Beyond Copper: Optical Opportunities for AI Scale-up Fabrics

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Agenda

- The Copper Wall: A System-level Constraint
- The Role of Optics in Scale-up Fabrics
- The Optical Integration Continuum
- CPO (Co-Packaged Optics): Benefits and System-level Tradeoffs
- Optical Disaggregation
  - XPO (eXtra-dense Pluggable Optics)
  - Open CPX
- Takeaways
- Call to Action

The Copper Wall: a System-Level Constraint

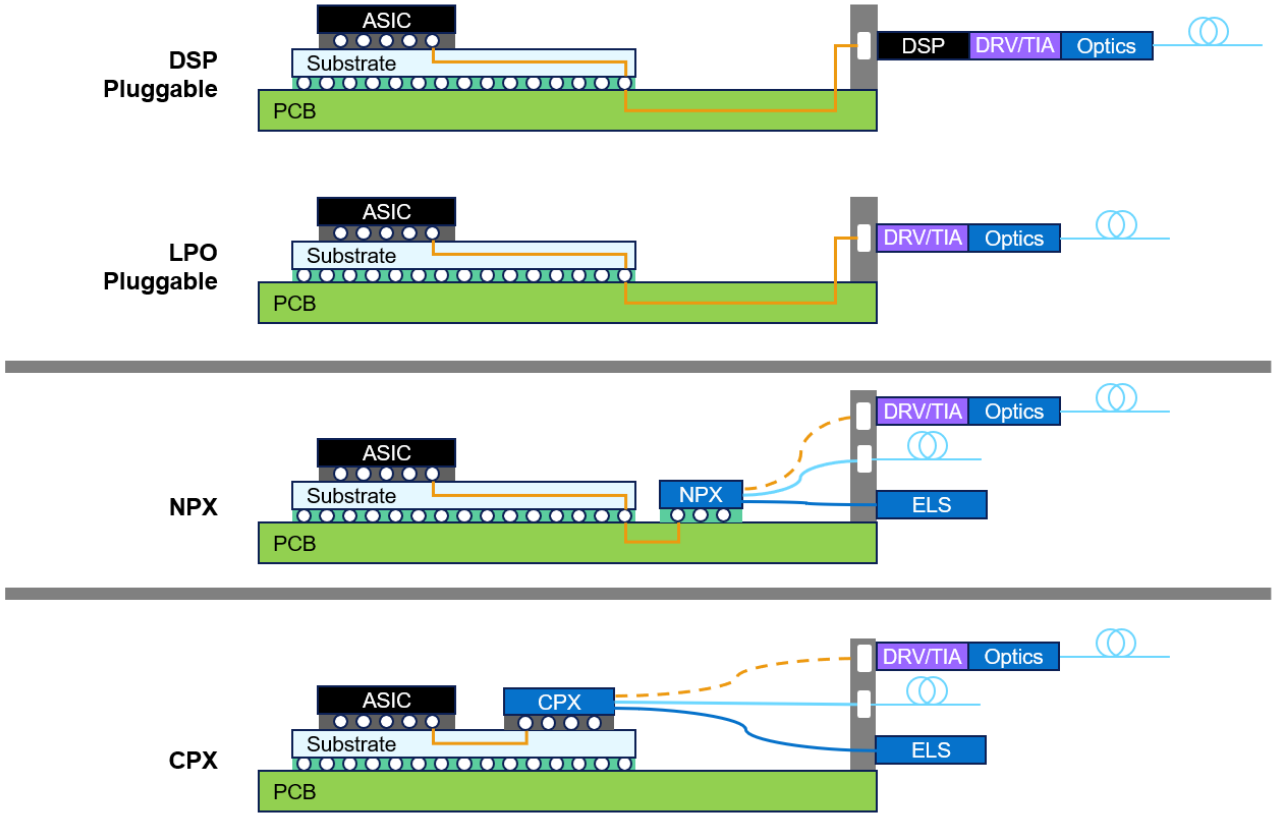
- As scale-up domains grow, the interconnect increasingly influences bandwidth, latency, power and rack-level design.
- The copper wall:
  - At 200 Gb/s per lane, passive-copper reach is typically limited to a few meters.
  - At 400 Gb/s per lane and above, electrical reach is expected to become even more constrained (<1m).
- This creates a fundamental system-design challenge:
  - Short-reach copper favors compact, single-rack topologies.
  - Larger scale-up domains require power-efficient connectivity across racks.
- Larger scale-up domains require longer reach, lower power consumption, higher bandwidth density and manageable cable routing.

The Role of Optics in Scale-up Fabrics

- Optics becomes attractive when system-level power, bandwidth and cable management dominate over transceiver cost:
  - Lower loss over rack-scale distances
  - Less dependence on retimers
  - Smaller and lighter cable infrastructure
  - Tighter integration with XPUs and switch ASICs
- However, replacing every copper cable with traditional pluggable optics can introduce unacceptable power, cost and reliability trade-offs.
- The transition is therefore likely to be hybrid:
  - Copper where reach remains practical
  - Optics where distance, density or power makes copper inefficient

The Optical Integration Continuum

- No single technology optimizes reach, power, density, cost, manufacturability and serviceability at the same time.
- The optical technologies landscape:
  - Silicon photonics
  - Indium phosphide
  - Thin film electro optical materials
    - lithium niobate (TFLN), barium titanate (BTO)
  - VCSELs
  - Emerging technologies such as µLEDs
- The optical integration ranges from retimed and linear pluggable optics, to near-packaged and co-packaged optics.



FRO: Fully Retimed Optics
LRO: Linear Receive Optics
RTLR: Retimed Transmit, Linear Receive
LPO: Linear Pluggable Optics
NPC: Near Package Copper
NPO: Near Package Optics

NPX: Near-packaged Optics or Copper
CPC: Co-Packaged Copper
CPO: Co-Packaged Optics
CPX: Co-Package Optics or Copper
ELSFP: External Laser Small Form-Factor Pluggable

CPO: Benefits and Deployment Considerations

Why CPO is attractive
Shorter high-speed electrical channels
Lower electrical I/O and retimer power
Higher bandwidth density
Potential for larger scale-up domains and improved system efficiency

System-level Tradeoffs
More complex package, thermal and board co-design
New manufacturing and test requirements
Reduced field serviceability
Larger “blast radius”
Potential component and vendor lock-in

- CPO reduces electrical reach, lowering power and enabling higher bandwidth density.
- However, these gains come with new challenges in packaging, manufacturing, serviceability and ecosystem maturity.
- CPO improves power efficiency and bandwidth density, but successful deployment requires balancing system performance with manufacturability, serviceability and ecosystem openness.

Optical Disaggregation – XPO

- XPO is a high-density, serviceable design to preserve a pluggable ecosystem at higher bandwidth density.
- The architecture separates the optical module from the switch ASIC or XPUs by using fly-over cables.
- Potential system benefits include:
  - Higher bandwidth (8x) and front-panel density (4x)
  - Improved serviceability compared with CPO
  - Direct liquid cooling (DLC) for high-power optical modules
  - Support for both low-power LPO optics and higher-power coherent DWDM optics
  - Greater flexibility in optical technology and supplier selection



XPO module with 64 x 200G lanes (12.8T)

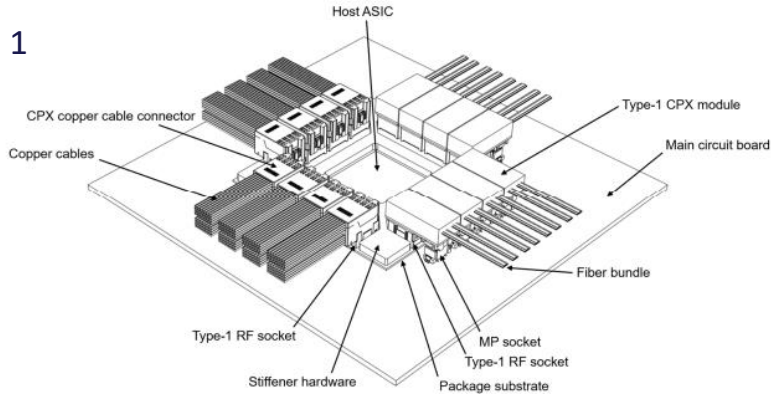


OSFP module with 8 x 200G lanes (1.6T)
Sources: Arista

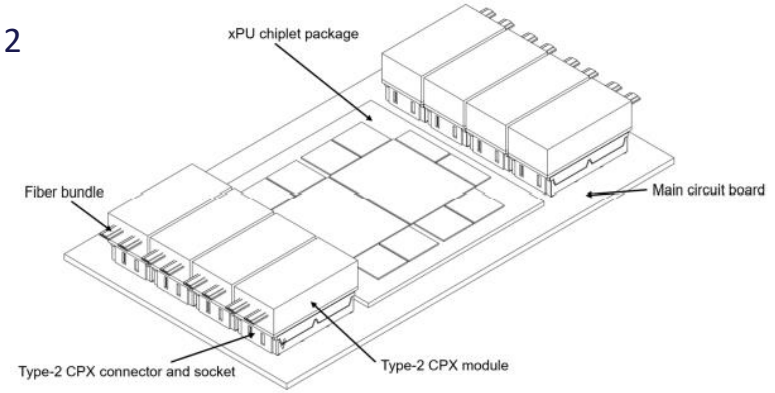
Optical Disaggregation – Open CPX

- Open CPX defines a pluggable optical engine connected through a standardized socket and electrical connector rather than permanently attaching optics to the electronic package.
- Similar to CPO, Open CPX can:
  - Shorten high-speed electrical channels
  - Reduce channel loss and retiming requirements
  - Improve bandwidth density near the package
- An Open CPX ecosystem can enable:
  - Multi-vendor interoperability
  - Independent evolution of optics and electronics
  - More flexible system integration

Type 1



Type 2



Sources: Open CPX MSA

Takeaways

- At future lane speed, copper will increasingly constrain the system architecture.
- Optics can enable larger and more power-efficient scale-up domains.
- System designers must balance bandwidth, power efficiency, interoperability and serviceability considerations when selecting among different approaches.
- Open optical ecosystems are critical for scalable AI infrastructure.

Call to Action

- What the Industry Needs:
  - Accelerate industry standard for optical disaggregation
  - Preserve interoperability and serviceability as optical integration increases
- Dell's Commitment:
  - Active member of both XPO and Open CPX MSAs
  - Founding member of OCP's Open Silicon Photonics for AI Systems (being developed under OCP's Server)

  → Dell supports open, disaggregated optical solutions that preserve interoperability, serviceability and multi-vendor innovation.
- Call to Action:
  - Work together across the industry to build open and interoperable optical solutions that can scale the next generation of AI infrastructure.

Thank You!

