



# The Emergence of USB-C Active Optical Cables for Rugged and Demanding Environments

**V**ision camera and sensor systems are rapidly requiring better, more reliable data transmission, and more of it across longer distances at faster speeds. The manufacturing trends towards smart factories, increased use of robotics, and more and more machine vision applications within those industries are driving this demand.



Current commodity cables fall short of keeping up with these advancements as they may be inexpensive, but they are typically limited to transmitting data across no more than 10 meters, have poor reliability, and frequently fail in demanding environments.

Multi-function cables combine copper and fiber with a USB-C connection to form a hybrid active optical data cable. This combination yields a streamlined solution with enhanced power delivery, designed and tested for rugged environments.

## Why a Rugged Design for Interconnect Solutions?

Industry 4.0 is the digital transformation of manufacturing, process industries, and value creation leveraging data analysis. Application areas include Industrial Internet of Things (IIoT), oil and gas, agriculture, logistics, transportation, energy/utilities, mining, aviation, and other use cases which are typical to these industries. Connectivity applications in close proximity to IIoT machinery may be subject to loosening due to repetitive motion from robotics and vibration from motors, belts, cooling fans and other routine environmental factors.

As internet connectivity expands through manufacturing, medical and industrial environments, the need to transmit data reliably has increased exponentially. In demanding applications with



machine connectivity, the ability to perform well in shock and vibrate, high mating cycles, ingress, emissions, pull strength, rolling and torsional flex tests is critical. Further, power delivery supporting greater voltage over longer distances with minimal voltage drop, incorporating optical fiber for longer data reach and reducing interconnect weight with increased durability and reliability, are important characteristics.

## State of Play for Machine Vision Interfaces

There are various global machine vision standards which make vision technology less expensive and easier to

use. Standards development is key to the success of the industry ~ *Source A3 Vision & Imaging*. Let's examine the most prominent interconnects for capturing, processing and analyzing data.

### CoaXPress (CXP)

The CoaXPress (CXP) standard was released in December 2010. It provides a high speed interface between camera and frame grabbers and allows long cable lengths. CXP interfaces use 75 ohm coaxial cables and support data transfer speeds of up to 12.5 Gbps per channel, with the ability to use multiple channels to support even faster data transfer rates. A CXP cable can supply up to 13W of power per cable, has a typical cable length range of up to 25 meters, and requires both the device and the host to support the GenICam camera programming interface. While single-lane coaxial cables are inexpensive, the cost to set up multi-lane cable assemblies and frame grabbers adds up very quickly.

### Camera Link

The Camera Link standard was launched in the year 2000 by Automated Imaging Association (AIA) and has been upgraded

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progressively to support higher data speeds, with some versions requiring two cables for transmission. Three main configurations are available including Base (2.04 Gbps), Medium (5.44 Gbps) and Deca/Extended (6.8 Gbps). The base standard uses an MDR (Mini D Ribbon) 26-pin connector, while the medium/full configuration doubles capacity using a second cable. Deca/Extended versions go beyond limits imposed by Camera Link, carrying up to 6.8 Gbps of data. Like CXP interfaces, Camera Link requires frame grabbers and additionally needs to be compatible with the Power over Camera Link (PoCL) standard to supply power. Using PoCL, a PoCL camera

Enhancements to the USB standards, specifically USB 3.2 Gen2x1, has increased the bandwidth to 10 Gbps, effectively doubling the operational performance of the USB 3.1 Gen 1 interface. Subsequent additions to the standards have increased the performance further by providing a path to 20 Gbps (USB 3.2 Gen2x2) while also adding enhanced power delivery (USB-PD 3.1) to the mix.

USB supports Direct Memory Access (DMA). With this DMA capability, image data can be transferred from a camera directly into host system memory where it is available for use by application software. DMA coupled with the widespread support for USB and availability of drivers for USB controllers on virtually any hardware platform makes USB ideal for use in embedded systems. Because of DMA support there is no need for a frame grabber.

## What Are Industrial Active Optical Cables and How Do They Compare to Commodity AOCs?

Active optical cables combine optic to electric transmitters and receivers in a bundled approach which secures future-facing technologies. Simply stated, active optical cables combine data (fiber optics) and power delivery (copper wires) in the same cable assembly (better known as a hybrid cable) with the addition of active components embedded within the connector ends. Active optical cable offers all the advantages of optical fiber without the hassle of fiber termination. The industrialized version of active optical cables provides reliability for rugged and dynamic environments. Active optical cables focus on challenging environments including considerations such as high duty and mating cycles, pull strength, torsional and rolling flex cycles, shock and vibration, and EMI/EMC, which are critical to maintaining a safe, secure, and robust interconnect system. Active optical cables include copper power and control lines designed to optimize power supply across distance, decrease voltage drop, and provide a very flexible and rugged cable. The embedded electronics are protected by tough and resilient connector and back shell arrangements.

### Interface Comparison Chart

Interface	Standards Based	Bandwidth (Gbps)	Cable Length (Meters)	Power Delivery (Watts)	Power + Data (on one cable)
CoaXPress (CPX-12)	Yes	12.5/channel (50 with 4 in 1 cable)	30	13W / Cable	Yes
Camera Link (Full)	Yes	0.85	5	PoCL: 4 W	Yes
Nortech AOX (USB-C) USB 3.2 Gen 2x1	Yes	10	50+	240 W	Yes

Interface	Frame-Grabber	# Cables Required	System Cost (single camera)	Market Acceptance
CoaXPress (CPX-12)	Yes	1 to 4	High	Growing
Camera Link (Full)	Yes	2	High	Declining
Nortech AOX (USB-C) USB 3.2 Gen 2x1	No	1	Med	Growing

can be powered by a PoCL frame grabber through the Camera Link cable. Maximum cable length is in the range of four to 15 meters depending on the camera clock rate. For example, the maximum cable length for Camera Link (Full) operation is five meters.

### Universal Serial Bus (USB)

USB is everywhere. Simply look around and count the number of USB devices and accessories within a few feet of your workspace. The standard was first established in 1996 and has evolved ever since. Most USB machine vision cameras use the USB 3.1 Gen 1 interface. This interface provides up to 4 Gbps of image data bandwidth between the camera and the host system. The USB3 Vision standard helps ensure compatibility between a wide range of cameras and software by defining a common set of device detection, image transfer and camera control protocols.

For the Machine Vision space there are four basic connector interfaces:

- USB (Micro-B & USB-C)
- CoaXPress
- Camera Link
- Gigabit Ethernet

For Medical:

- Gigabit ethernet
- CoaXPress
- USB-C
- SC & LC connectors
- SFP & SFP+ connectors (small form-factor pluggable, and even smaller SFP+)
- MT connectors (for 10 or 12 fiber ribbon cable)

For Data Centers, High Performance Computing, and Networking:

- SFP+
- QSFP, QSFP+ (quad-small form-factor pluggable, and even smaller QSFP+)
- RJ45

For Consumer Electronics:

- HDMI
- USB-C
- Display Port
- Thunderbolt (uses USB-C connector)

## What Type of Connectors and Cable Constructions Are Available?

When it comes to construction there are a variety of connectors and cable construction from which to choose.

environments. USB-C active optical with power delivery offers high-speed data, power, and control in a consolidated cable. Transmitting data over fiber optics offers inherent EMI and EMS immunity. Utilizing fiber optics within a shielded hybrid cable assembly further enhances data quality to create the superior choice for machine vision applications.

### European Union Standardization

In 2022, European Union lawmakers reached an agreement to standardize portable electronics to a common USB-C charger, simplifying the management of phones, tablets, cameras and other portable devices. This move by the European Union shows a general shift across industries to standardize on a common port, in this case the USB Type-C, for all mobile phones, tablets, headphones, and many more peripheral devices. This mandate by the EU has global implications and will streamline supply chains due to better economies of scale.

The benefits of USB Type-C go well beyond the decision by the European Union to mandate a common connector standard. Instead of being limited to 15 watts of power for charging, USB-C supports larger charging currents ranging from 3A to 5A, enabling faster charging as well as reverse charging. New data transfer rates of 10 Gbps and 20 Gbps will speed up the performance of devices such as cameras, sensors, and external hard drives, in some cases by an order of magnitude.

Ease of use is a major consideration as there are no requirements for firmware at the component level or drivers at the system level; plug and play is at the heart of the USB standard. Adding to this, the Type-C connector standard allows a user to plug in the cable using any orientation (swapping end-for-end or flipping/rotating the connector-ends), taking the guess work out of how to plug in a cable.

### Machine Vision

USB Micro-B supports 5 Gbps operation while USB-C support 10-20 Gbps.

CoaXPress (AKA CXP) is based on coax cables with BNC connectors

Gigabit ethernet cables support 1 Gbps over RJ45 connectors (CAT5, CAT6, and CAT7)

CameraLink: Mini delta ribbon (MDR) connectors and shrunk delta ribbon (SDR) connectors.

MDR connectors enjoy widespread acceptance

SDR connectors typically used where small system architecture is needed

Enhancements of the USB standards, specifically USB 3.2 Gen2, has increased the bandwidth to 10 Gbps, more than doubling the operational performance of the USB 3.1 Gen 1 interface. Subsequent additions to the standards have increased the performance further by providing a path to 20 Gbps (USB 3.2 Gen2x2) while also adding extended power delivery (240W) to the mix.

USB supports Direct Memory Access (DMA). With this DMA capability, image data can be transferred across from the USB directly into memory where it is available for use by software. DMA coupled with the widespread support for USB and availability of drivers for USB controllers on virtually any hardware platform makes USB ideal for use in embedded systems. Because of DMA support there is no need to add a frame grabber to the mix (frame grabber required for CoaXPress and Camera Link).

Customized cable construction may be configured for a specific application, including full-featured support for

- Loose tube
- Jacketed
- Ruggedized
- High flex (rolling flex, torsional flex, strength member such as Kevlar)
- Tight bend (high strained count copper, bend insensitive fiber)

### Why USB Type-C with Power Delivery (USB-PD 3.1)

It is no secret USB-C connectors are quickly becoming the industry standard for many architectures and protocols. Hybrid active optical USB-C power delivery cables are becoming increasingly popular due to their ability to deliver significant power and data over distance.

Machine vision systems require high-speed data transfer with power and control to function efficiently in electrically 'noisy'

### Active Optical vs Traditional Copper

AOC cables have many benefits over copper cable. These benefits include reduced weight, higher bandwidth, longer cable lengths, lower connectivity loss, EMI/EMS immunity, highly ruggedized, superior data quality, and technology supporting **ESG** (environmental, social, and governance standards). AOC uses electrical-to-optical conversion on the cable ends to improve the speed and distance performance of the cable without sacrificing compatibility with standard electrical interfaces.

To learn more visit our website: <https://www.nortechsys.com/insights/active-optical-cables-vs-traditional-copper/>

There is no need to add a data acquisition card to a system design. As previously mentioned, USB supports direct memory access (DMA) and its drivers are already built into all major operating systems. No frame grabber required. Adding a frame grabber typically requires a more powerful and expensive computing platform, such as a commercial grade 1U or 2U server to house the PCI-based capture card.

## When Would You Use a Hybrid Active Optical Cable?

Our customers are demanding enhanced solutions, especially in the medical field. Many of the medical imaging and data acquisition systems, which were traditionally RF based, are now incorporating both passive and active optical fiber solutions.

### Typical Applications

- Lighter thinner cables and connectors
- Reduce or eliminate radiated and conducted EMI
- Increased signal to noise ratio for high-speed data signals
- Improved immunity to crosstalk or EMI
- Reduce interconnect size to USB-C (or other small form factors)
- Reduce interconnect weight, mass and volume
- Reduce system complexity by consolidating data and power
- Utilize 'intelligent' connectors
- Robust roadmap for increased data throughput
- Long-reach installations
- Standardize on future-facing capabilities
- Standardize on high quality and durability

### Sample Machine Vision Use Cases for USB-C AOC

- Eliminate Frame Grabbers for reduced systems cost
- Eliminate Linear Re-drivers for enhanced reliability and performance
- Robotic-leveraged vision systems
- USB-C hubs and copper cables with limited Gbps and physical length

## Sample Medical Use Cases for USB AOC

- MRI. Adding a camera system in the bore of a magnet to subtract patient movement, thus improving image quality. Incorporating optical fiber is a great mitigation technique for reducing noise in a high energy field.
- Surgical equipment. Extending the reach of traditional copper-based solution by incorporating optical fiber. Optical fiber is a great method to mitigate electrical interference in a highly energized environment and is a cost effective solution for providing electrical isolation between subsystems.
- Medical mobility. Remote assistance for field triage in a man-made or natural disaster situation, for quick patient analysis. Providing reliable and flexible real-time data and imagery to off-site medical experts for analysis and assistance.
- Collaboration. Power and transmit data from remote camera systems in an operating theater, allowing real time collaboration.
- Secure communications. Dedicated data channels so patient records are not compromised.
- High performance audio/visual interconnect. Enabling real-time medical collaboration under the most trying circumstances.

## Machine Vision Applications Of Active Optical Xtreme

Machine vision is a technology that uses cameras, software algorithms, and other processing hardware to generate rapidly increasing amounts of video and still imagery for real-time analysis.

Vision systems are used in various manufacturing industries, such as automotive, semiconductor, and electronics, to inspect products for quality and defects. Other common uses include remote collaboration, human safety, security, target identification, automated sorting, measurement, process optimization, and documentation.

Today, more applications require faster transmission rates with higher quality across longer distances. Machine vision and imaging applications are not only more diverse but are demanding more data, longer distances, excellent reliability, and simplified interconnect architecture (smaller, lighter, faster), all at a lower system cost. Machine vision systems require high-speed data transfer with power and control to function efficiently in electrical environments.

To read more, visit our website: <https://www.nortechsys.com/insights/machine-vision-applications-of-active-optical-xtreme/>

## Nortech's Active Optical Xtreme™ Platform

Nortech's primary design goal was to create competitive, small form-factor active optical cable technologies capable of *longer distances, higher bandwidths, higher densities, and increased power delivery*, to name a few of the key features. In addition, the design had to be robust, flexible, scalable, and customizable to serve a broad range of applications. We have met all initial design objectives with products we are calling *Active Optical Xtreme™* (AOX™ for short). AOX™ is now an industry-leading and highly customizable product platform allowing Nortech to tailor specific product solutions to solve design challenges. The result is a simpler system architecture

and, ultimately, expansion of our customers' technology roadmaps.

### More Specifically, Why USB Type-C Active Optical Cables With Power Delivery

*Our Active Optical Xtreme cables with enhanced power delivery are currently being deployed in machine vision applications spanning 50 meters and beyond.*

One of the major drawbacks for USB-C cables is there can be confusion about capability since they all may physically look similar. USB Type-C refers to the connector style and not the actual internal specification. Care should be taken to ensure all cable assembly specifications meet system requirements. A second and potentially more troubling problem for USB-C is rampant sub-standard quality cables and accessories which can potentially cause damage to devices and even present a human safety hazard. These issues are mainly caused by the increasing amount of power USB-C cables are beginning to carry when accompanied by poor quality design and workmanship. Low-cost cables for all applications, especially sensitive medical applications, present high risk.

Distance has always been a challenge for traditional copper USB cables. We have overcome this challenge with a customizable, standards-based active optical cable platform (AOX™). Our AOX™

cables with enhanced power delivery are currently being deployed in machine vision applications spanning 50 meters and beyond.

Transitioning to a hybrid bulk cable design (optical fiber for data delivery and copper wire for power) has allowed Nortech to shrink the overall cable diameter - creating a smaller more flexible cable than an all-copper solution. Our modular technology enables us to add rapid customizations such as high flex, ruggedization, and secured connectors (thumb screws) as part of our AOX™ platform offerings.

The overall result of changing to USB-C active optical cable with power delivery (AOX™) is a dramatic capability increase and footprint/weight/cost savings with a simplified system architecture.

AOX™ is a small form factor USB type C active optical cable, blending power delivery over highly flexible copper wires with high-speed data over tactical fiber optic channels. These initial market-entry cable designs offer a unique combination of EMI-resistant data with power delivery and communication signals over long lengths in a durable family of solutions. In a broad sense, these features offer multiple advantages over traditional copper-wire and multi-cable architectures.

Key characteristics of AOX™ are world-class data performance, high power, unique combination of data and power, long reach, EMI resistant, durable and ruggedized, high flex and torsional performance, flame retardancy, UL compliant or listed. AOX™ eliminates need for linear re-drivers or linear re-timers common in long-reach copper communication cables. Streamlines multiple copper cables and connectors (data and power) into a single low-profile hybrid cable and connector. Reduces data loss through high-performing fiber optics. Reduces weight and mass (size) vs copper solutions.

### New Paradigm for Industrial and Medical Applications

With USB-C there is one type of cable, one type of port, and between them is a small form-factor, standardized connector: *one interface*



to rule them all. Incorporating power delivery extends the list of devices and applications now supported. Changing to active optical cables expands cable length possibilities - breaking through the previous limits of copper architectures. Nortech Systems offers a framework (AOX™) encompassing all the above best-in-class features.

Our architecture has been designed to be flexible in terms of application usage, and customizable to meet the changing system configurations in multiple industries. This means the same family of cables is usable for a wide variety of use cases (ex. custom system interfaces for data such as MRI/CT/Ultrasound/X-ray, cameras, hard drives, monitors, audio interfaces, smartphones, tablets, and even charging a laptop)

## About Nortech Systems

Nortech Systems is a leading provider of design and manufacturing solutions for complex electromedical devices, electromechanical systems, assemblies, and components. Nortech Systems primarily serves the medical, aerospace & defense, and industrial markets. Its design services span concept development to commercial design, and include medical device, software, electrical, mechanical, and biomedical engineering. Its manufacturing and supply chain capabilities are vertically integrated around wire/cable/interconnect assemblies, printed circuit board assemblies, as well as system-level assembly, integration, and final test. Headquartered in Maple Grove, Minn., Nortech currently has seven manufacturing locations and design centers across the U.S., Latin America, and Asia. Nortech Systems is traded on the NASDAQ Stock Market under the symbol NSYS. Nortech's website is [www.nortechsys.com](http://www.nortechsys.com).

## Appendix A:

### AOX Architecture

USB Specification	USB 3.2 Gen2 AOC with Power Delivery (USB PD 3.1)
Small Form Factor:	USB Type-C
Bandwidth:	10 Gbps
Power Delivery:	100 Watts (20V, 5A), 240 Watts (48V, 5A)
Length (general):	Customizable beyond 50 meters
Max Operating Temp:	70°C
Cabling:	Hybrid Bulk Cable (Optical fiber & Copper)
Optical Fiber:	OM3 MM, 50/125, max attn 3.5 dB/km @850nm
Backshell:	Metallic, customizable shape and retention
EMI/EMC requirements:	Covered by (IPC640-D – 3.2.1.h)
USB-IF standing:	Active Member
Biocompatible:	Available on request
Non-magnetic:	Available on request
Nortech USB-IF VID:	DEC 7810, HEX 1E82
Additional Features:	High Flex Cycles, Ruggedization

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## Appendix B:

### Summary of Ratings for Rugged, Extreme Environments

		Nortech Active Optical Xtreme	Other Active Optical Cables
Quality & Data	Eye Mask Margin @ 10 Gbps	0 incursion 90% Mask	Mult hits 90% Mask
	Eye Mask Hit Ratio 100 Cycles	0 incursions	Typ 4-20 incursions
	Bit Error Rate 10 <sup>-12</sup> @ 10 Gbps	Pass	Fail > 7 Gbps
	IPC-A-640 Class 2 or 3	Yes, CL 3 by request	Poor workmanship
	IPC-A-610 Class 2 or 3	Yes, CL 3 by request	Poor workmanship
	IPC-WHMA-A-620 Class 2 or 3	Yes, CL 3 by request	Poor workmanship
	USB 3.2 Gen 2x1 Data Rate	Compliant	Non-Compliant
Length	Maximum	>50m	3-5m
	Custom Lengths available	Yes	No
Power	Source Max: 48V, 5A (240W)	240W @ 50m	60W @ 1m-15m
	IR Voltage Drop (@ 30m)	10% nom	20% - 80%
	USB PD 3.1 (USB-C 250W)	Compliant	Non-Compliant
Mechanical	Fiber Optical Construct	Tactical grade, bend insensitive	Non-Tactical
	Pull Test (USB Spec = 9 lbs)	75 lbs	9-10 lbs
	Rolling Flex	>4,000,000	Not Rated
	Torsion	>50,000	Not Rated
Environmental	EMI FCC Class B, CISPR 32	Compliant	Non-Compliant