

Engineering Guideline  
**Ethernet-APL**



**Planning, installation and commissioning of  
Ethernet-APL networks**

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## Version history

Version	Originator	Date	Change Note / History / Reason
1.00	Niemann	07.06.2021	Release Version
1.01	Niemann	29.07.2021	Minor corrections
1.06	Niemann	22.09.2021	Changes to align the English and the German version
1.09	Niemann	06.12.2021	Finalization after WG Review
1.11	Niemann	06.12.2021	Final adaptation between German and English version
1.12	Niemann	31.07.2022	Editorial review comments processed. Fig. 6-3 changed, Fig 6-4 new
1.13	Niemann	02.08.2022	Unpowered Trunk removed from documentation
1.14	Niemann	19.09.2022	Cleaned Version for release

## 1 Management Summary - Scope of this Document

This chapter serves as an entry point to the reader in order to get an understanding about the concept of the document and the intended audience.

### 1.1 Management Summary

This document shall support users in using the Ethernet advanced physical layer (Ethernet-APL) network technology. Ethernet-APL uses a two wire Ethernet technology which provides both communication and power to devices. Defined strictly as a physical layer, Ethernet-APL supports any Ethernet-based protocol including those with real-time capabilities. Therefore, FieldComm Group, ODVA Inc, OPC Foundation and PROFIBUS and PROFINET International (PI) cooperate in the development of the APL technology as well as in the design of this document.

The first sections address individuals that shall perform planning tasks for Ethernet-APL. Subsequent chapters deal with the installation, bonding and shielding and the first step of network commissioning, the acceptance testing of the installation.

As the document has been produced by members from multiple organizations, it does not refer to any specific Ethernet protocol. If specific protocols get mentioned, it is for the sake of understanding. The reader should not derive any preference from the naming or the order of that naming.

As this document addresses different target groups, it may be read in sections according to the needs and to the interest of the reader. The next chapter will provide guidance, what chapters are relevant for which audience.

### 1.2 Scope of this Document and target audience

This document covers the planning process, the installation process and the acceptance testing of Ethernet networks with the Ethernet **A**dvanced **P**hysical **L**ayer (Ethernet-APL). Persons involved in one of the three activities will find information in the respective chapters of this document. Table 1-1 gives an overview about the main objectives and the target audience of the document.

Table 1-1: Main objective of this document and related target audience

Main objective	Description of target audience	Relevant chapters of this document
Planning 	Target audience is a person that is involved in the planning process for an Ethernet-APL network. This person has knowledge about automation technology and has experience in planning of automation systems and - where applicable - has knowledge of planning tasks in areas with explosive atmosphere. The sections listed in the right column provide the information about the planning process of an Ethernet-APL system.	2 Introduction 3 Introduction to the APL technology 4 Planning process of APL networks 5 Functional bonding and shielding 8 Migration of existing installations
Installation 	Target audience is a person that executes and/or supervises installation tasks on site. The person is experienced in installation tasks and usually executes and/or instructs/supervises installation personnel. This person is experienced with the installation of sensors and actuators in the process industry and is knowledgeable about installation aspects with respect to grounding, shielding, explosion-protection, lightning protection and installation. The sections listed in the right column provide the additional information about the installation process of an APL system.	2 Introduction 5 Functional bonding and shielding 6 Installation of APL networks
Acceptance test as first step of commissioning 	Target audience is a person that does the visual inspection of the installation, on site acceptance test, loop test and initial startup of the system.	2 Introduction 6 Installation of APL networks

The Ethernet-APL Port Profile Specification [APS2021] provides additional, technical information. Individuals interested in further technical details are invited to read this document. Individuals interested in the APL concept for intrinsic safety (2-WISE) may read [IEC 60079-47] as well.

## 1.3 Wording

This document uses the following wording in order to indicate if an action is compulsory or not:

### Shall

The words “must”, “shall”, or “is required” denote an absolute mandatory requirement.

### Should

The words “should” or “recommended” indicate a requirement that, given good cause/reason, can be ignored. However, the consequences of ignoring the requirement must be fully understood and well justified before doing so.

### May

The words “may” or “optional” identify a requirement that is completely optional and can be supported at the discretion of the implementation.

In order to ease reading, the word “APL” will be used instead of “Ethernet-APL” in the rest of this document.

## 1.4 Safety hints

The document contains safety relevant information. This information is marked with the symbol shown in Figure 1-1.



Figure 1-1: Symbol indicating safety relevant information

The safety relevant information must be followed in order to ensure the safety of the plant and the personnel working in the plant.

When performing planning and installation tasks the following safety hints must be observed:



Electrical equipment may need to be certified when used in areas with explosive atmosphere. For details refer to your Ex specialist or supplier.



The definition of Ex zones and the planning of electrical equipment in areas with explosive atmosphere must be conducted by qualified personnel only. The local regulations apply.



This document explains only special planning aspects for APL. It does not show the full scope of planning for Ex installations.



The APL devices used, must be certified for the use in the intended hazardous area location. Ex certificates / manufacturer declarations must be available and checked during the planning process. The hazardous area risk analysis must be executed and documented during the planning process according to the national legislation.



During the planning process for the bonding system, observe the rules and regulations that apply in the country, where you perform the installation.



Grounding the cable shield on both ends in an area with explosive atmosphere is only permissible if "it is highly ensured that potential equalization exists between each end of the circuit". The use of Ex e / non incensive type installation material in combination with a meshed bonding network is a good basis for this.



During the installation process, observe the rules and regulations that apply in the country, where you perform the installation.



Especially for installations in explosive atmospheres, the requirements from [IEC 60079-14] or the respective local rules and regulations shall be followed.



During installation observe the applicable national safety and installation regulations for data and power cables. The specifications provided in this guideline are based on applicable IEC standards.

## 2 Introduction

This document describes the engineering process of Ethernet-APL systems. Ethernet-APL is based on IEEE and IEC standards and provides a two wire Ethernet connection to the field. Ethernet-APL is mainly intended to connect field devices (sensors and actuators) to a control network. The two-wire connection conveys 10 Mbit/s Ethernet communication as well as power for the devices. Ethernet-APL is designed to work in areas with explosive atmosphere. This document provides a guideline for the planning, installation and commissioning process of Ethernet-APL.

### 2.1 Preface

This document starts with a brief introduction to the Ethernet-APL technology (chapter 3) After that this document guides the reader in an action-oriented manner through the planning process It describes typical use cases in the planning process (see chapter 4) and typical tasks during the installation process (chapter 6). The document continues with the acceptance test of the Ethernet-APL network (chapter 7) and with a look at electromagnetic compatibility in the chapter functional bonding and shielding (chapter 5). Users of existing fieldbus technology will find migration information in chapter 8.

In case the reader is interested in only one special aspect, e. g. installation, feel free to jump directly to the respective chapter. The document is intended to allow a direct step to the respective chapter without the need of studying previous chapters.

The information in this document is presented in a way which tries to be as brief and easy to understand as possible. It is nevertheless assumed that users have basic knowledge of Ethernet and Industrial Ethernet technology, electrical engineering, network technology, planning and installation basics in areas with explosive atmosphere and planning basics with respect to EMC, grounding and shielding. This guideline is not intended as an Ethernet-APL compendium. If you need more detailed information about the applications of Ethernet-APL in conjunction with the respective protocol layers above, use the appropriate documents published by the respective standards development organizations (SDOs) or comparable technical literature.

## 2.2 Liability exclusion

The standards development organizations (SDOs) cooperating within the Ethernet-APL project (FieldComm Group, ODVA Inc, OPC Foundation and PROFIBUS and PROFINET International) have taken utmost care in the preparation of this document and compiled all information to the best of their knowledge. This document is nevertheless based on present knowledge, is of an informative character, and is provided on the basis of a liability exclusion. Therefore, this document may be subject to change, enhancement or correction in the future without any reference. The cooperating standards development organizations (SDOs) expressly refuse all types of contractual or legal liability for this document, including the warranty for defects and the assurance of certain usage properties. Under no circumstances shall the cooperating standards development organizations (SDOs) accept liability for any loss or damage caused by or resulting from any defect, error or omission in this document.

## 2.3 Referenced documents and standards

The following documents and standards are referenced by this document. The list is in alphabetical and numerical order.

### 2.3.1 Referenced Standards

**[ASTM D4566-05]**

Standard Test Methods for Electrical Performance Properties of Insulations and Jackets for Telecommunications Wire and Cable

**[EN 50174-2]: 2018**

Information technology - Cabling installation - Part 2: Installation planning and practices inside buildings

**[EN 50174-3]: 2013 + A1:2017**

Installation technology – Cabling installation - Part 3: Installation planning and practices outside buildings

**[EN 50310]: 2016**

Application of equipotential bonding in buildings with information technology equipment

**[IEC 60079-10-1]: 2015**

Explosive atmospheres Part 10-1: Classification of areas - Explosive gas atmospheres

**[IEC 60079-11]: 2011**

Explosive atmospheres - Part 11: Equipment protection by intrinsic safety 'i'

**[IEC 60079-14]: 2013**

Explosive atmospheres - Part 14: Electrical installations design, selection and erection

**[IEC 60079-17]: 2013**

Explosive atmospheres - Part 17: Electrical installations inspection and maintenance

**[IEC 60079-25]: 2020, Ed. 3.0**

Explosive atmospheres - Part 25: Intrinsically safe electrical systems

**[IEC 60079-28]:2015**

Explosive atmospheres - Part 28: Protection of equipment and transmission systems using optical radiation

**[IEC TS 60079-47]: 2021**

Explosive atmospheres - Part 47: Equipment protection by 2-wire intrinsically safe Ethernet concept (2-WISE)

**[IEC 60364-4-44]: 2007 + AMD1:2015 + AMD2: 2018 CSV**

Low-voltage electrical installations - Part 4-44: Protection for safety - Protection against voltage disturbances and electromagnetic disturbances

**[IEC 60603-7-3]: 2010**

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

**[IEC 61076-2-101]: Ed. 3.0 b: 2012**

Connectors for Electronic Equipment - Product Requirements - Part 2-101: Circular connectors - Detail specification for M12 connectors with screw-locking

**[IEC 61076-2-104]: 2014**

Connectors for electronic equipment - Product requirements - Part 2-104: Circular connectors - Detail specification for circular connectors with M8 screw-locking or snap-locking

**[IEC 61156-13]: xxxxx (Not yet released)**

Multicore and symmetrical pair/quad cables for digital communications –Part 13: Symmetrical single pair cables with transmission characteristics up to 20 MHz – Horizontal floor wiring - Sectional specification.

**[IEC 61158-2]: 2014**

Industrial communication networks – Fieldbus specification – Part 2: Physical layer specification and service definition

**[IEC 61643-21]: 2000+AMD1:2008+AMD2:2012 CSV Consolidated version.**

Surge protective devices connected to telecommunications and signaling networks - Performance requirements and testing methods

**[IEC 61918]: 2018**

Industrial communication networks – Installation of communication networks in industrial premises.

**[IEC 61784-5-3]: 2018**

Industrial communication networks - Profiles - Part 5-3: Installation of fieldbuses – Installation profiles for CPF 3.



**[IEEE P802.3cg]: 2019**

IEEE Standard for Ethernet Amendment 5: Physical Layer Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors

**[ISO/IEC 7498-1]: 1994**

Information technology — Open Systems Interconnection — Basic Reference Model: The Basic Model

**[ISO/IEC\_11801-3]: 2017+AMD1:2021 CSV (Consolidated Version)**

Information technology – Generic cabling for customer premises – Part 3: Industrial premises

**[NE 74]: 2016**

NAMUR – User Association of Automation Technology in Process Industries: NAMUR Recommendation NE 74: Fieldbus requirements

**[NE 168]: 2018**

NAMUR – User Association of Automation Technology in Process Industries: NAMUR NE 168 Requirements for a field level Ethernet communication system

**[NEC 500]**

ANSI/NFPA 70, National electrical code, Article 500. Hazardous location coding system

**[NEC 505]**

ANSI/NFPA 70, National electrical code, Article 505. Zone locations

**[NEC 506]**

ANSI/NFPA 70, National electrical code, Article 506. Zone 20, 21, and 22 Locations

**[VDI 2183]: 2018**

VDI: Reliable operation of Ethernet-based bus systems in industrial automation

## 2.3.2 Documents referenced

**[APS2021]**

APL Port Profile Specification. Version 1.0. <https://www.ether-net-apl.org>

**[IEV 2020]**

IEV Wordbook of the German electrotechnical commission DKE. See <https://www2.dke.de/de/Online-Service/DKE-IEV/Seiten/IEV-Woerterbuch.aspx>

## 2.4 Symbols and their meaning

Table 2-1 shows the symbols used to structure the text of this document. Take special caution in case the symbol “Danger” is used. It is used to mark a danger to life and health. The observance of an instruction marked in this way is important.

Table 2-2 explains the symbols for cable types, connectors and power. Table 2-3 explains the symbols of the components used, while Table 2-4 explains the symbols for the plant areas.

Table 2-1: Symbols to structure the text








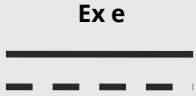
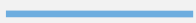
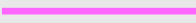
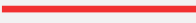






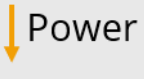
Symbol	Name	Meaning
	Tip	Used to mark a recommendation.
	Important	Used for information which, if not observed, may result in malfunctions during operation.
	Instruction	Used for direct instructions.
	Danger!	Safety relevant information. Used to mark a danger to life and health. The observance of an instruction marked in this way is extremely important!



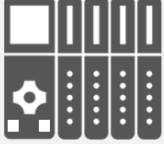
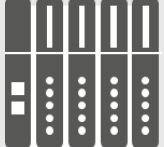
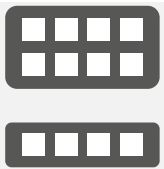
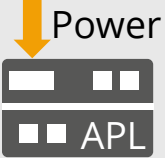

Table 2-2: Symbols for cable types and connector and power

Symbol	Name	Meaning
	Industrial Ethernet copper cable	Industrial Ethernet cable with copper wires. The dotted line indicates an inactive ring redundancy connection for increased availability requirements. Color used in this guideline: green.
	Industrial Ethernet FO cable	Industrial Ethernet fiber optic (FO) cable. The dotted line indicates an inactive ring redundancy connection for increased availability requirements. Color used in this guideline: orange Note: FO cable is not used for APL but for Industrial Ethernet only. Color used in this guideline: amber

Symbol	Name	Meaning
	Ethernet-APL	Ethernet-APL connection without Ex qualification. Color used in this Guideline: black.
	Ethernet-APL with increased safety (Ex e)	Ethernet-APL connection that can run in areas with explosive atmosphere. Increased safety (Ex e / non incendive). The dotted line indicates an inactive ring redundancy connection for increased availability requirements. Color used in this guideline: black plus designator Ex e or non incendive (NI). Color used in this Guideline: black.
	Ethernet-APL with intrinsic safety (Ex i)	Ethernet-APL connection that can run in areas with explosive atmosphere. Intrinsic safety. Color used in this Guideline: blue plus designator Ex i or I. S. Color used in this Guideline: light blue.
	Fieldbus	Fieldbus for example PROFIBUS DP or DeviceNet. Color used in this Guideline: violet.
	Current loop connection 4 ... 20 mA	Interface to connect field devices (sensors or actuators) to a remote IO. Color used in this guideline: red.
	Common bonding network	The common bonding network is used for protective purposes as well as for functional purposes. Color used in this Guideline: green/yellow.
	Minus conductor for 24 V DC and N conductor for 230 V AC	Used in schematic diagrams. Color used in this Guideline: dark blue.
	Ethernet port for copper media	Industrial Ethernet or Ethernet-APL connector for copper media.
	Ethernet port for fiber optic (FO) media	Industrial Ethernet connector for fiber optic (FO) port. Note: There are no fiber optic ports for Ethernet-APL. FO ports are used only for Industrial Ethernet.
	Conductive connection	Electrically conductive link / connection between two conductors.
	Auxiliary power input with forward	Device is powered by auxiliary power, e. g. 24 V DC, 230 V AC or other voltage supply. Thick arrow indicates that the device forwards power to devices on the subordinate network.
	Auxiliary power input without forward	Device is powered by auxiliary power, e. g. by 24 V DC, 230 V AC or other voltage supply. Thin arrow indicates that the device does not forward

Symbol	Name	Meaning
		power nor receive power via the network connection.

Table 2-3: Symbols for components

Symbol	Name	Specification
	Operator Console	Command and control station or human machine interface or operator station.
	Engineering Workplace	Workplace to configure the controllers, the remote IOs, or possibly also the operator console.
	Controller	A device that initiates the IO data traffic and executes the control logic.
	Remote IO	A field device that is allocated to a controller to perform IO functions. Interface modules usually provide standard interface signals like 24 V DC for binary in- and outputs or 4 ... 20 mA for analog in- and outputs.
	Switch	Standard Industrial Ethernet switch for use in non-explosive atmosphere or Zone 2 (Class I, Div. 2).
	APL power switch	Ethernet switch. Converts Industrial Ethernet to Ethernet-APL. Needs auxiliary power to power the subordinate APL network. Indicated by thick amber arrow.
	APL field switch without auxiliary power supply	This Ethernet-APL field switch connects to the APL Trunk to Ethernet-APL field devices (Spurs) and provides power for the APL field devices connected to the switch. Receives energy via a powered trunk. For possible variants see Figure 4-4.

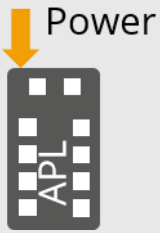
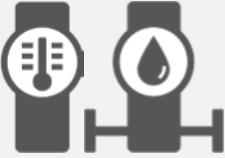
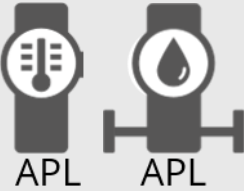




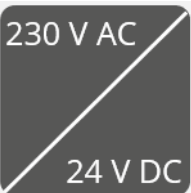



Symbol	Name	Specification
	APL field switch with auxiliary power supply	This Ethernet-APL field switch, with auxiliary power supply, connects the Industrial Ethernet to the Ethernet-APL field devices (Spurs) and provides power for the APL field. The switch is connected to auxiliary power and does not receive power via the industrial Ethernet. For possible variants see Figure 4-4.
	Standard field device	Field device, e.g., temperature transmitter, pressure transmitter, flow transmitter, positioner), that is connected to the control system via a 4 ... 20 mA current loop interface. HART-Protocol is frequently used for configuration and diagnostic purposes. Transmitters with external power supply (four wire transmitters) are possible, but will not be handled separately.
	APL field device	APL field device, (e.g., temperature transmitter, pressure transmitter, flow transmitter, positioner), with Ethernet-APL interface. Device is powered and communicates via Ethernet-APL. Transmitters with external power supply (four wire transmitters) are possible, but will not be handled separately.
	APL auxiliary device	A device which is connected within an APL segment but does not communicate. It may comprise a power load or introduce communication signal insertion losses. A surge protector is for example an auxiliary device.
	APL inline connection	An APL inline connection is a passive component that is used to connect APL cables.
	Isolating device coupler	Used for PROFIBUS PA and Foundation fieldbus H1. Limits the voltage and the current on the spurs.
	PROFIBUS DP to PA converter	Connects a PROFIBUS DP segment to a PROFIBUS PA segment. Typically, a converter has one PROFIBUS DP connection and multiple PROFIBUS PA connections. The multiple connections are not shown in the symbol.
	Auxiliary power supply	Used to power devices with auxiliary power. The shown example converts 230 V AC to 24 V DC. Other primary and secondary voltages are possible.

Table 2-4: Symbols for areas

Symbol	Name	Meaning
	EMI – Electromagnetic interference	Area where the occurrence of electromagnetic interference (EMI) must be expected.
	Explosive atmosphere	Area where the hazard of an explosion must be expected.
	Non-explosive atmosphere	Area where the hazard of an explosion is not present.

### 3 Introduction to the APL technology

This section introduces the APL technology and describes typical use cases.

#### 3.1 Basics of Ethernet communication

The Ethernet communication protocol uses, as do many other protocols, a layered approach shown in Figure 3-1, known as the ISO/OSI protocol stack.

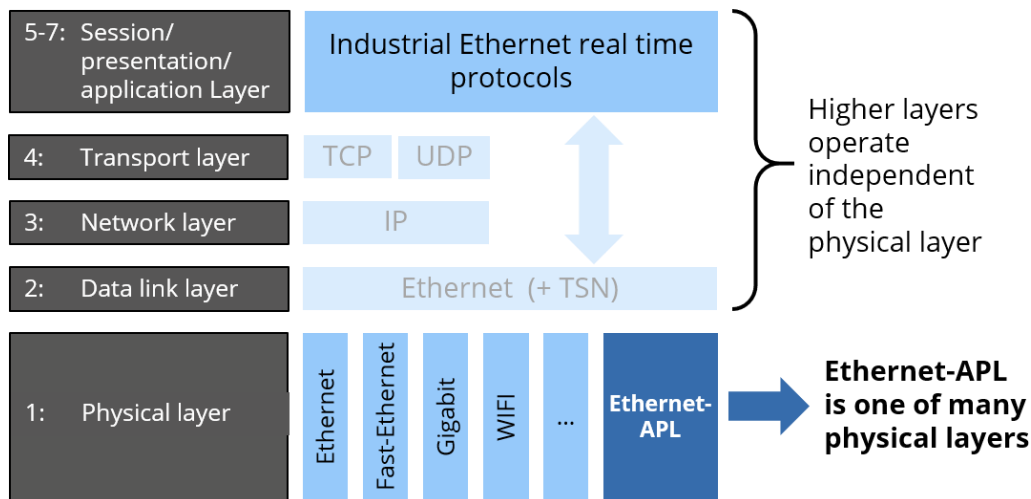


Figure 3-1: ISO/OSI Protocol stack of Ethernet

The layered approach allows changing parts of the protocol stack, while other parts remain. In Figure 3-1 the physical layer is the lowest layer. Here the transmission media, the data rates, and the connectors are specified. Figure 3-1 shows that different physical layers (e.g., Fast Ethernet, Gigabit-Ethernet, etc.) can be used. In the context of this document, the physical layer is of interest. It can be seen that Ethernet-APL is one of many physical layers meeting special needs in the automation domain. It can be used in parallel to other existing physical layers and it does not impact the layers above. The next section explains, how Ethernet-APL differs from other physical layers and explains the technological features.

## 3.2 What is Ethernet-APL?

The increasing use of Industrial Ethernet yields benefits with respect to network diagnosis, training of staff, and the use of single converged technology in case Ethernet technology is used throughout the plant. This would imply connecting the field devices to the converged Ethernet-network as well. The User Association of Automation Technology in Process Industries (NAMUR) defined in the recommendations [NE 168] and [NE 74] requirements for "Ethernet in the field". The [NE 74] states, for example, the following requirements (excerpt):

- Communication considering the requirements of the process industry (harsh environment, specific topology specifications)
- Operation in areas with explosive atmosphere shall be possible
- Handling by maintenance personnel shall be possible
- Robust and simple connection technology
- Cycle time for the transmission is between 10 ms and 2 000 ms, depending on the task
- All field devices shall support the same defined and standardized physical layer.
- The protocols shall be supported by all bus components (e.g., field devices, process control systems, infrastructure components, ...).
- All protocols used shall be interoperable with each other, i.e., simultaneous operation shall be possible.

With the Ethernet-APL physical layer, the cooperating standards development organizations (SDOs) define a communication solution to meet the demand of the process industry for a converging network architecture in the automation domain having the following features:

- Ethernet based communication
- Two-wire connection to the sensor
- Power supply of the devices via two-wire connection
- Re-use of existing cable installations shall be possible (depends on cable type)
- Operation of field devices and switches in the areas with explosive atmosphere is possible
- Replacement of failing devices during operation in areas with explosive atmosphere is possible.



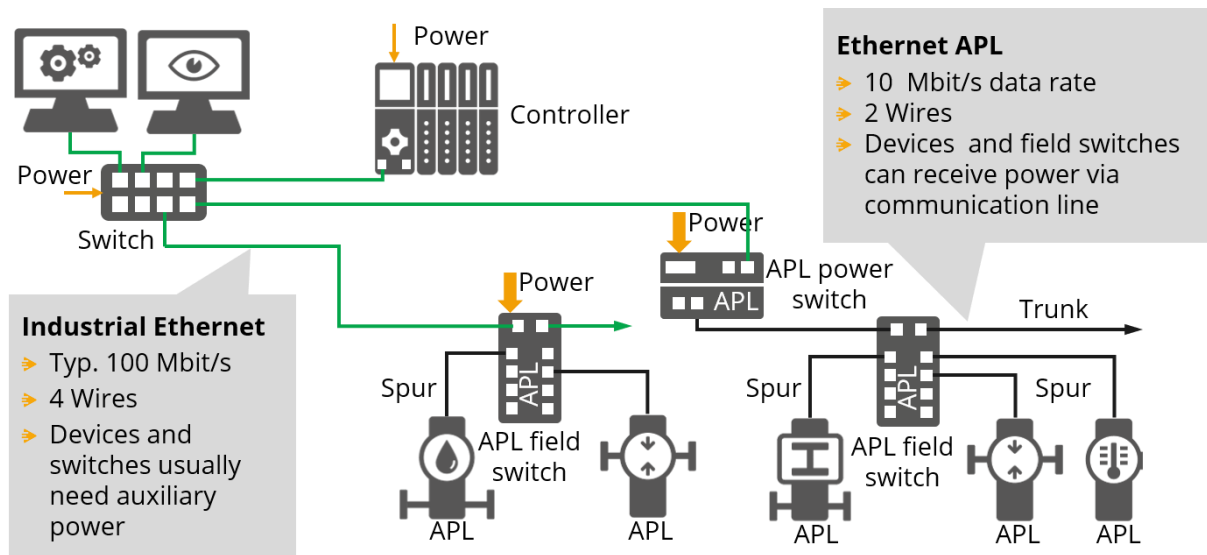


Figure 3-2: Differences between Industrial Ethernet and APL

Figure 3-2 shows the differences between an Industrial Ethernet (typ. 100 Mbit/s) and Ethernet-APL. In the top left corner, a controller is shown in combination with an engineering- and operator station. The two devices are depicted to be connected via 100 Mbit/s Industrial Ethernet. Both devices require auxiliary power. The Ethernet cable uses 4 wires; the communication usually runs in full-duplex mode at a length of 100 m maximum, when using copper media. The center of Figure 3-2 shows an APL power switch. The APL power switch connects, on the one side, to the fast Ethernet and receives auxiliary power. The APL power switch converts the 100 Mbit/s fast Ethernet to the 10 Mbit/s Ethernet-APL. The Ethernet-APL uses two wires (single pair) and provides full-duplex communication. The APL trunk connects the APL power switch with the APL field switches. The length of an APL trunk segment can be up to 1 000 m. The APL power switch provides, in parallel, electrical energy for the devices connected to the APL network –In this case, the APL field switch and the APL field devices. The APL field devices are connected via APL spurs to the APL field switches. In addition, Figure 3-2 also shows a field switch that is directly connected to the Industrial Ethernet control network. For the ease of understanding, the Industrial Ethernet network (green color) will be referenced as control network in this document.

## 4 Planning process of APL networks



This section will guide through the planning process for an Ethernet-APL System. Target audience for this chapter are individuals that are involved in the planning process for an APL network.

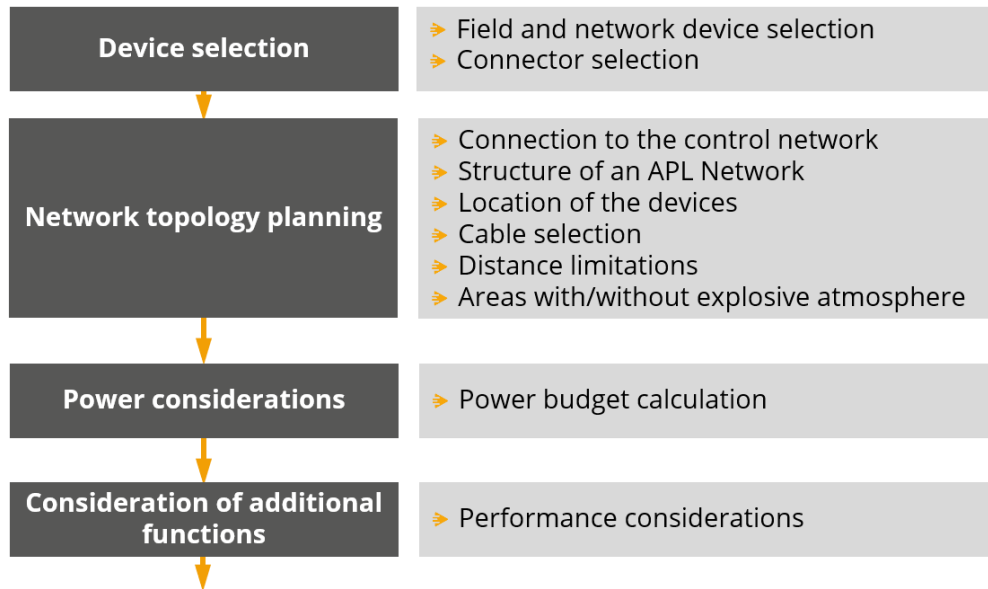


Figure 4-1: The APL Planning process

Figure 4-1 gives an overview on the APL planning process described in this section and the major planning steps.

### 4.1 Device selection

This document will make use of an APL sample application shown in Figure 4-2.

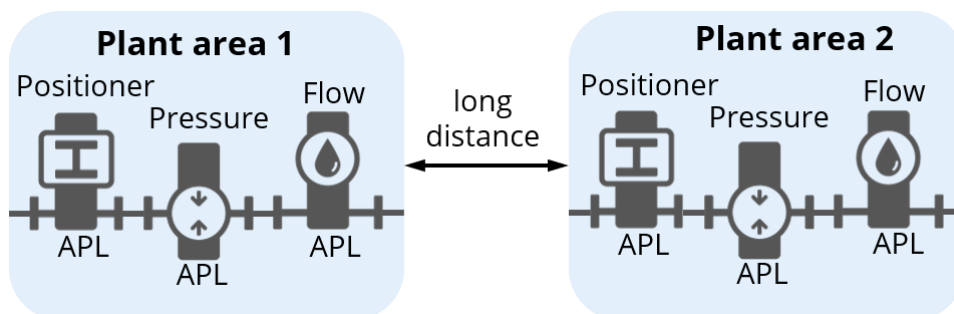


Figure 4-2: Sample application sensors / actuators

It is assumed that the application consists of two plant areas that are in different locations with a larger distance between them. In each of the plant areas, a gas flow in a pipe shall be controlled by using a control valve with positioner and a flow meter. In addition, the pressure in the pipe shall be measured. The devices in both plant areas shall be connected to a single controller that performs the control and measurement tasks. The next chapters will guide the process of building an APL based system in order to connect the sensors and actuators shown in Figure 4-2.

#### 4.1.1 Types of APL field devices

Looking back to the initial task in this planning example in Figure 4-2, it can be seen, that APL field devices need to be selected. In this case three different field devices are needed: Two temperature sensors, two flow sensors and two positioners. This chapter shall give guidance - what features need to be considered- when selecting an APL Field device.

<b>Application</b>	<ul style="list-style-type: none"> <li>➤ Flow</li> <li>➤ Temperature</li> <li>➤ Etc.</li> </ul>
<b>Port Compatibility</b>	<ul style="list-style-type: none"> <li>➤ Trunk,</li> <li>➤ Spur</li> <li>➤ Powered / unpowered ports</li> </ul>
<b>Connector</b>	<ul style="list-style-type: none"> <li>➤ Terminal</li> <li>➤ M12</li> <li>➤ M8 (not for intrinsically safe signals)</li> </ul>
<b>Ex Rating</b>	<ul style="list-style-type: none"> <li>➤ No Ex rating</li> <li>➤ Zone 2 /Class I, Div. 2</li> <li>➤ Zone 1 / Class I, Div. 1, etc.</li> <li>➤ Zone 0</li> </ul>
<b>Communication Protocol</b>	<ul style="list-style-type: none"> <li>➤ PROFINET</li> <li>➤ EtherNet/IP</li> <li>➤ HART-IP</li> <li>➤ OPC UA</li> <li>➤ etc.</li> </ul>

Figure 4-3: APL Device selection criteria

Figure 4-3 summarizes the criteria that need to be observed when selecting an APL device. For the sake of completeness, it shall be mentioned that the device needs to support the Advanced Physical Layer (APL) according to the APL port profile specification, which is required to be certified by a certification lab. [APS2021]. This specification describes the characteristics of the different APL ports, especially with respect to their power characteristics. As a next step, the device needs to be selected according to the desired application, like flow, temperature, or pressure. As already mentioned, APL devices usually receive their power via the network cable. Nevertheless, there are devices that require auxiliary power via a separate power line. In this case, the APL Port type will be “powered” but additional power will be provided to the device. For “powered” port types, APL differentiates between port classes that specify the power consumption of a device. For the phase of the device selection, it shall be sufficient that the manufacturer of the device specifies the port type and the port class.

APL devices use different types of connection such as screw or clamp terminals, M12 or M8. Usually, the connection technology is defined by the device. Further information about connection technologies will follow in section 4.1.5.

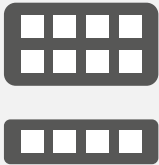
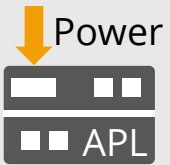

Depending on usage in areas with explosive atmosphere, the device needs to comply with the requirements for Zone 1 (Class I, Div. 1), Zone 2 (Class I, Div. 2). In cases where parts of the device are permanently in contact with a flammable medium, Ex Zone 0 also applies. In areas without explosive atmosphere, this aspect does not need to be considered. During the device selection phase, it must be verified that the device selected supports use in the intended zone or Class / Division. A respective certificate must be available.

The last point, for device selection, is the supported communication protocol. As APL describes the physical layer of the device only, the Industrial Ethernet communication layer above (e.g., EtherNet/IP, HART-IP, OPC UA, PROFINET) must be chosen according to the communication protocol used on the Control Network.

## 4.1.2 Types of switches

Table 4-1 lists the different types of switches that can be used in an APL system.

Table 4-1: Types of Switches

Symbol	Name	Description
	Switch	Standard Industrial Ethernet switch. The data rate is typically 100 Mbit/s or 1 Gbit/s for use in non-explosive atmosphere or in Zone 2 (Class I, Div. 2), if declared accordingly.
	APL power switch	An APL power switch converts Industrial Ethernet to APL and feeds power to the APL Ports. It needs auxiliary power in order to power the subordinate APL network. Auxiliary power supply is indicated by thick amber arrow.
	APL field switch without auxiliary power supply	This Ethernet-APL field switch connects the APL Trunk to Ethernet-APL field devices (Spurs) and provides power for the APL field devices connected to the switch. It receives energy via a powered trunk. For possible variants see Figure 4-4.

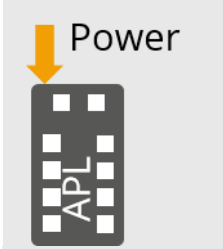
Symbol	Name	Description
	APL field switch with auxiliary power supply	This Ethernet-APL field switch, with auxiliary power supply, connects the Industrial Ethernet to the Ethernet-APL field devices (Spurs) and provides power for the APL field. The switch is connected to auxiliary does not receive power via the industrial Ethernet. For possible variants see Figure 4-4.

Figure 4-4 shows possible port combinations for an APL field switch

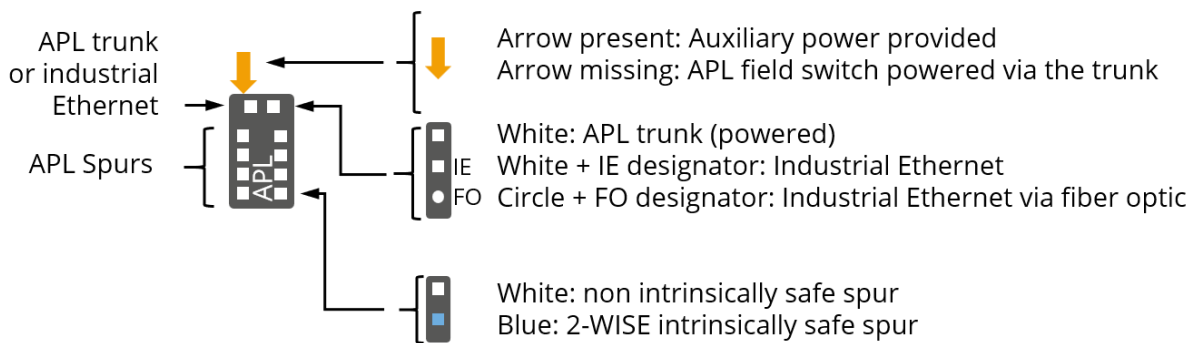




Figure 4-4: APL field switch types – possible variants

Please check Table 4-4 for information about the features of the different port types.

### 4.1.3 Further types of other APL Components

Besides the components described up to now, further components can be part of an APL network. Table 4-2 describes these components. The number of these devices in an APL segment is limited. Chapter 4.3.4 will later deal with these limitations .

Table 4-2: Type of other APL components

Symbol	Name	Description
	APL auxiliary device	A device, which is connected within an APL segment, but does not communicate. It may comprise a power load or introduce communication signal insertion losses. A surge protector is, for example, an auxiliary device.
	APL inline connection	An APL inline connection is a device that is used to connect APL cables.

#### 4.1.4 Cable types for APL networks

The supported APL cable is a balanced, shielded, twisted-pair cable with a characteristic impedance in the range of  $100 \Omega \pm 20 \%$  in a frequency range of 100 kHz to 20 MHz (measured according to [ASTM D4566-05] or equivalent international standard) as typically used for PROFIBUS PA and FOUNDATION Fieldbus H1. Wire diameters can be in the range of 26AWG (0.14 mm<sup>2</sup>) to 14AWG (2.5 mm<sup>2</sup>) either with solid or stranded wires.

The reference cable type for APL segments is fieldbus type A cable MAU types 1 and 3 (specified in [IEC 61158-2]). This cable meets the requirements for intrinsically safe applications as described in [IEC TS 60079-47] and may be used in non-IS applications as well.

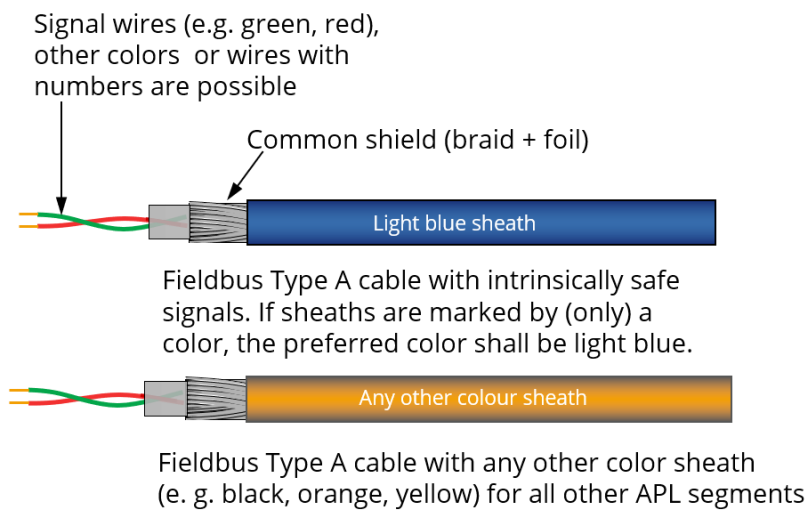


Figure 4-5: APL cable types

Figure 4-5 shows the structure of the described cable. The two signal wires are protected by a common shield and sheath. Intrinsically safe Ethernet-APL cable segments shall be marked to identify them. If intrinsically safe sheaths are marked by (only) a color, the preferred color shall be light blue. All other APL segments may have any other color sheath except of light blue. Check local installation guidelines, e. g. [IEC 60079-14] for detailed information with respect to installation in areas with explosive atmosphere.

### Installations based on an installed cabling structure (brownfield installations)

In cases where using an already installed cable infrastructure, it is mandatory that the performance of the data transmission is ensured. An examination shall be performed according [ISO/IEC 11801-3]. While for trunk cables, the insertion loss limit values of [ISO/IEC 11801-3] shall be used, for spur cables, a correction factor of 0.2 shall be applied to the insertion loss limit values of [ISO/IEC 11801-3] to reflect the maximum 200 m spur cable length in comparison to the maximum 1 000 m trunk cable length.

### Required cable parameters for re-qualification of existing cables for use in an APL system

Table 4-3: Maximum allowed cable lengths and cable parameters according APL cable category

Parameter	APL cable category			
	I	II	III	IV
Maximum trunk cable length in m	250	500	750	1 000
Maximum spur cable length in m	50	100	150	200
Coupling attenuation in dB	$\geq 60$ ( $f$ is frequency in MHz; $0.1 \leq f \leq 20$ )			
Cable return loss in dB	$\geq 15 + 8 \times f$ ( $f$ is frequency in MHz; $0.1 \leq f \leq 0.5$ )			
	$\geq 19$ ( $f$ is frequency in MHz; $0.5 \leq f \leq 20$ )			
Trunk cable insertion loss in dB	$\leq 10 \times (1.23 \times \sqrt{f} + 0,01 \times f + 0.2/\sqrt{f})$ ( $f$ is frequency in MHz; $0.1 \leq f \leq 20$ )			
Spur cable insertion loss in dB	$\leq 2 \times (1.23 \times \sqrt{f} + 0,01 \times f + 0.2/\sqrt{f})$ ( $f$ is frequency in MHz; $0.1 \leq f \leq 20$ )			
Cross talk in dB, (PSANEXT/PSAFEXT wire pair to wire pair) for multi core cables	$\geq 60$ ( $f$ is frequency in MHz; $0.1 \leq f \leq 20$ )			

NOTE 1 The values in Table 4-3 apply to both single pair and multi pair cables.

NOTE 2 Insertion loss and return loss shall be measured with a reference cable length of 500 m.

NOTE 3 The AC link segment requirements may also be verified using TIA SP1-1000 and ISO/IEC T1-A-1000 channel definitions, which might exclude IEC 61158 type A fieldbus cables from being compliant to these definitions.

NOTE 4 Depending on the APL cable category, the maximum cable length is limited. This allows the use of higher insertion loss cables, which, therefore, can only support a lower maximum APL segment length, while still fulfilling all requirements of this table.

NOTE 5 The cable return loss limit curve is 6 dB above the IEEE802.3cg limit curve, taking into account multiple additive signal reflections occurring at short cable lengths.

NOTE 6 For powered APL segments, the voltage drop over the cable has to be additionally taken into account in order to determine the maximum supported cable length.

Table 4-3 defines the APL cable categories I to IV and the associated maximum cable length for the trunk and the spurs and the cable parameters.

### **New installations using cables according to IEC 61156-13**

The standard [IEC 61156-13] is still under development. Currently, no statement can be made about the usability of cables according this standard. This document will be updated at a later point in time with respect to this issue.

In process industries, a wide range of cable types are used, which vary in performance and electrical characteristic. In principle, APL can be used with all of these cables, provided the specifications in Table 4-3 are met.



In case special requirements like moving cables, festoon cables, or special insulation material have to be observed, the cables shall be selected according to the needs but the electrical parameters must be observed.

#### **4.1.5 Connection technologies for APL networks**

The APL port profile specification [APS2021] defines the following connectors for APL devices

- Screw or spring clamp terminals / modular terminal blocks
- M12 connector, A-coded
- M8 connector, A-coded (not for intrinsically safe circuits)

A detailed description of the connectors and the pin assignment will follow in chapter 6.2. This section deals with the connector selection only. APL devices use different types of connectors. Therefore, the person that plans an APL network must plan connection hardware accordingly: cable gland, receptacle, or connector.



Usually, the APL device used defines the connector type. The person that plans the network must evaluate the connector types defined by the components and must plan the connection technology accordingly.



## 4.2 Possible topologies for an APL system

Returning back to the sample application shown in Figure 4-2, a total of six devices in two locations shall be connected to the control network via APL. Depending on the needs in the plant, different alternatives can be used to connect the field switches to the control network. Each alternative yields specific advantages that should be considered according to Table 4-4.

Table 4-4: Features of different APL network structures

Feature	Field switches with Industrial Ethernet	Powered APL trunk
Maximum spur length	≤ 200 m for cable category IV	≤ 200 m for cable category IV
Maximum trunk length / Industrial Ethernet length	Fiber optic: Depends on type of fiber. Typically, ≤ 2 000 m for multi-mode fibers. Copper cable: ≤ 100 m	≤ 1 000 m for cable category IV. Depends on power load of the field switches and the devices and the cable used.
Voltage drop on the trunk cable to be considered	No	Yes
Data rate on trunk / Industrial Ethernet	Typ. 100 Mbit/s	10 Mbit/s
Network load (communication load) on trunk / Industrial Ethernet to be observed	Yes, but at 100 Mbit/s data rate impact will be negligible	Yes
Auxiliary power needed in the field	Yes, to power the field switches	No, field switches are powered via trunk
Equipotential bonding	In case fiber optic is used to connect the field switches, equipotential bonding is uncritical	To be observed, especially when long trunk connections are used

The next sections will deal with the three alternatives in detail. The topology impact of Ex zones is considered in section 4.5. For all four alternatives, the considerations for the spurs are identical; therefore, this aspect is described first.

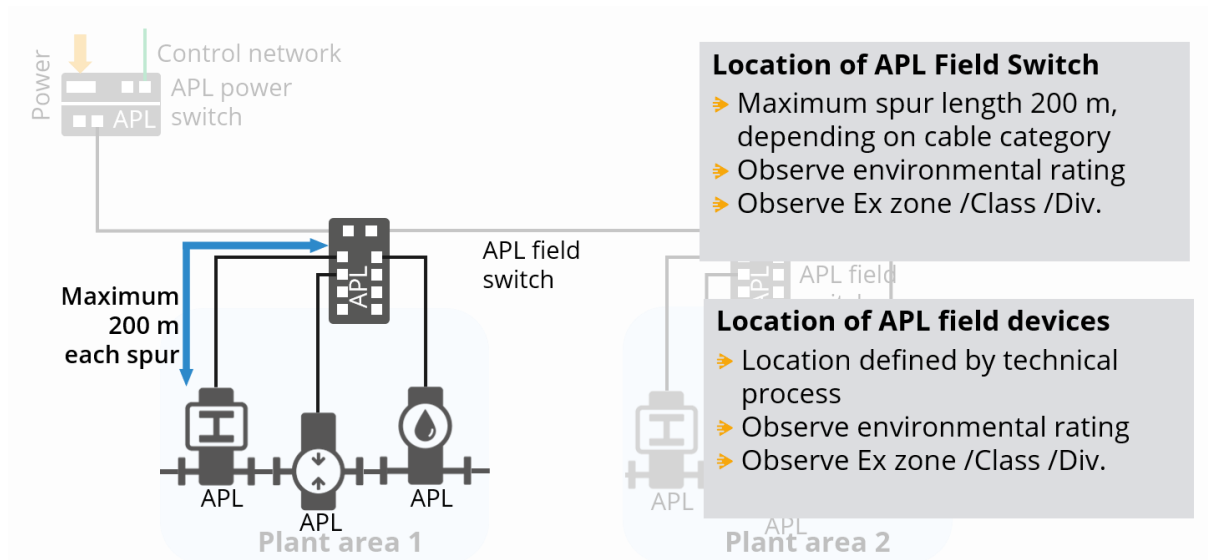


Figure 4-6: Location of Field Devices and Field Switches

Figure 4-6 shows the location of the field devices and the field switches. First, it has to be recognized that the location of the field devices is defined by the technical process. So, the person planning the APL network, has to consider the location of the field devices, defined in the piping and instrumentation (P&I) planning, as a precondition. In the following planning step, field switches have to be placed close to the field devices, observing the following conditions:

- Maximum distance between field device and field switch is 200 m, when using cable category IV according to cable category listed in Table 4-3.
- The Number of devices shall fit the number of ports on the switch (spur ports), including port reserve.
- A port reserve should be considered.
- The environmental rating of the field switch needs to be observed.
- The allocation of the field switch to the Ex zone /Class, Division, according to chapter 4.5, needs to be considered.

As a next step, the three previously described alternatives will be described in detail.

#### 4.2.1 Alternative 1: Field switches with Industrial Ethernet connection

This alternative uses standard Industrial Ethernet to connect the APL field switches to the control network. In this case, the control network is routed to the APL field switches via fiber optic. Copper cable is possible as well but length limitation has to be observed. A power switch is not necessary. The APL field switches need to be powered by an auxiliary power source.

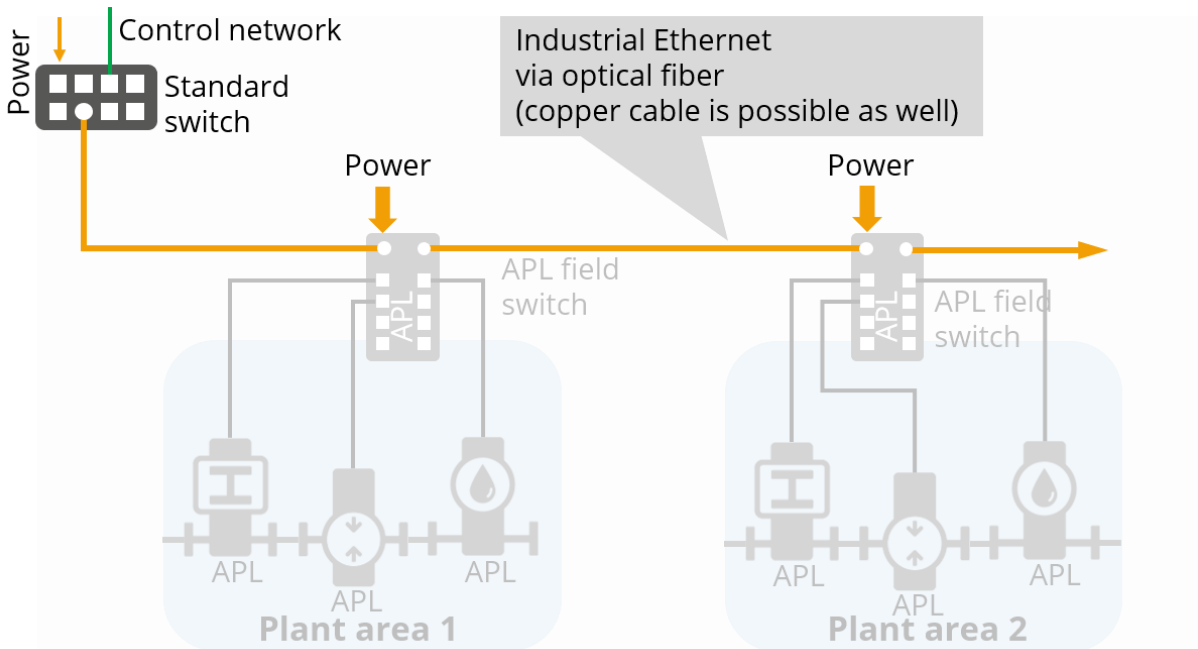


Figure 4-7: Field switches with Industrial Ethernet connection

Figure 4-7 shows the network structure using Industrial Ethernet cable. Copper cables allow distances up to 100 m. Multimode optical fibers typically allow distances between the APL field switches of up to 2 km.



Contact your supplier to find out which types of optical fibers are supported by the APL field switches.

## 4.2.2 Alternative 2: Powered APL trunk

This section deals with the powered APL trunk.

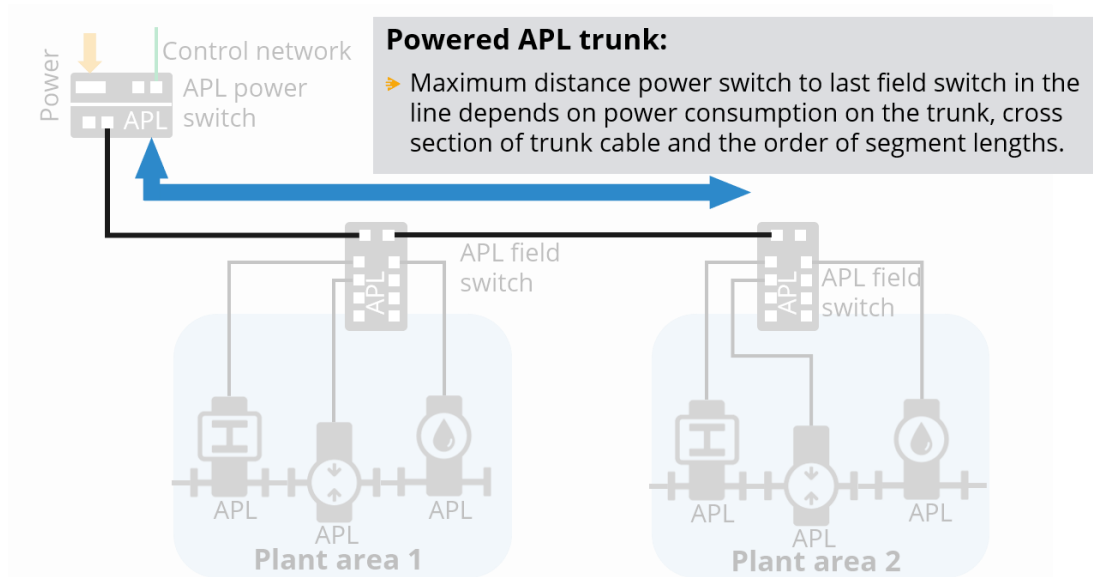


Figure 4-8: Maximum trunk length powered trunk

Figure 4-8 defines the last limitation for the placement of the APL field switches in cases where a powered trunk is used. The maximum distance for each segment in the line can be up to 1 000 m, depending on the following parameters:

- Output voltage of the APL power switch.
- Number of the APL field switches connected to the powered APL trunk.
- Number of the APL field devices connected to the field switches and their power consumption.
- Cross section (wire gauge) of the trunk cable.
- Temperature of the trunk cable, as resistance depends on ambient temperature.

Check Appendix 10.2 for calculation details. Chapter 4.10 provides some best practice examples for various scenarios. Place the APL field switches in a way that the calculated maximum distance is observed.



The location of the APL field devices is defined by the technical process and is used for the APL planning process. APL field switches are to be placed in a way that maximum spur length is 200 m, maximum distance between the power switch and the last field switch in the line has to be calculated. These cable lengths depend on the cable type specified in Table 4-3 and the prerequisites mentioned above.

After this introduction of typical network structures, the following section will guide through planning examples for explosive and non-explosive atmosphere.

## 4.3 APL topology planning basics

For the time being, we assume that all components are placed in an area without explosive atmosphere. Therefore, Ex considerations are not necessary at this point in time but they will be discussed later in chapter 4.5.

### 4.3.1 Structure of the superordinate network

As known from section 3, an APL system works in conjunction with the superordinate Industrial Ethernet network. As the structure of the superordinate network is not relevant for the APL planning process, the structure is not covered here. The only aspect to be observed is that the superordinate Industrial Ethernet network needs to be routed to the locations where the APL power switches or the APL field switches, with Industrial Ethernet connections, are located. See Figure 3-2.

### 4.3.2 Port compatibility APL networks

APL differentiates between trunks (T) and spurs (S). The features can be described as follows:

- Trunk (T): A trunk is the “main line” of the APL network. It connects the APL power switch to the APL field switches and APL field switches with each other. The length of
- Trunk segments must be  $\leq 1\ 000$  m each, but in addition the maximum allowed length of a powered trunk needs to be calculated according to Appendix 10.2.
- Spur (S): A spur cable connects a field device to a field switch. The length of a spur cable must be  $\leq 200$  m (cable category IV).

The combined use of trunks and spurs is shown in Figure 4-9. Note that the maximum length of a trunk and a spur is dependent on the cable category, as shown in Table 4-3.

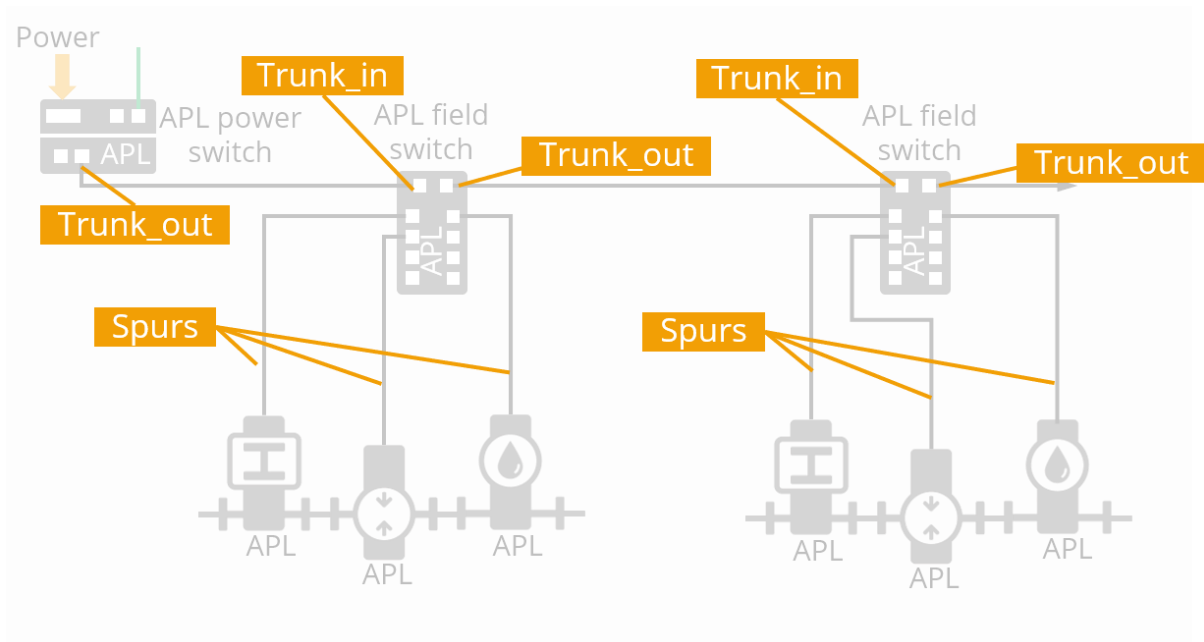


Figure 4-9: Structure of APL network with trunk and spurs

In Figure 4-9 the APL power switch connects to the trunk via a Trunk\_out port. The APL signal is then forwarded to Trunk\_in port of the first APL field switch in the line and then forwarded to further APL field switches. The APL field devices have spur ports that connect to the spur ports of the APL field switch. For the interconnection of ports, the following rules apply:

- A Trunk\_in port must only be connected to a Trunk\_out port.
- A spur port of an APL field device must only be connected to a spur port of an APL field switch.
- Only one APL field device may be connected to each spur.

In case topologies are used that directly feed the control network to the APL field switches (see section 4.2.1), only the rules for the spur ports apply.

### 4.3.3 Power classes

The power class describes the amount of power that a source port can drive or a load port sinks. Table 4-5 shows the APL power classes and permitted combinations.

Table 4-5: Power classes and permitted combinations

Power class of source port	Maximum voltage, minimum output power	Permitted segment class	Permitted power classes of load ports
A	15 V DC / 0.54 W	S (Spur)	A
C	15 V DC / 1.1 W	S (Spur)	A, C
3	50 V DC / 57.5 W	T (Trunk)	3
4 <sup>1</sup>	50 V DC / 92 W <sup>6</sup>	T (Trunk)	3, 4

The allowed combinations of ports on a trunk or a spur segment can be selected by checking the source power class and then by identifying the suitable permitted load power class.



Other combinations of classes than those given in Table 4-5 are prohibited. The permitted combinations of port classes do not imply that every combination is also permitted from an intrinsically safe viewpoint. This needs to be checked separately according to the 2-WISE-concept, which will be introduced in chapter 4.5. A load port may be specified for more than one load power class.

Power classes A, B, and C are primarily intended to be used for intrinsically safe rated spur ports for areas with explosive atmosphere but may also be used for non-intrinsically safe rated ports. A detailed description of the power classes, including the electrical ratings, can be found in [APS2021].

### 4.3.4 Inline connections and auxiliary devices

Up until now, this document mainly dealt with APL power switches, APL field switches, and APL field devices. Now two further device types will be covered: The APL auxiliary device and the APL inline connection. As already stated in chapter 4.1.3, an auxiliary device could be, for example, a surge protector. The APL inline connection is, for example, a junction box or a cable to cable connector, used to tie two cable segments together. This allows the connection and disconnection of devices, e.g., for maintenance purposes. As both components add reflections and insertion loss to the network segment, their number needs to be limited according to Table 4-6.

<sup>1</sup> Not yet specified in [APS2021]. Subject to future development



Inline connections and auxiliary devices are optional components.

Table 4-6: Maximum number of auxiliary devices and insertions per segment

Segment class		Supported cable length	Maximum number of auxiliary devices	Maximum number of inline connections (auxiliary devices + cable connectors)
S	Spur	≤ 200 m	2	4
T	Trunk	≤ 1 000 m per segment.	2	10

Table 4-6 lists the maximum allowed number of auxiliary devices per segment and the maximum number of inline connections per segment. An auxiliary device counts as one inline connection. If auxiliary devices are connected in parallel to an APL segment, then the wires between the segment cable and the auxiliary device are defined as a stub with a limited length of 10 cm.

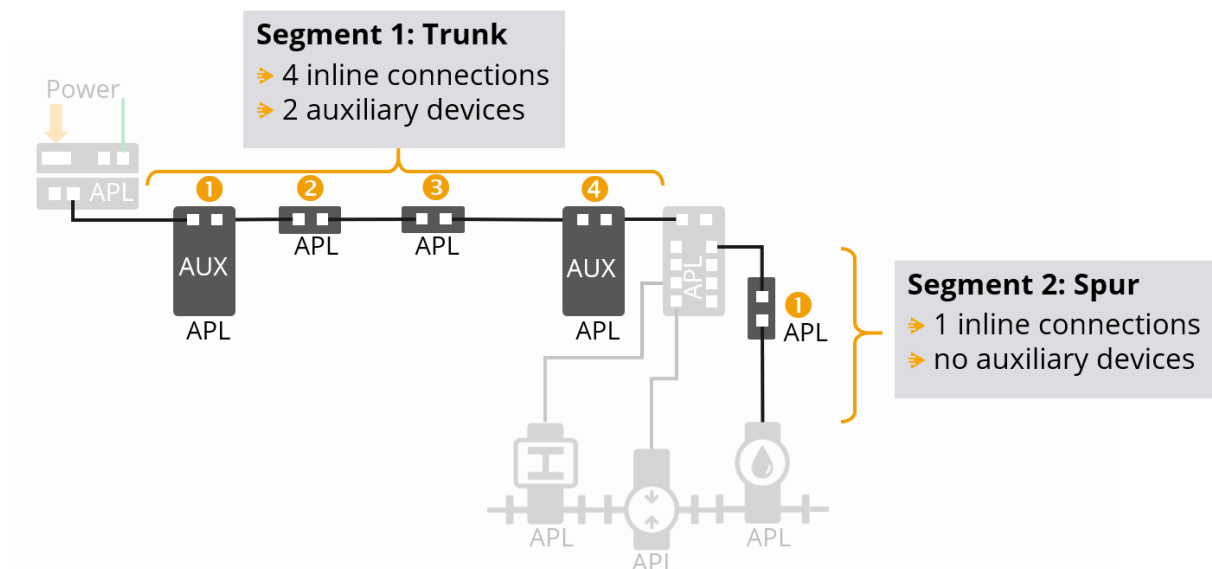


Figure 4-10: APL example system with auxiliary device and inline connections

Figure 4-10 shows an example of a network with auxiliary devices and cable connectors. It can be seen that the example fulfills the requirements defined in Table 4-6.



Check during the planning process whether all segments comply to the maximum number of auxiliary devices and the maximum number of insertions according to Table 4-6.



Check the documentation of the auxiliary device for further information.



## 4.4 Example APL application in areas without explosive atmosphere

This chapter will guide the reader through the planning process of an APL system in areas without explosive atmosphere. Readers interested in the planning networks for areas with explosive atmosphere, are invited to proceed directly to section 4.5.

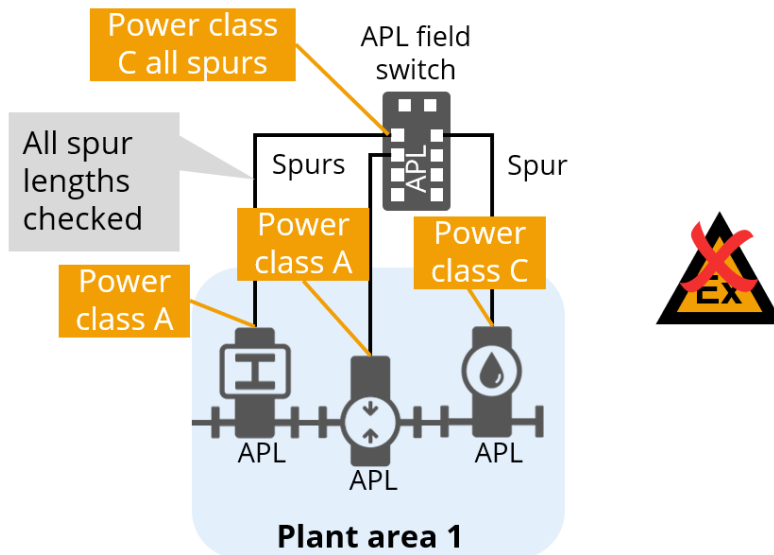


Figure 4-11: Sample application, non-Ex

Figure 4-11 shows a sample application. It is assumed that the field devices have been selected based on the needed functionality and that the selection is an input for the subsequent planning process of the APL network. Also, the physical location of the devices is an input to the planning process, as already stated in chapter 4.2. In the first run, the spurs are considered. During the planning process, the following steps should be executed:

**Step 1:** Check the maximum cable length for all spurs according to Table 4-3.

**Step 2:** Check that the APL field devices are only connected to the spur ports of the APL field switches.

**Step 3:** Check that Trunk\_in ports are only connected to Trunk\_out ports.

**Step 4:** Check that the field-switch fits the power demand of the connected APL field devices according to Table 4-5. The example in Figure 4-11 shows that source power class C (field switch spur port) can be combined with spur (load) port classes A, B, or C of the field devices.

In case a field switch directly connects to the control network (see chapter 4.2.1, only the maximum allowed cable distances have to be observed. The reader can proceed to section 4.6 .



Other network structures (field switches with direct connection to the control network) are possible. In these cases, only the power considerations for the spurs have to be made.

In case a powered APL trunk is used (see chapter 4.2.2), the following additional planning steps should be performed:

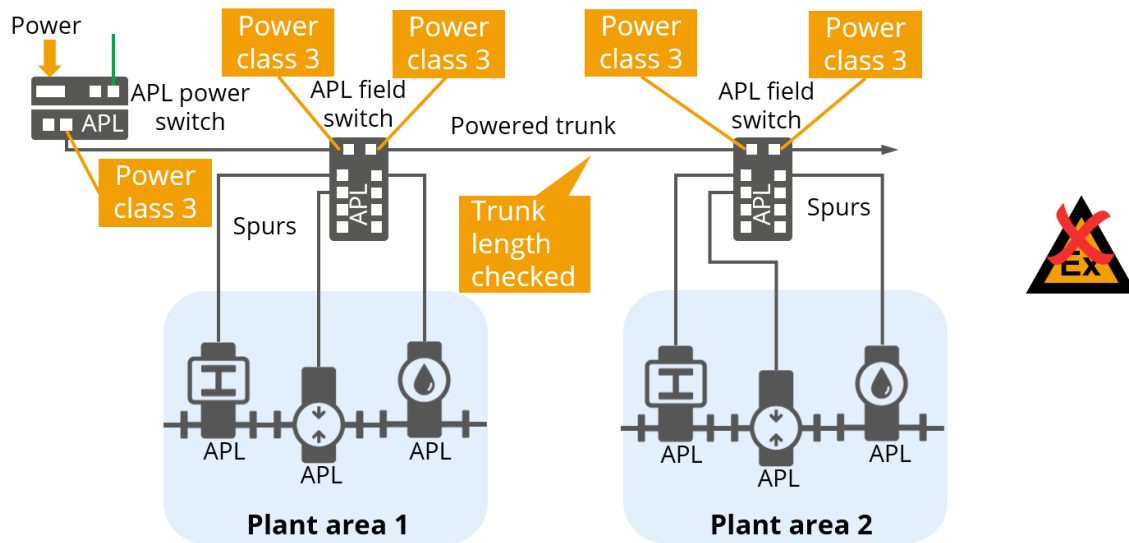


Figure 4-12: System structure with powered trunk

Figure 4-12 shows the status of the network planning.

**Step 4:** Check the cable length of the trunk according to Table 4-3



The max. allowed cable length depends on the category of the cable, the wire diameter, and the load conditions on the field switch spurs. Therefore, the voltage drop on the trunk needs to be checked according to the Appendix in section 10.2.

**Step 5:** Check that there is a match between the power classes for the Trunk\_out port of the power switch and the Trunk\_in ports of the field switches according to Table 4-5. In the example in Figure 4-12, the power switch and the two field switches have matching power classes. Other combinations, according to Table 4-5, are possible.

## 4.5 Network topology in areas with explosive atmosphere

This section deals with the network topology in areas with explosive atmosphere. The chapters 4.5.1 and 4.5.2 provide general information. Ex concepts according IEC/ATEX start at chapter 4.5.3, while Ex concepts based on NEC 500 start at chapter 4.5.5.

The following safety hints must be observed when planning installation in areas with explosive atmosphere.



Electrical equipment may need to be certified when used in areas with explosive atmosphere. For details, refer to your Ex specialist or supplier.



The definition of Ex zones and the planning of electrical equipment in areas with explosive atmosphere must be conducted by qualified personnel only. The local regulations apply.



This chapter explains only special planning aspects for APL. It does not show the full scope of planning for Ex installations.

### 4.5.1 APL protection classes intrinsic safety (Ex i)

The APL intrinsically safe concept 2-WISE [IEC TS 60079-47] (**2-Wire Intrinsically Safe Ethernet**) is based on the principles specified in the hazardous area standards [IEC 60079-11], [IEC 60079-14] and [IEC 60079-25]. To simplify the examination process for intrinsic safety parameters of APL devices and cables within APL segments, a new intrinsically safe system concept has been standardized in [IEC TS 60070-47]. It defines universal intrinsic safety parameter limits for equipment used in APL powered spurs.

#### 4.5.2 Verification of intrinsic safety for APL spurs (2-WISE-approach)

An intrinsically safe powered 2-WISE spur consists of:

- an intrinsically safe power source, provided by a switch,
- an intrinsically safe load port, provided by a field device, and optionally
- a maximum of two auxiliary devices (See Figure 4-13).

All equipment used must be certified according to 2-WISE. The cable used to connect switch, field device, and auxiliary device to a spur, may be up to 200 m and must follow the following specification:

- Cable resistance  $R_c$ : 15  $\Omega$ /km ... 150  $\Omega$ /km
- Cable inductance  $L_c$ : 0.4 mH/km ... 1 mH/km
- Cable capacitance  $C_c$ : 45 nF/km ... 200 nF/km



An APL spur segment may also comprise interconnection facilities such as terminal clamps and connectors. The interconnection facilities are specified as simple apparatus acc. to [IEC 60079-11] and have not to be considered for examination of intrinsic safety. The installation and documentation requirements from [IEC 60079-14] apply. Note: The [IEC 60079-25] provides an example of a descriptive system document. A documentation proposal can be found in the Appendix in chapter 10.4.

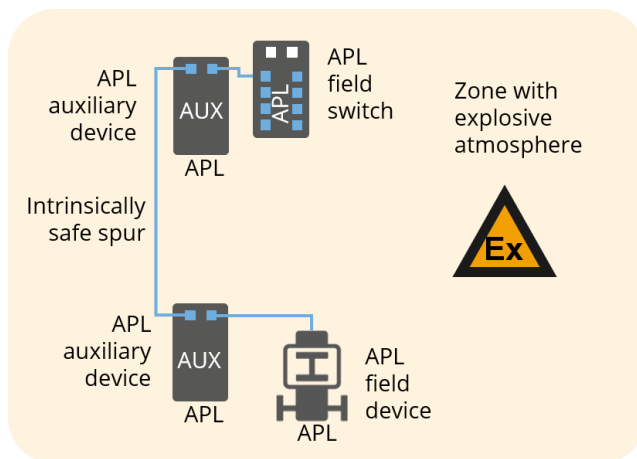


Figure 4-13: Setting considered by 2-WISE approach

The following rules apply:



A powered 2-WISE spur shall be considered intrinsically safe if: one 2-WISE source port, one 2-WISE load port, and up to two 2-WISE auxiliary devices are connected with a cable not exceeding a maximum length of 200 m. The cable shall follow to the specification above. The level of protection of the system is determined by the 2-WISE port with the lowest level of protection. The 2-WISE devices are marked with "2-WISE" and the corresponding protection class.



[IEC TS 60079-47] requires a descriptive system document for each 2-WISE segment containing the following information:

- The Level of protection (e.g., Ex ia or Ex ic) is determined by the 2-WISE port with the lowest level of protection. Example: If the field switch port has specification Ex ic and the device has specification Ex ia, the level of protection will Ex ic.
- The equipment group (e.g., IIC) is determined by the 2-WISE device with the least onerous equipment group.
- The temperature class (e.g., T3, T4) of each 2-WISE device.
- The Entity parameters of the cable used.

[IEC 60079-25] provides an example of a descriptive system document. A documentation proposal can be found in the Appendix in chapter 10.4.

### 4.5.3 Spur topology example in zones with explosive atmosphere according to IEC, ATEX or NEC 505

Figure 4-14 shows an example of a spur topology with field switches installed in Zone 2.

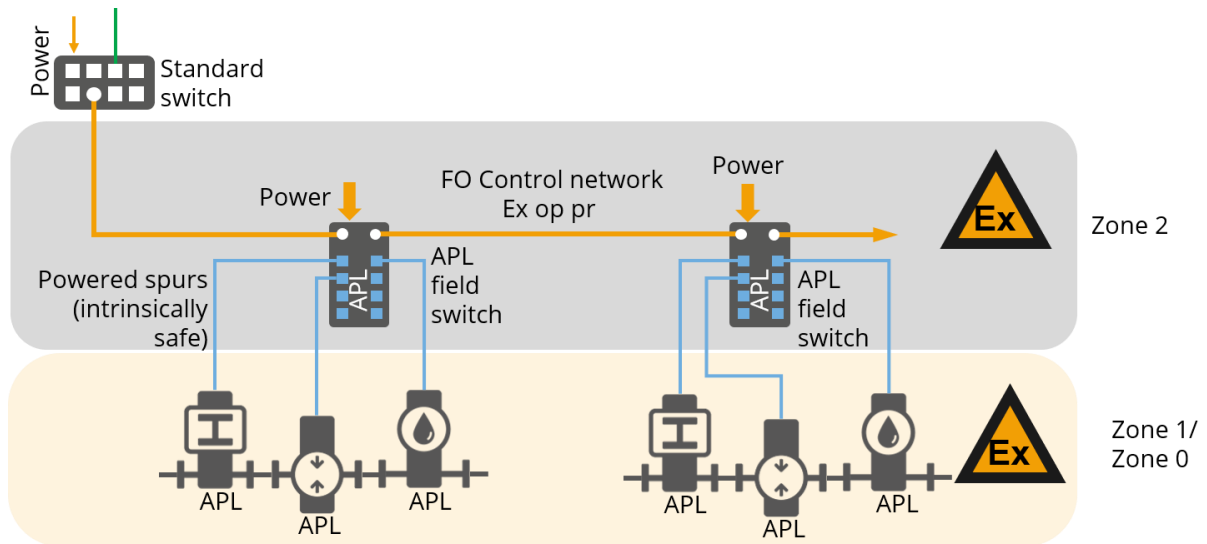


Figure 4-14: Spur topology with field switches installed in Zone 2

The field switches are directly connected to the Industrial Ethernet control network. An APL trunk is not used. The field switches are located in Zone 2. Intrinsically safe spurs connect the APL field switches to the field devices located in Zone 1 / Zone 0.

The topology has the following features:

- The APL field switches are separately powered and the APL field devices are powered through the field switch spurs.
- The Ethernet Control network (amber line) is classified as, at least, increased safety Ex op pr [IEC 60079-28] for Zone 2. In this case shown as fiber optic media.
- The spurs are classified as intrinsically safe, Ex ia for Zone 1 / Zone 0.



The devices must be certified for the use in the intended hazardous area location. Ex certificates / manufacturer declarations must be available and checked during the planning process. The hazardous area risk analysis must be executed and documented during the planning process according to local regulations.

#### 4.5.4 Trunk Topology example APL applications in zones with explosive atmosphere according to IEC, ATEX, NEC 505

Figure 4-15 shows an example of a powered trunk topology with field switches installed in Zone 1.

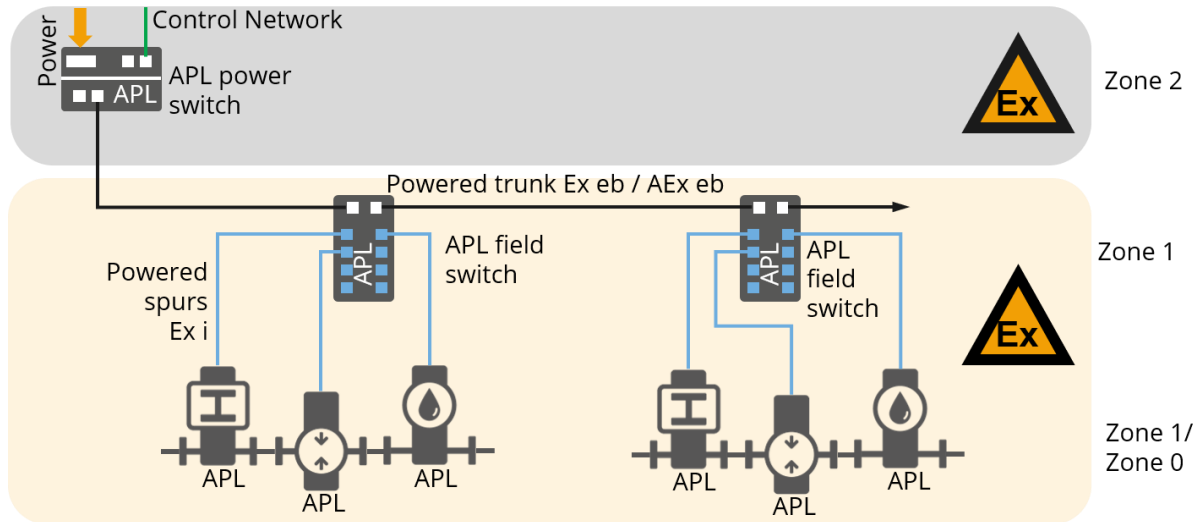


Figure 4-15: Ex Zones for powered trunk

The Topology has the following features:

- The APL field switches and the APL field devices are powered via the trunk.
- The trunk is classified as increased safety Ex eb / AEx eb for Zone 1.
- The spurs are classified as intrinsically safe Ex ia for Zone 1/0.
- Length limitations / voltage drop on the powered trunk have to be observed.



The devices must be certified for use in the intended hazardous area location. Ex certificates / manufacturer declarations must be available and checked during the planning process. The hazardous area risk analysis must be executed and documented during the planning process according to local regulations.

#### 4.5.5 Spur topology example with explosive atmosphere according to NEC 500

Figure 4-16 shows an example of a spur topology with field switches installed in Class I, Div. 2.

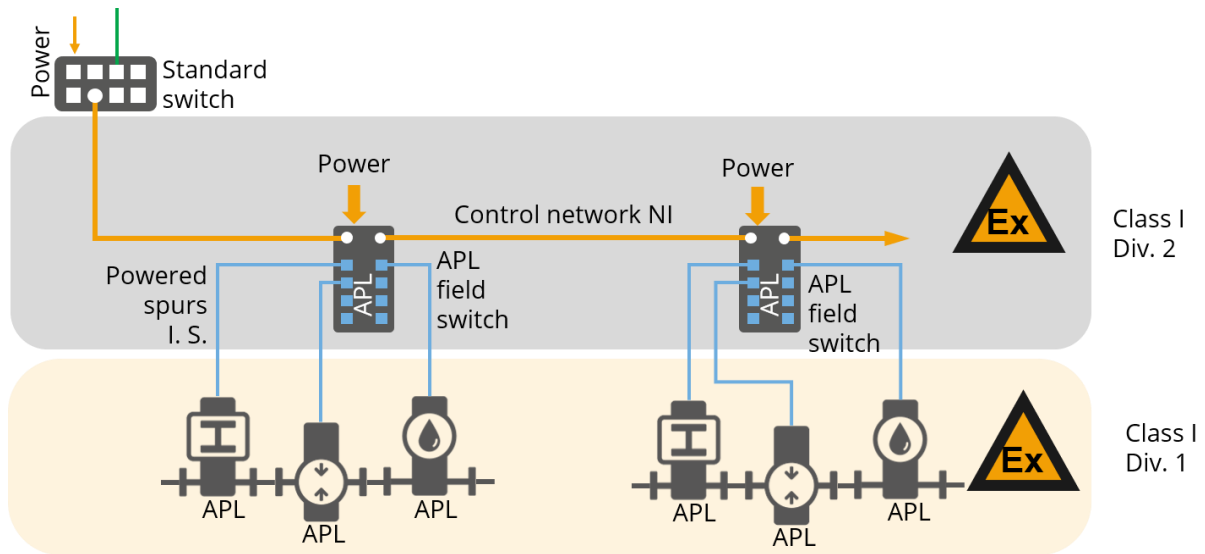


Figure 4-16: Spur topology with field switches installed in Class I, Div. 2

The field switches are directly connected to the Industrial Ethernet control network. An APL trunk is not used. The field switches are located in Class I, Div. 2. Intrinsically safe (I.S.) spurs connect the APL field switches to the field devices located in Class I, Div. 1.

The topology has the following features:

- The APL field switches are separately powered and the APL field devices are powered through the field switch spurs.
- The APL field switches are located in Class I, Div. 2.
- The control network is classified for Class 1, Div. 2.
- The spurs are classified as intrinsically safe for use in Class 1, Div. 1.



The devices must be certified for use in the intended hazardous area location. Ex certificates / manufacturer declarations must be available and checked during the planning process. The hazardous area risk analysis must be executed and documented during the planning process according to local regulations.



#### 4.5.6 Trunk topology example with explosive atmosphere according to NEC 500

Figure 4-17 shows an example of a powered trunk topology with field switches installed in Class I, Div. 2.

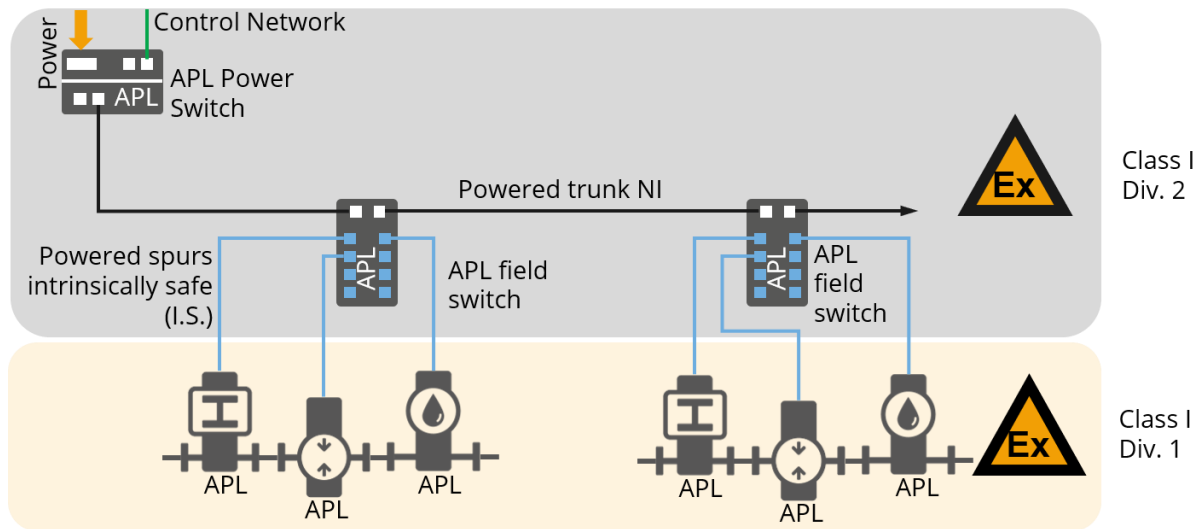


Figure 4-17: Class and Divisions for powered trunk

The topology has the following features:

- The APL field switches and the APL field devices are powered via the trunk.
- The APL power switch and the APL field switches are located in Class I, Div. 2.
- The trunk is classified as non incendive (NI).
- The spurs are classified as intrinsically safe for use in Class I, Div. 1.
- Length limitations / voltage drop on the powered trunk have to be observed.



The devices must be certified for the use in the intended hazardous area location. Ex certificates / manufacturer declarations must be available and checked during the planning process. The hazardous area risk analysis must be executed and documented during the planning process according to the national legislation.

## 4.6 Spare ports and power reserves

The planning process should include reserving spare ports for future expansion; therefore, APL power and field switches should be planned with spare ports. In addition to that, a power budget reserve should be considered for the APL power switches.

## 4.7 Access point for network diagnostic tools

For troubleshooting and network monitoring purposes, it is sometimes necessary to monitor the network traffic via a monitoring tool. In order to get access to the data traffic, it is helpful to use a switch with a mirror port, as shown in Figure 4-18.

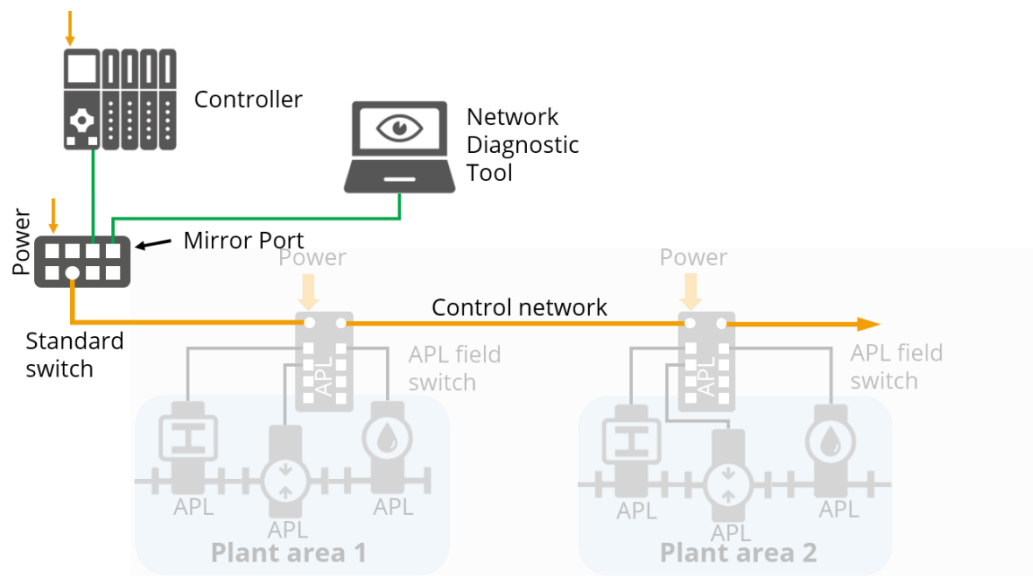


Figure 4-18: Network diagnostic via mirror port

A switch with a mirror port is able to copy the data stream that runs through a port of the switch to the mirror port. In this case the diagnostic tool will be able to read all traffic coming from and going to the APL devices. It has to be observed that the data volume of the monitored traffic stays below the maximum data rate of the mirror port.

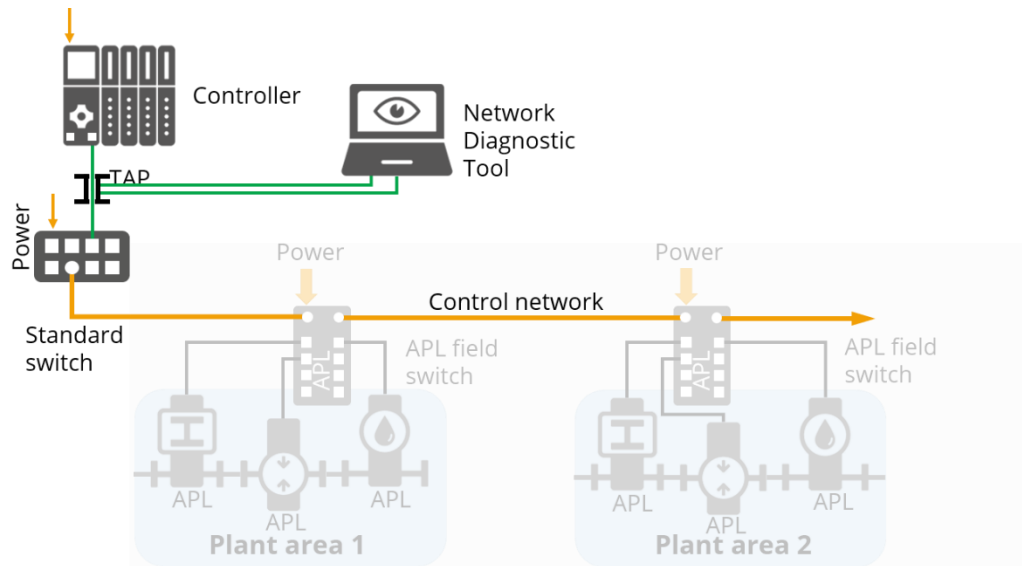


Figure 4-19: Network diagnostic via TAP

An alternative to the switch with mirror port, is the use of a Test Access Port (TAP). A TAP is looped into a connection, e.g., between the Controller and the first switch, as shown in Figure 4-19. By using this TAP, all traffic between the Controller, the underlying APL field switches, and the APL field devices can be monitored. The TAP is able to monitor a full-duplex connection in real time, without the limitations of a mirror port.

In addition to the described network monitoring, it is also possible to read diagnostic information from the APL field switches and the APL field devices via the Industrial Ethernet protocol.

## 4.8 Performance considerations

After the initial planning of the network, a rough performance estimation should be done in order to guarantee the real time capabilities of the APL network. It can be seen from both **Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 4-8 that the traffic to and from the devices merges on the APL trunk; therefore, a load consideration on the trunk closest to the power switch would be useful. The net load can be read from a diagram shown in section 4.8.1. The following section, 4.8.1, will continue with a recommendation for maximum load values for the APL. A description of the calculation scheme can be found in Appendix in section 10.1.

### 4.8.1 Network traffic load estimation

APL uses Ethernet data frames to communicate the measurement values. The minimum payload of an Ethernet data frame is 46 bytes. Smaller payloads will be padded to achieve the minimum payload size.

The following estimation assumes that the measurement values of a typical APL device fit into the minimum data frame, even if multivariable transmitters are used. Therefore, a data frame payload of 46 bytes is assumed for the following calculations. It is further assumed that the traffic

to and from the devices is spread over time. By using this assumption, the network load figures, shown in Figure 4-20, can be derived from the number of devices and the network update rate of the devices for up to 50 devices. In addition, Figure 4-21 shows the figures for up to 250 devices. For calculation details or mixed installations with different cycle times, check Appendix 10.1.

**Example:** It is assumed that a specific APL subnet will run on an update rate of 50 ms and that 20 sensors are connected to the network. In this case, we select 20 devices on the x-axis of Figure 4-20. The blue curve (50 ms) has to be selected in this case. (See blue arrows in Figure 4-20) The network load can now be estimated from the y-axis. The value is around 2.8 %. This is the total network load of sensors conveying data to the controller, respective of the power switch (in-bound traffic). Since APL supports full-duplex communication, data traffic from the controller to the actuators (outbound traffic) is concurrently possible. The calculation principle is the same.

It can be seen that network load only becomes an issue when high update rates are used. Typical cycle times in the process industry (100 ms ... 1 s) will not cause significant network loads, even with a larger number of sensors on one network. For example, 150 devices with a cycle time of 1 s cause a network load of 1.1 %. This leaves sufficient bandwidth for acyclic data transfer for configuration, diagnosis, and asset management.

Even though typical cycle times in the process industry cause only small loads, maximum recommended loads should be considered in order to leave sufficient reserves for future expansion during the lifetime of the communication system. The following section 4.8.2 will look at this issue.

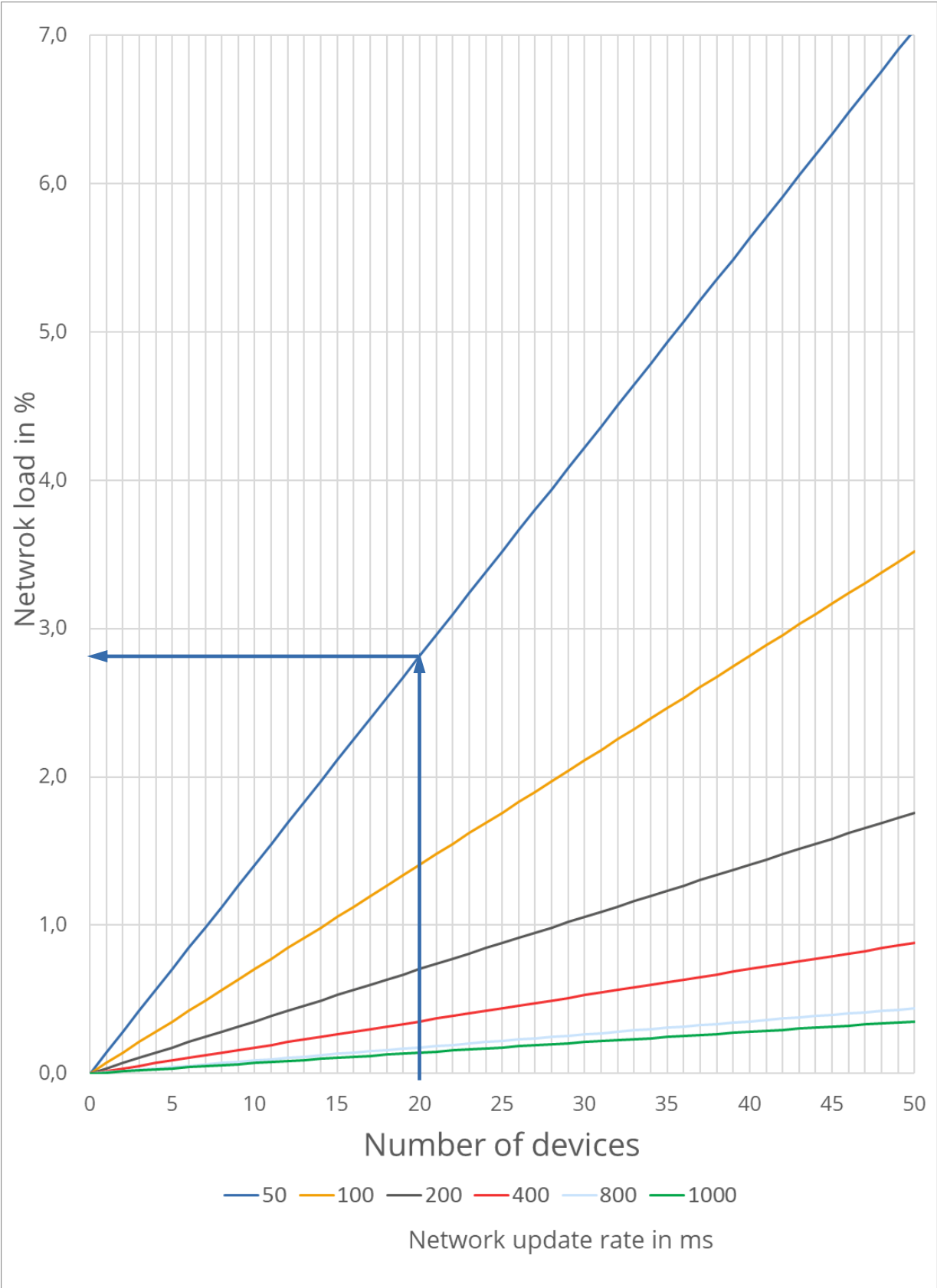


Figure 4-20: Network load estimation up to 50 devices for 10 Mbit/s Ethernet-APL

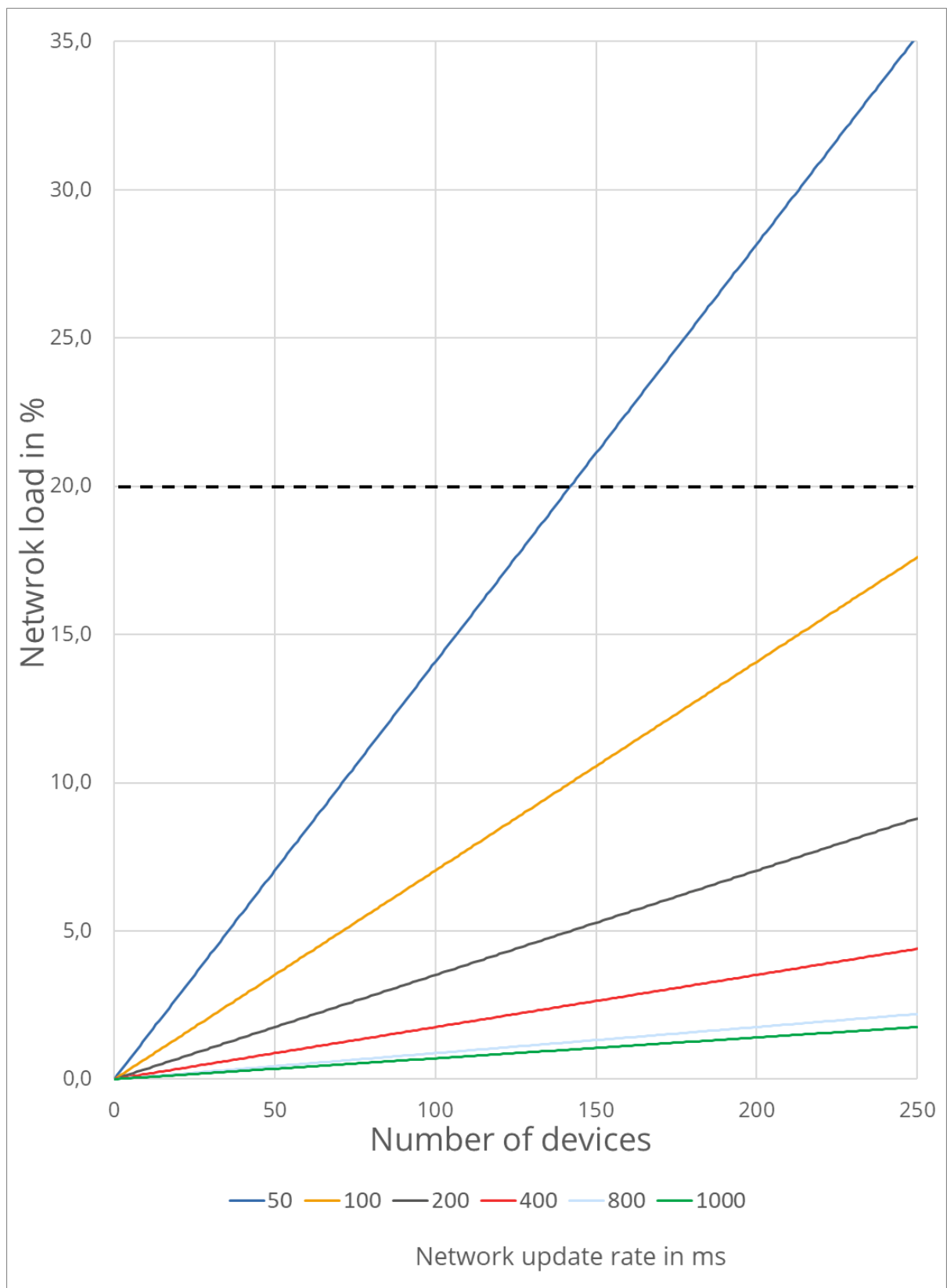


Figure 4-21: Network load estimation up to 250 devices for 10 Mbit/s Ethernet-APL

## 4.8.2 Network load recommendations

As shown in the previous chapter, the network load is dependent on the number of devices and the cycle time of the devices. The sum of the data traffic of all devices causes the overall network load for an APL segment. Table 4-7 makes a recommendation for the cyclic data traffic.

Table 4-7: Network load recommendations for cyclic data traffic on an APL segment

Network load	Recommendation
< 20%:	No action required.
20 ... 50%:	Check of network load recommended.
> 50%:	Take the appropriate measures to reduce the network load.

The figures have been defined considering the following aspects;

- Only cyclic data traffic is considered
- The remaining bandwidth leaves sufficient reserves for acyclic data traffic and network control traffic.
- The figures apply to a newly planned / commissioned segment. They include a reserve for future expansion during the lifecycle of the communication system.

It should be noted that the load should be considered on the trunk segment that is closest to the controller. Here, the traffic of the devices connected to the trunk adds up. In case the Industrial Ethernet runs to the field switches as shown in Figure 4-7, the load issue is usually uncritical due to the higher data rate of the Industrial Ethernet (100 Mbit/s) compared to the data rate on the APL trunk (10 Mbit/s).

Even though the cyclic traffic causes only a small network load, it might be necessary to reduce the network load in some cases, e.g., in case additional sensors shall be added. This can be achieved by two measures. First, increase the cycle time. Doubling the cycle time will reduce the respective network load by 50%. If this first option is not applicable, a second option would be to reduce the number of devices connected to a segment by using two independent APL segments instead of one.



The figures in Table 4-7 are rule-of-thumb figures, which provide an easy-to-understand design of the APL network. The network will remain operable in cases where the network load is exceeded.

## 4.9 Availability considerations

As redundancy concepts are dependent on the redundancy structures of the superordinate network, no further information about redundancy will be provided here.



Ask one of the standards development organizations (SDOs), cooperating in the APL project, for further information.

## 4.10 Best practice planning examples

This chapter provides best practice examples for the planning of APL networks. The objective of this chapter is that typical network topologies can be re-used as-is, without the need to perform calculations or further considerations.

### 4.10.1 Best practice planning examples with a powered APL trunk

The subsequent examples will introduce a set of sample applications that use a powered APL trunk as described in chapter 4.2.4. As the powered APL trunk provides energy for the APL field switches and the APL field devices connected to the field switches, the voltage drop on the trunk cable has to be considered. Table 4-8 shows the prerequisites for the following best practice examples.

Table 4-8: Prerequisites for best practice planning examples

Type	Assumption
Topology	Powered APL trunk (See section 4.2.4)
APL power switch	Power class 4 <sup>2</sup> (50 V DC / 92 W)
APL field switch	Trunk: With Trunk_in and Trunk_out ports; Power class C Spurs: 16 spurs; Power class A (15 VDC/0.54 W) per port
APL field devices	Maximum current consumption 55.56 mA each device
Trunk cable	Cable category IV, max. 1 000 m, 1.5 mm <sup>2</sup> (16AWG) Optional 2.5 mm <sup>2</sup> (14AWG) or 1.0 mm <sup>2</sup> (18AWG)
Spur cable	Cable category IV, max. 200 m, 0.75 mm <sup>2</sup> (20AWG)
Ambient temperature for cables <sup>3</sup>	-20 °C ... +55 °C

<sup>2</sup> Not yet specified in [APS2021]. Subject to future development

<sup>3</sup> The temperature range is used as assumption for the calculation of the voltage drop on the cables in the examples. Higher and lower temperatures are possible depending on cable specification. In this case re-calculation of voltage drop necessary



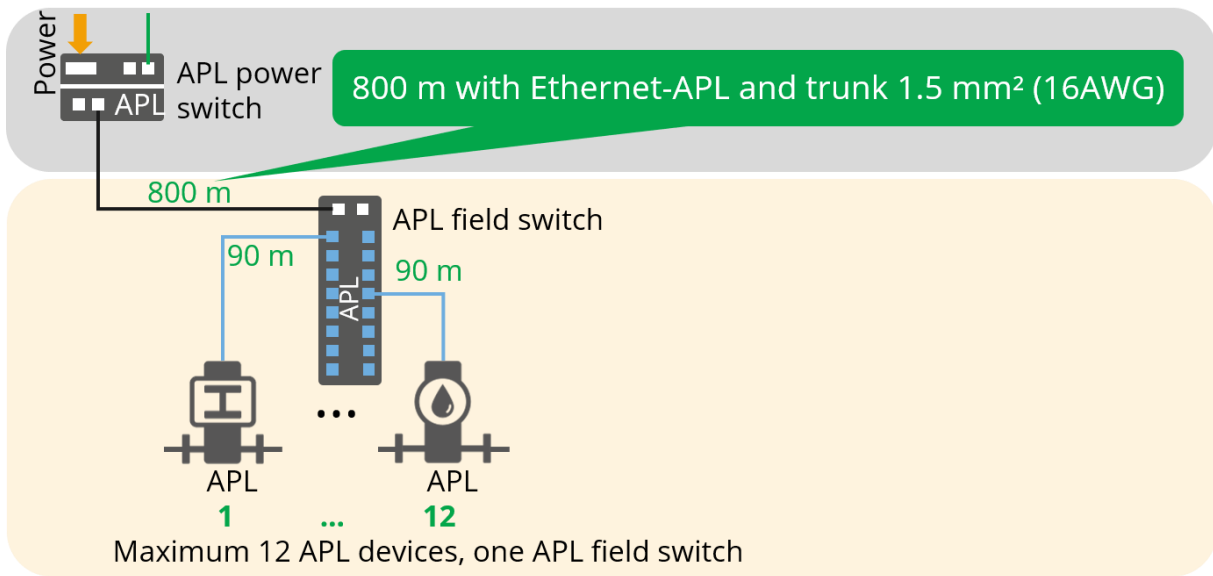


Figure 4-22: Single field switch with long powered trunk

Figure 4-22 shows a possible application where the field devices are connected in a central location. The described setting allows a trunk length of up to 800 m, up to 12 APL field devices connected to one APL field switch and spur lengths of up to 90 m.

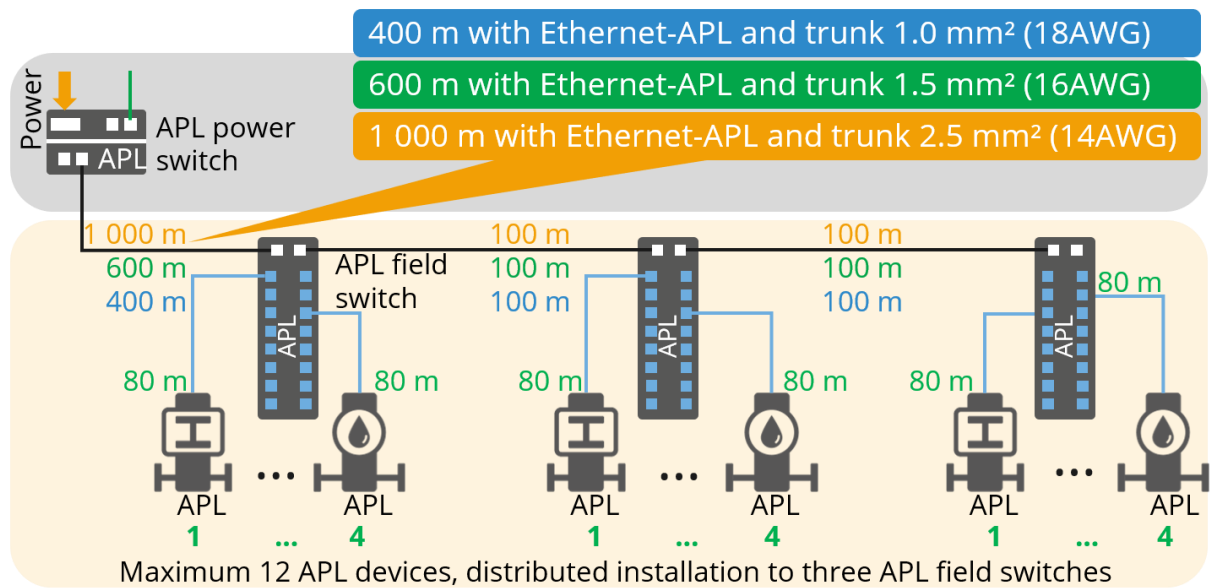


Figure 4-23: Decentralized installation with powered trunk

Figure 4-23 shows three APL field switches. Four APL field devices connect to each of the APL field switches, resulting in a total number of 12 APL field devices. The length of the spurs is considered to be 80 m each. The distance between the APL field switches is 100 m. Four APL field devices connect to each field switch. With this setting, the distance between the APL power switch and the first APL field switch can be 600 m using a trunk cable with 1.5 mm<sup>2</sup> (16AWG) or 700 m using a trunk cable with 2.5 mm<sup>2</sup> (14AWG).

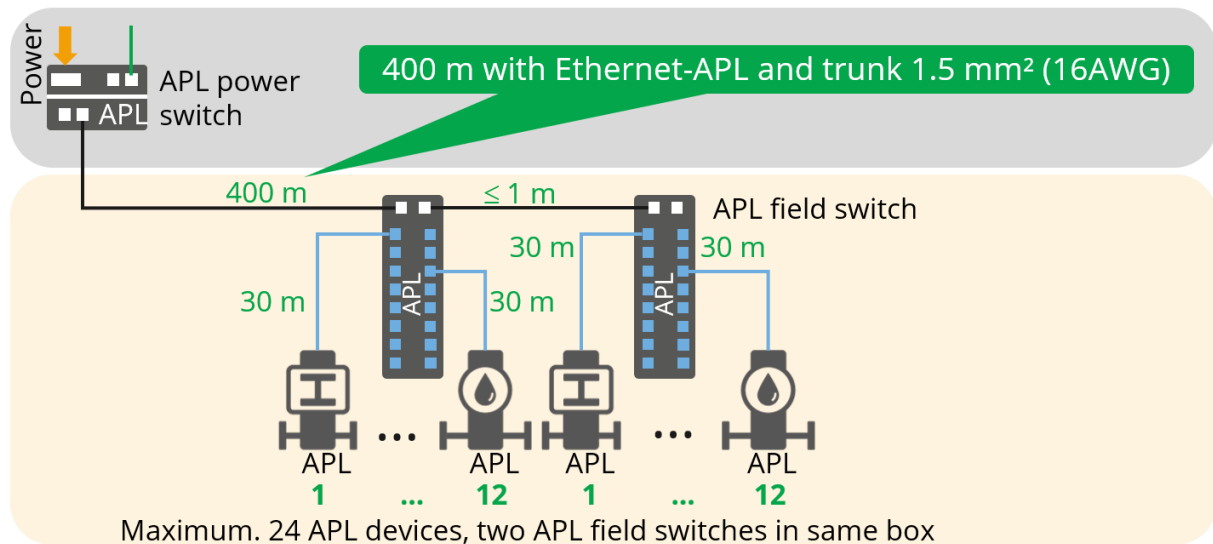


Figure 4-24: Installation with powered trunk and two field switches in single location

Figure 4-24 gives an example where two APL field switches are placed close to each other. Up to twelve APL field devices are connected to each of the switches, resulting in a total number of 24 devices. The spur lengths are assumed to be 30 m or less. The length of the trunk between the two APL field switches shall be  $\leq 1$  m. By using an APL trunk cable with a cross section of 1.5 mm<sup>2</sup> (16AWG), the length of the APL trunk between the APL power switch and the first APL field switch can be up to 400 m.

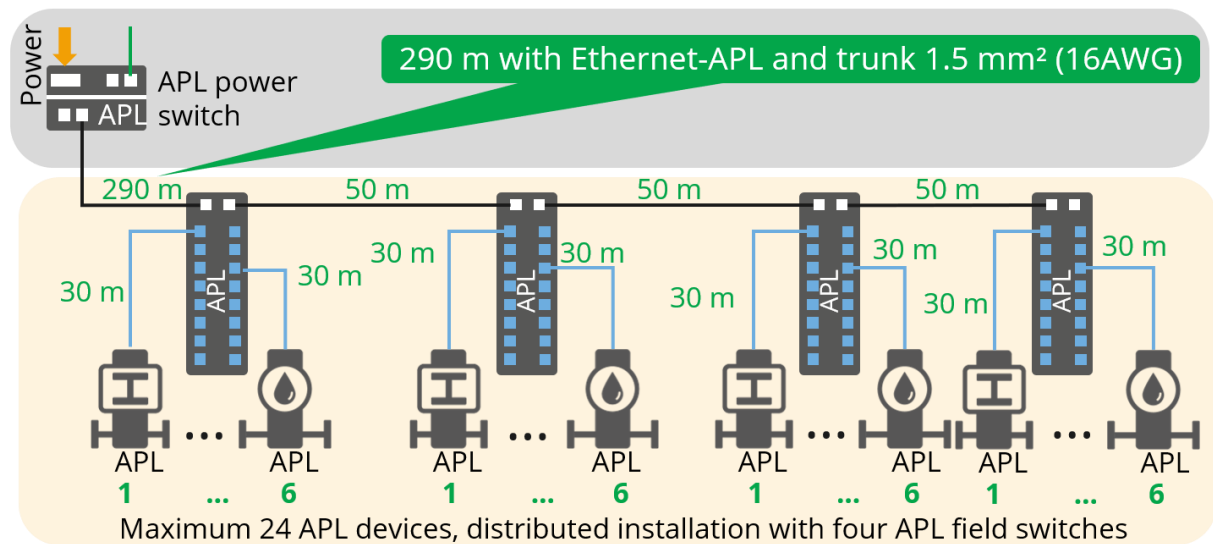


Figure 4-25: Decentralized installation with powered trunk

Figure 4-25 assumes a decentralized setting, with four APL field switches. Six field devices connect to each of the field switches, resulting in a total number of 24 APL field devices. It is assumed that the distance between the field switches is 50 m each. This results in a maximum length of 290 m for the trunk segment between the power switch and the first field switch. An APL trunk cable with a cross section of 1.5 mm<sup>2</sup> (16 AWG) is assumed.

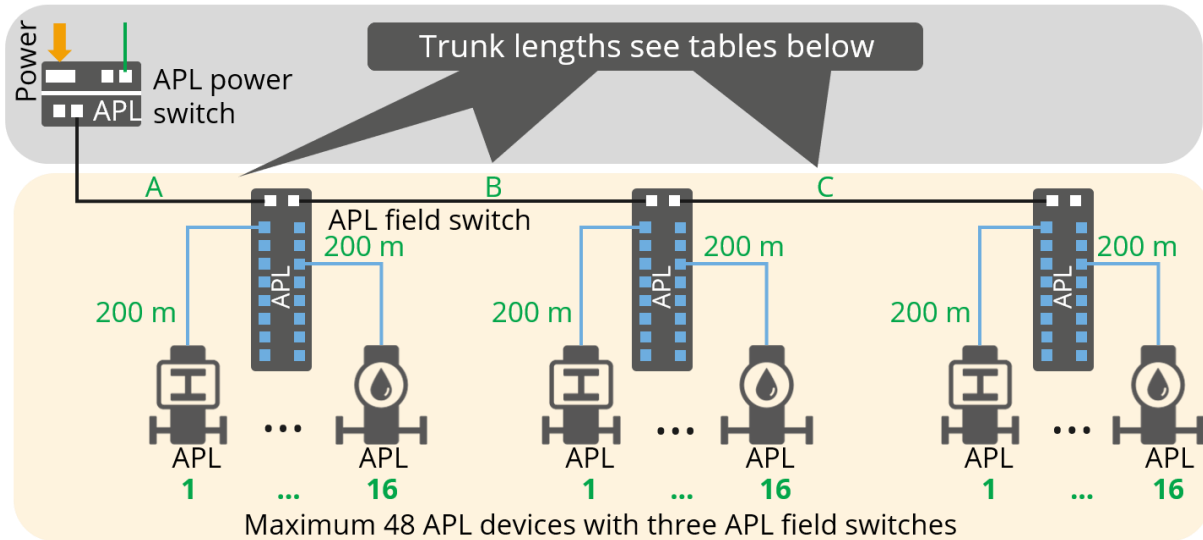


Figure 4-26: Installation with high number of field devices and maximum spur length

Figure 4-26 shows a setting where all 16 spur ports of the APL field switches are used at each APL field switch, resulting in a total of 48 APL field devices. The spur length is assumed to be 200 m, which is the maximum permissible length for spurs. Table 4-9, Table 4-10, and Table 4-11 show possible combinations for the distances A, B, and C depending on the cross section of the powered trunk cable.

Table 4-9: Powered trunk length variants with up to three APL field switches per trunk and up to 48 APL field devices with APL trunk cable 1.0 mm<sup>2</sup> (18 AWG)

Powered trunk 1.0 mm <sup>2</sup> (18AWG)			
Variants	Distance A	Distance B	Distance C
Variant 1	125 m	125 m	125 m
Variant 2	900 m	≤ 1 m	≤ 1 m
Variant 3	100 m	100 m	250 m
Variant 4	≤ 1 m	≤ 1 m	750 m

Table 4-10: Powered trunk length variants with up to three APL field switches per trunk and up to 48 APL field devices with APL trunk cable 1.5 mm<sup>2</sup> (16 AWG)

Powered trunk 1.5 mm <sup>2</sup> (16AWG)			
Variants	Distance A	Distance B	Distance C
Variant 1	185 m	185 m	185 m
Variant 2	1 000 m	≤ 1 m	≤ 1 m
Variant 3	100 m	100 m	500 m
Variant 4	≤ 1 m	≤ 1 m	1 000 m

Table 4-11: Powered trunk length variants with up to three APL field switches per trunk and up to 48 APL field devices with APL trunk cable 2.5 mm<sup>2</sup> (14 AWG)

Powered trunk 2.5 mm <sup>2</sup> (16AWG)			
Variants	Distance A	Distance B	Distance C
Variant 1	310 m	310 m	310 m
Variant 2	1 000 m	≤ 1 m	≤ 1 m
Variant 3	100 m	100 m	1 000 m
Variant 4	≤ 1 m	≤ 1 m	1 000 m

The previous examples considered a certain number of APL field switches, the number of APL field devices, the spur lengths, and then derived the maximum allowed trunk length from that. The following example, shown in Figure 4-27, assumed the maximum length for the trunk segments, the maximum length for the spurs, and then derives the maximum number of APL field devices from that.

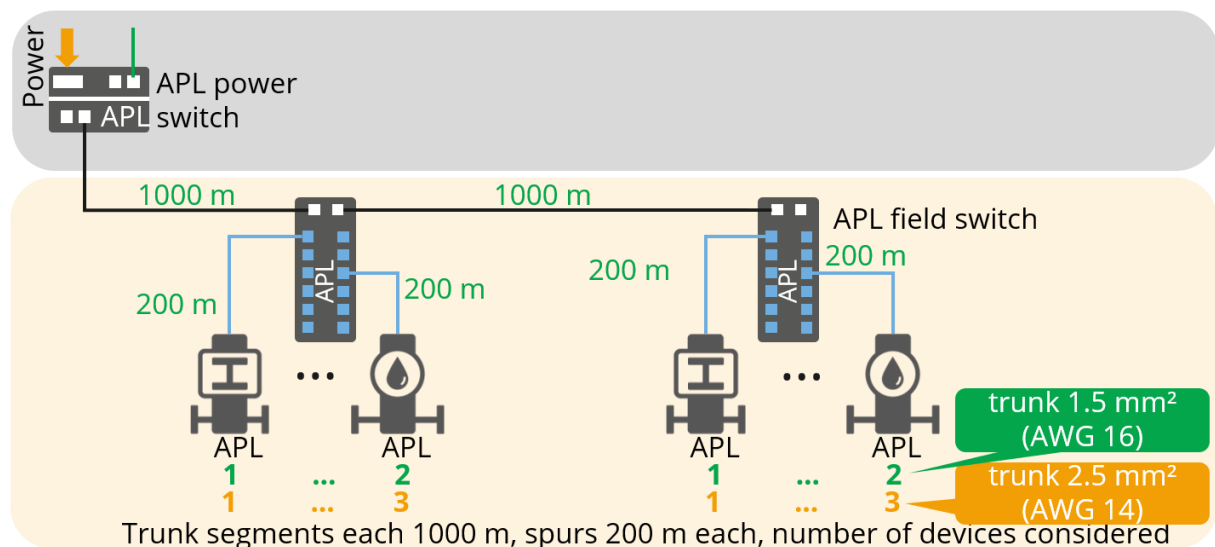


Figure 4-27: Installation with maximum distances, number of devices considered

Figure 4-27 shows that an APL trunk cable with a cross section of 1.5 mm<sup>2</sup> (16AWG), up to two APL field devices can be connected to each of the two APL field switches. When using an APL trunk cable with a cross section of 2.5 mm<sup>2</sup> (14AWG), the number of devices increases to 3 per APL field switch.

In case the best practice examples do not fit the needs or the reader, it is possible to individually calculate the ratings according to appendix 10.2., based on the individual data of the components used.

The power for the APL field switches and the APL field devices needs to be conveyed through the APL trunk cable. It can be seen from the previous example that this leads to certain limitations with respect to the number of APL field switches, the number of APL field devices, and the cable lengths. In case the planned application demands higher ratings, it is recommended to use a solution with Industrial Ethernet to the APL field switch, as described in the next chapter.

#### 4.10.2 Best practice planning example with Industrial Ethernet to the field switch

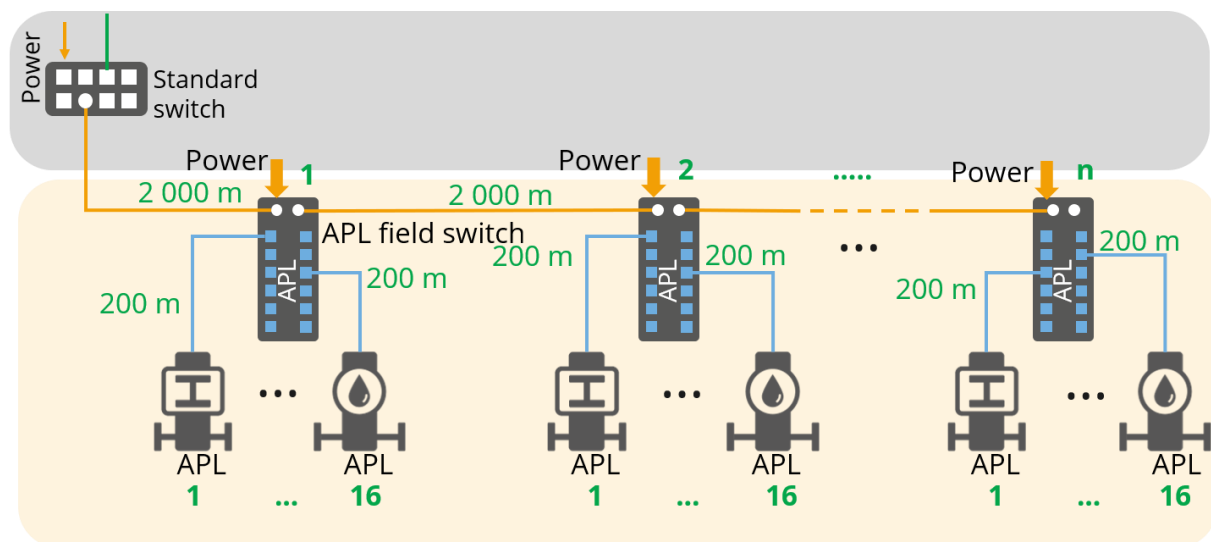


Figure 4-28: Industrial Ethernet with fiber optic connection to the field switches, high number of field devices and maximum spur length

In case the quality of the equipotential bonding system is unknown, a setup according to Figure 4-28 could be used. Here the Industrial Ethernet control network is directly routed to the field switches via a fiber optic cable. A multimode fiber would typically allow distances up to 2 000 m between the switches. The example assumes a number of  $n$  field switches with up to 16 APL field devices each. The main limitation of this example is the number of devices that can be connected to the superordinate PLC/DCS (host system) and the maximum allowed line depth (number of switches between the Controller and the most remote device) of the Industrial Ethernet network.

### 4.10.3 Summary best practice examples

This section summarizes the conclusions that can be derived from the best practice planning examples shown in the previous sections:

- A topology with a powered trunk has the following in features:
  - No auxiliary power for the field switches is needed. Power is provided via the powered trunk.
  - Maximum permissible length of the APL trunk depends on the localization of the APL field switches and the number and power consumption of the APL field devices connected to the APL field switches. Cross-section of the trunk cable is part of the length calculation.
  - Data rate on the APL trunk is 10 Mbit/s. Network communication load is to be observed.
  - Equipotential bonding is to be observed, especially for long trunk segments. Note: The cable shield may carry potential equalization currents in case both ends are connected to the Common Bonding Network (CBN).
  - Check chapter 4.10.1 for details.
- A topology that runs Industrial Ethernet to the APL field switches has the following features:
  - APL trunk is not used.
  - Auxiliary power in the field is needed to power the field switches
  - The data rate is uncritical, as the APL field switches directly connect to the Industrial Ethernet with 100 Mbit/s.
  - Equipotential bonding is uncritical, in case fiber optic cable is used for the Industrial Ethernet.
  - Check section 4.10.2 for details.

An additional comparison of the three described concepts can be found in Table 4-4.

## 4.11 Checklists for the planning process

The following checklists will summarize the planning steps given in this chapter. There are two checklists available. Table 4-12 is the checklist for APL planning in areas without explosive atmosphere. Table 4-13 provides the checklist for a planning in areas with explosive atmosphere.

Table 4-12: Checklist APL planning in areas without explosive atmosphere

No.	Task	Explanation / additional information	Check
1	Assign location of APL field devices	The technical process defines where the field devices need to be placed. Find out the location of the devices.	
2	Assign location of the field switches	The maximum spur length (distance between APL field switch and APL field device) is a maximum 200 m. Find out where the field switches need to be located to comply with the distance limitation on the spur.	
3	Define basic structure of APL network	Chapter 4.2 describes basic structures of APL networks: Industrial Ethernet to the field switch and powered APL trunk. Chose the structure that best fits the needs of your application.	
4	Check number of insertions	In addition to the APL field devices and the APL switches, additional components can be connected to the network. These are APL auxiliary devices (e.g., surge protectors) and insertions (e.g., connectors). The maximum allowed number has to be checked according to Table 4-6.	
5	Plan connection to the superordinate automation network	Plan where to connect the APL segment to the superordinate network. Note: this planning step depends on the system structure chosen in the previous step. The maximum trunk length needs to be observed. The segment length of a powered trunk needs to be calculated, as it depends on the power consumption of the devices, due to voltage drop. See chapter 4.10 for best practice examples and Appendix 10.1.2 for details.	
6	Verify the network load	Use Figure 4-20 or Figure 4-21 to verify the maximum network load of an APL segment.	
7	Document the results	The results of the planning process should be documented.	

Table 4-13: Checklist APL planning in areas with explosive atmosphere

No.	Task	Explanation	Check
1	Ex Zone planning	Perform the Ex zone /Class and Division planning. Assign the zones /classes and divisions according to the rules and guidelines in your country.	
2	Assign location of APL field devices	The technical process defines where the field devices need to be placed. Find out the location of the devices. Document in which zone / class division the devices will be located.	
3	Assign location of the field switches	The maximum spur length (distance between APL field switch and APL field device) is a maximum 200 m. Find out where the field switches need to be located to comply with the distance limitation on the spur.	
4	Define basic structure of APL network	Chapter 4.2 defines three basic structures of APL networks: Industrial Ethernet to the field switch and powered APL trunk. Chose the structure that best fits the needs of your application and to the Ex zones / classes divisions of your plant according to chapter 4.5.	
5	Check number of insertions	In addition to the APL field devices and the APL switches, additional components can be connected to the network. These are APL auxiliary devices (e.g., surge protectors) and insertions (e.g., connectors). The maximum allowed number has to be checked according to Table 4-6.	
5	Plan connection to the superordinate automation network	Plan where to connect the APL segment to the superordinate network. Note: this planning step depends on the system structure chosen in the previous step. The maximum trunk length needs to be observed. The segment length of a powered trunk needs to be calculated, as it depends on the power consumption of the devices, due to voltage drop. See chapter 4.10 for best practice examples and Appendix 10.1.2 for details.	
7	Verify the Ex concept	Check: Is the combination of field switches and APL devices according to the 2-WISE concept allowed? Do the spurs have the correct ignition protection rating according to the zone / class division allocation? Are the field switches located in the correct zone /class division?	
8	Verify the network load	Use Figure 4-20 to verify the maximum network load of an APL segment.	
9	Document the results	The results of the planning process should be documented	



## 5 Functional bonding and shielding

The following chapters give recommendations for the bonding and shielding concept of APL networks. Functional bonding and shielding serves two purposes. First, avoid potential differences that could ignite an explosive atmosphere. Second, improve the electromagnetic compliance of the plant's installation.



During the planning process for the bonding system, observe the rules and regulations that apply in the country where you perform the installation.



This chapter explains only special planning aspects for APL. It does not show the full scope of planning in areas with explosive atmosphere.

### 5.1 Bonding concept of APL

Prior to describing the bonding of APL networks, some basic terms will be explained in Table 5-1. The explanations are derived from the IEV wordbook [IEV2020].

Table 5-1: Explanation of terms around bonding

Term	Explanation
Equipotential bonding	Provision of electric connections between conductive parts, intended to achieve equipotentiality.
Protective equipotential bonding	Equipotential bonding for purposes of safety.
Functional equipotential bonding	Equipotential bonding for operational reasons other than safety.
Common equipotential bonding system / common bonding network:	Equipotential bonding system providing both protective equipotential bonding and functional equipotential bonding.
Meshed system:	System or part of a system consisting of multiple meshes.
Main earthing terminal / main earthing busbar / main grounding terminal / main grounding busbar	Terminal or busbar which is part of the earthing arrangement of an installation and enabling the electric connection of a number of conductors for earthing purposes.

The following chapters will mainly talk about equipotential bonding, since good equipotential bonding is key for the function of the APL cable shields. Usually, the equipotential bonding system is earthed at the main grounding terminal or at multiple locations. Nevertheless, the subsequent chapters will, in general, use the term “equipotential bonding” and will not talk about “earthing”. The term “equipotential bonding” does not imply a certain type of quality of the network. For a meshed equipotential bonding network, the word “meshed” is explicitly used.

It is recommended that you use a meshed common bonding network (meshed CBN) for APL installations. This means that a single bonding system is used to ensure electrical safety as well as functional potential equalization within the plant.

The standards [EN 50310] and [IEC 60364-4-44] specify the earthing and equipotential bonding measures for buildings with IT equipment. The explanations in the following section have been derived from these standards.

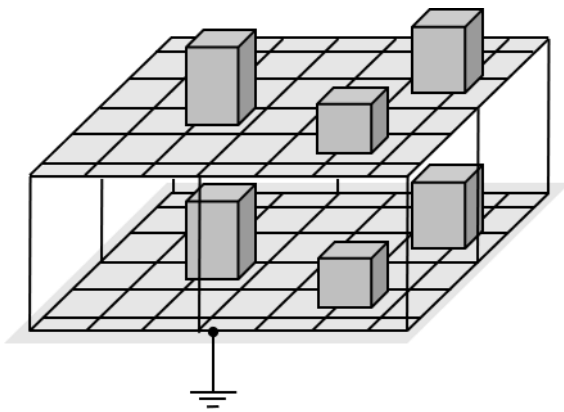


Figure 5-1: Meshed equipotential bonding network

The meshed equipotential bonding system, shown in Figure 5-1, consists of a meshed bonding grid. In the plant area, all metal parts such as cabinets, frames, supports and cable systems are locally meshed. By connecting all metal parts, a meshed equipotential bonding system is formed, which features a low impedance, due to its high number of short and parallel transmission routes. A network with this kind of meshing of all conductive objects is called a bonding network (BN). The equipotential bonding system has meshed equipotential bonding lines distributed over the entire building/plant. Therefore, a common system should be laid over several levels of the building/plant. If this bonding network is used for electrical safety purposes, as well as for functional bonding, it is called a common bonding network (CBN). **For the further discussion, a common bonding network is assumed.** The symbol that designates the connection to the CBN is shown in Figure 5-2.

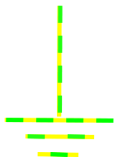


Figure 5-2: Designator for the connection to the common bonding network (CBN)

The goal of using a meshed equipotential bonding system is to reduce the line impedance of the bonding system between two devices. For this purpose, as many parallel and electrically conductive connections as possible are needed between the devices of the plant. As this would induce a tremendous cabling effort if only cables were used, the meshing is, in part, realized by using the metal parts of the plant such as pipes, frames, cabinets and cable ducts. You should also include the foundation earth electrode and the steel rebar on the building floors as part of the equipotential bonding system. In this case, however, the steel rebar of the foundation earth electrode must be either welded or permanently connected by other measures in order to ensure electrical conductivity.

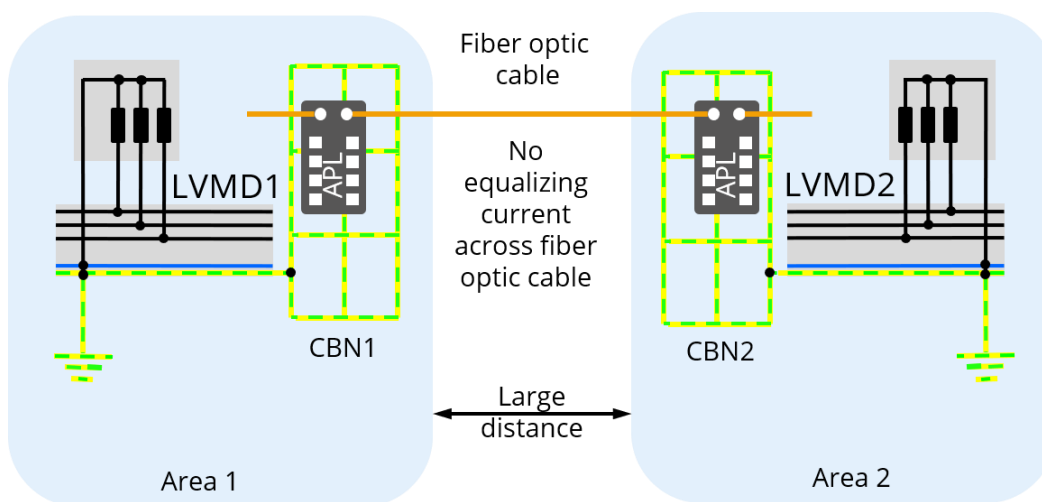


Figure 5-3: Different Common bonding networks

Figure 5-3 shows a plant with two plant areas that are powered by different low voltage main distribution systems (LVMD) and with a large distance between the two plant areas. In this case it is not possible to create a single common bonding network (CBN). To overcome this problem, the APL field switches should be connected via fiber optic (FO) cable and the common bonding networks should remain separated. See chapter 4.2.1 to learn about fiber optic connections between field switches.

## 5.2 Shielding concept of APL

Assuming a meshed CBN, as described in chapter 5.1, the cable shields of the APL network should be connected to the CBN at both ends of the cable. This applies for trunks as well as for spurs.

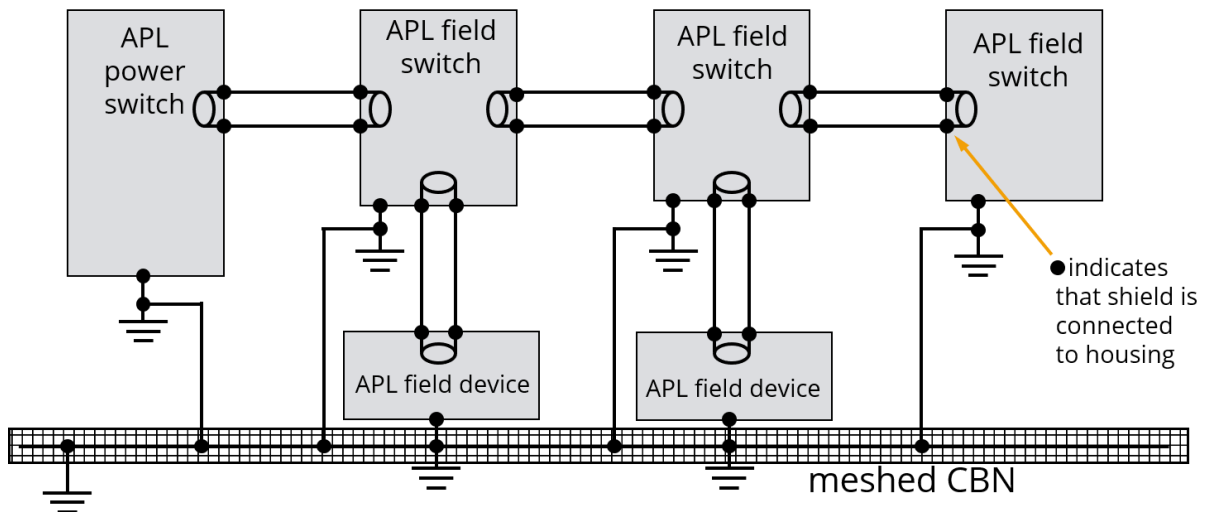


Figure 5-4: Cable shield connected at both ends to the CBN

Figure 5-4 shows the direct connection of the cable shields to the common bonding system at both ends. It can be seen that the components, or their conductive housings, are connected via the grounding terminals to the CBN. In parallel to this, the cable shields are connected to the housing. The connection of the shield depends on the design of the device. Usually, it is done according to Figure 6-3, Alternative 1, 2, 3, 4 or via the housing of the M12 or M8 connectors. The contact of the cable shield should be done with a large surface and a low impedance.

The advantage of a meshed CBN is that the electrical currents in the meshes of the grounding system are relatively low, which is due to the large number of parallel paths in the grounding system. Therefore, connecting cable shields at both ends is possible without the risk of cable shields carrying excessive vagabonding currents in the CBN. In case a meshed CBN is not available, or in case the potential equalization system suffers from vagabonding currents, cable shields should only be connected at one end directly to the CBN and via a capacitor at the other end, as shown in Figure 5-5.

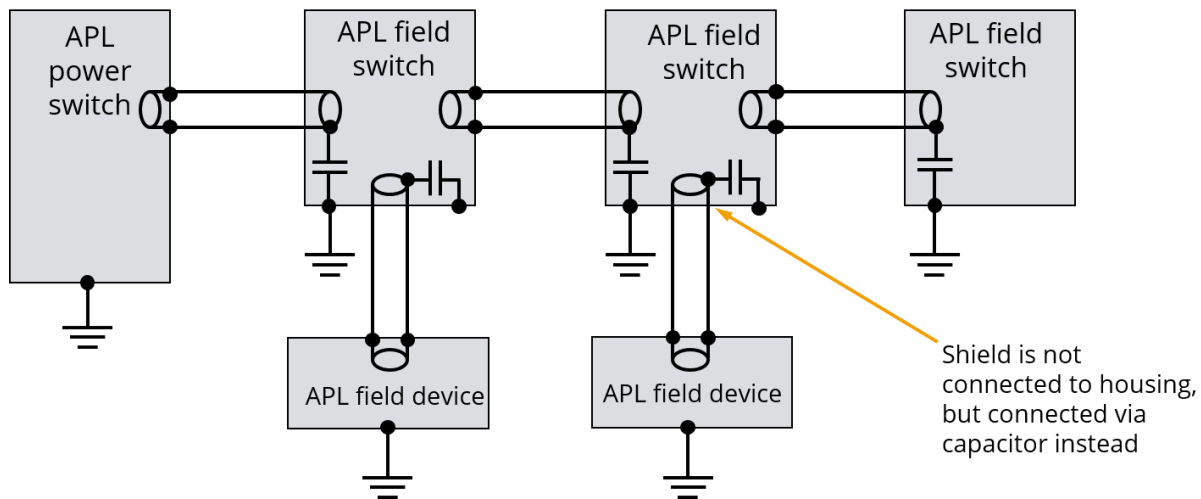


Figure 5-5: Cable shield connected with one end directly and the other end via capacitor to the CBN

APL field devices support direct shielding. APL switches usually support both direct and capacitive connection of the cable shield to the bonding network. For a capacitive connection of the cable shield see Figure 6-4, Alternative 5, 6 or 7.



Note that the connection of the cable shield via a capacitor reduces the immunity of the cable against magnetic fields. Magnetic fields are, for example, generated by unshielded power lines or unshielded motor lines. To compensate for this, the minimum distances between the APL cable and the power cable according to Equation 6-1 should be considered.

Please find additional information about improved EMC in the appendix in chapter 10.3.

### 5.3 Bonding and shielding in areas with explosive atmosphere

According to [IEC 60079-14], grounding the cable shield on both ends in the Ex area is only permissible if "it is highly ensured that potential equalization exists between each end of the circuit".

If the currents in the equipotential bonding cannot be minimized, i.e., the equipotential bonding is not ensured to a high degree, the current flow from the equipotential bonding via the shield must be prevented. [IEC 60079-14] prescribes in this case a one-sided shield connection or two-sided shield connection with capacitor at one end, which reduces the effectiveness of the shield. If necessary, this disadvantage can be compensated by increasing the distance between the APL cable and the power cable.



Grounding the cable shield on both ends in the Ex area is only permissible if "it is highly ensured that potential equalization exists between each end of the circuit". The use of Ex e type installation material, in combination with a meshed bonding network, is a good basis for this.

## 5.4 Surge Protection

A surge protective device (SPD) is an electrical device that is used to protect electronic equipment against electrical surges and voltage spikes. An SPD is an auxiliary device. According to Table 4-6, the number of auxiliary devices is limited to two per segment. This applies to trunks as well as to spurs.



Surge protective devices (SPD) shall protect electronic circuits against electrical surges and spikes. Observe local standards and regulations that apply for lightning protection in Industrial applications.



If surge protection must be applied due to the risk of a potential surge exposure, surge protectors at both ports – the switch port and the field device port – must be installed.

SPDs must be designed according to [APS2021] and may be connected inline between an APL port and the segment cable with a stub length of 10 cm maximum. The connection of the surge protection device to the equipotential bonding system must be low impedance in order to avoid high voltages caused by the current discharge of an overvoltage event (e.g., indirect lightning strike).

## 6 Installation of APL networks



The target audience of this section are individuals that execute and/or supervise installation tasks on site. The following chapters will guide the reader through the installation process of an APL network.



During the installation process, observe the rules and regulations that apply in the country where you perform the installation.



Especially for installations in explosive atmospheres, the requirements from [IEC 60079-14] or the respective local rules and regulations shall be followed.

### 6.1 Laying of cables

In order to minimize pickup of electromagnetic interferences, APL cables should be laid separately from power cabling. Parallel routing of APL and other cables should be minimized and the distance between these different cables should be maximized. The minimum cable bend radius and tensile strength shall be observed while laying APL cables.



During installation, observe the applicable national safety and installation regulations for data and power cables. The specifications provided in this guideline are based on applicable IEC standards.

#### 6.1.1 Cable spacing and cable routing

The following section gives general information on cable routing inside buildings as the referenced standard [EN 50174-2].



In general, power supply cables and communication cables shall be laid separately.

You should first check where the power supply cables are laid or planned to be laid in the plant. In practice, it may be impossible to completely separate the cables from each other. It is permissible to use the same cable duct provided that the required minimum distances are observed. Alternatively use special ducting with steel separators.

The Guidelines for the minimum distances between power cables and APL cables are based on the following assumptions:

- Power cables with 1 000 V maximum voltage at 50/60 Hz are used.
- A meshed bonding network is in place.
- The shield of the APL cable is connected at both ends to the common bonding network.

If your plant deviates from these assumptions, it is recommended to increase the cable distances recommended in this chapter. According to Table 4-3, APL cables are specified with a shield attenuation  $\geq 60$  dB. These cables fall into separation class c ( $\geq 55$  dB) according to Table 6-1. If you are unaware of the shield attenuation of the cable, use separation class b instead, according to Table 6-1.

To determine the minimum distance between APL cables and other electrical cables, proceed as follows:

- In the right table section (spacing) of Table 6-1, select the type of cable separation to be used. Read the minimum required separation distance  $S$  from the table for separation class c.
- In addition, observe the additional information for the different conduits a, b, c, or d according to Table 6-1.
- Estimate the number of power circuits running in parallel to the APL cable according to Table 6-2.



Table 6-1: Minimum required separation distances  $S$  between APL cables and power cables to EN 50174-2(2018)

		Conduits used for information technology cables and mains power cables		
Separation class	Separation without electro-magnetic barriers	Open metallic conduits <sup>a</sup>	Perforated metallic conduits <sup>b, c</sup>	Solid metallic conduits <sup>d</sup>
<b>b</b>	100 mm	75 mm	50 mm	0 mm
<b>c</b>	50 mm	38 mm	25 mm	0 mm
	a	Shielding effect (0 MHz to 100 MHz) equivalent to welded meshed steel basket with mesh size 50 mm × 100 mm. The same shielding effect can be achieved using steel cable trays (cable bundles, without cover) with a wall thickness of less than 1.0 mm and/or an evenly perforated surface of more than 20%.		
	b	Shielding effect (0 MHz to 100 MHz) equivalent to a steel cable tray (cable bundles, without cover) with a minimum wall thickness of 1.0 mm and an evenly perforated surface of not more than 20%. This shielding effect can also be achieved with shielded power cables, which do not provide the features specified in footnote d.		
	c	The top surface of the installed cables must be at least 10 mm below the top surface of the barrier.		
	d	Shielding effect (0 MHz to 100 MHz) equivalent to a steel installation pipe with a wall thickness of 1.5 mm. The specified separation distance must be considered in addition to the separation distance required by dividers/barriers.		

Table 6-2: Factor  $P$  for power cabling according to EN 50174-2(2018)

Type of electrical circuit <sup>a, b, c</sup>	Number of circuits	Factor for the power supply cabling $P$
20 A, 230 V, single-phase	1 to 3	0.2
	4 to 6	0.4
	7 to 9	0.6
	10 to 12	0.8
	13 to 15	1.0
	16 to 30	2
	31 to 45	3
	46 to 60	4
	61 to 75	5
	>75	6
a	Three phase cable must be treated as 3 single-phase cables.	
b	More than 20 A must be treated as a multiple of 20 A.	
c	Power cables for lower AC or DC power must be treated based on their rating, i.e., H. a 100 A / 50 V-DC cable is equivalent 5 of the 20-A-cables ( $P = 0,4$ ).	

- Calculate the recommended distance between the APL and the power cables according to Equation 6-1.

$$\textit{Recommended\_distance} = 2 \cdot \textit{Minimum\_distance}$$

$$\textit{Minimum\_distance} = S \cdot P$$

$$\textit{Recommended\_distance} = 2 \cdot S \cdot P$$

#### Equation 6-1: Calculation of recommended distance

As a next step we will do a calculation example for the recommend distances with the following assumptions:

- APL cable used with coupling attenuation  $\geq 55$  dB: Use separation class  $c$  according to Table 6-1
- Open metallic conduit: According to Table 6-1, a minimum separation distance  $S$  of 38 mm.
- 20 Power circuits with 20 A each according Table 6-2: Factor  $P = 2$
- Recommended distance is twice the minimum distance.

This results in:

$$\textit{Recommended\_distance} = 2 \cdot \textit{Minimum\_distance}$$

$$\textit{Minimum\_distance} = S \cdot P$$

$$\textit{Recommended\_distance} = 2 \cdot S \cdot P$$

$$\textit{Recommended\_distance} = 2 \cdot 38 \text{ mm} \cdot 2 = 152 \text{ mm}$$

#### Equation 6-2: Calculation Example for minimum distance



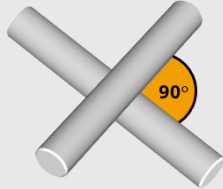
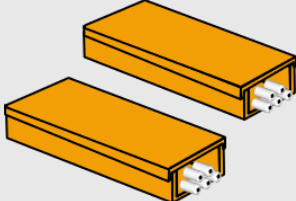
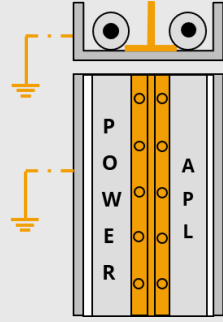
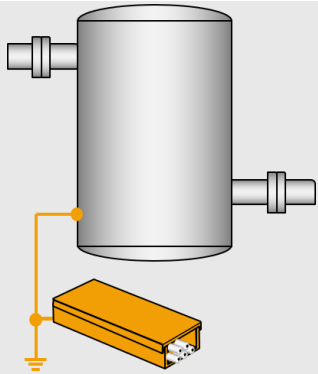
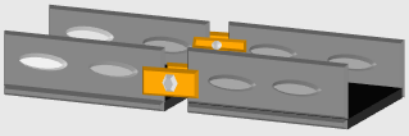
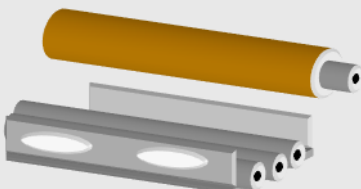
The information regarding the minimum cable distances refers to installations in which APL cables run parallel to unshielded power lines over longer distances. The values given here provide an orientation framework. For shorter parallel cable runs, e.g., inside machines with shielded power cables or when using hybrid cables, it is permissible to stay below the minimum distances. The application-specific reduced distances must be specified by the manufacturer of the system cables. This procedure is outlined in [EN 50174-2].

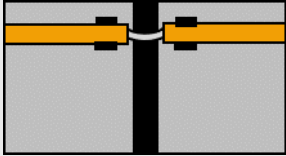
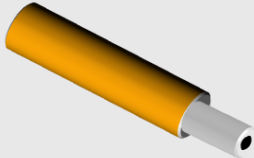
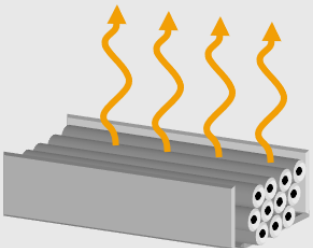


For more details about minimum separation distances, refer to standard [IEC 61784-5-3] or [EN 50174-2], respectively.

In addition, observe the cable routing recommendations given in Table 6-3.

Table 6-3: Cable routing recommendations


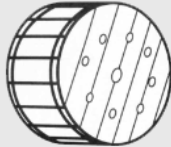
Recommendation	Drawing
<p>Where cables in different categories have to cross, they should always cross at right angles. Try to avoid running cables in different categories in parallel even for short distances.</p>	
<p>In case there is not sufficient space to achieve the required spacing between cables of different categories, the cables must be installed in separate, metallic, conducting ducts. Each duct should only carry cables of the same category. These ducts can be installed directly side by side.</p>	
<p>If a common metallic cable duct is used for all categories, observe the clearances specified in this chapter. In case there is insufficient space to do this, different cable categories must be separated by using metallic separators. These separators must be electrically connected to the channel over a large area.</p>	
<p>Connect metallic conductive cable trays or ducts to the equipotential bonding system of the plant.</p>	
<p>Lay the cables on metallic conductive cable trays. Connect the joints of the cable trays using a large conductive area. Make sure that the connection is made of the same material as the cable track (no mixing of materials).</p>	
<p>If an APL cable cannot be laid in a cable tray, use a cable protection conduit to ensure mechanical protection. In areas with heavy mechanical stress, lay the APL cables in metal-armored conduits. In areas with light to medium stress, plastic conduits can be used instead.</p>	

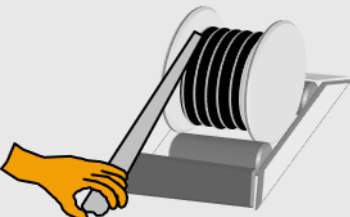
Recommendation	Drawing
<p>If there are 90° bends or building joints (e. g. expansion joints), the cable protection may have to be interrupted. In such cases, make sure that the minimum bend radius of the APL cable is observed. In addition, make sure that the cable cannot be damaged, e.g., by falling parts.</p>	
<p>In areas where people can step or climb, APL cables should be run in metal armored conduits or cable trays</p>	
<p>Observe potential heat dissipations when laying a larger number of power cables into one tray.</p>	

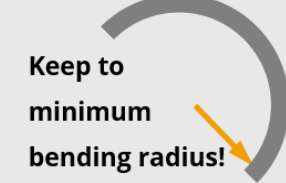
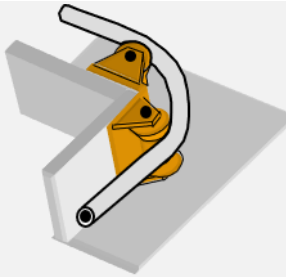
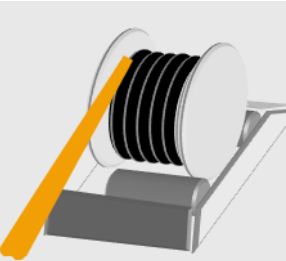

### 6.1.2 Instructions for cable laying process

Observe the following recommendations in Table 6-4 for the cable laying process.

Table 6-4: Cable laying recommendations

Recommendation	Drawing
<p>During transportation, storage and installation, APL cables must be sealed at both ends using a shrink-fit cap. This prevents oxidation of individual wires and accumulation of moisture and dirt inside the APL cable.</p>	
<p>Store and transport the cable reel according to the picture (side view), so that the coiled cable does not entangle.</p>	

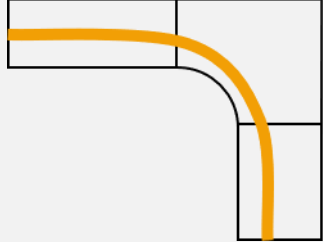
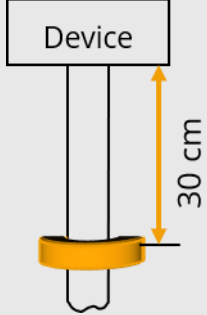
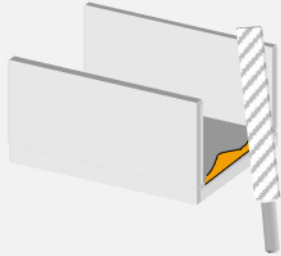
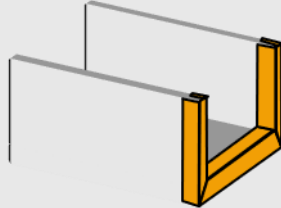
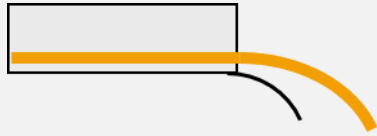
Recommendation	Drawing
<p>You will find temperature specifications of the cable in the manufacturer data sheets. Some manufacturers also print the temperature specifications on the cable sheath.</p> <p>The typical temperature range for APL cable that is installed and not subject to any movement is normally in the range of <math>-20^{\circ}\text{C}</math> to <math>+70^{\circ}\text{C}</math>. However, some APL cables have a deviating temperature range.</p> <p>As soon as the cable is subject to mechanical stress, caused by movement or during installation, the temperature range is reduced significantly. Observe the manufacturer's instructions.</p>	
<p>Carefully unreel the APL cable from the drum by hand, only.</p>	
<p>Do not apply force to pull the cable off.</p>	
<p>Do not squash the APL cable, e.g., by walking or driving over it.</p> <p>Avoid excessive loading of APL cables through pressure, e.g., caused by squashing due to improper attachment.</p>	
<p>Distortion and, in particular, twisting can degrade the electrical properties of APL cables. Therefore, do not distort or twist APL cables whilst unreeling or laying.</p>	
<p>Keep to the minimum permissible bending radius. Falling below the minimum bending radius may damage the APL cable. Consult the manufacturer data sheets for bending radius specification.</p> <p>Typically, for a single bend, the bending radius should not be smaller than 10 times the cable diameter. If multiple bending (<math>&gt;10 \times</math>) is expected, e.g., due to the</p>	

Recommendation	Drawing
<p>connection and disconnection of APL nodes, a larger bending radius is required (typically 20 times the cable diameter).</p>	 <p>Keep to minimum bending radius!</p>
<p>When laying APL cables, they can be subjected to additional mechanical load caused by excessive tension. For that reason, a larger bending radius is required during pulling than in the installed state. Pulling the APL cable over a quoin can be particularly damaging to the cable. It is, therefore, advisable to use guide pulleys.</p>	
<p>Always unreel the APL cable straight from the drum. Never unwind the cable without rotating the drum, since that can cause looping or kinking of the cable.</p>	
<p>The cable drum should always be mounted so as to rotate as the cable is pulled from the drum. This helps to avoid the formation of loops and associated cable kinks. In the case where a loop has been formed, the loop shall be carefully unwound to avoid twisting or distortion. Never simply pull or stretch the cable straight, since this can damage the APL cable and/or change its electrical properties.</p>	

### 6.1.3 Mechanical protection of APL cables

Observe the following recommendations in Table 6-5 to ensure the mechanical protection of APL cables.

Table 6-5: Mechanical Protection of APL cables

Recommendation	Drawing
<p>Use, whenever possible, ducts or cable channels with radiusses or chamfers. This helps to prevent a kink in the cable.</p>	
<p>For all cables that are subject to tensile stress, attach a strain relief about 30 cm from the connection point. Assembly components for strain relief are available from various vendors.</p>	
<p>Sharp edges may damage the APL cable. You should, therefore, de-burr sharp edges – e.g., the cutting edges of cable ducts – using a de-burring tool or file.</p>	
<p>Use plastic edge protectors to protect edges and angles.</p>	
<p>Use bend limiting parts in the direction of cable routing at the end of the duct or cable channel. This helps to prevent a kink in the cable.</p>	

## 6.2 Connecting the APL field devices

APL supports different means to connect APL devices. These are:

- Screw or clamping terminal
- M12 connector
- M8 connector (for non-IS devices only)

In general, the APL device (switch or field device) defines the connecting technology. The APL wiring needs to follow the connection technology defined by the devices. In case there are special requirements with respect to the connection technology, the APL devices need to be selected accordingly. Depending on the selected devices, it might be necessary to combine different connection technologies via one cable. For example, an M12 connector on one end of the cable and a terminal connection on the other end.



Figure 6-1: Possible color assignment for APL cable

Figure 6-1 shows a possible color assignment for an APL cable. APL defines the Signals “APL Signal +”, “APL Signal -” and “Shield (S)”. Even though the shield shall usually be connected with a large cross-section by a clamp to the housing or a ground bar, in some cases the devices might require a connection via a pig tail shown as “S”.



Check the manufacturers information with respect to this issue.

The color assignment red = APL Signal + and green = APL Signal -, is a proposal only. Other assignments are allowed but a consistent assignment shall be used throughout the installation. Also, wires with identical colors are possible when using numbers or other designators on the wires.

The following wiring rules shall be observed:

- The cable wire pair shall have distinctly marked conductors that uniquely identify individual conductors. Consistent polarization shall be maintained at all connection points.
- At the termination points and inline connection points of the APL segment cable, removal of the cable jacket and shield is permitted up to a length of 5 cm. In any case, the continuation of the cable shield, throughout the APL segment, shall be maintained.
- The twist of unshielded wire pairs should be extended to as close as practical to the terminal or connector of a port.



- Cable stubs connected to the APL segment cable are not permitted, with the exception of a maximum of two, up to 10 cm long stubs needed to connect APL auxiliary devices (e.g., surge protection devices) as explained in chapter 5.4.
- Neither conductor of the twisted pair shall be directly connected to the equipotential bonding system /ground at any point in the APL segment. Signals shall be applied differentially throughout the APL segment.

### 6.2.1 Direct connection of an APL device to an APL cable

Figure 6-2 shows the direct connection of an APL device to an APL cable via screw or clamping terminal and the respective pin assignment. Connect the wires according to the pin assignment. In case multiple APL wires are connected using a terminal with multiple pins, for example, on a terminal block in a cabinet, the repeated order of APL signal +, APL signal - and shield needs to be observed.

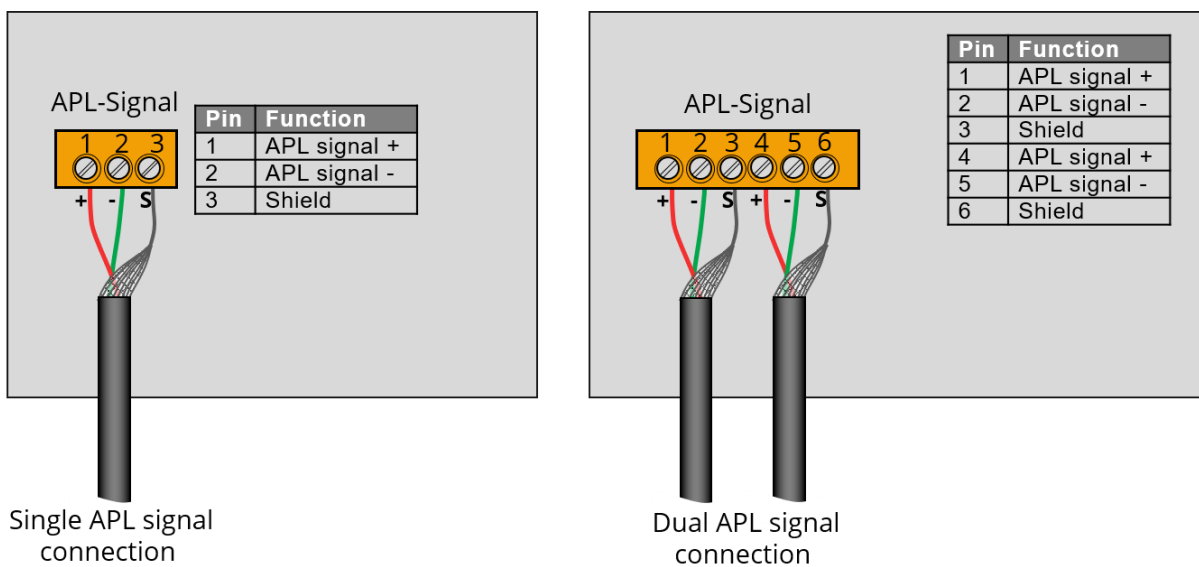


Figure 6-2: Direct connection of an APL device



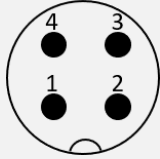
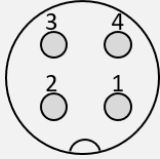
The information provided here is of generic nature in order to give an overview about the connection of APL devices. Check the manufacturers information of your device for details.

Connect the devices according to the previous instructions. Ensure the contact of the wires is well established and check that the wires are fastened in the correct order.

## 6.2.2 Connection of an APL device with M8 or M12 connector

Table 6-6 shows the pin assignment and the pin location for 4-pole M12 connectors connecting APL signals. Connect the wires for an M12 connector according to Table 6-6.

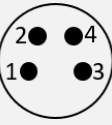
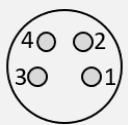
Table 6-6: Pin numbering for APL plug and socket M12 connector according [IEC 61076-2-101] A-coded.

Contact number	Function	Plug, 4 poles	Socket, 4 poles
1	APL signal -		
2	APL signal +		
3	Shield (see Note 1)		
4	Not used		
Metallic connector housing frame		Shield	

Note 1: If shield drain wire is used

Table 6-7 shows the pin assignment and the pin location for 4-pole M8 connectors connecting APL signals.

Table 6-7: Pin numbering for APL plug and socket M8 connector according [IEC 61076-2-104], A coded

Contact number	Function	Plug, 4 poles	Socket, 4 poles
1	APL signal -		
2	APL signal +		
3	Shield (see Note 1)		
4	Not used		
Metallic connector housing frame		Shield	

Note 1: If shield drain wire is used.



All pins defined as “not used” by this guideline, shall not be used for signaling and shall be left unconnected at all APL ports.



Check the manufacturers information to find out how the cable shield needs to be connected to the device.



Special care must be taken when assembling M8 and M12 connectors to ensure tight seal between connector body, grommet, and cable. If not, water ingress may eventually cause communication failure.

Connect the devices according to the previous instructions. Ensure the contact of the wires is well established and check that the wires are fastened correctly.

### 6.2.3 Handling of cable shields

Different types of APL devices provide different means to connect the cable shield to the potential equalization system. Figure 6-3 gives an overview on different ways to connect the cable shield directly to the CBN.

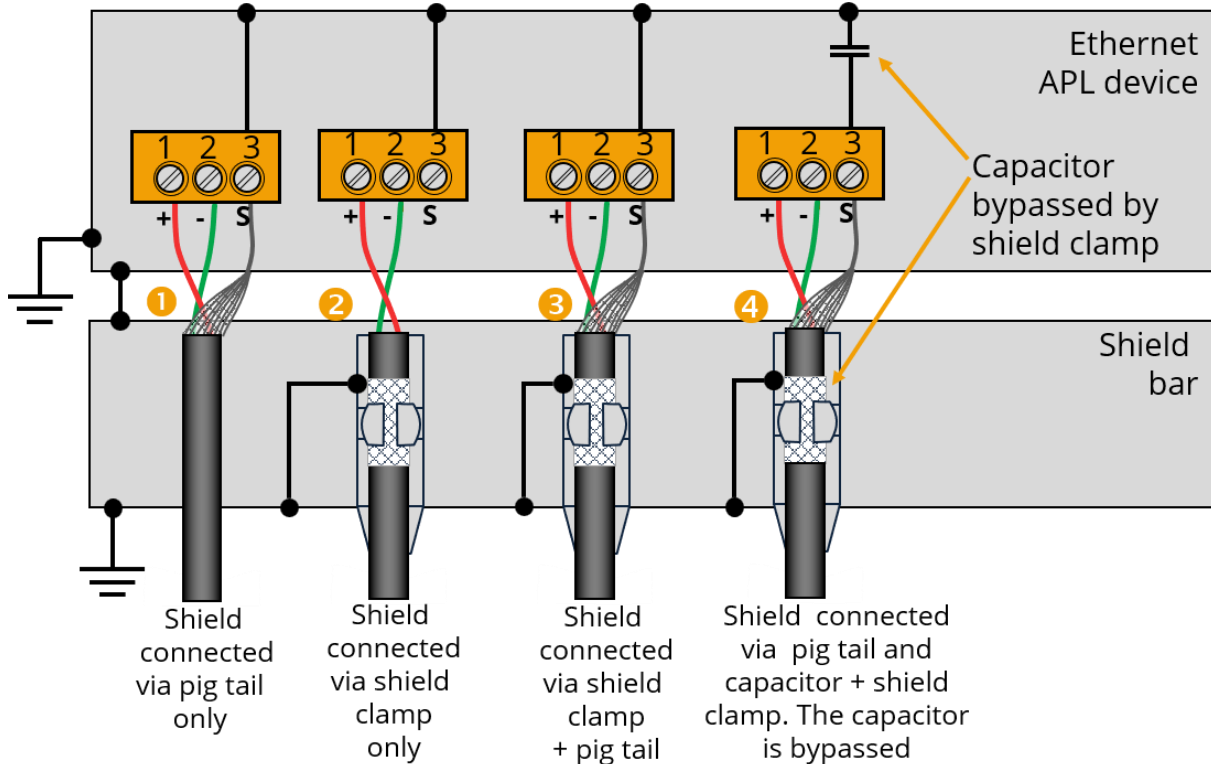


Figure 6-3: Shield connection alternatives with shield connected to CBN

**Alternative 1:** The shield is connected to terminal No. 3 of the APL connector. The pig tail adds inductivity to the connection and deteriorates the effectiveness of the cable shield. The use of an additional shield clamp according to alternative 2 or 3 should be considered

**Alternative 2:** The shield is connected to a shield clamp. If allowed by the manufacturer of the APL device, the pig tail can be omitted. This saves time and effort and reduces the impedance between shield connection and potential equalization system.

**Alternative 3:** In case the manufacturer of the device requires the shield to be connected to terminal No. 3 of the connector, an additional shield clamp can reduce the impedance of the connection between the shield and the potential equalization system.

**Alternative 4:** Some devices have a permanently installed capacitor between terminal No. 3 and the CBN. If a direct connection to the CBN is desired, a shield clamp can be used. In this case the capacitor is bypassed by the shield clamp.

In areas with explosive atmosphere, it is sometimes necessary to connect one side of the shield via a capacitor. Some devices have a suitable capacitor integrated.

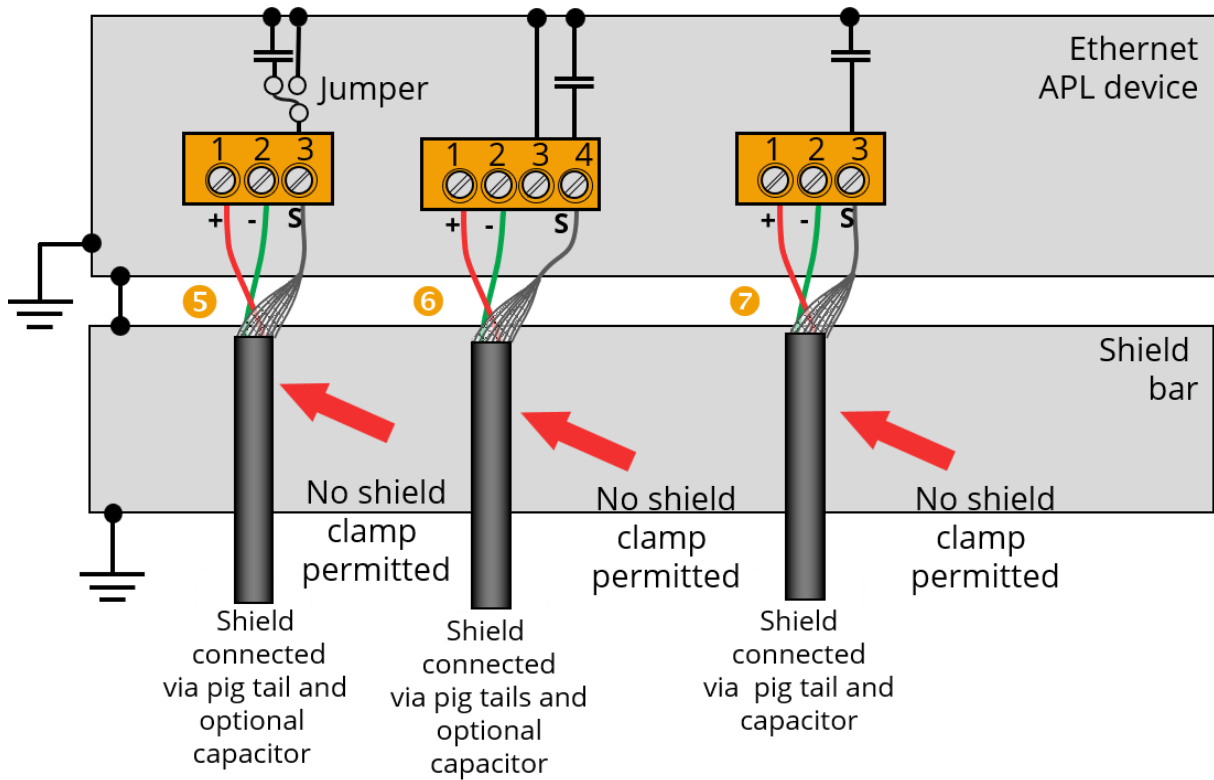


Figure 6-4: Shield connection alternatives with shield connected via capacitor.

**Alternative 5** shows a solution where the use of the capacitor can be selected via a jumper.

Note: In this case a shield clamp is not allowed, as it would bypass the capacitor.

**Alternative 6**: uses a an APL connector that provides four contacts. Contact No. 4 in this case provides for the shield connection via a capacitor. Note: In this case a shield clamp is not allowed, as it would bypass the capacitor. Contact No. 3 establishes a direct connection of the shield to the CBN. In this case a shield clamp would be allowed.

Alternative 7 shows a solution, where a capacitor is connected to pin 3 of the APL connector.

Note: In this case a shield clamp is not allowed, as it would bypass the capacitor.

Select the type of shield connection, that meets the requirements of your application and the grounding guidelines of your company. In case the direct connection of the shield to the CBN is allowed, the variants with the shield clamps allow a low impedance connection of the shield to the common bonding network and yield, from an EMC perspective, good results.



Check the manufacturers information in order to select the correct shield termination.

M12 or M8 connectors connect the cable shield via the metallic housing of the connector. In this case a good contact between the cable shield and the housing of the connector is ensured. In special cases, manufacturers use a shield drain wire connected to pin 3 of the connector instead. The cable has then to be connected according to the guidelines of the manufacturer.



Check the manufacturers information to find out how the cable shield needs to be connected to the device.

Chapter 5 provides detailed information about functional bonding and shielding.

## 7 Acceptance test of APL network installations as first step of commissioning



The acceptance test shall ensure that the installation has been performed correctly and it shall ensure that the commissioning of the system can start from a defined and stable base.

The acceptance test of the APL network consists of the following three steps:

- Step 1: Visual inspection of the cabling and the connectors
- Step 2: Cable measurements
- Step 3: Basic check without control system

In order to decouple the acceptance test and the commissioning of the system, these tests are arranged in a way that the checks can be performed with simple measurement tools only, specifically without the control system in place and in operation. The checklists provided in the subsequent chapters shall provide an idea of how to perform such tests. It is recommended that companies select items from the checklist according to their needs. The additional requirements for installations in explosive atmospheres are not covered here and shall be followed according to [IEC 60079-17] or the national rules and regulations.

### 7.1 Visual inspection of the installation

The first step can be performed by visual inspection and by using the planning documentation. The major goals of this step are to ensure and verify that the installation is done according to the plans and that the cables are undamaged and laid according to the guidelines. A visual inspection should be performed according to Table 7-1. Deviations between planning and installation should be identified and corrected or marked in the documentation.

Table 7-1: Checklist for visual inspection of the APL installation

Item	Item to be checked	Explanation / additional information	Check
1.	Cable laid according to plan?	For later maintenance work, it is crucial that planning and installation adhere to each other.	
2.	Cable type and wire gauge installed according to plan? Values of Table 4-3 observed?	APL requires cable types specified in Table 4-3. The use of other cable might impact the operation of the APL network.	
3.	Connectors used according to planning (open end, M12, M8)?	In some cases, the APL devices might not be installed yet. Therefore, it should be checked to determine if the defined connectors are in place. For devices already installed, this point can be skipped.	
4.	APL cable undamaged?	Damage to the cable (defective insulation, kinks, crushes) can impair the transmission quality of the APL signal. Damaged cables should be replaced.	

Item	Item to be checked	Explanation / additional information	Check
5.	Bending radius observed?	A too tight bending radius leads to unwanted reflections of the APL signal and impairs the transmission quality.	
6.	Cable junctions with power cables at right-angles?	This improves the EMC of the installation	
7.	Sharp edges at the cable-way removed or covered?	Sharp edges might cause an impairment of the cable insulation during the operation of the plant.	
8.	Precautions taken against mechanical damage at critical points? (e.g., bulk-head connectors)	Cabling that is exposed to mechanical stress might need additional protection.	
9.	Strain relief built in and fixed?	In case cabling is subject to strain, a strain relief additionally protects the cable.	
10.	Protective caps installed for unused cable entries?	All unused device cable entries should be sealed with protective caps to avoid dust and humidity entering the housing.	
11.	Equipotential Bonding implemented according to applicable regulations?	The equipotential bonding is key for a good EMC as well as for safety in locations with explosive atmosphere. See chapter 5 for details.	
12.	Cable shield applied at the APL switches and devices and connected to bonding system?	Preferably, the cable shield should be connected to the equipotential bonding system at both ends of the cable. Special rules apply for areas with explosive atmospheres or where an equipotential bonding system cannot be achieved. See chapter 5 for details.	
13.	Cableways connected to equipotential bonding system?	All metallic construction parts of the plant should be integrated into the common bonding network (CBN). See chapter 5 for details.	
14.	Cabling and devices labeled and marked?	The labeling of devices and cables eases troubleshooting during the operation of the plant and, by this, reduces the total cost of ownership during the lifetime of the plant.	
15.	Free APL port labeled for diagnostics connection?	At least one unused port should remain unused, identified, and labeled as an access point for diagnostic tools. See chapter 4.7.	
16.	Power distribution wired according to structure plan (Correct assignment of 24 V / 230 V/other)? Connections between N and PE checked. Connections between DC minus and CBN checked?	The power installation should be checked with respect to unwanted multiple connections between the N conductor and the CBN (230 V installations) and between the minus pole of the DC supply and the CBN. See chapter 10.3 for details.	
17.	Maximum number of inline connections observed?	The APL inline connection is, for example, a junction box or a cable-to-cable connector, used to tie two cable segments together. As both components add reflections and insertion loss to the network segment, their quantity needs to be limited according to Table 4-6.	

Item	Item to be checked	Explanation / additional information	Check
18.	Maximum number of auxiliary devices and inline connections per segment observed?	See Table 4-6.	

## 7.2 Cable measurements

In order to verify the integrity of the APL cabling and the maximum lengths of the trunks and spurs, a cable measurement device can be used. The functionality of such devices varies. Typical functions are:

- Length measurement of cables
- Identification of shorted or open wires
- Identification of the location of a cable break
- Measurement of Insertion loss and related signal parameters

During the acceptance test, the integrity of the cabling should be measured and documented for later use and troubleshooting during the operation of the plant. The check can be performed according to Table 7-2.

Table 7-2: Checklist for cable measurements

Item	Item to be checked	Explanation / additional information	Check
1.	Maximum length 200 m for all spurs verified	In case the spur length is exceeded, the operation of the APL network might be impaired.	
2.	Maximum length for all powered trunks verified according to planning	The length of a powered trunk depends on the load on the trunk and the cross-section of the cable. See chapter 4.2.2 and Appendix 10.2.	
3.	Integrity of the cable verified	The integrity of the cable may be measured in order to find short circuits, open wires, etc..	
4.	Measurement of the electrical parameters of the cable	See chapter 4.1.4. This measurement is especially beneficial in cases where an existing installation is reused.	



### 7.3 Basic check, without control system

The basic check, without control system, makes use of a standard PC /Laptop or a network monitoring system. Power up the APL segment and test the operation of the APL devices, for example, with a network monitoring system. The advantage of such a test is that it can be verified that at least a connection to the device is possible. The information provided by such a test, depends on the tool used and can vary. It may be executed as an optional test to speed up the commissioning phase. The check can be performed according to Table 7-3.

Table 7-3: Checklist for basic check without control system

Item	Item to be checked	Explanation / additional information	Type of check
1	Are all power switches and field switches powered up?	Usually, the switches have light indicators that show power and status of the connection (link indicators).	recommended
2	Are all APL devices visible within the monitoring system?	This test depends on the tool used. The goal of this test is to get an "alive signal" from all APL devices	optional
3	For powered trunks only: What is the supply voltage at the input of every field switch on the line.	The resistance of the network cable causes a voltage drop along the network cable. It is, therefore, useful to check if the supply voltage at each field switch is sufficient (minimum operating voltage, plus reserve)	optional

After these acceptance tests, the commissioning of the APL Segment can start.

## 8 Migration of existing installations

This section describes the migration from existing automation solutions to an Ethernet-APL-based solution. Three use cases will be discussed:

- System with central IO, 4 ... 20 mA devices, marshaling rack, and junction boxes
- System with Remote IO, 4 ... 20 mA devices connected to the remote IO
- System with fieldbus, like PROFIBUS PA or Foundation Fieldbus H1

For each of these use cases, a proposal will be given of how to migrate the existing system.



In case of cable reuse, always consider the age of the cable to be reused. Also, check the suitability of the cable for an APL network, e.g., does the cable comply with either of the cable categories defined in Table 4-3.

### 8.1 Migration of system with central IO and marshaling rack

Figure 8-1 shows an automation system with a centralized IO directly attached to the controller. The controller is equipped with IO modules; in this case, 4 ... 20 mA current loop inputs.

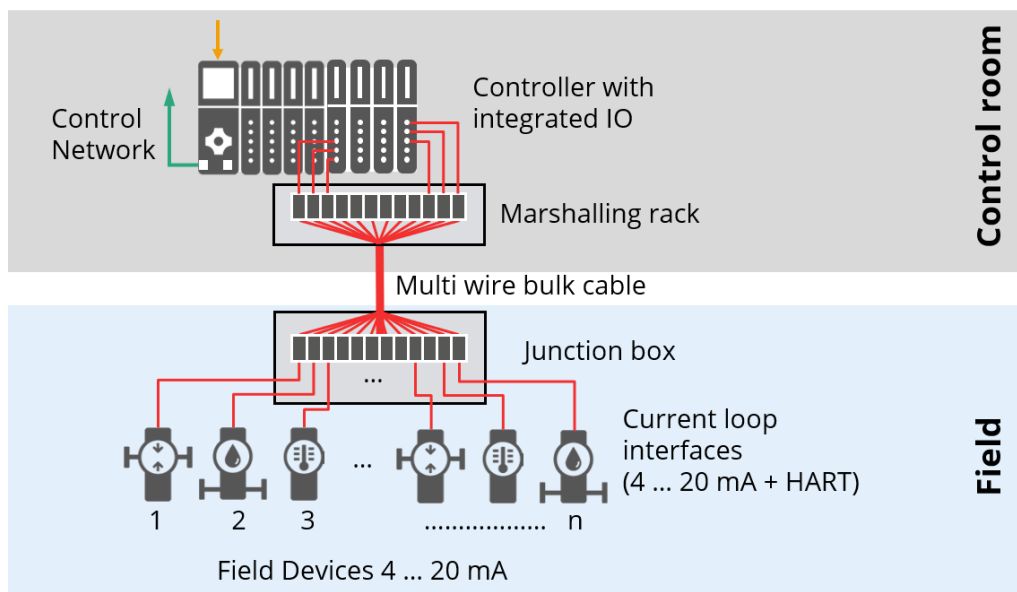


Figure 8-1: Control system with central IO to be migrated

The IO cabling is routed from the sensors in the field via a junction box, a multi-wire bulk cable, and a marshalling rack to the IO modules of the controller in the control room. Possibly, unshielded cabling is used for all parts of the system.

For the migration of such a system, it has to be noted that APL signals shall not be routed through multi-core bulk cables. Therefore, the bulk cable shall be replaced. The cabling from the devices needs to be checked. If it complies with the specification in Table 4-3, it could be reused. Otherwise, these cables shall also be replaced. There are different possibilities to migrate the system to APL. According to chapter 4.2, there are three possibilities to set up the APL system: Powered trunk, or Industrial Ethernet connection to the field switches.

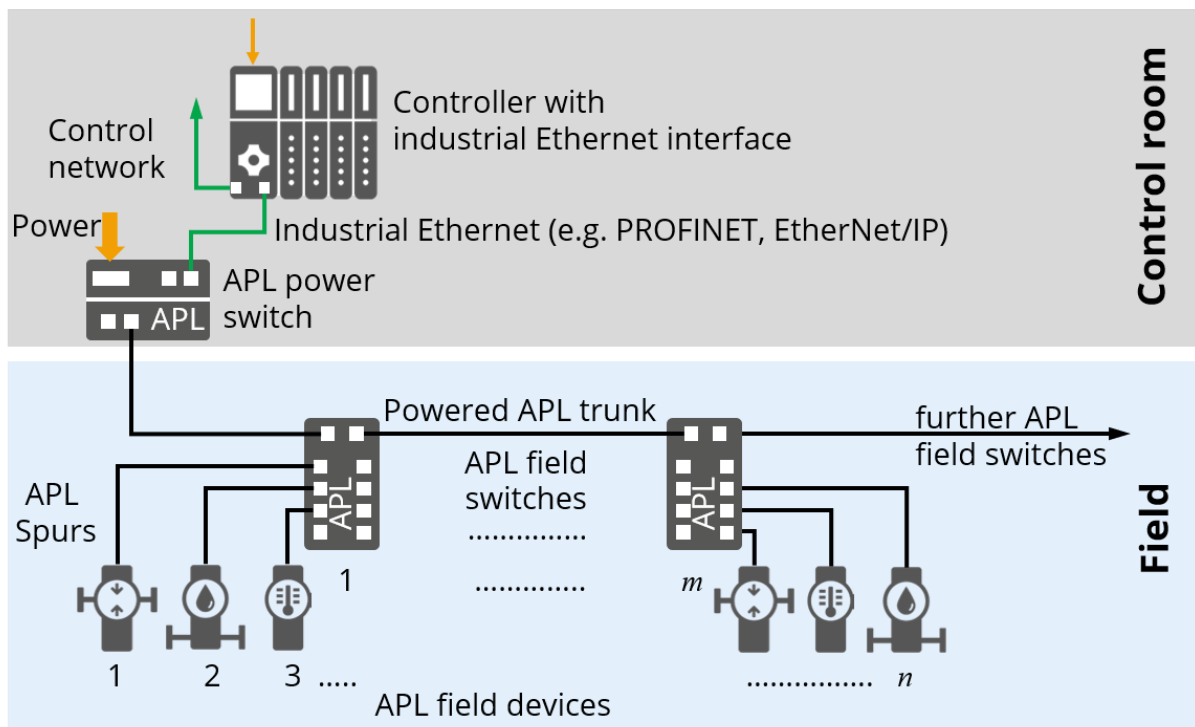


Figure 8-2: Migration proposal for control system with central IO

Figure 8-2 shows one of the possible migrations. The existing cabling has been renewed with APL cabling compliant to Table 4-3. The APL field devices (1 to  $n$ ) are connected to (1 to  $m$ ) APL field switches via APL spurs. As no auxiliary power is assumed to be available in the field, a powered trunk has been chosen. The APL field switch is connected via a powered APL trunk with the APL power switch located in the control room.



This is one out of many possibilities to set up the system. Other alternatives are possible. See chapter 4.2.

## 8.2 Migration of system with remote IO

Figure 8-3 shows a system with remote IO that is connected via fieldbus, e. g. PROFIBUS to a number of  $n$  4 ... 20 mA devices. As the impedance of the PROFIBUS DP communication cable is different from the APL cable, this cable cannot be reused.

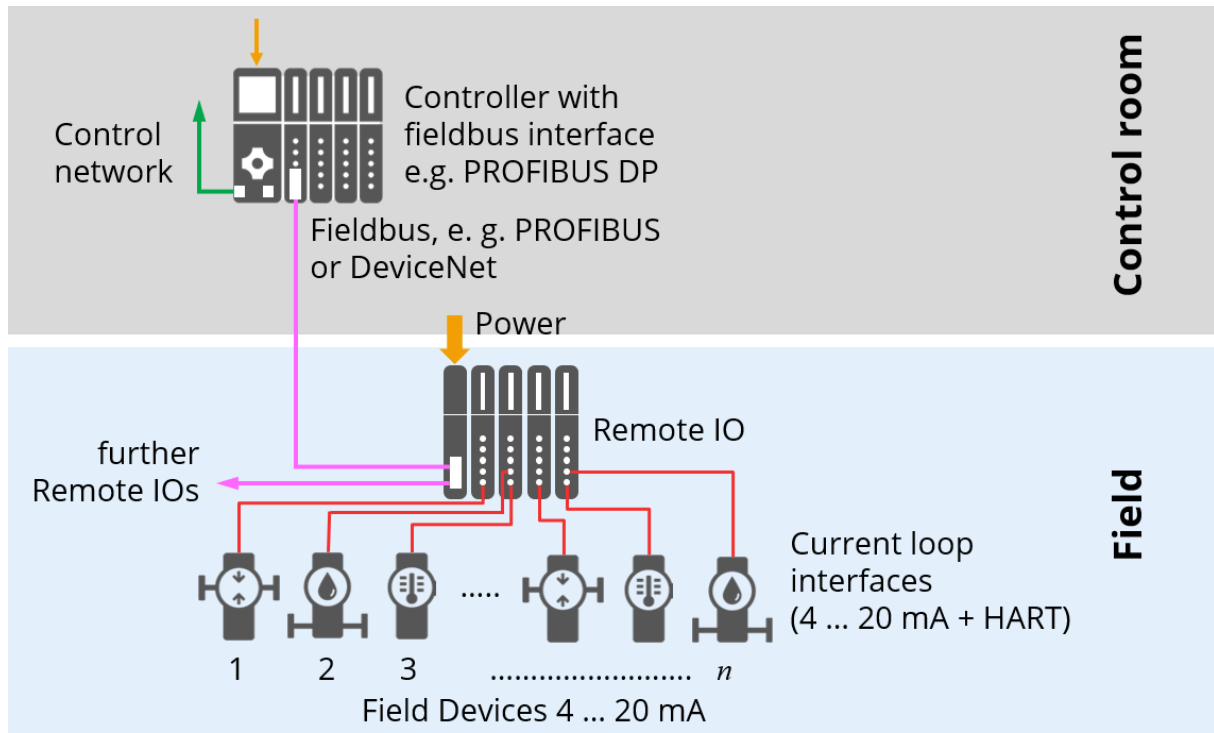


Figure 8-3: Traditional system architecture with remote IO to be migrated

The cabling from the devices needs to be checked. If it complies with the specification in Table 4-3, it could be reused. Otherwise these cables shall be replaced.

According to chapter 4.2, there are three possibilities to set up the APL system: Powered trunk or control network with fiber optic connection to the field switches. In general, the migration solution shown in Figure 8-2 can be applied here as well. As there is already auxiliary power in the field available, powering the remote IO structure, according to Figure 8-4, would also be possible. The controller needs to be upgraded to a version with an Industrial Ethernet interface.

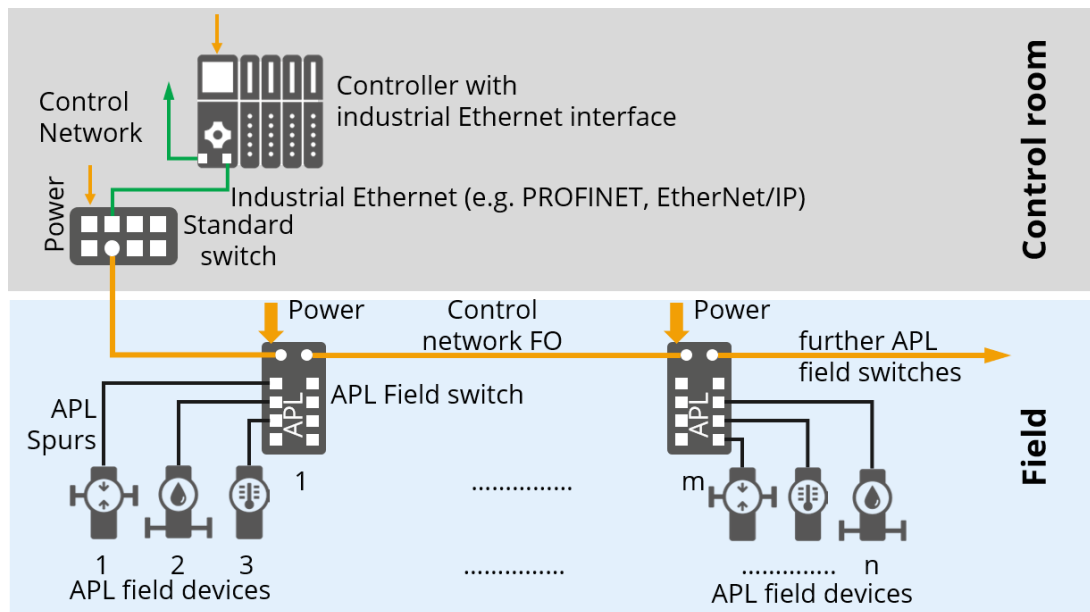


Figure 8-4: Migration proposal for control system with remote IO

In this case, the automation network runs via a fiber optic cable directly to the APL field switches. An APL trunk is not used. The field switches need to be provided with auxiliary power.

In parallel, a migration with a powered trunk, according to Figure 8-2, is also possible.



This is one out of many possibilities to set up the system. Other alternatives are possible. See chapter 4.2.

### 8.3 Migration of a system with fieldbus FF-H1

APL can also be used to migrate from existing fieldbus installations based on Foundation Fieldbus H1 (FF-H1).

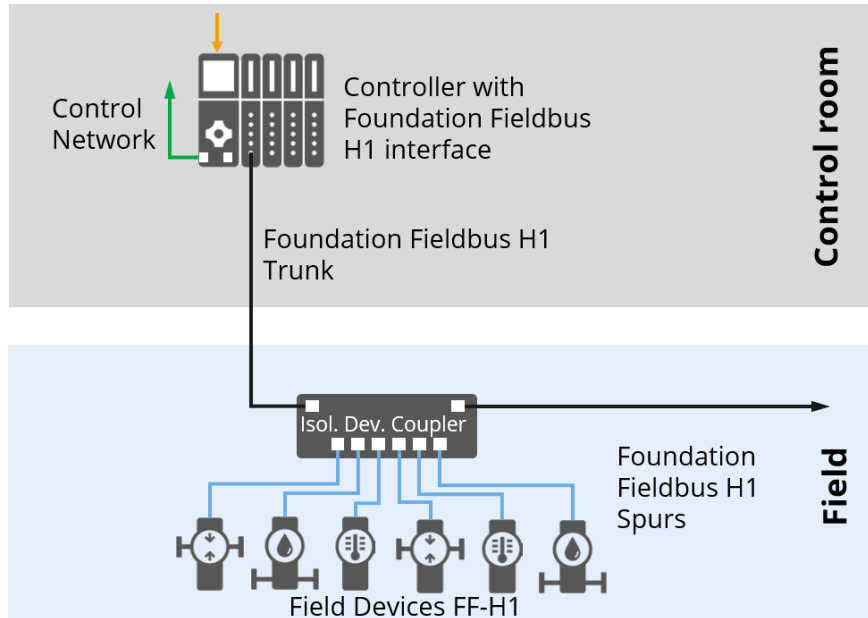


Figure 8-5: Control system with Foundation Fieldbus H1 to be migrated

Figure 8-5 shows a Foundation Fieldbus H1 based system. The controller is equipped with an FF-H1 interface module. From there, the FF H1 trunk runs to the field. An isolating device coupler serves the purpose of a distribution box and limits the voltages and current on the spurs. Since the FF-H1 cable usually has the same parameters as the APL cable (see Table 4-3), the existing cabling can be reused.

The proposed migration solution would be the same as in Figure 8-2 or Figure 8-4. The controller needs to be upgraded to a version with an Industrial Ethernet interface.



This is one out of many possibilities to set up the system. Other alternatives are possible. See chapter 4.2.

## 8.4 Migration of a system with fieldbus PROFIBUS PA

Figure 8-6 shows a system based on both PROFIBUS DP and PA that is to be migrated. The controller is equipped with a PROFIBUS DP interface. A PROFIBUS DP to PA converter (DP/PA Link) converts the PROFIBUS DP signal to a PROFIBUS PA signal. The PROFIBUS PA signal then runs to the field. A field isolating device coupler serves the purpose of current and voltage limitation for the intrinsically safe PROFIBUS PA spurs.

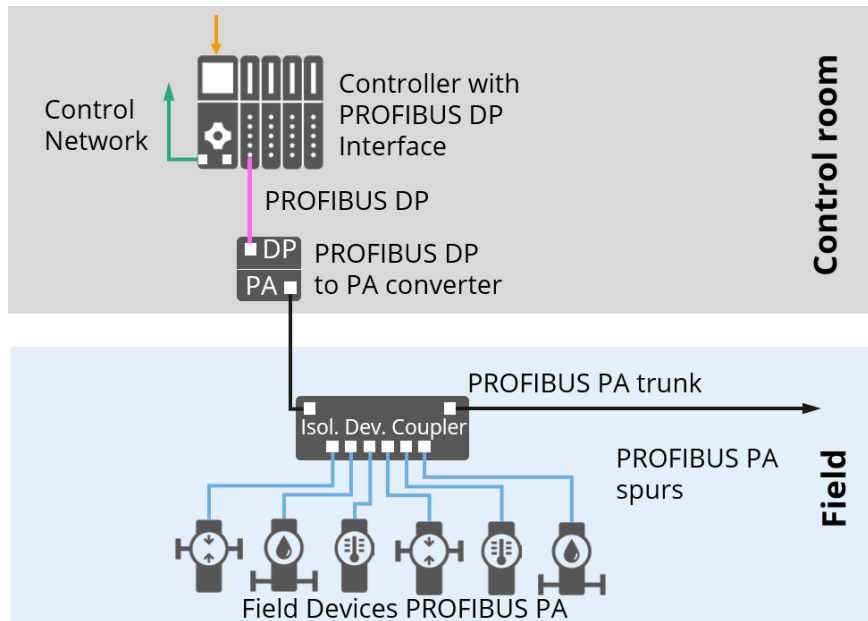


Figure 8-6: Control system with PROFIBUS PA to be migrated

The proposed migration solution would be the same as in Figure 8-2 or Figure 8-4. The controller needs to be upgraded to a version with an Industrial Ethernet interface.



This is one out of many possibilities to set up the system. Other alternatives are possible. See chapter 4.2.

## 9 Glossary

Table 9-1 explains the most important terms used in this document.

Table 9-1: Glossary

Term	Explanation
2-WISE	2-WISE is the 2-Wire Intrinsically Safe Ethernet concept for APL, designed to simplify the examination process for entity parameters of components and cable entity parameters within APL segments. This is achieved by defining universal entity parameter limits for APL ports, according to location and type of hazardous atmosphere, and listing a concise set of rules for the segment's setup. 2-WISE is standardized in [IEC TS 60079-47].
Acceptance test	Test to check the proper installation of an APL network. This is a process prior to commissioning the system
Advanced Physical Layer	The Advanced Physical Layer (APL, Ethernet-APL) is based on 10BASE-T1L physical layer, specified in [IEEE 802.3cg]. Additional specifications, for use in process industries, are provided within the APL documentation, such as the Ethernet APL port profile specification [APS2021].
APL field switch	An APL field switch is an APL switch having at least one port to which an APL spur can be connected.
APL inline connection	An APL inline connection is a passive component that is used to connect APL cables.
APL IS protection class	Designator to specify the Ex characteristics of an APL Port. Not used in this document.
APL port	The electrical and mechanical interface of a device to an APL segment. A 10BASE-T1L-compatible PHY provides the communication interface.
APL power switch	An APL switch, including at least one port feeding power to a trunk.
APL segment	An APL segment is the complete electrical connection, including two APL ports. It consists of two APL ports connected at each end of a two-wire, shielded cable, optionally equipped with a maximum of two auxiliary devices, and containing up to 10 inline terminal connections. An APL segment is either a trunk or a spur.
APL spur	An APL spur is an APL segment with a maximum cable length of 200 m, optionally equipped with a maximum of two auxiliary devices, and up to 4 inline terminal connections. Typically, a spur connects a field device to a field switch.
APL switch	An APL switch is an Ethernet switch, including at least one APL compliant port.
APL trunk	A trunk is an APL segment with a maximum cable length of 1 000 m, optionally equipped with a maximum of two auxiliary devices, and up to 10 inline terminal connections.
Auxiliary device	A device which is connected within an APL segment and does not include a 10BASE-T1L PHY e.g., it may comprise a power load or introduce communication signal insertion losses. A surge protector is an example of an auxiliary device.
Auxiliary power	Power provided to energize components of the automation system, including network components. Frequently used voltages are 110 V AC, 220 V AC, or 24 V DC.



Term	Explanation
Auxiliary power supply	Used to power devices with auxiliary power. e.g., converts 230 V AC to 24 V DC. Other primary and secondary voltages are possible.
Cable shield	Surrounding earthed metallic layer to confine the electric field within a cable and/or protect the cable from electrical influence
Cable stub	A cable stub is an unterminated branch of a cable $\geq 10\text{cm}$ in length.
Common bonding network (CBN)	Equipotential bonding system providing both protective equipotential bonding and functional equipotential bonding. See detailed definitions in Table 5-1.
Controller	A device that initiates the IO data traffic and executes the control logic.
Control network	An Industrial Ethernet-based network that typically connects controllers, e.g., PLCs with IO devices like remote IO, frequency converters, etc.. APL power switches are connected to the control network.
Ethernet	Data transmission system. See IEEE 802.3 for details.
Ethernet Advanced Physical Layer	See Advanced Physical Layer
Ethernet-APL	See Advanced Physical Layer
Engineering workplace	Workplace to configure the controllers, network instrumentation, or remote IO or possibly also the operator console.
EMC	Electromagnetic compatibility. Ability of a system or a component to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.
EMI	Electromagnetic Interference. An electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics/electrical equipment.
Equipotential bonding	Provision of electrical connections between conductive parts; intended to achieve equipotentiality.
Equipment Group	System for the classification of equipment with regard to its intended use in areas with potentially explosive atmospheres. IEC 60079-0 specifies three equipment groups: <ul style="list-style-type: none"> <li>➤ Group I: Equipment intended for use in mines susceptible to fire-damp.</li> <li>➤ Group II: Subdivided into groups IIA, IIB and IIC, equipment intended for operation in areas where explosive gas atmospheres are to be expected, with the exception of mines susceptible to fire-damp;</li> <li>➤ Group III: subdivided into groups IIIA, IIIB and IIIC, equipment intended for operation in areas, in which dusty atmosphere is to be expected, with the exception of mines susceptible to fire-damp.</li> </ul>
Ex e	See increased safety
Ex i	See intrinsic safety
Explosive atmosphere	Area where the hazard of an explosion must be expected.
Fieldbus	Communication system for digital real-time communication in automation systems.
Field device	Equipment that is connected to the field side of a control system. Types of field devices include actuators and sensors.
Field switch	See APL field switch

Term	Explanation
Functional equipotential bonding	Equipotential bonding for operational reasons other than safety.
Increased safety (Ex e)	Type of protection applied to electrical apparatus in which additional measures are applied so as to give increased safety against the possibility of excessive temperatures and of the occurrence of arcs and sparks in normal service and under specified abnormal conditions.
Industrial Ethernet	Ethernet used in an Industrial environment supporting real-time control.
Industrial Ethernet copper cable	Ethernet cable with copper wires. The cable consists typically of 4 wires and supports 100 Mbit/s data rate. Other settings (e.g. 8 wires and 1 Gbit/s) are possible). Maximum length 100 m.
Industrial Ethernet fiber optic cable	Ethernet cable with fiber optic. The cable consists typically of 2 fibers and supports 100 Mbit/s data rate. Other data rates are possible. Maximum length depends on type of fiber.
Inline connection	Mated device or combination of devices, including terminations used to connect cables or cable elements to other cables or application specific equipment. (e.g., terminal blocks)
Installation	Process to install an APL system. e.g., consists of laying of cables, installation of connectors, connecting cables to devices, etc..
Intrinsic safety (Ex i)	Type of protection based on the restriction of electrical energy within apparatus and of interconnecting wiring exposed to the potentially explosive atmosphere to a level below that which can cause ignition either by sparking or heating effects.
I.S.	See intrinsic safety
Isolating device coupler	Used for PROFIBUS PA and Foundation Fieldbus H1. Limits the voltage and the current on the spurs.
Line depth	The line depth of an Industrial Ethernet network describes the maximum number of switches between the controller and the last device in a line. Some Industrial Ethernet protocols have limitations with respect to the line depth in combination with fast cycle times.
Load port	APL port that is powered via an APL segment
Low voltage main distribution system (LVMD)	Distribution system for electrical energy, e.g., in a production plant.
Main earthing terminal	Also: Main earthing busbar / main grounding terminal / main grounding busbar: Terminal or busbar which is part of the earthing arrangement of an installation and enabling the electric connection of a number of conductors for earthing purposes.
Meshed bonding network	Equipotential bonding network consisting of multiple meshes.
NAMUR	User Association of Automation Technology in Process Industries. See: <a href="http://www.NAMUR.net">www.NAMUR.net</a>
Network traffic load	Value that indicates the network load in terms of the maximum amount of data that can be transferred per time unit. Percentage specification.
NI	See non incendive
Non-explosive atmosphere	Area where the hazard of an explosion is not present.
Non incendive (NI)	Non incendive circuit, as applied to areas with explosive atmosphere. A circuit, other than field wiring, in which any arc or thermal effect produced under intended operating conditions of the equipment, is not capable,

Term	Explanation
	under specified test conditions, of igniting the flammable gas-air, vapor-air, or dust-air mixture.
Operator console	Command and control station to supervise and control a technical process in conjunction with the automaton system. Other expressions: Human machine interface or operator station.
P&I Planning	Piping & Instrumentation planning.
Physical layer	Layer 1 of the Open Systems Interconnection model (OSI). See [ISO/IEC 7498-1]:1994 for details.
Power switch	See APL power switch
Planning	In this document: The whole range of work to plan an APL network. e.g., consists of: Selection of devices, network topology planning, planning of the bonding system, etc..
Power class	Designator for APL ports with respect to the provision and consumption of electrical power. See Table 4-5 for details.
Powered APL trunk	APL segment that connects APL switches with each other and that transmits power from the APL power switch to the APL field switches.
PROFIBUS DP to PA converter	Connects a PROFIBUS DP Segment to a PROFIBUS PA Segment. Typically, a converter has one PROFIBUS DP connection and multiple PROFIBUS PA connections.
Protective equipotential bonding	Equipotential bonding for the purposes of electrical safety.
Remote IO	A field device that is allocated to a controller to perform IO functions. Interface modules usually provide standard interface signals like 24 V DC for binary in- and outputs or 4 ... 20 mA for analog in- and outputs.
Segment	See: APL Segment
Shield	See: cable shield
Source port	APL Port that provides power for an APL segment
Spur	See: APL spur
Superordinate industrial Ethernet network	General expression for the network to which the APL part is connected.
Surge protective device (SPD)	A surge protective device (SPD) is an electrical device that is used to protect electronic equipment against electrical surges and voltage spikes. An SPD is an auxiliary device.
Switch	A network device that filters and forwards data packets between LAN segments.
Test Access Port (TAP)	A TAP is a device that is inserted into a network connection. It copies the data passing it to a monitoring device for diagnosis and troubleshooting purposes.
Time sensitive networking (TSN)	Group of IEEE standards to define measures for improved real-time behavior of Ethernet. Includes time synchronization, scheduling, traffic shaping, time slots, frame preemption, and other methods.
Trunk	See: APL Trunk

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## 10 Appendix

This Appendix provides in-depth information for individuals with an interest in APL planning guidelines. Basic information about the topics discussed here can be found in chapter 4.8

### 10.1 APL Network traffic load calculation details

This section gives additional information about the load calculation for APL networks. Basic information about the load estimation and recommended load limits can be found in chapter 4.8.

APL devices sharing the same network may include instrumentation, such as transmitters and valve positioners, but also vibration monitoring systems, video cameras, IR cameras, HMI panels, and controllers. The bandwidth used by these devices varies.

#### 10.1.1 Network traffic load calculation basics

This section provides the basics used for the APL network load calculation. Some basic assumptions are made in order to simplify the calculation and to allow the computation without a calculation tool.

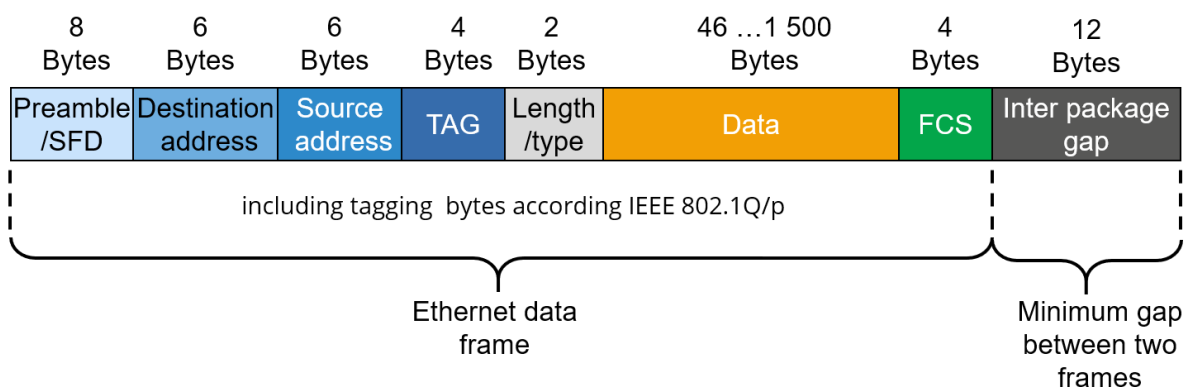


Figure 10-1: IEEE 802.3 data frame

Figure 10-1 shows an IEEE 802.3 data frame, usually called Ethernet data frame. The frame includes a 4-byte tagging information, according IEEE 802.1Q/p, which allows the prioritization of data packets. It can be derived from Figure 10-1 that the minimum payload is 46 bytes. Due to the IEEE 802.3 specification, the payload cannot be smaller than this. If we assume for an APL field device that it transfers 4 Byte measurement value, plus 2 Byte status information, plus administrative information, it is obvious that this information will fit into the minimum data packet length. Even multivariable transmitters will likely be able to fit all information into the minimum data frame. It is assumed that the devices submit data toward the controller. Network control traffic and acyclic traffic is not considered here.

This leads to the assumption that the minimum data frame (46 bytes payload, 88 bytes in total, including inter-package-gaps) will be sufficient for a typical APL field device. If we combine this

with the data rate of 10 Mbit/s for the APL network, we get to Equation 10-1 that calculates the load in %, depending on the number of device and the cycle time.

$$\text{load in \%} = \frac{\text{number\_of\_devices} \cdot 88 \frac{\text{byte}}{\text{device}} \cdot 8 \frac{\text{bit}}{\text{byte}} \cdot 100\%}{\text{cycle\_time in ms} \cdot 0,001 \frac{\text{s}}{\text{ms}} \cdot 10 \cdot 10^6 \frac{\text{bit}}{\text{s}}}$$

Equation 10-1: Network load for typical APL devices

If we apply Equation 10-1 and vary the number of devices and the cycle time, we get to Figure 10-2, which shows the network load depending on the number of devices and the cycle time of the devices for up to 50 devices. Figure 10-3 shows the same information for up to 250 devices.

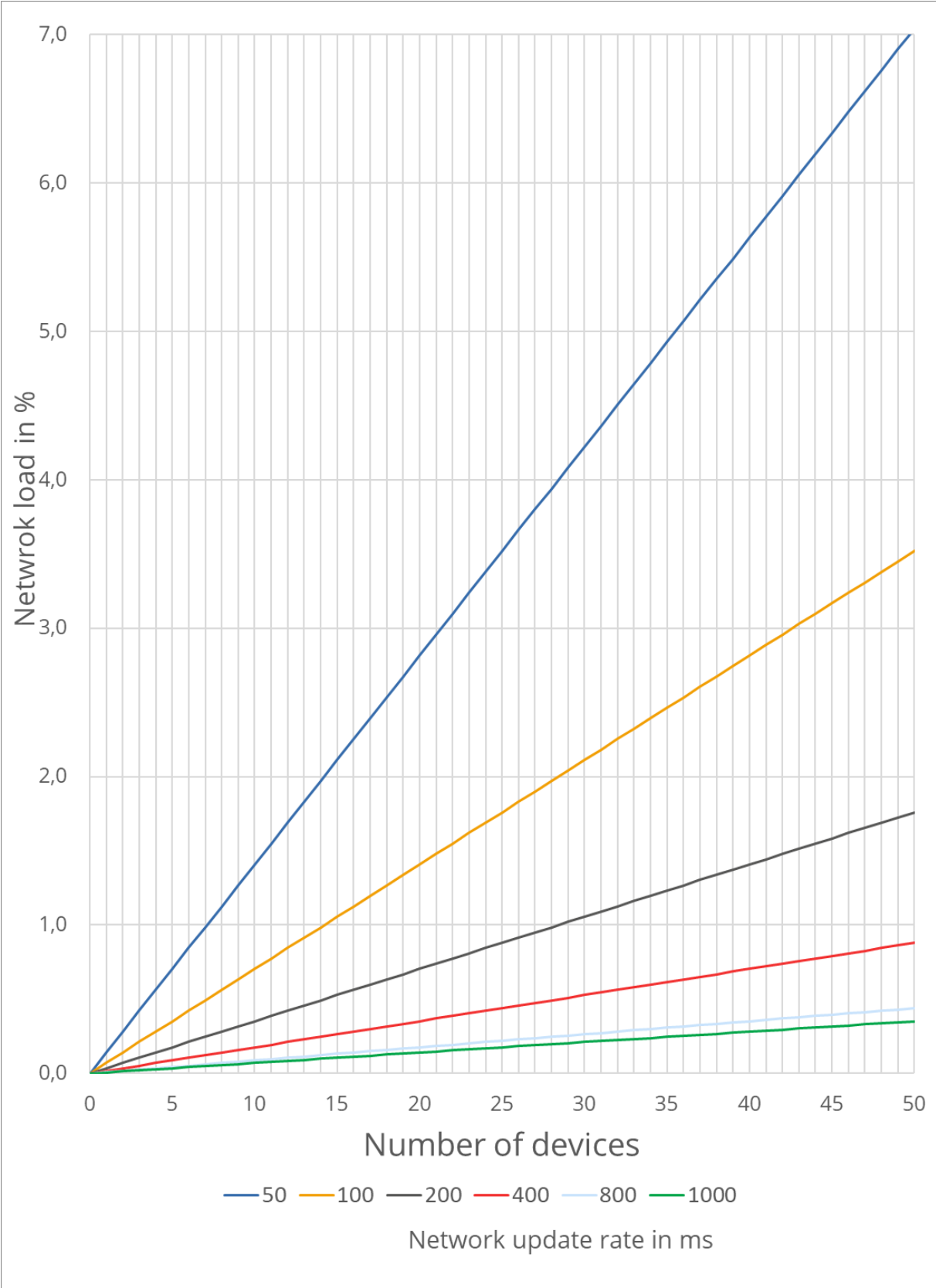


Figure 10-2: Network load as function of number of devices and cycle time up to 50 devices

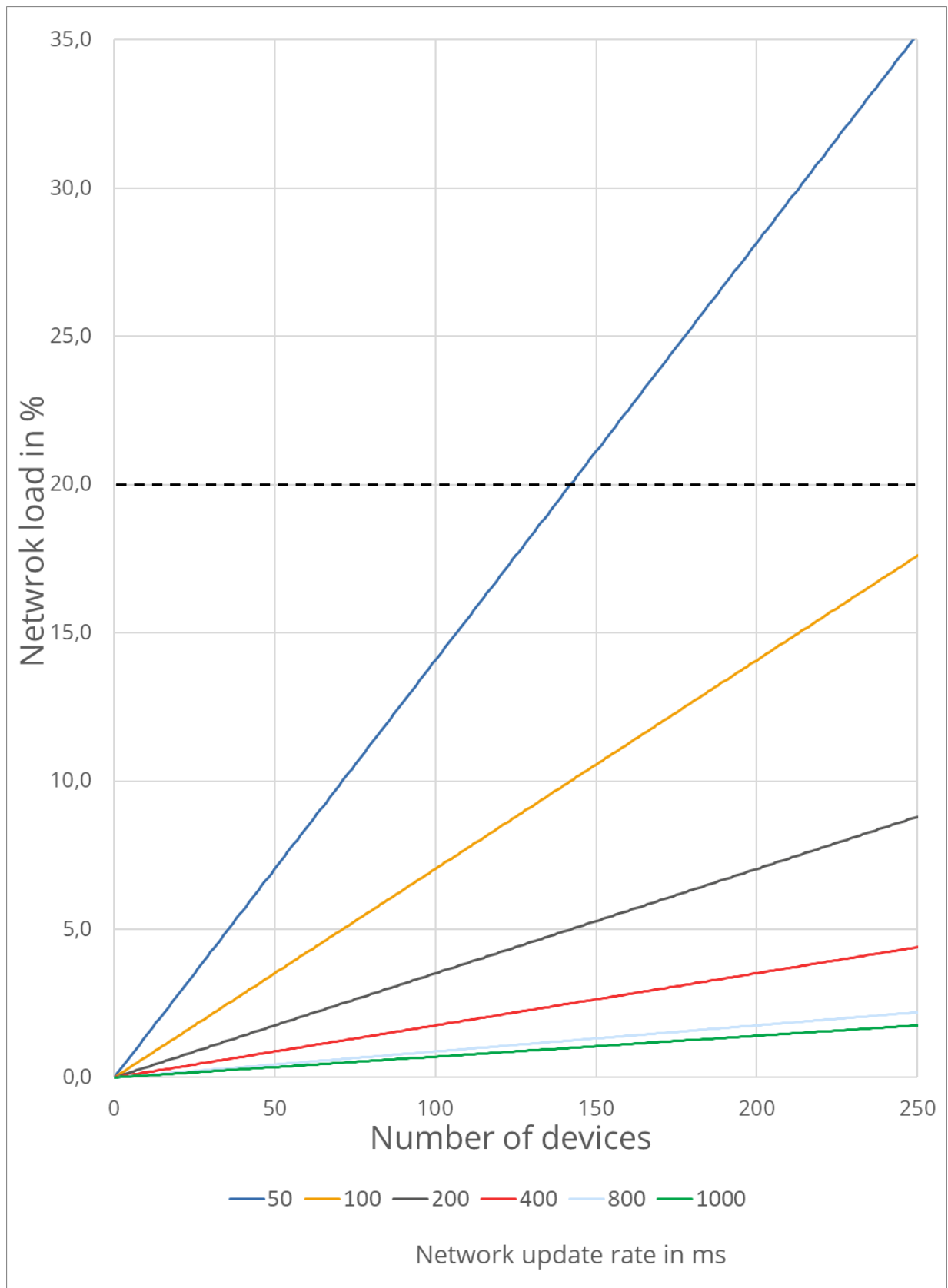


Figure 10-3: Network load as function of number of devices and cycle time up to 250 devices



If we assume an IO update cycle time of 50 ms, which is much shorter than typical values seen in the process industry, it can be seen that 50 devices lead to a network load of around 7 %. This would leave enough bandwidth for acyclic data transfer, e.g., diagnostic or configuration data access, via OPC UA or HART-IP.



APL supports a full duplex communication with a data rate of 10 Mbit/s in both directions over two wires. The calculation made above, considers only the direction from the sensors towards the controller. If actuators are used on the APL network, a similar load calculation has to be done for the opposite direction. Note: The loads for inbound and outbound traffic do not need to be added but can be handled separately.

### 10.1.2 Example calculations – network load for typical use case

This section describes a load calculation for an APL network. It is assumed that devices with different cycle times are used in parallel. The assumed setup is:

- *Load<sub>1</sub>*: 50 sensors with a cycle time of 200 ms each, for control loops
- *Load<sub>2</sub>*: 10 sensors with a cycle time of 4 ms each, (e.g., pressure sensor for fast emergency shutdown)
- *Load<sub>3</sub>*: 20 actuators with a cycle time of 200 ms each, for control loops.

As APL supports full duplex communication, providing a data rate of 10 Mbit/s in each direction, the sensors and the actuators can be calculated independently from each other.

#### Direction from the sensors to the controller (inbound)

$$Load_1 \text{ in } \% = \frac{50 \text{ devices} \cdot 88 \frac{\text{byte}}{\text{device}} \cdot 8 \frac{\text{bit}}{\text{byte}} \cdot 100\%}{200 \text{ ms} \cdot 0,001 \frac{\text{s}}{\text{ms}} \cdot 10 \cdot 10^6 \frac{\text{bit}}{\text{s}}} = 1.76 \%$$

Equation 10-2: Load calculation for Load<sub>1</sub>

$$Load_2 \text{ in } \% = \frac{10 \text{ devices} \cdot 88 \frac{\text{byte}}{\text{device}} \cdot 8 \frac{\text{bit}}{\text{byte}} \cdot 100\%}{4 \text{ ms} \cdot 0,001 \frac{\text{s}}{\text{ms}} \cdot 10 \cdot 10^6 \frac{\text{bit}}{\text{s}}} = 17.6 \%$$

Equation 10-3: Load calculation for Load<sub>2</sub>

$$Load_{inbound} \text{ in } \% = Load_1 + Load_2 = 1.76 \% + 17.6 \% = 19,36 \%$$

Equation 10-4: Load calculation inbound load total

It can be derived from Equation 10-4, that the network load for the inbound traffic (traffic from the sensors to the controller) is 19.36 %. This is below the recommended maximum permissible network load of 20 % according to Table 4-7. In a next step, the outbound traffic needs to be calculated.

#### Direction from the controller to the actuators (outbound)

$$Load_3 \text{ in } \% = \frac{20 \text{ devices} \cdot 88 \frac{\text{byte}}{\text{device}} \cdot 8 \frac{\text{bit}}{\text{byte}} \cdot 100\%}{200 \text{ ms} \cdot 0,001 \frac{\text{s}}{\text{ms}} \cdot 10 \cdot 10^6 \frac{\text{bit}}{\text{s}}} = 0.71\%$$

Equation 10-5: Load calculation for Load<sub>3</sub>

Equation 10-5 shows that the network load for the outbound data traffic is 0.71 %. This is also below the recommended maximum permissible network load of 20 %

### 10.1.3 Calculation of netload for larger data packages

The previous chapters assumed, for the sake of simplicity, that the data packet of an APL device does not exceed the minimum package size of an Ethernet data packet (46 bytes payload, 88 bytes in total including inter-package-gaps). In case a load calculation with larger data packages is to be performed, the calculation can be done according Equation 10-6, where  $n$  specifies the number of bytes to be transferred (payload).

$$Load \text{ in } \% = \frac{\text{number}_{of \text{ devices}} \cdot (n + 42) \frac{\text{byte}}{\text{device}} \cdot 8 \frac{\text{bit}}{\text{byte}} \cdot 100\%}{\text{cycle\_time in ms} \cdot 0,001 \frac{\text{s}}{\text{ms}} \cdot 10 \cdot 10^6 \frac{\text{bit}}{\text{s}}}$$

$$46 \leq n \leq 1\,500$$

Equation 10-6: Load calculation for data packets with variable sized

Due to size limitations of an Ethernet data packet,  $n$  must be larger or equal 46 and lower or equal 1 500.

## 10.2 Length calculation for powered APL trunks

Powered trunks, as describe in section 4.2.2, convey the energy for the APL field switches and the APL field devices via the trunk cable.

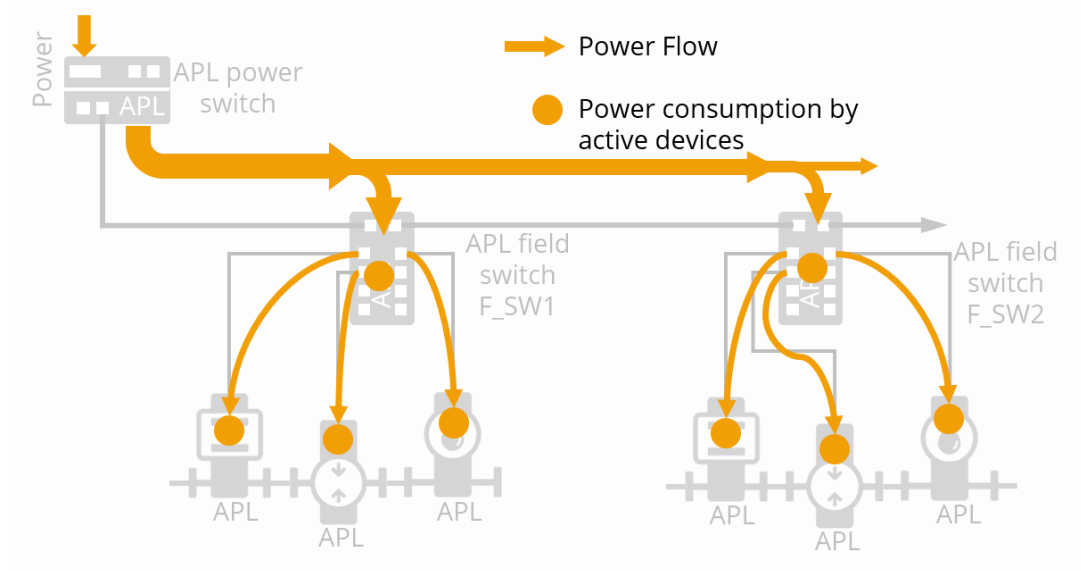


Figure 10-4: Energy flow powered trunk

Figure 10-4 shows the energy flow on a powered APL trunk. The APL power switch feeds the power into the APL trunk. The APL field switches consume a fraction of the power for their own operation. At the same time, they distribute the power to the APL field devices that are connected to the respective field switch. It can be seen from Figure 10-4, that all APL field switches and all APL devices consume power (see amber dots in the drawing).

As the cabling has a certain resistance, the current flow on the trunk and on the spurs leads to voltage drops. These are dependent upon the current that the active devices draw.

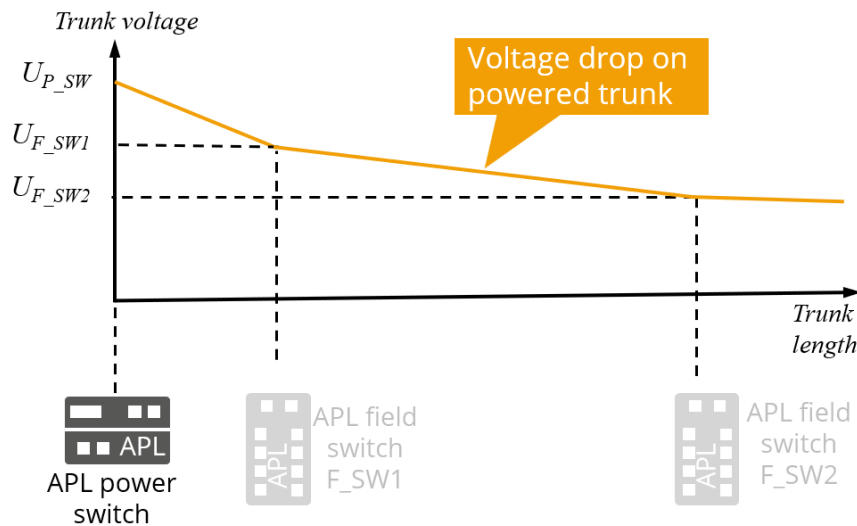


Figure 10-5: Voltage drop on powered trunk

Figure 10-5 shows the voltage drop on a powered trunk. The output voltage of the power switch on the trunk,  $U_{P\_SW}$ , is the starting point. The first segment of the trunk between the power switch and the APL field switch, F\_SW1, has to convey the power for all APL field switches and all APL field devices that are powered by the APL power switch. The resulting voltage drop is dependent on:

- Load current on the segment
- Length of the segment
- Cross section of the wires (wire gauge)
- Temperature of the cable

The segment between the APL field switch, F\_SW1 and F\_SW2, needs to convey the energy for the APL field switch, F\_SW2, the devices connected to this switch, and possibly further switches and devices. Therefore, the load is lower, compared to the first segment.

At the date of release of this document, no firm figures about the power consumption and no voltage current characteristic were available to the author. Therefore, a calculation scheme is not yet available. Contact your vendor or user organization for calculation examples and tools.

## 10.3 Recommendations for improved EMC

One reason to use capacitors for connecting cable shields to the common bonding network are to restrict vagabonding currents in the CBN. The use of the capacitors suppresses vagabonding currents running through the cable shields, which would be the case where the shield is connected at both ends to the CBN. This however has the disadvantage that the shielding effect against magnetic fields is reduced. Therefore, it would be more useful to eliminate the root cause of the problem, the vagabonding currents, instead of dealing with the negative effects of using capacitors. There are several reasons for vagabonding currents. The next chapters indicate the reason and give hints on how to resolve the problem.

### 10.3.1 Disadvantages of TN-C power systems

The TN-C system uses a PEN conductor, that serves two purposes: It provides a return path for the regular current and PE for grounding metallic parts of an electric device.

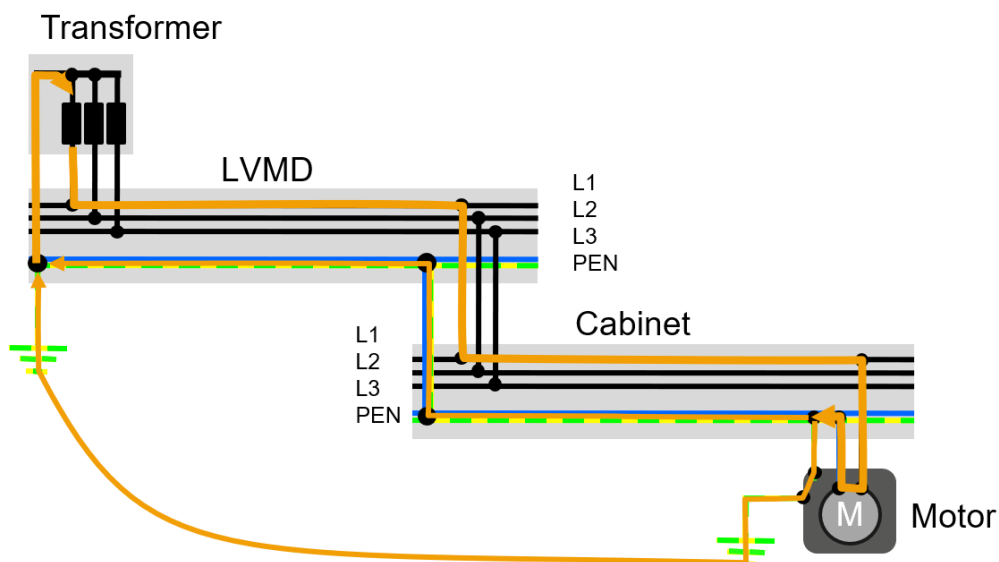


Figure 10-6: Vagabonding currents caused by TN-C System

Figure 10-6 shows a motor connected to a TN-C system. The current (amber lines) runs from the mains transformer via the phase L1 to the motor and through the PEN conductor back to the transformer. At the same time, the housing of the motor is connected to the PEN conductor and to the metallic construction / potential equalization system. As the star point of the transformer is also connected to the potential equalization system, a portion of the current can also run through the potential equalization system. This leads to the vagabonding currents discussed earlier.



In order to avoid vagabonding currents, the usage of TN-C power systems should be avoided. Also, TN-C systems are not allowed for installations in explosive atmospheres.

### 10.3.2 Usage of TN-S power system

A TN-S power system uses five conductors. The phases L1, L2 and L3, the neutral conductor, N, and the Protective Earth PE. The N and the PE conductor are connected via the PEN bridge, close to the transformer. The PE is connected at multiple points to the common bonding network (CBN).

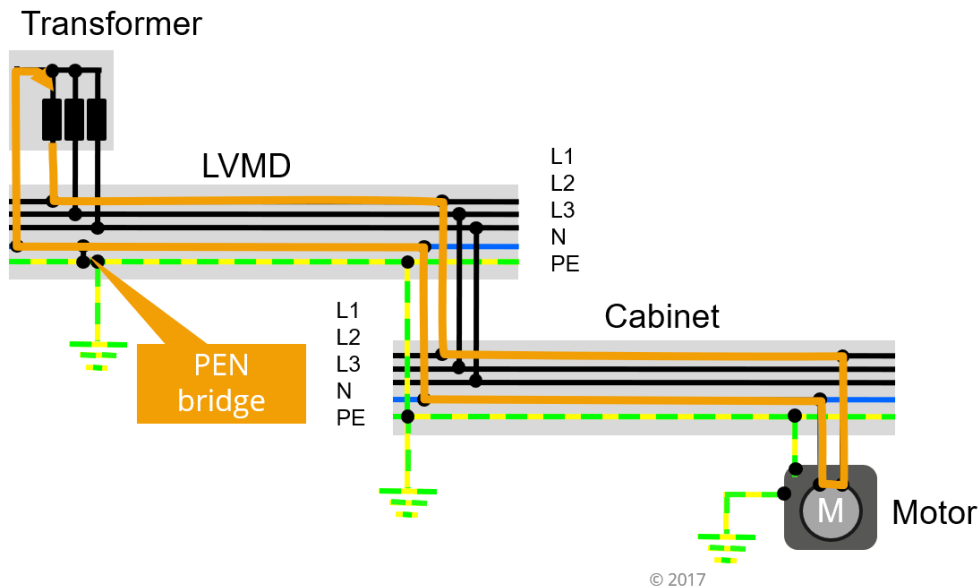


Figure 10-7: TN-S System

Figure 10-7 shows a TN-S power system. It can be seen that the operating current (amber line) runs from the transformer via the phase L1 to the motor and via the N conductor back to the transformer. Even though the Motor is connected to the PE and is connected to the equipotential bonding system, no current runs through the grounding system. Therefore, the TN-S system prevents vagabonding currents in the potential equalization system.



In order to avoid vagabonding currents, a TN-S power system should be used

When using the TN-S system, the N and the PE conductor are connected at a single point close to the transformer. Figure 10-7 shows the PEN bridge on the left side of the drawing.

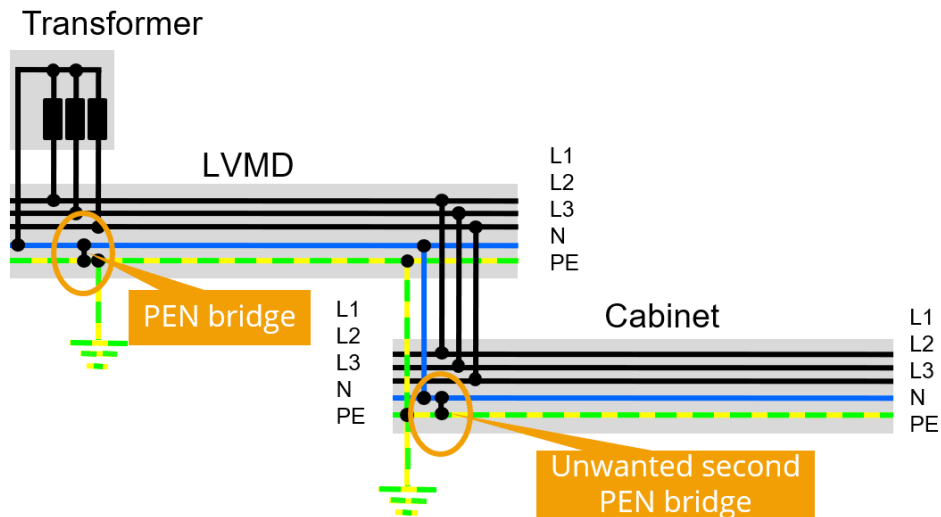


Figure 10-8: TN-S System with second PEN bridge

In some cases, installation personnel may connect the N and the PE conductor in other locations as well. This leads to unwanted, additional PEN bridges, shown in the right part of Figure 10-8. These additional PEN bridges have to be avoided, as they cause vagabonding currents in the common bonding network.

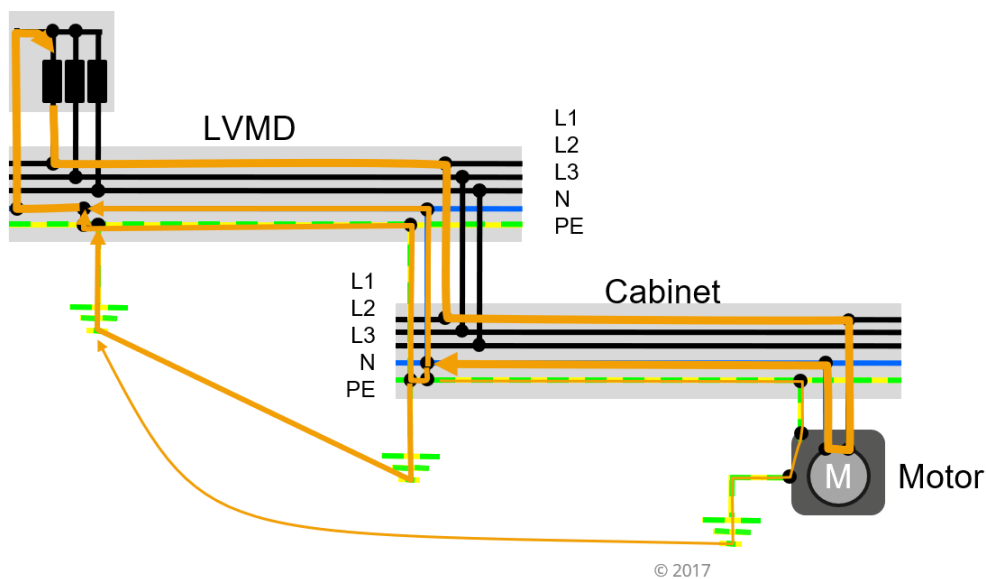


Figure 10-9: Vagabonding currents in TN-S network due to second PEN bridge

Figure 10-9 demonstrates the impact of a second PEN bridge. It can be seen that the second (unwanted) PEN bridge allows the current in the N conductor to transit into the PEN conductor and, from there, into the common bonding network.



Install only one PEN bridge close to the transformer. Additional PEN bridges should be avoided in order to prevent vagabonding currents in the CBN.

### 10.3.3 Connection of auxiliary DC power supplies negative to CBN

In many cases the negative of an auxiliary DC power supply is connected to the common bonding network, as shown in Figure 10-10. For this example, a 24 V DC power supply has been chosen.

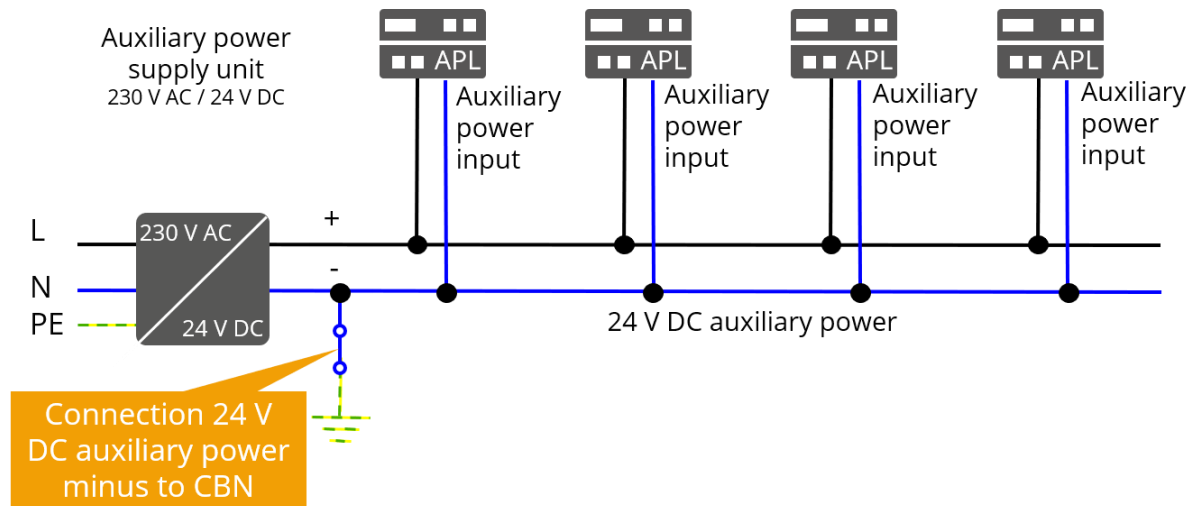


Figure 10-10: Connection of 24 V DC auxiliary power supply minus to CBN

Figure 10-10 shows an auxiliary power distribution from the power supply to four APL power switches. Close to the power supply, the negative of the 24 V DC power supply is connected to the bonding network. This connection serves safety purposes. In some cases, installation personnel create additional (unwanted) connections between the 24 V DC negative and the CBN. This unwanted connection is shown on the right side of Figure 10-11.



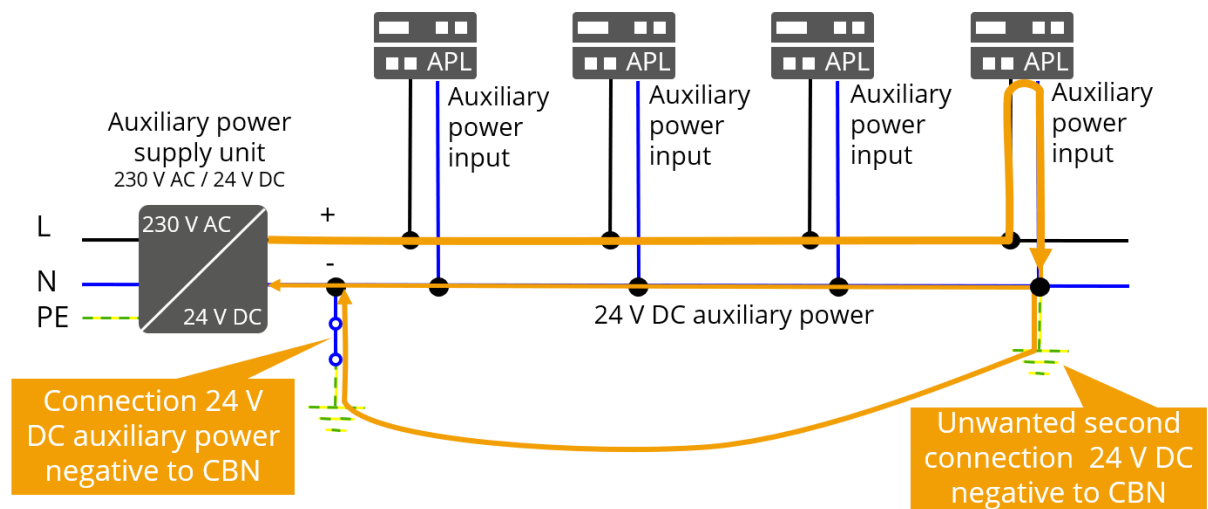


Figure 10-11: Second, unwanted connection of 24 V DC power supply minus to CBN

It can be seen that the current, that should flow through the negative conductor to the power supply, now separates into one part flowing through the negative conductor and the other part that flows through the CBN back to the power supply (amber line). This leads to vagabonding currents in the CBN.



If the negative of a 24 V DC power supply is connected to the common bonding network, it should be connected only once, close to the power supply. Multiple connections should be avoided.

To avoid the problem described above, an insulated DC system with insulation monitoring may also be used.

## 10.4 Documentation Proposal for APL 2-WISE Systems

Table 10-1: Documentation Proposal for APL 2-WISE Systems

	No.	Device Name	Manu- fac- turer	Type	Certificate	Equip. group (IIB, IIC)	Level of pro- tec- tion (ia, ib)	Max. ambi- ent tempera- ture	2-WISE type
Field switc	1	APL field switch	ABX	FS_001	Ex-95.D.yxy	IIC	ib	50 °C	APL Field switch
APL field devices	1	Temperature Sensor	XYZ	TS XYZ	Ex-95.D.xyz	IIC	ib	50 °C	APL field device
	2								APL field device
	3								APL field device
	4								APL field device
	5								APL field device
	6								APL field device
	7								APL field device
	8								APL field device
	9								APL field device
	10								APL field device
	11								APL field device
	12								APL field device
Additional information	All devices shall comply to the 2-WISE concept according to IEC TS 60079-47:2021 / VDE V 0170-47:2021-06								
	<b>2-WISE Power Source ports (for IIB &amp; IIC) (APL field switch)</b>					<b>2-WISE Power Load ports (for IIB &amp; IIC) (APL field device)</b>			
	Output power $P_o \leq 5,32$ W Output voltage $U_o$ 14 V to 17,5 V Short circuit current $I_o \leq 380$ mA Unprotected residual capacitance $C_i \leq 5$ nF Unprotected residual inductance $L_i \leq 10$ $\mu$ H					Input power $P_i \geq 5,32$ W Input voltage $U_i \geq 17,5$ V Input current $I_i \geq 380$ mA Max. internal capacitance $C_i \leq 5$ nF Max. internal inductance $L_i \leq 10$ $\mu$ H Leakage current $\leq 1$ mA			
	<b>Cable parameters required for use in a 2-WISE intrinsically safe system</b>					<b>Auxiliary devices (e.g. surge protectors)</b>			
	Loop resistance 15 $\Omega$ / km ... 150 $\Omega$ / km Inductance 0,4 mH / km ... 1 mH / km Capacitance 45 nF / km ... 200 nF / km					Input power $P_i \geq 5,32$ W Input voltage $U_i \geq 17,5$ V Input current $I_i \geq 380$ mA Max. internal capacitance $C_i \leq 5$ nF Max. internal inductance $L_i \leq 200$ nH Leakage current $\leq 50$ $\mu$ A			
For the use of <u>simple apparatus</u> in 2-WISE circuits, the internal inductance $L_i$ and internal capacitance $C_i$ of each simple apparatus connected to a 2-WISE system shall be less than 1 $\mu$ H and 1 nF respectively.									

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