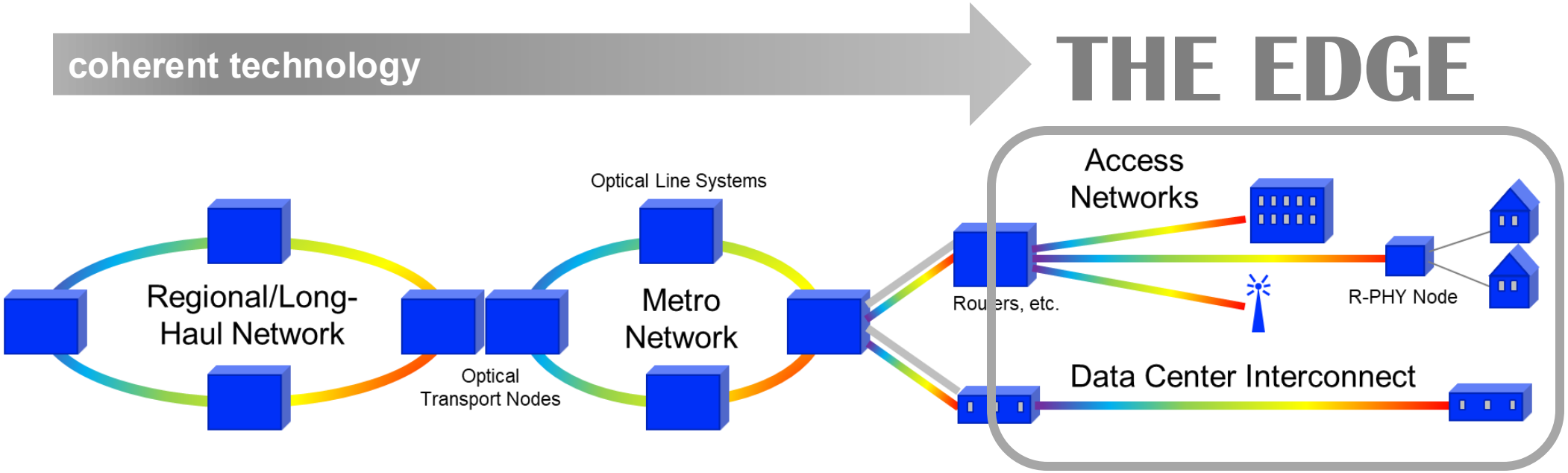




LightCounting and internal estimates

COHERENT TECHNOLOGY IS MOVING CLOSER TO THE EDGE

- **Data Center Interconnect (DCI) – 400G ZR being widely deployed at hyper-scalers**
  - IP-over-DWDM – pluggable DWDM coherent transceivers are plugged directly into routers
- **Access networks:**
  - Applications: wireless back-haul, business services, cable access networks, PON backhaul
  - Migration from 10G/25G DWDM direct-detect to 100G ZR DWDM coherent technology in QSFP28
    - CMIS and SFF8636, C Temp/I Temp



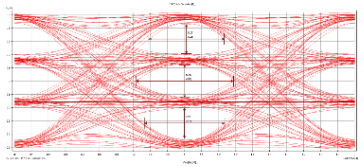
TRANSCEIVERS: PRODUCTS & TECHNOLOGY PLATFORMS

- 3 decades of Technology evolution and deployment
- Data rates ranging from 100 Mbps to 3.2 Tbps
- Direct detect transceivers and coherent transceivers
- Form factors include SFF, SFP, SFP+, XFP, CXP, CFPx, QSFP+, QSFP-DD, OSFP, ITTRx, AOC, Endurance, and CPO optical engines
- Protocols include Ethernet, OTU, CPRI/eCPRI, Fibre Channel, InfiniBand
- Applications in hyperscale data centers, OEMs, carriers, and enterprises

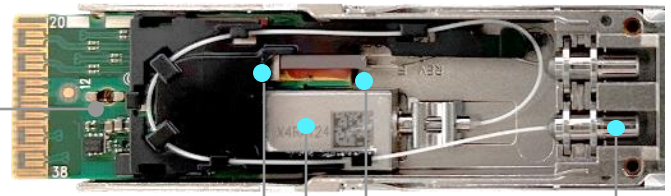
TRANSCEIVERS: IM DD AND COHERENT

PAM4 Eye Diagram in Datacom transceiver

- Intensity Modulation
- Direct Detect
- Typically up to 10km



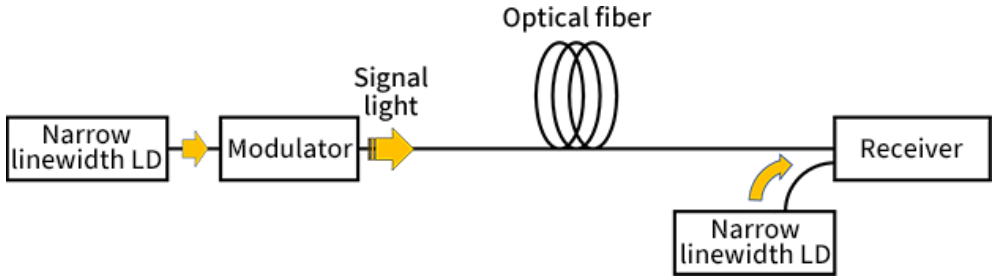
OPTICAL TRANSCEIVER

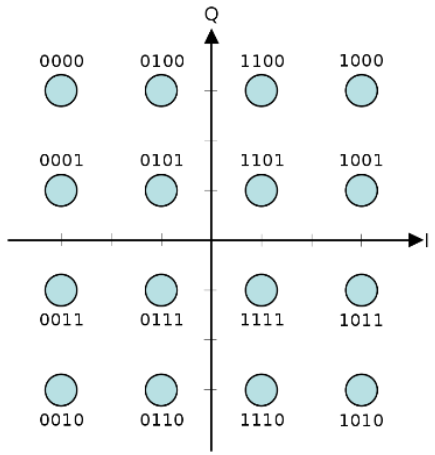


Integrated Circuits Detectors Source Lasers Passive Optics

Coherent Transmission's key technologies for 100G/400G/800G/1.2T&1.6T

- Phase and Intensity Modulation
- Coherent Detection
- > 80km





16 QAM (Quadrature Amplitude Modulation)

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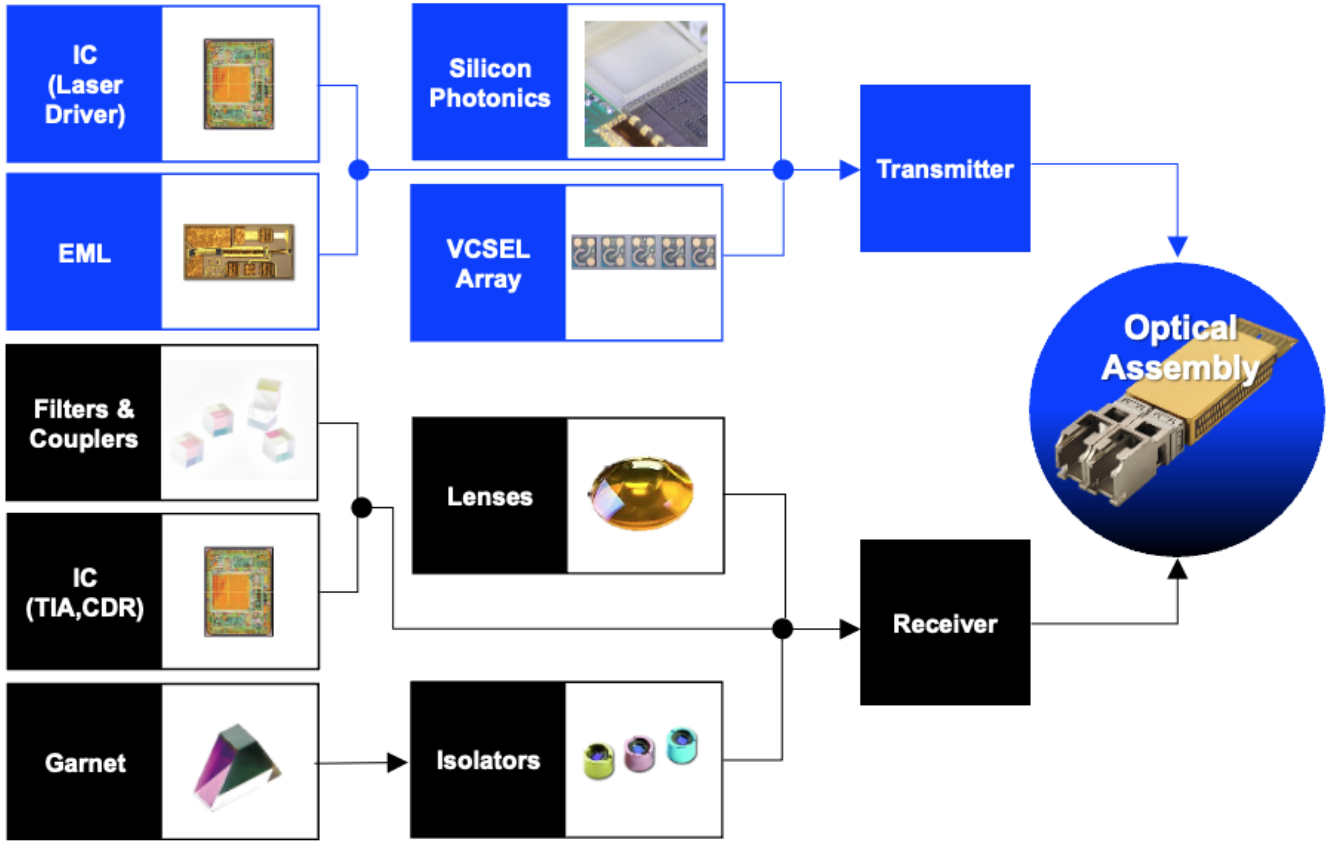
INDUSTRY'S MOST VERTICALLY INTEGRATED DATACOM TRANSCEIVER WITH UNMATCHED SUPPLY CHAIN RESILIENCY



Compound Semi Fabs in EU, Japan and US
Assembly operations in Southeast Asian and China

Achievements in Optical Networking

- **Transceiver Shipments**: >350M transceivers shipped
- **EML Capacity:** Increased shipments by 10X over the last two years and ramped capacity to 7M die per quarter
- **EML Innovation:** First to demonstrate a 200G Differential EML for 1.6T.
- **Garnet Production:** The world's largest producer of garnet for isolators, with investments to nearly double capacity year over year
- **6" Wafer Achievement:** Industry's first 6-inch wafer for GaAs and InP
- **Laser Technology:** Developed award-winning, unique 200G lasers designed for the most demanding links.

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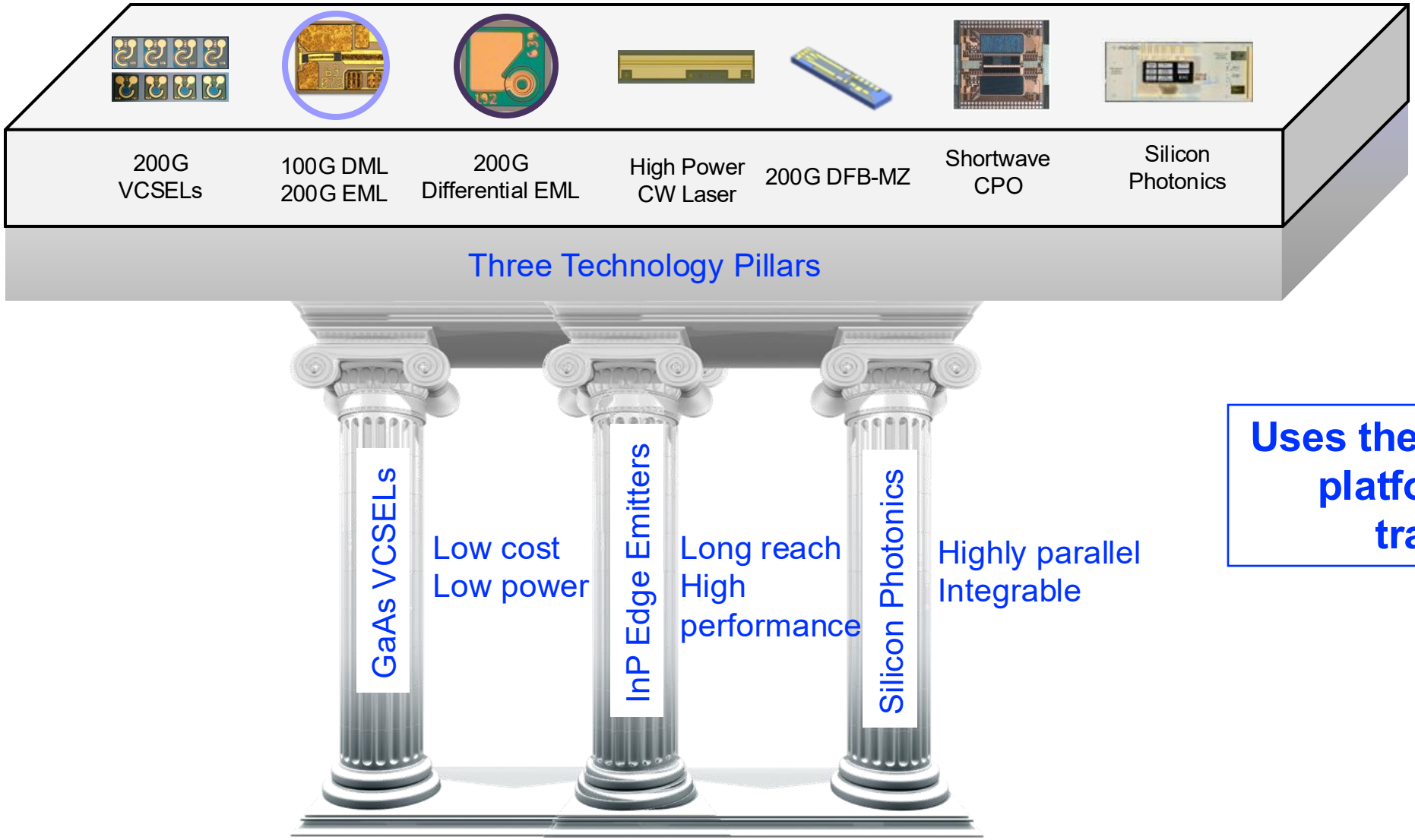
THE RIGHT TECHNOLOGY FOR EACH APPLICATION



Uses the optimal optical platform for each transceiver

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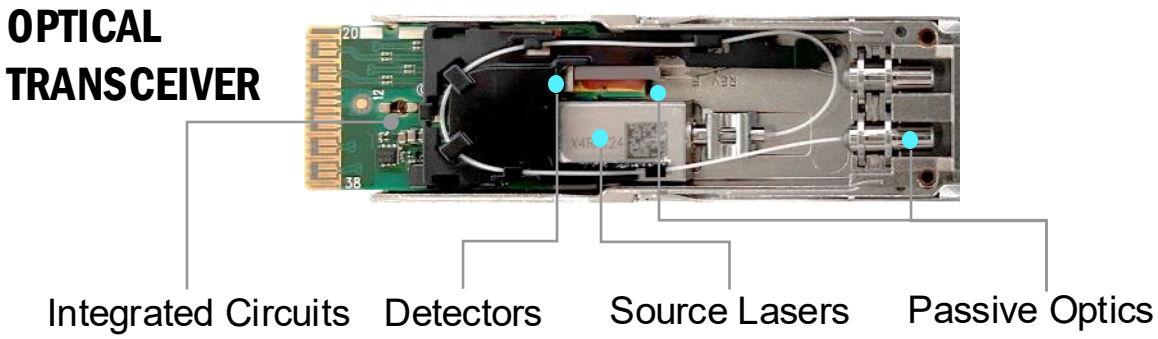
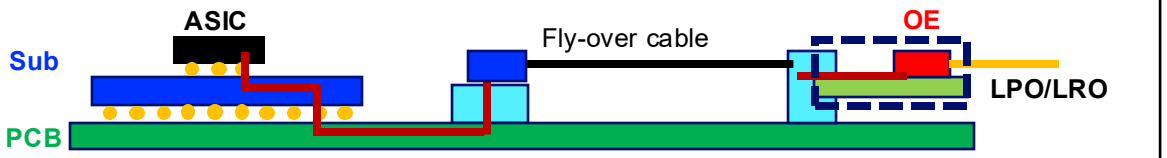
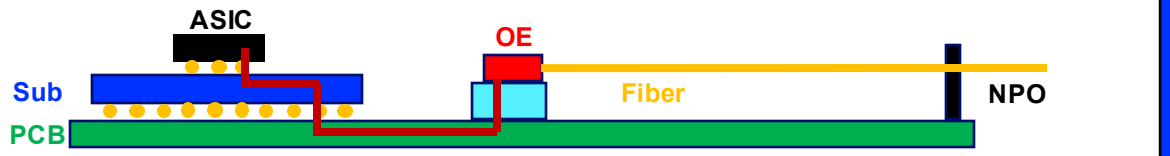
TECHNOLOGY CHALLENGES FOR HIGH-SPEED OPTICAL TRANSCEIVERS

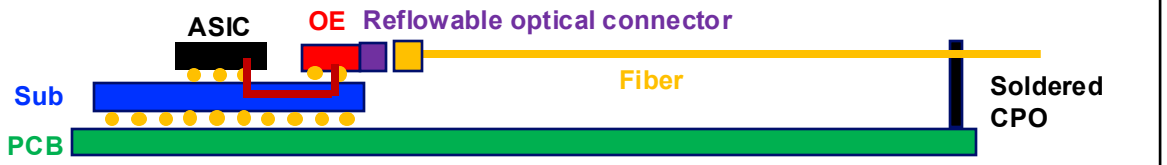
- **Key Building Blocks**
  - DSP (3nm)
  - Lasers
  - Modulators
  - Detectors
  - Passive Optics
- **Challenges and Physics Limits**
  - Speed limit
  - Power Consumption
  - Heat dissipation
  - Integration



PLUGGABLE/CPO: NO ONE SIZE FITS ALL



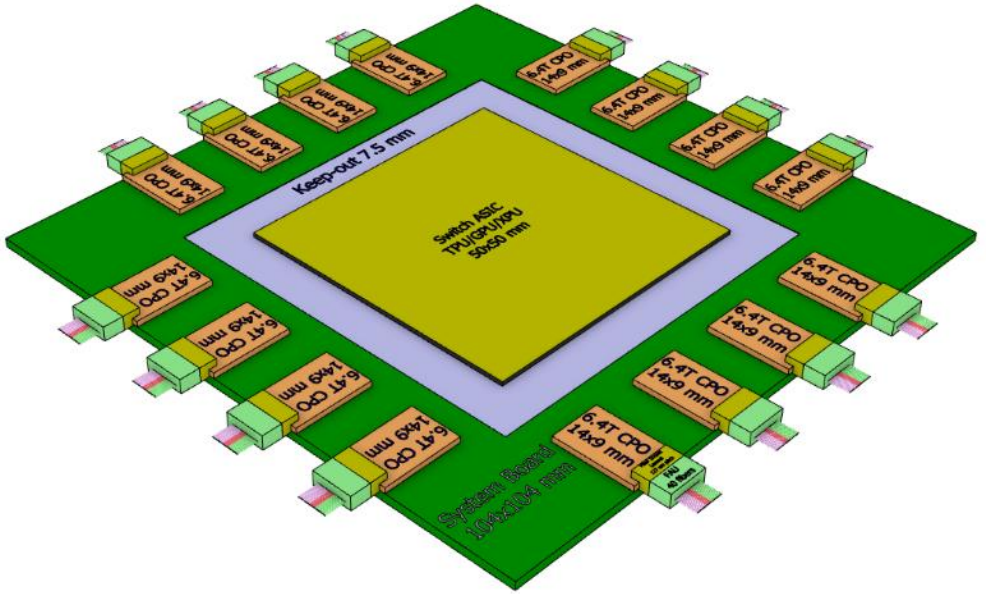


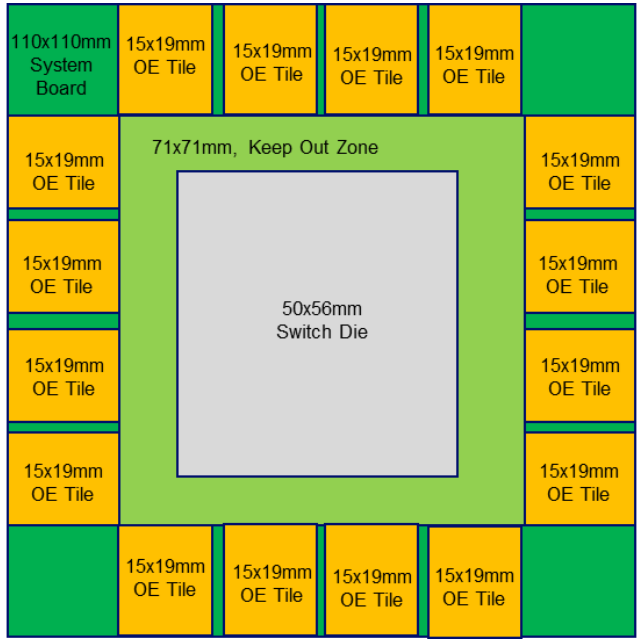


Form-factor	Channel Loss	Power	Pluggability	Service-ability	Density
Pluggable (Retimed)	↓	↓	↑↑↑	↑↑↑	↓
LPO/LRO	↑	↑↑	↑↑↑	↑↑↑	↓
NPO	↑↑	↑↑	↑↑	↑↑	↑
Socketed CPO	↑↑↑	↑↑↑	↑↑	↑	↑↑
Soldered CPO	↑↑↑	↑↑↑	↓	↓↓↓	↑↑↑

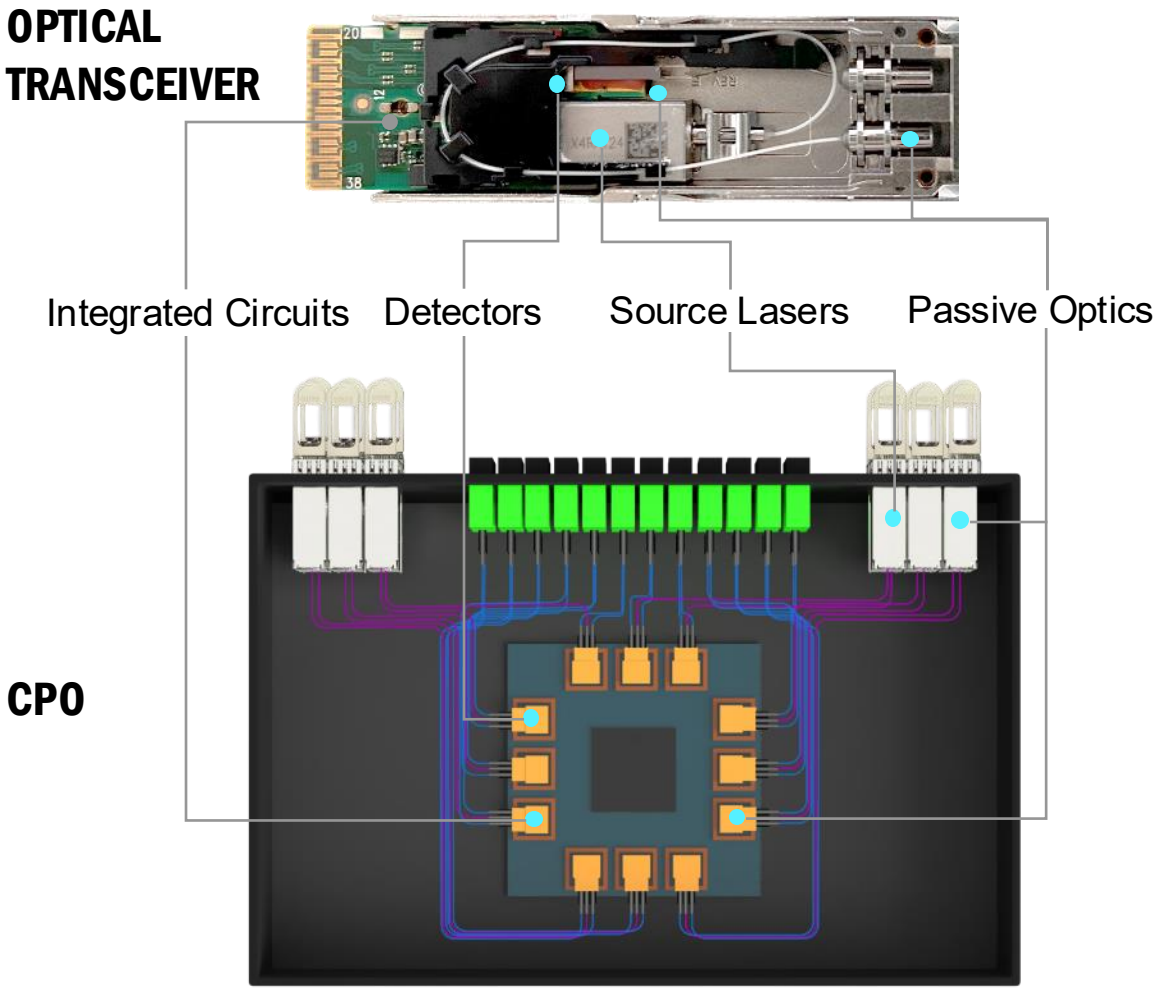
CPO OVERVIEW

- System board size: 110x110 mm
- CPO count: 16
- CPO size
- ASIC size allocated: 50x50 mm
- CPO to CPO gap
- CPO host lane count: 32 + 32
- CPO bandwidth: 32x200 = 6.4 Tbps
- Energy efficiency: <5pJ/bit
- Total system bandwidth: 6.4x16=102.4T in each direction





CPO REQUIRES ALL ENABLING TECHNOLOGIES OF PLUGGABLES AND MORE…



Capability	Type	Pluggable	CPO
Assembly and Test	Components and Modules	✓	✓
Sources	GaAs VCSELs	✓	✓
	InP EMLs	✓	
	InP CW Lasers	✓	✓
	Silicon Photonics	✓	✓
Detectors	GaAs Detectors	✓	✓
	InP Detectors	✓	✓
Passive Optics	Isolators	✓	✓
	Lens Arrays	✓	
	Optical Multiplexer Demultiplexer	✓	✓
Thermal Control	Thermoelectric Coolers	✓	✓
Integrated Circuits	Laser Drivers	✓	✓
	TIA	✓	✓
	External Laser Source		✓
	Polarization-maintaining Fiber		✓
	Fiber Attach Unit		✓

We make all the photonic building blocks for CPO

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OPTICAL BANDWIDTH CONTINUES TO GROW DRIVEN BY THE DEMAND OF AI

- **Broad set of technologies**
- **Varity of solutions**
  - High Speed Transceivers
  - Co-Packaged Optics
- **Future favors vertically integrated players**

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