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TECHNICAL SPECIFICATION

Industrial networks – Ethernet-APL port profile specification

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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CONTENTS

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INDUSTRIAL NETWORKS –

Ethernet-APL port profile specification

FOREWORD

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IEC TS 63444 has been prepared by subcommittee 65C: Industrial networks, of IEC technical committee 65: Industrial-process measurement, control and automation. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
65C/1250/DTS	65C/1275/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

IEEE Std 802.3™-2022, Clause 146 specifies the Ethernet Physical Layer 10BASE-T1L, suitable to be used for full-duplex communication over a single balanced pair of conductors.

This physical layer is specifically designed for industrial applications, supporting the main requirements for advanced, robust process control and monitoring in safe or hazardous areas.

The primary physical layer solution focuses on four requirements:

- support of single pair cables providing both communication and optional power;
- increased data bandwidth, 10 Mbit/s;
- support of extended Ethernet cable length of up to 1 km;
- support of intrinsically safe protection for use in hazardous areas.

IEEE Std 802.3-2022, Clause 146 only specifies the digital communication method and its electrical characteristics. To assure interoperability between the various interconnected components at different parts of the network, applying this new physical layer for industrial applications requires a further set of specifications and classifications. The "Ethernet Advanced Physical Layer" (Ethernet-APL or APL) references and standardizes industrial automation extensions.

This document specifies port profiles for use in non-hazardous and hazardous areas, with and without power. Ethernet-APL intrinsically safe profiles facilitate the examination of the interconnection of different Ethernet-APL ports. Most common industrial rated connectors for use in process industries are part of this document. A multi-length cable category system maintains communication integrity, while permitting cable constructions optimized for specific applications or environmental ratings.

Ethernet-APL impacts the various physical layers in IEC 61158-2 and its associated Types. This document provides a neutral approach for the new advanced physical layer which can be then transferred to the next editions of different IEC intrinsically safe fieldbus documents. The following documents are representative of potentially affected next editions: IEC 61158-2, IEC 61784-1 series, IEC 61784-2 series, IEC 61918, IEC 61784-5 series.

This document is not intended to assure interoperability at the product level but only at the port level. No reference is made to any Ethernet-based communication protocol above the physical layer.

INDUSTRIAL NETWORKS –

Ethernet-APL port profile specification

1 Scope

This document is applicable to process automation equipment using a 10BASE-T1L compliant (see IEEE Std 802.3-2022, Clause 146) Physical Layer (PHY). Ethernet-APL intrinsically safe profiles with different predefined entity or limitation parameters (for example voltage, current, power, capacitance, inductance, cable length) simplify the examination of the interconnection of different Ethernet-APL ports.

The following technical features are part of this document:

- topology with trunk/spur installation capability;
- 2-wire technology (full-duplex communication data rate of 10 Mbit/s);
- long distance (refers to cable lengths of several hundred meters, with spans up to 1 000 m);
- intrinsic safety (installation of Ethernet-capable field devices in hazardous areas);
- power supply to field devices over the same 2-wire cable used for data communication.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60079-11, *Explosive atmospheres – Part 11: Equipment protection by intrinsic safety "i"*

IEC 60079-14, *Explosive atmospheres – Part 14: Electrical installations design, selection and erection*

IEC 60079-25, *Explosive atmospheres – Part 25: Intrinsically safe electrical systems*

IEC TS 60079-47:2021, *Explosive atmospheres – Part 47: Equipment protection by 2-wire intrinsically safe ethernet concept (2-WISE)*

IEC 61010-1, *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements*

IEC 61076-2-101, *Connectors for electronic equipment – Product requirements – Part 2-101: Circular connectors – Detail specification for circular connectors for M12 connectors with screw-locking*

IEC 61076-2-104, *Connectors for electronic equipment – Product requirements – Part 2-104: Circular connectors – Detail specification for circular connectors with M8 screw-locking or snap-locking*

IEC 61158-2:2023, *Industrial communication networks – Fieldbus specifications – Part 2: Physical layer specification and service definition*

IEC 61643-21, *Low voltage surge protective devices* − *Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods*

IEEE Std 802.3-2022, *IEEE Standard for Ethernet*

ASTM D4566-05, *Standard Test Methods for Electrical Performance Properties of Insulations and Jackets for Telecommunications Wire and Cable*; available at < ASTM D4566-05 - Standard Test Methods for Electrical Performance Properties of Insulations and Jackets for Telecommunications Wire and Cable (ansi.org)> [viewed 2023-10-13]

3 Terms, definitions, abbreviated terms and acronyms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
Advanced Physical Layer
APL
physical layer based on 10BASE-T1L according to IEEE Std 802.3-2022 with additional optional features like intrinsic safety, power over 2 wires

Note 1 to entry: Additional requirements for use in process industries are specified in this document.

3.1.2
APL segment
segment that consists of two APL ports, each containing a 10BASE-T1L compatible PHY, connected at each end of a two-wire, shielded cable

Note 1 to entry: An APL segment can optionally be equipped with a maximum of two auxiliary devices and can contain up to 10 inline terminal connections. An auxiliary device corresponds to one inline connection; for example, having two auxiliary device connected to one APL segment will reduce the number of inline connections by two.

Note 2 to entry: An APL segment is either a trunk or a spur.

3.1.3
APL switch
Ethernet switch including at least one APL compliant port

3.1.4
APL port
electrical and mechanical interface of a device to an APL segment

3.1.5
auxiliary device
device, which is connected within an APL segment and does not include a 10BASE-T1L PHY

Note 1 to entry: Auxiliary devices are defined in Annex B.

Note 2 to entry: An auxiliary device can comprise a power load or introduce communication signal insertion losses.

EXAMPLE A surge protector is an example of an auxiliary device.

3.1.6
cable stub
unterminated branch of the segment cable

3.1.7
cascade port
APL port used in powered daisy chain networks

Note 1 to entry: If the cascade port is used in a powered ring network it shall be either a power source port or a power load port depending on the status of the ring.

3.1.8
inline connection
mated device or combination of devices, including terminations used to connect cables or cable elements to other cables or application specific equipment

3.1.9
current event
change of load current during power-up sequence with a specific characteristic

Note 1 to entry: A current event could be either a current step or a current spike.

3.1.10
field switch
APL switch having at least one port to which a spur can be connected

3.1.11
port
interface between a device and an APL segment

3.1.12
port class
port powering characteristics

3.1.13
power switch
APL switch including at least one port feeding power into a trunk

3.1.14
PHY
physical layer circuitry required to implement physical layer functions

3.1.15
overcurrent condition
condition when a power load port draws more than the minimum continuously provided current $I_{PS(min)}$ of the power source port

3.1.16
spur
<APL> segment which connects a field device to a field switch

3.1.17
segment
point-to-point connection between two APL ports

3.1.18
surge protective device
SPD
electrical device that is used to protect electronic equipment against electrical surges and voltage spikes

Note 1 to entry: A SPD is an auxiliary device.

3.1.19
trunk
<APL> segment which connects a power switch to a field switch or a field switch to a field switch

3.1.20
2-WISE
2-Wire intrinsically safe Ethernet concept based on APL with standardized limits for intrinsic safety parameters, designed to simplify the examination process for components and cable parameters within APL segments

[SOURCE: IEC TS 60079-47:2021, 3.3, modified − a new term has been assigned.]

3.1.21
2.4 V_{pp} operating mode
10BASE-T1L compliant operating mode with a signal amplitude of 2,4 V_{pp}

Note 1 to entry: This mode is used on APL trunk segments.

3.1.22
1.0 V_{pp} operating mode
10BASE-T1L operating mode with a signal amplitude of 1,0 V_{pp}

Note 1 to entry: This mode is used on APL spur segments.

3.2 Abbreviated terms, symbols and acronyms

C_{in}	unlimited input capacitance of a load port
E_{in}	initial inrush energy of a load port or cascade port during power-up, caused by charging-up its input capacitance
EMC	electromagnetic compatibility
Ex	indicates that the electrical equipment corresponds to one or more of the types of protection which are subject of the standards IEC 60079-0 or IEC 60079-11
$I_{CSp(max)}$	maximum current during a current spike event of a load port during start-up
$I_{PS(min)}$	minimum continuously provided current at the power source terminals except during inrush or an overcurrent condition
$I_{PL(min)}$	minimum consumed current at the power load terminals except during inrush or an overcurrent condition
$I_{PL(max)}$	maximum consumed current at the power load terminals during an under voltage condition
$I_{PL(reverse)}$	reverse current for polarity sensitive power load ports
$P_{PL(min)}$	minimum available power at the power load terminals
$P_{PS(min)}$	minimum available output power at the power source terminals
PSANEXT	power sum alien near end crosstalk loss
PSAFEXT	power sum alien far end crosstalk loss
Q_{CSp}	electric charge during a current spike event for a load port during power-up
R_{out}	internal resistance of a power source port
$U_{PS(max)}$	maximum allowed voltage at the power source terminals over the full range of operating conditions
$U_{PS(min)}$	minimum available output voltage at the power source terminals over the full range of operation conditions

$U_{PL(min)}$ minimum available voltage at the power load terminals

4 APL overview

4.1 General

APL has been specifically designed to modernise digital instrumentation solutions used for industrial process control, offering enhanced features of communication, powering and device control in between Zone 2, 1 and 0, or Zone 20, 21 and 22.

Figure 1 illustrates an example of an APL network connected to a control network. The communication link between the control network and the APL segment is performed through a power switch, which additionally feeds power onto the APL trunk. A field switch is connected to the opposite end of the APL trunk, which is powered by the trunk, whereon it feeds the power to each spur port and to a second trunk port. The second trunk port provides a new powered trunk segment for a second field switch and so on. Each spur port finally terminates at a field device, which may also be powered in accordance with the applicable hazardous area classification. Field devices, which shall be intrinsically safe certified, can be located within any rated hazardous area. The number of cascaded field switches is limited because of the available power. To calculate the number of cascaded field switches, the following applies: the output power of the source port is the input power of the load port minus the power consumption of the device and minus the internal losses.

It is strongly recommended to maintain cable type continuity in an APL segment as to minimize the effect of insertion and return loss.

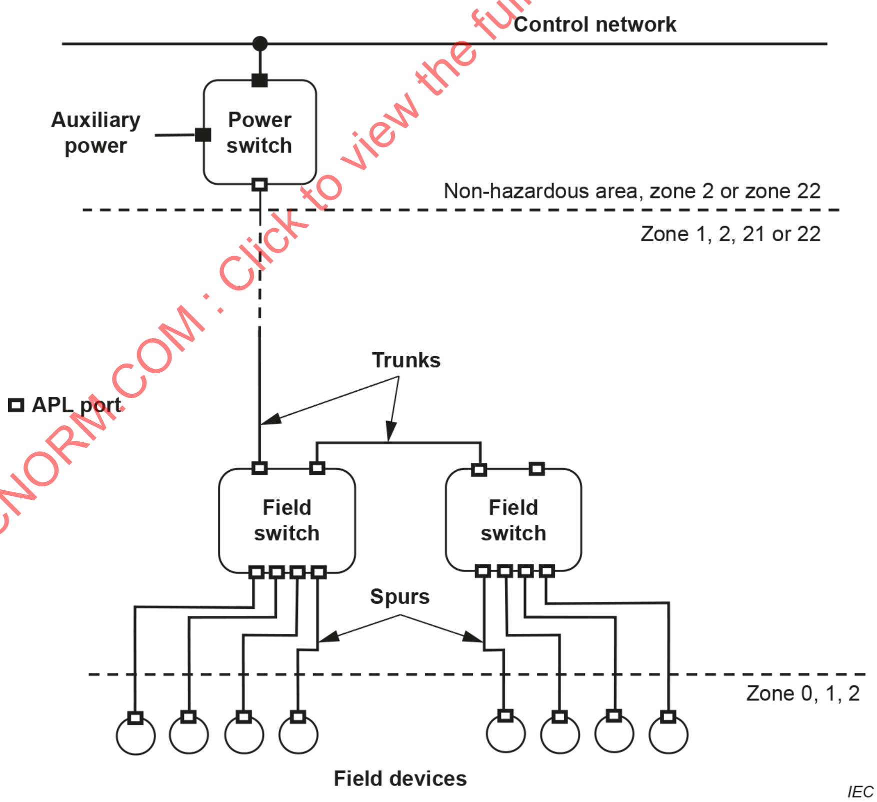


Figure 1 – APL topology example

An APL trunk shall be conformant to IEEE Std 802.3-2022, Clause 146, 10BASE-T1L link segment definition in "2.4 V_{pp} operating mode" and an APL spur shall comply with IEEE Std 802.3-2022, Clause 146, 10BASE-T1L link segment definition in "1.0 V_{pp} operating mode". An APL segment can comprise either a trunk or a spur.

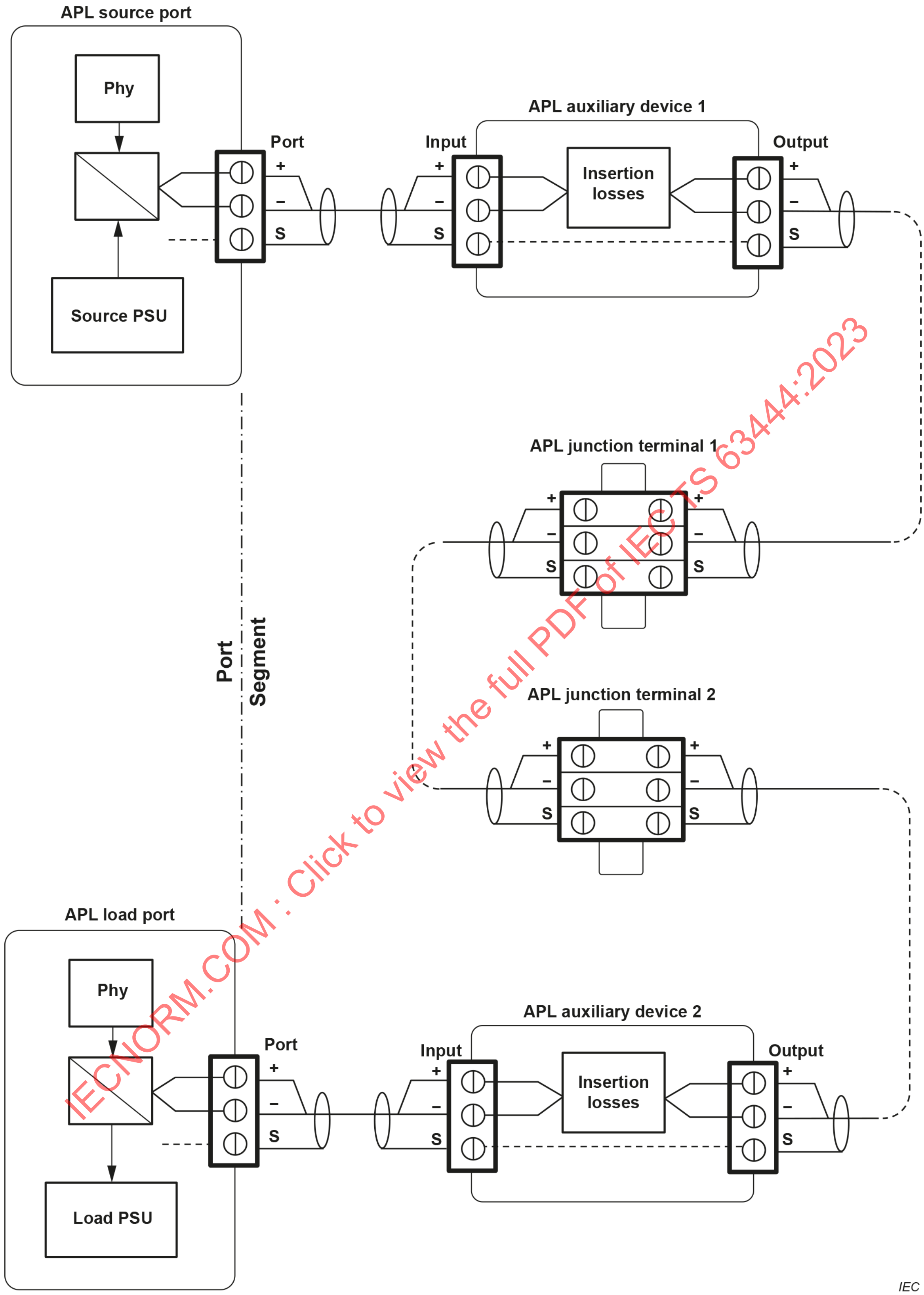
As shown in Figure 2, an APL segment comprises two ports connected to each end of a trunk or spur cable, with auxiliary devices and terminal blocks or connectors in between. A spur always ends at a field device. The cable, optional auxiliary devices and junction terminals are defined within this specification.

For powered segments, one source port provides power into the segment, and the load port or the auxiliary device consumes power from the segment.

For use in hazardous areas according to IEC 60079-14, in which intrinsically safe rated circuits are required, the ports can be classified as intrinsically safe according to level of protection ia, ib, ic.

NOTE A particular national or regional standard, code or directive could use other particular notations, differing from international IEC notations.

Different terminal blocks are supported with terminal options as screw-type or spring-force-type.



NOTE 1 Auxiliary devices can cause additional insertion loss for example by integrated inline resistors.

NOTE 2 An auxiliary device, typically a surge protector, does not contain a PHY.

Figure 2 – Example APL segment including auxiliary devices and inline terminals

4.2 APL relationship to IEEE Std 802.3-2022 and 10BASE-T1L

APL is based on the 10BASE-T1L physical layer (PHY) specification of IEEE Std 802.3-2022, Clause 146. APL specifies the application of 10BASE-T1L to industry sectors, particularly to process industries.

APL is compatible with 10BASE-T1L, but limits PHY options to suit the intended applications.

Table 1 defines the APL option support.

Table 1 – IEEE Std 802.3-2022 PHY, management and power options

PHY option	Description	Reference in IEEE Std 802.3-2022	APL support
PCS	Physical coding sublayer	146.3	Required
PMA	Physical medium attachment, 10BASE-T1L	146.4	Required
AN	Auto-Negotiation	Clause 98	Required
LSM	Low speed mode	98.5.6	Required
10T1L	10BASE-T1L	Clause 98, Clause 146	Required
EEE[a]	Energy efficient Ethernet (EEE) capability	Clause 78, 146.1.2	Prohibited
RTDL	2.4 V_{pp} operating mode	146.5.4.1	Conditional
PSETE	Power over data lines (PoDL[b]) of single balanced twisted-pair Ethernet, PSE type E for 10BASE-T1L	104.1.3	Prohibited
PDTE	Power over Data Lines (PoDL[b]) of single balanced twisted-pair Ethernet, PD Type E for 10BASE-T1L	104.1.3	Prohibited
MDI4[c]	MDI line powering voltage tolerance	146.8.5	Prohibited
*INS[d]	Installation / cabling	146.7	See 7.5

[a] EEE can interfere with low latency applications and disturb power distribution. EEE can be implemented in a PHY but disabled.

[b] PoDL for 10BASE-T1L does not provide an intrinsic safety capability. PoDL for 10BASE-T1L does not provide cascade operation capability.

[c] MDI4 is related to PoDL enabled ports. APL power concepts require lower voltage levels due to hazardous area use and dedicated safety concepts avoiding hazardous situation if applying higher voltages to a port. A port can be damaged by blowing an internal non-replaceable fuse.

[d] The asterisk character "*" in front of an item name like "*INS" is a syntax element specified in IEEE Std 802.3-2022, 8.8.3.4 saying: "Each item whose reference is used in a conditional symbol is indicated by an asterisk in the Item column."

The equivalent of the Ethernet MDI is an APL connector or terminal block as defined in Annex A.

A trunk port shall only operate in 2.4 V_{pp} operating mode.

A trunk port shall not enable communication but can still link up when the connected port at the far end tries to establish a link with a transmit voltage other than 2,4 V_{pp}.

A spur port shall only operate in 1.0 V_{pp} operating mode.

A spur port shall not enable communication, but can still link up, when the connected port at the far end tries to establish a link with a transmit voltage other than 1,0 V_{pp}.

As APL ports shall have Auto-Negotiation enabled, the transmit amplitude shall be fixed by setting the IEEE Std 802.3-2022, Clause 98 Auto-Negotiation Technology Ability Field Bits A23

(10BASE-T1L increased transmit level request) and A24 (10BASE-T1L increased transmit / receive level ability) for a trunk port to 1 and for a spur port to 0.

Additionally in the IEEE Std 802.3-2022, Clause 98, Auto-Negotiation Technology Field Bit A9 (10BASE-T1L capability) shall be set to 1 and all other bits besides A23 and A24, which shall be set to support the correct transmit amplitude, shall be set to zero.

Additional requirements for APL conformance tests are provided in 4.3.

4.3 Conformance test requirements

IEEE Std 802.3-2022, 146.5.4.2, defines a maximum droop of 10 % when running the 10BASE-T1L PHY in test mode 2 and driving into a 100 Ω external termination. Performing APL conformance tests, an additional power coupling network could be required during these tests utilizing a 1 mH inductor and a 100 Ω in series with 0,5 µF termination impedance. Based on this power and termination network, the overall droop could be higher than 10 %. An APL port conforming to the APL port profile specification shall not produce a droop higher than 13 % when being tested in combination with the above mentioned power coupling network. Including measurement tolerances during the conformance test, the measured droop shall not be higher than 15 %. The droop is measured between 400 ns and 1 066,7 ns after the zero crossing. To reduce the influence of measurement noise, the bandwidth of the droop measurement should be not greater than 20 MHz. This can be achieved by post processing (e.g. time-averaging) higher bandwidth samples. If the observed waveform differs substantially from the expected trapezoidal waveform with exponential droop, then the first measurement point should be taken at the (smoothed) peak, with the second measurement 666,7 ns later.

An APL port shall be able to withstand a peak-to-peak signal amplitude of up to 1,55 V_{pp} without causing a transmit distortion of more than 50 mV_{pp}.

The time between activating the Auto-Negotiation process between two ports and the established communication link shall take maximum 7 s.

5 Port classification

5.1 Overview

Ports are classified by different classes which determine the interoperability between two ports. The port classification scheme is illustrated in Figure 3. For each port class, several options are defined. Not all combinations of options are permitted. Allowed combinations of options are specified in the respective port class subclauses.

The intrinsically safe protection classes are listed in Table 8 for more information.

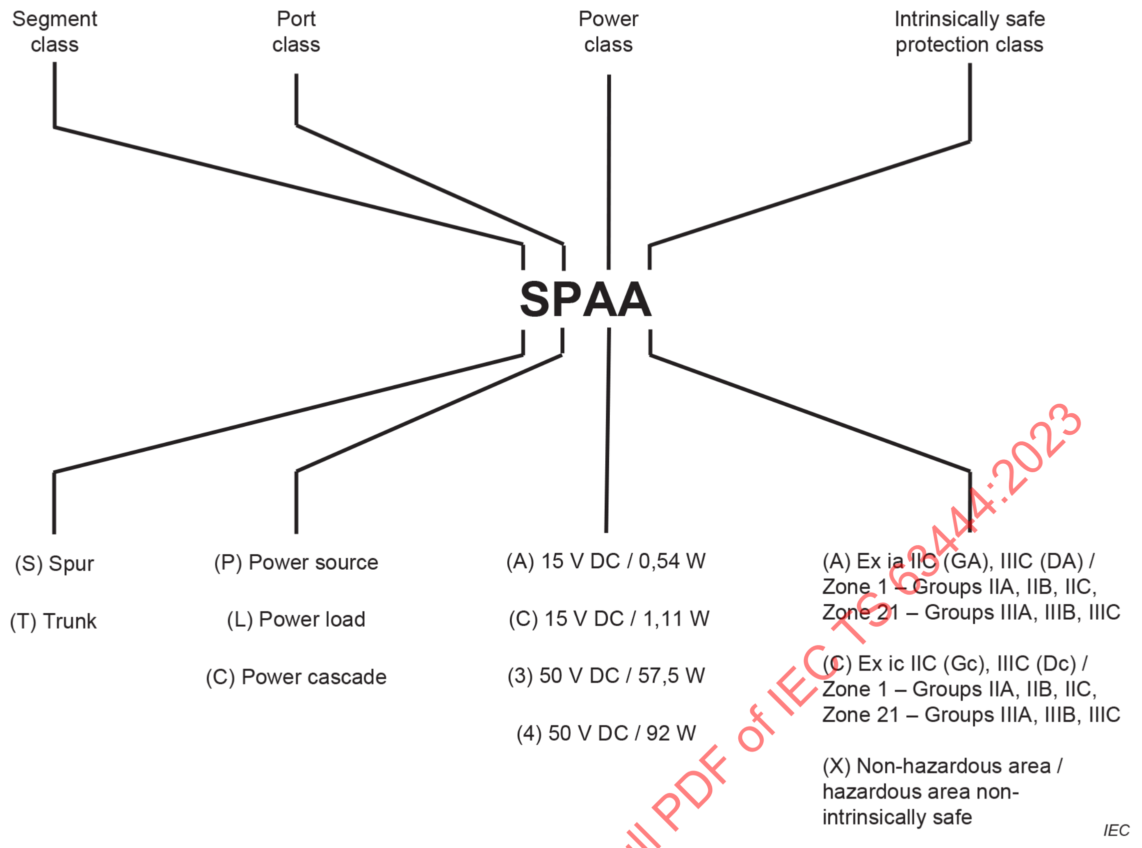


Figure 3 – Port classes and related options

5.2 Segment class

Table 2 specifies the segment classes. The APL segment class defines the type of supported segments specified in IEEE Std 802.3-2022, Clause 146.

Table 2 – Segment class

Segment class		10BASE-T1L operating mode	Supported cable length m	Maximum number of auxiliary devices	Maximum number of inline connections in an APL segment
S	Spur	1,0 V_{pp}	0 to 200	2	4
T	Trunk	2,4 V_{pp}	0 to 1 000	2	10

Maximum number of inline connections does not include cable terminations of the APL ports.

An auxiliary device corresponds to one inline connection; for example, having two auxiliary device connected to one APL segment reduces the number of inline connections by two.

Auxiliary devices, having inline resistance, reduces the supported cable length in powered APL segments due to the additional voltage drop and insertion loss.

5.3 Port class

The port class defines the port powering characteristics.

Table 3 summarizes the different port classes and the permitted combinations of port classes used to form an APL segment.

Table 3 – Port classes

Port class		Permitted combinations
P	Power source port provides power to a power load port.	P-L, P-C_L
L	Power load port requires power from a power source port.	P-L, C_P-L
C	Powered port which can be power source (C_P) or power load port (C_L). Cascade ports can be used in a powered ring or in a powered daisy chain configuration. A cascade port feeding power (C_P) receives its power from a cascade port operating as a load port (C_L) in the same device. The cascade load port (C_L) in turn is connected to either a power source port (P) or to another cascade port operating as a source port (C_P) in a different device. See Figure 4.	P-C_L, C_P-L, C_P-C_L
If a port class C is connected to a port class P port, the C port shall remain passive (C_L) and shall not feed any power into the APL segment. A cascade source port (C_P) powered by a cascade load port (C_L) can have reduced output values. The output power of the source port (C_P) is the input power of the load port (C_L) minus the power consumption of the device and minus the internal losses. Cascade ports are only permitted on the trunk.		
NOTE Powered ring topology is out of scope of the port profile specification. To support a powered ring topology in a future revision of this document, additional port classes will need to be added. A passive cascade port class implementations does not necessarily support future active ring configurations.		

Figure 4 shows a trunk topology with cascaded field switches.

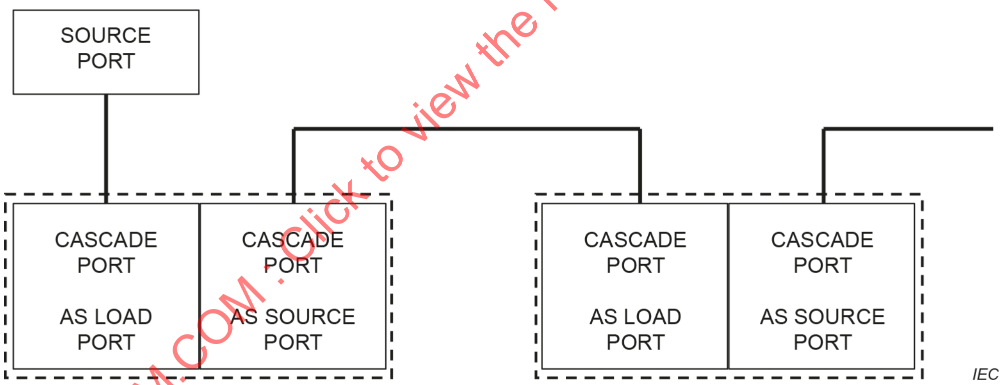


Figure 4 – Powered trunk segments with cascade ports

5.4 Power class

The electrical characteristics of power source ports "P", power load ports "L" and cascade ports "C" are categorized by their power class. Power classes A and C shall be used for intrinsically safe rated spur ports intended to be used primarily in hazardous area applications. Power class 3 is intended to be used for non-intrinsically safe rated trunk ports.

Table 4 defines the permitted combinations of segment classes, port classes and power classes.

Table 4 – Power classes

Source power class	Maximum voltage / minimum output power	Permitted segment classes	Permitted port classes	Permitted load power classes
A	15 V DC / 0,54 W	S	P, L	A
C	15 V DC / 1,11 W	S	P, L	A, C
3	50 V DC / 57,5 W	T	P, L, C	3
4	50 V DC / 92 W	T	P, L, C	3, 4

Combination of classes other than those given in Table 4 are prohibited. The permitted combinations of port classes do not imply that every combination is also permitted from an intrinsically safe viewpoint.

A load port can be specified for more than one load power class.

Cascade (C) ports can only be connected to a power source port having equal or lower maximum output values (voltage, current and power) than the input values specified for the cascade port.

Figure 5 provides an example of power class matching. A field device port with classification SLAA can be connected either to a field switch port with classification SPAA or SPCC.

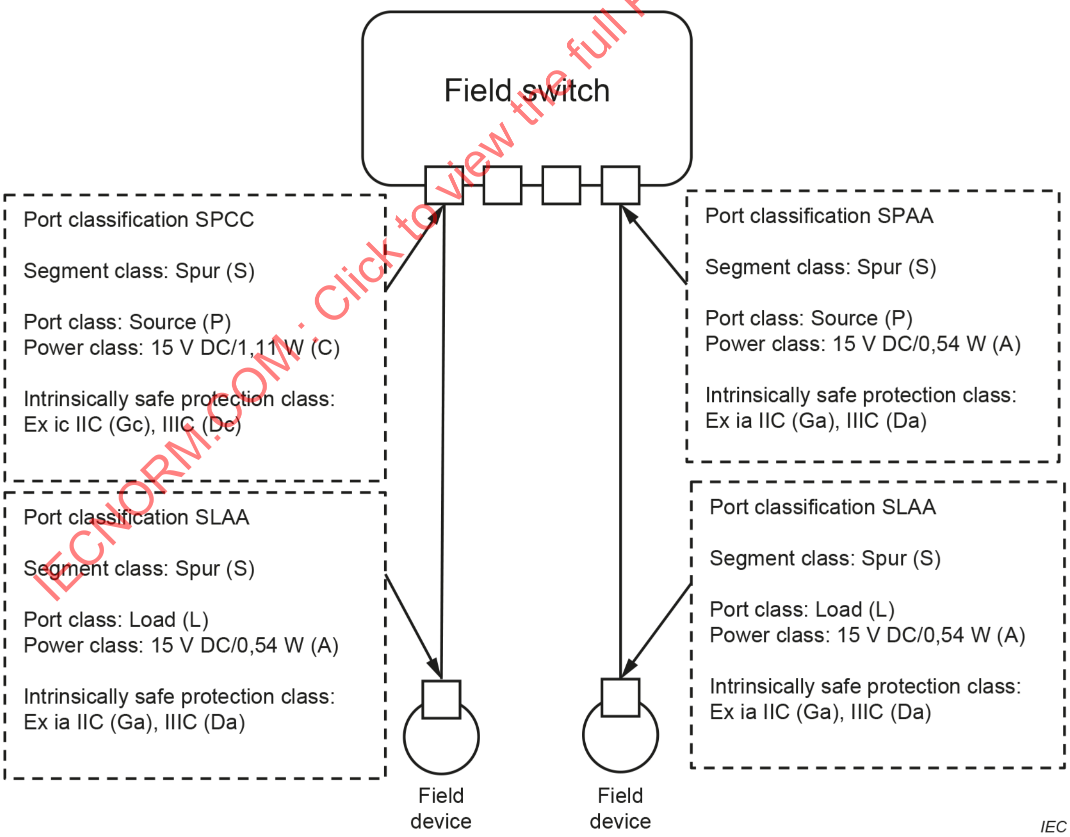


Figure 5 – Example of port class matching between source and load

Table 5 shows the power class requirements.

Table 5 – Electrical characteristics of power classes

Parameter	Power class			
	A	C	3	4
$U_{PS(max)}$ (V DC)	15 [f]	15 [f]	50 [d]	50 [d]
$U_{PS(min)}$ (V DC)	9,6	11,61	46 [g]	46 [g]
$I_{PS(min)}$ (mA)	55,56	95	1 250 [g]	2 000 [g]
$P_{PS(min)}$ (W)	0,54	1,1	57,5 [g]	92 [g]
$U_{PL(min)}$ (V DC)	9,0 [b]	10,6 [b]	28,8 [c]	28,8 [c]
$P_{PL(min)}$ (W) [a]	0,5 [b]	1,0 [b]	36 [c, h]	57,6 [c, h]
$I_{PL(min)}$ (mA)	20		40 [e]	
$I_{PL(max)}$ (mA)	See footnote [j]			
$I_{PL(reverse)}$ (mA)	Not applicable		≤ 10 [i]	

NOTE 1 $U_{PS(max)}$ and $U_{PS(min)}$ are specified for steady state operation without communication voltage.

NOTE 2 All parameters in Table 5 reflect the electrical DC characteristics. The communication signal is added as an additional signal source to the DC electrical parameters.

[a] $P_{PL(min)}$ is the product of the minimum continuously provided current $I_{PS(min)}$ and the minimum available voltage $U_{PL(min)}$.

[b] $U_{PL(min)}$ and $P_{PL(min)}$ are determined by cable losses due to the wire resistance of AWG 18 cable with a length of 200 m at a wire temperature of 70 °C (equivalent to 10,6 Ω loop resistance) at maximum load.

[c] Calculation is required, considering load condition and the cable resistance at the maximum wire temperature, to guarantee $U_{PL(min)}$ and $P_{PL(min)}$.

[d] $U_{PS(max)}$ shall be overvoltage protected to less than 60 V DC.

[e] For power class 3, the minimum specified current consumption $I_{PL(min)}$ is only required if a diode function, as e.g. a reverse polarity protection, within the signal path of a load port is used.

[f] Safety voltage limits of power classes A and C are defined in IEC TS 60079-47.

[g] For cascade power ports, $U_{PS(min)}$, $I_{PS(min)}$, and $P_{PS(min)}$ can be lower than the specified values.

[h] For cascade load ports, $P_{PL(min)}$ can be lower than the specified value.

[i] Only for polarity sensitive ports.

[j] If the voltage at the load port drops below $U_{PL(min)}$, a load port shall under no circumstance draw more current than the minimum supply current $I_{PS(min)}$ of the power source port the load port is designed for.

Under the defined conditions, APL ports shall conform to the requirements given in Table 6 and Table 7.

Table 6 – Electrical characteristics for trunk ports

Parameter	Port class	Symbol (unit)	Max	Comment
Differential in-band ripple and noise [a]	P, L, C, U	$U_{noise\ PP}$ (V)	0,01	100 kHz ≤ f ≤ 10 MHz
Differential out-band ripple and noise [a]	P, L, C, U	$U_{noise\ PP}$ (V)	Rise with 20 dB per decade to lower frequencies, max. 0,1	f ≤ 100 kHz
			Rise with 20 dB per decade to higher frequencies, max. 0,1	10 MHz ≤ f

Parameter	Port class	Symbol (unit)	Max	Comment
Change rate of current, dI_{CR} / dt	L, C	dI_{CR} / dt (mA / ms)	100	In all operating conditions.
Current steps (see Figure 6)	L, C	I_{CS} (mA)	50	A maximum of six current events in an interval of 1 000 ms until the device associated with the port has reached normal operation.
Current spikes Charge and amplitude (see Figure 6)	L, C	Q_{CSp} (µC)	20	
		$I_{CSp(max)}$ (mA)	$I_{PS(min)}$	
Maximum time duration of a current spike	L, C	$t_{CSp(max)}$ (ms)	10	
Change rate of voltage, dU_{CR} / dt [b,c]	P, C	dU_{CR} / dt (V / ms)	Unlimited	0 ms to 50 ms after applying power to the port.
			0,1	> 50 ms after applying power to the port.
Over current capability factor	P	F_{IOC}	Minimum 1,2 times $I_{PS(min)}$ for 10 ms	A power source port shall be able to feed 1,2 times of its rated supply current for a time of at least 10 ms.
Over current limitation factor	P	F_{IOL}	Maximum 1,6 times $I_{PS(min)}$ for 50 ms	A power source port shall limit its output current to a maximum of 1,6 times of its rated supply current for a maximum time of 50 ms to prevent overload of series fuses in load ports.
Unlimited input capacitance [d]	L, C	C_{in} (µF)	3	Including signal coupling capacitors and EMC capacitors
Inrush energy [e]	L, C	E_{in} (µJ)	5 000	—
Inrush duration [f]	L, C	t_{IR} (ms)	3	—

[a] The noise specification is met, if without an active communication signal, at the output of a second order band-pass filter with corner frequencies of 100 kHz and 10 MHz, the measured voltage is ≤ 10 mV_{pp} and the out-band noise voltage having the filter removed is ≤ 100 mV_{pp}.

[b] dU_{CR} / dt is measured in steady state condition.

[c] dU_{CR} / dt only includes voltage changes introduced by the source port. It does not include voltage changes introduced by current changes.

[d] Any capacitance which leads to an initial inrush current spike as shown in Figure 6, which means that it generates a current step with more than 50 mA, a current spike with more than 20 µC or a current peak above $I_{PS(min)}$, shall be added to the unlimited input capacitance.

[e] The inrush energy E_{in} is the product from supply voltage and supply current and is measured from the time the device is powered up until the first time the supply current falls below $I_{PS(min)}$ after previously exceeding $I_{PS(min)}$.

[f] The inrush duration t_{IR} is the time the device is powered up until the first time the supply current falls below $I_{PS(min)}$ after previously exceeding $I_{PS(min)}$.

Table 7 – Electrical characteristics for spur ports

Parameter	Port class	Symbol (unit)	Min	Max	Comment
Differential in-band ripple and noise [a]	P, L	$U_{\text{noise PP}}$ (V)	—	0,01	100 kHz ≤ f ≤ 10 MHz
Differential out-band ripple and noise [a]	P, L	$U_{\text{noise PP}}$ (V)	—	Rise with 20 dB per decade to lower frequencies, max. 0,1	f ≤ 100 kHz
			—	Rise with 20 dB per decade to higher frequencies, max. 0,1	10 MHz ≤ f
Change rate of current, dI_{CR} / dt	L	dI_{CR} / dt (mA / ms)	—	10	In all operating conditions
Current steps[d,e] (see Figure 6)	L	I_{CS} (mA)	—	50	A maximum of six current events in an interval of 1 000 ms until the device associated with the port has reached normal operation
Current spikes[e] Charge and amplitude(see Figure 6)	L	Q_{CSp} (µC)	—	20	
		$I_{CSp(max)}$ (mA)	—	$I_{PS(min)}$	
Maximum time duration of a current spike	L	$t_{CSp(max)}$ (ms)	—	10	
Change rate of voltage, dU_{CR} / dt [b, c]	P	dU_{CR} / dt (V / ms)	—	Unlimited	0 ms to 50 ms after applying power to the port
			—	0,1	> 50 ms after applying power to the port
Unlimited input capacitance [f] (see Figure 6)	L	C_{in} (µF)	—	1	Including signal coupling capacitors and EMC capacitors
Inrush energy [g]	L	E_{in} (µJ)	—	200	For load ports
Inrush duration [h]	L, C	t_{IR} (ms)	—	1	
Internal resistance	P	R_{out} (Ω)	2	—	Minimum internal resistance for all power source spur ports

[a] The noise specification is met, if without an active communication signal, at the output of a second order band-pass filter with corner frequencies of 100 kHz and 10 MHz, the measured voltage is ≤ 10 mV$_{pp}$ and the out-band noise voltage having the filter removed is ≤ 100 mV$_{pp}$.

[b] dU_{CR} / dt is measured in steady state condition.

[c] dU_{CR} / dt only includes voltage changes introduced by the source port. It does not include voltage changes introduced by current changes.

[d] For the fulfilment of the current step requirement during the first 50 ms of the power-up sequence, it is assumed that the input voltage of a power load port is monotonously rising.

[e] Current steps with an amplitude of less than 3 mA and current spikes with an electric charge of less than 500 nC with a load current less than $I_{ps(min)}$ are not defined as current steps during power-up.

[f] Any capacitance which leads to an initial inrush current spike as shown in Figure 6, which means that it generates a current step with more than 50 mA, a current spike with more than 20 µC or a current peak above $I_{PS(min)}$, shall be added to the unlimited input capacitance.

[g] The inrush energy E_{in} is the product from supply voltage and supply current and is measured from the time the device is powered up until the first time the supply current falls below $I_{PS(min)}$ after previously exceeding $I_{PS(min)}$.

[h] The inrush duration t_{IR} is the time the device is powered up until the first time the supply current falls below $I_{PS(min)}$ after previously exceeding $I_{PS(min)}$.

All power source ports shall comply with IEC 61010-1.

In case of an overcurrent or a short circuit condition, a power source port or power cascade port shall not be damaged. A power cascade port can be protected by its own or by the upstream power source port.

For overvoltage protection purposes, APL ports shall withstand a minimum differential peak current of 25 A for a pulse shape of 8 µs / 20 µs according to IEC 61643-21.

Figure 6 shows an example of start-up behavior for a load port. A load port connected to a spur port can create six current steps in a time period of 1 000 ms after applying power to the port. A change rate of current dI_{CR} / dt of less than 10 mA / ms at the spur is not counted as a current step. The maximum amplitude of a current step shall be 50 mA.

For a load port or cascade load port at the trunk, the sequence of shown current steps can be repeated until the device associated with this port has reached normal operation. A current step with a change rate of current dI_{CR} / dt of less than 100 mA / ms at a trunk load or cascade port is not counted as a current step.

A power source port shall be able to handle the specified start-up behavior of a power load port with respect to inrush requirements and current steps / spikes.

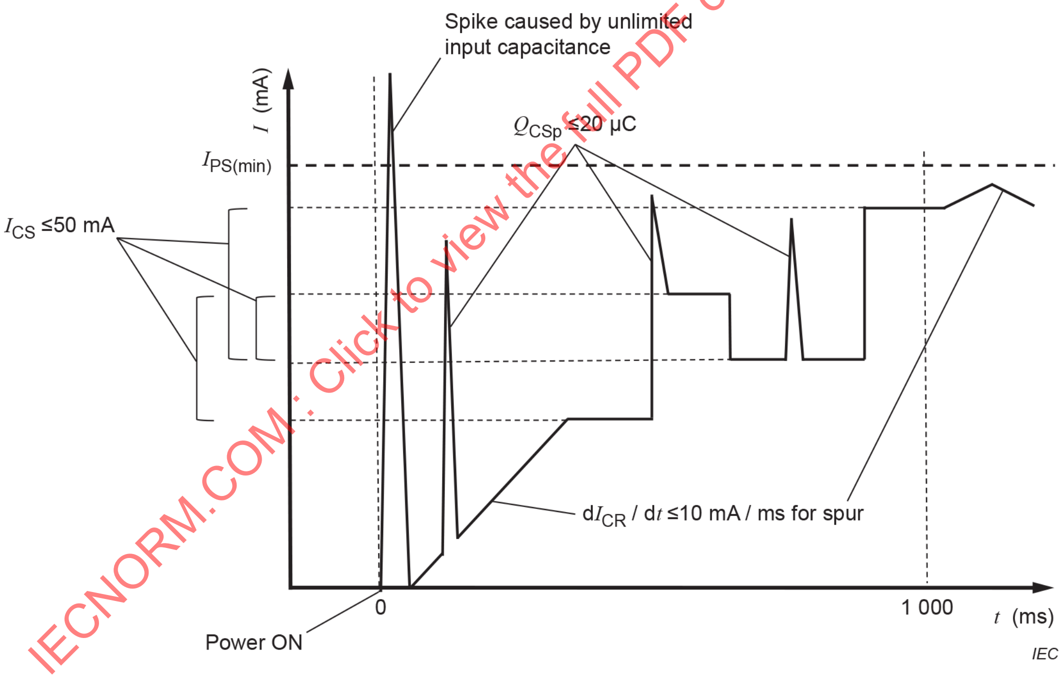


Figure 6 – Illustrative current step characteristics during start-up of a load port

5.5 Intrinsically safe protection class

5.5.1 General

The intrinsically safe protection class defines the level of protection related to intrinsically safe usage of a port circuit. Ports can be dual certified, if an equivalent protection level between IEC standards and North American standards exists. Table 8 shows the intrinsically safe protection classes. The definitions and reference standard in Table 8 are examples. National or regional Ex certification schemes, other than based on IEC Standards, could show different markings, types of protection or protection levels on the Ex product.

Table 8 – Intrinsically safe protection class

Intrinsically safe protection class	Definition	According to standard	Permitted port class	Permitted power class of a load port
A	Intrinsically safe Ex ia IIC (Ga) / IIIC (Da)	IEC 60079-11	P, L	A
C	Intrinsically safe Ex ic IIC (Gc) / IIIC (Dc)	IEC 60079-11	P, L	A, C
X	Non-hazardous area / Hazardous area non-intrinsically safe	—	P, L, C	3, 4
NOTE A particular national or regional standard, code or directive could use other particular notations, differing from international IEC notations (e.g. CEC or NEC).				

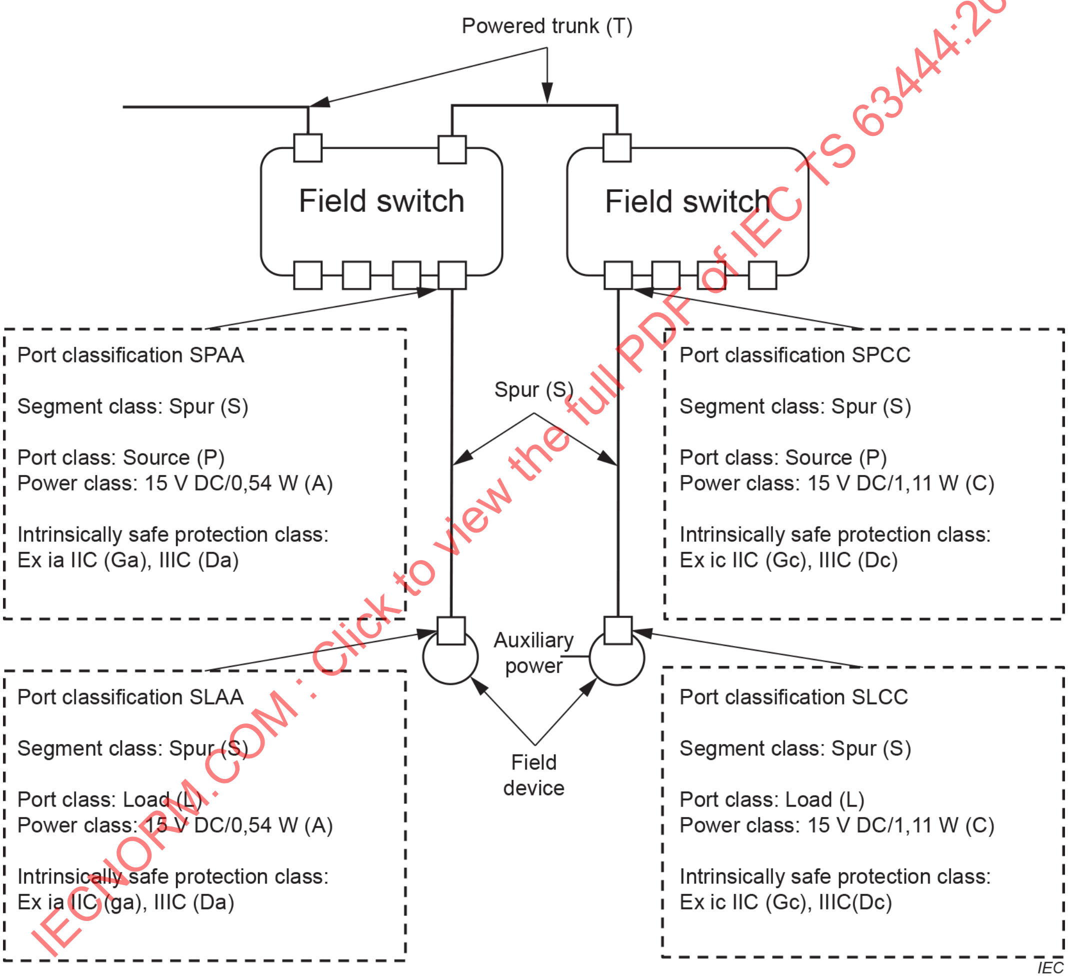


Figure 7 – Example of intrinsically safe protection class matching to port class and power class

Figure 7 provides an example of power class and intrinsically safe protection class matching.

For intrinsically safe protection class A, one option provides power from a power source (P) to a power load (L).

5.5.2 Intrinsically safe concept

Intrinsically safe ports of protection classes A and C, auxiliary devices and cables shall follow the intrinsically safe concept called "2-WISE", 2-Wire intrinsically safe Ethernet, standardized in IEC TS 60079-47.

2-WISE technical principles and definitions conform to IEC 60079-11, IEC 60079-14 and IEC 60079-25.

2-WISE is an intrinsically safe system concept where an APL segment is assessed in such a way that the interconnection of ports, auxiliary devices and cable is simplified. No examination of the interconnection of intrinsically safe ports by comparing the safety parameters is required.

6 General port requirements

6.1 Terminals and connectors

Terminal blocks and connectors shall conform to the specification given in Annex A.

6.2 Cable shield termination

To minimize the impact of electromagnetic interferences to the equipment of an APL based communication system, special attention is required on how cable shields are managed. The integrity of the shielding throughout the APL segment, including terminations and cables, shall be maintained.

To ensure the highest rejection against electromagnetic interferences, direct grounding of both ends of the cable shield with low impedance is recommended. Direct grounding at both ends shall only be used if the equipotential bonding system of an installation is controlled and equalized. In installations where grounding of both ends of the shield is not possible or could lead to shield ground loops or circulating currents, one end of the cable shield shall be capacitively grounded, and the other end shall be directly grounded.

To support both shield grounding methods, APL ports need to support individual shield connection options for both direct grounding and capacitive grounding, at least at one port of an APL segment. As it is not possible to implement both grounding options for all APL ports, the port and segment type class determines which grounding options a port shall at least provide.

Table 9 provides the minimum required cable shield termination options a port shall support.

Table 9 – Minimum required shielding options of a port

Port class	**Segment class**	
	Trunk	**Spur**
P (Power source)	Direct	Capacitive
L (Power load)	Capacitive and direct	Direct
C (Cascade port)	Capacitive and direct	Not applicable

The value of the capacitor used for capacitive coupling the shield to ground shall be 3 nF to 10 nF including tolerances. Additional requirements for the capacitors can exist due to applications in hazardous areas or due to personal safety.

Direct or capacitive grounding cables shields can be subject to further requirements due to hazardous area use (e.g. see IEC 60079-14) or multiple other standards.

The use of a capacitive grounded shield connection at an APL port of a device could require isolation to earth, to the housing, to the APL signal lines, to auxiliary power lines and other shield connections of the device, depending on the applicable safety standards for the device (see Figure 8).

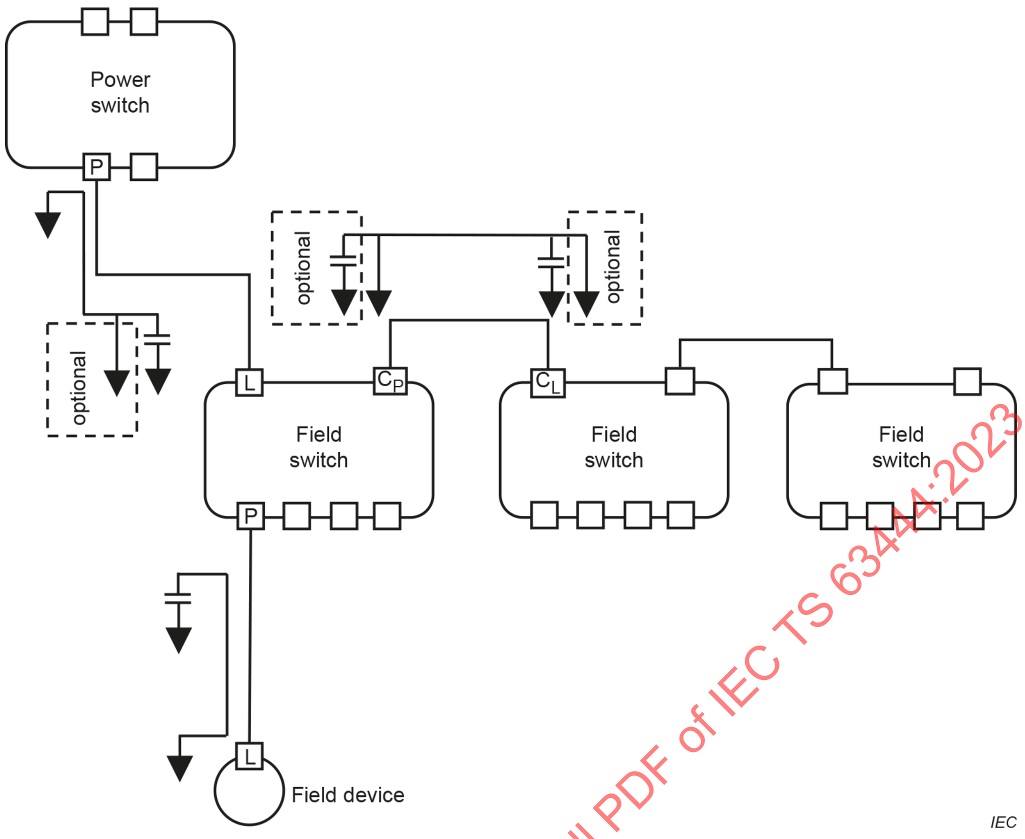


Figure 8 – Cable shield grounding options

If the equipotential bonding system is controlled and equalized, use direct shield grounding on both sides.

6.3 Polarity sensitivity

The polarity sensitivity of a port shall depend on the power class and the port class, see Table 10. A polarity sensitive port, having terminals to connect individual wires of a cable, shall be distinctly marked with "+" and "−".

Table 10 – Polarity sensitivity

Power class	Power characteristics	Port class	Polarity sensitivity
A	15 V DC / 0,54 W	Load	Insensitive
C	15 V DC / 1,1 W	Load	Insensitive
3	50 V DC / 57,5 W	Load	Insensitive or sensitive
		Cascade	
4	50 V DC / 92 W	Load	Insensitive or sensitive
		Cascade	

6.4 Electrical isolation

The isolation breakdown requirements of the APL port circuits from ground, auxiliary power supply circuits from ground and APL port circuits from auxiliary power supply circuits shall be in accordance with IEC 61010-1.

Additionally, isolation between APL ports and between APL ports and other circuits in one device can be subject to further requirements due to hazardous area use.

An APL port shall provide at least 1 MΩ DC isolation resistance between the signal wires and ground.

If multiple spur ports are implemented in one device, the isolation between spurs is optional. If galvanic isolation is supported, the isolation voltage shall be at least 50 V_{RMS}.

NOTE In measurement and control applications, additional isolation between communication circuits and auxiliary power could be necessary.

6.5 Short circuit behavior

Power source ports shall withstand continuous short circuits between its signal wires and signal wires to ground without any damage. After releasing the short circuits, ports shall change automatically into normal operation.

If components include multiple ports, then multiple shorts to ground of the different ports do not need to be taken into account.

7 Network configuration rules

7.1 Segment components

An APL segment can comprise:

a) cable;
b) two APL ports;
c) two auxiliary devices;
d) terminals blocks / connectors.

7.2 Topology

An APL segment connects two APL-compliant ports – one connected to each end of a segment – with in-series auxiliary devices, terminal blocks/connectors and cabling.

For each auxiliary device used in an APL segment, the number of permitted inline connectors is reduced by one, see Table 2.

A powered APL segment shall connect only one power source to one power load port.

NOTE Cascade ports either work as a power source or power load port depending on the type of port to which they are connected to.

If two cascade ports are connected together, one works as a source port, the other as a load port.

7.3 Cables

7.3.1 General

The supported APL cable is a balanced, individually shielded twisted-pair cable with impedance in the range of 100 Ω ± 20 % in a frequency range of 100 kHz to 20 MHz (measured according to ASTM D4566-05 or equivalent international standard) to support a full-duplex data rate of 10 Mbit/s. Permitted wire diameters are in the range of AWG26: 0,13 mm² to AWG14: 2,0 mm² either with solid or stranded wires.

NOTE The wire diameter and the type of wires limit the maximum supported cable length.

In process industries, a wide range of cable types is used, which vary in performance and electrical characteristic. These cables typically meet the requirements for intrinsically safe applications as described in 2-WISE, but verification is required. These cables may also be used in non-intrinsically safe applications.

The preferred cable type for APL segments is based on fieldbus type A cable MAU types 1+3 according to IEC 61158-2:2023, Clause B.1. This cable meets the requirements for intrinsically safe applications as described in 2-WISE and may be used in non-intrinsically safe applications as well.

Due to different constructions and manufacturing processes, critical parameters such as insertion loss can reduce the maximum specified cable length. Cable manufacturers need to classify their specific cables into an APL category system to allow users and designers to determine the maximum usable cable length with a specific cable.

7.3.2 Cable category system

The APL cable category system specifies the maximum supported cable length for trunks and spurs dependent on the characteristics of a cable, see Table 11.

Mixture of different cable category is not recommended.

Table 11 – Cable category system

Parameter	Cable category			
	I	II	III	IV
Maximum trunk cable length [m]	250	500	750	1 000
Maximum spur cable length [m]	50	100	150	200
Coupling attenuation [dB]	≥ 60 (*f* is frequency in MHz; 0,1 ≤ *f* ≤ 20)			
Cable return loss [dB]	≥ 15 + 8 × *f* (*f* is frequency in MHz; 0,1 ≤ *f* ≤ 0,5)			
	≥ 19 (*f* is frequency in MHz; 0,5 ≤ *f* ≤ 20)			
Trunk cable insertion loss [dB]	$\leq 10 \times \left(1{,}23 \times \sqrt{f} + 0{,}01 \times f + 0{,}2 / \sqrt{f}\right)$ (*f* is frequency in MHz; 0,1 ≤ *f* ≤ 20)			
Spur cable insertion loss [dB]	$\leq 2 \times \left(1{,}23 \times \sqrt{f} + 0{,}01 \times f + 0{,}2 / \sqrt{f}\right)$ (*f* is frequency in MHz; 0,1 ≤ *f* ≤ 20)			
Cross talk [dB], (PSANEXT/PSAFEXT wire pair to wire pair) for multi core cables	≥ 60 (*f* is frequency in MHz; 0,1 ≤ *f* ≤ 20)			

The values in this table apply for single pair and multi pair cables.

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

The AC link segment requirements can also be verified using ISO/IEC TR 11801-9906 (Class T1-A-1000) channel definitions, which could exclude IEC 61158-2 type A fieldbus cables from being compliant to these definitions.

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.

The cable return loss limit curve is 6 dB above the IEEE Std 802.3-2022, Clause 146, limit curve taking multiple additive signal reflections occurring at short cable lengths into account.

For powered APL segments, the voltage drop over the cable shall be additionally taken into account to determine the maximum supported cable length.

7.3.3 Cables for use in intrinsically safe installations

Requirements for cables used in the APL intrinsically safe system (2-WISE) are listed in IEC TS 60079-47.

7.4 Wiring rules

In polarity sensitive systems, 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 50 mm. 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 possible 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 100 mm long stubs needed to connect surge protection devices as shown in Figure B.2.

Neither conductor of the twisted pair shall be directly connected to ground at any point in the APL segment. Signals shall be applied and preserved differentially throughout the APL segment.

7.5 APL segment definition

An APL trunk segment shall follow the link segment definitions of IEEE Std 802.3-2022, 146.7, for a PHY operating in "2.4 V_{pp} operating mode".

An APL spur segment shall follow the link segment definitions of IEEE Std 802.3-2022, 146.7, besides the exception that the following formula is used for the insertion loss of a spur segment:

$$\text{Insertion loss } (f) \leq 2 \times \left(1{,}23 \times \sqrt{f} + 0{,}01 \times f + \frac{0{,}2}{\sqrt{f}} \right) + 4 \times 0{,}02 \times \sqrt{f} \qquad \text{[dB]}$$

Where f is the frequency in MHz; $0{,}1 \leq f \leq 20$.

8 Electromagnetic compatibility

Equipment containing an APL port could need to comply for the limitation of electromagnetic interference with more stringent requirements than applicable local and national codes, as agreed upon between customer and supplier.

NOTE The Ethernet-APL EMC test specification as defined in IEC 61326-2-7 provides test configurations, operational conditions and performance criteria for Ethernet-APL equipment having one or more ports implemented which conforms to this document.

Annex A
(normative)

Connectors

A.1 General

Depending on the application and/or installation requirements, different types of cable terminations could be required. To accommodate these variations, this normative annex defines connectors of type M8, M12, and terminal blocks.

Selection of connectors shall take environmental conditions into account to guarantee the integrity of the communication signal over the required service time. Table A.1 contains the supported connectors and terminal blocks. Table A.2 contains the electrical requirements for the terminal blocks and connectors.

Table A.1 – Supported terminal block / connector types

Terminal block / connector type	Port type	Application
M8 / M12	P, L, C	Port to cable
Terminal block	P, L, C	Port to cable Cable to cable
Inline terminal	P, L, C	Cable to cable

Table A.2 – Electrical requirements terminal block / connector

Specification	Min	Max
Current per contact	4 A	
Rated voltage contact to contact	50 V DC	
Isolation voltage contact to shield	1 500 V AC	
Insertion loss		0,04 for 0,1 MHz ≤ f < 4 MHz
		0,02 × √(f / MHz) for 4 MHz ≤ f ≤ 20 MHz
Return loss		28 + 8 × f dB for 0,1 MHz ≤ f < 0,5 MHz, 32 dB for 0,5 ≤ f ≤ 20 MHz
PSANEXT		73 dB for 0,1 MHz ≤ f < 0,95 MHz, 50,5 dB – 17 × $\log_{10}(f / 20)$ for 0,95 MHz ≤ f < 3,68 MHz, 63 dB for 3,68 MHz ≤ f ≤ 20 MHz
DC resistance per contact		0,025 Ω

The values specified in Table A.2 shall be maintained across the full environmental temperature range of the device the terminal block /connector are used with.

The parameters given in Table A.2 are required for connector and terminal block selection. For practical reasons, for connectors built into an APL port implementation, no specific connector performance tests are required, as it is expected that the connector performance is validated during the port specific APL conformance tests (e.g. MDI return loss).

A.2 M8 / M12 connectors

A.2.1 General

M12 connectors are admissible in hazardous and non-hazardous locations. M8 connectors are admissible only in non-hazardous locations.

A.2.2 Requirements

All M8 connectors shall conform to IEC 61076-2-104 (A-coding) and meet the requirements set out in Table A.2.

All M12 connectors shall conform to IEC 61076-2-101 (A-coding) and meet the requirements set out in Table A.2.

A.2.3 Pin assignment

The contacts of the M8 / M12 circular connectors shall be assigned to functions as shown in Table A.3 plus Figure A.2 and Figure A.3.

Power source ports, cascade power source ports shall use sockets (S). Load ports and cascade load ports shall use plugs (P) as illustrated in Figure A.1.

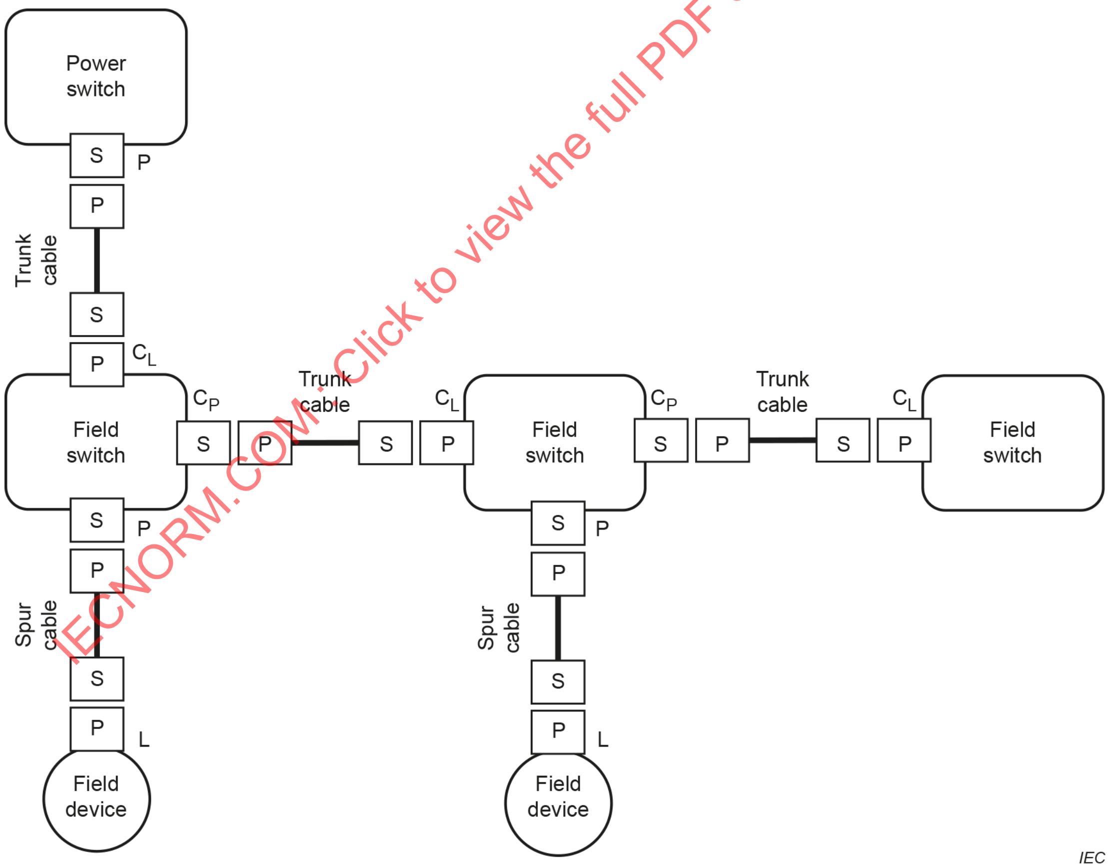


Figure A.1 – Port class to connector type matching