M12 CONNECTIVITY FOR INDUSTRIAL ETHERNET IN RAILWAYS

A TE Connectivity Rail briefing paper

Selecting the best cable and M12 connectors for industrial Ethernet networks in the rail industry

INDUSTRY 4.0 IS CHARACTERIZED BY GROWING RELIANCE ON DATA GATHERING, ANALYSIS AND TRANSMISSION FOR REMOTE SENSING, MONITORING AND DIAGNOSTICS, AS WELL AS SOPHISTICATED CONTROL SYSTEMS, AUTOMATION, SECURITY AND INFOTAINMENT.

These rely on high-availability data transmission, often carried by Ethernet. However, major differences between industrial environments mean that it can be challenging to choose the right cables and connectors for industrial Ethernet networks. Being sealed and rugged, M12 connectors are popular for connecting network components in rail applications as well as industrial machinery and factory automation.

In this white paper, Egbert Stellinga, TE Connectivity's Product Manager for rail data connectivity, explains how to select the best cable and M12 connectors for industrial Ethernet networks, the differences between different cable and connector versions, and their advantages and disadvantages.

Contents

Cable

To select the correct connection system, it's important to start by defining the cable. Choosing the cable will establish the bandwidth, power capacity and level of protection. For applications with specific needs, customized cables can be created and manufactured but buyers can also opt for a standardized cable assembly.

DATA SPEED

Ultimately, the role of cables and connectors is to deliver enough bandwidth to meet the needs of devices connected to the network – so the first step is to evaluate how much data is required. The cable and connector can then be selected based on the required data speed of all the connected devices.

Cable systems for data and information technology systems are governed by the international standard ISO/IEC 11801. Since it was introduced in the 1980s, the standard has been refined to support higher bit rates and longer distances over multi-pair cable networks.

Standard	Data Speed	Max Length	Bandwidth
Cat 5	100Mbps	100m	100 MHz
Cat 5e	1Gbps	100m	100 MHz
Cat 6	1Gbps 10Gbps	100m 55m	250 MHz
Cat 6_A	10Gbps	100m	500 MHz
Cat 7	10Gbps	100m	600 MHz
Cat 7_A	10Gbps	50m	1 GHz
Cat 8	40Gbps	30m	2 GHz

Ethernet cables are grouped into sequentially numbered categories (“Cat”) based on different specifications. These categories are used to easily identify the type of cable needed for a specific application and some categories are updated with further clarification or testing standards (e.g. 5e, 6a). Manufacturers must meet minimum technical specifications, enabling buyers to compare like with like easily.

Bandwidth is the maximum amount of data that can be transmitted. It can be compared to a two-lane versus a five-lane highway. Travelling at the same speed, more cars can pass along the five-lane highway than the two-lane highway in an hour. Likewise, the higher the bandwidth the greater the data transmission capacity of the network.

MECHANICAL CONSIDERATIONS

There are notable differences between the cable categories. Type of cable include unshielded, shielded, stranded and solid cable. It is important to understand the comparative advantages of these and their applications.

Twisted pairs

So how can a physical cable eliminate interference and allow for faster speeds? The answer is through use of wire twisting and isolation. Cable twisting was invented by Alexander Graham Bell in 1881 for telephone wires that ran alongside power lines. He discovered that by twisting the cable after the distance between every three or four utility poles, interference dropped and range increased.

Today twisted pairs, or differential pairs, are the basis for all Ethernet cables as they eliminate interference between internal wires (XT), and external wires (AXT). Cable twisting length is not standardized, but typically there are 1.5-2 twists per centimeter in Cat-5(e) and two or more twists per centimeter in Cat-6.

Figure 1: S/STP TE Connectivity Cat 7 cable (Shielded/shielded Twisted pair cable, meaning both the twisted pair as well as the cable have been shielded)

SHIELDED VERSUS UNSHIELDED

Manufacturers use shielding to further protect cables from interference. This takes the form of a conducting layer around a twisted pair or an entire cable cross section. This acts as a Faraday cage that protects the cables inside from Electromagnetic Interference (EMI) by giving the voltage generated by interference a pathway to earth.

A low cost unshielded twisted pair may be suitable for cables that run between computers and devices. However, for areas with high interference, or cables that run outdoors or inside walls, it is worth investing in shielded cables as they offer higher levels of protection.

In general, the higher the Cat speed of the cable, the more shielding is applied in the product.

Putting a shield around each pair of wires in the cable protects the pairs from crosstalk from other wires in the bundle internally as well as external interference. The coding STP or UTP denotes whether pairs of wires inside a cable are shielded or are unshielded. Manufactures can further protect cables from alien crosstalk (AXT) by an overall screen around an entire UTP or STP cable and this adds the prefix S. Technically the picture in Figure 1 above shows a Screened STP cable (S/STP). In higher speed cables, more sophisticated measures can be taken to further reduce crosstalk. An example is the x-member that is present in all cat 6a cables.

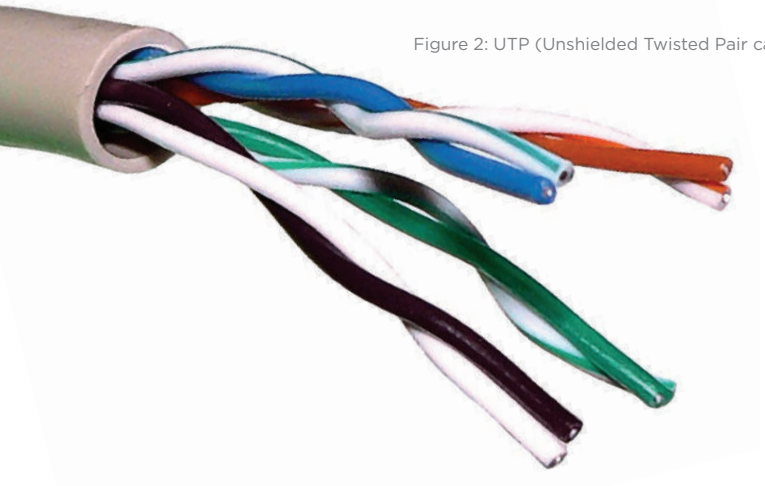

Figure 2: UTP (Unshielded Twisted Pair cable)

Cable Construction	Individual Twisted pair (XT)	Whole Cable (AXT)
UTP	Unshielded	Unshielded
S/UTP	Unshielded	Shielded
STP	Shielded	Unshielded
S/STP	Shielded	Shielded

SOLID VERSUS STRANDED WIRE

Solid and stranded refers to the type of copper conductor in the Ethernet cables. Solid cable is based on a single length of copper, whereas stranded cable uses a series of copper strands twisted together.

Stranded cables are more flexible and should be used in dynamic applications involving movement or motion of the cables. Solid cables are not as flexible, but provide better attenuation characteristics and are therefore better suited to permanent installations.

Figure 3: Stranded (Top) vs solid (Bottom) wire

OTHER CABLE SELECTION CONSIDERATIONS

Besides the speed and cable construction, further considerations need to be made based on the application of the cable and its specific requirements. For example, the rail industry requires specific resistance against chemicals, fire and smoke, as defined in the standard EN45545-2. Further considerations can impact the choice of insulation material around the cable or other aspects of cable performance, such as:

- Flame retardancy
- Halogen free
- Toxicity
- Low smoke
- Oil resistance
- Fuel resistance
- Temperature range
- Minimum bending radius
- Number of bends

POE (POWER OVER ETHERNET)

There is a growing trend for devices such as wireless access points, IP cameras, and VoIP phones to rely on a single cable to provide both data connectivity and electrical power.

These calls for Power over Ethernet or PoE, where electric power is transmitted alongside data on twisted pair Ethernet cabling. POE methods have been standardized since 2003 under IEEE 802.3. It normally requires category 5 cable or better for high power levels, but category 3 cable can be used if less power is required.

Power is typically transmitted over two or more of the differential pairs in the Ethernet cable. Power is supplied either from a PoE-enabled networking device, such as an Ethernet switch, or from a mid-span power supply, also known as a PoE power injector, that can be used in combination with a non-PoE switch.

Name	Standard	Power budget	Remark
POE	802.3af	15.4W per port	-
POE+	802.3at	25.5W per port	-
4PPOE	802.3bt	55W per port	Future generation
POE type 4	802.3bt	100W per port	Future generation

PoE's growing popularity and potential to support more sophisticated systems with higher electrical loads have led standards body the Electrical and Electronics Engineers (IEEE) to consider ways of increasing the amount of power that can transmitted.

The upcoming IEEE 802.3bt standard, also known as the 4PPoE (4 Pair Power over Ethernet) standard, is slated for early 2018 and will introduce two additional power types: up to 55 W (Type 3) and up to 90-100 W (Type 4). Each twisted pair will need to handle a current of up to 600 mA in Type 3 or 960 mA for Type 4.

Additionally, the IEEE is planning support for 2.5GBASE-T, 5GBASE-T and 10GBASE-T, which will govern data transmission rates of 2.5, 5 and 10 Giga bits per second (Gbit/s). This development will open the door to new and expanded applications, such as operating high-performance wireless access points, surveillance cameras or even Ethernet-powered laptop docking stations.

The M12 Connectors

The other aspect of an industrial Ethernet cable system is selection of connectors. These ensure a reliable and repeatable connection between cables, switches and terminal equipment. Most people are familiar with the RJ45 type of Ethernet connectors as they are the type of plug and socket used to connect a laptop or desktop computer into a Local Area Network in office buildings or at home.

However, M12 connectors are used widely in industrial environments. These provide the same Ethernet networking connectivity as RJ45 connectors but provide safe and reliable connections for industrial environments where continuous operation is a priority. The main difference between the two is the ruggedness of the connector and the protection it affords.

Figure 4: Example of an RJ45 connector

M12 connectors are tough, heavy-duty connectors that are locked into place with a 12mm screw thread and designed to withstand harsh industrial applications under the standard IEC 61076-2-101, which also covers the smaller M8 family of connectors that are also used in industrial machinery and industrial control systems. Such applications are characterized by shock, vibration, pollution, extreme temperatures and moisture. In addition, they must meet stringent safety standards such as low smoke and toxicity requirements. Examples can be found in industrial machines, rail applications, mining equipment and bus applications.

M12 CODINGS

Another difference between M12 and RJ45 connectors is that M12 connectors can have several different configurations, also known as codings. Codings are the standard arrangements of pins and sockets on the 'mating face' of a connector. Only male and female connectors that share the same coding can mate together to form a secure connection – so choice and consistency of coding is important and different applications types tend to use different codings.

Figure 5: Example of a terminated M12 X-coded connector

The most common codings for industrial applications are D, A and X-Coding. The table below shows typical applications for each of the codings

D4	100Mbit Industrial ethernet	
A4	Sensors, DC power and 1Gbit ethernet (8p)	
A5		
A8		
X-Code	10Gb	

PLASTIC OR METAL BODY?

M12 connectors are available as either plastic or metal body variants. Each version has advantages and disadvantages in terms of cost, ruggedness and protection against electromagnetic interference (EMI). While metal body connectors are more expensive, they also offer the highest levels of protection – therefore selection must be based on the needs of the application.

	Plastic body	Metal body
Cost	Low	Higher
Ruggedness	Strong	Strongest
EMI Shielding	None	Good

Further considerations when choosing between plastic or metal bodies are:

- Water Ingress requirements (IP Rating)
- Resistance against chemicals
- Industry requirements, for example the food and beverage industry requires stainless steel products, whereas the railway industry has specific fire and smoke requirements

Figure 6: D4 Male and female M12 connector with metal body for railway use

CONTACT TERMINATIONS

There are several different methods for terminating cables inside the connectors and as a rule of thumb, as the termination method becomes more sophisticated, the more resilient the termination.

Ruggedness	Termination	Advantages and disadvantages
	Soldering	Soldering cannot withstand shock and vibration. Not commonly used.
	Screws	No special tooling is required but screws can become loose when exposed to vibration.
	IDC (Insulation-displacement contact)	Typically no special tooling is required but IDC results in relatively large sized connectors. Offers medium resistance against shock and vibration
	Crimp	Gives the best resistance against shock and vibration but requires special crimp tool to make the connection

Insulation-Displacement Contact (IDC) technology

A small blade is integrated into the terminal fittings of the (IDC) system. During installation, the blade is forced through the insulation material to make a connection, bypassing the need to strip the conductors of insulation before making the connection. When properly made, the connector blade cold-welds to the conductor, making a theoretically reliable gas-tight connection that ensures the contacts do not corrode.

Crimp technology

Gas-tight and compact connectors are synonymous with crimp technology. The conductor is inserted into the crimp contact and compressed by controlled deformation. This technology is similar to a cold-welding process and provides maximum aging resistance and mechanical resistance to shock and vibration. Automated crimp machines facilitate the efficient, streamlined production of system cable assemblies. Crimp technology can also be deployed in the field by using hand crimp tools. The technical requirements for crimp technology are standardized in IEC 60 352-2.

Figure 7: M12 X-code crimp contact

Figure 8: Contact crimping tool and positioner

STRAIN RELIEF

The function of a strain relief is to absorb the stresses at the interface between a flexible cable and the rigid conductors inside the connector. It is an essential feature for the mechanical and electrical integrity and overall performance of all types of electrical cables and connectors. Strain reliefs can be made using the following technologies:

Strain relief type	Advantage	Disadvantage
Overmolded strain relief 	• Very reliable solution usually integrated with connector booth	• Needs expensive processing equipment to mold and form the strain relief • Not field-installable
PG clamp 	• Field installable • Requires no special tooling	• Cable can be rotated in strain relief • If the PG clamp is not securely tightened or becomes loose during its lifetime, the strain relieving function is lost
Crimped strain relief 	• Cable cannot be rotated in the strain relief • Tamper proof (once installed the strain relief cannot be disassembled) • Field installable	• Requires special tooling to crimp the strain relief onto the cable jacket • New crimping necessary when repair is needed

The PG clamp strain relief is based on an elastomeric ring which is positioned around the cable (yellow part above). When the ring is compressed in the axial direction, it will expand in the radial direction, causing the cable to be friction-locked inside the PG clamp.

As the cable is friction locked, there is a risk that the cable can be rotated or twisted in the PG clamp, especially in conditions where the cable is very oily or in polluted environments. This cable rotation can lead to breakage of the conductor strands inside the connector. The first sign of this damage is the appearance of intermittent connection problems. This eventually leads to complete loss of connectivity of the equipment. Tracking down the issue typically takes a lot of time and leads to further downtime of the equipment. Therefore, in heavy industrial applications a crimped strain relief is preferred.

Figure 9: Example of one side of a cable assembly

M12 cable assemblies

The cable assembly brings the connectors and the cables together. It offers a ready-made connectivity system that allows for the connection of several devices to one another. Based on the type of installation and the potential to terminate cables on the equipment, it is possible to choose either to use pre-terminated cables or perform a field installation. The advantage of a field installation is that the cable length can be customized to the installation and there is no risk of damaging the connectors during installation. However, in some cases, termination of the connectors can be challenging and enhanced testing of the cable cannot normally be performed in the field.

TE's offer

Being the largest connectivity supplier in the world, TE Connectivity has a large cable, connector and cable assembly portfolio enabling M12 connectivity. Products vary from plastic body M12 to the most ruggedized M12 cable assembly available on the market, featuring crimping contacts and a crimped cable jacket to give electrical system maximum protection against downtime.

WIRE & CABLES

TE Connectivity's portfolio contains a large breath of cable assemblies specifically aimed towards the application and industry requirements. As an example, the rail industry requires wear-resistant cables with fire and smoke performance according to EN45545-2.

Rail Industry cable part numbers and specifications are as follows:

TE Part Number	Description	Construction	No of conductors	Diameter (mm)	Color
2320808-1	Cat5e 22 AWG TECC0026C5	S/UTP	4x AWG22	6.7	Blue
2297799-1	Cat7 24 AWG TECC0011C7	S/STP	8 x AWG24	8.4	Blue

Further information can be found in the Rail Power and Signal applications section of TE's website, which can be found at **te.com/rail and then visiting the applications / power and signal page**.

CONNECTORS

The M12 connector family and its smaller cousin the M8 series are characterized by their applications

General Industrial M12 and M8 connectors:

The M12 and M8 connector systems are used widely in machine industrial automation and control applications. They enable reliable communication in industrial environments. TE's connector solutions include an extensive connector range of Printed Circuit Board (PCB) headers, cable assemblies and Input/Output (IO) boxes. They provide users with a future-proof interface that supports higher bandwidth needs of up to 10 Gb/s.

A full range of connectors is available either shielded against EMI with Ingress Protection (IP) against dust and water ingress at up to the IP65 and IP67 standards that ensure full protection against dust and either low-pressure water jets or short duration immersion in water.

Figure 10: M12 Rail X-code connector for industrial applications

TE's M8/M12 connectors and cable assemblies are easy to install, help decrease downtime and increase production efficiency. Detailed information is published on **te.com/m8m12.**

M12 connectors for Rail applications:

M12 Rail Connectors are characterized by reliable 360-degree shielding against EMI, crimp termination, jacket crimping and compact outer dimensions. Even in extremely tough industrial environments these high-quality products ensure safe signal transfer. The M12 Rail series is a combination of various different ranges to meet all solutions including A, D and X-coding as well as straight, right-angle, panel mount and PG clamp.

The cable jacket crimp versions can be found on TE's website at te.com/rail and then searching 'M12 Rail Series or via this hyperlink to the M12 Rail Series on TE's website.

Alternatively, the PG clamp version is listed on the website on this link to M12 Rail PG Clamp or by searching for 'M12 Rail PG Clamp' to find it on TE's website.

CABLE ASSEMBLIES

TE's M12 cable assemblies are available in several types and several lengths. TE provides standardized off-the-shelf cable assemblies as well as fully-integrated customized cables designed specifically for the customer's requirements.

TE uses state-of-the-art tools such as automatic cutting and stripping tools and dedicated crimp tooling and the M12 technology offers high-reliability solutions for a vast number of applications. Furthermore, TE also can help to further integrate its cable assembly into customer systems, for example by integrating cable marking systems and over-molded structures. These capabilities are supported with a global engineering team and extensive laboratory testing to make sure TE's customer's products can stand the test of time.

About the author - Egbert Stellinga: "I help engineers transform their ideas into creations"

Egbert Stellinga is a Product Manager for data connectivity products and cable assemblies for rail applications at TE Connectivity.

He is a senior product management professional with an engineering background and 15 years' worth of product management experience in several industries. He has been in the connector industry for more than 25 years enabling the connected world that will change how people live.

Usually the connector doesn't stand on its own. It interfaces with many components surrounding the connector. Not only electrically but also mechanical. During the integration of multiple components, problems can occur. Egbert's goal is to eliminate these issues upfront in close corporation with the customer.

ENABLING THE BEST-IN-CLASS CONNECTIVITY SOLUTION IS EGBERT'S PASSION!

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About TE Connectivity

TE Connectivity is a technology leader that designs and manufactures the electronic connectors, components and systems inside the products that are changing the world – making them smarter, safer, greener and more connected.

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1-1773947-7 03/18 Original

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