Introduction

High-speed interconnects are playing an increasingly more important role in data centers. This application note provides:

- An introduction to the terminology related to high-speed copper and optical cables and transceivers in general
- An introduction to Mellanox’s interconnect product families
- Practical hints related to installation of cables and transceivers

Data centers often use several different types of high-speed interconnects matching each interconnect type to specific requirements.

DACs (Direct Attach Copper) is the lowest cost, but after about 3-7 meters the attenuation of the signal is significant and it becomes unrecognizable.

AOCs (Active Optical Cable) are used from 3 meters to about 30 meters. It is not practical to install AOCs that are longer than 30 meters.

More expensive SR (Short Range), SR4 (Short Range 4 Channels) multi-mode transceivers can be used up to 100 meters after which the signal degrades. Parallel single-mode transceivers (PSM4) are used from 500 m - 2 km. After 500 meters the cost of 8 fibers adds up with each meter, so multiplexing the four channels signals into two single fibers is more economical with CWDM4 (Coarse Wavelength Division Multiplexer 4 Channels) for up to 2 km and LR4 (Long Range 4 Channels) up to 10 km.

Figure 1 – Different types of interconnects
NOTE:
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1. **Cable and Connector Definitions**

*Table 1 – Cable and Connector Definitions*

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<tr>
<td>DAC (Direct Attach Copper) cable with QSFP connector</td>
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<td>QSA (QSFP to SFP Adapter)</td>
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<td>QSFP transceiver</td>
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<td>SFP transceiver</td>
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<tr>
<td>QSPF-DD - double density QSFP, a proposed new standard for 200/400 Gb/s links along with OSFP (octal SFP)</td>
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1.1 **Terminology and Basics**

1.1.1 **Cable Form Factors and Connector Types**

**SFP (Small Formfactor Pluggable)** – A transceiver or cable with a single lane (channel) in each direction. All cables and transceivers commonly used in data-centers are bidirectional.

**SFP+** denotes the 10 – 14 Gb/s type of AOC/transceivers, while **SFP28** is the notation for the 25-28 Gb/s products with an SFP form factor. The noted data rate is the data rate in each direction.

**QSFP (Quad Small Formfactor Pluggable)** – A bidirectional transceiver or cable with 4 lanes in each direction.

**Standards:** Electrical pinout, memory registers, and mechanical dimensions for both **SFP** and **QSFP** devices are defined in the public MSA (Multi-source Agreement) standards available at: www.snia.org/sff/specifications.
QSFP+ denotes cables/transceivers for 4 x (10 – 14) Gb/s applications, while QSFP28 denotes the 4 x (24 – 28) = 100 Gb/s product range with QSFP form factor.

QSFP-DD (Double-Density) supports up to 400 Gb/s in aggregate over an 8 x 50 Gb/s electrical interface. The cage and connector design provides backwards compatibility to QSFP28 modules which can be inserted into a QSFP-DD port and connected to 4 of the 8 electrical channels.

AOC (Active Optical Cable) – An optical fiber cable with an optical transceiver with the fibers bonded inside and not removable. The optical transceiver converts the host electrical signals into light pulses and back.

Transceiver (transmitter and receiver) is a converter with an electrical connector in one end and optical connector in the other end. It can have one or more parallel lanes in each direction (transmit and receive).

Transceiver or AOC? – You can argue that two transceivers connected with a patch cable replace an AOC. However, if you don’t have cleaning tools and experience with optical connectors, it is safer to use an AOC where the optical cable is fixed inside the ‘connectors’. The AOC’s ‘connectors’ are actually similar to detachable transceivers, but they work as a kit with a well-known transceiver at the other end. AOCs don’t have any issue with multi-vendor interoperability. Nevertheless, it is easier to replace a pair of transceivers than an AOC since you don’t have to install a new cable as the cable is already there.

Traditionally, AOCs are more common in InfiniBand installations, while transceivers with patch cables are more common in Ethernet systems.

DAC (Direct Attach Copper) cable or PCC (Passive Copper Cable) – A high-speed electrical cable with an SFP or QSFP connector in each end, but no active components in the RF connections. The term ‘passive’ means that there is no active processing of the electrical signal. The DACs still have an EEPROM, a memory chip in each end, so the host system can read which type of cable is plugged in, and how much attenuation it should expect.

1.1.2 Optical Transmission and Fiber Types

MMF (Multi-Mode Fiber) – The type of fiber used for VCSEL (Vertical Cavity Surface Emitting Laser) based transmission, normally operating at 850 nm wavelength. Its maximum reach is 100 m for 25 Gb/s line rates.

OM2, OM3, OM4 (Optical Multi-mode) are classifications of MMF for different reach. Higher number indicates lower degradation of the optical signal, and longer reach. MMF cables usually have the following color scheme

- OM2 – orange – used for data rates at 1-14 Gb/s, 62.5 µm fiber core diameter
- OM3 – aqua – 70 m reach for 25/100 Gb/s transceivers, 50 µm core diameter
- OM4 – aqua or purple – 100 m reach for 25/100 Gb/s transceivers, 50-um core diameter
Figure 2 – Multi-mode fiber patch cords [2]

SMF (Single-Mode Fiber) – The type of fiber used for Indium Phosphide or Silicon Photonics based transceivers, operating at 1310 or 1550 nm wavelength. Single-mode fiber usually has a yellow jacket and can reach 100s of km.

CWDM, WDM, DWDM, (Coarse Wavelength Division Multiplexing, Normal, Dense) – a technology for transmitting multiple optical signals through the same fiber. All signals have different wavelengths (color). WDM transceivers make it possible to reduce the number of fibers in the link to two, one for transmit, and one for receive.

Dense WDM employs a very narrow 4.5 nm laser wavelength spacing for single-mode.

Coarse WDM employs a wide 20 nm laser wavelength spacing for single-mode.

Short WDM (SWDM) employs 4 different wavelengths multi-mode VCSEL lasers.

PSM4 (Parallel Single-Mode 4 fiber) is the opposite of WDM in the sense that each signal is transferred in its own fiber. This requires 4 fibers in each direction, but enables simpler transceiver design since all signals can have same wavelength and no optical MUX/DeMUX is required and no TEC (Thermo Electric Cooler) to stabilize the laser wavelengths. PSM4 is a MSA (Multi Source Agreement), i.e. a standard supported by a number of transceiver vendors.

1.2 Reach of Transceivers

Transceivers are classified with data rate and reach, governed by the IEEE Ethernet standards. For 100 Gb/s (100 GbE) transceivers the most common definitions are:

100GBASE-SR4 - 100 Gb/s, SR4=Short Reach (100 meters on OM4 fiber), 4 fibers
100GBASE-LR4 _ 100 Gb/s, LR=Long Reach (10 km using WDM on SMF)
100GBASE-ER4 b - 100 Gb/s, ER=Extended Reach (30-40 km using WDM on SMF)
100GBASE-ZR - 100 Gb/s, ZR is not an IEEE standard, 80+ km reach.
100GBASE-CR4 - the standard for DAC cables (twisted pair) for short reaches, up to about 7 m.

The interface types listed above are the most common ones for 100 GbE transceivers. The IEEE 802 standards define a wide range of standards for different Physical Media Devices (PMDs).
1.3 Optical Connector Types

High-speed cables make use of edge ‘gold-finger’ connectors on the electrical side which attaches to the host system (switch, network card on server/storage). On the optical side, the following connector types are the most common:

**MPO** (Multi-fiber Push On), is a connector standard supporting multiple rows with up to 12 fibers in each. A QSFP transceiver with MPO receptacle uses the outermost 4 positions on each side.

**Figure 4 – Single-row MPO Connector**

See also **Figure 17**.

**MTP connectors** are a vendor specific proprietary high-precision version of MPO connectors.

**LC connectors** are used for both single-mode and multi-mode fibers and are used in both SFP and QSFP MSA transceivers.
There are plenty of other optical connector standards. MPO and LC are commonly used for datacenter patch cables and transceivers.

1.4 Networking Standards

LinkX™ is the product line brand for Mellanox’s DAC, AOC and transceivers products that supports InfiniBand, Ethernet and CPRI (Common Public Radio Interface) networks.

InfiniBand (IB) is a computer-communications standard used in high-performance computing that features very high throughput and very low latency. InfiniBand is commonly used in HPC (High-Performance Computing) and hyperscale datacenters. InfiniBand is promoted by the InfiniBand Trade Association (IBTA), http://www.infinibandta.org/. See [4] for an introduction.

Ethernet (ETH) is a family of general computer networking technologies commonly used inside and outside datacenters. It comprises a wide number of standards, commonly referred to as IEEE 802.3, which is promoted by IEEE (www.ieee.org).

1.5 Difference Between 100G InfiniBand (IB) and Ethernet (ETH) cables

The main differences are:

- CDR (Clock and Data Retiming) default state:
  - IB EDR: CDR is bypassed/disabled. This ensures backward compatibility to FDR devices.
  - Ethernet 100G: The CDR is default on, and must be disabled at lower data rates, e.g. 40 Gb/s.

2. Copper cables:
  - IB EDR: The link budget usually assumes that the signal attenuation is small enough to allow operation without Forward Error Correction (FEC).
  - Ethernet 100GbE: RS-FEC enabled by default.

3. Identifier:
  - IB EDR and QSFP+: Backward compatibility to FDR devices.
  - Ethernet 100G: QSFP28.

The EEPROM memory map of QSFP28 (100 Gb/s cables/transceivers) is defined in specification SFF-8636 and for SFP28 (25 Gb/s cables/transceivers) in SFF-8472 [1].

Memory map differences summary (informative):

• IB EDR loss budget (asymmetric): IB Vol 2 Annex A2.5 EDR Overall Link Budget for Linear Channels (informative)

• Ethernet: IEEE 802.3 clause 92 – copper cables, clause 83 – PMA including CDRs.

4. Bit Error Ratios:

• IEEE defines the BER of 1E-5 for Ethernet that is corrected with FEC in the host to 1E-12

• InfiniBand assumes no use of FEC in the host and requires 1E-15 BER.

1.6 LinkX Products are Proven to Provide BER < 1E-15

The Ethernet standards define FEC (Forward Error Correction) on by default for AOCs and optical transceivers. This implies that the Bit Error Rate (BER = bit errors/bits transmitted) maximum is 1E-12 after FEC (pre-FEC of maximum 1E-5).

All LinkX products are tested in Mellanox end-to-end systems for pre-FEC BER of 1E-15 as part of our product qualification, more specifically the System Level Performance Quality Assurance (SLPQA) test.
2. **Cable Installation and Management Guidelines**

2.1 **Warnings**

This section is based on experience from damages found on cables returned to Mellanox, which in most cases cannot be repaired.

- Do not twist the cables.
- Do not pull the cables.
- Do not staple the cables.
- Do not uncoil the cable, as a kink might occur.
- Do not step on the cable or connectors. Plan cable paths away from foot traffic or rolling loads.
- Do not pull the cable out of the shipping box through any opening or around any corners. Unroll the cable as you lay it down and move it through turns.
- Do not open a kink by twisting the cable. If it is not severe, open the kink by unlooping the cable.
- Do not pack the cable to fit a tight space. Use an alternative cable route.
- Do not hang the cable for a length of more than 2 meters (7 feet). Minimize the hanging weight with intermediate retention points.
- Do not drop the cable or connectors from any height. Gently set the cable down, resting the cable connectors on a stable surface.
- Do not cinch or fix the cable with hard fasteners or cable ties. Use soft hook-and-loop fasteners or Velcro ties for bundling and securing cables.
- Do not drag the cable or its connectors over any surface. Carry the entire cable to and from the points of connection.
- Do not force the cable connector into the receptacle by pushing the cable. Apply connection or disconnection forces at the connector only.
- Avoid over-bundling the cables or placing multiple bundles on top of each other. This can degrade the performance of the cables underneath.
- Do not bend the cable beyond its recommended radius. Ensure that cable turns are as wide as possible.
2.2 Illustrated Do Not’s

**CAUTION:** Do not kink cables.

**CAUTION:** Do not bend cables beyond the recommended minimum radius.

**CAUTION:** Do not pull cables without using the proper pulling equipment to eliminate strain on the cable or connector.

**CAUTION:** Do not twist the cables.

**CAUTION:** Do not step, stand or roll equipment over the cables.
CAUTION: Do not lay cables on the floor.

CAUTION: Do not pull cables without using the proper pulling equipment to eliminate strain on the cable or connector.

Figure 8 – Deformed Optical Cable
2.3 **Proper Working Environment**

Small impurities like dirt and dust can destroy fiber optics. Airborne particles are about the size of the core of a single-mode fiber. They dampen the signal and may scratch the connectors if not removed.

**CAUTION:** Dirt is the most common cause of scratches on polished cable connectors and high loss measurements.

- Work in a clean area. Avoid working around heating outlets, as they may blow dust on the optical connectors.
- Always keep dust caps on connectors, bulkhead splices, patch panels or any other connection inlets.
- Avoid exposing cables to direct sunlight and areas of condensation.
Remove unused cables which can restrict air flow. This is to prevent overheating.

Avoid placing copper cables near equipment that may generate high levels of electromagnetic interference, e.g. power converters or air conditioners.

Avoid running electrical cables near power cords, fluorescent lights, building electrical cables, and fire prevention components.

### 2.4 Correct Installation within the Rack

Make sure that:

- You will be able to replace any transceivers and system units (e.g. fan units) in the switch easily.
- The rack is wide enough to place the cables between the switch and the rack side walls.
- The cables do not block air flow.
- The cables do not block transceiver or system unit extraction.
- The cables are tied to the rack structure to remove strain and tension on the connectors.
- The weight of the cables is supported by the cable management system and the rack floor.
- You shall provide strain relief on the cable. Support the cables every 2 meters or place cables in a tray.
- You shall not place cables and bundles where they may block other equipment.
- You shall avoid routing cables through pipes and holes, as this may limit additional future cable runs.
- You shall use Velcro based ties every 12” (30cm) to 24” (60cm).
- You shall lay cables in trays when possible.

**NOTE:** Test every cable as it is installed. Connect both ends and make sure that it has a physical and logical link before connecting the next cable.
Figure 10 – Correct Installation Examples

Figure 11 – Plan for Leaf Extraction
2.5 Cable Management Recommendations

- Single-mode fibers come in two dimensions, 50 and 62.5 µm core diameter. Do not mix 50 µm cables with 62.5 µm cables in the same link.

- Bundle cables together in groups of relevance (for example, ISL (Inter-Switch Link) cables and uplinks to core devices) to ease management and troubleshooting.

- Use cables of correct length. Leave only a little slack at each end. Keep cable runs under 90% of the max distance supported for each media type, as specified in the applicable standard.

- Keep copper and fiber runs separated.

- Install spare cables in advance for future replacement of damaged cables.

- Use color coding of the cable ties. The colors should indicate the endpoints. Place labels at both ends, as well as along the run.

- Locate the main cabling distribution area in the middle of the data center.
2.6 Proper Cable Insertion

Please follow the instructions below to ensure smooth cable insertion and to avoid damage to the connector or target port.

1. Grasp the cable by the lower part of the connector between your thumb and index finger. See Figure 12.

2. Hold the cable connector perpendicularly to the ports panel, and gently push the connector into the port cage.

Do not hold or use the pull-tab to insert the cable. The pull-tab is intended for cable extraction only.

Figure 12 – Insert Connector Perpendicularly to Panel

Figure 13 – Incorrect Insertion
**Proper Cable Extraction**

For a transceiver with integrated cable and pulltab, perform the following steps:

1. Grasp the pulltab and pull it firmly, but gently outwards perpendicularly to the panel’s face, until the transceiver is released from the panel’s port cage.
2. Slide the transceiver and cable from the port.

Do not grasp the cable’s jacket for extraction. Use the pulltab as shown in Figure 9.

*Figure 14 – Extract Pulltab Perpendicularly to Panel*

*Figure 15 – Incorrect Extraction*
3. Frequently Asked Questions (FAQ)

3.1 Optical Cables and Transceivers

Q: Is there any difference between electrical cables and optical cables and transceivers that I should be aware of when using the latter?

A: Optical cables offer a much longer reach for transmission of high-speed data. For AOCs the optical interface is not accessible, and the installation of the AOC is the same as for an electrical cable.

For optimal performance of EDR (25 Gb/s SFP28/100 Gb/s QSFP28) cables and transceivers, it is imperative to optimize the optical transmitter’s input equalizer and the optical receiver’s output pre-emphasis to the host system (server, switch) characteristics. This is normally done by the host system in accordance with the MSA recommendation in SFF-8636 [1]. Alternatively, the AOC/transceiver can be specifically programmed to match the actual host system.

Optical links can also be composed of a pair of optical transceivers with an optical fiber cable between them. The transceivers have a detachable, accessible optical interface. Due to the small dimensions of the optical light beams, both the transceivers and the optical connectors on the cable must be cleaned prior to insertion.

Q: How do I clean the transceiver’s optical connector?

A: A QSFP transceiver and its mating cable are terminated in MPO or MTP connectors. Fiber cleaning equipment is available in the market for easy cleaning of both cable connectors and transceiver connectors.

Similar optical fiber cleaners are available for the LC type connectors that are used with SFP+, and SFP28 transceivers.

Q: With light coming out of the connector, is there a risk of eye damage?

A: The optical transceivers of the LinkX family emit infrared, invisible light. The power is a few mW only, and the connectors have no focusing lens at the emission point, so the light beam is spread out when leaving the connector. However, you should never look directly into a connected optical cable or a transceiver plugged into a host system.

Q: Your transceiver does not come with optical patch cables. Which cables should I use?
A: Optical cables with multi-mode or single-mode fiber are available from many suppliers. These cables are often referred to as optical patch cables. They have MPO or MTP connector at the ends. Each cable end has two guide pins mating with two holes inside the transceiver.

![Figure 17 – Male MPO Connector with Guide Pins](image)

Single-mode connectors are mostly green or yellow. Multi-mode connectors are mostly aqua, beige or black.

Please note that the cable you purchase is a ‘cross-over’ cable in which the fiber 1 in one end is fiber 12 in the other. This allows you to connect the transmitters of one end to the receivers in the other. If you connect multiple cables to form the link, you need an odd number of ‘cross-over’ cables to make the link work.

For single-mode fiber cables, or in case multiple cables are required, use MTP connectors. MTP connectors are a high precision/ lower tolerance version of the MPO.


### 3.1.1 Mechanical Characteristics

**Q:** How much does an AOC typically weigh?

**A:** In QSFP AOCs and between QSFP transceivers, a fiber cable with 8 fibers is used. This type of fiber cable weighs approximately 10g/m. The weight per meter is practically the same for single mode and multi-mode fiber cables with the shielding used for indoor cables in data centers.

QSFP AOCs of the same length weigh the same, irrespective of the data rate.

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<th>Description</th>
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<td>MFA1A00-C005</td>
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<td>Mellanox® active fiber cable, ETH 100GbE, 100Gb/s, QSFP, LSZH, 5m</td>
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<tr>
<td>MFA1A00-C010</td>
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<tr>
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<tr>
<td>MFA1A00-C030</td>
<td>390</td>
<td>Mellanox® active fiber cable, ETH 100GbE, 100Gb/s, QSFP, LSZH, 30m</td>
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</table>
Q: How much does a PCC (DAC) weigh?
A: Different types of cables are used for different PCCs. In the MCP1600 EDR PCCs, an 8-pair 24 AWG cable is used. This cable weighs 114 g/m. Add an additional 40 g per QSFP connector/shell at each end.

In the MCP2M00 PCC, a 2-pair 30 AWG cable is used. It weighs 24 g/m. Add 20 g per SFP28 connector/shell at each end. This adds up to approximately 90 g for the 2 m MCP2M00-002 SFP28 cable.

Q: How much does a transceiver weigh?
A: A QSFP transceiver weighs approximately 43 g, excluding the protective covers.

An SFP transceiver weighs approximately 20 g. The QSA (QSFP to SFP) adapter weighs approximately 25 g.

Q: Why do some of your datasheets have two specifications of a cable’s minimum bend radius?
A: Cables typically tolerate a sharper bending (more stress) closer to their central part, than to the strain relief and connector. The assembly bend radius indicates the larger minimum bend radius to use when bending the cable where it comes out of the connector shell.
References


