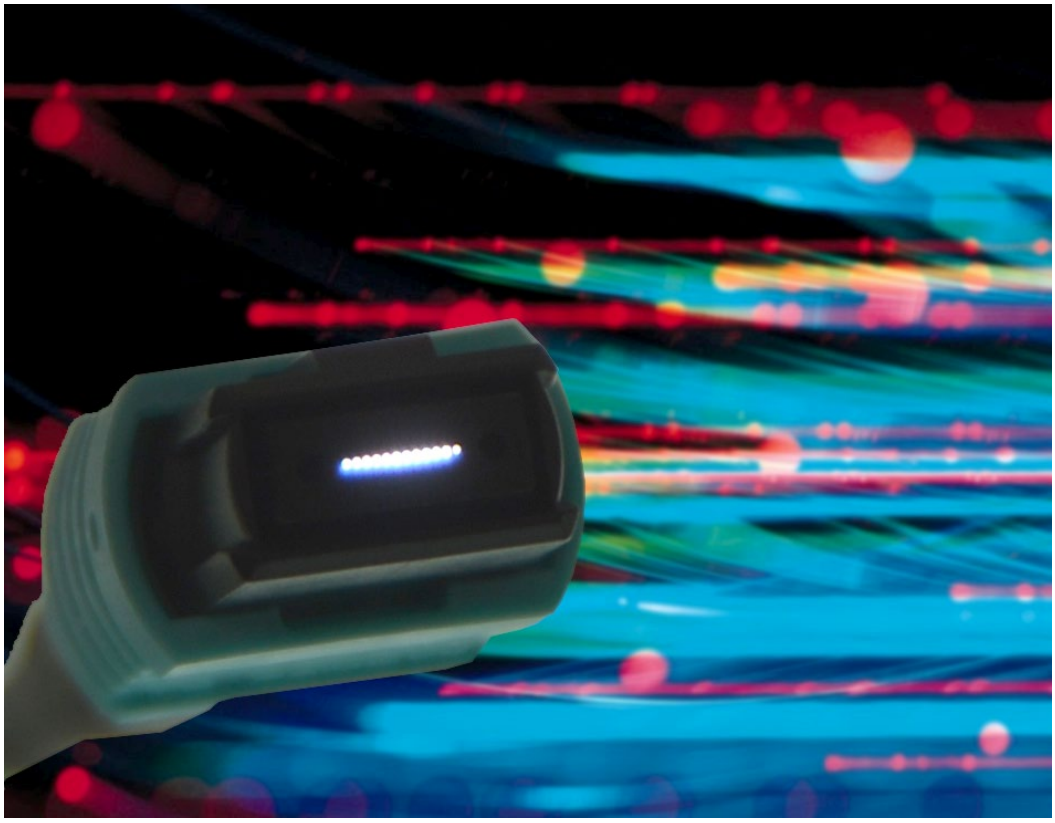
Active Silicon OPTICAL FIBER TECHNOLOGY

WHITE PAPER

OPTICAL FIBER TECHNOLOGY FOR COAXPRESS OVER FIBER



Active Silicon

Head Office:

Active Silicon Ltd
1 Waterside Court, Waterside Drive,
Langley, Berks, SL3 6EZ, UK.

Tel: +44 (0)1753 650600
Email info@activesilicon.com
Website: www.activesilicon.com

North America:

Active Silicon, Inc.
479 Jumpers Hole Road, Suite 301,
Severna Park, MD 21146, USA.

Tel: +1 410-696-7642
Email: info@activesilicon.com
Website: www.activesilicon.com

Introduction

Fiber Optics are an amazing technology, they have done wonders for modern telecommunications, spanning oceans, powering datacenters, and moving data around our cities, hospitals, and high-rise buildings. They bring many advantages: noise immunity, low loss (so long distances can be spanned) and galvanic isolation. These features make optics a useful technology for machine vision applications.

When first working with Fiber Optics you will be confronted with many acronyms and unfamiliar terms. This white paper is an introduction to this technology with the machine vision system designer/engineer in mind. We hope to make the technology more accessible, easier to understand and relatable to current CoaXPress or Camera Link based connection systems.

Fiber Optic Basics

This may be understood by many, but fiber optics utilize the reflection or refraction of light in a glass fiber. Fiber optic cables are made of a glass core fiber and a glass outer cladding. The interface between these two materials creates a mirror to reflect the light, or a specific graded refractive core bends the light back along the cable.

There are two types of optical cable we are interested in for machine vision applications: single-mode and multimode fiber. At first glance, **multimode fiber** looks superior as it sounds like it can pass multiple signals. On the contrary, it is named because the light can take multiple modes/paths down the fiber. These multiple modes disperse a signal pulse, as the multiple paths travel different distances hence have different flight times. This dispersion essentially limits the distance a fiber can span or limits the bandwidth of the signal transmitted. An example of this is shown in Figure 1.

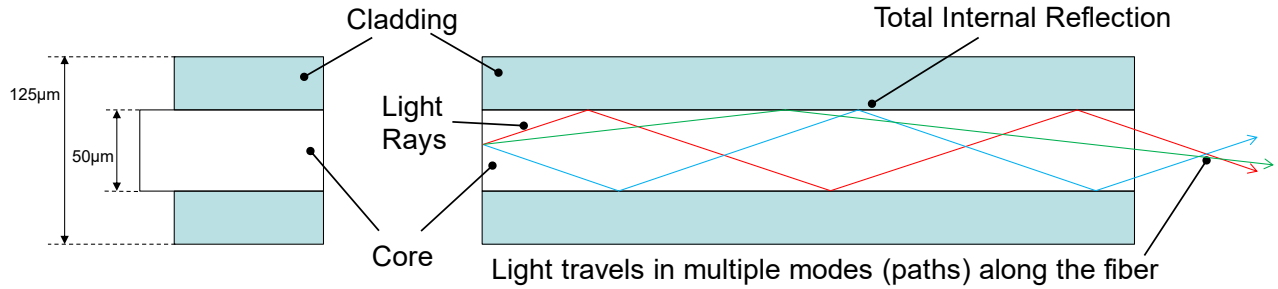


Figure 1. Light Paths in Multimode Fiber

Single mode fibers utilize a much smaller diameter core fiber, this limits the modes possible for the light to travel. But the smaller diameter of the inner core means it needs a laser to generate the signal (multimode solutions usually use LEDs). Single mode fiber systems tend to be around five times more expensive than multimode solutions but can transmit many kilometers.

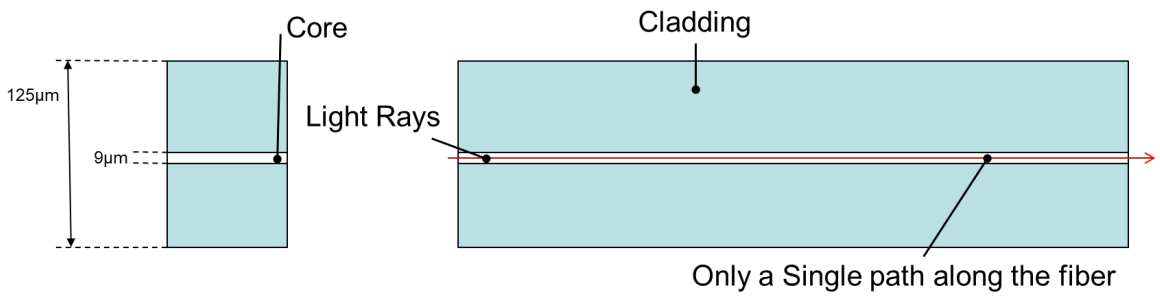


Figure 2. Light Path in a Single Mode Fiber

The most likely choice for many industrial machine vision applications is multimode fiber. Multimode fiber and LED/VCSEL based optical transceivers using OM3 (Optical Multimode) cable can traverse 100m, or with OM4 cable around 150m. Single mode solutions are available for applications that need to house a control PC some distance from the camera. Active Silicon CoaXPress over Fiber solutions are designed with enhanced power supplies and cooling to also work efficiently with single mode/long-reach applications.

CoaXPress over Fiber Bridge Protocol

Current CoaXPress over Fiber (COF) solutions (CXP2.1 plus COF Bridge Protocol v1.1) are implemented using 40G QSFP+ optical transceiver modules. These modules are typically designed for 40Gbit Ethernet solutions, they connect electrically using 4 x 10.3125Gbps links. This begs the question, “How do you get 4 x 12.5 Gbps CoaXPress signals in 4 x 10.3Gbps links?” The answer is the bridge protocol, where the 8b/10b encoding of CoaXPress is removed and re-mapped to the 64b/66b encoding of Ethernet. This efficiency allows the data content of 4 x CXP-12 lanes to fit in one 40G Ethernet link, and allows users to utilize established optical transceiver technology.

Connectivity Solutions using QSFP+ Connectors

There are different solutions to connect the QSFP+ connector on a camera to the QSFP+ connector on the frame grabber.

Direct Attach Copper

Direct Attach Copper or DAC cables not an optical solution but are a pair of dummy optical transceiver modules with a set of twin coaxial copper cables (50 Ohm) between them, that connect the camera QSFP+ to the QSFP+ connector on the frame grabber. DAC cables are useful for connectivity on a bench or a short distance between a camera and frame grabber of a meter or two. At larger distances, losses in the coax cable are too high for the link equalization in the camera and frame grabber to handle. DAC cables are relatively cheap but can be quite bulky compared with optical cabling and maybe susceptible to electrical interference.

Figure 3. QSFP+ Direct Attach Copper Cable

Optical Transceivers

An Optical Transceiver (also called a separable optical module) is a QSFP+ module with a port to connect a fiber optic cable. A full link would have two of these transceivers and an optical fiber cable between them. The choice of transceiver depends on how far you need to send the data and for most applications the distances will be within reach of SR - Short Reach or eSR (extended Short Reach) 50m-450m modules. For this reach, the use of 850nm wavelength light and multi fiber multimode ribbon cables 4xTX (transmit) plus 4xRX (receive) would be a good option.

There are transceivers that are designed for LR - Long Reach applications which allow for up to 10km reach. These use a different wavelength, at 1310nm, and they need to be coupled with single mode fiber

(usually a multi-fiber ribbon). LR transceivers can also use Coarse Wavelength Division Multiplexing (CWDM), which uses four different wavelength light sources to send and receive data on two single mode fibers. CWDM solutions are significantly more expensive and use more power. Active Silicon CoaXPress over Fiber frame grabbers are designed with enough power and cooling capability to safely implement CWDM solutions. Optical Transceivers need to be coupled to fiber cable, see the following sections.

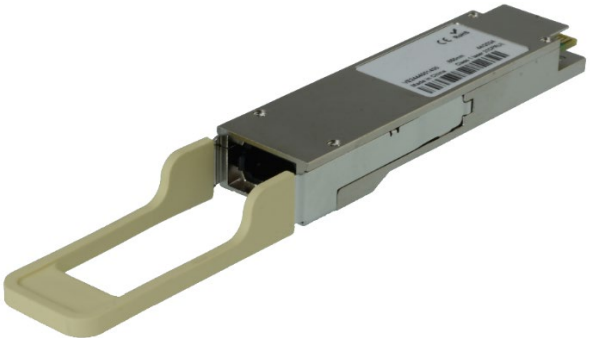


Figure 4. QSFP+ Optical Transceiver

Active Optical Cables

Active Optical Cables (AOC) are two optical transceivers permanently connected by a fixed fiber optic cable. AOC cables are usually cheaper than two separate transceivers and fiber cable but more expensive than a DAC cable. If a transceiver fails, you need to replace the whole cable. AOC cables are a desirable choice for a bench or prototyping solution. Although, it is less useful in a machine or factory setting as it is difficult to route the bulky cable end transceiver through a conduit for implementation in a machine or factory setting.

Figure 5. QSFP+ Active Optical Cable

Implementing Optical Fiber in Machine Vision Systems

The practical implementation of a fiber optic system for machine vision depends very much on the system it is being implemented into. The guidelines below explain the details of different fiber optic cabling, how they work in system design and how they compare with Camera Link or CoaXPress systems.

Currently, most CoaXPress over Fiber devices and hosts use a QSFP+ cage, the connection method is down to the user. DAC and AOC solutions are great for bench and lab work or as system deployments if cables do not need to route through conduit.

For other deployments the choice of QSFP+ optical transceivers and fiber ribbon cable is an excellent choice. These are the workhorse connectivity solution for Data Centers. As such, the infrastructure for fiber management (patch panels, bulkhead connectors etc.) is readily available.

Fiber Optic Cabling

To connect to optical transceivers, a fiber cable and associated connectors are needed. The principal connector type for short reach QSFP+ optical transceivers is the MPO/MTP* connector. This type of connector uses a fiber ribbon (a multi-strand fiber cable, with all strands aligned at the connector), for SR these are usually OM3/OM4 fiber ribbon cables. The picture below shows an example of an MPO/MTP connector and cable assembly.

Figure 6. A Fiber Ribbon Cable with a Female MPO/MTP Connector*

Fiber optic cable classification includes plenty of acronyms. Below we explain abbreviations used and point out important things to consider when choosing those cables.

SR4 and LR4 Fiber Cabling

SR4 cable – Short Range (4xTX/4xRX fibers) – is commonly used in data centers and corporate networks. It is available from many sources and similar ordering codes are used by different vendors. See below a typical fiber cable ordering code. In the following sections we break down the description and explain it in more detail.

MTP*-12, F to F, UPC, 12F, OM3, OFNP, Type B, 3m (10ft)

"MTP*-12" denotes the connector type used on both ends of the cable, MTP or MPO (see glossary for more information). The 12 in the name denotes the number of fibers.

"F to F" is the gender of the cable at both ends – here Female to Female. The male connector found in the QSFP+ modules and male to male patch cables have registration pins fitted; this ensures the fiber cores are correctly aligned. Any MPO/MTP connection must be one male connector connecting to a female connector. This is important to keep in mind, especially as it is possible with bulkhead ports to connect two female connectors, but without the male registration pins (see Figure 7) an accurate alignment of the fiber cores is not guaranteed.

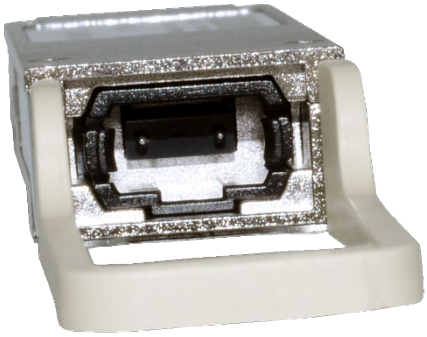


Figure 7. End-view of QSFP+ SR4 Optical Transceiver Showing "Male" Registration Pins

"UPC" denotes the finish that has been applied to the end of the connector (how the ends have been polished). UPC stands for Ultra Physical Contact. Alternatives are Physical Contact (PC; not seen as much on OM3 and OM4 cables) and Angled Physical Contact (APC, mainly on single mode fibers). The differences are highlighted in Figure 8 below. UPC results in less Insertion Loss than PC. APC has lower return loss due to the angled front face, as reflections do not bounce back down the fiber.

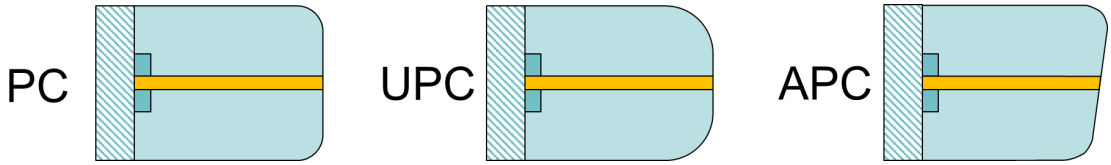


Figure 8. Comparison of Fiber Connector Polish (showing outer sheath, cladding and core)

The most important aspect of the connector end polish is that they should be matched with a similar end polish. Trying to mate an APC cable to a UPC cable is at best going to lead to a poor connection and could lead to damage to the end of the fiber. Therefore, do not mix the different end polish types.

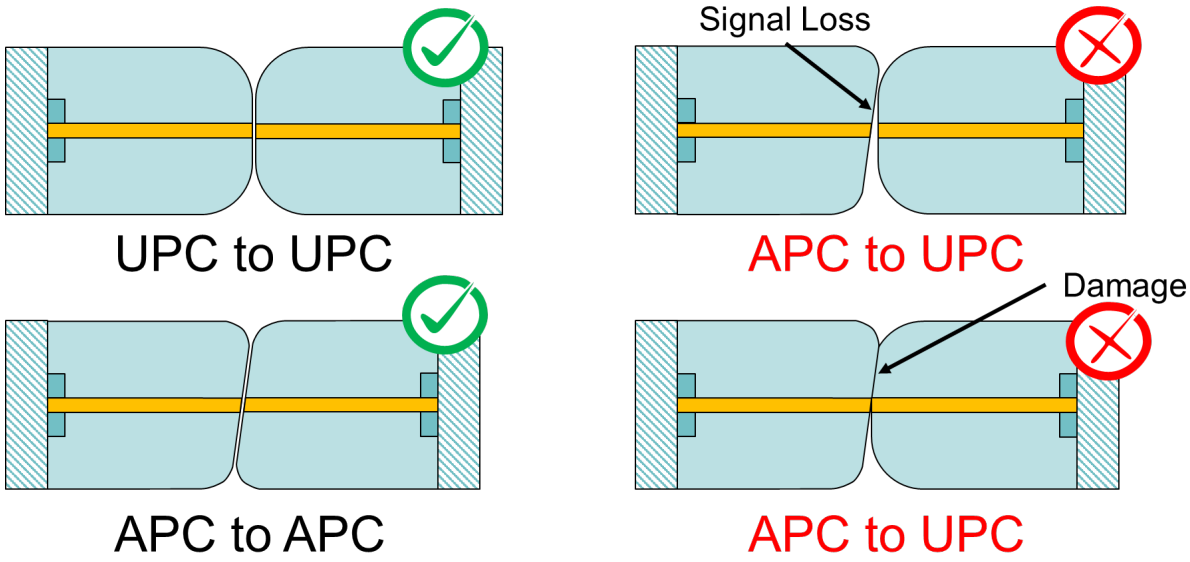


Figure 9. Correct and Incorrect Fiber Mating

"12F" is the number of fibers in the connector. Eight are needed as a minimum in a SR4 or LR4 solution, where four are RX and four are TX. The arrangement of the fibers is shown in Figure 10. The example

shows a twelve-fiber connector, these are more commonly available than eight fiber cables, the middle four fibers are not used.

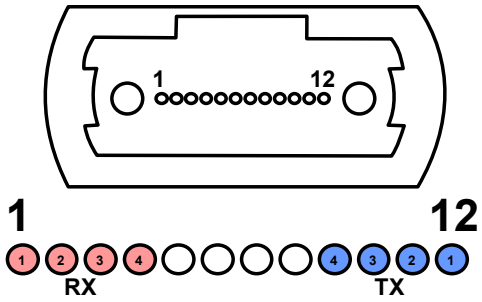


Figure 10. Fiber Arrangement in an MPO/MTP Connector*

"OM3" is the fiber type. A OM3 cable will reliably link up to 100m and an OM4 cable to about 150m. Enhanced Short Range transceivers may give slightly more reach.

"OFNP" denotes the jacket type of the fiber and the fire rating of the cable. Two common jacket types are listed below with a note on the environment they are suitable for. Fire rating requirements can be different from country to country, and we suggest consulting the relevant authorities or a specialist, to assure you comply with the local regulations.

OFNP – Optical Fiber Nonconductive Plenum – Higher UL-910 fire rating for plenum spaces (above ceiling tiles) and risers.

OFNR – Optical Fiber Nonconductive Riser – Designed for riser shafts between floors, but not plenum spaces.

"Type B" denotes the polarity of the cable. In any system the TX fibers coming from one optical transceiver have to connect to the RX ports on the other transceiver. This can be done in two ways, either by using bulkhead connectors that have one "Key Up" port and one "Key Down" port, which essentially swap over the fibers connecting TX to RX (Type A, Figure 11). The second option would be to use an MPO/MTP* cross-over cable (Type B, Figure 12).

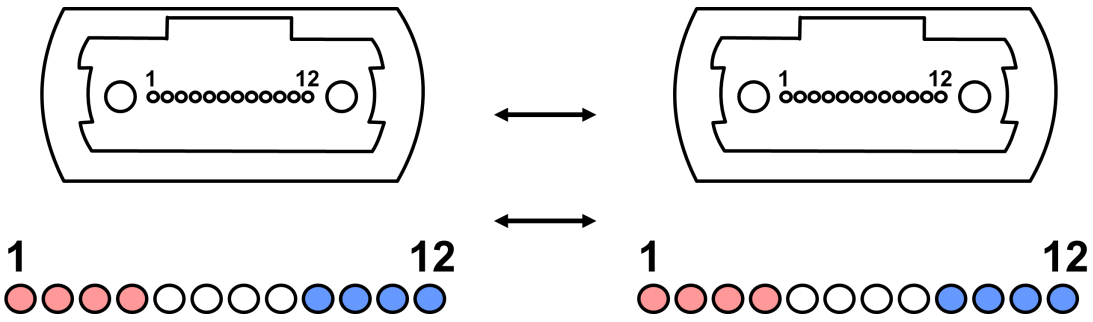


Figure 11. Type A Straight Fiber Ribbon

If you are just connecting a camera to a frame grabber on the bench you will need a Type B F-F cable. Active Silicon offers fiber cables in standard lengths and optical transceivers that have been thoroughly tested with multiple cameras and Active Silicon frame grabbers.

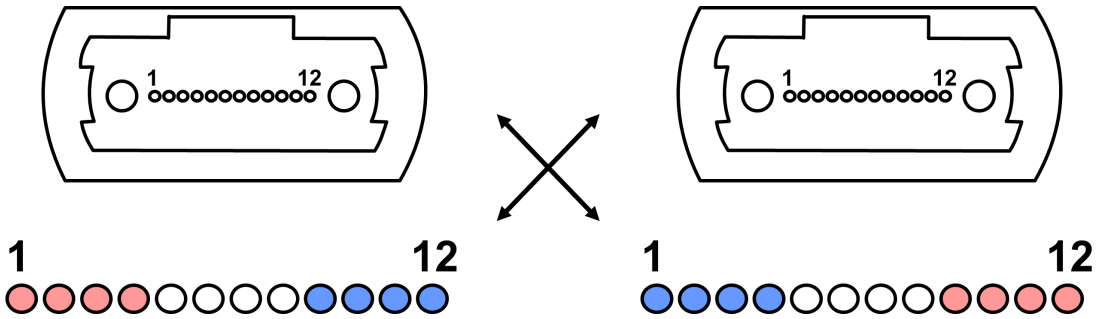


Figure 12. Type B Crossover Fiber Ribbon Cable

If you are connecting a full system (camera to a patch lead to patch panel, trunk cable, patch panel to patch-lead to frame grabber), it is important to make sure that after all those links the TX is still transmitting to the RX (having an odd number of bulkhead key-up to key-down connectors and type B cables).

"3m (10ft)" is just the length of the cable.

Additional Features of Fiber Optic Cables

Compared to CoaXPress or Camera Link cables, fiber optic cables are generally much smaller in diameter and lighter. They also have a slightly tighter minimum bend radius even as small as 10mm (0.5 inch) for some cables compared to 50-60mm (2.5 inch) for CoaXPress. It is still important to not kink the cables or repeatably flex the cables unless the are marketed for high flex use.

One major benefit of fiber optic connectivity is future proofing, the fiber you install today for COF with 4x10Gbps optics will likely work well for 4x25Gbps optics with next generation COF, only at the extremes of distance is this likely to be an issue.

Trouble Shooting

There are a few things to look out for when using fiber optic technology. This section highlights a few common mistakes and issues when using fiber optics.

Optical transceiver, DAC and Active Optical Cables – when inserting them into the QSFP+ cages it is easy to think you have seated the transceiver correctly, but a firm push is needed to make sure the QSFP+ connector is correctly engaged. If you have any **connectivity issues** it is worthwhile pulling out the transceiver and reinserting it. A correctly orientated and inserted QSFP+ optical transceiver module is shown in Figure 13.

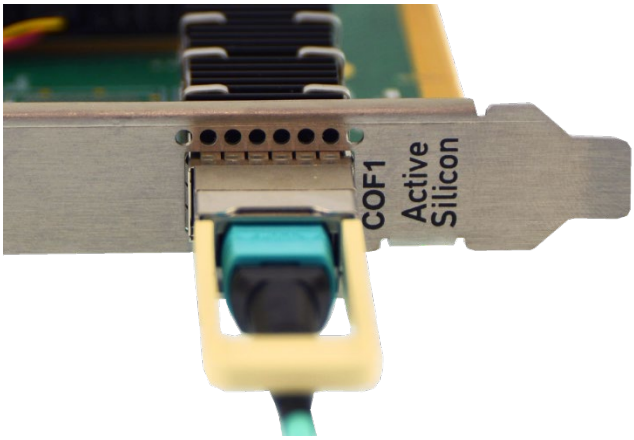


Figure 13 - View of a correctly orientated QSFP Transceiver module with handle adjacent to airflow holes.

Please note that the Optical Transceivers, DAC and AOC cables are active electronic devices connecting directly to FPGAs and hence appropriate **ESD precautions** should be taken.

Cleanliness is particularly important, keeping the fiber connectors and transceivers free from dirt, dust and any contaminants is imperative. Make sure that fiber connectors are covered with their dust covers whenever they are not mated to another component. Even so it is useful to have a fiber cleaner to hand to eliminate this variable if a system is not working correctly. Active Silicon offers a simple click to clean MPO/MTP* cleaner for cleaning both cable connectors and the optical transceiver ports. See Figure 14.

Figure 14.Sticklers MPO Click Cleaner (Image courtesy of Microcare)

Cable polarity – Always make sure the combination of patch cables, bulkhead connectors and trunk cables in your system are delivering TX from one transceiver to the RX of the other. Perhaps trying with a single known good Type B (crossover) cable to resolve uncertainties.

Wrong speed - using the wrong speed optic transceivers. Current COF solutions on the market utilize 40G Ethernet optical transceivers, it is possible to put other QSFP form factor transceivers in the connector cage. The correct transceiver modules for 40G have a beige handle.

Fiber cable breaks can sometimes be detected with a simple torch at one end and viewing with a mobile phone camera at the other. See note on laser safety below.

Laser Safety Warning

Optical transceivers are very safe devices, any likely to be used for machine vision applications are at most Class 1 laser devices (safest type).
Even so, you should never look directly at the output port or the end of an optical fiber with the naked eye or any optical instrument.
A mobile phone camera or laser power meter is a much better solution.

Conclusion

Fiber optic technology offers distinct advantages for machine vision systems, including high-speed data transfer, immunity to electromagnetic interference, and the ability to span long distances without significant signal degradation. The augmentation of CoaXPress with fiber optics into CoaXPress over Fiber (COF) solutions, presents a cost-effective and scalable approach for high-bandwidth and long-distance applications.

When it comes to connectivity, you have flexible choices: Direct Attach Copper (DAC) cables for short distances, Optical Transceivers for flexible, scalable solutions, or Active Optical Cables (AOCs) that streamline installations without sacrificing performance.

Key factors for success in implementing fiber optic systems include ensuring correct cable polarity, fiber cleanliness, and proper connector engagement.

Fiber optics and particular CoaXPress over Fiber provide a robust solution, ideal for high-performance, noise-resistant machine vision applications.

Optical Fiber Accessories from Active Silicon

PART NUMBER	***DESCRIPTION***
AS-CBL-OPT-A04QQ-A-3M	Optical Assembly with two QSFP+ 40G 850nm, Multimode, MPO transceivers with 3m of OM3 12 strand fiber ribbon cable (type B) F-F with MPO connectors
AS-CBL-OPT-A04QQ-A-100M	Optical Assembly with two QSFP+ 40G 850nm, Multimode, MPO transceivers with 100m of OM3 12 strand fiber ribbon cable (type B) F-F with MPO connectors
AS-CBL-DAC-AQQ-1M	QSFP+ to QSFP+, Direct Attach Cable (DAC), 40G Ethernet, AWG30, 1m, passive
AS-CBL-OPT-C04QQ-A-10M	QSFP+ to QSFP+, Active Optical Cable (AOC), 40G Ethernet, 10m, OM3 type B Fiber.
AS-CBL-OPT-MPO-A-CLEAN	Sticklers MPO CLEANCLICKER 600 fiber optic connector cleaner, 600+ cleans; MPO

Resources

JIIA CXP-001-2021 – CoaXPress Specification v2.1

JIIA CXPR-008-2023 – CoaXPress over Fiber Bridge Protocol

JIIA CXPR-007-2020 - Optical Interface Guideline for CoaXPress

MTP® vs MPO Cable: What Are the Differences? - FS.com

Fiber Optics: Understanding the Basics - Photonics Marketplace

Glossary

Acronym	Full Name	Description
LED	Light Emitting Diode	Cost effective light source for Optical Transceivers
MPO	Multi-fiber Push On	The most common type of fiber ribbon connector, interchangeable with MTP
MTP	Multi-fiber Termination Push on	US Conec brand of enhanced MPO connectors, interchangeable with MPO
OM3	Optical Multimode 3	Multimode Optical Fiber 3 suitable for ~100m at 850nm
OM4	Optical Multimode 4	Multimode Optical Fiber 4 suitable for ~150m at 850nm
QSFP	Quad Small Form-factor Pluggable	Electrical connector/cage for 4 x 1Gbps signals
QSFP+	Enhanced Quad Small Form-factor Pluggable	Electrical connector/cage for 4 x 10Gbps signals
VCSEL	Vertical-Cavity Surface-Emitting Laser	A relatively low-cost laser light source for Optical Transceivers
CXP	CoaXPress	Leading Machine Vision standard using coax cable
CoF (COF)	CoaXPress over Fiber	CoaXPress standard bridged to use fiber instead of coax cable
8b/10b	8 Bit / 10 Bit Encoding	This encoding system used in CoaXPress ensures DC balance and enough transitions for accurate data flow in CP systems.
64b/66b	64 Bit / 66 Bit Encoding	An encoding system used in Ethernet systems to ensure accurate data flow.
DAC	Direct Attach Copper	Two QSFP+ Connectors joined using twin-coax cable (short connections 1 or 2m only)
SR4	Short Range 4	A fiber connection that uses four multimode fibers for transmit (and 4 for receive) usually a fiber ribbon of 8 or 12 fibers with MPO/MTP* Connectors, ~100-150m max distance
LR4	Long Range 4	A fiber connection that uses four single mode fibers for transmit (and four for receive) usually a fiber ribbon of 8 or 12 fibers with MPO/MTP* Connectors. 2-10km max distance.
OFNP	Optical Fiber Nonconductive Plenum	Optical Fiber Nonconductive Plenum – Higher UL-910 fire rating for plenum spaces (above ceiling tiles) and risers.
OFNR	Optical Fiber Nonconductive Riser	Designed for riser shafts between floors, but not plenum spaces

About Active Silicon

Active Silicon is a leading manufacturer of imaging products and embedded vision systems. We provide camera electronics for image data transmission, frame grabbers for data acquisition and embedded systems for image processing and machine control.

Founded in 1988, Active Silicon has a proven track record in providing reliable, high-quality products for a variety of industries world-wide. Our products have applications in many areas of science and industry including manufacturing, life sciences, medical imaging, security and defense. From space missions to large scale deployment of industrial vision systems, we have provided imaging components and embedded systems that help our customers provide world-class solutions.

Active Silicon is proud to be part of the Solid State plc group. Solid State plc, listed on the London Stock Exchange AIM market (AIM:SOLI), is a manufacturer of computing, power and communications products, and a value-added distributor of electronic and opto-electronic components.

Head Office:

Active Silicon Ltd
1 Waterside Court, Waterside Drive,
Langley, Berks, SL3 6EZ, UK.

Tel: +44 (0)1753 650600
Email info@activesilicon.com
Website: www.activesilicon.com

North America:

Active Silicon, Inc.
479 Jumpers Hole Road, Suite 301,
Severna Park, MD 21146, USA.

Tel: +1 410-696-7642
Email: info@activesilicon.com
Website: www.activesilicon.com