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The Ethernet-APL Engineering Process

A brief look at the Ethernet-APL engineering guideline

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The vision of an "Industrial Ethernet down to the sensors and actors" has become reality. At the Achema fair in June 2021 Ethernet-APL was introduced. This technology is based on a 2-wire Ethernet that conveys information as well as energy to the sensors and actuators of the automation system. Ethernet-APL is based on 2-wire Ethernet standard IEEE 802.3cg [1] running at 10 Mbit/s. An additional specification, the Ethernet-APL Port Profile Specification [2], defines additional parameters for the use of the technology in the process industry, especially in areas with potentially explosive atmospheres. As a next step, potential users need to become familiar with the engineering process of Ethernet-APL networks. For this purpose, the Ethernet-APL project provides the Ethernet-APL Engineering Guidelines [3] that cover the main areas of planning, installation and acceptance testing.

#Ethernet-APL #2-wire Ethernet #two wire Ethernet #engineering guideline

Der Ethernet-APL-Entwicklungsprozess

Ein kurzer Blick auf die Ethernet-APL Engineering Guideline

Die Vision von „Industrial Ethernet bis zu den Sensoren und Aktoren" wird Realität. Auf der Messe Achema im Juni 2021 wurde Ethernet-APL in den Markt eingeführt. Basis dieser Technologie ist ein 2-Draht-Ethernet, das sowohl Informationen als auch Energie zu den Sensoren und Aktoren des Automatisierungssystems überträgt. Ethernet-APL basiert auf dem 2-Draht-Ethernet-Standard IEEE 802.3cg [1], der mit 10 Mbit/s arbeitet. Eine zusätzliche Spezifikation, die Ethernet-APL Port Profile Specification [2], definiert zusätzliche Parameter für den Einsatz der Technologie in der Prozessindustrie, insbesondere in explosionsgefährdeten Bereichen. Im nächsten Schritt müssen sich potenzielle Anwender mit dem Engineering-Prozess von Ethernet-APL-Netzwerken vertraut machen. Zu diesem Zweck stellt das Ethernet- APL-Projekt die Ethernet-APL-Engineering-Guideline [3] zur Verfügung, welche die wichtigsten Bereiche der Planung, der Installation und den Abnahmetest abdeckt. Dieser Artikel soll einen Überblick über den Ethernet-APL-Engineering-Prozess geben und die relevanten Planungsschritte beschreiben.

#Ethernet-APL #2-Draht-Ethernet #Zweidraht-Ethernet #APL Engineering Guideline

1. Introduction to Ethernet-APL

This chapter will give ab brief introduction to Ethernet-APL and the underlying technological principles. Figure 1 shows the ISO/OSI protocol stack of Ethernet according to ISO/IEC 7498-1 [4].

It can be seen that Ethernet-APL resides at the layer 1 of the protocol stack, the physical layer. This is also indicated by the abbreviation chosen: APL stands for Advanced Physical Layer. It can also be seen that Ethernet-APL is one of many other physical layers, used for Ethernet and that the physical layer can be used independent of the other layers above. Therefore, Ethernet-APL can be used with any Ethernet based protocol, e. g. in combination with EtherNet/IP, HART-IP, OPC UA or PROFINET. The design of Ethernet-APL follows the requirements defined in the NAMUR recommendations NE 74 [5] and NE 168 [6]. With the Ethernet-APL physical layer, the cooperating standards development organizations (SDOs) defined a communication solution to meet the needs of the process industry for a converging network architecture in the automation domain supporting the following features:

- Ethernet based communication
- 2-wire connection to the sensor
- Robust and simple connection technology
- Power supply of the devices via 2-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

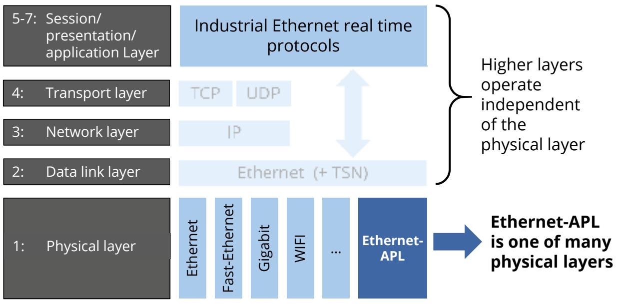

Figure 1: ISO/OSI Protocol stack with Ethernet-APL

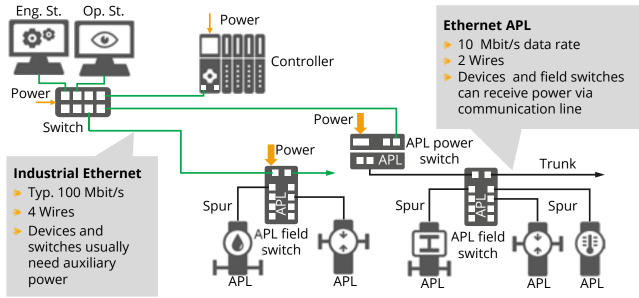

Figure 2: Differences between 100 Mbit/s Industrial Ethernet and Ethernet-APL

» Replacement of failing Ethernet-APL field devices that are connected to the spurs, in areas with explosive atmosphere is possible during operation.

Figure 2 shows the differences between the commonly used 100 Mbit/s Industrial Ethernet physical layer and the Ethernet-APL physical layer.

In the top left corner, a controller is shown in combination with an engineering- and operator station. The devices are connected e. g. via a 100 Mbit/s Industrial Ethernet. All devices need 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 2 shows an Ethernet-APL power switch. The Ethernet-APL power switch is on the uplink side connected to the 100 Mbit/s Industrial Ethernet backbone and receives auxiliary power. The Ethernet-APL power switch converts the 100 Mbit/s Industrial Ethernet to the 10 Mbit/s Ethernet-APL. The Ethernet-APL uses 2 wires (single pair) and provides full duplex communication via the 2 wires. The Ethernet-APL trunk connects the Ethernet-APL power switch with the Ethernet-APL field switches. The length of an Ethernet-APL trunk segment can be up to 1 000 m. The Ethernet-APL power switch provides in parallel to the data electrical energy for the devices, connected to the Ethernet-APL network: In this case the Ethernet-APL field switch and the Ethernet-APL field devices. The APL field devices are connected via Ethernet-APL spurs to the Ethernet-APL field switches. In addition, the image also shows a field switch that is directly connected to the 100 Mbit/s Industrial Ethernet control network. For the ease of understanding, the 100 Mbit/s Industrial Ethernet network (green color) will be referenced as control network in this document.

2. Cabling and connection technology

The supported Ethernet-APL cable is a balanced, shielded twisted-pair cable with a characteristic impedance in the range of 100 Ω ± 20 % in a frequency range of 100 kHz to 20 MHz (measured according to ASTM D4566-05 [7] 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^2) to 14AWG (2.5 mm^2) either with solid or stranded wires.
The reference cable type for Ethernet-APL segments is fieldbus type A cable, MAU types 1 and 3, as specified in IEC 61158-2 [8]. This cable meets the requirements for intrinsically safe applications as described in IEC TS 6007947 [9] and may be used in non-IS applications as well. A detailed specification of the cable parameters can be found in the Ethernet-APL port profile specification [2], defining four cable categories (I to IV). A cable with the category IV will allow trunk lengths of up to 1 000 m and spur lengths of up to 200 m. In case a powered trunk is used, the maximum trunk length also depends on the voltage drop across the cable. Shorter distances have to be expected in this case for trunk cables. Best practice examples for a powered trunk can be found in the Ethernet-APL Engineering guideline [3].
In case using an already installed cable infrastructure, it is mandatory that the performance of the data transmission is ensured. An examination shall be performed according to ISO/IEC 11801-3 [10]. Usually, this task is performed with a measurement device that supports the measurement of the specific cable parameters. While for trunk cables the insertion loss limit values of [10] 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 [10] to reflect the maximum 200 m spur cable length in comparison to the maximum 1 000 m trunk cable length.
The standard IEC 61156-13 [11] will specify a single pair cable for 2-wire-Ethernet with solid wires, but the standard is still under development. An additional standard for stranded wires will follow. Currently no firm statement can be made about the usability of cables for Ethernet-APL according to IEC 61156-13, but a large number of existing cables today meets already the requirements of Ethernet-APL. Information with respect to the applicability of this standard will be given at later point in time.
The Ethernet-APL port profile specification [2] defines the following connection technologies for Ethernet-APL devices

» Screw or spring clamp terminals / modular terminal blocks

» M12 connector, A-coded

» M8 connector, A-coded (not for intrinsically safe circuits)

3. Ethernet-APL Network Structures

Ethernet-APL offers a variety of network structures that allow the users to set up the Ethernet-APL network according to the needs of the plant.

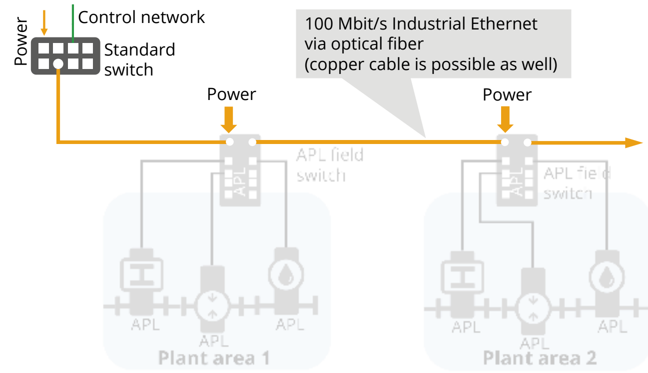

Figure 3: Field switches with 100 Mbit/s Industrial Ethernet connection

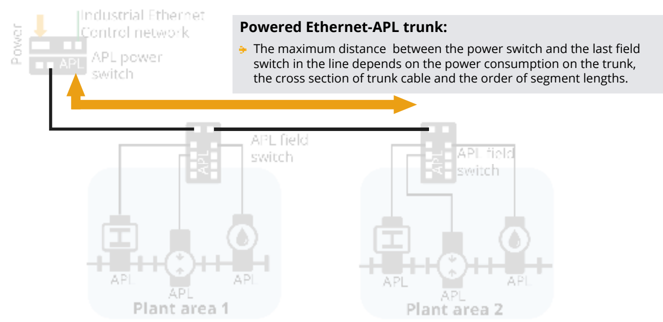

Figure 4: Powered Ethernet-APL trunk

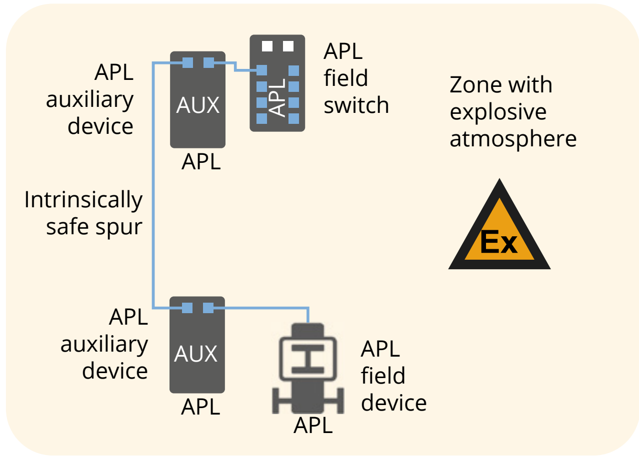

Figure 5: Setting for 2-WISE approach

Figure 3 shows one of the possible network structures. The network structure uses 100 Mbit/s Industrial Ethernet and fiber optic cabling to connect the Ethernet-APL field switches. This means that the 10 Mbit/s Advanced Physical Layer is only used for the spurs, but not for the connection of the field switches to the control network. The connection between the field switches uses Industrial Ethernet and operates with at least 100 Mbit/s. This concept requires auxiliary power for the field switches.

The system shown in Figure 4 uses the powered Ethernet-APL trunk. The Ethernet-APL power switch converts the 100 Mbit/s Industrial Ethernet signal on the Control Network to the Advanced Physical Layer and in addition powers the Ethernet-APL trunk. Therefore, no auxiliary power is needed in the field. The Ethernet-APL field switches convey information as well as electrical power to the Ethernet-APL field devices. It can be derived from Figure 3 and Figure 4 that the two network structures have specific features. Table 1 compares the features of the two network structures.
Based on the individual feature of the network structures, the planner can choose the one that fits best the needs of the application.

4. Explosion protection

An easy to use explosion protection concept is key for application of a communication technology in areas with explosive atmosphere. Comparable to the known FISCO concept for classical fieldbuses, an intrinsic safety concept has been developed for Ethernet-APL. This concept is called the 2-WISE

Table 1: Features of Ethernet-APL network structures

Feature	Field switches with 100 Mbit/s Industrial Ethernet	Powered Ethernet-APL trunk
Maximum spur length	≤200 m for cable category IV	≤ 200 m for cable category IV
Maximum trunk length	Fiber optic: Depends on type of fiber. Typically, ≤ 2 000 m for multimode 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 trunk cable to be considered	No	Yes
Data rate on trunk	Typ. 100 Mbit/s	10 Mbit/s
Network load on trunk 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

concept (2-wire Intrinsically Safe Ethernet) as defined in IEC TS 60079-47 [9]. It defines universal intrinsic safety parameter limits for equipment used in Ethernet-APL powered spurs.
Figure 5 shows the setting for the 2-WISE approach. An intrinsically safe powered 2-WISE spur may comprise an intrinsically safe power source, provided by a switch, an intrinsically safe load port, provided by a field device, and a maximum of two auxiliary devices (e. g. surge protectors). All used equipment 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 Ω/km … 150 Ω/km
Cable inductance	L_c:	0.4 mH/km … 1 mH/km
Cable capacitance	C_c:	45 nF/km … 200 nF/km

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 with 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 protection class. After consideration of the intrinsically safe spurs, now the connection between the field switches shall be considered. With reference to the different network structures, described in chapter 3, corresponding explosion protection concepts can be derived.
Figure 6 shows an explosion protection concept based on the network structure initially introduced in Figure 3. The field switches are directly connected to the 100 Mbit/s Industrial Ethernet control network with fiber optic cable. An Ethernet-APL trunk is not used. The field switches are located in Zone 2. Intrinsically safe spurs connect the Ethernet-APL field switches with the field devices, located in Zone 1 or Zone 0. The topology has the following features:

» The Ethernet-APL field switches are separately powered and the Ethernet-APL field devices are powered through the field switch via the spurs.

» The Ethernet Control network (amber line) is classified at least for use in Zone 2. In this case shown as fiber optic media.

» The spurs are classified intrinsically safe, Ex ia so that the Ethernet-APL field devices can be used in Zone 1/0.

If the field switches shall be located together with the field devices in Zone 1, an alternative structure can be used.
Figure 7 shows a topology that uses the powered Ethernet-APL trunk.
The topology has the following features:

» The Ethernet-APL field switches and the Ethernet-APL field devices are powered via the trunk.

» The trunk is classified increased safety Ex eb for Zone 1.

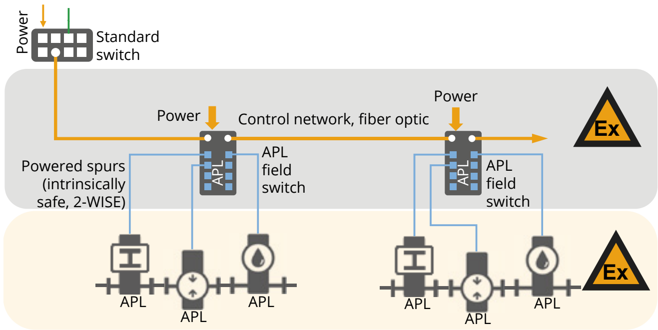

Figure 6: Topology with 100 Mbit/s Industrial Ethernet connection and field switches installed in Zone 2

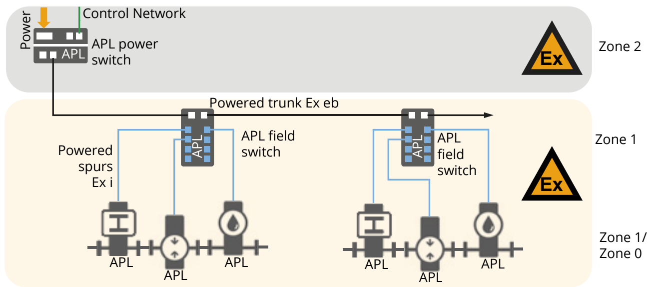

Figure 7: Topology with powered trunk and field switches located in zone 1

» The spurs are classified intrinsically safe Ex ia for Zone 1/0.

» Length limitations/voltage drop on the powered trunk have to be observed.

Other configurations are possible. Please refer to the Ethernet-APL Engineering Guideline [3] for further information and the application of these concepts for the US market using classes and divisions according to NEC 500.

5. Network traffic considerations

Ethernet-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 Ethernet-APL device fit into the minimum data frame, even if multivariable transmitters are used. Therefore, a data frame of 46 bytes payload is assumed for the following calculations. By using this assumption, the network load shown in Figure 8 can be derived from the number of devices and the update time of the devices for up to 50 devices.
The network load can be verified as follows: It is assumed that an Ethernet-APL network will run on an network update time 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 8. The blue curve (50 ms network update time) has to be selected in this case. The network load can now be read from the y-axis. The value is around 2.8 %. This is the total network load of sensors conveying data to the controller, respective the power switch (inbound traffic). As Ethernet-APL supports full duplex communication, at the same time data traffic from the

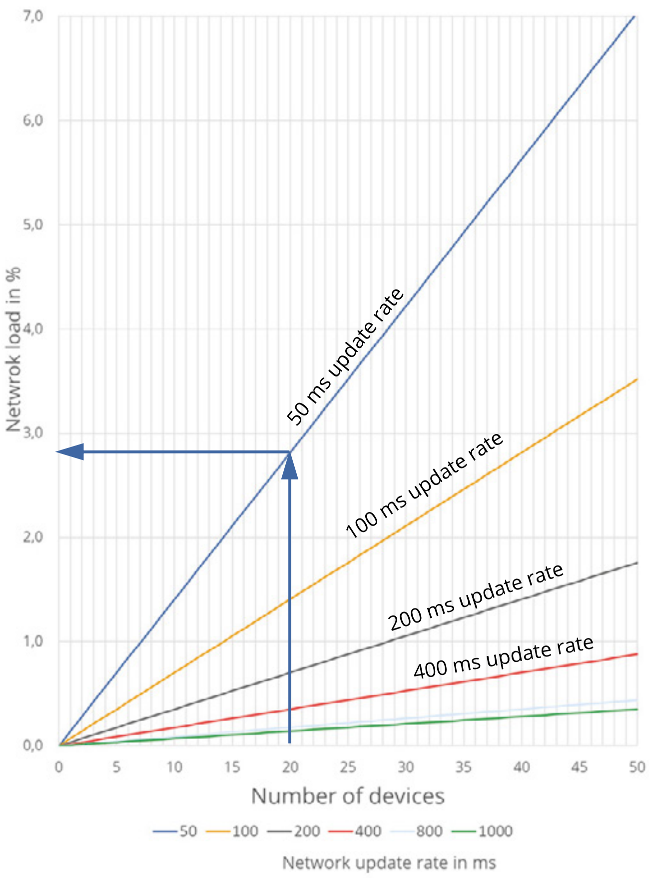

Figure 8: Network load estimation up to 50 devices for 10 Mbit/s Ethernet-APL

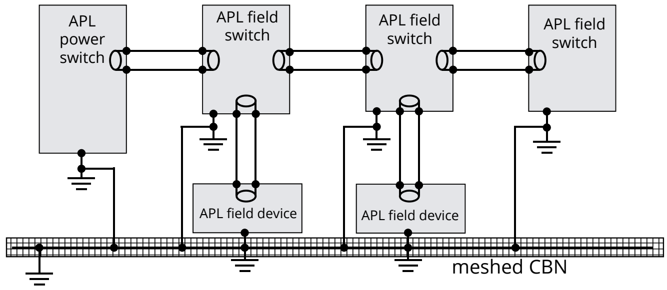

Figure 9: Cable shield connected at both ends to the CBN

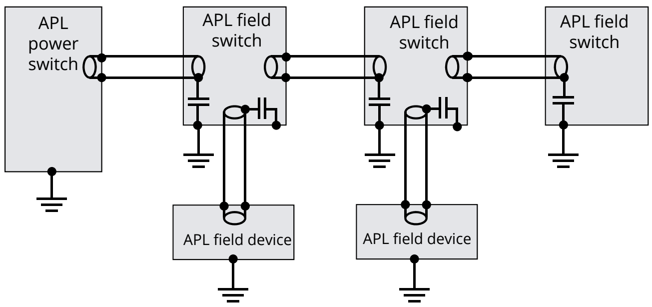

Figure 10: Cable shield connected with one end directly and the other end via capacitor to the CBN

controller to the actuators (outbound traffic) is possible. The calculation principle for inbound and outbound traffic is the same. It can be seen that network load only becomes an issue, when fast network update times are used. Typical update times in the process industry (100 ms … 1 s), will only cause small network loads, even with a larger number of sensors on a single network. For example: 150 devices with an update 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. The detailed calculation of this example can be found in the appendix of the Ethernet-APL Engineering Guideline [3]. Even if Ethernet-APL provides sufficient bandwidth in typical applications, appropriate traffic prioritization support is required from protocol layers 2 – 4 to ensure that real time communication is not disturbed by acyclic data transfer.

6. Shielding concept of Ethernet-APL

Ethernet-APL uses shielded cables as described in chapter 2. Assuming a meshed common bonding network (CBN) according to EN 50310 [12] and IEC 603644 44 [13] the cable shields of the Ethernet-APL network should be connected to the CBN at both ends of the cable. This applies for trunks as well as for spurs.
Figure 9 shows the direct connection of the cable shields to the common bonding network at both ends. It can be seen that the components or their housings are connected via the grounding terminals to the CBN. In parallel to that the cable shields are connected to the housing. 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 currents in the meshes of the grounding system are relatively small, which is due to the large number of parallel paths in the CBN. Therefore, connecting cable shields at both ends is possible without the risk of cable shields carrying excessive vagabonding currents. 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 10.
Ethernet-APL field devices support direct shielding. Ethernet-APL switches support both direct and as an option capacitive connection of the cable shield to the bonding network. 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 that carry currents above 50 Hz (e.g. lines that connect a motor to a frequency converter). To compensate for this, the minimum distance between the Ethernet-APL cable and the power cable should be increased. According to IEC 60079-14 [14], grounding the cable shield on both sides 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. The IEC 6007914 [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. Nevertheless, also with capacitive shielding, the devices will meet the usual EMC

requirements. If necessary, this disadvantage can be compensated by increasing the distance between the Ethernet-APL cable and the power cable that carry currents above 50 Hz (e.g. lines that connect a motor to a frequency converter).

7. Conclusion / Summary / Outlook

This article gives a brief overview on the planning principles for Ethernet-APL networks. Due to the length constraints of such an article, only the basic principles could be touched. Detailed information will be given in the Ethernet-APL Engineering Guideline [3]. There further information, including best practice examples, migration examples, installation instructions, surge protection and instructions for an acceptance test, will be provided.

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