



PUB00148R1

EtherNet/IP Media
Planning and
Installation Manual

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About this manual

I Scope

This manual covers the planning and installation of EtherNet/IP industrial control networks supporting 10/100/1000 Mb/s.

Media types supported for EtherNet/IP control networks are:

- 1-Pair balanced twisted pair cabling
- 2-pair balanced twisted pair cabling
- 4-pair balanced twisted pair cabling
- Optical Fiber cabling

Other data rates, media types, and the planning and installation of generic cabling systems is beyond the scope of this document.

This manual provides:

- A QuickStart
- An overview of Ethernet media in a control application
- Guidelines for planning the EtherNet/IP media network
- Guidelines for verifying and certifying the EtherNet/IP media network
- Procedures for troubleshooting the EtherNet/IP media network

II Who Should Use This Manual

This manual is intended for use by control engineers, i.e., planners, installers, verifiers, acceptance test personnel, administration, and maintenance personnel, i.e., plant electricians. These persons are responsible for designing, implementing, installing, and maintaining industrial control systems using EtherNet/IP networks. It describes the required media components and how to plan, install, verify, troubleshoot, and certify the network.

III References

ANSI/TIA-1005-A – Telecommunications Infrastructure Standard for Industrial Premises

ANSI/TIA-5017 – Telecommunications Physical Network Security Standard

ANSI/TIA-568.0-E – Generic Telecommunications Cabling for Customer Premises

ANSI/TIA-568.2-D – Balanced Twisted-Pair Telecommunications Cabling and Components Standard

ANSI/TIA-568.3-D – Optical Fiber Cabling Components Standard

ANSI/TIA-607-D – Bonding and Grounding

BICSI TDMM – Telecommunication Distribution Methods Manual

IEEE 1100-2005 – IEEE Recommended Practice for Powering and Grounding Electronic Equipment

IEEE 518 Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources

IEEE Std 802.3™-2021 – IEEE Standard for Ethernet

IEC 60529 – Degrees of protection provided by enclosures (IP code)

IEC 60603-7-2 – Connectors for electronic equipment – Part 7-2: Detail specifications for 8-way, unshielded, free and fixed connectors, for data transmission with frequencies up to 100 MHz, 2010

IEC 60603-7-3 – Connectors for electronic equipment – Part 7-3: Detail specifications for 8-way, shielded, free and fixed connectors, for data transmission with frequencies up to 100 MHz, 2010

IEC 60603-7-4 – Connectors for electronic equipment – Part 7-4: Detail specifications for 8-way, unshielded, free and fixed connectors, for data transmission with frequencies up to 250 MHz, 2010

IEC 60603-7-5 - Connectors for electronic equipment – Part 7-5: Detail specifications for 8-way, shielded, free and fixed connectors, for data transmission with frequencies up to 250 MHz, 2010

IEC 60793-2-10 – Optical fibres – Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres

IEC 61076-2-101 – Connectors for electronic equipment – Product requirements – Part 2-101: Circular connectors – Detail specification for M12 connectors with screw-locking

IEC 61076-2-109 - Connectors for electronic equipment – Product requirements – Part 2-109: Circular connectors – Detail specification with M12 x 1 screw-locking, for data transmission frequencies up to 500 MHz, 2014

IEC 61076-3-106 - Connectors for electronic equipment – Product requirements – Part 3-106: Rectangular connectors – Detail specification for protective housing for use with 8-way shielded and unshielded connectors for industrial environments incorporating the IEC 60603-7 series interface, 2006

IEC 61754-20 – Fibre optic interconnecting devices and passive components – Fibre optic connector interfaces – Part 20: Type LC connector family

IEC 61754-24 – Fibre optic interconnecting devices and passive components – Fibre optic connector interfaces – Part 24: Type SCRJ connector family

ISO/IEC 11801-1 – Information technology – Generic cabling

ISO/IEC 11801-3 – Information technology – Industrial cabling

ISO/IEC 30129 - Information technology – Telecommunications bonding networks for buildings and other structures

ODVA PUB00002 – The CIP Networks Library, Volume 2: EtherNet/IP Adaptation of CIP

ODVA PUB00269 – Securing EtherNet/IP networks

NFPA 79 – Electrical Standard for Industrial Machinery

TIA-604-02 - Fiber Optic Connector Intermateability Standard, Type ST (FOCIS 02)

TIA-604-03 - Fiber Optic Connector Intermateability Standard, Type SC (FOCIS 03)

TIA-604-10 - Fiber Optic Connector Intermateability Standard, Type LC (FOCIS 10)

TIA / TSB 185 Environmental Classification (MICE) Tutorial

IEC 61918 Digital data communication for measurement and control. Profiles covering installation practice for Fieldbus communications media within and between the Automation Islands

Note: The reader is cautioned to ensure that the latest versions of the standards listed here are referenced.

IV Definitions

Active Connectivity Device – An active network element with two or more Active Interfaces, dedicated to packet movement functions such as switching, bridging, and routing.

Active Devices – An active network element with a single Active Interface. These devices are generally dedicated to an automation application function such as a PLC, IO module, or a Sensor. These devices require a connection to an Active Connectivity Device or may be end-connected to an Active Two Port Device.

Active Interfaces – The portion of an active network element used to transmit signals through attached cabling.

Active Network Element – Network element containing electrically and/or optically active components that allows extension of the network.

Active Two Port Devices – An active network element with two Active Interfaces. These devices are generally dedicated to an automation application function and used for connectivity in linear or ring topologies. These devices can form a network without Active Connectivity Devices.

Adaptor – A passive component that changes from one electrical or optical interface to another of a different type.

Automation Island (AI) – The premises where combination of all systems that control, monitor, and protect the process of a plant is installed.

Automation Outlet (AO) – Fixed connecting hardware where the AI network terminates, that provides the interface which an industrial communications device is connected to the installed cabling.

Note: For generic cabling in accordance with ISO/IEC 11801-3, the AO replaces the Telecommunications Outlet (TO) and is the demarcation point between the generic communication cabling and the automation specific cabling.

Backbone – The part of a cabling system where physical connections are aggregated.

Note: An example may be the connection from an internet router to a mainframe network switch.

Balanced Cabling – Cabling consisting of one or more metallic symmetrical cable elements (twisted pairs, quads).

Note: Where used, this installation manual assumes twisted pair except for flat cable used for 10BASE-T1S protocol

Bonding – Act of connecting together exposed conductive parts and extraneous conductive parts of apparatus, systems, or installation that are essentially the same potential.

Bridge – A device, operating at the link layer of the OSI model, used to connect two networks.

Bulkhead – A wall or a barrier that maintains the ingress and climatic environmental classification applicable on either side.

Bulkhead Cable Gland – Hardware at an enclosure bulkhead that provides cable passage for power or signal while maintaining environmental integrity.

Bulkhead Connection – A connection through a bulkhead connector.

Bulkhead Connector – A connector assembly mounted to a bulkhead which provides electrical or optical signal pass-through while maintaining environmental integrity.

Bus Bar – A low impedance conductor to which several electronic circuits can be connected at several points.

Cable – An assembly of one or more conductors and/or optical fibers with a protective covering and possibly filling, insulation and protective material.

Cabling – A System of communication cables, cords, and connecting hardware that can support the connection of automation equipment.

Channel – A transmission path connecting any two pieces of application specific equipment.

Note 1: Equipment cords are included in the channel, but not the connecting hardware into the application specific equipment.

Note 2: Channel specified in this standard may only be comprised of passive components.

Connection (of conductors) – An intentional electrical contact between conductors.

Connection (of optical fibers) – An intentional alignment between optical fibers to allow light (visible or non-visible) to pass through.

Connector (for conductors) – A device providing connection and disconnection to a suitable mating component.

Connector (optical fiber) – A component normally attached to an optical fiber or piece of apparatus, for the purpose of providing optical interconnection/disconnection of optical fibers or cables.

Cord – A cable unit, or cable element with a minimum of one termination.

Cord Sets – Cable constructions terminated with connectors at both ends.

Coupler – A component that changes from one electrical or optical interface to another of the same type.

Crossconnect – A connection scheme between cabling runs, subsystems, and equipment using patch cords or jumpers that attach to connecting hardware on each end

Device – See Active Device.

Distributor – A collection of components (such as patch panels, patch cords) used to connect cables.

Earth (noun) – Conductive mass of earth, whose electric potential at any point is conventionally taken as zero.

Note: This installation manual uses “Earth” with recognition of “Ground” as an equivalent term.

Earth (verb) – Make an electric connection between a given point in a system or an installation or in equipment and a local earth.

Enclosure – Housing affording the type and degree of protection suitable for the intended application.

End-to-End Link – Transmission path between equipment including the end connections attached to the equipment.

Equipment Cord – Cord connecting one end of the cabling subsystem to transmission equipment.

Equipotential – State when conductive parts are at a substantially equal electric potential.

Equipotential Bonding – Provision of electric connections between conductive parts, intended to achieve equipotentiality.

Equipotential Bonding System – Interconnection of conductive parts providing equal potential bonding between those parts.

Functional Earthing – Earthing a point or points in a system or in an installation or equipment for purposes other than electrical safety.

Note: Functional earthing is preferred in this document for communications systems or networks.

High Flex Cable – A cable that can withstand a high number of repeated flexes (usually millions of cycles) while maintaining the specified performance.

Horizontal Cables – The cables between the communication outlet and the communication closet.

Note: These cables will typically be solid core construction and permanently installed

Industrial – Is used to describe the set of attributes that make up the hardened elements of the physical layer and media components including active interfaces. These areas are typically MICE 2 and MICE 3 environmental areas.

Jack – Part of the connector which mates with a plug.

Linear Topology (Active) – Topology where the nodes are connected in series, with two nodes connected to only one other node and all others each connected to two other nodes (that is, connected in the shape of a line).

Link - A transmission path between two points, not including terminal equipment, work area cables, and equipment cables.

Note: For example, a segment of cabling between two jacks is a link.

Maintenance – Combination of all technical and corresponding administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function.

Note 1: See "preventive maintenance", and "corrective maintenance", for a more detailed definition of maintenance.

Note 2: The required function may be defined as a stated condition.

Maintenance Intervention – Taking measures for retaining the specified condition.

Network – All the media, connectors, repeaters, routers, gateways, and associated node communication elements by which a given set of communicating devices are interconnected.

Patch Cord – A cord used for a cross-over connection.

Pathway – Cable route used to accommodate cables between termination points.

Note: The cable route (e.g., conduit, ductwork, tray, or tube) is defined by a physical structure.

Permanent Link – Transmission path between distributors or between the telecommunications/automation outlet and the intermediate distributor.

Note 1: It excludes apparatus attachment cords, equipment cords, patch cords and jumpers but includes the connection at each end.

Note 2: This is a modification to the definition of ISO/IEC 11801 in order to allow it to be used for the CPs in accordance with IEC 61784-5 series.

Plug – connector attached to a cable

Potential Equalization Conductor – A conductor connected in parallel with the screens/shields of signal and/or data cables to limit the current flowing through the screens.

Preventive Maintenance – Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item.

Protective Earthing Conductor – Conductor provided for protective earthing.

RC Earthed - Earthed via a parallel RC circuit.

Recovery (of a high resilience item) – Event when an item regains its specified degree of communication performance and fault resilience after correction of a fault - one fault and possibly after multiple faults.

Repair – Take measures for the re-establishment of the specified condition.

Repeater – Two-port active physical layer device that receives and retransmits all signals to increase the distance and number of devices for which signals can be correctly transferred for a given medium.

Resistance to Earth – Real part of an impedance to earth.

Ring – Active network where each node is connected in series to two other nodes.

Scheduled Maintenance – Preventive activity (time or number-of-actions directed) performed either on predefined schedule or on units of use (e.g., number of start-ups).

Segment – Collection of cable sections of a network that is terminated at both ends by its characteristic impedance.

Note: Segments are linked by repeaters within a logical link and by bridges to form a network.

Shield (of a cable) – Surrounding metallic layer to confine the electromagnetic field within the cable and to protect the cable from external electrical influence.

Note 1: Metallic sheaths, armour, and earthed concentric conductors may also serve as a shield.

Note 2: For generic cabling in industrial premises ISO/IEC 11801-3 uses the term screen instead of shield.

Splice – A permanent, or semi-permanent, joint whose purpose is to couple optical power between two optical fibers or to join two electrical conductors.

Note: Joining without connectors.

Star – Network of three or more devices where all devices are connected to a central point (which may be active or passive).

Telecommunication Outlet (TO) – Fixed connecting device which provides an interface to the terminal equipment.

Topology of a Network – Pattern of the relative positions and interconnections of the individual elements of the network.

Note: The term topology is sometimes overloaded to include considerations of the delay, attenuation and physical media classes of the paths interconnecting network nodes.

Troubleshooting – Locating the fault(s).

Validation – Part of the acceptance test that is solved with measurements.

Verification – Action to assess that an installation is in accordance with its specification.

Note 1: The installer usually performs this action.

Note 2: This action usually covers verification of component correct selection, physical layout, communication earthing, isolation, and continuity of network components.

Wire Map – Mapping of connector pin-to-pin terminations of a cable.

Work Area Cables – The cables between the work area station and the communication outlet.

Note: These cables will often be stranded constructions

Zoning – Risk mitigation tactic of an open network by segmenting infrastructure services into logical groupings that have the same or similar communication requirement (e.g., bandwidth or security policies/restrictions). The zones are separated by perimeters implemented through security and network devices.

V Abbreviated Terms

For the purposes of this document, the following abbreviated terms apply.

AC – Alternating current

A.I. – Action item

AI – Automation Island

AO – Automation outlet
BD – Building distributor (ISO/IEC 1 1801-1)
BER – Bit error rate
BFOC – Bayonet fiber optic connector
BICSI – Building Industry Consulting Service International
BNC – Bayonet Neill Concelman (connector for coaxial cable having a bayonet-type shell)
CBN – Common bonding network
CIP – Common Industrial Protocol
CP – Communication profile (IEC 61784-1)
CPF – Communication profile family (IEC 61784-1)
DC – Direct current
DCR – Direct current resistance
E2E – End-to-end
EFT – Electrical fast transient
EFT/B – Electrical fast transient / burst (IEC 61000-4-4)
ELFEXT – Equal level far-end crosstalk
ELTCTL – Equal level transverse conversion transfer loss
EMC – Electromagnetic compatibility (IEC 60050-161, 161-01-07)
EMI – Electromagnetic interference (IEC 60050-161, 161-01-06)
ESD – Electrical static discharge
FD – Floor distributor (ISO/IEC 11801-1)
ffs – For further study
FI – Fieldbus interface
FOC – Fiber optical connector
F-SMA – Fiber sub miniature version A (IEC 61754-22)
GiPCF – Graded Index Polymer Clad Fiber
HP – Horsepower
ID – Intermediate distributor
IDC – Insulation displacement contact
IID – Industrial intermediate distributor
IP – International protection (IEC 60529)

LC – Optical fiber connector in accordance with IEC 61754-20

LLCR – Low level contact resistance

LSOH – Low smoke zero halogen

LV – Low voltage

Max. – Maximum

MD – Machine distributor (ISO/IEC 11801-1)

MDI – Medium dependent interface (IEEE 803.2)

MDIX – Medium dependent crossover interface (IEEE 803.2)

MHV – Medium high voltage

MICE – Mechanical, Ingress, Climatic/Chemical, Electromagnetic (See ANSI/TIA-1005-A, TIA TSB-185, ISO/IEC TR 29106, and/or ISO/IEC 11801-1)

Min. – Minimum

MMF – Multimode Fiber

MTBF – Mean time between failures

MTTR – Mean time to repair (use deprecated in IEC 60050-191:1990, 191-13-08)
replaced with mean time to recovery

PCF – Polymer Clad Fiber

PE – Protective Earth

PEC – Potential Equalization Conductor

PEN – Protective Earth Neutral

PoE, PoE+, PoE++ - Power over Ethernet, Power over Ethernet Plus, Power over Ethernet Plus Plus

POF – Polymer Optical Fiber

PwE – Power with Ethernet

SELV – Safety Extra Low Voltage

SFP – Small form-factor pluggable

SMF – Single Mode Fiber

ScTP – Screened Twisted Pair (Copper Cable)

STP – Shielded Twisted Pair (Copper Cable)

TCL – Transverse conversion loss

TCTL – Transverse conversion transfer loss

UTP – Unshielded Twisted Pair (Copper Cable)

VI Units of Measure

This installation manual uses standard SI units in addition to those listed below.

American Wire Gauge (AWG)

Celsius (°C)

decibel (dB)

Foot (ft)

Inch (in)

Kilobit (kb)

Kilobit per second (kb/s)

Megabit (Mb)

Megabits per second (Mb/s)

Pound force (lbf)

1 EtherNet/IP Media System QuickStart

1.1 Introduction

1.1.1 What this Chapter Contains

This chapter provides an overview of things to consider when planning an EtherNet/IP network and selecting the appropriate media components. It provides guidance for designing and installing Control and Information Networks as defined by the Common Industrial Protocol (CIP) - both inside and outside the automation island. If the network is to be installed as a Generic Telecommunications Infrastructure the planner should consult BICSI (Building Industry Consulting Services International). In addition, IEC 61918 should be used with this document.

1.1.2 Understanding the Environment

Environmental classifications are addressed in chapter 9 (MICE Tutorial) and are intended as a mechanism to simplify application analysis and suitability. The environment can be categorized by three distinct environmental classifications for four types of conditions: Mechanical, Ingress, Climatic/Chemical, and Electromagnetic (abbreviated as MICE). The MICE table (Table 9-1-Table 9-4) can be used to determine the environment class. The design, component selection, and installation for the network should take the environmental class (as defined by the MICE table) into consideration.

The installation environment for each category should be identified and referenced against the equivalent MICE levels. There are three ways and combinations to build the system to meet the requirements of the environment:

- 1) Select components for direct application in the environment (no extra protection against the environment needed.)
- 2) Select components that do not fully meet the requirements of the environment (additional protection, isolation and/or separation will be required).
- 3) Select components that are based on any combination of the above two (in which only minor protection, isolation and/or separation is required).

For example: the environment may have interference levels equivalent to those described in MICE E3. If components that only meet MICE E1 have been selected, additional isolation and/or separation in the form of attenuation from the interference sources should be provided. In this case, conduit is one means of providing the isolation and attenuation from the interference sources.

Note: Prior document revisions commonly used the term electromagnetic noise. In this revision all references to electromagnetic noise has been replaced with electromagnetic interference (EMI).

For a detail description of mitigating variables including mechanical, ingress, climatic, chemical, and electromagnetic environments refer to chapter 9 (MICE Tutorial).

1.2 Roles and Responsibilities

Planner – responsibility is to create the system design and the following tasks listed below. The tasks are listed in sequential order of execution based on the overall control system functional specification.

- Determine network topology (s) required to accomplish the required functioning of the control system.
- Select data rates within the topology (s).
- Evaluate environmental considerations within the topology (s).
- Evaluate or specify the facility and installation earthing and bonding strategy in line with ANSI/TIA-607 and ISO/IEC 30129.
- Select components to satisfy the above steps.
- Select mitigation approaches for the above steps.
- Provide detailed cabling design based on system specification.
- Create a wiring diagram and installation documents.
- Create a Bill of Materials.
- Update the wiring diagram and installation documents with the installer's feedback.
- Define the acceptance criteria to be given to the person carrying out the network acceptance test. The acceptance criteria shall include testing coverage, for example percentage of channels/links tested.
- Provide guidelines for maintenance of the network.

Installer – responsibility is to carry out installation of the cabling defined above, meeting the requirements of the planner.

- Perform the installation according to the planner documentation.
- The installer shall report any inconsistencies back to the planner.
- The installer shall follow the component manufacturer's installation recommendations.
- The installer shall label the cabling according to the information provided by the planner. If there is no guidance, the installer shall provide adequate labeling.
- Provide the labeling details back to the planner.
- If there is no verification entity, the installer shall perform verification of the network and provide a report back to the planner.

Network Verifier – responsibility is to verify that the network has been installed correctly.

- Comply with the planner documentation.
- Verify connector termination has been carried out correctly.
- Verify earthing and bonding in accordance with local codes and ANSI/TIA-607 or ISO/IEC 30129.
- Provide any inconsistencies to the installer for correction.
- Provide a report containing verification findings back to the planner.

Acceptance Testing –responsibility is to determine that the cabling can provide the quality of service to meet the application needs. Acceptance testing is defined by the planner and is a planner's measure of successful installation. Network certification testing is defined by an appropriate standard as a measure of successful installation. Acceptance testing and certification testing can be but are not required to be the same.

- Test per the planner documentation.
- Provide inconsistencies back to the installer for correction.
- Generate a final report for the planner.

Maintenance –responsibility is to carry out maintenance through its lifecycle:

- Monitor network performance.
- Executes moves, adds, and changes to the network.
- Document changes in network wiring diagram and administration files
- Maintenance:
 - Schedule maintenance
 - Perform condition-based maintenance
 - Perform corrective Maintenance
- Generate maintenance reports throughout the network lifecycle.

1.3 Planning the Network

The process for planning and laying out the EtherNet/IP network should consist of the following steps:

- Determine the type of application.
- Determine placement of major components such as switches and devices.
- Determine the length of channel cabling needed to reach each device. The placement of switches may need to be adjusted to meet Ethernet's 100 m (328 ft.) channel limit.
- Consider application specific requirements.
- Identify any applicable local codes to apply.
- Evaluate the grounding system.
- Determine environmental requirements based on MICE tables (Table 9-1, Table 9-2, Table 9-3, and Table 9-4), shock and vibration, ingress protection rating, temperature, the presence of chemicals and electrical interference.
- Select materials based on above requirements.
- Plan the installation to provide adequate protection from damage by machinery.
- Plan the installation to provide maximum isolation/separation from interference generating devices.
- Specify the network installation.
- Plan the verification of the network.
- Specify how to certify the network.
- Specify administration and documentation of the network.

These steps along with the implications and expectations are further outlined in chapters 3 (Planning the EtherNet/IP Copper Cabling) and 4 (Planning the EtherNet/IP Fiber Optic Cabling).

1.4 Guidance for Network Planning and Design

This section provides guidance for the planner to design the EtherNet/IP network in accordance with the applications and the control system functional requirements. Further, this section provides an overview of the primary considerations when designing the EtherNet/IP network.

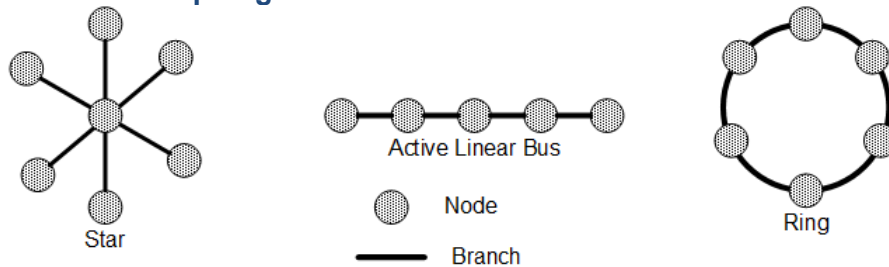
This section concludes with a logical step by step process for determining the cable type that needs to be used in the control system network.

1.4.1 Topology

Since topologies have different requirements and there may be more than one topology type in the network, the planner shall consider the application needs with respect to data rate, environmental factors, product requirements and connectivity.

There are three basic topologies for Ethernet based networks. EtherNet/IP supports all three of the standard active physical topologies as detailed in Figure 1-1. For active linear bus and ring topologies the switching device may be embedded in a node making it an Active Connectivity device. An active linear bus and ring device requires two or more physical connections to the cabling infrastructure.

Figure 1-1 – EtherNet/IP Topologies



EtherNet/IP does support a passive linear bus topology for a specific subnetwork media; however specific considerations of this network topology are out of scope.

1.4.2 Which Data Rate Should be Used

In ring or active linear topologies and backbone applications, the capability of the network is limited by the device with the lowest maximum data rate, so for these types of applications 1000 Mb/s data rates are recommended.

Where expected interference is transient, a higher data rate will make it less likely for a packet transmission to intersect with transient interference for the same amount of data flow. In other words, given the same amount of traffic, it is preferable to operate at a link's maximum available data rate to improve tolerance to random and transient interference. Only when application data rate isn't critical and where interference is continuous, the lowest data rate at which the application will operate should be used.

Optical fiber generally provides higher interference immunity than other cabling options regardless of data rate.

1.4.3 Channel Requirements

Component selection should be based on current and future bandwidth and application needs.

- 2-pair or 4-pair cabling (note 2-pair cabling supports up to 100 Mb/s)
- CAT 5e, 6, or 6A

4-pair cabling is recommended for all new installations with Category 5e as an absolute minimum performance requirement. Category 6 is preferred for new installations, however Category 6A may need to be considered for future proofed installations. It is recommended that shielded twisted pair copper cabling or optical fiber cabling is considered for installations on the plant floor where high EMI environments can exist.

The minimum cabling performance that will support EtherNet/IP is Category 5e. For high interference environments there are other attributes applied to cabling that the planner should consider during the design phase. Refer to Chapter 3 for copper cabling and chapter 4 for optical fiber cabling. There are reasons to select one category cabling over another. In general, the higher the category the better the cabling performance as the cabling will be designed to a higher internal signal to noise ratio and will be capable of a higher data rate to a longer length. A caveat to this is the performance in the presence of external interference, especially for unshielded cable constructions. A higher category cable should still be selected to satisfy the EMI requirements defined in Section 8.4.1.4.

1.4.4 Network Security

Network security is beyond the scope of this manual. The planner should provide appropriate security using gateways, firewalls, routers and/or appropriate security software. The planner should consider physical security to protect the network from both physical damage and unauthorized access. Options exist such as physical layer security devices (e.g., port blocking components), door access and badge access control.

EtherNet/IP networks have provisions for supporting secure system designs aligned with IEC 62443. IEC 62443 breaks down the design of security within a system to security levels based on risk level. For each level there are different measures such as identification and authentication, data access control, tamper detection, data access restriction, data confidentiality, response time, and resource availability. Use of the CIP Security acts as a measure to encrypt data and prevent unauthorized access or breach of confidentiality. Even with the use of CIP Security other aspects of the system may need mitigations depending on the level of security risk identified. For securing the infrastructure in EtherNet/IP systems, refer to ODVA PUB00269 Securing EtherNet/IP™ Networks for more information. For securing the physical infrastructure for zones where it is deemed necessary or appropriate, see ANSI/TIA-5017 for more information for deterrence or restricted access measures that may be taken.

1.4.5 Network Access

Careful consideration should be given to the placement of access to ports to prevent unauthorized connection of devices into control networks. Cabinets and housings of control networks should not be accessible to unauthorized personnel. Cabling components should be protected from damage by machinery or tampering (see Section 3.1.4).

1.4.6 Number of Ports Needed

While planning the network, the number of switches and the number of ports for each switch chassis will need to be determined. Each network device will require a corresponding switch port for connection to the network. The number of ports per switch chassis will also depend on the physical network layout. The system design should provide for growth of at least 20%, and in some cases up to 50% in case of system expansion (see Section 3.1.3).

1.4.7 Network Switches

In this document where the term switch is used it is always referring to a network switch. Network switches provide connections that eliminate collisions. In control applications where real time data access is critical, Industrial Ethernet/IP enabled switches should be considered. The use of managed switches is recommended for the following reasons:

1. Remote management
2. Bandwidth control
3. Port Priority
4. Full duplex
5. Enhanced security
6. Internet Group Management Protocol snooping (IGMP)
7. Port mirroring
8. VLAN capability to break up broadcast domains

1.4.8 Placement of Network Components (Environment Commensurate with Manufacturer's Limits)

Zone architecture is an industry term that describes a network topology in which devices pass data to each other through interconnecting switches. Industrial plant automation systems are evolving from a hierarchical layering point-to-point, dedicated connections to a more switch-centric design where traffic now can be seamlessly passed with much greater flexibility and enhanced throughput. Instead of inflexible direct connections between devices, switches and a converged plant architecture allow data to be switched and routed with security across the plant automation system as well as upstream for higher value creation.

Placement of network components should be carefully planned to minimize cable lengths, the effects of the environment and the need for mitigation. Network components should be installed in accordance with the manufacturer's specifications and considering the environment as defined in MICE criteria. A Zone architecture is recommended that is based on high data rate media, (e.g. optical fiber, routed to a network switch that is environmentally hardened or within a zone enclosure, and shorter copper cabling for the downlinks leading to each control panel associated with the machine). This approach is particularly applicable to cases where groups of similar types of machines are located together within a plant floor environment.

1.4.9 Bulkhead Feedthroughs

Bulkhead feedthroughs should be used whenever cable entry through an enclosure wall is required. The most common types of bulkhead feedthroughs are either connector assemblies or cable glands. The connector or cable gland are located within the bulkhead

enclosure wall to protect the environmental performance of the enclosure. For performance reasons, consult the manufacturer on the number of bulkhead connector feedthroughs allowed within a channel or link. Bulkhead connectors are preferred for system interconnection flexibility but may have negative impacts to reliability or environmental compatibility.

Plan the mounting location so that the connector is not exposed to damage from plant activity. More details can be found in Section 2.5.

1.4.10 Patch Panels

Patch panels should be used to maintain system flexibility in a control network. Patch panels can be used to decouple the deployment of the control system from the deployment of the I/O system. In addition, use of patch panels facilitates link testing, troubleshooting and shortens recovery time when an outage is experienced. Patch panels do require additional space that may not be available on machines and/or in machine areas. Other options, such as DIN rail mounted components, exist to facilitate patching in these situations. The number of connections within a channel will affect the network meantime between failure (MTBF). This assertion is based on the number of potential failure points increasing by the number of additional connections. In addition, be aware that additional connectors come with an associated loss budget in terms of transmission performance. Therefore, it is essential to consider both maintainability and network robustness goals when designing these links. If a combination of bulkhead connections and patch panels is being used, then the planner must be aware of the total number of connections allowed in a channel (4 or in special cases 6 - see Section 3.1.8).

1.4.11 Selecting Cable to Suit the Environment

The planner should consider the environmental conditions of the installation area. The MICE criteria can assist the planner in the categorization of the environment. Proper cable designs can be selected based on the environment and installed in accordance with this planning and installation guide. The planner shall consider local and national regulations and manufacturer's specifications in material selection and installation locations. When applying the MICE concept, the planner should also consider the electromagnetic environment of the entire channel. Unlike the mechanical, ingress, and climate/chemical environmental impact, the electromagnetic environment will impact the entire channel as electromagnetic interference will conduct along copper cable.

When selecting cables, the jacket construction must be compatible with the temperature and contaminants in the environment. Cable jackets and conductor insulation may be easily damaged at extreme temperature ranges. Chemicals can be absorbed into the cable jacket and wire insulation, causing plastic deterioration and performance degradation. Isolation and/or separation may be used to convert a harsh environment to a compatible environment per the MICE concept. The operating environment and voltages of power sources used in the vicinity of the cabling must be considered following local and national codes. The typical Ethernet cable voltage rating is 300 V. Inside a control panel, where other 600 V circuits exist, a 600 V rated cabling may be necessary. This cable type uses a thicker jacket and is tested to meet Appliance Wiring Material (AWM) requirements by UL.

The ambient temperature of the installed cable must be considered as the attenuation of the cable will increase as temperature rises. In addition, high temperatures may degrade the cable materials. For more information regarding the MICE criteria, see Chapter 9.

Chapter 3 (Planning the EtherNet/IP Copper Cabling) and Chapter 4 (Planning the EtherNet/IP Fiber Optic Cabling) provide specifications for copper and fiber cabling.

Different cable constructions provide different levels of mechanical suitability. Dynamic bend radius, pulling strength, and installation method may impact expected cable life in the intended application.

1.4.12 Know The Segment Lengths and Limits

EtherNet/IP accepts the use of channel, permanent link, and end-to-end link system constructions composed of multiple cable segments and connections providing for the interconnection of each cable segment.

The allowable length of a segment is dependent on the cable and its respective attenuation derating requirements, see Chapter 3 (Planning the EtherNet/IP Copper Cabling) for maximum channel/link lengths when using stranded type cables in the channel.

1.4.13 Planning The Cable Routing

Route the cable as described in Chapter 3 of this manual.

- If the application is in a high electrical interference environment (e.g. E3), plan to use STP/ScTP cabling or alternate media such as optical fiber. See MICE tutorial in chapter 9.
- Cable segments should be as short as possible. If there is unavoidable excess cable, it should be configured in a 'figure 8 pattern', adhering to the manufacturer's bend radius requirements. Using a 'figure 8 pattern' will help to minimize the added inductance and minimize performance degradation from any excess length.

Types of Pathways:

- Conduit
- Duct and Raceway
- Grid Type
- Ladder Racks
- J hooks

Further details and tradeoffs of pathway types are described in Section 3.2.4

1.4.14 Installation of the Cable

Appropriate planning should be applied for the installation of the cable per EtherNet/IP specifications and the manufacturer's requirements. Consideration for bend radius and pull strength should be applied (see Sections 5.2.1.1 and 5.2.1.2 for copper cabling and Sections 5.3.1.1 and 5.3.1.2 for fiber cabling). Consult the cable manufacturer when installing UTP cables in a metallic cable pathway (e.g., conduit or cable tray), as the electrical performance can be affected by the metal. Avoid routing near equipment that generates strong electric or magnetic fields (see Chapter 3 (Planning the EtherNet/IP Copper Cabling) and Chapter 9 (MICE Tutorial) for more information). Cables must be properly supported to prevent damage (e.g., using hangers and raceways). Cable support loading requirements must be observed to prevent cable crushing.

1.4.15 Terminating Cable Ends

The performance of the system depends on the cable termination. Careful cable end preparation will help with installing the connector onto the cable (see Section 5.2.5). Performance should be verified by testing. In a structured cabling implementation, it is usual that the permanent link will be tested after installation. The use of ODVA compliant components and adherence to proper installation practices in this document will help to ensure that the channel's performance will be met.

1.4.16 Connecting Network Devices

Connect the devices to the network in accordance with the manufacturer's instructions. Be aware of Electrostatic Discharge (ESD) built up on cables. Cables should be discharged to earth prior to connecting into active ports. Cables may be earthed via a low impedance path to earth such as a bonded rack, grounding bus bar, or building metal. A grounding patch cord consists of a patch cord with a plug (or jack if needed) on one end of cable and all conductors terminated together with a clip or lug to terminate to ground.

1.4.17 Verifying and Troubleshooting the Network

The planner is strongly encouraged to require that each cable segment is verified for proper connection and level of performance. Off-the-shelf cable testers are available (see Chapter 6 (Verification of the EtherNet/IP Network)). Correct all errors/faults before placing cabling system into service. See Chapter 7 (Troubleshooting the EtherNet/IP Network) for more information on troubleshooting. For the purposes of EtherNet/IP networks, verification is performed at the component level to ensure the right components are used and that there are no component level defects.

1.4.18 Acceptance Testing of the Network

Differentiated from network verification, acceptance testing, or network certification is executed at the system level to confirm that components are assembled in the proper manner according to the system specification. Acceptance testing is defined by the planner and is a planner's measure of successful installation. Network certification testing is defined by an appropriate standard as a measure of successful installation. Acceptance testing and certification testing can be but are not required to be the same. The planner is strongly encouraged to require acceptance testing or certification testing of the network and verification of the installation including earthing and bonding. Certification or acceptance testing can be performed on permanent links, channels, and/or end-to-end links. Off-the-shelf cable testers are available (see Chapter 8 (Certifying the EtherNet/IP Network)). Correct all errors/faults before placing cabling system into service. See Chapter 7 for more information on troubleshooting.

2 Overview of the EtherNet/IP Media System

2.1 Industrial Control System Applications

Ethernet is widely used in the business world for information applications. Technology has widespread availability, familiarity, and cost benefits, making it attractive for use in industrial control systems as well.

Different systems can allow different approaches to complexity of the planning and installation processes. The fundamental target of scaling the planning complexity to the application needs is a risk management procedure centering around the availability of data on demand. One aspect of this is the needed application response time against the corresponding cycle time. As the application becomes more critical or as the needed response time approaches the cycle time, the impact of a data failure can be more severe. As such, more proactive protections and mitigations need consideration to combat the risk of failure by reducing the probability of failure.

One simple method to determine these risk mitigation procedures is to segregate applications used only for information applications (Information Technology/IT systems) as opposed to those used for control applications (Operations Technology/OT systems). Additional considerations for OT systems and control applications are highlighted in more detail in this document.

2.1.1 Information Applications

Typically, industrial information applications are used to download programmable logic controller (PLC) programs, monitor processes, gather statistics, process data, and report diagnostics. Other information applications include Ethernet enabled diagnostic tools and office applications. Performance of these types of applications is not as critical as in a control application where speed, throughput, response time, and downtime are critical to a manufacturing process. Because an IT network system will typically not have a critical time dependency, intermittent packet loss is of less risk, and therefore is covered by standard IT cable specifications and planning procedures as defined in ISO/IEC 11801-1 and ISO/IEC 14763-2.

2.1.2 Control Applications

Industrial control applications require fast response times and maximum network availability. These two attributes are of the highest importance. Intrusion into the network must be limited, for example by use of firewalls, wireless bridges, etc. The installation of the network must be robust enough to prevent mechanical damage and electrical interference ingress that could result in degradation of network performance and/or network outages ultimately leading to manufacturing process downtime.

Control applications may have additional specific requirements placed on the network to maintain the safety, security, and availability of the application.

EtherNet/IP delineates components into “Commercial” components, which are those that meet the minimum requirements of generic category cabling and/or IEEE 802.3, and “Industrial” components, which have been enhanced to meet specific aspects of industrial applications and environments. Some Commercial Ethernet components are not compatible with industrial environments found in industrial manufacturing plants. The planner is encouraged to select components meeting the specifications of ODVA Industrial

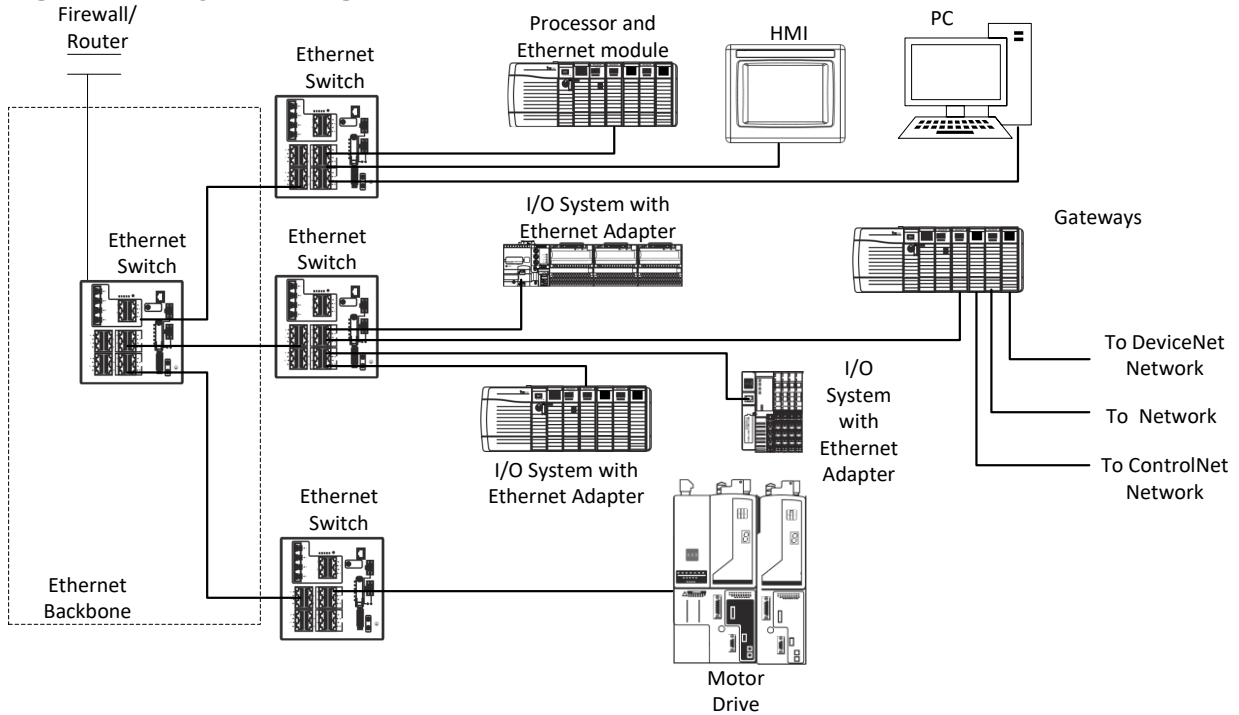
components. The planner should be aware of the following list when selecting Commercial components for the control system:

- Poor EMI performance including active interfaces
- Performance degradation of the cabling caused by temperature and/or humidity
- Impedance tolerance in excess of +/-5%, resulting in high system reflections
- Chemical incompatibility without further mitigation
- Susceptibility to electrical interference without further mitigation
- Vibration related failures without further mitigation
- Damage due to bending and flexing without further mitigation

These types of hostile environments require components designed for industrial use. Careful planning, as described in the MICE classification and compatibility process detailed in chapter 9, may be needed. As an example, cabling not rated for IP65/IP67 may need to be placed in enclosures. Cables not designed for high interference environments may need to be isolated by installing them in conduit or otherwise separating them from high interference generating and conducting devices.

An example of an EtherNet/IP control system is shown in Figure 2-1.

Figure 2-1 – System Diagram



The following sections describe the basic media components of an EtherNet/IP industrial control system.

2.2 Basic Media Components of an EtherNet/IP Industrial Control System

EtherNet/IP is implemented on the OSI network model to maximize scalability and flexibility through keeping complexity at the edge of the network. All EtherNet/IP links operate at the physical and data link layers. Ethernet switches operate at the data link layer (also referred to as layer 2) and Ethernet routers operate up to the network layer (also referred to as layer 3). The transport layer and above are implemented in end devices through various CIP protocols. This relationship is shown in Figure 2-2.

Figure 2-2 – EtherNet/IP OSI Network Model Relationship

4-7	Application Layer through Transport Layer	CIP (End-to-end Device level)
3	Network Layer	Internet Protocol (IP) Routing Layer
2	Data Link Layer	MAC Switching Layer
1	Physical Layer	Link Layer

2.2.1 Ethernet Backbone

The Ethernet backbone is the part of the network that handles the bulk of network traffic. It employs the highest speed transmission paths in the network and may also run the longest distance. A backbone can span a large geographic area or be small enough to be contained in a single cabinet. Smaller networks (or subnets) are attached to the overall network’s Ethernet backbone.

Regardless of the traffic type, control or information, ODVA-conformant media is recommended (such as 2-pair and 4-pair copper cabling or optical fiber). If the network is being used for information only, the backbone cabling described in TIA 568 series and TIA-1005-A is recommended. For information regarding the installation practices used for generic information systems used on the plant floor consult BICSI Telecommunications Distribution Methods Manual (TDDM) and/or ISO/IEC 14763 series.

Note: Even though Commercial Category 5e cabling can support the bandwidth required for 1000 Mb/s EtherNet/IP, the planner is strongly encouraged to use the Industrial 1000 Mb/s cabling performance requirements defined in Chapter 3 (Planning the EtherNet/IP Copper Cabling).

2.2.2 Routers

Routers are used to segment LANs (Local Area Network) to balance traffic within workgroups and as “firewalls” to filter traffic for security purposes and policy management. Routers are also used at the edge of the network to connect remote locations.

A typical architecture connects several routers together via a high-speed LAN topology such as Fast Ethernet or Gigabit Ethernet. Routers are connected to the backbone, allowing all networks in an enterprise to work together.

Routers operate at the network layer of the OSI Model and up. They can only route a message that is transmitted by a routable protocol such as Internet Protocol (IP). Because routers inspect the network address in the protocol, they do more processing and may add more latency than a bridge or switch (see the following sections), which both work at the Data Link Layer (layer 2). Generally, because of the processing overhead, it is not recommended to pass I/O data through a router in real time.

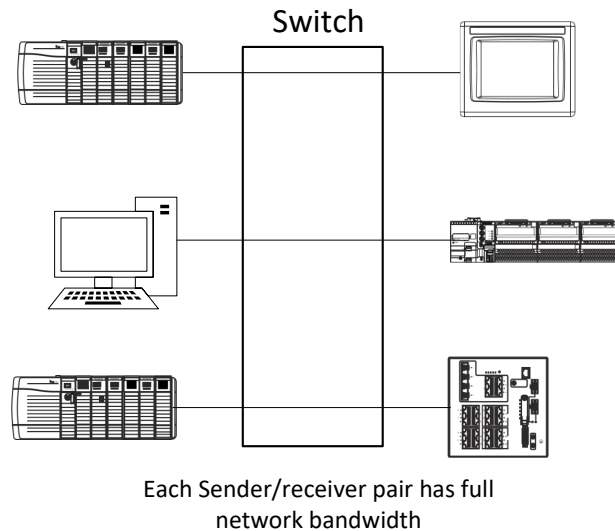
2.2.3 Bridge

A bridge is a device that connects two network segments together. The segments may be of similar or dissimilar types. A bridge is inserted into a network to “segment it” so that traffic can be contained within each segment to improve performance.

2.2.4 Ethernet Switches

Switches are multiport bridges that can simultaneously move data between pairs of ports at full wire speed. The planner should select managed switches for the reasons described in Section 1.4.7.

Figure 2-3 – Network Switch System



Switches are available for standard 10/100/1000 Mbps Ethernet. Hubs are not supported in this document.

2.2.5 Gateways

The term “gateway” when used here refers to a device that performs protocol conversion between different types of networks or applications. Such gateways function at the Transport Layer of the OSI Model and above. They perform complete conversions from one protocol to another, rather than simply support one protocol from within another. An example of a gateway in EtherNet/IP networks includes a device that functions to convert between EtherNet/IP and DeviceNet application layers.

2.2.6 Network Segments

A network segment is a group of functionally associated devices connected and isolated by switches, routers, bridges, or gateways. Networks may be divided into multiple segments for security and to improve traffic flow by filtering out packets that are not destined for the network segment.

2.2.7 Active Devices

Many different configurations of Active Devices are available in support of the various topologies supported by EtherNet/IP. Active two port devices are optimized for active linear and ring topologies. Active devices with only one port are targeted toward star or direct connection topologies. Network switch devices provide a high degree of flexibility to support different topologies and allow interfacing between different topologies and types of devices.

Network specific functions (when considering total network needs) can include bandwidth, latency, redundancy/availability, functional safety rating, and security classification.

Active devices with a single port can be applied without consideration of the total network.

Active two port devices combine device function and basic infrastructure function. Because of this, the performance of the total network should be considered in device selection and application. Bandwidth and latency performance of connected devices may be impacted by devices elsewhere in the active linear or ring network.

Network switch devices act as the primary infrastructure layer. Plans must consider total network functions for the commissioned system as well as needs for maintenance and expandability.

2.3 Connectors

EtherNet/IP recognizes three connector types: 8-way modular connectors (commonly referred to as RJ-45), 4-pole M12 D-coded and 8-pole M12 X-coded connectors. The connectors are defined in international standards IEC 60603-7 series, IEC 61076-3-106 (Variant 1), IEC 61076-2-101 and IEC 61076-2-109. Some connector designs provide sealing to IP65/IP67 in accordance with IEC 60529 (Ingress Protection Rating) when the plug is mated with the corresponding jack. See chapter 3 for connector details and requirements.

Connector designs are available with external housing construction made of either plastic or metal. The planner is cautioned against mixing unshielded connectivity with shielded cabling in the same channel. Doing so will compromise shielding integrity and interference immunity of the channel. Only Active Devices with shielded jacks should be considered for EtherNet/IP networks such that they can support both shielded channels and unshielded channels. Unterminated cable shields must be avoided.

2.4 Cord Sets

Cord sets can be built on-site using cable and field attachable connectors or can be purchased as factory-made cord sets. For all cord sets, the conductor count in the cable shall be limited by the connector used with the least number of positions (e.g., a M12-4 D-coded connector shall only be used with 2-pair cables). The permissible types of plug-to-plug configurations include:

The 2-pair cord sets supported by EtherNet/IP include:

- 8-way modular to 8-way modular
- M12-4 D-coded to M12-4 D-coded
- 8-way modular to M12-4 D-coded
- M12-4 D-coded to M12-8 X-coded
- 8-way modular to M12-8 X-coded

The 4-pair cord sets supported by EtherNet/IP include:

- 8-way modular to 8-way modular
- M12-8 X-coded to M12-8 X-coded
- 8-way modular to M12-8 X-coded

Note: In any of these configurations, an 8-way modular connector can be a sealed or non-sealed variant.

Each cord set may come as shielded or un-shielded. Connector housings for the shielded cord sets shall be metal shell variants. All the above can be configured as crossover cables. Chapter 5 (Network Installation) provides details on the pin/signal and pair assignments for each of the connector styles based on specified wiring code.

2.4.1 Rules for Mixing 2-pair and 4-pair Cabling in the Same Channel

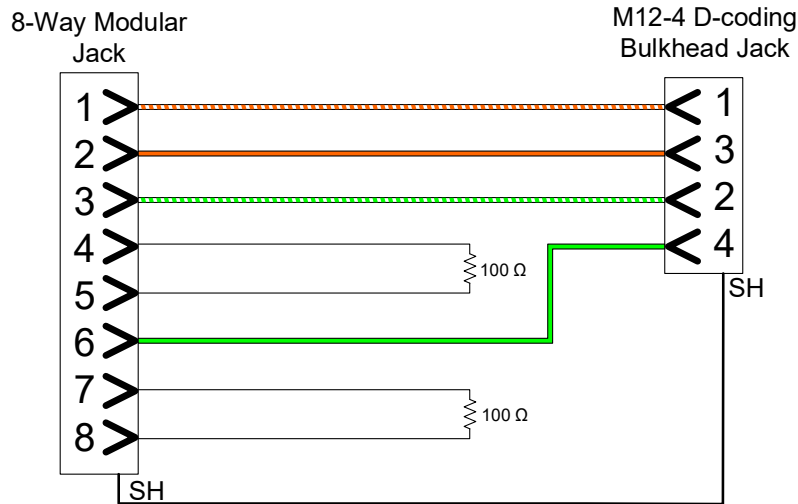
Due to potential interference between unterminated pairs within a cable, two pair cables shall be used when using 4-pole M12 D-coded or more generally any 2-pair connectors. Where an application must transition between 2-pair and 4-pair cord sets, any unused pairs of the 4-pair cable shall be terminated. Four pair cables should be used when using 8-pole M12 X-coded connectors. In some cases, it may be necessary to mix connector types for adapter cables in which case the minimum pin count should apply as the recommended conductor count.

Note: Because it can be difficult to identify the pair count after a cord set is installed, it is recommended that cables used for EtherNet/IP applications are marked with the pair count on the jacket label.

As many applications still only require 100 Mb/s function, many connected devices will have 2-pair connectors and need a migration strategy to support interoperability within more flexible 4-pair installations. Best practice for these types of installations will be to install 4-pair cables along most of the length of the channel. This of course requires conversion to 2-pair cables local to the 10/100 Mb/s active device. Unused pairs must be terminated. This is most easily done in a designated bulkhead adapter that has the termination resistors integrated as depicted in Figure 2-4. In this fashion most of the

channel can be installed and supported with 1000 Mb/s capability and existing 10/100 Mb/s devices can still be used. If the 10/100 Mb/s devices ever need to be replaced or upgraded, this provides the option to replace with a 1000 Mb/s equivalent providing more expansive feature sets by only replacing the active device, the short 2-pair cord, and the bulkhead adapter. This type of installation should be verified or certified as a permanent link such that the 4-pair construction and performance is confirmed and an upgrade to 1000 Mb/s functionality only requires verifying the performance of the short patch cord that is replaced.

Figure 2-4 – Example Bulkhead Adapter Schematic



2.4.2 Cord sets Providing Crossover Function

A crossover cable is defined as a cable that has a connector with T568B wiring code on one end and T568A wiring code on the other. ODVA 1000BASE-T devices require the use of physical layers supporting Auto-MDIX. This is a feature that will automatically detect whether the channel is cross-over coded and correct the signaling to match. This feature has also been added to many new lower speed physical layers to prevent the need of crossover cables in a channel making them a legacy system requirement. Where used, only one crossover cable shall be used within a channel. All other connections shall be straight-through. Crossover cables are not recommended for 1000 Mb/s channels.

2.5 Modular Network Construction

A modular system design may be desirable. Bulkhead feedthroughs aid in providing modularity. Modular design allows pretesting, proof of concept at one location, and easy disassembly and reconstruction at the final location. In addition, failed systems can be corrected quickly by replacing subassemblies. Systems utilizing connectors instead of wire glands or conduit allow for easy replacement of the entire enclosure, thus reducing mean time to repair (MTTR) and downtime for a failed communications network.

2.5.1 Couplers and Adapters

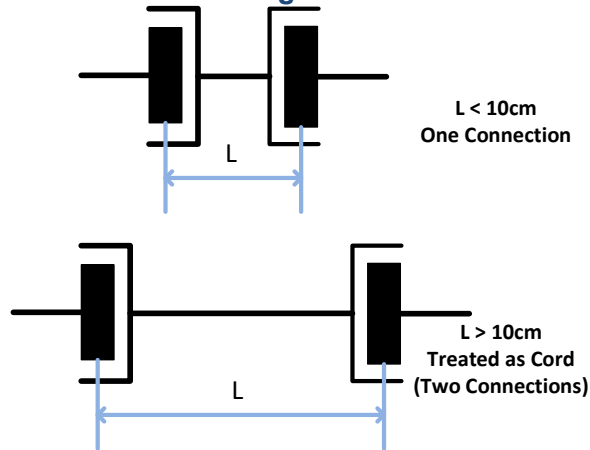
A coupler consists of two closely spaced (less than 10 cm) electrically connected interfaces. Both interfaces are of the same physical mating interface and maintain the same circuit count.

An adapter consists of two closely spaced (less than 10 cm) electrically connected interfaces. Both interfaces have different physical mating interfaces; for example, an M12-4 D-Coded connector to an 8-way connector. Adapters may be of different circuit counts.

Couplers and adapters shall conform to the transmission requirements of one connection of the appropriate media and category to be counted as one connection, see Figure 2-5.

If two mating faces are not electrically close or the coupler or adaptor does not meet the transmission requirements of the appropriate media and category, then the coupler or adaptor shall be treated as a cord set.

Figure 2-5 – Coupler and Bulkhead Length Rules



2.5.2 Panel Feedthroughs

To maintain environmental integrity (IP rating), panel feedthroughs should be used wherever cabling must pass through an enclosure wall. The planner must be aware of the rules for the number of allowed connections in a channel as defined in Section 3.1.8. Refer to Section 3.1.14 for rules on selection and application of panel feedthroughs.

Panel feedthroughs may be either cable glands where a cable is passed through the enclosure wall and sealed, or bulkhead connectors where two cables meet at the enclosure wall. Bulkhead connectors may be bulkhead adapters where the connector type changes on either side of the enclosure wall or simple couplers where the connector type is the same on both ends.

2.5.2.1 Bulkhead Connections

Bulkhead is a term used to define a mounting style of connectors. Bulkhead adapters are typically used at environmental or enclosure boundaries to facilitate connection and disconnection of the cabling to the enclosure. Bulkhead wiring is always constructed straight through to follow the wiring code used by the cord sets applied. Bulkhead adapters are designed to be inserted into a panel cut-out.

The transmission performance requirements for a bulkhead connector are the same as that for a single connector and are defined in Section 3.3. Where more than 4 connections are needed in a channel, the guidance of Section 3.1.8 shall be applied. Figure 2-6 is an example of M12-4 D-Coded and M12-8 X-Coded EtherNet/IP bulkhead adaptor.

Figure 2-6 – Example of typical M12 to 8-way modular bulkhead adaptor (M12 X-coded to 8-way shown)



2.5.3 Patch panels

A patch panel is a group of sockets that function as a manual switching center between incoming and outgoing lines in communications systems. In an industrial control system, patch panels may be used to interface I/O devices and switches. Patch panels are not required in industrial control areas but can be utilized if additional flexibility is required. For deciding whether patch panels are beneficial for the target application, see the considerations in Section 1.4.10.

2.5.3.1 Wiring Examples

Patch panels provide flexibility and ease of network reconfiguration. The following wiring examples range from a complex system to a simple patch cord.

Controllers and I/O devices may be directly connected in a configuration or connected via switches, as shown Figure 2-7 through Figure 2-10.

Figure 2-7 – Wiring without patch panels.

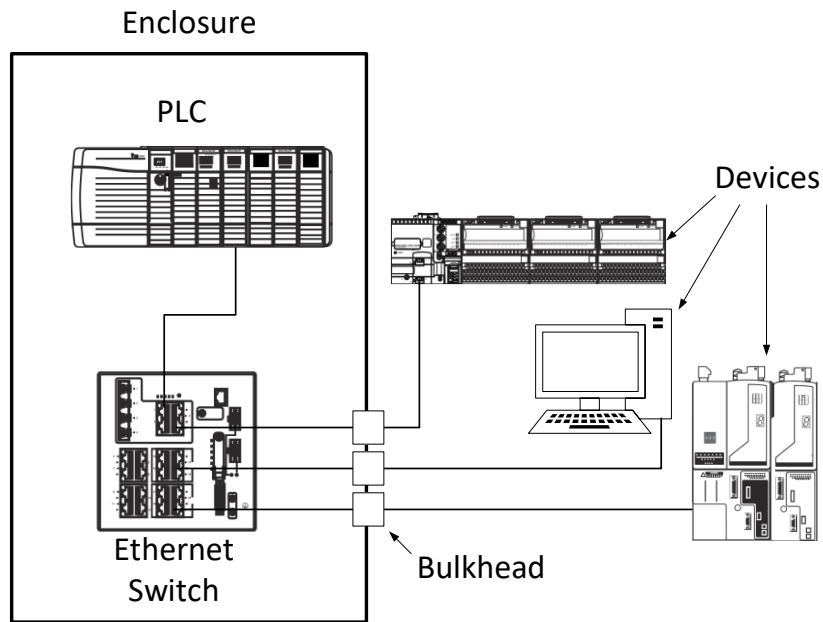


Figure 2-8 – Direct connection using a crossover cable.

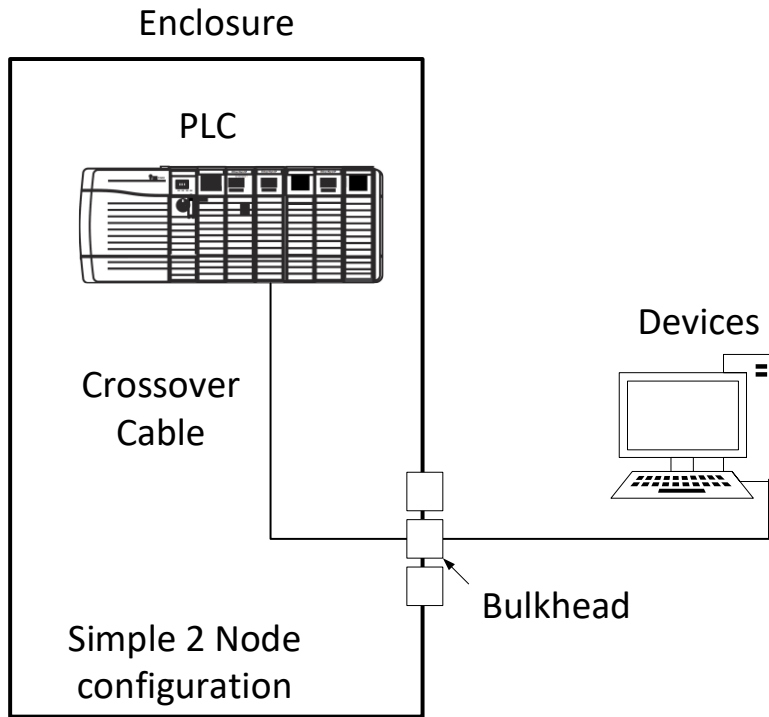


Figure 2-9 – Star topology using a patch panel.

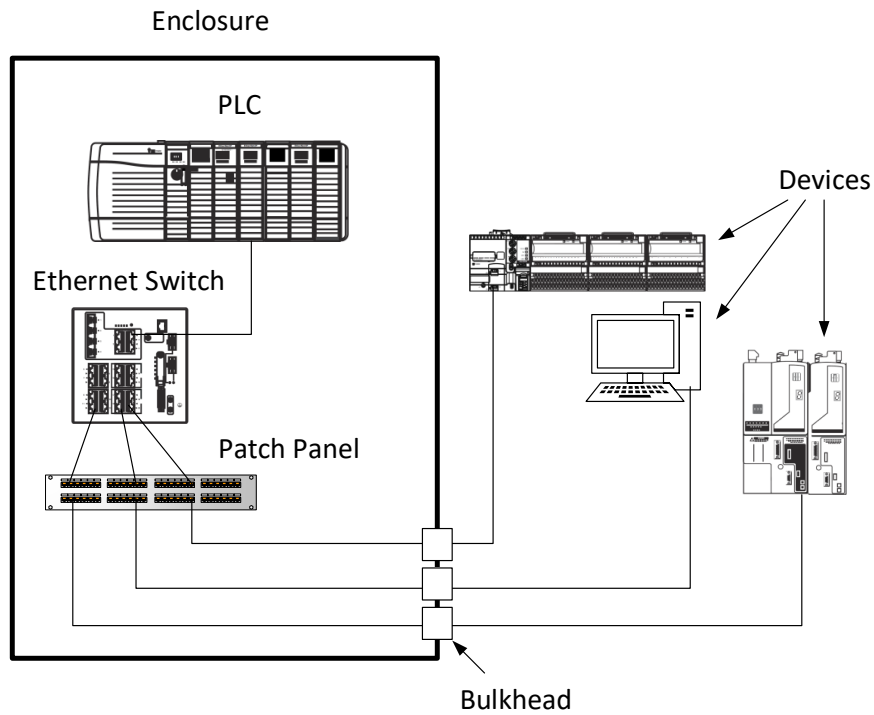
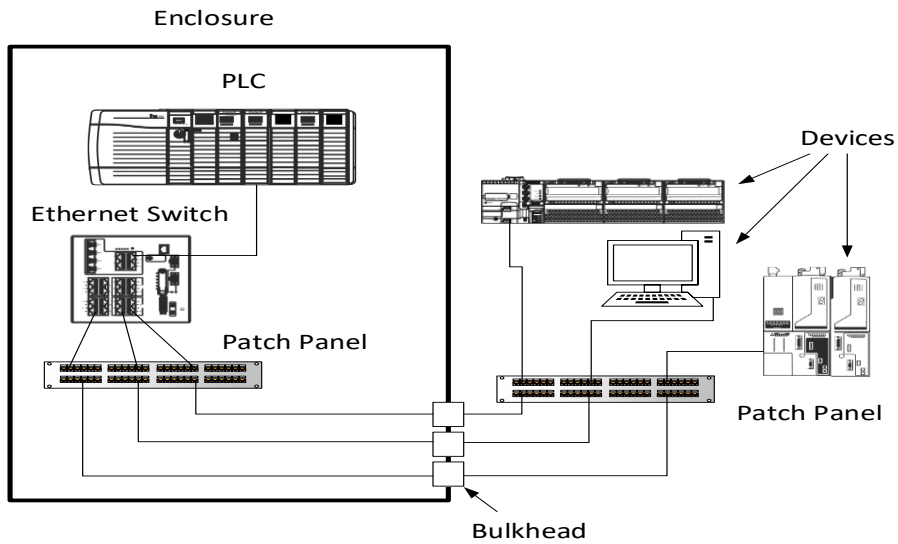


Figure 2-10 – Hierarchical star using patch panels.



2.5.4 Enclosures

In an industrial environment, the controller and switch are often mounted inside a protective enclosure, (i.e. IP-rated or NEMA-rated enclosure) to protect sensitive equipment from harsh environments. Connectivity is facilitated via bulkhead connectors, wire glands or conduit.

3 Planning the EtherNet/IP Copper Cabling

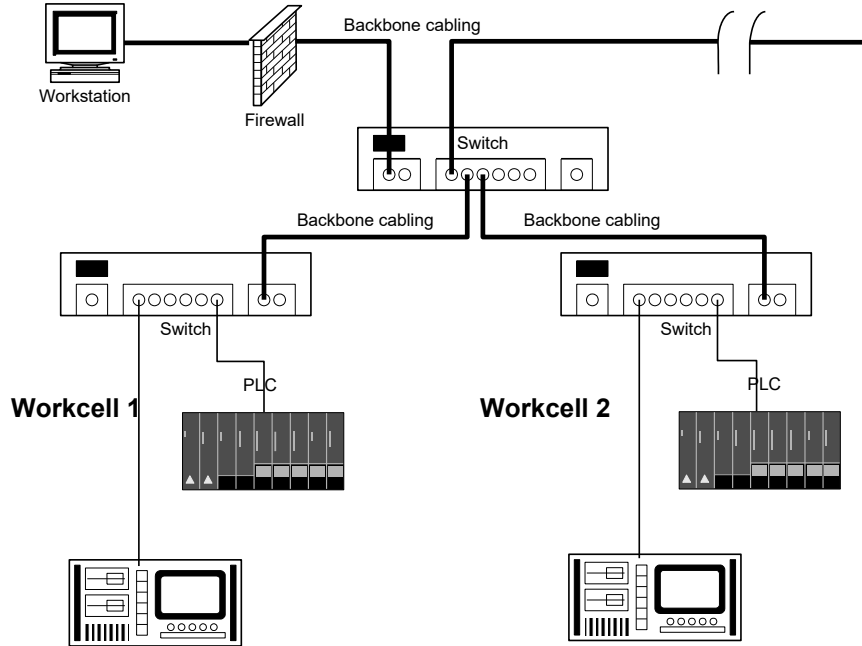
Chapter 2 provided an overview of the EtherNet/IP media system. This Chapter provides media system details that are necessary to consider in the planning process for an installation.

3.1 Planning the System

3.1.1 Determining Connectivity to the Backbone

In EtherNet/IP systems, backbone is a term used to describe a common network infrastructure link that has a higher need for data bandwidth and reliability due to shared data requirements. Because of this, extra care should be taken in selection of backbone connectivity to ensure a long supportable lifecycle. The following sections describe some of the variables the planner should consider when designing and securing the network.

Figure 3-1 – Example Backbone Connectivity.



Topology will play a role in cabling requirements as any cabling part of a backbone will have higher associated risk if it becomes compromised. A hierarchical star topology will typically require the most cabling and most planning, however, it will lessen the requirements on most of the cabling used in the system. Ring topologies share bandwidth throughout the ring, therefore you should design for the highest speed in your ring. Because devices can be daisy chained the overall amount of cabling is reduced, but the risk of misapplication or failure of cabling increases as the system can only survive a single fault before the entire application is compromised. Bus topologies have high system dependency where a single failure can take down the entire system. Because of this, bus systems are generally recommended to be localized and placed at the edge of the network.

3.1.2 Network Security

A failure of network security may result in a loss of access to the control network, the loss of confidential information, compromised integrity of operations, or even compromised safety of the control system. The planner is strongly encouraged to provide appropriate security through the use of filtering devices, gateways, firewalls, routers, and/or appropriate security software. The planner and maintenance personnel are cautioned about installing devices on the control network that could bypass network security such as telephone modems. See ODVA PUB00269 – Securing EtherNet/IP networks CIP Security.

Network maintenance personnel should be made aware that inadvertent intrusions resulting from system maintenance and housekeeping, network upgrades, or broadcast storms may disrupt the control system. Details of network security are beyond the scope of this manual, and the planner is advised to consult appropriate standards.

It is recommended that the security of applications be considered as a risk assessment process in line with the guidance of Section 1.4.4.

3.1.3 Determining the Number of Switch Ports and/or Device Ports

The number of ports required depends on the number of devices to be connected to the network. A port is required for each node in the system. If nodes may be added later, the planner should consider ordering and installing the cable and connectors for these additional nodes with the initial network. This will minimize disruption to the network during operation. The planner may wish to design the system with 20 % or more excess switch ports for future expansion.

When considering applications with Active two port devices, the switching requirements may be distributed. Multiple devices can be aggregated to a single switch port at the cost of dividing up the bandwidth. When considering these devices, maintenance port access should be considered which may require the addition of an ethernet tap device. In addition, the planner may wish to reserve at least 20% bandwidth for future expansion.

Consider the number and locations of the following when determining how many ports are needed on the network.

- Workstations
- I/O racks and modules
- HMIs
- PLCs
- Sensors/actuators (EtherNet/IP-based)
- Future expansion

Excess ports should be marked as control ports for future expansion to alert maintenance personnel.

3.1.4 Placement of Active Network Components

The planner must consider the environment when specifying, selecting, and determining placement of active network components. Unless industrial hardened (e.g., On-machine components), active network components should be installed in suitable enclosures to protect them from the harsh environment per the MICE tables (Table 9-1, Table 9-2, Table 9-3, and Table 9-4). The temperature and vibration inside the enclosures (closets) should also be considered since the enclosures may not be temperature controlled, or shock mounted.

3.1.5 Environmental Evaluation

Cabling components need to be evaluated for compatibility in accordance with the MICE environmental risk assessment process. This includes consideration of temperature and climate for heat and humidity considerations, consideration of shock and vibration for placement around heavy machinery, consideration of chemicals present that may corrode or absorb into jacket materials, as well as consideration of electromagnetic interference that may be present. Components can either be selected to be compatible or have mitigations applied to isolate or shield them from the more severe environmental conditions. See Chapter 9 (MICE Tutorial) for a more detailed description of the MICE concept and associated mitigations.

3.1.6 Choosing Cable Category

Category 5e, category 6, and category 6A components are supported by EtherNet/IP with applicable data rates up to 1000 Mb/s. In new installations, the use of 2-pair cables will limit the maximum bandwidth to 100 Mb/s and may limit the expandability of the cable for new or future applications. For guidance on the consideration of 2-pair applications within more flexible channels see Section 2.4.1.

Category 6A cable maintains an internal signal to noise ratio to support up to 10 Gb/s in a benign electromagnetic environment. Performance of 10GBASE-T in a heightened industrial electromagnetic interference environment has not been evaluated. In the transition from 10/100 Mb/s to 1000 Mb/s, it was found the data rates had an increased sensitivity to interference. Therefore, in practice, to achieve the higher data rate it requires further enhanced cabling, or an additional length/attenuation derating factor applied. It can be expected that similar effects may be observed in expanding to future data rates that may deem existing cable insufficient for higher data rates in the same external environments.

Note: If considering cable to support extended data rates, it is advisable to place preference on shielded cabling or optical fiber cabling that have more operating margin in existing technology against environmental interference.

3.1.7 Copper Connectors

Selection of connectors in EtherNet/IP systems is driven first by the necessary connected devices and their needed bandwidth and second by the applied environment. Where speeds of 1000 Mb/s are needed, 8-way modular connectors or M12 X-coded connectors

shall be used. Where the applied environment calls for enhanced ingress protection, sealed connectors (including M12 X-coded connectors, sealed 8-way modular connectors, and M12 D-coded connectors) shall be used.

Where bandwidth and capability of extended ingress protection are both critical to the application, it may be difficult to select between 8-way modular and M12 X-coded technologies, as either choice is sufficient to meet the application needs. In some cases, sealed 8-way modular connectors may be preferred to allow limiting the number of patch cords that need to be supported and stocked for replacement. In other cases, M12 X-coded connectors may be preferred to minimize panel space taken up at an enclosure entry. For detailed connector requirements see Section 3.3.

3.1.8 Number of Connections in a Channel

A Mated Connection is defined as an electrically conductive communications path comprised of a mated jack and plug. The number of mated connections allowed in a channel shown in Table 3-1 is determined by the desired channel performance (Category) and the performance level of the components selected. Alternate configurations should be field tested according to Chapter 6 to ensure adequate performance.

Couplers, adapters, and other bulkhead connections may be counted as one connection, provided that the electrical length is less than or equal to 10 cm (as defined in Section 2.5.1). Jack-to-Jack cable assemblies, whereby the electrical distance is greater than 10 cm, must be counted as cord sets which will include 2 connections. Cable lengths between connecting hardware greater than 10 cm must be counted in the total channel/link appropriate cable length budget. Consult the manufacturer about specific performance capabilities.

Table 3-1 – Number of connections in a channel

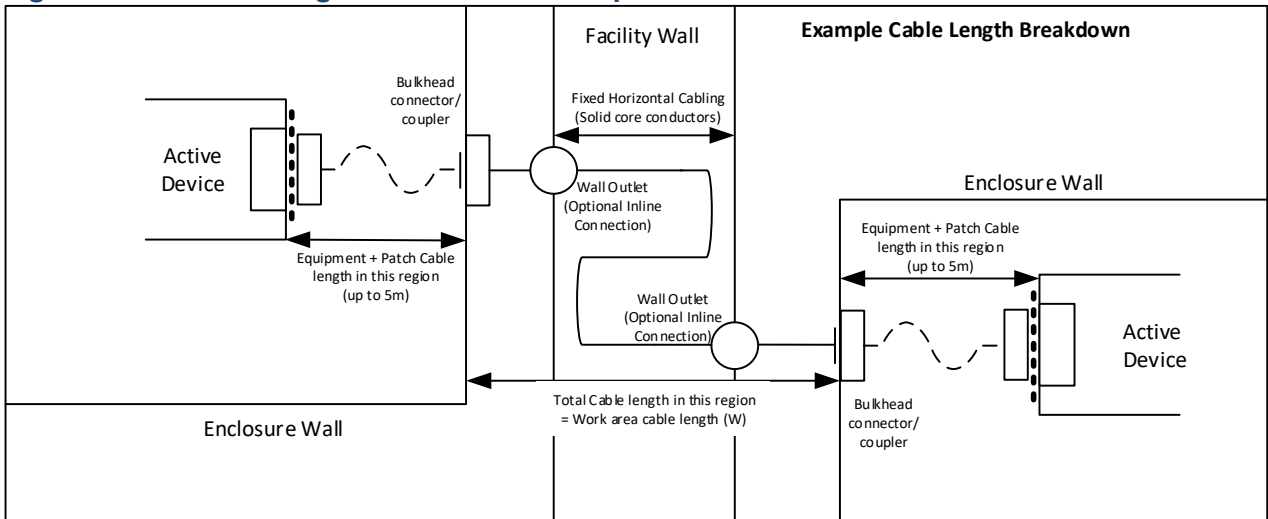
Desired Channel performance	Number of Mated connections	Category connector (required)	Category cable (required)
5E	4	5E	5E
5E	6	6A	5E
6	4	6	6
6A	4	6A	6A

3.1.9 Channel and Link Lengths and Limits (Copper)

Cables with stranding or smaller gauge sizes will have higher attenuation than horizontal cabling which typically uses larger solid core conductors. As a result, use of these cables may not allow support of the full 100 m length. Further cable attenuation increase will result from raising the cabling ambient temperature. This section describes calculation methods to determine the allowable cabling lengths based on selected cables and target ambient temperature.

EtherNet/IP specifications limit each segment of horizontal wiring to 100 m or up to 90 m horizontal wiring with up to two, 5 m patch cords. Some applications will require longer patch cords. In these applications the total length of horizontal wiring must be adjusted to compensate for the added loss of each connector pair and additional patch cord length beyond 10 m.

Figure 3-2 – Cable Length Breakdown Example



$$C = \frac{(102 - H)}{(1 + D)} \tag{1}$$

$$T = H + C \tag{2}$$

$$W = C - 10 \tag{3}$$

where

C is the maximum combined length of the work area cable, equipment cable, and patch cord, with derating factor applied; expressed in m;

H is the length of the horizontal cable, expressed in m;

D is the de-rating factor for the cord type;

W is the maximum length of the work area cable, expressed in m;

T is the channel limit, which includes total length of horizontal, patch, and equipment cords, expressed in m.

Table 3-2 – Stranded Copper Cable Derating

Cable Gauge ²	D	H	W	C	T
	Derating	Horizontal Length	Work Area Length	Total Patch, Equipment, and Work Area Length	Channel Limit ($T \leq 100m$)
#24 ¹	0.2	0	75	85	85
#24 ¹	0.2	25	54	64	89
#24 ¹	0.2	50	33	43	93
#24 ¹	0.2	90	0	10	100

#24 ¹	0.2	100	0	0	100
#26	0.5	0	58	68	68
#26	0.5	25	41	51	76
#26	0.5	50	25	35	85
#26	0.5	87	0	10	97
#26	0.5	100	0	0	100

¹ For calculation purposes, #23AWG conductors are treated identically to #24AWG conductors

² #28AWG and smaller conductors are not supported

³ For length values of “0”, it applies that no usage of that type of cabling is used in that channel configuration

Elevated temperatures cause higher signal loss in copper cables due to increased resistance. This added loss must be considered in addition to the type of copper cable (solid or stranded conductor patch cord) to determine the maximum channel length. Any shielded (STP) copper cable typically exhibits 0.2% attenuation increase for every 1 °C temperature rise above 20 °C to 60 °C. Unshielded (UTP) Category 5e cables typically exhibit 0.4% attenuation increase for every 1 °C temperature rise from 20 °C to 60 °C. Unshielded (UTP) Category 6 cable exhibit 0.4% attenuation increase for every 1 °C temperature rise from 20 °C to 40 °C and 0.6% attenuation increase for every 1 °C temperature rise from 40 °C to 60 °C, due to more copper and plastic content. The change in attenuation with temperatures beyond 60 °C is product specific. Consult the supplier for more information.

The attenuation for a channel is limited to a fixed amount, as the attenuation per length of a cable increases, the channel length must decrease to compensate. The relationship between attenuation and channel length is inversely proportional as shown in the formulas below.

$$A_{Elev.Temp.} = (A_{Increase Coefficient} * \Delta T + 1) \cdot A_{20C} \quad (4)$$

$$L_{Elev.Temp.} = \frac{1}{(A_{Increase Coefficient} * \Delta T + 1)} \cdot L_{20C} \quad (5)$$

where

$A_{Elev.Temp}$ is the elevated temperature attenuation, expressed in dB;
 $A_{Increase Coefficient}$ is the attenuation temperature coefficient, expressed in dB/°C;
 A_{20C} is the attenuation at 20 °C, expressed in dB;
 ΔT is the change in temperature, expressed in °C;
 $L_{Elev.Temp}$ is the elevated temperature maximum length, expressed in m;
 L_{20C} is the maximum length at 20 °C, expressed in m.

Note: The entire length should be treated as if the temperature is the worst-case temperature to ensure a conservative, simplified calculation.

The following examples show how to calculate the maximum channel length for a given configuration and temperature.

Consider an example using an unshielded #24 AWG solid conductor, category 5e horizontal cable at 60 °C. All channels are limited to 100 m maximum. This distance must be de-rated to accommodate the elevated temperature. Since 60 °C is 40 °C above 20 °C, then 40 °C times 0.4% equals a 16% increase in attenuation. This equates to a 13.8% reduction in length. The length reduction is calculated by taking the percent reduction times the cable type length limit: 13.8% x 100 m = 13.8 m.

The maximum channel length is calculated by subtracting the elevated temperature length reduction from the cable type channel limit: 100 m – 13.8 m = 86.2 m. The maximum channel length for all unshielded #24 AWG solid, category 5e horizontal cable at 60 °C is 86.2 m.

For all unshielded #24 AWG stranded conductor, category 5e patch cable at 60 °C we have the following:

- Cable type channel limit (as defined in Table 3-2) = 85 m
- Temperature change = 40 °C
- Attenuation Temperature coefficient = 0.4%
- Total attenuation change = 16%
- Length reduction = 11.8 m

Maximum channel length for all unshielded #24 AWG stranded, category 5e patch cable at 60 °C is 73.2 m.

For 25 m unshielded #24 AWG solid, category 5e horizontal cable with some length of #24 AWG, stranded cable at 40 °C we have the following:

25 m of unshielded #24 AWG solid, category 5e horizontal cable at 40 °C has the loss of 8% more per length of cable:

- 25 x 1.08 = 27 m effective length
- Based on the 27 m, the effective maximum stranded patch length (see equation (1) is:

$$\frac{102-27}{1+0.2} = 62.5 \text{ m}$$

- 62.5 m of 24AWG stranded cable has 8% more loss at 60C, than the actual length at 20C. Using equation (5), the elevated temperature max length is:

$$\frac{62.5m}{1.08} = 57.9 \text{ m actual length}$$

The actual maximum stranded length = 57.9 m.

The total channel length limit is the sum of the actual solid, horizontal cable maximum length limit plus the actual stranded, patch cable maximum length limit: 25 m + 57.9 m = 82.9 m.

Stated differently, the maximum channel length limit for 25 m of unshielded #24 AWG solid conductor, category 5e horizontal cable is 82.9 m at 40 °C with a maximum of 57.9 m of unshielded #24 AWG stranded conductor, category 5e patch cable.

3.1.10 Selection of EtherNet/IP Components

A higher data rate will provide a greater throughput. For Fast Ethernet, the use of low interference, high performance cables and connectors is highly recommended. Any degradation in interference rejection will degrade an entire channel between a switching device and the peripheral equipment. If using an Industrial EtherNet/IP device, it has been specially designed for high-interference rejection. Low-interference cable designs usually have a greater transverse conversion loss (TCL) value.

Note: Introducing non-EtherNet/IP or Commercial EtherNet/IP devices, cables or connector components into the network may degrade the interference rejection of the system and disrupt an otherwise properly functioning network.

For example, standard Commercial cables have a TCL of about $60-20\log(f)$, whereas an Industrial performance cable will have a TCL better than $80-20\log(f)$. The shaded area in Figure 3-3 shows performance of UTP cables.

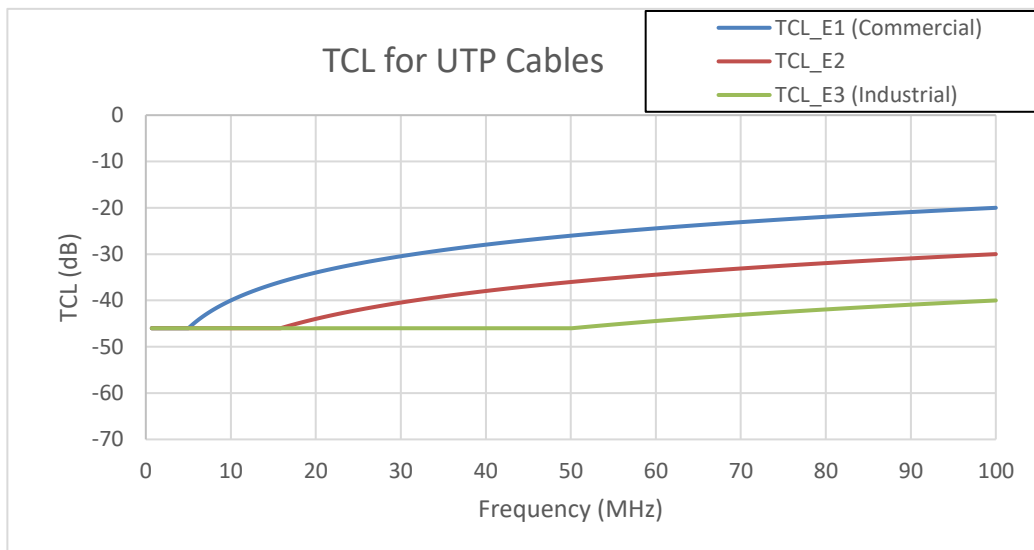


Figure 3-3 – TCL for UTP balanced cables.

3.1.11 Use of Shielded Cables

As explained by the MICE tutorial in Chapter 9, the local environment is determined by where the cable will be routed – this should guide cable selection and application. Shielded cables may perform better in high EMI noisy environments than non-shielded cables. However, shields can cause ground loops that can be very disruptive to industrial networks. Therefore, for best performance use shielded cables in MICE E3 environments where the building ground is at equal potential. If shielded cables are used, then grounding of the shields must be performed in such a way as to eliminate ground loops. This can be done by providing a grounding system as detailed in ANSI/TIA-607 and ISO/IEC 30129.

Consider shielded cables or separation between the network cabling and the interference generating sources (including wiring) as defined in Section 3.2.2 if the application includes one or more of the following:

- Induction welding processes
- Proximity to high power RF radiation
- Electrostatic processes
- High-current devices (greater than 100 A)

Note: Active network components should be grounded per the manufacturer's recommendations.

3.1.12 Un-Shielded Twisted Pair (UTP) Cable

UTP cable can provide options for situations where ground offsets occur, such as lightning surges, or surges caused by high current switching inductive loads. See the MICE criteria described in chapter 9 (MICE Tutorial).

3.1.13 Grounding Shielded Cables

The planner should consult the installation data sheet for each device to be installed for that device's grounding requirements. ODVA provides for two types of grounding of active devices, 1) direct grounded shield and 2) an RC (parallel resistor – capacitor) grounded shield. The latter provides for ground isolation in areas where ground offsets exist. The direct grounded active devices may require an equipotential grounding system to mitigate ground offsets. Most switch manufacturers require their equipment to be grounded, and as a result the communications ports are grounded.

3.1.14 Use of Bulkhead Connectors/Adapters and Bulkhead Cable Glands

Enclosures may sometimes be placed close to the work area and in harsh conditions. Entry into and exit out of these cabinets (either through openings in the side, back, bottom, top, or door) may require an adapter to transition from the dry, clean interior of the cabinet to the potentially wet or dirty exterior, i.e., from one MICE environment to another. The bulkhead should be specified in such a way to minimize exposure to liquids, dust, mechanical damage, and vibration. Bulkhead feedthroughs should be used where cables enter or exit the cabinet to maintain enclosure seal integrity. The sealed IP65/IP67

connectors specified in the ODVA Industrial EtherNet/IP specification are available as bulkhead connectors. Also see Section 2.5 for details on modular network construction.

The planner must be aware of metallic bulkhead connectors that connect the cabling at the enclosure wall. This may form a ground loop that could disrupt communications. Where a ground loop may be formed, a separate grounding conductor should be installed to provide an equal potential between the two points. An alternative method would be to isolate the bulkhead connector using an insulator between the bulkhead connector and the enclosure wall.

When bulkhead connectors are used, they need to be counted in the number of connections within a channel as shown in Table 3-1.

An example of an EtherNet/IP bulkhead connector is shown in Figure 2-6.

See manufacturer's data sheet for mounting hole cutout dimensions. Consider the panel wall thickness minimum and maximum for the enclosure when selecting a bulkhead connector.

3.1.15 Surge Suppression

Transient EMI can be generated whenever inductive loads (such as relays, solenoids, motor starters, or motors) are operated by "hard contacts" such as pushbutton or selector switches. This manual assumes that users will guard their systems against the effects of transient EMI by using surge-suppressors to suppress transient EMI at its source and not on the communications lines.

Inductive loads switched by solid-state output devices alone do not require surge suppression. However, inductive loads of AC output modules that are in series with hard contacts require surge suppression to protect the I/O module and communications system from interference.

EtherNet/IP devices are designed with a base set of EMI immunity requirements that include a standard surge protection level to ± 2 kV of a typical 8/20 μ s surge waveform. This level is intended to cover protection levels associated with transient coupling from parallel wires but will not cover high energy surges such as lightning strikes. Commercial components may not be designed to these same levels and may require additional protection.

Because high energy surges put the cabling system at risk, cabling run at a building entry or near a power distribution entry point should have additional surge protection applied. Any cable run outdoors should have an identified surge protection strategy or may need auxiliary surge protectors applied to the cabling near either end.

3.1.16 Use of Ferrite Beads and Cores

Ferrites can provide additional suppression of transient EMI and can be installed over Category EMC2 and Category EMC3 conductors (as defined in Table 3-3). The ferrite bead material can influence the interference attenuation and frequency range. Select the correct material and core size to fit the application. These can be secured with heat-shrink tubing or hook and loop cable management. A cable transient EMI induced onto the cable can be suppressed by a ferrite bead located near the end of the cable. The ferrite bead suppresses the EMI before it enters the equipment connected to the end of the cable.

Note: When ferrite beads are used with UTP the signal attenuation will increase. Ensure the channel still complies with the requirements of the channel.

3.2 Planning The Cable Routing

Refer to the Telecommunications Industry Association publication, ANSI/TIA 1005-A, Telecommunications Pathways and Spaces, for additional information.

Plan the cable routing very carefully and avoid routing cables near equipment that generates electromagnetic interference. Group the cables into alike circuits as shown in Table 3-3 and Table 3-4.

In particular, the planner should be concerned with routing near and around:

- Fluorescent and LED Lighting
- Motors
- Variable Frequency Drives
- Arc welders
- Induction heaters
- RF fields (transmitters)
- High speed switching circuits
- Conductors providing power to any of the above

ODVA guidelines mirror the guidelines for The Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources in IEEE standard 518-1982. When planning the cable system, there are certain installation considerations depending on the application.

Additional guidelines are provided in IEEE 1100-2005, which defines three categories of conductors, and the EMC levels associated with them. Table 3-3 highlights the additional spacing that may be required for communication cables, given any conductors carrying voltages exceeding SELV levels. (See Table 3-4).

3.2.1 General Wiring Guidelines

Follow these guidelines for wiring all EtherNet/IP cables in addition to guidance provided in Table 3-4:

- A bonding system and earthing strategy aligned to ANSI/TIA-607 and ISO/IEC 30129 is desired to reduce ground loops and interference ingress. Shield termination should be implemented according to the applied earthing strategy.
- Consult the cable supplier to be sure the electrical performance will not be affected when placing UTP cables in conduit or metallic pathways.
- Use the correct cabling components for the environment. (See MICE tutorial in Chapter 9).
- Protect the cables and connectors from accidental and/or intentional damage.

For more information on general wiring guidelines, see IEEE publication IEEE 1100-2005 Wiring and Grounding Guidelines, ANSI/TIA-607-D, Grounding and Bonding Requirements, and ISO/IEC 30129.

3.2.2 Categorize Conductors

Segregate all wires and cables into the following three EMC categories per IEEE 518 as shown in Table 3-3.

Table 3-3 – Grouping of Circuits with Respect to Interference

Group conductor cables fitting this description	Into this Category	Examples:
<p>Control & ac Power --- high-power conductors that are more tolerant of electrical interference than category 2 conductors and may also cause more interference to be picked up by adjacent conductors</p> <ul style="list-style-type: none"> corresponds to IEEE levels 3 (low susceptibility) & 4 (power) 	<p>EMC1 (> MICE₃)</p>	<ul style="list-style-type: none"> AC power lines and I/O circuits High-power digital I/O High-power digital DC I/O Power connections (connectors) from motion drives to motors
<p>Less tolerant of electrical interference than category-1 conductors and should also cause less interference to be picked up by adjacent conductors (they connect to sensors and actuators relatively close to the I/O modules)</p> <ul style="list-style-type: none"> corresponds to IEEE levels 1 (high susceptibility) & 2 (medium susceptibility) 	<p>EMC2 (MICE₂ to MICE₃)</p>	<ul style="list-style-type: none"> Analog I/O lines and dc power lines for analog circuits Low-power digital ac/dc I/O lines Low-power digital I/O lines Communications cable (EtherNet/IP, DeviceNet and ControlNet) to connect between processors or I/O adapters modules, programming terminals, computers, and data terminals
<p>Intra-enclosure — interconnect the system components within an enclosure</p> <p>corresponds to IEEE levels 1 (high susceptibility) & 2 (medium susceptibility)</p>	<p>EMC3 (MICE₁)</p>	<ul style="list-style-type: none"> Low-voltage dc power lines Communication's cables to connect between system components within the same enclosure

3.2.3 Routing Conductors Inside or outside enclosures

To guard against coupling interference from one conductor to another, follow the general guidelines in Table 3-4 when routing wires and cables both inside and outside of an enclosure. Use the spacing given in these general guidelines with the following exceptions:

- Connection points (for conductors of different EMC categories) on a device are closer together than the specified spacing.
- Application-specific configurations for which the spacing is described in a publication for that specific application.

Note: These guidelines are for interference immunity only. Follow all local codes for safety requirements.

Table 3-4 – Routing of Cables to Guard Against Interference

Route this category of conductor cables:	According to these guidelines:
EMC1 (> MICE ₃)	Route conductors according to local or national electrical safety regulations.
EMC2 (MICE ₂ to MICE ₃)	<p>These conductors can be routed in the same cable tray or raceway with machine power conductors of up to 600 V ac (feeding up to 100 hp devices).</p> <ul style="list-style-type: none"> • If it must cross power feed lines, it should do so at right angles. • Route at least 1.5m (5 ft) from high-voltage enclosures, or sources of rf/microwave radiation. • If the conductor is in a metal wireway or conduit, each segment of that wireway or conduit must be bonded to each adjacent segment so that it has electrical continuity along its entire length and must be bonded to the enclosure at the entry point. • Properly shield (where applicable) and route in a raceway separate from EMC1 conductors. • Apply the guidance of Table 3-5 • If not in a contiguous metallic wireway or conduit, route at least 15 cm (6 in) from EMC1 conductors of less than 20 A; 30 cm (1 ft) from ac power lines of 20 A or more, but only up to

	100 kVA; 60 cm (2 ft) from ac power lines of greater than 100 kVA.
EMC3 (MICE₁)	Route conductors external to all raceways in the enclosure or in a raceway separate from any EMC1 conductors with the same spacing listed for EMC2 conductors, where possible.

3.2.4 Pathways

Consult the local, regional (state), and national codes regarding the grouping of cables. Never run Ethernet cables any closer than the limits in Table 3-5.

Table 3-5 – Routing Communications Cabling in Metallic Pathways

Contiguous Metallic Pathways	Route the Cable at Least this Distance	From Interference Sources of this Strength	From cables containing voltages
	8.3 cm (3.25")	EMC 1 conductors of less than 20 A	24-100 VDC/VAC
	15 cm (6")	AC power lines of 20 A or more, up to 100 kVA	101-200 VAC
	30 cm (12")	AC power lines greater than 100 kVA	201-400 VAC

3.3 Selecting Copper Connectors

EtherNet/IP recognizes three connector types: 8-way modular (RJ45) connectors, 4-pole M12 D-coded and 8-pole M12 X-coded connectors. The sealed connectors are defined in international standard IEC 61076-3-106 (Variant 1), IEC 61076-2-101 and IEC 61076-2-109 respectively. These connector designs provide sealing to IP65/IP67 in accordance with IEC 60529 (Ingress Protection Rating) when the plug is mated with the corresponding jack. The unsealed connectors supported are 8-way modular connectors defined in the IEC 60603-7 series and provide IP20 level of protection.

Ethernet connectivity is built upon a modular construction utilizing switching and patching to foster more of a plug and play environment. Individual pieces can easily be replaced or rerouted while keeping the base infrastructure in place. Because of this, active devices and active connectivity devices are generally constructed with jacks and cord sets are often constructed with plugs at either end. To couple plugs, couplers and bulkhead connectors may be applied and are typically constructed of jacks. Exceptions to these trends exist such as modular plug terminated links (plug to jack cable assemblies); however, these implementations are less common and add complexity to the modular

system construction. In the following sections, where requirements are listed, they apply to a mated connection including plug and jack combined performance.

Connector designs are available with external housing construction made of either plastic or metal. The planner is cautioned against mixing unshielded connectivity with shielded cabling in the same channel. Doing so will compromise shielding integrity and interference immunity of the channel. Only active devices with shielded connectivity should be considered for use in EtherNet/IP networks. Unterminated cable shields shall be avoided.

3.3.1 IP65/IP67 sealed connectors

If the application exposes cable and connectors to liquid, dust or airborne contaminants as described in the MICE table (Table 9-2), use the appropriately rated connector. To achieve IP65/IP67 ratings, sealed connector/adaptor and cable glands should be utilized. (See Section 2.5.2).

IMPORTANT

Not all connectors are suitable for harsh environments. Carefully select the connector for the intended environment.

3.3.2 8-way Modular Connectors (RJ45)

8-Way modular connectors are suitable for information applications and some control applications. Without additional protection they should only be considered for MICE 1 environments. Some 8-way modular connectors may not have sufficiently low interference characteristics thereby compromising the necessary signal to noise ratio in high interference environments. Other 8-way modular connectors may be more susceptible to shock and vibration related degradation. Sealed 8-way modular connectors are typically industrial-hardened (i.e., compatible with higher MICE environments) and may not have the same selection limitations as for unsealed 8-way modular connectors.

Table 3-6 contains the connector parameters for the 8-way Modular Connectors (sealed and unsealed) for industrial EtherNet/IP systems. Where these specifications are not met there is higher risk for environmental incompatibility with typical industrial environments (e.g., corrosion or vibration) and additional protection may need to be applied. See the MICE tutorial in Chapter 9 for more information.

Table 3-6 – 8-way Modular Connector Parameters

Industrial EtherNet/IP 8-way Modular Connector Parameters		
Specification	Type	
Parameter	Shielded 8-way Modular Connector	8-way Modular Connector
Conductors	8+1 Shielded	8
Contact LLCR over life	< 20 mΩ	< 20 mΩ
Initial Contact LLCR	< 2.5 mΩ	< 2.5 mΩ
Contact Life	750 insertions and extractions min.	750 insertions and extractions min.

There are two 8-way modular wiring methods in use today. The signals on pairs 2 and 3 are swapped at both ends, depending on whether using T568A or T568B wiring code. It is not recommended to mix the two wiring methods in the same channel as this may impair the channel's performance. The T568A and T568B wiring codes, for the 8-way modular connector, are shown in Figure 3-4.

Figure 3-4 – 8-way plug Pin/Pair Wiring Assignments

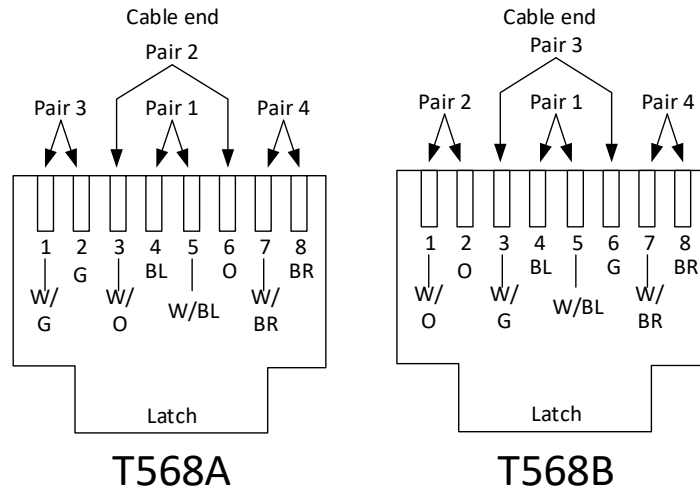
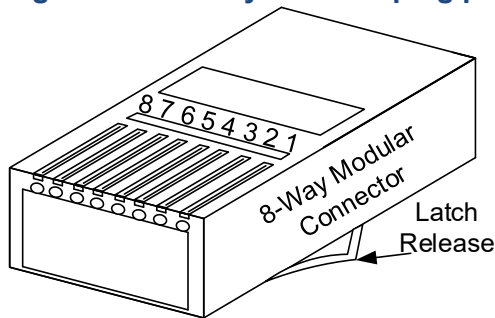


Figure 3-5 – 8-way modular plug pin out Face (Connector) view



Note: TIA 568B should be used unless otherwise specified. The specified wiring scheme is applied throughout the entire link or channel.

3.3.2.1 EtherNet/IP Unsealed 8-way Modular Connectors

Unsealed 8-way modular connectors, alternatively called RJ45 connectors, are the most common type of ethernet connector needed where environments do not require connector ingress protection. Form factors and compatibility are maintained with generic information technology systems but may have considerations to improve environmental compatibility with mechanical or electromagnetic environments common in industrial facilities. Some unsealed 8-way modular connectors may not be directly targeted at industrial environments so care should be taken in applying the MICE environmental risk assessment process.

3.3.2.2 EtherNet/IP Sealed 8-way Modular Connectors

Sealed 8-way modular connectors play an important role in providing a reliable connection in harsh environments. EtherNet/IP supports an 8-way modular jack or plug housed in a Variant 1 form referred to in IEC 61076-3-106. This connector is suitable for use in information and control applications.

Figure 3-6 – Example 8-way modular sealed jack and plug in a plastic housing.



Figure 3-7 – Example 8-way modular sealed plug and jack in a metal housing



3.3.3 4-Pole M12 D-Coded Connectors

4-Pole M12 D-coded connectors are sealed to meet the IP65/IP67 specification for EtherNet/IP and are designed to operate in harsh environments in accordance with IEC 61076-2-101.

4-pole M12 D-coded connectors only use 2-pair cables. If support for data rates exceeding 100Mb is required, the 4-pair cables must be used, along with an 8-pole connector (8-pole M12 X-coded, or 8-way modular connector). The planner should consider future migration in selecting cabling systems. See Section 2.4.1 for rules on 2-pair and 4-pair cabling within a channel.

Table 3-7 delineates the M12-4 D-Coded connector parameters for Industrial EtherNet/IP systems. Where these specifications are not met there is higher risk for environmental incompatibility with typical industrial environments (e.g., corrosion or vibration) and additional protection may need applied. See the MICE tutorial in Chapter 9 for more information.

Table 3-7 –M12 D-Coded Connector Parameters

Industrial EtherNet/IP 4-pole M12 Connector Parameters		
Specification	Type	
Parameter	M12 Shielded	M12 Unshielded
Conductors	4+1 Shield	4
Contact LLCR over Life	Maximum: 5 mΩ over life	
Initial Contact LLCR	Nominal: < 1 mΩ	
Contact Plating	30 micro inches gold over 50 micro inches nickel or 5 micro inches gold minimum over 20 micro inches palladium nickel over 50 nickel or equivalent plating system	
Contact Life	100 insertions-extractions	

Figure 3-8 – M12 D-Coded Connectors

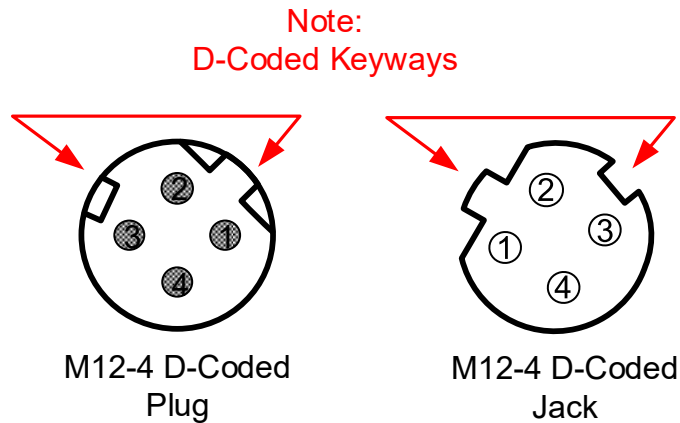


Pin assignments for the 4-pole M12 D-coded connector are shown in Figure 3-9. Pin/Pair assignments can be found in Section 5.2.4.3.

IMPORTANT

For field installed connectors, manufacturer’s assembly instructions should be adhered to closely to avoid possible degradation or compromise of performance.

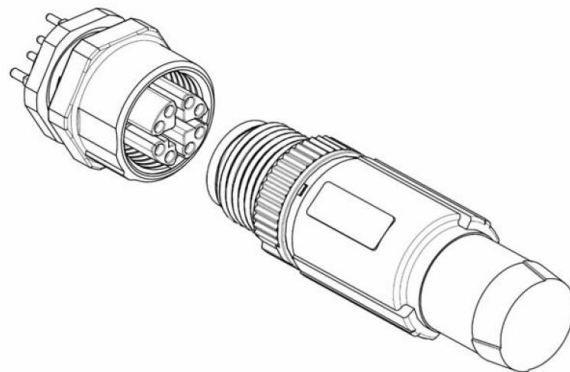
Figure 3-9 – M12 D-Coded Connector Keying



3.3.4 8-Pole M12 X-Coded Connectors

The 8-pin M12 X-coded connector is based on the well-known and industrially accepted M12 connector design. This connector is suitable for EtherNet/IP data transmission up to 1000 Mb/s. The connector used in EtherNet/IP networks shall be compliant with the definition of IEC 61076-2-109. For conformance to Gigabit applications, the M12 X-coded connector shall be used with 4-pair shielded or unshielded Ethernet cables only. The connector performance shall meet the minimum requirements of the IEC 61076-2-109. The connector used in EtherNet/IP networks shall be compliant to both IP65 and IP67 ingress protection ratings at a minimum. Figure 3-10 shows a representation of the plug and jack.

Figure 3-10 – M12 X-Coded Connectors



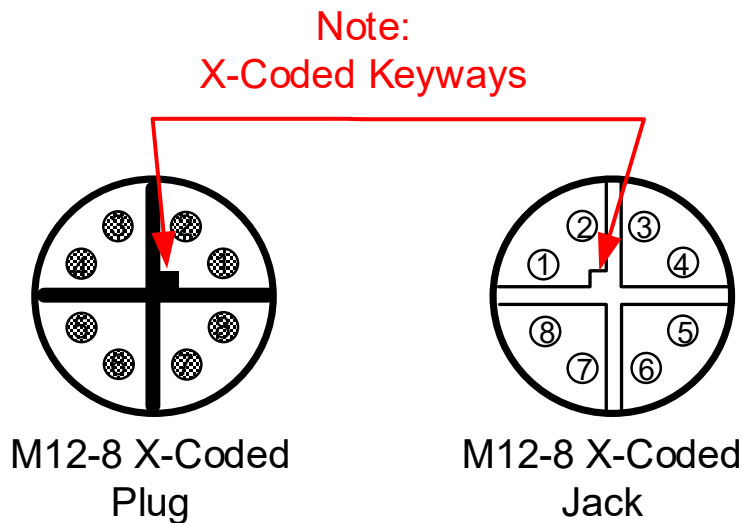
The M12 X-coded connector shall meet the specifications of IEC 61076-2-109 and Table 3-8. Where these specifications are not met there is higher risk for environmental incompatibility with typical industrial environments (e.g., corrosion or vibration) and additional protection may need to be applied. See the MICE tutorial in Chapter 9 for more information.

Table 3-8 – M12 X-Coded Connector Parameters

Industrial Ethernet/IP 8-pole M12 Connector Parameters		
Specification	Type	
Parameter	M12 Shielded	M12 Unshielded
Conductors	8+1 Shield	8
TCL for 1000 Mb/s	94-20*log(f) 0.7 ≤ f ≤ 250 MHz	
TCTL for 1000 Mb/s	71.5-20*log(f) 0.7 ≤ f ≤ 30 MHz	
Contact plating	30 micro inches gold over 50 micro inches nickel or 5 micro inches gold minimum over 20 micro inches palladium nickel over 50 nickel or equivalent plating system	
Contact Life	100 insertions-extractions	

Pin assignments for the M12-8 X-coded connector are shown in Figure 3-11. Pin/Pair assignments can be found in Section 5.2.4.4.

Figure 3-11 – M12 X-Coded Connector Keying



3.4 Selecting Copper Cable

When selecting cable, the cable construction must be compatible with the environment as described by the MICE tables (Table 9-1, Table 9-2, Table 9-3, and Table 9-4). Do not overlook the cable’s electrical performance specifications across temperature ranges, as many off the shelf cables may not meet TIA/EIA standards at temperatures commonly seen in industrial installations. Cable jackets may be easily damaged at low temperature

ranges. Either select cables suitable for the environment or convert the environment to meet the cable specifications through environmental conditioning, isolation, and/or separation techniques. See formulas and tables for cable length de-rating provided in Section 3.1.9.

Chemicals can be absorbed into jackets and wire insulation, causing plastic deterioration and performance degradation. Therefore, special cable constructions or other protection methods may be required (such as separation and/or isolation) in certain chemical environments.

Cables should be selected according to the EMI strategies listed in Section 8.4.1.4. Only cables meeting this specification should be considered for Industrial Ethernet/IP networks.

M12-4 D-coded, M12-8 X-coded, and Sealed 8-way modular connector cable entry point diameters vary. Check with connector and / or cable manufacturer to ensure cable-connector compatibility.

Note: Insulated conductors outside the ranges of 0.032" (.8mm) to 0.039" (1.0 mm) and or cable with larger sheath diameters larger than 0.25" (6.35mm) may not be compatible with some connectors. Consult the connector and or cable manufacturer for cable compatibility.

3.4.1 Two-pair Versus Four-pair Cables

Two-pair cables offer some advantages over 4-pair cables. Two-pair cables are easier to terminate and have less chance of crosstalk. The disadvantage is that they may not follow current generic cabling practice and may not support all the applications (1000 Mb/s, 10 Gb/s and PoE). As a result, 2-pair cables may not support future expansion and/or other services. If the installation needs to be flexible in that generic cables are installed to support multi-services, such as voice, video, and data, then the planner should consider 4-pair cables. Careful long-range planning should be done before selecting a cable pair count. If the plans are to migrate to higher data rates in the future, cables and components should be selected that will support future requirements. For example, backbone cables and materials should be selected to support greater data rates. An example recommended implementation is detailed further in Section 2.4.1.

The connector pole count should always be matched with the cable conductor count. The only exception to this rule is for the 8-way modular connectors. It is acceptable to terminate a 2-pair cable into an 8-way modular connector. Four-pair cables shall not be used with a 2-pair connector, such as the M12-4 D-coded connector as there is no means to terminate the unused 2-pair, possibly creating EMC problems. Where transitioning from 2-pair to 4-pair cables, the unused pairs of the 4-pair cable should be terminated with 100 Ω . This is most easily implemented by bulkhead adapters that have this termination resistors attached internally.

3.4.2 Unshielded and Shielded Cables

For details on choosing a cable with or without a shield, see previous Sections 3.1.11 through 3.1.13.

Cable constructions are often listed based off two levels of shield constructions. The first letter indicates the overall shield, and the second letter refers to the shield construction around each pair. The construction abbreviations are U for unshielded, F for Foiled, and S, for shielded. These constructions are often categorized as one of the following:

1. U/UTP – A completely unshielded cable.
2. These cable types provide improved robustness against formation of ground loops but sacrifice overall EMI performance making them less suitable for E₃ environments (See Section 9).
3. F/UTP – A shielded cable with an overall foil and no shielding applied between individual pairs.
 - a. Shield connection is made via an internal drain wire.
 - b. Without additional strength members, foil shields are typically more susceptible to tearing from mechanical stress, making them less suitable for M₂ or M₃ environments.
4. U/FTP – A shielded cable with no overall shield, but foil shielding applied around each individual pair.
 - a. Shield connection is made via internal drain wires.
 - b. Without additional strength members, foil shields are typically more susceptible to tearing from mechanical stress, making them less suitable for M₂ or M₃ environments.
5. S/UTP – A shielded cable with an overall braided or braided and foiled shield and no shielding applied between individual pairs.
6. S/FTP – A shielded cable with an overall braided or braided and foiled shield with a foil shield applied around each individual pair.
 - a. These cable types present the best shielding performance.
 - b. These cables will often have a larger cable diameter.

3.4.3 Oil-resistant and Chemical-resistant Jackets

If the application requires control of equipment that uses cutting oil or lubricating chemicals, cable jackets should be oil resistant. Further, all chemicals in the application should be considered. See the MICE table (Table 9-3) for common industrial chemicals and their concentrations. Consult the cable manufacturer for further guidance regarding specific chemical compatibility.

3.4.4 Plenum and Riser Rated Cables

Plenum or riser installations require special material compounds in the makeup of the cables. If the application requires cables to be run in riser or plenum spaces, then use the corresponding cables. Consult the local authority having jurisdiction for specific requirements.

3.4.5 Weld splatter-resistant Cables

If the application requires control of welding equipment, then carefully route the cables to reduce damage from weld splatter and interference ingress. All cables should be routed to cross the welding and motor control cables at right angles and should never run parallel to

control and high-current welding cables. The cables should be protected from the weld splatter either by an added protective sheath or by selecting cables with the proper jacket insulation.

3.4.6 High-flex Cables

Typically, Ethernet cables are constructed of #22 AWG to #26 AWG gauge solid copper conductors. High-flex applications require cables with stranded conductors, but may also require special jacket materials, shield constructions, or filler materials. Stranded conductors will have a higher loss as indicated in Table 3-2 and as such will not be able to achieve the same channel length as a solid conductor construction.

Note: Weld Splatter and High-flex applications are commonly found together.

3.4.7 600 V Rated Cables

Industrial Ethernet cables are available with UL AWM 600V recognition; per NFPA 79 guidelines, this 600 V construction and agency approval means these cables can be installed in cable trays near other 600 V cables, if all other requirements are met, and installation best practices are observed. Refer to the manufacturer's instructions and local wiring codes for more information.

3.4.8 Patch Cords, Jumpers, Equipment Cords, and Work Area Cords

Patch cords, equipment cords, and work area cords generally are used for short distance connections, however in industrial installations the length may be extended. Basic construction of cord sets is of a plug connector on both ends of the cable since almost all active and passive devices come equipped with a jack.

3.4.9 Extension Cords

In some cases, it may be necessary to extend a cable. In this case, an extension cord can be used. An extension cord shall be constructed as a plug at one end and a jack at the opposite end. This type of cord construction is also referred to as a Modular Plug Terminated Link or MPTL and can be tested as such.

4 Planning the EtherNet/IP Fiber Optic Cabling

4.1 Planning the Optical Fiber System

General planning of fiber optic cabling systems is much the same as for copper cabling systems. For planning of the active components the guidance of Sections 3.1.1, 3.1.2, 3.1.3, 3.1.4, 3.1.5, and 3.1.14 apply. This document does not go into the differences of glass versus plastic fiber-optic cables, and it is up to the user's discretion on which to choose.

4.1.1 Common Optical Fiber Topologies

Because optical fiber can achieve greater distances than copper media at higher bandwidth with greater electromagnetic interference immunity, it is commonly chosen for a backbone. Two common configurations that optical fiber can serve as backbone media are in a hierarchical star topology as shown in Figure 4-1 or in a ring topology as shown in Figure 4-2. Comparing these two topology choices, the ring topology will provide less total bandwidth but will provide additional fault tolerance in the case that any single switch or backbone fiber link fails.

Figure 4-1 – Example of Optical Fiber Hierarchical Star Topology

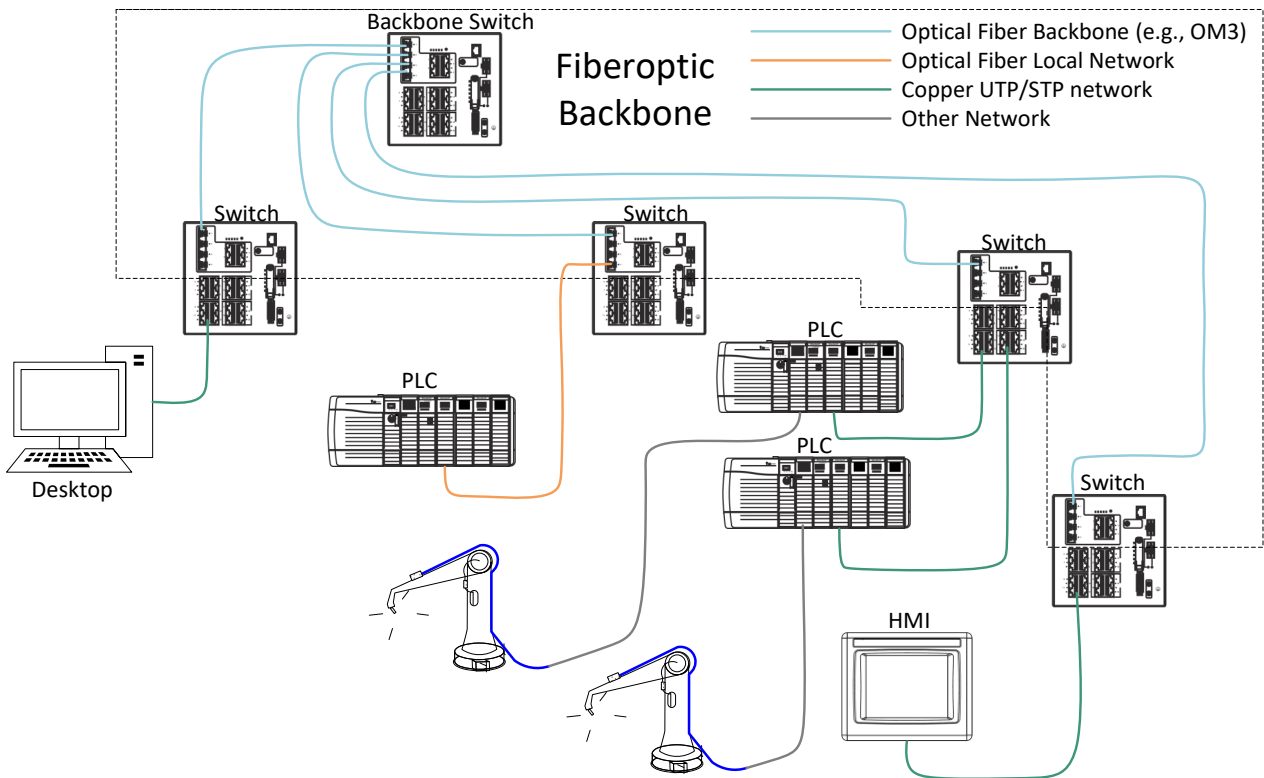
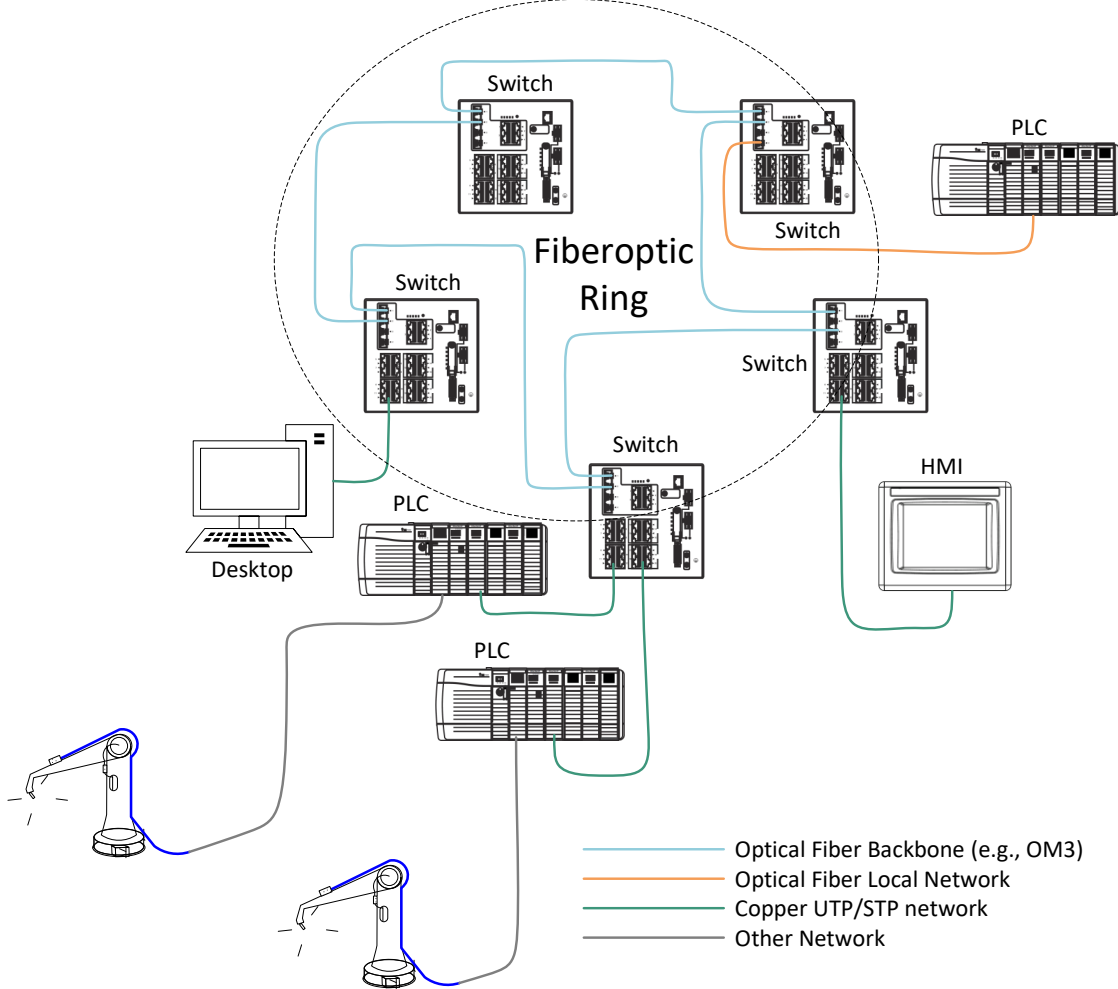


Figure 4-2 – Example of Optical Fiber Ring Topology



4.1.2 Choosing Cable Type

Cable types for optical fiber are divided between multi-mode and single-mode categories. Multi-mode fiber is ranked from OM1 to OM5, and single-mode fiber is classified as OS1 or OS2.

For single-mode fiber, OS1 is generally rated as indoor fiber, while OS2 is rated as outdoor fiber with a lower loss for greater length. Both OS1 and OS2 can achieve up to 10 km link lengths with proper planning. Addition of connectors into the channel will contribute to loss and may require length derating. Single-mode fiber is used for 1000BASE-LX, 1000BASE-LX10, and 100BASE-LX10.

For multi-mode fiber, all categories OM1 through OM5 are sufficient for 1000Mbps communication. All multimode fiber categories can provide up to 2000 m link lengths but may have length limitations based on the number of connectors or the modal bandwidth of the fiber. Higher categories may provide lower loss or a greater modal bandwidth allowing for margin for future. OM1 categories use a 62.5µm core as compared to 50 µm core for the other multimode classes, making it incompatible with the higher classes. OM2 and OM3 classes are recommended for new designs. OM2 is suitable for 1000 Mbps

applications and OM3 is suitable up to 10 Gbps applications. Multi-mode fiber is used for 1000BASE-SX, 1000BASE-LX, 100BASE-FX, 1000BASEX-LX10, and 100BASE-LX10.

4.1.3 Fiber Optic Connectors

Selection of fiber optic connectors in EtherNet/IP systems is driven first by the necessary connected devices and their needed bandwidth and second by the applied environment. All fiber connectors are available in simplex and duplex configurations. For EtherNet/IP applications, duplex configurations are more common as all supported channels utilize a duplex fiber with a transmit and receive pair.

- LC connectors are the smallest footprint using a latch like an 8-way copper connector.
- SC is a larger connector style also using a push/pull style interconnect.
- The ST variant differs by using a bayonet style interconnect.

Each of these connector styles are compatible with multi-mode or single-mode fiber types. LC style connectors are typically recommended for new designs as their small size makes them more compatible with SFP transceiver modules commonly used by EtherNet/IP active devices. Where interfaces may be exposed to corrosive gases, dust, or particulates, it is recommended to apply environmental mitigation such as using sealed connectors.

SC-RJ connectors are supported with plastic optical fiber (POF) for shorter multimode applications.

4.1.4 Number of Connectors in a Channel

In optical fiber systems there is no limit on the number of connectors, instead the total channel insertion loss is the limit. Increasing the number of connectors will increase the contributed loss and lessen the allowable cable length that can be used. See Section 4.1.5 for detailed information.

4.1.5 Channel and Link Lengths

Optical fiber channels are limited by the allowable attenuation. The total contribution from cables plus connectors should not exceed that of the attenuation budget. Generic attenuation budgets for cables and connectors are listed below that can be applied in absence of details from the Manufacturer's data sheet.

Table 4-1 – Optical Fiber Cable Attenuation

Cabled Optical Fiber Attenuation (maximum)						
	Multi-mode (OM1-OM5)		OS1		OS2	
Wavelength (nm)	850	1300	1310	1550	1310	1550
Attenuation (dB/km)	3.0	1.5	1.0	1.0	0.4	0.4

Table 4-2 – Optical Fiber Connector Attenuation

Connection Type	Maximum attenuation (dB)
Mated Connector	0.75
Splice	0.3

Table 4-3 – Attenuation Limits

	Maximum channel attenuation (dB)	
	Multi-mode	Single-mode
1000BASE-SX	3.56 @ 850 nm	
1000BASE-LX	2.35 @ 1300 nm	4.56 @ 1310 nm
100BASE-FX	6.0 @ 1300 nm	
1000BASE-LX10	2.4 @ 1300 nm	6.0 @ 1310 nm
100BASE-LX10	2.4 @ 1300 nm	6.0 @ 1310 nm

To determine the allowable total length, subtract the loss from the connectors from the maximum channel attenuation and divide the remainder by the attenuation per km of cable. For multi-mode applications, if the calculated length is greater than the modal bandwidth limit, then the length is limited by the modal bandwidth.

An example using 1000BASE-LX protocol:

Table 4-4 – Calculated Length Limits using single-mode fiber

Type of Cable	Total Allowable Channel Length					
	Number of Connections	2	3	4	5	6
OM2 cable	550 m	67 m	N/A	N/A	N/A	N/A
OS1 cable	3.06 km	2.31 km	1.56 km	810 m	60 m	N/A

4.2 Planning the Fiber Optic Cable Routing

It is recommended that the planner conduct a route survey and inspection prior to cable installation. Spaces and pathways should be inspected to determine optimum splice locations and support structure (ducts, trays, conduits) assignments. Refer to Section 3.2 for general guidance.

4.3 Selecting Fiber Optic Connectors

The EtherNet/IP Specification supports fiberoptic systems using the LC, SC, ST, or SC-RJ connectors.

Table 4-5 – Connector Support by Fiber Type

Connector Type	Fiber Type				
	POF 1 mm	Hard Clad Silica 200/230 μm	50/125 μm	62.5/125 μm	9/125 μm
LC		X	X	X	X
SC	X	X	X	X	X
ST	X	X	X	X	X
SC-RJ	X	X	X	X	X

Table 4-6 – Optical Fiber Connector Transmission Requirements

Connector Type	Insertion Loss	Return Loss
SC, ST and LC	0.75 dB max.	Single-Mode: 26 dB min. Multi-mode 20 dB min.

Many fiber connectors are manufacturer specific and require the manufacturer’s specific tools for installation. Please consult the manufacturer about installation tools and methods for installing the connector.

4.3.1 LC Style Connector

LC is a small form factor connector that uses a plastic or ceramic 1.25 mm diameter ferrule. It is available in simplex or duplex configuration. The LC connector is available in sealed housing compliant with Variant 1 of IEC 61076-3-106 and EtherNet/IP specification. Examples of the simplex, duplex, and sealed versions are shown in Figure 4-3 through Figure 4-5.

Figure 4-3 – LC simplex connector



Figure 4-4 – LC duplex connector



Figure 4-5 – IP65/IP67 sealed LC duplex connector



4.3.2 SC Style Connector

The SC connector is a push-pull style connector with a plastic housing and 2.5 mm diameter plastic or ceramic ferrule. SC style connectors are available for both SM and MM optical fiber cable, hard clad silica and POF. They are used in both simplex and duplex configurations.

Figure 4-6 and Figure 4-7 show an SC simplex and an SC duplex connector, respectively.

Figure 4-6 – SC simplex connector

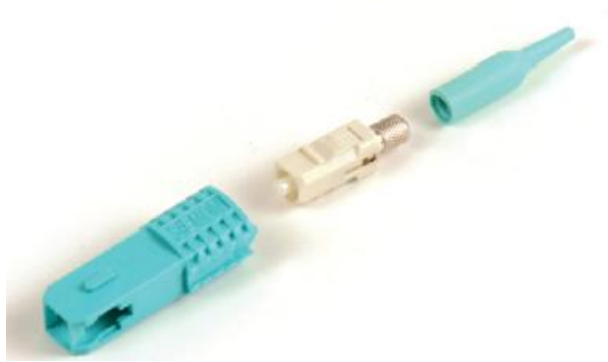


Figure 4-7 – SC duplex connector



4.3.3 ST Style Connector

The ST is a bayonet style connector with a 2.5 mm ferrule diameter. Most ferrules are ceramic, but some are metal or plastic. The ST is an externally spring-loaded connector; consequently, pulling on the fiber cable may cause optical disconnect. ST connectors are available for both single-mode (SM) and multi-mode (MM) optical fiber cables, hard clad silica, and plastic optical fibers (POF). An example of the ST connector is shown in Figure 4-8.

Figure 4-8 – ST Fiber Optic Connector



4.3.4 SC-RJ Style Connector

The SC-RJ connector is a push-pull style connector with plastic housing and a 2.5 mm ferrule diameter. The SC-RJ is a space saving adaption of the SC duplex connector. These connector types accommodate larger optical fiber diameters, making them more commonly used with plastic optical fibers. With the move to higher data rates and the high loss of plastic optical fibers, this connector is generally considered legacy technology. An example of the SC-RJ connector is shown in Figure 4-9.

Figure 4-9 – SC-RJ Fiber Optic Connector



4.4 Selecting Fiber Optic Cable

Single-mode fiber is differentiated by OS1 or OS2. The primary difference is OS2 presents lower loss and as such can be used for longer lengths. Because of this it is generally regarded as outdoor cable. OS1 has higher loss and is generally regarded as indoor cable. Because OS1 allows fiber with more loss, the relative cost is also lower.

Multi-mode fiber uses a larger core diameter which allows for modal dispersion. Higher classes of multi-mode cable use techniques to reduce the contributed modal dispersion, allowing them to achieve a higher bandwidth to a longer length. Because of this their attenuation profiles are very similar, but they are generally differentiated by a metric called modal bandwidth, specified in units of MHz x km. OM1 is the lowest class and is generally considered legacy because of its larger core diameter making it less effective when

converting to another class. OM2 supports 1 Gbps fiber protocols with its modal bandwidth. OM3 can support up to 10 Gbps fiber protocols with its modal bandwidth. OM4 and OM5 multimode fibers can both support speeds higher than 10 Gbps. Generally, OM2 and OM3 are recommended for new Ethernet/IP systems.

Fiber optic "cable" refers to the complete assembly of one or more fibers, strength members and a jacket. Fiber optic cables come in multiple configurations. Careful consideration should be given when selecting the cable, so that it is compatible with the network's environment as defined by the MICE table (Table 9-1, Table 9-2, Table 9-3, and Table 9-4).

For future network expansion and maintenance/failure replacements, the planner is encouraged to consider specifying additional or spare fibers in the backbone.

Figure 4-10 – Single-mode fiber example

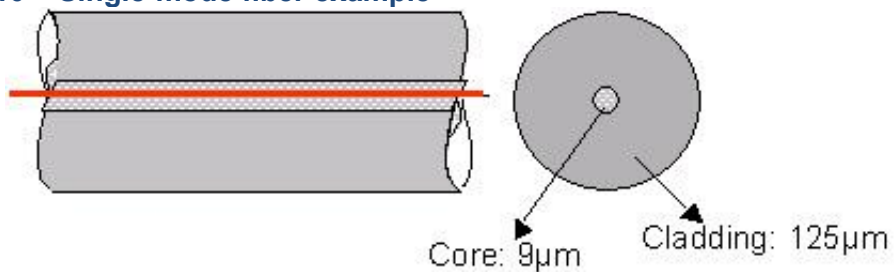
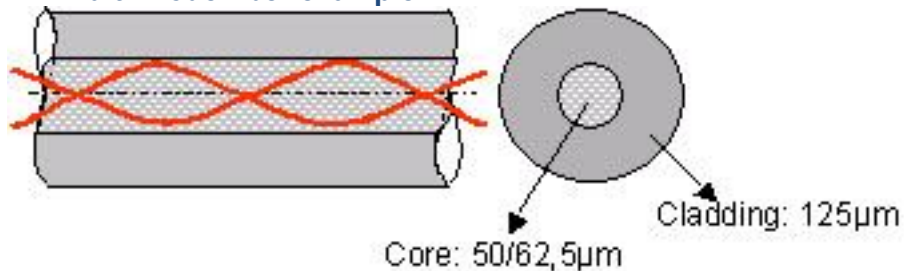


Figure 4-11 – Multi-mode fiber example



4.4.1.1 Operating Wavelengths by Fiber Type

Table 4-7 – Fiber type vs. Operating Wavelength

Mode	Size	Wavelength
GI, MM	1 mm POF	650 nm
GI, MM	200µm Hard Clad Silica	650 nm 850 nm
Multi-Mode	50/125 µm & 62.5/125 µm	850 nm 1300 nm
Single-Mode	9/125 µm	1310 nm 1550 nm

4.4.1.2 Bandwidth by Fiber Type

Table 4-8 – Fiber Type and Bandwidth

Fiber Type	Type	Max. Attenuation 650 nm (dB)	Max. Attenuation 850 nm/1300 nm (dB)	Min. Bandwidth 850 nm/1300 nm (MHz)
62.5/125 µm	OM1		3.0/1.0	200/500
50/125 µm	OM2		2.5/0.8	500/500
	OM3		2.5/0.8	2000/500
	OM4		2.5/0.8	4700/500
	OM5		2.5/0.8	4700/500
62.5/125 µm (FDDI)			4.0/2.0	160/500
100/140 µm			5.0/2.0	100/100
9/125 µm	OS1/OS2		-/0.4	
1 mm POF		18		
200/230 µm Hard Clad Silica		12	8	5

4.4.1.3 Core and Cladding Diameters by Fiber Type

Table 4-9 – Optical Fiber core and cladding size

Core Cladding vs Fiber Sizes			
Fiber Type	Core Diameter (µm)	Cladding Diameter (µm)	Numerical Aperture
50/125 µm	50 ± 3.0	125 ± 3.0	.200 ± .015
62.5/125 µm	62.5 ± 3.0	125 ± 3.0	.275 ± .015
62.5/125 µm (FDDI)	62.5 ± 3.0	125 ± 3.0	.275 ± .015
100/140 µm	100 ± 4.0	140 ± 6.0	.290 ± .015
9/125 µm			
1 mm POF			
200/230 µm Hard Clad Silica	200 ± 4.0	230 ± 10.0	.370 ± .02

4.4.2 Types of Fiber Optic Cable

4.4.2.1 Simplex and Zipcord

Simplex cables are one fiber that is “tight buffered” (coated with a 900 µm buffer over the primary buffer coating) with Kevlar™ (aramid fiber) strength members and jacketed for indoor use. The jacket can be from 1.6 mm to 3 mm in diameter. Zipcord is simply two of these joined with a thin web. It’s used mostly for patch cord and backplane applications, but zipcord can also be used for desktop and equipment connections.

Distribution cables: They contain several 900 µm tight-buffered fibers bundled under the same jacket with strength members and sometimes a glass-reinforced plastic (GRP) rod to stiffen the cable and prevent kinking. These cables are small, and used for short, dry conduit runs, riser and plenum applications. The fibers are contained within a 900 µm buffer and can be directly terminated but, because their fibers are not individually reinforced, these cables need to be terminated within a distribution box, patch panel or junction box.

4.4.2.2 Breakout Cables

They are made of several simplex cables bundled together. This is a strong, rugged approach, but is larger and more expensive than using distribution cables. It is suitable for conduit runs, risers and plenum applications. Because each fiber is individually reinforced, this design allows for quick termination to connectors and does not require patch panels or junction boxes. Breakout cable can be more economic where fiber count is small, and distances are short.

4.4.2.3 Loose Tube Cables

These cables are comprised of several fibers, which are wound around a central strength member inside a small plastic tube and jacketed, providing a small, high fiber count cable. This type of cable is ideal for outside plant applications, as it can be made with loose tubes filled with gel or water absorbent powder to prevent harm to the fibers from water. Loose tube cables are typically installed in conduits, innerduct, overhead or direct buried.

Since the fibers have only a thin protective coating, they must be handled carefully and protected to prevent damage.

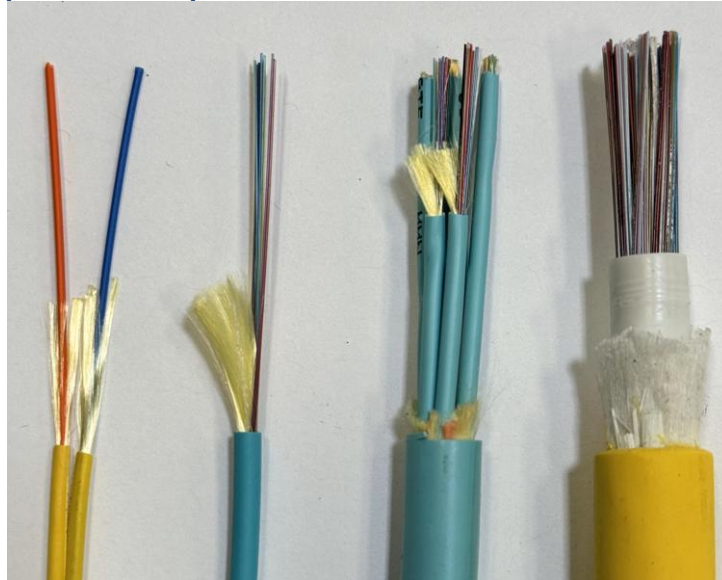
4.4.2.4 Armored cable

Armored cable is generally used for outside plant environments. It can be placed in conduit systems, direct buried, aerial spans and anywhere additional mechanical protection is required. Proper grounding techniques must be followed. Most cable types (simplex, zipcord, distribution, breakout cables, and loose tube cables) are available with armor. If armored cable is used for inside plant environments, the jacket material must have the proper safety ratings for indoor use.

4.4.2.5 Aerial Cable

There are several types of aerial cables available with different mechanical support members. Aerial cables are for installation on poles or building columns.

Figure 4-12 – Types of fiber optic cables



4.4.3 Choosing a Cable

Consult the manufacture for the correct cable for the application and environment as defined by the MICE tables (Table 9-1, Table 9-2, Table 9-3, and Table 9-4).

4.5 Planning and Installation of Fiber Optic Cables

Optical fiber cables may be routed in a variety of pathway types. Pathways shall meet the requirements as specified in ANSI/TIA-569-B. Types of pathways include:

- Under floor systems like Trench Duct or Cellular
- Access Floor
- Cable Tray / Wireway
- Non-Continuous like “J” Hooks, Bridle Rings, Slings etc.
- Conduit Systems
- Power poles
- Modular Furniture
- Wall Cavities
- Raceway (non-metallic or metallic)

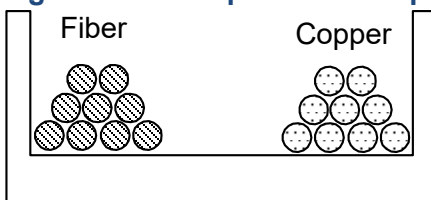
Pathways must be suitable for the environment in which they are routed. Plenum or non-plenum areas must also meet local, and national codes.

To prevent damage to the fiber cable such as crushing or bends, fiber cables should be separated from copper cables when possible. Some optical fiber cables may be armored and have heightened mechanical compatibility, others may not and instead may need to be mitigated with a continuous pathway, see Chapter 9 (MICE Tutorial) for more information on environmental mitigation. The use of multichannel raceway/material, innerduct, or physical separation helps protect the fiber cable.

Fiber Pathways:

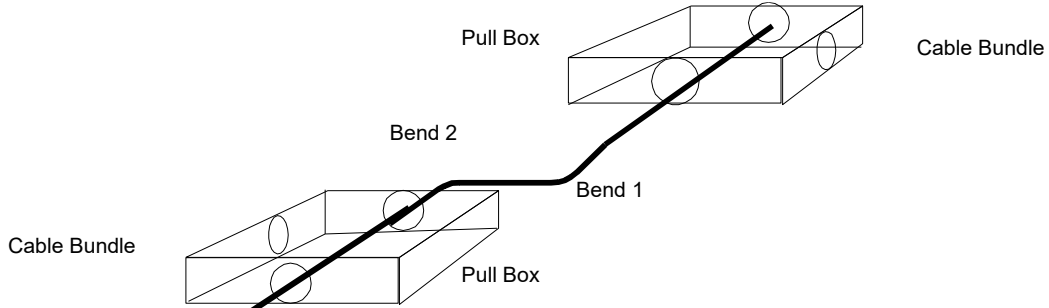
- a) Conduit provides a continuous pathway providing an enhanced degree of mechanical protection. Its use does require pulling of the cable and as such may add complexity to installation through the need of pull boxes to prevent damage. Because it is pulled it also requires field termination which may lead to higher loss connections. The fill percentage allowable with conduit is relatively low. As more cables are added, increased friction increases the chance for cable damage during the installation. Conduit provides the highest degree of protection to the fiber.
- b) Duct/Raceway type pathways provide continuous support to the fiber. These pathways allow the laying of cable after removal of a cover or panel and as such allow use of factory terminated cable with a higher allowable fill percentage. This also allows for ease of adding additional cables later. Ducts and Raceways provide a high degree of protection to the fiber.
- c) Grid type pathway provides point based mechanical support that is not continuous. The supports are typically every 3 inches. These pathways allow laying of cable and as such allow use of factory terminated cable with a high allowable fill percentage. After laying the cable hook and loop type cable management is used to stabilize the cable bundles. Grid type pathways provide a high degree of ease to add additional cables but only provide a moderate degree of fiber protection.
- d) Ladder racks provide point based mechanical support that is not continuous. The supports are typically every 12 inches. These pathways allow laying of cable and as such allow use of factory terminated cable with a high allowable fill percentage. After laying the cable hook and loop type cable management is used to stabilize the cable bundles. Ladder racks provide a high degree of ease to add additional cables but only provide a moderate degree of fiber protection. Because of the low-density point support, ladder racks are typically not suitable for unprotected fiber.
- e) J hooks provide point-based support with additional support every 4-5 feet. The relative cost and simplicity of installation is low; however, they are not suitable with unprotected fiber. These pathways provide very little to no protection to the fiber.
- f) When fiber cables are in the same wireway, the fiber cables shall be on one side and the copper cables on the opposite side as shown in Figure 4-13.

Figure 4-13 – Separation of Optical Fiber and Copper Cables in Wireways



In underfloor systems (cellular/trench) or conduit, install a pull box when runs exceed 30 m (100 ft.) or when there are more than two 90-degree bends. Center-pull and/or back-feeding methods are recommended to reduce cable loading as shown in Figure 4-14

Figure 4-14 – Cable Load Reduction



4.5.1 Conduit and Innerduct

Building cables can be installed unprotected or placed inside appropriately rated innerduct. This innerduct may be brightly colored to provide easy identification of fiber optic cable. Color designations for fiber type are specified in Table 4-10.

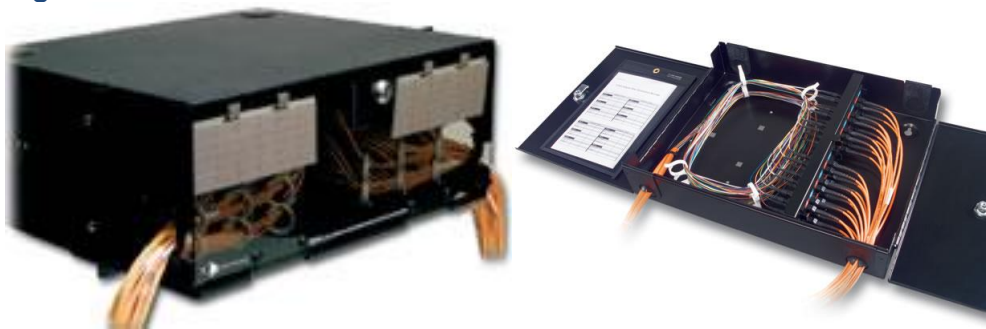
Table 4-10 – Fiber Category Color Designations

Type	Single Mode		Multimode				
Category	OS1	OS2	OM1	OM2	OM3	OM4	OM5
Color	Yellow	Yellow	Orange	Orange	Aqua	Aqua	Lime Green

4.5.2 Cable Plant Hardware

Various enclosures, cabinets, racks and panels are used to protect and organize splice and termination points. The network planner should know the type of network, support systems and cable routes to be taken. Then the connection/splice locations can be determined, and the hardware planned.

Figure 4-15 – Rack and wall mounted fiber enclosures and breakout kits



4.5.2.1 Slack Spools

Because fiber optic cable is bending sensitive, excess cable length should be managed in slack spools. Slack spools are a cable management tool to gather a length of fiber while maintaining a proper bend radius.

4.5.2.2 Breakout Kits

Breakout kits are used for loose tube fiber optic cables to protect and separate for individual termination or splicing.

4.5.2.3 Splice enclosures

Splice enclosures are used to protect fiber optic splice points.

4.5.2.4 Splice Panels

Splice panels are used to connect individual fibers from cables to pigtailed.

4.5.2.5 Patch Panels

Patch panels provide a centralized location for interconnecting, testing, and monitoring. See Section 2.5.3 for more information.

4.5.2.6 Racks and Cabinets

Racks and cabinets are used to house patch panels, splice panels, and provide cable management facilities.

4.6 Fiber Optic Installation Guidance

4.6.1 Water Protection

Cables designed for outside plant and wet locations typically contain water- or moisture-blocking material. There may be special handling requirements for these types of cables. The planner and installer are strongly encouraged to consult the manufacturer for handling and termination requirements.

4.6.2 Local and National Fire Codes

The planner and installer are strongly encouraged to consult the local and national fire codes for material and installation and cable-marking requirements. Some cable constructions may not be suitable for indoor, unprotected installations. There are several cable constructions available such as riser, plenum, LS0H and PMSHA. Consult the local and national codes for marking requirements to help in identifying the correct cable for the installation environment. For US and Canada installations, cables without markings should not be installed indoors as they may not pass inspections.

4.6.3 Injury Risk while Prepping Fiber Ends

When prepping fiber ends, the installer should use safety glasses and cut resistant gloves. Glass scrap pieces will be very thin especially after jacketing is stripped and can easily cut skin. If a cut occurs, these small glass scraps can be difficult to remove fully without breaking. Care should be taken to discard glass scraps as soon as possible to limit this risk.

4.6.4 Pulling Fiber Optic Cable

All fiber cables have two tensile strength limits, long term (unloaded) and short term (loaded). Short term is the maximum tension placed on the cable during installation and long term is the maximum tension placed on the cable during service. These limits must not be exceeded. The planner and installer are strongly encouraged to consult the manufacturer’s data sheet for the tensile ratings.

The installation methods and rules for both copper and optical fiber are similar. The following recommendations should be considered during installation process:

- Do not pull on the fibers; pull on the strength members only. Some manufacturers provide a pulling grip for cables.
- If lubricants are used, ensure that they are compatible with the cable being installed.
- For long runs, pull boxes should be installed to reduce the pulling tension on the cable. See Table 4-11 below.
- Consider using an automated puller with tension control.
- Do not exceed the cable bend radius both during installation and for fixed installation. Consult the manufacturer’s data sheet for these limits. If the bend radius is not available, see Table 4-11 for guidance.
- Do not twist the cables during installation. Cables should be spooled out as they are pulled to prevent twisting. Breakaway swivels can be used to eliminate twisting during pulling.
- Check the length. Make sure the cable is long enough for the intended installation. Splices should be minimized.
- Many fiber connectors are manufacturer specific and require the manufacture’s specific tools for installation. Consult the manufacturer about installation tools and methods for installing the connector.
- Secure vertical cable every 91 cm (36 in.). Secure horizontal cable every 120 to 150 cm (48 to 60 in.)

Table 4-11 – Fiber Optic Bend Radius and Pull Force

Service		Bend Radius		Max. Pull Force
		Loaded	No-Load	
Inside Plant	Horizontal/Centralized 2 & 4 fibers intended to be pulled through horizontal pathways	50 mm (2 in.)	25 mm (1 in.)	222 N (50 lbf)
	All other inside plant cables	15X diameter	10X diameter	222 N (50 lbf)
Outside Plant		20X diameter	10X diameter	2670 N (600 lbf)

5 Network Installation

This chapter provides guidance for copper and fiber cabling.

Note: Read Chapter 3 and Chapter 4 before installing the network.

5.1 Installing the Active Devices

If you are using off-the-shelf commercial active devices, consult the manufacturer's data sheets for installation requirements in the environment. Some active devices, located in MICE 2 or 3 environments, may require mitigation strategies such as: enclosures, shock mounting, or temperature controls. The placement of the active device is important from an access perspective. Active devices should be located to minimize the cable lengths to other devices. This may conflict with the environmental specifications of the active device. Consider using industrial rated active devices for harsh applications.

5.2 Installing the Copper Cabling

Install the fixed horizontal cable, observing the cable supplier's installation instructions and following the guidelines in this subclause.

5.2.1 General Copper Cabling Installation Considerations

5.2.1.1 Bend Radius

Twisted pair cable bend radius should not exceed those listed in Table 5-1.

Table 5-1 – Permissible Copper Cabling Bend Radius

Cable Type	Cable bend radius
UTP	4x
STP	8x
Hybrid bundled or multipair cable	10x
Note: x refers to a multiplying factor against the cable diameter. For example, if the cable diameter is 5 mm, the UTP bend radius would be 20 mm minimum.	

Note: These requirements are referenced from ANSI/TIA 568.0-E and applicable in absence of manufacturer guidance. For more details or exceptions to these requirements see the manufacturer's data sheet.

5.2.1.2 Pull Strength

Refer to manufacture's guidelines for maximum pull tension. If the manufacturer's guidelines are not available, the pull strength should not exceed 111 N (25 lbf) for copper cabling as defined in ANSI/TIA 568.0-E.

5.2.2 Terminating the Fixed Horizontal Cable

The installation may require the use of punch-down terminations for terminating the fixed cable. Termination tools can be simple plastic throw-away tools with a short life; others are intended for long-term use and will punch-down the wire and cut/trim at the same time. Read and understand the tool manufacturers' user manual on proper use and tool life. In addition, consult the termination system data sheet for recommendations on the process and which tools are allowed.

Note: It is cautioned that the improper application of terminations to fixed horizontal cabling may negatively impact the applicable cabling life and increase the likelihood of failure.

Care should be taken on routing the cable pairs into the connection so as not to degrade the cabling performance. Do not untwist the pairs or the conductors within the pair any more than necessary.

5.2.3 Types of Cables

EtherNet/IP allows for multiple types of cable types, each with slightly different application targets. Common cable constructions are defined in Section 3.4.2.

Further cables are differentiated by their conductor sizes. The larger the conductor size (the smaller the AWG number), the lower loss the cable will have. Of a particular gauge, a stranded conductor will have higher loss than a solid core conductor but will have an improved flexibility and resistance to mechanical stress. Relationship of conductor loss to overall allowable link length is discussed further in Section 3.1.9.

5.2.4 Connector Wiring Codes

A summary of supported connector types and their respective wiring codes is provided in Table 5-2 Further detail is provided for the 8-way modular connector in Section 5.2.4.2, the M12 D-coded connector in Section 5.2.4.3, and the M12 X-coded connector in Section 5.2.4.4.

Table 5-2 – Summarized Connector Wiring Codes

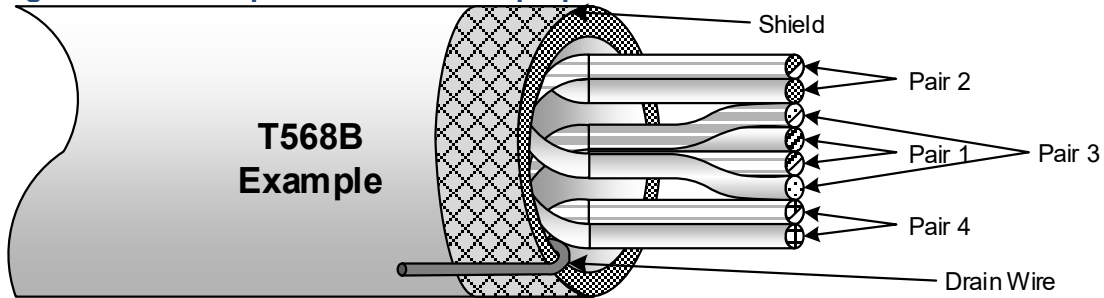
Connector Types			Wiring Codes			
8-Way Modular (RJ45)	8-Pole M12 X-Coded	4-Pole M12 D-Coded	T568B	T568A	T568B (2-Pair)	T568A (2-Pair)
1	1	1	White / Orange	White / Green	White / Orange	White / Green
2	2	3	Orange	Green	Orange	Green
3	3	2	White / Green	White / Orange	White / Green	White / Orange
4	8	-	Blue	Blue		
5	7	-	White / Blue	White / Blue		
6	4	4	Green	Orange	Green	Orange
7	5	-	White / Brown	White / Brown		
8	6	-	Brown	Brown		

5.2.4.1 When to use T568A or T568B

EtherNet/IP recognizes both T568A and T568B pin/pair assignments. It is recommended that T568B wiring scheme be used, although T568A may be used if needed. T568A scheme exists for backwards compatibility with telephone systems. Neither offers any performance gains over each other. Some government agencies require T568A wiring.

Note: Mixing of T568A and T568B wiring shall only be for crossover cords in the channel.

Figure 5-1 – Example of T568B cable preparation



Note: The performance of the channel will depend on cable preparation.

- **Extend the pair twists out as far as possible.**
 - **Pair 3 (T568B) is evenly split across pair 1**
-

5.2.4.2 8-way Modular Connector

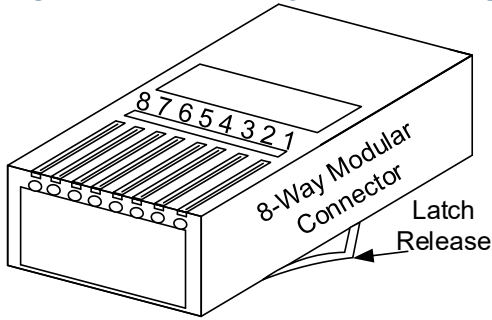
The following 8-way modular pin assignment in Table 5-3 and

Figure 5-2 applies to the IP 20 and sealed variants.

Table 5-3 – 8-way Modular Connector Pin/Pair Assignment

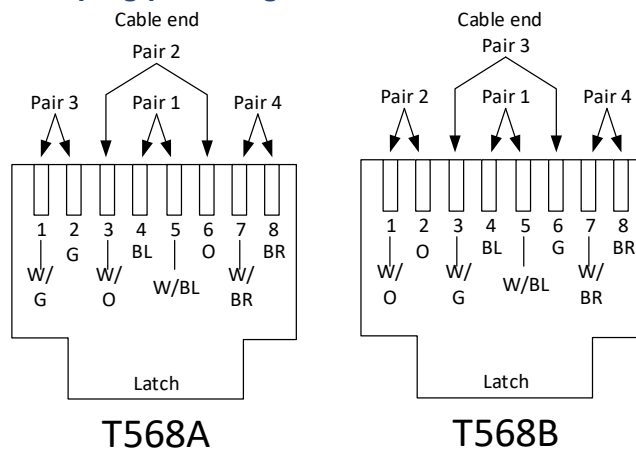
PIN	Pin T568B	Pair Assignment	Pin T568A	Pair Assignment
1	White / Orange	Pair 2	White / Green	Pair 3
2	Orange		Green	
3	White / Green	Pair 3	White / Orange	Pair 2
4	Blue	Pair 1	Blue	Pair 1
5	White / Blue		White / Blue	
6	Green	Pair 3	Orange	Pair 2
7	White / Brown	Pair 4	White / Brown	Pair 4
8	Brown		Brown	

Figure 5-2 – An 8-way modular plug pin out Face (Connector) View



Pin/Pair assignments for the 8-way modular connector are as shown in Figure 5-3.

Figure 5-3 – 8-way modular plug pin Assignments



5.2.4.3 4-Pole M12 D-coded Connectors

Figure 5-4 – 4-pole M12 D-coded pin out Face (connector) view

Note:
D-Coded Keyways

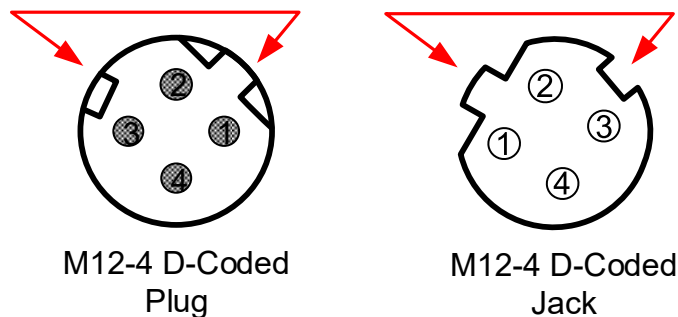
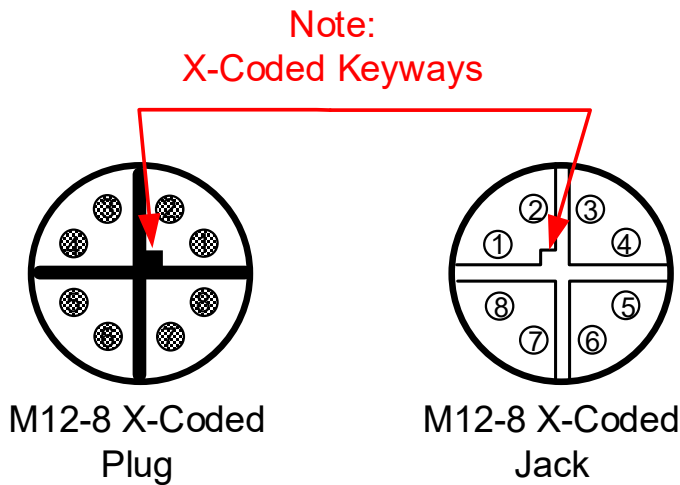


Table 5-4 – M12 D-Coded Connector Pin/Pair Assignment

M12-4 Pin	Pin Assignment T568B	Pair Assignment	Pin Assignment T568A	Pair Assignment
1	White / Orange	2	White / Green	2
2	White / Green	3	White / Orange	3
3	Orange	2	Green	2
4	Green	3	Orange	3

5.2.4.4 8-Pole M12 X-coded Connectors

Figure 5-5 – 8-pole M12 X-Coded Connector Keying Face (connector) view



The 8-pole M12 X-coded connector shall be wired in accordance with the pin/wire assignments in Table 5-5.

Table 5-5 – Sealed M12-8 X-Coded Connector Pin/Pair Assignment

M12-8 Pin	Pin Assignment T568B	Pair Assignment	Pin Assignment T568A	Pair Assignment
1	White / Orange	2	White / Green	3
2	Orange		Green	
3	White / Green	3	White / Orange	2
4	Green		Orange	
5	White / Brown	4	White / Brown	4
6	Brown		Brown	
7	White / Blue	1	White / Blue	1
8	Blue		Blue	

5.2.5 Constructing Cord Sets

There are two main types of cord sets used by EtherNet/IP systems: standard cord sets and crossover cord sets. Standard cord sets are defined by using the same wiring code for the connectors at both ends of the cable (i.e., T568B to T568B or T568A to T568A). T568B wiring code is preferred for new installations. A crossover cable will use a mixed wiring code, where one end of the cable uses a T568B wiring code and the other end uses T568A wiring code. These definitions apply regardless of the connector types selected. See the wiring tables above for proper wiring code for each supported connector type.

All ODVA compliant 1000 Mb/s applications are required to support a physical layer feature called Auto-MDIX and most newer 10/100 Mb/s applications also support this feature. Auto-MDIX is a feature where a device can automatically detect the wiring scheme and automatically adjust its signaling to be compatible with standard or crossover type connections. Because of this, standard cord sets are recommended for all new installations to simplify the cabling administration.

Construction of conversion cables is permissible. Conversion cables constructed with M12 X-coded connector to 8-Way modular connectors shall be constructed from 4-pair cables containing the wire color codes defined in Table 5-2. Construction of crossover cables between T568A and T568B is permissible.

The 2-pair cord sets supported by EtherNet/IP include:

- 8-way modular to 8-way modular
- 4-pole M12 D-coded to 4-pole M12 D-coded
- 8-way modular to 4-pole M12 D-coded
- 4-pole M12 D-coded to 8-pole M12 X-coded
- 8-way modular to 8-pole M12 X-coded

The 4-pair cord sets supported by EtherNet/IP include:

- 8-way modular to 8-way modular
- 8-pole M12 X-coded to 8-pole M12 X-coded
- 8-way modular to 8-pole M12 X-coded

5.2.5.1 Field-terminating the Cable Ends

The performance of the system depends on the cable termination. Careful cable end preparation is essential for proper connector installation and signal integrity.

Note: Preparation of the conductors prior to installation into the connector back end is of most importance.

Some field-attachable 4-pole M12 D-coded, 8-pole M12 X-coded, or 8-way modular connectors utilize Insulation Displacement Contact (IDC) technology and do not require crimp tools. Only a sharp cutting tool is necessary to strip away the cable outer jacket. Other connector types include pre-terminated, over-molded cord sets (no assembly required), screw types, crimp types, or solder types. Follow the manufacturer's assembly instructions for correct installation.

5.2.5.2 Terminating Modular 8-way Plugs

Depending on the connector selected, the installation procedure can significantly differ. For best guidance refer to the manufacturer's instructions. Wiring codes should follow Table 5-3 for 8-way modular connections. Consider the guidance of Section 5.2.4.1 to select when to apply T568A or T568B wiring codes.

5.2.5.3 Terminating an M12 Connector

Depending on the connector selected, the installation procedure can significantly differ. For best guidance refer to the manufacturer's instructions. Wiring codes should follow Table 5-4 for M12 D-coded connections and Table 5-5 for M12 X-coded connections. Consider the guidance of Section 5.2.4.1 to select when to apply T568A or T568B wiring codes.

5.2.5.4 Terminating UTP Cable

For terminating UTP cables, there are no shield elements to consider. The jacket should be removed to a length defined by the manufacturer's instructions and any filler materials trimmed away from the terminations. When stripping the jacket, care should be taken not to damage the insulation of any individual conductors, if any conductors have damaged insulation, the end of the cable should be cut-off and the termination process restarted. The individual twisted pairs should be untwisted only to the length needed to enter the connector conductor organizer. Any excess length of the conductors should be trimmed as close to the terminations as possible. The conductor's termination step should then be applied according to the manufacturer's instructions. After conductor termination, some connectors will have an additional step to attach to the cable jacket; this step is desirable to prevent mechanical stress on the internal conductors and may be required to preserve the specified ingress protection rating.

5.2.5.5 Terminating STP Cabling

STP cable will follow the same general process as UTP, but with additional requirements for shield termination. Terminating the shield to the connector is done only after the twisted pairs are terminated.

When stripping the jacket, care should be taken to not cut any of the braided shield strands. If multiple strands of the shield are damaged, restart the termination process by cutting off the damaged cable end. Once the jacket is properly removed, any braided shield should be folded back along the jacket, and any foil shield(s) should be trimmed away from the twisted pairs (see Figure 5-1 as example). If a drain wire is present, it is equally important not to damage any of the drain wire strands.

The shield termination step largely varies by connector vendor but generally the larger the contact area between the connector and the cable shield, the better shielding performance. This implies a braid should remain spread out around the cable to maximize contact area.

Note: Always terminate the shield of the cable.

5.2.6 Installing Bulkhead Feedthroughs

There are two reasons to use bulkhead feedthroughs: modularity and serviceability. When cables need to exit an enclosure, it is necessary to protect the internal environment. Therefore, wire glands and feedthroughs rated for the external environment must be used. It is advisable to always place these devices on the top or bottom of the enclosure or on sides not exposed to other machinery where they will be damaged. Whenever mating cord sets are not available for immediate connection, use dust caps to maintain an IP seal and prevent degradation.

5.2.7 Installing the Cable

When installing the cable, there are a few options available depending on the cord sets and pathways selected. The cable can either be laid or pulled. A cable should only be pulled if there is not a connector preinstalled at the end and must be pulled if the pathway does not have open access. Laying a cable involves placing it in a pathway, which means less friction, less mechanical stress, and smaller chance for built up electrostatic potential. For this reason, laying is generally preferred where possible. Laying must be used with pre-terminated cord sets. In addition to this general guidance, consider the following considerations:

- Refer to the guidelines in Sections 3.2 and 4.5 when routing the cable.
- Plan the location in such a way that the connector cannot be damaged.
- Sealed connectors can be located outside the enclosure in areas that are subject to dust, liquids, and vibration.
- Install the cable per the manufacturer's requirements for bend radius and pull strength. Refer to Table 5-1 for additional information.

5.3 Installing the Optical fiber cabling

Refer to manufacturer's recommendations for installation guidance.

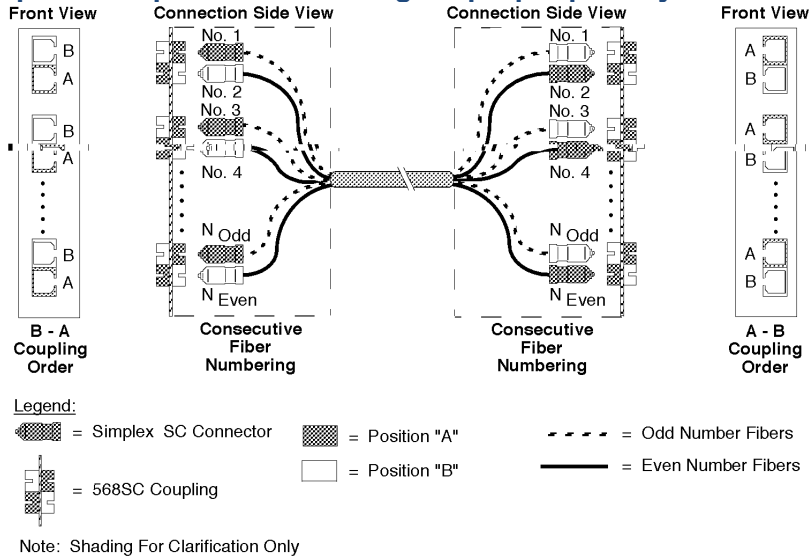
The bend radius for intra building 2 and 4-fiber horizontal optical fiber cables shall not be less than 25 mm (1 in.) under no-load conditions. When under a maximum tensile load of 222 N (50 lbf), the bend radius shall not be less than 50 mm (2 in.). Cable bend radius should not exceed those listed in Table 5-1.

The bend radius for intra-building optical fiber backbone cable shall not be less than that recommended by the manufacturer. If the bend radius is not available, then the applied bend radius shall not be less than 10 times the cable outside diameter under no-load conditions and not less than 15 times the cable outside diameter when the cable is under load.

The bend radius for inter-campus optical fiber backbone cable shall not be less than that recommended by the manufacturer. If no recommendation is provided or known, then the bend radius shall not be less than 10 times the cable outside diameter under no-load conditions and not less than 20 times the cable outside diameter when the cable is under a tensile load up to the rating of the cable, usually 2670 N (600 lbf).

Install each cabling segment so that odd numbered fibers are Position A at one end and Position B at the other end while the even numbered fibers are Position B at one end and Position A at the other end. See Figure 5-6.

Figure 5-6 – Specified optical fiber cabling for proper polarity



Achieve the Duplex SC implementation using consecutive fiber numbering (i.e., 1,2,3,4...) on both ends of an optical fiber link, but the Duplex SC adapters shall be installed in opposite manners on each end (i.e., A-B, A-B... on one end and B-A, B-A... on the other).

For other duplex connector styles, polarity may be achieved either by using the above method for the Duplex SC or by using reverse-pair positioning. Reverse-pair positioning is achieved by installing fibers in consecutive fiber numbering (i.e., 1,2,3,4....) on one end of an optical fiber link and reverse-pair numbering (i.e., 2,1,4,3....) on the other end of the optical fiber link.

Figure 5-11 illustrates the proper orientation of the Duplex SC adapter at the main cross-connect, intermediate cross-connect, horizontal cross-connect and telecommunications outlet/connector to ensure proper polarity of an optical fiber system from the cross-connect to the telecommunications outlet/connector. Optical fiber links not shown in Figure 5-6 shall be installed to ensure that on one end, the Duplex SC adapter is installed in the A-B orientation and, on the other end, installed in the B-A orientation.

5.3.1 General Optical Fiber Installation Considerations

Because optical fiber has a high immunity to electromagnetic interference and has a high resistance to light entering the fiber laterally, the largest factor that will impact the cable reliability is attenuation. The fiber attenuation is driven based on component selection and application. The two primary contributors to fiber loss introduced in installation are connector loss or cable bending losses.

Single mode fiber has a smaller core making it more susceptible to connector losses, but less susceptible to cable bending losses. Multimode fiber has a larger core giving it more resistance to connector losses, but more susceptibility to cable bending losses. Because single mode fiber is so sensitive to connector losses the cleaning and polishing of the fiber end is critical, and as such field termination of connectors is often not recommended. Instead, application of field terminated pigtails with fusion splicing to the main cable length is preferred.

5.3.1.1 Bend Radius

Cable bend radius should not exceed those listed in Table 5-6.

Table 5-6 – Permissible Fiber Optic Cabling Bend Radius

Cable Type	Cable bend radius	
	No load	Loaded (during installation)
Fiber up to 4-strand	1 in. (25.4 mm)	2 in. (50.8 mm)
Fiber greater 4-strand	See manufacturer's data sheet (if not available 10x diameter)	See manufacturer's data sheet (if not available 15x diameter)

These requirements are applicable in absence of manufacturer guidance. For more details or exceptions to these requirements see the manufacturer's data sheet.

5.3.1.2 Pull Strength

Refer to manufacturer's guidelines for maximum pull tension. If the manufacturer's guidelines are not available, the pull strength should not exceed 222 N (50 lbf) for fiber cables of 2 and 4 fibers.

5.3.2 Types of Optical Fiber Cables

Refer to Section 4.4.2 for fiber optic cable types.

5.3.3 Types of Optical Fiber Connectors

All ODVA supported optical fiber applications are duplex protocols which refers to having a designated Tx and Rx pair. This is mostly driven by device connectivity which dominates using the LC formfactor for reduced size. Some devices may also utilize duplex SC interfaces.

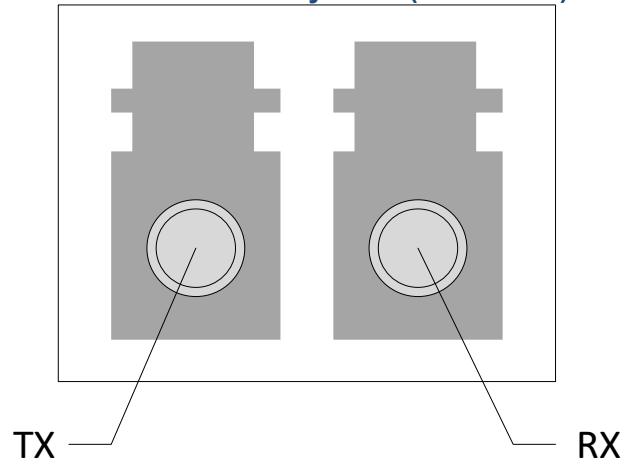
Secondary with the connector type Fiber optic connectors have options for ferrules. This includes physical contact (PC), ultra physical contact (UPC), and angled physical contact (APC). PC types have ferrules in either side of the connector with parallel mating faces that leave a gap between the fibers leading to higher connector loss, but less risk of transferring dust and damage. UPC types have ferrules in either side of the connector with parallel mating faces that are virtually gapless, resulting in reduced loss against PC, but increased risk of dust and damage transfer. APC types have ferrules in either side of the connector that have mating faces angled by 8° resulting in an even further reduced loss. UPC type ferrules can be mated with PC type ferrules, but the connector performance will be limited by the PC ferrule.

Note: APC ferrule types are incompatible with PC and UPC type ferrules and intermating has a chance to result in physical connector damage.

5.3.3.1 LC connector

LC connectors are often used as duplex style. This has a defined polarity associated with a defined transmit and receive polarity at the device. The device polarity is shown in Figure 5-7.

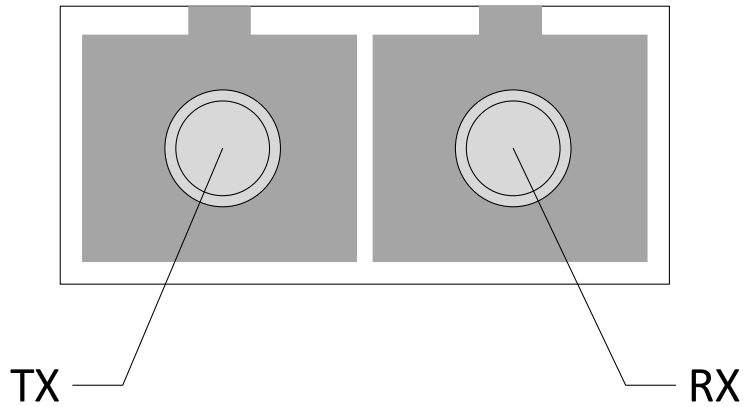
Figure 5-7 – Fiber Optic LC Connector Polarity Face (connector) view



5.3.3.2 SC connector

SC connectors are often used as duplex style. This has a defined polarity associated with a defined transmit and receive polarity at the device. The device polarity is shown in Figure 5-8.

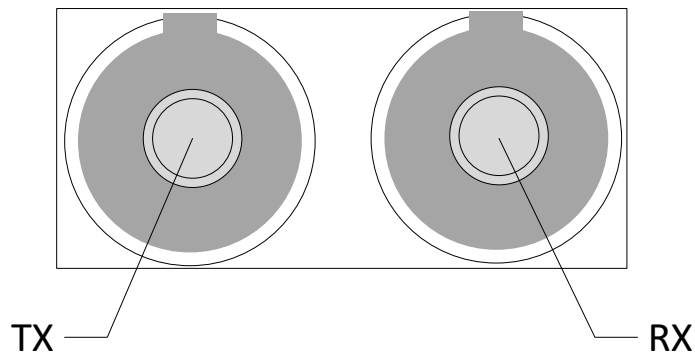
Figure 5-8 – Fiber Optic SC Connector Polarity Face (connector) view



5.3.3.3 ST Connector

ST style connectors only support simplex connections, and a duplex ST only consists of two ST simplex connections. For solution consistency, where used it is recommended to use the same pin orientations and labels or color codes for marking polarity.

Figure 5-9 – Fiber Optic ST Connector Polarity Face (connector) view



5.3.4 Constructing Fiber Optic Cords

All ODVA supported optical fiber applications are full duplex protocols which refers to having a designated Tx and Rx pair. This indicates that channels must be constructed with a single point of crossover. Because of this all cords are defined as either standard cords or crossover cords.

5.3.4.1 Patch Cords, Equipment Cords, and Work Area Cords

Optical fiber patch cords shall consist of 2-fiber cables of the same fiber type as the optical fiber channel, terminated with connectors at both ends. Patch cords are also used for equipment cords and work area cords. Optical fiber patch cords shall be configured so that A connects to B and B connects to A. (See Figure 5-10 and Figure 5-11).

Figure 5-10 – Optical fiber cabling plan for premises cabling

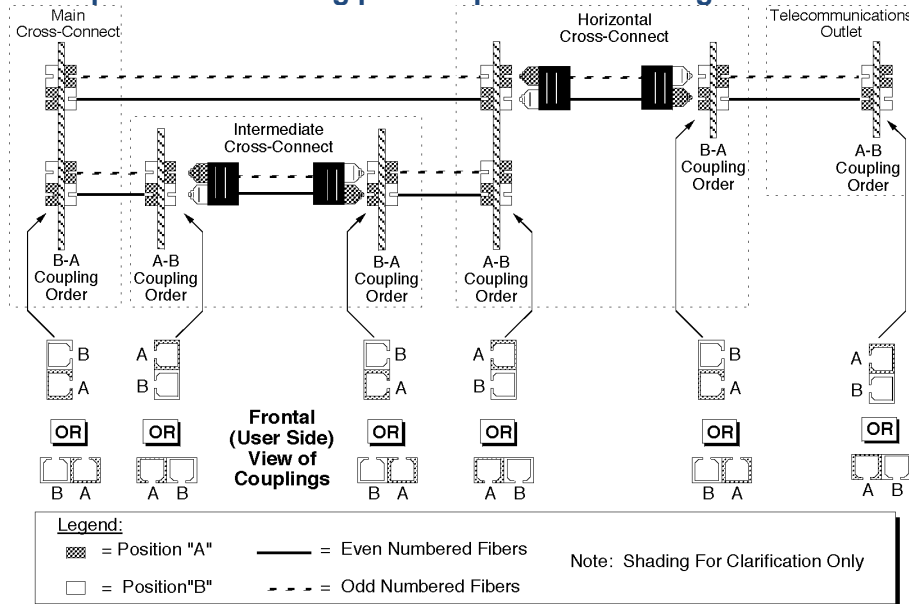
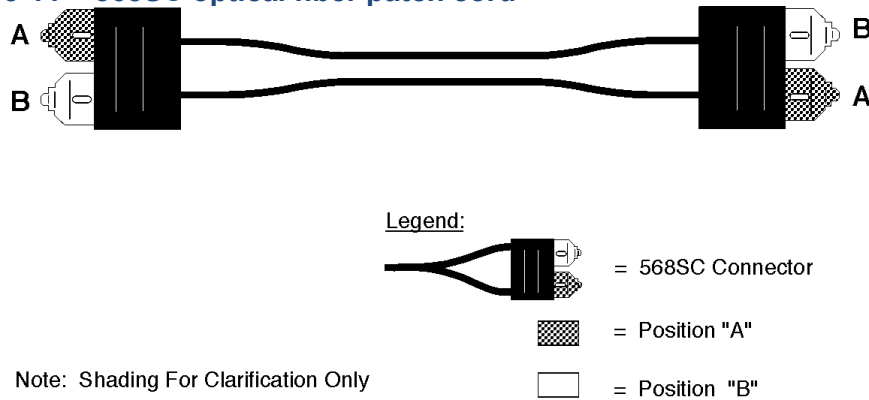


Figure 5-11 – 568SC optical fiber patch cord



5.3.5 Field Application of Optical Fiber Cabling

Single mode fiber has a smaller core making it more susceptible to connector losses, but less susceptible to cable bending losses. Multimode fiber has a larger core giving it more resistance to connector losses, but more susceptibility to cable bending losses. Because single mode fiber is so sensitive to connector losses the cleaning and polishing of the fiber

end is critical and as such field termination of connectors is often not recommended. Instead, application of field terminated pigtails with fusion splicing to the main cable length is preferred.

5.3.5.1 Fiber Cutting, Cleaning, and Polishing

Prepping fiber optic cables for termination either with a splice or connector starts with the same few steps. Take note that these steps should only be performed with safety glasses for protection and all scraps need to be disposed of properly. Bare fibers can be sharp and provide risk to splinter into eyes or skin.

- Place the boot for connector mechanical strength or splicing cover on the cable for final attachment later
- Remove the cable jacket with a precision stripper being sure to keep any cable strength members for attachment of a connector body. See manufacturer's instructions of the connector or splice for specific length needed
- Fiber outer coating should be removed using a precision stripper in small ~1cm lengths to prevent damage of the glass core. See manufacturer's instructions of the connector or splice for specific length needed
- Fiber inner coating should be removed using the smallest setting of a precision stripper
- Some termination styles will cleave the fiber after a ferrule is attached. If a ferrule is used, affix the fiber to the ferrule using the glue or epoxy designated by the manufacturer's instructions.
- At this point the fiber should be cleaved using a precision cleaver to the length designated by the selected termination style. Take care to carefully discard all scraps as glass fibers will be sharp and easily become splinters in eyes or skin.
- Fiber should be cleaned using a clean wipe and isopropyl alcohol to remove any dust or debris. Take care to wipe from the jacket/buffer to the end of the fiber to prevent cracking the fiber core
- If a connector with glue or epoxy was used, the surface will need to be polished according to the manufacturer's instructions. This usually involves a step of coarse to fine polishing pads applied to the surface in a circular motion.
- Ferrule or fiber can now be inserted into the connector. Apply mechanical attachment according to the manufacturer's instructions
- Once connector is assembled, if it is not attached to anything, a dust cap should be applied to prevent surface scratching or contamination

5.3.5.2 Fusion Splicing

Fusion splicing is a junction of two fibers where the cores are welded together, often using an electric arc. A fusion splice is a way to get a high-performance junction with lower attenuation and reflections than a connector. Fusion splicing is typically applicable only to

single mode fibers. For multimode cables, the wider core sizes often make it more difficult to align the two sides of a splice especially when considering a graded index profile.

1. Slide protective sleeve over one of the fibers to be spliced
2. Strip each end of the fiber
3. Use a precision cleave device to cleave each fiber end to achieve a precise end to create the splice
4. Place the fibers into the fusion splicer
5. Let the fusion splicer run its automatic alignment and implement the actual splicing
6. Slide the protective sleeve down and heat shrink it using the splicer or a heat gun to protect the splicing junction
7. Place the splicing junction into a splicing box often looping the cable in the splicing box for strain relief protection

6 Verification of the EtherNet/IP Network

Follow the guidelines in this chapter to verify the EtherNet/IP cabling system. Verification testing is primarily limited to simple tests to confirm that the system has been installed and wired correctly.

Verification is usually performed by the installer as a final check of the link cabling. If needed and available, the verification testing may include equipment and work area cordage. In this case the tests become channel tests. The text describes the use of an appropriate diagnostic tool, such as the commercially available Ethernet cable tester. It is recommended that the network be certified following successful verification. See Chapter 8 for information on certification.

6.1 Preparing for Network Verification

Each cable segment on the network should be verified for transmission performance as the segment is installed and connectorized. A variety of test tools are available to perform verification and diagnostics on the network.

6.1.1 Passive Test Tools for Copper Cabling

- Digital Multimeter (DMM) – A device capable of measuring resistances. Based on a cable wiring map, the resistance of each conductor can be measured to get a verification of connectivity to the correct pins and an estimate of the cable length when comparing the resistance per length of the cable.
- Verification Test Tool – A device to provide wire map, cable length, cable tracer, and similar functions as an ohmmeter.
- Category Cabling Certification Tester – Level V tester according to IEC 61935-1 is preferred. This device measures all transmission parameters of a cable. Provides measures of length and margin above limits of performance. Many of these devices can also locate where faults (e.g., opens, shorts) occur, if present in a cable.

Note: When testing 2-pair systems, some testers perform the Wire Map function first. If the tester is not programmed or programmable to ignore pairs 1 and 4 in a 2-pair system, the test may terminate with a fault. This may prevent measurement of the remainder of cable pair parameters. It is important to select the proper test equipment.

6.1.2 Passive Test Tools for Fiber Optic Cabling

- Visible Laser – Devices used to send visible light (typically red) through a fiber. Presence of the red light out of the end of the fiber indicates end to end continuity. In addition, any points of high loss from excessive bending or from fiber breaks can be visibly observed
- Light Source and Power Meter – Devices used to measure the optical attenuation through a fiber and verify proper wiring across Rx and Tx Pairs. With attenuation these can identify operating margin above risk of failure and can estimate length when compared to fiber attenuation per length.

- Microscope – A device used for inspection of optical fiber ends and connectors. These will verify absence of dust or scratches that could inhibit performance.
- Optical Time Domain Reflectometer (OTDR) – A device that looks at the propagated reflection along an optical fiber. It identifies where high concentrations of attenuation per length exist and can be used to localize where faults may occur along an optical fiber channel.

6.1.3 Active Test Tools

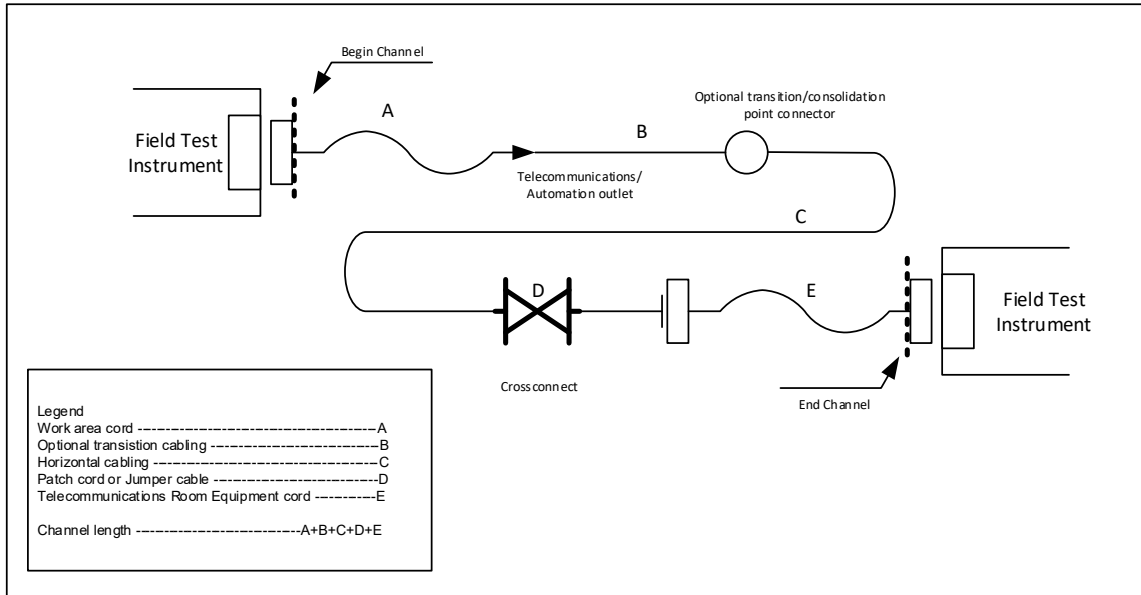
Active test tools can be used to verify that the cabling and the active devices are working properly together. These tools are generally recommended to be used only after verification of the cabling with passive tools. Active test tools often verify the link-up condition and often send large volumes of traffic to identify risks of cabling errors. Active tools are available as software packages on personal computers or may have dedicated hardware.

6.1.4 What Verification or Certification Cabling Structure Should be Used?

6.1.4.1 Channel Test Configuration

The channel test configuration is to be used by system planners and users of data communications systems to verify the performance of the overall channel. The channel includes horizontal cable, a work area equipment cord, a telecommunications outlet/connector, an optional transition/consolidation connector, and two connections in the telecommunications room. The connections to the test equipment at each end of the channel are not included in the channel electrical definition. The channel definition does not apply to those cases where the horizontal cabling is cross connected to the backbone cabling and is beyond the scope of this manual. See Figure 6-1 for a schematic representation of a channel test configuration.

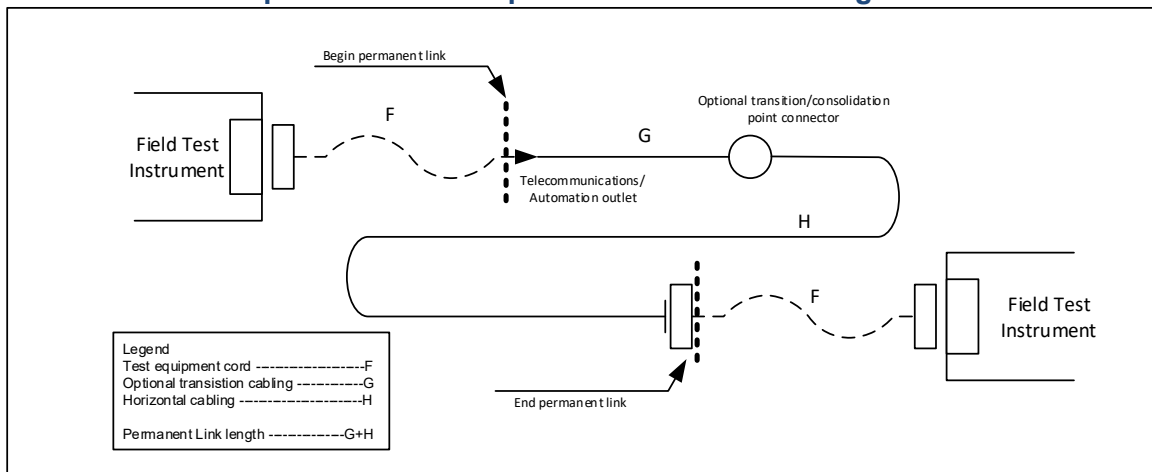
Figure 6-1 – Schematic representation for a channel test configuration



6.1.4.2 Permanent Link Test Configuration

The permanent link test configuration is to be used by installers and users of data telecommunications systems to verify the performance of permanently installed cabling. A schematic representation of the permanent link test configuration is illustrated in Figure 6-2. The permanent link consists of horizontal cabling and one connection at each end and may also include an optional transition/consolidation point connection. The permanent link excludes both the cable portion of the field test instrument cord and the connection to the field test instrument.

Figure 6-2 – Schematic representation of a permanent link test configuration

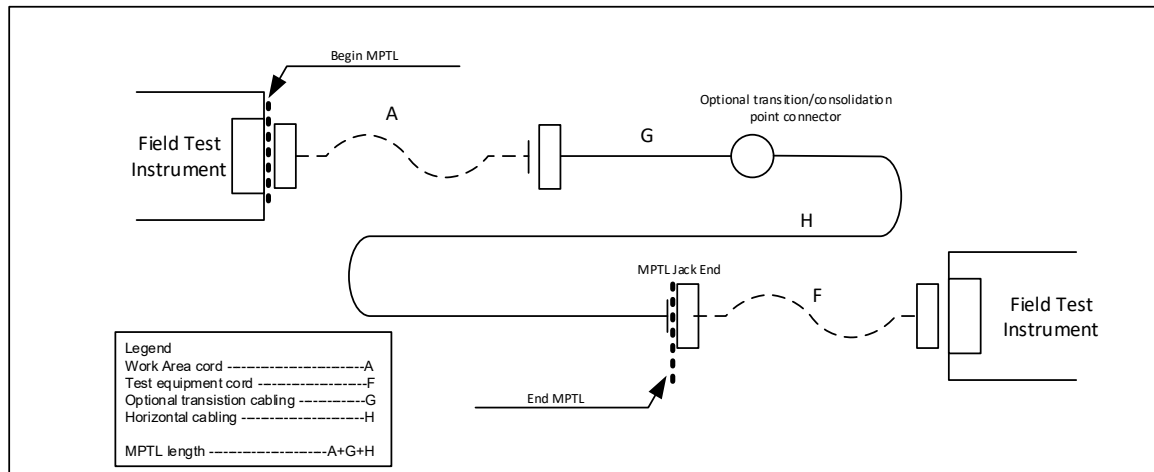


Note: If cross-connections are used, then channel testing or end-to-end link testing is recommended

6.1.4.3 Modular Plug Terminated Link Test Configuration

The modular plug terminated link (MPTL) test configuration is used by installers and users of data telecommunications systems to verify the performance of partial channel components ending in a modular jack or bulkhead connector. A schematic representation of the MPTL test configuration is illustrated in Figure 6-3. The MPTL consists of cabling with a jack at one end and a plug at the other. MPTL may also include optional inline connections. The MPTL excludes the connection from the MPTL jack-end to the field test instrument.

Figure 6-3 – Schematic representation of a modular plug terminated link test configuration

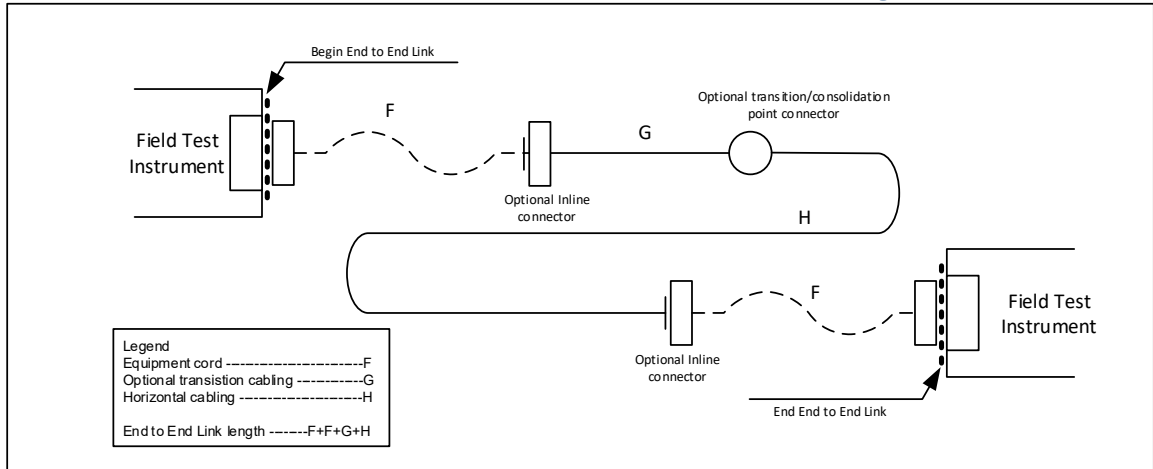


6.1.4.4 End-to-end Link Test Configuration

The end-to-end link test configuration is used by installers and users of data telecommunications systems to verify the performance of partial channel components or an entire channel including the field terminated connector ends to connect to active devices. A schematic representation of the end-to-end link test configuration is illustrated in

Figure 6-4 The end-to-end link can consist of cabling with jacks at both ends. An end-to-end link may also include optional inline connections. A direct attach cable is a special case of an end-to-end link where no inline connections are used. For this direct attach cable condition an end-to-end link test configuration can also be used.

Figure 6-4 – Schematic representation of an end-to-end link test configuration



6.2 Verification of Active Devices

6.2.1 Checking Shield Termination

Active devices should be checked for shield termination impedance, and the result should be compared against the intended Earthing system. A device shield termination can be verified by taking a DMM to measure resistance from the connector shield to a local Earth point. If the impedance reads low (less than 1 Ω), then the device is directly earthed. If the impedance reads 1 MΩ then the device implements an integrated RC filter to mitigate ground loops.

If two devices with direct earthed shields are to be connected, the Earthing system should be an equipotential bonding system, or an equipotential bonding conductor should be applied in parallel with the cable to be used. See ANSI/TIA-607 and ISO/IEC 30129 for more detail.

6.2.2 Verification of Error-Free performance

At commissioning of a system, active device indicators should be checked for intended operation. In addition, all EtherNet/IP devices should be checked for error-free performance using the diagnostic error counters explained in Section 7.6. If counters are steadily increasing, this generally implies an error in the installation and troubleshooting guidance of Chapter 7 should be applied.

6.3 Verification of Copper Cabling

6.3.1 What Should be Verified for Copper Cabling?

Primary verification parameters that may require specialty tools highlighted in Section 6.1.1 are:

- Wire map
- Electrical Length
- Shield Continuity

- Transmission parameter performance

Earthing per design documentation

Primary verification parameters for visual inspection are:

- Physical Length
- Kinks in cable
- Defects in the jacket (such as breaks, abrasions, or burns)
- Bend radius
- Dust caps for connectorized cabling and unused device ports
- Cable end seals for un-terminated cables
- Labeling per design documentation (outlets and cables)
- Routing of cables with respect to other EMC 1, 2 and 3 circuits.

6.3.1.1 Wire Map Test

The wire map test is intended to verify pin to pin termination at each end and check for installation connectivity errors. For each of the 8 or 4 conductors in the cable, the wire map indicates:

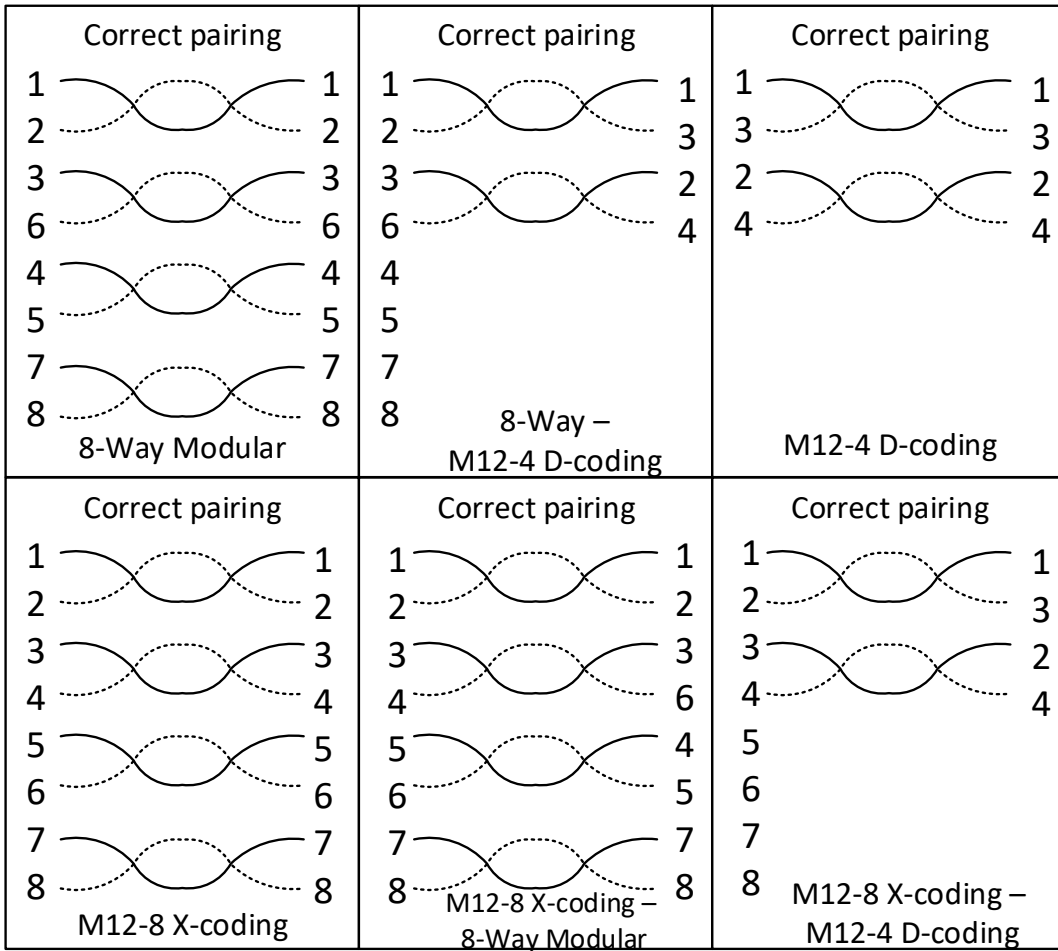
- Continuity to the remote end
- Shorts between any two or more conductors
- Reversed pairs
- Split pairs
- Transposed pairs
- Any other miswiring

Note: If the verification test indicates split pair error condition, the cable must be re-terminated to correct the error before placing the cable in service. Split pairs are caused by using one conductor from two pairs for one signal pair function. For example, orange wire and green/white for TX+ and TX- would cause a split pair. Split pair errors always produce two error conditions in the tester.

6.3.1.1.1 Correct Wire Map Straight Through Cables

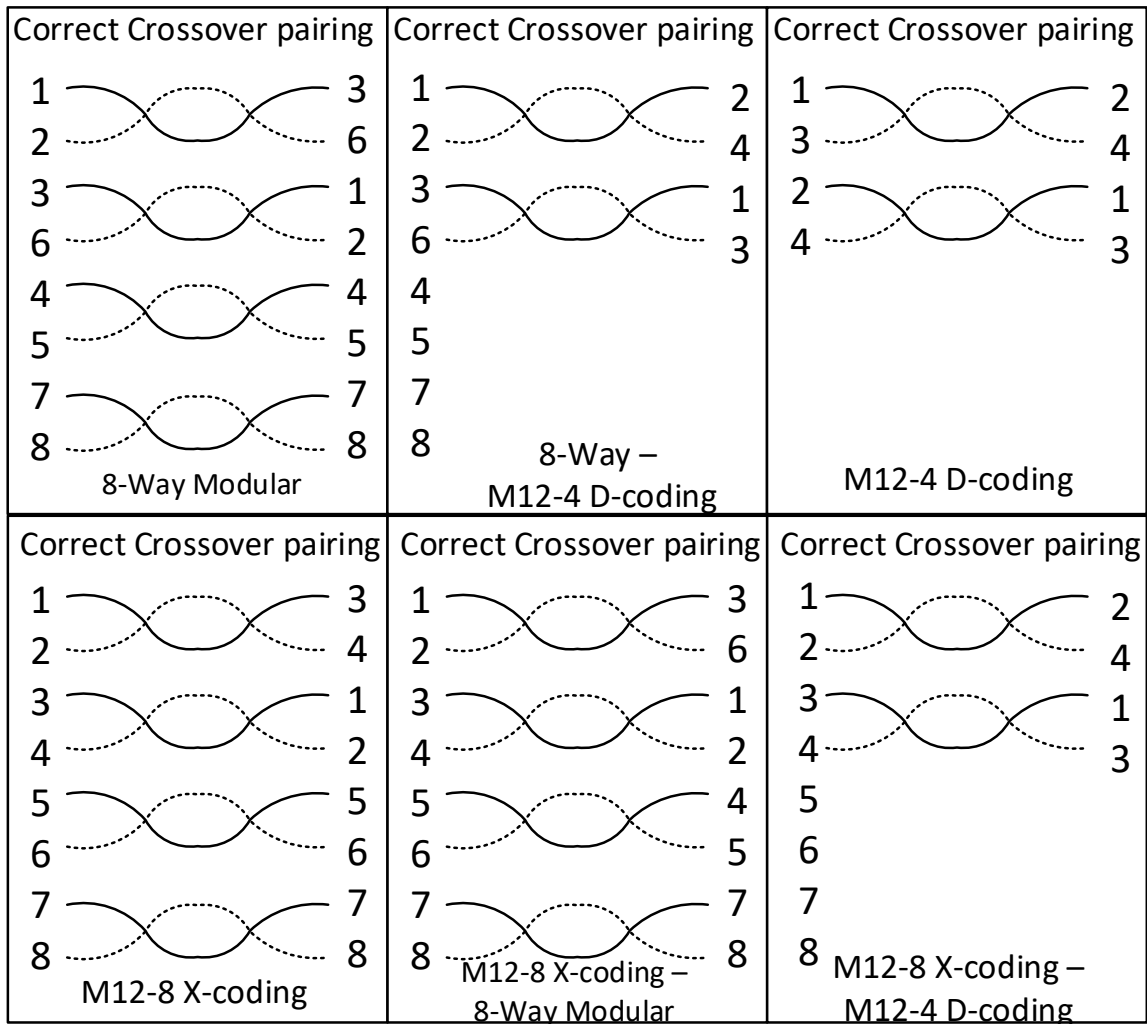
Correct connectivity of telecommunications outlets/connectors is defined in ANSI/TIA/EIA 568.2 using either T568A or T568B wiring codes. The T568B wiring code is illustrated in Figure 6-5.

Figure 6-5 – Wire mapping for non-crossover cabling



6.3.1.1.2 Correct Wire Map for Crossover Cables

Figure 6-6 – Wire mapping for crossover cables



6.3.1.1.3 Reversed Pairs

A reversed pair occurs when the polarity of one wire pair is reversed at one end of the link (also called a Tip/Ring reversal). It is not recommended to leave these cables reversed, instead the connector should be removed and the cable re-terminated with the correct wiring.

6.3.1.1.4 Transposed or Crossed Pairs

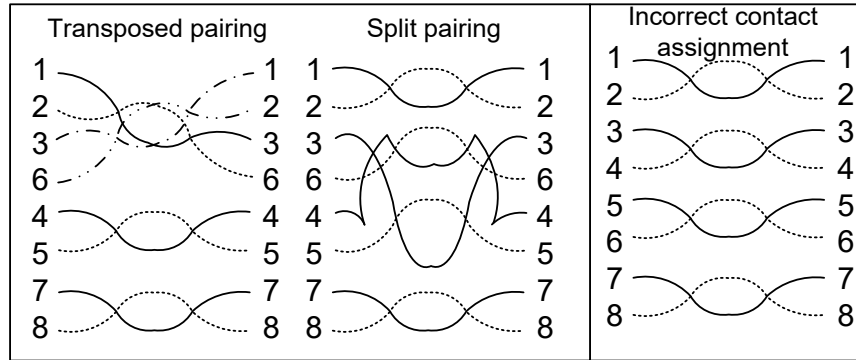
A transposed pair occurs when the two conductors in a wire pair are connected to the position for a different pair at the remote connection. Pair transpositions are sometimes referred to as “crossed pairs”. Refer to Figure 6-7 for an illustration of transposed pairs.

6.3.1.1.5 Split Pairs

Split pairs occur when pin to pin continuity is maintained, but physical pairs are separated. Refer to Figure 6-7 for an illustration of split pairs.

6.3.1.1.6 Examples of Incorrect Wire Mapping

Figure 6-7 – Examples of incorrect wire mapping



6.3.1.2 Physical Length vs. Electrical Length

The physical length of the permanent link/channel is the sum of the physical lengths of the cables between the two end points. Physical length of the permanent link/channel may be determined by physically measuring the length(s) of the cable(s) or estimated from the length markings of the cable(s) when present.

6.3.1.2.1 Length Limits for Links and Channels

In copper cabling, the physical length of the permanent link shall not be greater than 90 m (295 ft.). Test equipment cords are excluded from the permanent link model. The physical length of a channel or end-to-end link shall not be greater than 100 m (328 ft.), including equipment cords and patch cords. Because an MPTL will need to have at least an equipment cord attached for use, its length must be limited to less than 95m (312 ft.). If the channel or link has been de-rated for elevated temperature cable attenuation or the use of stranded cable, then the total channel length is less than 100m (328 ft.) and the permanent link will be less than 90 m (295 ft.). See Section 3.1.9.

6.3.1.3 Number of Connections

In copper cabling, the number of connections for 2-pair and 4-pair cabling will be limited to 4 or 6 in special cases outlined in Table 3-1. This means a permanent link will be limited to at most 5 connections, a channel will be limited to at most 6 connections, an end-to-end link will be limited to at most 6 connections, and an MPTL will be limited to at most 5 connections.

6.3.1.4 Transmission Parameters

In copper cabling, transmission parameters will impact the capability of the cabling to support higher speed applications or heightened EMI environments. Transmission parameters should be verified to the requirements outlined in Section 8.4.1.3 and Section 8.4.1.4. For speed considerations transmission parameters should be verified according to appropriate cabling category specifications in ANSI/TIA 1005-A or ISO/IEC 11801-3.

Where installed in heightened EMI and claiming compatibility through component enhancement as detailed in Section 9.3.3, follow the guidance of Section 8.4.1.4.

6.4 Verification of Fiber optic Cabling

6.4.1 What should be verified for fiber optic cabling?

Primary verification parameters that may require specialty tools highlighted in Section 6.1.2 are:

- Wire map
- Optical Length
- Transmission parameter performance

Primary verification parameters for visual inspection are:

- Physical Length
- Kinks in cable
- Defects in the jacket (such as breaks, abrasions, or burns)
- Bend radius
- Dust caps for connectorized cabling and unused device ports
- Cable end seals for un-terminated cables
- Labeling per design documentation (outlets and cables)

6.4.1.1 Length

The physical length of the permanent link/channel is the sum of the physical lengths of the cables between the two end points. Physical length of the permanent link/channel may be determined by physically measuring the length(s) of the cable(s) or estimated from the length markings of the cable(s) when present.

6.4.1.1.1 Length Limits for Links and Channels

In optical fiber cabling, the physical length of the link or channel shall be limited according to the attenuation budget of the applied transceiver protocol. The maximum length will be scaled considering the number of connections as outlined in Section 4.1.5. Generally, 10 km is considered the maximum length for single mode fiber and 2 km is considered the maximum length for multimode fiber, however certain transceiver protocols will allow for a larger attenuation that may be able to exceed these levels. It should also be noted that due to receiver sensitivities certain optical fiber transceiver protocols may have minimum lengths to prevent overdriving the receiver. Optical attenuators should be applied to channels not meeting the minimum attenuation requirements for the selected protocol.

7 Troubleshooting The EtherNet/IP Network

This chapter provides information on test tools that are available and a systematic method for quickly testing, localizing, and repairing an EtherNet/IP network. It describes the use of appropriate diagnostic tools such as the commercially available Ethernet cable tester to aid in localizing faults in the network.

7.1 Determining if there is a network failure

In some cases, it may be obvious that a network failure has occurred. What is usually clear is that the machine has stopped for some reason. This section is provided for those cases where the fault is not clear. Examples of this may be intermittent failures or interference related failures; in many cases they are related. Most control networks have error reporting capabilities. The communications management software can collect and report errors to the operator. The error reporting can be used for an early warning system and a diagnostic tool to help determine the source of a pending failure or failure that has occurred. Error counter histograms are particularly useful in correlating errors to events such as a drive coming online.

In information applications, signs of a network failure may be an increasing response time to requests for information. As with control applications, the error reporting capabilities can be an early warning sign to localize a failure or to indicate that network maintenance should be planned.

7.2 Tools for Determining Network Failures

There are many off-the-shelf test tools available to help diagnose the network. The tools can be divided into two categories and are described below.

7.2.1 Passive testers

Passive testers are designed to test the cabling system and components. They require full access to a network. Devices must be disconnected and, in some tests, require special terminators to be installed at one end of the channel/permanent link. Passive testers are available for verification and certification and are detailed in Section 6.1.

7.2.2 Active

Active test tools typically communicate on the network and are application specific. For example, EtherNet/IP is an application using IEEE std 802.3-2018 signaling and therefore requires IEEE std 802.3-2018 compliant tools. Active diagnostic tools report errors to the application layer using the cabling and active physical layer devices, such as switches and routers. Some of these tools can produce alarms to the operator when events occur.

One specific example of an active test tool is a bit error ratio tester. These tools consist of traffic generator and analysis functions to validate complex traffic patterns that may be hard to reproduce in normal operation as well as to analyze the rate of errors in the network to evaluate network reliability.

Note: There are many off-the-shelf active testers available that can help to determine if communications to the switch are functioning. Some testers available will communicate with the switch and/or router and attempt to get an IP address through DHCP. If successful, one could assume that the channel is functioning (DHCP must be enabled in the server). These devices have a MAC address and can be assigned a fixed IP address. They then can be used to ping specific addresses for diagnostic purposes.

7.2.3 Network Verification

Network verification has limited usefulness in troubleshooting a network as verification only is a basic check done at the time of installation. Verification tools are effective in quickly determining if the cabling system has been wired properly or if there has been damage causing an open or short.

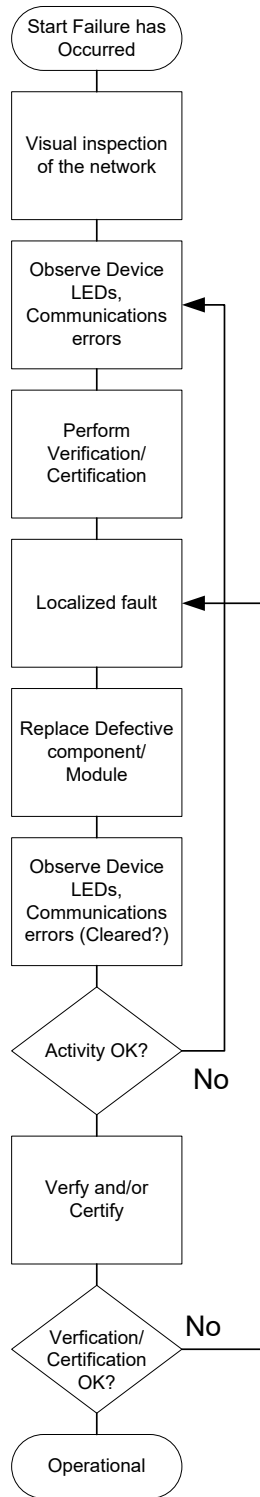
7.2.4 Network Certification

Network certification includes electrical or optical performance testing of each channel and is therefore useful in the diagnostic process. If certification was performed initially, post failure results can be compared to the initial certification. These types of testers are generally more expensive and more complex to use.

7.3 Quick Troubleshooting

A systematic approach should be used for troubleshooting. Figure 7-1 is an example of a basic troubleshooting process.

Figure 7-1 – Basic Troubleshooting Flow Chart



7.4 Detailed Troubleshooting Process

This process can be used to find most cabling faults.

Visually inspect the network (channel/permanent link)

- a. Observe cabling
- b. If cable is cut or damaged, repair or replace the cable. If connector is damaged, repair or replace the connector. Observe device indicators (including the switch)
 - i. Activity indicator at one end and not the other may indicate a cabling fault in one pair and or a device fault.
 - ii. An activity indicator out at both ends may indicate a device fault at one end and or a total cable fault.
 - iii. All indicators out at a device may indicate a device fault or power fault.
- c. If the cabling is suspected, disconnect the active devices, and test the channel. Localize and correct the cabling failure.
- d. If a verification tool is used in the previous step and no problem is reported, perform a certification level test on the channel/permanent link.
 - i. If a problem is reported, localize and replace the component(s)
 - ii. If no problem is reported by the test equipment, proceed to troubleshooting the active devices per the manufacturer's steps.
- e. After correcting faults in the cabling system, perform a channel/permanent link certification test and update the applicable network documentation.

7.5 Common Symptoms / Causes of Failures

Table 7.1 provides common symptoms and causes of failures to help with the troubleshooting process.

Table 7-1 – Network failures and potential causes

Symptom	Possible Cause	Suggested Action
High error rate	<ul style="list-style-type: none"> Damaged cable Electrical Interference nearby Wrong cabling used 	<ul style="list-style-type: none"> Perform certification
No communications	<ul style="list-style-type: none"> Severed cable Disconnected node Incorrect wire map 	<ul style="list-style-type: none"> Check for power to switch and device Correct wiring and connection Check wire map
No Link Indication	<ul style="list-style-type: none"> Severed Cable Disconnected connector Device/switch powered down 	<ul style="list-style-type: none"> Correct cut or disconnected cable/connector Replace defective switch/device Correct power
Burst Error Indication	<ul style="list-style-type: none"> Interference generating device Poor cabling Grounded Shield 	<ul style="list-style-type: none"> Correlate burst interference to burst errors. Provide additional separation, check for improper grounding Check for low interference cabling.
Continuous error condition (some data getting through)	<ul style="list-style-type: none"> Incorrect cabling for application or interference level. Ground loop in cabling Incorrect wire map 	<ul style="list-style-type: none"> Use proper cabling to support application Locate shorted shield and remove or provide additional path for interference current Correct wire map
Continuous error condition (no data getting through)	<ul style="list-style-type: none"> Severed cable Check Link indicator Disconnected node 	<ul style="list-style-type: none"> Check for power to switch and device Replace defective switch/device Correct wiring and connection

7.6 Diagnostic Error Counters

Communications error counters are extremely useful in predicting future failures or locating existing failures. The most commonly available error counters are required for 1000 Mbps EtherNet/IP devices and are available at CIP object class 0xF6 attribute 5 or 13.

Using this CIP object, it is possible to inspect network performance at any point in the network and further, alarms can be set at error counter thresholds to warn operators that a failure may be imminent. The other benefit of having these error counters available at CIP devices is that by stepping through a network node by node, the zones where increasing errors are present can be identified and troubleshooting effort can be minimized.

A network that exhibits slowly increasing error rates over time is an indication of a degrading network. This can be caused by failing connectors, moisture ingress or even temperature rises. Error counters that detect burst counts can be an indication of interference. This can be the fault of a poorly designed network, cables that are too close to interference generating machinery, or a ground failure.

7.6.1 How to Interpret CIP Diagnostic Error Counters

Counts are available in Media Counters (attribute 5) and High Capacity Counters (attribute 13) of the Ethernet Link Object (0xF6) as shown in Table 7-2 and Table 7-3. Attribute 13 is present in all 1000 Mbps EtherNet/IP devices and is identical to the specific counts in attribute 5, however the count capacity is higher. Attribute 13 targets to the counters more applicable for diagnosing cabling level errors.

Table 7-2 – EtherNet/IP Diagnostic Error counters

EtherNet/IP link object Class 0xF6 Attribute 5	
Count Name:	Struct Data type of:
Alignment Error Count	UDINT
FCS Error Count	UDINT
Single Collision Count	UDINT
Multiple Collision Count	UDINT
SQE Test Error Count	UDINT
Deferred Transmission Count	UDINT
Late Collision Count	UDINT
Excessive Collisions Count	UDINT
MAC Transmit Error Count	UDINT
Carrier Sense Error Count	UDINT
Frame Too Long Error Count	UDINT
MAC Receive Error Count	UDINT

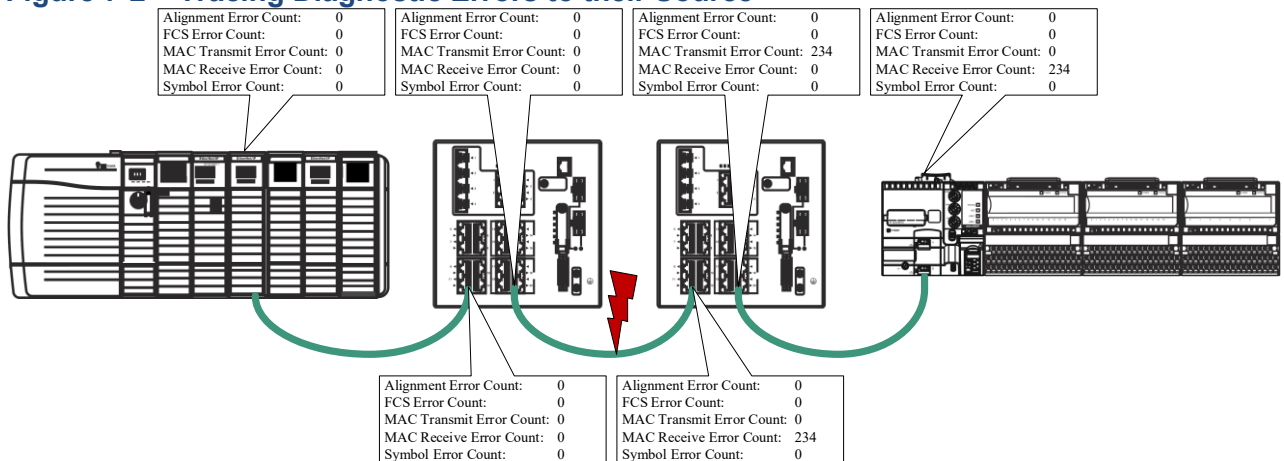
Table 7-3 – EtherNet/IP High-Capacity Diagnostic Error counters

EtherNet/IP link object Class 0xF6 Attribute 13	
Count Name:	Struct Data type of:
High-Capacity Alignment Error Count	ULINT
High-Capacity FCS Error Count	ULINT
High-Capacity MAC Transmit Error Count	ULINT
High-Capacity StatsFrameTooLong Error Count	ULINT
High-Capacity MAC Receive Error Count	ULINT
High-Capacity Symbol Error Count	ULINT

- Alignment Errors – Errors are detected where a packet is an invalid size, and this also causes a failure of the packet integrity check
- FCS Errors – Errors are detected where a packet could be valid, but it has a failure of the packet integrity check
- MAC Transmit Errors – Errors are detected in the transmitted packet internal to the device (within the Media Access Controller)
- StatsFrameTooLong Transmit Errors – Frames for which transmission fails due to an internal MAC sublayer transmit error.
- MAC Receive Errors – Errors are detected in the received packet internal to the device (within the Media Access Controller)
- Symbol Errors – An invalid data symbol was detected within a packet

Cabling level errors are likely to show up as FCS errors and MAC receive errors, although MAC transmit errors are also important to trace the errors to their source. When control loop latency is important, network switches and device level ring devices are often set to a cut through and forward mode. Essentially this means a device won't wait until a packet is complete and verified as valid before sending it along to its intended destination. In these configurations an error received is then also forwarded as a transmit error. For this reason, when looking at MAC receive error count it is important to look at the difference in counts of the link partner MAC transmit error count. In this manner a chain of errors can be followed along a data path until there are no MAC transmit errors on one side, but MAC receive errors picked up on the other end as shown in Figure 7-2. This condition will signify errors sourced in the cabling and may indicate poor cabling performance or insufficient environmental mitigation against the installation environment.

Figure 7-2 – Tracing Diagnostic Errors to their Source



In this example even though receive errors are detected at the remote IO system, tracing them through the switch can find that all the receive errors at the remote IO were detected as sent errors on the switch. Looking further at the switch-to-switch link, we find that the source switch detected no errors while the receiving switch detected receive errors. This discrepancy indicates the switch-to-switch link is where the errors originated.

7.7 Troubleshooting Electromagnetic Interference

Electromagnetic interference can be particularly troublesome in the troubleshooting process because it cannot be physically observed as with other environmental events.

In EtherNet/IP networks, electromagnetic interference will most commonly present itself as a periodic or sporadic increase in packet errors, specifically FCS errors or internal MAC receive errors.

7.7.1 Identify Interference Sources

Step 1: Identify where network errors are sourced and what behavior they exhibit. If errors are rare or inconsistent, one way to provide more error statistics is to add additional information traffic along the network to increase percent bandwidth consumption. A heavily loaded network will show errors more easily as there is a higher probability of interference presence intersecting with data being sent. The simplest form of generation of information traffic is by sending pings to targeted addresses.

Step 2: Locate potential sources of disruption with respect to the compromised cabling. Identifying these sources will often provide a clearer path to isolation of the root cause, and to where additional protections are needed. A good place to start are the common sources outlined in Section 9.4.5.

Step 3: Step through targeted resolution of specific sources. The simplest method is to disable certain parts of the system that are controlling the suspected source. If the source is disabled and errors go away, it confirms which cable needs mitigation applied.

7.7.2 Corrections for an Unshielded Link

If the Link in question is unshielded:

Step 4: Apply mitigations according to Section 9.4. Mitigations can consist of separation, isolation, or enhancement. Separation consists of moving the interfering and affected cables away from each other. Isolation consists of applying a shielding or filter such as a ferrite to reduce either the amount of interference transmitted or received. Enhancement consists of selecting cabling for the interfering cable that will prevent transmission of electromagnetic interference or selecting cabling for the affected cable that will be more robust against the interference present. Depending on the size and scope of the installation, any one of these options may be more practical, however any should be acceptable to achieve the needed mitigation.

7.7.3 Corrections for a shielded link

If the link in question is shielded:

Step 4: Understand shield application constraints. What are the shield termination methods at either end or how do the functional earth buses at either end connect to the facility protective bonding system?

Step 5: Confirm the shield grounding performance by measuring the RMS current through the ethernet cable or measuring the RMS voltage at both product functional earth references.

Step 6: If excessive grounding interference is confirmed or suspected, apply an 8 AWG or larger equipotential bonding conductor across the functional earth references of both sides routed in parallel to the ethernet cable having issues. If this does not resolve the issue, further mitigation should be resolved in a similar manner to unshielded cables. See step 2 to step 4 for unshielded cabling segments above.

Note: This step assumes that earthing networks at either end can dissipate the EMI energy and consideration of earthing network topologies should be considered.

8 Certifying the EtherNet/IP Network

The following chapter contains guidelines for certifying the EtherNet/IP network. It is important to certify a new network for the following reasons:

- A baseline should be established for future maintenance purposes such as troubleshooting and/or preventive maintenance.
- It reduces startup time by confirming that the installation supports the application requirements.
- Some cabling providers will provide a warranty for the network only upon successful passing of certification tests.

8.1 When to Perform Certification

In general, this process is performed after the installer has verified that the network components have been installed properly. As detailed in Chapter 6, verification can vary in detail and is left to the discretion of the planner and installer. Certification, on the other hand, is much more prescriptive and is detailed in this chapter and related standards. A distinct difference between certification and verification is that certification requires calibrated and certified test equipment, which records transmission performance according to predefined cabling structures and conformance paths. The process of conformance is usually carried out by specialists trained in network certification. This process should also include a report detailing:

- Areas that do not meet the requirements of the design documentation
- Channel/link performance requirements
- Successful pass of all aspects

Network certification should be performed on:

- Newly installed networks
- Networks that have had substantial repairs or changes
- On a cyclic basis (preventative maintenance)

A plan should be established detailing when network certification should be performed, based on the requirements of the owner and provider. The plan should include report requirements, limits, and steps to take in the event the network fails certification.

8.2 What Should be Certified

Certification should include the following aspects of the network:

- -Physical installation attributes that may affect life of installation
 - Location of cabling with respect to electrical interference and environmental conditions
 - Grounding of devices and equipment where specified
 - Wire ways
 - Bend radii
 - Cable supports or hangers (as required)
 - Cable loading and crushing
 - Terminations
 - Proper media commensurate with the environment
- -Electrical performance which meets the needs of the application

- Electrical and physical lengths of channels and permanent links
- Swept frequency measurements as detailed later in this chapter

8.3 Tools Required for Network Certification

The network test tools required for certification are usually more complex than the go/no go tools used in verification. These tools are required to perform both DC and swept frequency at both the local and remote ends of a channel or permanent link. There are several off-the-shelf test tools that provide different levels of accuracy.

In addition to accuracy, the test time and frequency range are also variables. For example, testers may take anywhere from 5 to 20 seconds per channel or link. Additionally, they may only test Category 5E (100 MHz) channels/permanent links. The test tool usually requires separate test heads for testing channels, links, and patch cords. Or for optical fiber, a certification tester may only test multimode wavelengths of 850 nm and 1300 nm. It is important to have a tester that can test all components and parts of a channel.

Additional tools that are beneficial for the certification process are:

- Digital camera
- Digital multimeter with milliohm scale
- Hand tools and software for generating reports

It is assumed that the certifier has access to a computer and design documentation.

8.4 Certifying Terminated Cable Segments

Transmission performance depends on cable characteristics, connecting hardware, patch cords, the total number of connections, and the care with which they are installed and maintained. This section addresses field test specifications for post installation performance measurements of cabling designed in accordance with the ODVA specification.

The information contained in this manual is related to the channel, the permanent link, the modular plug terminated link, and the end-to-end link test configurations as described in chapter 6. This section provides additional information, including specifications for field test instruments, test methods and interpretations of test results, leading to a practical solution to the issues related to field-testing.

8.4.1 100-Ohm Twisted-pair Transmission Performance and Field Test Requirements

This section specifies the electrical characteristics of field test instruments, test methods, and minimum transmission requirements for 100 ohm twisted pair cabling. It specifies transmission performance requirements for 100 ohm twisted pair cabling links that are consistent with the categories of 100 ohm twisted pair cable and connecting hardware specified herein. The requirements are targeted towards field-testing of installed 100 ohm twisted pair cabling links using field test instruments. Field test instrument characteristics needed for swept/stepped frequency measurements up to 100 MHz for Category 5e are described to ensure consistent and reasonably accurate measurements. Other methods using frequency domain or time domain measurement techniques that demonstrate equivalency are acceptable.

Field test methods and interpretation of test data leading to pass/fail criteria are described to certify the installed cabling. Users of this section are advised to consult applications standards, equipment manufacturers and system integrators to determine the suitability of these requirements for specific networking applications.

This section contains additional specifications for certification of installed cabling and is not intended to replace or supersede the basic requirements of this guide.

8.4.1.1 Test Configurations

The transmission requirements specified herein are applicable to unshielded twisted pair (UTP) and shielded twisted pair (STP) cabling links consisting of cables and connecting hardware specified in this guide. This section relates to performance with respect to 100 ohm 2-pair and 4-pair UTP and STP cabling only. Compliance with this guide does not imply compatibility with cables having nominal impedance values other than 100 ohms.

Channel, permanent link, end-to-end link, and modular plug terminated link test configurations are defined in chapter 6. Other compliant test configurations shall be tested using limits computed according to the ODVA specification.

Note:

- a. **If cross-connections are used, then channel testing or end-to-end link testing is recommended.**
 - b. **When testing 2-pair systems, some testers perform the Wire Map function first. If the tester is not programmed or programmable to ignore pairs 1 and 4 in a 2-pair system the test may terminate with a fault. This may prevent measurement of the balance of cable pair parameters. It is important to select the proper test equipment and test settings.**
-

Insertion loss, near end crosstalk loss, equal level far end crosstalk, return loss, transverse conversion loss, and equal level transverse conversion transfer loss are derived from swept/stepped frequency measurements or equivalent measurement methods.

8.4.1.2 Physical and Electrical lengths

The physical length of the permanent link/channel is the sum of the physical lengths of the cables between the two end points. Physical length of the permanent link/channel may be determined by physically measuring the length(s) of the cable(s), determined from the length markings on the cable(s), when present, or estimated from the electrical length measurement. The electrical length is derived from the propagation delay of signals and depends on the construction and material properties of the cable (see ANSI/TIA 568.2).

When physical length is determined from electrical length, the physical length of the link calculated using the pair with the longest electrical delay shall be reported and used for making the pass or fail decision. The pass or fail criteria is based on the maximum length allowed for the channel or permanent link given in Chapter 3, plus the nominal velocity of propagation (NVP).

Note: If using electrical length, calibration of NVP is critical to the accuracy of length measurements (see ANSI/TIA 568.2).

8.4.1.3 Transmission Parameters

All balanced twisted pair links require measurement of the transmission parameters specified below to certify the cabling element under test. Field test tool must be Level II or higher and it is highly recommended in using a Level V tester for network certification.

- Insertion loss
- Return loss
- Near end crosstalk (NEXT)
- Power sum near end crosstalk (PSNEXT)
- Equal level far end crosstalk (ELFEXT)
- Power sum equal level far end crosstalk (PSELFEXT)
- Propagation delay
- Delay skew

The parameters list below are considered as optional but are highly recommended to be measured and recorded as part of the certification process of the cabling element under test.

- Resistance
- Transverse conversion loss (TCL)
- Equal level transverse conversion transfer loss (ELTCTL)

Each transmission parameter shall be verified according to the limits specified in ANSI/TIA 1005-A or ISO/IEC 11801-3.

8.4.1.4 Transmission Parameters: Enhancement Mitigation

Where enhancement is claimed to achieve installed environment compatibility, the following parameters shall be measured to certify the cabling element under test. Where enhancement according to Chapter 9 (MICE Tutorial) is claimed to achieve electromagnetic environmental compatibility, a Level V field tester is required.

- Insertion loss
- Return loss
- Near end crosstalk (NEXT)
- Power sum near end crosstalk (PSNEXT)
- Equal level far end crosstalk (ELFEXT)
- Power sum equal level far end crosstalk (PSELFEXT)
- Propagation delay
- Delay skew
- Resistance
- Transverse conversion loss (TCL)
- Equal level transverse conversion transfer loss (ELTCTL)

Each transmission parameter shall be verified according to the limits specified in ANSI/TIA 1005 or ISO/IEC 11801-3 as well as conforming to one of the conformance paths below, corresponding to the requirements of a given application.

Path a) The UTP cable supporting 10BASE-T or 100BASE-T applications shall be selected and installed based on the ability to meet the Transverse Conversion Loss (TCL) and Equal Level Transverse Conversion Transfer Loss (ELTCTL) requirements at both ends of the cabling in accordance with Table 8-1 and the environment local to the cabling.

Table 8-1 –TCL and ELTCTL limits for unshielded twisted-pair cabling serving 10BASE-T and 100BASE-T applications

Parameter	Frequency MHz	Limit dB ^a
TCL	$1 \leq f < 100$	Compliant with ISO/IEC 11801 or ANSI/TIA 1005
ELTCTL	$1 \leq f < 30$	Compliant with ISO/IEC 11801 or ANSI/TIA 1005
^a Limits are applicable to all environmental classifications aligned with delineation in ISO/IEC 11801-1 and ANSI/TIA 1005		

Path b) The UTP cable supporting 1000BASE-T applications shall be selected and installed based on the ability to meet the Transverse Conversion Loss (TCL) and Equal Level Transverse Conversion Transfer Loss (ELTCTL) requirements at both ends of the cabling in accordance with Table 8-2 and the environment local to the cabling.

Table 8-2 –TCL and ELTCTL limits for unshielded twisted-pair cabling serving 1000BASE-T applications with further enhanced components

Parameter	Frequency MHz	Limit dB		
		E1	E2	E3
TCL	$1 \leq f < 30$	Compliant with ISO/IEC 11801 or ANSI/TIA 1005	$69,2 - 15 \cdot \log_{10}(f)$	$79,2 - 15 \cdot \log_{10}(f)$
	$1 \leq f \leq 100$		$76,6 - 20 \times \log_{10}(f)$ (max. 40 dB)	$86,6 - 20 \times \log_{10}(f)$ (max. 46 dB)
ELTCTL	$1 \leq f < 30$	Compliant with ISO/IEC 11801 or ANSI/TIA 1005	$42 - 20 \cdot \log_{10}(f)$ (max. 40 dB)	$52 - 20 \cdot \log_{10}(f)$ (max. 40 dB)

Path c) The UTP cable supporting 1000BASE-T applications shall be selected and installed based on the ability to meet the Transverse Conversion Loss (TCL) and Equal Level Transverse Conversion Transfer Loss (ELTCTL) requirements at both ends of the cabling while also restricting the insertion loss and indirectly the associated cable length in accordance with Table 8-3 and the environment local to the cabling.

Table 8-3 – Insertion Loss, TCL, and ELTCTL limits for unshielded twisted-pair cabling serving 1000BASE-T applications with additional length derating

Parameter	Frequency MHz	Limit dB ^a
Insertion Loss	1 □ f □ 100	$0,72 \times (1,967\sqrt{f} + 0,023 \times f + 0,1/\sqrt{f})$
TCL	1 □ f □ 100	Compliant with ISO/IEC 11801 or ANSI/TIA 1005
ELTCTL	1 □ f □ 30	Compliant with ISO/IEC 11801 or ANSI/TIA 1005
^a Limits are applicable to all environmental classifications aligned with delineation in ISO/IEC 11801-1 and ANSI/TIA 1005		

Path d) The STP cable shall be selected and installed based on the ability to meet the coupling attenuation requirements at both ends of the cabling in accordance with Table 8-4 and the environment local to the cabling.

Table 8-4 – Coupling attenuation limits for screened twisted-pair cabling

Parameter	Frequency MHz	Limit dB ^a
Coupling Attenuation	30 □ f □ 100	Compliant with ISO/IEC 11801 or ANSI/TIA 1005
^a Limits are applicable to all environmental classifications aligned with delineation in ISO/IEC 11801-1 and ANSI/TIA 1005		

8.4.2 Optical Fiber Transmission Performance and Field Test Requirements

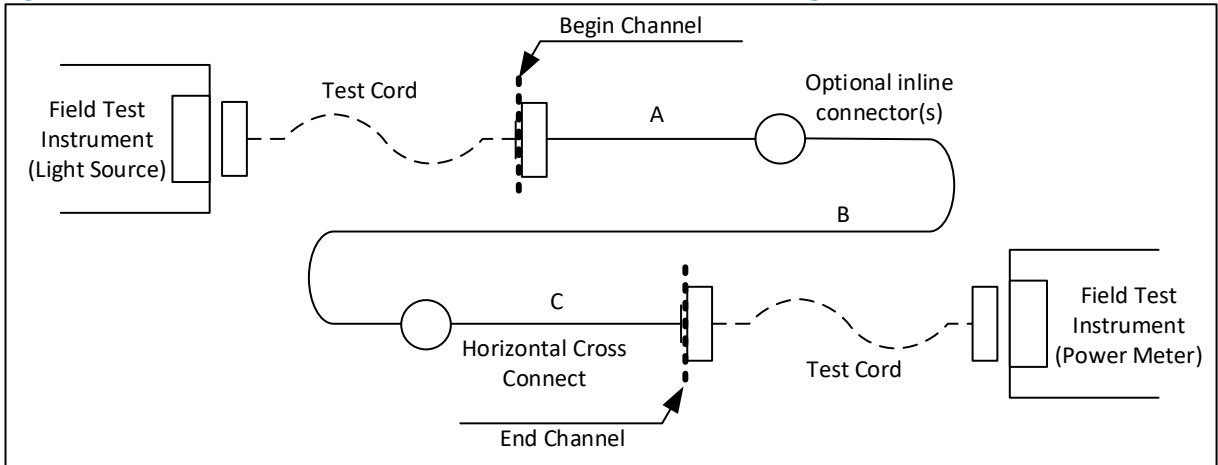
Optical fiber certification testing consists of attenuation measurements against a calibrated reference. To perform this testing, light source and power meter equipment are required.

8.4.2.1 Test Configurations

Where optical attenuation is certified, the test configurations are not bound as they are for copper cabling. Because optical attenuation is linear, adding a cord to a link cable will result in the loss profile of both plus the linking connector. As such optical fiber certification can be conducted on any point-to-point fiber connection when following the approach of Figure 8-1.

For multimode testing, the test cord used to launch at light source must meet the encircled flux requirements of TIA TSB-4979. This is used to ensure the correct launch into the fiber is achieved to get an accurate loss measurement.

Figure 8-1 – Optical Fiber Certification Example Test Configuration



8.4.2.2 Transmission Parameters

Optical fiber cabling requires measurement of the transmission parameters specified below to certify the cabling element under test.

- Optical attenuation (Insertion loss)
- Polarity

The optical attenuation shall be certified according to the most stringent protocol to be used on the link. The most stringent requirement is often set by the highest operating bandwidth. Table 8-5 provides optical attenuation limits for some common fiber optic protocols.

Table 8-5 – Optical Attenuation Limits for Common Protocols

IEEE 802.3 optical fiber PMD	Max Channel Attenuation (dB)			
	Multi-mode		Single-mode	
	850 nm	1300 nm	1310 nm	1550 nm
100BASE-FX	-	6.0	-	-
100BASE-LX10	-	2.4	6.0	-
1000BASE-SX	3.56	-	-	-
1000BASE-LX	-	2.35	4.57	-
1000BASE-LX10	-	2.4	6.0	-
10GBASE-LR	-	-	6.2	-
10GBASE-LRM	-	1.9	-	-
10GBASE-SR	2.9	-	-	-

9 MICE Tutorial

9.1 Introduction

Traditionally, system designers determine the suitability of products for their application and environment through a complex manual method. This requires understanding the environment in detail and correlating that information to the environmental data found in equipment data sheets. The process can be very daunting. As an example, a factory environment contains many devices that generate different electrical noises, and analyzing these noises requires an expert with specialized test equipment to perform site surveys.

To simplify the process of determining suitable products for an industrial application, the concept of MICE (Mechanical, Ingress, Climatic/Chemical, and Electromagnetic) was created. It was developed in an international forum through IEC and ISO/IEC. It is intended for designers and planners who are both specifying components to be purchased and defining mitigation and isolation protections.

The tables in the MICE document list the most common environmental parameters and generalize them into three different levels (1,2,3), to minimize the amount of different resolution paths to consider. This not only helps the system designer and end user but also helps product designers understand a common set of environmental parameters. Designers can then develop a set of practices to address components or installations that may not be in performance alignment, or potentially an application risk.

The MICE concept also works as a tool to facilitate more effective communication between ODVA vendors, OEMs, system integrators, and end-users. For this reason, ODVA encourages vendors to express their products' environmental compatibility in a uniform way, utilizing the MICE concept, because it is easily understood by the system designer/owner.

To that end, ODVA has included this technical chapter which details MICE and helps users classify their environment and match the parameters systematically to the product's environmental classification. Any differences are solved through mitigation techniques described in the various examples shared. This simplifies EMC compatibility (between products and environments) without the need of site surveys and allows for a more proactive approach to resolving environmental compatibility in the planning and specification phases of system development.

The subsequent sections will discuss the various classification levels, and methods of creating the ideal MICE environment, specific to a given application. Figure 9-1 illustrates an example of generic MICE areas on a factory floor, and these classifications are discussed in depth in section 9.4. Figure 9-2 attempts to show how enhancement and mitigation techniques work together to provide a cost effective and technically feasible solution; these strategies are discussed further in Section 9.3.

Figure 9-1 – MICE Areas

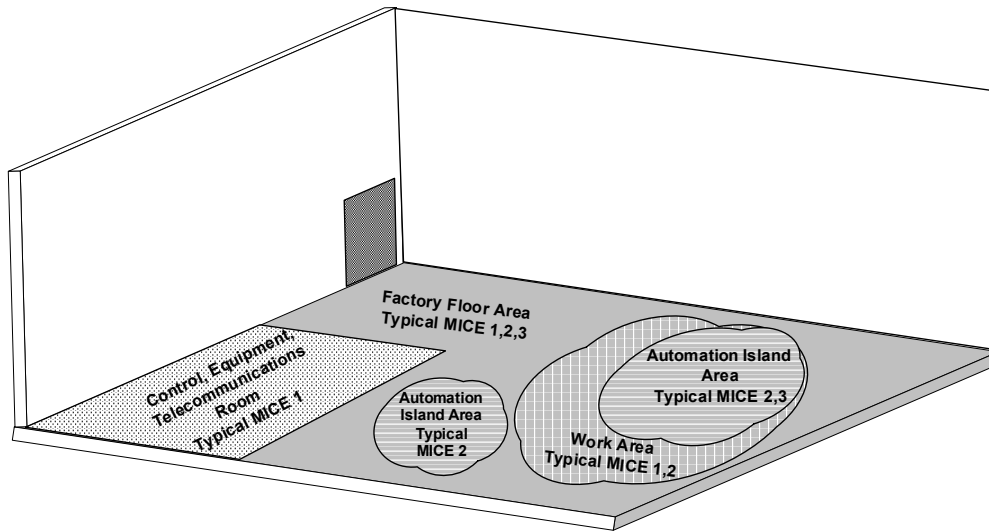
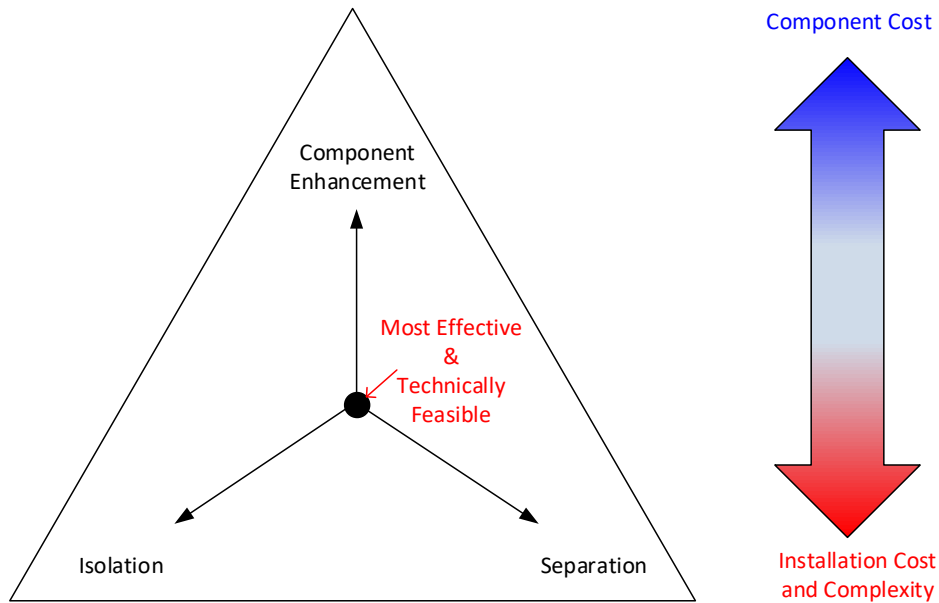


Figure 9-2 – Enhancement and Mitigation



9.2 MICE Table

MICE concept was developed in the regional, international, and national industrial standards committees such as ANSI/TIA, IEC, and ISO/IEC. The MICE tables shown in Table 9-1, Table 9-2, Table 9-3, and Table 9-4 are defined and controlled in ISO/IEC 11801-1, ANSI/TIA 1005, and IEC 61918, reproduction here is for informational purposes. The concept divides each of the environmental aspects (M, I, C, E) of an industrial area into 3 environmental classifications (1, 2, 3). $M_3I_3C_3E_3$ is the harshest, while $M_1I_1C_1E_1$ is equivalent to most commercial building environments. The MICE Tables show the parameters used to classify the local environment under the M, I, C and E criteria. While

the classification of an environment is determined by the most demanding parameter within each criteria group, the selection of components may reflect the specific demands of all the parameters within the group - including those that may be less demanding than the overall classification of the environment. There are some environments that extend beyond M₃I₃C₃E₃. These environments are considered beyond the typical (80%) of industrial environments and would require special handling beyond the scope of this concept. The values expressed in the MICE table columns are the upper boundary for each classification.

Table 9-1 – MICE Table (Mechanical)

Mechanical	M ₁	M ₂	M ₃
Shock/bump (see Note a)			
Peak acceleration	40 ms ⁻²	100 ms ⁻²	250 ms ⁻²
Vibration			
Displacement amplitude (2 Hz to 9 Hz)	1,5 mm	7,0 mm	15,0 mm
Acceleration amplitude (9 Hz to 500 Hz)	5 ms ⁻²	20 ms ⁻²	50 ms ⁻²
Tensile force	(See Note b)	(See Note b)	(See Note b)
Crush	45 N over 25 mm (linear) min.	1 100 N over 150 mm (linear) min.	2 200 N over 150 mm (linear) min.
Impact	1 J	10 J	30 J
Bending, flexing and torsion	(See Note b)	(See Note b)	(See Note b)
a) Bump: the repetitive nature of the shock experienced by the channel shall be taken into account. b) This aspect of environmental classification is installation-specific and should be considered in association with IEC 61918 and the appropriate component specification.			

Table 9-2 – MICE Table (Ingress Protection)

Ingress	I ₁ ^a	I ₂ ^b	I ₃ ^c
Particulate ingress (dia. Max)	12,5 mm	50 µm	50 µm
Immersion	None	Intermittent liquid jet £ 12,5 L/min ³ 6,3 mm jet > 2,5 m distance	Intermittent liquid jet £ 12,5 l/min ³ 6,3 mm jet > 2,5 m distance and immersion (£1 m for <=30 minutes)
a) This environmental condition can be satisfied by sealing to an IP category IP20 b) This environmental condition can be satisfied by sealing to an IP category IP65 c) This environmental condition can be satisfied by sealing to an IP category IP67			

Table 9-3 – MICE Table (Climatic and Chemical)

Climatic and chemical	C ₁	C ₂	C ₃
Ambient temperature	-10 °C to +60 °C	-25 °C to +70 °C	-40 °C to +70 °C
Rate of change of temperature	0,1 °C per minute	1,0 °C per minute	3,0 °C per minute
Humidity	5 % to 85 % (non-condensing)	5 % to 95 % (condensing)	5 % to 95 % (condensing)
Solar radiation	700 Wm ⁻²	1 120 Wm ⁻²	1 120 Wm ⁻²
Liquid pollution (see Note c) Contaminants	Concentration x 10 ⁻⁶	Concentration x 10 ⁻⁶	Concentration x 10 ⁻⁶
Sodium chloride (salt/sea water)	0	<0,3	<0,3
Oil (dry-air concentration) (for oil types see Note b)	0	<0,005	<0,5
Sodium stearate (soap)	None	>5 x 10 ⁴ aqueous non-gelling	>5 x 10 ⁴ aqueous gelling
Detergent	None	ffs	ffs
Conductive materials	None	Temporary	Present
Gaseous pollution (see Note c) Contaminants	Mean/Peak (Concentration x 10 ⁻⁶)	Mean/Peak (Concentration x 10 ⁻⁶)	Mean/Peak (Concentration x 10 ⁻⁶)
Hydrogen sulfide	<0,003/<0,01	<0,05/<0,5	<10/<50
Sulphur dioxide	<0,01/<0,03	<0,1/<0,3	<5/<15
Sulphur trioxide (ffs)	<0,01/<0,03	<0,1/<0,3	<5/<15
Chlorine wet (>50 % humidity)	<0,000 5/<0,001	<0,005/<0,03	<0,05/<0,3
Chlorine dry (<50 % humidity)	<0,002/<0,01	<0,02/<0,1	<0,2/<1,0
Hydrogen chloride	-/<0,06	<0,06/<0,3	<0,6/3,0
Hydrogen fluoride	<0,001/<0,005	<0,01/<0,05	<0,1/<1,0
Ammonia	<1/<5	<10/<50	<50/<250
Oxides of Nitrogen	<0,05/<0,1	<0,5/<1	<5/<10
Ozone	<0,002/<0,005	<0,025/<0,05	<0,1/<1
b) This aspect of environmental classification is installation-specific and should be considered in association with IEC 61918 and the appropriate component specification.			
c) A single-dimensional characteristic, i.e. Concentration x 10 ⁻⁶ , was chosen to unify limits from different standards.			

Table 9-4 – MICE Table (Electromagnetic)

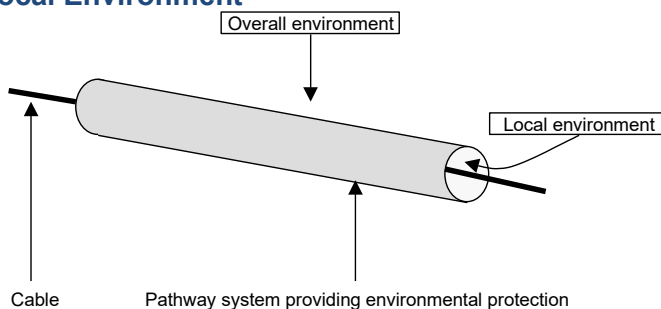
Electromagnetic	E ₁	E ₂	E ₃
Electrostatic discharge – Contact (0,667 µC)	4 kV	4 kV	4 kV
Electrostatic discharge – Air (0,132 µC)	8 kV	8 kV	8 kV
Radiated RF – AM	3 V/m at (80 to 1 000 MHz) 3 V/m at ((1 400 to 2 000 MHz) 1 V/m at (2 000 to 2 700 MHz)	3 V/m at (80 to 1 000 MHz) 3 V/m at ((1 400 to 2 000 MHz) 1 V/m at (2 000 to 2 700 MHz)	10 V/m at (80 to 1 000 MHz) 3 V/m at (1 400 to 2 000 MHz) 1 V/m at (2 000 to 2 700 MHz)
Conducted RF	3 V at 150kHz to 80MHz	3 V at 150kHz to 80MHz	10 V at 150kHz to 80MHz
EFT/B (comms) ¹	500 V	1000 V	1 000 V
Surge (transient ground potential difference) - signal, line to earth ¹	500 V	1 000 V	1 000 V
Magnetic Field (50/60 Hz)	1 Am ⁻¹	3 Am ⁻¹	30 Am ⁻¹
Note 1: Volume 2 EtherNet/IP Adaptation of CIP chapter 8 recommends industrial devices be designed compatible with 2kV EFT and surge levels to ensure compatibility with products that may have extended requirements such as variable speed drives. If devices do not support these extended levels careful consideration needs made to prevent interference coupling beyond the levels the system components are selected for.			

9.3 Environmental Compatibility Strategies

Cabling components or devices may not be exclusive to one level. For example, a cabling component may be available from a supplier, that is M_1 , I_3 , C_2 , and E_1 . The environment may be an M_3 , I_1 , C_1 , and E_1 . Where technical or economic restrictions preclude the use of components compatible with the overall environment, mitigation techniques may be applied to modify one or more of the M, I, C or E environments local to the components to allow appropriate components to be installed.

Mitigation techniques may involve the use of pathways or pathway systems to create a local environment conducive to the components contained within it; see example shown in Figure 9-3. The pathway system may be a raceway, cable tray, conduit, flat barrier, or enclosure. In addition, enclosures may be used to convert the harsh environment to an environment compatible with the components.

Figure 9-3 – The Local Environment



9.3.1 Separation

Separation is a form of mitigation that involves moving further away from the problematic source of the harsher environment. In terms of mechanical stress this may mean moving components away from a piece of heavy machinery. Likewise, in terms of electromagnetic environments, moving sensitive cables away from high power EMI producers will lessen the electromagnetic stress seen. Climatic stress can be separated by taking steps such as reducing the fill factor of cables in pathways (smaller bundles).

9.3.2 Isolation

Isolation is a form of mitigation that involves applying a barrier to generate a large environmental differential across it, thereby lessening the local environment to the components in consideration. In terms of electromagnetic stress, isolation may include properly bonded shielding or the application of metallic conduit. For mechanical stress, isolation may require shock mounted enclosures or suspension dampers. Isolation for climatic environments could include fan cooled enclosures or pathways. And chemical isolation may look like ingress isolation, with the application of an encompassing sealed enclosure.

9.3.3 Enhancement

Enhancement is defined as an environmental design tactic to use components that are individually compatible with the given environment. In doing so, no forms of additional mitigation are needed leading to a lower installation cost at the tradeoff of higher component cost.

9.4 MICE Concept In detail

Consideration of what a local environment is for mechanical, ingress, climatic, and chemical classifications can be applied based on the immediate surroundings. Electromagnetic interference is treated a bit differently because the cables themselves are designed to be good electrical conductors and so will act to carry the environmental disturbance along the entire length of the cable. For this reason, electromagnetic local environments can be defined by the highest disturbance along the channel length and will apply to all cabling subcomponents within the channel.

9.4.1 Mechanical Environments

Mechanical environments include shock, vibration, crush and impact. Look for product test levels in supplier data sheets. Isolation for devices and connectors, against shock and vibration, may include shock mounting. Cable crush and impact may be mitigated via selection of armored cables, isolation by placement or housing in conduit or raceways. Specific codes apply. Field devices may require exposure to operate, and the use of partial barriers can offer some protection.

9.4.2 Ingress Environments

Ingress environments include particulates and immersion. Field device and enclosure IP ratings provide higher mitigation levels and should be listed in supplier data sheets. In-cabinet devices with lower IP ratings may be isolated in higher rated enclosures. Cable mitigation is addressed via material selection, given certain materials absorb water and alter cable characteristics.

9.4.3 Climatic Environments

Climatic environments include varying temperature, humidity, and solar radiation conditions. Devices in outdoor cabinets may be protected by shade canopies over the enclosure and colored paint for reflection or absorption of sunlight. Additionally, the cabinet may be cooled by airflow or heated to prevent condensation. A mix of solutions may be required. Various material alternatives offered by suppliers should be listed in data sheets and are more robust against specific climatic conditions.

9.4.4 Chemical Environments

Chemical environments include exposure to a variety of liquids, solids, and gases. Some chemicals are airborne while others may come in contact by splashing or physical contact. Various material alternatives offered by suppliers should be listed in data sheets and are more robust against specific chemicals. Where appropriate materials are not available, some mitigation may be achieved by housing the component. End devices may be placed in cabinets. A sealed cabinet may be necessary for airborne chemicals. In-field cable mitigation may be achieved using conduit or closed raceways. Some field devices may be on the equipment and must be exposed to chemicals (splash). These have no mitigation except by proper construction.

9.4.5 Electromagnetic Environments

In a factory environment, electromagnetic interferences present a broad range of frequencies, along with several interference coupling mechanisms. A device not only generates harmful fundamental frequencies; it also may generate harmonics that can be just as disruptive to communications networks.

Table 9-5 provides general guidance as to the electromagnetic level (E_1 , E_2 , E_3) for many common interference generating devices. The level of interference is dependent on two factors: distance and magnitude. Therefore, the table is only provided as a rough guide for determining the possible electromagnetic classification (E_1 , E_2 , E_3).

Table 9-5 – Electromagnetic Separation Mitigation: EMI classifications versus distance

Interference generating device	Distance from cabling	“E” classification
Contactor relay	< 0,5 m	E_2
	> 0,5 m	E_1
Transmitters (<1 W)	< 0,5 m	E_3
	> 0,5 m	E_1 or E_2
Transmitters (1 W to 3 W)	< 1,0 m	E_3
	$\geq 1,0$ m	E_1 or E_2
Transmitters (TV, radio, mobile, base station)	< 0,3 km	E_3
	$\geq 0,3$ km	E_1 or E_2
High HP motors	< 3 m	E_3
	> 3 m	1
Motor controllers	< 0,5 m	E_3
	0,5 m to 3 m	E_2
	> 3 m	E_1
Induction heating < 8 MW	< 0,5 m	E_3
	0,5 m to 3 m	E_2
	> 3 m	E_1
Resistance heating	< 0,5 m	E_2
	> 0,5 m	E_1
Fluorescent lights	< 0,15 m	E_3
	> 0,15 m	E_1 or E_2
Thermostatic switches 110 V to 230 V	< 0,5 m	E_2 to E_3
	> 0,5 m	E_1

Table 9-6 provides the coupling mechanism for each of the interfering devices. This table will help to guide the designer, installer and troubleshooting personnel in mitigating or correcting interference. For example, in an environment where a relay contactor is found to cause interference, the mechanism for interference ingress is coupling through adjacent lines (EFT). To correct this situation, additional separation should be provided to reduce the magnitude of coupling.

Table 9-6 provides an insight into the coupling mechanism of common interferences

Table 9-6 – Interference Coupling Modes

Type	Interference	Coupling mechanism
Electric motors	Surge and EFT	Local Earth, Conducted
Drive Controllers	Conducted and Surge	Local Earth, Conducted
Relays and Contactors	EFT	Radiated, Conducted
Welding	EFT, Induction	Radiated Magnetic
RF Induction Welding	Radio Frequency	Radiated, Conducted
Material Handling paper/textile	ESD	Radiated
Heating	EFT	Local Earth, Conducted, Radiated
Induction Heating	EFT, Magnetic	Local Earth, Conducted, Radiated
Radio Communications	Radio Frequency	Radiated

9.4.6 Component selection

The components used within a channel should be selected to be compatible with the MICE classification of the channel at the point where the components are to be installed. If components are not available that directly meet the local environmental conditions, then some form of mitigation will be required. The following examples will help to explain how the MICE concept and mitigation work together to help network designers select and install cabling components and devices.

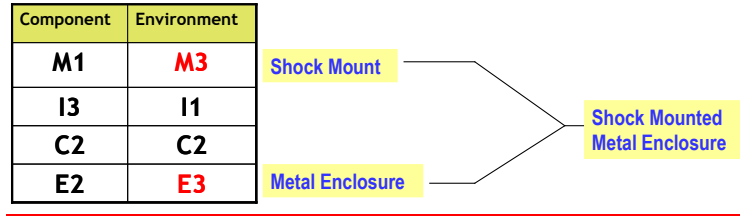
Determining the component rating may involve referencing datasheets against Table 9-1, Table 9-2, Table 9-3, and Table 9-4. For each table individually, the equivalent rating is the lowest performance that the component meets or exceeds the specifications in all rows.

9.4.6.1 Example 1

The targeted MICE area is specified in Figure 9-4. The desired component has been determined to be compatible with a MICE environment as described in the left column. The environment in which the component must be installed is described in the second column. By inspection of the component and environment, parameters “M” and “E” do not meet or exceed, which means mitigation is required. Parameters “I” and “C” exceed the environmental condition and therefore need no action.

The harsh M₃ environment can be converted to an M₁ local to the component by shock mounting the equipment in an enclosure. The high EMI can be reduced by using a metal EMI, shock mounted enclosure as indicated in Figure 9-4. Both M₃ and E₃ problems are solved.

Figure 9-4 – Example 1 of mitigation

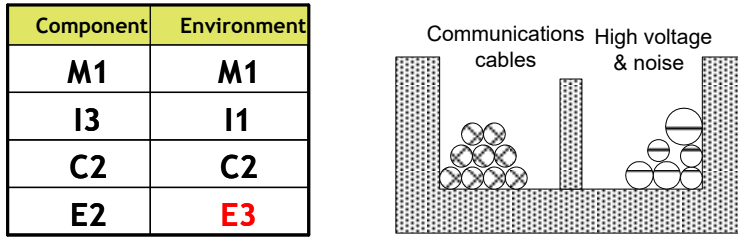


9.4.6.2 Example 2

This is an example of a cable installation where the environment is described as in Figure 9-5. By inspection, the cable does not match the environmental conditions for EMI (E). Therefore, some form of mitigation is required.

Mitigation can be solved in two ways, separation and/or isolation. The drawing in Figure 9-5. shows how mitigation is achieved using separation and isolation.

Figure 9-5 – Example 2 of mitigation



By providing physical separation between the high EMI conductors and the communications cabling, the interference coupling will be reduced. An additional reduction in interference coupling can be achieved by adding a metallic wall between the conductors thus providing additional isolation. Either or both methods may be independently sufficient to reduce the interference coupling or may be required together.

9.5 References

In many cases component vendors may advertise MICE environmental compatibility levels or may specify specific environmental test case criteria. This allows for easy indication of acceptable environments, to compare to the MICE criteria. In some cases, a vendor may only point to standards that specify the environmental criteria used as basis. It is for this reason that the source references for the MICE environmental categories are included here, to help identify the intended environmental compatibility of components.

Most of the environmental levels and categories are found in four standards IEC60721 series, IEC 60654 series, IEC 60529 and IEC 61000 series. This information is useful in providing justification for the classification boundaries within the MICE table. Further, the designer can use these tables to make informed decisions on variations of the MICE levels for specific environmental conditions where products may be targeted that fall outside the MICE boundaries. The following table details the standards and publication dates. The reader is encouraged to obtain the latest copy of these standards for further detail.

Table 9-7 – MICE environmental standard references

IEC 60068-2-5:1975	Environmental testing - Part 2: Tests. Test Sa: Simulated solar radiation at ground level
IEC 60654-4:1987	Operating conditions for industrial-process measurement and control equipment. Part 4: Corrosive and erosive influences
IEC 60721-3-3:2002	Classification of environmental conditions - Part 3-3: Classification of groups of environmental parameters and their severities – Stationary use at weather protected locations
IEC 61000-2-5:1995	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 5: Classification of electromagnetic environments. Basic EMC publication
IEC 61000-6-1:2005	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments
IEC 61000-6-2:2005	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
IEC 61131-2:2007	Programmable controllers - Part 2: Equipment requirements and tests
IEC 61326:2001	Electrical equipment for measurement, control and laboratory use - EMC requirements
IEC 60529:2001	Ingress Protection (IP ratings)

9.5.1 Mechanical Environment References

Table 9-8 shows the readily available standards and levels used in derivation of the mechanical boundaries used in Table 9-1.

Table 9-8 – Derivation of boundaries for mechanical criteria

Mechanical	M ₁	M ₂	M ₃
Shock/bump			
Peak acceleration	40 ms ⁻²	100 ms ⁻²	250 ms ⁻²
Vibration			
Displacement amplitude (2 Hz to 9 Hz)	1,5 mm	7,0 mm	15,0 mm
Acceleration amplitude (9 Hz to 500 Hz)	5 ms ⁻²	20 ms ⁻²	50 ms ⁻²
Shock/bump/vibration (source material)	IEC 60721-3-3 Class 3M2	< IEC 60721-3-3 Class 3M6	IEC 60721-3-3 Class 3M8
Crush	45 N over 25 mm (linear) min.	1 100 N over 150 mm (linear) min.	2 200 N over 150 mm (linear) min.
Impact	1 J	10 J	30 J

From IEC 60721-3-3:2002:

3M1 applies to locations with insignificant vibration and shock.

In addition to the conditions covered by 3M1, 3M2 applies to locations with vibration of low significance (products mounted on light structures subject to negligible vibration).

In addition to the conditions covered by 3M5, 3M6 applies to locations where the level of vibration is high (e.g., close to heavy machines).

In addition to the conditions covered by 3M7, 3M8 applies to locations where the level of vibration is extremely high (e.g., products mounted on power hammers).

9.5.2 Ingress Protection Environment References

Table 9-9 shows the readily available standards and levels used in derivation of the mechanical boundaries used in Table 9-2.

Table 9-9 – Derivation of boundaries for ingress protection criteria

Ingress	I ₁	I ₂	I ₃
Particulate ingress (dia. max)	12,5 mm	50 mm	50 mm
Immersion	None	Intermittent liquid jet <=12,5 l/min >= 6,3 mm jet > 2,5 m distance	Intermittent liquid jet <=12,5 l/min >= 6,3 mm jet > 2,5 m distance and immersion (<=1 m for <=30 minutes)
Ingress protection (source material)	IEC 60529 Class IP20	IEC 60529 Class IP65	IEC 60529 Class IP67

9.5.3 Climatic Environment References

Table 9-10 shows the readily available standards and levels used in derivation of the mechanical boundaries used in Table 9-3.

Table 9-10 – Derivation of boundaries for climatic criteria

Climatic	C ₁	C ₂	C ₃
Ambient temperature	-10 °C to +60 °C	-25 °C to +70 °C	-40 °C to +70 °C
	Existing ISO/IEC 11801	IEC 60721-3-3:2002 Class 3K8H	IEC 60721-3-3:2002 Class 3K7
Rate of change of temperature	0,1 °C per minute	1,0 °C per minute	3,0 °C per minute
	IEC 60721-3-3:2002 Class 3K1	IEC 60721-3-3:2002 Class 3K7	IEC 61131-2
Humidity	5 % to 85 % (non-condensing)	5 % to 95 % (condensing)	5 % to 95 % (condensing)
	IEC 60721-3-3:2002 Class 3K3	IEC 60721-3-3:2002 Class 3K4	IEC 60721-3-3:2002 Class 3K5
Solar radiation	700 Wm ⁻²	1 120 Wm ⁻²	1 120 Wm ⁻²
	IEC 60721-3-3:2002 Class 3K3 – 3K6	IEC 60721-3-3:2002 Class 3K7. IEC 60068-2-5:1975 contains a table covering wavelengths from UV to IR that totals 1 120 Wm ⁻² .	

From IEC 60721-3-3:2002:

3K1 applies to fully air-conditioned enclosed locations. Air temperature and humidity control are used continuously to maintain the required conditions. Installed products may be exposed to attenuated solar radiation and to movements of surrounding air due to draughts from the air-conditioning system. They are not subjected to heat radiation, condensed water, precipitation, water from sources other than rain, or formation of ice.

These conditions may be found in room of such construction that a confined range of temperature and humidity may be maintained.

In addition to the conditions covered by 3K1, 3K2 applies to continuously temperature-controlled enclosed locations. Humidity is not controlled. Heating, cooling, or humidification is used where necessary to maintain the required conditions, especially where there is a large difference between them and the open air-climate. Installed products may be exposed to solar radiation and to heat radiation. They may be subject to movements of surrounding air due to draughts in buildings. These conditions may be found in manned offices, workshops, and other rooms for special applications.

In addition to the conditions covered by 3K2, 3K3 applies to continuously temperature-controlled enclosed locations. Humidity is not controlled. Heating or cooling is used where necessary to maintain the required conditions, especially where there is a large difference between them and the open air-climate. These conditions may be found in normal living or working areas e.g., living rooms, rooms for general use (theatres, restaurants etc.), offices, shops, workshops for electronic assemblies and other electro-technical products, telecommunications centers, storage rooms for valuable and sensitive products.

In addition to the conditions covered by 3K3, 3K4 applies to temperature-controlled enclosed locations with a wide range of relative humidity. Humidity is not controlled. Installed products may be subject to condensed water and to water from sources other than rain. These conditions may be found in certain living or working areas e.g., kitchens, bathrooms, workshops with processes producing high humidity, certain cellars, ordinary storage rooms, stables, garages. For the more humid open-air climates they may also be found in living rooms and rooms for general use.

In addition to the conditions covered by 3K4, 3K5 applies to enclosed locations having neither temperature nor humidity control. Heating may be used to raise low temperatures, especially when there is a large difference between them and the open air-climate. Product may be subject to the formation of ice. These conditions may be found in some entrances and staircases of buildings, garages, cellars, certain workshops, buildings in factories and industrial process plants, certain telecommunications buildings, ordinary storage rooms for frost-resistant products, farm buildings etc.

In addition to the conditions covered by 3K4, 3K6, 3K7 and 3K8H apply to weather-protected locations having neither temperature nor humidity control. The locations may have openings to the open air. The climatic conditions may be affected by the open-air climate and the type of building. Installed products may be exposed to solar radiation. They may also be subject to wind-driven precipitation including snow. These conditions may be found in some entrances of buildings, some garages, in sheds, shacks, lofts, telephone booths, buildings in factories and industrial process plants, unattended equipment stations, unattended buildings for telecommunications purposes, ordinary storage rooms for frost-resistant products, farm buildings etc.

9.5.4 Chemical Environment References

Table 9-11 shows the readily available standards and levels used in derivation of the mechanical boundaries used in Table 9-3.

Table 9-11 – Derivation of boundaries for chemical criteria

Chemical	C ₁	C ₂	C ₃
Liquid pollution (see Note) Contaminants	Concentration x 10 ⁻⁶	Concentration x 10 ⁻⁶	Concentration x 10 ⁻⁶

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Sodium chloride (salt/sea water)	0	<0,3	<0,3
	IEC 60721-1		
Oil (dry-air concentration)	0	<0,005	<0,5
Sodium stearate (soap)	None	5 x 10 ⁴ aqueous non-gelling	> 5 x 10 ⁴ aqueous gelling
Detergent	None	Ffs	ffs
Conductive materials	None	Temporary	Present
Gaseous pollution (see Note) Contaminants	Mean/Peak (Concentration x 10 ⁻⁶)	Mean/Peak (Concentration x 10 ⁻⁶)	Mean/Peak (Concentration x 10 ⁻⁶)
Hydrogen sulfide	<0,003/<0,01	<0,05/<0,5	<10/<50
	The limits are taken from IEC 60654-4:1987 for the environmental descriptions Class 1, 2 and 3. They are within the same region as those in IEC 60721-3-3 A.1:1994 for the environmental descriptions 3C1, 3C2 and 3C4. Note: for comparison the values in IEC 60721-3-3 A.1:1994 have been converted from mg.cm-3 using the STP density = 1.539.		
Sulphur dioxide	<0,01/<0,03	<0,1/<0,3	<5/<10
	The limits are taken from IEC 60654-4:1987 for the environmental descriptions Class 1, 2 and 3, with the exception of Class 3 (max < 15). They are identical to the environmental descriptions IEC 60721-3-3 A.1:1994 for the environmental descriptions 3C1 and 3C2 and within the same region for the environmental description 3C4 (mean < 4,5, max < 14). Note: for comparison the values in IEC 60721-3-3 A.1:1994 have been converted from mg.cm-3 using the STP density = 2.927.		
Sulphur trioxide (ffs)	<0,01/<0,03	<0,1/<0,3	<5/<15
	There are no limits in IEC 60654-4:1987 or IEC 60721-3-3.		
Chlorine wet (>50 % humidity)	<0,000 5/<0,001	<0,005/<0,03	<0,05/<0,3
	The limits are taken from IEC 60654-4:1987 for the environmental descriptions Class 1, 2 and 3. There are no limits in IEC 60721-3-3.		
Chlorine dry (<50 % humidity)	<0,002/<0,01	<0,02/<0,1	<0,2/<1,0
	The limits are taken from IEC 60654-4:1987 for the environmental descriptions Class 1, 2 and 3. They are within the same region as those in IEC 60721-3-3 A.1:1994 for the environmental descriptions 3C1, 3C2 and 3C4. Note: for comparison the values in IEC 60721-3-3 A.1:1994 have converted from mg.cm-3 using the STP density = 3.124.		
Hydrogen chloride	-/<0,06	<0,06/<0,3	<0,6/3,0
	There are no limits in IEC 60654-4:1987. The limits are taken from IEC 60721-3-3 A.1:1994 for the environmental descriptions 3C1, 3C2 and 3C4. Note: for comparison the values in IEC 60721-3-3 A.1:1994 have converted from mg.cm-3 using the STP density = 1.639.		

Chemical	C ₁	C ₂	C ₃
Hydrogen fluoride	<0,001/<0,005	<0,01/<0,05	<0,1/<1,0
	The limits are taken from IEC 60654-4:1987 for the environmental descriptions Class 1, 2 and 3. They are within the same region as those in IEC 60721-3-3 A.1:1994 for the environmental descriptions 3C1, 3C2 and 3C4. Note: for comparison the values in IEC 60721-3-3 A.1:1994 have been converted from mg.cm-3 using the STP density = 0.901.		
Ammonia	<1/<5	<10/<50	<50/<250
	The limits are taken from IEC 60654-4:1987 for the environmental descriptions Class 1, 2 and 3. They are within the same region as those in IEC 60721-3-3 A.1:1994 for the environmental descriptions 3C2, 3C3 and 3C4. Note: for comparison the values in IEC 60721-3-3 A.1:1994 have been converted from mg.cm-3 using the STP density = 0.771.		
Oxides of Nitrogen	<0,05/<0,1	<0,5/<1	<5/<10
	The limits are taken from IEC 60654-4:1987 for the environmental descriptions Class 1, 2 and 3. They are within the same region as those in IEC 60721-3-3 A.1:1994 for the environmental descriptions 3C1, 3C2 and 3C4. Note: for comparison the values in IEC 60721-3-3 A.1:1994 have been converted from mg.cm-3 using the STP density = 1.350 (averaged on NO, NO2 and NO3).		
Ozone	<0,002/<0,005	<0,025/<0,05	<0,1/<1
	The limits are taken from IEC 60654-4:1987 for the environmental descriptions Class 1, 2 and 3. They are within the same region as those in IEC 60721-3-3 A.1:1994 for the environmental descriptions 3C2, 3C3 and 3C4. Note: for comparison the values in IEC 60721-3-3 A.1:1994 have been converted from mg.cm-3 using the STP density = 2.144.		
Note: A single dimensional characteristic, i.e. Concentration x 10⁻⁶, was chosen to unify limits from different standards."			

From IEC 60654-4:1987:

Class 1: Environments sufficiently well controlled so that corrosion is not a factor in determining corrosion.

Class 2: Environments where the effects of corrosion are measurable and may be a factor in determining equipment reliability.

Class 3: Environments where there is a high probability that corrosive attack will occur.

From IEC 60721-3-3:2002:

- 3C1R applies to locations with stringently monitored and controlled atmosphere (clean room category).
- In addition to the conditions covered by 3C1L, 3C1R applies to locations where the atmosphere is continuously controlled.
- In addition to the conditions covered by 3C1R, 3C1 applies to locations in rural and some urban areas with low industrial activities and moderate traffic. Increased contamination in urban areas in winter due to heating methods. Salt mist may be present in sheltered locations of coastal areas.
- In addition to the conditions covered by 3C1, 3C2 applies to locations with normal levels of contaminants experienced in urban areas with scattered industrial activities or heavy traffic.
- In addition to the conditions covered by 3C2, 3C3 applies to locations in the immediate neighborhood of industrial sources with chemical emissions.

- In addition to the conditions covered by 3C3, 3C4 applies to locations within industrial process plants. Emissions of chemical pollutants in high concentrations may occur.

9.5.5 Electromagnetic Environment References

Table 9-12 shows the readily available standards and levels used in derivation of the mechanical boundaries used in Table 9-4.

Table 9-12 – Derivation of boundaries for electromagnetic criteria

Electromagnetic	E ₁	E ₂	E ₃
Electrostatic discharge – Contact (0,667 µC)	4 kV	4 kV	4 kV
Electrostatic discharge – Air (0,132 µC)	8 kV IEC 61000-6-1/61326	8 kV	8 kV
Radiated RF - AM	3 V/m @ (80 to 1 000) MHz 3 V/m @ (1 400 to 2 000) MHz 1 V/m @ (2 000 to 2 700) MHz IEC 61000-2-5	3 V/m @ (80-1 000) MHz 3 V/m @ (1 400 to 2 000) MHz 1 V/m @ (2 000 to 2 700) MHz	10 V/m @ (80 to 1 000) MHz 3 V/m @ (1 400 to 2 000) MHz 1 V/m @ (2 000 to 2 700) MHz
Conducted RF	3 V@ 150 kHz to 80 MHz IEC 61000-6-1/61326	3 V@ 150 kHz to 80 MHz	10 V@ 150 kHz to 80 MHz IEC 61000-6-2/61326
EFT/B (comms)	500 V IEC 61000-6-1	1 000 V IEC 61000-2-5/61131-2	1 000 V IEC 61326:2001 Annex A Table A.1
Surge (transient ground potential difference) - signal, line to earth	500 V IEC 61000-6-2	1 000 V	1 000 V
Magnetic Field (50/60 Hz)	1 Am ⁻¹	3 Am ⁻¹ IEC 61000-6-1	30 Am ⁻¹ IEC 61000-6-2/61326