

Media Planning and Installation Manual



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Table of Contents

| | | |
|------------------|--|-----------|
| <i>Preface</i> | About This Manual | ix |
| | Who Should Use This Manual | ix |
| | What This Manual Contains | ix |
| | Related Publications | x |
| | | |
| <i>Chapter 1</i> | EtherNet/IP Media System Quick Start | 1 |
| | Understanding Your Environment | 1 |
| | Planning Your Network | 4 |
| | Selecting and Laying Out Network Media | 5 |
| | Which data rate should be used? | 5 |
| | Channel requirements | 5 |
| | Network security | 5 |
| | Network access | 5 |
| | Hubs | 5 |
| | Switches | 6 |
| | Number of ports needed | 6 |
| | Placement of network components (environment commensurate with manufacturer's limits) | 6 |
| | Bulkhead feed-throughs | 6 |
| | Patch panels | 6 |
| | Selecting cable to suit the environment | 6 |
| | When to use shielded, balanced twisted-pair (STP/ScTP) or unshielded twisted pair (UTP) cable | 7 |
| | Grounding shielded cables | 7 |
| | Know your segment lengths and limits | 7 |
| | Planning your cable routing | 7 |
| | Installing cable | 8 |
| | Terminating cable ends | 8 |
| | Connecting network devices | 8 |
| | IP65/IP67 sealed connectors | 8 |
| | Verifying and troubleshooting the network | 8 |
| | Certifying the network | 8 |
| | MICE Tutorial | 9 |
| | How to Use the MICE Concept in Your Application | 10 |
| | Examples of Mitigation | 11 |
| | | |
| <i>Chapter 2</i> | Overview of the EtherNet/IP Media System | 13 |
| | Industrial Control System Applications | 13 |
| | Information applications | 13 |
| | Control applications | 13 |

| | |
|---|----|
| Basic Media Components of an EtherNet/IP Industrial Control System | 15 |
| Ethernet backbone | 15 |
| Routers | 15 |
| Hubs | 15 |
| Bridges | 16 |
| Ethernet switches | 16 |
| Gateways | 16 |
| Network segments | 17 |
| Direct connections | 17 |
| Connectors | 17 |
| Standard 8-way modular connectors (RJ45) | 18 |
| EtherNet/IP sealed 8-way modular connector housings | 18 |
| 4-pole M12 D coded connectors | 20 |
| Cord Sets. | 22 |
| Rules for mixing 2-pair and 4-pair cabling in the same channel. | 22 |
| Cord sets providing connectivity between connectors of the same family. | 22 |
| Cord sets providing connectivity between two connector families | 24 |
| Cord sets providing crossover function | 24 |
| Modular Network Construction | 24 |
| Bulkhead feed-throughs | 24 |
| Patch panels | 24 |
| Wiring examples | 24 |
| Enclosures. | 27 |

Chapter 3 Planning Your EtherNet/IP Copper Cabling 29

| | |
|---|----|
| Planning Your System | 29 |
| Determining connectivity to the backbone | 29 |
| Network security | 30 |
| Determining the number of ports and/or device ports | 30 |
| Terms to Know | 30 |
| Copper Connectors | 31 |
| 8-way connector pin out | 31 |
| 4-pole M12 “D” coded connectors | 32 |
| Constructing Cord Sets. | 32 |
| 8-way Modular Crossover Cable | 33 |
| Conversion from One Connector Family to Another | 35 |
| Straight-through conversion | 35 |
| Crossover conversion | 36 |
| Channel and Link Lengths and Limits for Copper. | 36 |
| Patch cords. | 36 |
| Use of EtherNet/IP Components. | 39 |
| Use of Shielded Cables. | 40 |
| General Wiring Guidelines | 41 |
| Planning Your Cable Routing. | 41 |
| Categorize conductors | 42 |
| Routing conductors inside or outside enclosures. | 42 |
| Wiring external to enclosures | 43 |
| Raceway layout considerations | 44 |
| Pathways. | 44 |
| Wiring inside enclosures | 44 |
| Building Wiring and Ground Methods | 45 |
| TN-C wiring and ground scheme | 45 |
| TN-S wiring scheme | 45 |

| | |
|--|----|
| Grounding and Bonding for Performance | 46 |
| Star/multi-star earthed bonding system | 46 |
| Equipotential bonding system (highly meshed) | 47 |
| Grounding shielded cable | 50 |
| Controlling earth currents | 50 |
| Connecting shielding with equipotential bonding | 53 |
| Designing an installation with non-earthed reference voltage | 53 |
| Earthing and Bonding | 54 |
| Selecting Copper Cable | 55 |
| Two-pair versus four-pair cables | 56 |
| Oil- and chemical-resistant jackets | 56 |
| Plenum-rated cables | 56 |
| Riser-rated cables | 56 |
| Weld splatter-resistant cables | 56 |
| High-flex cables | 57 |
| Extension cords | 57 |
| Number of Connections in a Channel | 58 |
| IP65/IP67 sealed connectors | 58 |
| Placement of Active Network Components | 59 |
| Selecting and locating I/O | 59 |
| Use of bulkhead feed-throughs and cable glands | 59 |
| Ambient Temperature | 60 |
| Surge Suppression | 61 |
| Use of Ferrite Beads and Cores | 61 |

Chapter 4 Planning Your EtherNet/IP Fiber Optic Cabling 63

| | |
|--|----|
| Types of Fiber Optic Connectors | 63 |
| ST connector | 63 |
| SC connector | 63 |
| LC connector | 64 |
| Fiber Optic Cables | 65 |
| Operating wavelengths by fiber type | 66 |
| Bandwidths by fiber type | 66 |
| Core and cladding diameters by fiber type | 66 |
| Types of Fiber Optic Cable | 67 |
| Simplex and zipcord | 67 |
| Distribution cables | 67 |
| Breakout cables | 67 |
| Loose-tube cables | 67 |
| Armored cable | 67 |
| Aerial cable | 68 |
| Choosing a Cable | 68 |
| Planning and Installing Fiber Optic Cables | 68 |
| Conduit and innerduct | 69 |
| Cable plant hardware | 69 |
| Breakout kits | 70 |
| Splice enclosures | 70 |
| Splice panels | 70 |
| Patch panels | 70 |
| Racks and cabinets | 70 |
| Fiber Optic Installation Guidance | 70 |
| Water protection | 70 |
| Local and national fire codes | 71 |
| Pulling Fiber Optic Cable | 71 |

| | | |
|------------------|--|-----------|
| | Pulling tension | 71 |
| Chapter 5 | Network Installation | 73 |
| | Installing the Horizontal Cabling | 73 |
| | Bend radius | 73 |
| | Pull strength | 74 |
| | Terminating the Fixed Horizontal Cable | 74 |
| | Types of cables | 74 |
| | Field-terminating cable ends | 74 |
| | Terminating 8-way modular plugs | 75 |
| | Terminating UTP cable | 75 |
| | Terminating an M12-4-pin connector | 79 |
| | Terminating ScTP cabling | 80 |
| | Cable Routing | 82 |
| | Installing Switches | 82 |
| | Installing Bulkhead Feed-Throughs | 82 |
| | Installing the Cable | 83 |
| | Connection of Verification and Maintenance Equipment | 83 |
| | Optical fiber cabling | 83 |
| | Patch cords, equipment cords and work area cords | 84 |
| Chapter 6 | Verification of your EtherNet/IP Network | 87 |
| | Verifying Terminated Cable Segments | 87 |
| | List of recommended specialized equipment | 87 |
| | Channel test configuration | 88 |
| | Permanent link test configuration | 88 |
| | What should be verified? | 89 |
| | Wire map test | 90 |
| | Wire map for straight-through cables | 90 |
| | Wire map for crossover cables | 90 |
| | Reversed pairs | 90 |
| | Transposed or crossed pairs | 91 |
| | Split pairs | 91 |
| | Examples of incorrect wire mapping | 91 |
| | Physical Length vs. Electrical Length | 91 |
| | Length | 91 |
| | Length limits for permanent links and channels | 92 |
| Chapter 7 | Troubleshooting Your EtherNet/IP Network | 93 |
| | Tools for Determining Network Failures | 93 |
| | Test tools | 93 |
| | Passive testers | 93 |
| | Active test tools | 94 |
| | Network Verification | 94 |
| | Network Certification | 94 |
| | Diagnostic error counters | 94 |
| | Determining if you have a network failure | 95 |
| | Quick troubleshooting process | 95 |
| | Detailed troubleshooting process | 97 |
| | Common symptoms/causes of failures | 98 |

| | | |
|------------------|--|------------|
| Chapter 8 | Certifying your Ethernet/IP Network | 99 |
| | When to Perform Certification | 99 |
| | What Should Be Certified | 100 |
| | Tools Required for Network Certification | 100 |
| | Electrical Tests | 101 |
| | Certifying Terminated Cable Segments | 101 |
| | 100-ohm, twisted-pair transmission performance and field test requirements | 101 |
| | Test Configurations | 102 |
| | Channel test configuration | 102 |
| | Permanent link test configuration | 103 |
| | Physical and electrical lengths | 104 |
| | Insertion loss | 105 |
| | Cabling return loss | 108 |
| Chapter 9 | Index | 111 |

Preface

About This Manual

Who Should Use This Manual

This manual is intended for use by control engineers responsible for designing, implementing, and maintaining industrial control systems using EtherNet/Industrial Protocol (EtherNet/IP™). It describes the required media components and how to plan for, install, verify, troubleshoot and certify your network.

What This Manual Contains

This manual provides:

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

Related Publications

Refer to the current version of the following publications for additional information on planning your EtherNet/IP network:

- ANSI/TIA/EIA-568 series for generic cabling systems
- Draft ANSI/TIA-1005 Industrial Telecommunications Infrastructure Standard for Manufacturing, Process & Refining
- IEEE 1100 Wiring and Grounding Specification
- ISO/IEC 11801 for generic cabling systems
- Draft ISO/IEC 24702 Information Technology - Generic Cabling - Industrial premises
- Draft IEC 61918 Digital data communication for measurement and control. Profiles covering installation practice for fieldbus communications media within and between automation islands
- IAONA Industrial Ethernet Planning and Installation Guide
- ODVA EtherNet/IP Specification
- CSA C22.1 Canadian Electric Code for Canadian-based systems
- IEEE 518 Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources
- IEEE 802.3 Telecommunications and information exchange between systems - local and metropolitan networks - Part 3
- NFPA 70 (National Electric Code) U.S.-based systems

Chapter 1

EtherNet/IP Media System Quick Start

This chapter provides an overview of considerations for planning your network and selecting appropriate media components. It provides guidance for installing Control and Information Networks as defined by the Common Industrial Protocol (CIP)—both inside and outside the automation island. If your network is to be installed as a Generic Telecommunications Infrastructure, you should consult BICSI (Building Industry Consulting Services International) and ISO 61918 for installation guidance.

Understanding Your Environment

Your environment can be categorized by three distinct environmental classifications for four types of conditions: mechanical, ingress, climatic chemicals and electromagnetic. These environmental classifications are addressed in the Mechanical Ingress Climatic and EMC (MICE) table in [Table 1.1 on page 1.2](#). The MICE table can be used to determine your environment class. The design, installation and component selection for your network should take your environment class (as defined by the MICE table) into consideration.

To identify your environment class, determine which classification best describes your environment for each category (M, I, C, and E). There are three ways and combinations to build your system to meet the requirements of your environment:

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

EtherNet/IP Media System Quick Start

For example, your environment may have noise levels equivalent to those described in MICE E3 (EMC 3). If you have selected cabling components that only meet MICE E1, you will need to provide additional isolation and/or separation in the form of attenuation from the noise sources. In this case, conduit is one means of providing the required isolation and attenuation from noise sources. See [“MICE Tutorial” on page 9](#) for further information on how to apply the MICE concept to your design.

Table 1.1 Environmental Classifications for MICE

| Mechanical | M₁ | M₂ | M₃ |
|--|-------------------------------------|--|--|
| Shock/bump ⁽¹⁾ | | | |
| Peak acceleration | 40 ms ⁻² | 100 ms ⁻² | 250 ms ⁻² |
| Vibration | | | |
| Displacement amplitude (2-9 Hz) | 1,5 mm | 7,0 mm | 15,0 mm |
| Acceleration amplitude (9-500 Hz) | 5 ms ⁻² | 20 ms ⁻² | 50 ms ⁻² |
| Tensile force ⁽²⁾ | See Note 2 | | |
| Crush | 45 N over 25 mm (linear) min. | 1100 N over 150 mm (linear) min. | 2200 N over 150 mm (linear) min. |
| Impact | 1 J | 10 J | 30 J |
| Bending, flexing and torsion ⁽²⁾ | See Note 2 | | |
| Ingress | I₁ | I₂ | I₃ |
| Particulate ingress (dia. max) | 12.5 µm | 50 µm | 50 µm |
| 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) |
| Climatic Chemicals | C₁ | C₂ | C₃ |
| 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) | |
| Solar radiation | 700 Wm ⁻² | 1120 Wm ⁻² | 1120 Wm ⁻² |
| Liquid pollution ⁽³⁾ contaminants | (Concentration X 10 ⁻⁶) | | |
| Sodium chloride (salt/sea water) | 0 | <0,3 | <0,3 |
| Oil (dry-air concentration) ⁽²⁾ | 0 | <0.005 | <00.5 |
| Sodium stearate (soap) | None | 5 X 10 ⁴ aqueous non-gelling | >5 X 10 ⁴ aqueous gelling |
| Detergent | None | ffs | |

Table 1.1 Environmental Classifications for MICE (Continued)

| Conductive materials in solution | None | Temporary | Present |
|---|---|--|--|
| Gaseous pollution contaminants | Mean/Peak (Concentration X 10 ⁻⁶) | Mean/Peak (Concentration X 10 ⁻⁶) | Mean/Peak (Concentration X 10 ⁻⁶) |
| Hydrogen sulphide | <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) | <0,0005/<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 |
| Electromagnetic | E₁ | E₂ | E₃ |
| Electrostatic discharge - Contact (0,667 μC) | 4 kV | | |
| Electrostatic discharge - Air (0,132 μC) | 8 kV | | |
| Radiated RF - AM | 3 V/m @ 80-1000 MHz 3 V/m @ 1400-2000 MHz 1 V/m @ 2000-2700 MHz | | |
| Conducted RF | 3 V @ 150 kHz-80 MHz | | 10V @ 150 kHz-80 MHz |
| EFT/B | 500 V | 1000 V | |
| Surge (transient ground potential difference) - Signal, line to earth | 500 V | 1000 V | |
| Magnetic Field (50/60 Hz) | 1 Am ⁻¹ | 3 Am ⁻¹ | 30 Am ⁻¹ |
| Magnetic Field (60-20000 Hz) | ffs | | |

- (1) Bump: the repetitive nature of the shock experienced by the channel shall be taken into account.
- (2) This aspect of environmental classification is installation-specific and should be considered in association with IEC 61918 and the appropriate component specification.
- (3) A single dimensional characteristic, i.e, concentration x 10⁻⁶, was chosen to unify limits from different standards.

Planning Your Network

The process for planning and laying out your Ethernet network should consist of the following steps:

1. Determine the type of application:
 - a. Information
 - b. Control
2. Consider your information system as part of the CIP network:
 - a. Determine placement of major components such as switches and devices. A device is any Ethernet-enabled interface except switches (input/output, HMI, PLC, NIC, etc.)
 - b. Determine the length of the cabling needed to reach each device. End-to-end cabling is referred to as the “channel,” which includes equipment cords and patch cords. The placement of switches may need to be adjusted to meet Ethernet’s 100 m (328 ft.) segment limit and to accommodate devices.
 - c. Determine operating environmental conditions based on the environmental classes in the MICE table ([Table 1.1 on page 1.2](#)), including shock and vibration, temperature, ingress protection requirements, the presence of chemicals and electrical noise.
 - d. Select and order materials based on environments.
 - e. Install the network.
 - f. Verify the network.
 - g. Certify the network.
3. Consider your control system:
 - a. Determine placement of major components such as switches and devices.
 - b. 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.) segment limit.
 - c. Evaluate your grounding system.
 - d. Determine environmental requirements based on the MICE table ([Table 1.1 on page 1.2](#)), including shock and vibration, ingress protection requirements, temperature, the presence of chemicals and electrical noise.
 - e. Select and order materials based on above requirements.
 - f. Plan your installation to provide adequate protection from damage by machinery.
 - g. Plan your installation to provide maximum isolation/separation from noise-generating devices.
 - h. Install the network.
 - i. Verify the network.
 - j. Certify the network.

Selecting and Laying Out Network Media

The following presents an overview of primary considerations for selecting appropriate media and laying out your network.

Which data rate should be used?

For the best noise immunity, use the lowest data rate at which your application will run (10 Mb/s and 100 Mb/s), keeping in mind that optical fiber generally provides higher noise immunity than other cabling options.

Channel requirements

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

- 2-pair or 4-pair cabling
- CAT 5, 5e, 6
- Optical fiber

The minimum cabling performance that will support EtherNet/IP is Category 5 as defined by ANSI/TIA/EIA-568-B.2 Annex N. There are reasons to select one category of cabling over another. In general, the higher the category, the better the cabling performance. Another consideration is balance. Category 5e, 6 and the newest proposed category, known as augmented 6 or Category 6a, will support current applications such as 1 Gb/s and 10 Gb/s. Generally speaking, the greater the cabling category, the less EMC protection that is needed. Consult your cable supplier for guidance on EMC protection for the specific cable being used.

Network security

Network security is beyond the scope of this manual. However, the control network should be properly isolated from the office environment and the Internet. Security is provided through the use of gateways, firewalls, routers and/or appropriate security software.

Network access

Careful consideration should be given to the placement of access ports to prevent unauthorized connection of devices into control networks. Cabinets housing control networks should not be accessible to unauthorized personnel. Cabling components should be protected from damage by machinery or tampering. (See [Chapter 3](#).)

Hubs

Careful consideration also should be given to the use of hubs. Hubs are generally discouraged in control applications. They do not provide security and do not help to control collisions among signals from devices concurrently accessing the network media. Collisions cause transmission retries or dropped frames and increase jitter in control systems.

Switches

Switches provide connections that eliminate collisions. In control applications where real-time data access is critical, network switches should always be considered in place of hubs. Selecting switches that have the ability to provide full duplex, Internet Group Management Protocol (IGMP) snooping and port mirroring is beneficial in troubleshooting.

Number of ports needed

While planning your network, you must determine the number of switches you will need and the number of ports for each switch chassis. Each network device will require a corresponding switch port for connection to the network. The number of ports per switch chassis also depends on your physical network layout. Provide for growth of at least 20 percent in case of system expansion. (See [Chapter 3](#).)

Placement of network components (environment commensurate with manufacturer's limits)

Placement of network components should be carefully planned to minimize cable lengths and the effects of the environment. Network components should be installed in accordance with the manufacturer's specifications and considering the environment as defined in the MICE table ([Table 1.1 on page 1.2](#)).

Bulkhead feed-throughs

Bulkhead feed-throughs should be used whenever connectivity through an enclosure is required. A bulkhead feed-through provides a cable passage through an enclosure wall. The most common types of bulkhead feed-throughs are either connector assemblies or cable glands. The connector or cable gland should be located within the enclosure wall to minimize liquid and dust ingress and cable abrasion. For performance reasons, consult your manufacturer on the number of bulkhead feed-throughs allowed within a channel or link.

Plan your mounting location so that the connector is not exposed to damage from plant activity.

Patch panels

Patch panels should be used to maintain system flexibility in a control network to accommodate frequent adds, moves and changes. Patch panels require additional space that may not be available on machines and/or in machine areas. Patch panels and additional connections within a channel also may affect the network's mean time between failures (MTBF).

Selecting cable to suit the environment

Cable should be selected and installed in accordance with the planning and installation guide, local and national regulations, manufacturer's specifications and considering the environment as defined in the MICE table ([Table 1.1 on page 1.2](#)).

When selecting cable, 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.

Do not overlook the cable's electrical specifications over the temperature range. Commercial, off-the-shelf cables may not meet industry performance requirements over expanded temperature ranges. Cable jackets and conductor insulation may be easily damaged at extreme temperature ranges. See the MICE table ([Table 1.1 on page 1.2](#)), [Chapter 3](#) (copper cable) and the Fiber section of [Chapter 4](#) (fiber cable).

When to use shielded, balanced twisted-pair (STP/ScTP) or unshielded twisted pair (UTP) cable

STP/ScTP cable (Sc = screened) provides an added level of noise immunity. If your cable is to be installed in a high noise environment, then shielded cable or an alternative media such as optical fiber should be considered. See the MICE table ([Table 1.1 on page 1.2](#)) and [Chapter 3](#).

Grounding shielded cables

Single point grounds are very important for reducing or eliminating ground loops in shielded communications cables. See [Chapter 3](#).

Consult the installation data sheet for each device installed for that device's grounding requirements. Most hub/switch manufacturers require their equipment to be grounded. Note that grounding the equipment will ground the shield when connected via a shielded 8-way modular connector or a shielded M12-4 "D" coded connector. A single-point ground can be achieved by installing a standard unshielded plug at one end of the channel.

Know your segment lengths and limits

The length of your segment is dependent on the cable. See [Chapter 2](#) and [Chapter 3](#) for maximum channel/link lengths when using stranded type cables in the channel.

Planning your cable routing

Route your cable as described in [Chapter 3](#) of this manual.

- If your application is in a high noise environment, plan to use STP/ScTP cabling or alternate media such as optical fiber. ["MICE Tutorial" on page 9](#) for detailed information.
- Cable segments should be as short as possible. It is not advisable to coil up excess cable.

Installing cable

Install the cable per the manufacturer's requirements for bend radius and pull strength. (See [Chapter 5](#)) Consult the cable manufacturer when installing UTP cables in a conduit as metal can affect electrical performance. Avoid routing near equipment that generates strong electric or magnetic fields. (See [Chapter 3](#) for more information.) Cables must be properly supported to prevent damage using hangers and raceways. Cable support loading requirements also must be observed to prevent cable crushing.

Terminating cable ends

The performance of your system depends on cable termination. Careful cable end preparation will help you to install the connector onto the cable. (See [Chapter 5](#).)

Connecting network devices

Connect devices to your network per the manufacturer's instructions. Be aware of electrostatic discharge (ESD) build-up on cables. Cables should be discharged to earth prior to connecting into active ports. Cables may be grounded with a grounding patch cord terminated to earth ground via a low impedance path-to-ground 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 the cable and all conductors terminated together with a clip or lug to terminate to ground.

IP65/IP67 sealed connectors

Use the appropriate connectors for your environment(s). If cables and connectors will be exposed to liquids or dust, use IP65/IP67 sealed connectors (See [Chapter 2](#)) and bulkhead feed-through connectors. For more information on environmental aspects, see the MICE table ([Table 1.1 on page 1.2](#)) and the "[MICE Tutorial](#)" on [page 9](#).

Verifying and troubleshooting the network

The user is strongly encouraged to verify each cable segment for proper connection and level of performance. Off-the-shelf cable testers are available. (See [Chapter 6](#).) Correct all errors/faults before placing cabling system into service. (See [Chapter 7](#) for more information on troubleshooting.)

Certifying the network

The user is strongly encouraged to certify each cable segment for proper connection and level of performance. Off-the-shelf cable testers are available. (See [Chapter 8](#).) Correct all errors/faults before placing cabling system into service. (See [Chapter 7](#) for more information on troubleshooting.)

MICE Tutorial

MICE is a relatively new concept in which an installation environment can be classified in terms of environmental and EMI levels. [Table 1.1 on page 1.2](#) defines three classifications for Mechanical, Ingress, Climatic and Electromagnetic levels, thus the name MICE. These levels begin at the low end (M1I1C1E1), which best describes most office spaces, and extend to the higher levels that best describe typical industrial spaces (M3I3C3E3).

| Office | Lt. Industrial | Industrial |
|--------|----------------|------------|
| M1 | M2 | M3 |
| I1 | I2 | I3 |
| C1 | C2 | C3 |
| E1 | E2 | E3 |

Figure 1.1 MICE classifications.

Not all areas fall exclusively into one classification. For example, an automation island may have mechanical shock at >150 ms, whereby it may be classified as an M3 environment. The environment may only have light dust consistent with the levels in I2. Temperature in the areas where the cables and equipment are routed/installed may be 65 degrees C. In which case, the climatic classification in the automation island is C2. The machinery in the automation island may consist of welding robots that produce EMI levels in the E3 classification. This MICE environment can then be summarized as M3, I2, C2 and E3.

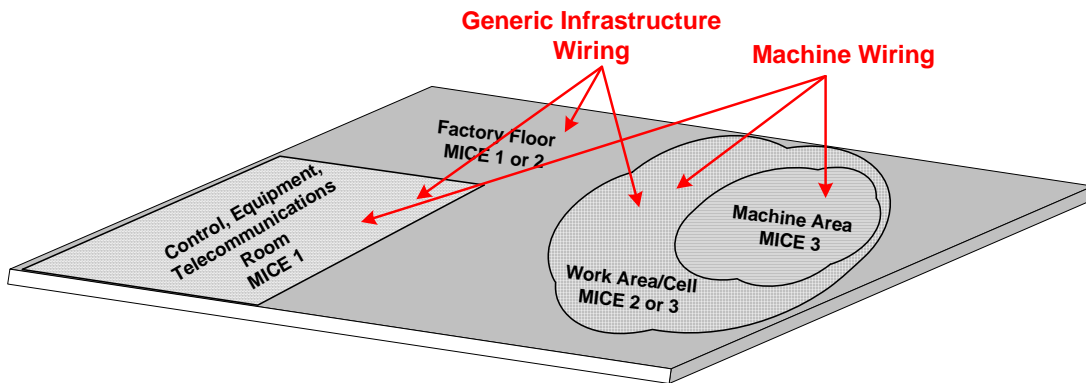


Figure 1.2 Typical MICE areas within a facility.

Not all areas fall exclusively into one classification. For example, an automation island may have mechanical shock at >150 ms, whereby it may be classified as an M3 environment. The environment may only have light dust consistent with the levels in I2. Temperature in the areas where the cables and equipment are routed/installed may be 65 degrees C. In which case, the climatic classification in the automation island is C2. The machinery in the automation island may consist of welding robots that produce EMI levels in the E3 classification. This MICE environment can then be summarized as M3, I2, C2 and E3.

How to Use the MICE Concept in Your Application

As a network designer, you should be aware of the environment in the areas where cabling and equipment will be installed. By systematically classifying the environments in installation areas, decisions can be made on component selections and additional mitigation needs. Cabling systems can be designed using all enhanced components that require no mitigation. In some cases, this may restrict flexibility or may present cost or availability issues. The concept allows the designer to balance component cost (and availability) with mitigation costs, thereby designing the most robust, cost-effective cabling system as shown in [Figure 1.3](#). Mitigation can be broken down into two forms: separation and isolation.

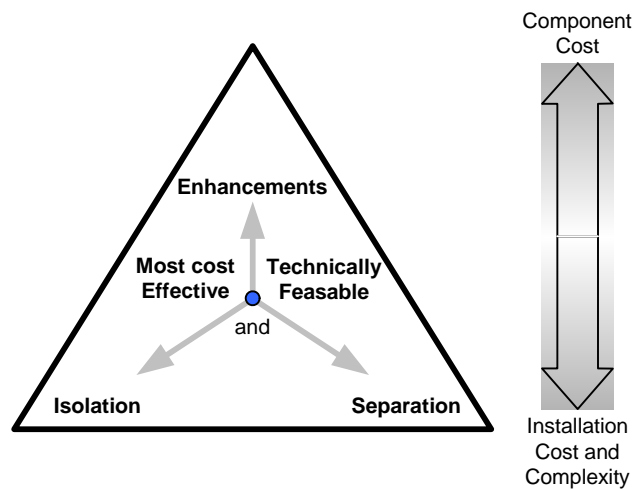


Figure 1.3 Enhancement, isolation and separation

Examples of Mitigation

Mitigation simply converts one MICE environment into another that is compatible with the cabling components and equipment to be installed.

Example 1

The proposed component and targeted installation area are classified as shown in [Table 1.2](#).

Table 1.2 Example 1 MICE Classifications

| Component | Environment |
|-----------|-------------|
| M1 | M3 |
| I3 | I1 |
| C3 | C2 |
| E2 | E3 |

Since the component does not map directly in to the environment, the environment must be mitigated. The harsh M3 environment can be converted to an M1 by shock-mounting the equipment in an enclosure. The high EMI can be reduced by using a metal EMI shock-mounted enclosure, thereby solving both the M3 and E3 problems as shown in [Figure 1.4](#).

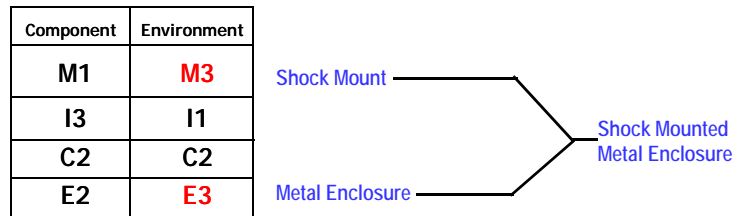


Figure 1.4 Mitigation for example 1.

Example 2

Here, cable rated for an E2 environment is to be installed in an environment with E3 EMI levels as shown in [Table 1.3](#).

Table 1.3 Example 2 MICE Classifications

| Cable | Environment |
|-------|-------------|
| M1 | M1 |
| I3 | I1 |
| C2 | C2 |
| E2 | E3 |

Since the selected cable does not meet the EMI requirements, some mitigation is required. Mitigation can be solved with separation and/or isolation. [Figure 1.5](#) shows how this can be done in a raceway.

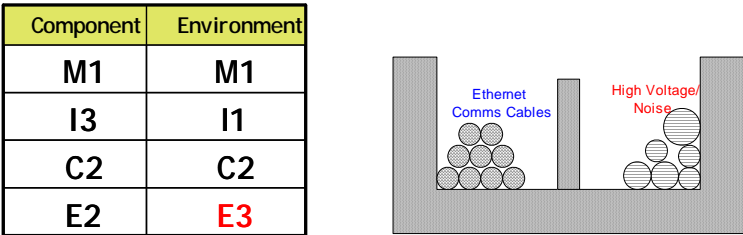


Figure 1.5 Mitigation for example 2.

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

Chapter 2

Overview of the EtherNet/IP Media System

Industrial Control System Applications

Ethernet is widely used in the business world for information applications. The technology has widespread availability, familiarity, and cost benefits, making it attractive for use in industrial control systems as well. However, industrial information and control applications have some inherent differences, resulting in the requirements described in the following sections.

Information applications

Typically, industrial information applications are used to download programmable logic controller (PLC) programs, monitor processes, gather statistics, process data, and report diagnostics. Performance for these types of applications is not as critical as it is in a control application where speed, throughput, response time, and downtime are critical to a manufacturing process.

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 by the use of firewalls or wireless bridges. The installation of the network must be robust enough to prevent mechanical damage and noise ingress that could cause degradation of the network's performance, resulting in manufacturing process downtime.

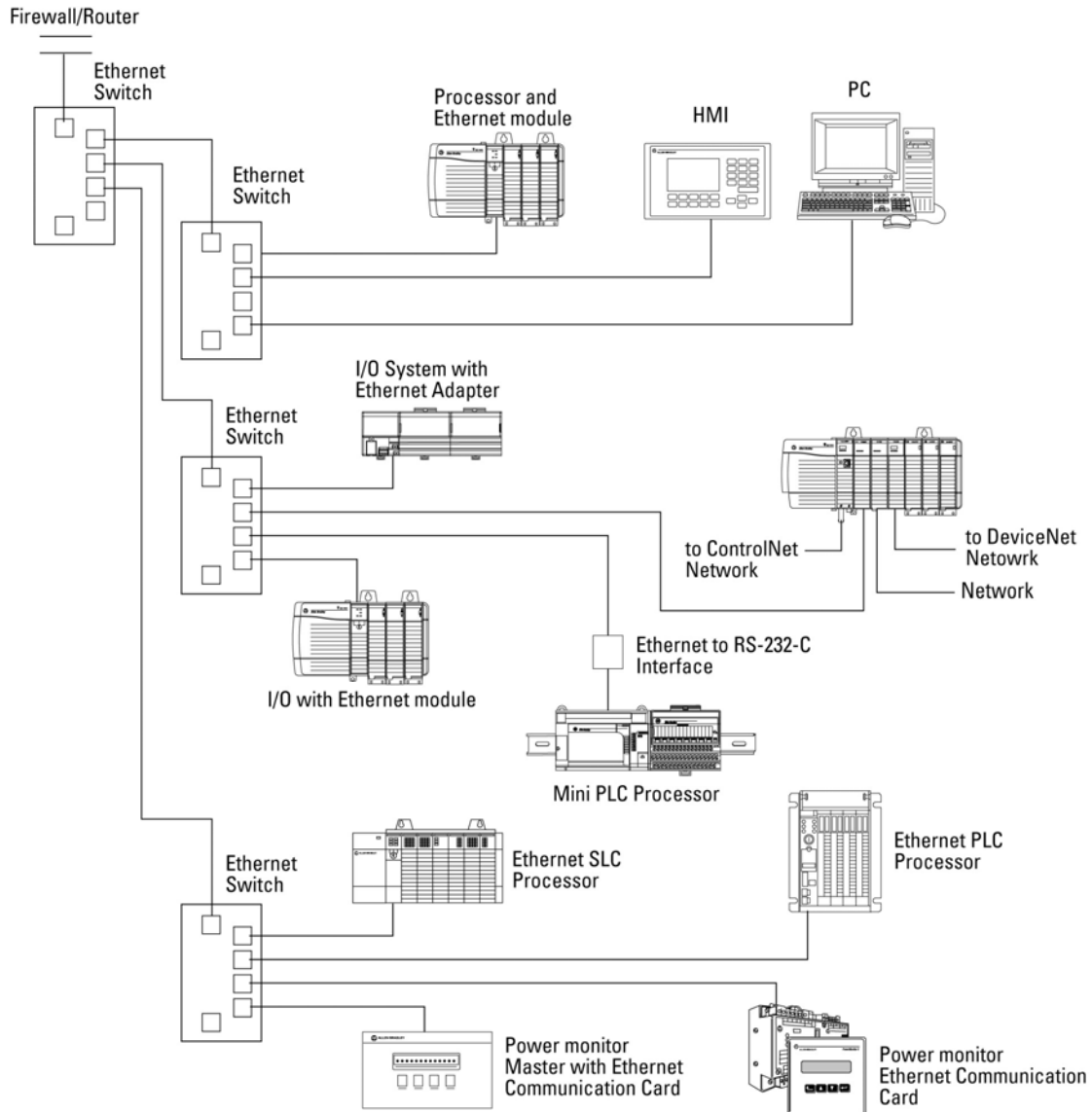
Some commercial, off-the-shelf Ethernet products are not compatible with industrial environments such as those found in industrial manufacturing plants. Among the problems encountered with some off-the-shelf commercial products:

- Poor cabling balance, including active interfaces,
- Performance degradation caused by temperature and/or humidity,
- Impedance tolerance in excess of +/-5%, resulting in high system reflections,
- Chemical incompatibility,
- Susceptibility to electrical noise,
- Vibration-related failures, and/or
- Damage due to bending and flexing.

Overview of the EtherNet/IP Media System

These types of hostile environments require components designed for industrial use. Otherwise, careful planning, the added expense of additional separation and/or isolation and/or other circuits may be needed. As an example, cabling not rated for IP65/IP67 may need to be placed in enclosures. Cables not designed for high noise environments may need to be isolated by installing them in conduit or otherwise separating them from high noise generating and conducting devices.

An example of an EtherNet/IP control system is shown in [Figure 2.1](#).



31159-M

Figure 2.1 System diagram.

Basic Media Components of an EtherNet/IP Industrial Control System

Ethernet backbone

The Ethernet backbone is the part of the network that handles the major 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.

Note: If your network traffic is information and control, the backbone cabling should be 4-pair copper, and/or optical fiber. If the network traffic is control only, then any ODVA-recognized media is acceptable (such as 2-pair and 4-pair copper cabling or optical fiber.)

Routers

Routers are used to segment LANs in order to balance traffic within workgroups and are used 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 have to inspect the network address in the protocol, they do more processing and add more latency than a bridge or switch (see the following sections), which both work at the Data Link Layer (Layer 2). Because of the processing overhead, I/O data cannot be passed through a router in real time.

Hubs

A hub is a central connecting device in a network. It joins communications lines together in a star configuration. Also sometimes called “multiport repeaters,” hubs regenerate the data bits in order to maintain a strong signal.

When designing your control system, it is important to understand that all devices connected to a hub compete for the network media, resulting in collisions and decreased network bandwidth. As a result, hubs are more suitable for use in information networks than in control networks.

Important: Hubs are not recommended for control applications due to collisions that can occur on high traffic systems.

Bridges

Bridges are devices that connect two network segments together. These 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.

Ethernet switches

Over the last decade, hub technology has been supplanted by a new, high-speed switch technology that allows traffic between any two ports on the switch to pass through without contention. Switches are basically multi-port bridges that can simultaneously move frames between pairs of ports at full wire speed.

For example, a 16-port 10BaseT hub shares a 10 Mbps bandwidth with all 16 attached nodes. By replacing the hub with a switch, each sender/receiver pair has the full 10 Mbps capacity, so a 16-port full-duplex 10BaseT switch would effectively have an 160 Mbps bandwidth, supporting 8 virtual connections, supporting 8 pairs as shown in [Figure 2.2](#). A switch segments a network into many parallel dedicated lines to produce a contention-free architecture.

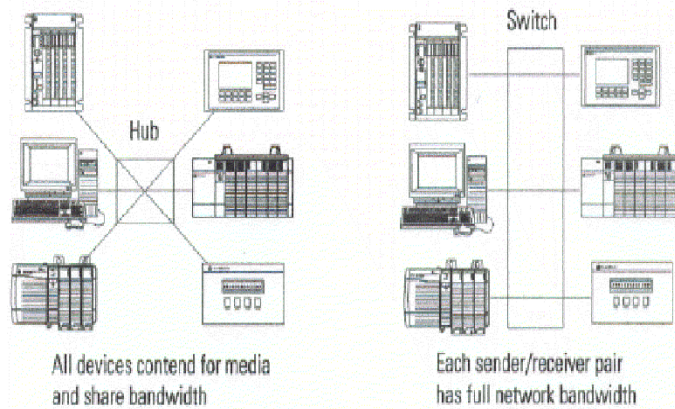


Figure 2.2 Hub versus switch system.

Switches are available for both standard 10/100 Mbps Ethernet and 1 Gbps gigabit Ethernet. In a control application in which real-time data access is critical, network switches are required in place of hubs.

Gateways

The term “gateway” can have different meanings. It may refer 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 supporting one protocol from within another. Sometimes routers can implement such gateway functions.

A gateway can also mean a device that acts as a go-between, connecting two or more networks that use the same protocols. In this case, the gateway functions as an entry/exit point to the network. Transport protocol conversion may not be required, but some form of processing is typically performed.

Network segments

A network segment is a group of functionally associated devices connected together and isolated by bridges, routers or switches. 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.

Direct connections

Direct connections from one device to another via a single Ethernet cable are possible as shown in [Figure 2.3](#). No hubs, switches, or other connective devices are used. The appropriate crossover cable will be required unless your device supports auto MDIX function. See [Chapter 3](#) for the appropriate connector wiring.



Figure 2.3 Example of an application with no switch.

Connectors

EtherNet/IP offers two connector types: encapsulated 8-way modular connectors and 4-Pole M12 “D” coded connectors. The connectors are defined in an international standard IEC 61076-3-106 (Variant 1) and IEC 61076-2-101 respectively. Both connector designs provide sealing to IP65/67 in accordance with IEC60529 (International Protection Class).

Both connector designs are available with external housing construction made of either plastic or metal. The material of the connector external housing construction is application dependent. See the MICE table ([Table–5.1 on page 5.72](#)) for further details.

Standard 8-way modular connectors (RJ45)

Unprotected 8-way modular connectors are not designed to meet the IP65/IP67 specification for EtherNet/IP. In addition, their balance can be low, and the amount of crosstalk can be too high for industrial applications. Further, some 8-way modular connectors may be susceptible to vibration-related problems.

EtherNet/IP sealed 8-way modular connector housings

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

Table 2.1 contains the connector parameters for 8-way modular connectors (sealed and unsealed) for industrial EtherNet/IP systems.

Table 2.1 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 | < 2.5 mΩ | < 2.5 mΩ |
| Contact life | 750 insertions and extractions min. | 750 insertions and extractions min. |

Sealed 8-way modular connectors shall meet the EtherNet/IP specification and utilize the encapsulation method selected by ODVA.

Important: Not all 8-way modular connectors are suitable for harsh environments. Carefully select 8-way modular connectors for the intended environment. Only consider connectors recognized by the ODVA Industrial EtherNet/IP specification.



Figure 2.4 The 8-way modular sealed jack and plug in a plastic housing.



Figure 2.5 The 8-way modular sealed jack and plug in a metal housing.

There are two 8-way modular wiring methods in use today. Pairs 2 and 3 are swapped depending on whether you are using T568A or T568B. It is not recommended to mix the two wiring methods in the same channel as this may impair the channel's performance. The two pin/pair assignments for the 8-way modular connector are as shown in [Figure 2.6](#).

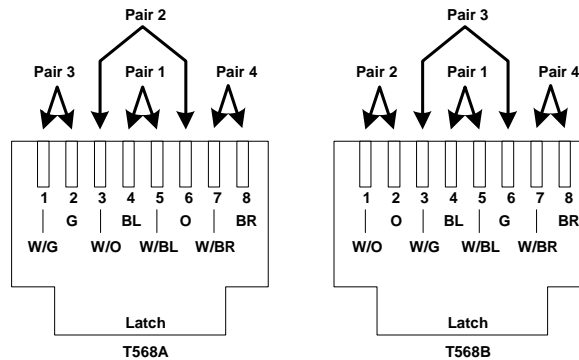


Figure 2.6 Pin/pair wiring assignments.

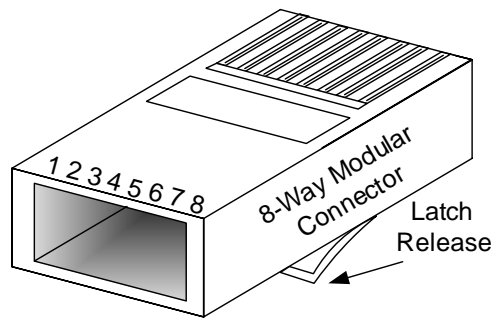


Figure 2.7 8-way modular plug pin out.

TIA T568A should be used in generic applications where support of 2-pair phone systems is needed. If 2-pair phone system support is not needed, then either wiring system (T568A or T568B) is acceptable. The selected wiring scheme is applied throughout the entire link or channel.

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 are to be used only with 2-pair cables. If support of all generic applications such as voice, video and data (1 G/b and 10 G/b Ethernet) is required, 4-pair cables, the 8-way modular connector and compatible components shall be used. See Chapter 4 for rules on 2- and 4-pair cabling within a channel.

Table 2.2 delineates the connector parameters for Industrial EtherNet/IP systems.

Table 2.2 Industrial EtherNet/IP 4-pole M12 Connector Parameters

| Specification | Type | |
|------------------------|---|----------------|
| | M12 Shielded | M12 Unshielded |
| Conductors | 4+1 Shield | 4 |
| Contact LLCR over life | Maximum: 5 mOhms over life | |
| Initial contact LLCR | Nominal: < 1 mOhm | |
| Contact rating | 3 amps minimum | |
| Contact plating | 30 micro inches gold ⁽¹⁾ over 50 micro inches nickel or 5 micro inches gold minimum over 20 micro inches palladium nickel over 50 nickel | |
| Contact life | 750 insertions-extractions | |

⁽¹⁾ Gold shall be 24 karat minimum.



Figure 2.8 M12-4 connectors.

4-pole, M12 circular connectors shall meet the EtherNet/IP specification.

Important: Follow manufacturer's assembly instructions to avoid possible degradation or compromise of performance.

Note:
"D" Coding Keyways

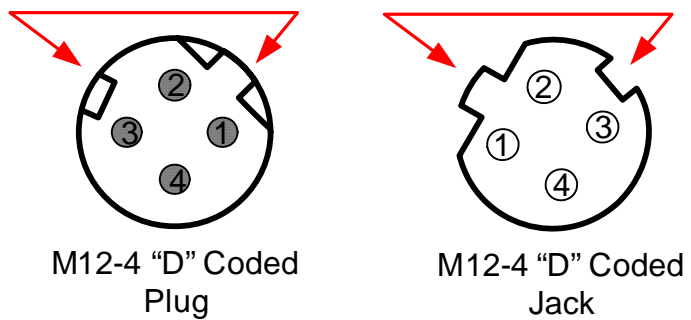


Figure 2.9 M12-4 connector keying.

Cord Sets

Cordsets can be built on-site using cable and field-attachable connectors or can be purchased as factory-made, over-molded cord sets. There are a minimum of four possible types of plug-to-plug configurations:

- Non-sealed 8-way plug to 8-way plug
- Sealed 8-way plug to sealed 8-way plug
- M12-4 “D” coded plug to M12-4 “D” coded plug
- 8-way modular plug to M12-4 “D” coded plug

Each may come as shielded or unshielded. In addition, connector housings for the shielded types can be obtained as metal shell variants. All of the above may also be purchased as crossover cables. Chapter 5 provides details on the pin/signal and pair assignments for each of the four cables plus the crossover cables.

Rules for mixing 2-pair and 4-pair cabling in the same channel

When utilizing 4-pole M12 “D” coded connectors, use 2-pair cables (shielded or unshielded).

Due to interference between the pairs of a cable, do not use 4-pair cable with 4-pole M12 D coding connectors. Two-pair cables may be used with 8-way modular connectors unless full application support is needed or future system expansion requires all 4-pair cables. If full support is needed, then only connectors supporting all 4-pair should be considered (i.e., 1 G/b, 10 G/b Ethernet, power-over-Ethernet, etc.).

Cord sets providing connectivity between connectors of the same family

8-way modular connector cord sets

Construct straight-through 8-way modular cords sets as detailed in this section. Pay particular attention to the cable pairing and color codes. Correct pairing of the connector pins is extremely important. In addition, note that pair 2 (T568A) or pair 3 (T568B) is split across pair 1.

8-way modular cords sets should be constructed with plugs at both ends. Extension cables may be constructed from one plug and one jack. Both connectors shall be cable-type connectors. See [Chapter 3](#) for the maximum length of cord sets in a channel.



Figure 2.10 8-way modular connector sealed cord set.

M12-4 “D” coded connector cord sets

M12-4 “D” coded cord sets should be constructed of plugs. In some cases, extension cables may be required, in which case they will be constructed of a plug and a jack. Pay particular attention to the color pin assignment. Correct pairing of the connector pins is extremely important. Both connectors shall be cable-type connectors. Cord sets can be factory made and field assembled. See section [Chapter 3](#) for the maximum length for cords sets in a channel. It is not recommended to use a 4-pair cable for the construction of a 2-pair channel. Do not mix 2- and 4-pair cables in a channel.



Figure 2.11 M12-4 sealed field constructed cord set.



Figure 2.12 M12-4 over-molded cord sets.

Cord sets providing connectivity between two connector families

Cord sets (field assembled or factory over-molded) can provide connectivity between one connector family and another. EtherNet/IP supports connectivity between the 8-way modular connector and the M12-4 “D” coded connector families. It is strongly recommended that 2-pair cabling be used for the construction of this cable.

Cord sets providing crossover function

The 8-way modular crossover cable provides full functionality for 10 Mb/s/100 Mb/s/1 Gb/s and 10 Gb/s data rates. M12 crossover cables only support 10Mb/s/100Mb/s data rates (as in all 2-pair systems). If your crossover cable only needs to support 10 Mb/s and 100 Mb/s, only pairs 2 and 3 need to be crossed. Pairs 1 and 4 can be configured as straight-through. Only one crossover cable should be used within a channel. All other connections shall be straight-through.

Modular Network Construction

A modular systems design may be desirable. Modular design allows pre-testing, 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 the mean time to repair (MTTR) and downtime for a failed communications network. Bulkhead feed-throughs provide modularity.

Bulkhead feed-throughs

Bulkhead feed-throughs and/or cable glands should be used wherever cables must pass through an enclosure wall.

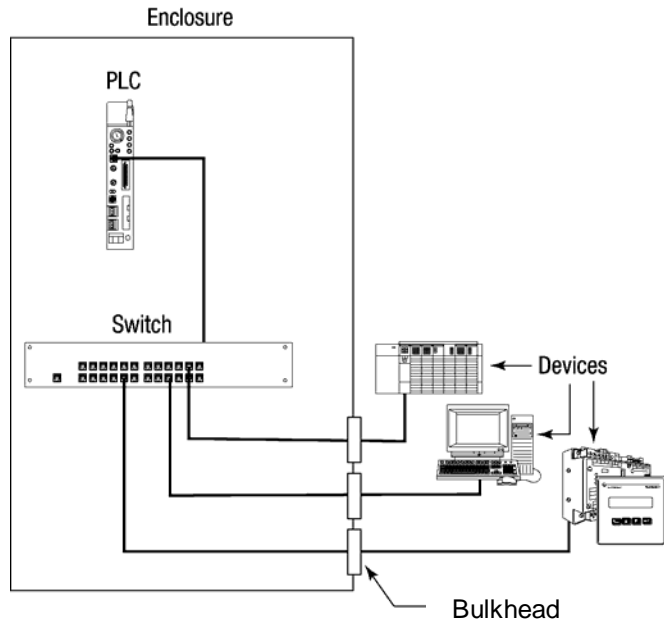
Patch panels

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.

Wiring examples

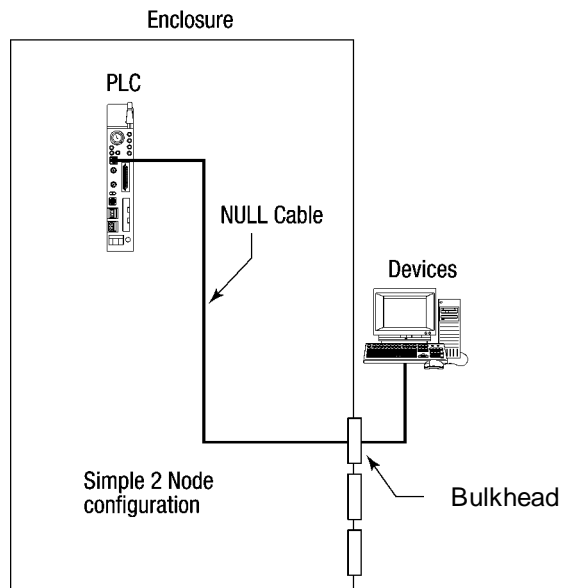
Patch panels provide flexibility and ease of network reconfiguration. In many control applications, flexibility and reconfiguring is not necessary. Patch panels require additional space. They add cost and present potential points of failure. The following wiring examples range from a complex system to a simple patch cord.

Note that patch panels are not specifically required for industrial control. Controllers and I/O devices may be directly connected in a configuration or connected via hubs or switches, as shown in [Figure 2.13](#) through [Figure 2.16](#).



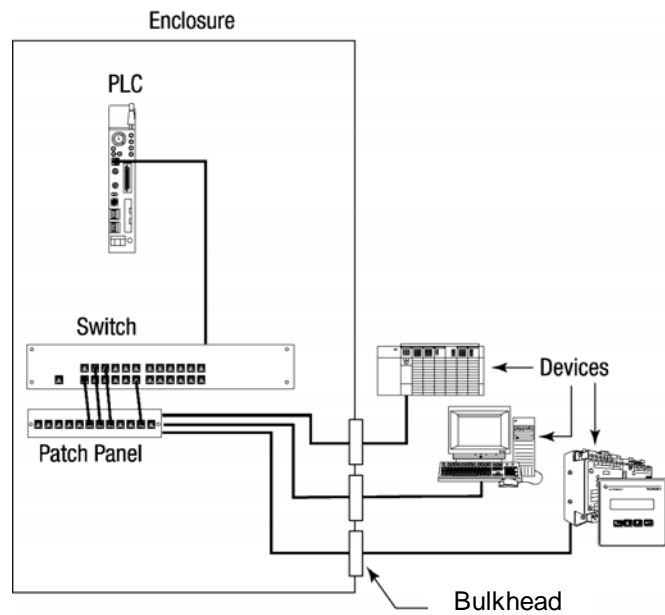
31185-M

Figure 2.13 Wiring without patch panels.



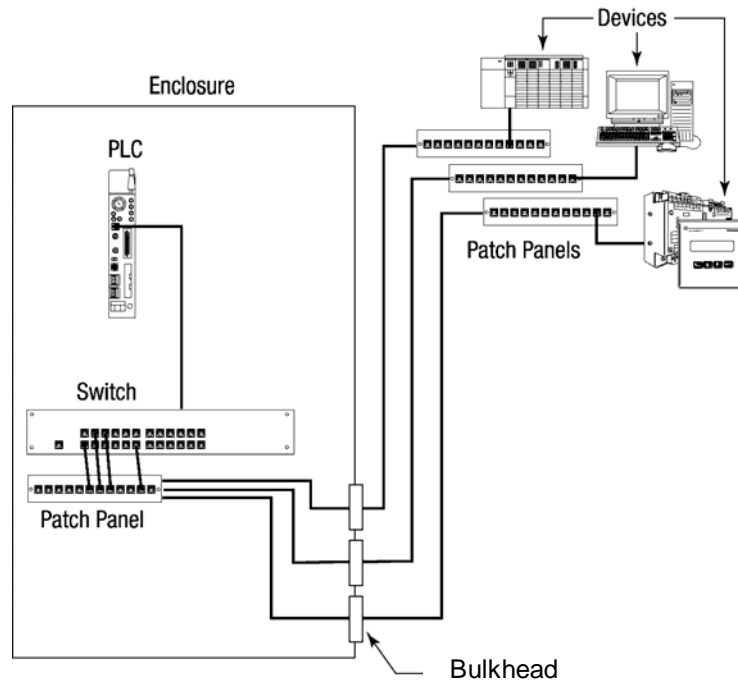
31184-M

Figure 2.14 Direct connection using a crossover (null) cable.



31179-M

Figure 2.15 Star topology using a patch panel.



31182-M

Figure 2.16 Hierarchical star using patch panels.

Enclosures

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

Chapter 3

Planning Your EtherNet/IP Copper Cabling

After reading this chapter, you may wish to consult the engineering drawings of your facility for specific information concerning the best location for installing your network. Chapter 2 details the connectors for EtherNet/IP. Here you'll find the wiring and pin-out for copper connectors and cord sets. In addition, this chapter provides the pin-out to convert from one copper connector to another using patch cords.

Planning Your System

Determining connectivity to the backbone

The following sections describe some of the variables you should consider when designing and securing your network.

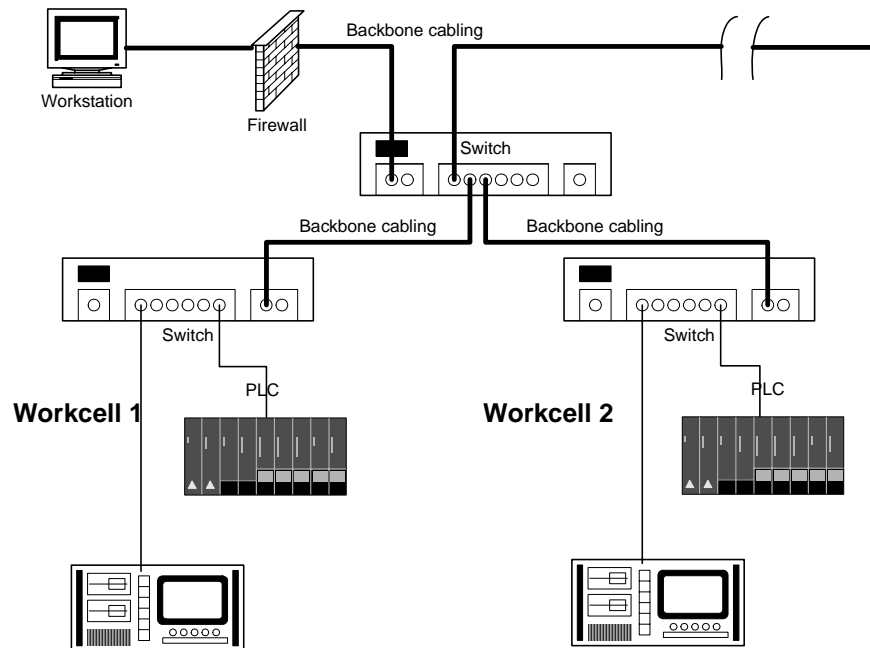


Figure 3.1 Backbone connectivity.

Network security

Control applications may require access to the control network 100% of the time. Intrusions by other users into the control network could cause processing delays and loss of control. For this reason, the control network must be isolated from the office environment and the Internet. The designer is strongly encouraged to provide appropriate security through the use of filtering devices, gateways, firewalls, routers, and/or appropriate security software. The designer and maintenance personnel are cautioned about installing devices on the control network that could bypass network security, such as telephone modems.

Network support personnel, in particular, must 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 designer is advised to consult appropriate standards.

Determining the number of 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 your system. If you plan to add nodes at a later date, you should consider ordering and installing the cable and connectors for these additional nodes when you install the initial network. This will minimize disruption to the network during operation. As a rule of thumb, the designer may wish to design the system with 20% or more excess switch and patch panel ports for future expansion.

Consider the number and locations of the following when determining how many ports you will need on your 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.

Terms to Know

Channel: The end-to-end transmission path between two points at which application-specific equipment is connected (TIA/EIA 862). For example, a segment of cabling between two plugs is a channel.

Link: A transmission path between two points, not including terminal equipment, work area cables, and equipment cables (TIA/EIA 862). For example, a segment of cabling between two jacks is a link.

Copper Connectors

There are two styles of 8-way modular connectors for EtherNet/IP. They are the standard, non-protected 8-way modular connector and the sealed 8-way modular connector. The two have the same pin wire assignment. They can be used in 2- and 4-pair cabling systems. EtherNet/IP also supports the M12-4 “D” coded connector. These can be used in 2-pair cabling systems. It is not recommended to use a 4-pair cable with the M12-4 “D” coded connector unless you provide proper termination of the unused pairs (1 and 4). See [Chapter 2](#) for details on the types of EtherNet/IP connectors.

8-way connector pin out

The 8-way modular pin assignment in [Figure 3.2](#) applies to the IP20 and sealed variant.

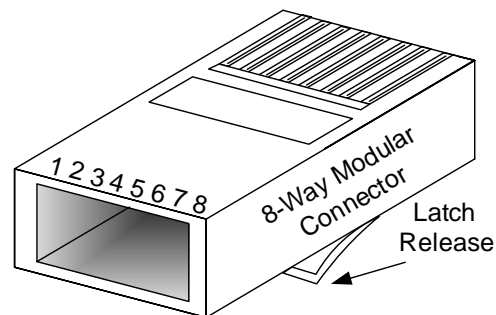


Figure 3.2 An 8-way modular plug pin out.

Pin/pair assignments for the 8-way modular connector are as shown in [Figure 3.3](#).

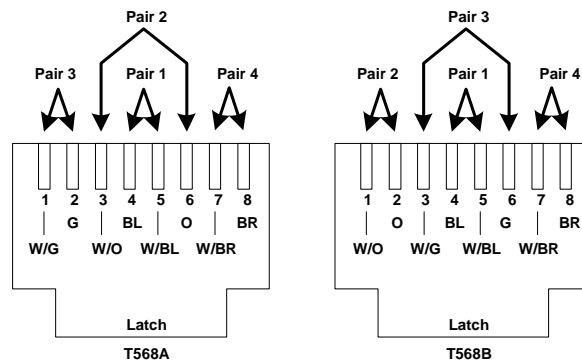


Figure 3.3 8-way modular pin assignments.

Note: Do not mix T568A and T568B wiring in a channel. See [Table 3.1](#) on [page 3.32](#) for both T568A and T568B pin/pair assignments.

4-pole M12 “D” coded connectors

Note:
“D” Coding Keyways

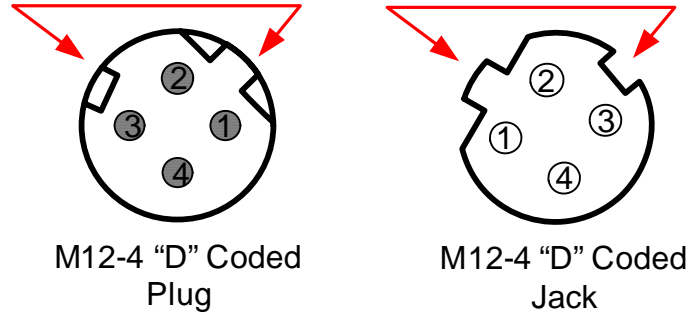


Figure 3.4 M12-4 “D” coded pin out.

Table 3.1 M12 Pin and Signal Assignment

| M12 Pole | Wire Color | Name | Signal |
|----------|--------------|-----------------|--------|
| 1 | White-orange | Transmit data + | TX+ |
| 2 | White-green | Receive data + | RX+ |
| 3 | Orange | Transmit data – | TX– |
| 4 | Green | Receive data – | RX– |

Constructing Cord Sets

This section details the pin/pair assignments for plug-to-plug cord sets. Cord sets can either be factory or field assembled. The following tables and schematics are provided to help in the construction and verification of cord sets. All cord sets shall conform to the channel de-rating based on the cable type and environmental conditions.

Figure 3.5 illustrates the pin/pair cable assignments for 8-way sealed and unsealed straight-through cord sets.

8-way Modular Crossover Cable

Cord set wiring for 8-way modular connectors

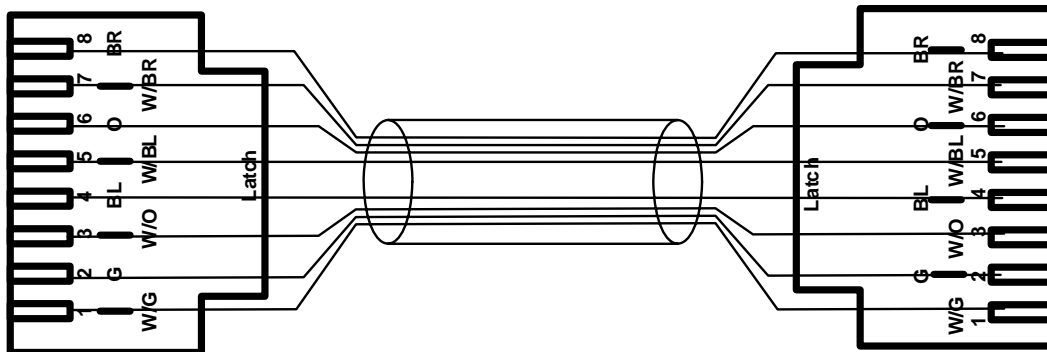


Figure 3.5 Cord set wiring for 8-way modular connectors.

Table 3.2 8-Way Modular Connector Pin/pair Assignment

| PIN | Signal Name | Pin T568A | Pair Assignment | Pin T568B | Pair Assignment |
|-----|-------------------|--------------|-----------------|--------------|-----------------|
| 1 | TXD+ | White Green | Pair 3 | White Orange | Pair 2 |
| 2 | TXD- | Green | | Orange | |
| 3 | RXD+ | White Orange | Pair 2 | White Green | Pair 3 |
| 4 | NA ⁽¹⁾ | Blue | Pair 1 | Blue | Pair 1 |
| 5 | NA ⁽¹⁾ | White Blue | | White Blue | |
| 6 | RXD- | Orange | Pair 2 | Green | Pair 3 |
| 7 | NA ⁽¹⁾ | White Brown | Pair 4 | White Brown | Pair 4 |
| 8 | NA ⁽¹⁾ | Brown | | Brown | |

⁽¹⁾ Not used for 10 Mb/s and 100 Mb/s networks.

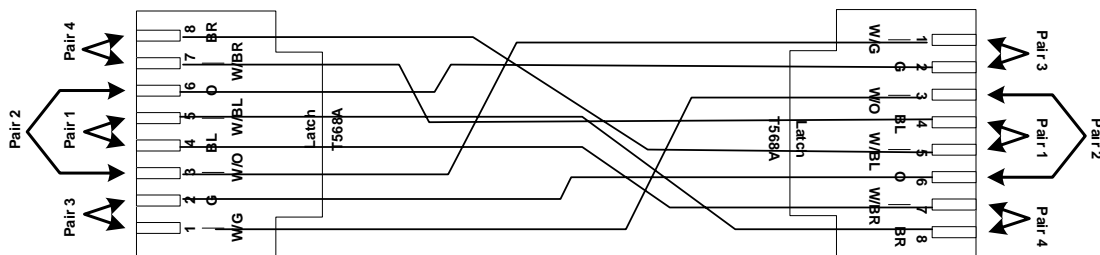


Figure 3.6 8-way modular full crossover cable.

Table 3.3 8-Way Modular Crossover Pin/pair Assignment

| PIN | Signal Name | T568A | | | T568B | | |
|-----|-------------------|--------------|-----------------|--------------|--------------|-----------------|--------------|
| | | Pin | Pair Assignment | Route to PIN | Pin | Pair Assignment | Route to PIN |
| 1 | TXD+ | White Green | Pair 3 | 3 | White Orange | Pair 2 | 3 |
| 2 | TXD- | Green | | 6 | Orange | | 6 |
| 3 | RXD+ | White Orange | Pair 2 | 1 | White Green | Pair 3 | 1 |
| 4 | NA ⁽¹⁾ | Blue | Pair 1 | 7 | Blue | Pair 1 | 7 |
| 5 | NA ⁽¹⁾ | White Blue | | 8 | White Blue | | 8 |
| 6 | RXD- | Orange | Pair 2 | 2 | Green | Pair 3 | 2 |
| 7 | NA ⁽¹⁾ | White Brown | Pair 4 | 4 | White Brown | Pair 4 | 4 |
| 8 | NA ⁽¹⁾ | Brown | | 5 | Brown | | 5 |

⁽¹⁾ Cross over of these wires is not needed for 10 Mb/s and 100 Mb/s channels.

Cord set wiring for M12-4 "D" coded connectors

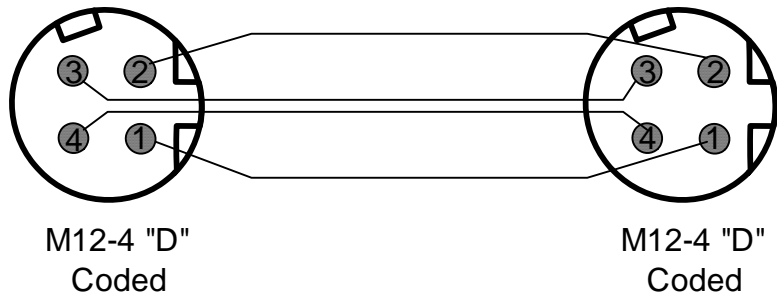


Figure 3.7 M12-4 "D" straight-through cord set.

Table 3.4 M12-4 "D" Coded Pin/pair Assignment

| PIN | Signal Name | Pin T568A | Pair Assignment |
|-----|-------------|--------------|-----------------|
| 1 | TXD+ | White Orange | Pair 2 |
| 3 | RXD+ | Orange | |
| 2 | TXD- | White Green | Pair 3 |
| 4 | RXD- | Green | |

Cord set wiring for M12-4 "D" coded crossover cable

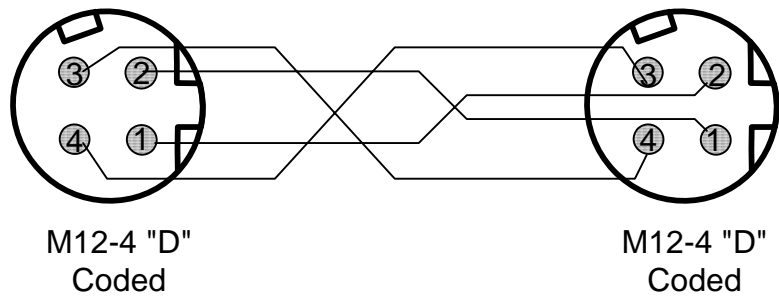


Figure 3.8 M12-4 crossover cable.

Table 3.5 M12-to-M12 Crossover Pin/pair Assignment

| M12 Pin | M12 Pin | Wire Color | Name | Signal |
|---------|---------|--------------|-----------------|--------|
| 2 | 1 | White Orange | Transmit data + | TX+ |
| 1 | 2 | White Green | Receive data + | RX+ |
| 4 | 3 | Orange | Transmit data - | TX- |
| 3 | 4 | Green | Receive data - | RX- |

Conversion from One Connector Family to Another

Straight-through conversion

Below is the pin-out information for a cord set (plug-to-plug) providing cross-connectivity between an 8-way modular connector and a 4-pole M12 "D" coded connector. Figure 3.9 shows the wiring for a straight-through conversion cable using an M12-4 "D" coded connector and an 8-way modular connector.

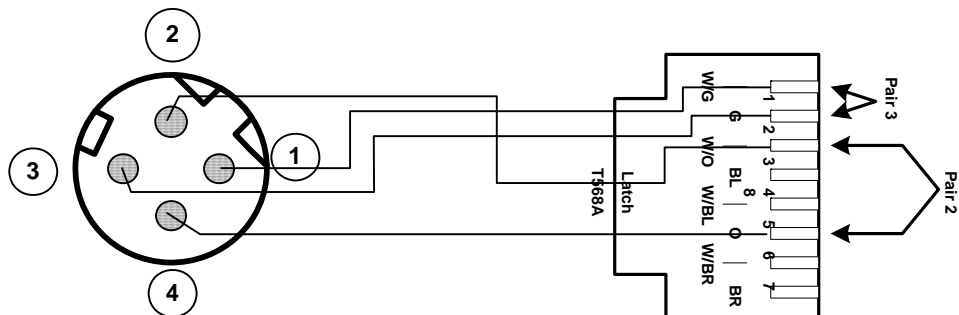


Figure 3.9 Conversion from M12-4 to 8-way modular connector.

Table 3.6 Connectivity Pin Assignments

| 8-Way Modular Connector | M12 Pin | Wire Color | Name | Signal |
|-------------------------|---------|--------------|-----------------|--------|
| 1 | 1 | White Orange | Transmit data + | TX+ |
| 3 | 2 | White Green | Receive data + | RX+ |
| 2 | 3 | Orange | Transmit data – | TX– |
| 6 | 4 | Green | Receive data – | RX– |

Crossover conversion

Figure 3.10 shows the wiring for a crossover conversion cable using an M12-4 “D” coded connector and an 8-way modular connector.

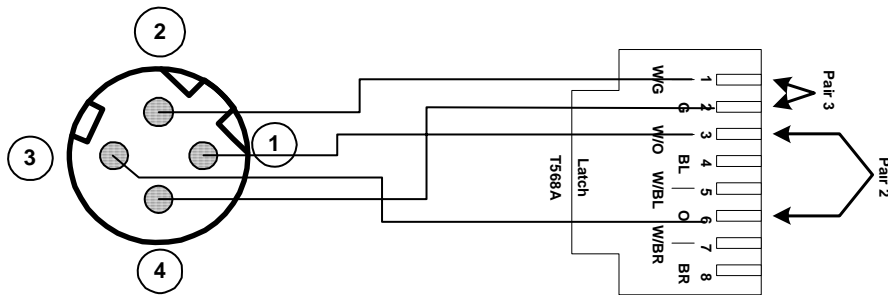


Figure 3.10 M12-4 to 8-way modular connector crossover cable.

Table 3.7 M12 to 8-way Modular Crossover Pin/pair Assignment

| 8-Way Modular Connector | M12 Pin | Wire Color | Name | Signal |
|-------------------------|---------|--------------|-----------------|--------|
| 3 | 1 | White Orange | Transmit data + | TX+ |
| 1 | 2 | White Green | Receive data + | RX+ |
| 6 | 3 | Orange | Transmit data – | TX– |
| 2 | 4 | Green | Receive data – | RX– |

Channel and Link Lengths and Limits for Copper

Patch cords

EtherNet/IP specifications limit each segment of horizontal wiring to 100 meters or up to 90 meters horizontal wiring with two, 5-meter 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 meters.

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

Where:

C = the maximum combined length (m) of the work area cable, equipment cable and patch cord.

H = the length (m) of the horizontal cable ($H + C \leq 100$ m).

D = a de-rating factor for the patch cord type (0.2 for 24 AWG UTP/24 AWG ScTP and 0.5 for 26 AWG ScTP).

W = the maximum length (m) of the work area cable.

T = the total length of horizontal, patch and equipment cords.

The maximum stranded cable length is limited to 85 meters for the channel.

Table 3.8 Stranded Copper Cable De-rating

| Patch Cable Gauge | D | H | W | C | T |
|-------------------|-----------------|--------------------------------|---|----------------------------------|---|
| | Patch De-rating | Horizontal Length, (H+C≤100 m) | Patch Length with 5 Meters of Equipment Cable | Total Length Patch and Equipment | Total Length of Patch, Equipment and Horizontal |
| #24 | 0.2 | 100 | 0 | 0 | 100 |
| #24 | 0.2 | 0 | 80 | 85 | 85 |
| #24 | 0.2 | 25 | 59 | 64 | 89 |
| #24 | 0.2 | 50 | 38 | 43 | 93 |
| #26 | 0.5 | 0 | 63 | 68 | 68 |
| #26 | 0.5 | 25 | 46 | 51 | 76 |
| #26 | 0.5 | 50 | 30 | 35 | 85 |
| #26 | 0.5 | 100 | 0 | 0 | 100 |

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 conductor horizontal or stranded conductor patch) to determine the maximum channel length. 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 a 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 your supplier for more information.

The channel length and attenuation are linearly related: a 12% increase in attenuation reduces the channel length 12%. The following examples show how to calculate the maximum channel length for a given configuration and temperature.

$$A_{\text{Elev.Temp.}} = A_{\text{Increase Coefficient}} * \Delta T$$

$$L_{\text{Elev.Temp.}} = A_{\text{Increase Coefficient}} * \Delta T$$

Where:

- $A_{\text{Elev.Temp.}}$ = elevated temperature attenuation
- $A_{\text{Increase Coefficient}}$ = attenuation temperature coefficient
- ΔT = change in temperature
- $L_{\text{Elev.Temp.}}$ = elevated temperature maximum length

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

Assume you want to use solid conductor, Category 5e, horizontal cable at 60 °C. You are limited to 100 meters based on the cable type. 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% length reduction. The length reduction is calculated by taking the percent reduction times the cable type length limit: 16% x 100 meters = 16 meters.

The maximum channel length is calculated by subtracting the elevated temperature length reduction from the cable type channel limit:
100 meters – 16 meters = 84 meters. The maximum channel length for all solid, horizontal Cat 5e cable at 60 °C is 84 meters.

For all stranded conductor patch Cat 5e at 60 °C we have the following:

- Cable-type channel limit= 85 meters
- Temperature change = 40 °C
- Temperature coefficient = 0.4%
- Total change = 16%
- Length reduction = 13.6 meters

Maximum channel length for all stranded, patch Cat 5 at 60 °C is 68.7 meters.

For 25 meters solid, horizontal Cat 5e cable with some length of #24 AWG, stranded conductor, Cat 5e patch at 40 °C we have the following:

Twenty-five meters of solid, horizontal cable at 40 °C has the loss of 8% more length of cable:

- $25 \times 1.08 = 27$ meters effective length
- Based on 27 meters, an effective length of patch = $(102-27)/(1+0.2) = 62.5$
- Total effective maximum stranded, patch length = 62.5 meters
- 62.5 meters of stranded, Cat 5e patch has 8% more loss than the actual length at 20 °C = $62.5/1.08 = 57.9$ meters actual length

The actual maximum stranded length = 57.9 meters.

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: $25 + 57.9 = 82.9$ meters.

The maximum channel length limit for 25 meters of solid conductor, horizontal Cat 5e cable is 82.9 meters at 40 °C with a maximum of 57.9 meters of stranded conductor, Cat 5e patch cable.

Use of EtherNet/IP Components

A higher data rate will provide a greater throughput. Error rate performance of 1×10^{-9} Bit Error Rate (BER) per IEEE 802.3 in elevated noise as described by MICE is highly desired.

As errors increase in the system, network traffic will increase. When traffic increases, so does response time. If your application depends on short response times, safeguards must be taken to minimize errors due to noise and other causes of increased traffic. Using full-duplex communications can further increase throughput by eliminating the collision domain. Errors in the system can be reduced by proper selection of network components and/or installation techniques.

For Fast Ethernet, the use of low-noise, high-performance cables and connectors is highly recommended. Any degradation in noise rejection will degrade an entire channel between a switching device and the peripheral equipment. If you are using an EtherNet/IP device, it has been specially designed for high-noise rejection. Introducing non-EtherNet/IP devices, cables or connector components into the network may degrade the noise rejection of the system and disrupt an otherwise properly functioning network. Low-noise cable designs usually have a greater transverse conversion loss (TCL) value.

For example, standard cables have a TCL of about $60-20 \times \log(f)$. The shaded area in [Figure 3.11](#) shows performance of UTP cables.

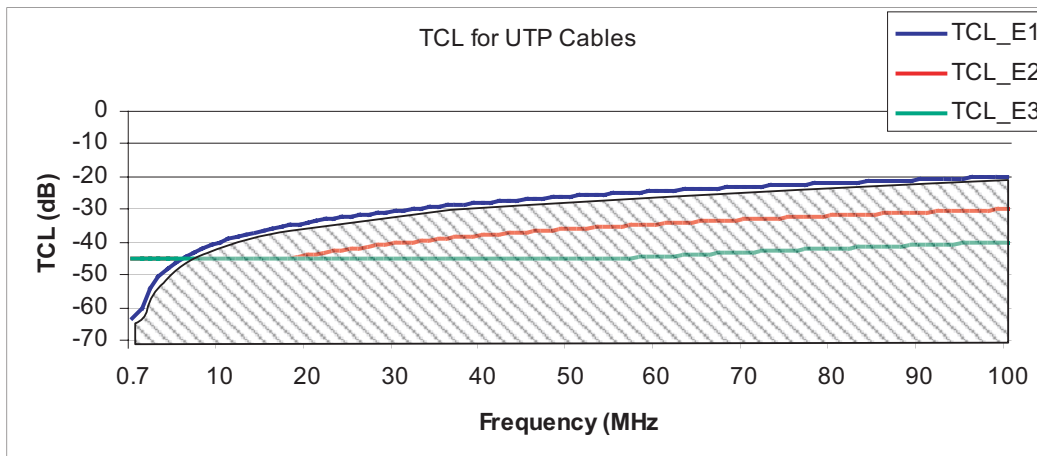


Figure 3.11 TCL for UTP balanced cables.

Use of Shielded Cables

Screened and shielded twisted pair

Depending on where cable is to be routed, you must select the correct cable for the environment per the MICE table ([Table–5.1 on page 5.72](#)). Shielded cables may perform better in high-EMI, noisy environments than non-shielded cable. However, shields cause ground loops that can be very disruptive to industrial networks. Therefore, use shielded cables in MICE E3 environments where the building ground is at equal potential. If shielded cables must be used, then grounding of the shields must be performed in such a way as to eliminate ground loops. This can be done by providing the a grounding system as detailed in [“Building Wiring and Ground Methods” on page 45](#) and/or through cable construction as detailed in [Chapter 5, Network Installation](#). In particular, if your application is in a high noise, MICE E3 environment or your cable must be run in close proximity to noise radiating sources, plan to use shielded cables.

Consider shielded cables or separation between the network cabling and the noise-generating sources (including wiring) as defined in the section under Categorize Conductors (below) if your 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 amps)

General Wiring Guidelines

Follow these guidelines for wiring all EtherNet/IP cables:

- If a cable must cross power lines, it should do so at right angles.
- Route at least 1.5 m (5 ft.) from high-voltage enclosures or sources of RF/microwave radiation, induction-heating equipment.
- If the conductor is in a metal pathway or conduit, each section of the pathway or conduit must be bonded to each adjacent section so that it has electrical continuity along its entire length.
- Equipotential is desired to reduce ground loops and noise ingress.
- Consult your 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 the MICE table, [Table–5.1 on page 5.72.](#))
- Protect the cables and connectors from accidental and/or intentional damage.

For more information on general wiring guidelines, see IEEE publication IEEE 1100 Wiring and Grounding Guidelines and the ANSI-J-STD-607-A, Grounding and Bonding Requirements.

Planning Your Cable Routing

Refer to the Telecommunications Industry Association publication, ANSI/TIA 569-B, Telecommunications Pathways and Spaces, for additional information.

Plan your cable routing very carefully and avoid routing cables near equipment that generates electromagnetic interference. Group your cables into like circuits as shown in [Table 3.9](#) and [Table 3.10](#).

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

- Lights
- Motors
- Drive controllers
- Arc welders
- Induction heaters
- RF fields (transmitters)
- Conductors providing power to any of the above

The following guidelines coincide with 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 your cable system, there are specific installation considerations, depending on your application.

There are three categories of conductors defined in IEEE 1100. Based on the ENC category of conductor in [Table 3.9](#), additional spacing may be required for the communications cables from the high-voltage conductors. (See [Table 3.10](#).)

Categorize conductors

Segregate all wires and cables into the three EMC categories shown in [Table 3.9](#).

Table 3.9 Grouping of Circuits With Respect to Noise

| Group conductor cables fitting this description | Into this category | Examples: |
|--|--------------------|--|
| <p>Control & AC Power: high-power conductors that are more tolerant of electrical noise than Category 2 conductors and may also cause more noise 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</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>Signal & Communications - low-power conductors that are less tolerant of electrical noise than category-1 conductors and should also cause less noise 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</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> <ul style="list-style-type: none"> Corresponds to IEEE levels 1 (high susceptibility) & 2 (medium susceptibility) | <p>EMC3</p> | <ul style="list-style-type: none"> Low-voltage DC power lines Communications cables to connect between system components within the same enclosure |

Routing conductors inside or outside enclosures

To guard against coupling noise from one conductor to another, follow the general guidelines in [Table 3.10](#) when routing wires and cables inside or outside 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 noise immunity only. Follow all local codes for safety requirements.

Table 3.10 Routing Cables to Guard Against Noise

| Route this category of conductor cables | According to these guidelines |
|---|---|
| EMC1 | These conductors can be routed in the same cable tray or raceway with machine power conductors of up to 600 Vac (feeding up to 100 HP devices). |
| EMC2 | <ul style="list-style-type: none"> • If it must cross power feed lines, it should do so at right angles. • Route at least 1.5 m (5 ft.) from high-voltage enclosures, or sources of RF/microwave radiation. • If the conductor is in a metal wire-way or conduit, 1) each segment of that wire-way or conduit must be bonded to each adjacent segment so that it has electrical continuity along its entire length, and 2) must be bonded to the enclosure at the entry point. • Properly shield (where applicable) and route in a raceway separate from EMC-1 conductors. • If in a contiguous metallic wire-way or conduit, route at least 0.08 m (3 in.) from EMC-1 conductors of less than 20 A; 0.15 m (6 in.) from AC power lines of 20 A or more, but only up to 100 kVA; 0.3 m (1 ft.) from AC power lines of greater than 100 kVA. • If not in a contiguous metallic wire-way or conduit, route at least 0.15 m (6 in.) from EMC-1 conductors of less than 20 A; 0.3 m (1 ft.) from AC power lines of 20 A or more, but only up to 100 kVA; 0.6 m (2 ft.) from AC power lines of greater than 100 kVA. |
| EMC3 | Route conductors external to all raceways in the enclosure or in a raceway separate from any EMC-1 conductors with the same spacing listed for EMC-2 conductors, where possible. |

Wiring external to enclosures

Cables that run outside protective enclosures are relatively long. To minimize cross-talk from nearby cables, it is good practice to maintain maximum separation between the Ethernet cable and other potential noise carrying conductors. You should route your cable following the guidelines in [Table 3.12](#).

Table 3.11 Spacing Relative to High-voltage Conductors

| Voltage Level | Minimum Distance |
|---------------|------------------|
| 0-100 V | 8 cm (3") |
| 101-200 V | 11 cm (4") |
| 201-300 V | 13 cm (5") |
| 301-400 V | 16 cm (6") |

Raceway layout considerations

The following guidelines coincide with the guidelines for “the installation of electrical equipment to minimize electrical noise inputs to controllers from external sources” in IEEE 518-1982. When planning your cable system there are specific installation considerations, depending on your application.

Pathways

Consult your local, state, and national codes regarding the grouping of cables. Never run Ethernet cables any closer than the limits in [Table 3.12](#).

Table 3.12 Routing Communications Cabling in Contiguous Metallic Pathways

| Route your Cable at Least this Distance | From Noise Sources of this Strength | From Cables containing these Voltages |
|---|--|---------------------------------------|
| 8.3 cm (3.25") | EMC 1 conductors of less than 20 amps | 24 to 100 |
| 15 cm (6") | AC power lines of 20 amps or more, up to 100 kVA | 101 to 200 |
| 30 cm (12") | AC power lines greater than 100 kVA | 201 to 400 |

Wiring inside enclosures

Cable sections that run inside protective equipment enclosures are relatively short. As with wiring external to enclosures, you should maintain maximum separation between your Ethernet cable and Category-1 conductors.

When running cable inside an enclosure:

- Route conductors external to all raceways in the same enclosure or in a raceway separate from Category 1 conductors.
- Maintain raceways with like conductors (i.e., communications, power and I/O).

Table 3.13 Conductor Spacing Within Enclosures

| Route Cable at Least this Distance | From Noise Sources of this Strength |
|------------------------------------|--|
| 0.08 m (3") | EMC 1 conductors of less than 20 amps |
| 0.15 m (8") | AC power lines of 20 amps or more, up to 100 kVA |
| 0.6 m (24") | AC power lines greater than 100 kVA |

Building Wiring and Ground Methods

There are two building wiring methods used: TN-C and TN-S. The method in use can have a direct effect on the noise performance of your communications system.

TN-C wiring and ground scheme

This wiring scheme is not recommended for installations that employ communications circuits. [Figure 3.12](#) shows how protective earth (PE) and Neutral are combined into one conductor. As a result, the noise generated by the loads (devices) is normally returned on Neutral. Devices that have PE connections are connected to this conductor. When PE and Neutral are one conductor, then the ground or PE also has the noise. Each device has its own noise contribution to this PEN conductor, causing additional noise currents and offsets between devices. The noise voltage offset currents will then flow between devices. Where communications cabling is part of the system, and in particular shielded cabling, some portion of the noise currents will be found in the communications cabling. This will have lesser effect on UTP-type cabling as the currents will be in the form of common mode.

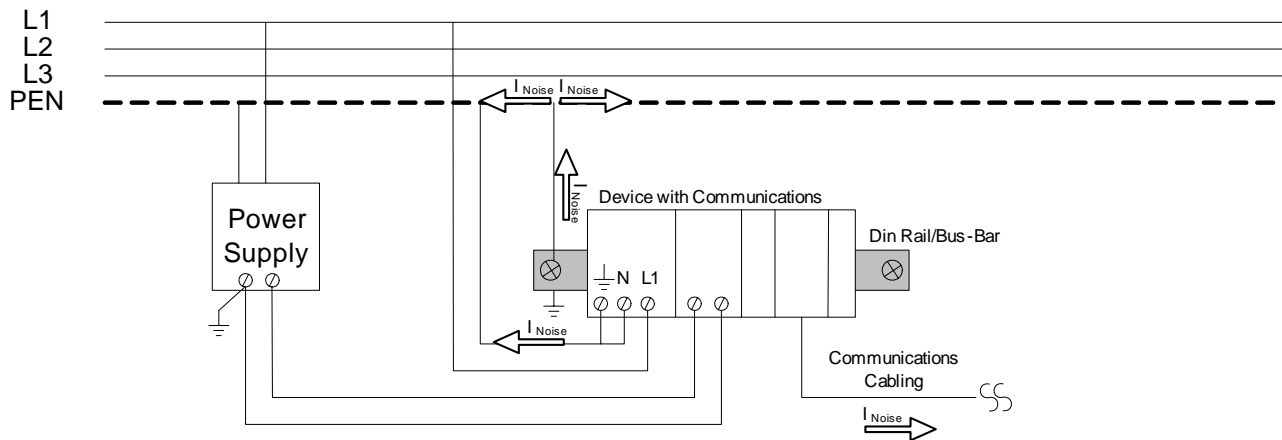


Figure 3.12 TN-C wiring and ground scheme.

TN-S wiring scheme

The TN-S wiring scheme ([Figure 3.13](#)) reduces the noise on the PE by separating the Neutral and PE into two circuits. This requires an additional conductor but also provides an additional layer of safety. The only noise currents on the PE are from devices that have coupling mechanisms to the local ground connections, such as motors and drive controllers. It is recommended that this system be used. However, either system must comply with local and national codes.

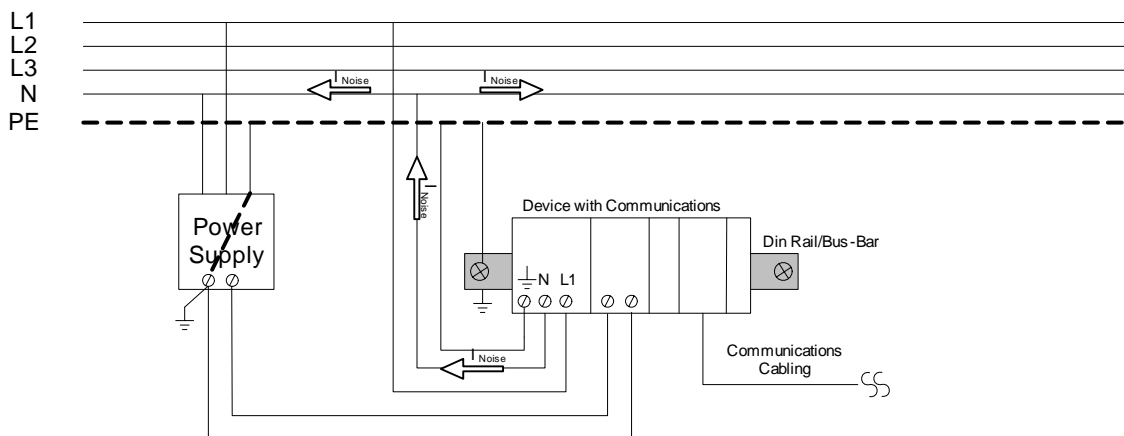


Figure 3.13 TN-S wiring and ground scheme.

Grounding and Bonding for Performance

There are two primary methods for grounding and bonding of equipment. This section covers how the ground distribution within the communications coverage area should be designed. EtherNet/IP is designed to work on both systems. However, if the condition of your building wiring and grounding system is not known, then it is recommended that you use the star/multi-star system. If either of these systems are not used, then the planner should use alternate transmission medium not providing earth continuity (such as fiber optic cable).

The two most popular systems are:

- Star/multi-star
- Highly mesh (equipotential)

Star/multi-star earthed bonding system

Noise currents in ground paths generated by high currents can be controlled by a star earthing system and by isolating the signal ground from the equipment ground. This is accomplished by providing two star grounds, one for the equipment and a second for the communications equipment. Shields for the communications equipment shall be referenced only to the signal ground, and no equipment shall be referenced to the signal ground. The star grounds of the two systems shall converge to one point within the building as shown in [Figure 3.14](#). Avoid daisy chaining of earths from one cabinet to another.

If there is no equal potential or the building earth system is not of low impedance or has excessive noise, then only one end of the cable shield should be terminated. Preferably the device's end should be open at the connector. The shield should be continuous up to the connector at the device.

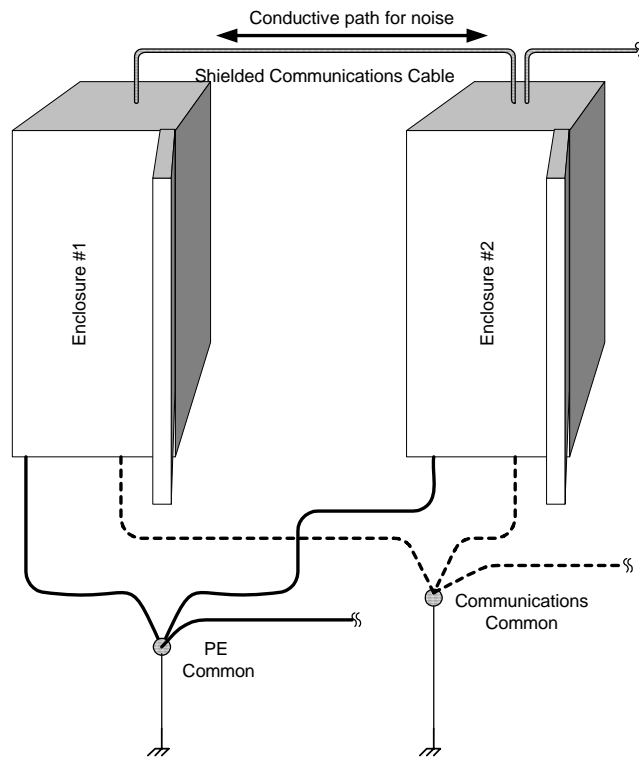


Figure 3.14 Wiring of the earths in a star-earth configuration.

Equipotential bonding system (highly meshed)

Equipment is normally arranged as a grounded system, whereby the ground of the power feed is connected to the functional ground over a large area using the TN-S system (Figure 3.13) as shown in Figure 3.15. The shield of the bus cable is connected to the potential equalization system over a large area where it enters the control cabinet. The potential equalization rail is grounded in each control cabinet and connected to the potential equalization rails of the other control cabinets.

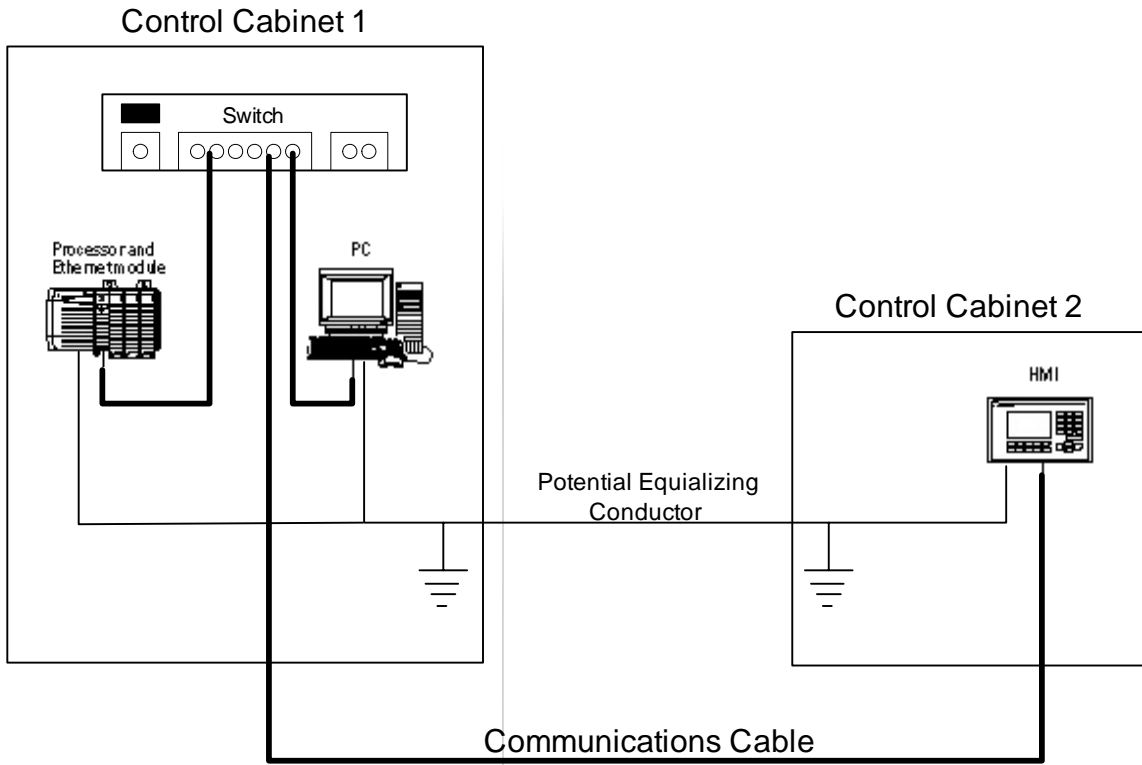


Figure 3.15 EMC-compliant installation of a plant with grounded reference voltage.

Buildings with information-related systems are to be fitted with a common bonding network (CBN) consisting of the closest-knit structure of conductive elements. This spreads the flow of interference over many paths. The equipotential bonding system always is earthed as shown in [Figure 3.16](#) and [Figure 3.18](#).

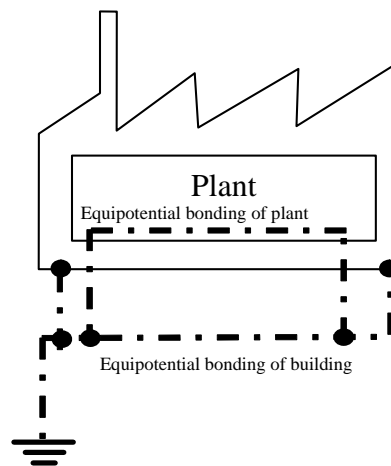


Figure 3.16 Equipotential bonding of a building.

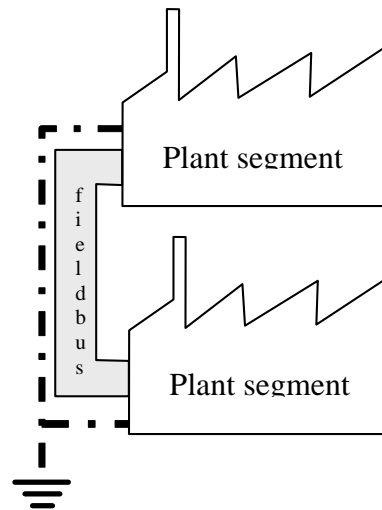


Figure 3.17 Equipotential bonding between buildings.

The shielding of metallic communication cables forms conductor loops together with the earth leads of the electrical installations or possibly with other electrically conductive building sections. Currents flowing in the environment (e.g., caused by electrical consumers or lightning strikes), induce interference voltage in these conductor loops. The resulting current flow shall be controlled by an equipotential bonding system, reducing the potential for interference or damage.

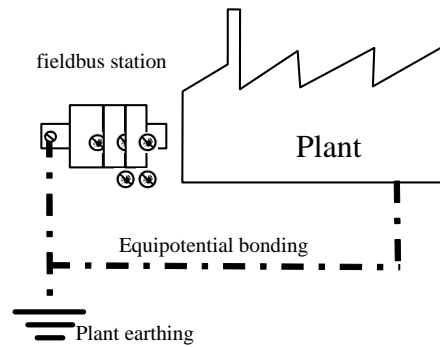


Figure 3.18 Equipotential bonding and earthing.

Grounding shielded cable

There are specific grounding requirements for shielded cable. Eliminating ground loops is extremely important in reducing noise interference caused by ground offsets or local ground transients. Ground offsets occur when there is a potential difference between two earth ground points in a system. This potential difference can be DC or AC or transients. A cable that connects the two points provides a secondary path for current to travel. The current through the communication cable's shield will couple noise into the communication system conductors. This noise will have a direct impact on the signal-to-noise performance of the system. There can be as much as a 45-volt, high-frequency offset (transient) in ground potential between the two ends of a 100-meter cable. This offset can cause noise currents in the shields. Consequently, to eliminate ground loops, the EtherNet/IP cable shield should be grounded at the switch end only.

Controlling earth currents

Earth offsets between cabling end points will induce noise in the cabling system. This is especially true in screened and shielded cabling systems. Earthing is important in reducing the effects of radiated and conducted interference. Controlling earth currents is extremely important in reducing interference caused by earth offsets.

The communications network designer should provide advice to the machine tool builder regarding the earthing scheme in the facility, so that machines are earthed according to the facility's earthing scheme.

The communications designer should specify how to achieve the required level of earthing that is defined as follows:

- The resistive earth impedance should be less than 0,6 ohm and less than 1 ohm. The resistive earth is measured between any two points at which communication devices are earthed or cable shields are earthed. This may require that a suitable wire gauge be used that is dependant on distance.
- Connection resistance of any grounding cable to equipment or bus bar shall be less than 0,005 ohm (5 milli Ohms).

As shown in [Figure 3.19](#), the communications network designer should require:

- Any paint from earth surface shall be cleaned before affixing the earth wire.
- Star washers between the bolt and earth lug and earth lug and earth plate shall be used.

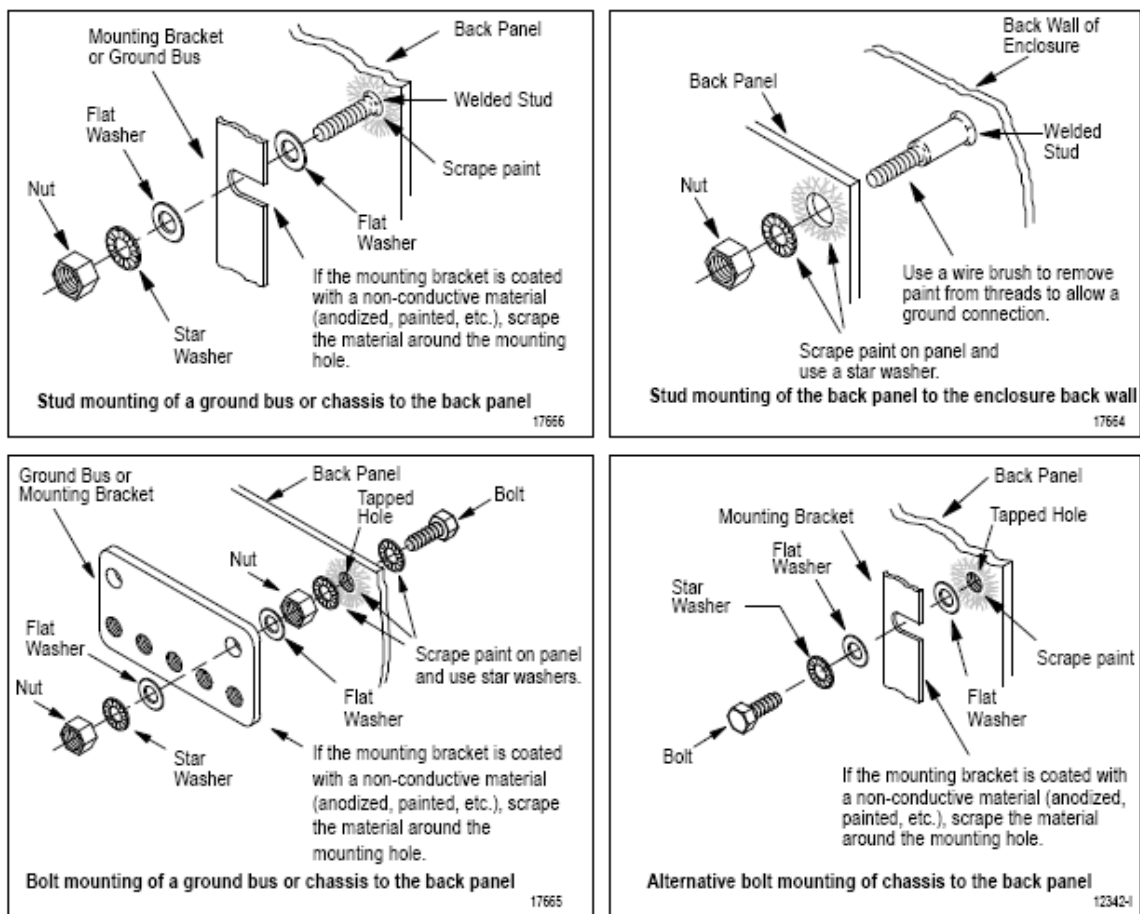


Figure 3.19 Mounting details.

Equipment is normally arranged as an earthed system, whereby the earth of the power feed is connected to the functional earth over a large area. (See [Figure 3.15.](#)) The shield of the bus cable is connected to the potential equalization system over a large area where it enters the control cabinet. The potential equalization rail is earthed in each control cabinet and connected to the potential equalization rails of the other control cabinets.

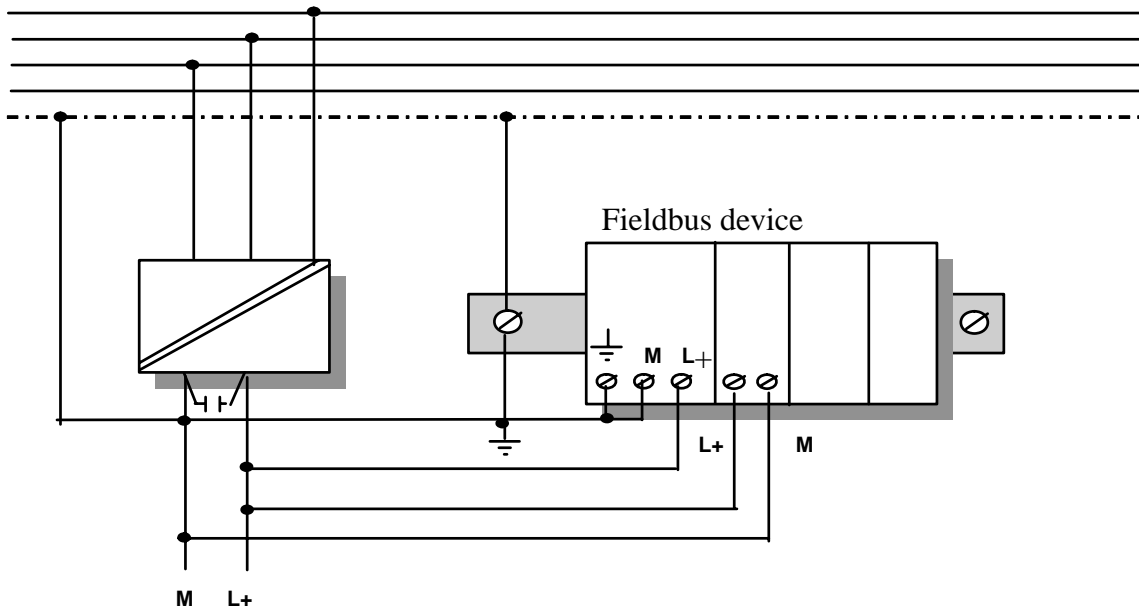


Figure 3.20 Schematic diagram of a plant with grounded reference voltage.

Situations where interference can present a problem include:

- Plant that extends over a large area
- Power is fed to the plant from different power sources
- Networking extends over several buildings

If one of these situations applies, the following should be observed by the planner and specified for the installer in order to provide an EMC-favorable earthing and equipotential bonding system:

- A common bonding network (CBN) with low impedance and high current carrying capacity is to be formed from all metallic constructional components of a building.
- Appropriate measures should be undertaken to protect equalization cables against corrosion to ensure long-term reliability.
- The cross-section of the potential equalization cable should be chosen with regard to the maximum potential equalization currents that can flow.
- For safety considerations, there may be national standards to be followed as well.

Note: Safety always takes precedence over EMC.

Connecting shielding with equipotential bonding

Shields shall be bonded in accordance with local and national standards. Where this conflicts with performance, other media should be selected.

Designing an installation with non-earthed reference voltage

In exceptional circumstances, equipment can be arranged as a non-earthed system. This can be necessary if high, short-circuit currents can occur (with induction furnaces, for instance). The term “non-earthed” also is used if a parallel resistor and capacitor (R/C) circuit is fitted between the communications shield and earth. (See [Figure 3.21](#).)

Many devices are fitted with an R/C circuit of this type to improve interference immunity. In addition, the non-earthed arrangement ensures that uncontrolled equalization currents do not destroy devices on the network. The relevant safety regulations shall be observed. Most EtherNet/IP devices are designed with the R/C circuit between the jack shield and earth ground on the device.

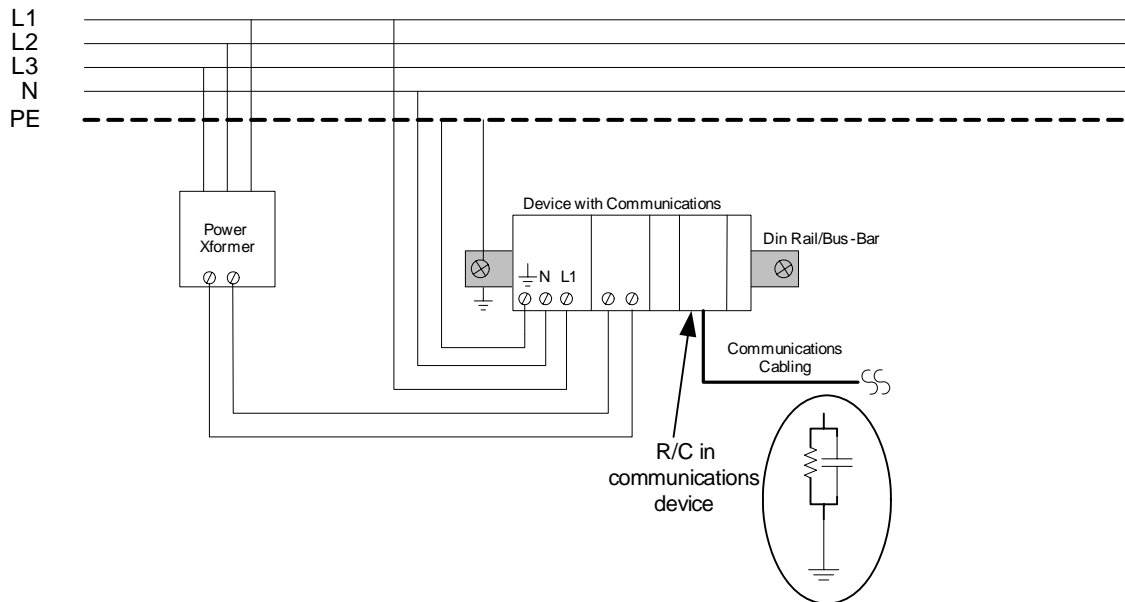


Figure 3.21 Schematic diagram of a plant with non-earthed reference voltage.

Earthing and Bonding

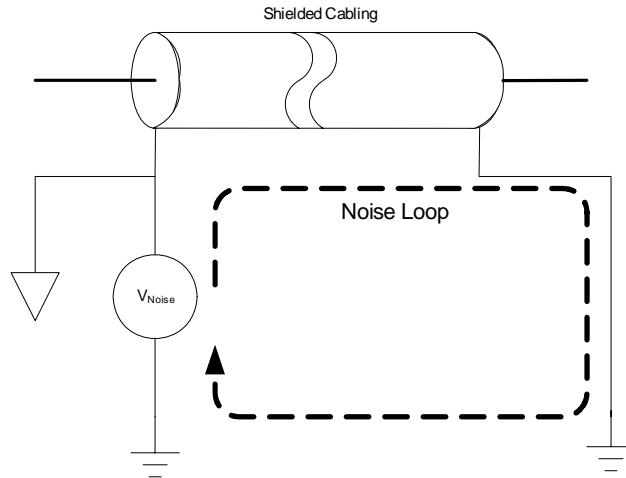


Figure 3.22 Ground noise loop in shielded cables.

If your device is other than a switch (or hub) and provides a low resistance (<500 k ohms) ground at the jack, do not connect the shield at the device end of the cable. Simply cutting back the shield and insulating it from the connector plug's shell can accomplish breaking the ground. (See [Figure 3.23](#) and [Figure 3.24](#).)

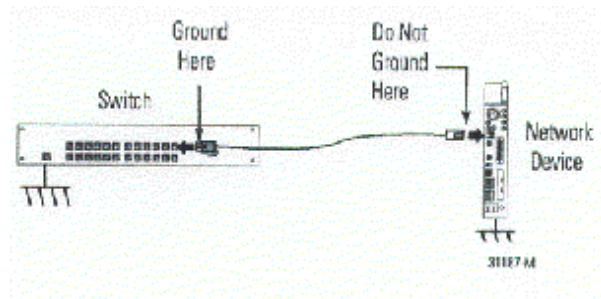


Figure 3.23 Grounding of a cable shield.

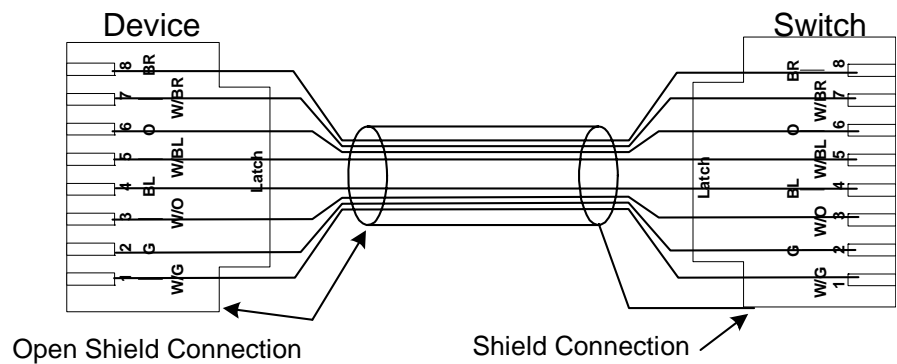


Figure 3.24 Open shield example.

For information regarding grounding and bonding requirements for your network, refer to IEEE 1100 Wiring and Grounding Specification, and to NFPA-70, the National Electric Code, CSA C22.1, the Canadian Electrical Code, and/or other applicable local, national, or international codes.

From a noise perspective, the grounding method you use is critical. Grounding and bonding techniques, as required by local, national and/or international code, may be contrary to recommended installation practices designed to reduce and/or eliminate EM noise. In these cases, the local, national and international codes shall be followed and alternate cabling solutions, such as UTP or fiber, should be considered.

Selecting Copper Cable

When selecting cable, the cable construction must be compatible with the environment as described by the MICE table ([Table-5.1 on page 5.72](#)). 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 cabling specifications through environmental conditioning, isolation, and/or separation techniques. See the formulas and tables for cable length de-rating provided earlier in this chapter.

Chemicals can be absorbed into the 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.

For cable specifications, refer to the EtherNet/IP specification. Only cables meeting this specification should be considered for Industrial EtherNet/IP networks.

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

M12-4 “D” coded and EtherNet/IP sealed 8-way modular connector cable entry point diameters vary. Check with the connector and/or cable manufacturer to ensure cable-connector compatibility.

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 be generic in nature and, therefore, may not support all of the applications (1 Gb/s, 10 Gb/s and POE). As a result, 2-pair cables may not support future expansion and/or other services. If your installation needs to be flexible in that generic cables are installed to support multi-services, such as voice, video and data, then you should consider 4-pair cables. Careful long-range planning should be done before selecting a cable pair count. If your plans are to migrate to higher data rates in the future, you should select cables and components that will support future requirements. For example, backbone cables and materials should be selected to support greater data rates.

The connector circuit 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.

Oil- and chemical-resistant jackets

If your application requires control of equipment that uses cutting oils or lubricating chemicals, cable jackets should be oil resistant. Further, all chemicals in your application should be considered. See the MICE table ([Table–5.1 on page 5.72](#)) for common industrial chemicals and their concentrations.

Plenum-rated cables

Plenum installations require special material compounds in the makeup of the cables. If your application requires cables to be run in plenums, use plenum-rated cables. Consult your local authority for specific requirements.

Riser-rated cables

Riser installations require special material compounds in the makeup of the cables. If your application requires cables to be run in risers, use riser-rated cables. Consult your local authority for specific requirements.

Weld splatter-resistant cables

If your application requires control of welding equipment, you should carefully route your cables to reduce damage from weld splatter and noise 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.

High-flex cables

Typically, Ethernet cables are constructed of #22 to #26 gauge solid copper conductors. High-flex applications require cables with stranded conductors.

Note: Weld splatter and high-flex applications are commonly found together.

Patch cords, jumpers, equipment cords, and work area cords

Patch cords, jumpers, 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 cords is of a male/plug connector on both ends of the cable since almost all active and passive devices come equipped with a female/receptacle jack.

Note: To prevent shorting in a powered system, all cables should end in a female/jack.



Figure 3.25 Sealed 8-way modular cord set.



Figure 3.26 Sealed M12-4 "D" coded cord set.

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.

Number of Connections in a Channel

The number of mated connections allowed in a channel is determined by the desired channel performance (category) and the performance level of the components selected. A mated connection is defined as an electrically conductive communications path comprised of a mated jack and plug. A plug-to-jack bulkhead may be counted as one connection.

Back-to-back-jack bulkheads may be counted as one connection, provided the jacks are less than or equal to 10 cm electrically apart (as defined in the ODVA standard). Jack-to-jack cable assemblies, whereby the electrical distance is greater than 10 cm, must be counted as two mated connections. Consult your manufacturer for specific performance capabilities. Cable lengths between connecting hardware greater than 10 cm must be counted in the total channel/link appropriate cable length budget. Alternate configurations should be field tested to ensure adequate performance.

Table 3.14 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 |

IP65/IP67 sealed connectors

If your application exposes cable and connectors to liquid, dust or airborne contaminants as described in the MICE table ([Table–5.1 on page 5.72](#)), use the appropriately rated connector. IP65/IP67 sealed connectors and bulkhead feed-throughs should be utilized. See [Chapter 2](#).

Important: Not all connectors are suitable for harsh environments. Carefully select connectors for the intended environment. Only consider connectors recognized by the ODVA Industrial EtherNet/IP specification.

Placement of Active Network Components

You must consider the environment when specifying, selecting and determining placement of active network components. Unless they are industrially hardened, active network components should be installed in suitable enclosures to protect them from the harsh environment per the MICE table ([Table–5.1 on page 5.72](#)). The temperature and vibration inside the enclosures (closets) should also be considered since the enclosures may not be temperature controlled or shock mounted.

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

Selecting and locating I/O

Consider the environment when selecting I/O devices and deciding where to locate them. Review the manufacturer's specifications with respect to:

- Vibration
- Temperature
- Humidity
- Electrical noise

In harsh environments, you may have to provide suitable enclosures for I/O devices.

Use of bulkhead feed-throughs and cable glands

Communication 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 possible wet or dirty exterior, i.e., from one MICE environment to another. The connector should be located in such a way to minimize exposure to liquids, dusts, mechanical damage and vibration. Bulkhead connectors or cable glands 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 feed-throughs.

The designer must be aware of metallic bulkhead feed-throughs 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 feed-through using an insulator between the bulkhead feed-through and the enclosure wall.

Bulkhead cable glands provide entry/exit passages for permanently installed cables.

Bulkhead feed-through connectors allow systems to be designed and built in modular configurations. This method should be considered based on user design and service preferences. Modularity provides quick deployment and ease of serviceability.

When bulkhead connectors are used, they need to be counted in the number of connections within a channel as shown in [Table 3.14 on page 3.58](#).

An example of approved EtherNet/IP bulkhead feed-throughs is shown in [Figure 3.27](#).



Figure 3.27 M12-4 to 8-way modular bulkhead adapter for transitioning from IP20 to IP67 environments.

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

Ambient Temperature

The ambient temperature of the environment should be considered in specifying the cables and connectors to be installed in accordance with MICE. Some off-the-shelf Ethernet cables may not be compatible with temperatures common in industrial environments. Attenuation tends to increase as temperature increases, limiting the maximum channel length. Cable jackets may be damaged in temperatures outside the ranges provided above.

Enhanced components, isolated pathways and/or separation from heat and/or cold sources are all techniques used to mitigate the effects of temperature.

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 noise.

Use of Ferrite Beads and Cores

Ferrites can provide additional suppression of transient EMI and can be installed over Category 2 and Category 3 conductors (as defined in Planning Your Cable Routing above). The ferrite bead material can have an effect on the noise attenuation and frequency range. Select the correct material and core size to fit your application. These can be secured with heat-shrink tubing or tie-wraps. A cable-transient EMI induced on 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 increases. Ensure the channel still complies with its channel requirements.

Chapter 4

Planning Your EtherNet/IP Fiber Optic Cabling

Types of Fiber Optic Connectors

The Ethernet/IP specification identifies three different fiber optic connectors: the ST, SC, and LC.

ST 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 ST connector is shown in [Figure 4.1](#).



Figure 4.1 ST fiber optic connector.

SC 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 also 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 4.2](#) and [Figure 4.3](#) show an SC simplex and an SC duplex connector, respectively.



Figure 4.2 SC simplex connector

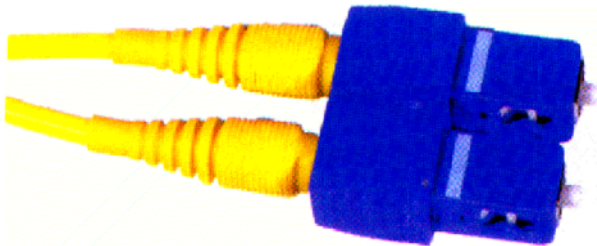


Figure 4.3 SC duplex connector

LC 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 configurations. The LC connector is available in a sealed housing compliant with Variant 1 of IEC 61076-3-106 and the Ethernet/IP specification. Examples of the simplex, duplex, and sealed versions are shown in [Figure 4.4](#) through [Figure 4.6](#).



Figure 4.4 LC simplex connector.



Figure 4.5 LC duplex connector.



Figure 4.6 IP65/IP67 LC sealed duplex connector.

Table 4.1 Connector Support by Fiber Type

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

Table 4.2 Connector Insertion Loss

| Connector Type | Insertion Loss | Return Loss |
|----------------|----------------|--|
| SC, ST, 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 your manufacturer for installation tools and methods for installing connectors.

Fiber Optic Cables

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 your network's environment as defined by the MICE table ([Table-5.1 on page 5.72.](#))

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

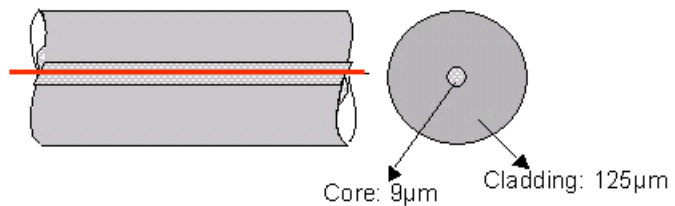


Figure 4.7 Single-mode fiber example.

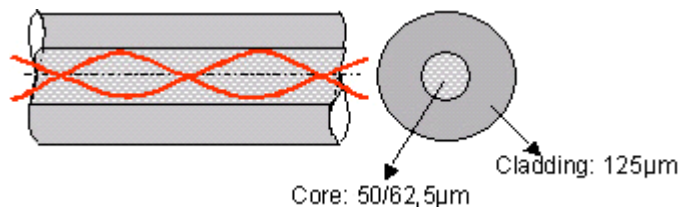


Figure 4.8 Multi-mode fiber example.

Operating wavelengths by fiber type

Table 4.3 Operating Wavelengths by Fiber Type

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

Bandwidths by fiber type

Table 4.4 Bandwidths by Fiber Type

| Fiber Type | Max. Attenuation 650 nm (dB) | Max. Attenuation 850 nm/1300 nm (dB) | Typical Attenuation 850 nm/1300 nm (dB) | Min. Bandwidth 850 nm/1300 nm (MHz) |
|--|------------------------------|--------------------------------------|---|-------------------------------------|
| 50/125 μm | — | 4.0/2.0 | 3.5/1.0 | 500/500 |
| 62.5/125 μm | — | 5.0/3.0 | 4.0/2.0 | 100/300 |
| 62.5/125 μm (FDDI) | — | 4.0/2.0 | 3.5/1.0 | 160/500 |
| 100/140 μm | — | 5.0/2.0 | 4.5/3.5 | 100/100 |
| 9/125 μm | — | — | — | — |
| 1 mm POF | — | — | — | — |
| 200/230 μm Hard-Clad Silica | — | 12@6.50 nm | — | 125 |

Core and cladding diameters by fiber type

Table 4.5 Fiber Sizes by Type

| Fiber Type | Core Diameter (μm) | Cladding Diameter (μm) | N.A |
|--|---------------------------------|-------------------------------------|-----------------|
| 50/125 μm | 50 \pm 3.0 | 125 \pm 3.0 | .200 \pm .015 |
| 62.5/125 μm | 62.5 \pm 3.0 | 125 \pm 3.0 | .275 \pm .015 |
| 62.5/125 μm (FDDI) | 62.5 \pm 3.0 | 125 \pm 3.0 | .275 \pm .015 |
| 100/140 μm | 100 \pm 4.0 | 140 \pm 6.0 | .290 \pm .015 |
| 9/125 μm | — | — | — |
| 1 mm POF | — | — | — |
| 200/230 μm Hard-Clad Silica | 200 \pm 4.0 | 230 \pm 10.0 | — |

Types of Fiber Optic Cable

Simplex and zipcord

Simplex cables are one fiber that is tight-buffered (coated with a 900-micron 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 also can be used for desktop and equipment connections.

Distribution cables

Distribution cables contain several 900 μm , tight-buffered fibers bundled under the same jacket with strength members and sometimes include a glass-reinforced plastic (GRP) rod to stiffen the cable and prevent kinking. These cables are small in size and used for short, dry conduit runs, and 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.

Breakout cables

Breakout cables 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, and riser 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 economical where fiber count is small and distances are short.

Loose-tube cables

Loose-tube 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 the 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.

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.

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.

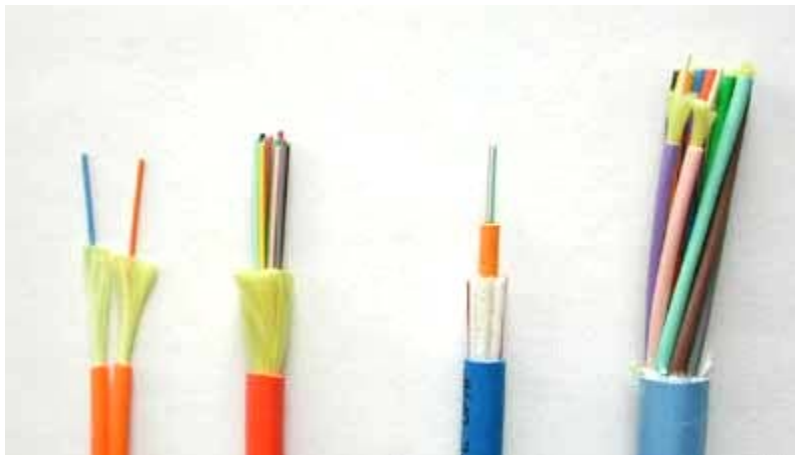


Figure 4.9 Types of fiber optic cables (left to right): zipcord, distribution, loose-tube, and breakout.

Choosing a Cable

Consult the manufacturer for the correct cable for your application and environment as defined by the MICE table ([Table–5.1 on page 5.72](#)).

Planning and Installing 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, such as trench duct or cellular
- Access floors
- Cable trays/wire ways
- Non-continuous paths, such as J-hooks, bridle rings, slings, etc.
- Conduit systems
- Power poles
- Modular furniture
- Wall cavities
- Raceways (nonmetallic 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, such as crushing or bends, fiber cable should be separated from copper cables when possible. The use of multi-channel raceway/material, innerduct, or physical separation helps protect fiber cables.

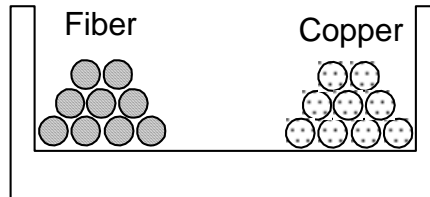


Figure 4.10 Separation of fiber and copper cables in wire ways.

In under-floor systems (cellular/trench) or conduit systems, 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 4.11](#).

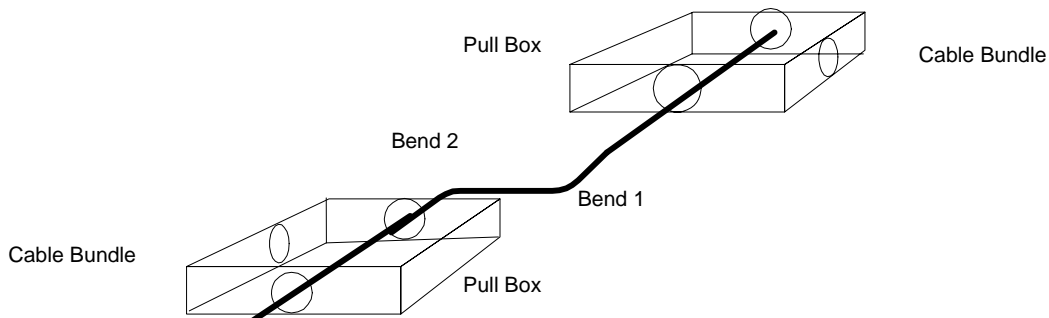


Figure 4.11 Cable loading.

Conduit and innerduct

Building cables can be installed unprotected or placed inside appropriately rated innerduct. This innerduct may be bright orange or yellow to provide easy identification of fiber optic cable.

Cable plant hardware

Various enclosures, cabinets, racks and panels are used to protect and organize splice and termination points. The network designer 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.

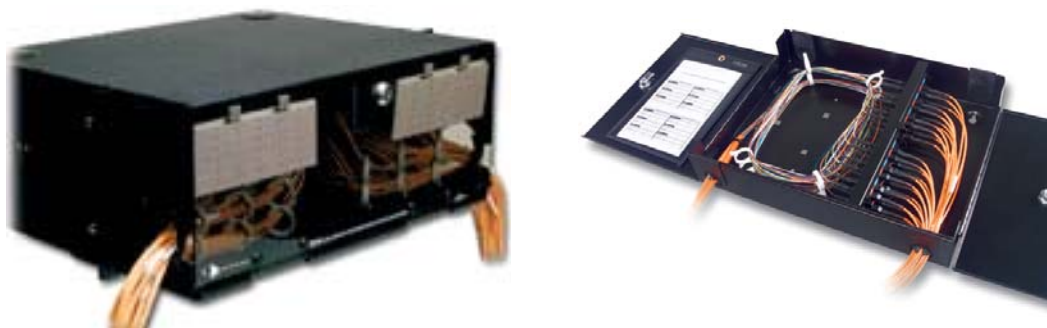


Figure 4.12 Rack and wall-mounted fiber enclosures and breakout kits.

Breakout kits

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

Splice enclosures

Splice enclosures are used to protect fiber optic splice points.

Splice panels

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

Patch panels

Patch panels provide a centralized location for interconnecting, testing and monitoring.

Racks and cabinets

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

Fiber Optic Installation Guidance

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 designer and installer are strongly encouraged to consult the manufacturer for handling and termination requirements.

Local and national fire codes

The designer and installer are strongly encouraged to consult 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 local and national codes for marking requirements to help you identify the correct cable for the installation environment. For U.S. and Canadian installations, cables without markings should not be installed indoors as they may not pass inspections.

Pulling Fiber Optic Cable

Pulling tension

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 designer and installer are strongly encouraged to consult the manufacturer's data sheet for 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, make sure 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 4.6](#) below.)
- Consider using an automated puller with tension control.
- Do not exceed the cable bend radius during installation or for fixed installation. Consult the manufacturer's data sheet for these limits. If the bend radius is not available, see [Table 4.6](#) for guidance.
- Do not twist the cables during installation. Cables should be spooled out as they are pulled to prevent twisting. Break-away 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 manufacturer's specific tools for installation. Consult your manufacturer for installation tools and methods for installing connectors.
- Secure vertical cable every 91 cm (36 in.). Secure horizontal cable every 120 to 150 cm (48 to 60 in.).

Table 4.6 Fiber Optic Bend Radius and Pull Force

| Service | Bend Radius | | Max. Pull Force |
|---|---------------|---------------|------------------|
| | Loaded | No-Load | |
| Inside Plant | | | |
| Horizontal/Centralized <ul style="list-style-type: none"> • 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) |

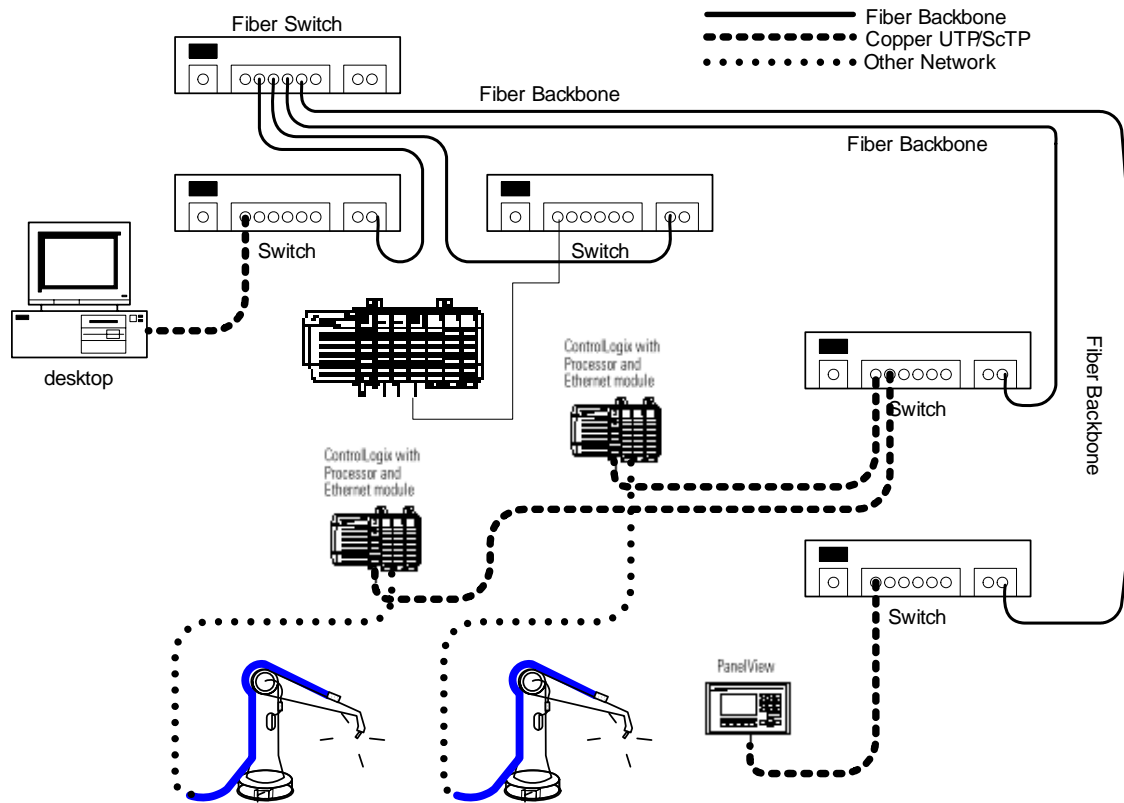


Figure 4.13 Configuration of fiber cable within a building.

Chapter 5

Network Installation

This chapter provides guidance for installing copper and fiber cabling. Fiber optic connectors require installation tools specified by the respective connector manufacturer. For installation assistance, either consult the manufacturer of the fiber optic connector system you plan to use or contact a fiber specialist.

Important: Read [Chapter 3](#) and [Chapter 4](#) before installing your network.

Installing the Horizontal Cabling

Install your point-to-point horizontal cable, observing your cable supplier's installation instructions and the following guidelines.

Bend radius

Cable bend radius should not exceed those listed in [Table 5.1](#).

Table 5.1 Permissible Cabling Bend Radius

| Cable Type | Cable bend radius | |
|------------------------------------|---|---|
| | No load | Loaded during install |
| UTP | 4X diameter | 4X diameter |
| ScTP | 8X diameter | 8X diameter |
| Hybrid bundled or multi-pair cable | 10X diameter | See mfg. data sheet |
| Fiber up to 4 strand | 1 inch (25.4 mm) | 2 inch (50.8 mm) |
| Fiber greater than 4 strand | See mfg. data sheet; if not available, 10X diameter | See mfg. data sheet; if not available, 15X diameter |

Pull strength

Refer to manufacturer's guidelines and data sheets for maximum pull tension. If the manufacturer's guidelines are not available, the pull strength should not exceed 25 lbs. for copper cabling, and 50 lbs. for fiber cables of 2 and 4 fibers or the manufacturer's recommendation.

Terminating the Fixed Horizontal Cable

Your installation may require the use of punch-down blocks for terminating the fixed cabling. The proper tools are required for this operation. Punch-down tools come in different styles and quality. Some are simple, plastic throwaway tools with a short life. Others are long-life and will punch-down the wire and cut/trim at the same time. Read and understand the tool manufacturer's users' manual on its use. In addition, consult the punch-down block data sheet for recommendations on the process and which tools are allowed.

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

Types of cables

EtherNet/IP supports un-terminated cables and pre-terminated or over-molded cord sets. Un-terminated cables are discussed below for M12-4 "D" coded cord sets and 8-way modular connector cord sets.

Field-terminating cable ends

The performance of your system depends on the cable termination. Careful cable end preparation is essential for proper connector installation and signal integrity. Pay particular attention to the amount of untwisting of the conductor pairs. (See [Figure 5.3](#).) Maintain twist as close as possible to the termination point. Cross over wire 6 as shown in [Figure 5.2](#). Trim conductors as short as possible before installing them into the connector body. The length of the jacket must be long enough to fit inside the connector back end. The length of the conductors beyond the end of the jacket should not be longer than 12.7 mm (0.5 in.). Refer to the procedures described in the following sections.

Important: Proper preparation of the conductors prior to installation into the connector back end is critical to performance.

Terminating 8-way modular plugs

You will need the following tools to terminate the ends of your UTP or STP Ethernet cable to the connector:

- ODVA-approved modular 8-Way plug (sealed or unsealed)
- Cable cutting and preparation tool
- Cable jacket stripper
- Crimp tool

Terminating UTP cable

Terminate UTP cable as follows:

1. Using a stripping tool similar to the one in [Figure 5.1](#), strip back 1 inch of jacket. Be careful not to cut the insulation of the wire. If you damage the wire insulation, cut off the end of the cable and start over.

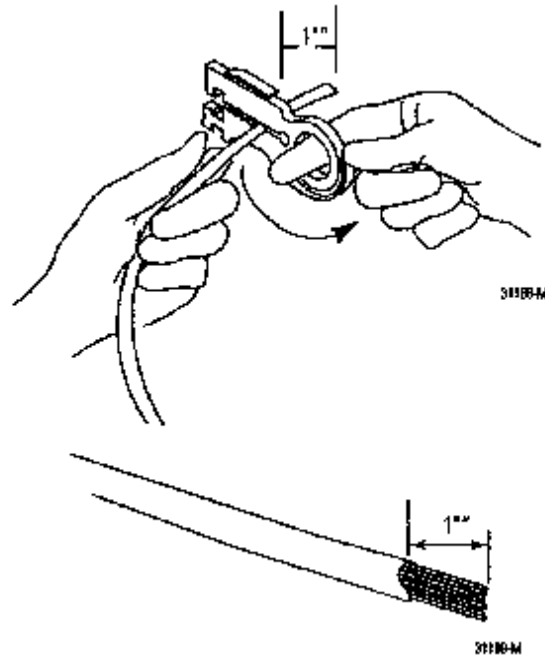


Figure 5.1 Stripping the cable jacket.

2. Separate the individual wire pairs. Untwist only back to the jacket edge. (See [Figure 5.3](#).) Use the T568A or T568B color code and pairing chart in [Table 5.2](#) to identify correct placement of conductors into the connector.

When to use T568A or T568B

EtherNet/IP recognizes both T568A and T568B pin/pair assignments. It is recommended that the T568A wiring scheme be used; although T568B may be used if needed. T568A scheme exists for backwards compatibility with

telephone systems. Neither offers any performance gains over the other. Some government agencies require T568A wiring. Do not mix T568A and T568B in your system except with cross-over cords.

Table 5.2 Color codes for 4-pair horizontal cables

| Conductor Identification | Color Code | Abbreviation |
|--------------------------|------------------------|----------------|
| Pair 1 | White-Blue Blue | (W-BL) (BL) |
| Pair 2 | White-Orange Orange | (W-O) (O) |
| Pair 3 | White-Green Green | (W-G) (G) |
| Pair 4 | White-Brown Brown | (W-BR) (BR) |

3. Align the wires into color groups as shown in [Figure 5.2](#).

Important: If you are wiring to T568A, then the white/orange and orange pair is split across blue and white/blue pair.
If you are wiring to T568B, then green/white and green pair is split across blue and white/blue pair.

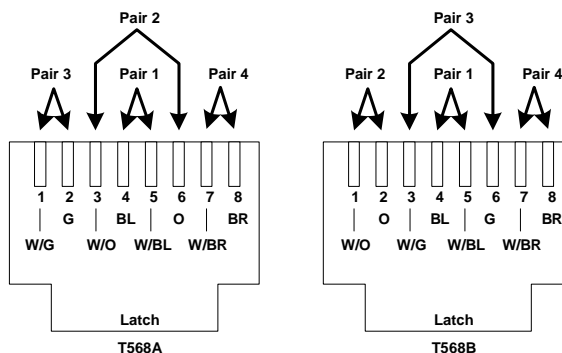


Figure 5.2 Pin/pair wiring.

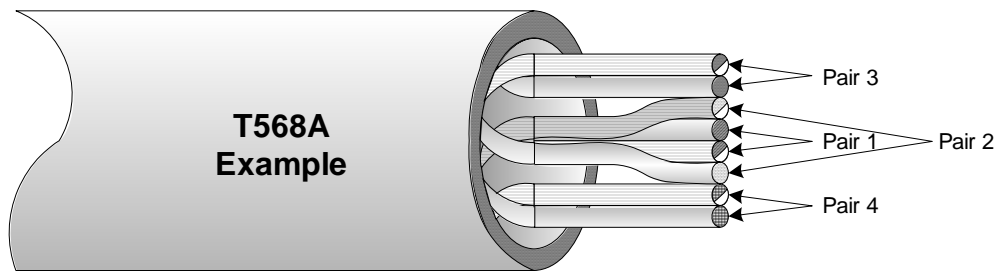


Figure 5.3 Example of T568A cable preparation.

4. Prepare the conductors for trimming, heeding the important directions and warnings in the bulleted list below.

Important: The performance of your channel will depend on this step.

- Extend the pair twists out as far as possible.
- Make sure pair 2 (T568A) is evenly split across pair 1.
- The conductor lengths must be trimmed evenly.
- Conductor trim length is dependent on the connector manufacturer's instructions.

-
5. Hold the conductors in the proper orientation and trim off excess length using a pair of sharp cutters. The finished length beyond the jacket should be less than 0.5 inches. See the connector manufacturer's instructions.
 6. Confirm the correct orientation of the conductors as shown in [Figure 5.4](#), then insert the conductors into the connector body. Note that each wire has its own slot in the connector body.

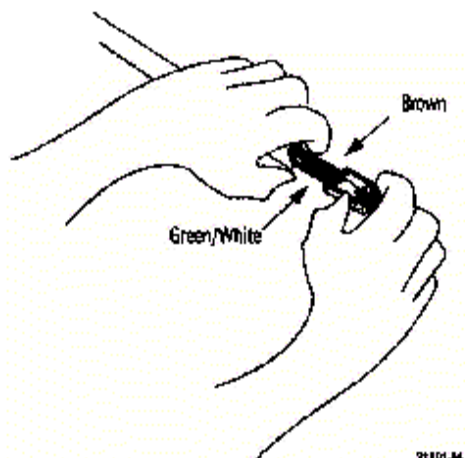


Figure 5.4 Orientation of the conductors.

7. Push the cable into the connector body until all the wires touch the end of the connector body. The jacket should be inserted far enough into the connector body that the cable clamp will engage and hold the jacket.
8. Insert the connector into the crimp tool as shown in [Figure 5.5](#) and crimp the connector. Be sure that the connector is fully seated into the crimp dies.

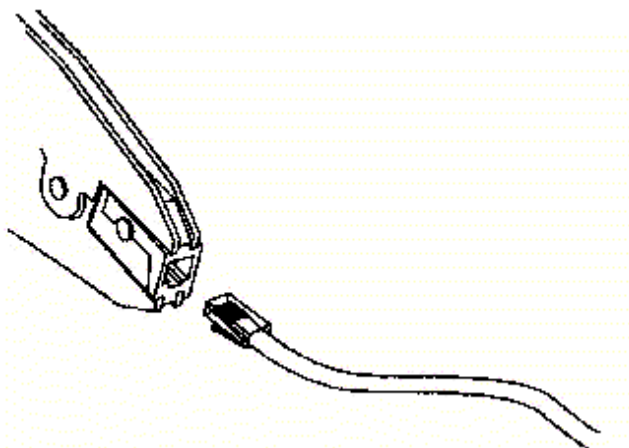


Figure 5.5 Crimp tool.

9. Check the crimp by pulling gently on the connector. If the jacket or conductors slide out, cut the connector off and start over.
10. Electrically test the connection using an appropriate tester, such as a commercially available Ethernet test tool as defined in [Chapter 6](#).

Terminating an M12-4-pin connector

M-12 connectors generally do not require the use of terminating tools. Consult the appropriate connector manufacturer for instructions and any required tools.

Note: Some field-attachable M12-4 “D” coded 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 M12-4 “D” coded connector types include over-molded cord sets (no assembly required) in screw or solder types. Follow the manufacturer’s assembly instructions for correct installation.

The typical M12 4-pin IDC termination technique consists of the following steps:

1. Strip back the jacket by approximately 15 to 20 mm ($\frac{1}{2}$ to $\frac{3}{4}$ in.).
2. Assemble the connector parts as directed by the manufacturer's data sheet.
3. Arrange the wires according to the orientation of the connector and the manufacturer's data sheet.
4. Trim off the excess length of the conductors.
5. Assemble the housing and tighten the cable gland to engage the IDC contacts and strain relief.
6. Test the channel.

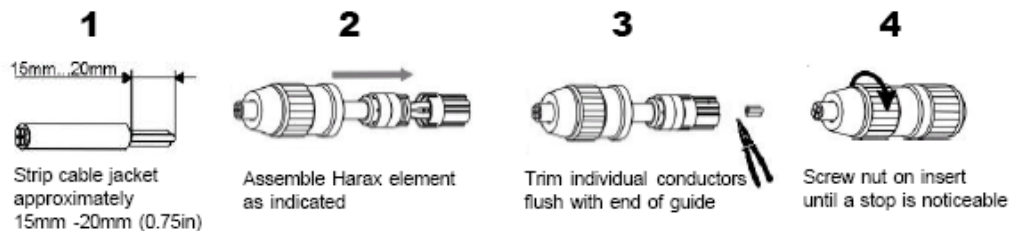


Figure 5.6 Example of M12-4 “D” coded connector assembly.

Table 5.3 M12-4 “D” coded connector pin assignment for non-crossover cable

| Pair (T568A) | Pin | Signal |
|--------------|-----|--------|
| Pair 3 | 1 | TX+ |
| | 3 | TX- |
| Pair 2 | 2 | RX+ |
| | 4 | RX- |

Terminating ScTP cabling

There are several variants of shielded twisted pair cables available, offering different levels of shielding effectiveness. In general, they are all terminated the same way. This manual refers to all these variants as ScTP cables. Depending on the type of shielding used on the cable, the process of preparing and terminating the cable may be different. Refer to cable and/or connector manufacturer's recommendations for proper termination methods.

ScTP cable is typically terminated as follows:

1. Preparing the shield to provide 360 degrees of coverage over the conductors and being careful not to cut the shield, drain or insulation of the wires, strip back 1 inch of jacket using the jacket strip tool as shown in [Figure 5.7](#). If you damage the shield, drain or insulation, cut off the end of the cable and start over.

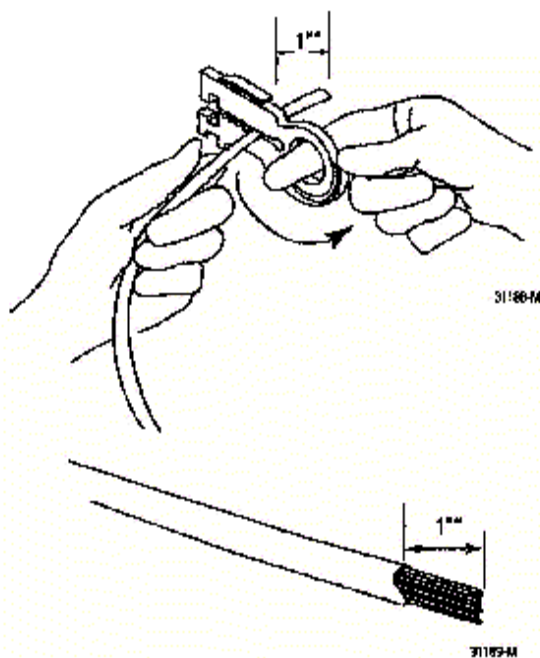


Figure 5.7 Stripping ScTP cables.

2. Separate the individual wire pairs. Untwist only back to the jacket edge as shown in [Figure 5.8](#).
3. Fold the drain wire and/or shields back in line with the cable as shown in [Figure 5.8](#).
4. Align the wires into color groups as shown in [Figure 5.8](#).

Important: If you are wiring to T568A, then the white/orange and orange pair is split across blue and white/blue.
If you are wiring to T568B, then green/white and green is split across blue and white/blue pair.

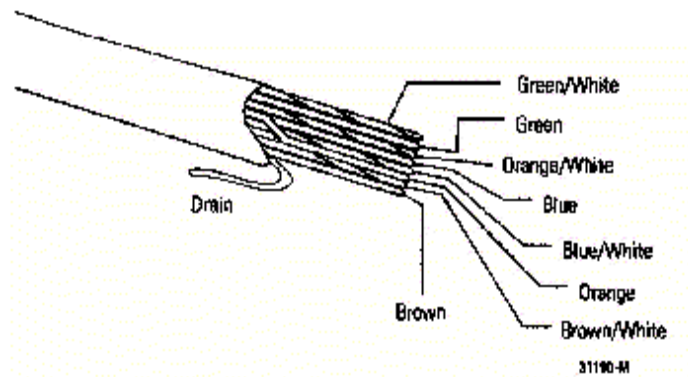


Figure 5.8 Wire preparation.

5. Hold the conductors in the proper orientation and trim off the excess length using a pair of sharp cutters. The finished length beyond the jacket should be less than 0.5 inch.
6. Confirm the correct orientation of the conductors and insert the conductors into the connector body. Note that each wire has its own slot. Follow T 568A or T568B wiring convention as shown in [Figure 5.3](#).

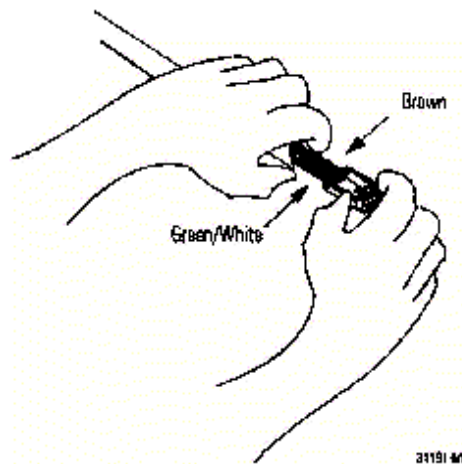


Figure 5.9 Inserting the wires into the connector body.

7. Push the cable into the shielded connector body until all the wires touch the end of the connector body. The jacket should be inserted far enough into the connector body that the cable clamp will engage and hold.
8. Insert the connector into the crimp tool as shown in [Figure 5.10](#). If the shield is not to be connected, make sure it is cut off or insulated from the connector shell. Crimp the connector, making sure that the metal tabs on the connector are crimped around the wire.

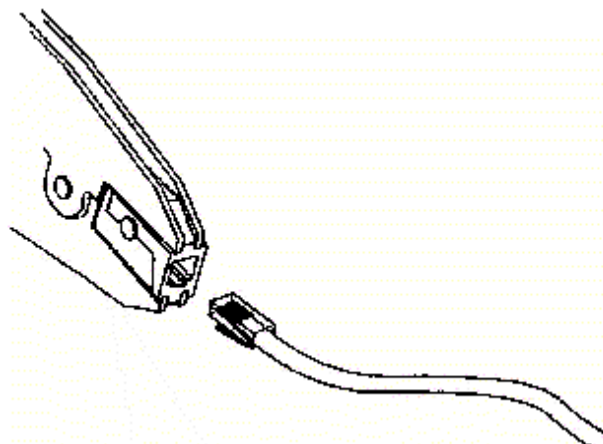


Figure 5.10 Crimping the connector.

9. Check the crimp by pulling gently on the connector. If the jacket or conductors slide out, cut the connector off and start over.
10. Electrically test the connection using an appropriate test tool, such as a commercially available Ethernet test tool.

Cable Routing

See [Chapter 3](#) (copper) and [Chapter 4](#) (fiber) for details on cable routing.

Installing Switches

If you are using off-the-shelf, commercial switches, consult the manufacturer's data sheets for installation requirements in your environment. Switches may need enclosures, shock mounting and temperature controls to convert a MICE 2 or 3 environment to a MICE 1 environment. The placement of the switch is important from an access perspective. Switches should be located to minimize the cable lengths to the devices. This may conflict with the environmental specifications of the switch. Consider using an industrially-rated switch for harsh applications.

Installing Bulkhead Feed-Throughs

There are two reasons to use bulkhead feed-throughs: modularity and serviceability. When cables need to exit an enclosure, it is necessary to protect the internal environment. Therefore, wire glands and feed-throughs rated for the external environment must be used. It is advisable to always place these devices on the bottom or top of the enclosure or on sides not exposed to other machinery where they can be damaged.

Installing the Cable

- Refer to the guidelines in [Chapter 3](#), [Chapter 4](#), and [Chapter 5](#) when routing your cable.
- Plan your location in such a way that the connector cannot be damaged.
- Sealed connectors can be located outside enclosures 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 on page 5.73](#) and [Table 4.6 on page 4.72](#) for additional information.

Connection of Verification and Maintenance Equipment

Observe the following precautions when using diagnostic and maintenance equipment. See [Chapter 6](#) for network verification and troubleshooting.

Optical fiber cabling

The bend radius for intra-building 2- and 4-fiber horizontal optical fiber cable 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 on page 5.73](#).

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 even numbered fibers are Position B at one end and Position A at the other end. See [Figure 5.11](#).

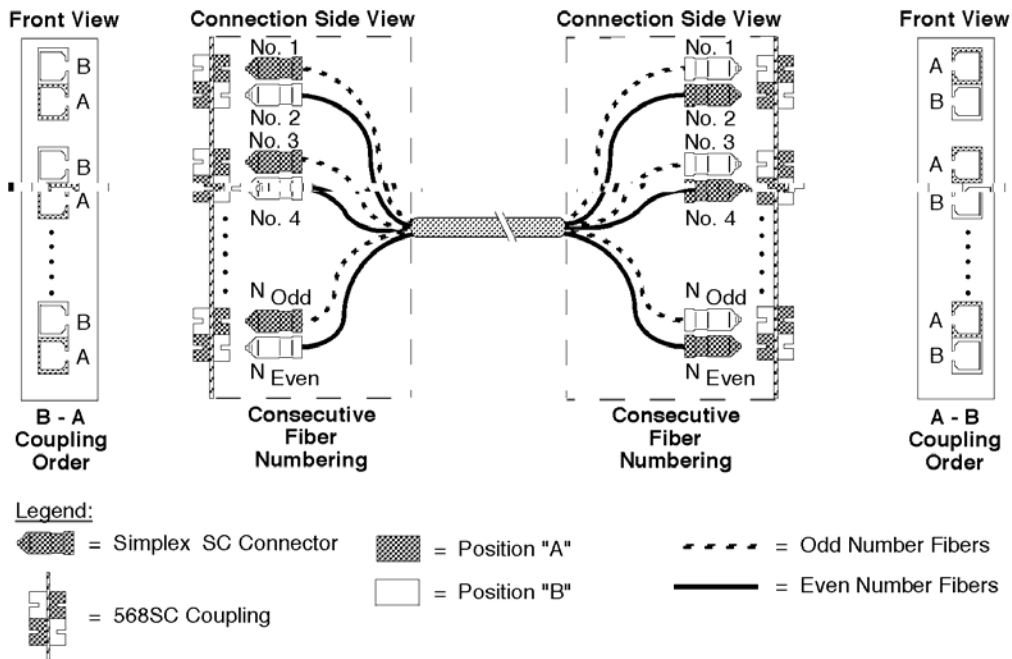


Figure 5.11 Specified optical fiber cabling for proper polarity.

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

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 5.12 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. Install optical fiber links not shown in Figure 5.13 to ensure that on one end, the Duplex SC adapter is installed in the A-B orientation, and on the other end, it is installed in the B-A orientation.

Patch cords, equipment cords and work area cords

The 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 5.13.)

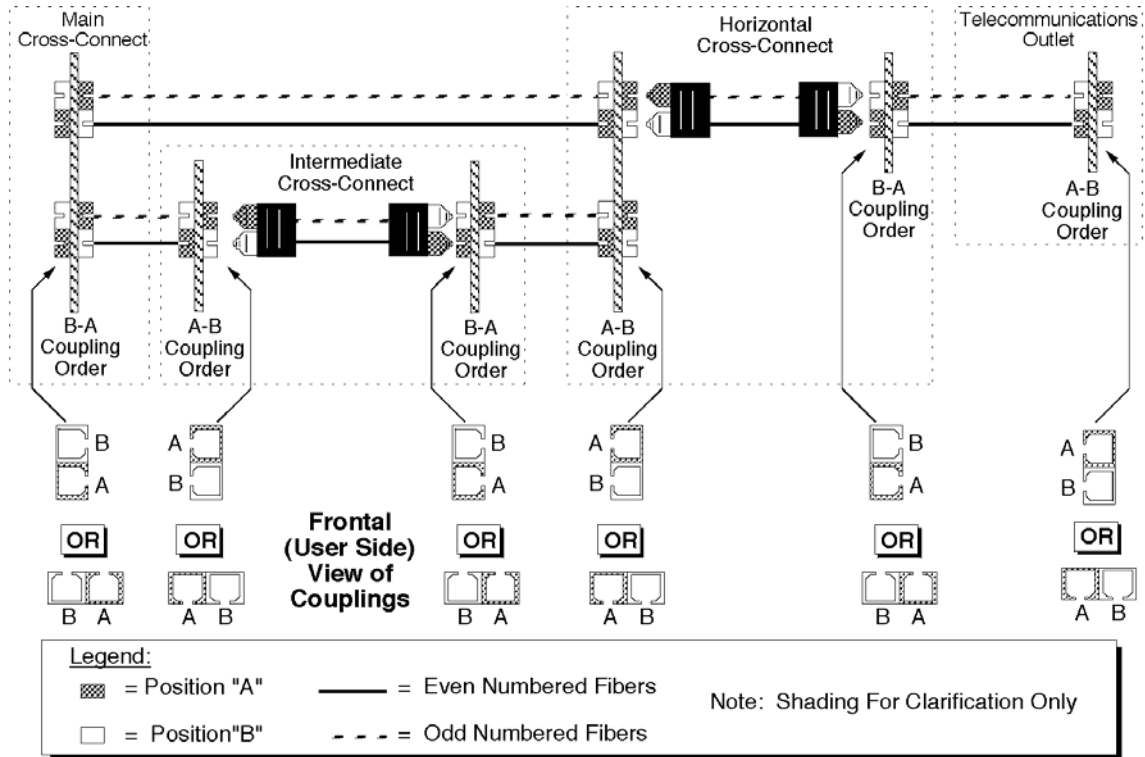


Figure 5.12 Optical cabling plan for premises cabling.

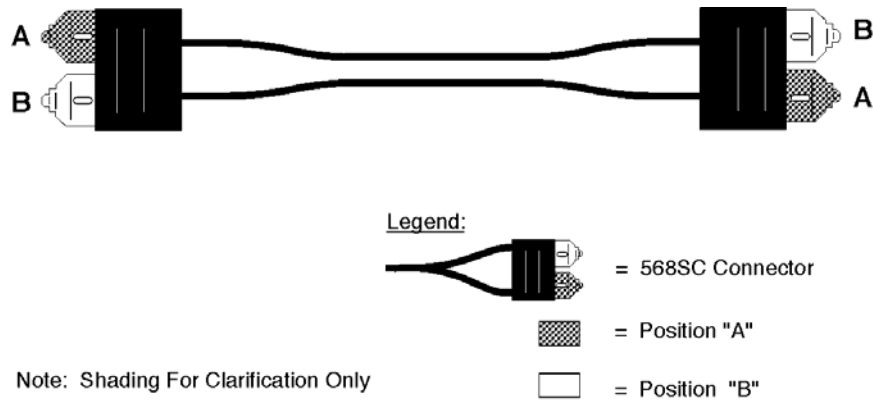


Figure 5.13 568SC optical fiber patchcord.

Verification of your EtherNet/IP Network

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

Verifying Terminated Cable Segments

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

List of recommended specialized equipment

- Multi-meter (DVM)
- Verification test tool that provides wire map, cable length, and cable tracer functions (for troubleshooting)

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.

Channel test configuration

The channel test configuration is to be used by system designers and users of data communications systems to verify the performance of the overall channel. The channel includes up to 90 m (295 ft.) of horizontal cable, a work area equipment cord, a telecommunications outlet/connector, an optional transition/consolidation connector, and two connections in the telecommunications room. The total length, including equipment cords, is 100 m (328 ft.). 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.

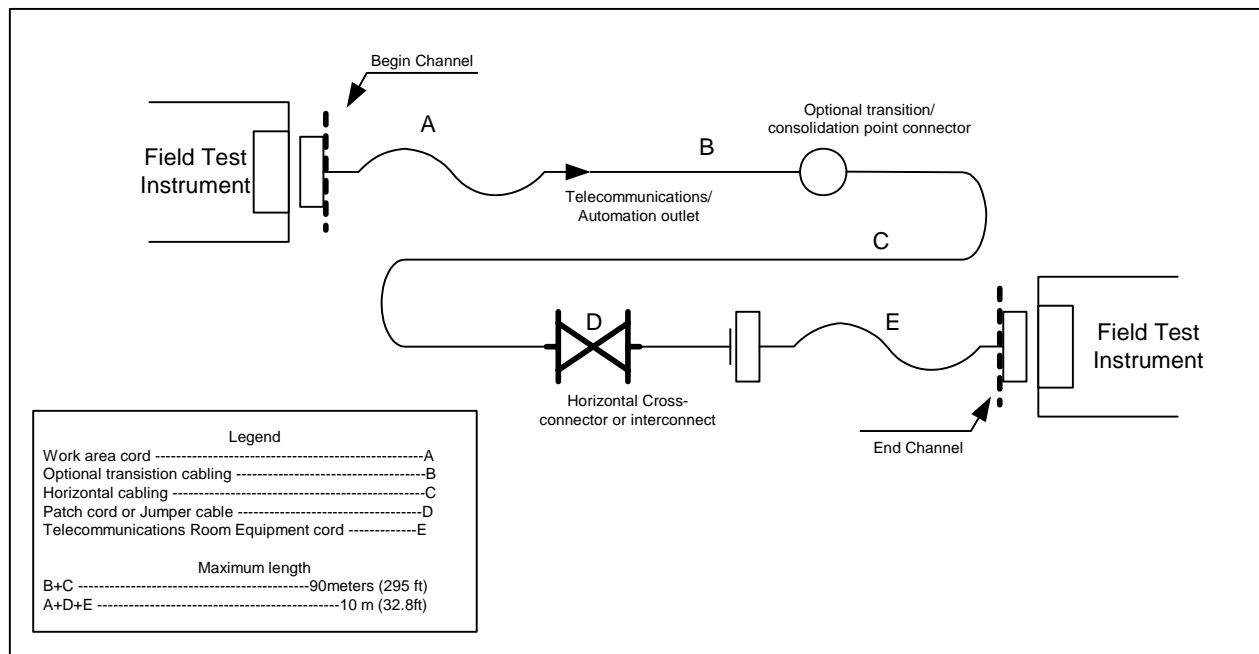


Figure 6.1 Schematic representation for a channel test configuration.

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 is illustrated in [Figure 6.2](#). The permanent link consists of up to 90 m (295 ft.) 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.

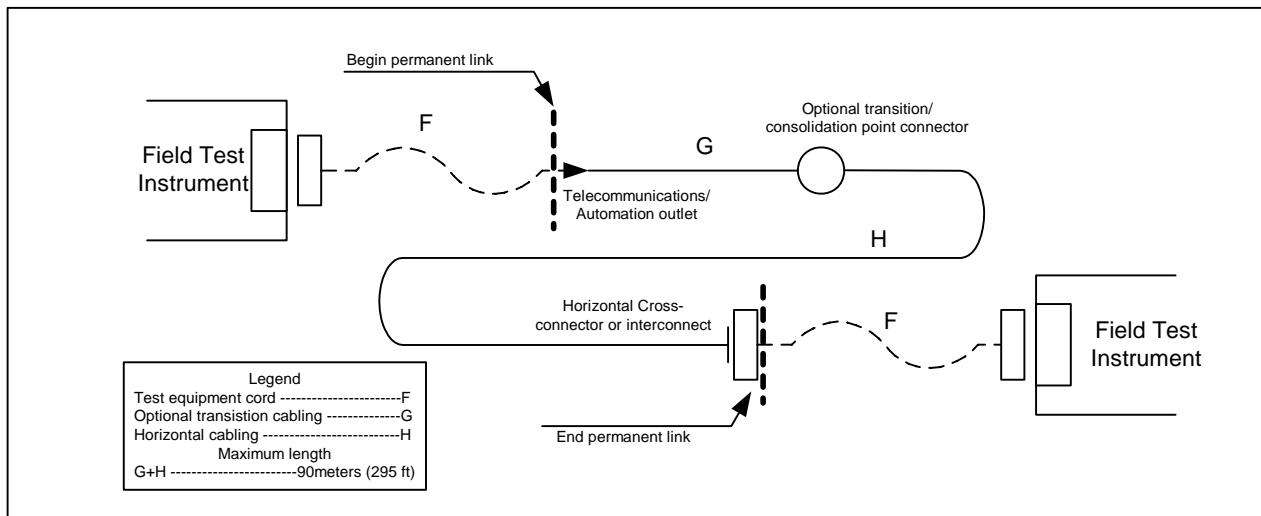


Figure 6.2 Schematic representation of a permanent link test configuration.

Note: If cross-connections are used, then channel testing is recommended.

What should be verified?

Primary verification parameters include:

- Wire map
- Jacketed length
- Shields floating or not floating (Note: The shield may intentionally be open at one end. See [Figure 3.22 on page 3-54.](#))
- Kinks in cable
- Breaks in the jacket, abraded or burned
- Bend radius
- Dust caps for connectorized cabling
- 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

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 miss-wiring

Wire map for straight-through cables

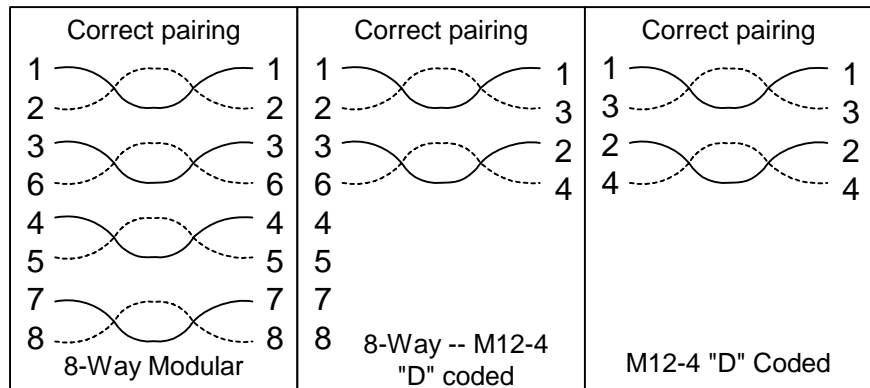


Figure 6.3 Wire mapping for 8-way modular and 8-way modular to M12-4 non-crossover cabling.

Wire map for crossover cables

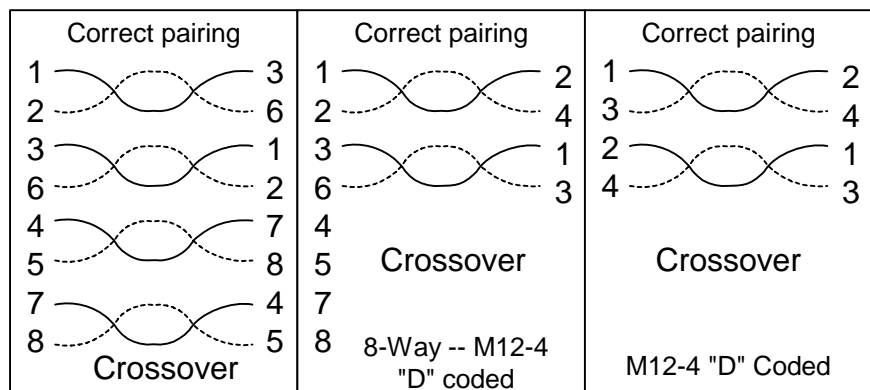


Figure 6.4 Wire mapping for crossover cables.

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.

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 6.5](#) for an illustration of transposed pairs.

Split pairs

Split pairs occur when pin-to-pin continuity is maintained, but physical pairs are separated. Refer to [Figure 6.5](#) for an illustration of split pairs.

If your verification test indicates a 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.

Correct connectivity of telecommunications outlets/connectors is defined in ANSI/TIA/EIA 568 B.2 and is illustrated in [Figure 6.3](#).

Examples of incorrect wire mapping

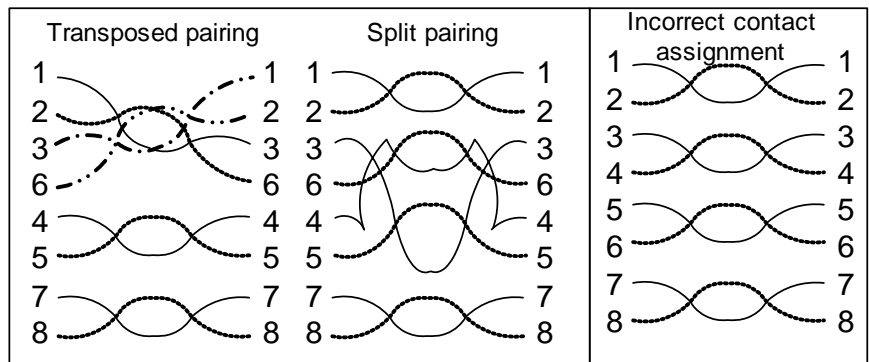


Figure 6.5 Examples of miss-wiring.

Physical Length vs. Electrical Length

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), determined from the length markings on the cable(s), when present.

Length limits for permanent links and channels

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 the channel shall not be greater than 100 m (328 ft.), including equipment cords and patch cords. If the channel or permanent link has been de-rated because of temperature cable attenuation, then the total channel length is less than 100 m (328 ft.), and the permanent link will be less than 90 m (295 ft.). See the de-rating table, [Table 3.8 on page 3.37](#).

Chapter 7

Troubleshooting Your 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.

Tools for Determining Network Failures

Test tools

There are many off-the-shelf test tools available to help diagnose your network. The tools can be divided into two categories: passive and active.

Passive testers

Passive testers are designed to test the cabling system and components. They require full access to a network. Devices have to 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.

Verification testers are usually less expensive and only provide basic information, such as wire map and length. A verification type tester is more than sufficient for locating an open or shorted cable in a channel or permanent link. More complex testers are available that will perform swept frequency tests and provide permanent link/channel performance testing, such as return loss (impedance), attenuation, near-end cross talk (NEXT), and far-end cross talk (FEXT) to name just a few. Most, if not all, perform the functions of verification. This type of tester can certify the channel or permanent link for a specific application need. For example, if your application is EtherNet/IP requiring Category 5e performance level, the certifying tester will perform go/no-go testing to this level. These types of testers come in varying levels of accuracies and bandwidth support. Currently, the most accurate tester is a Level IV. This tester is capable of providing precision measurements. You should purchase an appropriate (verification or certification) tester(s) based on your needs.

Active test tools

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

Network Verification

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

Network Certification

Network certification includes electrical performance testing of each channel and is 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.

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

Diagnostic error counters

Communications error counters are extremely useful in predicting future failures. Alarms can be set at error counter thresholds to warn operators that a failure is imminent. 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 rising temperatures. Error counters that burst counts can be an indication of noise. This can be the fault of a poorly designed network, cables that are too close to noise generating machinery, or a failing ground.

Determining if you have 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 noise-related failures. In many cases, these are related. Most control networks have error reporting capabilities within the devices. The communications management software has the ability to collect and report the errors to the operator. The error reporting can be used for an early warning system and as a diagnostic tool to help determine the source of a pending failure or a failure that has occurred. Error counter histograms are particularly useful in correlating errors to events, such as a drive coming online.

Quick troubleshooting process

A systematic approach should be used for troubleshooting. [Figure 7.1](#) is an example of a basic troubleshooting process.

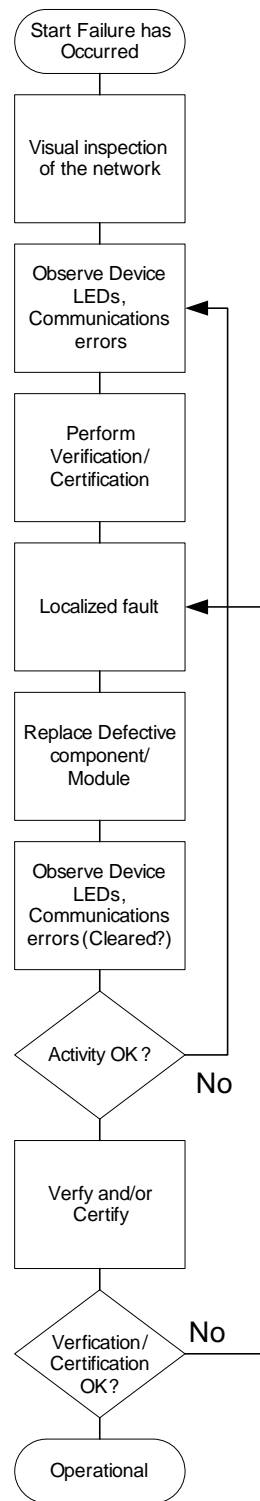


Figure 7.1 Basic troubleshooting flow chart.

Detailed troubleshooting process

This process can be used to find the majority of cabling faults.

Visually inspect the network (channel/permanent link):

1. Observe cabling.
 - a. Correct cut or damaged cable.
 - b. Correct damaged connectors.
2. Observe device indicators, including the switch.
 - a. An activity indicator at one end and not the other may indicate a cabling fault in one pair and or a device fault.
 - b. An activity indicator out at both ends may indicate a device fault at one end and or a total cable fault.
 - c. All indicators out at a device may indicate a device fault or power fault.
3. If the cabling is suspected, disconnect the active devices and test the channel. Localize and correct the cabling failure.
 - a. 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.
 - b. If a problem is reported, localize and replace the component(s).
 - c. If no problem is reported by the test equipment, proceed to troubleshooting the active devices per the manufacturer's directions.
4. After correcting faults in the cabling system, perform a channel/permanent link certification test and update the applicable network documentation.

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 Possible Causes

| Symptom | Possible Cause | Suggested Action |
|--|--|---|
| High error rate | <ul style="list-style-type: none"> • Damaged cable • Electrical noise near by • 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"> • Noise-generating device • Poor cabling • Grounded shield | <ul style="list-style-type: none"> • Correlate burst noise to burst errors. Provide additional separation. Check for improper grounding. • Check for low noise cabling. |
| Continuous error condition (some data getting through) | <ul style="list-style-type: none"> • Incorrect cabling for application or noise 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 noise 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. |

Chapter 8

Certifying your EtherNet/IP Network

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

- A baseline can be established for future maintenance purposes, such as troubleshooting and/or preventive maintenance.
- It reduces start-up time by confirming that the installation can support the application requirements. For example, if your application requires 10/100 Mb/s, then the certification will confirm that the network meets the minimum Category 5e channel and permanent link limits as defined by TIA and the ODVA standard.
- Some cabling providers will provide a warranty for the network only upon successful passing of certification tests.

When to Perform Certification

In general, this process is performed after the installer has verified that the network components have been installed properly. The process of conformance is usually carried out by specialists trained in network certification. This process should also include a report detailing any of the following:

- Areas that do not meet the requirements of the design documentation
- Channel/permanent 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 (for 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, and the limits and steps to be taken in the event the network fails certification.

What Should Be Certified

Certification should include the following aspects of the network:

- Physical installation attributes that may affect life of installation, such as
 - Location of cabling with respect to electrical noise and environmental conditions
 - Grounding of devices and equipment where specified
 - Wire ways
 - Bend radii
 - Cable supports (hangers)
 - Cable loading and crushing
 - Terminations
 - Proper media commensurate with the environment
- Electrical performance commensurate with the needs of the application
 - Electrical and physical lengths of channels and permanent links
 - Swept frequency measurements (as detailed later in this chapter)

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. Field test tools must be Level II or higher, and it is highly recommended that you use either a Level III or IV tester for network certification. Additionally, the test time and frequency range is a variable. For example, testers may take anywhere from 5 to 20 seconds per channel or permanent link and may only test to Category 5e channels/permanent links. The test tool usually requires separate test heads for testing channels, permanent links and patch cords. It is important to have a tester that is capable of testing all components and parts of a channel.

Additional tools that are beneficial for the certification process include:

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

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

Electrical Tests

The following list of electrical tests should be performed on a network according to the design documentation. At a minimum, the electrical measurements should be performed after the initial installation to ensure that the cabling system will support the intended application(s).

- Length
- Insertion 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)
- Return loss (impedance)
- Propagation delay
- Delay skew
- Resistance (optional)

Certifying Terminated Cable Segments

Transmission performance depends on cable characteristics, connecting hardware, patch cords and cross-connect wiring, 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 guide is related to the channel and to the permanent link test configurations as specified in the following sections. 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.

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 two 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 also are acceptable.

Field test methods and interpretation of test data leading to pass/fail criteria are described to verify 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.

These additional specifications for verification of installed cabling are not intended to replace or supersede the basic requirements of this guide.

Test Configurations

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

Channel and permanent link test configurations are defined in the following paragraphs. Other compliant test configurations shall be tested using limits computed according to the ODVA specification.

Channel test configuration

The channel test configuration is for use by system designers and users of data communications systems to verify the performance of the overall channel. The channel includes up to 90 m (295 ft.) of 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. Those cases are beyond the scope of this manual. See [Figure 8.1](#) for a schematic representation of a channel.

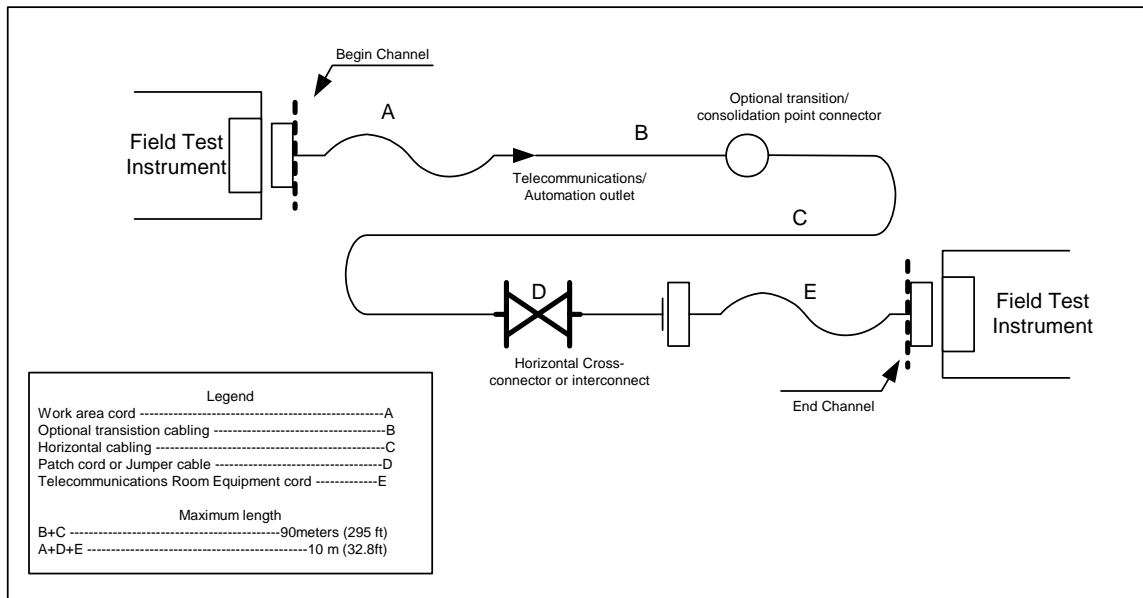


Figure 8.1 Channel test configuration.

Permanent link test configuration

The permanent link test configuration is for use by the certifying technician to certify the performance of installed cabling. A schematic representation of the permanent link is illustrated in Figure 8.2. The permanent link consists of up to 90 m (295 ft.) of horizontal cabling and one connection at each end. It 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.

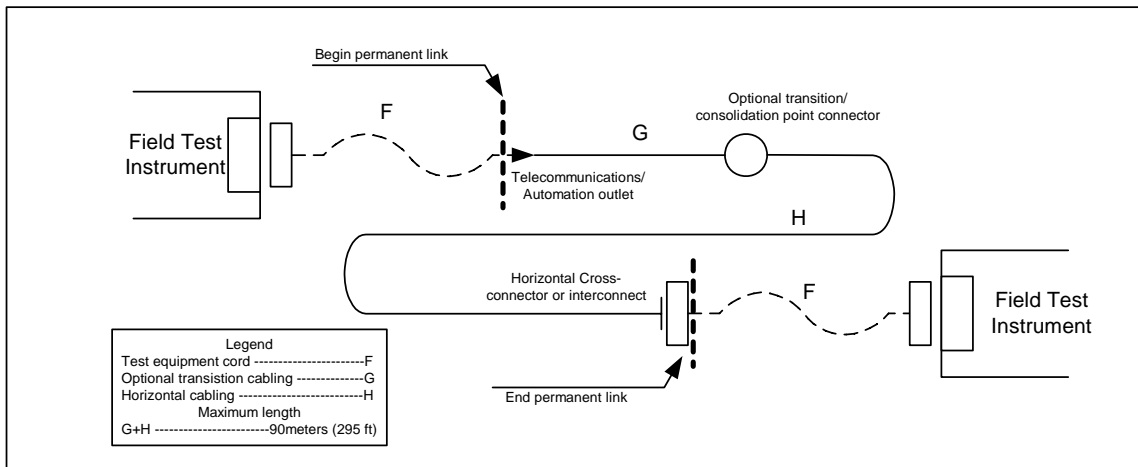


Figure 8.2 Permanent link test configuration.

Note:

1. If cross-connections are used, then channel testing is recommended.
2. Other parameters such as longitudinal balance and longitudinal impedance, which may be of importance to specific networking applications, are under study.
3. 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.

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

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/EIA 568 B.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: Calibration of NVP is critical to the accuracy of length measurements. (See ANSI/TIA/EIA 568 B.2.)

Insertion loss

Insertion loss is a measure of signal loss in the permanent link or channel. Worst case insertion loss relative to the maximum insertion loss allowed shall be reported.

The channel insertion loss is derived as the sum of the following:

- Insertion loss of four connectors
- Insertion loss of 10 m (33 ft.) of 24 AWG UTP/24 AWG ScTP patch, work area, and equipment cords or 8 m (26 ft.) of 26 AWG ScTP patch, work area, and equipment cords at 20 °C
- Insertion loss of 90 m (295 ft.) cable segment at 20 °C

The permanent link insertion loss is derived as the sum of the following:

- Insertion loss of three connectors,
- Insertion loss of 90 m (295 ft.) cable segment at 20 °C.

Insertion loss requirements are derived from the following equations:

$$insertion\ loss_{channel} = insertion\ loss_{4connections} + insertion\ loss_{cable,90m} + insertion\ loss_{cords,10m} \quad (3)$$

$$insertion\ loss_{permanent\ link} = insertion\ loss_{3connections} + insertion\ loss_{cable,90m}$$

The maximum insertion loss contribution allowed for equipment cords and patch cords is 20 percent higher than for the horizontal cabling as specified in ANSI/TIA/EIA 568 B.2. The maximum insertion loss contribution allowed for ScTP equipment cords and patch cords is 50 percent higher than for the horizontal cabling as specified in ANSI/TIA/EIA 568 B.2. If 50 percent de-rating is used, the maximum total length of patch cables, equipment cords, and work area cords shall be 8 m (26 ft.), so that the overall insertion loss limits for the channel are not exceeded.

Examples of the worst-case insertion loss at selected frequencies for the channel and permanent link are shown in [Table 8.1](#) and [Table 8.2](#) respectively.

Table 8.1 Channel Insertion Loss

| Frequency (MHz) | Category 5e (dB) |
|-----------------|------------------|
| 1.0 | 2.2 |
| 4.0 | 4.5 |
| 8.0 | 6.3 |
| 10.0 | 7.1 |
| 16.0 | 9.1 |
| 20.0 | 10.2 |
| 25.0 | 11.4 |
| 31.25 | 12.9 |
| 62.5 | 18.6 |
| 100.0 | 24.0 |

Insertion loss is determined at 20 °C for channel test configuration.

Length of horizontal cabling is 90 m (295 ft.).

Length of equipment cords, patch cords and jumpers is 10 m (33 ft.).

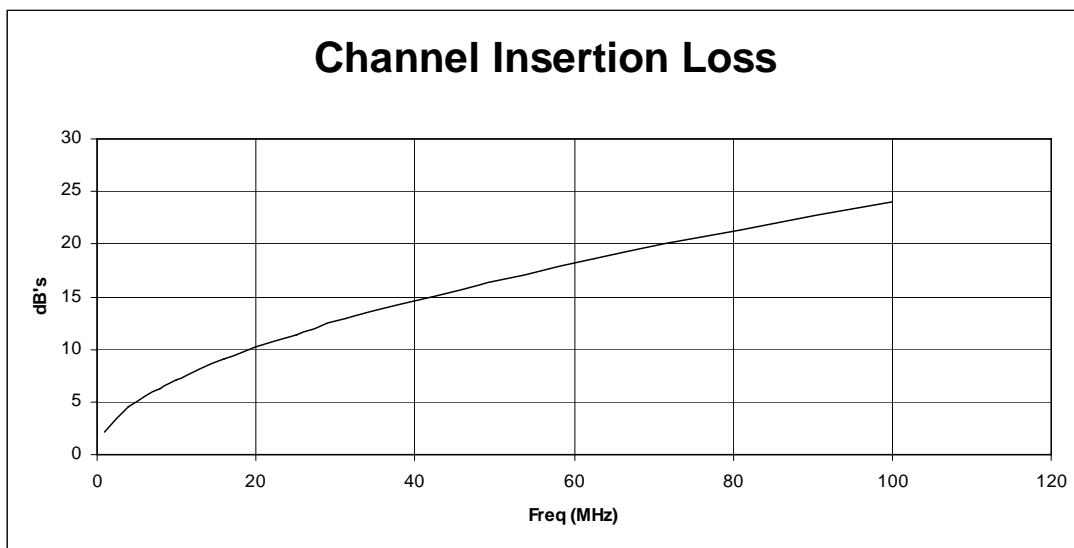


Figure 8.3 Channel insertion loss limit.

Table 8.2 Permanent Link Insertion Loss

| Frequency (MHz) | Category 5e (dB) |
|-----------------|------------------|
| 1.0 | 2.1 |
| 4.0 | 3.9 |
| 8.0 | 5.5 |
| 10.0 | 6.2 |
| 16.0 | 7.9 |
| 20.0 | 8.9 |
| 25.0 | 10.0 |
| 31.25 | 11.2 |
| 62.5 | 16.2 |
| 100.0 | 21.0 |

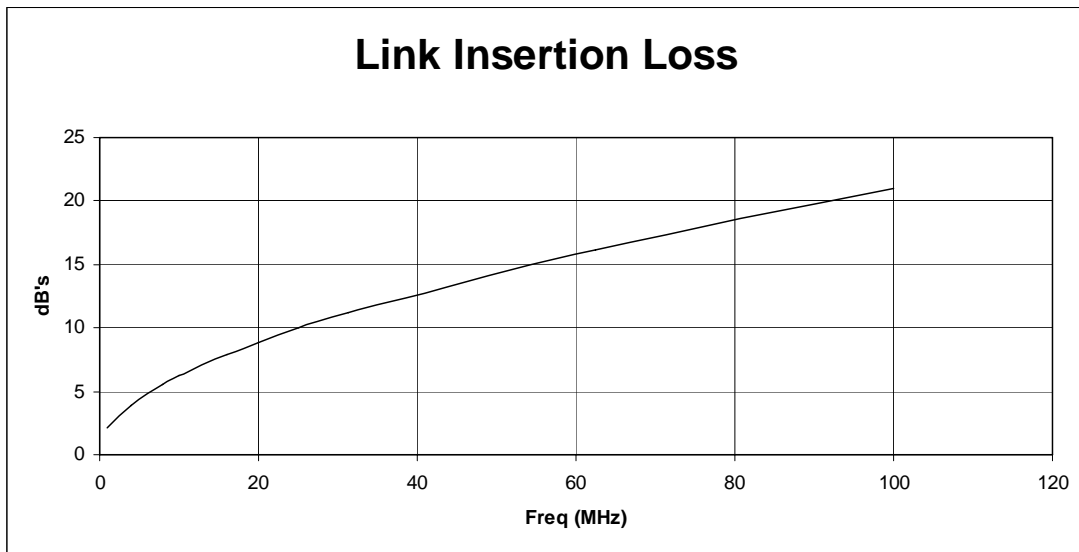


Figure 8.4 Permanent link insertion loss.

Length of horizontal cable is 90 m (295 ft.). Insertion loss increases with temperature. The user can estimate the insertion loss of cable segments at temperatures other than 20 °C using a 0.4% per degree Celsius factor for category 5e cable. The temperature coefficient and the maximum temperatures are specified in ANSI/TIA/EIA 568 B.2.

Note:

1. When using percent variations in quantities normally expressed in dB, this procedure uses percent variations in the dB values.
2. Although the terms attenuation and insertion loss are often used interchangeably, attenuation implies that the terminating impedance at the device under test is the same as the characteristic impedance of the cable.

Cabling return loss

Return loss is a measure of the reflected energy caused by impedance variations in the cabling system. For all frequencies from 1 to 100 MHz, the category 5e minimum return loss of the cabling shall be measured in accordance with annex E of ANSI/TIA/EIA 568 B.2 and shall meet or exceed the values shown.

Table 8.3 Category 5e Channel Return Loss

| Frequency (MHz) | Category 5e (dB) |
|-----------------------|-----------------------|
| $1 \leq f < 20^{(1)}$ | 17 |
| $20 \leq f \leq 100$ | $17 - 10 \log (f/20)$ |

⁽¹⁾ *f* is the frequency in MHz.

Table 8.4 Category 5e Channel Return Loss

| Frequency (MHz) | Category 5e (dB) |
|-----------------|------------------|
| 1.0 | 17.0 |
| 4.0 | |
| 8.0 | |
| 10.0 | |
| 16.0 | |
| 20.0 | |
| 25.0 | 16.0 |
| 31.25 | 15.1 |
| 62.5 | 12.1 |
| 100.0 | 10.0 |

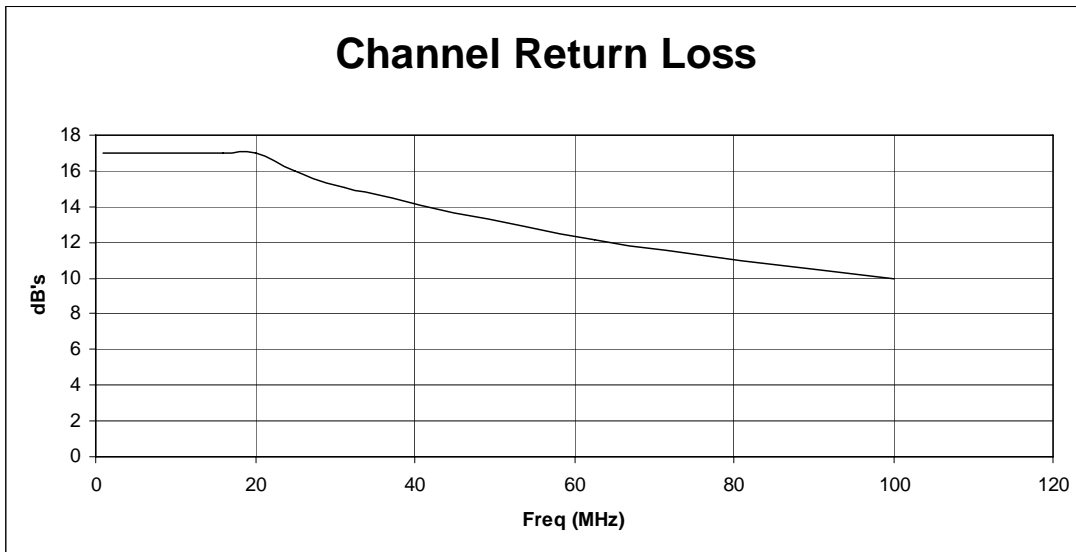


Figure 8.5 Channel return loss.

Table 8.5 Category 5e Permanent Link Return Loss

| Frequency (MHz) | Category 5e (dB) |
|-----------------------|-----------------------|
| $1 \leq f < 20^{(1)}$ | 19 |
| $20 \leq f \leq 100$ | $19 - 10 \log (f/20)$ |

⁽¹⁾ *f* is the frequency in MHz

Table 8.6 Category 5e Permanent Link Return Loss

| Frequency (MHz) | Category 5e (dB) |
|-----------------|------------------|
| 1.0 | 19.0 |
| 4.0 | |
| 8.0 | |
| 10.0 | |
| 16.0 | |
| 20.0 | |
| 25.0 | 18.0 |
| 31.25 | 17.1 |
| 62.5 | 14.1 |
| 100.0 | 12.0 |

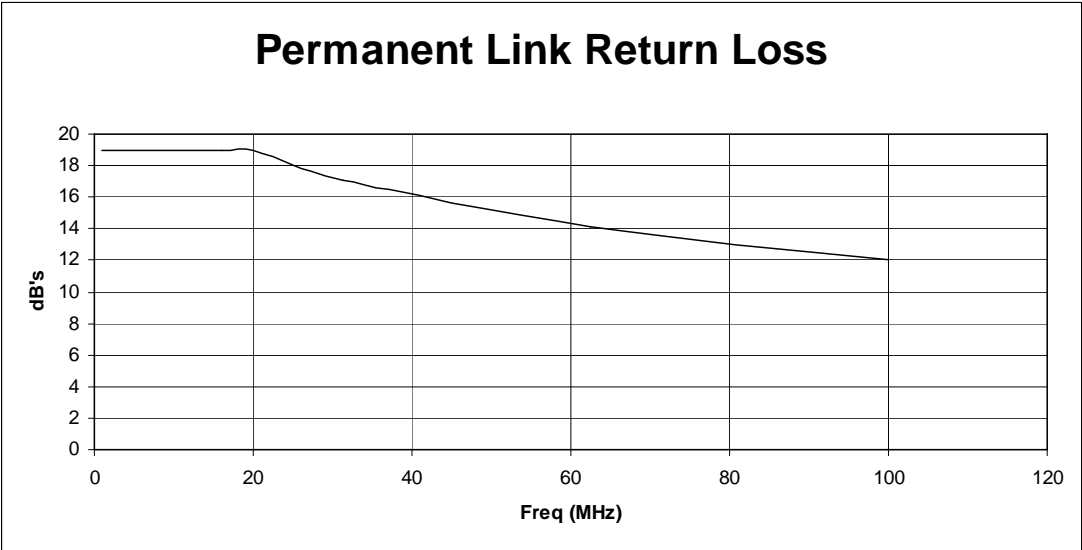


Figure 8.6 Permanent link return loss.

Numerics

- 100-ohm, twisted-pair performance 101
- 2-pair and 4-pair rules 22
- 4-pole M12 D coded connectors 20
- 8-way modular
 - connector cord set 22
 - plug termination 75

A

- Access, network 5
- Active network components 59
- Active test tools 94
- Ambient temperature 60
- Application
 - control 13
 - information 13
 - MICE concept 10

B

- Bandwidth, fiber optic 66
- Bend radius 73
- Bonding 54
 - equipotential 47
 - Star/multi-star 46
 - Star/multistar 46
- Breakout kits 70
- Bridges 16
- Building wiring 45
- Bulkhead feed-through installation 82
- Bulkhead feed-throughs 6, 24, 59

C

- Cabinet, fiber optic 70
- Cable
 - 2-pair and 4-pair rules 22
 - certifying 101
 - fiber optic 65
 - field-terminating ends 74
 - glands 59
 - grounding shielded 7
 - high-flex 57
 - install 83
 - install horizontal 73

- installing 8
 - plan routing 41
 - plant hardware 69
 - plenum-rated 56
 - pull strength 74
 - pulling fiber optic 71
 - radius 73
 - riser-rated 56
 - screened 40
 - segment verification 87
 - shielded twisted pair 40
 - shielded use 7
 - terminate 75
 - terminate horizontal 74
 - terminate ScTP 80
 - termination 8
 - types 74
 - unshielded 7
 - weld splatter 56
- Cabling return loss 108
 - Categorize conductors 42
 - Certification tools 100
 - Certification, network 94
 - Certifying
 - electrical tests 101
 - terminated cable segments 101
 - what to certify 100
 - when to perform 99
 - Channel connections 58
 - Channel requirements 5
 - Channel test configuration 88, 102
 - Communication error 94
 - Component placement 6
 - Conductors
 - categorize 42
 - routing 42
 - Conduit, install fiber 69
 - Connecting devices 8
 - Connections in a channel 58
 - Connectivity between families 24
 - Connector 17
 - 4-pole M12D coded 20
 - Ethernet/IP sealed 8-way modular 18

- fiber optic 63
 - LC 64
 - RJ45 18
 - SC 63
 - ST 63
- terminate M12-4-pin 79
- Control applications 13
- Controlling earth currents 50
- Copper
 - bulkhead 59
 - cable glands 59
 - cable selection 55
 - equipment cords 57
 - extension cords 57
 - four-pair 56
 - high-flex 57
 - jumpers 57
 - patch cords 57
 - plenum-rated 56
 - resistant jackets 56
 - riser-rated 56
 - selecting I/O 59
 - two-pair 56
 - weld splatter-resistant 56
 - work area cords 57
- Cord set 22
 - 8-way modular 22
 - connectivity 22
 - crossover function 24
 - M12-4 "D" coded 23
 - two connector family 24
- Core diameter, fiber optic 66
- Cores 61
- Crossover cord set 24

D

- Design, non-earthed 53
- Diagnostic error counters 94
- Direct connections 17

E

- Earth current, controlling 50
- Earthing 54
- Electrical length 91, 104
- Electrical tests 101
- Enclosure, modular network 27
- Environment
 - MICE classifications 2
 - overview 1
 - selecting cable 6
- Equipment cord 57
- Equipment cords 84
- Equipotential
 - bonding connection 53
 - bonding system 47
- Ethernet
 - backbone, industrial 15
 - bridges 16
 - connectors 17

- direct connection 17
- gateways 16
- hubs 15
- network segment 17
- RJ45 connector 18
- routers 15
- switches 16

EtherNet/IP sealed 8-way modular 18

Extension cords 57

F

- Failure symptoms and causes 98
- Ferrite beads 61
- Fiber optic
 - bandwidth 66
 - breakout kits 70
 - cable plant hardware 69
 - cables 65
 - conduit and innerduct 69
 - connectors 63
 - core and cladding diameter 66
 - fire codes 71
 - install guide 70
 - LC connector 64
 - patch panels 70
 - plan and install 68
 - pull tension 71
 - pulling cable 71
 - racks and cabinets 70
 - SC connector 63
 - splice enclosures 70
 - splice panels 70
 - ST connector 63
 - verification equipment 83
 - water protection 70
 - wavelengths 66

- Field-terminating cable ends 74
- Fire codes, fiber optic 71

G

- Gateways 16
- Ground methods 45
- Grounding
 - shielded cable 50
 - shielded cable overview 7

H

- High-flex cables 57
- Horizontal cable termination 74
- Horizontal cable types 74
- Horizontal installation 73
- Hubs 5, 15

I

- Industrial
 - backbone 15
 - control applications 13
 - control components 15
- Information applications 13

- Innerduct, install fiber optic 69
 - Insertion loss 105
 - Install fiber optic cable 68
 - Installing bulkhead feed-throughs 82
 - Installing cable 8
 - Installing switches 82
 - Installing the cable 83
 - IP65/IP67 sealed connectors 8, 58
- J**
- Jackets, oil and chemical resistant 56
- L**
- LC connector 64
 - Length
 - channel limits 92
 - electrical 91
 - permanent limits 92
 - physical 91
- M**
- M12-4 "D" coded connector cord set 23
 - M12-4-pin connector 79
 - Maintenance equipment connection 83
 - MICE
 - apply concept 10
 - classifications 2
 - tutorial 9
 - Mitigation examples 11
 - Modular network construction 24
- N**
- Network
 - access 5
 - certification 94
 - channel requirement 5
 - component placement 6
 - components, active 59
 - diagnostic error counters 94
 - failure determination 95
 - hubs 5
 - lay out 5
 - media 5
 - planning 4
 - ports 6
 - security 5
 - segment 17
 - switches 6
 - verification 94
 - Network failures
 - active test tools 94
 - passive tester 93
 - test tools 93
 - tools for determining 93
 - Non-earthed reference voltage design 53
- P**
- Passive testers 93
 - Patch cords 57, 84
 - Patch panel
 - fiber optic 70
 - modular construction 24
 - overview 6
 - Pathways 44
 - Permanent link test configuration 88, 103
 - Physical length 91, 104
 - Plan fiber optic cable 68
 - Planning network 4
 - Plenum-rated cables 56
 - Ports 6
 - Pull strength, cable 74
 - Pulling tension, fiber optic 71
- R**
- Raceway considerations 44
 - Racks and cabinets 70
 - Reversed pairs 90
 - Riser-rated cables 56
 - Routers 15
 - Routing conductors 42
 - Routing, planning 41
- S**
- SC connector 63
 - ScTP cable, terminate 80
 - Security, network 5
 - Selecting I/O 59
 - Shielded
 - cable grounding 50
 - cable use 7
 - cables 40
 - Shielding with equipotential bonding 53
 - Splice enclosures 70
 - Splice panels 70
 - Split pairs 91
 - ST connector 63
 - Standard 8-way modular connectors (RJ45) 18
 - Star/multi-star 46
 - Surge suppression 61
 - Switches
 - Ethernet 16
 - install 82
 - overview 6
- T**
- T568A or T568B use 75
 - Temperature, ambient 60
 - Terminate
 - 8-way modular plugs 75
 - field-terminating 74

- horizontal cable 74
- M12-4-pin connector 79
- ScTP cable 80
- UTP cable 75
- Terminating cable ends 8
- Test configuration
 - channel 102
 - permanent link test 103
- Test configurations 102
- Test tools 93
- TN-C wiring 45
- TN-S wiring 45
- Tools for certification 100
- Transmission performance 101
- Transposed or crossed pairs 91
- Troubleshooting process 95–97
- Troubleshooting table 98
- Tutorial, MICE 9

U

- Unshielded cable use 7

V

- Verification
 - fiber optic 83
- Verification equipment connection 83
- Verification, network 94
- Verify
 - channel test 88
 - crossover cable 90
 - incorrect wire map example 91
 - link test 88
 - parameters 89
 - recommended equipment 87
 - reversed pairs 90
 - straight pairs 91
 - straight-through cable 90
 - terminated cable segments 87
 - transposed or crossed pairs 91
 - wire map test 90

W

- Water protection, fiber optic 70
- Wavelength, fiber optic 66
- Weld splatter-resistant cables 56
- Wire map
 - crossover cables 90
 - incorrect example 91
 - straight-through cables 90
 - test 90
- Wiring
 - building 45
 - external to enclosures 43
 - guidelines, general 41
 - inside enclosure 44
 - modular network example 24
 - TN-C methods 45
 - TN-S scheme 45
- Work area cords 57, 84