OCP SPECIAL FOCUS: PHOTONICS

Integrated Optics at Scale: From 51.2T Validation to Future 102.4T Product

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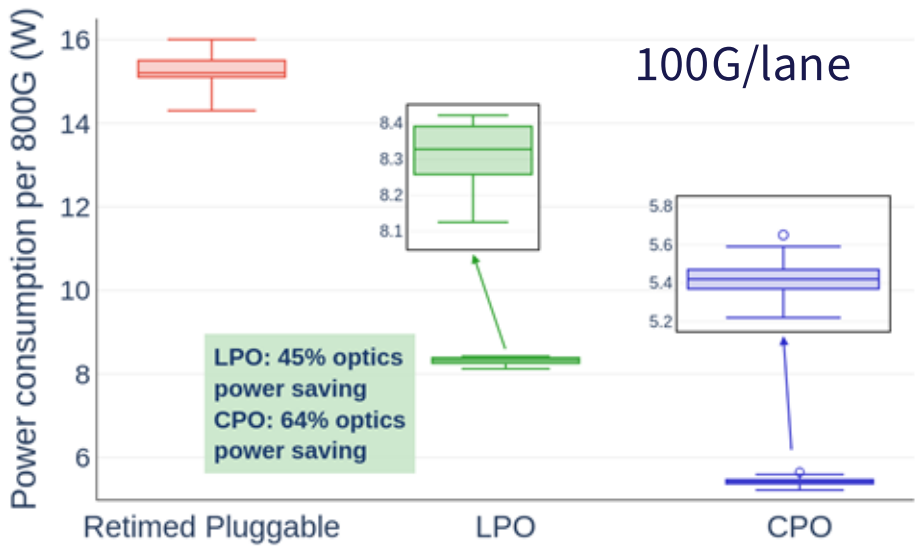
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OCP PLATINUM Member

Integrated Optics Motivation

- Power consumption
- Disaggregation
- Density
- Reliability



Siamak Amiralizadeh et al. “Co-packaged Optics Technology Evaluation for Hyperscale Data Center Fabric Switches” invited paper, ECOC 2025

ORv3 HPR

MP



≤ 72 Accelerators

Cabled Backplane
48 VDC / ± 400 VDC
Air / Liquid Cooled
IT/Power Rack Single-Wide

ORW

2026-Q3



≤ 144 Accelerators

Cabled Backplane
48 VDC / ± 400 VDC
Air / Liquid Cooled
IT Rack Double-Wide

What is next?



≥ 256 Accelerators

?
Primarily Liquid Cooled
IT Rack Size TBD

CPO Evaluation Infrastructure



FRO: Fully retimed optics

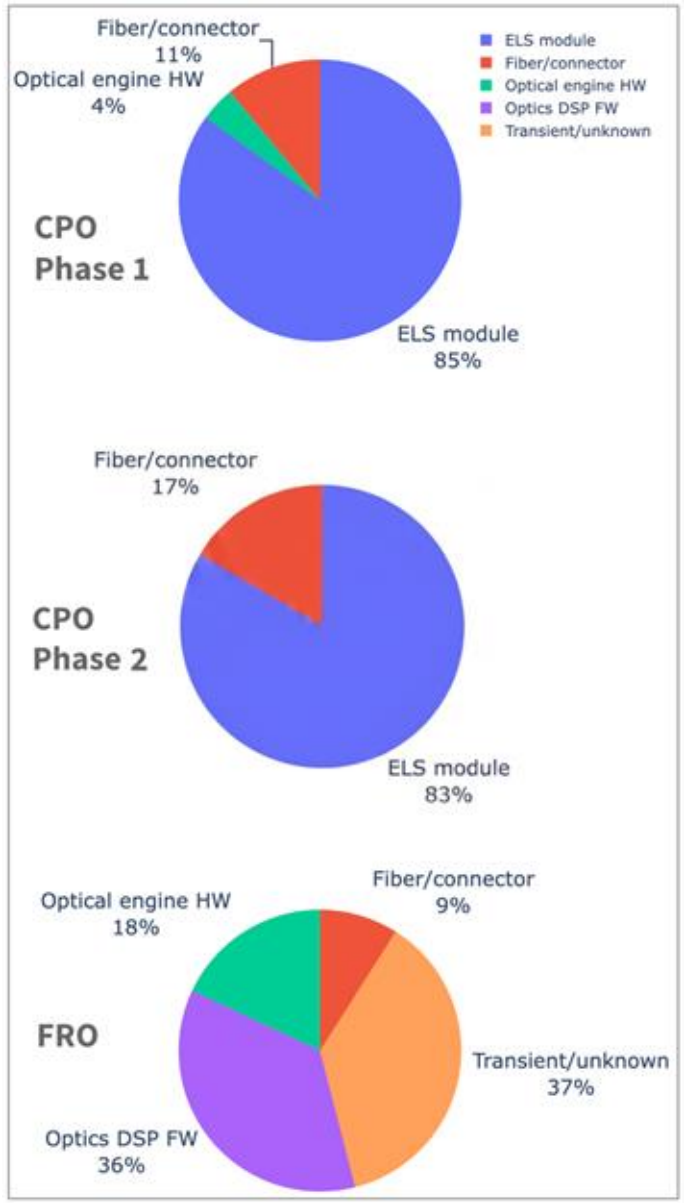
Optics	Operating Temperature	400G Port Count	400G Device Hours
FRO, 2x400G FR4	40 °C	1,792	8 M
CPO, 128x400G FR4 (Phase 1)	40 °C	8,960	50 M
CPO, 128x400G FR4 (Phase 2)	15 °C to 35 °C	38,400	175 M

- Meta has collected over 1.8 million system hours of data to assess reliability, availability and serviceability (RAS) of these technologies
- A/B test methodology comparing CPO switch systems with pluggable-based Minipack3 platform (control group)
- Phase 1 units were deployed in stressed lab temperature condition to gain an initial insight on failure rates and modes
- Phase 2 units were manufactured with updated build standards and are intended to give higher-confidence statistics on the interruption rates under normal operation conditions

Learnings and Insights I

- ELS module, root-caused to a laser drive SMT component, drove most CPO failures. A fix was implemented and verified by design change.
- Transient/unknown interruptions were common in FRO but essentially absent in CPO.
- Dirty fiber/connector failures stayed consistent across both CPO and FRO and remain a challenge across our deployments.

Failure category	CPO Phase 1	CPO Phase 2	FRO
ELS module	85%	83%	NA
Fiber/connector	11%	17%	9%
Optical engine HW	4%	0%	18%
Optics DSP FW	NA	NA	36%
Transient/unknown	0%	0%	37%

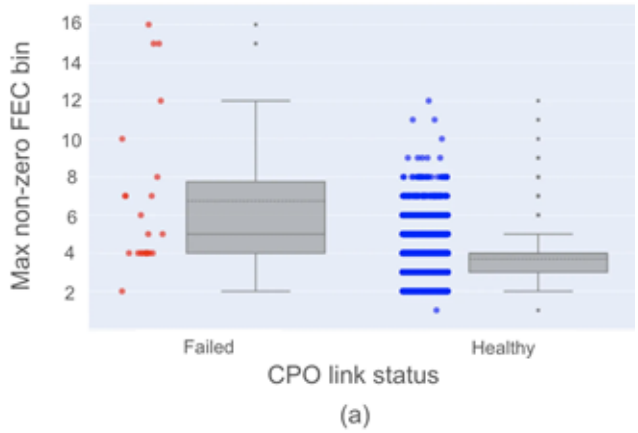


Learnings and Insights II

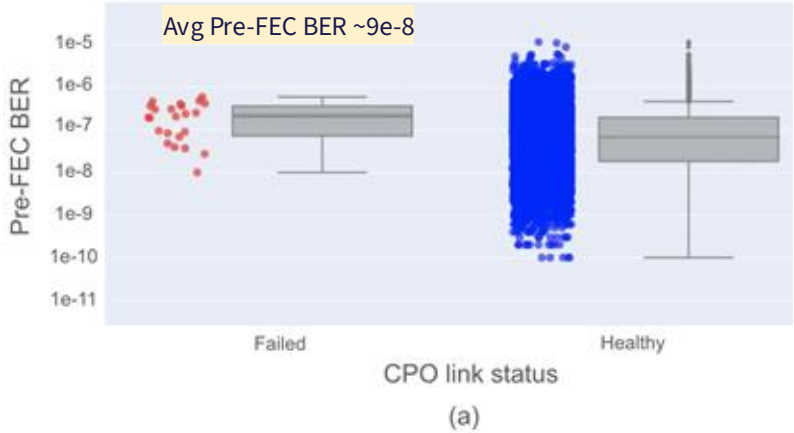
- Backend AI network has more stringent reliability requirements and failure thresholds than frontend network
  - Single uncorrectable codeword (UCW) used as the criteria for “interruption” in the link
- Pre-FEC BER is not a reliable predictor of link health as a single metric
  - Data showed minimal correlation between pre-FEC BER values and link health.
- CPO outperformed FRO on failure rate despite worse pre-FEC BER.

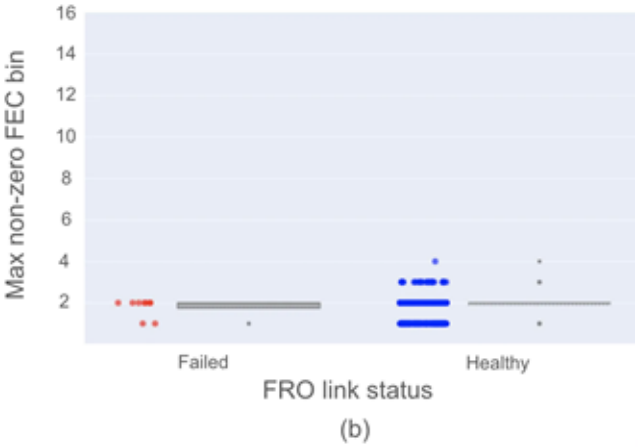
CPO Phase 1 (8,960 ports) vs FRO Links (1,792 ports)

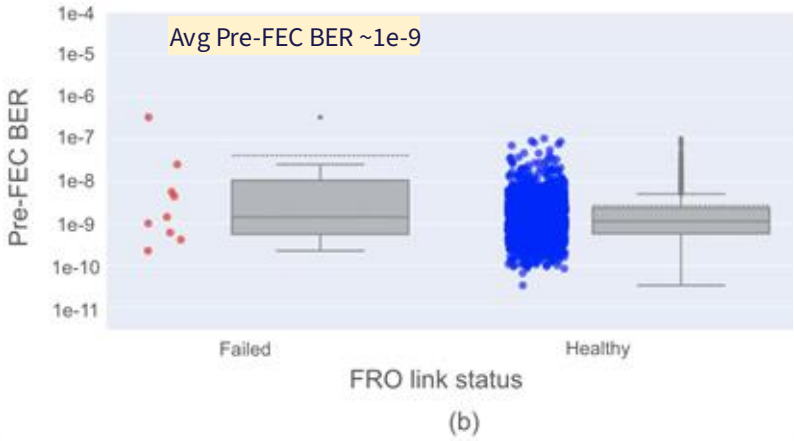
Data is maximum of last 30 minutes before UCW



Data is maximum of last 30 minutes before UCW







Drew Alduino et al. “A RAS Investigation of Integrated Optical Scale-Up Solutions for AI Interconnects” invited paper submitted to JLT, 2026

51.2T CPO RAS Evaluation

- Data shows that CPO ports are more reliable than retimed pluggable module ports, potentially due to:
  - Reduced number of interfaces and deeper level of integration
  - Flexibility in co-design of the system with improved operating condition for key components
  - Integration of optics within the platform allows system level test and screening in the manufacturing line
  - Reduced human intervention
- No unserviceable failures during the 1.35 million system hours of testing for phase 2 CPO systems
- Field serviceable ELS modules alleviate serviceability and reliability concerns

Optics	Assumption	ALIR	MTBI
FRO	All interruptions	1.22%	0.72M
CPO (Phase 1)	All interruptions	0.47%	1.85M
CPO (Phase 2)	All interruptions	0.2%	4.5M
	All interruptions except ELS SMT component failures	0.04%	25M
	Non-serviceable interruptions	0	175M

MTBI: Mean time between interruptions
ALIR: Annual link interruption rate

Transition to 102.4T with Integrated Optics

- The 51.2T validation proved viability of integrated optics technology for high volume manufacturing
- Next target: 102.4T CPO/NPO product
- Key optical specifications:
  - Interoperable with retimed pluggables optics (TP2 and TP3 compliance)
  - CMIS 5.3 management interface
  - Reach: 500m (spec). Can support up to 2km.
  - 60% optics power saving compared to retimed pluggables

Integrated Optics Implementation Trade-offs

- CPO and NPO both improve density and shorten the ASIC-to-optics channel, cutting power & cost vs. retimed pluggables
- **Common considerations:**
  - With power savings established over retimed pluggables, integrated optics' main hurdle is unknown RAS at scale
  - Interoperability across multiple vendors, chipsets, and retimed pluggables require TP2/TP3 compliance
  - Field serviceability with external laser source (ELS)
  - Reliability is implementation- and vendor-specific

CPO — Co-Packaged Optics

Optical engines integrated directly onto the switch-ASIC package substrate.

Advantages

- Shortest electrical path → lowest insertion loss & best signal integrity
- Fewest interfaces / RF reflection points → most scalable to higher lane rates (200G → 400G+)
- System-level RAS partially proven through 51.2T CPO
- Simpler accountability model than NPO

Challenges

- Less modular — optical engines are typically soldered to the package and tied to the ASIC vendor's implementation
- Higher optics supply chain risk

NPO — Near-Packaged Optics

Optical engines mounted near the ASIC linearly driven from the SerDes.

Advantages

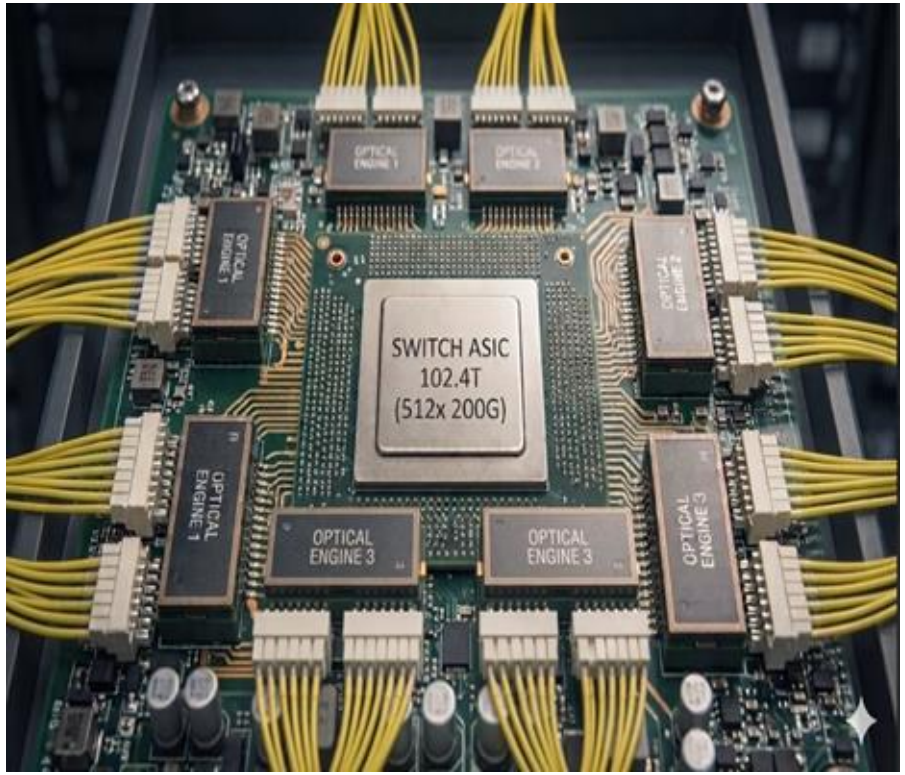
- Modular interposer approach can foster a broader multi-vendor ecosystem
- Comparable power savings to CPO at 102.4T switch bandwidth (200G/lane)
- Socketed options improve manufacturing flexibility / reworkability.
- Enables integrated and pluggable optics mixed Switch design, which can be required for some network deployments.

Challenges

- Longer traces + extra connectors → increased signal integrity and TP2/TP3 compliance risk at scale w/o retimers
- Linear-drive viability degrades at higher lane rates (e.g., 448G/lane); retimers may be needed, eroding the advantage toward pluggable levels. RAS needs to be proven: new mechanics & failure modes

102.4T Integrated Optical Switch Design

- 102.4T ASIC with CPO / NPO reduces the electrical lengths and improves signal integrity.
- External laser modules
  - Field replaceable laser modules help manage the serviceability risk as the technology matures
  - OIF ELSFP compliance to enable open ecosystem and multi-sourcing
- Fibers harness
  - Detachable fiber connectors to support manufacturability
  - MMC16 front panel optical connectors for high density design



102.4T Integrated Optical Switch Specifications

	102.4T CPO/ NPO Switch
Form Factor	• 1.5OU, 64 data ports (16x4 MMC16 connectors), 16 ELSFP ports connected to the OEs through Fibre Attach units (FAU).
System PCBA's	• SMB (Switch Main board): Includes the SMB CPLD, switch ASIC, clock, and other peripheral circuits. • MCB (Main Carrier board): Includes the MCB CPLD, IOB FPGA, COMe Module, and RunBMC card • LED Board: Features 65 R/G/B tri-color LEDs per PCBA to indicate the status of 64 MMC-16 ports • ELSFP Board: Equipped with an E1.S connector, QSFP, ELSFP LED. • IO Board: Contains RJ45 MGMT ports, USB interface, and system status LEDs. • RunBMC (Baseboard Management Controller) Board: Reused from Minipack 3. • COMe Module
Cooling Optics configuration	• Fit into Meta ORv3-HPRv1 rack in a canister with tool-less ejectors • 100% liquid cooled due to dust contamination risk (ASIC, CPO/NPO, ELSFP modules)

102.4T Integrated Optical Switch Design Factors

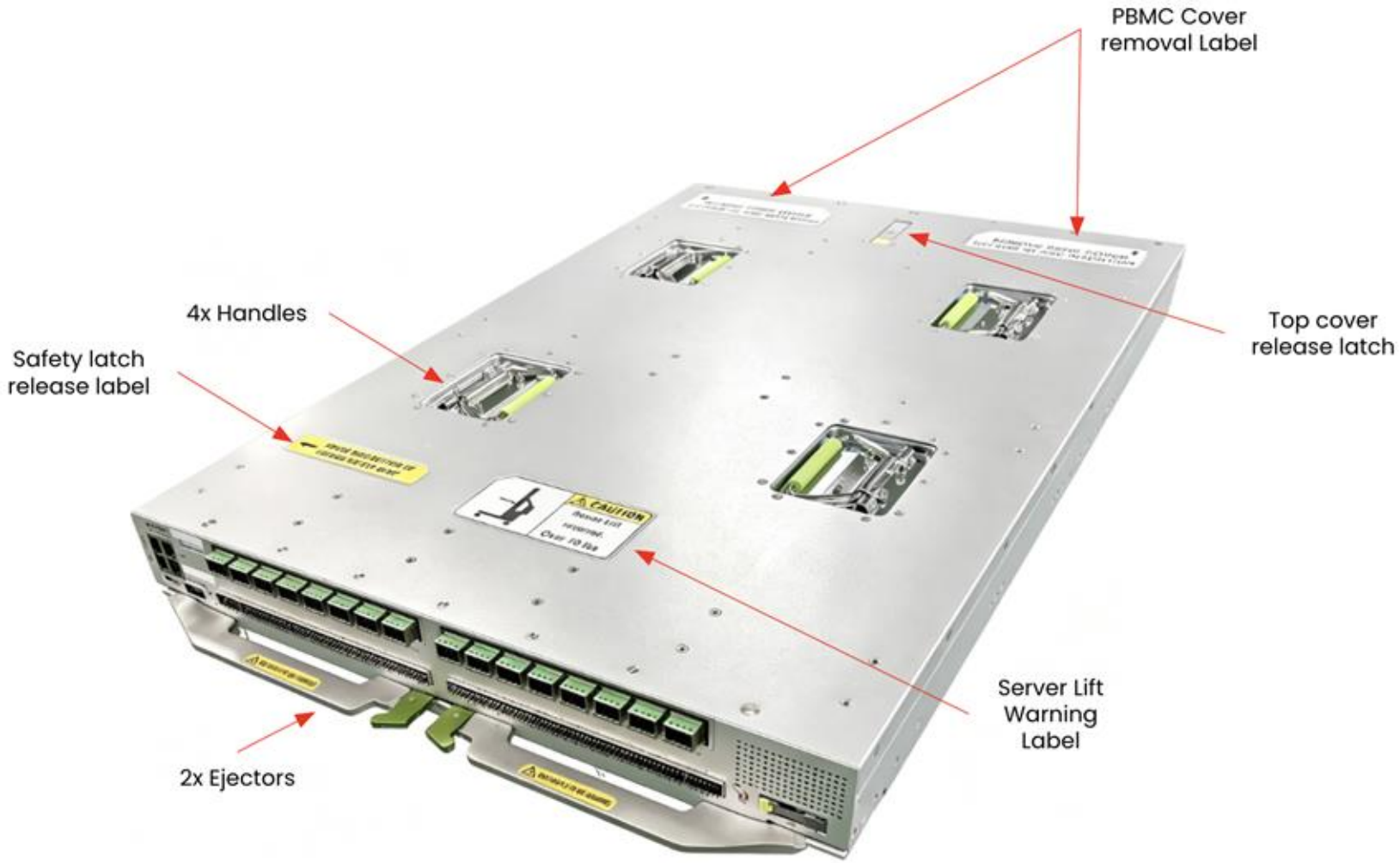
- **Architectural Simplification:** Integrated Optics improves high-speed system design by moving complexity directly onto the substrate.
- **Board Complexity & Materials:** While the high count of power rails necessitates a high layer count board, integrated optics can benefit from the use of more cost-effective, PCB materials.
- **Critical Design Challenges:** Achieving optimal power integrity and effectively placing power components in relation to optical engines remain significant hurdles that require meticulous mitigation strategies.
- **Manufacturing Considerations**: Fibre Array Unit pose challenges for reliable cable attachment and routing.

102.4T Integrated Optics Switch IO Ports





Switch Blade POC External View



Integrated Optical Backplane

- High-Density Architecture: The 1.5 OU design with integrated optics enables denser switch racks.
- Future-Proof Innovation: Integrated optics enable advanced solutions like optical backplanes.
- Enhanced Signal Integrity : Optical backplanes overcome copper signaling limitations.
- Dust tolerant optical connectors: Provide superior reliability and dust resilience.
- Serviceability: Easier deployment and reduced repair time.



Call to Action

- AI networking requires innovative and scalable solutions to keep up with the compute demand in a power-efficient way
- Industry-wide effort needed to mature the ecosystem to support future integrated optics technologies
  - Mature HVM process
  - Multi-vendor ecosystem
  - Standardization
  - Innovations to scale for future generations
- 51.2T CPO shows significantly better reliability than pluggables in our evaluation; more data needed across vendors and integrated-optics technologies.
- Industry-wide efforts are needed to drive the CPO/NPO technology to a high maturity level.

Thank You!

