TURCK

Industrial
Automation

The Field Guide
for Industrial Ethernet

FIELD GUIDE

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HISTORY OF ETHERNET

Robert Metcalf and David Boggs invented Ethernet while working for Xerox PARC after being tasked to share a laser printer with a network of personal computers. By 1979 Robert Metcalf convinced several companies that in order for Ethernet to be accepted worldwide they would need to create a standard. The group "DIX" was formed by Digital Equipment Corporation, Intel, and Xerox and the Ethernet from that period is often referred to as DIX. The first version of the standard was officially published on September 30, 1980 as "The Ethernet, A Local Area Network. Data Link Layer and Physical Layer Specifications."[1] The next version was published a few years later as Version 2 and defines what is known today as Ethernet 2. Today, the group (known as the IEEE 802 LAN/MAN Standards Committee) maintains the 802 family of standards which continues to expand with the advancements in technology. Two relevant standards are the 802.2 which defines Ethernet and the 802.3 which defines Industrial Ethernet. In February of 2013 the 802.3 "Standard for Ethernet" study group was formed to look into Ethernet requirements for network latency and real-time control for industrial automation.

WHAT IS INDUSTRIAL ETHERNET

Industrial Ethernet is based on the IEEE 802.3 standard for Ethernet commonly found in the office environment but modified for use in industrial automation. In order for Ethernet to be used in the industrial environment it must be adapted to withstand the environmental conditions that are not found in traditional installations. Considerations include exposure to extreme temperatures, humidity, vibration and noise that can be induced by drives, robots or other equipment often found on the factory floor. Industrial applications also have unique requirements including:

- **Reliability:** Automation environments require equipment to run and do not tolerate unscheduled downtime.
- **Environment:** The designs for wiring, connectors and other Ethernet devices must be designed to tolerate harsh applications including exposure to oils, moisture, ozone, UV, welding, extreme temperatures and flexing.
- **Noise:** Unlike office environments; which normally run on 110 VAC, factories operate with a variety of AC and DC circuits including both high and low voltage. Industrial Ethernet is exposed to equipment running on all of these variations as well as equipment like motor drives, welders and robots. This results in increased RFI and EMI interference which can decrease system performance.
- **Vibration:** Industrial Ethernet cable, wiring and devices are often mounted directly onto equipment. Machine vibration or movement can accelerate the rate of component wear causing decreased performance or permanent damage. Industrial connectors and cable are designed to withstand the severe effects of vibration.
- **Legacy Equipment:** Industrial automation equipment is generally made up of a combination of both old and new machines and often from many different equipment manufacturers. Industrial Ethernet products are designed to deal with most variations in this environment including serial interfaces, and devices that allow bridging between dissimilar technologies.

CONSIDERATIONS WHEN DESIGNING AN INDUSTRIAL ETHERNET NETWORK

When designing an Industrial Ethernet network it is important to consider several important points including:

- Network Topology
- Communication Protocol
- Environmental Conditions

Network Topology

Network topology is the physical arrangement of the components used in the layout of a network including devices and cabling.

1 The History of Ethernet (http://www.youtube.com/watch?v=g5MezxMcRmk), NetEvents.tv.2006. http://www.youtube.com/watch?v=g5MezxMcRmk Retrieved April 4, 2013.

A Star topology consists of each network node being connected to a central location (usually a switch) using a point-to-point connection (Figure 1). The physical layout of the network does not need to look like a star but rather each node must be connected to one central point.

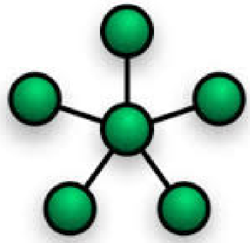


Figure 1

A Ring topology is a network that is connected in a circular fashion where data primarily travels in a single direction (Figure 2). In this topology every node is critical as data travels through each device in the ring until it reaches the destination.

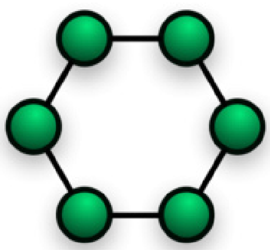


Figure 2

A Line topology is a network where each node is connected to a main line or trunk. The information travels in both directions to all nodes connected on the line until a match for the information is found (Figure 3).

Figure 3

A Tree topology is a network that consists of a hierarchy of nodes. The first level in a network tree consists of a single node, also called a root (Figure 4). This node is then connected to either an additional single node or multiple nodes in a lower level in a point to point manner. The lower levels then connect in a similar manner.

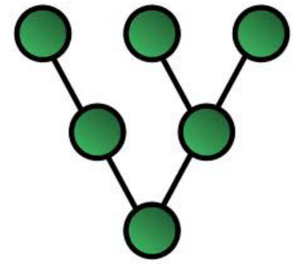


Figure 4

Communication Protocol

EtherNet/IP™ is a communication protocol that was originally developed by Rockwell Automation and is now supported by the ODVA for use in industrial automation and process control environments. It takes the Common Industrial Protocol (CIP) and implements it onto the foundation of Ethernet. CIP envelops a wide-ranging suite of messages and services for a variety of applications, including safety, control, configuration and information. EtherNet/IP provides users with tools to deploy standard Ethernet technology for industrial applications.

EtherNet/IP is very flexible with star, tree or line topology but using managed switches is preferred in industrial applications. The use of managed switches allows the network to be configured to perform as close as possible to a real-time behavior that is often required in industrial applications.

EtherNet/IP follows the MICE guidelines (TIA 802.9) for applying Commercial and Industrial Ethernet based on environmental conditions (see more on MICE later in this paper). Encapsulated 8-way modular and 4-Pole M12 "D" coded connectors as well as 8-Pole M12 "A" coded connectors are allowed. ODVA recommends isolating the shield at one end of the channel by grounding at the switch. See ODVA for specifications.

Modbus TCP is the Modbus RTU protocol with a TCP interface running on Ethernet. Modbus was originally designed by Modicon (Schneider Electric) and is now managed by the Modbus-IDA User Organization. TCP refers to Transmission Control Protocol , which provides the transmission channel for Modbus TCP messaging. Modbus TCP is used often in the industrial environment due to its ease of deployment and maintenance, and because it was developed specifically for industrial applications.

Modbus TCP can be used with star, tree or line network topology and can be implemented with Ethernet technology that has been adapted for use in the industrial environment. Modbus uses standard EtherNet/IP cables and it also recommends grounding the system at one end.

Modbus TCP follows the MICE guidelines (TIA 802.9) for applying Commercial and Industrial Ethernet based on environmental conditions.

PROFINET™ is a communication protocol that was developed by Siemens and managed by Profibus International (PI) based on the open Ethernet standard. PROFINET features a modular design structure allowing users to select the cascading functions including standard TCP/IP for applications not requiring real time performance, Real Time (RT) for applications requiring the transfer of critical information and Isochronous Real Time (IRT) for applications using functionality like motion control.

PROFINET can be used with line, ring, star and tree network topology and uses Ethernet technology that has been adapted for use in industrial environments.

It is recommended by PI to connect the shield on both cable ends to ground for optimal electromagnetic compatibility. When separate potentials exist the shield should be connected only on a single end to ground. It is preferred that the connection between shield and ground be achieved via the metal case and the screw top of the connector. (See PI for specification)

PROFINET should never be more than 100Mb per second so CAT 5 cable is sufficient though CAT 5E, CAT 6 or higher cables are always backward compatible. The cabling can consist of 2 pair or quad (preferred) and be type A, B, or C.

- **Type A:** Stationary with no movement after installation (Solid Cable)
- **Type B:** Flexible, occasional movement or vibration
- **Type C:** Special applications including highly flexible, permanent movement, vibration or torsion.
- **Note:** TURCK provides a single cordset solution for Type B and Type C for industrial applications.
- PROFINET follows its own specification regarding environmental conditions in industrial applications. The guidelines are identified as "inside" and "outside" areas based on areas they are installed.
  - Inside – environments found in control stations, control rooms or inside switch cabinets.
  - Outside – environments with higher demands relating to temperature, dust, moisture, vibration etc.
    - (See PI cabling guide for specification)

EtherCAT™ is a communication protocol that was developed by Beckhoff Automation and managed by the EtherCAT Technology Group (ETG). The technology uses a clear master/slave communication model.

EtherCAT can be used with line, tree and star network topology and can be implemented with standard Ethernet technology.

EtherCAT requires that Ethernet cables must meet the minimum requirements for category 5 (CAT 5) and used 4 wires for signal transfer. EtherCAT uses RJ45 connectors and the cable length between two EtherCAT devices must not exceed 100 m.

TURCK's standard offering of EtherNet/IP cables are suitable for use with the EtherCAT protocol.

Environmental Conditions

MICE

As Ethernet continues to expand into more harsh environments the need for standards continues to grow. The Telecommunications Infrastructure Association (TIA) has created a guideline specifying possible environmental conditions for cables and connectors including Mechanical, Ingress, Climatic/Chemical and Electromagnetic (MICE). The MICE guidelines are basically broken down into three sections dependent on the severity of environmental conditions.

MICE 1 (M1,I1,C1,E1) – Is considered a worst case office environment including a control or telecommunication room which is usually enclosed and separated from any other environmental conditions. This area could use RJ45 (IP20) style industrial grade connectors and cable.

MICE 2 (M2,I2,C2,E2) – Is considered worst case light Industrial application which includes location on the factory floor and in the area around a work cell or on a machine. This area could use an RJ45 (IP67) or M12 overmolded connector and industrial grade cable.

MICE 3 (M3,I3,C3,E3) – Is considered worst case heavy industrial application which includes placement on machines and equipment and exposed to the environmental conditions common in Industrial Manufacturing. This area should use M12 overmolded connectors and industrial grade cable designed for continuous exposure.

The full MICE TIA 802.0 Specification is available as a separate PDF document and lists all of the specific conditions and details relating to environmental conditions. Any application could contain a combination of these conditions and cordsets should be selected based on the worst case scenario.

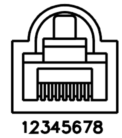
UNDERSTANDING YOUR OPTIONS FOR INDUSTRIAL ETHERNET CONNECTORS AND CABLING

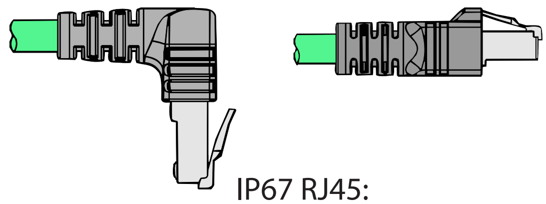
After the network communication and layout has been selected it is time to move into selecting your connector and cable options. Considerations should include current and future bandwidth requirements as well as the environmental conditions to which the network will be exposed to.

Connector Options

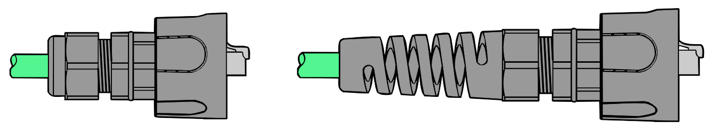
RJ45 plug connectors are the most widely established connector technology for Ethernet systems and conform to the international IEC 60603-7 standard. These 8-pin components are available for both CAT 5E and CAT 6A RJ45 connectors. Their ease of use and quick connect/disconnect feature make them a natural choice for office and clean room environments. They are commonly used in Industrial Environments as a patch cable converting office Ethernet to the factory floor. These connectors are capable of handling both 2 and 4 pair wiring and come in both IP20 and IP67 styles.

IP20 RJ45:



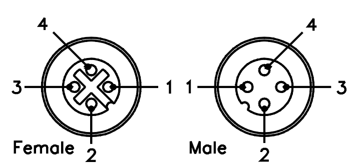


IP67 RJ45:

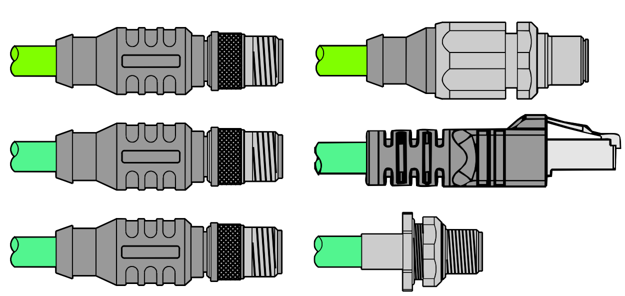


M12 Ethernet Connectors are the superior choice for Industrial applications. Their rugged overmold design provides ingress protection against dirt and water as well as resistance to machine vibration and accidental impact. These factors make them a better choice for maintaining signal integrity and performance.

IP68 rated for industrial applications, M12 connectors are also available with stainless steel components suitable for environments requiring corrosion resistance. Similar to RJ45 connectors, they can be used for 10 BASE-T, 100 BASE-T and 1000 BASE-T transmissions.



IP68 M12:



When choosing connectors for an application the MICE guidelines can be an excellent guide. It is important to consider the conditions that the connector will be exposed to including how and where it will be mounted, what shielding is required and the conditions of the overall operating environment. For this reason TURCK offers a wide variety of M12 connector options that are appropriate for Industrial Ethernet applications.

Cable

Color codes for connectors and cables are defined in the ANSI/TIA/EIA-B.2 and B.3 specification and are shown in the table below.

Two Pair Color Code

Pair Assignment	Signal Name	2 Pair Color Code
Pair 1	TX+	White/Orange (W-O)
	TX-	Orange (O)
Pair 2	RX+	White/Green (W-G)
	RX-	Green (G)

Four Pair Color Code

Pair Assignment	Signal Name	4 Pair Color Code
Pair 1	NA	White/Blue (W-BL)
	NA	Blue (BL)
Pair 2	TX+	White/Orange (W-O)
	TX-	Orange (O)
Pair 3	RX+	White/Green (W-G)
	RX-	Green (G)
Pair 4	NA	White/Brown (W-BR)
	NA	Brown (BR)

Cable Terminology

Ethernet Backbone – Is part of the overall network infrastructure that interconnects various parts of the overall network together, allowing information to exchange hands.

Horizontal Cabling (trunk) – Is defined as 4 balanced twisted pair cabling that connects central locations (like control rooms) to individual cells or work areas on the floor. These cables generally run through duct, cable trays or ceiling areas throughout a facility. (In Industrial Ethernet applications we could identify with this as a trunk cable)

Stranded Conductor Cable (patch or equipment cable) – A section of Ethernet cable with a connector on both ends, most commonly defined as a cable from a wall jack to a computer in the commercial environment. (In Industrial Ethernet applications we could identify this as a drop cable)

Twisted Pair – Wiring where two conductors that are part of the same circuit are twisted together. This process is intended to help cancel out EMI and interference from other sources like neighboring pairs in normal environments where telephone lines or commercial Ethernet would run.

ANSI/TIA/ EIA-B.2 and B.3	# Pairs	AWG	Conductors
Horizontal Cable	4 Pair	Minimum 24	Solid
Backbone Cable	Greater than 4 Pair	22 – 24	Solid
Stranded Conductor Cable (patch or equipment	4 Pair	Minimum 24	Stranded

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Length Determination for Combination of Horizontal (H) (solid) and Stranded Conductor Cable (SCC) (patch and equipment)

Stranded Conductor Cable AWG (patch or equipment)	Stranded Conductor Cable Derating	Horizontal Length (H+SCC<=100m)	Stranded Conductor Length (patch or equipment)	Total combined length of stranded conductor and horizontal cable
#24	0.2	100	0	100
#24	0.2	0	80	85
#24	0.2	25	64	89
#24	0.2	50	43	93
#26	0.5	0	68	68
#26	0.5	25	51	76
#26	0.5	50	35	85
#26	0.5	100	0	100

Selecting the Right Cable

Ethernet cables will continue to change as faster data rates are needed in both commercial and industrial environments. The ODVA states that the minimum cable type that is supported for EtherNet/IP is Category 5E TIA/EIA-568-B.2. Factors to take into consideration when choosing your cable type are network support, cross talk and bandwidth. The cable types below are all recognized:

Standard	MHz Rating	Maximum Length	Network type(s)
CAT 5E	100	100m	10BASE-T, 100BASE-TX, 1000BASE-T
CAT 6	250	100m	10BASE-T, 100BASE-TX, 1000BASE-T, 1000BASE-TX
CAT 6A	500	100m	10BASE-T, 100BASE-TX, 1000BASE-T, 1000BASE-TX, 10GBASE-T

10BASE-T (10 mbit Ethernet), 100BASE-TX (100 mbit "Fast" Ethernet), and 1000BASE-T ("GigE" Gigabit Ethernet).

10BASE-T and 100BASE-TX each require 2 twisted pairs while 1000BASE-T, 1000BASE-TX, and 10GBASE-T require 4 twisted pairs.

When selecting a cable type it is important to consider that your network will always run at the speed of your slowest device. Use of a CAT 6A cable will not enable your network to run at Gigabit speed unless every component in that network is certified to operate at that speed. The maximum length of 100 meters between devices regenerating the signal ensures that data arrives intact and prevents bandwidth bottlenecks. The 100-meter total includes patch cables which have their own max length specifications.

Shielding:

EMI/RFI stands for "Electro-Magnetic Interference" and "Radio Frequency Interference" which is high frequency / low energy noise emitted by factory devices such as motors, welders, power cables and processing equipment. The noise emitted disrupts packet transmission by overwhelming the normal signal information within the electrical circuit. A double shielding approach is most effective in isolating the data communication from the external environment. The shielded cable usually has both a inner foil shield and a copper braid. This approach takes advantage of the greater coverage of foil and the superior conductivity of the copper braid. Additionally, proper bonded grounding of all components is crucial to attaining effective shielding. When in doubt if shielding is required, error on the side of caution choosing shielded cables to prevent against costly system downtime and errors.

Note: The order of the foil and braids are not defined by a specific standard but our experiences shows that braid and then foil helps with flexlife.

SUMMARY

Ethernet technology will continue to evolve in providing faster transmission rates required by robotics and motion controls. Factory floor Industrial Ethernet requires special attributes for environmental conditions including noise, oil & chemical exposure, motion, and temperature fluctuation. Referencing the MICE guidelines prior to connector and cable selection will ensure optimal system integrity and performance. Adhering to recommended installation lengths between hubs and device level will keep system troubleshooting to a minimum.