Exploring Optical Connectors and Fibers for Next-Gen Switch Fiber Technology

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Background/Motivation

• Machine-to-machine traffic (east-west), make up as much as ~70% of total traffic in data centers driving the fast-growing market for switches and optical links [1]

• Switch ASIC with 51.2 Tbps capacity available
  - Recently launched Tomahawk 5, 51.2T
    ▪ The ASIC launched in August 2022, enables 512x100Gbps, 128x400Gbps, 64x800Gbps ports
  - Very high fiber density, high power consumption, high attenuation in electrical lanes when pluggable transceivers used

• Onboard optics (OBO) and co-packaged optics (CPO) can enable power efficient links
  - Efficient high-density connectivity needed for on-board and switch external connections (servers/switches), using structured cabling guidelines and best practices

• In this webcast we review internal and external connectivity options of next generation switches based on OBO/CPO

COBO On-Board Optics (OBO)

- Idea of OBO is not new, proprietary systems have been in place for decades, but there was no standards-based approach before COBO was established.

- Recently, electrical and optical densities, and increase in power consumption (which means increased cooling need) for high-speed pluggable modules created engineering challenges.

- To address these technical challenges, COBO was formed to establish a new ecosystem of on-board optics.

- OBO specification was approved in December 2018, for 8 and 16 lane versions for 1x400G and 2x400G Ethernet applications.
COBO and OIF Co-packaged Optics (CPO)

- After finishing the OBO specification, COBO started working on Co-packaged Optics (CPO)
  - CPO White Paper was released recently, where implementation guidelines and options are detailed for CPO
  - For CPO, external laser (ELS) is added as an option, which requires additional connectivity
    - PM fiber may be needed for ELS connection

- In addition to COBO, recently Optical Internetworking Forum (OIF) started a 3.2T Co-Packaged Module project for intra data center switching applications (2021)
  - The 3.2T Co-Packaged Optical Module Implementation Agreement (IA)
    - 100G electrical lanes (32 lane)
    - Optical interface options supporting 400GBASE-FR4 and 400GBASE-DR4, backwards compatible to 200G interfaces

51.2 Tbps switch CPO layout example
(Source: COBO CPO WP)

Co-packaged vs Near-packaged (using an interposer) (Source: COBO CPO WP)
# Technology, Optical Capability and Use Case Comparison

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Pluggable</th>
<th>OBO</th>
<th>CPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signalling</td>
<td>56G and 112G PAM4</td>
<td>56G and 112G PAM4 (112 focus)</td>
<td>56G and 112G PAM4 (112G focus)</td>
</tr>
<tr>
<td>Target Reach</td>
<td>Vary (2m - 40km) (module cost dependence, SM, MM)</td>
<td>Intra-data center</td>
<td>Intra-data center</td>
</tr>
<tr>
<td>Optical Lane Formats</td>
<td>SR4/SR8, DR4, FR4</td>
<td>SR4/SR8, DR4, FR4</td>
<td>SR4/SR8, DR4, FR4</td>
</tr>
<tr>
<td>Connector Locations</td>
<td>Module</td>
<td>OBO module, faceplate</td>
<td>ASIC, faceplate</td>
</tr>
<tr>
<td>Manufacture Capability</td>
<td>Mature transceiver market</td>
<td>Independent OBO module (not dependent on SiPh Integration)</td>
<td>Not mature: SiPh integration expected</td>
</tr>
<tr>
<td>Servicability</td>
<td>Mature</td>
<td>Evolving</td>
<td>Challenging, new approach required</td>
</tr>
<tr>
<td>Module Standardization</td>
<td>Yes (IEEE)</td>
<td>Yes</td>
<td>Required for package level interoperability</td>
</tr>
<tr>
<td>OE Module Failure</td>
<td>Simple module replacement</td>
<td>OBO does not impact ASIC</td>
<td>ASIC package replacement may be required</td>
</tr>
</tbody>
</table>

Source: COBO CPO WP
Traditional and New Connectivity

- **OBO/CPO internal connectivity creates risk and challenge for serviceability** (very high density of short pigtails, difficulty cleaning and inspecting, difficulty of fusion splicing if need arise etc.)
  - It is recommended to use structured cabling (patch cords, patch panels and conversion/mesh cassettes) for moves, changes etc.
  - A benefit of following structured cabling guidelines for CPO, OBO
CPO Mid-board Connector To Reduce Risk

- Mid-board connector for co-packaged optics is to reduce risk of fiber damage during installation
Connector Options for Dense OBO, CPO Interface

- There have been some new innovative dense fiber optic connectors recently from multiple manufacturers (most are not standards based yet)
  - MXC (expanded beam) (16 fiber, 32 fiber)
  - MMC (16 fiber) (Dense VSFF)
  - SN-MT (16 fiber) (Dense VSFF)
  - AirMT (12, 24 fibers)

- Even though they are not standardized, they need to comply with connector performance standards (IEC, TIA)
  - IL is significant – limited power budget for these applications
  - ORL and Reflectance are important especially for SM applications (DR4, FR4)
    - MPI, RIN

1,152 fibers in 1RU using MPO-16 adapters
1,152 fibers in 1RU using MMC adapters

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## Connector Options for Dense OBO, CPO Interface

<table>
<thead>
<tr>
<th>Connector Type</th>
<th># of Fibers per Connector</th>
<th># of Connectors per 1RU</th>
<th># of Fibers per 1 RU</th>
<th>400GBASE-DR4 (1024 fibers)</th>
<th>400GBASE-FR4 (256 fibers)</th>
<th>Connector Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplex LC</td>
<td>2</td>
<td>144</td>
<td>144</td>
<td>2U+</td>
<td>2U</td>
<td>IEC 61754-20:2012</td>
</tr>
<tr>
<td>SEN (CS)</td>
<td>2</td>
<td>320</td>
<td>320</td>
<td>2U+</td>
<td>1U</td>
<td>TIA-604-19</td>
</tr>
<tr>
<td>MDC</td>
<td>2</td>
<td>432</td>
<td>432</td>
<td>2U+</td>
<td>1U</td>
<td>IEC 61754-37 (draft)</td>
</tr>
<tr>
<td>SAC (SN)</td>
<td>2</td>
<td>432</td>
<td>432</td>
<td>2U+</td>
<td>1U</td>
<td>IEC 61754-36 (draft)</td>
</tr>
<tr>
<td>MPO-12</td>
<td>12</td>
<td>80</td>
<td>960</td>
<td>2U</td>
<td>1U</td>
<td>TIA-604-5, IEC 61754-7-1</td>
</tr>
<tr>
<td>MPO-16</td>
<td>16</td>
<td>80</td>
<td>1280</td>
<td>1U</td>
<td>1U</td>
<td>TIA-604-18, IEC 61754-7-4</td>
</tr>
<tr>
<td>AirMT-12</td>
<td>12</td>
<td>128</td>
<td>1536</td>
<td>1U</td>
<td>1U</td>
<td>TIA-604-5, IEC 61754-7-1</td>
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<tr>
<td>MPO-24</td>
<td>24</td>
<td>80</td>
<td>1920</td>
<td>1U</td>
<td>1U</td>
<td>TIA-604-5, IEC 61754-7-2</td>
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<tr>
<td>MPO-32</td>
<td>32</td>
<td>80</td>
<td>2560</td>
<td>1U</td>
<td>1U</td>
<td>TIA-604-18, IEC 61754-7-3</td>
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<tr>
<td>AirMT-24</td>
<td>24</td>
<td>128</td>
<td>3072</td>
<td>1U</td>
<td>1U</td>
<td>TIA-604-18, IEC 61754-7-3</td>
</tr>
<tr>
<td>MXC-32</td>
<td>32</td>
<td>104</td>
<td>3328</td>
<td>1U</td>
<td>1U</td>
<td></td>
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<tr>
<td>MMC-16</td>
<td>16</td>
<td>216</td>
<td>3456</td>
<td>1U</td>
<td>1U</td>
<td></td>
</tr>
<tr>
<td>SN-MT-16</td>
<td>16</td>
<td>216</td>
<td>3456</td>
<td>1U</td>
<td>1U</td>
<td></td>
</tr>
</tbody>
</table>

Source: COBO CPO WP
Significance of Connector End-face Cleanliness

- Fiber optic connectors are very sensitive to end-face cleanliness, for IL and RL performance
  - There are numerous studies for how they deteriorate IL/RL performance, especially for single mode cabling
- End face cleanliness is a bigger challenge for multi-fiber (MPO, MMC, SN-MT etc.) connectors
- Cabling industry has established best practices for cleaning and inspection but it’s impossible to completely get rid of this problem due to installation environments
- Most connector manufacturers have done a great job to ship connectors with very minimal debris etc. on the fiber end-faces
- An area of improvement in production for multi-fiber connectors is to use a larger field of view imaging system at production, so a greater area of connector ferrule end face is visible
  - This helps to eliminate debris on the ferrule end-face, which does not have immediate impact to connector performance, but eventually can migrate to an area near the fiber causing issues
  - Inspection speed is also critical, for improving manufacturing efficiency

Source: 2022 IWCS, paper 3-1: Development of Best Practices and Guidelines for the Use of Expanded Beam Connectors in Data Center Applications
Expanded Beam and Airgap Connectors

- One potential method to overcome issues with connector end-face cleanliness is expanded beam connectors
  - Generally, expanded beam connectors have higher IL compared to traditional pc connectors
  - Although not standardized in international standards organizations, several connector manufacturers are offering them, especially multi-fiber style connectors that can find an application in OBO, CPO
  - Though expanded beam connectors perform quite well under dust, debris, they need special cleaning tools/methods
- Another innovative connector design is using small air-gap
- Manufacturing of both expanded beam and air-gap connectors are more complex compared physical contact connectors
Opportunities for MMF and/or Multimode Waveguides?

- MMF was not left out of OBO/CPO in principle
  - Though most OBO/CPO work is closely associated with SiPh and SMF
  - Recent OIF 3.2T CPO project focused only on SM applications (DR4, FR4)

- However, SMF being more susceptible to connector end-face contamination, are there opportunities to use MMF or MM waveguides for switch ports that do not require reaches beyond 100m, such as switch-to-server links?
  - VCSEL more efficient and demonstrated robustness to contamination and misalignments
  - SMF susceptible to contamination, might need expanded beam connectors (MMF might not need)
MWIS (Multimode Waveguide Interconnect System)

C2M MWIS

NPO-like MWIS

C2M (Conventional)

Source: COBO website

CPO-like MWIS

C2M (Conventional)

CPO-like C2C

C2C MWIS

Offset Launch

Four levels of roughness in the waveguide

Offset Receiver

Source: COBO website
Summary

• Pluggable optical modules ecosystem based on IEEE and MSA’s has been in place for decades providing flexible and serviceable high speed switch optical connectivity.

• As data rates increases beyond 100Gbps per electrical lane it becomes challenging to connect the ASIC to pluggable module due to port density, power consumption and thermal limitations.

• OBO/CPO can address these problems
  - By bringing high BW optical connections very close to the switch ASIC
  - By increasing faceplate density

• We have reviewed internal and external connectivity options for CPO/OBO, including new non-standard dense connectors, and addressed topics about optical performance, density, reliability, serviceability etc.
  - Use of high density multifiber connectors (MPO12 at least)
  - Benefitting from structured cabling best practices
  - Protecting the connectors close to the active equipment
Thank you...

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