10 Mb/s Single Twisted Pair Ethernet
Process Industry Requirements

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Overview

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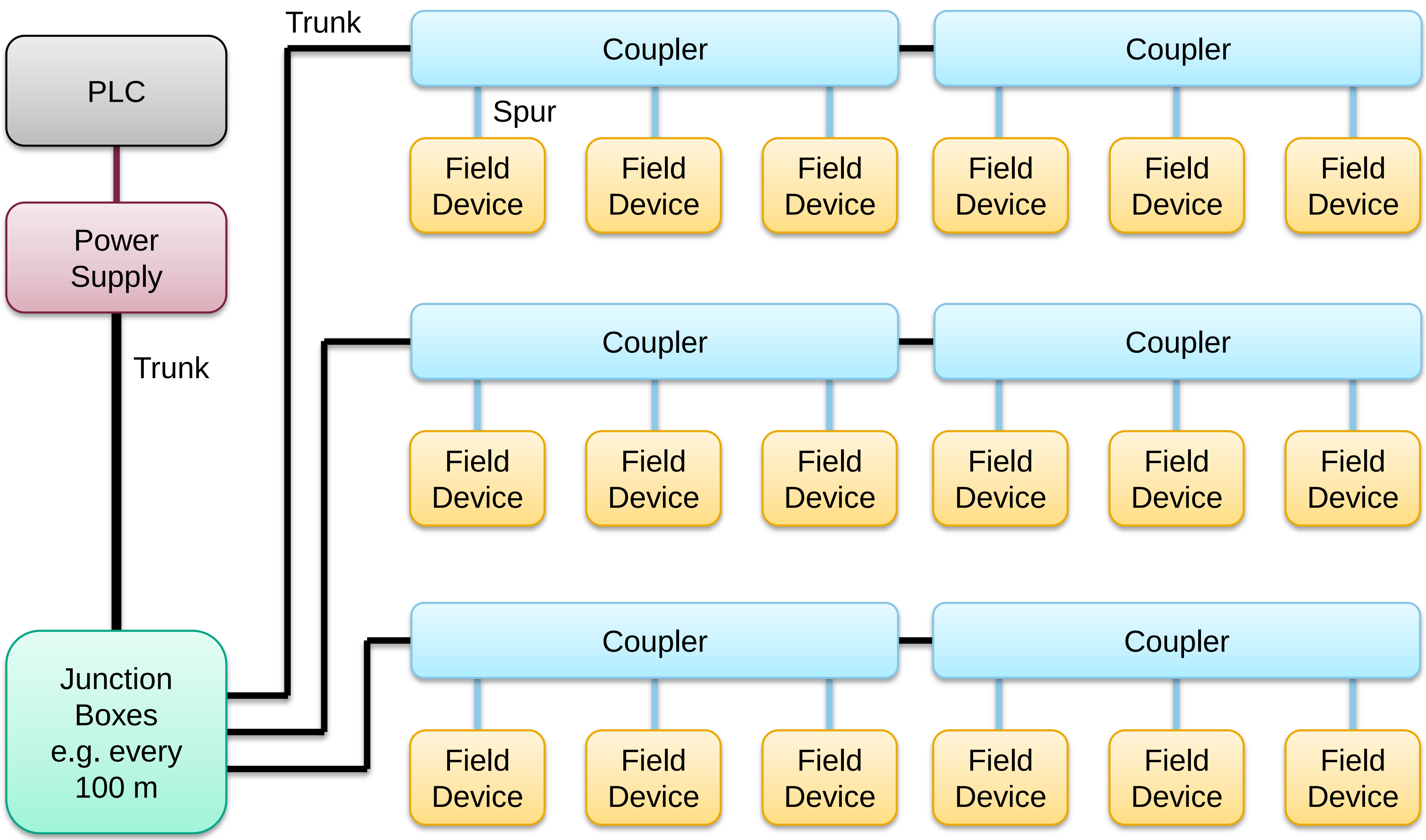
Introduction

- Currently in process automation field devices are mainly connected to a controller using 4-20 mA, HART and Fieldbus (Profibus PA, Foundation Fieldbus).
- Common for all these technologies is, that most of the field devices are using a single twisted pair for communication and that the devices are also powered over these two wires.
- The power demand of current field devices is quite low, typically in the range of about 100 mW or less and the used communication speeds support cable runs of more than 1000 m.
- A crucial requirement in process industry is also the possibility to use the technology in hazardous areas, where intrinsic safety plays a major role.
- One goal in process industry is to homogenize the used communication technologies and also to increase the available bandwidth in the future to support easier integration, configuration and maintenance.
- To provide an easy upgrade path the expectation is, that the existing cabling can be reused to run also the new Ethernet based physical layer wherever possible.

Current Fieldbus Infrastructure I



Current Fieldbus Infrastructure II

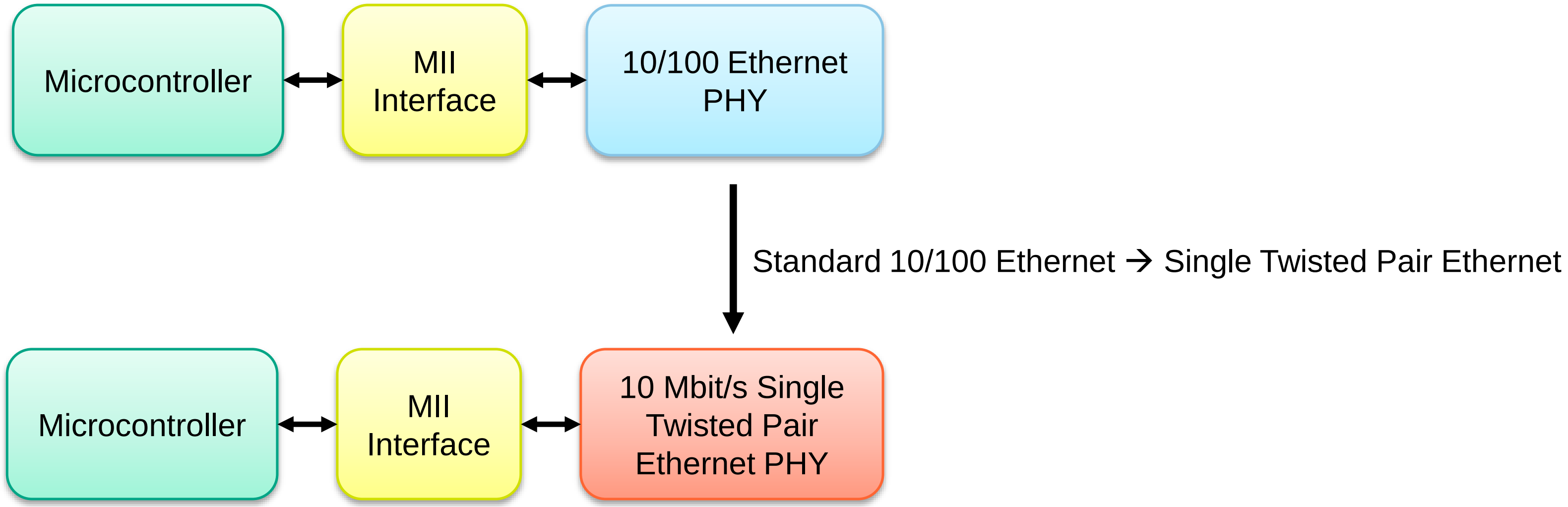
- Typically several power supplies connected to a PLC are placed within a cabinet in the control room.
- From the cabinet to the field single trunk cables or multicore trunk cables (with individual shields to reduce crosstalk) are used.
- To ease the installation of a trunk cable, several junction boxes are used to connect shorter cables to one common trunk cable.
- The junction boxes contain robust screw terminals or spring-type terminals.

Current Fieldbus Infrastructure III

- In the field the communication signal and energy coming from the trunk cable is distributed to several field devices using spur cables.
- The type of explosion protection for the trunk cable is often implemented in increased safety (Ex e), while the type of explosion protection for the spur cables is mostly implemented intrinsically safe (Ex i).
- The reason for the different protection methods are the different energy levels needed on trunk and spur.
- Using intrinsic safety on the spur side limits the available power to about 500 mW, which is well above the power demand that current field devices need for operation.

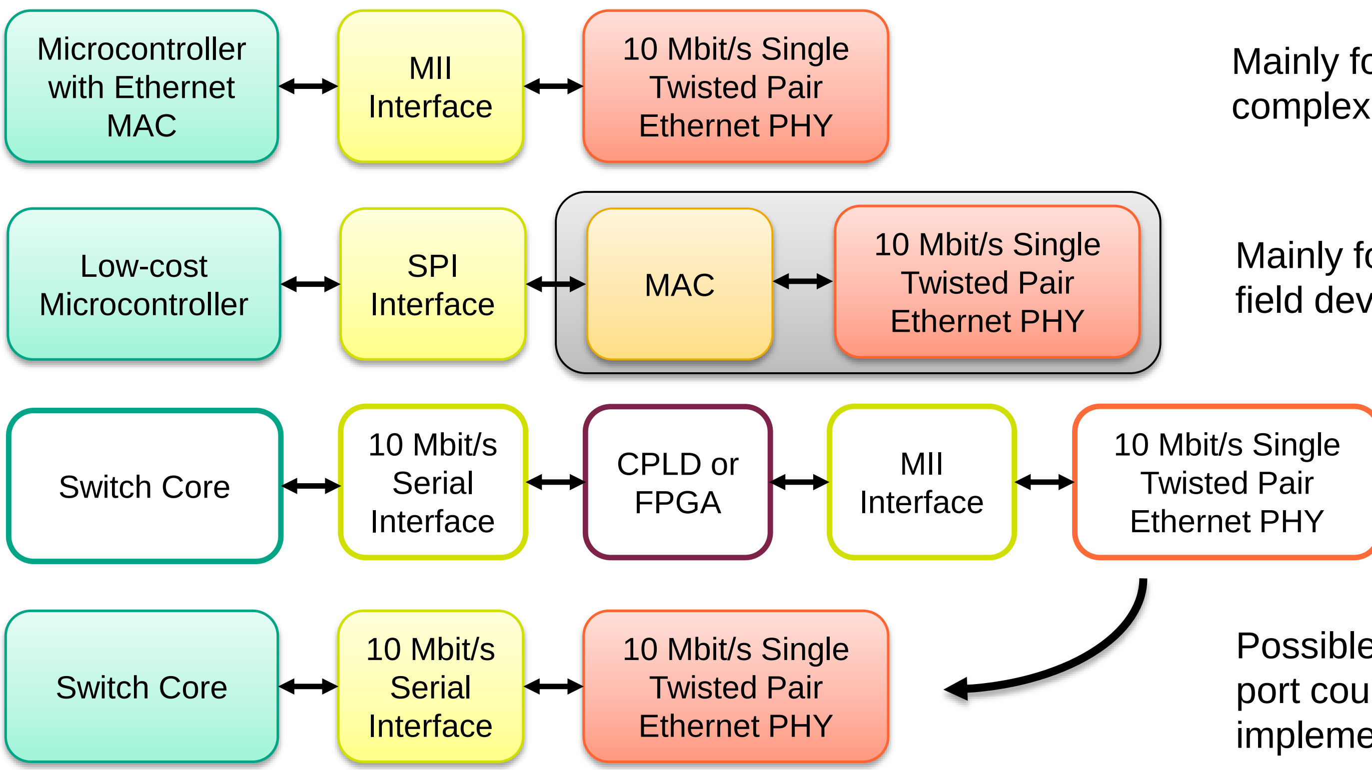
Requirements for Ethernet Infrastructure I

- **Ethernet compatible full duplex communication with 10 MBit/s.**
  - No change of the Ethernet MAC layer.
  - Using standard interfaces for connecting the PHY chip to a microcontroller.
  - Easy upgrade path of existing Ethernet field device electronics by exchanging the PHY chip.
  - No need for change in software architecture.



Requirements for Ethernet Infrastructure II

- **PHY interface configurations.**
  - Depending on how the PHY is being used, several interfaces to a microcontroller or switch core/FPGA seem to be suitable for an easy implementation.



Mainly for usage in more complex field devices.

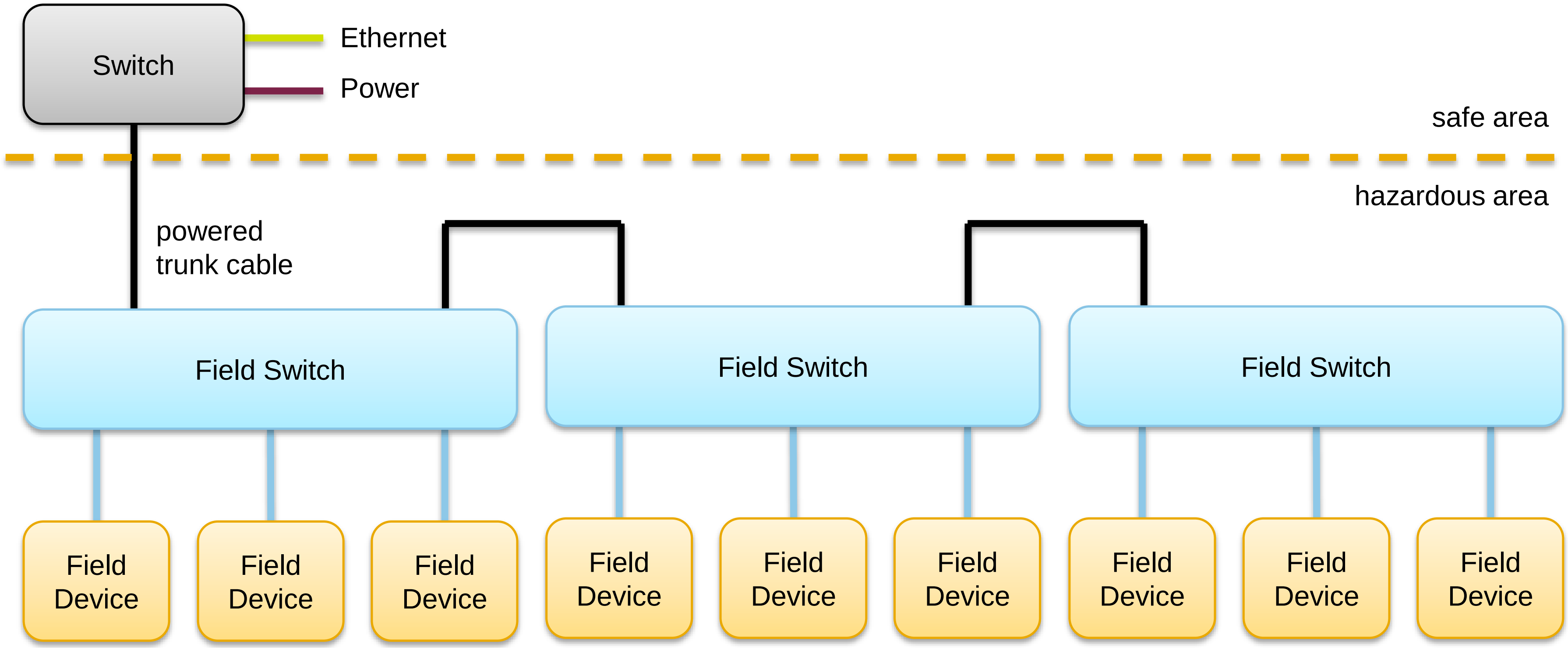
Mainly for usage in simple field devices.

High effort, high cost, higher power required.

Possible solution for high port count, low power switch implementations.

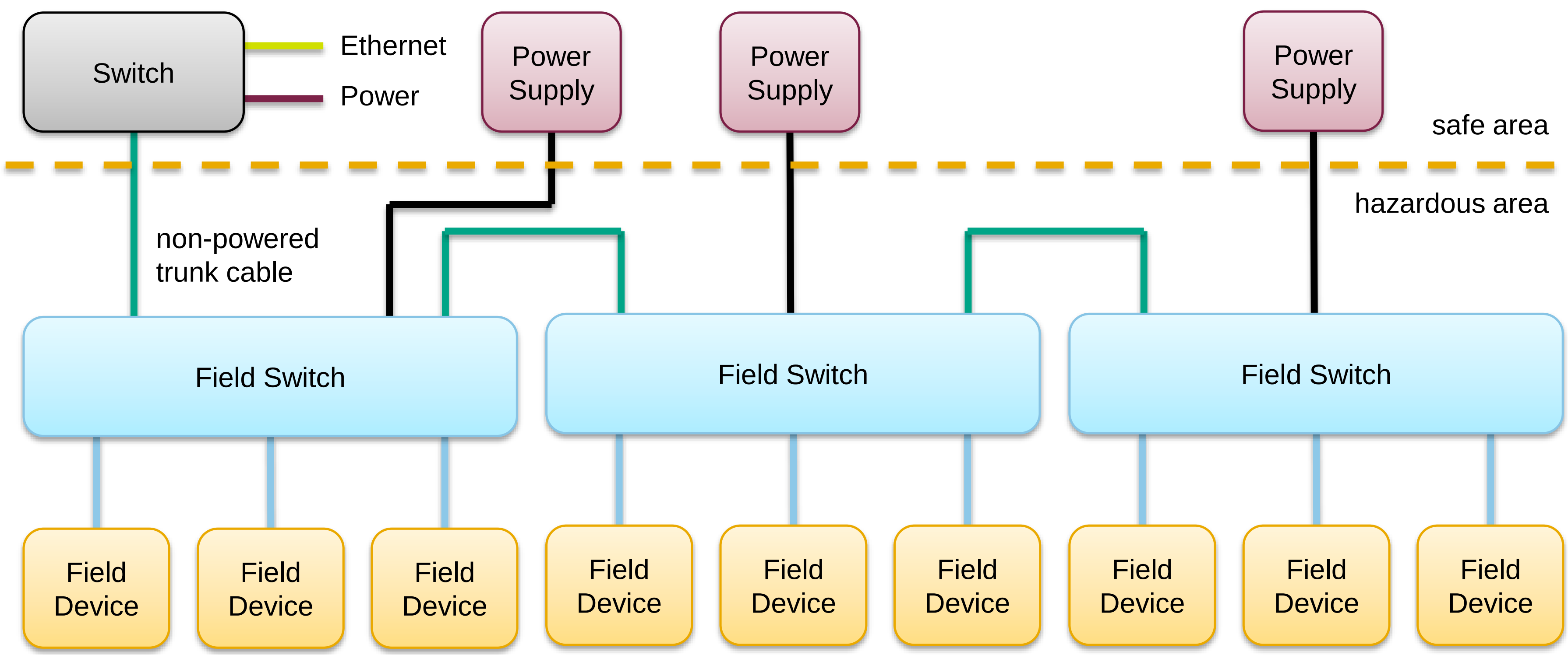
Requirements for Ethernet Infrastructure III

- **2-Wire system for communication and power.**
  - 2-Wire technology is the current standard technology for connecting field devices in process automation.
  - Needed for acceptance in process industry due to cost constraints and ease of installation.
  - Especially in sites with hazardous area requirements providing additional auxiliary power is very costly.



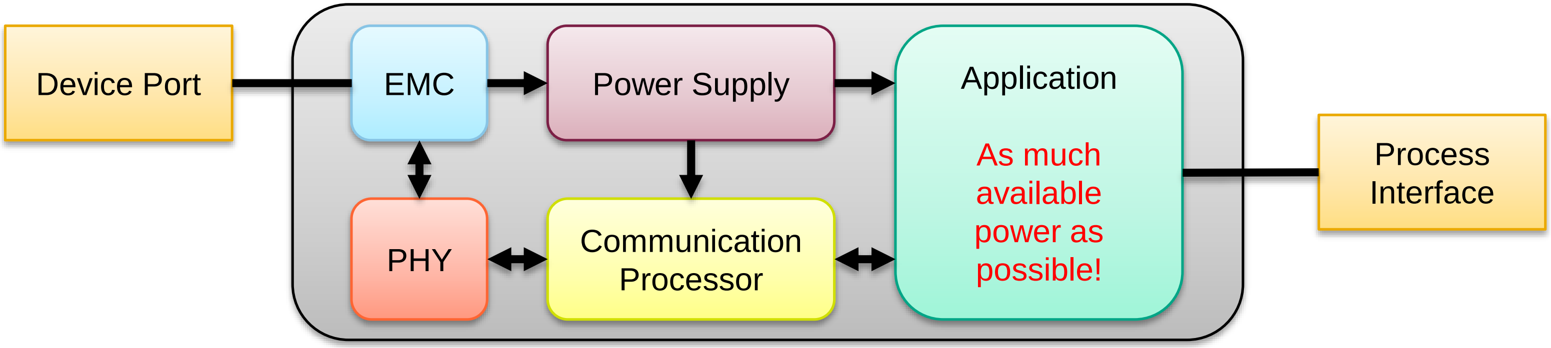
Requirements for Ethernet Infrastructure IV

- **Alternatively separate powering of the field switches.**
  - There may be smaller plants with no hazardous areas, where auxiliary power is available.
  - Auxiliary power allows the connection of high power field devices to the infrastructure.
  - Additional cost for wiring of the external power, which is often not easily available in hazardous areas.



Requirements for Ethernet Infrastructure V

- **Low energy consumption.**
  - To reduce the overall installation cost, each powered 10 Mbit/s single twisted pair Ethernet segment must be able to power up to 50 field devices.
  - Taking e.g. a 48 V/1.25 A/60 W power supply into account, after 1000 m of AWG14 cable about half of the power is available for the electronics, the rest of the power is lost due to cable resistance. Therefore in this example 30 W are available for the infrastructure components and the field devices.
  - Assuming, that half of the power is needed by the infrastructure components and the other half of the power is available for the field devices, this leads to a maximum power of 300 mW per device including the communication interface but also the application power, which must be maximized.
  - Assuming 100 mW application power and 100 mW power for the communication processor, a maximum of 100 mW is available for the Ethernet PHY (neglecting the losses in the devices power supply).
  - Taking also the power supply losses into account the power consumption of a PHY chip needs to be more likely in the range of 60 to 80 mW.



Requirements for Ethernet Infrastructure VI

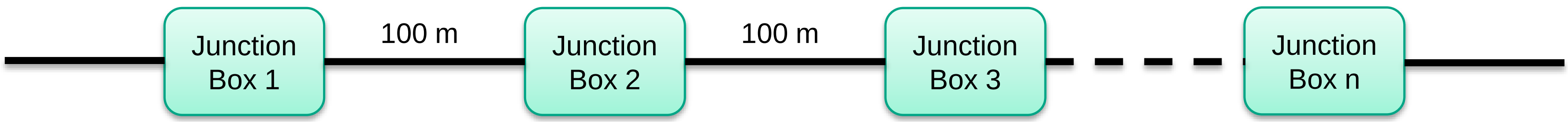
- **Overall trunk cable length up to 1000 m.**
  - Classic Fieldbusses (Profibus PA and Foundation Fieldbus) allow a segment length of 1900 m.
  - A trunk cable length of 1000 m is suitable for more than 95 % of all applications.
  - A maximum cable length of 1000 m is a compromise between possible distance and signal damping.

- **Overall spur cable length up to 200 m.**
  - Classic Fieldbusses (Profibus PA and Foundation Fieldbus) allow a maximum spur length of 120 m.
  - Nevertheless there are some applications, where a few field devices will need to be mounted in a distance longer than 120 m, so that 200 m seem to be suitable to reach also distances far away from the field switch.

Requirements for Ethernet Infrastructure VII

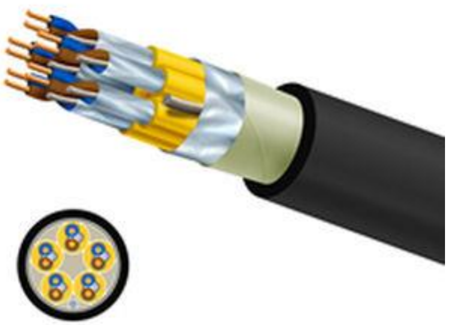
- **Use of existing fieldbus cable (Fieldbus Cable Type A).**
  - Fieldbus Cable Type A is based on the communication cables used in process automation the best suited cable for transmission of energy and communication data over longer distances.
  - The cable is available in a variety of types, including rugged cables and cables resistant to chemicals.
  - In most sites using Profibus PA or Foundation Fieldbus, this cable is already used, so that an easy retrofit is possible, if this cable is supported.
  - For greenfield applications, also the definition of a cable with tighter tolerances is possible, nevertheless existing cabling infrastructure needs to be supported.

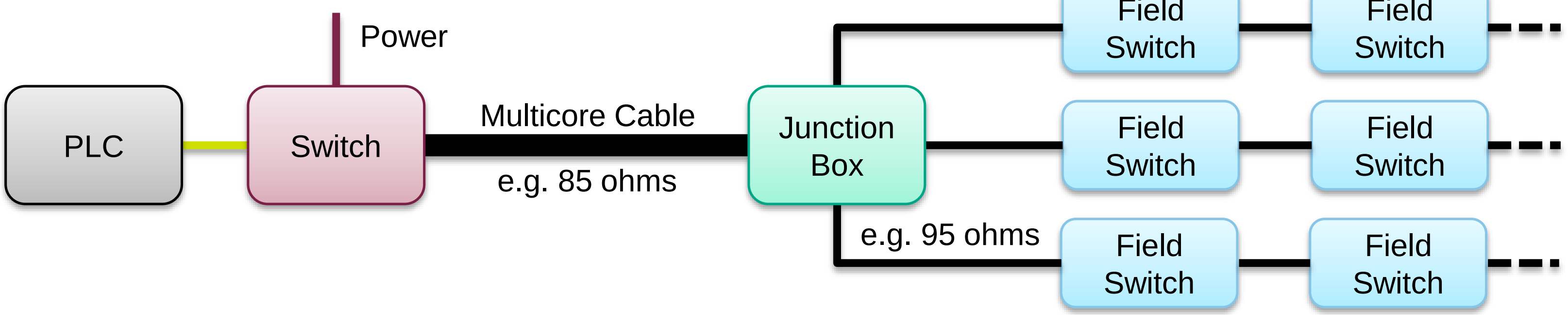
- **Allowance of junction boxes on the trunk cable to ease installation.**
  - Due to the weight and size of the cable, it is usual to split longer cables into shorter pieces and connect them using field junction boxes (e.g. one junction box every 100 m).
  - These junction boxes add some additional insertion loss.



Requirements for Ethernet Infrastructure VIII

- **Use of cables from different vendors and of different types on the same trunk.**
  - In existing plants there is the possibility, that within the same trunk cable different cable types are used.
  - E.g. for the first section an individually shielded multicore cable is used and in the field the different segments are connected to individual trunk cables.
  - Depending on the cable manufacturer, cable type, wire diameter etc. the characteristic impedance of the different cable sections can be different, so that signal reflections may also occur within the trunk cable.
  - These reflections (return loss) need to be filtered out by the adaptive echo canceller circuit.

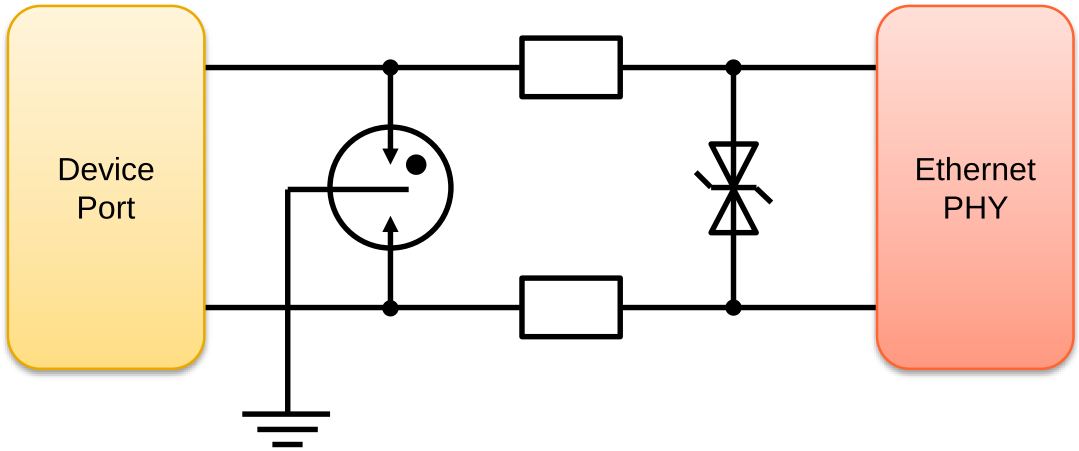




- **Use of existing installation cables for e.g. 4-20 mA devices.**
  - The damping of such cables is much higher, so that the cable length will be reduced.
  - Most of the multicore cables will have individually shielded twisted pairs.
  - Nevertheless there will be also multicore cables out in the field, which are not individually shielded.

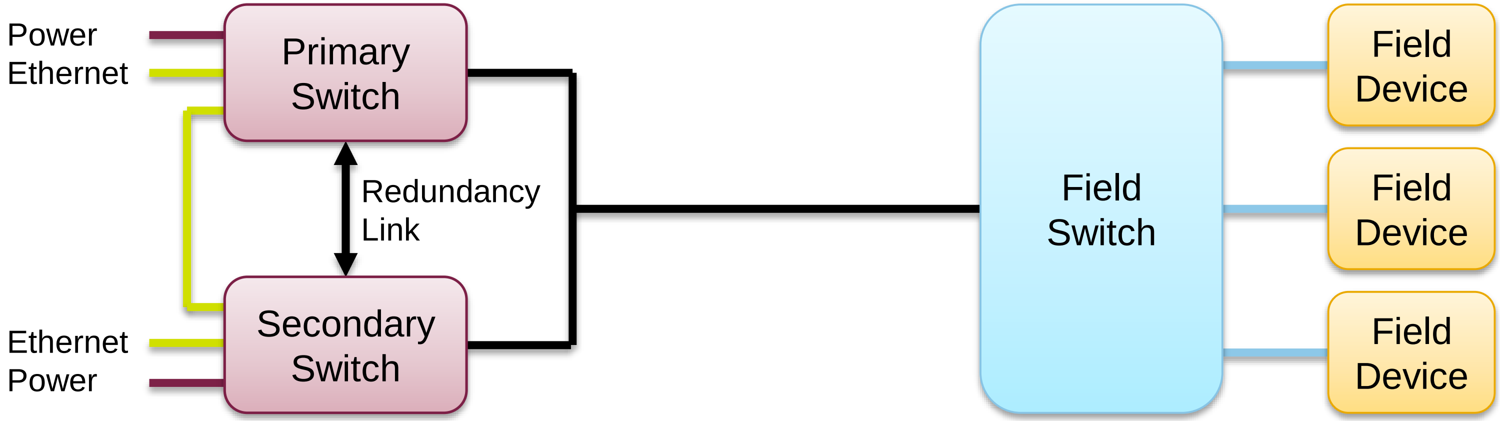
Requirements for Ethernet Infrastructure IX

- **Attachment of auxiliary devices (e.g. lightning protection).**
  - Running long distance cabling in process plants often requires additional protection against indirect lightning strikes.
  - In hazardous area locations, depending on the risk potential, protection against indirect lightning strikes can be mandatory.
  - Lightning protection devices will add additional capacitance and likely some additional resistance.



Requirements for Ethernet Infrastructure X

- **Ethernet PHY Redundancy.**
  - Today redundancy in industrial Ethernet networks typically utilizes redundant ring structures.
  - These ring structures are based on device redundancy and media redundancy.
  - In current process automation installations device redundancy (redundant power supplies and redundant gateways) is often implemented, but there is no media redundancy.
  - In process plants the communication cables are often installed protected against mechanical force, especially in hazardous locations, so that a failure is very unlikely.
  - In addition, especially when taking longer cable runs into account, installing redundant cabling can get expensive.
  - While in multi-drop topologies device redundancy is quite simple to implement, in point-to-point topologies, this needs the possibility to put the PHY drivers into high impedance state.



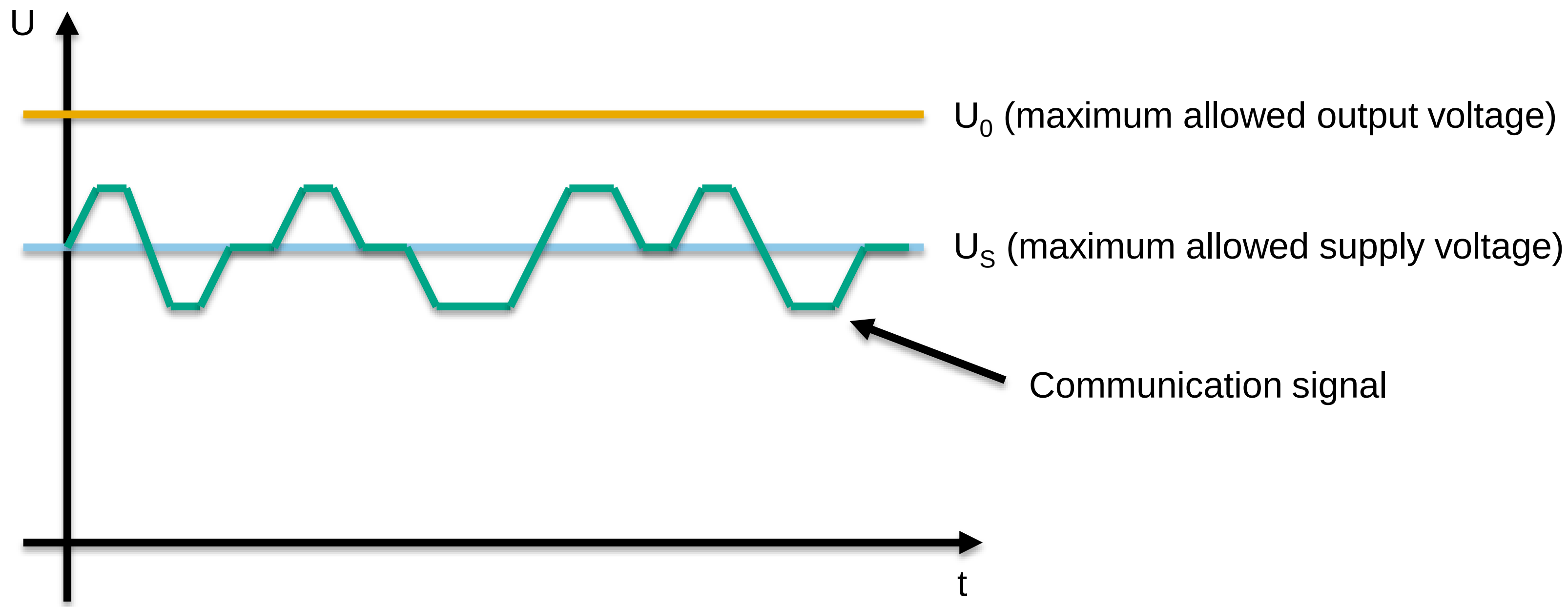
Requirements for Ethernet Infrastructure XI

- **Increased safety as explosion protection method on trunk side.**
  - Due to the higher available supply voltage and energy the trunk wiring will be implemented in most applications in increased safety (Ex e).
  - This protection method does not limit the provided energy, but special measures (e.g. certified, vibration resistant terminals, creepage and clearance distances, mechanical protection of wiring) are required, so that arcs due to loose wiring or shorts are prevented.
  - The used wiring technology can have an influence on the communication signal.

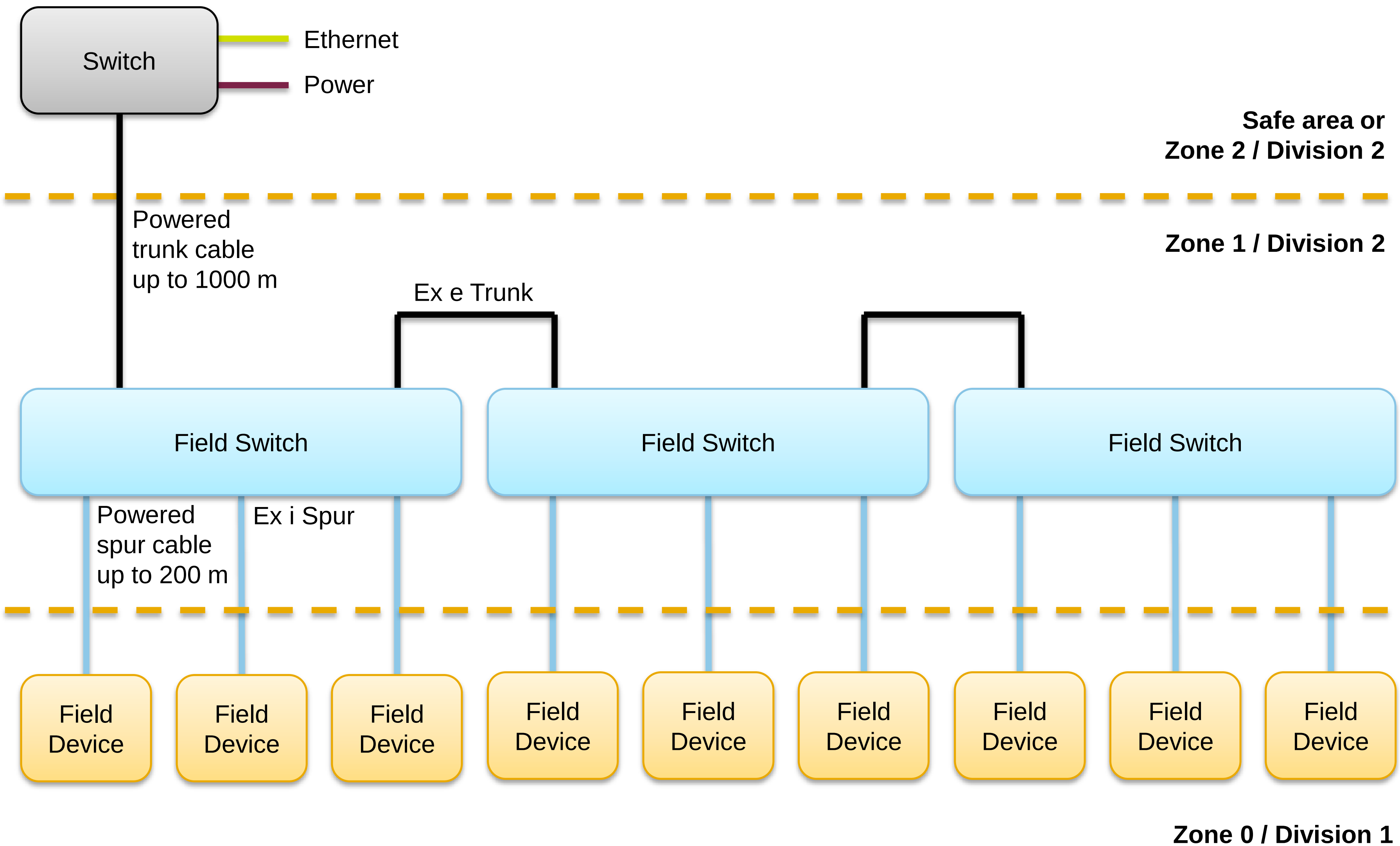
- **Intrinsic safety as explosion protection method on spur side.**
  - To be able to provide easy installation and because the needed energies are much lower for a single field device in most applications as protection method for the spur side intrinsic safety (Ex i) is being used.
  - Intrinsic safety allows easy maintenance and installation in live systems without the need for gas clearance or shutdown.
  - Intrinsic safety will have some influence on the used modulation scheme and signal amplitude.

Requirements for Ethernet Infrastructure XII

- **Support for connection of intrinsically safe field devices.**
  - Supply voltage and current for field devices must be limited to safe values.
  - Therefore also the communication signal amplitude needs to be limited.
  - For the functionality of the device it is important to have as much energy as possible for the application.
  - As it is important to maximize the available energy for the field device, the amplitude of the communication signal needs to be minimized to stay below the maximum allowed voltage.



System Structure



Ex Zones

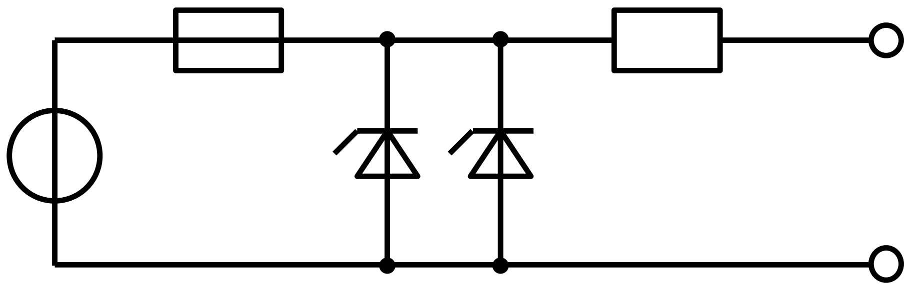
- Depending on the probability for the existence of explosive atmosphere, different zones are distinguished.

Zone 0 Division 1	... is an area in which a potentially explosive atmosphere exists permanently, for long periods of time or frequently (typically ≥ 1000 h/year).
Zone 1	... is an area in which under normal operating conditions occasionally a potentially explosive atmosphere is present (typically ≥ 1 h/year and < 1000 h/year).
Zone 2 Division 2	... is an area in which under normal operating conditions there is no potentially explosive atmosphere present or a potentially explosive atmosphere only briefly occurs (typically < 1 h/year).

- Depending on the level of protection no countable fault (Ex ic, Zone 2), one countable fault (Ex ib, Zone 1) or two countable faults (Ex ia, Zone 0) must be assumed within the safety limiting electronics.

Intrinsic Safety I

- Intrinsic safety is reached by limiting the provided voltage, current and energy in a way, so that even under the assumption of a failure (e.g. a short of the wires) within a hazardous area unsafe conditions do not occur.

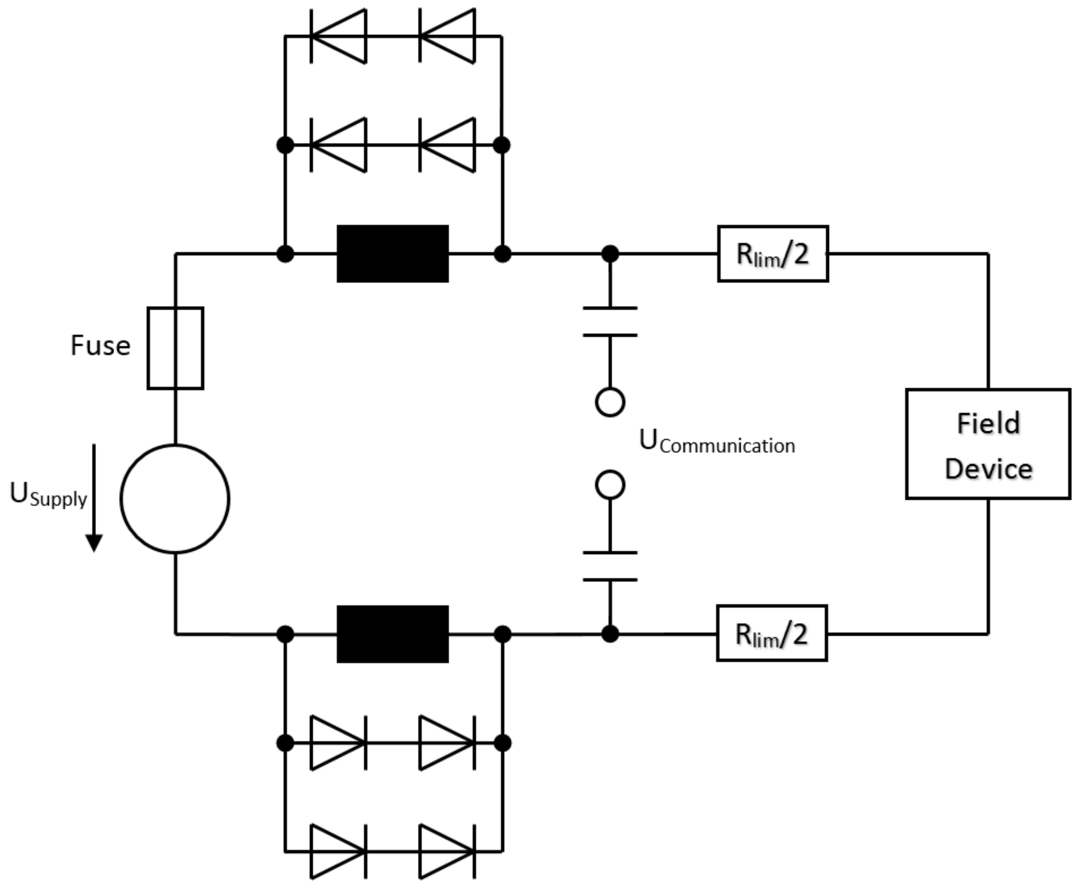


Simple Zener barrier:
shunt Zener diodes limit voltage,
series resistor limits current.

- Due to required creepage and clearance distances the limiting electronics will have to be implemented independently from the Ethernet PHY, nevertheless the used modulation must fit to the limiting electronics.
- Because the maximum possible signal amplitude is limited, a modulation signal, which is DC free and which is also keeping baseline wander effects low has the benefit, that the maximum signal amplitude is only affected by the signal itself and not by high pass effects of the system, so that the possible modulation amplitude is higher.

Intrinsic Safety II

- The following schematic shows in a very principle way, how an intrinsically safe spur output could look like (U_{Supply} is assumed to be already limited according to IEC60079-11):

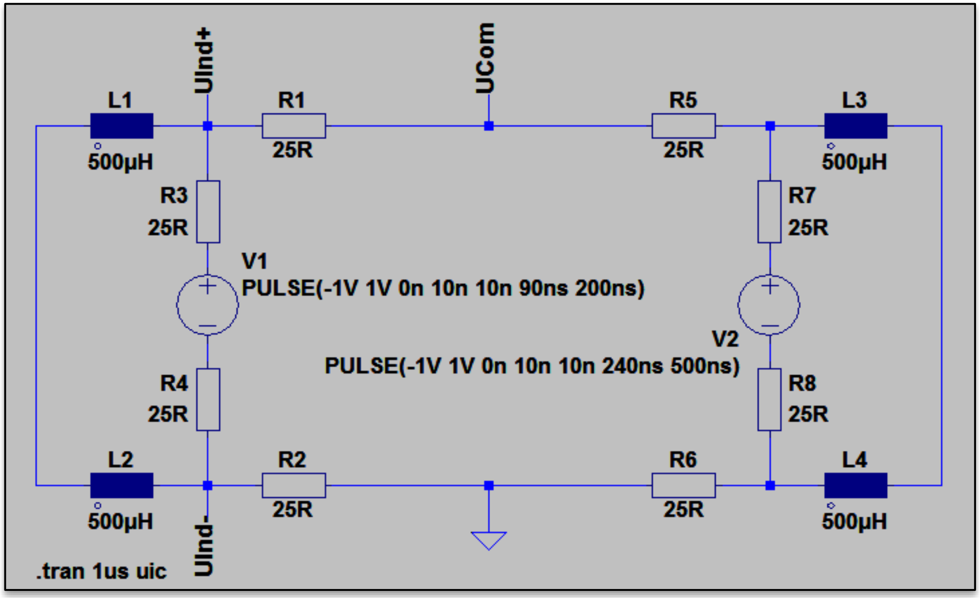


Intrinsic Safety III

- The resistors for limiting the current are in series with the termination resistors.
- Therefore the termination resistors of the PHY must be adoptable to the current limiting resistors to match the overall impedance with the characteristic impedance of the cable.
- Additionally the echo cancellation circuit must be adoptable to the changed termination resistors.
- Due to intrinsic safety requirements additional clamping elements, mainly silicon diodes have to be added, which have with their parasitic capacitance an additional influence on the communication signal.
- Depending on the used supply and voltage limiting circuit and depending on the internal structure of the Ethernet PHY, it could be necessary to provide the possibility to connect an external compensation network or to compensate the parasitic effects by the adaptive echo canceller and equalizer.

Intrinsic Safety IV

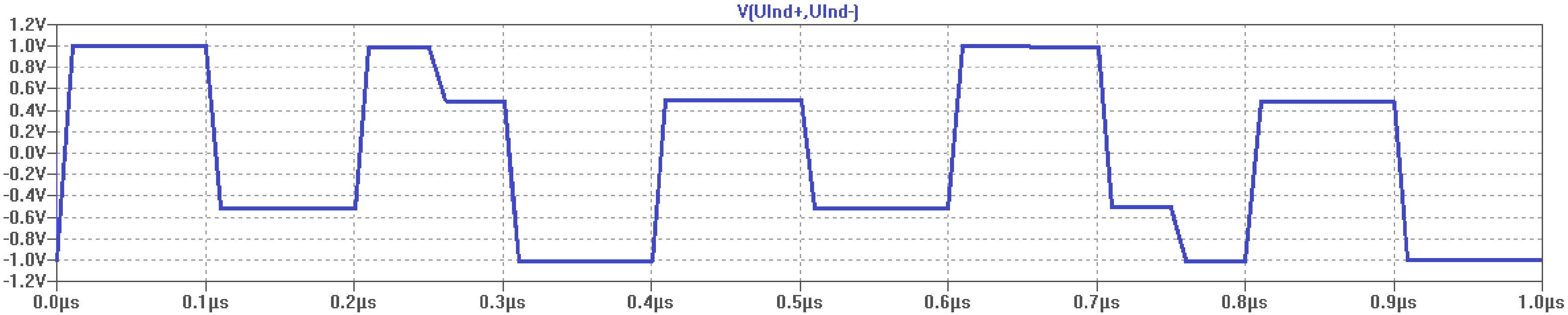
- **Maximum possible signal amplitudes at the power feeding inductors.**



The maximum signal amplitude has a significant impact on the available supply power of a field device.

A system with two active transceivers transmitting with a signal amplitude of 1 V_{pp} (±0.5 V) on each side leads to a signal amplitude of about 2 V_{pp} (±1 V) at the power decoupling inductors.

In intrinsically safe systems these inductors need to be clamped by redundant diodes or other measures to limit the energy stored in these inductors.



Intrinsic Safety V

- Intrinsic safety requires to take the maximum forward voltage at the maximum current of each clamping diode into account (e.g. 0.8 V).
- As the diodes may not disturb the low energy communication signal the allowed diode forward voltage for not influencing the communication signal is much lower (e.g. 0.25 V).
- Depending on the amount of clamping diodes needed in series, the available DC power for a field device can be evaluated:

Signal amplitude	Clamping diodes in series	Available field device power
0.5 V_{pp} (±0.25 V)	2 Diodes	700 mW
1.0 V_{pp} (±0.50 V)	4 Diodes	500 mW
2.0 V_{pp} (±1.00 V)	8 Diodes	125 mW

- As the spur cable length is much shorter than the trunk cable length, to maximize the available power for a field device, it seems to be reasonable to reduce the signal amplitude on the spur side, while transmitting with the full signal amplitude on the trunk side.

Power Profiles

- As the physical layer allows a powering of the devices it makes sense to think about the standardization of power profiles.
- From the use cases there seem to be at least three relevant power profiles:
  - **Non-Ex-Profile(s):** At least one power profile should be assigned to non-Ex field devices. As for PoE it could also make sense to have more than one power profile for non-Ex field devices, to be able to reflect different power classes.
  - **Ex-ia/ib-Profile:** This profile would be the basic profile for intrinsically safe field devices. Because for Ex ia/ib the same safety factor (1.5) to the maximum supply values has to be applied, devices for Zone 0 and Zone 1 area usage can be handled with the same power profile.
  - **Ex-ic-Profile:** This profile would be an additional power profile for Ex ic, Zone 2 devices. For Ex ic no safety factor needs to be applied, so that a higher output power is possible compared to Ex ia/Ex ib.
- If there would be some kind of discovery process after connecting a device to a field switch port, then also accidently wrong connected devices could be identified, before applying the full power to the device and a warning message could be sent to the user.

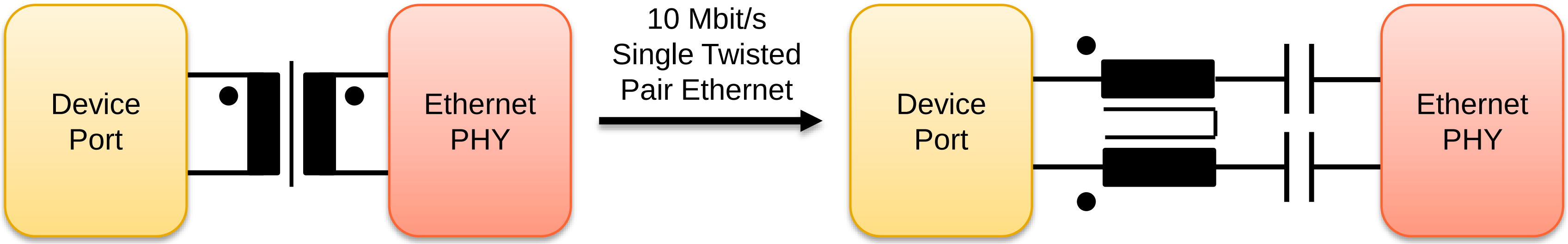
EMC Requirements I

- EMC requirements for process control equipment are specified in **IEC61326-1** and **Namur NE21** (chemical industry requirements).
  - Surge test level is 2 kV with 2 ohms series resistance coupled to the shield, failure criterion B.
  - ESD Levels are 8 kV (Air) and 6 kV (Contact) discharge, failure criterion A.
  - Burst Level is 1 kV, failure criterion A.
  - Conducted Immunity Levels are 10 V/m (10 kHz – 80 MHz), failure criterion A.

Failure criterion A: No loss of communication allowed.

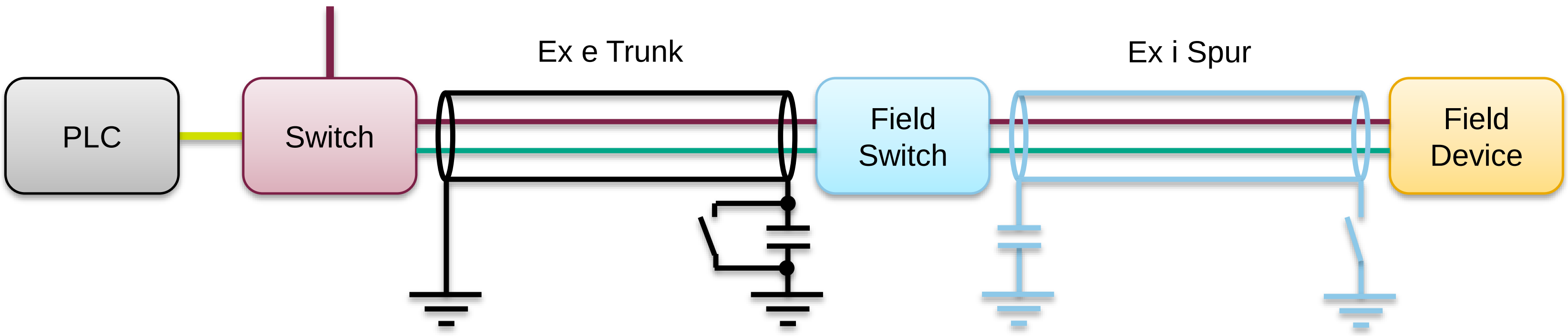
Failure criterion B: Temporary loss of communication allowed, after disturbance the communication has to restart automatically without user input.

- Due to overlaid DC power it is reasonable to use a capacitive coupling of the PHY and no transformer isolation as usual for other Ethernet PHYs, thus the PHY will likely see higher voltages compared to other Ethernet PHYs in case of EMC events.



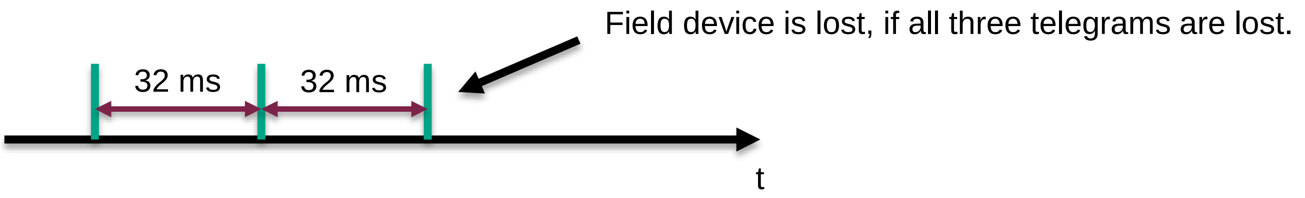
EMC Requirements II

- **Single side shielding.**
  - Ethernet cable shields are normally hard grounded on both cable ends.
  - In process automation applications there exist different shielding concepts:
    - Hard grounding on both ends of a cable shield is normally best from EMC point of view, but requires equipotential bonding in most cases.
    - A trunk cable shield is therefore typically hard grounded at the power supply side and capacitive or hard grounded at the field switch side.
    - A spur cable shield is therefore typically capacitive grounded at the field switch side and not grounded or hard grounded at the field device side.



EMC Requirements III

- **Short link restart times.**
  - Typical Ethernet PHYs need quite a long time to start the communication link (e.g. 500 ms or longer).
  - Industrial communication protocols typically have much shorter communication intervals.
  - A field device normally is lost, if 3 consecutive telegrams from this device are lost.
  - Assuming 32 ms cycle time, if a link fails for more than about 64 ms, all nodes connected to this link will get a communication failure.
  - Industrial communication networks can see significant higher EMC disturbance levels than office networks.
  - To prevent a network failure, if the link is lost, a kind of quick warm start of the PHY with reduced training sequence seems to be necessary, to get the link up again within a time frame of less than about 50 ms.
  - Taking faster cycle times into account, this time can even be shorter.



Cable Properties

- The new physical layer needs to be compatible to Fieldbus Type A cables.
- These cables are specified with a wide characteristic impedance range between 80 ohms and 120 ohms at 39 kHz.
- Measurements show, that at higher frequencies the characteristic impedance of these cables is typically between 90 and 100 ohms for AWG18 cables and between 80 and 90 ohms for AWG14/AWG16 cables.
- AWG18/1 installation cable has a maximum insertion loss of about 25 dB @ 4 MHz for 1000 m of cable.
- AWG14/AWG16 cables have due to the higher wire diameter a lower insertion loss.
- Cables consisting of stranded wires have a significant higher insertion loss compared to wires consisting of a single core wire.
- Return loss is mainly created by the impedance mismatch of the cable in relation to the transceiver impedance or by connecting different cables together to one trunk cable.

Thank You