



Latest Trends in High-Speed Optics

IX Fórum 11

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Greg Hart

Finisar Corporation

World's Largest Supplier of Fiber Optic Components and Subsystems


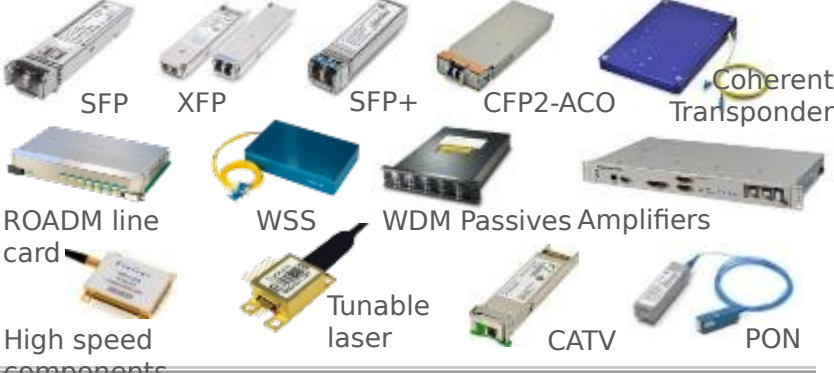


- Optics industry leader with \$1.4B+ in annual revenue
- Founded in 1988
- IPO in 1999 (NASDAQ: FNSR)
- 13,000+ employees
- ~25% market share
- Best-in-class broad product line
- Vertically integrated with low cost manufacturing
- Significant focus on R&D and capacity expansion
- Experienced management team
- 1300+ Issued U.S. patents



Corporate Headquarters: Sunnyvale, CA USA



Broad Product Portfolio and Customer Base

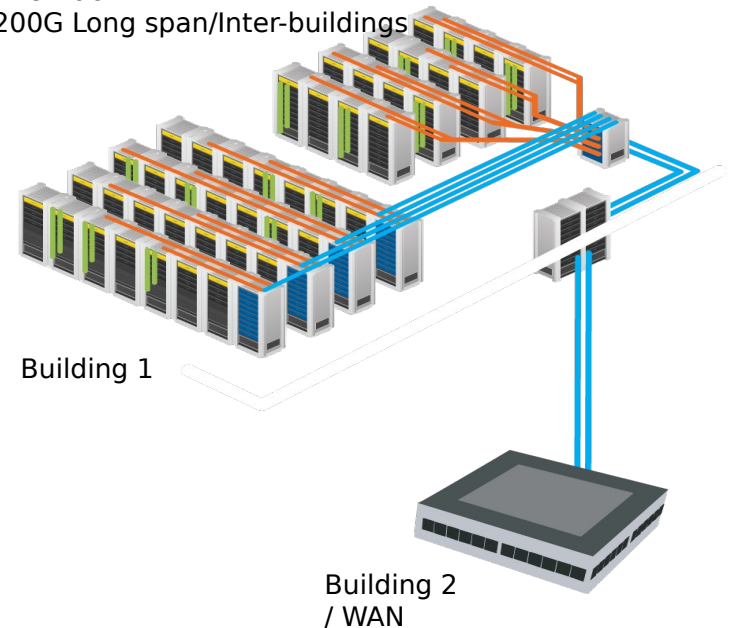
| | DATACOM | TELECOM |
|-----------|---|---|
| PRODUCTS |  <p>SFP SFP+ QSFP/QSFP28 CFP2/CFP4 CFP</p> <p>Optical Engine (BOA) CXP Active Optical Cables XFP X2/XENPAK</p> |  <p>SFP XFP SFP+ CFP2-ACO Coherent Transponder</p> <p>ROADM line card WSS WDM Passives Amplifiers</p> <p>High speed components Tunable laser CATV PON</p> |
| CUSTOMERS |  <p>EMC² intel extreme networks CISCO</p> <p>BROCADE JUNIPER NETWORKS DELL</p> <p>NetApp IBM EMULEX H3C</p> <p>hp QLOGIC ORACLE Mellanox</p> |  <p>HUAWEI ERICSSON ZTE中兴 CIENA</p> <p>Alcatel-Lucent ADVA HITACHI Inspire the Next</p> <p>NOKIA eci FUJITSU infinera NEC</p> <p>Coriant cyan transmode</p> |

Data Center Connections are Transitioning

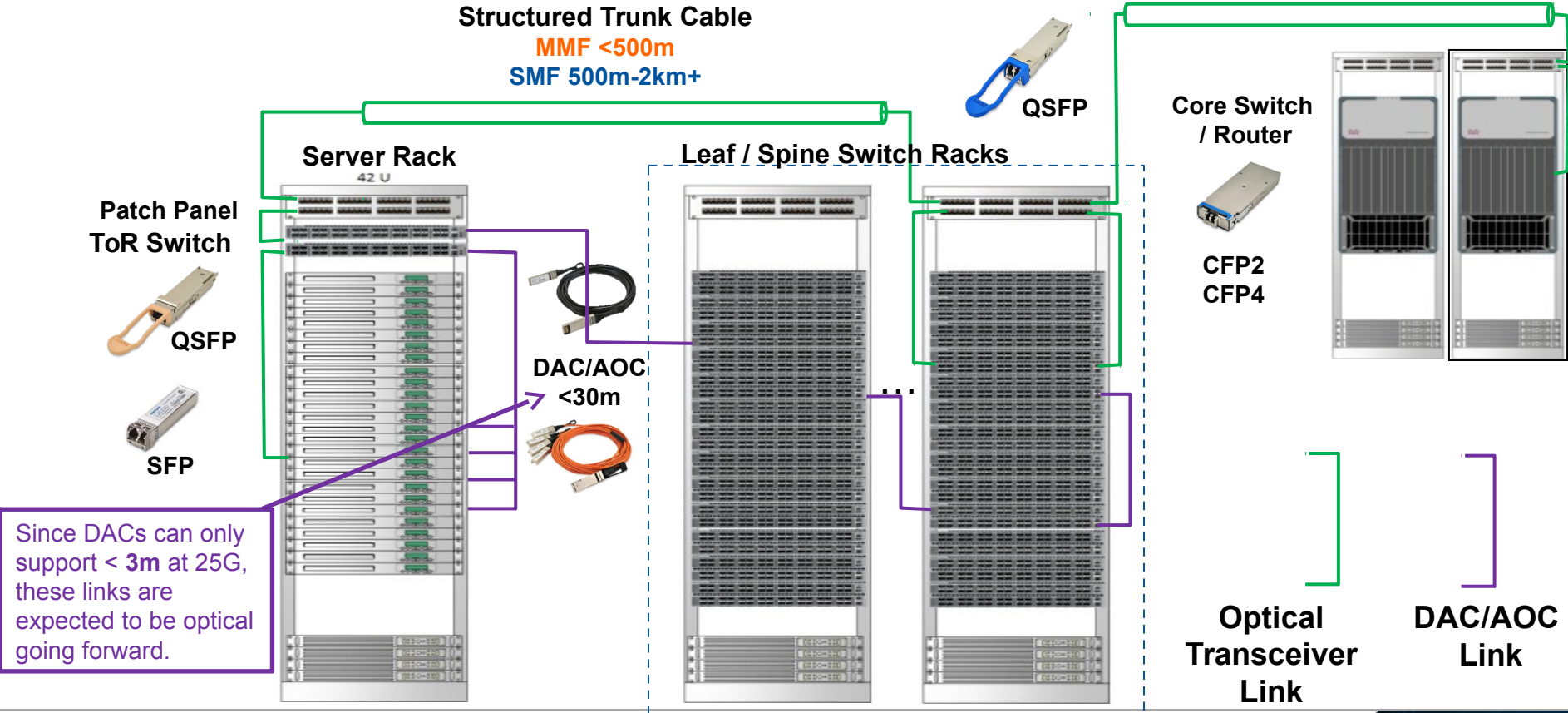
- Due to the significant increase in bandwidth demand, Data Center connections are moving from 1G/10G/40G, to 25G/100G/200G

- Within the Data Center Rack
 - **10GE** still being deployed
 - **25GE** starting to be deployed now
 - 50GE (or 100GE) to the server will follow
- Between Data Center Racks
 - **10GE and 40GE** still being deployed
 - **100GE** starting to be deployed now
 - What follows? 200GE or 400GE?
- Long Spans/DCI & WAN
 - **10G DWDM** still being deployed
 - **100G/200G Coherent** starting to be deployed now
 - What follows? 400G, 800G, or 1.6T?

— 10G/25G Intra-rack
— 10G/40G/100G Inter-rack
— 10G/40G/100G/200G Long span/Inter-buildings



Rack Connections in Hyperscale Data Centers



Market moves to cost-Effective 25G and 100G Optical Modules



25GE Optical Transceivers

- Used for 25GE server ports and also on some Ethernet switch ports
- SFP28 form factor is standardized by SFF-8402 (SFF Committee)
- It has a 1-lane, retimed 25G I/O electrical interface
- Supports up to 1.5W power dissipation
- SR (100m, 300m) and LR (10km)



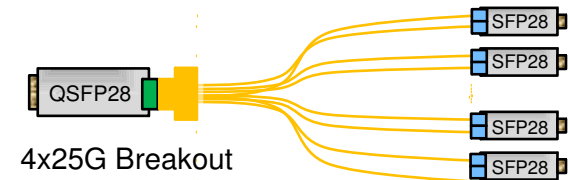
100GE Optical Transceivers

- QSFP28 is the 100GE module form factor of choice for Ethernet switches
- QSFP28 form factor is standardized by SFF-8665 (SFF Committee)
- It has a 4-lane, retimed 25G I/O electrical interface (CAUI-4)
- Supports up to 3.5W power dissipation
- SR4 (100m, 300m), SWDM4 (100m+), CWDM4 (2km) and LR4 (10km)



Active Optical Cables in QSFP28 and SFP28

- Cost-effective integrated cabling solutions for in-rack and rack-rack connections



100G Optical Standards and MSA Proliferation

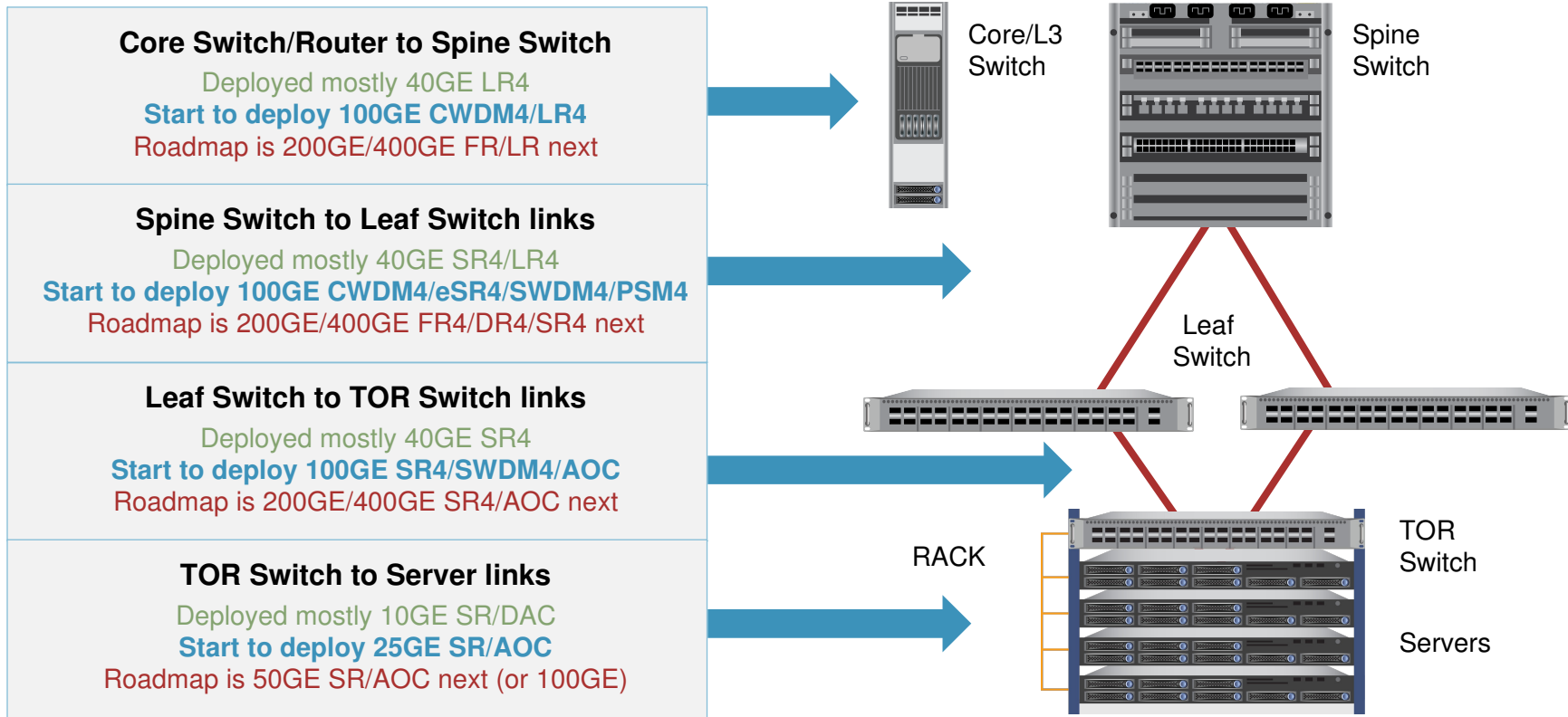
- MANY optical interface choices in the market.
- Proliferation is impacting interoperability, multi-sourcing, and cost reductions through consolidated volume ramp – causing confusion and slowing down buying decisions.
- Choose **broadly supported**, standards or MSA-based optics (e.g., 100G CWDM4).
- Engage with **broad-based optics suppliers** to help navigate the available choices – remove technology bias.

- Standards alphabet soup!

SR4, eSR4, SR10, 4xSR, 10xSR, 12xSR, LR4, LR4-Lite, eLR4, PSM4, 4xEDR, Omni-Path, 4xPCIe4, ER4, ER4f, FC-PI-6 128G FC, 4x32G FC SMF, 4x32G FC MMF, OTU4, CWDM4, eCWDM4, SWDM4, eSWDM4

100-128 Gb/s

Typical 100GE Deployments in the Data Center



Types of 100G QSFP28 Modules in the Market^(*)

| | PARALLEL (MPO) | DUPLEX (LC) |
|------------|---|---|
| MULTIMODE | SR4 & 4x25G-SR 70/100m SR4 w/Low-Latency 30/40m eSR4 300/400m | <p style="text-align: center;"><i>Support for existing 10G fiber infrastructure?</i></p> |
| SINGLEMODE | PSM4 500m | LR4 / eCWDM4 (4WDM-10) 10km CWDM4 2km <i>Support for 500m duplex?</i> eLR4 (4WDM-20) 20km ER4f (4WDM-40) 40km |

Multimode distances refer to OM3/OM4; Single mode distances refer to SMF.

BLACK = Standardized IEEE interfaces
RED = MSA or Proprietary interfaces



^(*) Announced to be either in production or under development by at least one optical supplier.

Responding to 100G Market Needs: CWDM4-OCP

- Large data center users like Facebook want a **cost-effective** single mode 100G QSFP28 module that is best adapted to their specific, **well-controlled infrastructure conditions**.
- Using a 100G CWDM4 'Lite' interface over duplex single mode fiber infrastructure together with a more limited reach of **500m** and a narrower case temperature range of **15-55°C** provides an **optimized solution** for this need.
- Facebook has submitted **the CWDM4-OCP specification** as a contribution to OCP.

[http://www.opencompute.org/wiki/Networking/SpecsAndDesigns#Facebook - CWDM4-OCP](http://www.opencompute.org/wiki/Networking/SpecsAndDesigns#Facebook_-_CWDM4-OCP)



OPEN
Compute Project



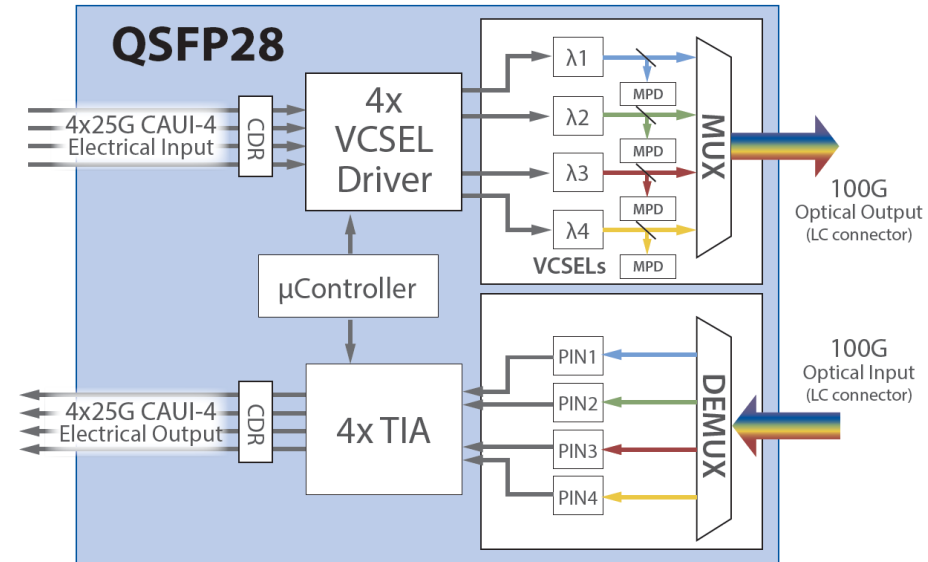
Why Duplex Multimode Fiber Matters

- **For Brownfield Applications:**
 - Most data centers today are still architected around 10G Ethernet
 - Primarily focused on using **10GBASE-SR over duplex MMF (LC connector)**
- Data centers are migrating switch-to-switch links from 10G to 40G/100G, but want to maintain their existing fiber infrastructure.
 - SR4 interface requires using MPO connectors on the equipment side (not LC).
 - *Not present in legacy fiber plant.*
 - LR4 and CWDM4 interfaces require single mode fiber.
 - *Not present in legacy fiber plant.*

Many data centers want to upgrade from 10G to 40G
and 100G
without changing their duplex MMF infrastructure

Responding to Market Needs: SWDM4

- **Shortwave WDM** (SWDM) technology uses multiple wavelengths in the 850nm region, optically multiplexed and demultiplexed inside the transceiver.
- SWDM4 enables the transmission of 40G (4x10G) and 100G (4x25G) **over existing duplex multimode fiber with LC connectors**.
- 40G and 100G QSFP SWDM4 modules are already available and have been publicly demonstrated.



Why Duplex Multimode Fiber Matters

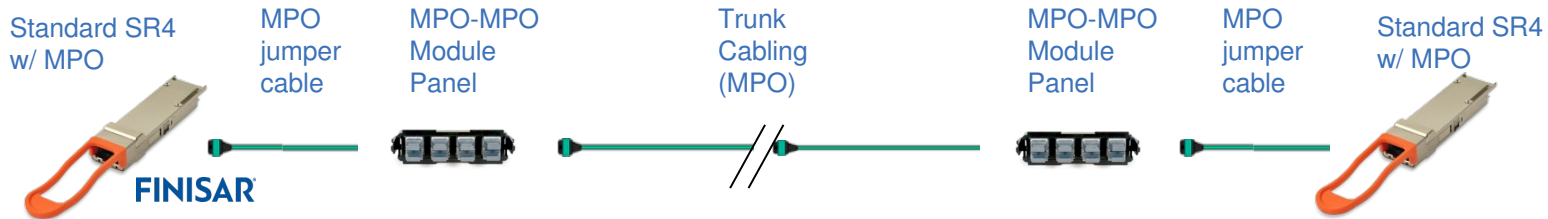
- **For Greenfield Applications:**

- Many new data centers require very high bandwidth density and longer reaches.
- Using SWDM4 requires 2 fibers per full-duplex link instead of 8. This significantly **increases the bandwidth density** per OM3/OM4 fiber and **decreases the cost** of new trunks/structured cabling infrastructure, while still using cost-effective multimode transceivers.
- For larger data centers, new OM5 multimode fiber can **extend the reach of SWDM4 optics**, since it allows wavelengths up to 953nm to propagate further.
- OM5 MMF also **future-proofs the fiber infrastructure** for possible future 200G, 400G and 800G interfaces.

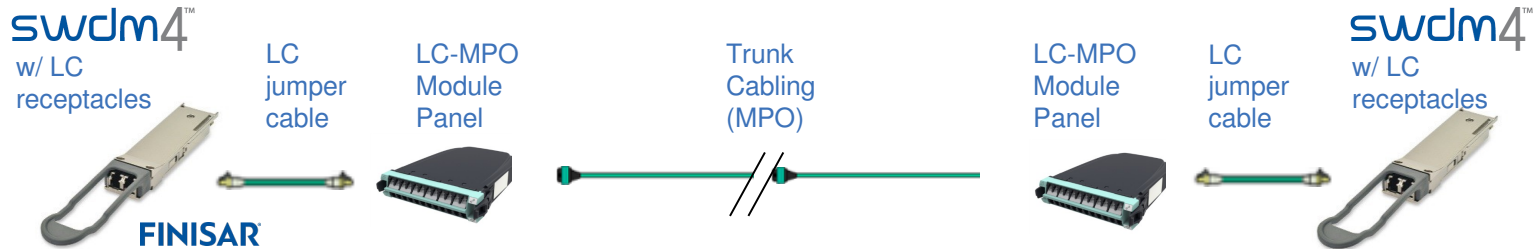
For new data centers using 40G/100G, *SWDM is a perfect solution to decrease infrastructure cost, and/or to increase link performance.*

Using 100G SWDM QSFP28 Transceivers

Structured 100G Cabling with SR4 modules



Structured 100G Cabling with SWDM4 modules



Savings by using SWDM4:

- ◆ Reuse existing 10G MMF cabling infrastructure
- ◆ Use 2 multimode fibers instead of 8 fibers per 100G Ethernet link

- Industry group to promote SWDM technology for duplex multimode fiber in data centers.
- Finisar is a founding member of the SWDM Alliance and SWDM MSA.
- More information at www.swdm.org



Founding Members

Anritsu COMMScope®

CORNING DELL EMC

FINISAR H3C

Hisense HUAWEI

HUBER+SUHNER Excellence in Connectivity Solutions INNEOS

JUNIPER NETWORKS LUMENTUM ofS
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PANDUIT® Prysmian Group SURUGA SEIKI

YOFC 长飞

40G and 100G SWDM4 QSFP Transceivers

- Supports both legacy and wideband **duplex multimode fiber**.
- Duplex LC connectors.
- 4x10G or 4x25G VCSEL transmitters.
- Fully electrically and mechanically compliant to QSFP host requirements.
- Longer reach and easier to deploy than proprietary “BiDi” solutions.



swdm4™

| Data Rate | Module Type | OM3 Reach | OM4 Reach | OM5 Reach |
|-----------|------------------|-----------|-----------|-----------|
| 40G | QSFP+ SWDM4 | 240m | 350m | 440m |
| 100G | QSFP28 SWDM4 | 75m | 100m | 150m |
| 100G | QSFP28 eSWDM4(*) | 200m | 300m | 400m |

(*) under development

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|------------|---|---|
| MULTIMODE | SR4 & 4x25G-SR 70/100m SR4 w/Low-Latency 30/40m eSR4 300/400m | SWDM4 75/100m 150m on OM5 eSWDM4 200/300m 400m on OM5 |
| SINGLEMODE | PSM4 500m | LR4 / eCWDM4 (4WDM-10) 10km CWDM4 [Lite] <i>Support for 80km+ ?</i> 2km [500m] eLR4 (4WDM-20) 20km ER4f (4WDM-40) 40km |

Multimode distances refer to OM3/OM4; Single mode distances refer to SMF.

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Coherent Transmission for Transport Applications

- 100G/200G links require a transponder box to convert to coherent optical transmission in order to support 80~100km and beyond.
- Several system OEMs provide a 1RU “pizza box” for DCI applications, which use pluggable Coherent CFP2-ACO optical modules from suppliers like Finisar.



Coriant Groove G30
(supports Bidi Coherent)



Nokia WaveLite Metro 200



Fujitsu 1FINITY T300



Cisco NCS1000



PacketLight PL-2000AD

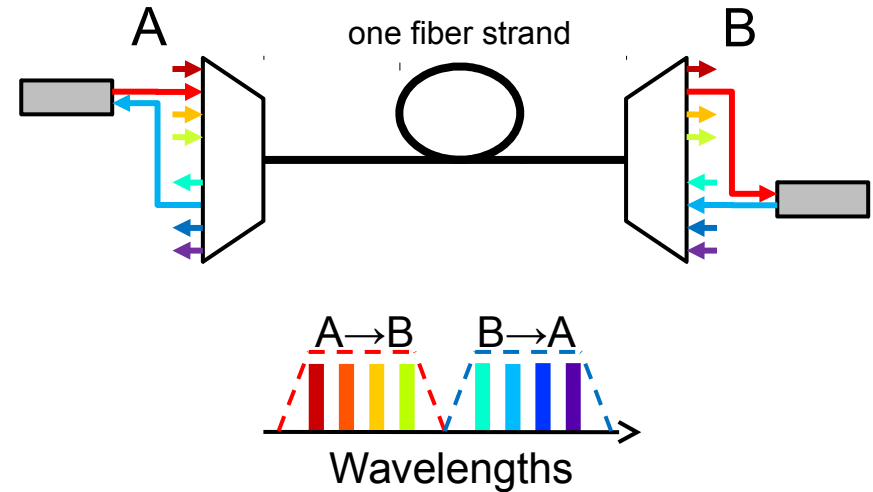
- Accton/Edgecore has recently contributed to TIP the design for their open-source “Cassini” packet transponder box for DCI and backhaul applications, featuring pluggable coherent ports.



Edgecore “Cassini”
open-source design





Bi-Directional Coherent Transmission

- Some carriers lease dark fiber by individual fiber strand instead of per fiber pair.
- Bi-directional transmission over a single fiber strand allows significant operational cost savings.
- Bi-directional coherent transmission requires separate wavelengths for each direction.
- This can only be achieved if the coherent module has separate lasers for Tx and Rx, a unique feature supported by the Finisar CFP2-ACO.



We recommend using transport systems with pluggable Coherent CFP2-ACO optics instead of fixed ports.

Mainstream 1RU Ethernet Switch Roadmap

| FIRST AVAILABLE | ELECTRICAL I/O [Gb/LANE] | SWITCHING BANDWIDTH | TOR/LEAF DATA CENTER SWITCH CONFIGURATION | |
|-----------------|--------------------------|---------------------|--|---|
| ~2010 | 10G | 1.28T |  <p>32xQSFP+ (40G)</p> | |
| ~2015 | 25G | 3.2T |  <p>32xQSFP28 (100G)</p> | 3.2Tb/s switches based on 100G QSFP28 modules starting to be deployed in data centers today. |
| ~2017 | 25G | 6.4T |  <p>32 ports of 200G</p> | Given the multiple switching ICs expected to be available, the market is likely to be fragmented in the future. |
| ~2018 | 50G | | | |
| ~2020 | 50G | 12.8T |  <p>32 ports of 400G</p> | |

Beyond the 3.2Tb/s Switch

- Large growth in bandwidth demand is pushing the industry to work on technologies and standards to support future **6.4T and 12.8T switches**.
- 50G, 200G and 400GE Standards are being defined by IEEE.
- Modulation is moving from NRZ to **PAM4** for both electrical and optical interfaces.
- Optics suppliers are investing large R&D \$\$ on supporting these new rates.
 - New transceiver module form factors (**CFP8, QSFP56, QSFP-DD, OSFP, SFP56**).
 - Advanced VCSELs, InP DFB lasers and Si Photonics technologies.
 - ICs and manufacturing test platforms that support PAM4 modulation.

50G, 200G and Next-Gen 100G Ethernet Standardization

200GE interfaces being standardized in IEEE 802.3bs

| INTERFACE | LINK DISTANCE | MEDIA TYPE | TECHNOLOGY |
|--------------|---------------|-----------------------|--------------------------|
| 200GBASE-SR4 | 100 m | 8f Parallel MMF (MPO) | 4x50G PAM4 850nm |
| 200GBASE-DR4 | 500 m | 8f Parallel SMF (MPO) | 4x50G PAM4 1300nm window |
| 200GBASE-FR4 | 2 km | Duplex SMF (LC) | 4x50G PAM4 CWDM |
| 200GBASE-LR4 | 10 km | Duplex SMF (LC) | 4x50G PAM4 LAN-WDM |

50GE interfaces being standardized in IEEE 802.3cd

| INTERFACE | LINK DISTANCE | MEDIA TYPE | TECHNOLOGY |
|------------|---------------|-----------------|------------------------|
| 50GBASE-SR | 100 m | Duplex MMF (LC) | 50G PAM4 850nm |
| 50GBASE-FR | 2 km | Duplex SMF (LC) | 50G PAM4 1300nm window |
| 50GBASE-LR | 10 km | Duplex SMF (LC) | 50G PAM4 1300nm window |

Next-Generation 100GE interfaces being standardized in IEEE 802.3cd

| INTERFACE | LINK DISTANCE | MEDIA TYPE | TECHNOLOGY |
|--------------|---------------|-----------------------|------------------|
| 100GBASE-SR2 | 100 m | 4f Parallel MMF (MPO) | 2x50G PAM4 850nm |
| 100GBASE-DR | 500 m | Duplex SMF (LC) | 100G PAM4 1310nm |

400G Ethernet Standardization

400GE interfaces being standardized in IEEE 802.3bs

| INTERFACE | LINK DISTANCE | MEDIA TYPE | TECHNOLOGY |
|---------------|---------------|------------------------|----------------------|
| 400GBASE-SR16 | 100 m | 32f Parallel MMF (MPO) | 16x25G NRZ Parallel |
| 400GBASE-DR4 | 500 m | 8f Parallel SMF (MPO) | 4x100G PAM4 Parallel |
| 400GBASE-FR8 | 2 km | Duplex SMF (LC) | 8x50G PAM4 LAN-WDM |
| 400GBASE-LR8 | 10 km | Duplex SMF (LC) | 8x50G PAM4 LAN-WDM |



400GE CFP8 and QSFP-DD Optical Transceiver Modules



CFP8 is the *1st-generation* 400GE module form factor, to be used in routers and DWDM transport client interfaces.

Module dimensions are **slightly smaller than CFP2**

Supports either **CDAUI-16** (16x25G NRZ) or **CDAUI-8** (8x50G PAM4) electrical I/O



QSFP-DD (and similar) modules being developed as *2nd-generation*, for higher port-density.

Enables **12.8Tb/s** in 1RU via 32 x 400GE ports

Supports **CDAUI-8** (8x50G PAM4) electrical I/O only

Host is backwards compatible with QSFP28

Trends in High-Speed Optics

- 25G/100G is providing a **very cost-effective upgrade** from 10G/40G and will be the mainstay of Ethernet over the next 5 years.
- A very large number of 100G SR4, SWDM4 and CWDM4 ports will be **deployed in the next 2-3 years**.
- These multi-source interfaces are likely to be the **volume/cost leaders** in mainstream deployments over the next 5+ years.
- SWDM4 enables upgrading to 40G/100G **using duplex multimode fiber**.
- 100G 'Lite' variants can **provide benefits** in controlled environments.
- **Coherent technology** being used for DCI/backhaul applications at 100G/200G and beyond.
- The industry is already working on **200G and 400G** for next-generation Data Centers.



FINISAR[®]

Thank You / Q&A

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