Industrial Communications Interconnect Continues to Advance with Trending Technology

White Paper

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Introduction

Modern industrial spaces, such as factories, logistic centers, transportation facilities, mining, materials processing, and energy production are becoming increasingly electrified. Either to enhance the automation of the industrial space or to improve efficiency through more data-driven processes, industrial communications technologies are now more prevalent in these spaces than ever. This trend is only going to continue with the growing accessibility of machine learning/artificial intelligence (ML/AI) industrial systems, such as autonomous mobile robots (AMRs), a trend often referred to as Industry 4.0 and/or Industrial Internet-of-Things (IIoT). Given the diverse range of industrial communications and sensing applications and the technologies that emerged from these applications, there is also a diverse range of industrial communication systems and interconnect. As interconnect is the backbone of any communication systems, it is valuable for industry professionals to be apprised of the various industrial communications interconnect technology available today and the considerations at play when choosing interconnect for a given application.

This whitepaper aims to provide a foundational understanding of industrial communications interconnect and some discussion of how trends in communications technology are impacting industrial communications and the interconnect necessary to build these systems.

Industrial Communications Technology Overview

Industrial communications technology spans from the analog, RF, and digital communications from sensors and actuators to high-speed data communications used to communicate with cloud services and control complex automation systems. Many legacy industrial communications systems carried analog and RF signals, as well as relatively slow digital signals. Much of this is changing with the increased use and accessibility of packet-based communications technologies and the interconnect that is designed to support these technologies, such as transmission control protocol/internet protocol (TCP/IP) over Ethernet. There are also now more sensor and actuator platforms that use digital communications instead of analog or RF, even to very high speeds. RF is still often, and increasingly, used often as a backbone for high-speed digital communications over wireless and long-distance links. Optical communications are also growing in use in industrial environments to support very long-distance communications at high speeds, especially for networking communications between industrial sites that are widely spaced.

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Industrial Communications Protocols Shortlist

- ANSI C12.18
- ANSI C12.21
- ANSI C12.22
- AS-i
- BSAP
- CC-Link Industrial Networks
- CIP (Common Industrial Protocol)

- Controller Area Network or CANbus (CAN bus)
- ControlNet
- Data Distribution Service (DDS)
- DeviceNet
- DF-1
- DirectNet
- DLMS/IEC 62056
- DNP3 – Distributed Network Protocol
- EtherCAT
- Ethernet Global Data (EGD)
- Ethernet Powerlink
- Ethernet
- Fanuc Focas
- Fieldbus (foundation fieldbus)
- FINS
- GE SRTP
- GPRS
- Hart
- Honeywell SDS
- HostLink Protocol
- I2C
- IEC 60870-5
- IEC 61107
- IEC 61850
- IEC 62351
- Interbus
- IO-Link
- LSV-2
- M-Bus
- MACRO Fieldbus
- MECHATROLINK
- MelsecNet
- MelsecNet II
- MelsecNet/B
- MelsecNet/H

- Modbus
- Modbus ASCII
- Modbus PEMEX
- Modbus Plus
- Modbus RTU
- Modbus TCP/IP
- MPI
- MTConnect
- OMS
- OPC
- OPC UA
- OpenADR
- Optomux
- OSGP
- PieP
- Profibus
- PROFINET
- PROFINET IO
- RAPIEnet
- RS-232
- RS-485
- SERCOS III
- SERCOS interface
- Sinec H1
- SPI
- SSCNET
- SynqNet
- TCP/IP
- TTEthernet
- Umati
- ZigBee Smart Energy 2.0

Many legacy industrial communication protocols required direct master/slave communications or single-way, and direct-connect communications between two nodes. This requires wiring to go between each sensor, actuator, or controller node, and commonly leads to very large wiring harnesses and structures between industrial installations. What is more common now is to use digital communication protocols that are address-based and packet-based, which allows for a single communications link to support communication among many nodes. This reduces the overall interconnect burden between nodes and simplifies the control, data storage/logging, and many aspects of the design features. One of the most prevalent examples of this is the growing use of IT technologies as industrial communications, and the joining of industrial networking technologies with industrial communications. This allows for passthrough of industrial communications between systems to be monitored/logged by the industrial networking systems, including cloud infrastructure. This new paradigm is leading to enhanced integration between cloud and internet technologies and industrial communication systems. There are a growing number of applications where industrial systems are being completely controlled, monitored, and maintained entirely through remote cloud services.

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These new technologies are enabling higher tiers of efficiency, alongside data driven predictive maintenance and forecasting. To achieve a high level of automation and remote analysis/control capability, however, the industrial communications systems do need to feed into gateways to networking technologies. This involves a substantial amount of interconnect and hardware between the sensor, actuator, and control nodes and the networking technology.

Industrial Communications Interconnect Styles

Industrial communications interconnects are used on every level of electrical platforms. This includes circuit boards, cables, and panels. There are cases where it is desirable to connect each electrical platform to each other through various types of interconnect. The main styles are listed below.

Industrial Interconnect Styles

- Board-to-Board
- Cable-to-Cable
- Cable-to-Board/Wire-to-Board
- Panel Feedthrough/Bulkhead

Original Equipment Manufacturers (OEMS) include board-to-board and wire-to-board/cable-to-board connecter interfaces for their boards. There are wire harnesses and adapters that can be used to interface cabling to these connector interfaces. In some cases, the cable-to-cable connectors are the same or similar to the cable-to-board/wire-to-board connector interfaces that are mounted on the electronics boards. Most cable-to-cable and cable-to-board/wire-to-board connectors require specialized tools to reliably attach the connectors to the cabling/wiring. Training and experience are often essential in properly installing the connectors on industrial cable/wire, which is why many organizations opt to purchase pre-attached connector-cable/wire combinations called cable/wire assemblies.

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Common Industrial Connector Types

- D-Sub
- Fiber Optic
- RJ45
- USB
- Mini I/O

- SCSI
- HDMI
- DisplayPort
- M8
- M12
- BNC
- TNC
- Screw Terminal
- F Connector
- XLR
- IEEE-488 GPIB
- IX Industrial
- 110 Keystone Jack
- Splices
- SMA
- N-type

Panel feedthroughs, or bulkhead connectors are connector types that are used to interface through a panel or electronics housing. Panel feedthroughs/bulkhead connectors are often environmentally sealed and also contain some form of electrical filtering or protections, such as electromagnetic interference (EMI) filtering/shielding. These types of connectors may have a connector type on the inner panel/bulkhead side or may require some type of crimp or solder connection to a wire/cable.

Industrial Communications Interconnect Considerations

Choosing an appropriate industrial communications interconnect type can depend on many factors. These factors include electrical, mechanical, environmental, compliance/standards, availability, cost, and others. In many industrial cases the environmental parameters are a major limiting factor on the types of interconnect that can be used. Therefore there is a vast array of industrial-grade connector standards and product lines, some of which are open standards and some proprietary.

Industrial Connector Considerations

- Bandwidth and data rate
- Voltage, Current, & Power Rating
- Environmental Ruggedness
- EMI Performance, EM Shielding, RF Shielding
- Mechanical Robustness
- Size, weight, pitch, and form factor
- Insertion dynamics
- Standards Compliance & Safety Regulations

Each industrial interconnect use case will have a matrix of the considerations with differing priorities for the consideration categories. For instance, in oil/gas applications, an interconnect solution may need to meet various national and international standards for safety and internal environmental standards. While a logistics/fulfillment facility may not have as strict environmental or safety standards but may be more concerned with price and or form factor. In some cases, it may be necessary to use a certain interconnect solution because it supports a specific communication protocol. That communication protocol may have certain electrical requirements that dictate the types of interconnect solutions that can be used.

For instance, Ethernet-based solutions are based on twisted-pair wiring and connectors compatible with twisted-pair wiring, category (CAT) cabling and RJ45 or other Ethernet compatible jacks (i.e., M12 and M8). The type of cabling and connectors that support Ethernet have electrical limitations and ratings to represent these limitations, and it is essential to select a cable and connector solution that is compatible with the Ethernet electrical performance requirements. An example of this is that Ethernet cabling categories (CAT) are used to designate the nominal bandwidth, maximum data rate, and shielding type of an Ethernet cable, among other specifications.

Category	Standard Bandwidth	Max Data Rate	Shielding
Cat 5	100MHz (up to 350)	100 Mbps	UTP or STP
Cat5e	100MHz (up to 350)	1,000 Mbps / 1 Gbps	UTP or STP
Cat6	250MHz (up to 550)	1,000 Mbps / 1 Gbps	UTP or STP
Cat6a	250MHz (up to 550)	10,000 Mbps / 10 Gbps	UTP or STP
Cat7	600MHz	10,000 Mbps / 10 Gbps	Shielded
Cat7a	1000MHz	40,000 Mbps/ 40 Gbps	Shielded
Cat8	2000MHz	25 Gbps or 40 Gbps	Shielded

Many connector types also have electrical specifications that limit the electrical performance of certain communication standards. An example of this is high-speed digital signals sent over coaxial connectors. Coaxial connectors all have a maximum frequency, and they can efficiently carry signals from DC to the maximum operating frequency. Digital signals have frequency components that are essentially the same as RF signals, and the maximum digital signal throughput is a function of the maximum frequency capability of a coaxial connector and other electrical specifications of the coaxial connector.

There are also frequency limits to other types of interconnect, however, those meant for digital interfaces tend to be specified with a throughput limit or maximum bits-per-second instead of, or alongside, a maximum frequency limit. With many modern industrial sensor and communication systems, the throughput of the data is much higher than in previous years, and many legacy digital and communications interconnects are unable to support the new requirements for throughput or signal integrity.

Types of Industrial Communications Interconnect for The Modern Era

Legacy connector and cable types, such as D-sub, BNC, XLR, GPIB, and various proprietary connector types have long been adapted for rugged industrial applications. For these types of connectors and associated cabling, there are a host of industrial-grade options for virtually every application including the harshest environments. Though Ethernet, fiber optic, USB, and various RF interconnects have been introduced more recently into industrial environments, there is a growing body of choices for ruggedized interconnect solutions suitable to most industrial applications. There are also an increasing variety of interconnect styles that can be adapted to various regimes of signal types, including power, analog, digital, and RF.

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The following is a discussion of various interconnect solutions for modern signal types and standards growing in use for industrial applications. These include Ethernet, USB, RF, and high-speed networking.

Industrial Ethernet

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Ethernet connectivity is the main interface used for consumer and commercial internet and networking technologies ubiquitous around the globe. Hence, technologies that interface using Ethernet are increasingly common. This is why there are a host of industrial applications that are now making use of Ethernet to enable higher tiers of automation and ML/AI applications. Ethernet is a well-established standard with levels of throughput and capability that are readily adapted to industrial environments. Moreover, to better comply with the demand for more rugged Ethernet connectors there are an increasingly large array of industrial Ethernet options, including M12 and M8 connectors alongside the legacy RJ45.

As RJ45 connectors were originally designed for telephony in relatively clean and sterile environments, this connector type often is not suited to industrial use cases. There are ruggedized RJ45 connector types, however, they tend to be relatively bulky and present some intrinsic weaknesses to moisture ingress and particulate contaminates degrading the contact surfaces. M12/M8 connector styles are more rugged, by design, and are usually much smaller pitch and profile than RJ45, especially M8. There are M12 connectors that are capable of providing high throughput Ethernet, such as category 7 (CAT 7) or 10gig Ethernet. Hence, there are often adapter cables that go from RJ45 to M12, where the RJ45 connector is used for standard networking gear with RJ45 interfaces, and the M12 connector side is used to interface with more rugged M12-based hardware in the field or more rugged parts of the facility.

Industrial USB

USB, especially the latest USB-C standard, are compact and high bandwidth digital peripheral interfaces extremely common to modern computers and computer/digital accessories. USB protocols are capable of carrying Ethernet, control, typical digital data exchange, audio/video, and virtually any other digital signals that don't exceed the bandwidth of the connection. With the latest USB standards, USB 4.2, the transfer speeds for USB can exceed 80 Gbps. More common USB 3.2 can still reach an impressive 20 Gbps, which is now often necessary for high-definition video interfaces or when there is a need for using a single interface to run several peripherals/accessories. An example is the use of several USB interface cameras and sensors in a robotic system.

Having access to industrial-grade USB interconnects allows for the integration of ruggedized consumer/commercial electronics in industrial systems. That, and the use of the USB interface, which is now globally ubiquitous, may be a more desirable option than legacy proprietary digital interfaces specifically designed for ruggedized environments. With the heightened use of USB in industrial environments there are now a greater variety of industrial-grade and ruggedized USB options, including high-port count USB hubs, often used to interface between industrial computer control systems and a large number of distributed USB peripherals. Industrial automation systems, many of which are based on standard computer systems, are increasingly reliant on USB interfaces for high-speed data transmission. This trend is also driving the development of more industrial devices with built-in USB interfaces, making designing, and installing industrial automation systems much easier than in the past where there were only a mix of various proprietary connector options.

Industrial RF

There are several factors driving the increased use of RF interconnect in industrial spaces. These include the use of higher speed digital interfaces that often need to span long distances, which can often better be achieved using coaxial transmission lines, and the more expansive use of wireless sensing, communication, and networking technologies. Industrial use cases of radio and radio communication systems have been common in the past for voice and simple text messaging. However, modern industrial environments are gradually adopting cellular telecommunications, wireless networking with Wi-Fi, and various industrial Internet-of-Things (IoT) standards to power a diverse range of sensor, actuator, and monitoring/security devices often distributed throughout an industrial facility.

RF interconnect common to industrial environments are coaxial cable assemblies with threaded connectors or bayonet connectors, usually with SMA, N-type, BNC, or other coaxial connector standards like 4.3/10, F connector, etc. There is expanding use of push or blind-mate style coaxial connectors, such as SMB, SMP, Mini-SMP, MCX, and various push-connect types of other common coaxial connector standards. The push or blind-mate connector types present a quicker and easier interconnect process and often allow for smaller connector profiles and tool-less insertion, which is not recommended for threaded-type coaxial connectors.

Industrial High-speed Networking (Fiber Optic)

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Fiber optic is the backbone of internet traffic around the world for long distance interconnect runs. As many industrial facilities cover large expanses of land and need to interface with cloud services provided through the internet, fiber optic is now spreading throughout many large industrial facilities and applications, such as mining, rail, oil/gas, transportation hubs, etc. Fiber optic cabling and connectors are relatively delicate and require very careful attachment to fit fiber optic connectors to the cables. Despite this, Fiber optic solutions for even extremely harsh environments have emerged as a means of connecting the most distant parts of the world. Hence, there are a plethora of industrial-grade fiber optic options to enable 100gig and beyond Ethernet connectivity. An advantage of fiber optic interconnect is the inherent immunity to electromagnetic interference. As fiber optic signals are carried along an optical waveguide that is optically isolated from the outside world, these signals are not subject to interference or interception in the same way that conductive interconnect, such as twisted pair Ethernet, are. Moreover, fiber optic interconnect is among the highest available bandwidth and throughput interconnect and is far less lossy a medium than conductive interconnect, which allows for fiber optic signals to travel even hundreds of kilometers without crippling signal loss. For critical communication scenarios that require extreme levels of throughput, security, electromagnetic immunity, and even distance, fiber optic interconnect is one of the top available options. A caveat here is that fiber optic technology is often more expensive than conductive interconnect and does require specialized tools and experience to install and maintain.

Conclusion

The rise of the machines, mainly greater uses of automation and communication in industrial environments, is also heralding the rise in use and complexity of industrial interconnect. There are now many new interface entrants to the industrial interconnect arena, such as Ethernet, USB, fiber optic, and high frequency RF. These interfaces and their associated interconnect are aiding in solving modern industrial sensing, actuating, communications, automation, and monitoring/security challenges, and are only more likely over time to see these interconnect styles in industrial use cases as industrial-grade or ruggedized variants.