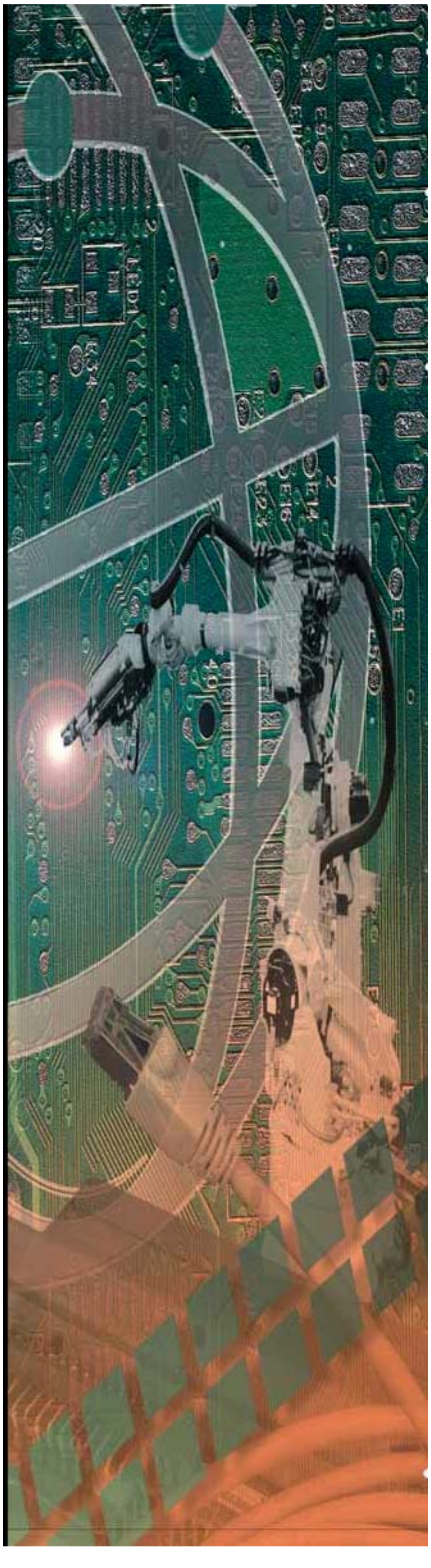
Industrial Ethernet Planning and Installation Guide



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IAONA Industrial Ethernet -Planning and Installation Guide

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All illustrations, charts and layout examples shown in this document are intended solely for purposes of example. Since there are so many variables and requirements associated with any single installation, IAONA assumes no responsibility or liability (including intellectual property liability) for actual use based upon examples shown in this publication.

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Contents

1 General

1.1 Scope

Within premises and industrial plants, the importance of the information technology cabling infrastructure is similar to that of other fundamental building utilities such as heating, lighting and mains power supplies. As with other utilities, interruptions to service can have serious impact. Poor quality of service due to lack of planning, use of inappropriate components, incorrect installation, poor administration or inadequate support can threaten an organization's effectiveness.

For the cabling of office buildings and campuses the international standards ISO/IEC 11801 and EN 50173 have proven to be very successful. They give a structure to the cabling by dividing it into conformance classes and 3 topology layers and by specifying appropriate categories for the components.
If one tries to apply them to cabling projects in industrial plants, there are several issues. This Installation Guide bridges the gaps as long as the appropriate standards for industrial IT cabling are on their way.

There are four phases in the successful installation of information technology cabling in industrial plants. These are:

1. design - the selection of cabling components and their configuration;
2. specification - the detailed requirement for the cabling, its accommodation and associated building services addressing specific environment(s) identified within the premises together with the quality assurance requirements to be applied;
3. implementation - the physical installation in accordance with the requirements of the specification;
4. operation - the management of connectivity and the maintenance of transmission performance during the life of the cabling.

This Installation Guide is intended to be used by personnel during the specification phase of the installation together with those responsible for the quality planning and operation of the installation and by the personnel directly involved in the implementation phase of the installation.

It contains requirements and guidance related to the installation planning and practices and for the specification and quality assurance of the information technology cabling in industrial plants by defining:

1. aspects to be addressed during the specification of the cabling;
2. requirements for the documentation and administration of cabling;
3. recommendations for repair and maintenance.
4. planning strategy (road map) and guidance depending on the application, electromagnetic environment, building infrastructure and facilities, etc.
5. design and installation rules for metallic and optical fiber cabling depending on the application, electromagnetic environment, building infrastructure and facilities, etc.
6. requirements on satisfactory operation of the cabling depending on the application, electromagnetic environment, building infrastructure and facilities, etc.
7. the practices and procedures to be adopted to ensure that the cabling is installed in accordance with the specification.

1.2 Normative references

This Installation Guide incorporates by dated or undated reference, provisions from other Standards. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this Installation Guide only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.
Both European and International Standards are cited, as in Europe the use of some EN standards is mandatory through directives that are transposed into national law.

1.2.1 International standards

ISO/IEC 11801	Information technology –Cabling systems for customer premises
ISO/IEC 14763-1	Information technology – Implementation and operation of customer premises cabling – Part 1: Administration
ISO/IEC 14763-2	– Part 2: Planning and installation
ISO/IEC 8802-3	Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications
ISO/IEC 9314-3	Information processing systems – Fibre distributed Data Interface (FDDI) – Part 3: Physical Layer Medium Dependent (PMD)
ISO/IEC 9314-4	– Part 4: Single-mode fibre physical layer medium dependent (SMF-PMD)
IEC 60038	IEC standard voltages
IEC 60068-1	Environmental Testing – Part 1: General and Guidance
IEC 60068-2	– Part 2: Tests
IEC 60332-1	Tests on electric cables under fire conditions – Part 1: Test on a single vertical insulated wire or cable
IEC 60332-2	– Part 2: Test for vertical flame spread of vertically-mounted bunched wires or cables
IEC 60512-2	Electromechanical components for electronic equipment – Basic testing procedures and measuring methods – Part 2: General examination, electrical continuity and contact resistance tests, insulation tests and voltage stress tests
IEC 60512-3	– Part 3: Current-carrying capacity tests
IEC 60512-4	– Part 4: Dynamic stress tests
IEC 60512-5	– Part 5: Impact tests (free components), static load tests (fixed components), endurance tests and overload tests
IEC 60512-6	– Part 6: Climatic tests and soldering tests
IEC 60512-7	– Part 7: Mechanical operating tests and sealing tests
IEC 60512-8	– Part 8: Connector tests (mechanical) and mechanical tests on contacts and terminations
IEC 60512-11	– Part 11: Climatic tests – Section 7: Test 11g: Flowing mixed gas corrosion test – Section 14: Test 11p: Flowing single gas corrosion test
IEC 60529	Degree of protection provided by enclosure (IP Code)

IEC 60603-7-1 + A1	Connectors for frequencies below 3 MHz for use with printed boards – Part 7: Detail specification for connectors, 8-way, including fixed and free connectors with common mating features, with assessed quality – Part 7-1: Generic specification – General requirements and guide for the preparation of detail specifications, with assessed quality
IEC 60603-7-2	Connectors for electronic equipment – Part 7-2: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 100 MHz
IEC 60603-7-3	– Part 7-3: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 100 MHz
IEC 60754-2	Test on gases evolved during combustion of electric cables – Part 2: Determination of degree of acidity of gases evolved during the combustion of materials taken from electric cables by measuring pH and conductivity
IEC 60754-2-am1	Amendment No. 1
IEC 60793 series	Optical fibres
IEC 60794 series	Optical fibre cables
IEC 60825-1	Safety of laser products – Part 1: Equipment classification, requirements and user's guide
IEC 60825-2	– Part 2: Safety of optical fibre communication systems
IEC 60874-1	Connectors for optical fibres and cables – Part 1: Generic specification
IEC 60874-2	– Part 2: [IEC 60874-2 Ed.2.0 (1993, standard for F-SMA connector) has been withdrawn by TC86B in 2002 without replacement]
IEC 60874-10	– Part 10: Sectional specification for fibre optic connector – Type BFOC/2,5
IEC 60874-14	– Part 14: Sectional specification for fibre optic connector – Type SC
IEC 60874-19	– Part 19: Sectional specification for fibre optic connector – Type SCD(uplex)
IEC 61034-1	Measurement of smoke density of cables burning under defined conditions – Part 1: Test apparatus
IEC 61034-2	– Part 2: Test procedure and requirements
IEC 61076-2-101	Connectors with assessed quality, for use in d.c., low-frequency analogue and in digital high speed data applications – Part 2-101: Detail specification for circular connectors with screw and snap-in coupling M8 and M12 for low-voltage switchgear and controlgear
IEC 61076-3-106	– Part 3-106: 8 way shielded and unshielded connectors for frequencies up to 600 MHz for industrial environments incorporating the 60603-7 series interface
IEC 61156-1	Multicore and symmetrical pair/quad cables for digital communications Part 1: Generic specification
IEC 61156-2	Part 2: Horizontal floor wiring, Sectional specification
IEC 61156-3	Part 3: Work area wiring, Sectional specification
IEC 61300-2	Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2: Tests
IEC 61753-1-1	Fibre optic interconnecting devices and passive components performance standard – Part 1-1: General and guidance – Interconnecting devices (connectors)
IEC 61984	Connectors – Safety requirements and tests

1.2.2 European standards

EN 50173-1	Information technology – Generic cabling systems – Part 1: General requirements and office areas
EN 50174-1	Information technology – Cabling installation - – Part 1: Specification and quality Assurance
EN 50174-2	– Part 2: Installation planning and practices inside buildings
EN 50174-3	Information technology – Cabling installation - – Part 3: Installation planning and practices external to buildings
EN 50265-2-1	Common test methods for cables under fire conditions - Test for resistance to vertical flame propagation for a single insulated conductor or cable – Part 2-1: Procedures - 1 kW pre-mixed flame
EN 50288-2-1	Multi-element metallic cables used in analogue and digital communication and control – Part 2-1: Sectional specification for screened cables characterized up to 100 MHz - Horizontal and building backbone cables
EN 50310	Application of equipotential bonding and earthing in buildings with information technology equipment
prEN 50346	Information technology – Cabling installation - Testing of installed cabling
EN 60068 series	(harmonized with IEC 60068 series)
EN 60512 series	(harmonized with IEC 60512 series)
EN 60664-1	Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests
EN 60945	Maritime navigation and radiocommunication equipment and systems – General requirements – Methods of testing and required test results
EN 61131-2	Programmable controllers – Part 2: Equipment requirements and tests
HD 384.3	IEC 364 Electrical installations of buildings – Part 3: Assessment of general characteristics
HD 625-1	Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests

1.2.3 Other references

DIN VDE 0100	Erection of power installations with rated voltages up to 1000 V
DIN VDE 0110 Teil 1	Isolationskoordination für elektrische Betriebsmittel in Niederspannungsanlagen – Grundsätze, Anforderungen und Prüfungen
DIN VDE 0185	Blitzschutz
DIN VDE 0482 Teil 265-2-1	Allgemeine Prüfverfahren für das Verhalten von Kabeln und isolierten Leitungen im Brandfall – Prüfung der vertikalen Flammenausbreitung an einer Ader oder einem Kabel – 1-kW-Flamme mit Gas-Luft-Gemisch
EIA/TIA 526-14	Optical Power Loss Measurements of Installed Multimode Fiber Cable Plant
EIA/TIA 568-B	Commercial Building Telecommunications Wiring Standard B.1: General Requirements B.2: Balanced Twisted Pair Cabling Components B.3: Optical Fiber Cabling Components Standard

EIA/TIA 606	Administration Standard for Telecommunications Infrastructure of Commercial Buildings
EIA/TIA 607	Commercial buildings grounding and bonding requirements
IEEE 518-1982	IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources
IEEE 802.3	IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications
IEEE 802.3af	– Data Terminal Equipment (DTE) Power via Media Dependent Interface (MDI)
IEEE 802.3p	– Layer Management for 10 Mb/s Baseband Medium Attachment Units (MAUs)
IEEE 802.3q	– Guidelines for the Development of Managed Objects (GDMO)

1.3 Definitions

1.3.1 Active equipment

equipment connected to equipment interfaces of generic cabling in order to support applications.

1.3.2 Equipotential lines

Electrically conducting means securing the same (ground) potential in distributed locations of the network.

1.3.3 Machine

a piece of equipment having a specific and defined overall function within industrial premises that is served by one or more machine network interfaces. For the purposes of this document, systems containing multiple machines can be considered as a single machine.

1.3.4 Machine attachment cabling

cords used to connect a machine outlet to a machine network interface.

1.3.5 Machine distributor

the distributor used to make connections between the machine cable, other cabling subsystems and active equipment.

1.3.6 Machine network

an arrangement of active and passive components within a machine served by a machine network interface.

1.3.7 Machine network interface

the interface between the machine attachment cabling and the machine network.

1.3.8 Machine outlet

a fixed connecting device where the machine cable terminates. The machine outlet provides the interface to the machine attachment cabling.

1.3.9 PE conductor

Protective earthing conductor.

1.3.10 PEN conductor

Earthed conductor combining the functions of both protective conductor and neutral conductor.

1.3.11 Permanent cabling

Permanently installed cabling (typically outside of cabinets).

1.3.12 Flexible cabling

Cabling which is not permanently installed but can be removed and moved between operations.

1.4 Comparison between office and industrial installation

The big success of ISO/IEC 11801 and EN 50173 in the IT cabling of office buildings and campuses is based on the definition of a cabling structure of 3 layers and on the definition of conformance classes for data links and performance categories for the components.
Comparing those standards with the requirements in the industry, one finds differences mainly in the topology of the cabling network and in the extended environmental protection requirements for the components used. Both are covered extensively by this Installation Guide.
The communication-related parameters of the above named standards can be applied to industrial data networks without modifications.

1.4.1 Topology

The topology of the generic cabling standards is shown in **Figure 1.1**.

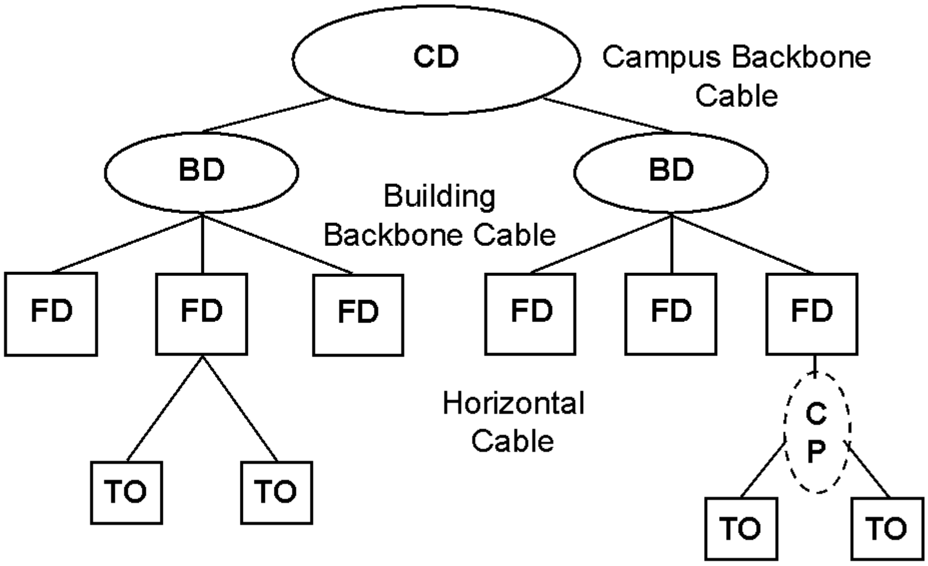


Figure 1.1: structured IT cabling according to EN 50173 and ISO/IEC 11801
CD = campus distributor CP = consolidation point
BD = building distributor TO = terminal outlet
FD = floor distributor

Each building has at least one building distributor BD. All BDs are connected via a star topology to the campus distributor CD: the central communication unit of the company. Redundant links for safety reasons are possible between the BDs. In a building, floor distributors FD are placed in the different stories, each serving up to 2,000 m^2 of office floor generally.

If in this company the Ethernet network has to be extended into the shop floors, one finds typically a building with only one floor, but extending over maybe 20,000 m^2. The term “floor distributor” loses its meaning. Nevertheless the structure between the buildings will be the same and covered by the above named standards.

More difficult it gets when we think of a petrochemical plant, where most of the production facilities are without a building at all.

A thorough analysis of the gaps shows that still most of the structure is relevant. Only some extensions have to be added. The details of the topology extensions you find described in chapter 2.1.

1.4.2 Components

The passive components, regarding their communication performance, are well described in the generic cabling standards. But the components designed for office use will not stand long in the rude environment of production machines. They have to be protected by housings or they have to protect themselves.

Therefore two classes of environmental protection have been identified and distinguished for installation areas of industrial communication systems:

(1) “Light Duty”: the area inside of installation cabinets and
(2) “Heavy Duty”: the area in the polluted working area of production facilities.
“Polluted” means: dirt, liquids, chemicals, EMC, ...

The classes are relevant for the passive as well as for the active components, as they have to work together in the same areas.

The “Light Duty” class is for an already protected area, but must be distinguished from the better protected office environment. The installation cabinet may be mounted on or near moving machine parts, therefore has to withstand mechanical forces. The temperature range can be higher than in typical offices. Only dust and moisture are kept away from the components during operation.

The environmental protection classes are specified in more detail in chapter 2.1.7.

There surely are more than the two sets of requirements for other areas where industrial IT cabling has to be installed. But the two classes should support most of the installations. For the others, additional or extended requirements will take effect and must be added in the single cases.

2 System planning

2.1 Topology

2.1.1 Conformance with and difference to existing standards

Studies showed that the structured topology described in EN 50173 and ISO/IEC 11801 can almost completely be projected to industrial plants, only minor modifications have to be considered.
One is the expression “floor distributor” which is no longer applicable to e.g. a fabrication hall with one floor extending over several hundreds of meters in length. It is proposed to use the term “machine distributor” instead, because on shop floors, those devices will normally serve a production unit within a radius of about 30 m. The functionality, though, is exactly the same as for the known floor distributor.

The logical tree structure shown in **Figure 1.1** can also be applied to industrial plants. **Figure 2.1** shows an example for a fabrication hall. The campus cabling is completely covered by the named standards. The building distributor of the fabrication hall serves several machine distributors. If there is an office room inside the hall, it will contain a floor distributor with the standard office horizontal cabling to terminal outlets in the wall.
In the production units, the more stringent environment protection classes defined in chapter 2.1.7 come into effect. The selection of the passive and active components should be according to the recommendations given in sections 2.4 and 2.5, respectively.

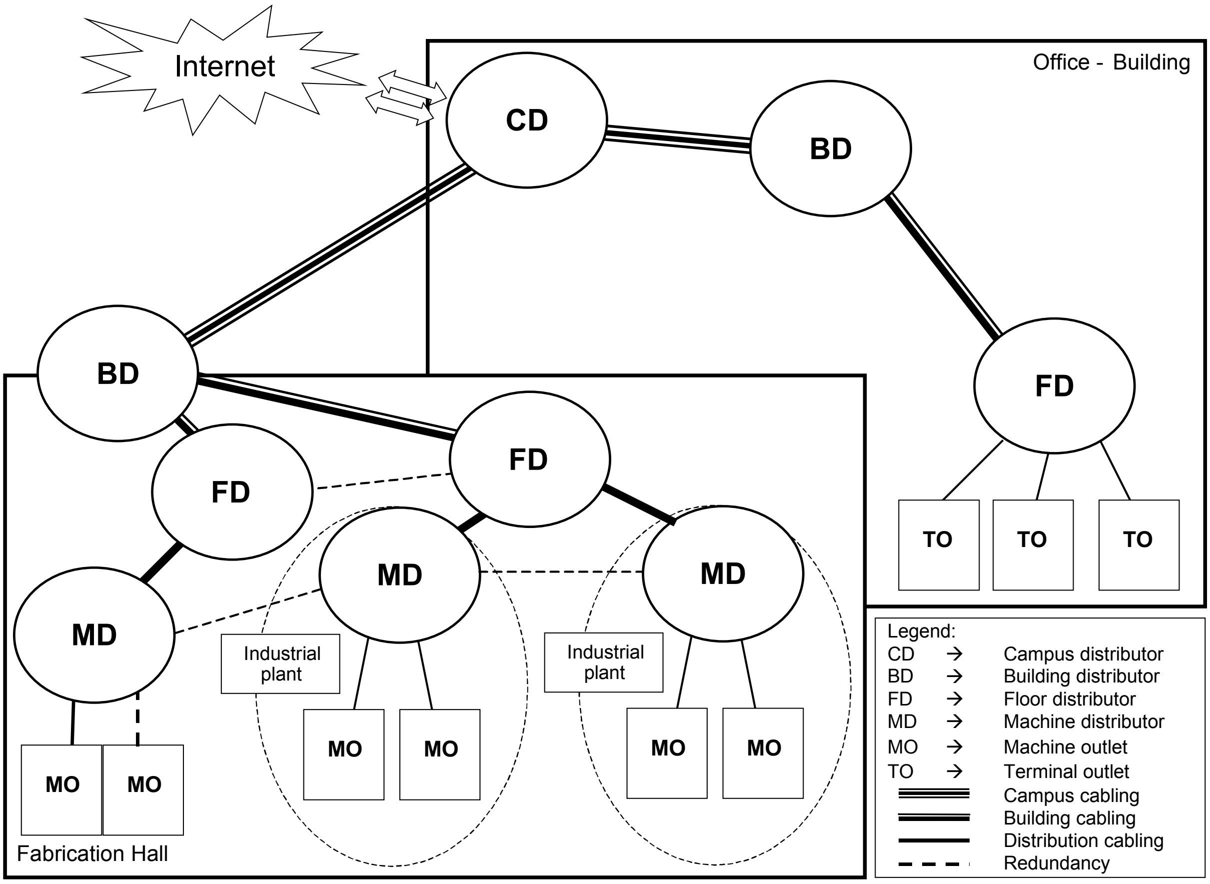


Figure 2.1: Example of building backbone cable arrangement at industrial sites

The area served by a machine distributor MD can be a group of smaller machines, one big machine with several Ethernet devices or even be a part of a very big machine, e.g. a printing facility. As shown in **Figure 2.1**, the MD can be placed at the edge or somewhere inside the served area. The length restrictions of the horizontal cabling have to be observed.

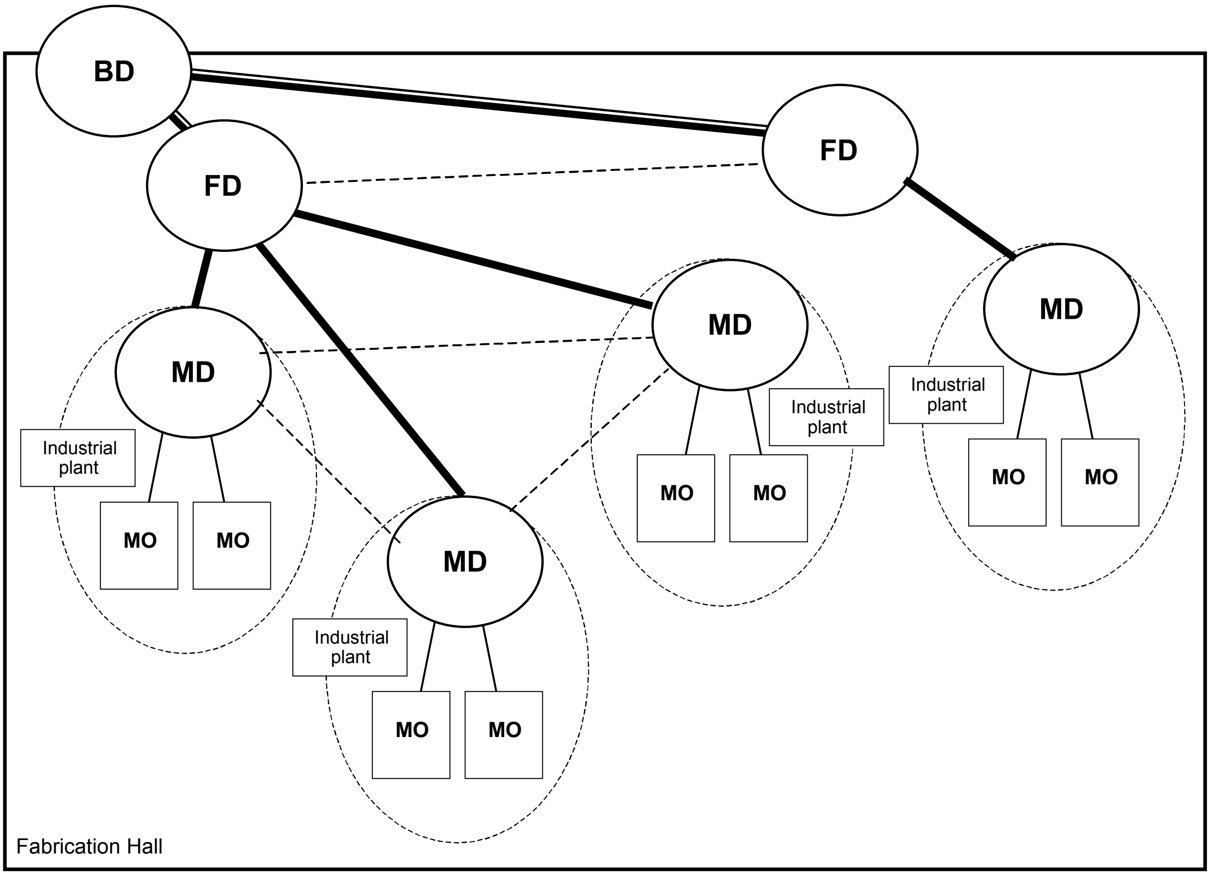
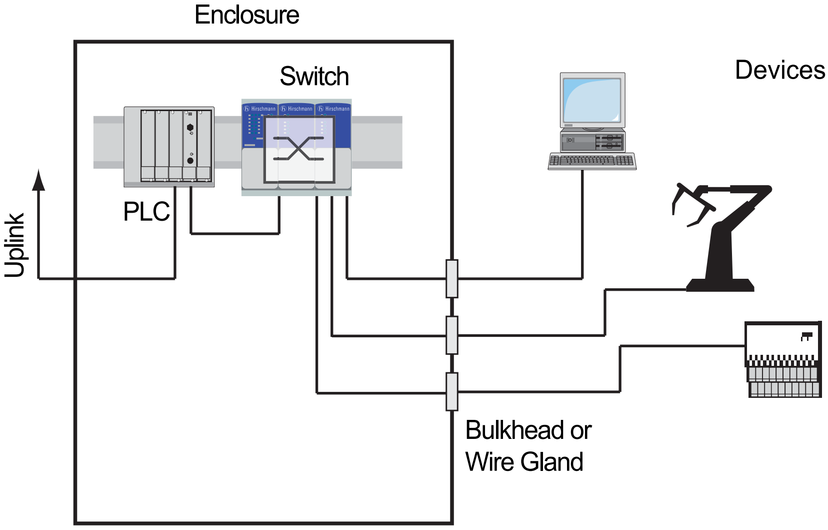


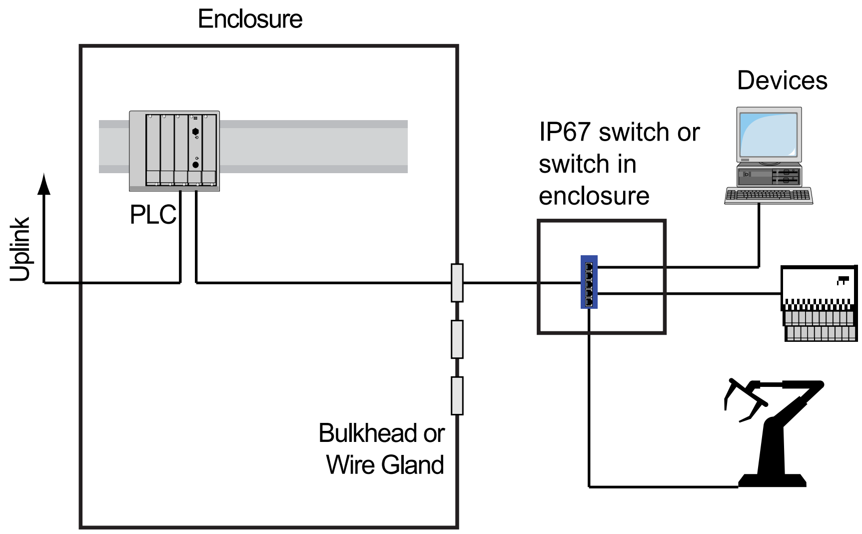
Figure 2.2: Detail of fabrication hall with ring topology of machine distributors

Figure 2.2 outlines the fact that with redundant links between machine distributors and an appropriate redundancy protocol of active devices used as MDs, also ring structures can be formed

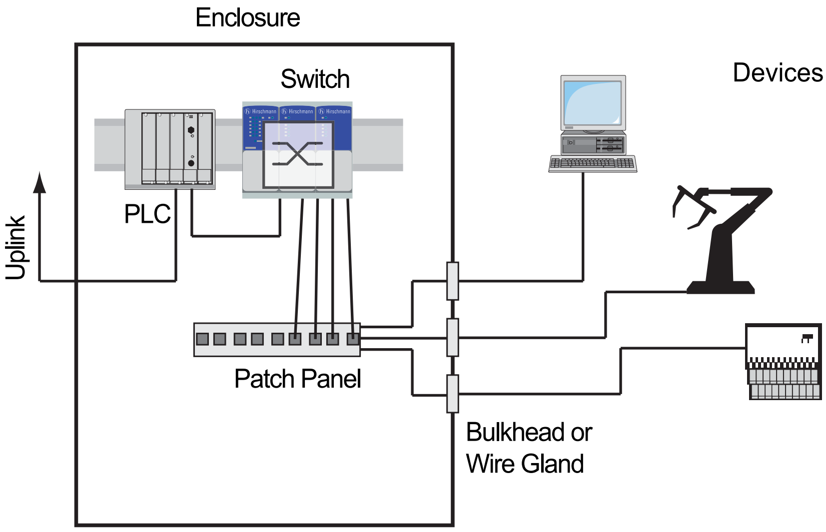
2.1.2 Typical industrial topologies



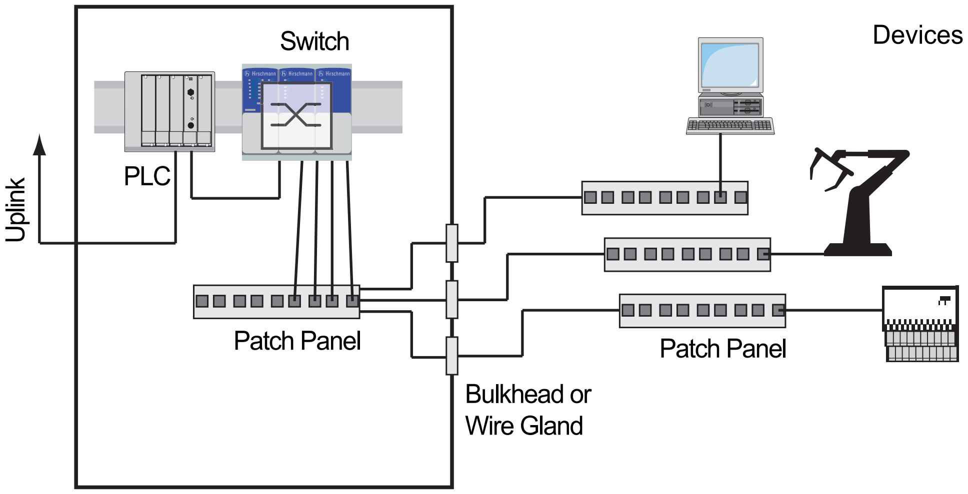
example 1



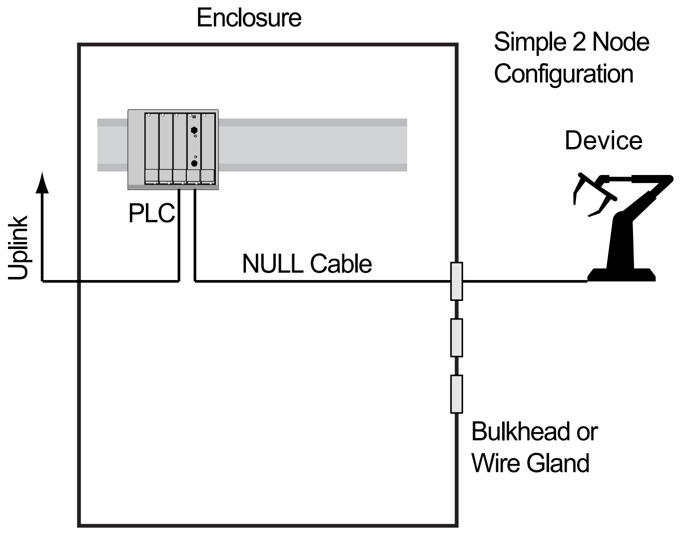
example 2



example 3



example 4



example 5

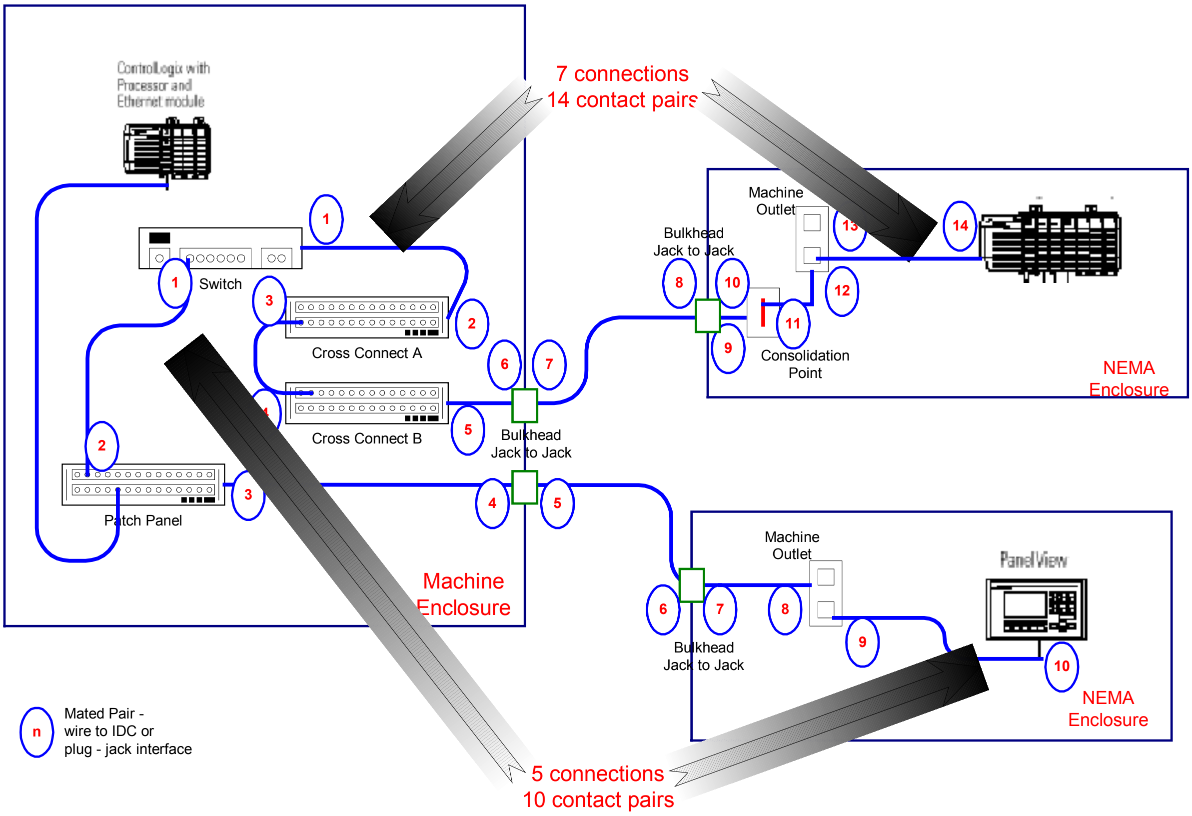


Figure 2.3: Typical industrial installation with bulkhead feedthroughs in enclosure walls and many other connections

2.1.3 Redundancy links

In the IT cabling of offices, redundancy links are mainly needed in or close to the backbone. In industrial IT cabling it is common practice to extend redundancy and security throughout the network. They are mostly even more important close to the process control. **Figure 2.1** shows the possibilities which have to be planned according to the availability requirements of each link resp. device connection.

2.1.4 Machine outlet = connection interface to the generic cabling

The MOs surely will not look the same as the wall outlets in the offices. They are just defined as the connection interfaces to the generic cabling. In office cabling and therefore in the generic cabling standards, usually new buildings will be equipped with the complete IT cabling (pre-cabling). In the industry, it is common practice to install the cabling completely with each new layout of the production floor. Therefore patch panels and wall outlets normally don't exist and the connectors are limited to the necessary minimum. There are no regularly distributed MOs throughout the hall like in pre-cabled offices.

This means, that in many cases the MO even does not exist ! There is only one cable from the MD to the Ethernet end device or underlying infrastructure components. In such a case, the MO logically can be identified with the cable connector that is plugged into the end device. The horizontal cable link, as defined and described by the generic cabling standards, always extends from the distributor to the end device. So from the communication point of view, there is also no difference between industry and office cabling.

2.1.5 Link length

For other physical topologies like at chemical or petrochemical plants with extended link lengths, the communication parameters of the standards can remain in effect as well. The horizontal link is not restricted to 100 m, as people sometimes believe. With appropriate components, e.g. fiber optic cable, also links of several kilometers, even several tens of kilometers can be realized and are covered by the cabling standards. Also copper links at lower bitrates can be extended well beyond 100 m.

On the other hand, if only flexible cable is used, ISO/IEC 11801 class D copper links have to be limited with respect to the cable's communication parameters.

2.1.6 Bus topology

If bus topologies of the cabling are necessary, e.g. for fieldbus systems or for chains of Ethernet switches, they can, in accordance with EN 50173 or ISO/IEC 11801 and using the same cabling components and link specifications, be added at a MO as sketched in Figure 2.4:

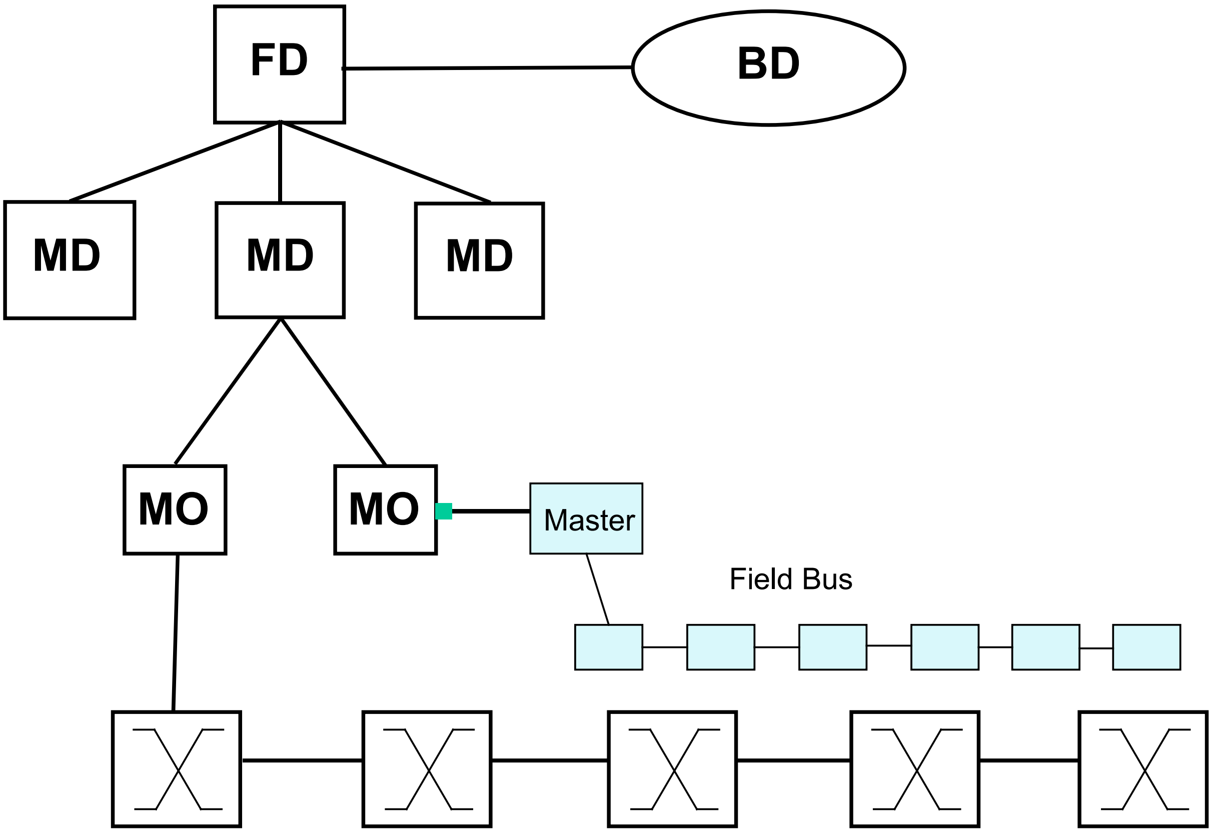


Figure 2.4: Bus topology connected to MO

2.1.7 Ring topology

Additionally, and extending the generic cabling standards, it is common practice in industrial IT cabling to chain Ethernet switches and close the loop at the end to form a redundant ring structure. Figure 2.5 demonstrates how also such topologies can be handled without contradiction to the generic cabling standards.

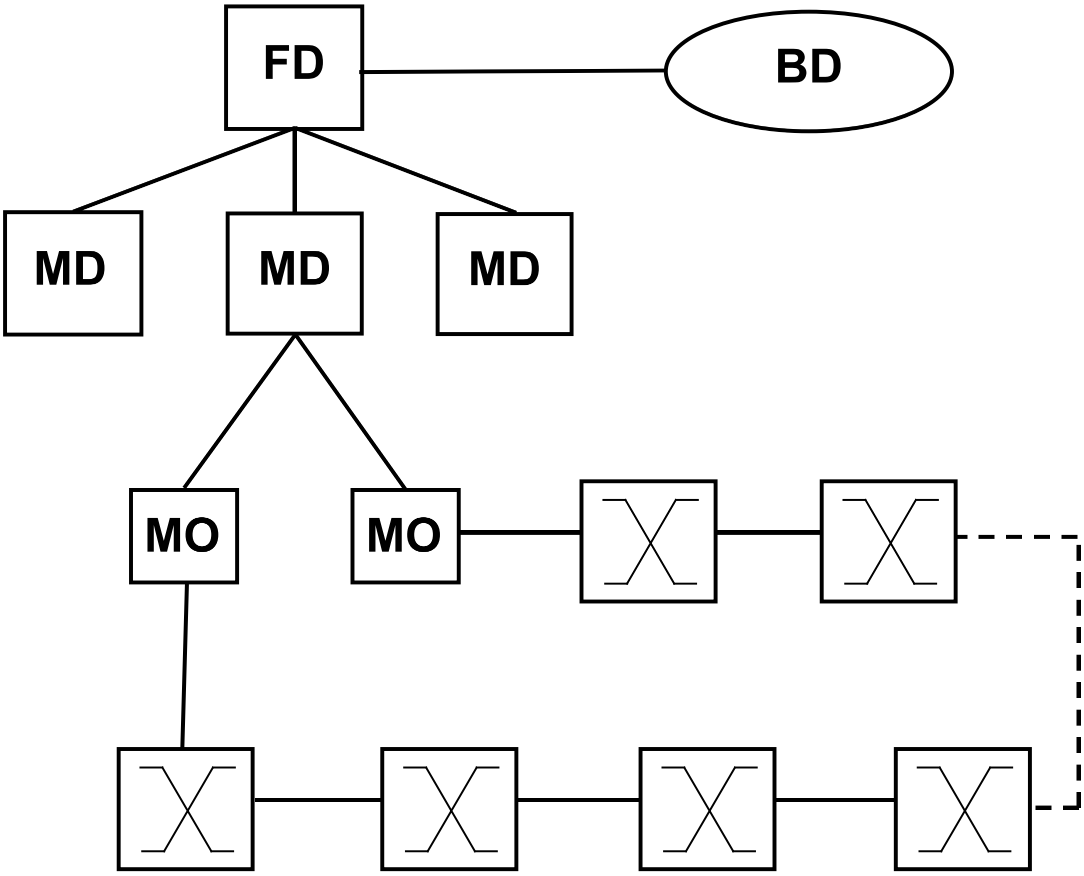


Figure 2.5: Ring topology of Ethernet switches connected to MOs

The MOs don’t even have to exist like sketched above: they could also be ports of the MD directly.

2.1.8 Process control example

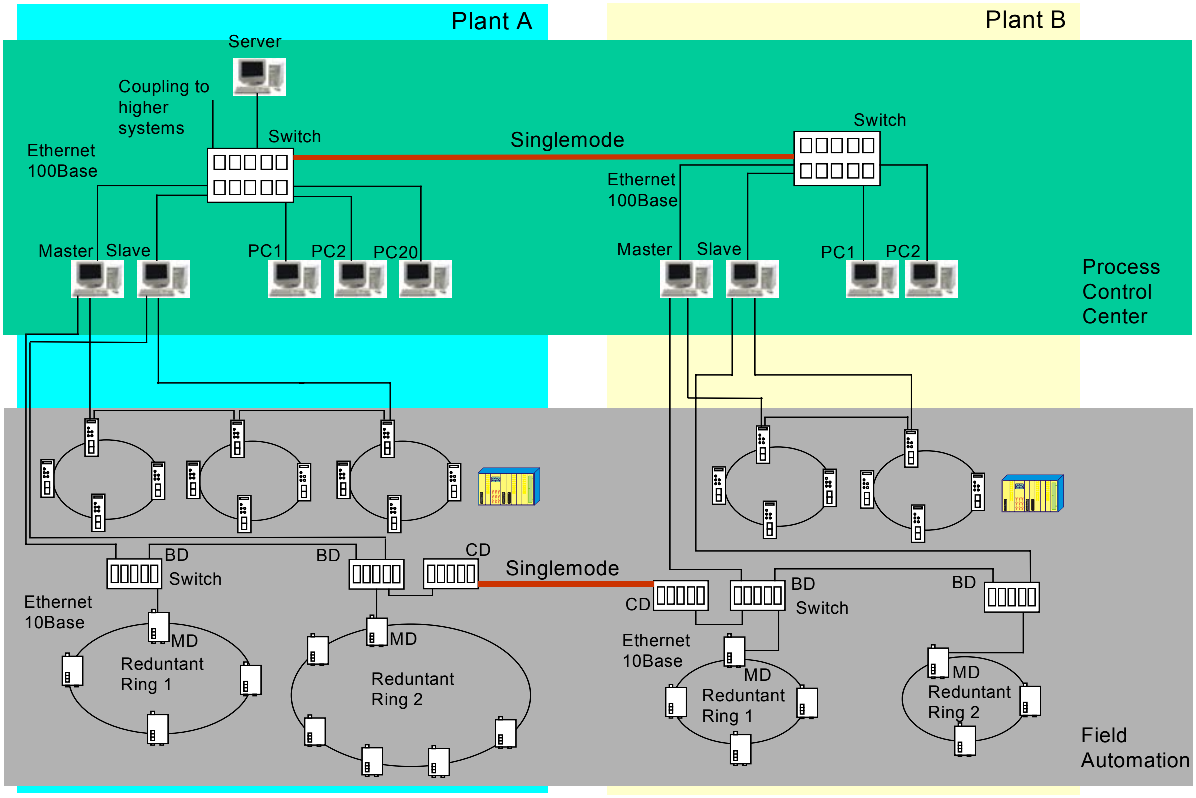


Figure 2.6: Practical example for industrial topologies: two clarification plants

Some clarification should be provided with the example in **Figure 2.6** of two plants (left and right), each with a small office (process control center, upper area) and the field installation (plant automation, lower area).
The offices are equipped with a modular Ethernet switch, representing a collapsed backbone architecture and linked via a singlemode optical cable with the other plant. This could, with more open applications, also be an Internet connection. the PCs are all connected to MOs directly linked to the collapsed backbone switch. In each plant are Fieldbus ring structures in the field linked to control PCs in the process control center ("Master" and "Slave"). This corresponds with the schematic in Figure 2.4, although the field bus topology is closed to a redundant ring like shown in Figure 2.5 for Ethernet switches.

The office network is completely separated from the field network and both can therefore be treated like different campuses. The field "campus" has its own campus distributor CD: an industrial Ethernet switch, linked to its correspondent in the other plant with a singlemode optical link. Connected to this CD are two "building" distributors BD, each serving a larger field area via several machine distributors MD in redundant ring configuration.
The "Master" and "Slave" PCs are connected to this second network via a second network interface card and a MO linked directly to a BD. They can therefore be part in both networks without providing a direct link between them.

2.2 General requirements

Parameter	Value	notes
ambient temperature	0 ... +55°C	Installation > 5°C
storage temperature	-25 ... +70°C	IEC 61131-2
temperature shock	5 ... 55°C, 3°C/min	IEC 60068-2-14 test N b
humidity (operating)	10 ... 95% non condensing	IEC 60068-2-30, variant 2
Shock	15 G, 11 ms acc. to EN 60068-2-27 or IEC 60068-2-27 criterion: no mechanical or functional changes	
Vibration	5 G @ 10...150 Hz acc. to EN 60068-2-6 or IEC 60068-2-6, criterion A	
grounding		see chapter 3.1.6
cabling class (min. requirement)	EN 50173:2002 or ISO/IEC 11801, Class D	
Resistance against aggressive environment where applicable	IEC 60068-2-x Environmental testing – Part 2: Tests - 9: Guidance for solar radiation testing - 10: Test J and guidance: Mould growth - 45: Test XA and guidance: Immersion in cleaning solvents - 60: Test Ke: Flowing mixed gas corrosion test - 70: Test Xb: Abrasion of marking and lettering caused by rubbing of fingers and hands	Recommended environmental testing procedures. Indicating the concentration, temperature, application time and failure criterion, the test of special chemicals or products has to be agreed upon between the supplier and the customer.

2.3 Environment protection classes

Parameter	light duty	heavy duty	notes
degree of protection (Industrial Protection Class)	IP 20 according to IEC 60529, EN 60529	IP 67 according to IEC 60529, EN 60529	
humidity (non operating)	95% non condensing	temperature cycle 25 to 55 to 25°C at 80 ... 95% condensing	IEC 60068-2-30 test D b

Transmission performance shall be assured by the selection of cabling components suitable for the environmental Class(es) or by the use of pathway systems and installation practices that provide the required protection to the installed cabling.

2.4 Selection of passive components

By selecting the passive components according to the specification tables below, a seamless and reliable Ethernet / Fast Ethernet network in the sense of the standards for structured cabling, EN 50173 and ISO/IEC 11801, can be designed for the industrial installation areas specified in the following chapter. Special applications or environments can require modifications of these parameters.

2.4.1 Cable

2.4.1.1 Copper cable

	both areas		notes
General			
category (min. requirement)	EN 50288-2-1 or IEC 61156, 100 MHz EN 50173-1 or ISO/IEC 11801, Cat. 5		
max. link length	according to table in EN 50173-1		
Electrical	ISO/IEC11801 Cat 5 minimum		See note 2
permanent cabling			
number of pairs	2 or 4		2 pairs possible below generic cabling structure1)
conductor cross section min./max.	AWG 24/1 to AWG 22/1 corresponding to 0.202 to 0.325 mm^2		
conductor type	solid wire		
max. cable length	100 m		greater lengths are possible if the channel parameters are met by using better components3)
pulling strength			
radial pressure	not specified		
Torsion	no torsion allowed		
Shielding	braided shielded and / or braided foiled shielded		optional: individually screened
sheath material	not specified		
flexible cabling			also stationary installed flexible cable
number of pairs	2 or 4		2 pairs possible below generic cabling structure1)
conductor cross section min./max.	AWG 26/7 to AWG 24/7 corresponding to approx 0.140 and 0.226 mm^2	AWG 22/7 Corresponding to approx 0.34 mm^2 4)	Conductors with higher strand count are allowed for greater cable flexibility
max. cable length	approx. 50 m for reliable operation	Up to 100 m for reliable operation	greater lengths possible according to calculation3)
pulling strength			
radial pressure			
Torsion	not specified		
Shielding	braided shielded and / or braided foiled shielded overall		optional: individually screened and overall screened
sheath material	not specified		
minimum bending radius	according to EN 50173:2002 or ISO/IEC 11801		
color codes	EIA/TIA 568-B		
flame resistance	IEC 60332-1, EN 50265-2-1		
Halogen free	IEC 60754-2, IEC 61034		
Approbations	not specified		

	light duty	heavy duty	notes
permanent cabling			
outer cable diameter	2 pairs: 5 to 7 mm 4 pairs: 6 to 8.5 mm	2 pairs: 6 to 8 mm 4 pairs: 7 to 9.5 mm	
flexible cabling			
outer cable diameter	2 pairs: 4 to 5 mm 4 pairs: 5 to 6 mm	2 pairs: 5 to 6 mm 4 pairs: 6 to 7 mm	

1) cost-sensitive cabling which normally will be replaced with device upgrade. In the industrial environment telephony or other applications are not likely to be routed through the same cables. Gigabit Ethernet is not expected soon in this area.
It is not advised to use a 4 pair cable with a 4 pin connector as the un-terminated 2 pairs could cause interference with the terminated 2 pairs.

2) In high noise environments and extreme temperatures cables defined under ISO/IEC 11801 may not provide enough noise rejection. Careful attention should be given to the selection of cables based on electrical performance such as Return Loss, Balance (ELTCTL).

3) If the design exceeds the length specified in this table and/or hub technologies are used, refer to chapter 2.5.2.

4) Some connectors may not support AWG 22

2.4.1.2 Fiber optic cable

2.4.1.2.1 Mechanical requirements

This Planning And Installation Guide addresses the intrabuilding and work area cabling in addition to the existing standards.
Generally the requirements of the manufacturer apply. If not available, the tables below give a minimum requirement for each parameter.

	light duty	heavy duty	notes
permanent cabling			
bending radius (fiber)			
Static	15x outer diameter of the cable	15x outer diameter of the cable	
during installation	20x outer diameter of the cable	20x outer diameter of the cable	
crush force			
Static	20 N/cm	20 N/cm	
during installation	200 N/cm	200 N/cm	
pulling strength			
Static	100 N	100 N	
during installation	200 N	400 N	
flexible cabling	fiber without additional mechanical protection	fiber cable with internal mechanical protection	
bending radius (fiber)			
Static	10x outer diameter of the cable	15x outer diameter of the cable	
during installation	15x outer diameter of the cable	20x outer diameter of the cable	
crush force			
Static	3 N/cm	20 N/cm	
during installation	10 N/cm	200 N/cm	
pulling strength			
Static	5 N	100 N	
during installation	15 N	400 N	

2.4.1.2.2 Fiber types

	both areas	notes
glass fiber	IEC 60793-2	
singlemode	SI 9/125	
Multimode	GI 50/125 or GI 62.5/125	GI 50/125 preferred in Europe
hard cladded silica fiber (HCS)	SI 200/230	
polymer fiber (POF)	SI 980/1000	

2.4.1.2.3 Applications

	both areas	notes
POF	based on 10Base-FL, 100Base-FX	
HCS	based on 10Base-FL, 100Base-FX	
MMF	100Base-FX	
SMF	100Base-FX	

2.4.2 Connectors

2.4.2.1 General

	both areas	notes
field termination	yes	
mounting situation	line-up possibility for socket	
pull-out forces (connector - socket)	200 N	
strain relief (cable - connector - socket)	50 N	
break protection	yes	
Coding	no	
Polarization	yes	
corrosion stress	EN 60068-2-60, IEC 60068-2-60, Bellcore GR-1217-core, Telcordia, further variants for different environments	
static side load	EN 60512-5, IEC 60512-5	especially in the heavy duty area the connectors sometimes are used as "climbing aids"
Labeling	ISO/IEC 14763-1 EN 50174-2	

	light duty	**heavy duty**	**notes**
locking mechanism	yes	yes	*As development and standardization of industrial communication connectors for high bitrates are still under way at the release date of this document, the definition of one certain type of locking mechanism is not possible at this time*
resistance against aggressive environment	no	salt mist 5%, 2 hrs, 40°C, soak humidity 93%, soak duration 168 hrs, cycles: 4	IEC 60068-2-52 (EN 60945:1997 marine standard)
		Sulphur dioxide: Environmental testing - Part 2-42: Tests - Test Kc: Sulphur dioxide test for contacts and connections	IEC 60068
climate storage		Test 11g - Flowing mixed gas corrosion test Test 11p - Flowing single gas corrosion test	IEC 60512-11 Ed. 2.0

2.4.2.2 Copper connectors

including electro-optical converters inside of electrical connectors

The connection technology described in this chapter is valid for installations with copper cables and electrical plug connectors in Light-Duty and Heavy-Duty environmental conditions.

	both areas	**notes**
Design	not specified	see below 1)
straight and angled	yes	
cable termination	single pair shielding should be supported	
pin material	not specified	
pin surface	Au	only for signal pins
insulation material	not specified	
conductor cross section (min./max.)	AWG 26/7 to AWG 22/1	a connector does not have to support all at once
wire type	solid and stranded	
electrical performance	Category 5	ISO/IEC 11801
nominal voltage rating	60 V	value demanded for IEEE 802.3af (DTE power over MDI)
nominal current	not specified	
PE connection	no	
rated impulse voltage	according to IEC 60038	
EMI shielding	yes	

	light duty	**heavy duty**	**notes**
Type	only mating interface backwards compatible1) to IEC 60603-7 (RJ-45)	IEC 61076-2-101 (M12) IEC 61076-3-106 Var 01 IEC 61076-3-106 Var 06 See table: heavy duty connector versions (mating interface backwards compatible1) to IEC 60603-7, RJ-45)	see note 1)
mating cycles	750 acc. to IEC 60603-7	100 acc. to IEC 61984	
interface type	according to EN 50173 or ISO/IEC 11801		
mating face	8 (RJ-45)	8 (RJ-45) or 4 (M12, D key)	4-pin connectors only can be used with 2-pair cable
pin assignment	ISO/IEC 8802-3		
cable diameter	4 to 8.5 mm	5 to 9.5 mm	
degree of pollution	HD 625-1 grade 2 (DIN VDE 0110 Teil 1)	HD 625-1 grade 2 (DIN VDE 0110 Teil 1) for the sealed connector	

1) mating interface compatibility means that an RJ 45 pin element must fit into the socket from a mechanical and electrical point of view in accordance with IEC 60603-7 (e. g. for service mains). Sealing is not required in a service case.

Heavy duty connector versions:

Type	IEC standard	Also recognized by 1)	
M12-4, 4 pole with D-coding	IEC 61076-2-101-A1	ODVA, PNO	
RJ45-IP67 circular bayonet locking	IEC 61076-3-106 (Variant 01)	ODVA	
RJ45-IP67 push-pull locking	IEC 61076-3-106 (Variant 06)	IDA, Interbus-Club	

1) For details see documentation of each organization.

The pin assignment is specified as follows:

Signal	**Function**	**pin assignment**	
		RJ-45 [1]	**M12**
TD +	Transmission data +	1	1
TD –	Transmission data –	2	3
RD +	Receiver data +	3	2
RD –	Receiver data –	6	4
+	3rd pair + [2]	4	-
–	3rd pair – [2]	5	-
+	4th pair + [2]	7	-
–	4th pair – [2]	8	-
screen	EMI shielding	housing	housing

[1] according to IEEE 802.3

[2] not used with industrial Ethernet

2.4.2.3 Fiber optic connectors

The connection technology described in this chapter is valid for installations with fiber optic cables and optical plug connectors in Light-Duty and Heavy-Duty environmental conditions.

	both areas	**notes**
Design	(not specified)	
straight and angled	only straight	
number of fibers per connector	1 or 2	
fiber assignment	EN 50173 or ISO/IEC 11801 or relevant connector standard	
dust cap for plug and jack	necessary	should be available
Performance	IEC Draft 61753-1-1 Fiber optic passive components performance standard, part 1-1: general and guidance	
fibre cable retention	IEC 61 300-2-4	

Note: Laser safety must be observed IEC 60825-2 Safety of optical fiber communication systems

	light duty	**heavy duty**	**notes**
POF 980/1000,	IEC 60874-10-3 [BFOC, "ST"], F-SMA Versatile Link	*no standard available today*	
HCS 200/230	IEC 60874-10-3 [BFOC, "ST"], F-SMA Versatile Link	*no standard available today*	
MMF 50/125, 62.5/125	IEC 60874-19-1 [SC] or IEC 60874-10-3 [BFOC, "ST"]	*no standard available today*	
SMF 9/125	IEC 60874-19-1 [SC] or IEC 60874-10-3 [BFOC, "ST"]	*no standard available today*	

2.4.2.4 Hybrid connectors

Each field device needs for its operation power supply and data lines. In the applications of industrial automation, actuators need “real” power for their operation. To achieve a cost effective device design and installation technique, the combination of the auxiliary power lines (standard voltage 24 V DC and rated current of 10 A) with the data communication wires (electrical or optical) is of great benefit and therefore **optionally possible in the Heavy Duty area**.
Caution: The EMC and local codes have to be carefully considered when combining copper data wires with power lines in the same jacket.

2.5 Selection of active components

2.5.1 Bandwidth profiles

2.5.1.1 Applications

Based on assumptions about the connected Ethernet end devices (PCs, workstations, PLCs, I/O devices, ...) and on the applications that probably will be used on them in the coming years, one has to calculate the traffic probabilities for each link in the planned network. Please keep in mind that Internet traffic doubles about every year whereas automation control traffic mainly depends on the complexity and real time necessities of the control network.
It is not sufficient to calculate the average load, peak loads have also to be estimated in order to avoid temporary overloads of the network.

2.5.1.2 Response times

Most applications are tolerant about delivery or response time variations. Less tolerant are audio or video streams which require a sufficient bandwidth and network throughput to deliver the expected quality.
Absolutely strong restrictions for response times are required by automation controls. The relevant segments should be kept free from any unnecessary traffic and dimensioned with at least a factor of ten of bandwidth reserve.
There will be an increasing management background load also in the automation control branches of the networks in the next years – but this will always be in temporary peaks and without stringent response time requirements. It can easily be handled by a switched network with traffic priorities (chapter 2.5.3).

Typical response times needed are for:
- video streams: 50 ms
- voice streams: 20 ms
- process control: 10 ms

2.5.2 Links (ISO layer 1)

2.5.2.1 Network expansion for hub based systems

Switches are the preferable solution for industrial applications (see 2.5.3.2).

Only for a HUB based system the following network expansion restrictions must be considered:
In Ethernet networks, the total network expansion is limited theoretically to 5,120 m by the round trip time which must be below the Ethernet slot time of 51.2 µs. If this criterion would not be met, collisions could not be detected throughout the network and thus the Ethernet media access (MAC) protocol CSMA/CD (carrier sense multiple access / collision detect) would not work.
In practice, each active device adds delays to the propagation time in the links and therefore reduces the network expansion. A rule of thumb says that not more than 4 hubs should be between two end devices, reducing the network expansion to 2,500 m.

A more precise calculation can be performed by using the Propagation Equivalence PE and Path Variability Value PVV. The values must be specified by the active device manufacturer.

The **Propagation equivalence** is applied in order to calculate the maximum allowed cable length between the two farthest devices in one segment. The delay caused by hubs, transceivers and NICs across the path is converted to meters. After deducting this total value of 4,520 m you receive the total maximum allowed cable length. NICs (network interface cards) or external transceivers on PCs or other terminal units have a propagation equivalence of 140 m with a TP connection.

The **Path variability value** is applied in order to calculate the maximum number of hubs and transceivers which may be cascaded in one collision domain. The path variability value is stated in bit times (BT). These are calculated for an Ethernet frame which is received on one port and sent out from another port of the same unit. The total bit times must be calculated for each individual path between all units (hubs and transceivers) of one domain. It must not exceed 40.

Annex 5.1.1 shows some example calculations.

2.5.2.2 Link media and link lengths

Another restriction applies for each individual link. According to the media and the appropriate transceiver used, the length of each link is restricted to certain values. ISO/IEC 11801 and EN 50173 show reference implementations for which minimum link lengths are achievable when using components that fulfill the minimum requirements of a certain Category. With components of higher quality greater lengths are possible, but the calculation has to take into account the worst case combination of all parameters' tolerances.

2.5.3 Segmentation of Ethernet domains (ISO Layer 2)

2.5.3.1 Ethernet hubs

The original bus structure of the Ethernet 10Base5 installations could be transformed to more flexible star and multi-star topologies using star couplers or hubs. Those are active devices with multiple ports that present each received frame at each of its ports (excepting the receive port).

In a logical sense, they act like a wired star point: they only modify the physical but not the logical shape of the network. Especially, they do not modify the collision sensing domain: each frame is distributed across the whole network and collisions have to be sensed also across the whole network.

2.5.3.2 Ethernet switches

In order to overcome the network expansion restrictions of the collision domains, Ethernet bridges were developed. They learn the Ethernet MAC addresses of connected devices at each port and deliver frames only to the port at which the address of the respective destination device is learned.

Each port of such a bridge represents a separate collision domain, therefore multiple collision domains, each with an expansion of several kilometers, can be cascaded.

As the Ethernet bridges are switching Ethernet frames between their ports, quite similar like the PBXs switch communications in public networks, they are called Ethernet switches today.

As Ethernet switches are much more intelligent than hubs and as they store the frame before it is re-sent, they can perform many other logical functions as will be described in the following chapters.

Additionally they can switch traffic between segments of different data rates and offer full duplex and collision free communication.

Typical throughput delays (port in to port out) for a 1518 byte Ethernet frame are:

Ethernet:	1.3	ms
Fast Ethernet:	150	µs
Gigabit Ethernet:	30	µs

2.5.3.3 Priority switching (IEEE 802.1D)

Many different applications can use the same Ethernet network at the same time. As explained in chapter 2.5.1.2, they can have very much differing requirements for latency or response times.

In an industrial Ethernet installation for example, small process control frames with stringent real time necessities can compete with heavy loads of software downloads or other file transfers. For the latter a delay in the range of seconds would not be a problem.

In many Ethernet switches it is therefore possible to prioritize the traffic: according to a tag added to the frames and indicating the priority, the frames are filed in separated queues inside the switches and sent according to the priority of the queues.
So high priority traffic can navigate through the network with no extra delay while lower priority frames must wait for their chance.

2.5.3.4 VLAN (IEEE 802.1Q)

Ethernet switches switch unicast frames only to one port, but in order to set up connections initially, they distribute broadcast frames still to all ports. If needed, such broadcast domains can also be segmented using the VLAN (virtual LAN) functionality: based on several criteria, logical segments (the VLANs) can be configured and broadcast frames are then broadcast only within those segments. This also means that no connection across the borders of the VLAN can be established and a kind of access security can be provided.

2.5.3.5 Real time Ethernet

With a fully switched full duplex non-blocking network architecture, real time Ethernet is possible today.
The network has to be planned in a way that traffic with real time requirements does not interfere with latency tolerant. High load traffic using segmentation and prioritization techniques and that the sum of possible delays is kept well below the necessary response time. The latter is no real problem as e.g. with Fast Ethernet six cascaded switches add up to a delay of below 1 ms.

2.5.4 Segmentation of IP subnetworks (ISO layer 3)

2.5.4.1 Routers

Based on filter masks laid over the Internet Protocol Address, subnetworks can be set up within the network. An appropriately configured router forwards a frame with a specific IP address only to its port with the matching subnetwork criterion. Non-routable traffic is kept completely in each subnetwork.
Routers have to decide the route for each frame individually, which costs a significant delay time. Moreover the delay time strongly depends on the number of criteria that have to be taken into account.

2.5.4.2 IP switches

Faster than routers are IP switches which calculate the routing decision only once for each IP address and then forward each frame with the same IP address based on this decision.
The switching for all but the first frame is simple Ethernet switching and therefore has the same delay time.

2.5.5 Network security (ISO layer 4 and above)

If above the Ethernet or IP address information also content or application based decisions shall determine the flow of the network traffic, Firewalls have to be used. They unfold each frame and “read” its content. Many filtering decisions can then be applied to this content and influence the further processing of this frame.

2.5.6 Network availability

2.5.6.1 Redundant links

For a high availability of the network, link redundancies should be planned. There are several methods and protocols that can switch from damaged links to redundant links between the same or different devices in the network.

2.5.6.1.1 Port redundancy

Two ports in the same device can be coupled via a default switching mechanism to switch very fast (below 1 second) between a faulty and the redundant link.

2.5.6.1.2 Link aggregation

Several links of the same kind and between two devices are switched to work like one logical link with the aggregated bandwidth of all of them. If one of the aggregated links fails, the others keep on working and take over the traffic from the faulty link immediately (no port switching is necessary). Only the aggregated bandwidth is reduced.

2.5.6.1.3 Spanning tree protocol STP

If networking devices are used that support the STP, BPDU frames are transferred between all of them that enable each device to calculate a topology of the logical network. If one link or one device fails, the topology is re-calculated and redundant links are switched to the forwarding state in order to take over. The topology change can take up to 30 seconds.

2.5.6.1.4 Dual homing

Devices that support this functionality can be bound to two different devices via redundant links. If one link or one device fails, the other link takes over below one second.

2.5.6.1.5 Ring redundancy

Devices supporting the ring redundancy can switch the redundant link in a ring topology on and reroute the traffic below one second.

2.5.6.2 Hardware redundancy

Above those network related availability features, also device related redundancies have to be considered better than bridging a faulty device is to avoid the fault itself.

Modular systems have many possibilities to avoid single points of failure. It is mainly a cost versus availability decision which level of hardware redundancy should be planned for each networking device.

2.5.7 Management

There are two general types of network components in Ethernet networks: managed and unmanaged. While unmanaged network components are typically plug-and-play devices used for smaller networks, managed network components offer an enhanced feature set with greater functionality.

To use the advantages given by managed network components the Simple Network Management Protocol SNMP can be used.

SNMP has become a standard method of managing devices across an internet, whether a LAN, a WAN or the Internet itself. It is now the most widely used management protocol on TCP/IP networks. SNMP is an application layer protocol, and forms part of the TCP/IP suite. SNMP allows an administrator to configure and monitor entire networks, thus optimizing performance and facilitating fault finding.

With SNMP there are two basic components, Agents and Network Management System (NMS). A device which can be managed contains software known as an Agent. The agent is responsible for collecting and storing information about the device, and presenting that information to the NMS in a format compatible with SNMP. Typical examples of manageable devices include hubs, switches, routers and servers.

The NMS consists of one or more devices running network management software. The NMS will usually provide the network administrator with a graphical view of the network, together with graphical views of the individual devices, color coded according to their operational status. The main processing of network information is done by NMS, which collects data from the Agents and presents this information in a format specified by the network administrator.

The managed devices contain a Management Information Base (MIB). The MIB is a collection of information about the device. The information is held as objects, and each object has an object identifier (OID) which allows the NMS to request specific information.

Remote Monitoring is an extension of SNMP, designed to allow remote and independent monitoring of network traffic. An RMON-enabled device can capture predefined data elements, and can either send statistics and alarms to an NMS on demand, or generate a Trap if a threshold is exceeded. The first RMON devices were known as RMON probes. These were physically separate devices which could be attached to a network segment. With the advances of processing power, RMON functionality is now built into the network components themselves like network components and routers as an RMON MIB.

In industrial applications and processes mainly SCADA systems (Supervisory Control and Data Acquisition) are used. With these systems the supervisor has the possibility to monitor all processes at any time. SCADA systems are following an open architecture and are therefore interoperable. SCADA systems are communicating in a defined data format called OPC.

In an application where industrial Ethernet components are used the network becomes a part of the whole automation process, all relevant data of the network has to be available in the SCADA environment as well. For this reason it is necessary to integrate the information provided in the MIB in SNMP format into the OPC format. For this purpose software tools are available which allow the integration of the network components into the SCADA environment – this can also be called "Integrated Architecture".

2.6 System calculation

2.6.1 Electrical cabling

2.6.1.1 Channel requirements

The requirements and the layout of communication channels has to be in accordance with ISO/IEC 11801, chapter 6 or EN 50173, clause 5. The overview is given in clause 5.1 of EN 50173:

This clause specifies the minimum channel performance of generic cabling. The performance of the cabling is specified for individual channels for two different media types (balanced cable and optical fiber). The channel performance specifications for balanced cabling are separated into Classes that allow for the transmission of the applications in annex C. In the case of cable sharing and alien crosstalk, additional requirements shall be taken into account for balanced cabling. The additional crosstalk requirements are specified in EN 50173, clause 7.3.
The channel performance requirements described in this clause shall be used for the design and may be used for verification of any implementation of this European standard, using the test methods defined, or referred to, by this clause. In addition, these requirements can be used for application development and trouble shooting.
The channel specifications in this clause allow for the transmission of defined Classes of applications over distances other than those of EN 50173, clause 6, and/or using media and components with different transmission performance than those of EN 50173, clauses 7, 8 and 9.

2.6.1.2 Link requirements

The link performance requirements for balanced copper cabling are defined in ISO/IEC 11801, chapter 6 or EN 50173, annex A.2.

2.6.2 Fiber optic cabling

The link performance requirements for fiber optic cables are defined in ISO/IEC 11801, chapter 8 or EN 50173, annex A.3.

2.6.2.1 Cable lengths

For reliable operation the fiber optic link shall not exceed the recommended link length specified by the device manufacturer. Up to this length a safe data transmission is guaranteed, if the cables are laid according to the instructions. Typically achievable link lengths are defined by **Table 2.1**
The cable length can further be reduced by additional connections (see **Table 2.2**), or can be extended by using special active devices or high performance passive components. In this case the length can be limited either by the optical power budget of the system (generally for 10 Mbps systems and all singlemode systems) or dispersion (generally for 100 Mbps systems on multimode fiber). Special calculations for each link have then to be performed and verified by measurements after the installation.

2.6.2.2 Power budget

Class	Distance m	Maximum Channel Attenuation dB				
		Multimode			Singlemode	
		660 nm	850 nm	1300 nm	1310 nm	1550 nm
OF-50	50	18.0	NA	NA	NA	NA
OF-100	100	4.0	NA	NA	NA	NA
OF-300	300	NA	2.55	1.95	1.80	1.80
OF-500	500	NA	3.25	2.25	2.00	2.00
OF-2000	2000	NA	8.50	4.50	3.50	3.50

Table 2.1: Optical fiber channel attenuation limits
according to EN 50173 (OF-300, OF-500, OF-2000)
and for large core fibers POF and HCS

		Implementation equations		Maximum length (m)
Large core	**Class**	**660nm**	**850 nm**	
POF	OF-50	L = 70-10x	Not applicable	50
HCS	OF-100	L = 400-150x	Not defined	100
Multimode	**Class**	**850 nm**	**1300 nm**	
Cable Category OM1/OM2/OM3	OF-300	L = 735-145x-90y	L = 1300-330x-200y	300
	OF-500	L = 935-145x-90y	L = 1500-330x-200y	500
	OF-2000	L = 2435-145x-90y	L = 3000-330x-200y	2000
Singlemode	**Class**	**1310 nm**	**1550 nm**	
Cable Category OS1	OF-300	L = 1800-500x-300y	L = 1800-500x-300y	300
	OF-500	L = 2000-500x-300y	L = 2000-500x-300y	500
	OF-2000	L = 3500-500x-300y	L = 3500-500x-300y	2000

L = the length of the channel in meters

x = total number of mated connections in the channel

y = total number of splices in the channel

the maximum length can be extended by using special active devices or high performance passive components

Table 2.2: Optical fiber channel parameters
according to EN 50173 (OF-300, OF-500, OF-2000)
and for large core fibers POF and HCS (OF-25, OF-50, OF-100)

3 System installation

3.1 Installation of copper cabling

3.1.1 Electrical connectors

Please observe the following points:

- Adjust the shield as extensively as possible under the strain relief or apply a shield sleeve;
- Establish a good contact between plug connector and module;
- Do not damage or squeeze conductors. Expose only enough copper to make an adequate connection to the connector contacts, as directed by the connector manufacturer;
- Only use plug connectors according to the requirements of chapter 2.4.2 and handle them according to the assembly instructions of the manufacturer;
- Connect the wires properly;
- Avoid cold soldering points;

3.1.2 Cabling in light-duty environment – general wiring guidelines

When preparing the installation of cables, the local conditions and the respective regulations for the implementation are decisive. Cables can, for instance, be installed in cable ducts or cable bridges.

A minimum distance of the cabling to possible interference sources is defined in the relevant regulations and standards. They have to be observed during planning and installation of an Industrial Ethernet system.
The following rules should be observed to protect your Industrial Ethernet system against the effects of Electromagnetic Compatibility (EMC), Electromagnetic Interference (EMI) and mechanical stresses.
The following guidelines apply to the location of communications conductors with respect to power conductors.

Plan your cable routing very carefully. You should spend sufficient time planning how to route your cable before attempting to do so. Cables should not be routed near equipment that generates strong electric or magnetic fields. In particular, you should be concerned with routing near and around:

- lights
- motors
- drive controllers
- arc welders
- conduit

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 certain installation considerations depending on your application.

Follow these guidelines for wiring all Ethernet communication 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.
- If the conductor is in a metal wireway or conduit, each section of the wireway or conduit must be bonded to each adjacent section so that it has electrical continuity along its entire length, and must be bonded to the enclosure at the entry point.
- Only shielded Ethernet cables should be placed into metal conduit. If you need to protect or route your Ethernet cable in a metal conduit then you must use a shielded cable. The shield must not come in contact with the conduit at any point.

Category	includes
EMC1	• AC power lines • High-power digital ac I/O • High-power digital dc I/O • Power connections (conductors) from motion drives to motors
EMC2	• 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 • Ethernet
EMC3	• Low-voltage dc power lines • Communication's cables to connect between system components within the same enclosure

Table 3.1: Cable categories regarding electromagnetic compatibility (EMC)

Some UTP cables may not function properly when installed in conduit, as the metal conduit can effect the electrical properties of an unshielded cable. Consult the cable manufacturer when installing UTP cables in conduit.

3.1.2.1 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 a maximum separation between the Ethernet cable and other potential noise conductors. You should route your cable following these guidelines.

cable in a contiguous metallic wireway or conduit	route your cable at least this distance	from noise sources of this strength
yes	0.08 m (3")	Cat. EMC1 conductors of less than 20 A
	0.15 m (6")	ac power lines of 20 A or more, up to 100 KVA
	0.3 m (12")	ac power lines greater than 100 KVA
no	0.15 m (6")	Cat. EMC1 conductors of less than 20 A
	0.3 m (12")	ac power lines of 20 A or more, up to 100 KVA
	0.6 m (24")	ac power lines greater than 100 KVA

Table 3.2: Cable routing distances regarding electromagnetic compatibility (EMC)

Consult your local, state, and national codes regarding the grouping of cables. In the absence of these codes the general rule for noise protection is a minimum distance of 8 cm (3") from electric light and power conductors and additional 3 cm (1") for each 100 volts over 100 volts:

voltage level	Minimum distance
0 – 100 V	8 cm (3")
101 – 200 V	11 cm (4")
201 – 300 V	14 cm (5")
301 – 400 V	17 cm (6")

Table 3.3: Cable routing distances regarding nominal voltage

3.1.2.2 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 Cat. EMC1 conductors. When you are running cable inside an enclosure, route conductors external to all raceways in the same enclosure, or in a raceway separate from Cat. EMC1 conductors.

route your cable at least this distance	from noise sources of this strength
0.08 m (3”)	Cat. EMC1 conductors of less than 20 A
0.15 m (6”)	ac power lines of 20 A or more, up to 100 KVA
0.6 m (24”)	ac power lines greater than 100 KVA

Table 3.4: Cable routing distances inside enclosures regarding EMC

3.1.2.3 Mechanical stress

- Choose the correct type of cable for the respective application (e.g. installation in internal or external area, trailing cables).
- Consider the minimum bend radius as defined in 3).
- Cables shall be installed such that movable machinery will not damage the cables.
- Do not install cables where exposed to drive ways and machine movements.
- Use cable ducts or cable bridges (wireways).

3.1.2.4 Electromagnetic interference

- Signal lines and power supply lines should not be installed in parallel. If necessary, use metal separation webs between the power supply and signal lines.
- Only use plug connectors according to the requirements of chapter 2.4.2.2 and handle them according to the installation instructions of the manufacturer.
- In case of external lines between buildings, you must observe the grounding according to the chapters 3.1.3 and 3.1.5.2.
- In the installation, all locking devices of the plug connectors (screws, cap nuts) have to be fully engaged to guarantee the best possible contact of the shielding with the ground. The connection of the grounding or the shielding of the cables has to be checked for low-impedance transition before the first start up.

3.1.2.5 Conductor lead-in in switch cabinets

- Install Ethernet cables in own cable ducts or cable bundles.
- If possible, do not install Ethernet cables parallel to power supply lines.
- Install Ethernet cables with a minimum distance of 10 cm to power lines.

3.1.2.6 Conductor lead-in in buildings

- Use metal conductor carriers.
- Install Ethernet cables together with power supply lines or parallel to them.
- Separate Ethernet cables on cable bridges or in cable ducts from power supply cables by means of separation webs.
- Install Ethernet cables as far away as possible from interference sources, like engines and welding devices.
- In case of long cable connections install an additional equipotential cable between the connection points.

3.1.3 Cabling in heavy-duty environment

In addition to the contents of chapter 3.1.1, the following indications have to be observed.

3.1.3.1 Conductor lead-in outside of buildings

- Install Ethernet cables in metal tubes grounded on both sides or in concrete cable ducts with a through-connected reinforcement.
- In case of long cable connections, install an additional equipotential cable between the connection points.

3.1.4 Electromagnetic compatibility

Electromagnetic compatibility (EMC) of an installation implies that the emission from an installed system remains below accepted limits as defined in the relevant standard and that the installed system can operate satisfactorily and exhibits the specified immunity levels in a specific electromagnetic environment.
The guidelines outlined in this clause shall be taken into account. Manufacturer's instructions that may require more stringent installation practices shall also be followed.
Safety always takes precedence over EMC.
Several International and European documents define different electromagnetic environments which influence the installation practice. A direct way to take account of these different environments is to consider the relevant disturbing sources.

3.1.5 Screening

A screen is formed by a conductive surface around the cores of a cable to avoid the coupling of noise by external EMI disturbances. A screen creates a separation between the external electromagnetic environment and the transmission line inside the screen.

3.1.5.1 Screening installation guidelines

The performance of the screen depends on the screening effectiveness of the components and on the way the components are connected to each other and to a local earth.

The following should be considered:
a) screen not bonded to equipment: not recommended;
b) screen bonded on both ends to equipment (i.e. connected to the chassis of the terminal equipment): reduces electro-magnetic radiation by the principle of the Faraday cage but may introduce current loops when the two end ground points are of different potential;
c) screen earthed on one end: provides protection against electrical fields and current loops;
d) screen earthed on both ends: provides protection against electrical fields and gives partial compensation for the interfering magnetic field due to current loops (problems in case of high screen currents);
e) screen in all above cases: virtually no effect against very low frequency magnetic fields (e.g. 50 Hz), unless special materials are used (µ-metal, Permalloy, etc.).

According to the above considerations:
a) the cable screen shall be continuous from the transmitter to the receiver. This means that a cable screen shall be connected in one of the two following methods (a1 or a2):
    a1. If there is an equal potential in the building ground system under all operating conditions then both ends on terminals or sockets should be grounded. Special care shall be taken to assess and address transients that occur in the two end points when the machinery is in operation;
    a2. If there is no equal potential or the building ground system is not of low impedance or has excessive noise, then only one end of the cable shield should not 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.
    a3. Devices should be designed with a resistor and capacitor (1 MΩ and 0.01 µF) in parallel with the device jack to earth ground on the board (see **Figure 3.1** below).
    a4. A device that is internally grounded should have the shield opened at the connector end or an external RC circuit wired to earth ground as shown in **Figure 3.1** .
    a5. Switches provide a direct connection for the cable shield to earth ground. The ground should not be defeated.

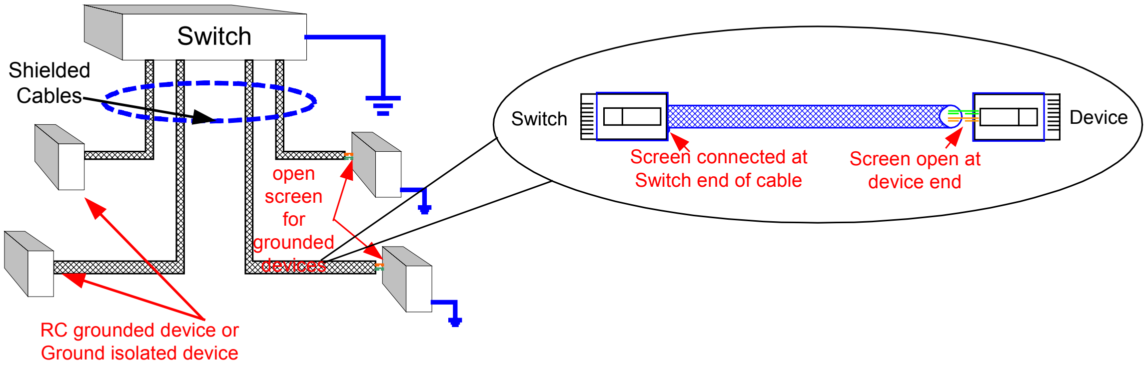


Figure 3.1: screen connection methods

b) the cable screen shall have a low transfer impedance;
c) special attention shall be given to the assembly of connection elements. The screen should be applied over 360 degrees according to the principle of a Faraday cage. The screening connection should be of a low impedance design;
d) the cable screen should totally surround the cable wires along its entire length. A screening contact applied only through the drain wire has little effect at high frequencies;
e) the screening should continue through an adequate screen connection; normal pin contacts shall not be used;
f) avoid (even small) discontinuities in the screening: e.g. holes in the screen, pigtails, loops which can decrease the overall effectiveness of screening. The shield continuity should be maintained to 360° at the connecting hardware.

3.1.5.2 Local requirements

Building grounds are unpredictable in some regions and have a tendency to degrade over time. In such cases screened cable should only be considered in environments where there is high noise generation equipment. Applications that use high magnetic fields or high power RF should use shielded cables. Such applications might be induction heating, RF cross linking and high power welding. Applications outside these environment should use high performance TP cables.

3.1.6 Bonding and earthing

Grounding or earthing serves for protecting personnel and machines against dangerous voltages. To avoid these dangers as much as possible, grounding in accordance with the national and local regulations and adapted to the conditions is mandatory. All Ethernet stations must be grounded to keep away possible interferences from the data telegram and to divert them to the ground.

In Europe, grounding is regulated in EN 50310, earthing and bonding for metallic communication cabling systems are standardized in EN 50174-2, chapter 6.7.
Chapter 6.7.1 of EN 50174-2:2000 explains:

The basic purposes of earthing and bonding are applicable to copper cabling systems:
- safety: touch voltage limitation and earth fault return path;
- EMC: zero potential reference and voltage equalization, screening effect.

Stray currents inevitably propagate in an earth network. It is impossible to remove all sources of disturbances at a site. Ground loops are also inevitable. When an external magnetic field affects the site, a field produced by lightning for example, potential differences are induced in the loops and currents flow in the earthing system. So the inside building earth network depends largely on the countermeasures taken outside the building.
As long as the currents flow in the earthing system and not in the electronic circuits, they do not have any harmful effects. However, when the earth networks are not at equal potential, the stray high frequency currents will flow where they can, i.e. on signal cables. Equipment can suffer disturbance and even be destroyed.
One method of controlling currents is by wiring the grounds in a star ground configuration. Further, providing multiple star ground systems is an effective means for controlling ground currents by

separating the communications and high noise generating device grounds from one another. Daisy chaining of grounds from one cabinet to another shall be avoided.

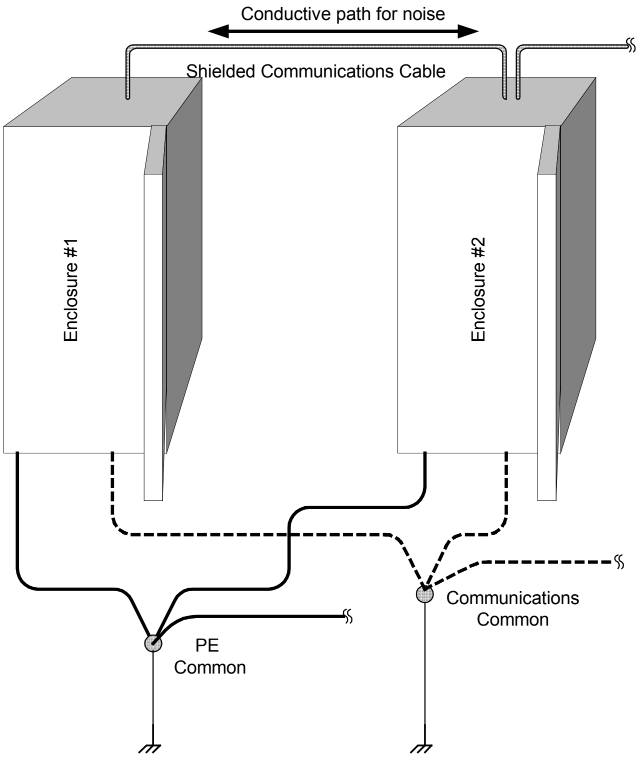


Figure 3.2: wiring the grounds in a star ground configuration

The specifications of EN 50310 are intended to provide optimum earthing and bonding conditions for buildings, where information technology installations are to be operated. EN 50310 shall be applied at least in the case of newly constructed buildings and whenever possible in existing buildings (e.g. on the occasion of refurbishment).

3.1.6.1 Earthing system

a) There should be no PEN within the building
b) Wherever possible, the TN-S system should be used. Exceptions exist due to existing high-voltage power distribution systems, which are TT or IT, or where a high continuity of supply is required by the application (hospitals) or by national regulations.

NOTE 1: A PEN conductor within the building can be considered on the path from the building entrance to the first termination point where it will have to be split into separate neutral conductor (N) and protective earthing conductor (PE).

NOTE 2: The different electricity distribution systems (TN-S, TN-C-S, TN-C, TT and IT system) are described in HD 384.3 S2.

3.1.6.2 Checklist

Aspects to be considered		Answer		Comment
		Yes	No	
1	**Building**			
1a)	Existing building?	Δ1)	O1)	
1b)	New building projected?	Δ	O	
1c)	New building existing?	Δ	O	
1d)	New and existing building mixed?	Δ	O	
1e)	Hospital?	Δ	O	
2	**Power distribution system**			
2a)	TN-S?	O	O	Best solution
2b)	TN-C-S?	Δ	O	
2c)	TN-C?	Δ	O	
2d)	TT?	Δ	O	
2e)	IT?	Δ	O	
3	**Disturbing sources**			
3a)	Transformer station?	Δ	O	
3b)	Proximity to electrical traction?	Δ	O	
3c)	Proximity to high voltage power lines?	Δ	O	
3d)	Arc welders?	Δ	O	
3e)	Frequency induction heaters?	Δ	O	
3f)	Transmitting equipment (radio, television, wireless telephone and radar)?	Δ	O	
3g)	Does the installed equipment2) comply with relevant European EMC-Standards?	O	Δ	
3h)	Power cables screened?	Δ	O	
3i)	Proximity to coaxial or unbalanced cabling?	Δ	O	
4	**Customer requirements concerning security**			
4a)	Very sensitive application(s)?	Δ	O	
4b)	Hospital environment?	Δ	O	
5	**Structure of the existing and/or future earthing and bonding network**			
5a)	Mesh topology, CBN or MESH-BN?	O		
5b)	Star topology, IBN or MESH-IBN?	Δ		
5c)	Trunk structure?	Δ		
5d)	More than one answer a),b),c)	Δ		
6	**Cable management systems, raised floors**			
6a)	1. generic cabling parallel to power lines 2. premises cabling parallel to power lines	Δ Δ	O O	
6b)	Plastic or metallic (aluminium or steel) cable management systems	Δ Δ Δ	O O O	Plastic Steel Aluminium
6c)	Plastic or metallic separation between information technology cabling and power lines?	Δ O O	Δ Δ Δ	Plastic Steel Aluminium
6d)	Are the metallic or composite cable management systems specially designed for EMC purposes earthed repeatedly or at least at both ends?	O	Δ	
6e)	Is the cabling between buildings carried out with metallic cables?	Δ	O	

NOTE 1 O = No action required Δ = See A.6.2.
NOTE 2 This refers not only to the connected equipment but also to other equipment in the environment (e.g. copiers, fluorescent lighting).

Table 3.5: Checklist for EMC considerations (from EN 50174-2)

3.1.6.3 National requirements

For safety considerations, there may be national standards to be regarded as well.

3.1.6.3.1 Germany

In Germany, the following standards and regulations have to be observed for grounding:
- DIN VDE 0110 Teil 1
- DIN VDE 0185
(See chapter 1.2.3 for further information.)

A minimum cable size of 2.5 mm^2 shall be used for grounding (spring cage terminal blocks 1.5mm^2). For certain devices larger cross sections of conductors may be necessary. The type of grounding depends on the assembly of the modules. With rail mounting, the rail must be connected with the protective earth through grounding terminal blocks before a module is snapped on. The connection of the module to the protective earth is normally done via a metal clip at the back of the module. In addition, there are modules that are screwed on a mounting surface (direct assembly). The PE connection of the housing can be done via a mounting screw on a grounded mounting surface or an external grounding connection.

3.1.7 Installation in an area with grounded reference potential

Causes of surge voltages

Surge voltages occur during switching processes, electrostatic discharge and lightening current discharge. The coupling mechanism for surge currents and voltages is inductive, capacitive or electrical. The network supply and data lines can be affected. In this way, surge voltages reach the input power units and the sensitive interfaces of systems and end terminals.

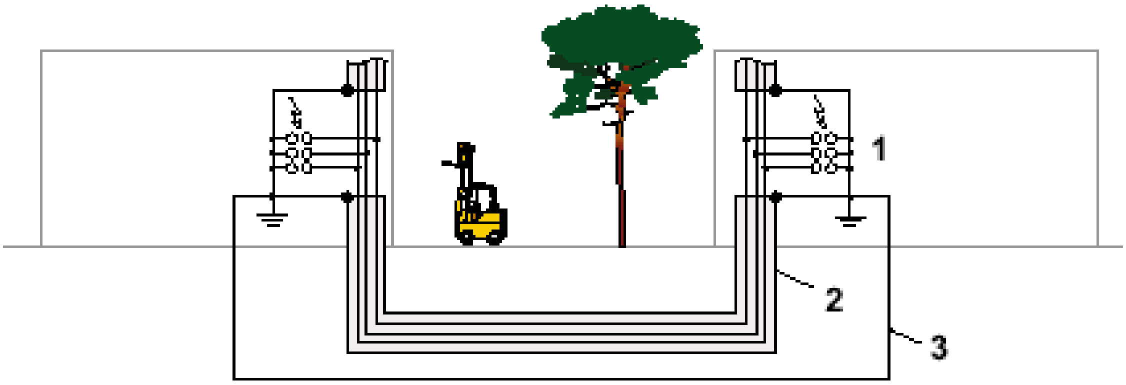


Figure 3.3: Surge voltage protection measures

1 Surge voltage protection devices
2 Cable shields
3 Equipotential cable

Surge voltage protection devices

Surge protection devices should be considered for all cables to provide protection to the devices (see **Figure 3.4**). Please observe all national and international regulations when installing surge voltage protection devices.

Grounding of cable shields

Ground the cable shields (**Figure 3.4**) directly after the building entry to avoid surge voltages. Hereby the cable shields have to have a sufficient cross section according to the respective standards.

Equipotential cable

Install an additional equipotential cable (**Figure 3.4**) between the grounding points of buildings that preferably are carried out in form of

- a metal-sheathed concrete duct
- an additional grounding cable
- a metal tube

3.2 Installation of fiber optic cable

3.2.1 Cabling in light-duty environment – general wiring guidelines

The properties of a fiber optic transmission system are mainly characterized by:

- the power of the optic Interface
- the kind of cable used
- quality of the installation and the plug configuration

Therefore, it is absolutely necessary to observe the cable laying directives to ensure a long-lasting perfect function of the transmission distance. In addition, the instructions of the cable, plug connector and device manufacturer have to be observed.

Use suitable components

- The components must be suitable for the use in the environmental and application conditions to be expected (chapter 2)
- It must be possible to use the components and active devices together

Observe bending radius !

Care should be taken to not go below the minimum bending radius described in the technical data of the cable. This is particularly important when you lead fiber optic cables through housings or lay them in cable ducts with a right angle. Pay close attention to the bending radius as defined in chapter 3) by fixing the cable and use strain relief at the plug connectors and bulkhead connectors.

Do not exceed tension load and crush forces

The permanent tension load of a cable shall not be exceeded as described in the cable manufacturer’s technical data sheet. The cable should be protected from inadvertent crushing during installation.

Laying in cable ducts

While installing the cable into cable ducts, care should be taken that the cable does not have loops or kinks. Loops and Kinks will adversely affect the performance of the cable and possibly permanently damage the cable.

Protection against sharp edges

Protect the cable against sharp edges with an edge protection.

Measurement of power

After having finalized the installation the luminous power and attenuation of the system have to be measured. The calculated attenuation budget must be confirmed.

3.2.2 Cabling in heavy-duty environment

In addition to the contents of the chapter 3.2.1, the following instructions have to be observed.
The cable and the components shall be selected to be suitable for the targeted environment and application. This particularly applies to:

- temperatures
- resistance against aggressive media
- mechanical loads like shock and vibration
- bending load in drag chain applications

The power budget must be considered when using special components with an increased attenuation,.

3.2.3 Cabling outdoor

In addition to the contents of the chapter 3.2.1 and 3.2.2, the following instructions should be observed.
The components must be suitable for the use in the environmental and application conditions to be expected. This particularly applies to:

- temperatures
- resistance against UV rays
- rodent protection

3.2.4 Fiber optic connectors

The connectors have to be installed according to the assembly instructions of the manufacturer.

3.3 Cable paths

The details for cabling pathways and spaces are described in EN 50174-1, chapter 4.8.
Here a general overview from chapter 4.8.1 of EN 50174-1:2000, **Location of pathways**:

“Pathways should not be installed within lightning conductor voids or lift shafts.
The entry points to the pathways shall:

a) be accessible and not be covered with permanent building installations;
b) allow installation, repair and maintenance to be undertaken without risk to personnel or apparatus;
c) provide adequate space for any equipment required for installation (including cable drums and drum stands);
d) enable installation of the cables whilst maintaining the minimum bend radii (installation) specified by the supplier or by the relevant standard. Where multiple cable types are involved, the largest minimum bend radius shall apply.

The location of pathways should avoid localized sources of heat, humidity or vibration that increase the risk of damage to either the cable construction or performance. For example, pathways shall not run adjacent to heating pipes unless appropriate components or protection is provided. The cabling installer shall ensure that all necessary guards, protective structures and warning signs are used to protect both the cabling and third parties as required by local or national legislation.
Where possible incompatibility exists then alternative pathways, pathway systems or components with enhanced environmental (or other) characteristics should be considered. Alternatively, atmospheric control of the internal pathways environment should be considered.
Pathway systems shall be designed and installed to eliminate the risk of sharp edges or corners that could damage the cabling installed within or upon them.
Pathways constructed using tray work should use pre-formed bends, compatible with the trays, to perform changes in pathway direction and shall be located to:

a) provide a minimum clearance of 25 mm from the fixing surface;
b) provide the greatest working space possible subject to a minimum of 150 mm above the tray to enable access during installation;
c) prevent damage to the installed cabling.

Indoor pathways constructed using trunk cables, ducting or conduit systems should provide access at intervals of not greater than 12 m to enable the use of draw boxes. The draw boxes shall be large

enough to maintain the minimum bend radii (installation) specified by relevant standards or by the supplier. Where multiple cable types are involved, the largest minimum bend radius shall apply.
Pathway systems should be selected and installed to ensure that water or other contaminant liquids cannot collect. Where conducting pathway systems are used, the electrical continuity of the installed sections shall be maintained and bonded to earth in accordance with relevant national or local regulations. The use of hidden pathways (such as within plastered wall surfaces) is not recommended but, if used, cabling should be installed in either vertical or horizontal pathways.
The cabling installer shall establish that the pathways defined in the installation specification are accessible and available in accordance with the installation program (see 5.2.3.1 *of EN 50174-1:2000*). The cabling installer shall advise the cabling owner of all proposed deviations. The cabling installer shall ensure that pathways are left clean and free from obstruction with all separators and bridging pieces in place before the installation of information technology cabling commences. Access points shall not be obstructed."

3.4 Labeling

The details for a standardized cabling administration are described in EN 50174-1, chapter 7.
Currently there is no international standard on this subject.
For a general guideline chapter 7.2 of EN 50174-1:2000, **Identifiers** is cited here:

"In certain cases, identifiers are coded to indicate other relevant information about the component. For example, where a 4 pair category 5 cable installed in the horizontal cabling is identified according to its type and location in the building using an appropriate coding method. 7.5 *(of EN 50174-1:2000)* indicates the cabling components for which identification shall be considered.
Labels are either fixed to the component or are part of the component itself. Certain components are labeled more than once. For example, a cable generally needs to be labeled at both ends as a minimum requirement.
In all cases:

a) care shall be taken that labels are applied such that they are easily accessed, read and modified if required;
b) labels shall be robust and the markings shall remain readable for the anticipated lifetime of the cabling
c) labels shall not be affected by dampness nor smudge when handled;
d) labels used in an outdoor or other harsh environment shall be designed to withstand the rigorous of that environment;
e) if changes are made (for example, at a patch panel), labels shall be inspected to determine if the information recorded on the labels requires to be updated."

3.5 Documentation

The details for a standardized documentation of cabling are defined in ISO/IEC 14763-1 and in EN 50174-1, chapter 6.
The general requirements are (chapter 6.1 of EN 50174-1:2000):

"The proposed level of documentation to be provided both during and following the installation shall be detailed within the installation specification.
This clause details the recommended level of documentation throughout the design and installation stages.
Commercial documentation should cover all technical and contractual aspects relating to the end user requirements and the installation undertaken and shall include:

- the installation specification (see 5.2 *of EN 50174-1:2000*);
- the quality plan (see 5.3 *of EN 50174-1:2000*);
- final cabling documentation (see 6.2 *of EN 50174-1:2000*).

Where appropriate, the documentation supplied shall include component acceptance test documentation.
Such documentation includes:

a) evidence of conformance of cables, connectors, cable assemblies etc.
b) cable acceptance test records and other information;
c) cable assembly acceptance test records and other information;
d) delivery information (e.g. dates of receipt and batch numbers or other unique product identifiers of cables and accessories)."

4 Conformance tests

The installed cabling has to be tested for its conformance with the standards and specifications listed in chapters 2 and 3. The class D link performance limits are listed in Annex A of EN 50173:2002 and ISO/IEC 11801:2002. The measurement is described in prEN 50346:2001.

Annex chapter 5.2of this “Planning And Installation Guide” gives detailed guidelines for the measurement process.

4.1 Length of permanent links and channels

The length of the permanent links and channels shall be in accordance to the Class D (EN 50173:2002 or ISO/IEC 11801:2002) or Category 5e (EIA/TIA 568-B) specification and shall be tested in accordance with prEN 50346:2001.

Annex chapter 5.2 of this Planning And Installation Guide gives detailed guidelines for the measurement process.

4.2 Overview of tests for copper channels

The copper cabling shall meet the appropriate Class D (EN 50173:2002 or ISO/IEC 11801:2002) or Category 5e (EIA/TIA 568-B) link and/or channel specifications.

The test equipment available on the market supports all of the necessary tests and supplies automatically the relevant tests limits and test adapters for link and/or channel measurements.

4.3 Overview of tests for fiber optic cabling

To meet constantly increasing demands for higher performance, fiber cabling has already become the de facto solution for long-haul backbone applications and is also making significant inroads into the horizontal cabling environment. Because of its significantly greater bandwidth capacity and better signal loss to distance characteristics, fiber optic cabling has quickly become the media of choice for higher traffic network links.

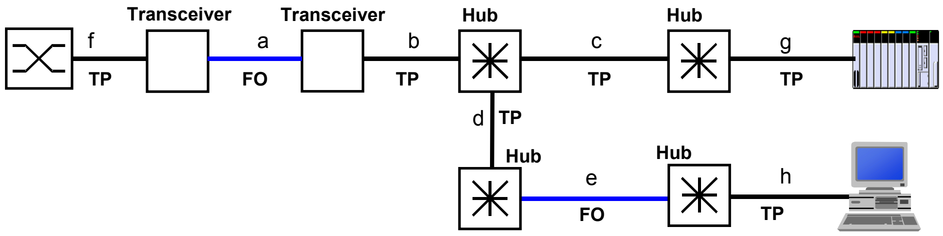
In a fiber networking environment, optical pulses are generated from a fiber optic transmitter (light source), that is used to convert the network signal from a digital signal to light. These light pulses are transmitted along the fiber core and decoded at the receiving end (fiber to copper receiver) to complete the physical layer signal transmission. Fiber cable media used in a network must be capable of supporting the transmission from point-to-point or end-to-end. Each transmission link has a transmit (+) and receive (-) fiber strand that propagates the signal. Some very advanced systems also use wave division multiplexing (WDM) that allows multiple transmit and receive signals to be carried at different wavelengths on a shared fiber strand.

From an installation and testing standpoint, this widespread trend toward fiber cabling present a number of new challenges and opportunities for the LAN premises cabling installer. For example, because fiber cabling for premises wiring can be either multi-mode or single-mode supporting different distances and wavelengths, cable installers need to plan their test equipment investments to cover the whole spectrum of fiber types. In addition, it makes good sense to invest in lower cost options for quick-test verification of cabling before it is installed and for checking out raw un-terminated cabling after installation.

5 Annex

5.1 Dimensioning the network

5.1.1 Network expansion



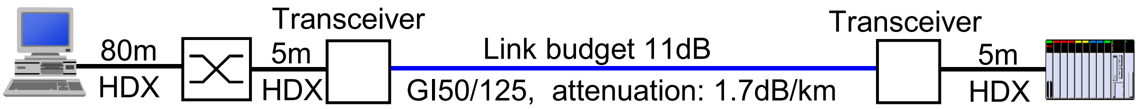
Propagation Equivalence distance f-g:
2 x140m (DTE ^{TP}) + 2 x100m (Transceiver) +
2 x190m (Hub) = 860m
max. distance f-g: 4520m - 860m = 3660m

Propagation Equivalence distance f-h:
2 x140m (DTE ^{TP}) + 2 x100m (Transceiver) +
1 x190m (Hub)+
2 x 390m (Hub) = 1450m
max. distance f-h: 4520m - 1450m = 3070m

Propagation Equivalence distance g-h:
2 x140m (DTE ^{TP}) + 2 x190m (Hub) +
2 x 390m (Hub) = 144 0m
max. distance g-h: 4520m - 1440m = 3080m

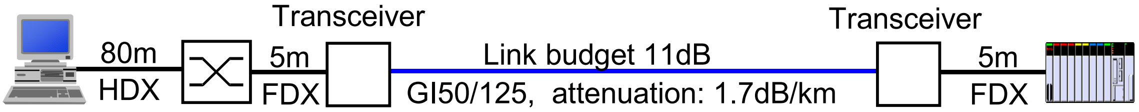
Figure 5.1: Example for network expansion calculation for a hub based Ethernet system

Half duplex segment:



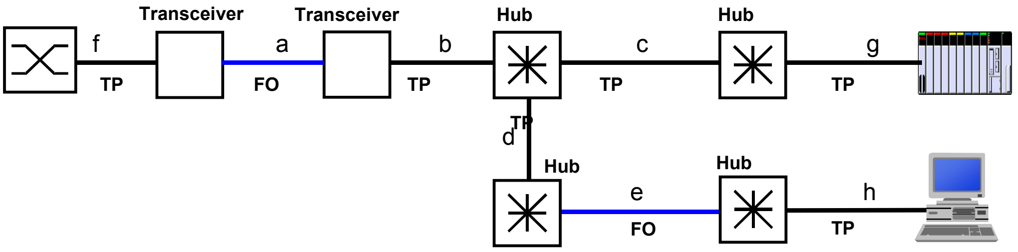
max. FO cable length = (412BT - Σ repeater delays - Σ TP- cable delays - system reserve) / 1.0BT/m
max. FO cable length = (412BT- 2 x 84BT - 10m x 1.112BT/m - 4BT) / 1BT/m = 228m

Full duplex segment:



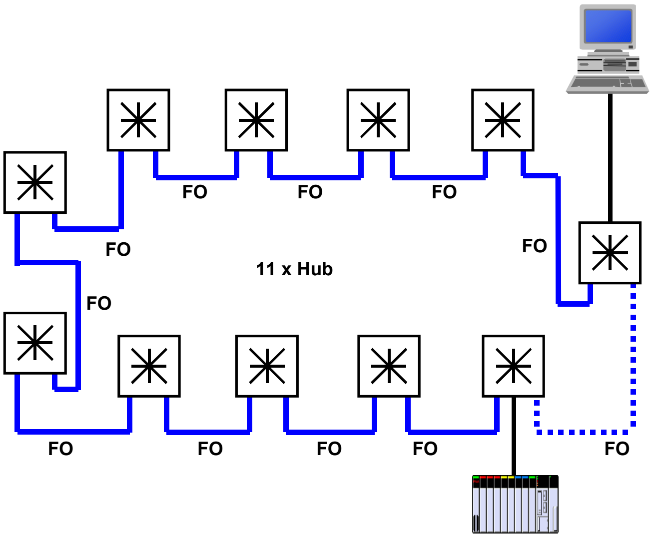
max. FO cable length = (Link budget - system reserve) / fiber attenuation
max. FO cable length = (8dB - 3dB) / 1.7 dB/km = 2940 m

Figure 5.2: Comparison of link length differences for half duplex (HDX) and full duplex (FDX) Ethernet systems



PVV Distance f-g:	2 x Transceiver	2 x 1 BT +	
	2 x Hub	2 x 4 BT = 10 BT	< 40 BT
PVV Distance f-h:	2 x Transceiver	2 x 1 BT	
	1 x Hub	1 x 4 BT	
	2 x Hub	2 x 6 BT = 18 BT	< 40 BT
PVV Distance g-h:	2 x Hub	2 x 4 BT +	
	2 x Hub	2 x 6 BT = 20 BT	< 40 BT

Figure 5.3: Example for cascade depth calculation



Path Variability Value of the longest path:

2 x 6 BT (FO/TP) = 12 BT

9 x 3 BT (FO/FO) = 27 BT

Total = 39 BT <40 BT

Propagation Equivalence of the longest path:

2 x 140m = 280 m

2 x 390m = 780 m

9 x 260m = 2340 m

Total PE = 3400 m

4520 m - 3400 m = 1120 m

Maximum cable length = 1120 m

Figure 5.4: Example for the calculation of a ring topology

5.2 Specification measurements

5.2.1 Twisted pair cabling

5.2.1.1 Overview of tests for copper cabling

This chapter focuses primarily upon presenting descriptions of the various tests that have to be carried out in order to fully comply with each applicable EIA/TIA and ISO/IEC standard.

5.2.1.2 Line map

Line mapping, also referred to as end-to-end connectivity, is a test that identifies the status of each wire in a twisted pair environment. Unlike telephone systems, which often reverse two or more conductors, LANs generally require that all lines are connected straight through from hub/concentrator to the workstation, except for null capable applications. The pairs are grouped as a transmit +/– pair and a receive +/– pair. It is very important that these lines are not crossed or shorted as the integrity of the network will suffer.

Local area networks implemented on twisted pair wiring rely on active electronic devices to make the physically star-wired nodes appear logically as a ring or a bus depending on the topology. The integrity of the twisted pair wiring system enables any workstation connected, to be consistently recognized by the network operating system and network hardware/software drivers.

Testing end-to-end connectivity used to be a tedious process. Prior to the development of modern loop-back devices, this could only be accomplished using a multimeter and a semi-conductor PN junction component such as a diode. By placing diodes of differing values between the desired pairs, continuity and cable connect direction could be measured by reversing the polarity of the ohmmeter on each pair and comparing the resistance with recorded values.

Using this method, an experienced technician might have qualified only 5-10 runs per hour.

A number of different test devices are now available, designed specifically to simplify this process. Their abilities range from simply identifying that wires are connected, to printing out the status of each individual conductor. These test devices use loopback plugs of various configurations to execute their testing.

Visual displays range from a panel of light emitting diodes (LEDs) to liquid crystal text (LCD) and printouts. The example below shows a comparison of correct and incorrect wiring for a LAN. The incorrect example has wire pairs 1,2 and 3,6 crossed.

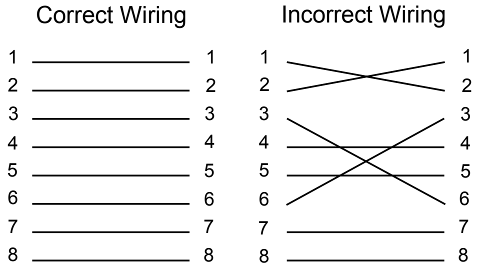


Figure 5.5: Line mapping

Test Results

Line Mapping	12345678	12345678
Office Id: 5	12345678	21645378
Pass Criteria	12345678	12345678

LAN connectivity examples with test results

The type of connectivity test equipment used will effect how the results of its tests are interpreted. For LED display testers, usually a lamp will light up indicating that the pair under test is connected (shorted) in the loopback connector at the far end. An open circuit will result in no illuminated LED for that pair. The drawbacks to this type of testing are that there is no indication of a short outside the loopback plug (at a cross-connect for example), and there is no way to determine if a wire reversal has occurred (i.e., 3,6 has become 6,3).

More advanced units incorporating LCDs and/or printers usually provide much more usable information. These devices not only indicate basic connection but will show wire reversals (or flips), open circuits, and short circuits and distance to fault information. Open or Short circuits are represented by an “o” or an “S” replacing that line’s number. Wire flips are easily detected by lining up near end and far end pin designators. Intelligent termination devices can also be used to provide different resistances on each pin as well as a variable value to facilitate quicker cable labeling and office identification.

5.2.1.3 DC loop resistance

All metallic cables insert a certain amount of DC resistance into a circuit, measured in ohms. Like the heating element in an electric oven, this resistance causes some of the electrical signal to be absorbed by the cable and dissipated as heat.

As a general rule, data cabling has a very low resistance value that does not add a significant load to the transmission system or network. However, if there is too much resistance present, excessive signal loss will occur and will be observed as a transmission problem.

DC resistance is often confused with impedance, a term describing the dynamic resistance to signal flow, usually at a specified frequency. Both are measured in ohms because they define different types of opposition to electrical current flow.

We will address impedance in more depth later. The main point here is that DC resistance increases proportionately with the length of cable being tested while (AC) impedance remains fairly constant regardless of length.

An ohmmeter is the most common tool used in DC resistance measurement. Alligator type test clips or some other shorting device is applied to two conductors at the far end of the cable under test (center to shield for coax, or between a pair for twisted pair). The loop resistance is then directly read from the ohmmeter.

The table below provides some common DC resistance specifications.

twisted pair	**Ohms / 100 m segment**	
AWG 24	18.8	
AWG 22	11.8	

Table 5.1: Common cable media resistance specifications

All pairs within the same cable should have nearly the same resistance.

Variations in loop resistance can often be a quick indication of a cabling problem.

Values at or below those shown in the table (measured with one end shorted) provide basic continuity information.

Some of the common causes of excessive or inconsistent DC resistance include:

- Mis-matched cable types
- Poor punch block connections
- Poor connector termination connections
- Cable damage
- Shorted cable causing low DC resistance values
- Excessively long cabling runs

5.2.1.4 Cable length testing

All LAN topologies have inherent cable length limitations. For coaxial, shielded twisted pair and other high-grade cable plants, these limitations exist because of network timing considerations. That is, if the cable were any longer, it would take the signal too long to go from one end to the other and back. Thus, the originating node would think that its target didn't get the message and would re-transmit, causing collisions. For unshielded twisted pair applications, cable length is restricted due to signal degradation problems. This means, if the cables were longer, there might not be enough signal left for the receiver to detect reliably.

Cable length testing is almost always done with a test instrument called a Time Domain Reflectometer (TDR). It works very much like a radar, sending a pulse of energy down the cable. When that pulse encounters an impedance mismatch like a short-circuit or an open-circuit, reflections are generated which travel back up the cable to the transmitter. By knowing how fast electricity travels in the cable under test, the TDR can figure the cable's length by measuring the time it takes for the reflection to come back from the impedance mismatch.

(For discussion purposes, we will assume we are measuring a disconnected, or open cable with no other damage. In this case, the impedance mismatch is at the far end of the cable which is disconnected.)

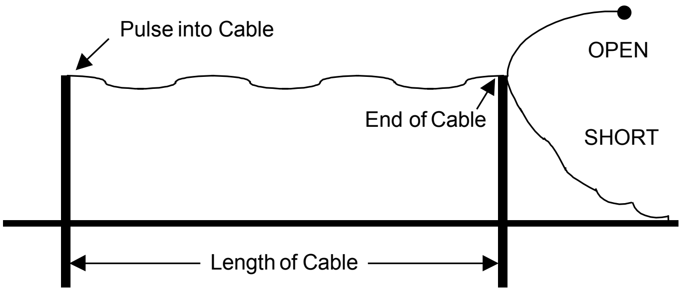


Figure 5.6: Time domain reflectrometry sample display

The speed at which electricity travels in a cable is called the *propagation rate* of the cable. *NVP,* or Nominal Velocity of Propagation refers to the same thing. It is expressed as a percentage of the speed of light. The speed of light is designated by a lower case "c" (i.e., cable labeled 65%c or .65c means its NVP is 65 percent of the speed of light).

Almost all TDR's have the capability to adjust the NVP for different cable types; the propagation rate may vary slightly even between two batches of the same cable type from the same manufacturer! There is even more margin for error when dealing with multiple manufacturer's cables in a single segment. Testing for NVP is essential for accurate length measurements. Any TDR you choose will only be as accurate as the propagation rate entered into it.

If you don't know the NVP of the cable you are testing, there are several ways to determine it. The first method would be to go to the cable specification manual or directly to the manufacturer and ask. This is fine, except that the value obtained would be considered "nominal". That is, it would be a baseline from which the actual cable might vary up to ±2%. At that point it becomes an accuracy question and your length readings will vary based on the TDR's accuracy + the NVP error (which could end up being as much as ±10%.)

The second method minimizes the errors involved. It requires that you have a known length of the cable you wish to test. You should know its length to within ±1 foot. To avoid short link problems resulting in inaccurate measurements, TSB-67 recommends that you should have at least 15 meters of cable. The next step is to attach it to your TDR and look at the end of the cable on the display.

Adjust the NVP until the TDR displays the length you know the cable to be. This will be the propagation rate for this cable. More sophisticated TDR-type testers have actual propagation rate tests which will calculate the NVP for you. These units also require that you know the length of the cable sample being evaluated.

TDR's vary in their ease of use, sophistication, and type of display. The least expensive units on the market usually give only a numeric reading on an LCD indicating the distance to a severe short or open circuit. As price and sophistication increase, displays range from "raw" oscilloscope-type screens (no user reference points) to detailed graphic printouts giving average impedance and distance references for the entire length of the cable. We will look at cable impedance in more detail in the next section. Typically, the high-end TDR's have many adjustments for sensitivity and display interpretation may require a highly trained user. They are, however, able to detect impedance mismatches in a cable, which are much more subtle than a simple short or open circuit. These can include bad taps, poor punch downs, split cable pairs, internal cable water damage, and other defects.

Length test results will apply to the topology being tested. The primary factor is whether or not there is too much cable on a given segment. Occasionally, installation personnel leave a length of cable in a wall or ceiling in anticipation of a future move. This is fine as long as it is considered as part of the overall run. Depending upon the type of TDR used, results will be either a numeric value in meters, or a trace on an oscilloscope-like screen.

Some of the primary causes of Capacitance Test failures include:

- Excessive bending or stretching damage to the cable
- Defective connectors
- Insulation damage at the connector
- Poor connections at punch-downs and wall plates
- Incorrect NVP settings
- Poor installation practices

5.2.1.5 Attenuation testing

Attenuation is the amount of signal lost or absorbed in the cable itself. It is somewhat confusing because it is a negative term. The more attenuation you have, the less signal present at the receiver. Attenuation is also a dynamic measurement, it changes with respect to frequency. Most cables attenuate more as the frequency of the carried signal increases.

Attenuation is typically measured in decibels (dB). This type of measurement requires a known signal level as a reference from which to calculate the amount of loss. The reference signal is usually set to 0 dB. All subsequent measurements are then negative (i.e., -15 dB, -35 dB, etc.). By convention, the minus sign (-) is dropped or assumed in the reading display. Therefore, attenuation readings will generally be seen as 10 dB, 22 dB, etc. An important point to note is that decibel readings are logarithmic and not linear like resistance and voltage measurements. What that means is that for every 6 dB decrease, the signal strength is cut by 1/2. See the following table for some comparative voltage measurements and their decibel equivalents to provide a perspective on the impacts of attenuation on signal strength. The values shown are illustrative only.

Our input signal is 500 mV. Since that is our reference, we calibrate our 0 dB to that value.

Millivolts (mV)	Decibels (dB)
500	0
250	- 6
125	- 12
62.5	- 18
31.25	- 24
15.63	- 30
7.82	- 36

Table 5.2: Decibels vs. Millivolts for a 500 mV reference

As you can see, a measurement of -20 dB would be a very significant amount of signal lost. Parameters such as DC resistance and characteristic impedance will affect a particular cable's attenuation performance. Just as with DC resistance, more cable will cause more attenuation. The values obtained should be fairly additive with respect to the cable length; that is, twice the cable should cause twice the attenuation across the frequency spectrum you are testing. Remember though, since we are reading in decibels that would be only 6 dB more attenuation!

In the axial and shielded cable world, attenuation is not a particularly burning issue. Most of these types of cables are typically over-specified for the applications in which they function to allow for a large margin of performance error. It can become a significant factor, however, as topological length limitations are approached. This is especially true when the cable is of unknown or questionable origin.

For TP (applications), however, the measurement of a particular segment's attenuation characteristics becomes more critical. TP cabling exhibits far more loss than its axial counterparts, especially at high frequencies. This is one reason for tighter restrictions on segment length. Originally designed for voice use, TP rarely carried frequencies greater than 5-10 kHz. At these levels, signals could travel several hundert meters before a repeater was needed. In a LAN, however, with transmission frequencies approaching 100 MHz and beyond, signals deteriorate beyond recognition within a few hundred meter. The typical LAN TP length limit for ordinary cable is 100 meters between repeating devices. In their 802.3 (10BASET-supplement) document, the IEEE specifies that, including all patch and cross-connecting equipment, the maximum allowable attenuation for any segment at 10 MHz will be no greater than 11.5 dB. Although that sounds rather harsh, if you refer to Table 5, you will see that -11.5 dB is really only about 25% of the original signal! That is actually quite a large margin. In actual testing, most cables display what appears to be a linear behavior when attenuation is measured over increasing signal frequency and plotted on a logarithmic scale.

The most useful specifications as they apply to attenuation testing are those which pertain to a particular cable segment. Nominal numbers for cable, measured in thousand foot increments, are difficult to transfer to real segment lengths

5.2.1.6 Near-end crosstalk (NEXT) testing

One of the most important test parameters in the TP world is near-end crosstalk or NEXT. Crosstalk is the tendency for a portion of a signal traveling in a pair of wires to be induced into adjacent pairs. The term comes from the early telephone days when conversations carried on nearby wires could be overheard on other circuits. The principle is the same, although the "conversations" consist of digital signals being transmitted and received between network nodes. These induced signals can have sufficient amplitude to corrupt the original signal or be falsely detected as valid data. Excessive NEXT can cause problems ranging from intermittent workstation lockups to complete network attachment failure.

Like attenuation, NEXT is typically measured in decibels (dB). It is based on a reference signal of known value so as to determine the amount of that signal which has been induced over to the adjacent pair. As a general trend, NEXT increases with signal frequency as attenuation does. Recent studies have shown that NEXT on TP is not totally linear with respect to frequency as previously thought. In fact, TP exhibits "peaks" and "valleys" of NEXT susceptibility that is very dynamic and changes even when the cable is moved slightly. The following table shows an example of the NEXT values for a sampling of currently-released cabling standards.

The following table shows characteristics for AWG 24 twisted pair cable (basic link: 90 m horizontal cable and 4 m equipment attachment cords).

Category	DC resistance	attenuation	NEXT
3	18.8 Ω / 100 m	6.1 dB @ 4 MHz 10 dB @ 10 MHz 13.2 dB @ 16MHz	30.7 dB @ 4 MHz 24.3 dB @ 10 MHz 21 dB @ 16MHz
4	18.8 Ω / 100 m	4.3 dB @ 4 MHz 6.8 dB @ 10 MHz 8.8 dB @ 16MHz 9.9 dB @ 20MHz	45.1 dB @ 4 MHz 38.6 dB @ 10 MHz 35.3 dB @ 16MHz 33.7 dB @ 20MHz
5	18.8 Ω / 100 m	4.0 dB @ 4 MHz 6.3 dB @ 10 MHz 8.2 dB @ 16MHz 9.2 dB @ 20MHz 21.6 dB @ 100MHz	51.8 dB @ 4 MHz 45.5 dB @ 10 MHz 42.3 dB @ 16MHz 40.7 dB @ 20MHz 29.3 dB @ 100MHz

Table 5.3: UTP cable specifications,
values derived from EIA/TIA 568-B, TSB-67 (at 20°C)

These peaks and valleys only appear when the frequency band is swept during testing; instead of making measurements at fixed frequencies between 100 kHz to 100 MHz, the cable is monitored as the test frequency increases gradually and constantly from base to high end.

It is important to note that the location and amplitude of these peaks change relative to the cable's position. Test results for cable on a spool will be very different for an installed segment. For loosely twisted cable, the change will be much more dramatic as the cable is flexed and stressed. The length of the cable will also affect its crosstalk characteristics. As the segment gets longer, its immunity to NEXT is decreased. Crosstalk, therefore, is another parameter affecting the maximum length of TP cable segments.

Paired cable's extent of immunity to NEXT is related to how tightly each conductor is twisted together with its other half. Flat cable would therefore have the least immunity to both NEXT and environmental noise because it is not twisted at all.

Testing proves this to be true and is the primary reason that this type of cable is unacceptable as a data transmission medium. Flat cable makes an adequate tele-phone extension cord and should not be used for anything else. Even when high quality twisted cable is used to interconnect network devices, care should be taken to maintain the integrity of the cable twist during installation. As little as half inch of untwisted cable at a punch-down or a connector, can cause marginal performance with respect to crosstalk susceptibility. Untwisted patch cables as short as an half meter can cause an entire cable segment to fail NEXT testing.

Similar to attenuation, NEXT test results are also read in negative decibels.

Using the same signal level reference (0 dB), we are now interested in the amount of that signal that has been induced into the adjacent pair of wires. Proper testing procedures dictate that both the disturbing (signal source) and disturbed (tested) pairs be terminated in a matching impedance. For most TP applications, this will be a 100-ohm resistor. Since near-end crosstalk is an undesirable characteristic, larger negative numbers are best. In essence, attenuation readings should be as close to zero as possible while NEXT readings should be as far away from zero as possible.

Because of their dynamic nature, crosstalk measurements should be taken after the installation is completely finished, so that all cable and interconnecting components can be evaluated as a system. This provides a more accurate picture of the transmission medium's capabilities under actual operating conditions.

NEXT should be measured between all pair combinations for complete compliance.

As mentioned earlier, NEXT is a test whereby you inject a signal on one pair and measure the induced noise on the adjacent pairs. This is performed with the swept/stepped frequency generator and TSB-67 requires it to be done in both directions. Because we are measuring near-end crosstalk, and since networks transmit and receive from both ends, a dual NEXT test is required.

NEXT behavior is unpredictable and must be tested using a sweeping source with specified measurement increments. A typical NEXT test from 1 MHz to 100 MHz will include a minimum of 483 measurement points. Unlike attenuation which gradually and regularly increases with test frequency, NEXT exhibits "peaks and valleys" of performance throughout the measured frequency band.

Category 5 testers measure NEXT and compare it against the suggested curve. It has been determined that within a four Pair cable sheath there are six different combinations of NEXT, and since the test should be performed from both ends, there are actually twelve NEXT combinations for a given link. The tester then gives a "pass/fail" indication of the installed link. If the link fails, the tester will default to the worst case measurement in the link. Keep in mind that you could have multiple incidences of NEXT failure and when you solve one, others will move up on the list. NEXT is also measured with respect to a 0 dB source signal, but since we are testing for induced signal onto an adjacent pair, the measured results should be as far from that reference as possible. For example, a measurement of 31.5 dB at 100 MHz (actually - 31.5 dB) is better than a result of 26.0 dB (-26.0 dB) at the same frequency.

When looking at the results for a NEXT sweep, be careful to evaluate the segment's performance over the range of frequencies. Some network systems, such as Ethernet, do not move data at a fixed frequency by virtue of their nature (i.e., CSMA/CD with Manchester encoded data). These systems operate over a range of frequencies often far lower and occasionally higher than their common rating.

For example, a 10BASE-T system is nominally rated at 10 Mbps. Actual data speed on the cable ranges from less than 4 Mbps during relatively idle moments to more than 10 Mbps during heavy file transfers. The Manchester encoding scheme contributes to these high frequencies because there is a state transition (0 to 1 and vice versa) for every data bit regardless of its value. Whenever possible, try to test the cable plant with signals approaching real data characteristics.

5.2.1.7 Attenuation to crosstalk ratio (ACR)

Absolute values for NEXT throughout the operating frequencies of the transmission medium are certainly important, however, equally important, is the relation-ship between NEXT and attenuation for the same frequency range. The attenuation to NEXT ratio (ACR), or signal-to-noise ratio (SNR), is a valuable indicator of cable performance. Essentially, it is the difference between the worst case attenuation and the worst case near-end crosstalk. It can be expressed as follows:

$$\text{ACR} = \text{NEXT wc} - \text{ATT wc}$$

where

NEXT wc = Worst Case Near-end Crosstalk in decibels

and

ATT wc = Worst Case Attenuation in decibels

Typically, the larger the ACR, the better the noise immunity.

ACR becomes increasing important for higher speed cabling categories that must reliably perform across a wide range of frequencies. Therefore attenuation and crosstalk requirements must be specified in detail for a variety of distinct frequency levels. The following table provides maximum attenuation and minimum NEXT limits at specified frequencies for Category 5 cabling installations.

maximum attenuation (dB / 100m)			minimum NEXT (dB)	
frequency (MHz)	**basic link**	**channel link**	**basic link**	**channel link**
1.0	2.1	2.5	60.0	60.0
4.0	4.0	4.5	51.8	50.6
8.0	5.7	6.3	47.1	45.6
10.0	6.3	7.0	45.5	44.0
16.0	8.2	9.2	42.3	40.6
20.0	9.2	10.3	40.7	39.0
25.0	10.3	11.4	39.1	37.4
31.25	11.5	12.8	37.6	35.7
62.5	16.7	18.5	32.7	30.6
100.0	21.6	24.0	29.3	27.1

Table 5.4: EIA/TIA 568-B attenuation and NEXT limits

Attenuation to Crosstalk Ratio (ACR) is one of the best indicators of the band-width capability of a link because it is derived from the worst case NEXT measurements with attenuation subtracted to come up with a value considered to be a margin. This margin is sometimes called "overhead" because it indicates that the signal is better than the minimum specified values. The point where NEXT and Attenuation meet is considered to be "0" dB signal reference. It is this point where it becomes difficult to ascertain a "0" or "1" value in digital logic because the noise is the same value as the signal (the stronger will win). Most people want a high ACR value, and 10 dB is considered to be a strong signal, whereas 3 dB ACR is better than 0 dB, but marginally weak. Many cable and hardware connectivity manufacturers are rating their products with ACR margins because the higher the value, the more bandwidth capability of the product.

5.2.1.8 ELFEXT

ELFEXT is "Equal-Level Far End Crosstalk" and it is essentially a measure of crosstalk noise between pairs at the receive end of the transmission line.

Simple FEXT measurements would not yield useful information because the amount of far end crosstalk varies significantly with the length of the cable. Therefore "equal level" FEXT is used to normalize for attenuation effects.

Basically the amount of far end crosstalk is measured and attenuation is subtracted to get ELFEXT, with higher values representing a better result. In essence, ELFEXT can also be thought of as far end ACR because it combines the measurement of both attenuation and crosstalk at the far end of the link.

5.2.1.9 Return loss

Return Loss is a measure of impedance mismatch at the far end of the cable.

The Return Loss test sends a signal from the near-end to the far-end of the link and then measures the amount of that signal that is reflected. Excessive Return Loss is indicated by a large reflection to the transmitting end. The smaller the number, the greater the Return Loss. A higher level of reflected signal could indicate potential problems with impedance mismatch at the far-end, such as faulty termination, connector problems, etc. While Return Loss testing has been included in European specifications for some time, the adoption of two-way Return Loss testing will now become a more routine world-wide requirement to achieve the transmission efficiencies required for higher speed networks. Good Return Loss is extremely important in new high-speed full duplex LAN applications, such as Gigabit Ethernet.

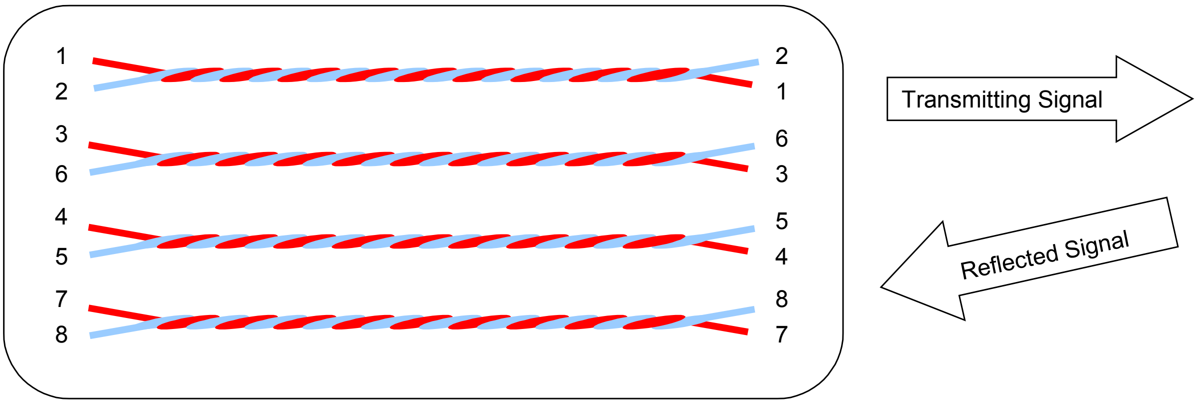


Figure 5.7: Return loss:
the attenuation of the reflected signal compared to the transmitting signal

Some of the primary causes of Return Loss failures include:

- Open, short or damaged cables or connectors
- Poor installation or poor cable quality
- Improper characteristics in installed cable, cable segments or patch cords
- Kinks in cable

5.2.1.10 PowerSum measurements

PowerSum measurements perform an additional mathematical calculation to meaningfully aggregate the data for all of the wiring pairs within a cable. For instance, PowerSum NEXT measures the near-end crosstalk effects of three pairs on the fourth pair. By stepping through all four pairs, testing each against the other three, an aggregate PowerSum evaluation can be derived for any combination of simultaneous transmitting and receiving. Likewise, PowerSum ACR measures the aggregate attenuation to crosstalk ratios.

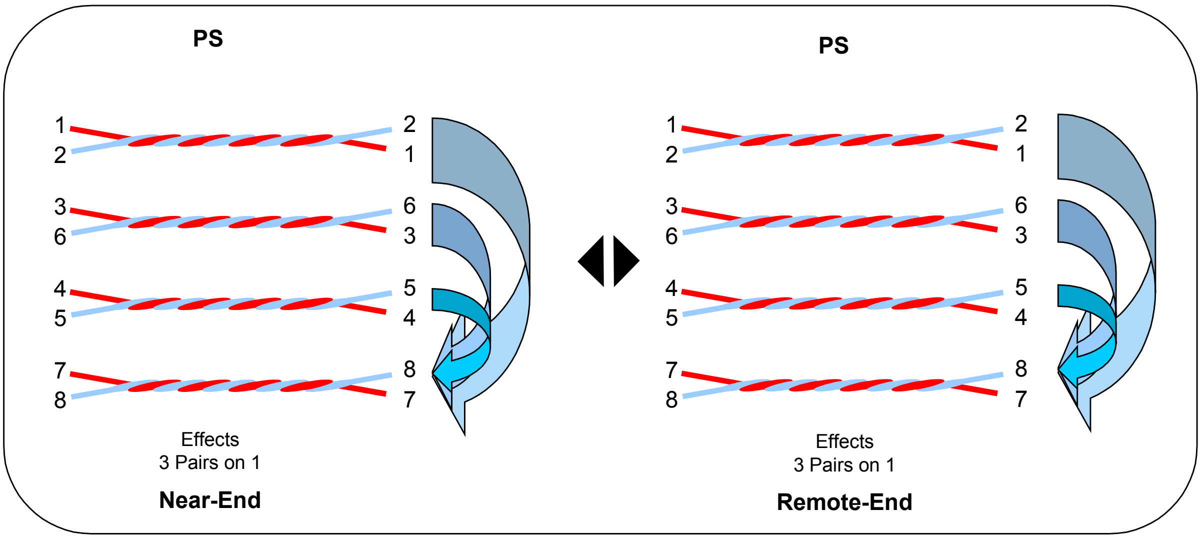


Figure 5.8: Power sum measurement

In contrast PowerSum ELFEXT performs a similar crosstalk test (three pairs at a time on each fourth pair), however it is conducted at the far-end of the structured wiring link. For speeds up to 100Base-T levels, this far-end crosstalk test has not been critical because typically only one pair would be transmitting and another receiving at any given point in time. The natural line attenuation occurring for any signal being received tended to make it too weak to have much crosstalk impact on the signal being transmitted. However, the high probability of as many as three signals being received simultaneously in higher speed networks certainly poses a real potential for a crosstalk impact on any transmission occurring over the fourth pair. This means that, in order to support the demands of Gigabit Ethernet, an enhanced CAT5 or a CAT6 installation must be tested for its susceptibility to far-end crosstalk problems.

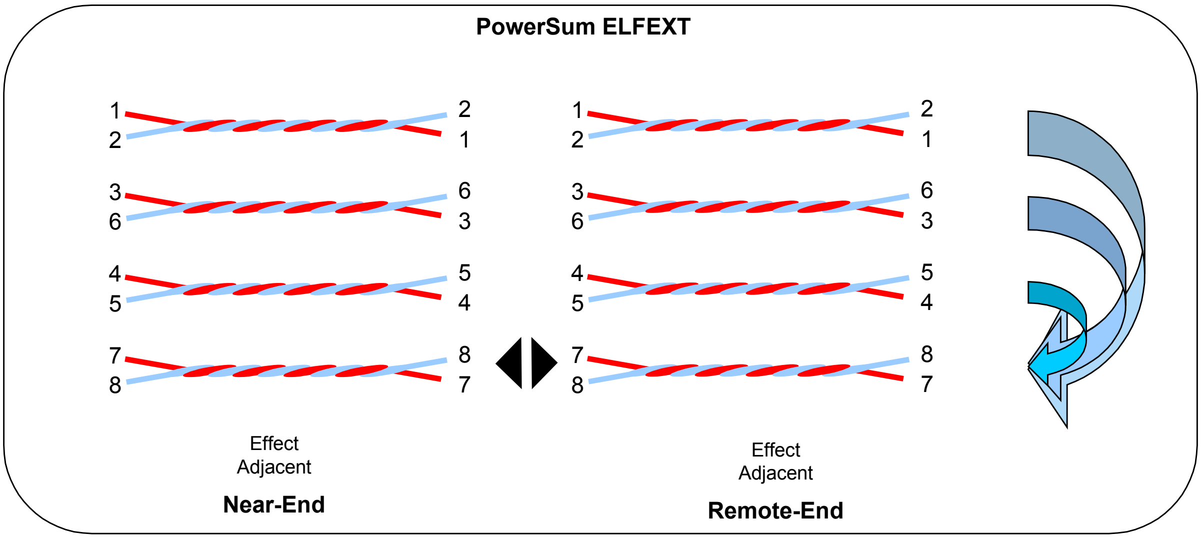


Figure 5.9: Power sum ELFEXT measurement

5.2.1.11 Delay and skew test

Delay and skew are measurements regarding the time that it takes for a test signal applied to one end of the cable to reach the other end. Delay measures the time delay on a specific pair, and skew relates that measured delay to the worst case pair within the cable.

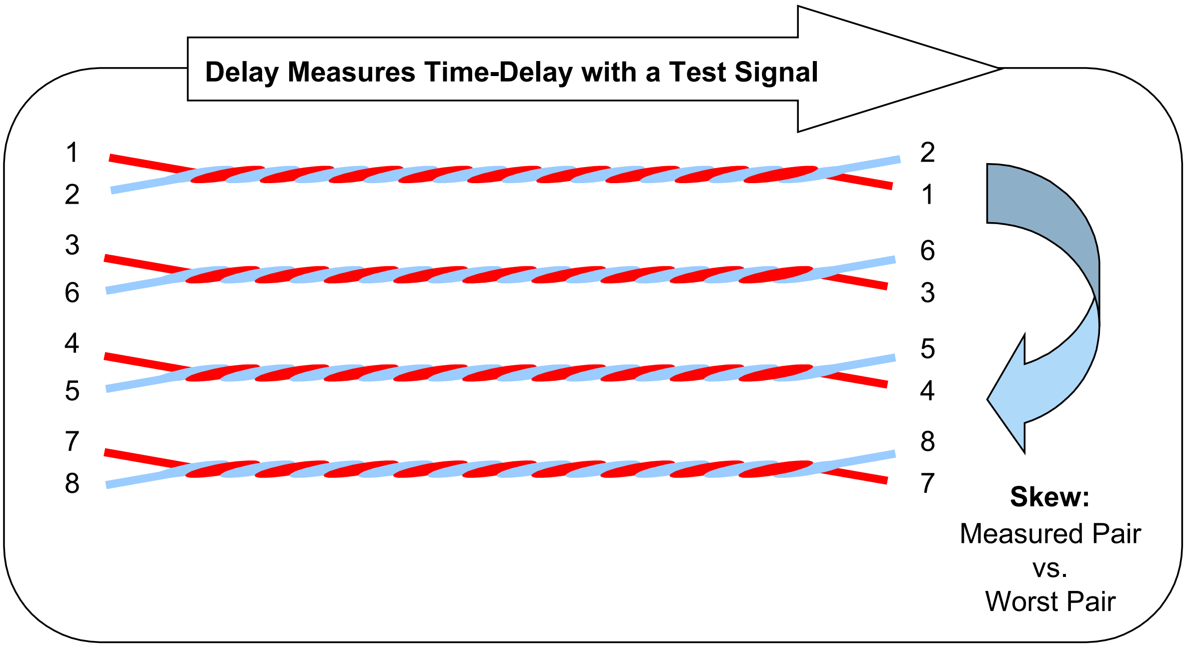


Figure 5.10: Delay and skew measurement

Cable structural integrity

Today's data circuits are very sensitive to irregularities in the physical media caused by kinking, stretching, binding, and general rough handling. While tying a knot in a toaster cord is okay, in a LAN circuit it can cause a small impedance mismatch, that affects the clarity and timing of the transmitted signal. Wire pairs in a typical Category 5 cable are comprised of two insulated conductors very tightly twisted around each other. It is imperative that the integrity of this twist be maintained throughout the entire Category 5 link to ensure performance through 100 MHz.

Problems in Category 5 installations such as excessive attenuation or near-end crosstalk that can be attributed to the cable are usually because the structural integrity of the cable has been compromised. The transmission media's quality is based upon the complex interrelationship between the conductors, conductor pairs, pairs within the sheath, and the insulation material.

Stretching, a common issue, can actually cause the wire thickness to change, thus providing less available signal path and, therefore, increased attenuation. This change in thickness of the copper conductor is not a regular occurrence and results in irregular portions of the cable being alternately thin, then normal.

When analyzed with a TDR, a trace resembling an offset sine wave is produced.

Abnormal geometry caused by stretching reduces the cable's designed immunity to attenuation, Return Loss and ELFEXT.

Kinking of the cable is occasionally difficult to avoid, especially with some of the current plenum (fire-resistant, usually coated with Teflon or equivalent) varieties of Category 5 TP. Tight radius bends cause similar problems. EIA/TIA 568-B standard requires that all category 5 cable installations maintain a minimum bend radius of no less than one inch in diameter. Impedance mismatching and excessive NEXT are two situations that can arise from a kinked cable. An impedance mismatch occurs because the cable is so tightly bent that the relationship between the conductors is disturbed, resulting in fluctuating capacitive and inductive characteristics at that particular point.

Binding occurs when the cable is pulled tightly around a sharp object such as a support beam, hanging ceiling hardware, or ventilation equipment. Damage can range from a slight flattening of the cable pairs to complete sheath destruction and removal of individual conductor insulation. Since all installed cable runs are less than or equal to 100 meters, a good rule of thumb is to stop pulling and guide the cable around intrusive objects if you find yourself really leaning into a particular pull. Problems caused can range from mildly excessive crosstalk to open and shorted conductors.

5.2.1.12 Connecting point issues

Until recently, the cabling itself was thought to be the primary cause of NEXT interference. Current manufacturing techniques, however, are producing very consistent, tightly twisted media that are capable of handling extremely high frequencies with minimal NEXT coupling. At issue today are the modular connectors and termination facilities. These are the points in the link at which the cable structural integrity is compromised to allow an interface to active or passive interconnect hardware (i.e., patch panels or hub/concentrators). The cable will sometimes be untwisted and spread apart a certain amount to allow connection to a plug, jack or punch-down block causing minor impedance mismatches and structural variations at these points. These connecting points are normally implemented using IDC (Insulation Displacement Connectors) style connectors. As of this writing, designs have been verified on an improved version of the original "66" (vertical orientation) style punch-connect termination block that exhibits category 5 compliance. Most terminations, however, are connected to "110" (horizontal orientation) style IDC blocks or on the back of patch panels on "110" style IDC connections. Connecting block devices that comply with category 5 performance criteria are available from many manufacturers and in configurations that differ from the "66" and "110" styles mentioned above.

As mentioned earlier, the EIA/TIA 568-B requires pair twists to be 1/2" or less of the termination point for a Category 5 compliant link. Care must be taken to insure that this limit is observed to minimize the susceptibility to NEXT interference at higher frequencies. Since each mating connecting point (i.e., plug and jack) adds 1" of untwisted cable to the overall link, cross-connects must be limited to one only, and patch cables to a maximum of two per any one horizontal cable segment.

Very simply put, the more connecting and termination points that exist, the more susceptible the system will be to interference and signal degradation.

It is recommended that the cable sheath be preserved as close to the connecting point as possible to maintain the inter-pair relationships (referred to as “cable lay") designed into the cabling. Previous installation practices where the sheathing was removed from several cm or meter of the cabling, severely impair the cable's ability to reliably transmit and receive high frequency signals.

5.2.2 Fiber optic cabling

5.2.2.1 Differences between singlemode and multimode fiber

There are many types of fiber used today in a variety of network environments. Multimode fiber is the type typically used in LANs with a 50/125 or 62.5/125 µm (micro meters = one millionth of a meter) core/cladding rating. Four multimode fibers have been used in datacom systems: 50/125, 62.5/125, 85/125 and 100/140 but 62.5/125 fiber has become dominant in the U.S.A. and 50/125 in Europe. 62.5/125 fiber was chosen as the preferred fiber for FDDI and ESCON. Multimode fiber used in LANs typically operates in two basic wave-lengths (850 nm and 1300 nm). Multimode fiber uses LED (light emitting diode) technology to transmit the optical signal allowing for significantly less expense and power consumption than with single-mode fiber. Multimode LEDs consume only tens of Milliwatts of power as compared to the greater than 100 mW required by singlemode lasers. In addition, the connector technology for multimode is significantly less expensive than for singlemode, because the parameters for launching the light into the fiber require less precision.

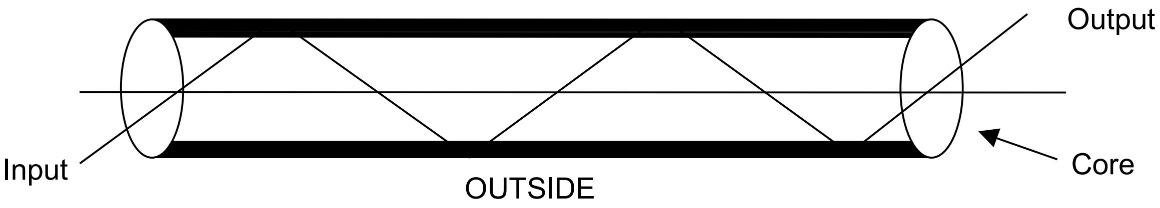


Figure 5.11: Light guiding principle of multimode fiber

In multimode installations, the optical signal is transmitted along the length of the core and the cladding is an outer covering with a lower refractive index.
The cladding redirects the fiber pulse towards the center, a process known as propagation. With multi-mode fiber, there are many different modes transmitted and this can be more easily understood if you think about light transmitted down the center, light transmitted (angled) towards the cladding (higher mode), and light transmitted towards the core (lower mode). These pulses are sent in a manner that the different modes of a signal actually arrive at the other end at different times and the maximum delay is limited to 15 to 30 ns (nanoseconds = one billionth of a second), hence the name multi-mode.

Single-mode fiber has its application in backbones and inter/intra building connections for LANs. In single-mode the fiber core is so narrow that the light can take only a single path down the fiber, thereby increasing both the bandwidth and the difficulty with accurately launching the light into the fiber. Single-mode fiber core/cladding size is 8.33/125 µm, which greatly restricts modal dispersion and increases propagation efficiency. Coupled with the higher power of laser light sources, the efficiency of single-mode fiber can extend link distances up to 3000 km. Long haul carriers use single-mode fiber for the trunk lines connecting cities to one another and typically can go from 60 - 80 km without using repeaters. The bandwidth throughput is almost unlimited for single-mode and many users pull single-mode fiber with the multi-mode and leave it disconnected until a future application can use its capabilities. One primary drawback for single-mode fiber is the cost of the electronics, mainly the requirements for expensive lasers. Another drawback is that the core is about seven times smaller than its multi-mode counterpart, so termination and splicing of single-mode require more training and proper tools.

5.2.2.2 Loss budget

Loss budget is the measured loss of the installed fiber link in both directions, summed and averaged. Primarily used by installers, this budget figure is compared to a computed maximum loss budget to determine the quality of the link. System designers then use the loss budget figure to compute their final margins of power budget. The original "paper calculations" and blueprint estimates for the system must then be updated with "real measurements" and documented on "as-built drawings" in order to ensure that the deployed net-work system can live within the actual fiber links' loss budget.
Loss budget is the primary benchmark measurement for fiber optic cable installers. In some cases the maximum permissible loss budget is pre-calculated and specified in the drawings by the system designer. In this case, the maximum limit for loss only needs to be used by the installer as the pass/fail demarcation point. However, in many cases the installers must determine the loss budget themselves and then stay below the calculated maximum loss figure during the testing phase in order to verify a fiber optic link is satisfactory.

Standards for optical loss budgets

Losses in fiber optic signals are measured in dB (decibels), and each component in a link (cable, connectors, splices, couplers, and patch cords) contributes to the overall loss. This overall loss is often referred to as the Optical Loss Budget (OLB).
Fiber testing methods and procedures are specified in EIA/TIA 568-B, and is entitled "Optical Fiber Link Performance Testing". This Annex document is informative in nature and defines the minimum recommended performance testing criteria for an optical fiber cabling system installed in compliance with the standards. It provides users recommended field test procedures and acceptance values.

The fiber link is defined as the passive cabling network which includes cable, connectors, and splices (if present) between two optical fiber patch panels. The single primary performance parameter that is measured when testing fiber is link attenuation or power loss. Bandwidth and dispersion are important factors but because they cannot be affected by installation practices, they are tested by the fiber manufacturer and not in the field.
The EIA/TIA 568-B Standard lists the following parameters as link attenuation coefficients, which are considered as the maximum allowed loss values in dB/km.

fiber type	**wavelength**		
	850 nm	**1300 nm**	**1310 nm**
62.5/125 µm	3.75 dB/km	1.55 dB/km	
9 /125 µm			0.50 dB/km

Table 5.5: EIA/TIA 568-B link attenuation coefficients

The standard also specifies connector and splice attenuation maximum loss values:

Connector Attenuation (dB) = number of connector pairs • connector loss (dB)

(Each mated connector pair = 0.75 dB loss)

Splice Attenuation (dB) = number of splices • splice loss (dB)

(Each splice loss allowance is 0.3 dB)

Based upon these values, each fiber type can support varying lengths (distances) because the link loss attenuation formula for the fiber cable can be referenced as a value of dB/km, with any length less than or more than one km being shown proportionately. For example, the following table shows calculated attenuation for various cabling lengths of 62.5/125 µm fiber (assuming two connector pairs).

wavelength	**cable length**			
	500 m	**1000 m**	**1500 m**	**2000 m**
850 nm	3.2 dB	5.2 dB	7.1 dB	9.0 dB
1300 nm	2.3 dB	3.0 dB	3.2 dB	4.3 dB

Table 5.6: calculated attenuation for various cabling lengths of 62.5/125 µm fiber
Note: these values are approximate and extrapolated from EIA/TIA 568-B, Annex H Optical Fiber Performance Testing; numbers do not include any splice loss. Add 0.3 dB for each splice in a link.

Some networking protocols are less tolerant than others and require much lower loss limits. One should take care that respective design, installation and test parameters are correct. For instance, many users have been unaware of the importance of loss budget calculations because their systems have been operating with older technology, thereby allowing the higher link losses. Now that newer high-speed technologies such as Gigabit Ethernet and Fiber Channel allow for much less loss tolerance, system designers must be much more cognizant of their overall loss budget and the impacts of link attenuation factors.

5.2.2.3 Fiber optic test tools

Fiber optic components are sensitive to physical stress that can actually induce additional loss factors. The mere physical movement of fiber optic cables and connectors can have measurable negative effects on fiber optic assemblies. For instance, a simple bend in single-mode fiber cable can induce several dB of loss. Just handling fibers to make measurements can cause readings to vary by several tenths of dB. After installation, the cumulative effect of handling, splicing, adding connectors, etc. typically results in a very complex set of factors that impact the fiber link's overall transmission characteristics.
Therefore installers need a full range of tools that efficiently support everything from conducting a quick test of fiber prior to installation to rigorously testing a variety of different long and short haul fiber links after installation.

5.2.2.3.1 Basic fault finders

Visual faultfinders provide a quick and inexpensive way to check cable prior to investing in the time and expense to install it. These instruments consist of a simple light source, such as a laser diode, that injects a highly visible red light into the cable, using either a continuous or pulsed mode. Because the light will "leak out" wherever there is a fault in the fiber jacketing due to kinks or breakage, the operator simply observes the cable for the presence of a steady or blinking red light in order to pin point the fault. Visual faultfinders can be used to check either multi-mode or single-mode cabling to lengths as long as 5km (3 miles). In addition to checking and verifying raw fiber cabling, visual faultfinders can also be helpful in locating faults for installed cabling when used with other test methods. Visual faultfinders can be especially effective at spotting the high percentage of breaks that typically occur within a few meters of the connectors.

5.2.2.3.2 Power loss meters

Equipment for measuring power loss essentially consists of an optical power source and a power meter. If relatively simple testing needs to be accomplished at a single wavelength, such as 850nm, an installer can simply invest in small, low-cost, pre-calibrated power sources and meters. These basic units typically provide a simple bar-graph readout of power loss, such as -2dBm increments, for quickly assessing the attenuation characteristics for a fiber link at the specified wavelength. For repetitive testing of a series of similar links, these devices can be a very cost-effective and easy-to-use alternative to higher end test capabilities, however they have the inherent disadvantage of lacking flexibility to test different wavelengths.

On the other end of the scale are full-featured programmable power loss meters and light sources that allow the operator to quickly switch between different wavelengths and to calibrate the meter reading precisely to the power output of the light source. The ability to stimulate and measure power loss for both multi-mode and single-mode fiber links at a variety of wavelengths and power levels make these instruments popular with installers that have to handle a wide range of fiber requirements. In addition, the ability to store many different readings and test settings in the device's local memory can be significantly helpful when testing a variety of different links.

5.2.2.3.3 Add-on fiber kits for copper test equipment

Of course, the investment in standalone high-end dedicated fiber test instruments can sometimes be prohibitive for installation contractors who are incrementally migrating from copper to a mix of copper and fiber LANs for their customers. In these instances, the use of add-on fiber accessory kits for existing copper cable test sets has become a very cost-effective alternative that provides most of the capabilities of a high-end fiber test device at a fraction of the cost. For example, an inexpensive add-on fiber kit can provide power source and metering capabilities to test both multi-mode and single-mode fiber while leveraging the existing measurement capability, display and memory of a copper-based test device. In addition to minimizing incremental equipment expense, many installers also find that the use of add-on fiber accessory kits significantly cuts down on re-training costs because their technicians don't have to learn a whole new device.

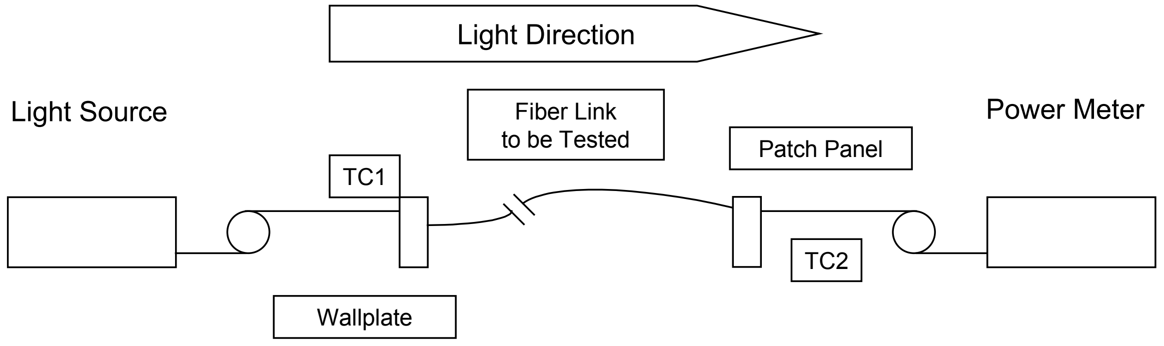
5.2.2.3.4 OTDR testers

Optical Time Domain Reflectometers (OTDRs) can be very valuable devices for checking longer-haul fiber links and/or complex LAN configurations, especially those with a number of splices and connections. Essentially, an OTDR injects a pulse of laser light into the fiber link and then samples return signals from the pulse over a specified time domain. Because any optical fiber exhibits a certain degree of backscattering, the reflected signal can be analyzed in the OTDR to provide an accurate representation of the link's performance characteristics over given distances. Individual events on the link, such as end-points, splices and connectors, can be identified and located, based upon the return time required for their reflected signal from the originating light pulse.

Because the OTDR is operated from only one end of the fiber link, a single operator can efficiently use it, whereas typical power loss measurements require a source at one end and a meter at the other. It can readily measure splice loss, cable attenuation and optical return loss for the full link or any point along it, thereby identifying overall link length as well as the existence of and distance to any discontinuities, such as breaks, splices, kinks, etc. Because OTDR information can be displayed in a comprehensive graphical representation, it can visually identify anomalies along the link that might not be apparent with other testing methods. For example, a link might meet the overall specifications for link loss, continuity, etc. but might still contain a number of point discontinuities (e.g. 0.2 or 0.3 dB) that could degrade its actual performance. Most OTDR devices also include built-in software algorithms that automatically analyze the link to high-light and pin-point the location of any threshold optical discontinuities that can impact performance.

5.2.2.4 Optical power loss measurement procedures

Once the application's OLB has been determined and the fiber has been installed, the link must be tested for compliance. The standards are very specific in how a fiber link is to be tested and recommends use of the OFSTP-14-Method B for an insertion loss test.
Current standards only require backbone fiber cabling to be tested in one direction at both operating wavelengths. Multi-mode links should be tested at 850 nm and 1300 nm and single-mode links should be tested at 1310 nm and 1550 nm in accordance with EIA/TIA 526-14-7.
Horizontal fiber links (fiber cabling from the patch panel to work area outlet) only need to be tested at one fiber wavelength because of the short length of cabling allowed (90 meters or less for the permanent link).



Link Loss = link in the wall loss + two connector losses + Test Cable 2 loss

(TC2 loss adds error of 0.04 dB @ 850 nm and 0.004 dB @ 1300 nm)

Figure 5.12: Optical power loss measurement

However it is important to note that going the extra step to test fiber strands at both wavelengths and both directions increases the predicted reliability of the link's performance. Remember, the standards are only minimum guidelines and by adding fiber testing in both directions, the installer can find all connections in a link that might be marginal.

5.2.2.4.1 Calculating maximum loss budget

The calculated maximum loss budget is developed by summing the maximum expected losses for each connector, splice and the cable's loss by length and wavelength. All these maximum loss specifications are available from the component or cable manufacturers. Cable is generally specified in maximum loss per kilometer (3280 feet), and the specification is different for respective light wavelengths. In multi-mode applications for LAN this often is a very simple task. Most links will be made up of a single cable with one connector on either end.

5.2.2.4.2 Measuring link loss

Once calculated, your maximum loss budget is now your PASS/FAIL demarcation point. Links measuring more loss budget than the amount calculated need troubleshooting to determine what is causing the excessive loss. Links with a measured loss budget lower than the requirement will pass, but need to be as to their measured values. In some cases, the values may only signify a marginal pass margin over and above the specified loss budget. Once the values are known, one can keep a close watch over the ones that are marginal and post them for regular maintenance.
To obtain accurate test readings, the power meter's reference level must be checked and set prior to testing. Setting the reference level means establishing the zero dB reference on which all the measurements are based. The actual readings of light received by the power meter are in dBm. The "m" indicates this reading is referenced to one milliwatt of power. Since the light sources rarely output zero dBm, and there are losses in the launch cable(s) and connectors, a reference dBm level is subtracted from each reading to obtain the relative dB readings. To obtain accurate loss testing information the reference levels for the Light Source to Power Meter should be set daily, using the equipment manufacturer's guidelines. Reference settings should also be checked with every battery change or anytime the launch cables are changed.
With all the preliminaries out of the way (reference levels and setup complete), the fiber optic links can be physically tested by connecting the light source at one end of the link and the power meter at the other end of the link to take comparative measurements. It is important to remember that this measurement will include everything between the source and the meter. If additional launch cables and/or connectors are added that were not used during calibration (reference level setting) these are

part of the system under test. Most test equipment uses ST type connectors and a hybrid ST to SC jumper may be required for those installations that use the SC connector recommended by the cabling standards.

While there is no specific order for performing the tests, most technicians prefer starting with the shorter light wavelength (850nm for multi-mode or 1310 nm for single-mode), then measuring the longer wavelength. The logic behind this is that the shorter one is generally more forgiving and produces a passing result more easily. In either case, the cable should be measured at both it's rated light wavelengths and in both directions.

5.2.2.4.3 Why measure both light wavelengths?

Because different wavelengths react differently to bends, splices and connector gapping. As an example - an 850 nm light wave will go around a bend like a sports car, but a 1300 nm light wave corners more like a semi-tractor trailer rig. An excessive bend may not show any significant loss at 850nm, but could show unacceptable loss at 1300nm. The only way to be sure the fiber will work at both light wavelengths is to test it at both light wavelengths.

5.2.2.4.4 Why measure in both directions?

EIA/TIA Standards don't require bi-directional measurement for backbones, but one must keep in mind the way light reacts across connectors. The fact that a light wave traveling from east to west through a connector exited on a polished end and entered the other with minimum loss does not guarantee it can cross this gap in the opposite direction equally well. The polished faces and alignment of the connectors is crucial to bi-directional performance. The only way to be sure the bi-directional performance is acceptable is to measure the fiber link in both directions. This will result in two measured values per strand, per wavelength. In addition, future technologies will most likely use the longer wavelengths because they support more bandwidth.

Most full-featured power meters will automatically compare the test results to the "Budget Loss" maximum entered earlier. If the measured loss is less than the maximum the instrument will immediately provide a PASSED or a FAILED indication.

5.2.2.4.5 Loss measurement test results documentation

Once the testing is completed there is always the paperwork to finish the job correctly. While requirements for documenting the test results will vary with different jobs, it is imperative to produce a clear record of how well each fiber optic link worked at the time of installation. Many available test instruments provide for storing, printing or PC uploading test results. In addition to this record, it is also strongly recommended that the original blueprints for the fiber link's installation be annotated with "As Built" notes including the loss measurement results. These records can prove invaluable at a later date for making moves, adds and changes (MACs) or repairing damaged cable. Refer to EIA/TIA 606 for full documentation references.

5.2.2.4.6 What causes failing loss measurements?

In essence, fiber links fail because too much of the light that has been injected at one end fails to reach the other end because it has been lost through either reflection or absorption. Reflected light never reaches its destination as it is reflected toward the source. Absorption of the light by the fiber optic cable reduces the amount of light at the destination.

While some absorption is normal and allowed for in the loss budget, excessive absorption can be caused by poor connector alignment, excessive bends in the cable, poor splice alignment, and/or cable manufacturing defects. On the other hand, the primary causes of reflection include poor connector polishing, poor connector alignment, dirty connector ends, and/or broken or cracked fiber cable.

One other cause for failing a loss measurement test is by gaining light. Since this is not possible under the laws of physics, it is normally attributed to a procedural error. The result is a test measurement value greater than the zero dB reference, which in most cases is caused by removing one or more launch cables that were used during the calibration (reference setting) phase. Typically the cable that causes this error is the one attached to the light source because it is the most critical to set the amount of light transitioned from the source's LED into the fiber optic cable's cone of numerical acceptance (NA). If this cable is dirty, reversed after setting the reference levels, or disconnected and reconnected at the source, this can change the initial amount of light entering the cable and make the stored reference level invalid. Another error is setting the reference level too quickly after turning on the light source. As the LED warms up it increases the amount of light output. Most sources need only one to two minutes turned on for the LED to reach peak output. In either of these cases, re-calibrating the reference level will correct the problem.