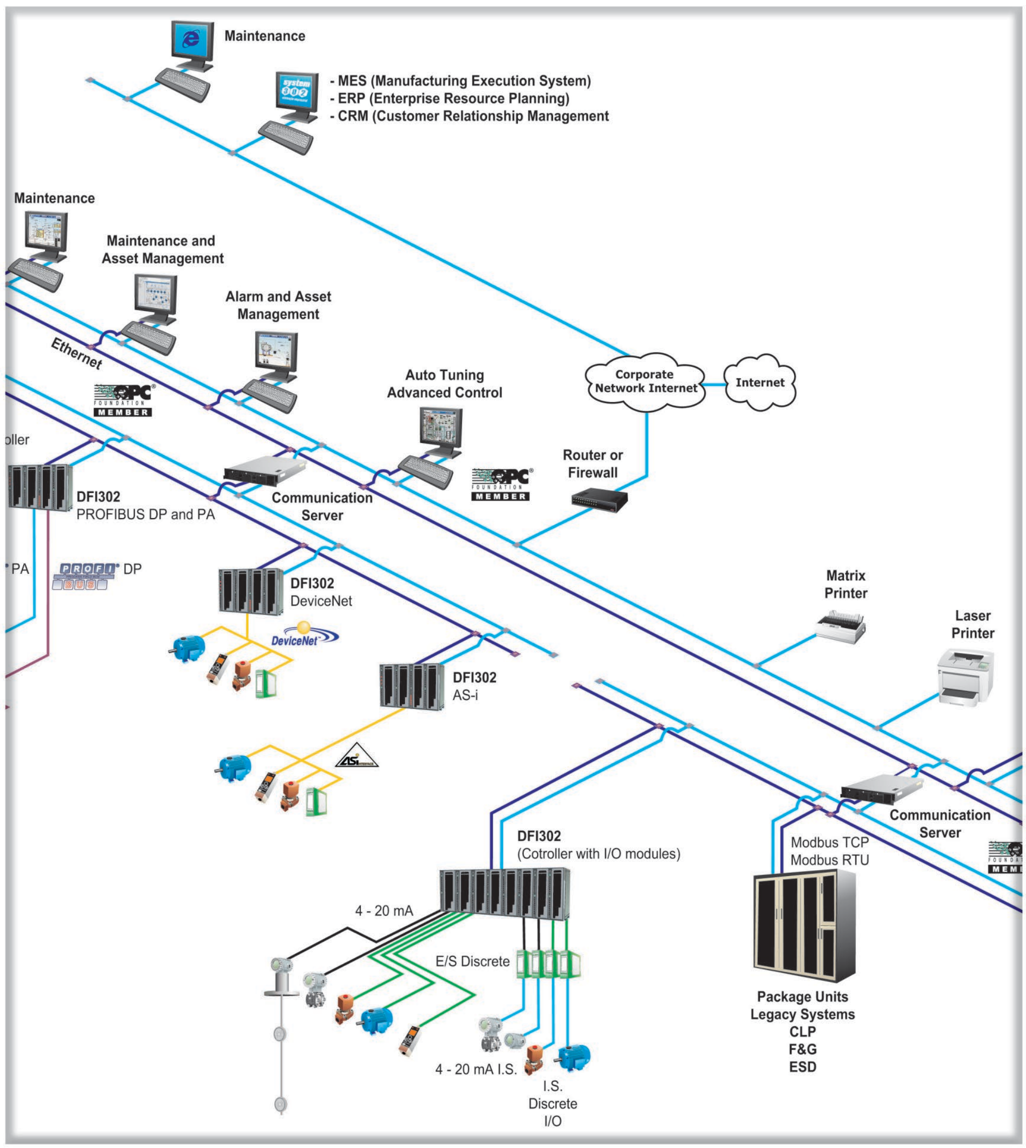
smar - SYSTEM302

INSTALLATION GUIDE

Electric Installation Guide



OCT / 22

SYSTEM302

SYS302I EGE

smar
NOVA SMAR S/A
www.smar.com.br

INTRODUCTION

This manual was prepared for users of the SYSTEM302 services and platforms and intends to offer the **General Procedures for Installing Smar Industrial Automation Systems**, including Field Devices, Programmable Controllers, I/O Modules, Operator Interface Terminals and Communication Networks.

It serves as an electric installation guide and covers the care to be applied against Electromagnetic Interference (EMI) and transients, which may cause inconvenient disturbances in an industrial automation system. The functional and features of a given product should be found on its specific manual.

IMPORTANT

These procedures are not intended to replace the local electrical regulations.
Although these rules apply to most installations, some severe electrical surroundings may need additional precautions.
Recommendations to avoid problems with Electrostatic Discharges (ESD):

- Always ground yourself before touching the electronic circuit, to avoid electrostatic discharge that may damage the equipment;
- Keep the doors of the modules closed when in operation;
- The equipment maintenance must always be carried out by a trained technician when the equipment is energized.

This section also presents categories of devices and cables, and the positioning and classification of cables, as they are included in the system general installation and do not depend on any specific network or equipment.

Electric Installation Guide Structure

This guide is subdivided in sections. Each one of them covers a given subject that many times can be applied generically to the system.

The Digital Networks section presents a more specific and detailed approach on electrical installations and good practices for industrial installations related to the System302 architecture.

Each section structure is described below.

Section 0: includes cover, introduction, list of symbols and abbreviations, and the general index to this guide.

Section 1: presents information on Plant Grounding (equipotential grounding, floating grounding, isolated grounding, etc.).

Section 2: refers to the installation, mounting, grounding and panels' power distribution.

Section 3: presents a detailed and specific outlook for Digital Networks.

Categories of Cables

All cables and wires must be grouped into the three categories described on Table 1. Refer to each input and output module specification to individually classify the cables in the correct category.

CATEGORY	DESCRIPTION	EXAMPLE
Category 1	**Control and AC Power Supply:** High-power cables that are more tolerant of electrical noises than the cables in Category 2. They may also cause more noise induced on the adjacent cables.	• AC power lines for power supplies and input and output (I/O) circuits; • High-voltage digital ACI/O lines connecting AC I/O modules rated for high voltage and high noise immunity; • High-voltage digital DC I/O lines connecting DC I/O modules rated for high voltage or with input circuits with long time-constant filters, for high noise rejection. They typically connect dry contact switches, relays, and solenoid valves.
Category 2	**Signal & Communication:** Low-voltage cables that are less tolerant of noise than the cables in Category 1. These cables should cause less noise induced on the adjacent cables (they are connected to sensors and actuators relatively close to the I/O modules).	• Analog I/O lines and DC power lines for analog circuits; • Low-voltage digital AC/DC I/O lines connecting I/O modules that are rated for low voltage, such as low-voltage output modules; • Low-voltage digital DC I/O lines connecting DC I/O modules that are rated for low voltage and have input circuits with short time-constant filters to detect pulses. They typically connect to devices such as switches, photoelectric sensors and encoders; • Communication cables interconnecting CPUs or connecting communication interface modules; programming terminals; computers; HART, PROFIBUS, Fieldbus, Modbus, AS-I and DeviceNet networks etc.
Category 3	**Inside the panel:** Cables interconnecting internal system components.	• Low-voltage DC power cables, power cables for racks; • Communication cables interconnecting system components inside the same panel.

Table I – Groups of Cables

Cable Routing

To reduce coupling noise from one cable to another, physically separate noisy wires (AC power cables and digital output cables) from low level lines (analog input and output cables and communication cables).

Follow the procedures in Table 2 when routing wires and cables inside and/or outside of a panel.

CATEGORIES	PROCEDURES
Category 1	• These cables can be routed in the same cable tray or conduit with machine power cables of up to 600 VAC (powering up to 100 HP devices).
Category 2	• If these cables must cross power feed lines, they should cross at right angles; • A minimum 1.5 m gap should be kept from high-voltage panels or radiofrequency/microwaves radiation sources; • If the cable is in a conduit, each conduit segment must be connected to the adjacent segment to provide continuity along its entire length, and must be connected to the panel at the entry point; • Properly shield (where applicable) and route in a conduit separate from the category-1 cables; • If **in an adjacent metallic conduit**, keep a minimum 3-in distance from category-1 cables of less than 20 A; a minimum 6-in distance from AC power lines of 20 A or more, but up to 100 kVA; and a 1-ft distance from AC power lines of greater than 100 kVA; • If **not in a continuous metallic conduit**, keep a minimum 6-in distance from category-1 cables of less than 20 A; a 1-ft distance from AC power lines of 20 A or more, but up to 100 kVA; and a 2-ft distance from AC power lines of greater than 100 kVA.
Category 3	• Route cables in conduits separated from category-1 cables with the same gap listed for category-2 cables, where possible.

Table 2 – Procedures for routing noise-protection cables

⚠ IMPORTANT
1. These procedures are for noise immunity only. Follow local regulations for safety requirements. 2. These procedures assume that the user follows the instructions on surge suppression described on section **"Plant Grounding",** in this manual. 3. Although these rules apply to most installations, some electrically harsh environments may require additional precautions.

ABBREVIATIONS

A: *Ampere singular and ampere plural unit* (In homage to French scientist André-Marie Ampere).
AC: *Alternate* Current.
AI: *Analog Input*.
AO: *Analog Output*.
ASCII: *American Standard Code for Information Interchange*.
AWG: *American wire gauge.*
BT: *Bus Terminator*.
BTA: *Barra de Terra de Sinal.*
BTC: *Housing Ground Bar.*
C: *Capacitor.*
CAT5e: *Category 5 Enhanced Cable*.
CCM: *Motor Control Center.*
CPU: *Central Processing Unit*.
CSMA/CD: *Carrier Sense Multiple Access with Collision Detection*.
D: *Diode.*
DC: *Direct Current*.
DD: *Device Description*.
FF: *FOUNDATION™* Fieldbus.
E/S: *Input/Output.*
ESD: *Electrostatic Discharge*.
EMI: *Electromagnetic Interference*.
FISCO: *Fieldbus Intrinsically Safe Concept*.
ft: *feet* (1 ft = 0,3048 meters).
FNICO: *Fieldbus Non-incendive Concept.*
FTP: *File Transfer Protocol*.
Gbps: *Gigabits per second.*
GND: *Ground circuit.*
GSD: *Generic Station Description Files.*
HART: *Highway Addressable Remote Transducer*.
HDLC: *High-level Data Link Control*.
HP: *Horsepower*.
HSE: *High Speed Ethernet*.
HTTP: *Hyper Text Transfer Protocol.*
IEC: *International Electrotechnics Commission.*
IEEE: *Institute of Electrical and Electronic Engineers.*
in: *inches* (1 in = 0, 0254 m).
IP: *Internet Protocol*.
km: *Kilometers*. *(0,621371 mile.*
kV: *kilo Volt.*
kVA: *kilo volt-Ampere*.
L: *Inductance.*
LAN: *Local Area Network*.
m: *meters. (1094 yards).*
mH: *mili-Henry (10^{-3} Henry).*
mm²: *square milimeters.*
Mbps: *Megabits per second.*
MHz: *MegaHertz (10^{6} Hertz).*
OFF: *Turn off.*
Ohm: *Electrical measure unit.*
ON: *Turn on.*
OSI: *Open Systems Interconnection*.
Architectural Model defined in 7 layers: application (layer 7), presentation (layer 6), session (layer 5), transportation (layer 4), network (layer 3), link (layer 2) and physical (layer 1);
PC: *Personal Computer*.
PELV: *Protective Extra Low Voltage.*
PID: *Proportional-Integral-Derivative* (*Action-based control algorithm).*
PLC: *Programmable Logic Controller*.
PSI: *Power Supply Impedance*.
PVC: *Polyvinyl Chloride or Vinyl*.
R: Resistor.

RC: *Snubber* (*Resistor-capacitor circuit).*
RF: Radiofrequency.
RFI: *Radio Frequency Interference*.
RL: Resistor-inductor circuit.
RTU: *Remote Terminal Units*.
SNMP: *Simple Network Management Protocol*.
STP: *Shielded Twisted Pair*.
SW: *Switch.*
V: *Volt (electric voltage unit).*
VAC: *Alternate voltage.*
VCC: *Continuous voltage current.*
TIA: *Telecommunications Industry Association*.
TCP: *Transmission Control Protocol*.
Trilhos DIN: *Module support rail.*
UDP: *User Datagram Protocol*.
UTP: *Unshielded Twisted Pair*.
VLAN: *Virtual Local Area Network*.
Vpp: P*eak-to-peak voltage*.
WAN: *Wide Area Network*.
Watt: *Power unit.*
µF: *micro-Faraday (10^{-6} Faraday). Capacitance unit.*
nF: *nano-Faraday (10^{-9} Faraday). Capacitance unit.*
SPUR: *Main fieldbus derivation.*
STUB: *SPUR derivation.*
SPLICE: *Equipment cable section.*
TRUNK: *Main network fieldbus.*
pF: *peak -Faraday* (*10^{-12} Faraday). Capacitance UNIT.*

TABLE OF CONTENTS

Section 1

PLANT GROUNDING

General Overview

What is electrical grounding?

The term grounding refers to the earth itself or a large mass of earth being used instead. When we say that something it is “grounded”, we mean that at least one of its elements is intentionally connected to the ground. On electrical systems, when voltages are mentioned in general their reference is the ground. Thus, the ground represents a reference frame (or a zero potential reference) from where all voltages are referred to.

What are the objectives of the electric grounding?

The first objective of the electrical system grounding is to protect persons and the assets against a failure on installation (i.e. short-circuit). Grounding should drain off electrostatic discharges accumulated on persons, on the structures, supports and housings of the equipment in general.

The second objective is to offer a safe, controlled, and low impedance path toward the earth for currents inducted by atmosphere discharges.

Basically, a grounding system aims to obtain a potential difference condition equals to zero among the equipment protection conductors, its housings, metal conductors and other conductive masses of a building, including iron structures and metal piping.

How to make a grounding?

In the design of a plant grounding system should be analyzed the physical conditions for each installation, the ground resistivity as well the existing several protection systems.

The forms of grounding are as follow:

- To ground the equipment to the ground of the power supply;
- To ground the equipment independent of the power supply;
- To ground all the equipment in only one point;
- To ground the equipment on an earth reference shield.

What is equipotential ground?

The ideal grounding condition for a plant and its facilities is finding the same potential at any point. This can be achieved by interconnecting every grounding system on the same potential equalization conductor. This condition is called equipotential.

NOTE
To guarantee the equipotential even during the occurrence of electric discharges, please see the section **Grounding the Cables Shielding,** of this guide.

Thus, for any person inside the facilities, even if there is an increase of local voltages, there will not have the risk of an electric shock once all elements will have the same ground potential.

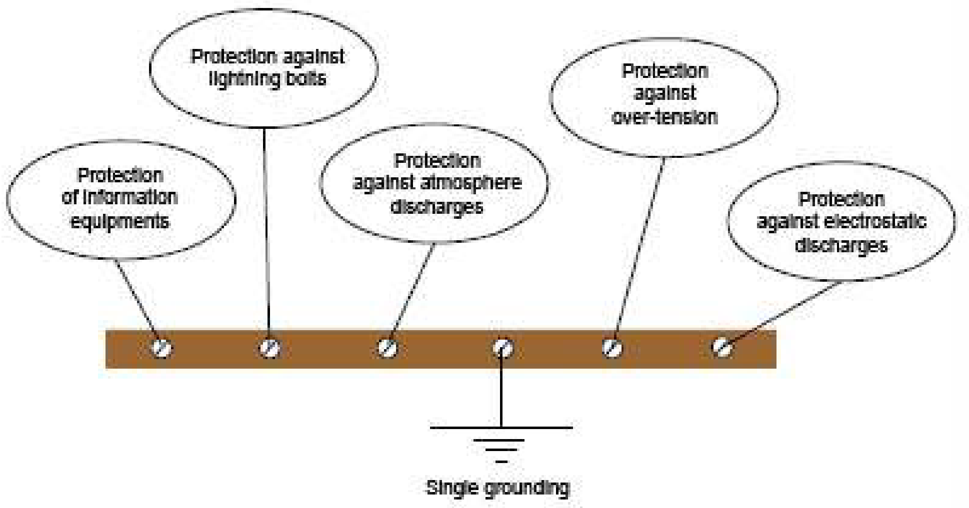


Figure 1.1 - Single grounding for all systems

Cable Shielding Grounding

In a functional point of view, the purpose of cable shielding is to create a capacitive coupling equipotential zone around the cable. But this is true only if the shielding is connected to the equipotential ground referential. In this condition, the recommendation is that both shielding ends be grounded.

However, if the equipotential grounding condition was not guaranteed, it is recommended to ground just one of the shielding ends, preferably on the system side. Otherwise, if the shielding is connected on both ends without grounding equalization, there will be a parasite current across the shielding, which may cause functional problems, besides the addition potential danger of electric shocks on the non-shielded end. Thus, it is recommended the use of an extra insulated shielded cable in the shielding, to avoid accidental electric shocks by contact.

The equipotential bonding system is used to equalize the earth potential at different locations of the plant so that no current flows over the shielding of the cable.

Use copper cables or galvanized ground strips for the equipotential bonding in the system and between system components.

Connect the equipotential bonding to the grounding terminal or bar with a large surface area.

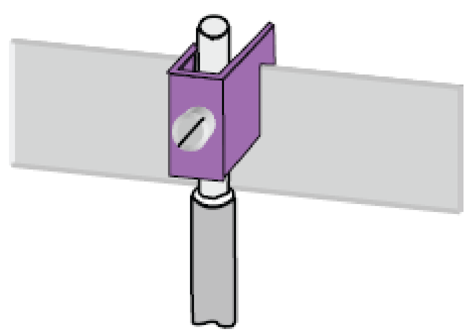


Figure 1.2 – Grounding terminal connection
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6, May 2006.*

- Connect all device shield and ground connections (if available) to the equipotential bonding system.

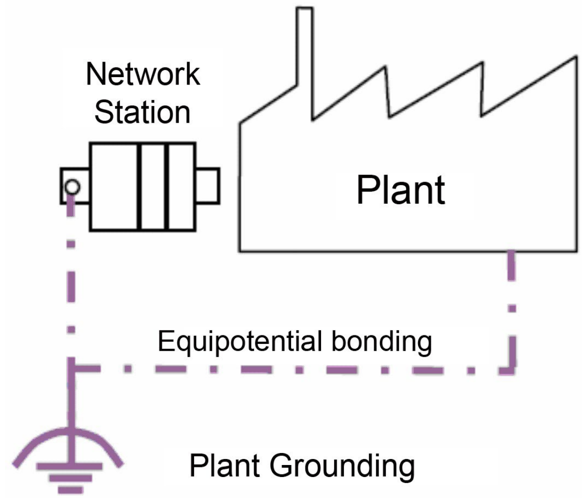


Figure 1.3 - Connection to an equipotential bonding system
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6, May 2006.*

- Connect the mounting surface (for example cabinet panel or mounting rails) with the equipotential bonding system.
- Connect the equipotential bonding system to the building equipotential bonding system as often as possible.

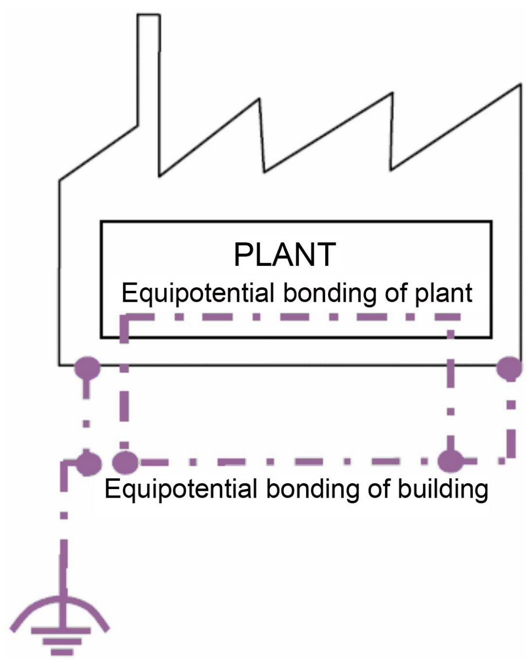


Figure 1.4 – Connection of the network equipotential bonding of plant to the building
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6, May 2006.*

- If parts are painted, remove the paint from the connecting point before the connection.

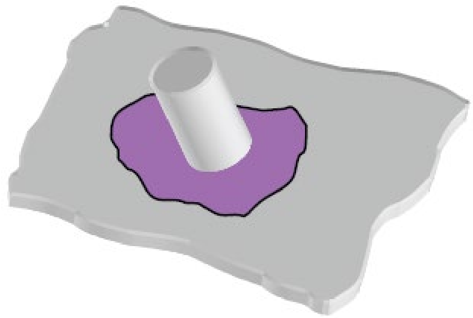


Figure 1.5 - Connection point
Source: *Profibus Cabling and Mounting Installation Procedures, Version1.0.6 – May 2006.*

- Protect the connecting point against corrosion after mounting, e.g., with zinc or varnish paint.
- Protect the equipotential bonding against corrosion. One option consists of painting the contact points.
- Use secure screw or terminal connections for all ground and bonding connections. Use locking washers to avoid the connections becoming loose because of vibration or movement.
- Use wire-end ferrules or cable lugs for flexible equipotential bonding cables. The cable ends should never be tinned (no longer allowed)!
- Route the equipotential bonding as close as possible to the cable.

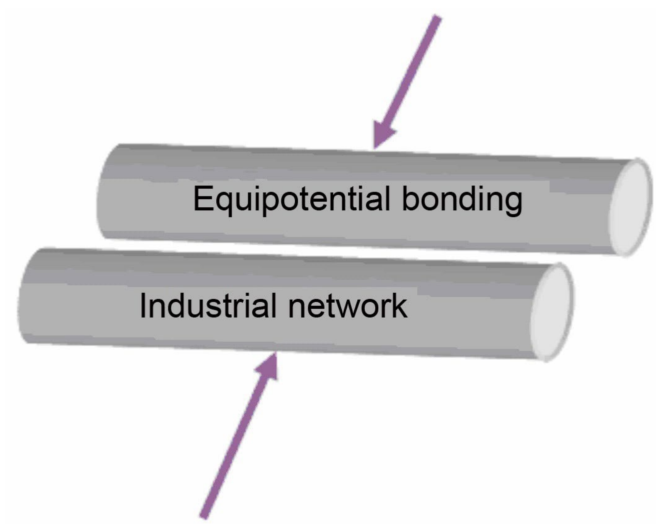


Figure 1.6 – Equipotential bonding routing
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006*

- Connect the individual parts of metal cable trays to each other. Use special bonding links or jumpers for this purpose. Ensure that bonding links are made from the same material as the cable trays. Cable tray manufacturers will be able to supply appropriate bonding links (Figure 1.7);

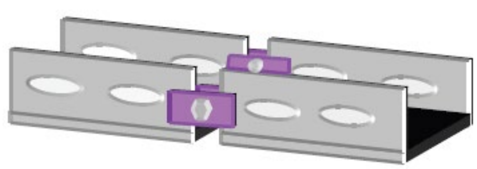


Figure 1.7 - Bonding links connection
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006.*

- Connect cable trays made out of metal as often as possible with the equipotential bonding system.

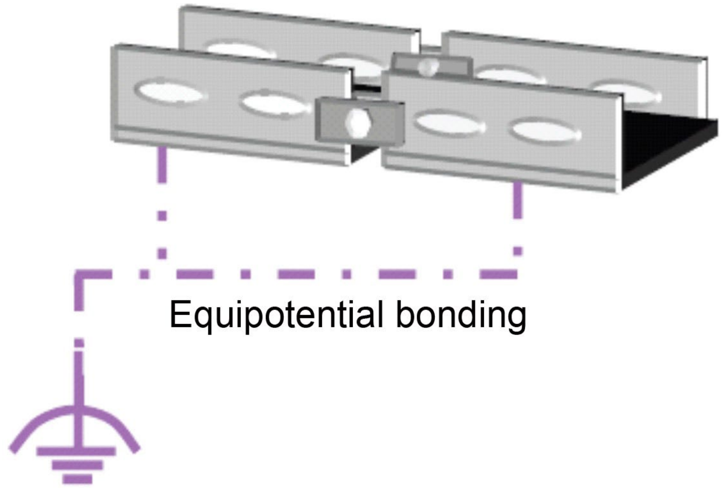


Figure 1.8 – Connection of trays to the equipotential bonding system
***Source*:** Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006.

Use flexible bonding links for expansion joints. Bonding links are available from cable manufacturers.

For connections between different buildings or parts of buildings, you must route an equipotential bonding parallel to the cable (Figure 1.9). Maintain the following minimum cross sections according to IEC 60364-5-54:

- **Copper** 6 mm²
- **Aluminum** 16 mm²
- **Steel** 50 mm²

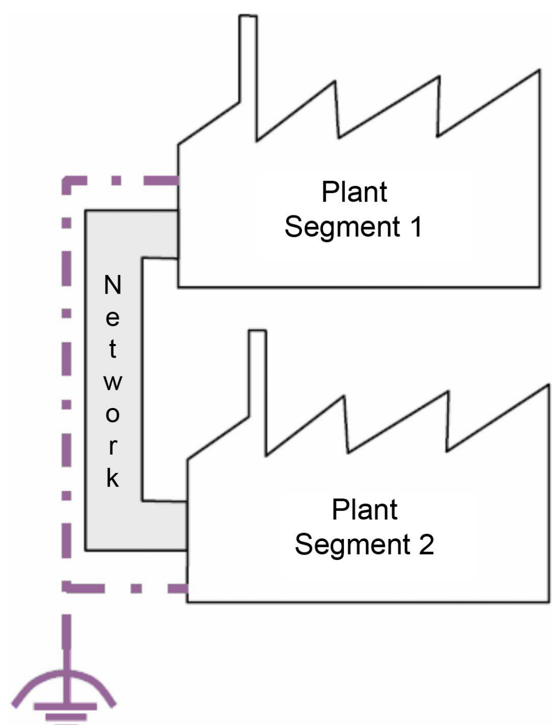


Figure 1.9 – Connection of networks between different buildings
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006.*

Connection of shielding to equipotential bonding

Several options are available for establishing the large-area connection between the shielding and the equipotential bonding system. The following figure shows various techniques that have proved themselves in the field.

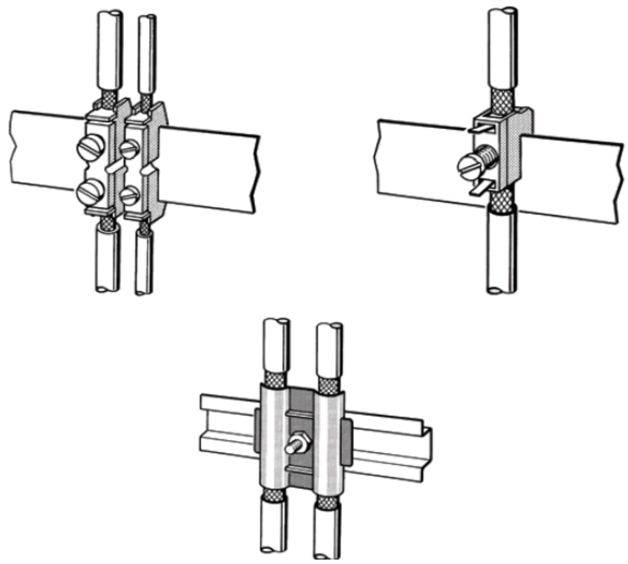


Figure 1.10 - Techniques for connecting the cable shield to equipotential bonding
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6, May 2006.*

ATTENTION
Ensure that the cable is not pinched by the shield connection clamp. Use a shield clamp that fits the cable diameter. Pinching can deteriorate the transmission characteristics of the cable.

The following must be observed when making the shielding connection:

- Only remove the cable outer insulation where required for bonding. cable is weakened where the sheath is removed.

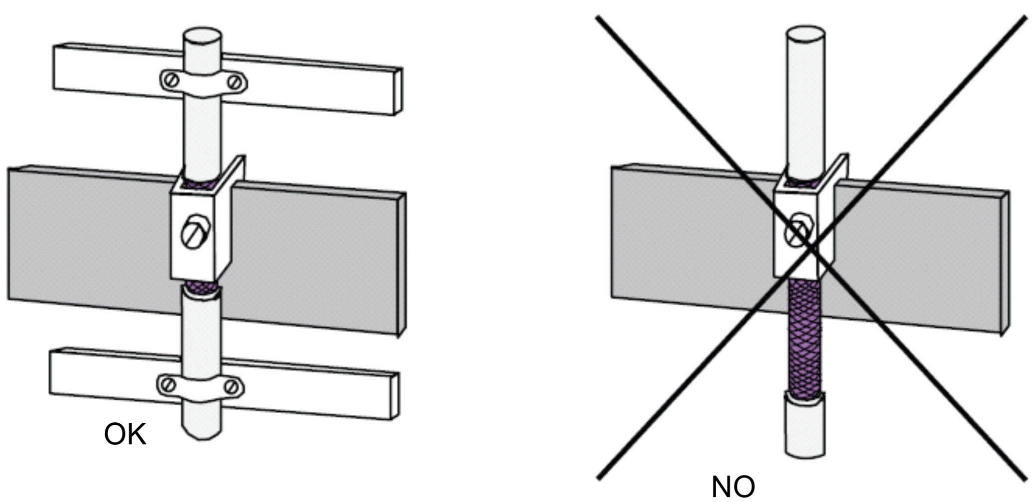


Figure 1.11 – Removal of the isolation cable
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006.*

- Ensure that you do not damage the braided shield when the outer insulation is stripped from of the cable.

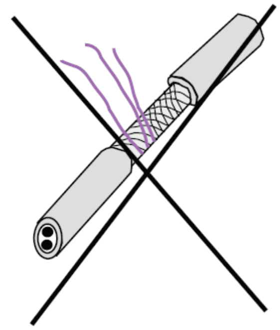


Figure 1.12 – Damages on a twisted shielding
***Source**: Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006.*

- Do not use the shield connection as a strain relief since this may reduce the effectiveness of the bonding and may cause the cable shield to be damaged (Figure 1.13). An exception would be when using parts that are specifically designed for this purpose.

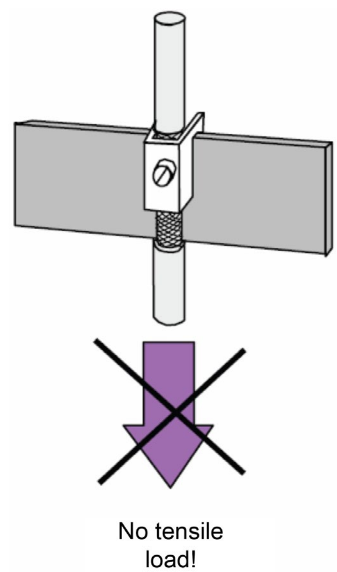


Figure 1.13 – Do not use the shielding connection for voltage discharge
***Source:** Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006.*

- To protect the weakened cable from damage, it should be secured either side of the bonding connection.

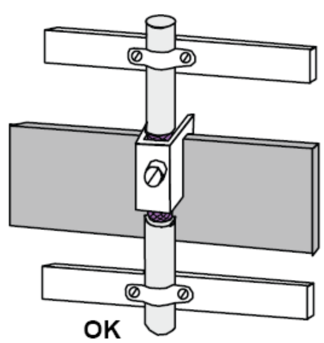


Figure 1.14 – Protection on both connection ends
***Source:** Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006.*

- Use only parts that match the diameter of the stripped cable.

- The connection between the shield and the equipotential bonding must only be made using the braided screen. Many cables also feature a foil screen (Figure 1.15). This foil must not be used for the connection. It is generally synthetically coated on one side to improve stability and the plastic coating acts as insulation.

- Do not attach the equipotential bonding rail to painted surfaces. Galvanized or plated surfaces are well-suited for this purpose.

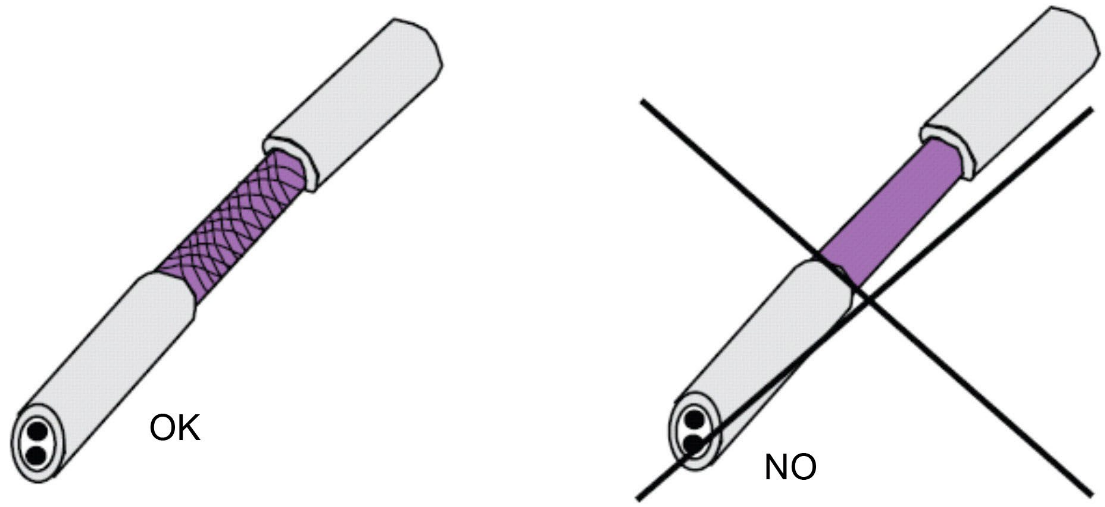


Figure 1.15 – Wire mesh (Ok) and metal plate cover (No)
Source: *Profibus Cabling and Mounting Installation Procedures, Version 1.0.6 – May 2006.*

- Use tinned, galvanized or other galvanically treated material. Ensure the surface is protected against corrosion to ensure a permanent contact.

Section 2

PANEL MOUNTING

General Mounting

Raceway Layout Considerations

Cables layout is based on the position of the different types of I/O modules are placed in the rack. Therefore, users must first establish where locating the I/O modules and then routing the cables direction.

When planning the location of the I/O modules, these must be grouped according to the cable category. By the same token, all AC/DC cables located in the same raceway must be isolated from the highest voltage applied to any cable in the raceway.

Figure 2.1 shows the procedures seen on Table 1.2 of this guide's **introduction** section.

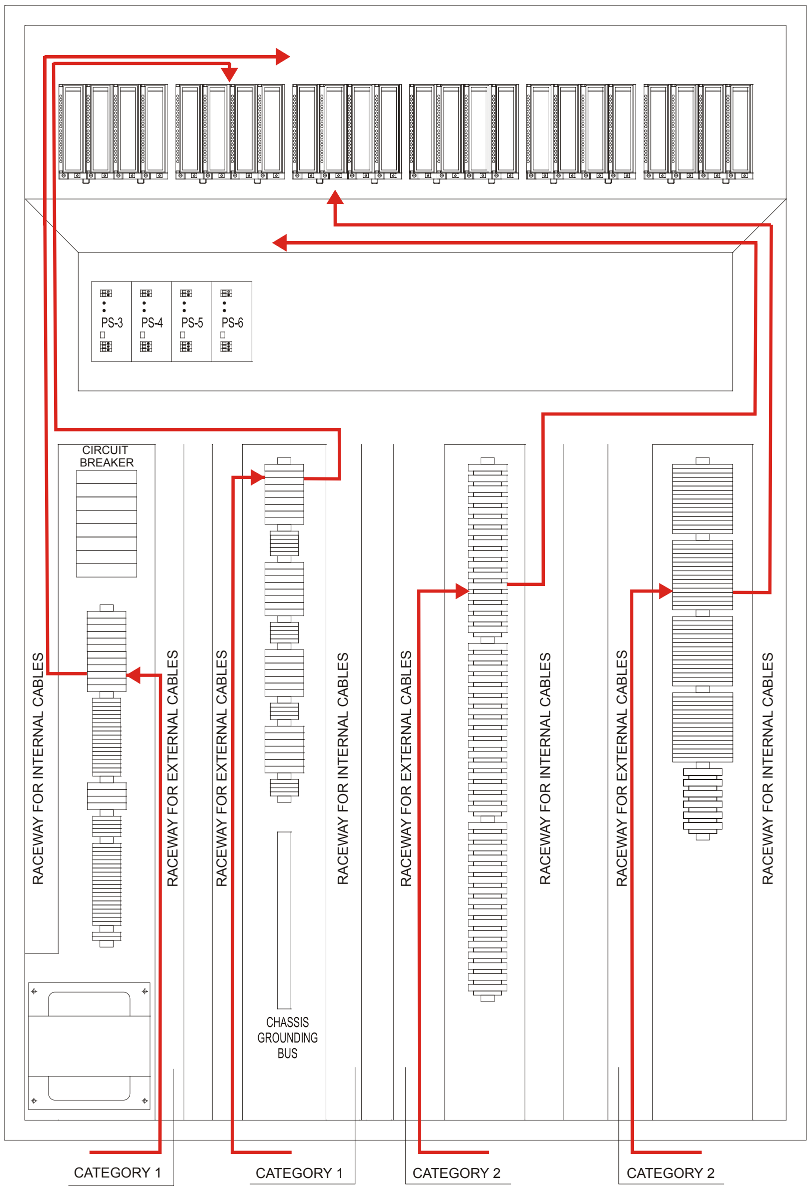


Figure 2.1 – Mounting details

Connection and Grounding

After establishing the entire layout, the user may begin mounting, connecting and grounding each chassis. The connection is the link of the chassis metal and mounting parts, structures, shielding and panel for reducing EMI effects and ground noises. Grounding is the connection to the ground circuit system to place equipment to the ground potential.

Every equipment powered with AC load must be grounded to the BTC Ground Bus, and every analog and digital equipment must be grounded to the BTA Ground bus. Figure 2.2 illustrates the BTA and BTC connections to plant ground circuit.

IMPORTANT
For total system safety, the BTA and BTC buses must be grounded separately to the plant grounding.

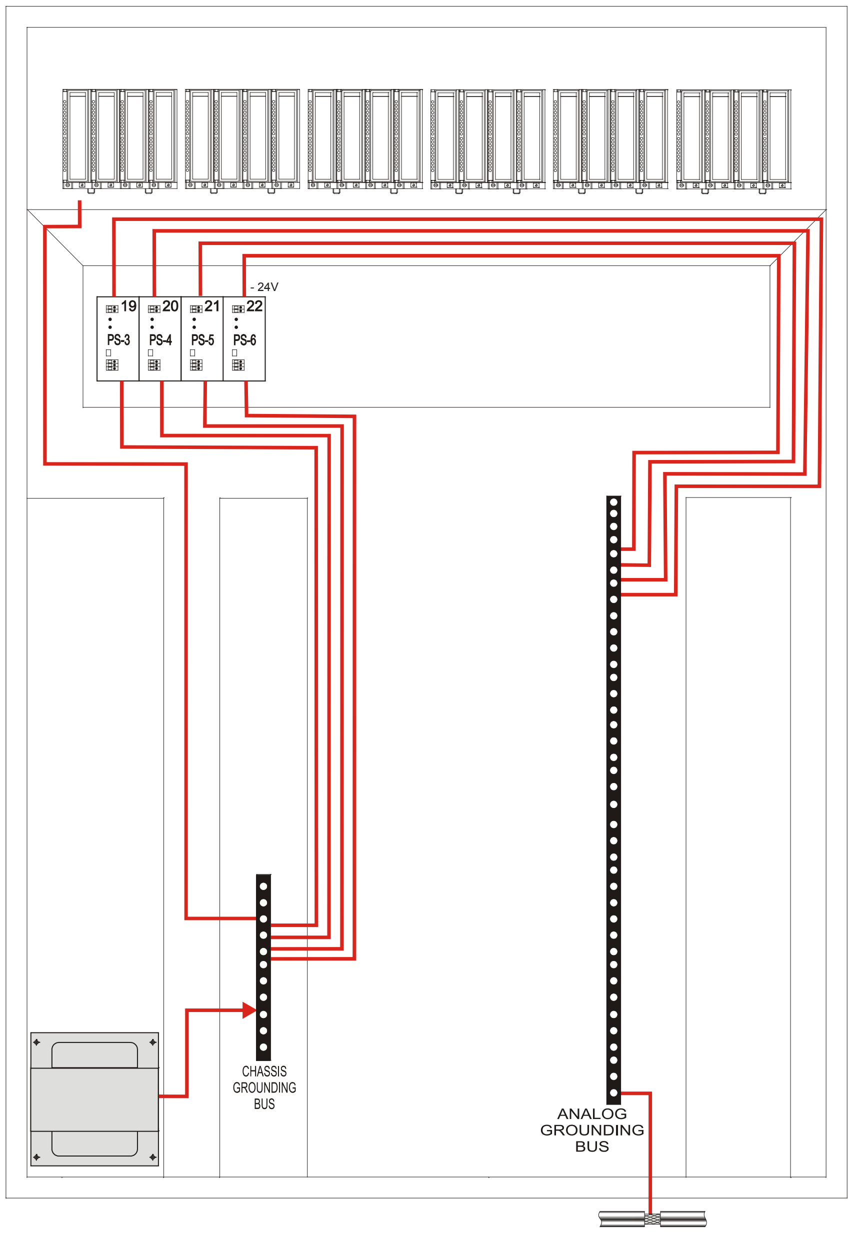


Figure 2.2 – Typical ground configuration

Most modules do not have a visible grounding, nor ground connector or terminal. However, they are mounted on the rack, on the DIN rail. The module frames are grounded via the DIN rail, on the rear grounding coil. Attach a grounding connector to the DIN rail and through an individual cable connect it on the (BTC) grounding bus.

Housing Ground Bus (BTC)

The BTC potential is the ground reference for all the AC electrical parts inside the panel. Connect the BTC to plant ground circuit using a copper cable with a minimum 8 AWG specification.

Signal Ground Bus (BTA)

The BTA potential is the ground reference for all the analog and digital parts of the devices inside the panel. Connect the BTA to the plant ground circuit using a copper cable with a minimum 8 AWG spec for EMI protection

Shielded Cables

Some I/O connections like analog and communication signals and pulse inputs need shielded cables to help reduce the effects of electric coupling;

- Ground each shield at a single point. Shielding ground at both ends form a ground loop that may cause system failures;
- Connect each shielding directly to the BTA;
- Use a shielded cable with twisted pair wire.

Avoid discontinuing the junction boxes shielding. Many types of shielded cable connections are offered by many manufacturers. Should it be necessary to discontinue the shielding on a junction box, do as follows:

- Do not remove the shielding protection more than needed to do the connection;
- Connect the shielding on both ends of the cable segments to ensure the continuity along the cable length.

Power Distribution

In order to isolate plant noises, the user may use an isolation transformer to connect the power supply. The transformer supplies DC isolation and protects the equipment against high voltage transients that may be generated in the power distribution system.

Many industrial applications already use a reducing transformer to lower the voltage to 120 or 220 Vac (Figure 2.3).

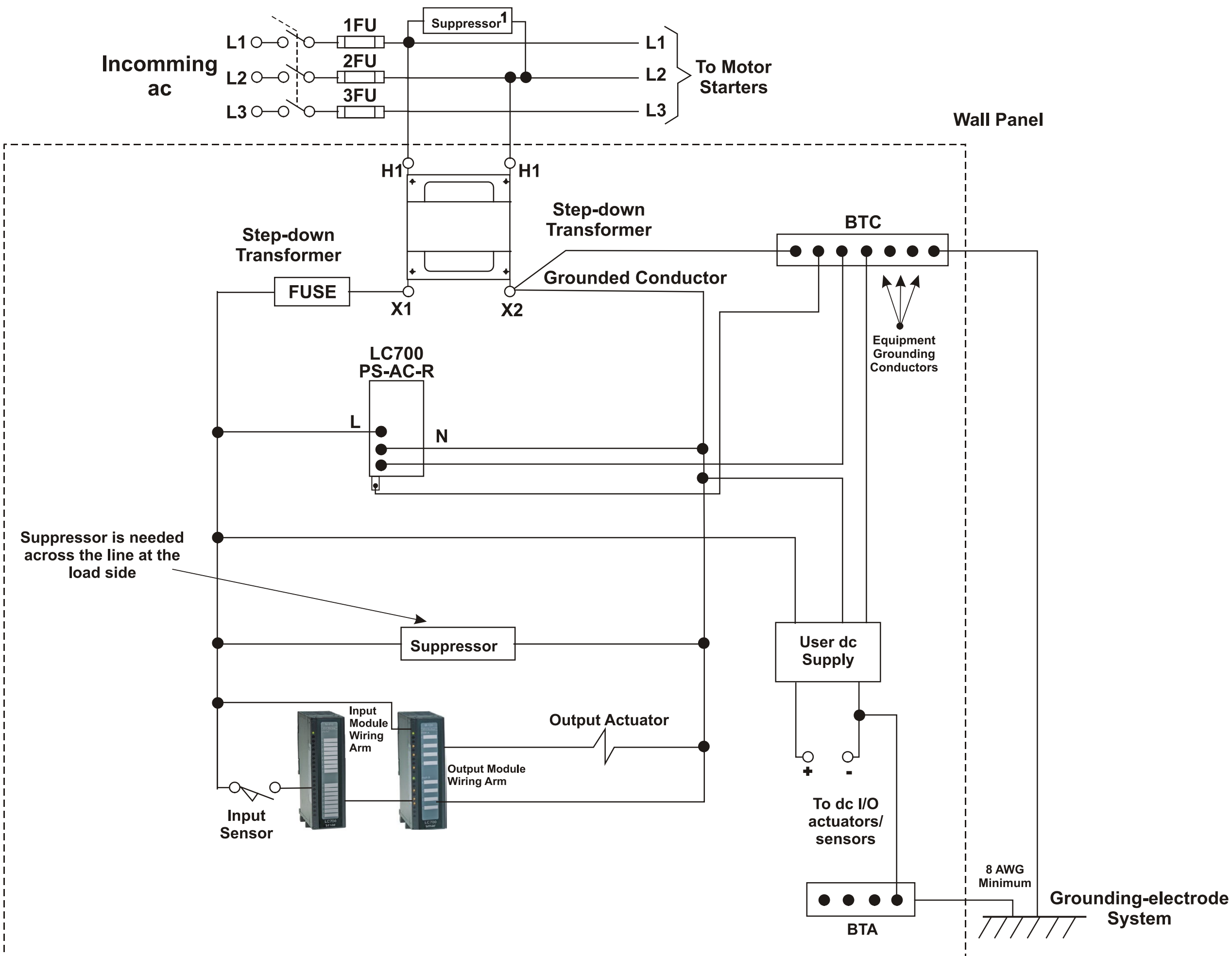


Figure 2.3 – Grounded AC power distribution system

NOTE
[1] To minimize EMI generation, connect a suppressor parallel to the inductive load. Contact the motor maker to verify which is the recommended transient suppressor. In many applications, a second transformer supplies power to input circuits and to the power supply, for circuit isolation.

Second Transformer

Power supplies have circuits that suppress the electro-magnetic interference generated by other devices. However, the isolation between the power supply and the output module circuits and between the input power supply and input circuits help prevent output transients from being induced in the power supply and the inputs. In many applications, the power supply is supplied to input circuits and power supplies through a second transformer (Figure 2.4).

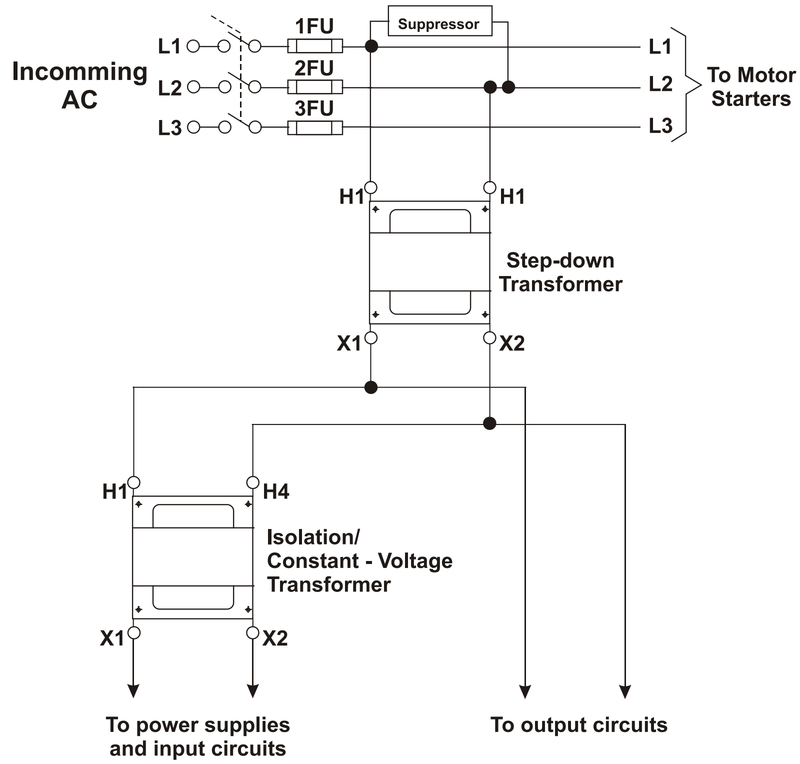


Figure 2.4 – Power supplies and input circuits receiving energy from a separate transformer

NOTE
To minimize temporary EMI generation when the power is cut off by the interrupter connect a suppressor across the transformer primary.

Surge Suppressor

During the commutation of inductive electric load there may be transient voltage peaks (electric noise) beyond 1 KV. In many cases, this noise interferes directly on the source of the conversion command and even may damage electronic components.

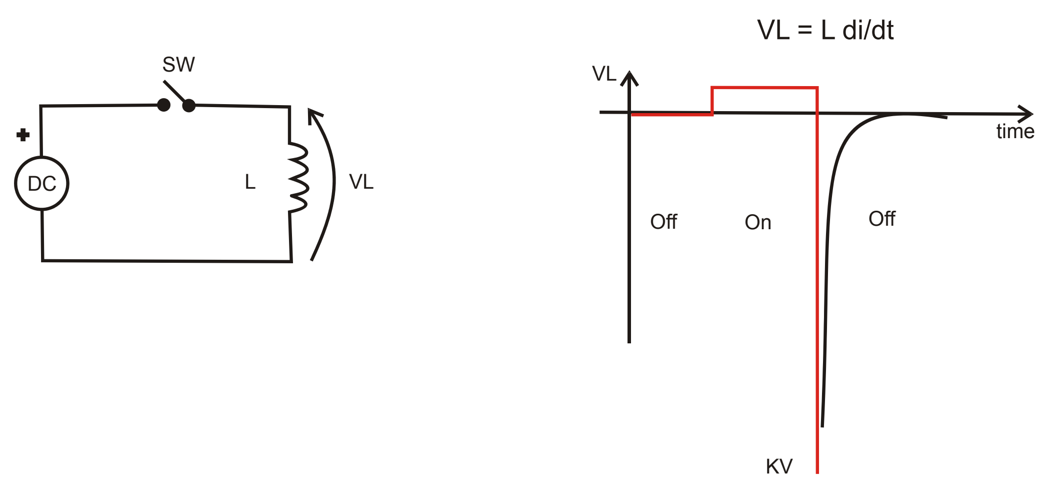


Figure 2.5 – Reverse voltage peak

There are alternatives to avoid the interference, like optical couplers, zero crossing switching, indirect startups that avoid noise on the command, etc. But the noise generated by the commuted device continues active and often it is induced on the system wiring, reaching other electronic automation points and causing intermittent system faults. So, these are not efficient ways to deal with noise. It must eliminated exactly on the source of the noise, meaning that a better performing filter should be mounted as close as possible to the commuted load.

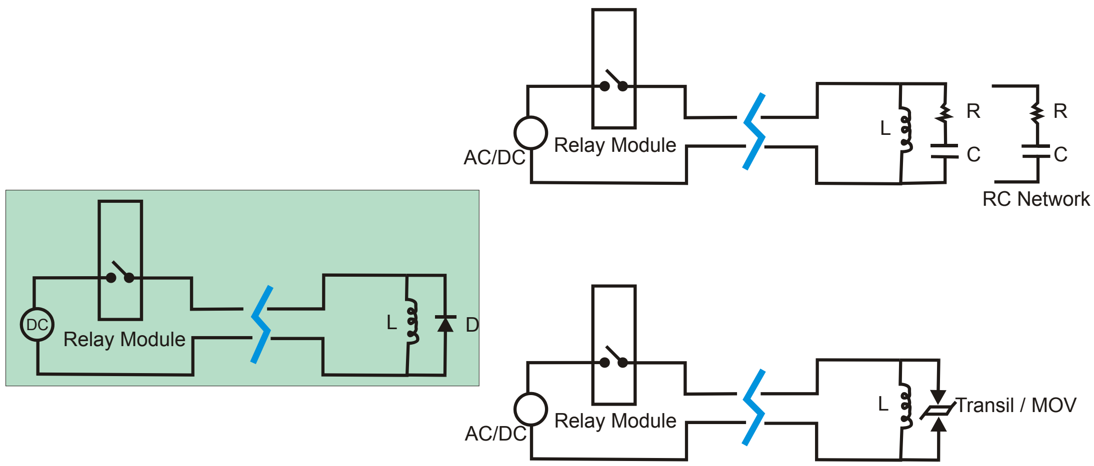


Figure 2.6 – AC/DC load filters

Inductance Load Switching

Check the specification for each I/O module related to the RC snubber circuit and the protection diode:

- **Inductive DC Load:** Although the DC load digital output module has a protection diode, the insertion is recommended of another protection diode close to the inductive load. This will prevent noise coupling to other cables in the same raceway.

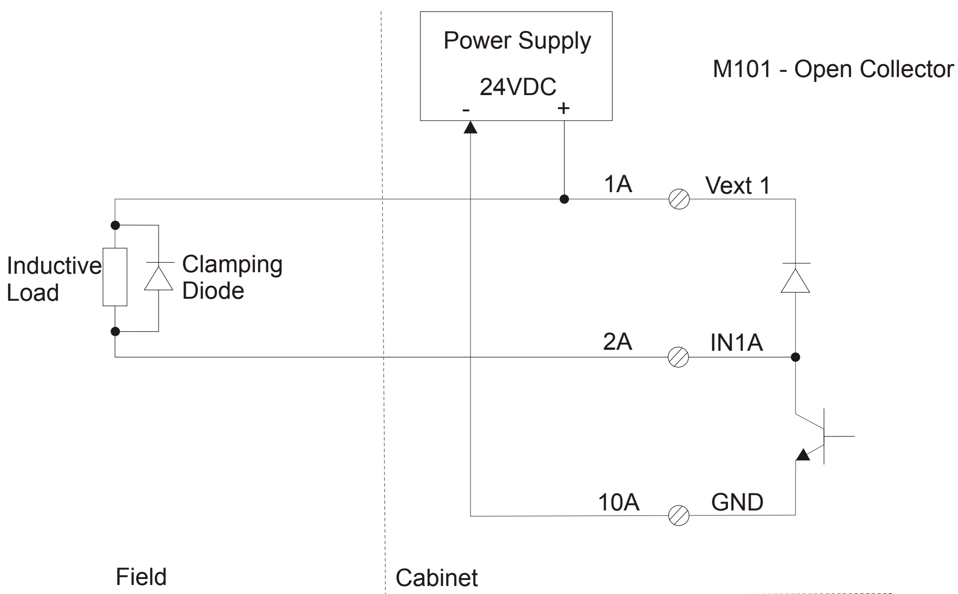


Figure 2.7 - Protection diode parallel to the DC load

- **Inductance AC Load:** Although the AC load digital output modules have a snubber circuit, it is recommended that another snubber circuit parallel to the load be inserted near to them. This will avoid coupling of noise from other cables in the same raceway.

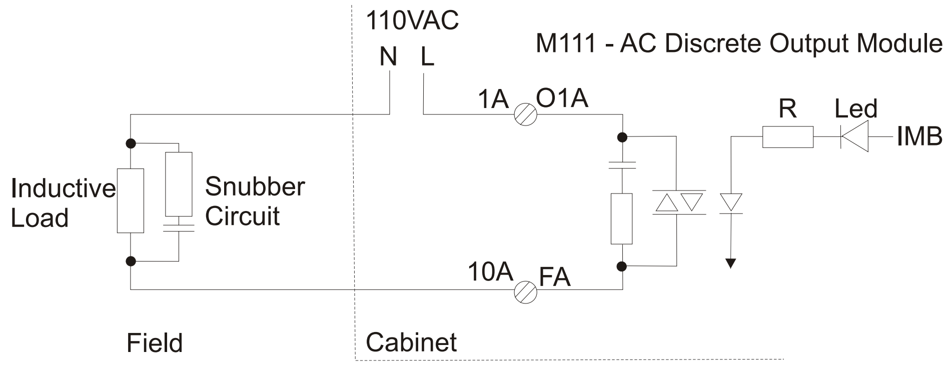


Figure 2.8 – Snubber circuit in parallel to an AC load

Suggestion for the RC network and the diode components

A maximum diode network current should be above o equal to the maximum load current, while the maximum voltage must be 3 to 4 times bigger than the circuit load in 24 Vdc and 8 to 10 times bigger than the circuit load in 110 Vdc.

The RC circuit (AC) must have a tension 2 to 3 times bigger than the power supply voltage. The values recommended are:

LOAD INDUCTANCE	CAPACITOR
25 -70 mH	0.500 µF
70 -180 mH	0.250 µF
180 - 10mH	0.100 µF

For loads up to 100 Ω, the RC resistor must have 1 to 3 Ω, 2 Watts.
For loads in excess to 100 Ω, the resistor value must be increased up to 47 Ω, 1/2 Watt.
Many manufacturers supply ready-made RC filters for mounting on contactors, valves and other inductance loads. Examples are *Murr Elektronik* (http://www.murrelektronik.com) or ICOS (http://www.icos.com.br).

Ferrite Beads

Ferrite Beads may provide additional suppression for EMI transients. The ferrite made by *Fair-Rite Products Corporation* (order code 2643626502) may be used in category 2 and 3 cables. They may be used with tying belts. With a ferrite located near a cable end, EMI transients induced on the cable may be suppressed by the ferrite before being installed on the equipment.

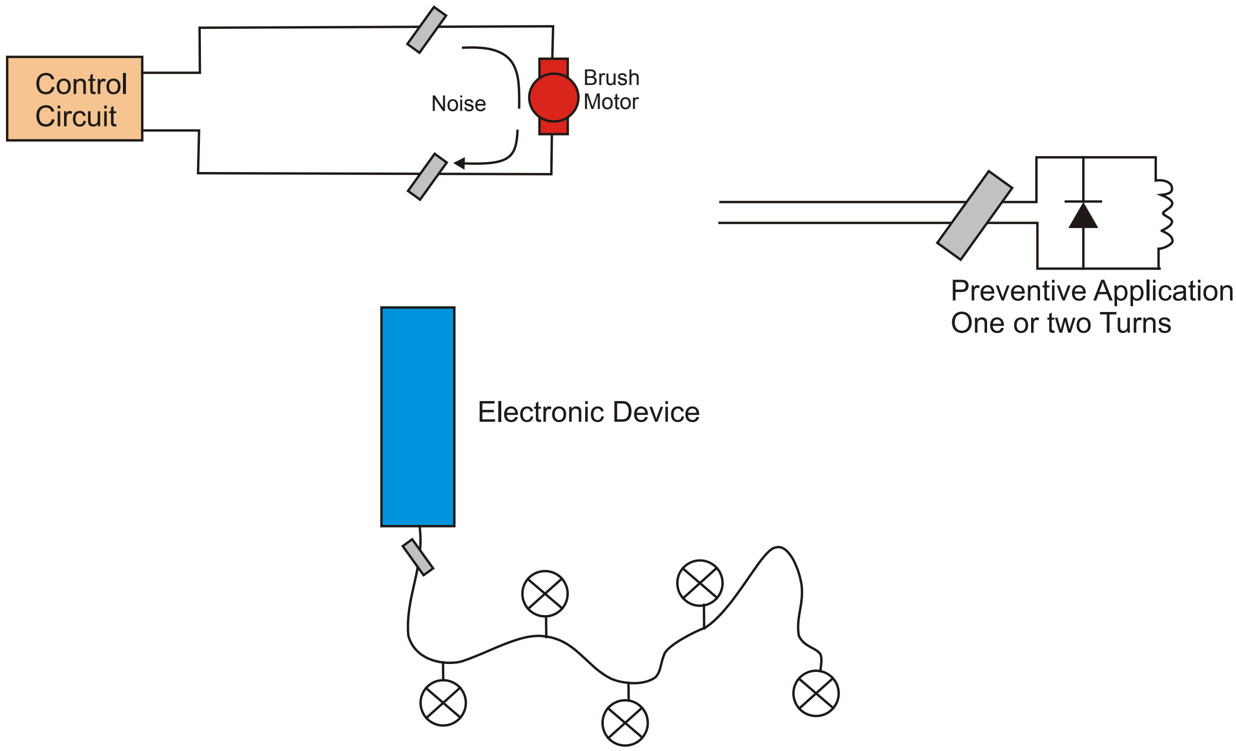


Figure 2.9 – Application of ferrites in control lines

DIGITAL NETWORK INSTALLATION

Ethernet Industrial Network

Introduction

A large part of Ethernet automation networks currently running in industry are designed with the same technology available to office and corporate networks.

These networks are divided in layers: the physical layer (fiber or twisted pair, layer 1), the methods of access (CSMA/CD, layer 2), the IP protocol (layer 3), TCP and UDP protocols (layer 4) as well as the HTTP, FTP, SNMP protocols, etc.

This section will cover only the network hardware part, namely, up to layer 3, as layer 4 relates to Ethernet network protocols.

The main goals for the good installation practices in the Ethernet industrial network are the use of all characteristics of this infrastructure, while respecting the requirements of the industrial automation environment, one that calls for robust installations, high performance in getting information, real time environment and data safety.

Ethernet has a logical bus technology dealing with collision domains. These collision domains must be minimized so that the network may be considered as deterministic. Normally, switches and routers are used to eliminate collision beyond the proper network segmentation

The design for Ethernet network implementation starts through the study of the factory blue print where the network distribution and details were designed. At this point, some aspects are considered for each network topology layer.

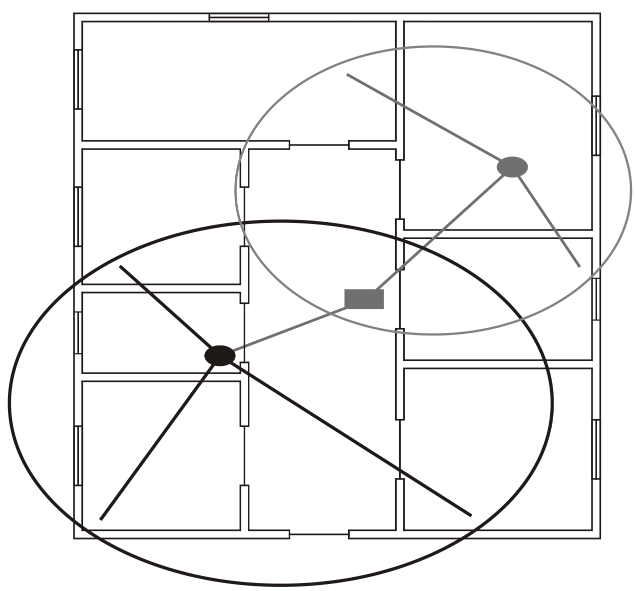


Figure 3.1 – Blue print study for Ethernet network implementation

Below are good techniques and practices:

NOTE
For the installation details, it is recommended the use of the manuals of each network equipment.

Layer 1 – The Physical Network

This stage defines:

1. Type of cable: typically, is a twisted pair, shielded CAT5e category cable, (100BASE-TX) for frequencies up to 100 MHz.

Shielded cables increase the network immunity against electromagnetic interference, as well as to reduce the cable environment electromagnetic emission. To ensure the immunity against the interference, a few rules should be followed:

The shielding circuit must cover the entire cable and components like network connectors and patch panels. Therefore, do not use patch cords without shielding (UTP).

- No opening parts must exist in the shielding. This will avoid EMI interference incoming.
- The circuit must be grounded on both cable ends. The elements to be interconnected are subject to the same potential difference. If otherwise, the use of optical fiber is mandatory, as shown in this section.

NOTE
If the above conditions cannot be met, it is recommended the use of a shield less cable (UTP), as it is more efficient than precarious shielded installations, which could tune in noise.

2. Type of topology: star topology, the most accepted currently, is shown below.

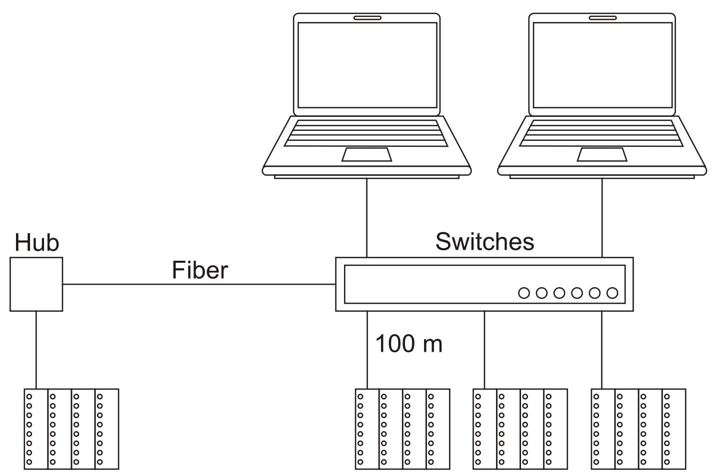


Figure 3.2 – Star Topology Network

In this type of topology the information sent to each network node is received through the switch.

The project also uses hubs, repeaters and transceivers, in addition to layer 1 components, like plugs, fiber, connectors and patch panels.

IMPORTANT
To facilitate preventive or reactive maintenance, keep the topology documentation updated constantly, while new components are included in the network

Layer 2

On the second stage, let us examine the LAN topology, one that adds devices for improving network performance and capacity. The use of switches reduces bottle necks and collision domain size. Managed switches are recommended for increasing the management capacity of multicast packages, package safety and possibility of network diagnostics.

Several protocols require special approach on the network topology used. By using devices that support HSE FF (FOUNDATION^{TM} *fieldbus High Speed Ethernet*) and the "producer-consumer" model as an example, it is established that the devices will use UDP multicast to send information to the other devices using the same control strategy. Using multicast traffic for control optimization, as stated in this protocol, may be a disadvantage if considering the exponential traffic increase in the network, should there be an unlimited growth of devices on the same network. Therefore, it is recommended not to install more than 32 pairs of control devices and up to three servers on the same network.

Another topology issue to be considered regarding multicast and/or broadcast is the filter used by the routers between different sub-networks, which is included on layer 3. Normally, the routers are recommended for segmenting different plant areas. This isolation between networks will avoid the exchange of packages between devices. See figure 3.3.

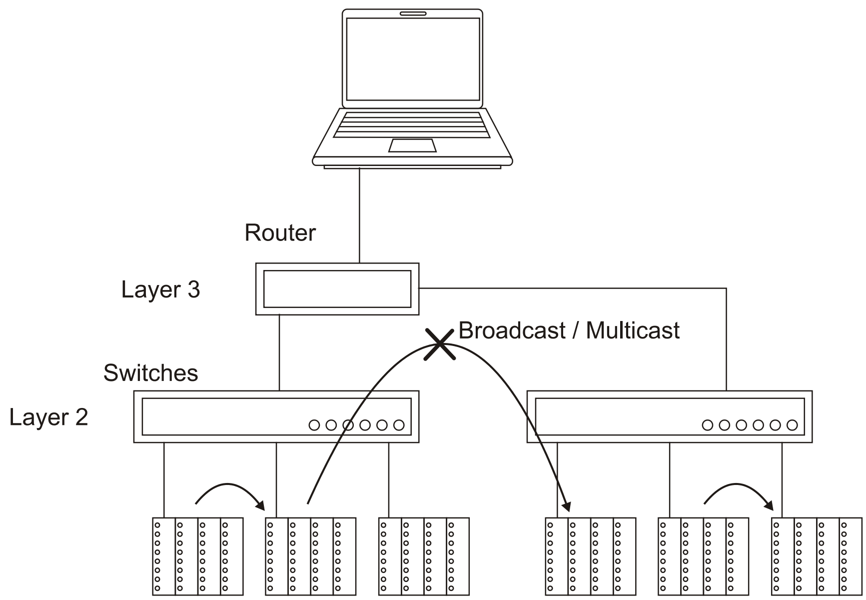


Figure 3.3 – Isolation of HSE networks by the use of routers.

Therefore, plan carefully which equipment should be used in the same plant area, as they will occupy the collision domain or the same network.

Layer 3

This is where the routers and the network segmentation are implemented.

The routers are used to open paths between the several plant networks, like LANs and WANs. The routers apply a logical structure on the network and are used on segmentation.

Routers, differently from bridges, switches e hubs, break up collision and broadcast domains and block the HSE multicast links mentioned before. The correct configuration of default gateways on a given network, through an embedded Web Server, provides diagnostics information for several networks, including the Internet (Figure 3.4).

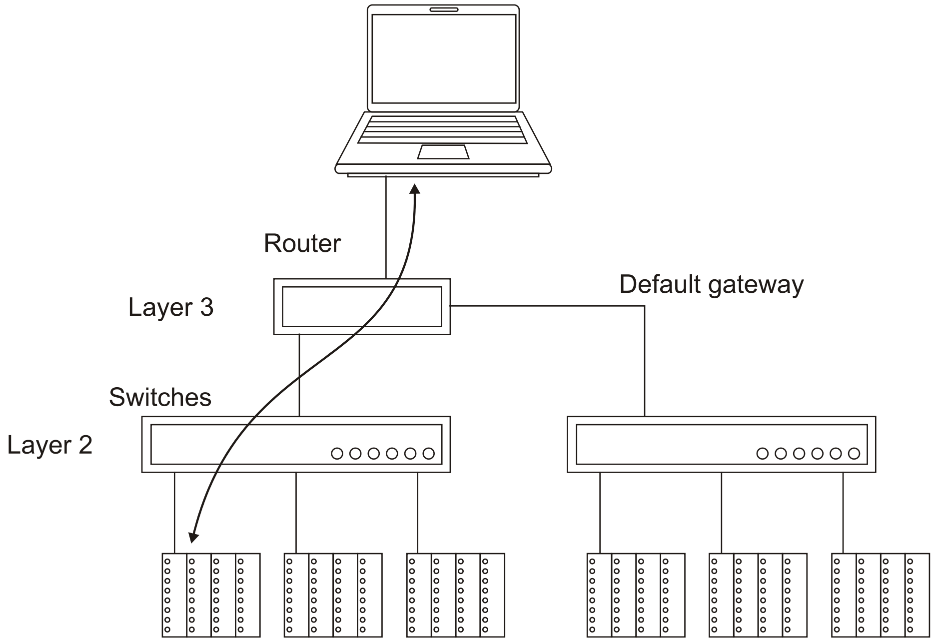


Figure 3.4 – The use of Default Gateways

Some switches have Virtual Local Area Networks (VLANs) also used for network segmentation.

These devices have a very fast internal backbone isolating the collision domains, without imposing any type of decrease on the network capacity. It is necessary a configuration on each port of the switch granting each one working in a different sub-network.

A switch with a VLAN implemented has multiple broadcast domains and works similarly to the router. However, it still needs a router (or any similar layer 3 device) to route one VLAN to another.

IMPORTANT

GUIDELINES ON ETHERNET NETWORK WITH RING TOPOLOGY

When using an Ethernet network with ring topology, it is not possible to eliminate the risk of Broadcast and Ring Loop, but some actions can help to minimize the problems caused.

It is necessary to pay attention to the following items below:

1-Do not use any connection that could generate a loop to the system, performed through unmanaged switches and/or hubs.

2 - By using Broadcast filters on switches, it is possible to limit the amount of Broadcast per second on the network, whose acceptable value always depends on each application. The “Best practice” says that if there are more than 500 Broadcasts per second, your network already has problems. It also says that more than 100 Broadcast per second is already an undesirable value for the network.

3 – The network segmentation through routers and firewalls, even in the event of a Storm, limits the harmful effects to a single region of the plant. The more segmented the network, the smaller the impact caused if a problem occurs.

4 - Evaluate and check that there are cables with faults, dryness, and degraded quality

5 - Evaluate if the redundancy protocol configured on the switches is **Hirschmann** proprietary or **RSTP (IEEE 802.1D or IEEE 802.1W** standard). Third-party switches on the same ring do not support the Hirschmann protocol. To do this, check the **Redundancy Manager** of the ring. Analyze via webserver and check the equipment's DIP switches.

6 - Disable **IGMP Snooping** on all switches, thereby increasing the availability and connectivity of links between network equipment.

7 – Some firmware of **DFI302** controllers has a protection to limit the impact of the loop on the ring. For this, it must be ensured that the **FEATURE_SEL** parameter, of the **RESOURCE** block, is configured with the value **0x8100**. The following firmware and above implement this protection. They are: **DF63V4_4_10**, **DF73V4_3_0**, **DF75V4_4_10**, **DF89V4_2_5**, **DF95V4_3_0**, and **DF97V4_3_0**.

Wiring Closet

The TIA/EIA-568-A specifies that the horizontal wiring ramification on an Ethernet LAN must be connected to a central spot in a star topology. The central point is called wiring closet, where the patch panel and the hub should be installed.

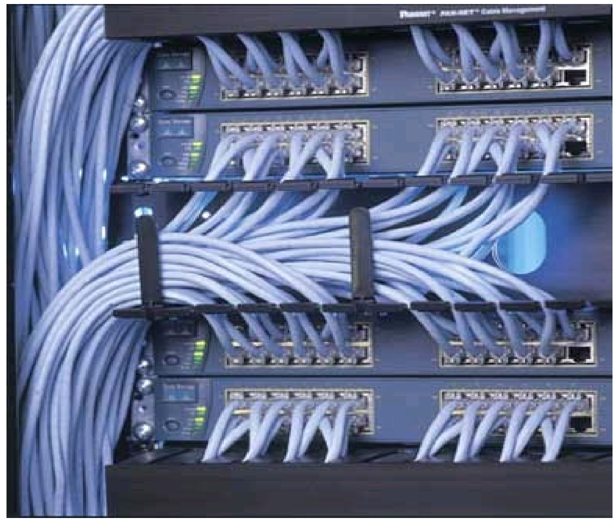


Figure 3.5 – Distribution of Ethernet cables on a panel

The wiring closet must be large enough for accommodating the equipment and the whole cabling, and include room for future expansion. Naturally, the wiring closet size will vary according to the LAN size and its required operating devices. A small LAN (typically one forming industrial networks) needs only the space for a big file cabinet, while a large LAN (data centers for large providers) needs an entire control room.

The TIA/EIA-569 specifies that each floor must have at least one wiring closet, and that additional wiring closets must be provided for each 1.000 m², if the area of the operated floor exceeds 1.000 m², or when the horizontal wiring length be in excess of 90 m.

The wiring closet must include air conditioned equipment and enough ventilation to keep the room temperature around 21 ºC, when the whole LAN equipment is fully operative. The relative humidity must be between 30% and 50%. Non-compliance with these specifications may result in serious copper wiring corrosion inside the UTP and the STP. This corrosion may disturb the proper network operation.

If the100 m response area of a star topology wiring closet cannot provide enough coverage for all of the devices that need to operate as a network, the star topology may be extended by using repeaters. These repeaters, whose purpose is to avoid signal weakening, are called hubs.

Generally speaking, when the repeaters or hubs are used in this manner, they will be located in additional wiring closets. They are called intermediary distribution installations and are connected in network to a main hub located in another wiring closet called main distribution installation.

Backbone Interconnection

Backbone is the central media through which several networks communicate. It is recommended the use of optical fiber cables for composing the backbone, connect the several wiring closets installed on different floors, that one in the same building and that one located between separate buildings. This is due to the fact that the several floors in the same building are powered by different electricity transformers. These transformers may have different groundings and cause the problems described above. Non-conductive optical fibers eliminate the problem.

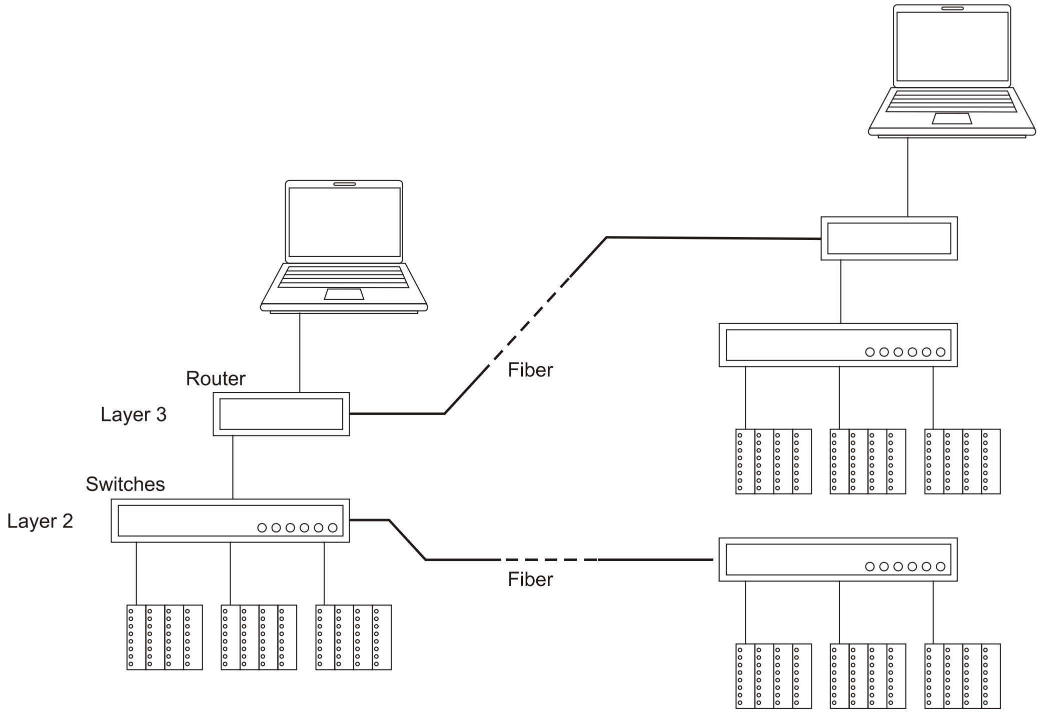


Figure 3.6 – Wiring closets interconnection

If the interconnection between different facilities requires twisted pair cables, use Ethernet surge protectors. Install the surge protectors on both interconnection ends.

Fieldbus Network

Network Wiring

Access the wiring block by removing the Electrical Connection Cover. This cover can be locked closed by the cover locking screw; to release the cover, rotate the locking screw clockwise. See Figure 3.7.

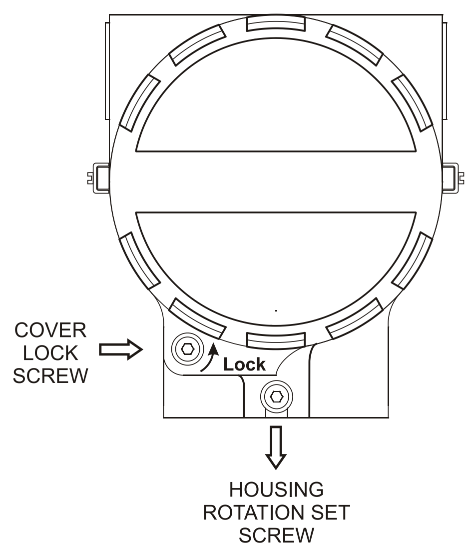


Figure 3.7 – Housing Rotation Set Screw and Cover Lock

NOTE
The covers should be closed by hand completely, until the O'Ring is tight. For more safety, do not use tools in this operation.

The cables course must be through the electric connections. Conduit threads should be sealed by means of code-approved sealing methods. The unused outlet connection should be plugged accordingly.

The wiring block has screws on which fork or ring-type terminals can be fastened. See Figure 3.8.

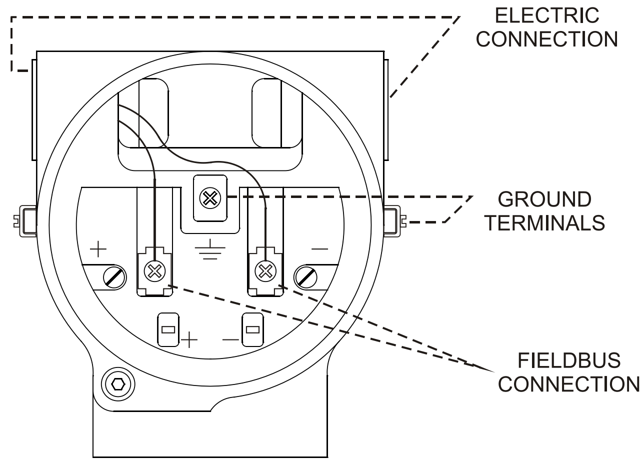


Figure 3.8 – Connection Block

NOTE
Due to each device particularity, check the electric connection block in the specific equipment manual.

For convenience there are two ground terminals: one inside the cover and one external, located close to the conduit entries. More details are described in Shield and Grounding item.

Avoid routing signal wiring close to power cables or switching equipment must follow the instructions on this guide's tables 1 and 2.

HAZARDOUS AREAS
1. In hazardous areas requiring explosion-proof equipment, the lids must be tightened at least 8 turns. To prevent humidity or corrosive gases from entering, tighten the lids until feeling the O-ring pressed against the housing. Complete one third more turn (120º) to ensure sealing. The lids must be locked by locking screws. 2. The signal cables connected to the linking terminals must pass through the electric connections on the housing. Connect them to a conduit or cable clamp. 3. The conduit threads must be sealed according to the area requirements. The unused passages must be closed with a stopper and sealed with an adequate sealing product. 4. If other certifications are needed, they must comply with the specific standards for installation restrictions.

The **Series 302** devices are protected against reverse polarity and can withstand up to 35 Vdc without damage.

The Figure 3.9 show as to connect a device in a fieldbus network.

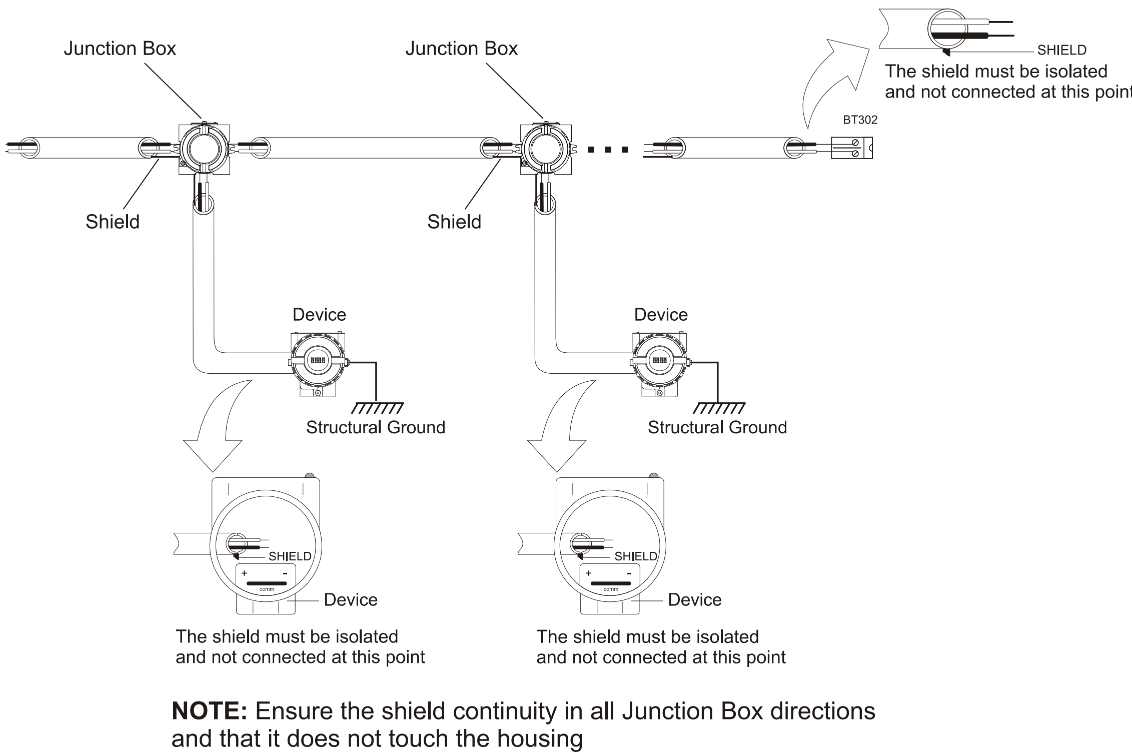


Figure 3.9 – How to connect an equipment to the Fieldbus Network

FOUNDATION™ fieldbus Physical Medium, Cabling, and Installation

The standard first versions specify two options for the physical layer: H1 and H2. The H1, with rate of 31.25 Kbits/s is oriented basically to field device (transmitters, valve positioners, etc.), and it can be used in areas requiring intrinsic safety (explosive atmospheres). The H2, with rate from 1 to 2.5 Mbps, would be used to integrate controllers and more complex devices.

Due to the fast technological evolution, the H2 was substituted by the HSE that uses Ethernet at 100 Mbps. Therefore, for field devices connection there is the FOUNDATION fieldbus H1, with physical layer based on ISAS50.02-1992 or IEC61158-2:2000. For connection among PLCs, Linking Devices, Gateways and PCs, there is the FOUNDATION fieldbus HSE, based on Ethernet (IEEE802.3-2000, ISO/IEC8802.3-2000).

FOUNDATION™ fieldbus H1 Network

A Fieldbus network is composed by several H1 buses, connected to each other by bridges or Foundation Fieldbus Linking Devices that connect the H1 networks to the HSE backbone.

According to definitions, each H1bus can hold, theoretically, up to 32 devices not powered by the bus. In practice, there may be up to 12 field devices powered by the bus and other 20 devices not powered by the bus, each one with a single logical address in the network (1 Byte). This limit is due mainly to the electric characteristics of the power supply and the current consumption of the devices. In practical terms, it is recommended that the total number of devices doesn't surpass 10, because the network traffic tends to become very high and there may be performance degradation. In classified areas, it is recommended to analyze the output of the intrinsic safety barrier to define the number of devices. With the FISCO concept, there may be a larger amount of devices per segment.

The wiring length can reach 1900 m, and up to 4 repeaters may be used with a 9500 m reach..

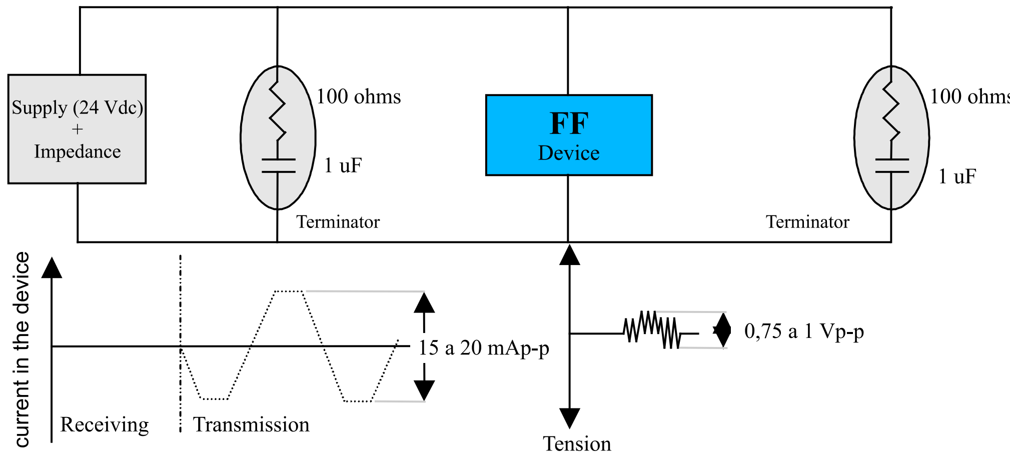


Figure 3.10 – Simplicity of the FOUNDATION™ fieldbus H1 Physical Layer (IEC61158-2)

The physical medium is a shielded twisted pair cable. The power supply and the communication are done by the same pair, needing at least 9 V in the terminal of the device to energize it. It is recommended that this tension be larger than 10 V, enough to keep a complete communication signal (0.75 Vpp to 1 Vpp), taking into account the cable tension loss, the bus total consumption, etc.

The signal modulation is done by the variation of a current of 10 mA to 31.25 Kbit/s in an equivalent load of 50 Ω, resulting in a modulated voltage of 0.75 Vpp to 1 Vpp overlapping the bus voltage (9 – 32 Vdc).

Both the current and the operation minimum voltage can vary according to the manufacturer or device model (consult the respective manual). For Smar devices, each fieldbus device consumes about 12 mA.

FOUNDATION™ fieldbus HSE Network

This network is based on the same Ethernet physical layer. Several manufacturers offer specific equipment for industrial applications, be it with adequate temperature range (-40 to 85 ºC), be with specific functions for real time data communication.

The communication and synchronism characteristics among the devices are basically the same as the H1, and the main differences are in determinism. Through the use of the Ethernet network in the Foundation Fieldbus HSE network it is possible to build an industrial control network with shelf components, independently of the manufacturer.

The HSE standard uses 100 Mbps, but nothing opposes the devices from communicating at higher rates, like 1 Gbps or even the new 10 Gbps standard.

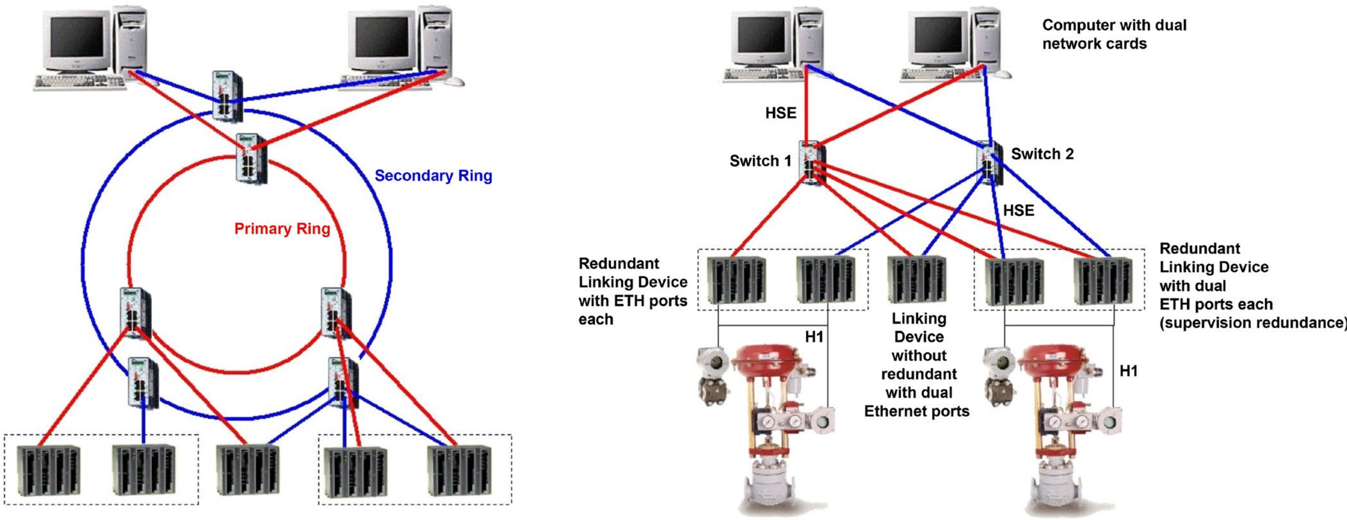


Figure 3.11 – Usual HSE network topologies: Ring and Star topology with Redundancy

Summary of characteristics H1 and HSE Networks

The Table 3.1 show a summary of characteristics presents in H1 and HSE networks.

	H1	HSE
Baud Rate	31.25 Kbits/s	10 Mbit/s or 100 Mbit/s
Distance (segment)	1.900 m	100 m
Two wires	Yes	No
Multidrop	Yes	No (UTP)
Bus-power	Yes	No
Intrinsically Safe	Yes	No
Redundancy	No	Yes
Deterministic	Yes	Yes (with *switches*)

Table 3.1 - Summary of the Characteristics of the Physical Layer FF

General Notions of Installation for the H1 Network

The H1 network represents a great digital communication solution for the factory ground, both in safe as classified areas. It accepts topologies in bus, ring, star or tree, and even distances up to 1900 m without repeater.

Using up to 4 repeaters it is possible to cover a radius of approximately 10 km. The maximum amount of devices in each H1 segment depends on the type of application, the length of the cables and even the performance wanted for the network.

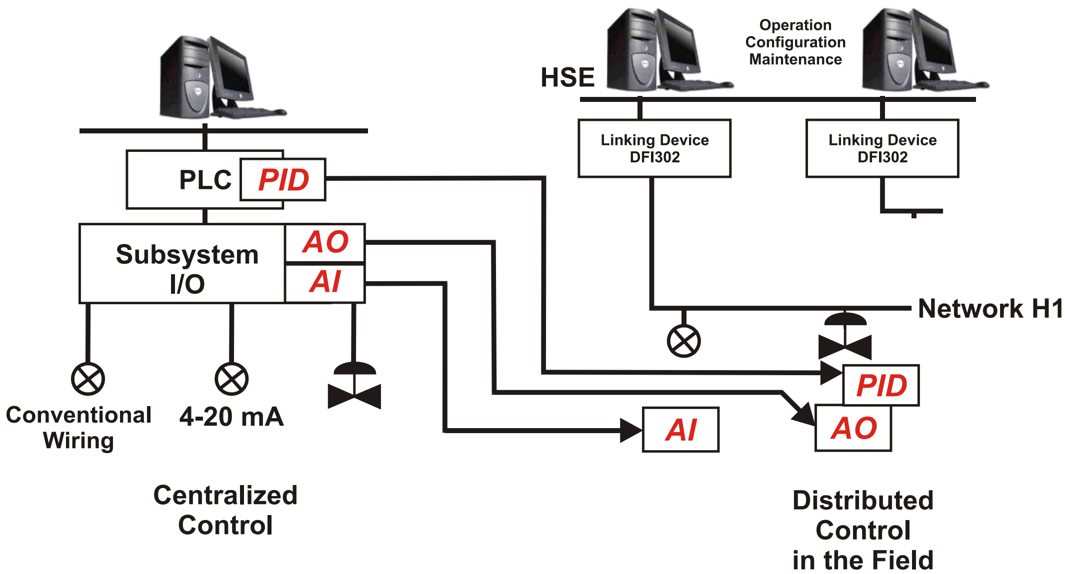


Figure 3.12 - Comparison of Wiring and Distribution of Control over the Network Devices

Main elements of the Foundation Fieldbus H1 Network

Cabling

The IEC61158-2 determines that the physical medium of the Foundation Fieldbus H1 network should be a twisted pair cable. The properties of a field bus are determined by the electric conditions of the cable used.

Although the IEC61158-2 doesn't specify the cable technically, the type A cable is highly recommended, in order to guarantee the best communication conditions and distances involved.

Table 1.2 presents in detail the specifications of the several cables at 25 ºC. It is worth to remind that most of the cable manufacturers recommend the operation temperature between -40 ºC and +60 ºC. It is necessary to verify the critical points of temperature through where the cabling passes and if the cable supports it. The type A cable resistance of 22 O/Km is valid at 25 ºC. For example, the resistance of the type A cable to 50 ºC is 24.58 Ω/Km. That should be taken into account in hot countries as Brazil.

	Type A	Type B	Type C	Type D
Cable Description	Twisted Pair with *Shield*	One or more total twisted pair with *Shield*	Several twisted pair without *Shield*	Several non-twisted pair without *Shield*
Nominal Driver Section Area (of the)	0.8 mm^2 (AWG 18)	0.32 mm^2 (AWG 22)	0.13 mm^2 (AWG 26)	0.25 mm^2 (AWG 16)
(Resistance DC Maximum) Maximum DC Loop Resistance (*loop*)	44 Ω/Km	112 Ω/Km	264 Ω/Km	40 Ω/Km
Characteristic impedance (to) at 31.25 KHz	100 Ω ± 20%	100 Ω ± 30%	**	**
Maxim Attenuation to 39 KHz	3 dB/Km	5 dB/Km	8 dB/Km	8 dB/Km
Maximum Unbalanced Capacitance	2 nF/Km	2 nF/Km	**	**
Group Delay Distortion (7.9 to 39 KHz)	1.7 µsec/Km	**	**	**
Surface Covered by the *Shield*	90%	**	-	-
Recommendation for Network Extension (including *spurs*)	1900 m	1200 m	400 m	200 m

Table 3.2 – Characteristics of the Several Cables Used in Foundation Fieldbus H1

The total length of the H1 cable should be considered from the exit of the point of PSI (*power supply impedance* – power supply with active impedance) until the most distant point of the segment, considering the derivations. Remember that spurs smaller than 1 m don't enter in this total.

The cabling total length is the sum of the main bus trunk size plus all the spurs (branches larger than 1 m), and with type A cable, the length is a maximum 1900 m in non-safety areas. In safe areas with type A cable, it is a maximum 1000 m, considering that the spurs cannot exceed 30 m.

In installation and distributions terms avoid splices, in other words, any part of the network with a specified conductive medium and a discontinuous length smaller than 1 m, for example: shielding removal, wire diameter changes, connection to bare terminals, etc. In networks with total length larger than 400 m, the sum of the lengths of all the splices should not surpass 2% of the total length and also, in lengths smaller than 400 m, should not exceed 8 m.

A H1 segment maximum length, when using different cable types is limited by the following formula:

$$\left(\frac{LA}{LA\max}\right)+\left(\frac{LB}{LB\max}\right)+\left(\frac{LC}{LC\max}\right)+\left(\frac{LD}{LD\max}\right)\langle= 1$$

Where:

LA : Length to the cable A ;
LB : Length to the cable B ;
LC : Length to the cable C ;
LD : Length to the cable D ;
$LA\max$: Maximum length allowed with the cable A (1900 m);
$LB\max$: Maximum length allowed with the cable B (1200 m);
$LC\max$: Maximum length allowed with the cable C (400 m);
$LD\max$: Maximum length allowed with the cable D (200 m).

In relation to the spurs be attentive to the lengths of the same. The amount of devices, < including repeaters, if any, should comply with the Table 3.3. In classified areas the maximum spur is 30 m.

Total H1 devices per segment	*Spur* length with 1 device	*Spur* length with 2 devices	*Spur* length with 3 devices	*Spur* length with 4 devices	Length Considering the Maximum Amount of Spurs (m)
1-12	120	90	60	30	12 x 120 =1440
13-14	90	60	30	1	14 x 90 = 1260
15-18	60	30	1	1	18 x 60 = 1080
19-24	30	1	1	1	24 x 30 = 720
25-32	1	1	1	1	1 x 32 = 32

Table 3.3 - Spur x Number of H1 Devices

NOTE: The cable capacitance limit should be considered. In the absence of the cable manufacturer´s data, a value of 0.15 nF/m can be used for fieldbus cables.

$$Ct = \sum (Ls * Cs) + Cd$$

Where:
Ct : Total capacitance in nF;
LS : *Spur* length in m;
Cs : Wire capacitance per segment in nF (Standard – 0.15);
Cd : Foundation fieldbus device capacitance;

The attenuation associated to this capacitance is 0.035 dB/nF. Therefore, the total attenuation is:
$A = Ct * 0.035\, dB / nF \langle 14\, dB$

Then, 14 dB will allow the minimum necessary signal to detect it with integrity.

There are some rules to follow in terms of cabling and separation from other cables, be it for signals or potency. Use preferably trays or metal ducts, observing the distances according to Table 1.4. Never pass the fieldbus H1cable beside high voltage lines because the induction is a noise source and it can affect the communication signal. Furthermore, the fieldbus signal should be isolated from noise sources, as power cables, motors and frequency. It is recommended to put in separated channels and ducts. The ideal is to use aluminum ducts, with internal and external electromagnetic shield. The *Foucault* currents are practically immune, due to the aluminum good electric conductivity. Remember that the crossing of cables should be at 90º angle.

H1 Network Terminators

Two bus terminators should be connected to the H1 network, being one in the PSI output and the other in the last device (usually the most distant from the PSI), depending on the adopted topology.

If in the cabling distribution there is a junction box in the end of the main trunk with several spurs, the field terminator should be placed in this point, to facilitate the maintenance when removing devices.

Check the correct connection of the terminator, reminding that the lack of terminators allows communication intermittency, once there is no impedance match and there is reflection signal increase.

The lack of a terminator or its connection in the incorrect point also degrades the signal, once it will also be part of the cabling as an antenna. Its lack can increase the signal in more than 70% and an additional terminator can increase the sign up to 30%. The attenuation and intermittency can generate communication failure.

The H1 network terminator is formed by a resistor of 100 ± 2% and a capacitor of 1 μF ± 20% in series.

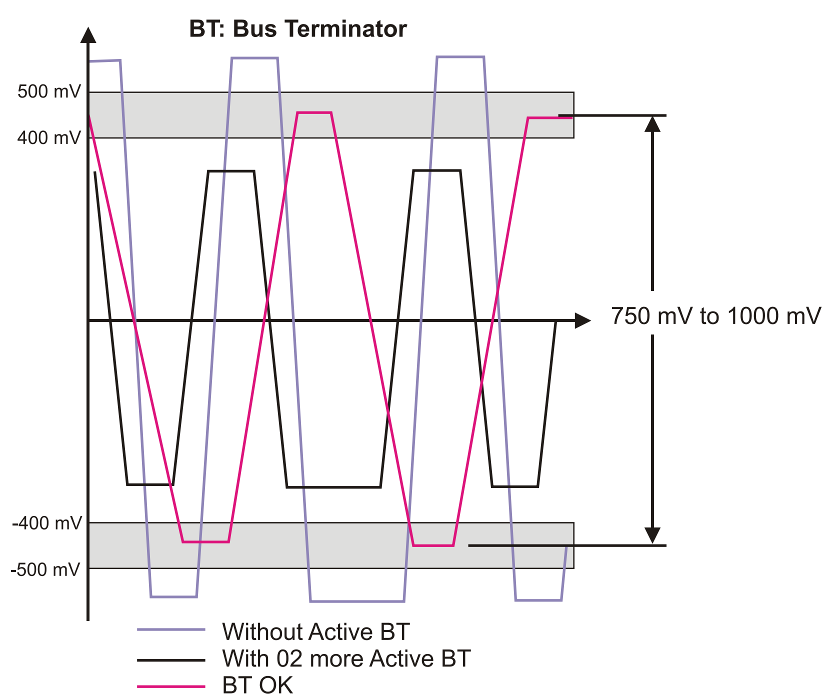


Figure 3.13 –Typical H1 Wave Forms According to the Termination

Following, the real waves forms related to the three cases mentioned on Figure 3.13.

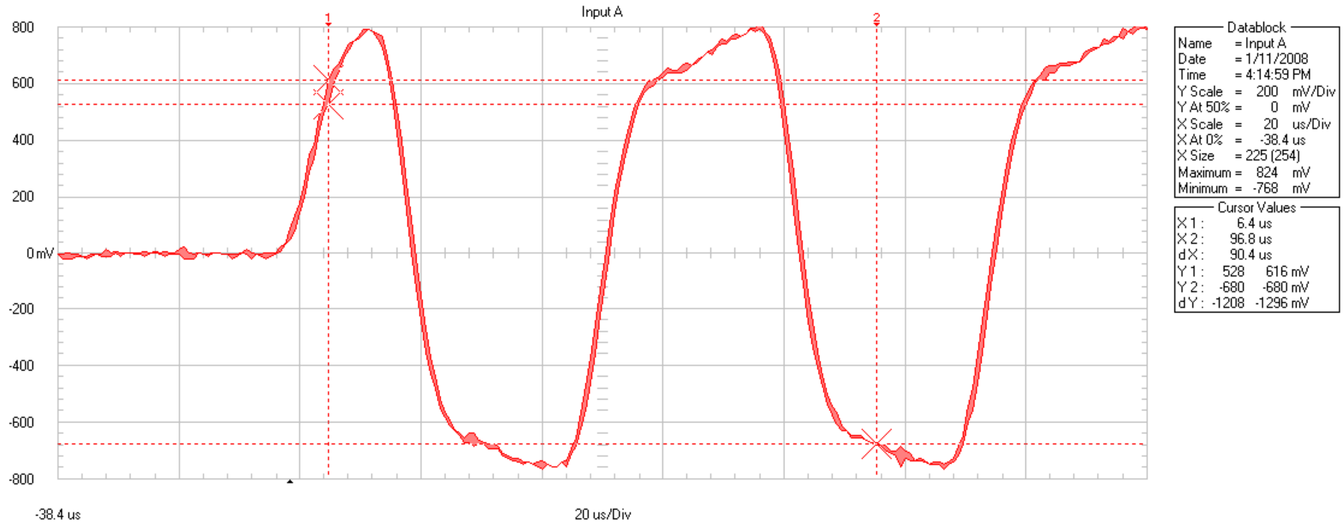


Figure 3.14 –Wave form without Active BT

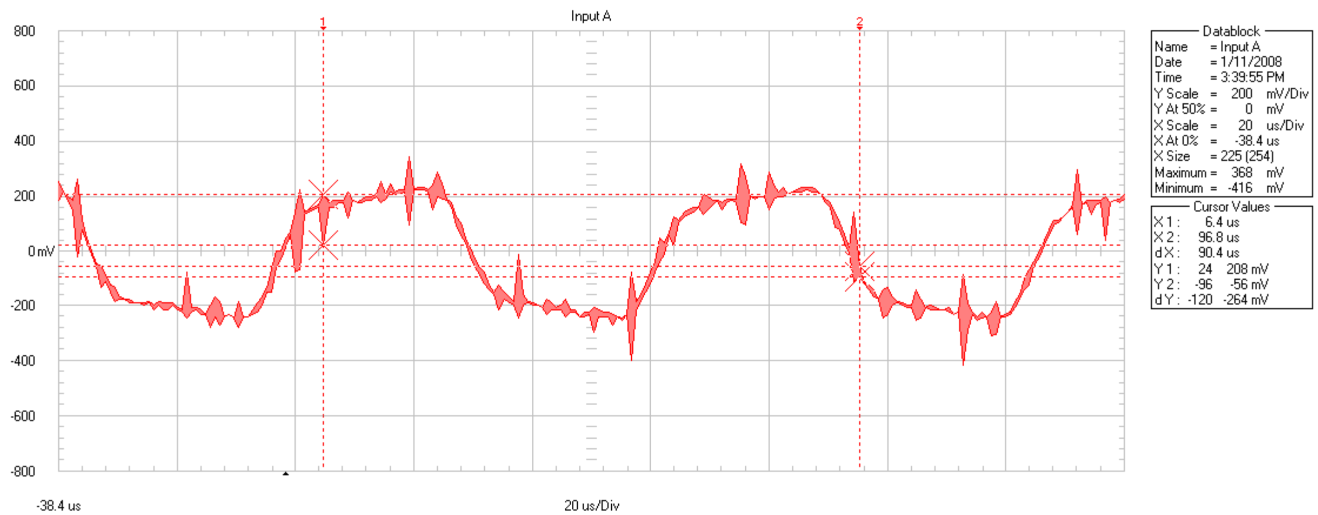


Figure 3.15–Wave form with more than 2 Active BTs

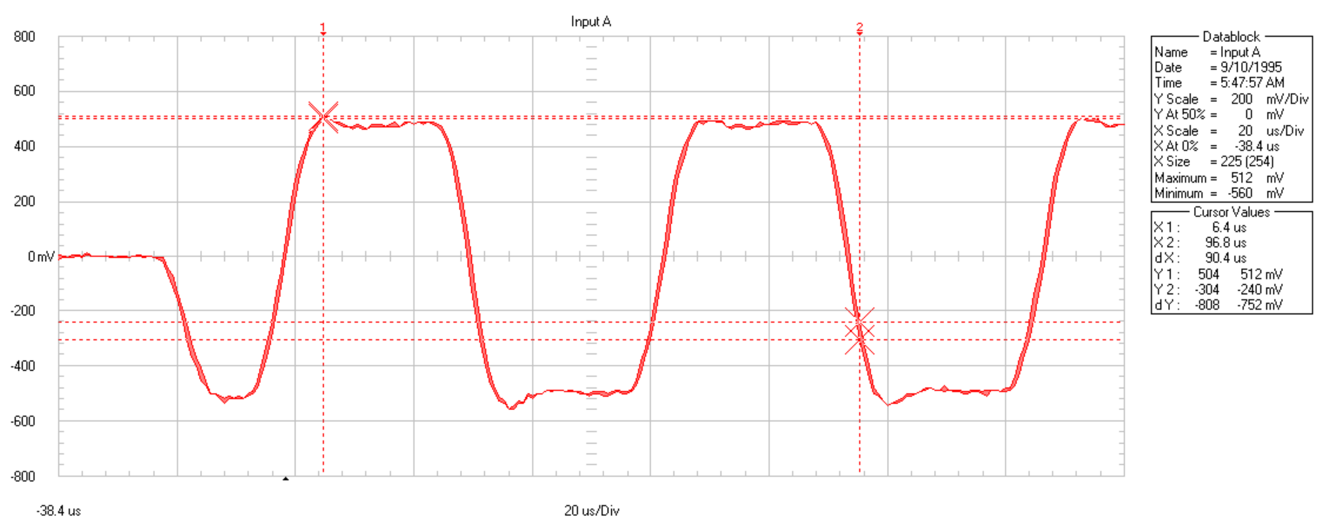


Figure 1.16 – Wave form with Correct BT

Check the position of the terminators in the following topologies.

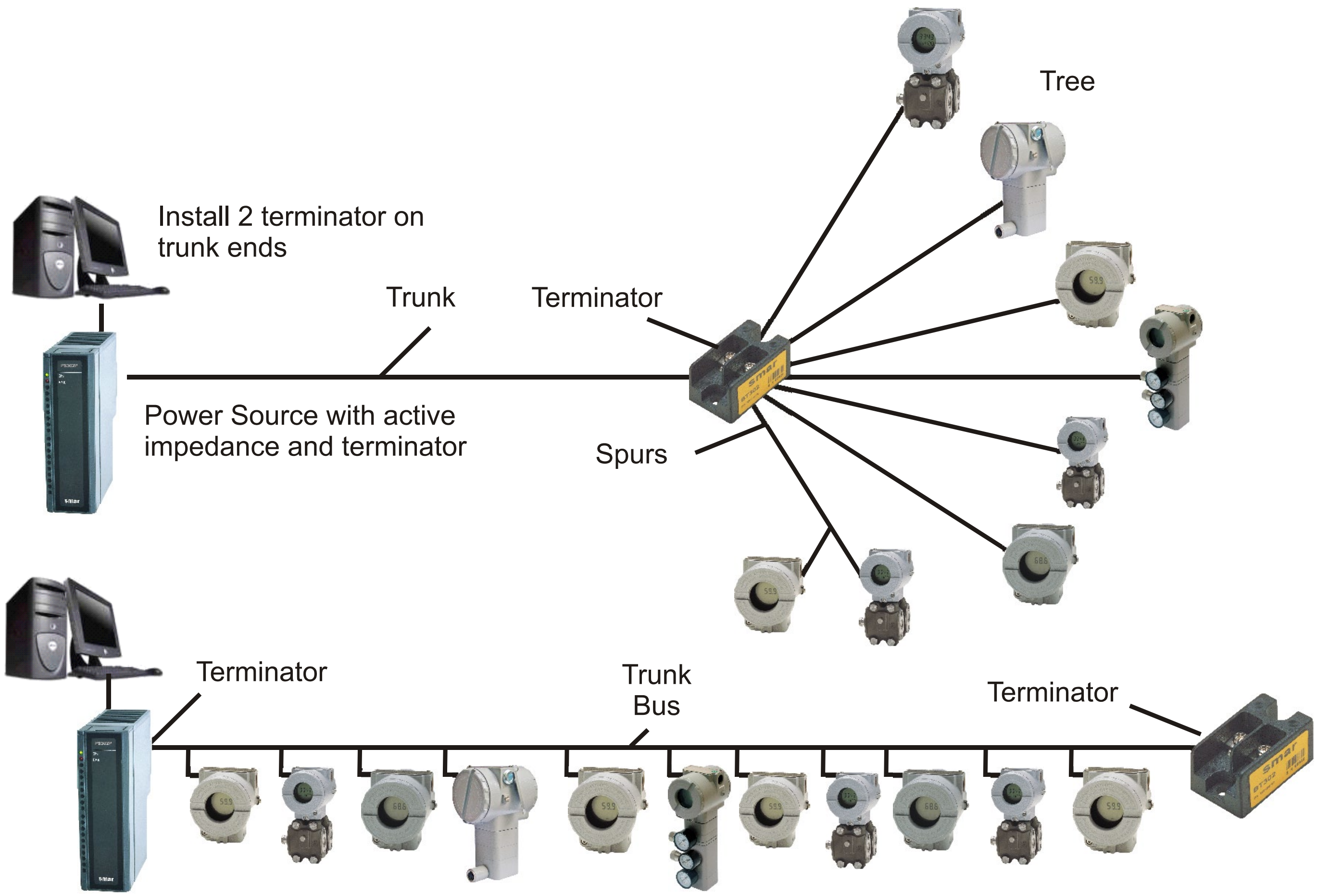


Figure 3.17 - Position of Terminators in Tree or Star Topologies and on the Bus

Power Supply

The power supply usually has an output of 24 Vdc with capacity of a few amperes. The power supply can operate in redundant mode, and it should failure indication and protection against surges, transients and short circuits. Smar makes the DF52 power supply that meets these characteristics.

In terms of power supply signal, consider as acceptable values in practice:

- 12 to 32 Vdc in the PSI output (Active Impedance)
- Ripple (mV):
  < 25: excellent;
  25 < r< 50: ok;
  50 < r < 100: acceptable;
  > 100: unacceptable.

In terms of communication signal, consider as acceptable values in practice:

- 750 to 1000 mVpp: ok;
  > 1000 mVpp: Very high. A terminator may be lacking.
  Some barriers and segment protectors, like spur guards, have high impedance in series and can produce signals up to 2000 mV and even allow the appropriate operation.
- < 250 mVpp: Very low. It is necessary to verify if there are more than 2 active terminators, power supply, etc.

Some devices have polarity, others not, so it is very important to assure the correct polarity of the devices. All the devices are connected in parallel, that is, all the negative terminals together and all the positive terminals together. The use of colored wires codified is recommended to distinguish the positive from the negative.

Active Impedance (PSI)
The active impedance avoids that the power supply low impedance lessens the communication signal of the bus, allowing the feeding to be supplied in the same wire pair.

It works as low impedance for DC and high impedance for AC communication signal and may have an additional internal terminator activated by a frontal key. The active impedance is fundamental for the network correct operation.

The Foundation Fieldbus impedance is on a device of non-isolated, active impedance control, complying with the IEC61158-2 standard. This device has an output impedance that works in parallel with the two bus terminators (a resistor of 100 Ω in series with a capacitor of 1 μF) assisting to the pattern and results in purely resistive line impedance for a wide frequency range. The Smar DF49 module has two channels and the DF53 module four channels.

Repeaters H1
The passive repeater increases the H1 segment range of 1900 m by amplifying its signal. Up to 4 repeaters may be used with 8-bit preamble or a maximum of 8 repeaters with 16-bit preamble. A maximum of 4 repeaters. It is usually allowed.

As the repeater isolates the communication signal and the power supply, it is possible to connect devices that drain more current from the bus or even to create new segments starting from the same main bus (Figure 3.18). Smar offers the RP302 repeater, as well as the DF47 model that works both as repeater and intrinsic safety barrier.

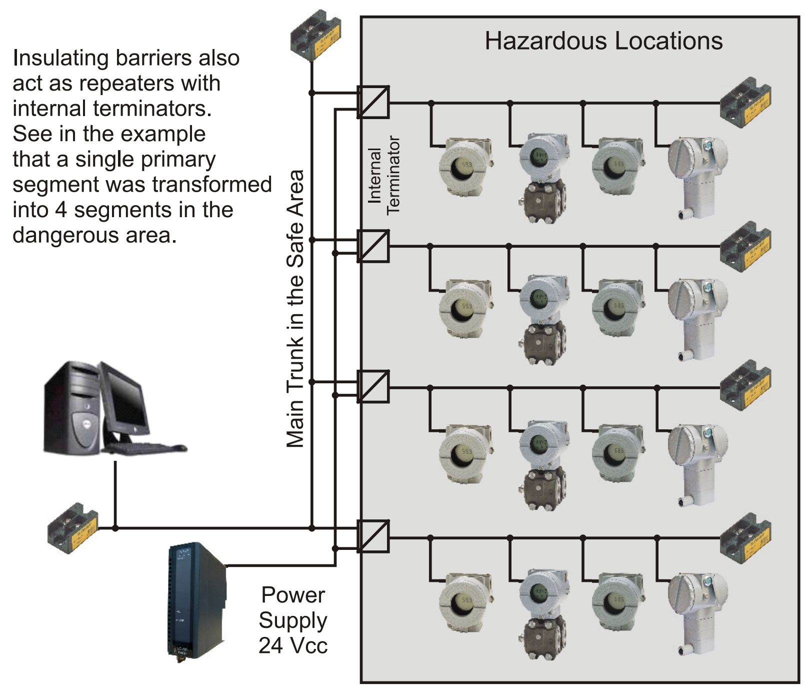


Figure 3.18 - Isolation Provided by the Barrier

Intrinsic Safety Barrier
The intrinsic safety barrier has the primary function to limit the energy available in the bus that circulates for the classified areas.

A classified area is that whose atmosphere is potentially explosive. The barrier usually isolates and repeats the FF signal, allowing several segments on the dangerous side to be connected to the safe side. See Figure 3.18. The Smar offers the model DF47, which works as repeater and intrinsic safety barrier, as well as the SB302 model, which is an isolated barrier.

Derivation Box
It allows the connection and disconnection of devices without interrupting the continuity of the bus, increasing the plant availability, and simplifying maintenance. It reduces start-up time, stoppage time and cabling costs.

In the Smar JM400 model, the weather-proof and explosion-proof housing prevents water, oil or dirt from reaching the electric connections IP66/68. Its cover lock mechanism doesn't require specific support. See Figure 3.19 and 3.20.

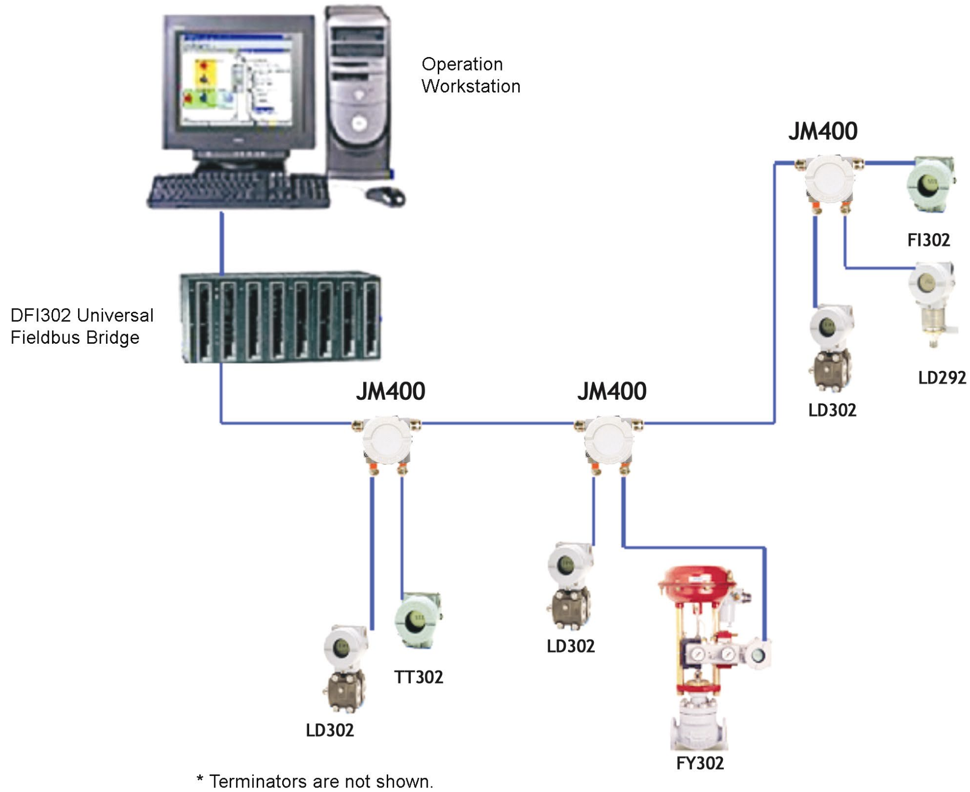


Figure 3.19 – Network with Derivation Box

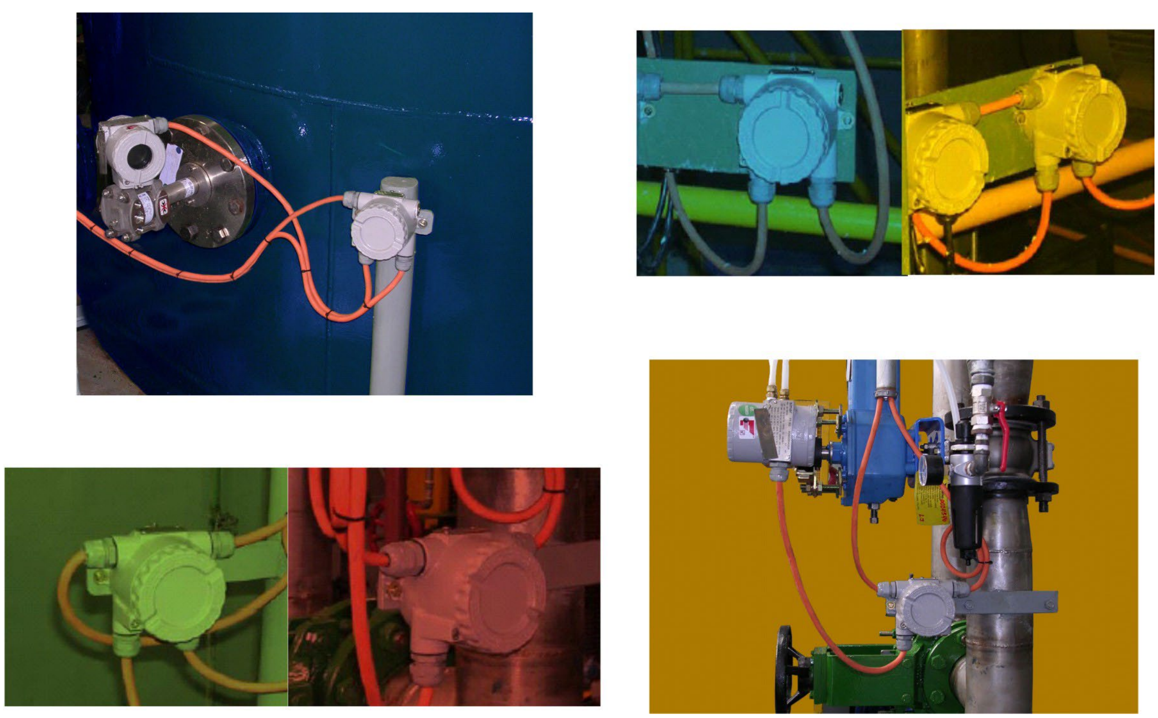


Figure 3.20–Field Network with Derivation Box

The FISCO Concept Installation
The FISCO model (*Fieldbus Intrinsically Safe Concept*) detailed on standard IEC 60079-27.

Following some FISCO model characteristics:
a) In *Ex ia* areas the maximum bus length should be 1000 m and in *Ex ib*, 5000 m;
b) Concerning cables (without restrictions for cabling up to 1000 m) observe the following parameters:
   - R´:15 to 150 Ω/km;
   - L´: 0.4 to 1 mH/km;
   - C´: 80 to 200 nF/km.

Type A cable: 0.8 mm² (AWG 18)

c) Concerning termination:
   - R = 90 to 100 Ω;
   - C = 0 to 2.2 μF.

The FISCO concept was optimized so that a larger number of field devices are allowed according to the bus length, taking into account the cable variation characteristics (R', L',C ') and terminators that assist categories and groups of gases with a simple evaluation of the installation involving intrinsic safety. Thus, it increased the current capacity per segment and facilitated the evaluation for the user. Besides, when acquiring certified products, the user doesn't need to worry with calculations, even in substitution of an operation.

The FISCO model represents a fast and easy way to project, install and operate H1 networks in installations on classified areas. The main idea is to supply more current to the H1 segment, enabling among other advantages the connection of a greater number of equipment, when compared to a conventional intrinsically safe installation. In summary, just follow the requirements below:

- Use certified and approved devices for FISCO applications;
- Check the parameters of each device (U_i, I_i, P_i): $U_0<U_i$, $I_0<I_i$, $P_0<P_i$;
- Observe the parameters of the used cables carefully (R, L, C). Use type A cable
- To observe the correct use of the terminators;
- Do not exceed the maximum length allowed for the cabling.

The main advantages when using a FISCO installation are:

- Plug&Play actions in hazardous areas;
- The system certification is not mandatory, but is up to user discretion;
- The expansion of the application is very simple;
- It is possible to connect the maximum number of devices in the classified area;
- The installation costs are reduced;
- There is no need for parameter recalculation when changing the devices.

FNICO
A new concept that also appears on the scene is FNICO (*Fieldbus Nonincendive Concept*), which is similar to the FISCO, but limited for use in Zone 2. Both concepts, FISCO and FNICO, are turning the fieldbus more attractive for use in hazardous areas.
FNICO is allowed in North America countries or those based on standards of this region. This concept considers:
- Input capacitance/inductance;
- Maximum cabling and spurs;

And the following:
- V_{max} of each field device > V_{oc} of the Repeater;
- I_{max} of each field device > I_{oc} of the Repeater;
- P_{max} of each field device > P_{oc} of the Repeater.

Repeaters with 215 mA of capacity are common.

Transient Suppressor

Whenever having an effective distance between 50 and 100 m on the horizontal or 10 m on the vertical position between two grounded points, the use of transient protectors is recommended, on the distance initial and final points. On the horizontal, its use is recommended between 50 and 100 m.

NOTE
The transient suppressor protects the electric circuit against overtensions.

The transient protector should be installed immediately after the PSI, before each device and also in the junction box. In classified areas, the use of certified protectors is recommended. See Figure 3.21.

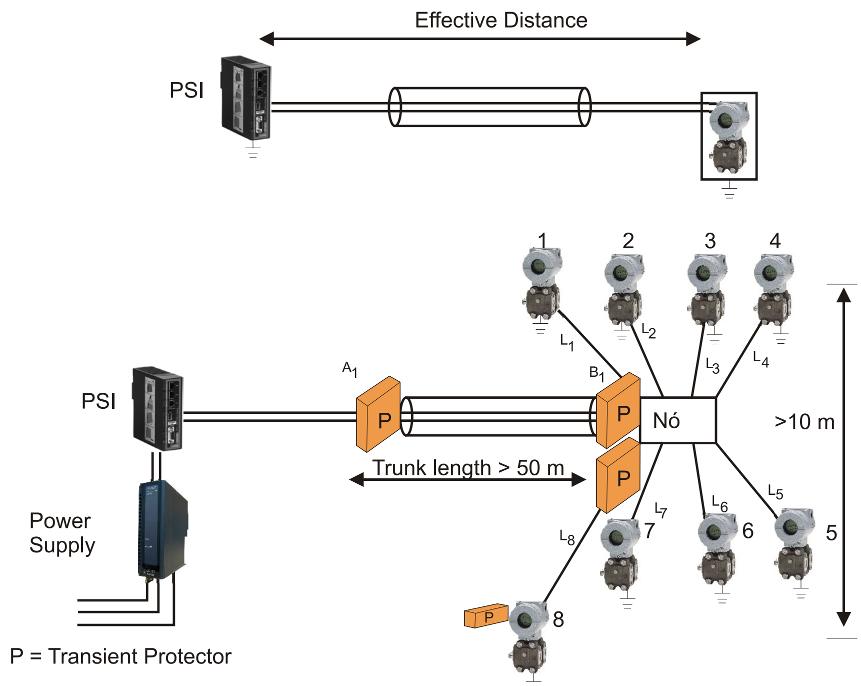


Figure 3.21 – Effective Distance on a Cable Distribution

Topologies

In relation to topology, there are the following models: Star or Tree, Bus and Point-to-point (Figure 3.22). In practice, there is usually a mixed topology.

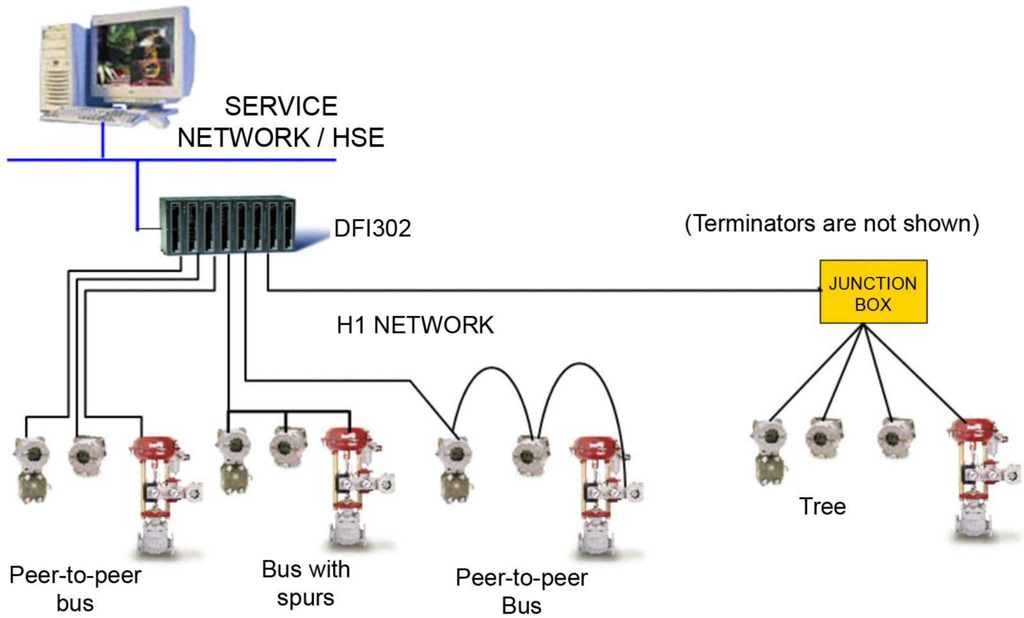


Figure 3.22 – Examples of Fieldbus Topology

Shield and Grounding

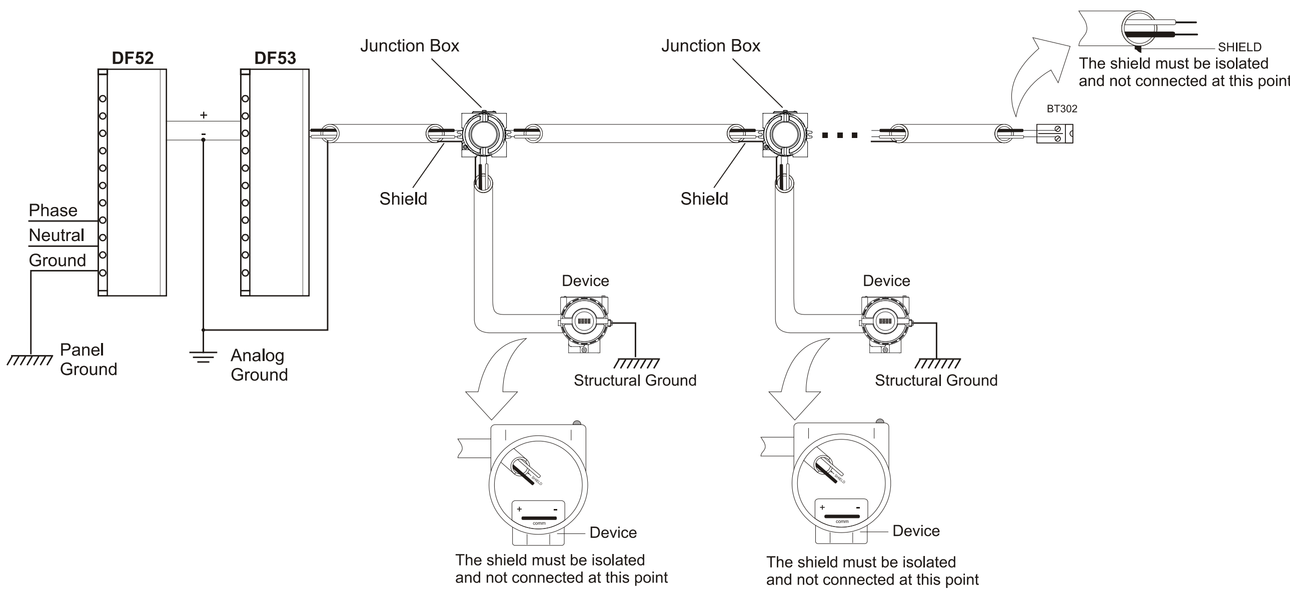
When considering shielding and grounding in field bus, the following should be taken into account:

- Electromagnetic compatibility (EMC);
- Protection against explosion;
- Protection of people.

According to the IEC61158-2, to ground means to be permanently connected to the ground through sufficiently low impedance and with enough conduction capacity to prevent any voltage to cause damages to equipment or people.

Voltage lines with 0 V should be connected to the ground and be galvanically isolated from the bus. The purpose of grounding the shield is to avoid high frequency noises.

Preferably, the shield should be grounded in two points, in the beginning and the end of the bus, as long as there is no potential difference between these points, allowing the existence of loop current and access to it. In practice, when this difference exists, the shield should be grounded in a single point, in other words, at the power supply or the intrinsic safety barrier. The continuity of the cable shield must be kept in more than 90% of the cable total length. See the Figure 3.23.



Note: Ensure the shield continuity in all Junction Box directions and that it does not touch the housing

Figure 3.23 - Shield grounding on one side only

The shield should cover the electric circuits completely through the connectors, couplers, splices and distribution and junction boxes.

The shield should never be used as a signal driver. The shield continuity should be checked until the last fieldbus device on the segment, and the connection and finishing inspected, because the shield should not be grounded to the equipment housing.

In classified areas, if a potential equalization between the safe area and the hazardous area would not be possible, the shield should be connected directly to the ground (Equipotential Bonding System) only on the dangerous area side. In the safe area, the shield should be connected preferably through a ceramic capacitive coupler, like a solid dielectric capacitor, $C \leq 10$ nF, isolation voltage ≥ 1.5 kV). See Figures 3.24 and 3.25.

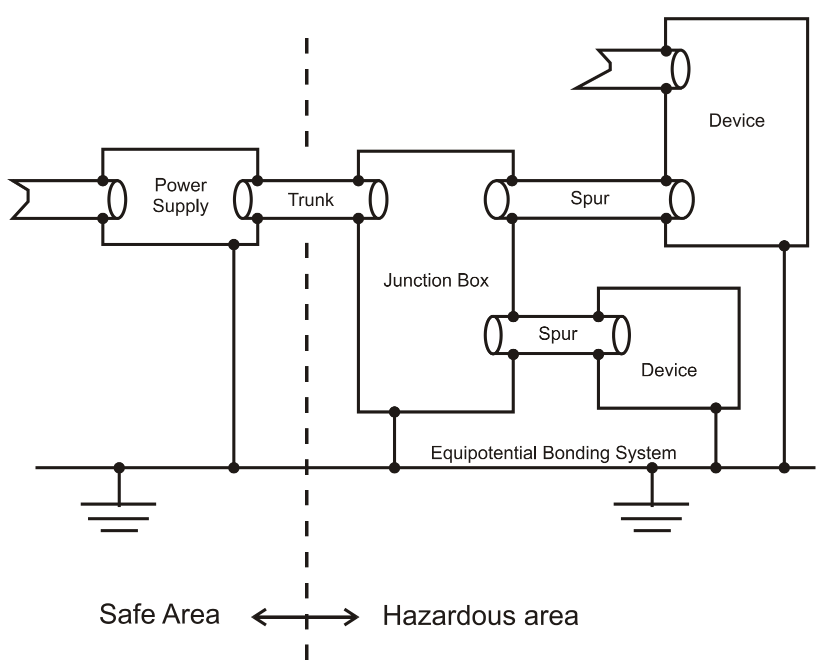


Figure 3.24 – Shield and Grounding Ideal Combination

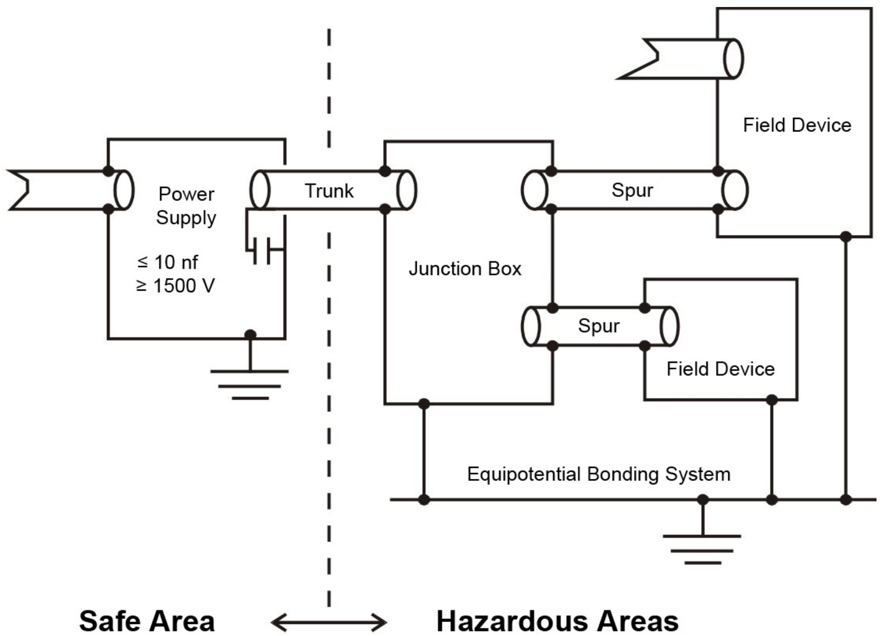


Figure 3.25 – Capacitive Grounding

Quantity of Foundation Fieldbus Equipment in a H1 Segment

The amount of equipment (N) for segment is a function of the quiescent consumption of each H1 equipment, the involved distances (type A cable loop resistance: 44 O/km), the drained current, of the area classification, besides the FDE current (usually 0 mA, depending on the manufacturer). The total segment current should be smaller than the one drained by the power supply. Smar devices consume 12 mA.

$$I_{Seg} = \sum I_{BN} + I_{FDE} + I_{FREE}$$

Because:

$$I_{Seg} \langle I_C$$

Where:

I_{Seg} : H1 segment current;

$\sum I_{BN}$: Sum of the quiescent currents of all the devices in the H1 segment;

I_{FDE} : Additional current in case of failure, usually negligible;

I_{FREE} : Recommended: 20 mA, rest current useful in case of expansion or change of manufacturer

I_C : Drained current.

Besides, it is recommended more than 9.0 V in the terminal block of the H1 device most distant from the PSI to guarantee its powering and correct communication:

$$V_{BN} = V_C - (R * L)$$

Where:

V_C : Power supply output voltage;

R : Loop resistance (Type A cable, R = 44 Ω/km);

L : H1 Bus total length;

V_{BN} : Voltage in the terminal block of the H1 devices most distant from the PSI.

Being

$V_{BN} \rangle\ 9.0V$. This guarantees the powering of the last H1 device. Remember that the communication signal should range from 750 to 1000 mV.
Some junction boxes or short circuit protectors for segments, called spur guards, are active and can be powered through the H1 bus; hence, it should be included in the calculation of the total current. Besides, each spur guard output has an allowed current limit that should be respected.

In classified areas follow the established limits.

Foundation Fieldbus in Hazardous Areas
According to the standards, the Foundation Fieldbus technology can be applied in hazardous areas with the following characteristics:

- Ex d: In this case choose the power supply Ex and conduits with Ex d approval;
- Ex i: There are three options. The first involves the Ex-i concepts and the second a combination of Ex and Ex i. The third option is the FISCO.

Summary of Classified Areas

ZONE/ EXPLOSION GROUP	IDENTIFICATION	OBSERVATION
Zone 0	(Ex ia) IIx	Devices installed in Zone 0 should operate in a segment with “Ex ia” protection.
Zone 1	(Ex ia) IIx (Ex ib) IIx	Devices installed in Zone 1 should operate in a segment with “Ex ia” or “Ex ib” protection. All the circuits connected to this segment should be certified for “Ex ia” or “Ex ib” protection.
Explosion Group IIC	IIC (Ex ia) IIC	If the measures are taken in an IIC explosion group, the devices and components should be certified for the IIC.explosion group
Explosion Group IIB	(Ex ia) IIC (Ex ib) IIB	For the IIB medium explosion group, both devices and components can be certified for the IIC or IIB groups.
Non -Ex	Non-Ex	Devices that are operating in a no-Ex segment should not be installed in explosion-risk areas.

Table 3.4 - Summary of Classified Areas

Intrinsic Safety Definition
Intrinsic safety limits the equipment circuit energy, so that they do not cause the ignition of potentially explosive atmospheres even in the occurrence of failures that may produce sparks or warm surfaces in contact.

As it deals with energy limitation, this is an adequate technique for electronic equipment, typically used in control and process instrumentation.

FOUNDATION™ fieldbus and Intrinsic Safety
The I.S. technology integrated in the DF47-12 and DF47-17 Intrinsic Safety Barriers completely isolates the control area in hazardous or risk areas. The I.S. power supply are designed for fieldbus devices that comply with the FISCO model.

The incorporation of a Fieldbus repeater that complies with IEC 1158-2-31 kbits/s essentially cleans and increases the communication signal, thus transmitting them to the classified areas. The networks on the DF47-12 and DF47-17 classified and protected sides are completely independent.

Besides, the bus ends on the classified network are included in the DF47-12 and the DF47-17, i.e., have only one external terminator.

NOTES
1. If the DF53 module terminator is not being used, install another terminator in the safe area. 2. The DF47 model was discontinued due to FISCO new recommendations. The substitution of the DF47-12 or the DF47-17 must be evaluated to comply with the current limits supported. The DF47-17 supports up to 7 devices from the Smar 302 line. In case the DF47-12 is the replace, only 5 devices from the Smar 302 line are supported.

BARRIERS DF47-12 AND DF47-17 DATA

- H1 Isolated Barrier and I.S. Power Supply compliant with the FISCO model;
- Fieldbus H1 signal repeater;
- Meets the IEC 1158-2, 31.25 kbits/s standard for Fieldbus (FOUNDATION™ fieldbus e PROFIBUS PA);
- Certified according to IEC, FM & CENELEC intrinsic safety standards;
- Complies with IEC60079-27, FISCO e FNICO for power supplies;
- Double marking in compliance with IEC60079-11 e IEC60079-27,
- Bus terminator on the non-safe side.

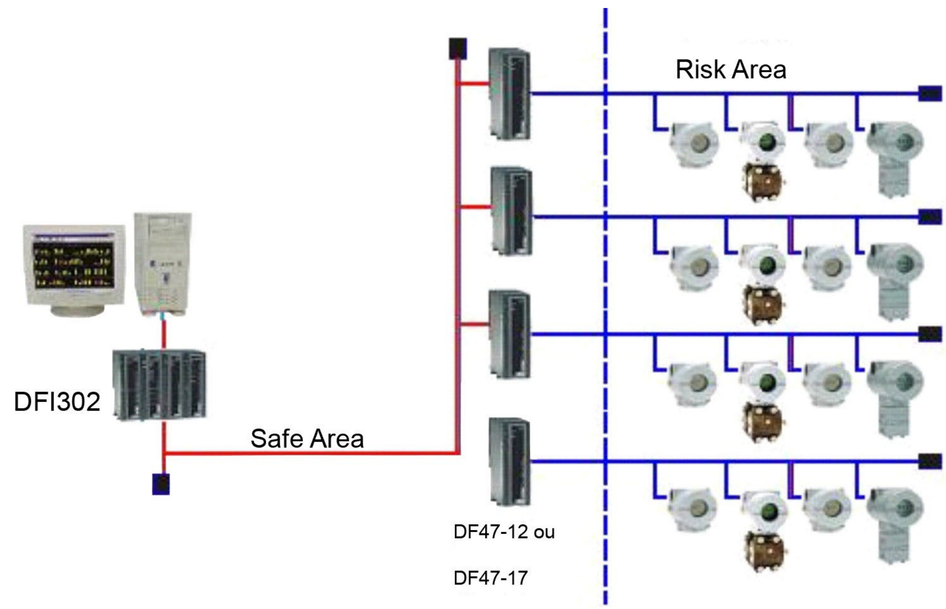


Figure 3.26 – DF47 Installation

With the limited energy available for each equipment on the hazardous area, some instruments must be powered by other power supplies. Therefore, devices like process analyzers, I/O subsystems, magnetic or Coriolis effect meters could combine intrinsic safety with other installation or contention techniques for protection against explosions.

When choosing the barrier, consider the number of devices, the quantity of cables and the capacitance/inductance limiting values for the Ex i installation.

Table 3.5 presents a brief comparison between the FISCO and FNICO models and the entity model.

	FISCO	Entity Model	FNICO
Cable Length	1000 m - ia (*) 5000 m - ib (*)	1900 m	1000 m
Maximum *Spur* Length	30 m(*)	120 m	30 m(*)
Cable and Length Reactance	Non-considered	Considered	Non considered

(*) Maximum analyzed length. It is possible (the) to use (of) a larger length.

Table 3.5 –FISCO vs. Entity Model

There is a set of rules for applications in hazardous areas that uses intrinsic safety methods. The fieldbus technology refers to the lengths of the segments, limits of currents in the power supply and parameters as capacitance and inductance, as well as parameters of equipment failures.

The FISCO method provides an easy implementation for applications intrinsically safe in fieldbus, giving flexibility, operational safety to the applications and reducing installation costs, since one can handle up to 10 devices in an Ex network. Besides, the possibility of online handling simplifies commissioning, startup, and maintenance. More power means more devices and less cables, hence less barriers.

Equipment compliant to FISCO can be directly connected to IS networks based on the entity model. The reverse condition needs to be evaluated.

Following are described some key points that should be considered during the implementation, involving classified areas and fieldbus:

- Which is the hazardous area? Remember that non-incendive is only allowed in Division 2 areas and intrinsic safety equipment only in Division Div 1 and Division Div 2 areas);
- Which size and scalability required? How many devices will be implemented? Will there be expansion?
- Will there be short circuit protection for the main trunk and the spurs?
- Which are the acceptable safety level and risks? (Projects involving intrinsic safety take into account the components failure and allow maintenance while being powered, although without heat. Conversely, non-incendive equipment doesn't allow maintenance being performed during powering or even heat exchange.
- Are there limitations to shutdowns?
- Do the engineering and the maintenance teams have proven experience with hazardous and classified areas?
- Do all the devices have certification compatible with the application?
- Are the facilities compliant to the area and country safety standards?

For more details consult IEC60079-27, "*Fieldbus Intrinsically Safe Concept* (FISCO)" and "*Fieldbus Non-Incendive Concept* (FNICO)".

Increasing the Reliability

There are several ways to increase the fieldbus network reliability. They are the following:

a) Power supply redundancy, according to Figure 3.27.

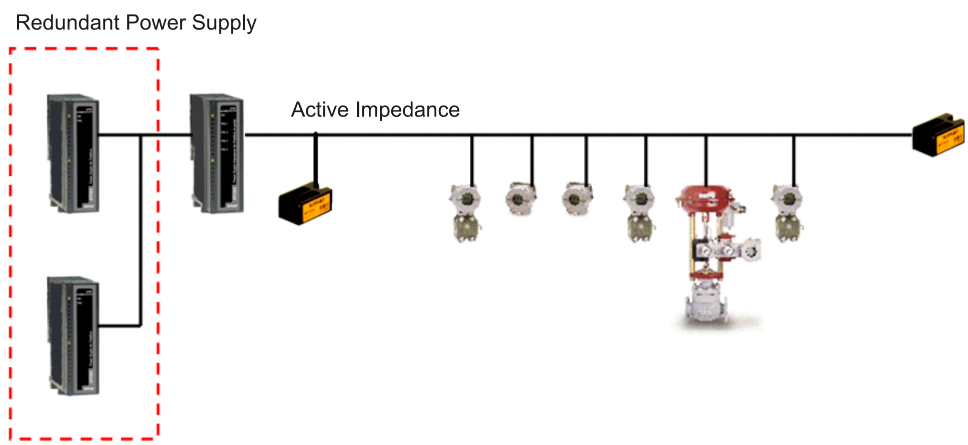


Figure 3.27 –Power Supply Redundancy

a) Double active power supplies and impedance, in case of a cabling break for: See Figure 3.28:
   - Guaranteed power supply;
   - Non-guaranteed Integral communication;
   - Guaranteed failure position.

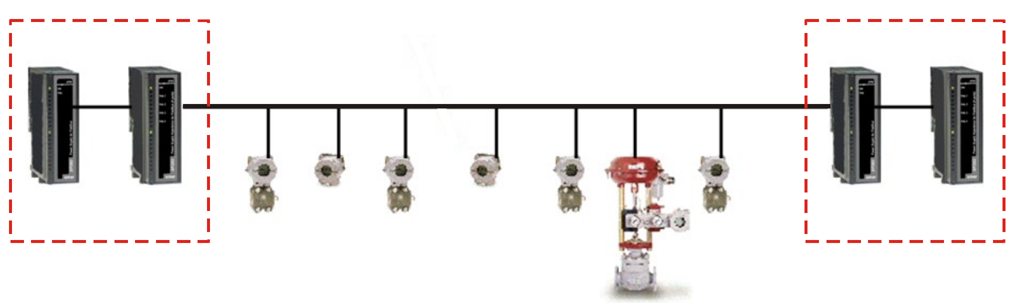


Figure 3.28 – Double power supply and PSI

Modbus Network

Modbus is an application layer protocol, positioned at the OSI model level 7, which provides client/server communication between devices connected on different types of buses and networks (Figure 3.29). The Modbus is a request/reply protocol and offers specified services through codified functions.

It is currently implemented using:
1- TCP/IP over Ethernet;
2- Asynchronous serial transmission over several medias:
   2.1- Wires (EIA/TIA-232-E, EIA-422, EIA/TIA-485-A);
   2.2- Fiber optics;
   2.3- Radio;
3- MODBUS PLUS, a high speed token passaging network.

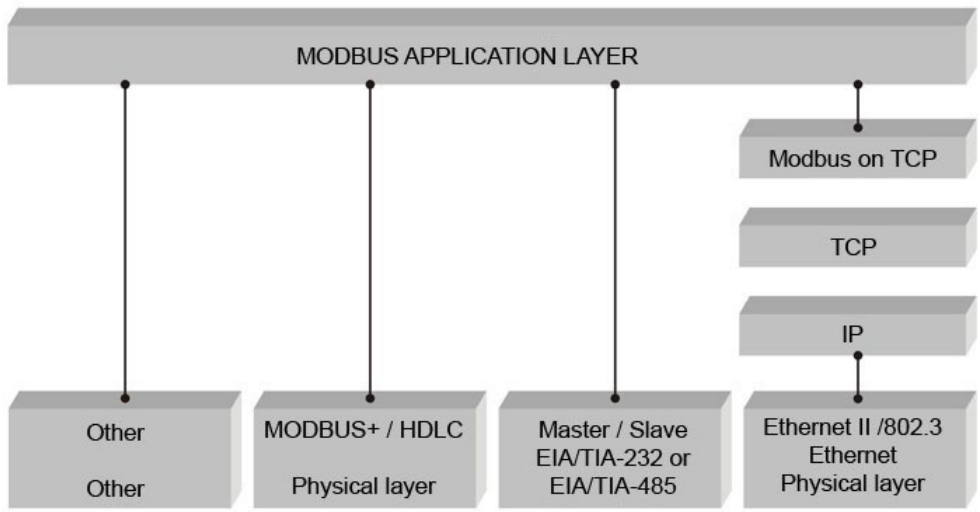


Figure 3.29 – Modbus communication stack

There are different versions of the Modbus protocol for serial port and Ethernet and other networks those support the TCP/IP protocol.

For serial connections there are two variations, with different numerical data representations and other protocol details. Modbus RTU is a compact binary data representation. Modbus ASCCII is based on ASCII characters. For connections over TCP/IP (example: Ethernet) there is a more recent Modbus/TCP variation. The data and functions model is identical for all the three formats, except for a different encapsulation.

There is also an extended Modbus Plus version, Modbus + or MB+, but remains proprietary to Modicon. It requires a dedicated co-processor for fast HDLC token rotation handling.

This section will deal specifically about Modbus on RS-485 physical layer networks.

Purpose of the RS-485 Standard

The TIA-EIA-485 Standard, also known as RS-485, defines the electric characteristics of the interfaces, formed by drivers and receivers, for use on balanced multipoint transmission lines (Figure 3.30). It does not say anything about the communication protocol to be used. As an electrical-only standard, it is referenced by higher level standards as their physical layer.

Network Topology

The bus nodes are linked by the RS-485 interfaces using a physical topology called daisy chain (consecutive nodes linked, in parallel, on a single bus), Figure 3.30 - left. Another way is when each node is connected to the bus trunk or main cable through small stubs (Figure 3.30 - right). The stubs must be the shortest possible.

Each bus node interface is generally designed for half-duplex transmissions, meaning that only one pair of wires is used, across which the data transmission/reception must occur at different times, Figure 3.30 - right. The use of a twisted pair adds up to the benefit of canceling part of the magnetic or electromagnetic noise coupled on the cable.

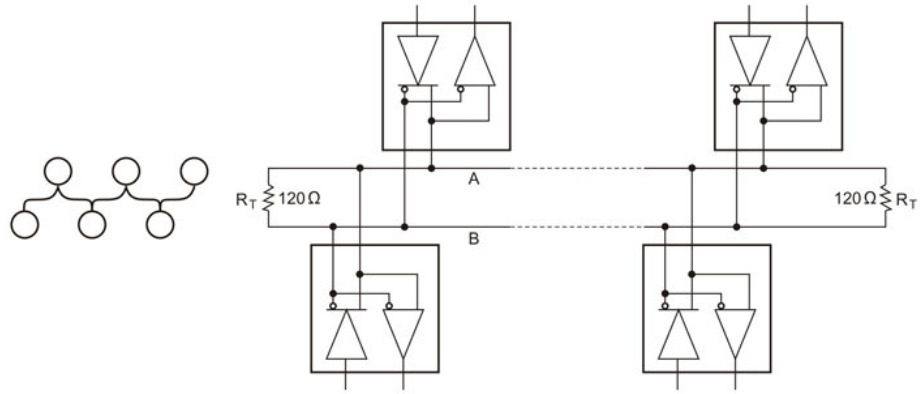


Figure 3.30 – Daisy chain topology (left), half-duplex bus structure with drivers and receivers interfaces (right).

This implementation requires that every node interface have signals for direction control, like the enable signals on drivers and receivers, to ensure that only one driver is active at a time on the bus. If more than one driver has access to the bus simultaneously, it will cause bus contention, which must be avoided by means of the operation protocol used.

Avoid other topologies like star, ring, backbone with stars or clusters and backbone with stubs, as shown on Figure 3.31. The topology recommended for RS-485 is the daisy chain type. The backbone with stubs type can be used with additional care.

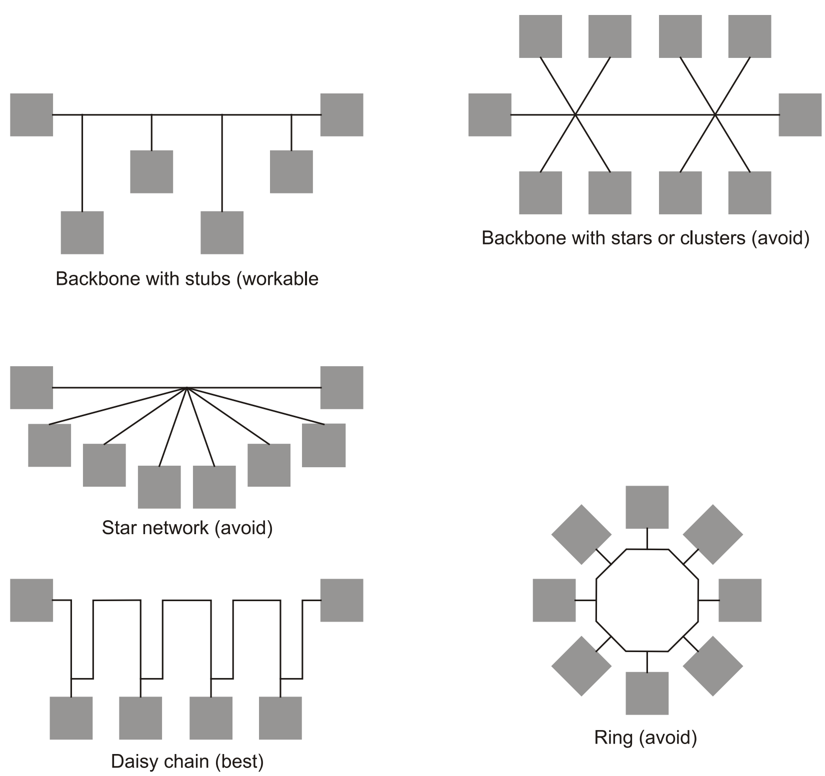


Figure 3.31 - Among many topologies, the daisy chain type is the most reliable for RS-485 networks

Signal Levels

The RS-485 bus is differential by its own nature. Two wires connected to the driver outputs A and B generate complementary voltages. Figure 3.32 shows how the V_{OA}, V_{OB} e V_O signals are defined. When V_{OA} is low, V_{OB} is high; reversely when V_{OA} is high, V_{OB} is low. Most interfaces keep their output in high impedance.

The RS-485 drivers must provide a minimum differential output of 1.5 V across a 54 Ohm load, while the RS-485 receivers must detect a minimum differential voltage of 200 mV (Figure 3.33). These two values enable sufficient margin for a reliable data transmission and tolerate a good amount of differential noise and signal attenuation through the cable and connectors. This robustness is the main reason for the RS-485 being suitable for long-range networks in noisy environments.

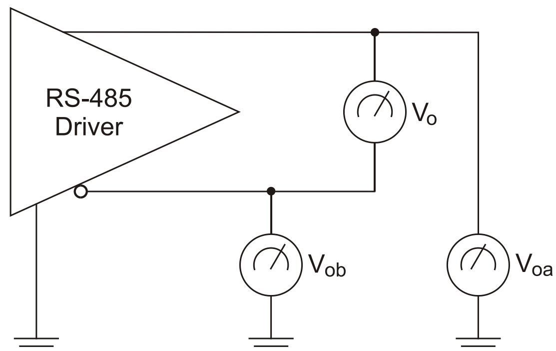


Figure 3.32 – Relation between VOA, VOB and VO signals

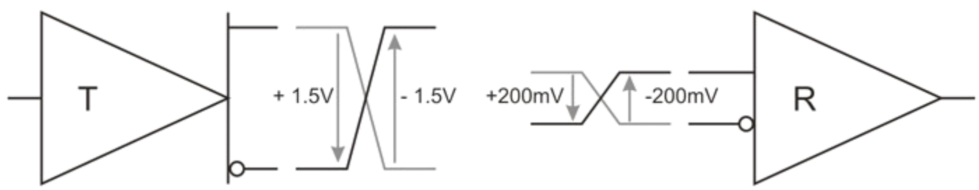


Figure 3.33 - RS-485 bus minimum signal levels

Cable Type and Number of Conductors

RS-485 applications use differential signalization over twisted pair cable. This equally couples external supply noises on both wires as a common-mode noise, which is rejected by the receptor differential input. If the wires are separated or distant from one to another, the noise will not be coupled equally and generates a differential noise. Therefore, during the cables installation be careful to not untwist the twisted pairs.

The A and B signals are complementary, though this does not imply that a signal is a current return to the other. The RS-485 is not a current loop and the interfaces must share a common ground. So, the RS-485 cannot be specified as a two-wire only network. It is recommended that one more wire be used as the interface common earth. The third wire avoids the high voltage between the interfaces.

A cable example is shown on Figure 3.34. It is a Belden good quality product with the following characteristics:

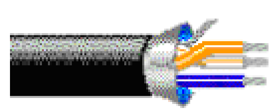


Figure 3.34 – Cable example, 3106A Paired – EIA Industrial RS-485 PLTC/CM – Belden

Model: Belden 3106A PLTC/CM;
Conductors: 22 AWG stranded tinned copper conductors
Presentation: 1 twisted pair + 1 conductor;
Shielding: Beldfoil® (100% coverage) + tinned copper braid (90% coverage) + drain wire;
Isolation: Datalene®
Impedance: 120 Ohms;
Capacitance: 11 pF/foot (33.33 pF/m);
Propagation speed: 78% (1.3 ns/foot, 3.94 ns/m);
Encapsulation: UV-resistant PVC.

Another option is to specify an extra twisted pair in order to have sufficient conductors for the ground signal. A two-wire RS-485 bus, therefore, requires two twisted pairs.

In addition to the network cables, the tracks and connector pins on the RS-485 interface printed circuit board must be equidistant, close and with the same length, to maintain the network electric characteristics.

Shielding

Most times, it is difficult to quantify if a shielded cable is necessary or not on a RS-485 system. As the additional cost for a cable to be shielded is minimal, it is worth using it when first installing the cabling on the system, considering future costs needed for changing a non-shielded cabling for a shielded one.

Bus Terminators and Stub lengths

Due to the high data sending and receiving rates, the RS-485 bus is considered as a transmission line. For avoiding signal reflections, a transmission line must always be terminated and a stub be the shortest possible. An adequate termination requires matching the termination resistors (RT) with the featured impedance (Zo) on the transmission line. As the recommended are Zo = 120 Ohms cables, the RS-485 bus backbone generally uses 120 Ohm resistors, one on each backbone end or extremity.

A stub length (the distance between an interface and the backbone) must be less than 1/6 of the electric length of signal it carries.

Stub Length < (1 / 6) * Eletr. Length.
Eletr. Length = ts * v * c

While:
Stub length = to maximum stub length without the terminator;
[unit in meters]

Electr. Length = signal electric length;
[unit in meters]

Ts = rise or fall time (the smallest one) of the driver output signal (time spent between 10 percent to 90 percent of the signal transition;
[unit in seconds]

v = velocity of the signal propagation on the cable relative to c;
[without unit]

c = velocity of light propagation on vacuum (300,000,000 m/s);

The important thing is the non-existence of interference from reflections in the middle of the bit (the receiver reading point), i.e., the interference from reflection must be so fast for them to occur during the signal rising or falling edge of the bit (during the transition), so that they stay away from the center of the bit, where the signal must be stable for correct receiver reading.

The rise and fall signal time are added in the assumption that this is half the wave period for the worst case. However, the waveform required on the RS-485 is generally that whose rise and fall time is at maximum 1/3 of the stable part of the bit. Or, 1/3 for rise, 1/3 for stable and 1/3 fall, making up the total bit width. Therefore, with drivers with fast rise and fall time transmitting at slow rates (the width of the bit stable part bigger than the rise and fall time) this supposition lacks real meaning.

So, the stub length (or that of a cable without terminator) can also be determined, based on the signal transmission rate. For example, at a transmission rate of 9600 baud, one bit has 104.00 us width. On a 4000.00 feet cable with propagation speed of 0.66*c a complete two-way trip is completed in 6.16 µs. Assuming that the reflections will weaken in 3 complete trips (back and forth on the cable), the signal will stabilize in 18.50 µs after the first bit transition (rising or falling edges). As the reflections will stabilize within 1/3 (≈ 35.00 µs) of the bit width (104.00 µs) there is no need for using a terminator, or the stub length is correct.

Fail Safe Operation

The fail safe operation is the ability of the receiver outputs a given state in absence of an input signal. Three possible causes may result in a signal loss:

a) **open circuit:** caused by a broken wire or the disconnection of a bus interface;
b) **short circuit:** caused by an isolation failure, that connects a differential pair wire to the other;
c) **idle bus:** occurring when no interface is transmitting.

A fail-safe circuit (for open circuit and idle bus) consists of a resistive voltage divisor that generates a differential voltage on the bus and in the receiver inputs sufficient to maintain the receiver outputs in a known state. To ensure enough noise margins, the receptor input voltage must include the maximum differential noise beyond 200 mV threshold. The values for fail-safe polarization resistors are calculated for the worst condition case, which is the maximum noise level plus the minimum power supply voltage level.

$R_B = (V_{Amin} * R_T) / (4 * V_{AB}) - (R_T / 4)$

While
R_B = polarization resistances;
[unit in ohms]

V_{Amin} = minimum power supply voltage;
[unit in volts]

R_T = termination resistances;
[unit in ohms]

$V_{AB} = V_{threshold} + V_R$ = input voltage required on the receivers;
[unit in volts]

$V_{threshold}$ = threshold input voltage on the receivers;
[unit in volts]

V_R = noise margin voltage;
[unit in volts]

Example:
For a minimum power supply voltage V_{Amin} = 4.75 V (5 V – 5%);
Limiar voltage V_{limiar} = 0.200 V;
Noise margin Vr = 0.050 V;
Input voltage required on receptor $V_{AB} = V_{LIMIAR} + V_R$ = 0.250 V;
And Zo bus characteristic impedance = 120 Ohms implying that the R_T terminators = 120 Ohms;
Then, R_B = 540 Ohms.

By inserting two serial 536 Ohm resistors with the first resistor terminator R_T (Figure 3.35 – left), the result is a fail-safe circuit for open circuit and inactive bus cases.

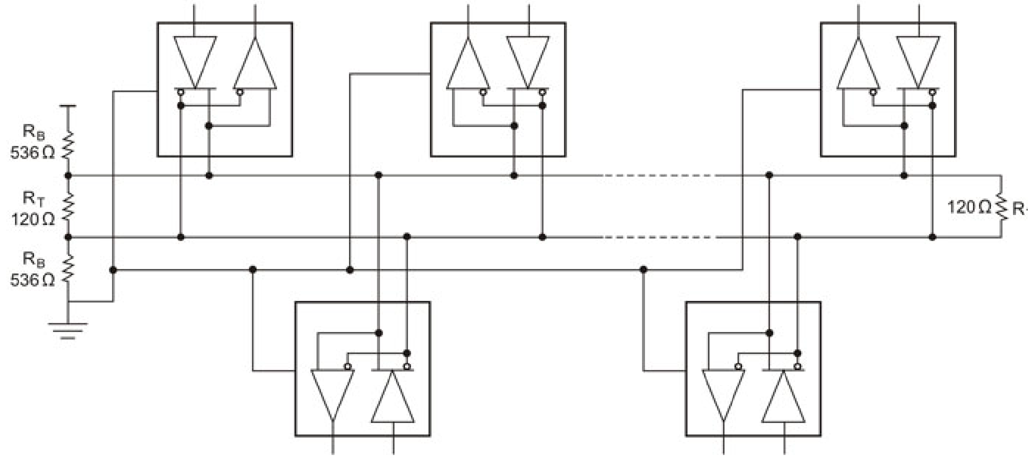


Figure 3.35 – External polarization for open circuit and inactive bus fail safe

For short-circuit fail safe, normally are inserted resistors in series with the bus so that during the short circuit the differential voltage on the bus stays on the required value. But this type of polarization harms the bus performance during the transmission, reason why it is used in a few cases.

Data Rate vs. Bus Length (with terminators, without reflection)

The maximum bus length also is limited by the data rate, due to the transmission lines losses and the signal jitter. The data reliability drops abruptly for a 10 percent jitter, or over, of the baud rate period. Figure 3.36 shows the maximum cable length versus the data rate on a RS-485 for a 10 percent jitter.

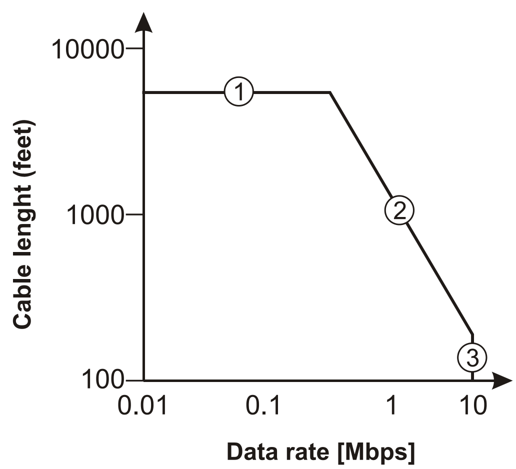


Figure 3.36 – Cable length versus data rate

On Figure 3.36, the section 1 represents the low data and long cable rate range whose line length is predominantly limited by the cable non-reactive (resistive) losses. On section 2, the cable reactive losses increase and the frequency reduces the maximum permitted length. For small lengths (section 3) the cable losses are negligible and only the driver rise time limits the maximum data rate possible.

Ground and Isolation

On a data bus, distant interfaces almost always present great ground potential difference. This adds to drivers output as a common mode noise. If these voltages are big enough they may exceed the receivers' common mode input range and damage them. Therefore, merely trusting the local ground as a reliable current return is not a good practice.

Connecting the interface grounds directly on the system ground wire also is not recommended, as it may cause ground loops that generate large current circulation through the ground that again will couple in the data bus as common mode noise.

Reducing the loop currents by inserting resistors on the ground course, as suggested by RS-485, solves half the problem. High loop current keeps the data bus sensitive to noises generated somewhere else in the loop. So, a robust data bus was not established yet.

The best solution for a long distance, robust, data bus is through galvanic isolation. In this case, the signal and power supply lines on the bus interface are isolated from the local interface signal and power supply. Power supply isolators like DC/DC converters and signal isolators like digital capacitive or optical isolators avoid current flow between distant ground interfaces and avoid creating current loops.

Figure 3.37 shows a detailed connection of multiple isolated interfaces. Here, all interfaces, with one exception, are connected to the bus through galvanic isolation. The non-isolated interface on the left provides a single ground reference to the internal bus.

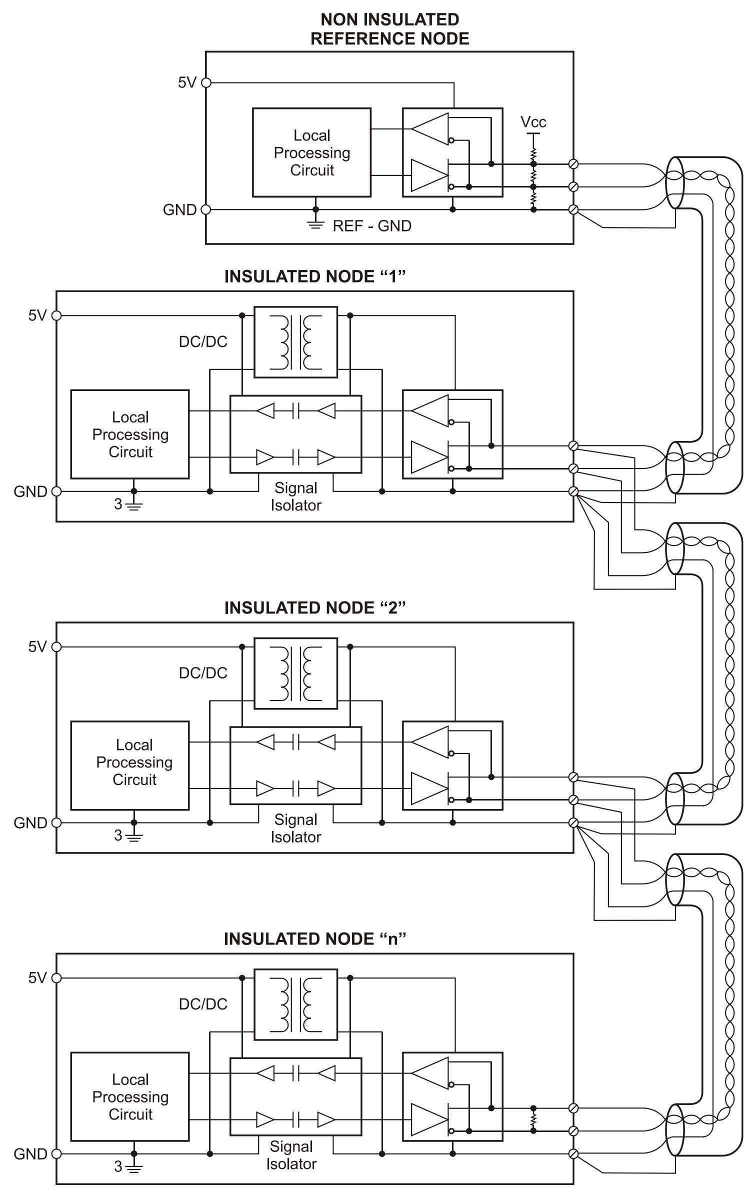


Figure 3.37 – Isolation between multiple interfaces as a single ground reference

PROFIBUS PA Network

Network Wiring

Access the wiring block by removing the Electrical Connection Cover. This cover can be closed by the cover locking screw. To release the cover, rotate the locking screw clockwise. See Figure 3.38.

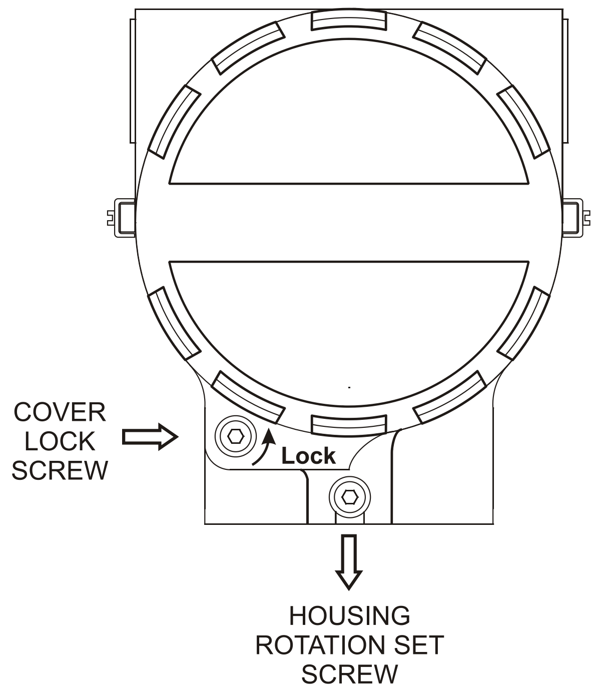


Figure 3.38 – Housing Rotation Set Screw and Cover Lock

Cable access to wiring connections is obtained by one of the two outlets. Conduit threads should be sealed by means of code-approved sealing methods. The unused outlet connection should be plugged accordingly.

The wiring block has screws on which fork or ring-type terminals can be tightened. For convenience there are two ground terminals: one inside the cover and one external, located close to the conduit entries. See Figure 3.39. For more details consult Shield and Grounded.

Avoid adjusting signal wiring close to power cables or switching equipment must comply with the guidance on tables 1 and 2.

NOTE
The passage of the signal wiring routes by which it has power cables or electrical switches must be avoided.

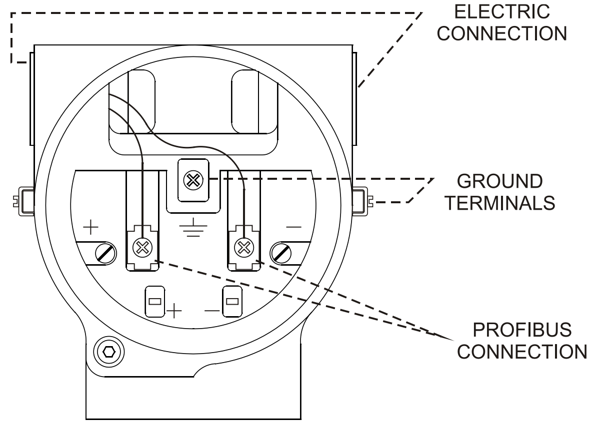


Figure 3.39 – Connection Blocks

HAZARDOUS AREAS
1. In hazardous areas requiring explosion-proof equipment, the covers must be tight shut with a minimum 8 turns. To avoid the penetration of humidity or corrosive gases, tighten the covers until the O-ring touches the housing. Give an extra 1/3 turn (120º) to ensure sealing. The covers must be locked with the locking screws. 2. The passage of the signal cables connected to the terminals must be through the housing electric connections, to be connected to a conduit or cable clamp. 3. The conduit threads must be sealed according to the area method. The non-utilized passage must be sealed with a plug and proper sealant. 4. If other certifications are needed, refer to the specific certification or standard for installation care.

The **Series 303** devices are protected against reverse polarity and can withstand up to 35 Vdc without damage. When in reverse polarity the device will not operate.

Physical Signaling

The **Profibus PA Series 303** devices use the 31.25 kbit/s (H1) voltage mode wire media option for the physical signaling. All devices on the bus must use the same Manchester modulation type. All devices are connected in parallel along the same pair of wires.

These devices are powered by bus, while some may be powered externally, not absorbing the energy PROFIBUS PA bus.

The signal used to communicate is a 750 mV to 1000 mV AC signal covering the DC supply signal.

In hazardous areas the number of devices must be limited by safety barriers, according to the area safety restrictions.

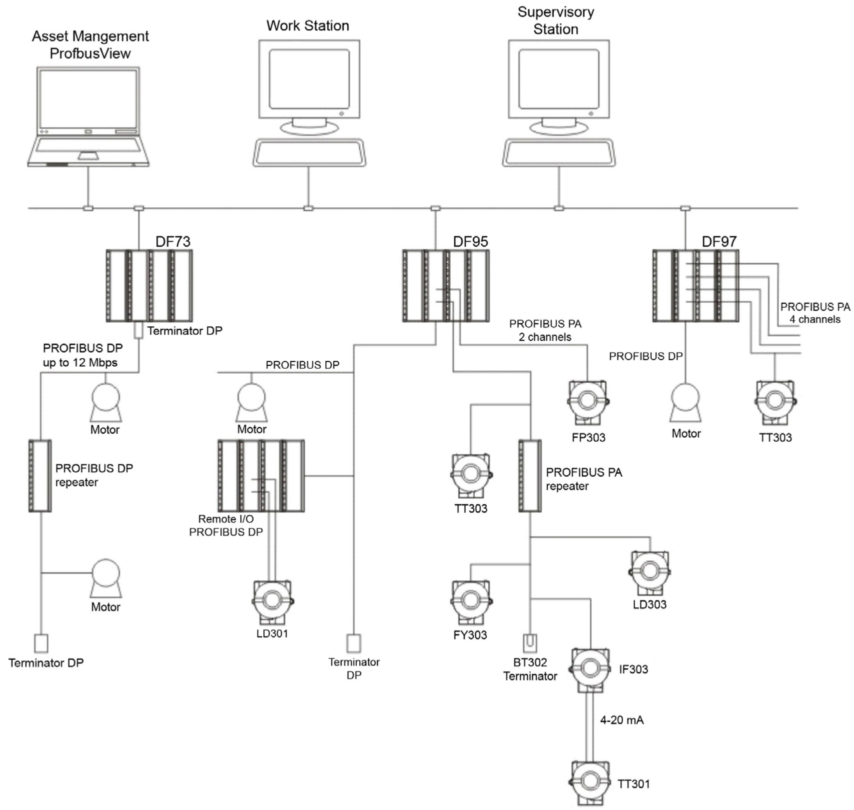
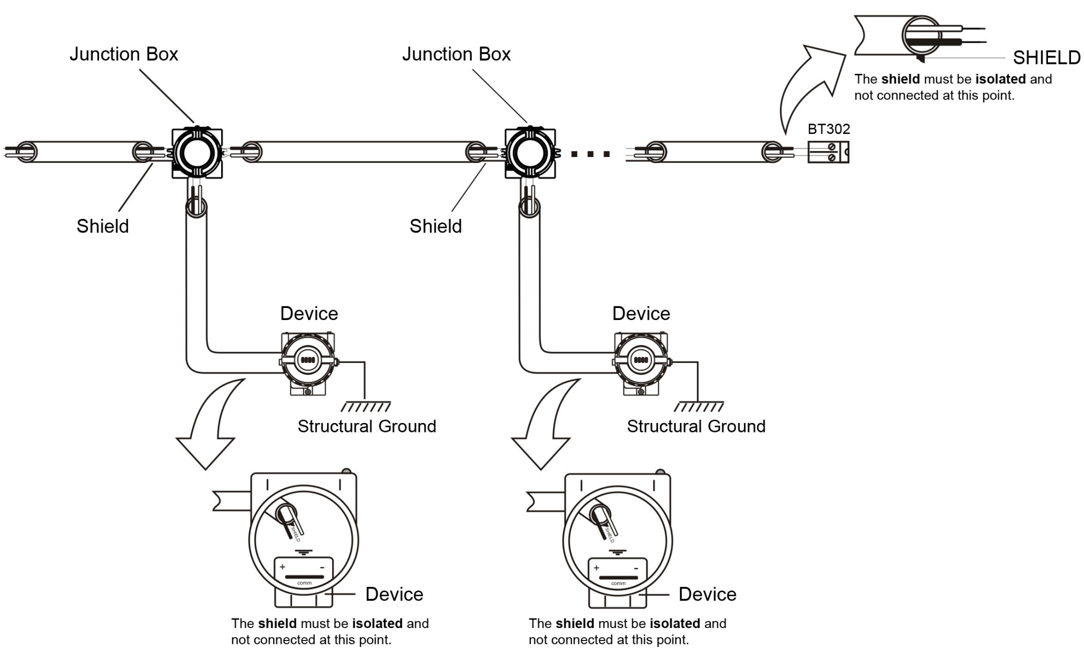


Figure 3.40 – Example of PROFIBUS network

Figure 3.41 illustrates how to connect an equipment to the PROFIBUS network.



Note: Ensure the shield continuity in all ***Junction Box*** directions and that it does not touch the housing.

Figure 3.41 – Connecting an Equipment to the PROFIBUS Network

PROFIBUS PA Physical Means, Cabling, and Installation

PROFIBUS PA is a bi-directional digital communications protocol that allows the interconnection of several equipment on a single network directly in the field, performing acquisition and actuation functions as well as monitoring processes and stations (HMIs) with supervisory software. It is based on the ISO/OSI standard, whose layers: Physical Layer, Communication Stack and User Application execute comprehensive management and applications of new models with basis on Function Blocks and Device Descriptions.

The Physical Layer (known as PA or H1) is defined by the IEC and ISA standards. It receives messages from the Communication Stack and converts them into physical signals among fieldbus transmissions and vice versa, by including and removing preambles and limiters in the beginning and the end of messages.

The Physical Layer is based on the IEC61158-2, with the following characteristics:

- Data transference by using Manchester coding, with 31.25 kbit/s rate;
- For a clear communication signal, each product must be powered at least with 9 volts. The H1 Physical Layer allows powering the equipment via bus, as the same pair of wires that power the equipment also provides the communication signal. There is some equipment powered externally;
- Maximum 1900 m/segment length without repeaters;
- By using up to 4 repeaters, the maximum length can reach 9.5 km;
- A PROFIBUS PA bus without intrinsic safety and external power on the communication wiring must support up to 32 equipment in application;
- PROFIBUS PA bus should support several equipment in application with intrinsic safety.

NOTE: It is possible to connect more equipment than specified, but this depends on their consumption, power supply and the features of the intrinsic safety barrier and the FISCO model;

- The bus nor the equipment should be disconnected while in operation;
- Topologies available in bus, tree, star or mixed.

The FISCO model (*Fieldbus Intrinsically Safe Concept*) is detailed on the IEC 60079-27 standard.

The FISCO model has the following restrictions:

- There is only one active element (power supply) in the field bus, located in a non-classified area;
- The other equipment in the area are classified as passive;
- Each field equipment must have a minimum 10 mA consumption;
- On Ex ia and Ex ib areas the maximum bus length must be 1000 m;
- Individual stubs should be limited to 30 m;
- Use 2 active terminators in the main bus, one in the beginning and one in the end of the bus;
- Use transmitters and barrier/power supplies approved by FISCO;
- The cables (without restrictions for cabling up to 1000 m) must have the follow parameters:
  - R´: 15 to 150 Ω/km;
  - L´: 0.4 to 1 mH/km;
  - C´: 80 to 200 nF/km.

  Cable type A: 0.8 mm² (AWG18)
- Each transmitter must be:
  - Voltage limited: $V_o < V_i$;
  - Current limited: $I_o < I_i$;
  - Power limited: $P_o < P_i$;

  Note: It is not necessary to calculate C and L to the segment.
- The terminator must have the follow parameters:
  - R = 90 to 100 Ω;
  - C = 0 to 2.2 μF.

The FISCO concept was optimized to allow greater number of field devices according to the bus length, considering the variation in the cable characteristics (R', L', C') and terminators, to meet categories and groups of gases with a simple installation involving intrinsic safety. By this, the capacity of current per segment increased and facilitated the user´s assessment. Moreover, by purchasing certified products, the user need not worry with estimates, even for a change in operation. See examples on figures 3.42 and 3.43.

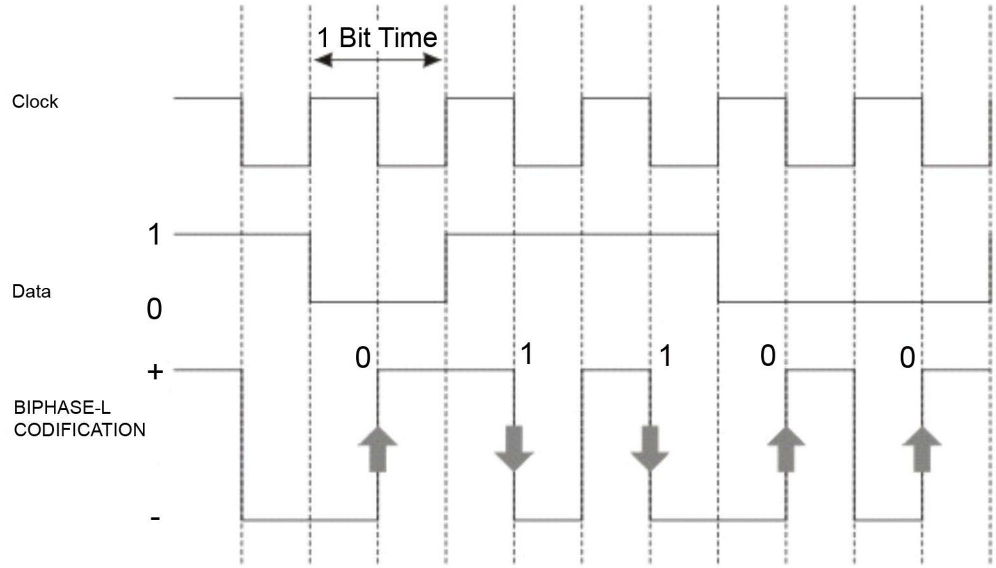


Figure 3.42 – Example of Fieldbus signal in tension mode

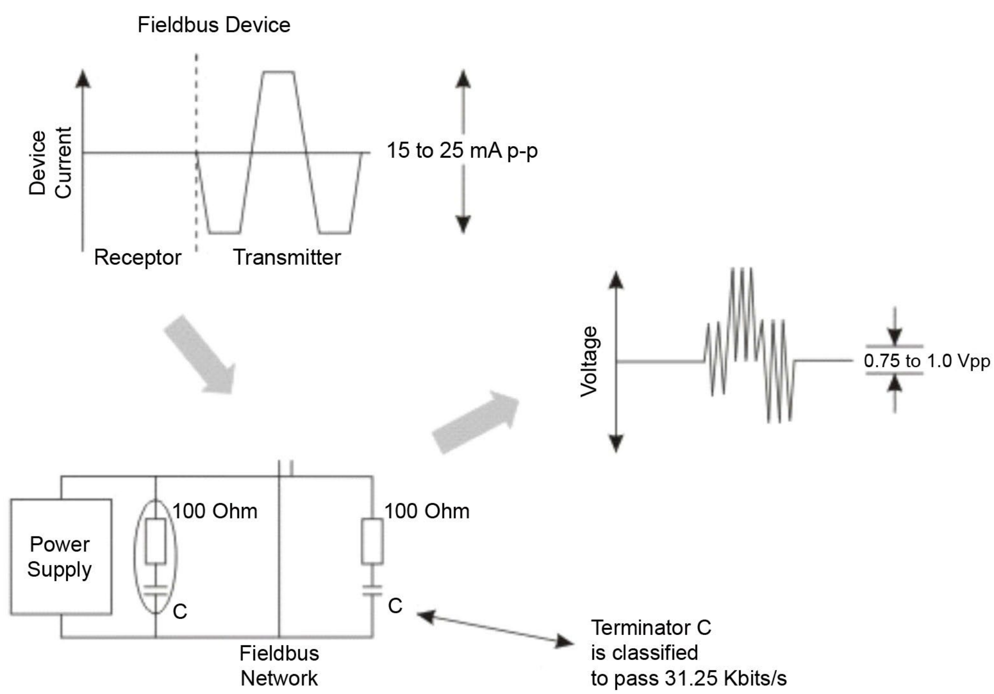


Figure 3.43 – Example of Manchester codification

An equipment transmission supplies 10 mA to 31.25 kbit/s in a load equal to 50 Ω, creating a peak to peak 750 mV to 1.0 V modulated signal voltage. The power supply can provide 9 to 32 VDC, but in safe applications (IS) it should meet the requirements of the intrinsic safety barriers. See Figure 3.44.

The total length of cable is the sum of the trunk (main bus) size and all the spurs (derivations larger than 1m) but for the type A cable it is the maximum unsafe areas in 1900 m. In safe areas it is a maximum 1000 m with the type A cable and the Spurs cannot exceed 30 m.

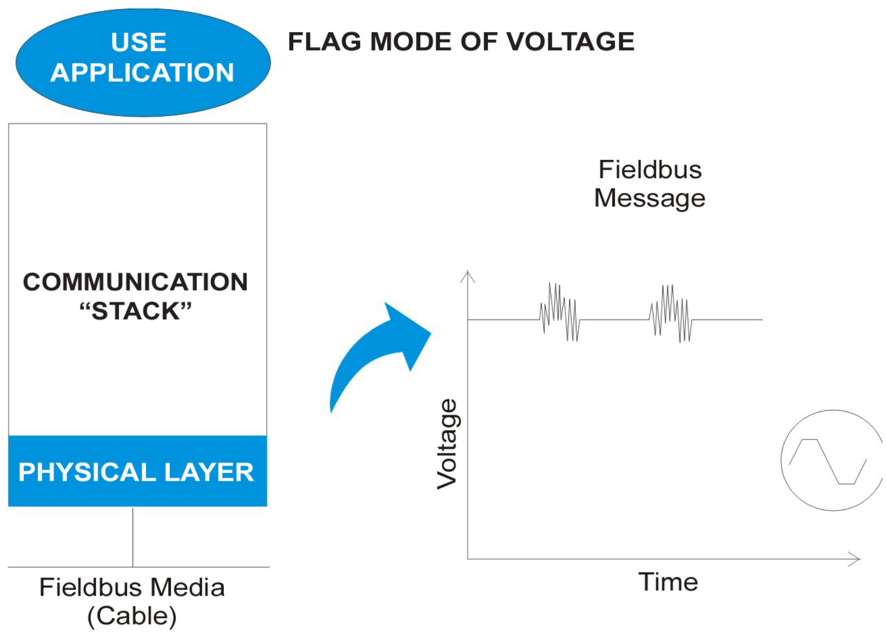


Figure 3.44 – 31.25 kbit/s Voltage Mode

Types of Cable Recommended

The IEC 61158-2 requires the PROFIBUS PA physical medium to be a shielded twisted pair cable. The properties of field bus are determined by the conditions of the electrical properties used. Although the IEC 61158-2 do not specify technically the cable, the A type cable is highly recommended to ensure the best conditions for communication and the distances involved.

Table 1.1 presents in detail the specifications of the various cables to 25 °C. Remember that most cable manufacturers recommend operating temperature between -40 ºC to +60 ºC. The temperature in the critical points that guide and support the cable wiring same needs to be checked. The strength of the type A 22 Ω/Km cable is valid at 25 ºC. The cable resistance increases with temperature, about 0.4% per ºC.

	Type A	Type B	Type C	Type D
Cable Description	Shielded twisted pair cable	One or more Shielded twisted pair cable	Several pair cable without Shield	Several non-twisted pairs without Shield
Nominal Conductor Area	0,8 mm² (AWG 18)	0,32 mm² (AWG 22)	0,13 mm² (AWG 26)	0,25 mm² (AWG 16)
DC Resistance Maximum (loop)	44 Ω/km	112 Ω/km	264 Ω/km	40 Ω/km
Characteristic Impedance of 31.25 KHz	100Ω ± 20%	100 Ω ± 30%	**	**
Maximum Attenuation at 39 KHz	3 dB/km	5 dB/km	8 dB/km	8 dB/km
Maximum Unbalanced Capacitance	2 nF/km	2 nF/km	**	**
Distortion of the Group Delay (7.9 to 39 kHz)	1,7 µs/km	**	**	**
Area Covered by Shield	90%	**	-	-
Recommendation for Network Extension (including Spurs)	1900 m	1200 m	400 m	200 m

Table 3.6 – Several Characteristics of the Cables Used for PROFIBUS PA

Cable Total Length and Rules of Distribution and Installation

The PROFIBUS PA total cable length should be totaled from the exit of the conversion DP/PA point to the farthest point of the segment, considering the derivations. Remember that spurs lower than 1 m do not enter this total.

The total length of cable is the sum of the trunk (main bus) size and all the spurs (derivations larger than 1m) but for the type A cable it is the maximum unsafe areas in 1900 m. In safe areas it is a maximum 1000 m with the type A cable and the Spurs cannot exceed 30 m.

It is recommended to avoid splice in the installation and distribution. The splices are any part of the network that has impedance change, which can be caused, for example, by changing the type of cable, discontinuity of the shield, crushing or very sharp bends in the cable etc. In networks with total length greater than 400 m, the sum of the lengths of all the splices should not exceed 2% of the total length and, in lengths less than 400 m, must not exceed 8 m.

The maximum length of a PA segment when using different types of cable is limited by the following equation:

$$\left(\frac{LA}{LA\max}\right)+\left(\frac{LB}{LB\max}\right)+\left(\frac{LC}{LC\max}\right)+\left(\frac{LD}{LD\max}\right)\langle= 1$$

Where:
LA : Cable A length;
LB : Cable B length;
LC : Cable C length;
LD : Cable D length;
$LA\max$: Maximum length allowed with the cable A (1900 m);
$LB\max$: Maximum length allowed with the cable B (1200 m);
$LC\max$: Maximum length allowed with the cable C (400 m);
$LD\max$: Maximum length allowed with the cable D (200 m);

To respect to Spurs, it is necessary to be attentive to the lengths them. The number of PA devices (to be considered when the repeaters) should be according to Table 3.7. In areas classified Spur the maximum is 30 m.

Total PA Device per Segment DP/PA Coupler Total PA	Equipment Spur Length (m) with 01 Device	Spur Length (m) with 02 Device	Spur Length (m) with 03 Device	Spur Length (m) with 04 Device	Length (m) Considering the Maximum Number of Spurs
1-12	120	90	60	30	12 x 120 = 1440
13-14	90	60	30	1	14 x 90 = 1260
15-18	60	30	1	1	18 x 60 = 1080
19-24	30	1	1	1	24 x 30 = 720
25-32	1	1	1	1	1 x 32 = 32

Table 3.7 –Spur vs. PA Devices

NOTE: The cable capacitance limit must be considered. In the absence of the cable manufacturer data, a value of 0.15 nF/m can be used for PROFIBUS cables.

$$Ct = \sum \left(Ls * Cs\right) + Cd$$

Where:
Ct : Total capacitance in nF;
LS : Spur Length in m;
Cs : Wire Capacitance per segment in nF (default: 0.15);
Cd : PA device capacitance.

The attenuation associated with this capacitance is 0.035 dB/nF. Thus, the total attenuation is:

$$A = Ct * 0.035\, dB / nF \,\langle 14\, dB$$

Since 14 dB will produce the minimum signal required to detect it with integrity.

There are some rules that must be followed in terms of separation between cabling and other cables, whether regarding signs or power. Preferably use tray or metal rails, observing the distances shown on Tables 1 and 2 in this guide. Never pass the PROFIBUS PA cable along high voltage lines, because the induction is a source of noise and can affect the communication signal. Moreover, the fieldbus signal must be isolated from noise sources, such as power cables, motors and frequency inverters. It is recommended them to be placed in separate tabs and rails. The ideal is to use aluminum conduits, with internal and external electromagnetic shielding. The Foucault current are practically immune, due to the good aluminum electrical conductivity. And remember that the cables should cross at an 90° angle.

Notice that a complete signal condition is guaranteed by appropriate grounding techniques.

PROFIBUS PA Network Terminators

Two bus terminators must be connected to the PROFIBUS PA network, one in the output of the DP/PA Coupler and the other in the last device (usually the most distant from the Coupler), depending on the topology adopted.

If the cabling has a junction box at the end of the main stem with several spurs, the field terminator should be placed in this point, which will facilitate the maintenance when removing the equipment.

Make sure the terminator connection is correct, remembering that the lack of terminators cause communication intermittency, without impedance and with increased reflection signal.

The lack of a terminator or its connection to the wrong point also degrades the signal, as it also work as part of the wiring as an antenna. This lack can increase the signal by more than 70% and an extra terminator can decrease the signal up to 30%. The attenuation and intermittency can generate communication failures.

The PA network terminator has a 100Ω ± 2% resistor and a 1μF ± 20% capacitor in series. See Figure 1.6. To verify typical wave forms of the H1 according to the termination, see Figure 3.45.

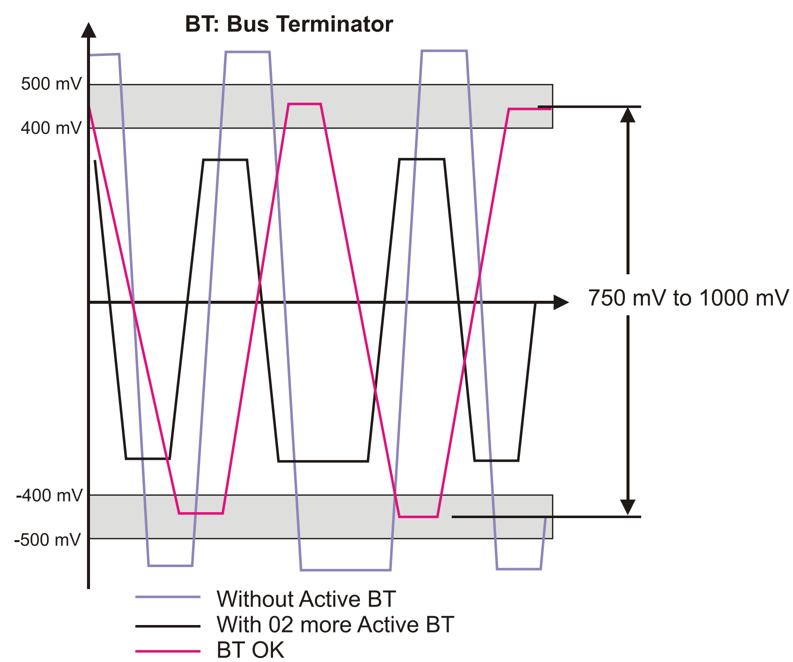


Figure 3.45 – Typical wave forms of the H1 according to the Termination

Topologies

The PROFIBUS PA network may have the following topologies: Star, Bus and Point-to-Point, represented on Figures 3.46. 3.47 and 3.48. In practice, a combined topology is normally used.

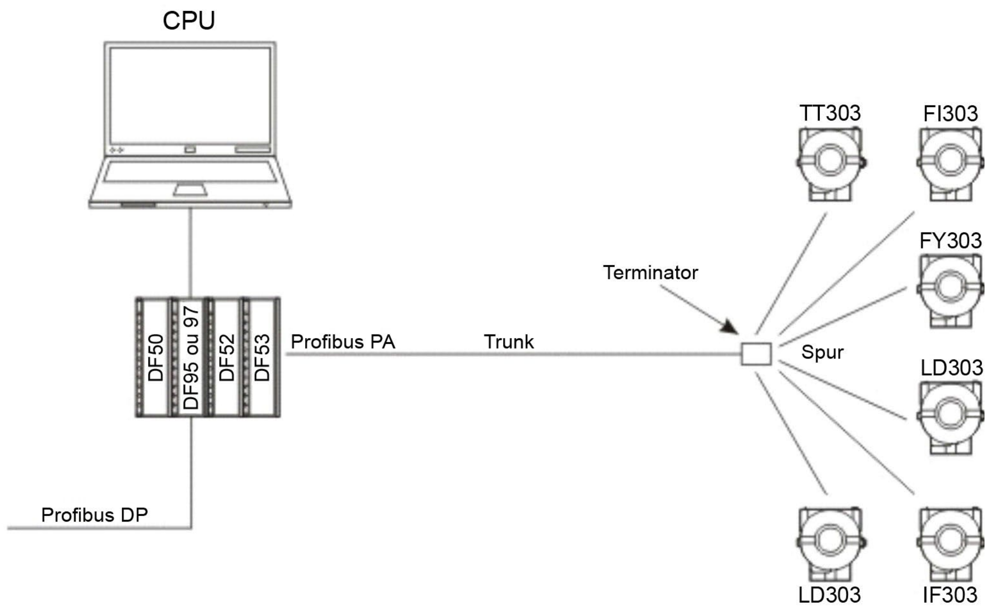


Figure 3.46 – Star Topology

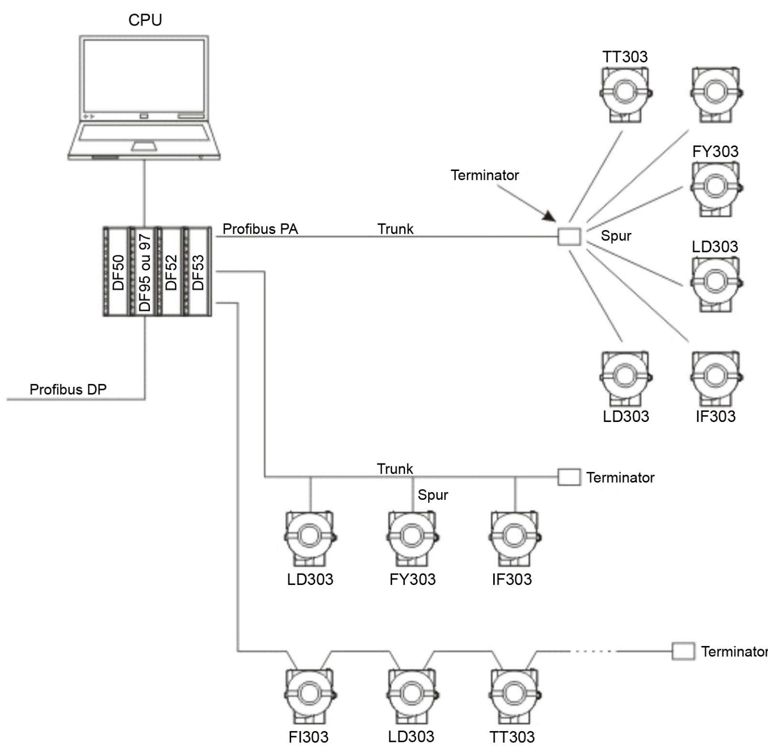


Figure 3.47 – Star, Bus and Point-to-Point Topologies

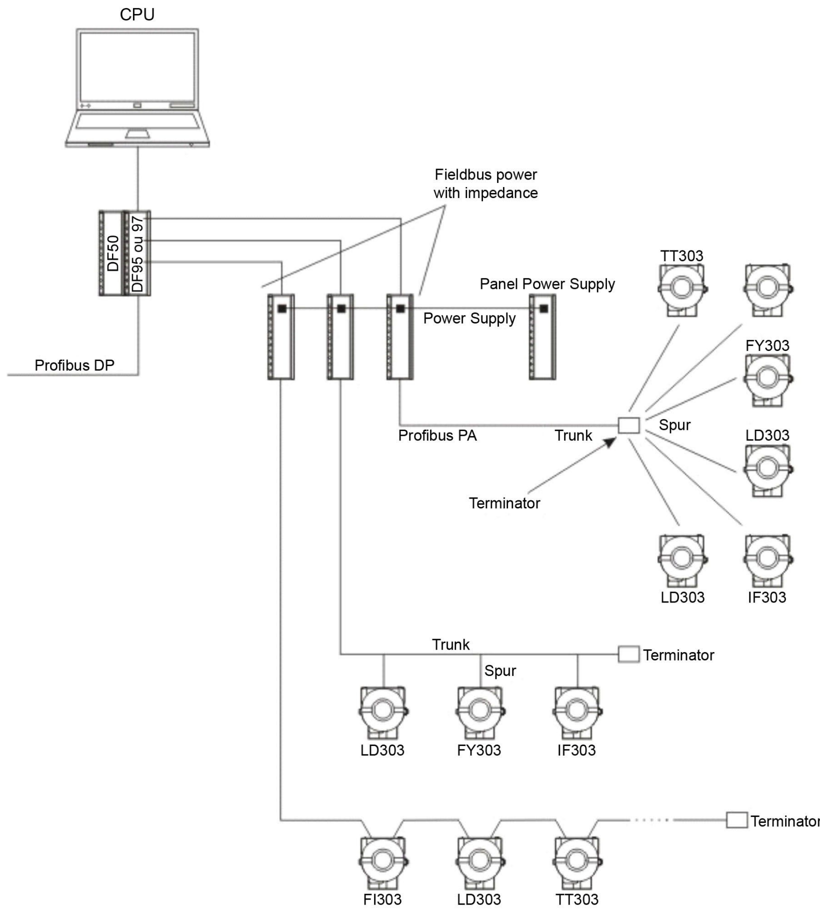


Figure 3.48 –Star, Bus and Point-to-Point Topologies using external bus power supplies

Repeaters

The PROFIBUS PA network has up to 4 repeaters. These are used when needing to increase the quantity of devices or increase the signals levels that have been weakened by the wiring length or expanding it the up to 9500 m.

Check for terminators in the end of the segment (beginning repeater) and the repeater output.
Whenever there is a repeater is as if there was a new network with the same rules seen before.

Transient Suppressor

Whenever there is an effective distance between 50 and 100 m horizontally or vertically 10 m between two grounded points, it recommends the use of transient suppressor in the initial and final points of the distance, as shown in Figure 3.49.

NOTE
The transient suppressor protects the electric circuit against overvoltages.

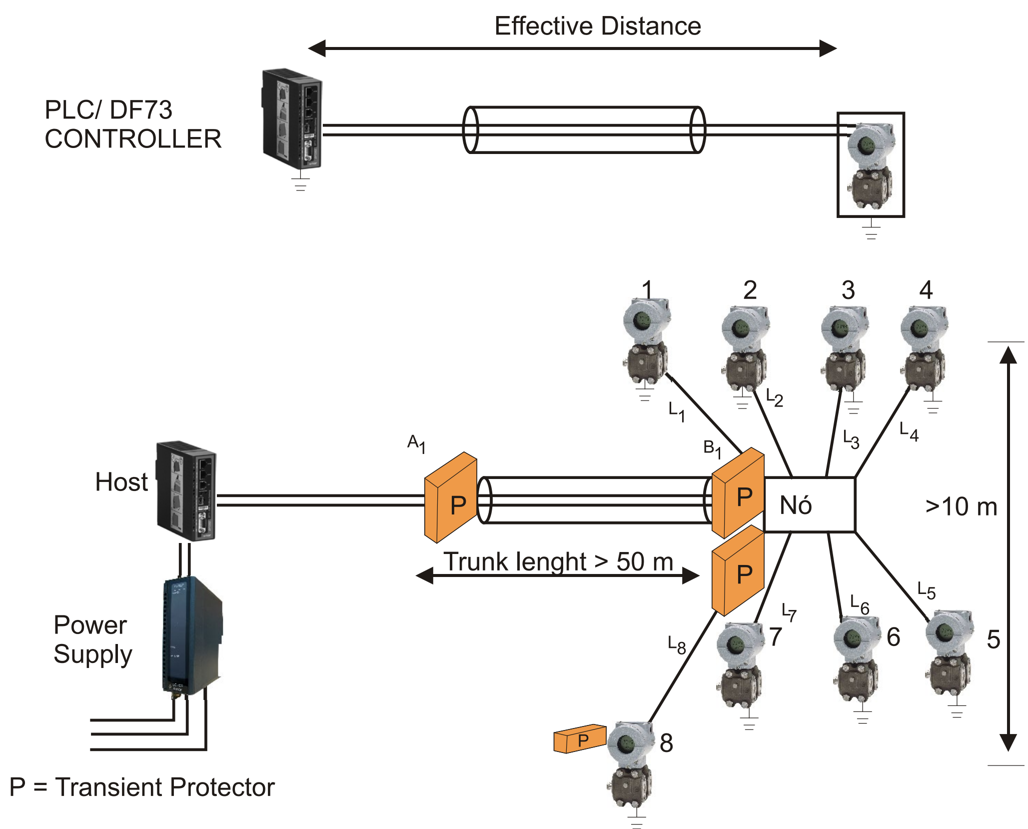


Figure 3.49 - Effective Distance on a Cable Distribution

Install the transient suppressor immediately after the DP/PA Coupler, before each equipment and junction box. In classified areas, use certified protectors.

Power Supply and Communication Signal

Power consumption varies from one equipment to another, as well as from manufacturer to manufacturer. All Smar PROFIBUS PA devices have the same current consumption (12 mA). The smaller is the device consumption, the best is its performance, especially in intrinsically safe applications. The cable resistance must not be very high as to cause a voltage drop, to have lower power supply levels in the more distant Coupler DP/PA device. The resistance must keep low to ensure good connections and joints.

For the power supply signal, the following values are considered as acceptable in practice:

- 12 to 32 Vdc, on the DP/PA Coupler output, depending on the manufacturer;
- Ripple (mV):
  - < 25: excellent;
  - 25 < r < 50: ok;
  - 50 < r < 100: marginal;
  - > 100: not acceptable.
- Voltage Level
  - 750 a 1000 mVpp: ok;
  - > 1000 mVpp: Very high. There may lack a terminator.

  NOTE: Some barriers and segment protectors (spur guard or segment protector) have high serial impedance and can result in up to 2000 mV signals and allow the adequate operation.
  - < 250 mVpp: Very low. Check if there is more than 2 active terminators, power supply, DP/PA coupler, etc.

Some equipment have polarity, others not, so it is very important to ensure the correct device polarity. All devices must be connected in parallel in the bus.

The use of coded color wires is recommended to distinguish the positive from the negative. Use data line A (negative) as green conductor and line B (positive) as red conductor.

NOTE
Avoid the inversion of data lines along the path of the PROFIBUS network, keeping the same nomenclature for all the cabling.

DP/AP Coupler

The DP/PA coupler is used to translate the PROFIBUS PA and PROFIBUS DP bus physical features, because it needs to convert physical environment (RS485/fiber optic) into IEC61158-2 (H1), whose communication speeds are different.

Addressing Using DP/PA Couplers

Figure 3.50 shows in detail the transparent addressing when couplers are used (low or high speed) on the PROFIBUS DP and PROFIBUS PA networks. The default address is 126 and only one device with 126 may be present on the bus at a time.

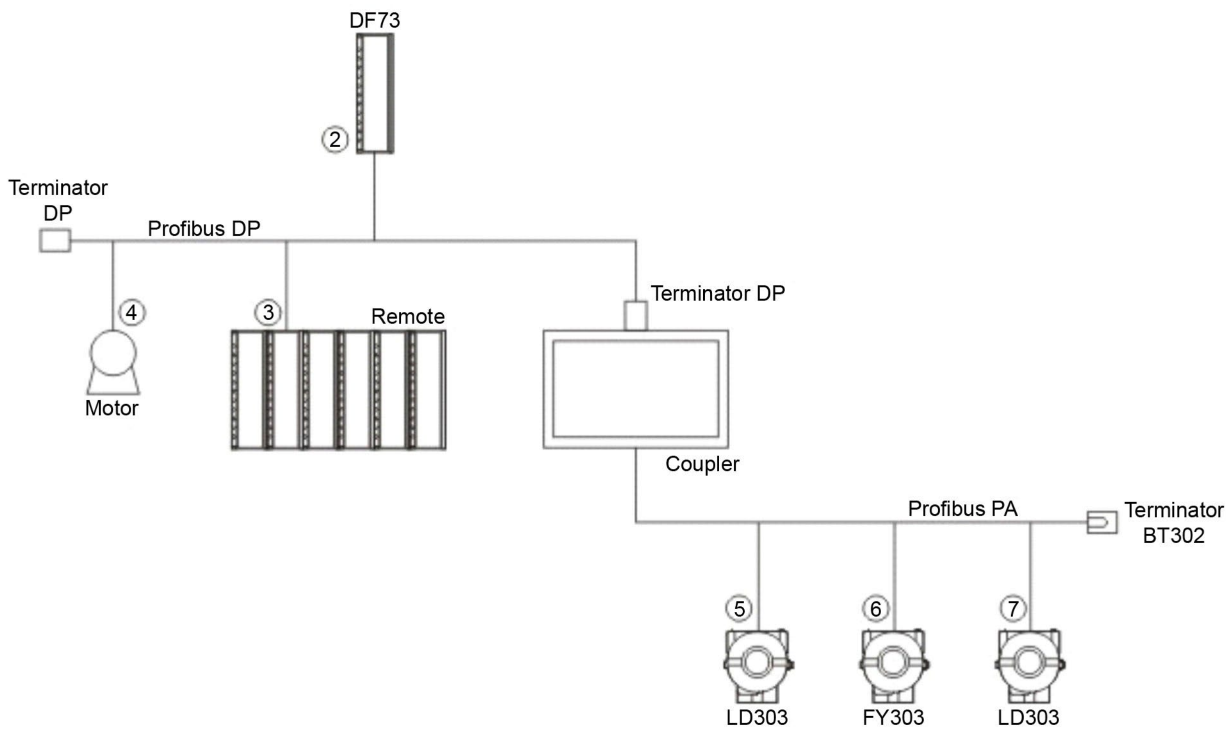


Figure 3.50 – Transparent Addressing using the DP/PA Coupler

Figure 3.51, on its part, shows in detail the extended addressing, when using the DF95 or the DF97.

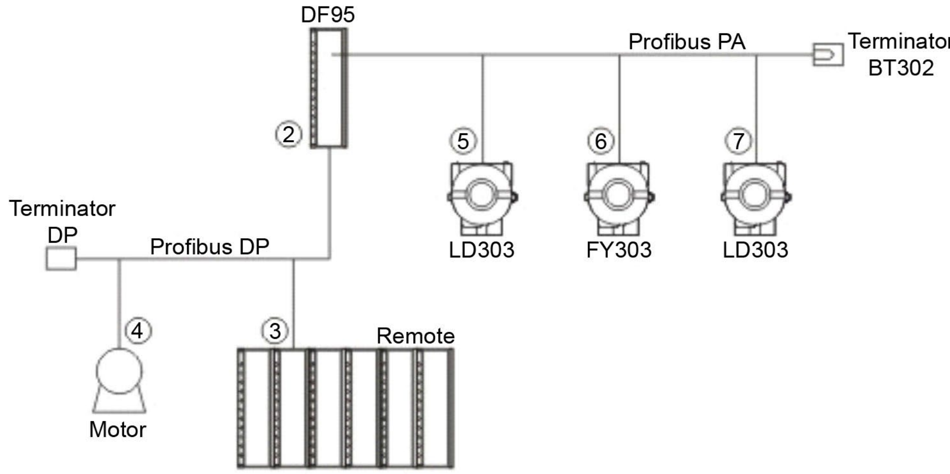


Figure 3.51 – DF95/DF97 Addressing

Shield and Grounding

When considering the question of grounding shield on fieldbuses, one should take into account:

- Electromagnetic compatibility (EMC);
- Explosion proof;
- People protection.

According to the IEC 61158-2, to ground means being permanently connected to the ground through sufficient low impedance and conductivity to prevent any tension that may cause damage to devices or people. Transmission lines with 0 Volts must be connected to ground and be galvanically isolated from the fieldbus bus. The purpose of grounding the shield is to prevent high-frequency noises.

Preferably, the shield must be grounded in two points: at the beginning and the end of the bus, provided there is no difference in potential between these points, allowing the passage of the loop current. In practice, when there is such a difference, it is recommended the shield to be grounded in only one point, i.e., in the power supply or the intrinsic safety barrier. It must ensure the continuity of the cable shielding in more than 90% of the total cable length.

The shield should completely cover the electrical circuit through the connectors, couplers, splice and distribution boxes and junction.

Never should be used the shield as driver of the signal. It is need to check the continuity of the shield until the last segment of the device PA, analyzing the connection and completion, because this should not be grounded in the housing of devices.

In classified areas, if a potential balance between safety area and hazardous area is not possible, the shield should be connected directly to ground (Equipotential Bonding System) only on the side of the dangerous area. In the safety area, the shield should be connected through a capacitive coupling preferably a ceramic capacitor (dielectric solid), $C \leq 10$ nF, isolation voltage ≥ 1.5 kV. See Figures 3.52 and 3.53.

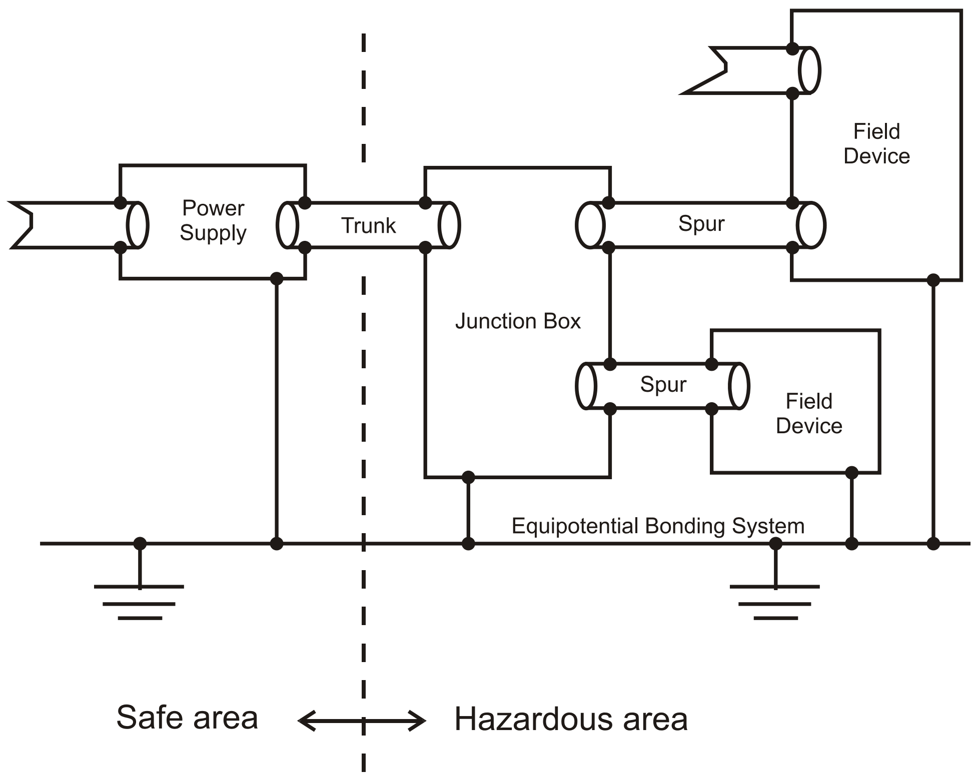


Figure 3.52 – Ideal Shield and Ground Combination

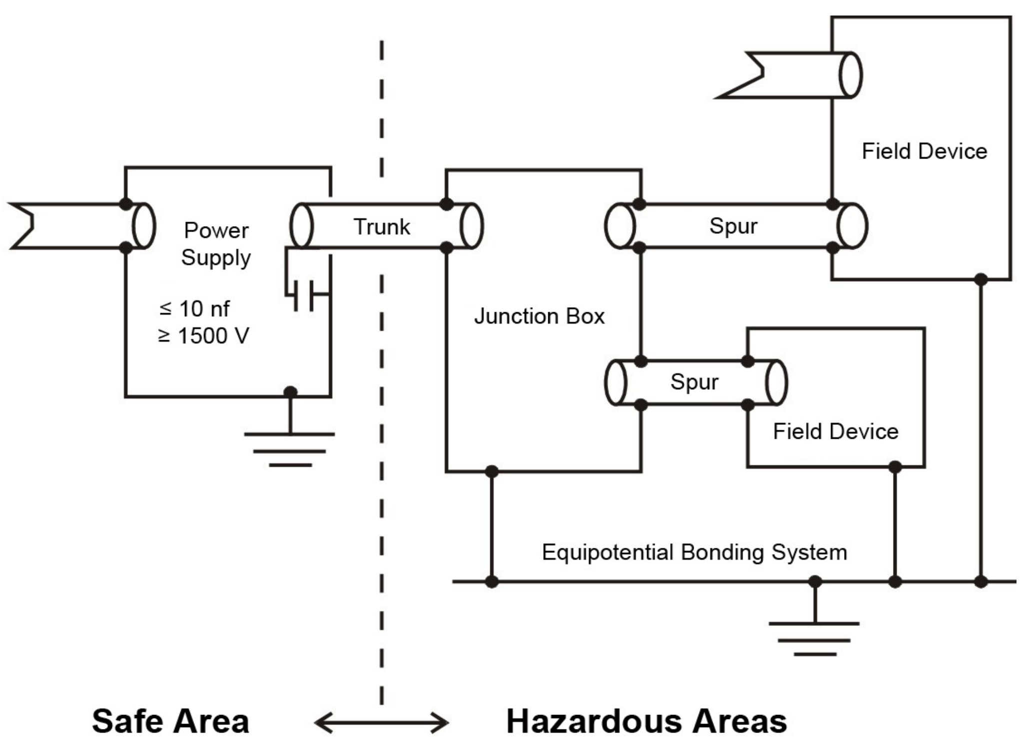


Figure 3.53 – Capacitive Grounding

Number of Devices in a PROFIBUS PA Segment

The number of devices (N) per PA segment is the purpose of quiescent consumption of each PA device, the distances involved (type A loop cable resistance: 44 Ω/km), the DP/PA Coupler and its drained current, area classification (couplers for classified area drain currents around 110 mA, 12V output voltage), besides the FDE current (usually 0 mA, depending on the manufacturer). In hazardous areas the device number must be limited by intrinsic safety barrier, according to security restrictions in the area and limits of the DP/PA coupler. See Figure 3.54.

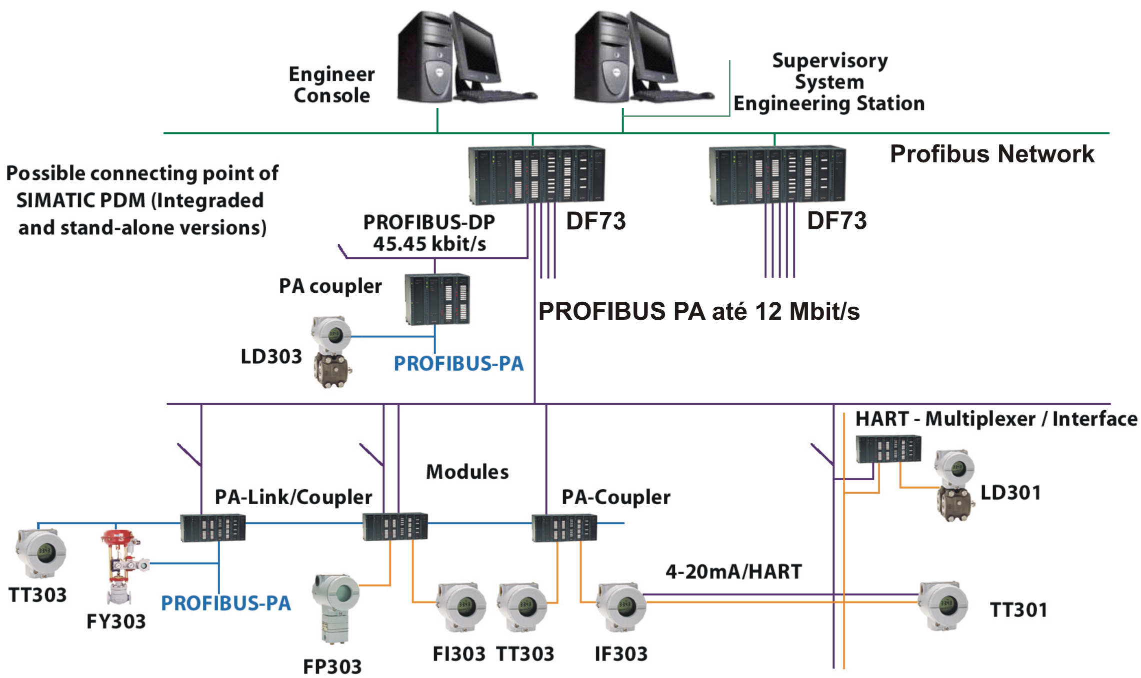


Figure 3.54 – Profibus Network

The total current in the segment must be less than that drained by the coupler. Smar devices consume 12 mA.

$$I_{Seg} = \sum I_{BN} + I_{FDE} + I_{FREE}$$

Where:

$$I_{Seg} \langle I_C$$

I_{Seg} : Current in the segment PA;

$\sum I_{BN}$: Sum of quiescent currents of all devices in the PA segment;

I_{FDE} : Additional current in case of failure, usually negligible;

I_{FREE} : Current off, useful in case of expansion or change of manufacturer, recommended 20 mA;

I_C : Current drained by coupler.

In addition, there must be at least 9.0 V in the terminal block of the most distant device from the DP/PA Coupler to ensure the correct power supply:

$$V_{BN} = V_C - (R * L)$$

Where:

V_C : DP/PA coupler output voltage;

R : Loop Resistance (Cable type A, R = 44 Ω/km);

L : Total length of the PA bus;

V_{BN} : Voltage in the terminal block of the most distant PA device from the DP/PA Coupler.

Being $V_{BN} \rangle 9.0V$. This ensures powering the latest PA device. Remember that the communication sign should have a range from 750 to 1000 mV.

Some junctions boxes or short-circuit protectors for segments, called spur guards are active and can be powered via PA (H1) bus, in which case it will be included in the total current. In addition, each spur guard output has a current limit that must be observed.

Connecting Equipment to Fieldbus

The fieldbus devices can be connected to or removed from a network fieldbus in operation. When removing a device, check that the fieldbus wires are not short-circuited or in contact with other wires, shielding or grounding.

It cannot be mixed devices fieldbus with communication different speeds in the same network. Powered device or not for the bus can be mixed and shared in the same network.

Fieldbus devices with different communication speeds cannot be mixed in the same network. Devices powered or not by the bus can be mixed and shared in the same network.

Procedure of Receiving

When receiving the equipment, unwrap it and connect it the power supply and check if the configuration of your address is in agreement with the application using the procedure of local adjustment or during the initialization when your address is shown in a short time.

The user can change the physical address of fieldbus device in an operational network without disconnecting it.

Network Devices

The address 126 is the *default* address for all the devices.

Using the Smar Profibus View or Siemens Simatic PDM, the user can change the device address and to configure it for a same generic default 126.

Troubleshooting

Basic *Troubleshooting:* The communication errors are detected automatically and indicated depending on the engineering tools. Troubleshooting is a useful way to remove the parts, one by one, until the failure is detected by elimination. It is also recommended to test the faulty device in your own work bench. Check the following parameters:

- If the polarity is correct;
- If the addressis correct;
- If the network is secure;
- If the power supply voltage is adequate, always with a minimum 9V current during the communication, plus the course of the Manchester sign.

If there is not any communication, there is a problem with your configuration or installation.

Advanced Troubleshooting: In order to find serious problems, bus analyzers can be used to study the communication messages;

An oscilloscope (balanced/isolated - for example, operated by battery) can also be a useful tool in severe cases.

Communication Errors

Installation problems, non-configuration, or other main causes of communication errors:

- Loose connections
- Badly installed terminator, without endpoint.
- Very low or unstable power supply;
- Very long spurs or excessive spurs;
- Wrong grounding or no grounding;
- Water leak due to poor electric connections and cable clamp.

Table 3.8 below display some symptoms, probable causes and recommendations that can be useful during the commissioning/startup phase and maintenance:

SYMPTOMS	PROBABLE CAUSES	RECOMMENDATIONS
Excessive noise or spiking in the bus or very high signal.	Humidity in the terminal block and/or connectors causing low signal isolation, low isolation or bad operation power supply and/or devices and/or terminators etc inadequate shield grounding, excessive log or spur, inadequate amount of terminators or noise source near the Profibus cabling.	Check every device connector and terminal block, and make sure that no humidity got in; detect bad contact, if the shield cables are well ended and grounded properly, the ripple level in the power supply and in the bus are within acceptable values, the terminator number and cable lengths and are within the recommended values and also the cabling is distant from noise sources. Check if the grounding is adequate. If damaged devices generate noises, disconnect one at a time and monitor the noise.
Excessive transmissions or intermittent communication.	Inadequate cabling or spur length; power supply voltage in the wrong device terminal block; bad device operation; improper terminals, inadequate shielding or grounding, the amount of devices for spur in the network etc.	Check the cabling lengths, if the power supply voltage of the devices is between 9 to 32 Vdc, if there are no noise sources close to the Profibus bus. In some situations, if damaged devices generate noises or intermittence, disconnect one at a time and monitor the status of the communication. Check the communication AC signal course (750 mV to 1000 mV). Check the shielding and grounding distribution. Check the number of devices in the network and per spur.
Communication fails with some devices.	Repeated address in the bus, feeding tension insufficient (<9.0 Vdc), position of the terminators, cable excess, number of devices besides allowed in the segment, etc.	Make sure all the devices have different addresses and note that when placing a device in the bus with address 126, place it according to the configuration, and only then include another device with address 126 in the bus. Check the cabling lengths and number of devices, as well as their power supply and terminators positioning.
Intermittent powering of some or all the equipment.	Short circuit between the bus shielding and the terminals, defective power supply, excessive equipment, or improper number of devices.	Check the shield isolation, the number of devices and their consumption, etc.
The PROFIBUS PA equipment does not communicate with the Siemens DP/PA link.	When the link is activated, the addresses from 3 to 5 are stored for future use and not used.	Change the PA device address.
The measurement value is not correct; it is not the same as indicated in the equipment LCD.	Conversion errors for IEEE 754 float or scale error.	Check if the bytes swap is necessary or if, in the Profibus system used, exists some function for this automatic conversion. Check the scale in the equipment and/or in the DP master.
The value measured in the Siemens S7 system is always zero.	Conversion error involving data consistence.	Use the reading function with, SF14 consistence.
The value sent by the PLC in the Siemens S7 system is always zero or it was written wrong in the device output.	Conversion error involving data consistence, or the status is not being reported appropriately or, still, the inadequate use of the GSD file if the modules were not concluded with Empty_Module.	When using the Siemens systems, make sure to use the writing function with SF15 consistence. Check the PLC and equipment scales and if the status has a value suitable for the equipment. Check if the cyclical configuration is adequate.
Without communication between the DP master and PA slaves.	Error in the baud rate selection of the DP/PA coupler or link, error in their parameterization or problem in the bus.	Check the configurations below: - P+F SK1: 93.75 kbits/s; - P+F SK2: up to 12 Mbits/s; - Siemens: 45.45 kbits/s; - Link Siemens: up to 12 Mbits/s; - The SK2 requires the conversion of the GSD files; - Review the cabling and terminators conditions, their lengths, spurs, sources, repeaters, etc.

Table 3.8 – Symptoms, Probable Causes and Useful Maintenance Recommendations

PROFIBUS DP Network

Physical Medium, Cabling, and Installation

RS 485 transmission is the transmission technology most used in PROFIBUS, although fiber optics is applicable for long distances beyond 80 km. Bear in mind that PROFIBUS DP devices are not powered by the bus. Below are the main characteristics:

- NRZ Asynchronous transmission;
- Baud rate from 9.6 kbit/s to 12 Mbit/s (single on bus and selectable) to fit the equipment that supports the lowest baud rate;
- Twisted pair Shielded cable;
- 32 stations per segment, 127 stations max;
- Distance dependent on the transmission rate (see Table 3.9);
- Expansible distance up to 10 km with the use of repeaters;
- Maximum 9 dB fading along the segment length;
- 9 PIN, D-Sub connector (most common).

The PROFIBUS is normally applied on areas involving high transmission rate and low cost, simple installation. The bus structure allows the addition and removal of stations without affecting others stations with further expansions, without affecting stations in operation.

When the system is configured, only one transmission rate is selected for every device on the bus. There must be active bus termination at the beginning and the end of each segment, according to Figure 3.55, and, in order to keep the communication signal integrity, both terminators must be powered to show the existence of a Vp signal. Use the communication signal only to power the terminators, otherwise it may cause a failure in communication.

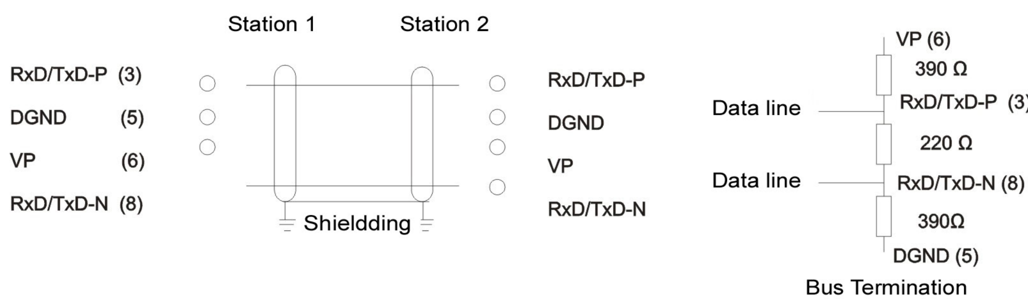


Figure 3.55 – Cabling and Termination for PROFIBUS RS- 485 Transmission

The network length is a very important factor, because the longest it is, the most it will distort the signals. The terminator is an impedance added to the PROFIBUS network to prevent this problem, as it harmonizes the network impedance and minimizes communication errors caused by signals distorted. Furthermore, if there is not a network terminator, the cabling will work as an aerial, contributing to signal distortion and noises. The typical impedance is the load value, which does not reflect any distortion when located at the end of this line. In other words, the load value provides a zero-reflection coefficient, or still a relation of stationary waves equal to one.

Both PROFIBUS DP and PROFIBUS PA networks require terminators, as their lack cause unbalance and delay on the propagation, as well as buffered resonant oscillations that will cause threshold (logic levels) transposition, while lowering the level of static noise. On the PROFIBUS DP, the terminators are active, e.g., they are powered. See Figure 3.56.

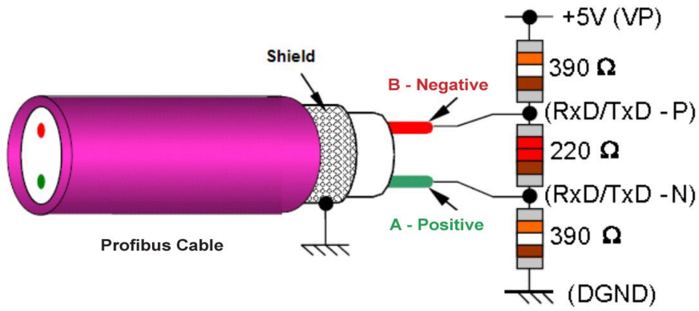


Figure 3.56 – PROFIBUS DP Bus Terminator

Necessary Precautions with PROFIBUS DP Terminator Network

Avoid installing PC-based stations as the last element in the network, because during the reset operation the +5 V line on the 9-in sub D connector is disabled and may cause intermittent communication. Use, instead, the active communication with its own power supply.

Figure 3.57 shows the active termination on the incorrect (left) position, whose level and waveform are degradable. The incorrect terminator activation causes impedance match and signal reflections, as one cable has the same impedance as the terminator.

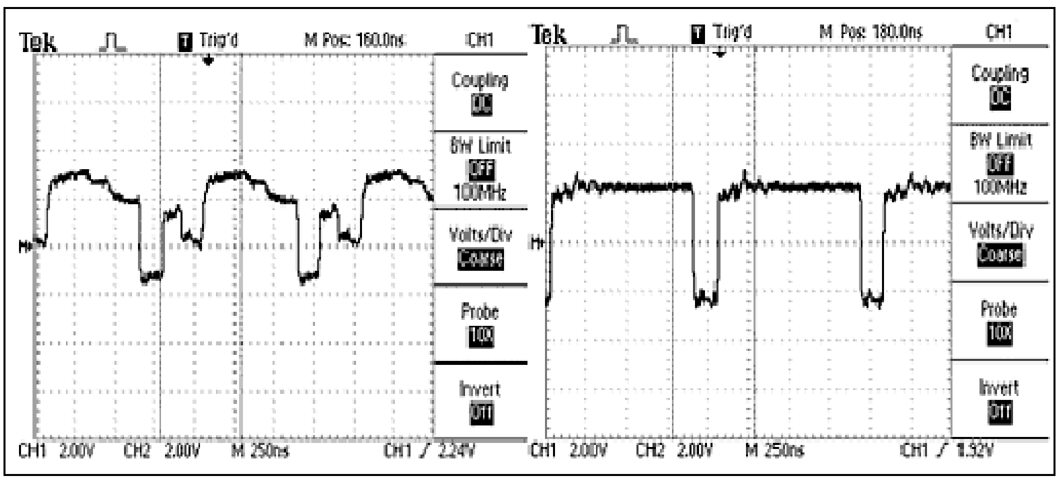


Figure 3.57 – Waveform on the PROFIBUS DP RS485 I

The lack of termination illustrated as the waveform on the left of Figure 3.58 causes impedance match and makes the PROFIBUS cable susceptible to signal reflections, working as an aerial. On the right waveform, the correct termination is seen.

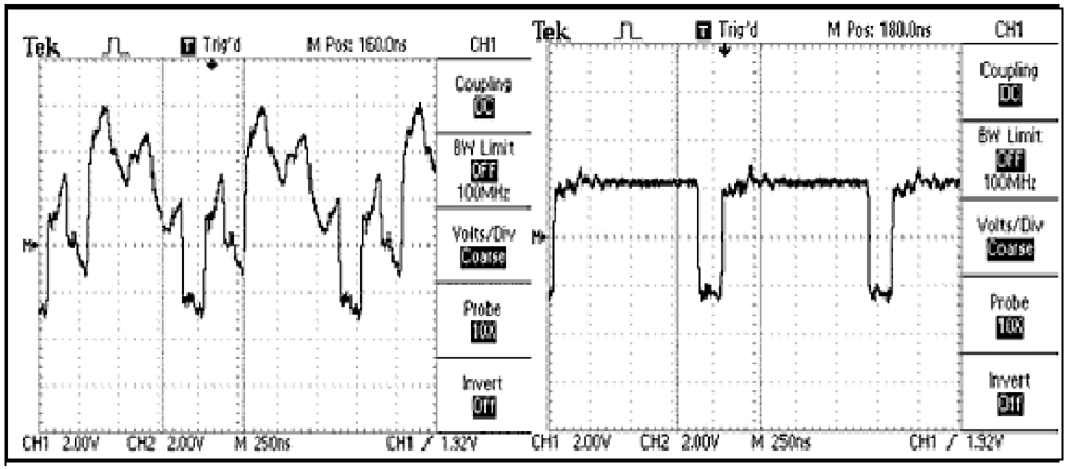


Figure 3.58 – Waveform on the PROFIBUS DP RS485 II

Repeaters

Repeaters must be used with more than 32 stations or dense networks. According to EN 50170, a maximum 4 repeaters are allowed between two stations. Depending on the manufacturer and the repeater features, up to 9 repeaters can be installed in cascade. Do not install more repeaters than allowed, due to network built-in delays and to the pre-established slot time – the maximum time the master will wait for a slave answer. See Figures 3.59 and 3.60.

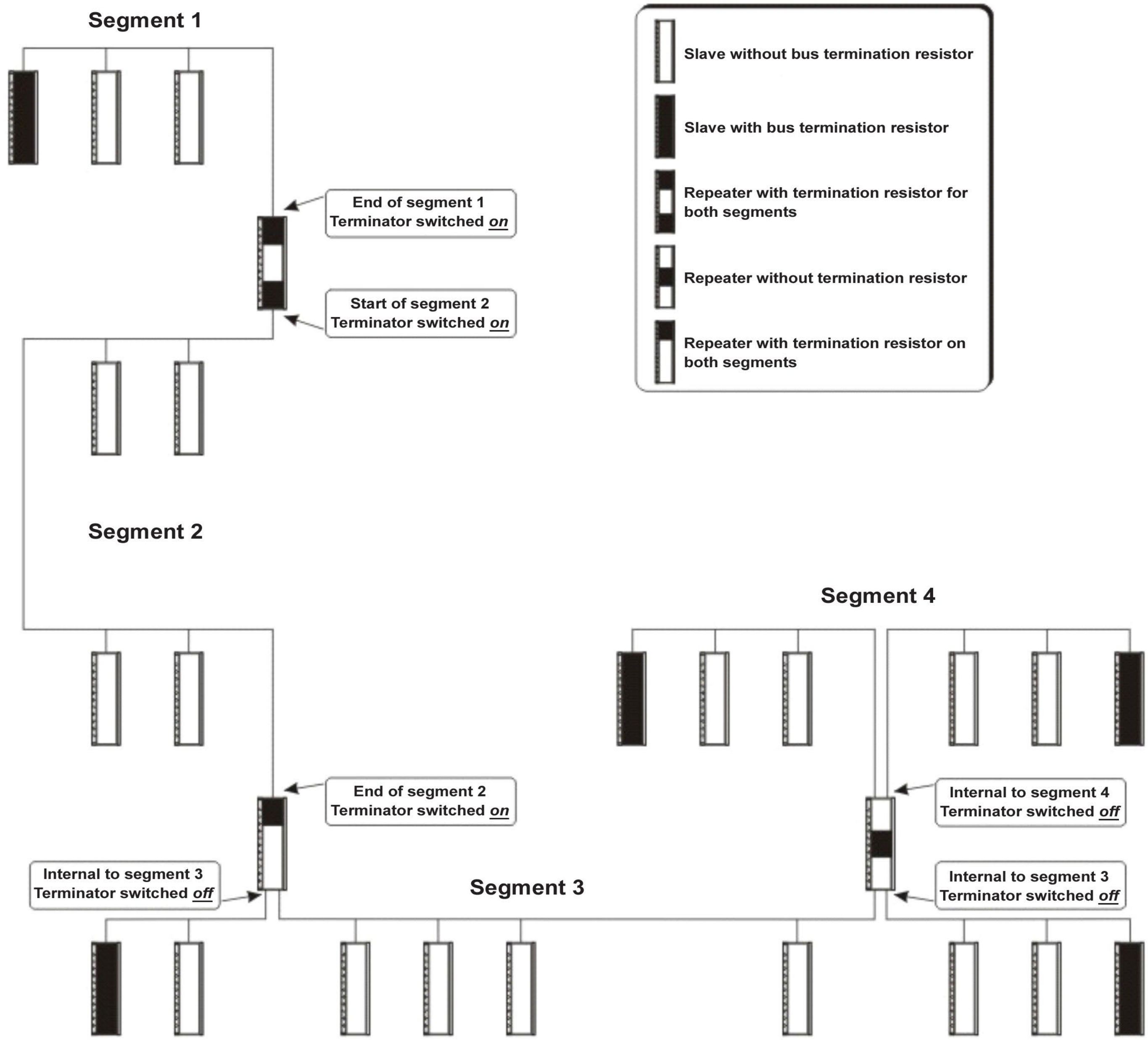


Figure 3.59 – PROFIBUS Installation Segmentation

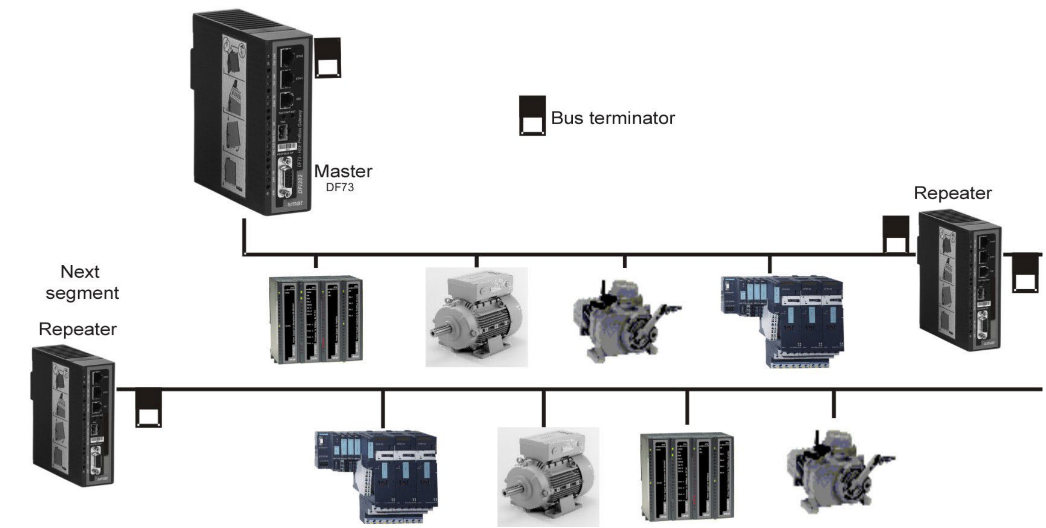


Figure 3.60 – General Segmentation Rule, Repeater and Bus Terminator

The maximum cabling length depends on the transmission speed, as shown on Table 3.9.

Type A Cable									
Baud Rate (Kbit/s)	9.6	19.2	93.75	187.5	500	1500	3000	6000	12000
Length / Segment (m)	1200	1200	1200	1000	400	200	100	100	100

Table 3.9 – Length in Function of Transmission Speed with Type A Cable

The PROFIBUS Standard considers the maximum capacitance for each communication rate. Table 3.10 shows the maximum lengths for main trunks and spurs in relation to the baud rate. The topology and cabling distribution are factors to consider for protection against EMI (Electromagnetic Emission)

It is worth noticing that at high frequencies the cables react as a transmission system with crossed and confused lines, whose electricity is reflected and spread from one circuit to another. Keep the connections in good conditions, as inactive connectors may develop resistance or turn into RF detectors.

Baud Rate (kbit/s)	Maximum Trunk (m)	Maximum Spur (m)	Maximum
9.6	500	500	10000
19.2	500	500	10000
93.75	900	100	10000
187.5	967	33	10000
500	380	20	4000
1500	193.4	6.6	2000
3000	100	0	1000
6000	100	0	1000
12000	100	0	1000

Table 3.10 – Maximum Main Trunk and Spur Lengths in relation to the Baud Rate

Recommended is to add a repeater where needing to create spurs beyond the main trunk. In practice, there may be a 5 % tolerance of these maximum lengths without the need for another repeater. When determining the maximum distance between two stations according to the communication rate use the following rule:

$$(Nrep+1)*seg$$

Where N_{rep} is the maximum number of serial repeaters, and seg is the maximum segment length according to the baud rate.

$$(9+1)*200=2000(m)$$

For instance, at a 1500 kbit/s rate (according to Table 3.9 it is possible to reach a maximum 200 m distance), the manufacturer of a given repeater recommends the use of a maximum 9 serial repeaters for finding:

$$(9+1)*200=2000(m)$$

Another practical detail, according to Figure 3.60, is the use of bus terminators, whose master is located at the beginning of the bus with an active terminator and the last and most distant slave also has an active terminator. This means that the last slave must be always powered, and during maintenance or replacement, there may be intermittent communication with the other devices.

Architecture or topology may allow something similar to what Figure 3.61 shows, where the master is located on the middle of the bus. The terminators must be located on the first slave (at the master farthest left) and on the last one (the farthest slave), always keeping them powered. During maintenance or replacement there may be intermittent communication with the other devices.

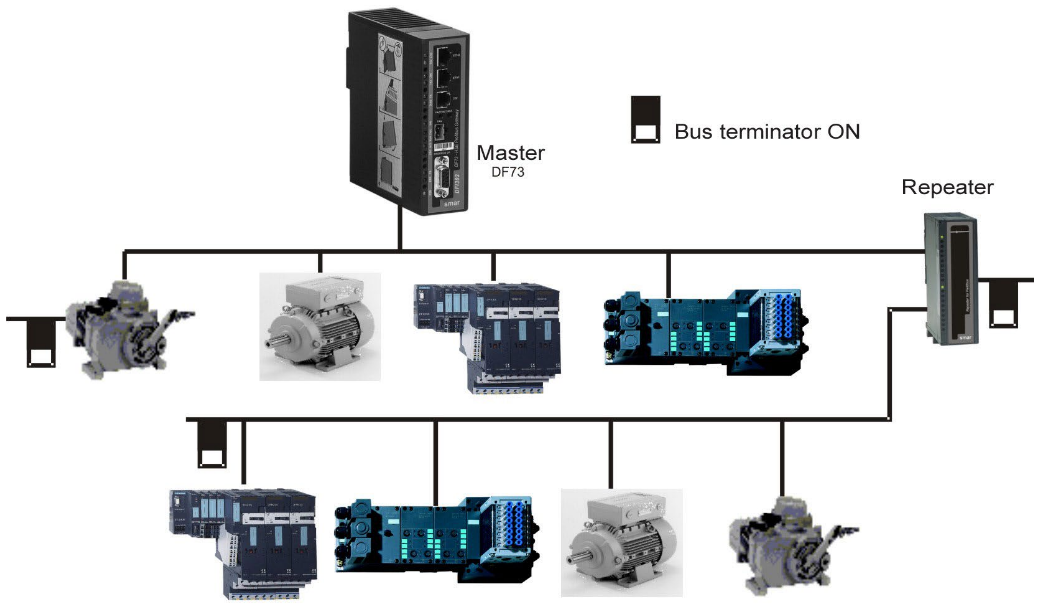


Figure 3.61 - Master Located on the Middle of the Bus

ATTENTION
The desired features for a PROFIBUS DP are: – Conductive area: 0.34 mm² (AWG 22); – Impedance: 35 to 165 Ω (nominal 150 Ω) on the 3 to 20 MHz frequencies; – Capacitance: < 30 pF/m; – Loop Resistance: < 110 Ω/km; – For the type A cable, the longest distance is 1200 m.

The loop resistance is determined through a short-circuit between the connectors on one cable end, and by measuring the resistance between the two connectors on the other end, whose values are applied to the formula:

$$\text{loop resistance } (Rs)(\Omega / Km) = \frac{\text{measured value } (\Omega) * 1000\,(\text{m})}{cable\ \ length\ \ for\ reference(m)}$$

The Rs value must be < 119 Ω/Km.

Remember that cables with larger capacitances may distort the edges and the shape of the communication signal with the communication rate, thus causing intermittent communication. Cables whose loop resistance is higher and capacitance is smaller than 30 pF/m may be used, but attention should be placed on signal fading.

Cable makers recommend that the operational temperature be between -40 ºC to +60 ºC. Check the critical temperature points where the cable goes and if it is stood by the cable. As an example, if the loop resistance of a PROFIBUS RS485 cable is 110 Ω at 20 ºC, it will bear an increase of 0.4 %/ºC.

A few recommendations:

- Avoid splices, or the discontinuation on any part of a network specified conductive medium, such as shield removal, change of cable diameter, connection to unsheathed terminals, etc. On networks with total length in excess of 400 m, the total splice lengths must not exceed 2 % of the total network length. On lengths smaller than 400 m, it must not exceed 8 m.

- On areas subject to lightings and high voltage peaks, recommended is the use of surge protectors. Whenever there is an effective distance longer than 100 m on the horizontal or 10 m on the vertical between two grounded points, use transient protectors. In practice, use between 50 and 100 m on the horizontal.

- When the communications rate is equal to or over 1.5 MHz, have at least 1 m cable between the two DP devices. The input capacitance on the two devices will make up for the cable capacity to preserve the common impedance. On a smaller distance, the input capacitance may cause reflections. At a rate below 1.5 MHz the effect is smaller.

- The Fieldbus cable must be isolated from the noise sources (power cables, motors, frequency inverters, etc.) and installed on separate conduits and raceways.

- When using multi-via cables, do not mix signals from different protocols;

- Whenever possible, use line filters, ferrites for cables, transient suppressors, spark gaps, feedthru and optical isolators for protection;

- Use aluminum raceways with external and internal electromagnetic shield. They are practically immune to Foucault currents due to aluminum good conductibility;

- For 12 Mbits/s rates, install 110 nH conductors, as per Figure 3.62;

- Before installing each equipment, read carefully the manual and the manufacturer recommendations;

- In cases with distance or high noise problems, use fiber optics for distances over 80 km;

- An optical link is customarily used. If applicable, be always alert when using optical repeaters. See Figure 3.63.

- Always check the addressing. ON PROFIBUS DP it is typically local, through dip switches.

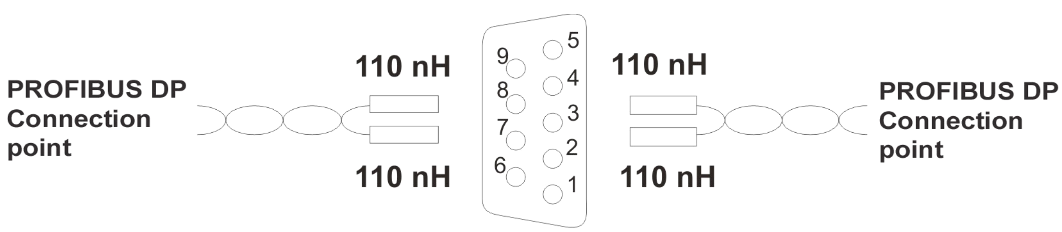


Figure 3.62 – Connection of Connectors and Inductors on the PROFIBUS DP network

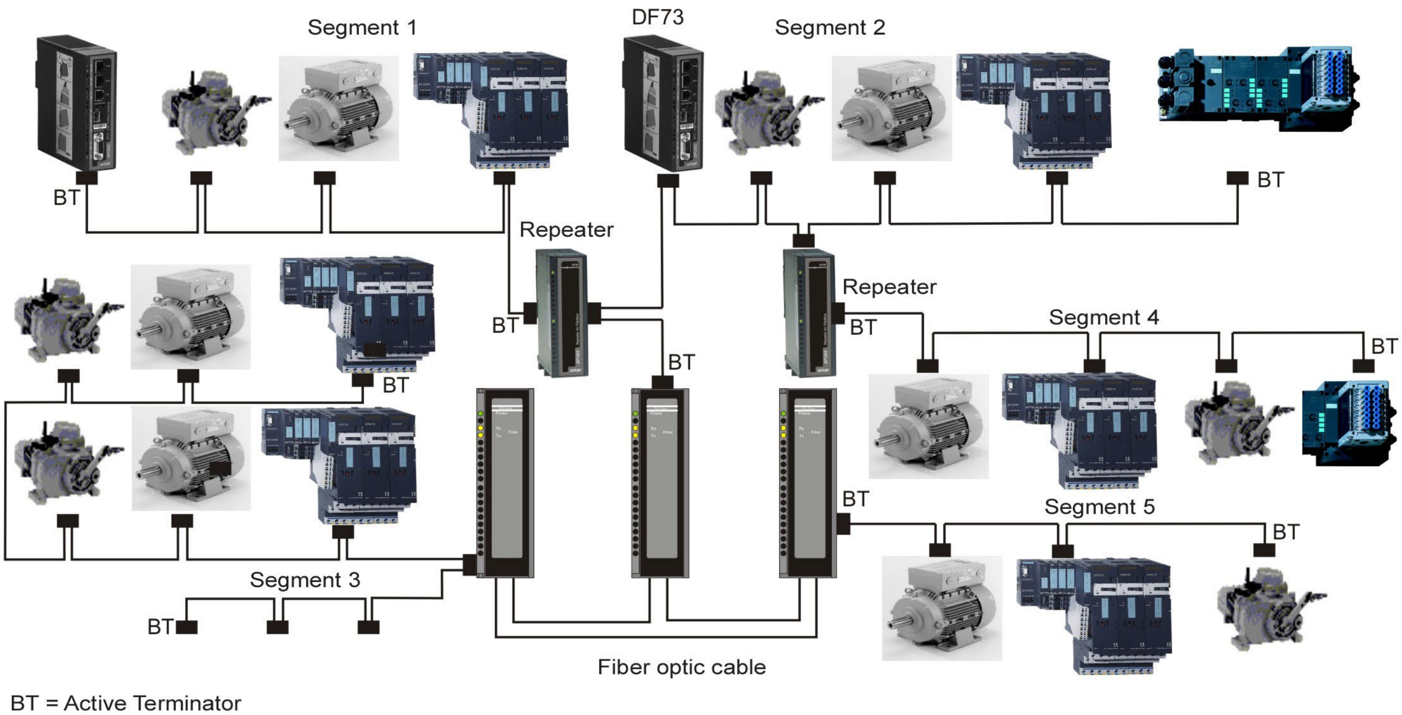


Figure 3.63 – Repeaters, Terminators and Optical Links

Connector

The pins of DB9 and M12 connectors, in compliance with the EN50170 standard, are as follows for the PROFIBUS DP network.

DB9 connector

PIN	SIGNAL	DESCRIPTION
1	Not connected	
2	Not connected	
3	RxD/TxD-P	Receive/ Transmit data – Positive – Line B
4	Not connected	
5	Not connected	
6	Not connected	
7	Not connected	
8	RxD/TxD-N	Receive/ Transmit data – Negative – Line A
9	Not connected	

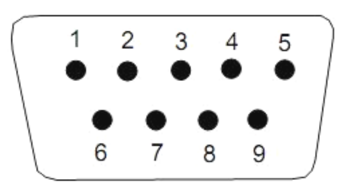


Figure 3.64 - DB9 connector

Data cable wire A – green
Data cable wire B – red

Figure 3.65 - EasyConn PB Connector

Note that the connector has input and output directions to the cable. This signaling must be followed to avoid future installation problems.

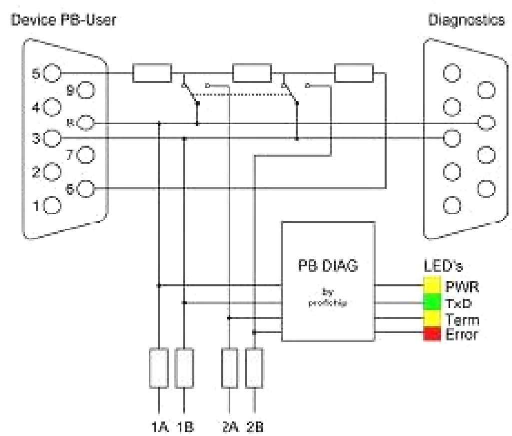


Figure 3.66 - Wiring diagram of a typical connector (EasyConn PB)

Above is the wiring diagram of a typical connector (EasyConn). Note the switches to the resistors (terminator switch). When active, it connects the segment formed by 1A and 1B up to the termination.

Also note that when the terminator is activated, the segment from 2A and 2B will be disabled.

M12 connector

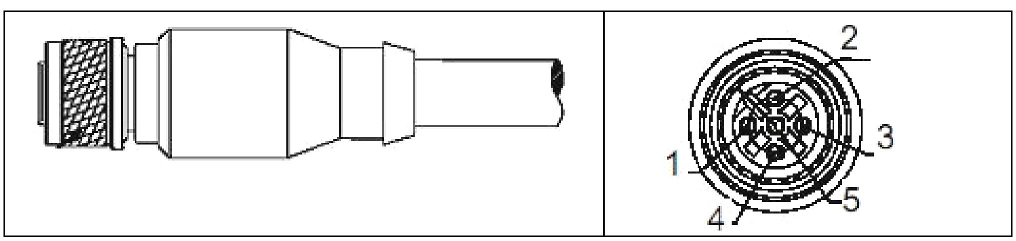


Figure 3.67 - M12 connector

PIN	DESCRIPTION
1	Not connected
2	Data core A (green)
3	Not connected
4	Data core B (red)
5	Not connected

ATTENTION
The shield of PROFIBUS DP cable must contact the metal housing of the DB9 or M12 connectors.

DeviceNet Network

See below a summary of the steps required to successfully implement a DeviceNet network.

- Topology and connections;
- How to determine the maximum trunk and spur lengths;
- Characteristics of DeviceNet cable standard;
- DeviceNet connectors;
- Network terminators;
- Power supply and grounding;
- How to connect power supplies to the network and to earth;
- General revision.

For more information on DeviceNet installation, consult "DeviceNet Cable System – Planning and Installation Manual" at http://www.odva.org.

Topology and connections

The DeviceNet network topology is based on a main trunk with spurs.

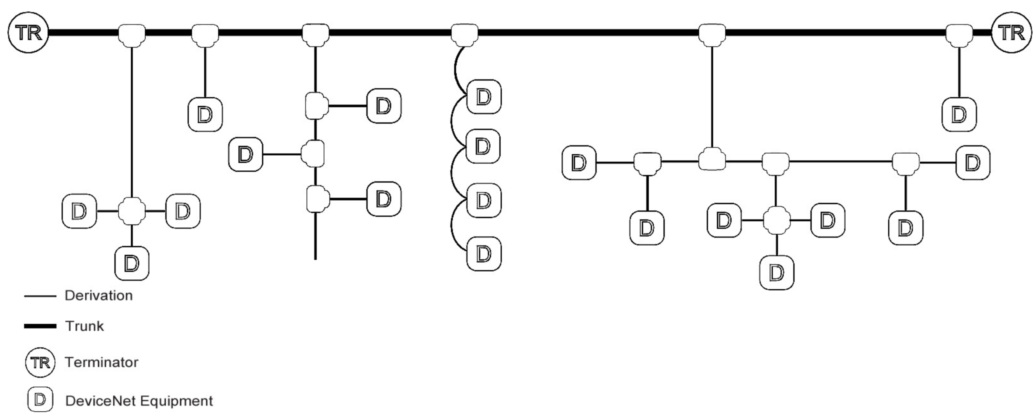


Figure 3.68 – DeviceNet network and compatible topologies

The main trunk must always terminate on both ends with 121 Ω, 1%, ¼ W resistors.
The most used thin and thick DeviceNet cables have 5 identified conductors for use according to the following table:

Cable color	Signal	Round cable	Flat cable
White	CAN_H	DN Signal	DN Signal
Blue	CAN_L	DN Signal	DN Signal
Naked	Drain	Shielding	Non-used
Black	V-	Power Supply	Power Supply
Red	V+	Power Supply	Power Supply

Table 3.11 – DeviceNet cables color scheme

The table below shows the maximum cable lengths, considering that the trunk is made of thick cable and the spurs are made of thin cable.

Cable type	Function	Communication rate		
		125 kbps	250 kbps	500 kbps
Thick cable	Trunk	500 m	250 m	100 m
Thin cable	Trunk	100 m		
Thick + Thin	Trunk	500 m	200 m	100 m
Flat cable	Trunk Trunk	420 m	200 m	75 m
Any type	Derivation	6 m		
Any type	Σ Derivations	156 m	78 m	39 m

Table 3.12 – Network length in relation to the cable used and the communication rate

The power supply must be connected to the network preferably with a thick cable, an equivalent or biggest section conductor. Pay much attention to the spurs. No network spur should be bigger than 6 m. The total spur length should also match the maximum communication rate allowed for the desired communication (see Table 3.12).

The maximum network length may be extended by means of isolating repeaters. The repeater divides the network in two segments powered by different supplies. The table then is applied to each separate segment. The network terminals connected to the repeater must be correctly terminated.

How to determine the maximum trunk and spur lengths

Normally, the maximum length is measured between the ends where the termination resistors are placed.
However, the right procedure is to measure between the most distant network ends. Should there be spurs on the network ends, and the trunk added to these spurs is bigger than the length between the terminating resistors, the spurs must be taken into account, as shown on the figures below:

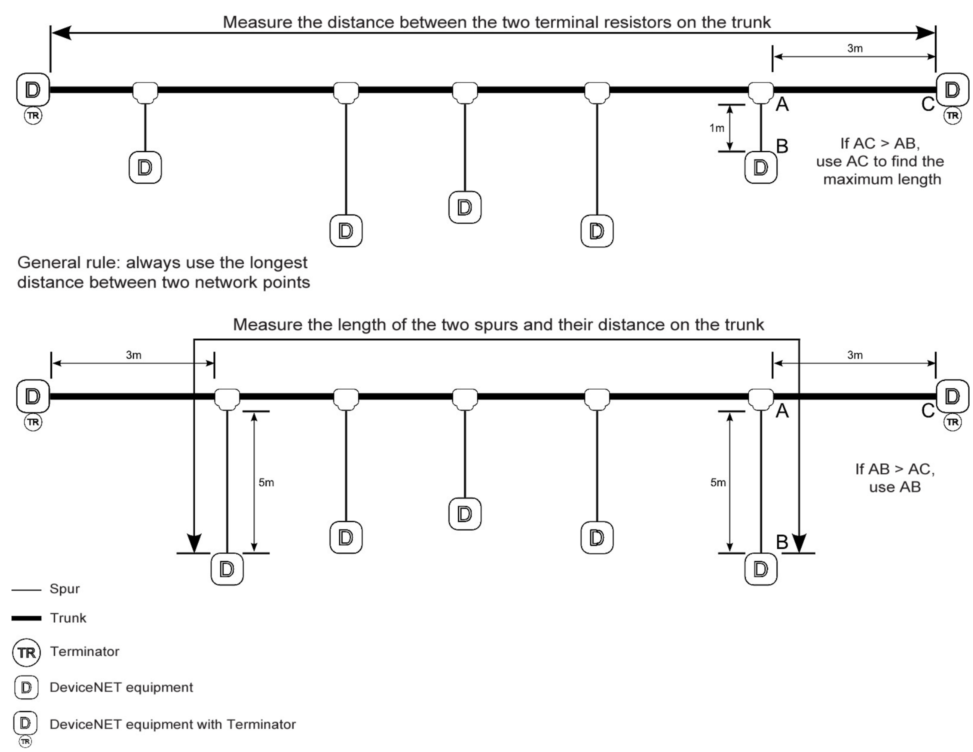


Figure 3.69 – Correct calculation for the maximum network length

The following figure shows an example of the communication rate limitation in function of the total spur length. The total length in this example is 42 m, which limits the rate to 250 or 125 kbps. Regardless of the trunk length, it is not possible to use 500 kbps.

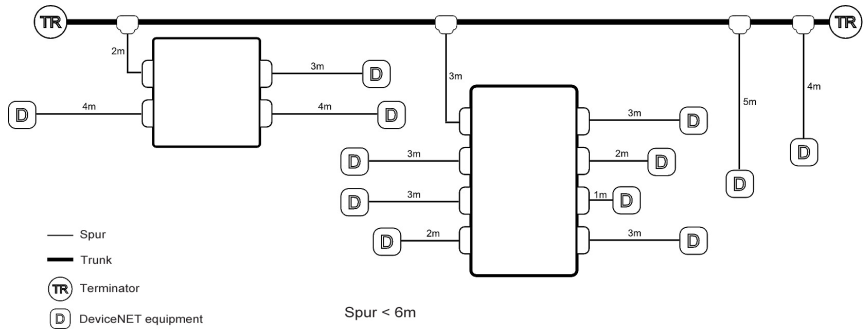
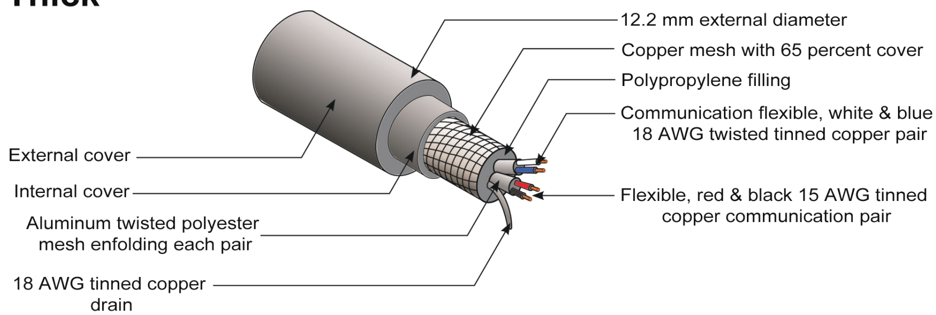


Figure 3.70 – Limitation of the communication rate by the spur length.

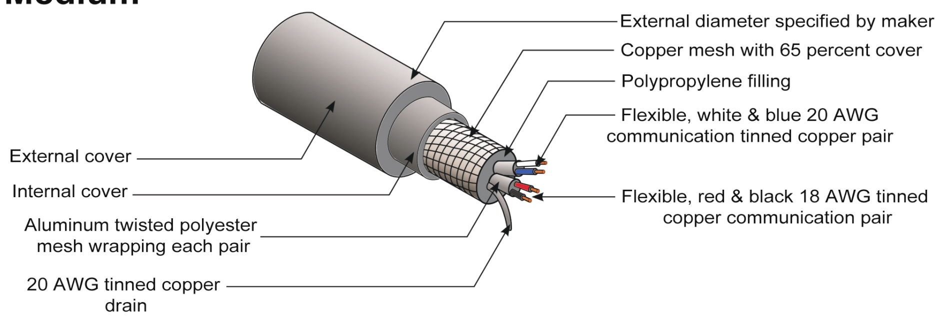
Characteristics of the DeviceNet standard cables

There are 4 types of standard cables: thick, medium, thin and flat. The most used is the thick cable for the trunk and the thin cable for the spurs.

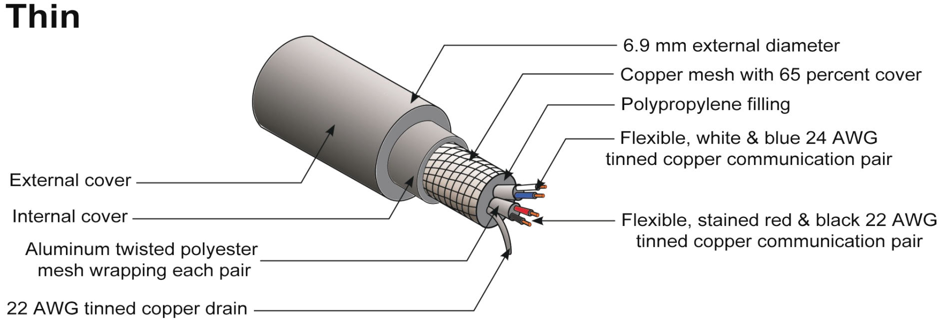
Thick



Medium



Thin



Flat

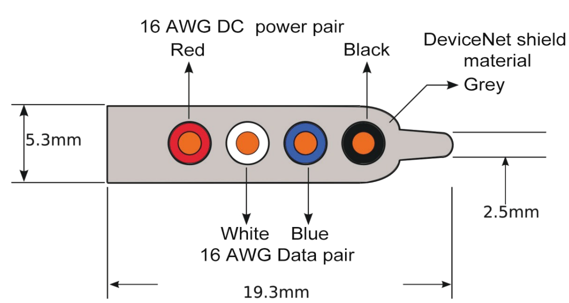


Figure 3.71 – Anatomy of DeviceNet standard cables

Cable type	Power conductor gauge (AWG)	Drain gauge (AWG)	Communication conductor gauge (AWG)	Maximum current (A)	Dimensions (mm)	Resistivity (Ohm/m)
Thick cable	15	18	18	8	12,5	0.015
Thin cable	22	22	24	3	7	0.069
Flat cable	16	-	16	8	5.3x19.3	0.019

Table 3.13 – DeviceNet cable features (thick, thin and flat)

DeviceNet Connectors

There are three basic connector types: open, mini-sealed and micro-sealed. Their use depend on the convenience and the device or connection features

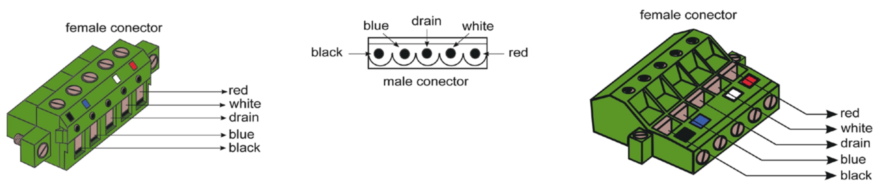


Figure 3.72 – Open style connector

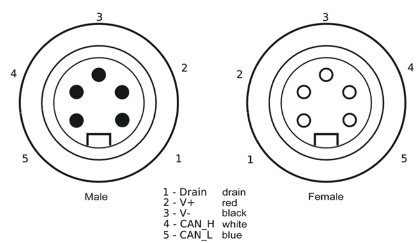


Figure 3.73 – Sealed connector

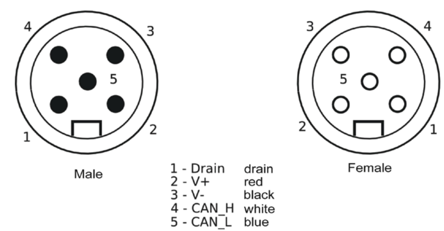


Figure 3.74 – Micro-Sealed connector

Network terminators

DeviceNet network terminations help minimize communication reflections and are essential for the network to function The 121 Ω, 1%, and ¼ W termination resistors must be located on the trunk ends, between the CAN_H e CAN_L white and blue cables.

- Do not install a terminator in a device or connector that when also removed may cause a general failure on the network. Leave the terminator always independent and isolated on the trunk ends, preferably inside protective cases or passage boxes.
- To check if the terminations are present on the network, measure the resistance between the CAN_H e CAN_L white and blue cables with the network switched off: the resistance measured must be between 50 and 60 Ohms.

Color	Signal	Round Cable	Flat Cable
white	CAN_H	signal	ending
blue	CAN_L	signal	ending
naked	drain	mesh	n/a
black	V-	power	power
red	V+	power	power

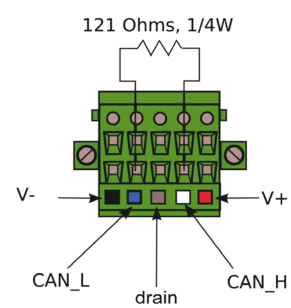


Figure 3.75 – Connecting termination resistors

Power supply and grounding

Dimensioning and installing power supplies for the DeviceNet network is one of the most important tasks on a physical Project. Most communication problems or intermittent device work are caused by failures in this part of the project or its execution. A few basic notions will be discussed following. For more details consult “DeviceNet Cable System - Planning and Installation Manual”, available at: http://www.odva.org.

DeviceNet cabling requires that the power supplies have a maximum 250ms rise time. Generally any 24 Vdc power supply may be used, as long as it meets this requirement. The maximum current on each network segment must be determined considering the application demand and the safety classification of every element.

Each 24 Vdc power supply cannot exceed ±3.25 percent of the nominal output voltage, while the following limits on each aspect must be considered:

- Variation on the output medium level: ±1,00%;
- Ripple on the output medium level: ±0.30%;
- Total temperature variation: ±0.60%;
- Useful life variation: ±1.05%;
- Load regulation: ±0.30%.

Hence, the total variation of the listed aspects cannot exceed ±3.25% of the nominal output voltage, and the following requirements should be verified:

- Output current: at least 20 percent bigger than the total consumed by the network devices.
- Isolation: DC output isolated from the AC input (at least 1 kVrms).

Connecting the power supply to the network and to grounding

- The power supply must be connected to the network preferably through a 4 mm² (#12 AWG) pair or two 2.5 mm2 (#15 AWG) pairs;
- The maximum cable length to the main trunk connection is 3 meters;
- Follow all the recommendations from the power supply maker;
- The innermost network power supply must have the V- terminal connected to the cable shield and the grounding. The shield is normally connected through a naked wire drain. The cable end must have the shield mesh well finished with thermo-retractile spaghetti;
- For multiple supplies use a specific supply connection called power tap, which normally has the protection illustrated below:

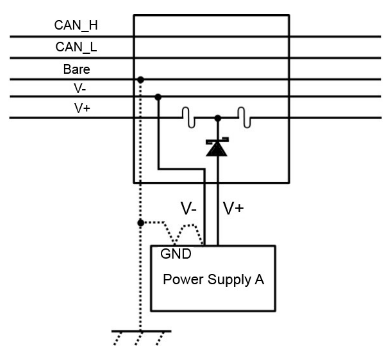
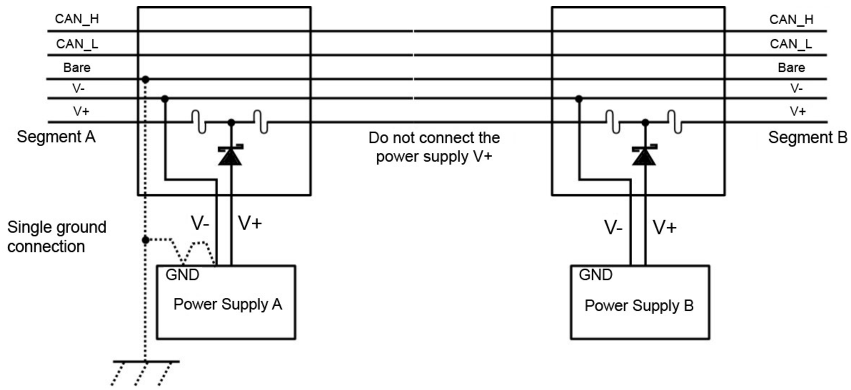


Figure 3.76 – Single power supply



3.77 – More than one network power supply

The main rule for the network grounding is that it must reach a single point, usually on the power supply or on the most central network supply, for multiple supplies.

The power supply V- terminal must be connected to the ground and to the cable shield. As said before, use the drain filter to ground the cable shield mesh. For the flat cable, without drain, just connect the power supply V- terminal to the ground.

- Use a copper mesh or flexible wire with the proper gauge for grounding. Preferably keep the length below 3 m with 10 mm^2 (#8 AWG) wire.

General revision

Several problems may be prevented if, before turning on the network power supply, you check the most important points listed next:

1. Review the total equipment consumption and their network power supplies and make sure not to exceed their limits.

2. The voltage drop must never exceed 5 V on any network V- terminal.

3. Though the network addressing allows a maximum 64 devices (0 to 63), in practice this number is 61, as three addresses are reserved one for the master, one for an additional configuration and diagnostics interface (a portable programmer or PC), other than address 63, which is normally kept free for maneuvering devices on the network.

    a. On DeviceNet devices without a dip switch or rotary key to select the address, the factory address is normally set at 63. Keeping this address free on the network allows installing a new equipment without causing a duplication. After being installed, the device gets a new address through the configurator

4. Make sure no derivative or spur have individually more than 6 m and that their total do not exceed the rate limit (see Table 3.1).

5. Do the same for the trunk: see that the total length is below the maximum allowed for used cable.

6. Check the terminal resistors at the network ends.

7. Verify the grounding connection:
    a. V- for the flat cable, at a single point.
    b. V- and drain (shield mess) for the thin and the flat cables.

8. Verify if all connections are correct and solid.

9. Make sure there are no short-circuits or broken wires in the network.

Connecting the network power supply

After checking all of the mentioned points on the general review, a network power supply can be established. However, before installing it, take a few precaution measures so that the system will work to perfection. To this effect, connect the 24 Vdc power supply but leave the DF79 master disconnected so that there is no communication. After checking every point, the commissioning stage may start with best chances for success.

1. **Communication terminals and conductors**: with the power supply disconnected, use an multimeter to measure the impedance between the CAN_L and CAN_H wires on each device connector. The value measured must be between 50 Ω e 66 Ω. If over 66 Ω, one of the wires may be broken or one the terminators missing. If the value is smaller than 50 Ω, there may be a short-circuit between the CAN_L and the CAN_H, or more than two termination resistors, defective or powerless devices. Check if the devices are properly connected, if they have internal termination resistors or inverted connections.

2. **Grounding:** cut the shield at some network points and set the multimeter on serial DC current. The measured current should be zero. If there is any current, the shield is connected to more than one point on the network, to the V- on some power supply, or to ground. Correct the installation. Remember to connect the shield again.

3. **Shield mesh:** connect an ammeter on the network end farthest from the power supply that may support the maximum current between the V+ and the cable shield. A significant current should circulate nearly the supply capacity. If no current circulates, the shield is interrupted at a connector or a spur box, or the shield drain wire is not connected at the power supply V-.

4. **Network power supply**: with the multimeter, measure the network voltage on each device, one that must be over 11 Vdc (21.6 Vdc for network-powered loads). In case any point shows a lower voltage, check the connectors and review the calculations for voltage drops according to each device consumption and their distance from the power supply. Check the current at each network segment with the multimeter. Measure and note down the voltage measured between the cable shield and the negative (V-) terminal on each device. The measured values should be between –5 V e 5 V, and the difference between the highest and the lowest values must be smaller than 5V. If otherwise, check the power supply, the current flowing on each segment and the cable integrity (conductors and shield).

5. **MAC ID address and communication rate**: normally each DeviceNet device has a diagnostics LED that is an excellent problem solver indication. The LED must be blinking or fixed in green. If it is red, the rate may be wrong or there even be two devices with the same MAC ID. Check the devices and correct the repeated addresses.

6. **Common mode voltage and differential voltage on communication:** with the multimeter black probe on V- (-24 Vdc), measure:
   a. CAN_H: 2.2 to 3.8 Vdc;
   b. CAN_L: 1.4 to 2.8 Vdc;
   c. CAN_H – CAN_L < 3 Vdc;
   d. The CAN_H signal value must never be smaller than the CAN_L. If this happens, search for an inverted connection on one of the devices, passage, or derivation boxes. If the difference between the smallest measured CAN_L value and between the biggest CAN_H value is over 3 volts, there must be a physical problem, excessive traffic, or common mode voltage (poor energy distribution).

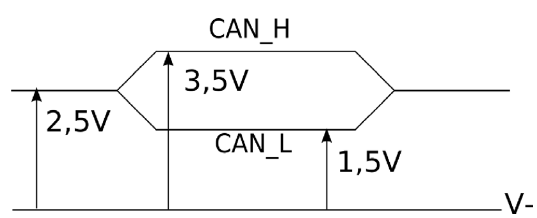


Figure 3.78 – Typical CAN signal voltage levels on the DeviceNet network

AS-i Network

The AS-i industrial networks were designed to be applied on automated environments to replace the traditional actuator and sensor switch (on/off) connections for a single bus. In addition it can also be connected to sensor and actuator buses those perform an analog conversion or vice versa.

Traditionally, these connections are made of twisted pairs that connect each actuator and sensor, one by one, to the corresponding controller, typically a PLC – Programmable Logic Controller.

The AS-i system is configured and controlled by a master that programs the interface between a controller and the AS-i system. The master continually exchanges information with all sensors and actuators linked to the AS-i bus in a pre-determined and cyclic way.

Figure 3.79 illustrates the entire AS-i system enhancing its main components: cable, AS-i power supply with its decoupling circuit, the AS-i master and slave.

- **Interface 1:** between the slave and the sensors and actuators;
- **Interface 2:** between the devices (power supply, master and slave) and the transmission medium;
- **Interface 3:** between the master and the host, in other words, any entity that accesses the AS-i network from an upper level.

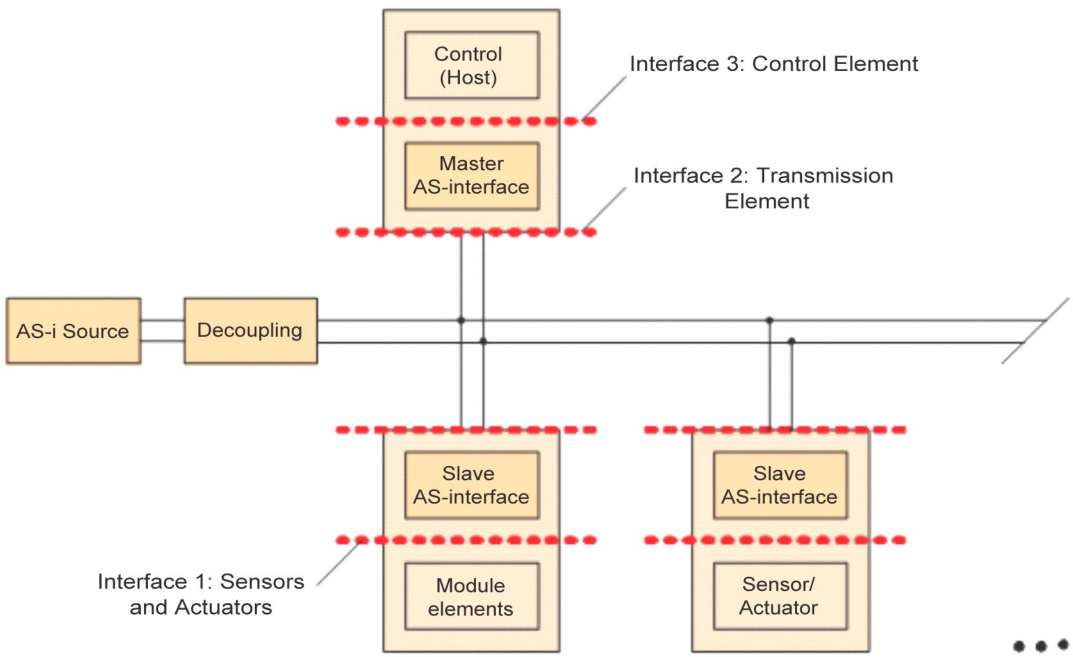


Figure 3.79 – Components and interface

The following sections will only describe the topics related to the AS-i system physical features, such as cables, power supply, network topology. Also presented is a set of standards and regulations required for installing, mounting and operating an AS-i network.

Characteristics

The name Actuator Sensor Interface is a simple and elegant solution to integrate discrete sensors and actuators on process control systems. This network has a series of features, as follows:

- **Compatibility:** Sensors and Actuators from different manufacturers may be connected to a standard digital serial interface;
- **Access procedure:** Cyclic polling, single-master system;
- **Addressing:** Slaves receive a permanent address from the master or hand-held type;

- **Topology:** Without restrictions (linear, ring, star or tree structure);
- **Medium:** Two unshielded, non-twisted cables (2 x 1.5 mm²) for data and electrical power (usually 24 Vdc), typically up to 200 mA per slave, up to 8A per bus;
- **Fast installation:** electromechanical interface with piercing technology;
- **Cable length:** range 100 m, scalable by repeater up to 300m;
- **Signals:** Data and electrical power via the same line, max. 8 A possible;
- **Number of slaves:** Up to 62 slaves per network (version 2.1);
- **Data:** 4 inputs and 4 outputs for each slave; for more than 31 slaves, only 3 outputs (maximum of 248 binary inputs/outputs per network).
- **Useful load:** 4 bits/slave/message transmitted. All slaves are requested sequentially by the master and receive 4-bit data. Each slave responds immediately with 4-bit data;
- **Cycle time:** Max. 5 ms and 10 ms according to 2.0 and 2.1 spefications, respectively;
- **Error detection:** Effective error detection and retransmission of incorrect telegrams;
- **AS-Interface chip:** 4 I/O configurable for data, 4 output parameters and 2 control outputs;
- **Master functions:** Cyclic slave scanning, data transmission for slaves and for the control unit (PLC or PC). Network initialization, slave identification, transferred slave and data diagnostic. Also, reports errors to the controller and addresses the replaced slaves;
- **Valves:** Installed directly on the application, reducing piping and increasing the actuator response speed;
- **Low cost:** Low connection cost per slave and eliminates PLC input and output modules;
- **Reliability:** Highly reliable operational level in aggressive industrial environments;
- **Open standard:** Developed by renowned industries affiliated to the AS-i International Association, whose transmission protocol is standardized;
- **Optional:** output power supply cable and stop control.

Standards and Regulations

AS-i components and installations shall comply with all statutory regulations and the latest edition of the following:

- Statutory Obligations (including the Electricity Ordinance, Chapter 406);
- **IEC 364:** Electrical installations of buildings;
- **IEC 60947-1:** Low-voltage switchgear and controlgear – Part 1: General rules;
- **IEC 529:** Degrees of protection provided by enclosures (IP Code);
- **IEC 439:** Low-voltage switchgear and control gear assemblies;
- **IEC 62026-1:** Low-voltage switchgear and controlgear – Controller-device interfaces (CDIs);
- **IEC 62026-2:** Actuator sensor interface (AS-i);
- **IEC 61131-2:** Programmable controllers – Part 2: Equipment requirements and tests;
- **IEC 61076-2-101:** Connectors for electronic equipment: Part 2-101 Circular connectors (M8 & M12);
- **EN 954-1:** Safety of machinery. Safety related parts of control systems. General principles for design;
- **CISPR 11:** Industrial, scientific and medical (ISM) radio-frequency equipment – Electromagnetic disturbance characteristics – Limits and methods of measurement.

In addition to the local regulations for installations, inspections and tests of equipment shall be taken into consideration.

Transmission Medium

AS-Interface is a standard and open network system (EN 50295) that connects actuators and sensors in a very simple way. A single cable connects the actuators and sensors with the upper control levels.

The connection of the elements can be done in tree structure, star, line, or a combination of both. Since there are no conventional connections and with the reduction of terminal block and connector links, costs and mounting time, as well as errors, decrease.

In the simple connection technique using parallel cables, each device’s contact is connected separately to the ends and terminal blocks of sensors and actuators. The AS-i network substitutes the traditional arrangement of multiple cables, passage boxes, conduits, trails, and cable ducts for a single cable specially developed for the AS-i network.

The AS-i network features a single pair of wires that transmits the data and electrical power to the sensors and actuators (usually 24Vdc) at the same time. The maximum network configuration includes 62 slaves that are accessed cyclically by a master on the upper control level. The response time is short for every connected slave: 10 ms (version 2.1).

Formerly, sensors and actuators were connected to the controller via the terminals, connectors and terminal blocks. AS-i enables the reduction of installation and maintenance costs, with a standard twisted cable that allows the exchange of data and electrical power between devices. Slaves are connected directly to the bus, without additional wiring. A flexible two-way cable was designed as standard for the AS-i network. There is also a round shape cable for use only under the manufacturer specification.

Standard Flexible Cable

This H05VV-F 2X1.5 high voltage flexible cable complies with the CENELEC or DIN VDE 0281 standards, it is inexpensive and easy to get.

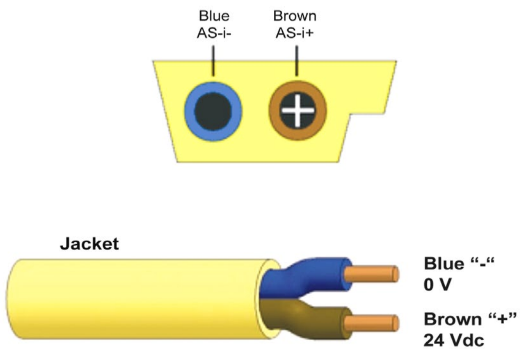


Figure 3.80 – AS-i bus standard cables
Source: *AS-International Association and Turck Networks (2008)*

The unshielded, non-twisted AS-i cable has two parallel conductors that convey data and power to the slaves. Its external jacket is yellow and has a characteristic geometric shape that was designed to avoid fixation with reversed polarity (Figure 3.81).

The cable does not need cutting or stripping to be connected. This practice generally causes undesirable voltage drops and is a constant bad contact source. On the other hand, it has an interesting way to be installed, this favors costs savings in its implementation.

This is a simple principle: the contact with the internal conductors is done by conductive blades that penetrate in the plastic insulation to reach the internal copper wires.

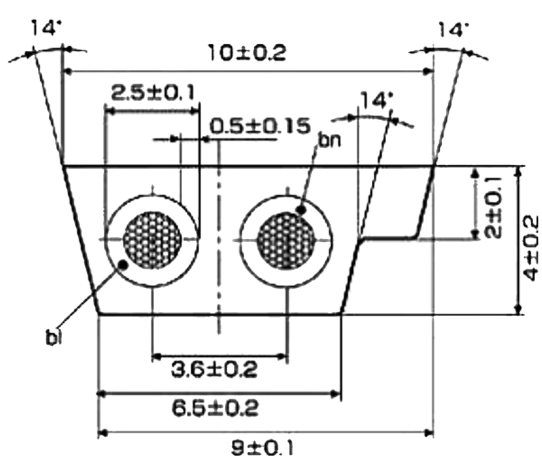


Figure 3.81 - View of the AS-i cable frontal section (in mm).

The internal shielding has a “healing” property that closes it when the blades are disconnected, without being seen when being cut lengthwise. Evidently the shielding remains perforated, but without the risk of a short circuit. Figure 3.82 illustrate the concept.

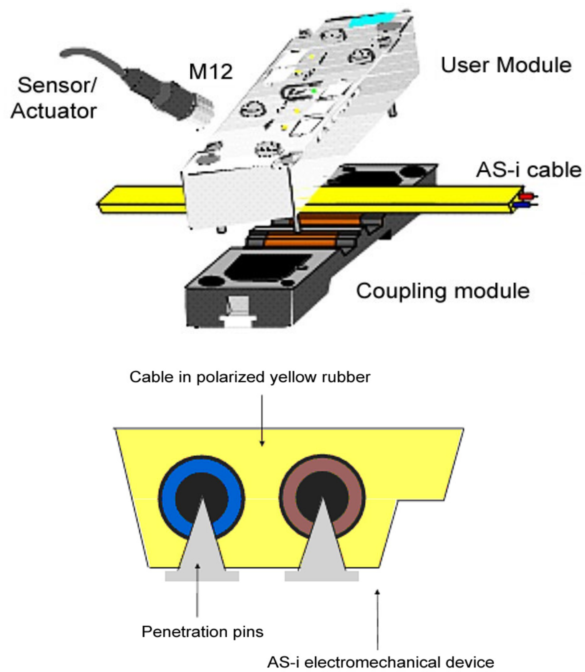


Figure 3.82 – a) Bus to module coupling b) Perforation pins.
Source: *AS-International Association (2008).*

In addition to the power supply available to slaves through the yellow cable – that became a sort of registered trademark for the AS-i system – and serves almost all purposes, some slaves may need a supplementary power supply, especially the most powerful actuators. An additional black cable with the same properties is used only for supplying power. It also uses the same previous penetration technique and supplies up to 24 Vdc.

When selecting an adequate transmission media, two relevant electrical considerations should be done: the DC resistance on the power supply and the transmission features on the frequency band used on the communication. At least 2A of current must be available for transmission on the slave power supply. Within these requirements, other cables can be used on specific cases, like for conducting larger currents or the need for movable cables. Besides these two types of cables there is also a red version for until 230 Vac.

Round Cable

This cable was designed specifically for the AS-i, with almost similar electrical features, but with a specific type of installation. This cable can be shielded or unshielded, but preferably the unshielded are used, with the following characteristics (at a frequency of 167 kHz):
R´: < 90 mΩ/m
C´: < 80 pF/m
Z : 70 Ω to 140 Ω
G´: ≤ 5 μS/m

It is also recommended a cable with a transversal cross-section of 2 x 1.5 mm^2.

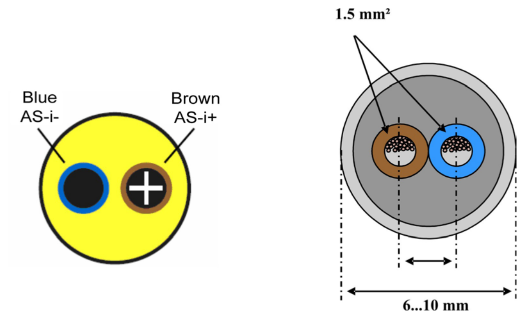


Figure 3.83 –Circular cables without shield
Source: *AS-International Association (2008).*

Connections of the AS-i line

Any connection to the AS-i line shall meet the following requirements, whether a conventional technology or an insulation piercing technology is used:

- Contact resistance maximum of 6 mΩ;
- Minimum allowable current of 1.5 Inom (minimum of 3A for a general AS-i line);
- Contact voltage range of 10 V to 70 Vdc;
- Shock and vibrations in compliance with item 7.4 of IEC 60947-5-2;
- Strain relief in compliance with annex E of IEC 60947-5-2;

If a clamp or a screw terminal connector is used for connections, its capability shall be at least a 2 x 1.5 mm^2. If plug connectors are used, the D.2 type according to annex D of IEC 60947-5-2 is preferred.

Cable Length

The maximum length for an AS-i network cable shall not exceed 100m without the use of repeaters. A maximum of two repeaters to extend the length of the line to 300 m is permitted.

The length of AS-i line is calculated by adding the line length to two times (2x) the length of the connection accessories. Example: 50 m of yellow cable and 5 tap-offs with 2 m of cable gives a network length of 50 + 2 x (5 x 2) = 70 m network.

Figures 3.84 and 3.85 show solutions for extender and repeater connections to extend the AS-i line.

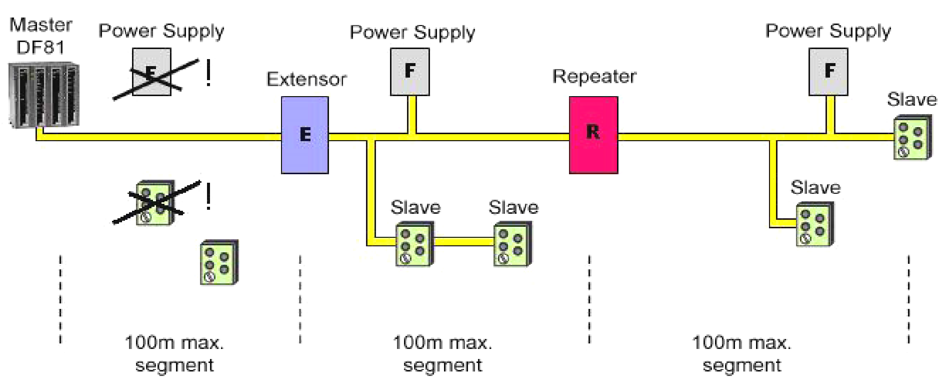


Figure 3.84 – Solution with an extensor and a repeater
Source: *AS-International Association (2008).*

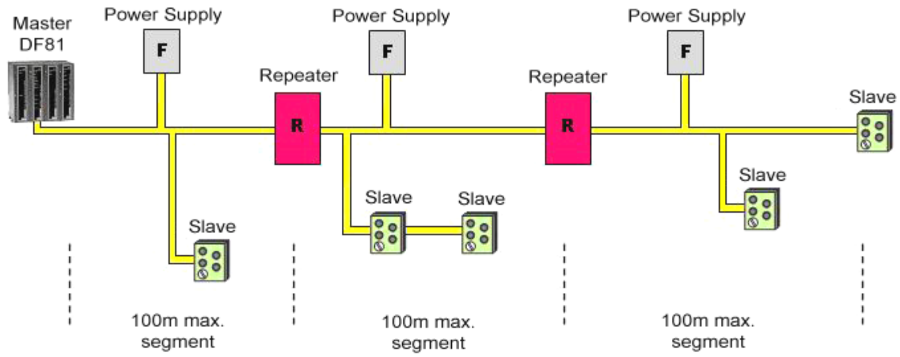


Figure 3.85 – Solution with two repeaters
Source: *AS-International Association (2008).*

Network structures

The topology for AS-i networks is left to the user's discretion to simplify the project. The restriction is not observed if the maximum limit for the cable length is 100 m. If longer lengths are required, repeaters are used to extend the network range, provided the limit of 62 slaves and one master is observed. No terminal impedance is needed, simplifying the installation. Structures in tree, linear, star or ring are possible (Figure 3.86).

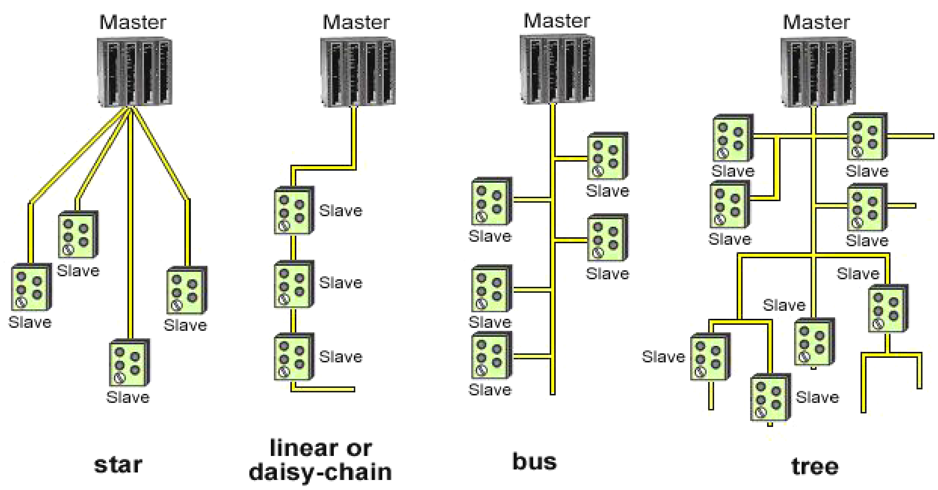


Figure 3.86 – Physical network topology
Source: *AS-International Association (2008).*

Power Supply

The AS-i power supply has four functions, as follows:

Power Supply

The power supply unit works with a voltage of 29.5 V to 31.6 Vdc, and supplies a current of 0 A to 8 A (typical current per slave is 200 mA) under normal operating conditions. The power supplied to the slaves and partially to the master through two wires is the same used to transmit AS-i data and can be connected to any point on the network. On long lines, the voltage drops must be considered but should not exceed 3 V on a whole 100 m cable. The unit has an internal overload protection circuit with current limit.

Balancing

The power supply unit also balances the AS-i network, which is operated as a non-grounded symmetrical system. For noise immunity the AS-i cable must installed as symmetrical as possible through the balancing circuit shown in Figure 3.83. The shielding connection must be at an adequate point on the machine or the system. Only at this point it can be connected to the system ground (GND).

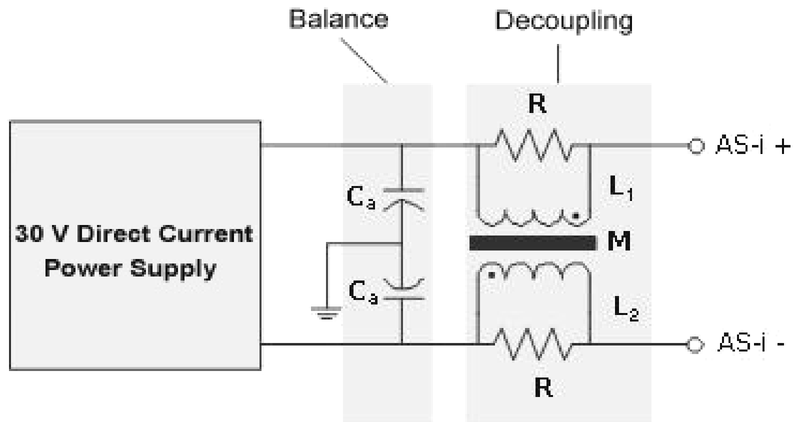


***Figure 3.*87 – Simplified AS-i source Diagram**

Data Decoupling

The third function of the power supply unit is decoupling data, which is normally done by the decoupling network on the power supply module. This network consists of two inductors of 50 μH each (L1 and L2) and two resistors of 39Ω each in parallel. The inductors perform a differentiation job on the voltage pulses to convert the current pulses generated by the transmitters connected to the network. At the same time, they prevent short circuits on the cable. The coupling between the inductors shall be as close as possible to 1, meaning that the mutual inductance must tend to 200 μH.

Safety

The fourth function is related to safety. The AS-i system was designed as a system for low voltages with safe separation (Protective Extra Low Voltage). In other words, according to the relevant IEC standards, safe separation between the power supply and the AS-i network is required.

Recommended Practices

Next is presented an outlook of an AS-i network installation, one that serves as a guide for the adequate installation of the system.

Considerations on Racks and Cables Layouts

Racks

The mounting of racks with I/O modules, power supplies and AS-i slaves are the first elements to be mounted on the system taking into consideration the distribution of slaves and I/O modules.

Cables

With relation to routing and configuration of AS-i cables, the following items must be considered:

- Whenever possible, use profiled yellow cable, whose brown color indicates the positive pole ("+") and blue the negative pole ("-");
- Yellow cables are used on AS-i communication network, black cables on the 24 V secondary power supply and red cables on the secondary 230 V supply.
- AS-i communication network cables must be routed far from power cables in conduits, raceways, cable belts and current cables, in addition to other cables that could interfere on data transmission.

- Whenever possible, use 16 AWG conductors in cabinets and panels. Never use conductors smaller than 18 AWG on any AS-i application;
- As much as possible, keep separated AS-i control component panels from auxiliary power supplies (DC or AC voltages) etc.;
- Do not install control wiring or AS-i cables in the same place, bed or conduit with auxiliary power supplies;
- Each AS-i master requires its own data cable. AS-i cables must never be aligned, fixed or connected together otherwise;
- Do not connect AS-i cable wiring to ground;
- The cables must be connected to the power supply only with it unplugged.

Power Supplies

- Always use power supplies with protective extra low voltage – *(PELV*) and integrated data decoupling. Connect ground to the grounding system;
- Never connect the ASi power supply negative to ground;
- Connect the ASi yellow cable when the power supply is unconnected and make sure that the power supply is correctly connected to the ASi 24 Vdc channel/master;
- Connect first the 24 Vdc power supply (DF50) and then the AS-i network power supply.

AS-i Masters

- Connect the AS-i yellow cable (brown for "+" and blue for "-") to the master when unconnected and on its respective polarity;
- The DF 50 power supply will be used to power the backplane that, consequently, will power the HSE/AS-i controller. A supplementary power supply must be connected to power the AS-i masters. The supplementary power supply voltage will be bounded to the slaves that will be used on the AS-i network.

Slave Nodes/Modules

- To add a slave to the AS-i network proceed as follows:
  - Pre-address the slaves with a portable programmer before adding them to the network;
  - Add the slaves one by one to the bus through automatic addressing, or change the addresses with the AS-i network configuration tool;
  - Each slave address must be singular. From 1 to 31 (version 2.0) or 1A to 31B (version 2).
  - If different slave versions are used on the same bus, the 2.0 version slaves will occupy two addressing positions, i.e., if a version 2.0 slave is inserted with an address equal to 1, a version 2.1 slave cannot be inserted with the same address as the 1 B.
- When replacing a slave, the new one must have the same attributes as the first (IO code, ID code and address).

Network extensions

- For AS-i network cabling, the maximum permitted limit is 100 m – including all of the topology spurs up to their terminals – without using repeaters and extensors.
- The AS-i networks do not need a terminal resistor.

For AS-i network extension, consider the following procedures:

Use of extensors:

- Use the standard AS-i network (yellow) communication cable;
- The maximum permitted cable length between an extensor and a master is 100 m;
- No slave or power supply should be connected between the master and the extensor;
- The positive and negative poles must never be inverted.

Use of repeaters:

- Use the standard AS-i network (yellow) communication cable;
- A maximum two repeaters can be connected in series to the network power supply for a maximum 300 m limit (3 segments a maximum 100 m each);
- The AS-i network power supply must be connected near to each repeater;
- Normally, an extensor cannot be applied after the repeaters.

Sensors and Actuators

- Sensors and actuators must be powered directly on the corresponding slave input or output;
- The module connection cables lengths to the AS-i network I/O devices must be the shortest possible, and the cables must be kept separated from transmission cables and motors. Typically, the minimum applied distance is 400 m and the maximum distance is 5 m.

Ensuring EMC Immunity

- Do not install the AS-i communication (yellow) cable with the power cables;
- Keep the maximum possible distance between the yellow AS-i cables and the power cables;
- Keep well separated the DC voltage from the AC voltage components in the panels and cabinets, for best wiring location and routing;
- Connect all contactors, relays, solenoid, locks etc. to proper noise suppressing elements;
- Filter and ground correctly all potential sources of noise;
- Always use shielded motor and transmission cables and ground them correctly.

System Diagnostics

- To localize errors on the AS-i network, check the statuses and diagnostics via the AS-i master flags and slave lists available on the network configuration tool or the communication transducer.

- Information on failures is also available on the master periphery fault parameter, version 2.1. This parameter covers low tension failure on the 24 Vdc supplementary supply, short-circuit and overload on the slaves;

- If there is no response from the slave, check if it was duly addressed, there is no rupture on the cable and the slave is correctly connected;

- Configure the SNMP winglet on the Server Manager with the specific controller information to be diagnosed and use an OPC client to navigate on the available MIB of the controller for its diagnostic and that of the AS-i network.

Mounting Tips

On Field

- Locate the power supplies near the highest current consuming slave;
- Keep the maximum possible distance between the AS-i cables and the power cables;

CCM Closet

- Twist each two cable pairs as a double cable;
- Do not install the AS-i cable close to the power line on the same multiple cable;
- Keep a minimum 15 cm distance between the AS-i cable and the power cable;
- Keep the maximum possible distance from noise sources, like frequency converters;
- Keep the maximum possible distance between CLPs and power elements;
- Do not overload the AS-i cable. A slave requires a least 26.5 V.

HART® Network & 4-20mA

The HART® protocol is the most used communication system on the industrial area in the world. Its main feature is its simplicity and total compatibility with the 4-20mA system – the world's most accepted measuring and control system. The HART® digital communication co-exists with the 4-20mA analog signal on the same cable pair without interfering with its analog measuring.

The HART® protocol works at a 1200 bps transmission rate, which enables monitoring variables at each 500 ms. The low communication rate was especially chosen to make it possible for a field device to have a quiescent current consumption compatible with 4-20mA devices, and to signal safety failures at the 3.6 mA range (for safety reasons, the quiescent consumption of a HART® device must be lower than 3.5 mA).

The communication signal, superposed to the analog signal, has a Frequency Shift Keying (FSK) modulation, which is an analog signal without any DC component and, therefore, does not interfere with the 4-20mA measuring. The FSK modulation works as follows: digital bit "1" is modulated at the 1200 Hz frequency and bit "0" is modulated at 2200 Hz, with bit width corresponding to one 1200 Hz period.

Since HART® is a master/slave protocol, the HART® system can be configured with one or more HART® slave transmitters connected to a maximum of two masters or Hosts (primary and secondary masters). Furthermore, the HART® system can be configured on *Single-drop* or *Multi-drop* mode according to the number of slave transmitters on the network.

On *Single-drop* configuration (one transmitter connected to the network), the HART® system works with analog 4-20mA signals, simultaneously with the digital communication signal, which results in a simple open control loop.

On *Multi-drop* configuration (two or more transmitters connected to the network), the functionality depends on the operation selected for the device: controller or transmitter. If the device is configured as a transmitter, 4-20mA analog output current will not be generated and the current will be fixed at 4 mA, while data exchange between the transmitters and the Host system occurs via digital communication. If the device is configured as a controller, the output current will be set by the PID control and the network should be carefully established in order not to cause interference between the control loops. In this case, control loops are connected in parallel, and the load impedance will be common to all parallel control loops.

Single-Drop Network

In this type of configuration, the transmitter is powered by a power supply with a 250 Ohm load resistor, connected to the input of a controller to handle the 4-20mA signal and enable the HART® digital communication. Usually, the analog input of a controller or indicator has a 100 to 250 Ohm impedance, therefore the load resistor could be reduced because HART® suggests a minimum total load impedance of 250 Ohm for the operation.

Normally, a standard HART® bus is based on a twisted pair of wires whose length do not exceed 1,500 m. In environments with electromagnetic or radio frequency interference, the twisted pair can be replaced with a shielded twisted pair of wires.

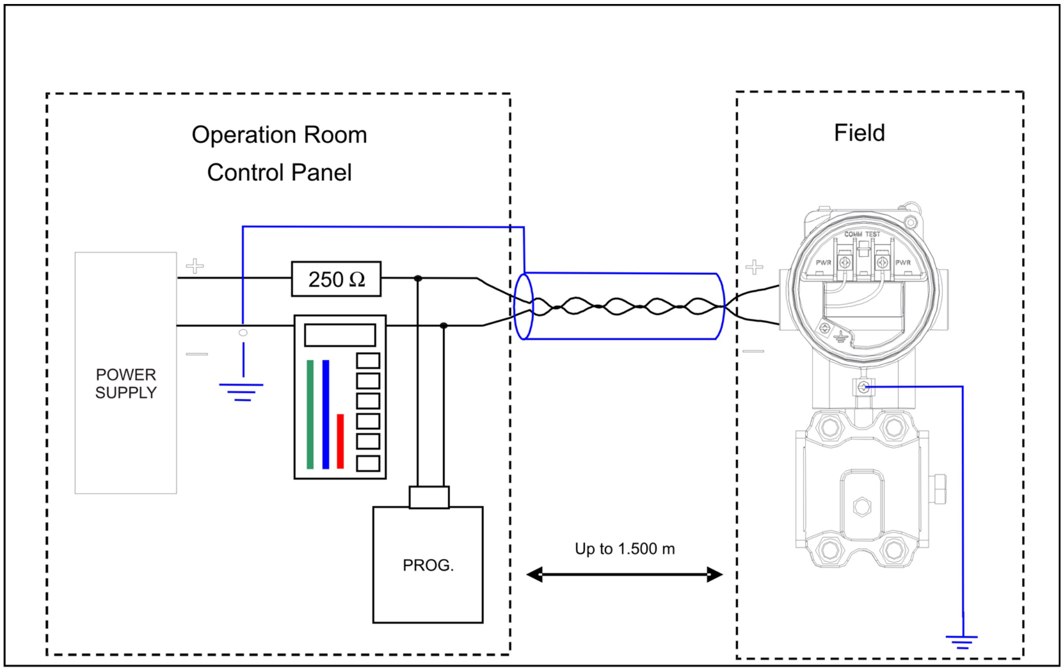


Figure 3.88 – Single-Drop Configuration – simple closed loop on transmitter mode

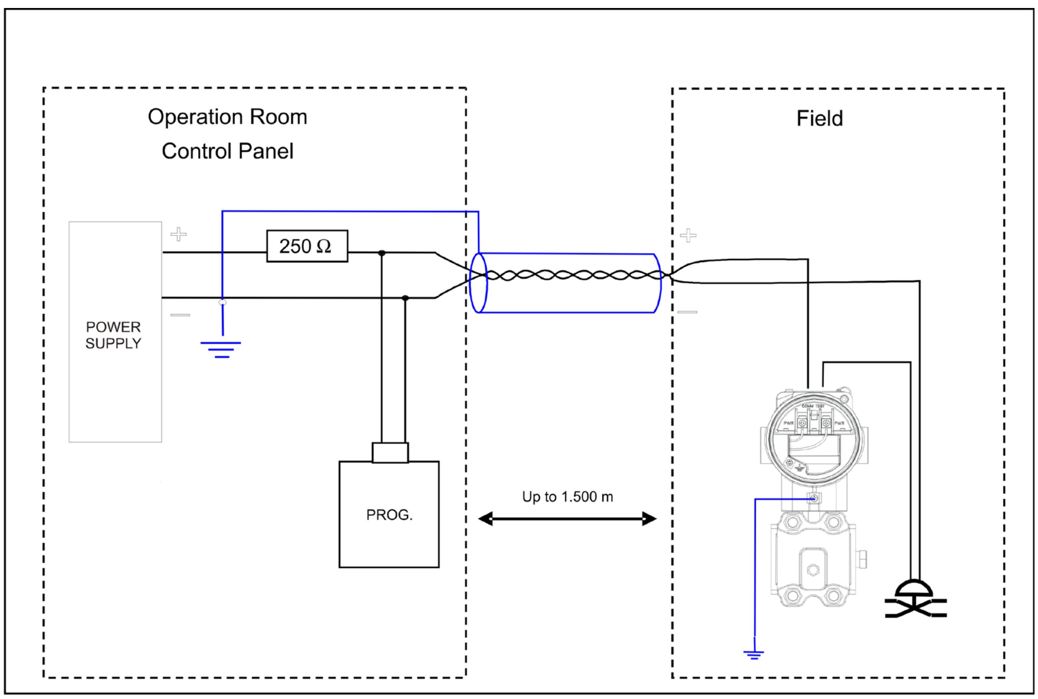


Figure 3.89 – Single-Drop Configuration – simple closed loop on controller mode

When grounding the configurations, consider the following guidelines:

a) It is recommended to ground the negative pole of the power supply to assure that the system operates with a stable electric reference;

b) For the operator's safety, the equipment housing must be grounded locally, on the plant grounding structure;

c) When using a shielded twisted pair of wires, the shielding must be grounded on the grounding system of the operation room, ensuring that this grounding point is unique; the cable shielding must be totally insulated at the other end to prevent ground loop and the risk of an electrical discharge to the operator;

d) To avoid 4-20mA spurious measuring, make sure the controller (input circuit) and the transmitter (terminal block) do not suffer current leaks, since both devices and the negative pole of the power supply are grounded, which could create a current loop parallel to the control loop. Low device input impedance also affects the integrity of the HART® digital communication signal, and increases the device's susceptibility to EMI/RFI effects, thus interfering on the sensor's measuring system.

e) To ensure an integral communication signal, free from electro-magnetic noises, the bus must ran through a correctly grounded tray (ground points at least at every 20 m), from beginning to end. In case there is no tray, a grounding bus must be extended parallel to the signal bus, grounding points as specified for the bus tray. If current is detected between grounding points, it will be caused by a ground unbalance and the control panel should not be connected directly to the plant. Signal bus should be mounted through optical or galvanic insulators, or an equipotent grounding system should be installed, if possible.

Multidrop Network

Transmitters in *Multdrop* network configuration are interconnected in parallel; the information from each device is obtained via HART® digital communication, and the 4-20mA signals become inactive, i.e., the transmitters operate in a fixed current at 4 mA. It is necessary to adopt a network with load impedance about 250 Ohm to enable the communication signal on this network. If the current on the load impedance causes high power dissipation and a high voltage drop, the resistive load impedance can be replaced by an equivalent active load impedance.

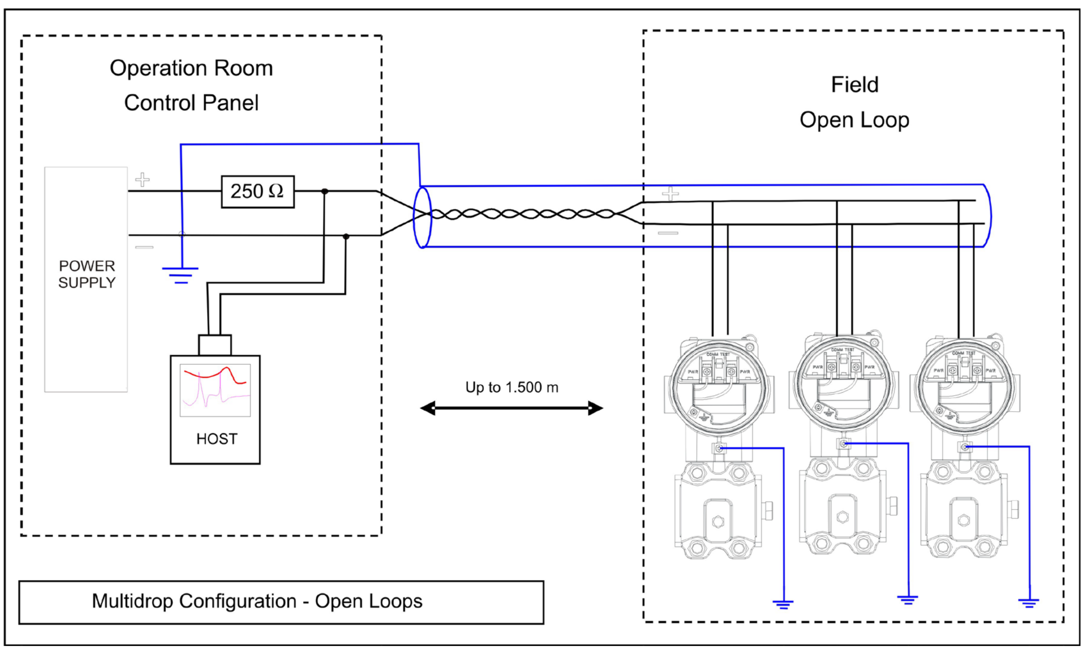


Figure 3.90 – Multidrop Configuration – open loops on transmitter mode

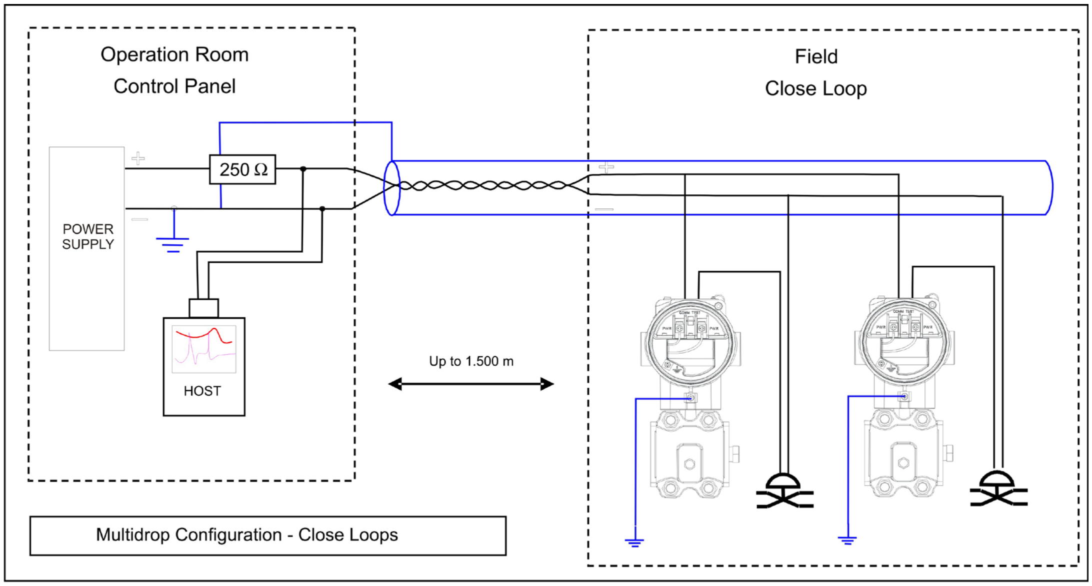


Figure 3.91 – Multi-Drop Configuration – closed loops on controller mode

The grounding guidelines for the *Single-Drop* configuration also apply for multidrop, along with the following recommendations:

a) The cable is segmented and reconnected to connect the transmitters; however, shielding must be fully recovered continuously until the last transmitter is connected. At each shield junction, the connection must be well executed and insulated to avoid any contact with cable trays, thus eliminating new grounding points.

b) Although the 4-20mA signal is not active in this configuration, low input impedance at the transmitter terminal block must be avoided, because it may strongly interfere with the integrity of the HART® digital communication signal, or even increase the transmitter's susceptibility to EMI/RFI, which affects the quality of the sensor measuring.

Network Configuration

The HART® network configuration starts by identifying the devices connected to the network and then, executing the HART® command transactions on the *Device Identifier* and the *Extended Device Type*. The *Device Identifier* is a unique serial number for a specific *Extended Device Type* and, therefore, each HART® device has its own single identity. The *Extended Device Type* is a parameter supplied by the HART® FOUNDATION™ that combines the *Manufacturer Code* with *Device Type* from the manufacturer.

The device can be identified on a network by the *polling address* or the *Tag*. The *polling address* is used by the HART® command 0, and the *Tag* is used either by command 11 (*Short Tag*) or command 21 (*Long Tag*), available in HART® 6 or higher.

On *Single-Drop* networks, the devices show the *polling address* equals to zero and on multidrop networks, from 1 to 15. HART® 7 specifications enable using *polling addresses* above 15 (up to 63), since HART® 7 enables a wireless network where devices would not generate 4-20mA current. The addresses 1 to 15 are reserved for multidrop networks in current, with devices generating a 4 mA fixed current.

Connecting Devices to the Network

HART® devices must be connected to the network observing the bus polarity, which defines the direction of the 4-20mA current. Many transmitters have a non-polarized input; however, input I/O boards are always polarized. Another important aspect when connecting I/O boards is checking whether the 4-20mA input can be used as a differential input or it is referred to as its ground (GND). This fact determines how an electric connection must be assembled, as well as where the load impedance is connected, because the connection between the transmitter and the load impedance can affect the electric voltage and increase the referential, which, consequently, could saturate the I/O board signal.

Another point worth mentioning is that, in most cases, HART® transmitters have housing test points to measure exactly the current supplied by the transmitter. Significant differences between the values measured on the housing and the I/O board, indicate there are leak points in the installation.