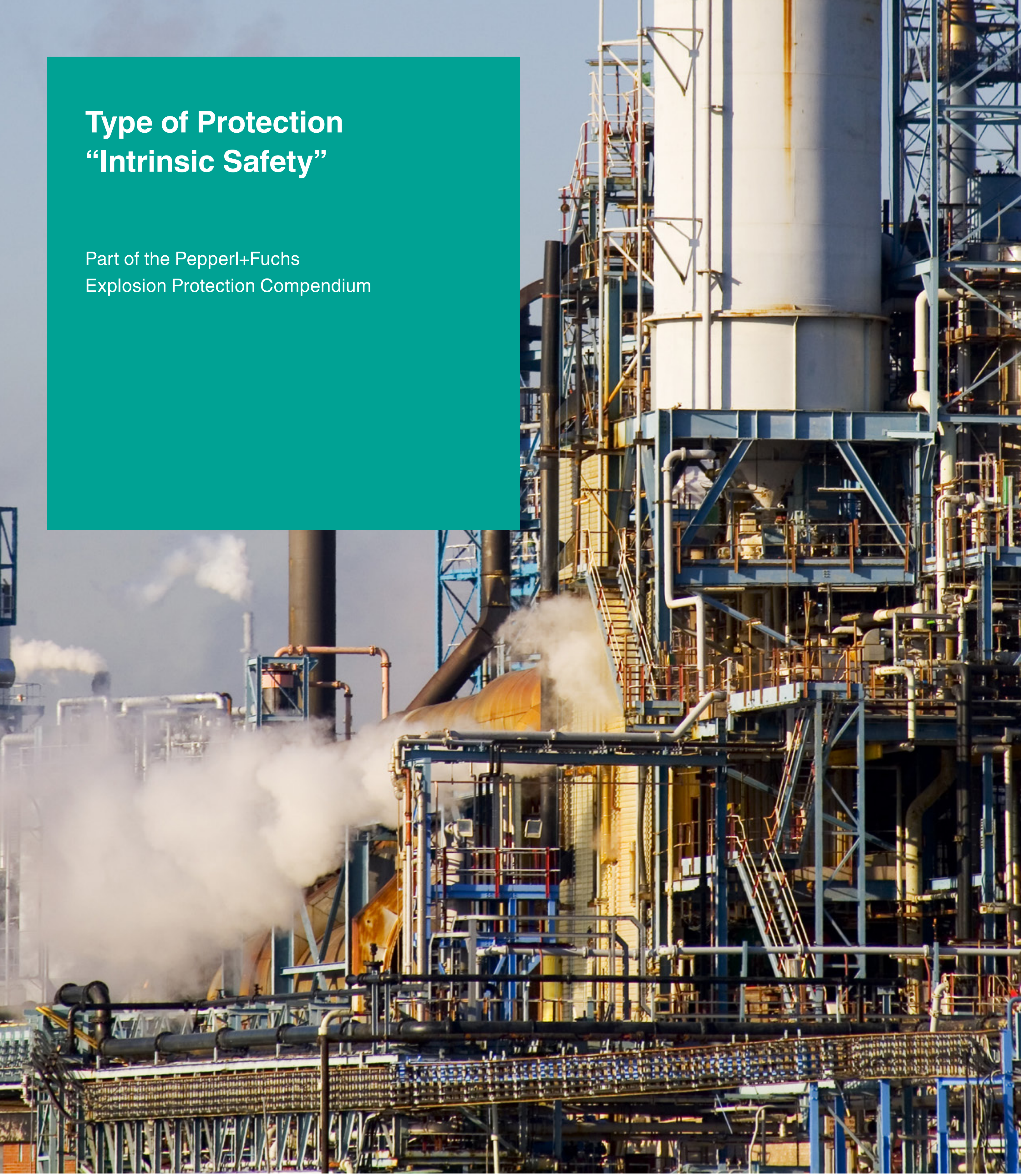
Type of Protection “Intrinsic Safety”

Part of the Pepperl+Fuchs
Explosion Protection Compendium



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Disclaimer

The contents of this publication have been compiled by the editor with due and thorough regard for the legal regulations valid at the date of publication and of established technical measures. Nevertheless, incomplete, inaccurate, or ambiguous assertions cannot be excluded. The publication consists of several individual volumes that contain general information on explosion protection.

Adherence to local, national, and international explosion protection laws and standards is a fundamental obligation of plant designers and operators. The contents of this publication are not intended for and are not suitable for assessing the hazard situation of a specific plant.

Explosion protection regulations are subject to legal guidelines and can vary by country. Further, industrial plants can differ greatly from one another in their design, materials used, and methods of operation. The individual volumes of this compendium provide an overview of topics relating to explosion protection. With this in mind, the technical and organizational measures for explosion protection can only be detailed generally and thus incompletely. In a given specific case, each plant operator must determine the requirements and approach based on an individual hazard assessment, and implement and document these in a fashion verifiable in accordance with the national regulations.

International and European IEC/EN standards are generally referenced in this publication. In the United States and Canada, most IEC/EN standards have UL or CSA national harmonizations. The national harmonizations are based on the IEC/EN standards but are not exactly the same.

With regard to the supply of products, the current issue of the following document is applicable: The General Terms of Delivery for Products and Services of the Electrical Industry, published by the Central Association of the Electrical Industry (Zentralverband Elektrotechnik und Elektroindustrie (ZVEI) e.V.) in its most recent version as well as the supplementary clause: “Expanded reservation of proprietorship.”

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About the Explosion Protection Compendium

This booklet is one part of an explosion protection compendium. The goal of these volumes is to give plant operators a general overview of explosion protection.

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Introduction

Compared with other types of protection, the type of protection "intrinsic safety" offers an alternative approach to preventing a surrounding potentially explosive atmosphere from igniting. In an intrinsically safe circuit, the current energy is so low that in the case of spark generation, ignition is not possible. This operating principle requires special considerations regarding the development of appropriate apparatus as well as the design and performance of intrinsically safe circuits.

Special requirements apply if there are several pieces of associated apparatus in the circuit or there is a non-linear output characteristic. These are described in the section "Interconnection of Apparatus," page 19. In this case, the methods set out in installation standard IEC/EN 60079-14, in Article 504 of the NEC, in Section 18 of the CE Code, and in other applicable standards are often not sufficient to provide appropriate verification. This publication also gives an overview of assessing simple apparatus.

This publication will cover intrinsic safety concepts in general, but many specific references will be made to IEC/EN-based standards and practices. These references will often be in accordance with the IEC Zone-based hazardous-area classification method rather than the North American Division-based concept. Concepts and requirements for proper intrinsic safety design and implementation are generally harmonized between the two standards. Classification notes are included where appropriate to provide additional information about Division standards.

Intrinsic Safety Operating Principle

When carrying out a hazard assessment for plants in explosion-hazardous areas, it is important to ask which ignition sources are present there. The relevant standard EN 1127-1 lists 13 “potential ignition sources” as possible causes of ignition of a potentially explosive atmosphere that is present. The most significant ignition sources include the following:

- Hot surfaces
- Flames and hot gases
- Mechanically generated sparks
- Electrostatic discharges
- Electrical installations

Electrical installations can pose an ignition hazard. This is why appropriate measures must be taken to reduce the risk of ignition to an acceptable level. Information about the types of protection used for electrical equipment can be found in the Pepperl+Fuchs Explosion Protection Compendium volume **Types of Protection for Electrical Apparatus**.

Minimum Ignition Energy as a Basis

The basic principle behind intrinsic safety, whereby a minimum level of energy is necessary to ignite a mixture of a combustible material and air, was already being discussed in the latter third of the 19th century. The verification for intrinsic safety could not be produced at this time, meaning that all electrical sparks were classified as ignitable.

As flammable substances were researched further over the following decades, a number of characteristics were determined that are still of fundamental importance for explosion protection to this day. This includes: ignition temperature, lower and upper flammable limits, and flash point of flammable liquids. More detailed information can be found in the Pepperl+Fuchs Explosion Protection Compendium volume **Physical-Technical Principles of Explosion Protection**.

In addition, a characteristic was discovered that plays an important role in intrinsic safety: “minimum ignition energy.” Standard EN 13237:2012 defines minimum ignition energy as follows: “Minimum ignition energy is the smallest amount of electric energy stored in a capacitor, determined under predefined test conditions, which is sufficient enough to ignite the flammable mixture in a potentially explosive atmosphere when discharged.”

Minimum Ignition Energy of Various Chemical Substances

Substance	Ignition Energy [mJ]
Acetone	1.15
Acetaldehyde	0.37
Methane	0.28
Butane	0.25
Propane	0.25
Diethyl ether	0.19
Ethylene	0.070
Hydrogen	0.019
Carbon disulfide	0.009

Figure 1. List of minimum ignition energy values for common substances. Source: NFPA 497 (2017)

Combustible substances are divided into explosive groups or gas groups depending on the level of minimum ignition energy determined by way of experiments. Substances are further divided into groups IIA, IIB, and IIC as ignition energy decreases.

Ignition Energy According to Explosion Group and Temperature Class

Explosion Group		Temperature Class					
IEC	NEC/ CE Code	T1 (> 450 °C)	T2 (> 300 °C)	T3 (> 200 °C)	T4 (> 145 °C)	T5 (> 100 °C)	T6 (> 85 °C)
IIA	D	Acetone Acetic acid Methane Propane Ammonia Benzene Toluene	Gasoline Methanol Butane	Hexane Diesel fuel no. 2 Fuel oil no. 2	Acetal-dehyde		
IIB	C	Hydrogen cyanide	Ethanol Ethen	Hydrogen sulfide			
IIC	B	Hydrogen					Carbon disulfide

Figure 2. Examples of ignition energies of different explosion groups in connection with temperature classes. Source: GESTIS

Basic Principle of Intrinsic Safety

If we relate minimum ignition energy to the apparatus being used, it quickly becomes clear that intrinsic safety is fundamentally different from other types of protection.

Spark generation must be avoided if a circuit or apparatus creates explosive energy. Intrinsically safe circuits do not create sufficient energy to ignite a spark. If this type of protection is used, spark generation is permitted in the explosion-hazardous area. This means it becomes easier to maintain and repair intrinsically safe circuits and, generally speaking, work can be carried out without costly work clearance procedures. It is important here to understand how an intrinsically safe circuit is defined.

According to IEC/EN 60079-11 and other national standards including ANSI/UL 60079-11 and ANSI/UL 913, an intrinsically safe circuit is designed to prevent sparks or thermal effects from igniting a surrounding potentially explosive atmosphere under normal operating conditions or defined fault conditions. This clearly shows that there are two aspects to intrinsic safety:

- Sources of ignition, “sparks” and “hot surfaces,” must never have any effect.
- It must be ensured that ignition is not only excluded during normal operation, but also in case of possible faults in the apparatus and within the entire circuit.

Intrinsic safety can be achieved by limiting current, voltage, and power of the respective supply. Sources of stored energy such as inductance and capacitance can be present in the circuit. These sources of stored energy increase the energy of any resulting spark and thus the risk of ignition. Therefore, these sources of stored energy must also be taken into account. Thus, the physical aspect of intrinsic safety is the result of limiting the following parameters:

- Voltage U
- Current I
- Power P
- Inductance L
- Capacitance C

The functional aspect describes the classification of apparatus and circuits into the following levels of protection:

- ia—2-fault tolerant operation (Zone 0/Division 1)
- ib—single-fault tolerant operation
- ic (previously nL)—normal operation / no fault tolerance (Zone 2/Division 2)

Levels of protection describe the fault tolerance within which a circuit remains intrinsically safe; a more detailed explanation follows.

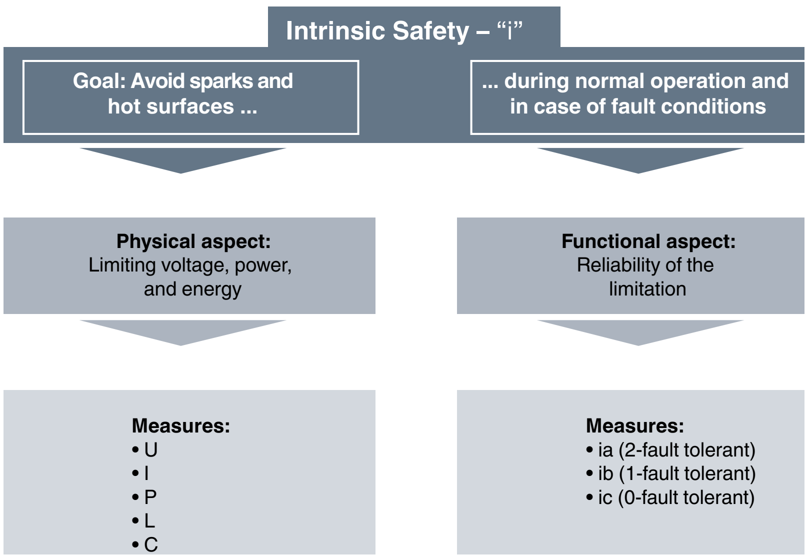


Figure 3. Physical and functional aspects of the type of protection intrinsic safety “i”

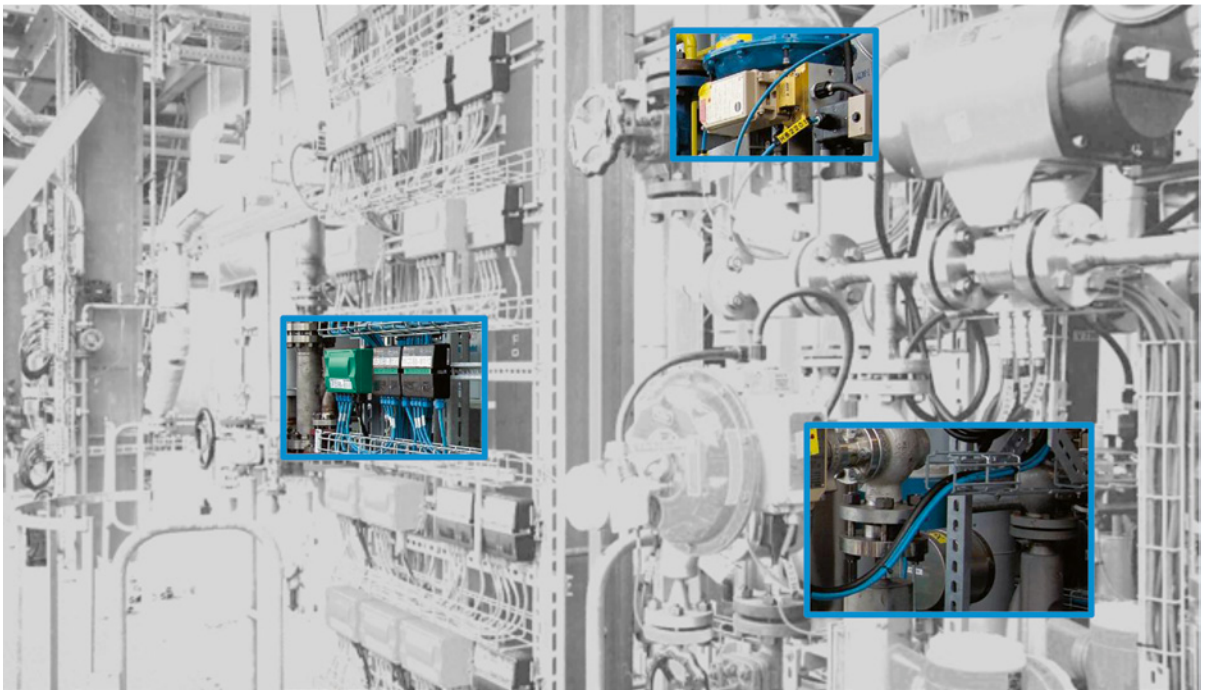
Basic Structure of Intrinsically Safe (Ex i) Circuits

A typical intrinsically safe circuit consists of a supply device (source), a field device (load), and a cable. The physical aspect of intrinsic safety shows that it is the supply device that determines the values of voltage (U), current (I) and power (P). Inductance (L) and capacitance (C) are mainly determined by the field device and the cable.

When designing an Ex i circuit, it is important to note that the energy input into the circuit does not become too high. Impermissible energy inputs are caused by the following:

- External electromagnetic coupling
- Connection with other circuits, e. g., due to damage
- Component faults in the intrinsically safe apparatus itself

These causes must be excluded.



Suitable Apparatus

To design intrinsically safe circuits efficiently, suitable apparatus must be included. The standards recognize these devices as “associated apparatus” and “intrinsically safe apparatus.”

In accordance with IEC/EN 60079-11, associated apparatus is electrical equipment with intrinsically safe and non-intrinsically safe circuits. Associated apparatus is designed in such a way that its non-intrinsically safe circuits cannot have a detrimental effect on the intrinsically safe circuits. Associated apparatus is usually the supply device in the switch cabinet.

Connected to this supply device is a field device that is usually located in the explosion-hazardous area. These field devices are “intrinsically safe apparatus.” These often include temperature, pressure, or level measurement sensors or proximity sensors for position detection. Information on marking both types of apparatus can be found in the Pepperl+Fuchs Explosion Protection Compendium volume **Types of Protection for Electrical Apparatus**.

Intrinsic Safety and Fault Tolerance

There must be no ignitable sparks, even under certain fault conditions, if we are to ensure that a circuit is intrinsically safe. If resistors and Zener diodes are used in a Zener barrier, these components can lead to dangerous failure, which violates this requirement. These faults can be controlled by using redundant current or voltage-limiting components.

According to IEC/EN 60079-11, ia, ib and ic levels of protection describe the fault tolerance within which a circuit remains intrinsically safe. In the following examples, using a Zener barrier as a basic associated apparatus, it is easy to see the difference between the individual levels of protection. The definition of ia level of protection is set out in the relevant standard.

In accordance with the standard, intrinsically safe circuits in electrical apparatus with ia level of protection must be designed in such a way that they do not cause ignition if voltages U_m and U_i are applied under the following conditions:

- During uninterrupted operation
- During uninterrupted operation and in the event of one fault (single-fault tolerance)
- During uninterrupted operation and in the event of two faults (two-fault tolerance)

Since the output signal must remain intrinsically safe even in the case of two voltage-limiting diodes malfunctioning, a basic Zener barrier with ia level of protection can be illustrated as follows:

Zener Barrier in Zone 0 / Division 1

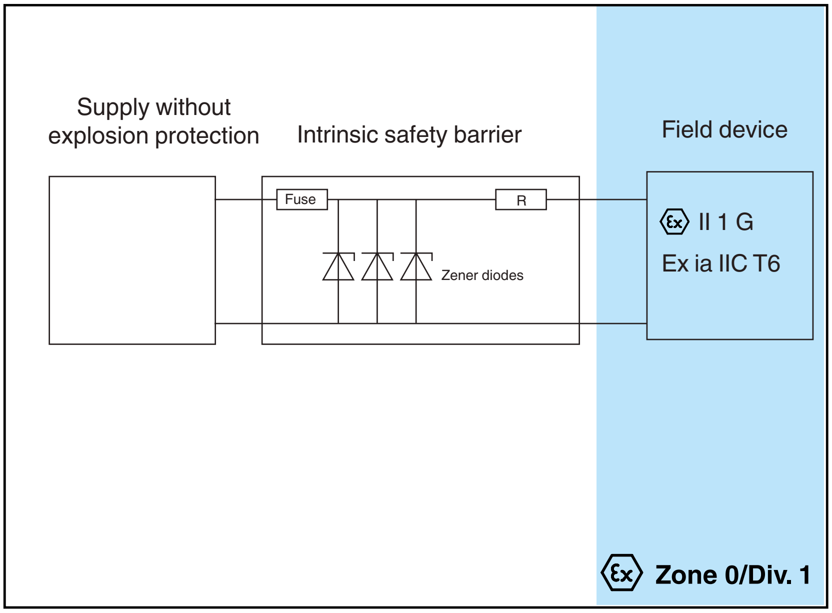


Figure 4. Sample circuit of a simple double-fault tolerant Zener barrier with level of protection “ia” for Zone 0 / Division 1

If two Zener diodes dangerously malfunction (open-circuit), then a third Zener diode remains operational and can thus be relied upon for safety protection. The current can be limited with a single resistor that is rated and designed for high reliability. The reasons for this are not necessary for understanding the basic principle.

Zener Barrier in Zone 1

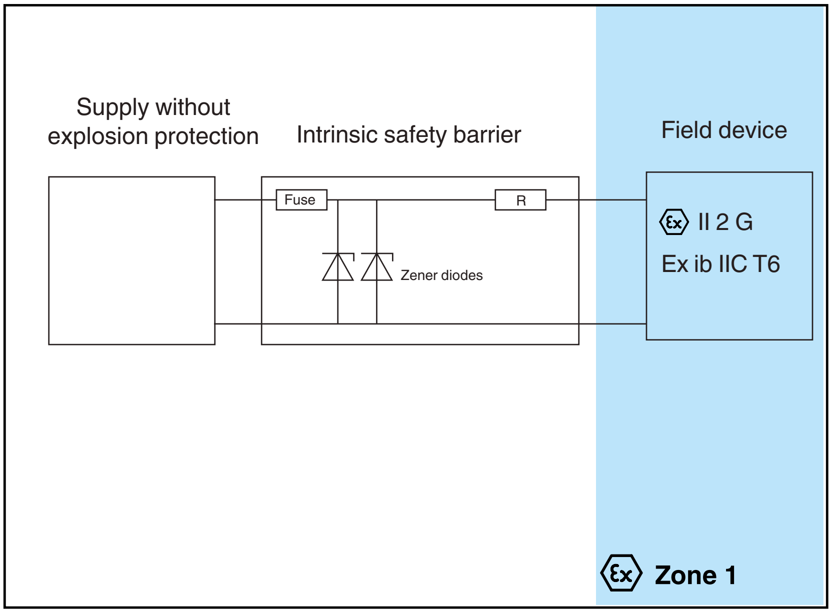


Figure 5. Sample circuit of a simple single-fault tolerant Zener barrier with level of protection “ib” for Zone 1

Zener Barrier in Zone 2/Division 2

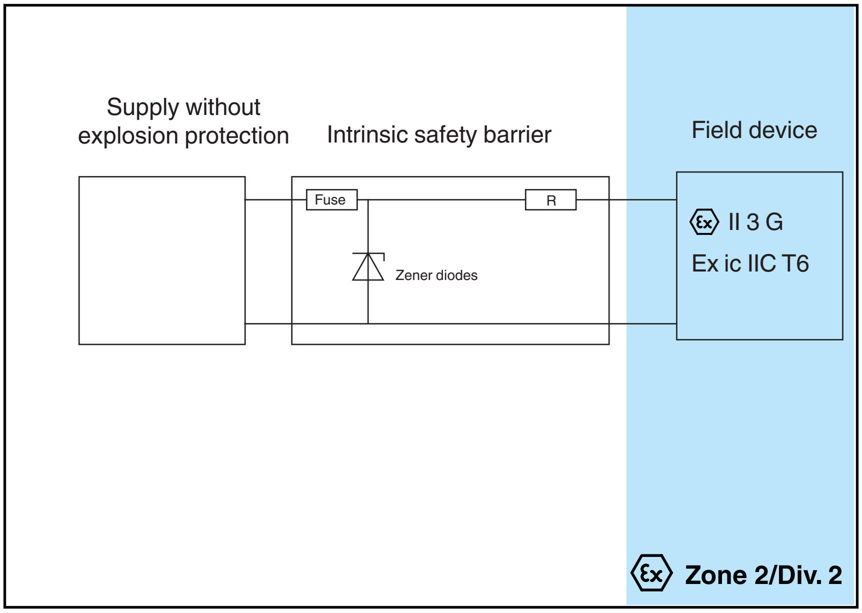


Figure 6. Sample circuit of a single Zener barrier without fault tolerance with level of protection “ic” for Zone 2 / Division 2

Typical classification of levels of protection and Zones in accordance with the installation standard IEC/EN 60079-14 can be supplemented by the corresponding device categories according to Directive 2014/34/EU. Classification is then as follows:

Zone	Equipment category	Intrinsic safety "i" level of protection	Suitable Division
0	1 G	ia	1
1	1 or 2 G	ia or ib	-
2	1, 2, or 3 G	ia, ib, or ic	2

Table 1. Relationship between level of protection, category, and Zone or suitable Division

This classification is necessary to select appropriate apparatus for intrinsically safe circuits in the relevant Zone or Division.

Note

A Note on the Correlation between Zones and Divisions for Electrical Equipment

The correlation between intrinsically safe equipment in Zone 0 / Division 1 and Zone 2 / Division 2 is generally valid. No such correlation exists for Zone 1 and any Division. However, intrinsically safe equipment that is suitable for Zone 1 is regarded as safe in a Division 2 area.

These relationships are defined in the NEC, Article 500, or in the appropriate certification safety standard, such as ANSI/UL 60079-11.

Verification of Intrinsic Safety

Before commissioning an intrinsically safe circuit, in accordance with IEC/EN 60079-14 (NEC for the US and CE Code for Canada), it is necessary to carry out the "verification of intrinsic safety." Since faults can no longer be corrected quickly during commissioning of the entire plant, this calculation should be carried out in the preceding planning phase. This prevents costly delays and ensures that the required documentation (EU declaration of conformity, instruction manuals, EU-type examination certificate, safety documents and other relevant information if necessary) is available.

In the introduction of Section 16, IEC/EN 60079-14 provides additional requirements for the type of protection "intrinsic safety." These requirements illustrate that the standard expects a different installation philosophy when it comes to intrinsically safe circuits. When installing intrinsically safe circuits, it must always be ensured that these circuits are protected against energy ingress from other electrical sources. An intrinsically safe circuit must be designed in such a way that the safely limited energy values contained therein are never exceeded, not even in the case of a break, a short circuit, or when grounding. It must be ensured that intrinsically safe circuits are separated from all other circuits at all times. This applies to any intrinsically safe circuits in the categories "ia," "ib," and "ic."

The "safely limited energy values" must be determined by verifying intrinsic safety. The verification of intrinsic safety is an integral part of the explosion protection document to be compiled before starting with installation work. Respective local or national safety regulations apply for the preparation of the explosion protection document.

IEC/EN 60079-14 finds corresponding verification documentation also mandatory. Once the intrinsic safety has been verified, it is the installer's responsibility to carry out any installation tasks in accordance with the "Additional Requirements" ofIEC/EN 60079-14. This applies especially to marking the circuits, adhering to the defined separation distances, and keeping different circuit types separate from each other.

The following sets out the basic method. It is assumed that the circuit only contains one associated apparatus, i. e., one source. Generally, this applies to most of the intrinsically safe circuits. The interconnection of several sources is dealt with in the section "Interconnection of Apparatus," page 19.

Basic Verification Method

When verifying intrinsic safety, we should mainly be answering two questions:

- Can ignitable sparks be generated?
- Can impermissibly hot surfaces be generated?

While the first point is obvious to anyone who knows the principle of intrinsic safety, the second point is often neglected when assessing simple electrical apparatus.

IEC/EN 60079-14 describes a mathematical verification method that is based on the following characteristic values:

- Voltage U
- Current I
- Power P
- Inductance L
- Capacitance C

Values that describe the associated apparatus are marked "o" for "out" (U_o or I_o, for example). The values of the intrinsically safe apparatus are marked "i" for "in" (L_i or C_i, for example).

Specification "U_o = 24 V" means that even in the case of component faults (see ia, ib, and ic levels of protection) at the output terminals of the associated apparatus, the maximum voltage of 24 V is maintained and controlled.

"P_i = 360 mW" for the intrinsically safe apparatus indicates that a maximum power consumption of 360 mW is permissible to ensure compliance with the specified temperature class. Values L_o and C_o are important for associated apparatus: U_o, I_o, and P_o indicate that no ignitable sparks are generated, even under fault conditions with sparks present at the output terminals.

L_o and C_o define the maximum limits of the additional sources of stored energy that can be connected to allow the circuit to remain intrinsically safe. Since the sources of stored energy are generally located in the field device as well as in the cable, verification needs to consider these values.

This results in the basic method of calculation as follows:

Associated apparatus	Cable	Intrinsically safe apparatus
$U_o \leq$		U_i
$I_o \leq$		P_i
$P_o \leq$		P_i
$L_o \geq$	$L_c + L_i$	
$C_o \geq$	$C_c + C_i$	

Special conditions, which are often set out in the apparatus or associated apparatus operating instructions, must also be taken into account. This includes information relating to the maximum permissible ambient temperatures, instructions for protection against electrostatic charge etc., which will not be considered further at this point.

Particular attention must be paid to the information on the maximum limit values for connectable inductance L_o and capacitance C_o. This information has been misunderstood for many years and only the fourth edition of the installation standard IEC/EN 60079-14 (IEC 2007/EN 2008) provides a clear definition.

The maximum limit values were determined by way of experiments and exist in the form of graphs and, to some extent, tables, which form an integral part of IEC/EN 60079-11. Both limit values have traditionally been determined independently.

The inductive minimum ignition curve describes the maximum (insulated) inductance L_o which may be connected to an associated apparatus with a given I_o without adversely affecting intrinsic safety. This value has been detected in laboratory measurements through experiments using spark test apparatus. These experiments did not take into account any capacitances in the circuit.

The capacitive minimum ignition curve describes the relationship between the U_o of the associated apparatus and the maximum connectable (insulated) capacitance C_o, without any significant inductances being located in the circuit. In addition, a restriction applies to C_o and L_o values shown in these tables and charts that the associated piece of apparatus must exhibit a linear output characteristic.

The following section covers these examples in more detail.

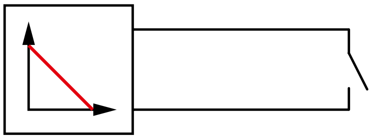
Issues with Mixed Circuits

The fact that L_o and C_o have been determined separately does not take into account that actual circuits are more than likely mixed. Each circuit contains L and C at the same time, be it just through cable reactances. Depending on the form of this source of stored energy, a distinction is made between the following reactances in intrinsic safety:

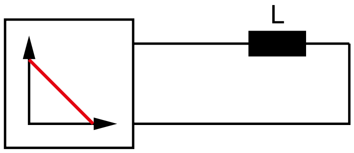
- Distributed reactances: L and C are distributed over the length of the cable ("lead reactances")
- Lumped reactances: actual components that are concentrated, i. e. "lumped" in the apparatus

Actual circuits can be classified according to one of the following four types:

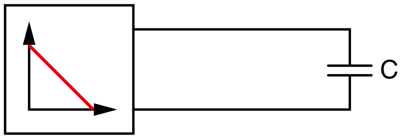
Circuit 1 with distributed reactances and without lumped L_i or C_i



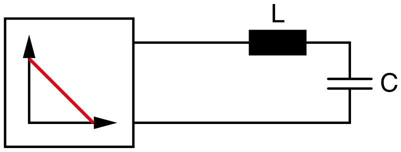
Circuit 2 with distributed reactances and lumped L_i without C_i



Circuit 3 with distributed reactances and lumped C_i without L_i



Circuit 4 with distributed reactances and lumped L_i and C_i



The basic method for verifying intrinsic safety shown only applies unconditionally if relating to circuits 1, 2, or 3. If the circuit contains lumped L_i and C_i at the same time (circuit 4), the calculation may be subject to certain restrictions. This structure is considered within the framework of the "50 % rule."

Example 1: Circuit with Distributed Reactances

Example: Using a switch amplifier as the associated apparatus and a limit fill level switch as intrinsically safe device to monitor the level within a container. The following parameters should be taken from the documentation for the selected equipment:

Associated apparatus	Cable	Intrinsically safe apparatus
10.5 V ≤		16 V
13 mA ≤		25 mA
34 mW ≤		169 mW
210 mH ≥	L_c+ 0 mH	
2.41 µF ≥	C_c+ 0 µF	

In this example, the associated apparatus itself does not have lumped inductances or capacitances, and the intrinsically safe field circuit contains distributed reactances without lumped L_i or C_i. That means, L_i and C_i are 0. Restrictions for the connection of L and C do not apply here. L and C can be used up to the maximum permissible limit values for the connection of the cable, provided that this is technically possible. With the amount of cable attached, it remains to be seen whether the overall loop functions as intended. At this point, two calculation methods are possible:

- Calculated based on the actual existing cable reactances L_c and C_c
- Calculating the maximum permissible cable length for which none of the two limit values L_o and C_o are exceeded

Since in this example the maximum connectable values L_o and C_o are very large, the latter method would lead to cable lengths in the kilometer range, for which the basic function of the control loop is no longer guaranteed and should be verified by test or further (not safety-related) electrical analysis. This is why the length of the cable in this example is limited to 200 m. The resulting line inductance and line capacitance is calculated. In addition, we require information about the cable and insulation specifications, which can be determined in three ways according to IEC/EN 60079-14:

- Based on information supplied by the cable manufacturer
- Through measurements carried out on a sample
- By taking default values C = 200 nF/km and L = 1 mH/km as a basis

If we calculate on the basis of the above limit values, the following cable reactances result with a cable length of 200 m:

- L_c = 1 mH/km × 0.2 km = 0.2 mH
- C_c = 200 nF/km × 0.2 km = 40 nF = 0.04 µF

Associated apparatus	Cable	Intrinsically safe apparatus
10.5 V ≤		16 V
13 mA ≤		52 mA
34 mW ≤		169 mW
210 mH ≥	0.2 mH + 0 mH	
2.41 µF ≥	0.04 µF + 0 µF	

In this example, all conditions for verifying intrinsic safety are fulfilled. The values U_i, I_i, and P_i are not exceeded, and the inductances and capacitances contained in the circuit do not exceed the permissible limit. This means that the interconnection can be considered intrinsically safe.

Example 2: Circuit with Lumped Reactances C

If the level sensor from the example has an effective internal capacitance of C_i = 0.2 µF, then the mathematical verification is as follows:

Associated apparatus	Cable	Intrinsically safe apparatus
10.5 V ≤		16 V
13 mA ≤		52 mA
34 mW ≤		169 mW
210 mH ≥	0.2 mH + 0 mH	
2.41 µF ≥	0.04 µF + 0.2 µF	

As described in the section “Issues with Mixed Circuits,” page 15, this type of interconnection is not critical; and as the two limit values L_o and C_o are still not exceeded, the circuit remains intrinsically safe. This also applies conversely, e. g., the sensor exhibits L_i = 3 mH, and thus C_i = 0 F.

Example 3: Circuit with Lumped Reactances L and C

If example 2 is expanded by considering a field device as apparatus that contains lumped inductance and lumped capacitance, then verification is now as follows:

Associated apparatus	Cable	Intrinsically safe apparatus
10.5 V ≤		16 V
13 mA ≤		52 mA
34 mW ≤		169 mW
210 mH ≥	0.2 mH + 5 mH	
2.41 µF ≥	0.04 µF + 0.3 µF	

When simultaneously connecting an associated apparatus with lumped inductances and capacitances, Edition 4 of the IEC/EN 60079-14 (IEC 2007/EN 2008) provides a particular solution. Until now, L_o and C_o have been determined separately. If the verification is performed with concentrated L and C, this poses the risk that the spark energy may become ignitable due to stored energy sources in the circuit. In this case, according to the standard the “50 % rule” has been in use since 2007/2008. If a safety control drawing is provided or specified as part of the certification, details relating to the 50 % rule may also be included and must be followed during the design and installation phases of the project.

The standard states that the previous verification methods apply only as long as the circuit corresponds with mixed circuit types 1 ... 3. If L_i and C_i are present at the same time, we must check how large these values are in comparison to L_o and C_o. The requirement is as follows:

- If the sum of all L_i and C_i in each circuit is > 1 % of L_o and C_o, there is a mixed circuit with increased ignition hazard. If this is the case, the output values L_o and Co must be reduced by 50 %.
- In all other cases, the original values for L_o and C_o can be used in the calculations.

This means that the sum of all lumped inductances L_i and the sum of all lumped capacitances C_i must exceed an imaginary “1 % hurdle” to form a mixed circuit. Care should be taken when reducing these values: if after halving capacitance C_o you get a value > 600 nF for explosion group IIC and/or > 1 µF for explosion group IIB, then there is an increased ignition hazard. The IEC/EN 60079-25 requires in this case a limit on these maximum values. There is no similar maximum limit for the inductances.

Note: IEC/EN 60079-14:2013 does does not specify this limitation, but it does reference IEC/EN 60079-25.

If these findings are applied to this example, the “1 % hurdle” results in
$0.01 \times L_o = 0.01 \times 210\ \text{mH} = 2.1\ \text{mH}$
$0.01 \times C_o = 0.01 \times 2.41\ \mu\text{F} = 24.1\ \text{nF}$

If we compare these values with the sum of the respective lumped L_i and C_i, then the following applies:
5 mH > 2.1 mH, i. e., $L_i > 0.01 \times L_o$
300 nF > 24.1 nF, i. e., $C_i > 0.01 \times C_o$

This is a mixed circuit and the original output values L_o= 210 mH and C_o= 2.41 µF are to be reduced. The application of the 50 % rule results in:
$L_o\ (\text{red.}) = 0.5 \times L_o = 0.5 \times 210\ \text{mH} = 105\ \text{mH}$
$C_o\ (\text{red}) = 0.5 \times C_o = 0.5 \times 2.41\ \mu\text{F} = 1.205\ \mu\text{F}$

If explosion group IIC is required, the new reduced value for C_o is impermissibly high and must be limited to C_o = 600 nF. This leads to the following verification:

Associated apparatus	Cable	Intrinsically safe apparatus
10.5 V ≤		16 V
13 mA ≤		52 mA
34 mW ≤		169 mW
105 mH ≥	0.2 mH + 5 mH	
0.6 µF ≥	0.04 µF + 0.3 µF	

Verification can be successful, even with reduced values, and the circuit can be considered intrinsically safe.

Interconnection of Apparatus

Designers are regularly faced with a situation where the planned circuit includes more than one piece of associated apparatus. For intrinsic safety, this means that in the case of a fault, now two sources supply the circuit at the same time and therefore values for voltage (U), current (I) and power (P) can arise that are higher than in the case of a single source. This fact must be taken into account for verification purposes.

In principle, there are no changes to the scope of application of the calculation methods previously described. However, it is first necessary to bring the existing sources together as one, in which the resulting values for U, I, and P can be determined. Generally, the following options are available.

If the associated apparatus relates to sources with linear output characteristics, then one of the two methods from the following references can be used:
- IEC/EN 60079-14:2013, Edition 5, Appendix H and I
- IEC/EN 60079-25:2010, Edition 2, Appendix B

Both methods provide slightly different values, as will be shown using an example. If one of the sources exhibits a non-linear characteristic curve, then it is appropriate to use the method from the following reference:

- IEC/EN 60079-25:2010, Edition 2, Appendix C (also known as PTB Report ThEx-10)

Interconnection of Linear Sources

In our example, we will show the following two sources connected together in various configurations.

$U_{o1} = 10$ V	$U_{o2} = 20$ V
$I_{o1} = 10$ mA	$I_{o2} = 20$ mA
$P_{o1} = 25$ mW	$P_{o2} = 100$ mW

First, it should be clarified whether the sources actually are linear. Since the condition $P_o = 0.25 \times U_o \times I_o$ is fulfilled in both cases, the sources in this example are linear.

Next, the question arises as to how both sources are interconnected. Is this a series connection, a parallel connection, or do both need to be assumed because the situation is unknown?

Series Connection

Intrinsically Safe Series Connection with Several Apparatus

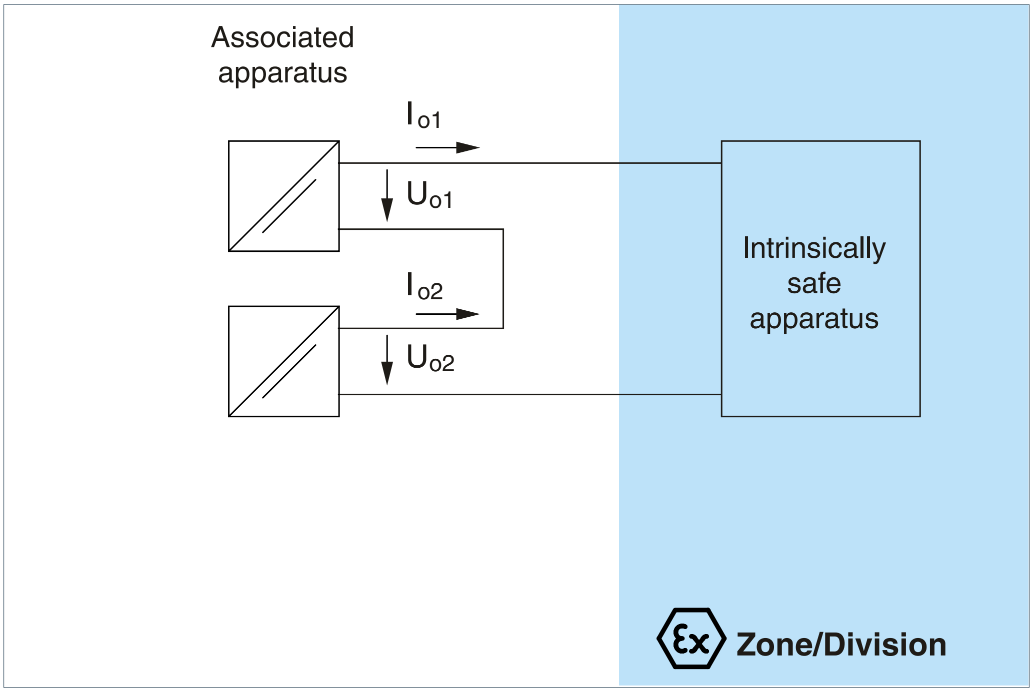


Figure 7. Example of an intrinsically safe series connection—the voltage values are added up

Voltages are added up in the case of a series connection. IEC/EN 60079-14, Annex I describes that in this case the resulting voltage is to be determined as the sum of the two individual voltages, while as resulting current, the larger of the two is to be applied.

In our example, this results in the following “alternative source”:
$U_o = 30$ V
$I_o = 20$ mA
$P_o = 0.25 \times U_o \times I_o = 150$ mW

Alternatively, According to IEC/EN 60079-25

In terms of circuit engineering, a more realistic point of view is provided by IEC/EN 60079-25, Annex B. As a combination of two linear sources, this method delivers slightly different values than the one described.

In the case of a series connection, the voltage of the resulting “alternative sources” is again created from the sum of the two single voltages. The current is determined according to the formula:
$Io = (U_1 + U_2) / (R_1 + R_2)$

The relevant internal resistance of the source can be calculated from U_o/I_o; in the example above, in both cases is 1 kΩ. This method results in the following values:
$U_o = 30$ V
$I_o = 30 \text{ V} / 2 \text{ k}\Omega = 15$ mA
$P_o = 0.25 \times Uo \times Io = 112.5$ mW

Parallel Connection

Intrinsically Safe Parallel Connection with Several Apparatus

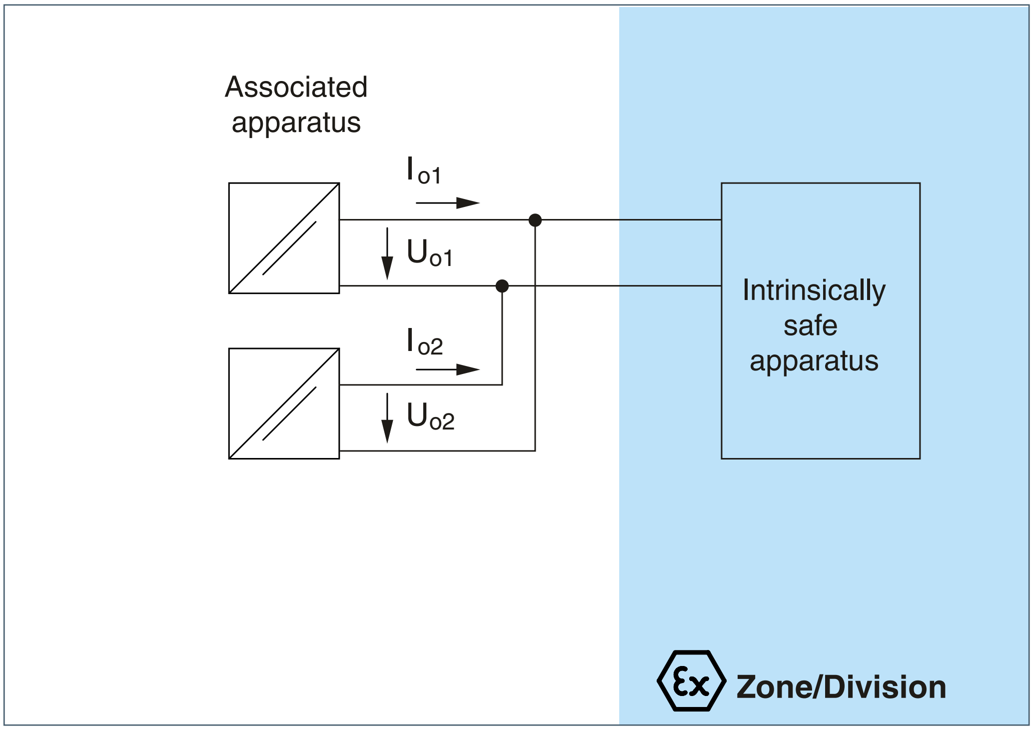


Figure 8. Example of an intrinsically safe parallel connection—the current values are added up

In the case of a parallel connection, currents are added up. The resulting voltage is considered to be the larger of the two in accordance with IEC/EN 60079-14, Annex I. Example:
$U_o = 20$ V
$I_o = 30$ mA
$P_o = 0.25 \times U_o \times I_o = 150$ mW

This consideration is not accurate from an engineering perspective. But this does not pose a problem as this simplification delivers values for U_o, I_o, and P_o that are higher than those that can actually occur. This can be seen for the value for the calculated output power P_o: in the resulting circuit, this is 150 mW. On the other hand, the sum of the two individual output powers only reaches 125 mW.

Alternatively, According to IEC/EN 60079-25

In terms of circuit analysis, a more realistic approach is provided by IEC/EN 60079-25, Annex B. As a combination of two linear sources, this method delivers slightly different values than the ones described.

In a parallel connection, the output current is calculated as the sum of the two individual currents. The resulting output voltage is calculated in accordance with the following formula:
$U_o = (U_{o1} \times R_{i2} + U_{o2} \times R_{i1} / (R_{i1} + R_{i2})$

Thus, the resulting sources are:
$U_o = 15$ V
$I_o = 30$ mA
$P_o = 0.25 \times U_o \times I_o = 112.5$ mW

Mixed Connections

Intrinsically Safe Series/Parallel Connection with Several Apparatus

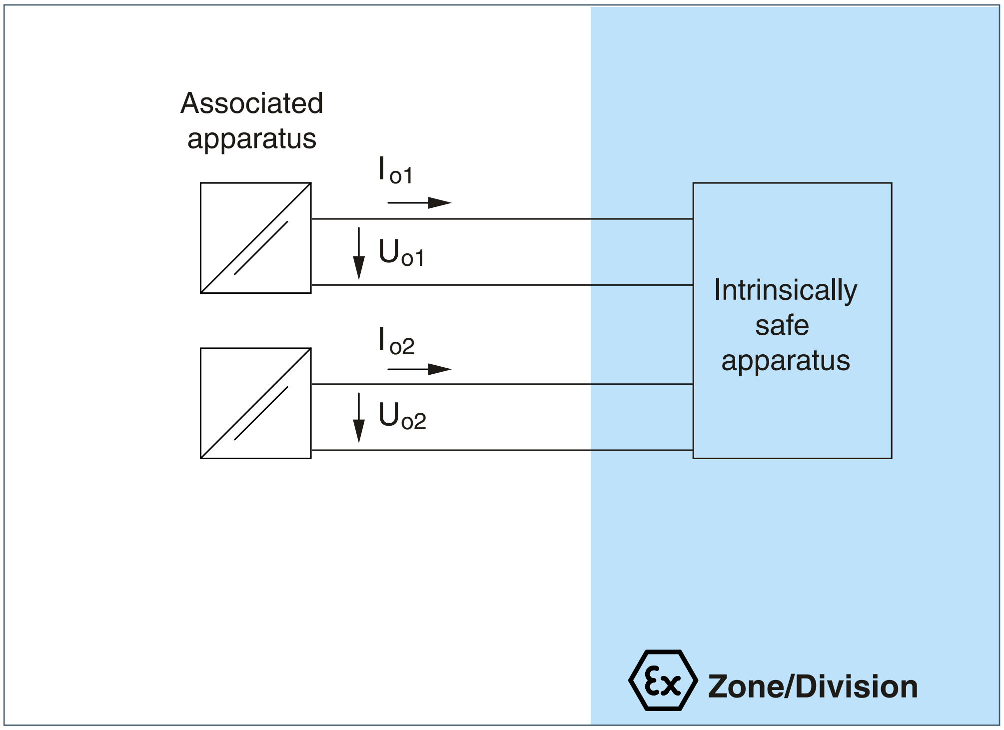


Figure 9. Example of an intrinsically safe series / parallel connection—the voltage and the current values are added up

Interconnection can also be carried out arbitrarily. In these cases, series or parallel connections must be taken into account depending on the fault to be investigated. The addition of the voltage values and the addition of the current values must be taken into account separately.

It is irrelevant whether the method is applied in accordance with IEC/EN 60079-14 or IEC/EN 60079-25: As a result, a new set of values is calculated for U_o, I_o, and P_o. These values resulting from multiple sources can be used for the verification of intrinsic safety as in the examples with only one source. The question remains as to which L_o values and C_o values should be used.

The documentation for each associated apparatus contains information on the maximum number of connectable sources of stored energy. These specifications are valid only for the specific values of U_o and I_o of the individual source. However, U_o and I_o have changed in the resulting circuit due to several sources being interconnected. This means that new L_o and C_o values must be determined. Regarding the minimum ignition curves of IEC/EN 60079-11, voltage (U) is correlated with capacitance (C), and current (I) is correlated with inductance (L). Therefore, the minimum ignition curves can be applied for these new values.

Minimum Ignition Curves in Accordance with IEC/EN 60079-11

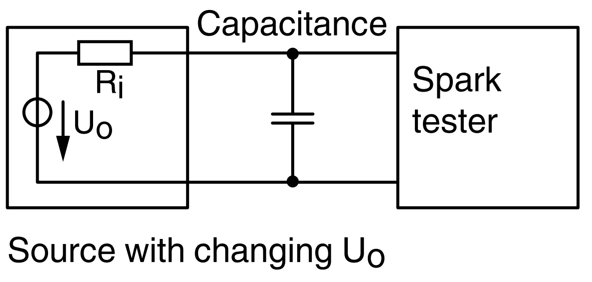
The maximum connectable C_o values and L_o values for the respective values U_o and I_o are determined by curves and tables in IEC/EN 60079-11, Appendix A. A safety factor must be taken into account when determining these values, depending on the level of protection of the circuit. This safety factor is applied to the values U_o and I_o. The values U_o and I_o are thus increased to the extent that they guarantee a sufficient level of safety compared with the reference data for L_o and C_o defined by way of experiments. These factors are:

- Level of protection ia and ib (1-fault and 2-fault operation, Zone 0/1 and Division 1): factor 1.5
- Level of protection ic (no-fault operation, Zone 2 and Division 2): factor 1.0

The following values, which are the result from the earlier example, will be used to determine C_o and L_o:

- U_o = 30 V
- I_o = 20 mA

Capacitive Circuits and Their Explosive Limits



Minimum Ignition Curve of Capacitive Circuits, Group II (Class I, Groups A, B, C*)

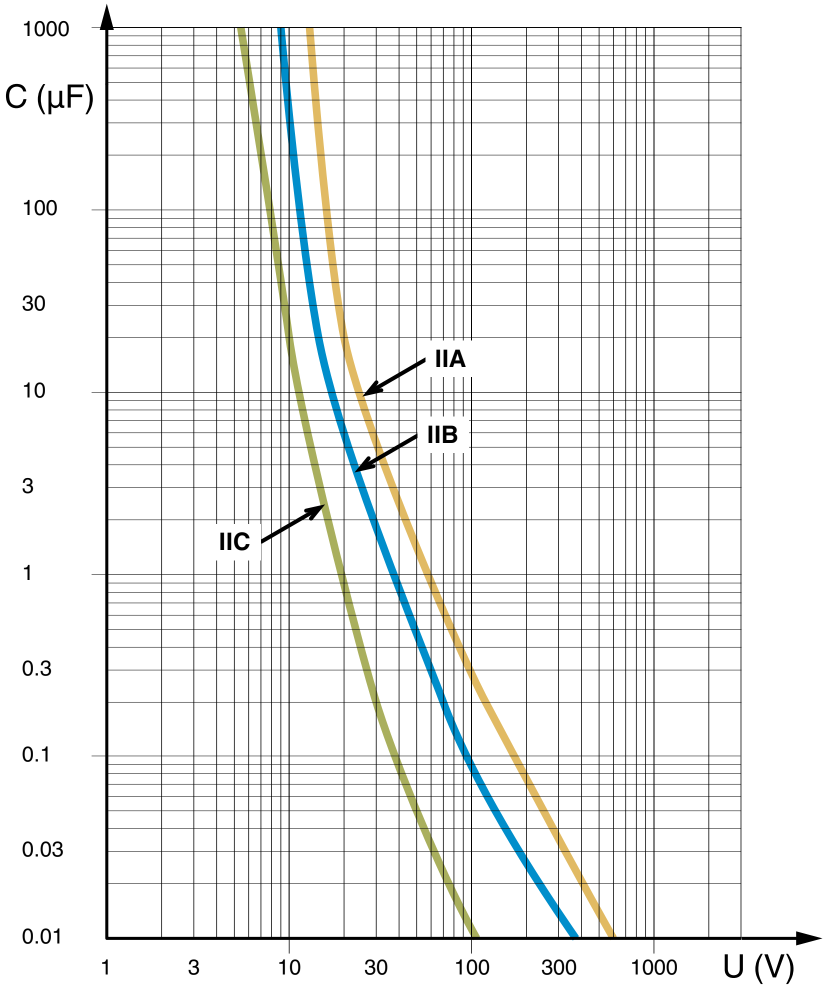


Figure 10. Example of a minimum ignition curve for a capacitive circuit of Group II.
Source: IEC/EN 60079-11, Appendix A, A.3. * The Groups A, B, and C correspond to "Class I" of the North American classification. As noted previously, these intrinsic safety requirements are well harmonized to the North American standard. The curves and tables that follow are also present in ANSI/UL 60079-11.
Note: Currently, no North American equivalent exists for the European Group I classification ("firedamp endangered mining").

Determining Minimum Ignition Values with the Capacitive Minimum Ignition Curve

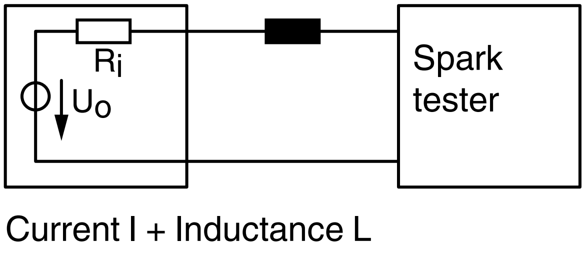
Depending on the respective group (Class I A, B, C), the capacitive minimum ignition curve describes the permissible combinations of U_o and C_o. The maximum connectable capacitance (C_o) decreases as the expected output voltage (U_o) rises.

Assuming it relates to the previously mentioned interconnection to an application in Zone 1 with the necessary ib level of protection, then the safety factor of 1.5 must be applied. This means that we determine C_o not for voltage U_o = 30 V, but for 45 V.

There is also a requirement that it relates to a hydrogen application, i. e., a group IIC gas, meaning a maximum capacitance of approx. 60 nF can be taken from the corresponding curve (see above).

Because it is not always easy to read the exact value from the diagram IEC/EN 60079-11, Appendix A provides an alternative by way of a tabular representation of U_o and C_o. The exact value of C_o = 66 nF can be taken from this table.

Inductive Circuits and Their Explosive Limits



Minimum Ignition Curve of Inductive Circuits, Group II (Class I, Groups A, B, C, D*)

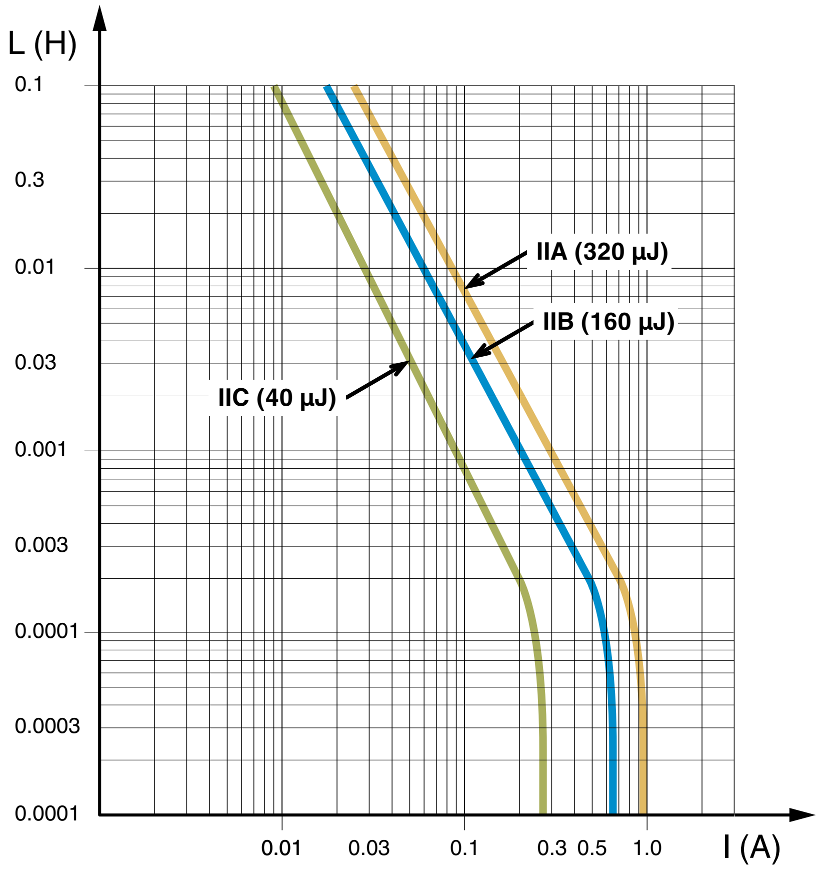


Figure 11. Example of an ignition curve of an inductive circuit. The given energy values refer to the part of the curve with constant energy. Source: IEC/EN 60079-11, Appendix A, drawing A.4. * The Groups A, B, C, and D correspond to "Class I" of the North American classification. As noted previously, these intrinsic safety requirements are well harmonized to the North American standard. The curves and tables that follow are also present in ANSI/UL 60079-11.
Note: Currently, no North American equivalent exists for the European Group I classification ("firedamp endangered mining").

Determining Minimum Ignition Values with the Inductive Minimum Ignition Curve

The inductance (L_o) can be determined as follows. The safety factor of 1.5 is applied the same way as when determining the capacitance (compare previous section). This means that L_o is determined for the current of 30 mA. The resulting value is approximately 90 mH. In a similar way, it is difficult to obtain an exact reading. Unfortunately, at this point there is no tabular representation as in the case of the capacitive curve. However, the exact result can often be determined with a little additional calculation:

In addition to the limit curves for the 3 groups IIA, IIB, and IIC, there is a specified energy limit (320 µJ, 160 µJ, and 40 µJ). This is the energy stored in the magnetic field, which has been determined by way of experiments using the minimum ignition curves. This energy can be determined as follows:

$W = 0.5 \times L \times I2$

This means L can be calculated exactly. If we solve the equation for L and apply the values above, this results in 88.9 mH for L_o. This is very close to the read value.

Then there are no further obstacles to verifying intrinsic safety in accordance with the method described. The following values that have been determined are taken as a basis:
$U_o = 30$ V
$I_o = 20$ mA
$P_o = 150$ mW
$L_o = 89$ mH
$C_o = 60$ nF

These values are to be treated in the same way as if they had resulted from a single source. The mathematical proof can be in tabular form.

However, consider the following limitations:
- Even if the procedure sounds easy, it needs practice and requires extensive engagement with the requirements of the relevant standards.
- Adding up several sources can at best meet the level of protection ib, regardless of the fact that the individual sources are rated for the level of protection ia. Therefore, special care must be taken if the application is in Zone 0.
- Be aware of mixed circuits when combining multiple sources. Just as in the case of a single source, simultaneously connecting to lumped L and C can lead to an increased ignition hazard. As long as the sum of all L_i and C_i in the circuit is less than 1 % of the newly determined values L_o and C_o, there is by definition no mixed circuit.

Interconnection of Non-Linear Sources

Verification becomes more laborious if a non-linear characteristic curve (trapezoidal or rectangular) is exhibited when interconnecting several associated apparatus. In this case, the method previously described for determining the values of the resulting source cannot be used.

In this case, to determine L_o and C_o values, IEC/EN 60079-25, Appendix C sets out a graphical method. This method is divided into the following steps:

- Determine the characteristics of the individually participating sources. For help, see IEC/EN 60079-25, Appendix C.1, “Basic types of non-linear circuits.”
- Determine the resulting characteristic curve depending on series or parallel connection .
- Select a suitable diagram depending on the inductance L_c and L_i available.
- Determine the corresponding C_o from the graph.

Diagram for Calculating Non-Linear Sources

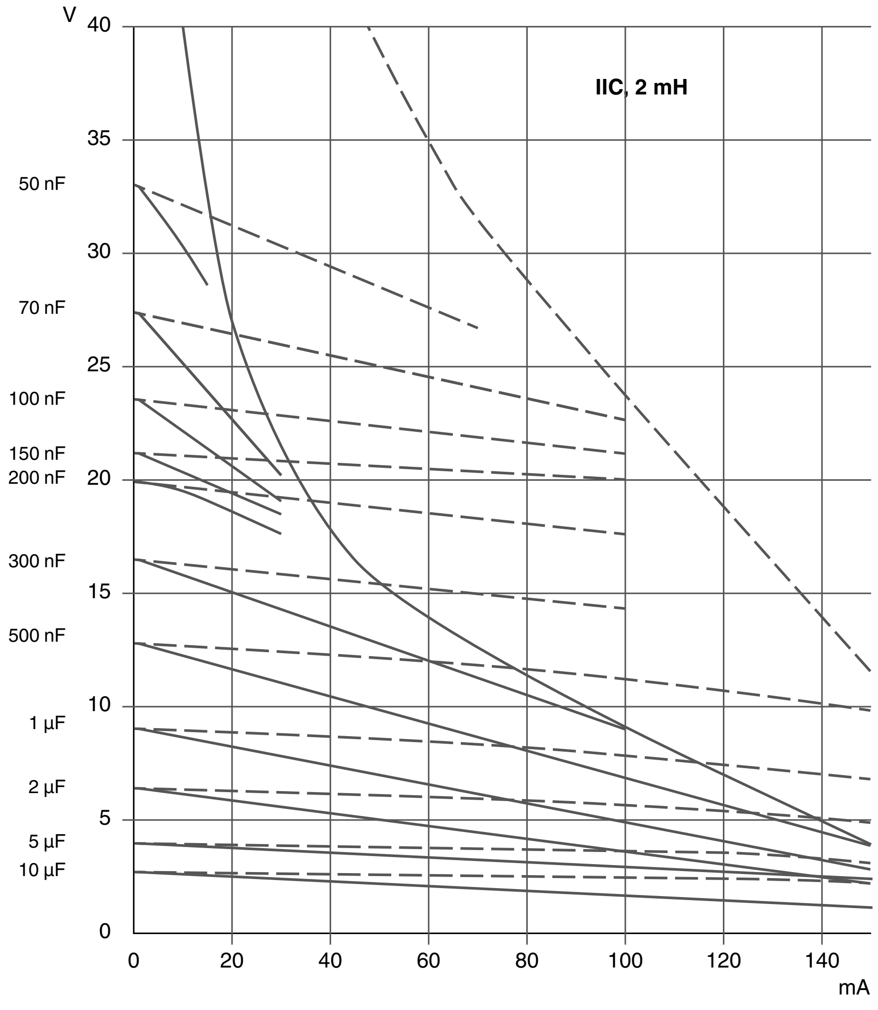


Figure 12. Diagram for equipment group IIC, 2 mH.
For the source, compare IEC/EN 60079-25, Annex C, drawing C.7d

The following example considers a single, linear source for the sake of clarity. Assuming that these have an output voltage U_o = 22 V and an output current I_o = 97 mA, the course of the continuous color characteristic curve (solid green line) is as shown:

Graphical Calculation of Non-Linear Sources According to IEC/EN 60079-25

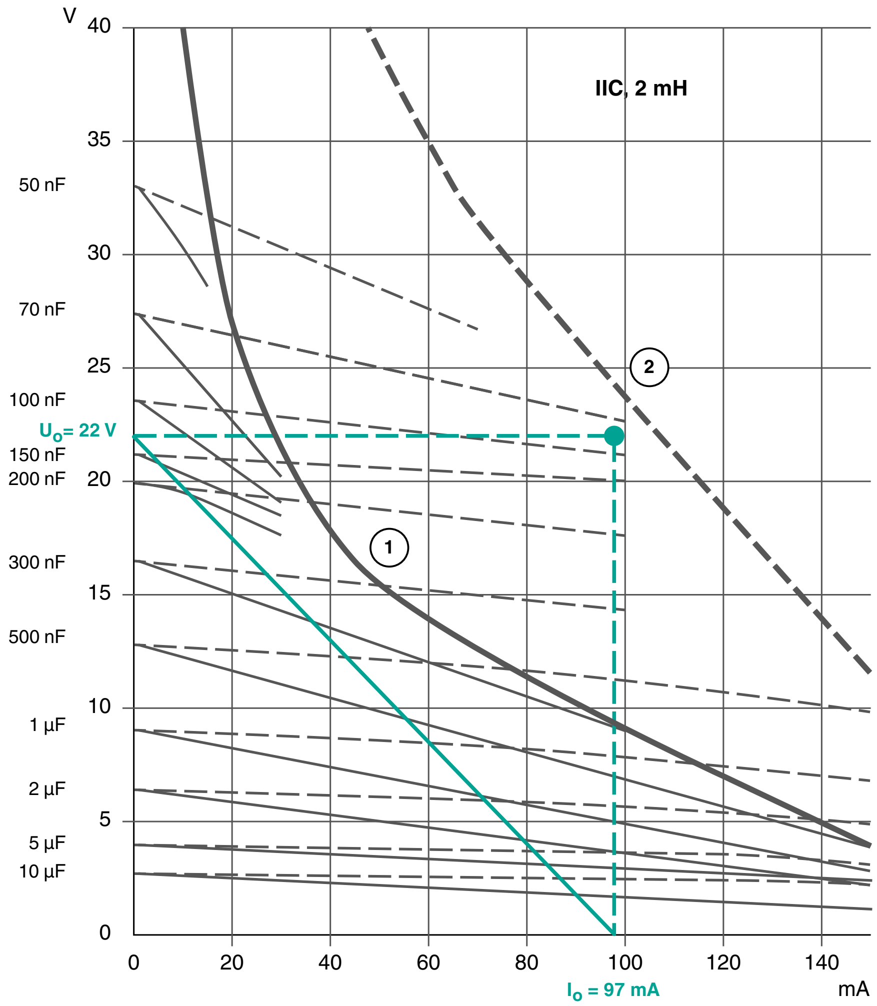


Figure 13. Diagram for equipment group IIC, 2 mH. The U_o and I_o values are higher in comparison with the given diagram. For the source, compare IEC/EN 60079-25, Annex C, drawing C.7d

1 Inductive limit curve of the rectangular source

2 Inductive limit curve of the linear source

Proceed as follows to determine the values graphically:

- Check whether this characteristic curve crosses the solid inductive limit curve (1) at any point. This is not the case in this example.
- Make sure that the point resulting from the characteristic curve (U_o, I_o) is located below the dashed inductive limit curve (2). This condition is fulfilled.

The following has been demonstrated up to this point:

- The source with U_o= 22 V and I_o = 97 mA at the output terminals is intrinsically safe.
- The maximum equipment group is IIC because this is what the diagram is based on.
  Note: corresponding diagrams for equipment group IIB are also available in the standard.
- Based on the chart, the maximum connectable inductance is 2 mH.
  Note: the official diagrams are available in IEC/EN 60079-25. In addition to a diagram for 2 mH, there are also diagrams for 0.15 mH, 0.5 mH, 1 mH, and 5 mH.

This approach applies regardless of whether it relates to the characteristic curve of a single source or to an interconnection of several sources. The missing C_o value is also determined as follows in both cases: In the figure above, scaling in [µF] and/or [nF] is located alongside scaling in [V] on the vertical axis, to which reference is made along with the limit curve clusters. The limit curve clusters are the solid and dashed line pairs that meet on the vertical axis and relate to the labeled capacitance value.

In this case, two conditions must be met:

- The (total) characteristic curve of the source(s) must not cross one of the solid capacitive limit curves. In this case, it does not cross 100 nF.
- The point (U_o; I_o) must be below one of the corresponding dashed capacitive limit curves. In this example, the point is above the dashed 100-nF curve. Therefore, the comparison must be carried out again for the next lower capacitance value, here 70 nF. The test now shows that the two named conditions are met. This is in addition to the verifications described above, which so far determine missing capacitance (C_o), which is considered 70 nF.

At this point, one might argue that for a single source with U_o= 22 V and I_o = 97 mA, values for L_o and C_o could already be found in the standard. However, these values were based on the explosive limit curves of IEC/EN 60079-11 and could only be used to a limited degree for mixed lumped circuits. The values determined using IEC/EN 60079-25, as illustrated above, apply for these mixed circuit configurations.

The following are general restrictions for IEC/EN 60079-25:

- The designer needs to practice using the method and needs an understanding of the exact wording of the corresponding standards.
- The circuit can only have one source with a non-linear characteristic.
- Even if all sources have the level of protection ia, the maximum level of protection for the interconnection of sources is ib.
- The method only describes the issue of spark ignition. The effect of feeding back currents or voltages from one source to another are not taken into account.

Installation Requirements

In order to safely operate your plant in an explosion-hazardous area, you need to familiarize yourself with the requirements for electrical apparatus as they can be found in the relevant IEC/EN standards. In North America, where Divisions are the prevalent designation for hazardous locations, NEC, Article 504, and CE Code, Annex J 18, contain the necessary installation requirements. Both standards also include extensive information for installation in Zone-related areas (NEC, Article 505 and CE Code, Section 18).

The most important requirements are introduced in the following sections. This information is in no way a substitute for those responsible in these areas carrying out comprehensive, meticulous research. Therefore, we suggest that you familiarize yourself with the exact wording of the standards to gain a comprehensive understanding of the requirements. Not all references made below are mentioned in the North American standards. However, the principles and requirements are good practice to follow. Installation in accordance with the local requirements must always be the focus of any hazardous-location rated plant.

Apparatus Requirements

Intrinsically safe and associated apparatus must at least meet the level of protection ic for Zone 2. Equipment intended for Division 2 must be rated for use in Division 1 or 2.

Intrinsically safe and associated apparatus must at least meet the level of protection ib for Zone 1.

Intrinsically safe and associated apparatus must at least meet the level of protection ia for Zone 0. Equipment intended for Division 1 must be rated for use in Division 1.

It is not necessary to carry out testing or marking for simple apparatus. However, it must comply with the requirements of IEC/EN 60079-11, the NEC/CE Code, or any further standards, if necessary, provided that the intrinsic safety depends on this.

If the associated apparatus is not rated to be installed in an explosion-hazardous area, it must be installed outside of explosion-hazardous areas. The maximum supply voltage must not exceed the safety-related maximum voltage (Um) of the associated apparatus.

Requirements for Cables and Leads

Only insulated cables and leads with a test voltage of ≥ 500 V AC or 750 V DC may be used.

The minimum diameter of a single conductor in the explosion-hazardous area must be ≥ 0.1 mm.

The electrical values (C_c and L_c) or (C_c and L_c/R_c) must be determined.

The protection of intrinsically safe circuits against external electrical or magnetic fields must be ensured. This can be carried out by using shields and twisted leads or by maintaining sufficient distance.

In addition to the requirements for preventing damage, one of the following two requirements applies:
- Cables and leads of intrinsically safe circuits must be kept separate from all the cables and leads of non-intrinsically safe circuits.
- Cables and leads of intrinsically safe or non-intrinsically safe circuits must be reinforced, metal-coated, or shielded.

Cores of intrinsically safe and non-intrinsically safe circuits must not be fed into the same leads.

Intrinsically safe circuits must be kept separate from non-intrinsically safe circuits in cable bundles or cable ducts by an insulating material intermediate layer or by a grounded metal intermediate layer. Unused conductors of multi-core cables must be secured from intermingling and insulated from each other and from earth by means of appropriate terminals. If an earth connection already exists in the cable via an associated apparatus, cables must be insulated from earth.

Cables and leads of intrinsically safe circuits must be identified:
- If sheathings or coatings are marked using a color, the color must be light blue.
- If marking is in light blue, light-blue coated cables and leads must not be used for any other purpose.

If there is a blue neutral conductor in C&I cabinets, switchboards, or distribution systems, the neutral conductor must be safeguarded against confusion. This can be done as follows:
- Cores identified as intrinsically safe can be laid together in light blue cable harnesses
- Cores identified as intrinsically safe can be labeled accordingly
- Cores identified as intrinsically safe can be clearly arranged and spaced apart

Connecting Intrinsically Safe Circuits

The terminals of intrinsically safe circuits must be marked as such.

Terminals of intrinsically safe circuits must be reliably kept separate from non-intrinsically safe circuits, for example, separated by a separation wall or a clearance of ≥ 50 mm.

The following minimum clearance distances must be complied with:
- 3 mm between non-insulated conductive parts and grounded or other conductive parts
- 6 mm between the non-insulated conductive parts and separate intrinsically safe circuits

Grounding Intrinsically Safe Circuits

The circuits must be built in an earth-free way or connected to a point on the equipotential bonding system.

Resistances of 0.2 MΩ … 1 MΩ for discharging electrostatic charges do not count as grounding.

Grounding that is necessary for safety reasons must be connected via the shortest path to the equipotential bonding system.

Multiple grounding is permissible if the circuit has been divided into multiple galvanically isolated subcircuits, each of which is grounded at only one point.

The earth connection cross-section (copper) is: 2 x min. 1.5 mm^2 or 1 x min. 4 mm^2

Grounding Conductive Shields

An essential conductive shield may only be grounded at one point, usually at the end in the non-explosion hazardous area.

If a grounded intrinsically safe circuit passes through in a shielded cable, the shield should be grounded at the same point as the intrinsically safe circuit.

If an earth-free intrinsically safe circuit passed through the shielded cable, the shield should be grounded at a point on the equipotential bonding system.

If it has been ensured that there is equipotential bonding between each end of the circuit, cable shields and lead shields may be connected at both ends of the cable and the lead and, if necessary, at intermediate points to earth.

Multiple grounding via small capacitors (e. g., 1 nF, 1500 V, ceramics) is permissible, provided that the total capacitance does not exceed 10 nF.

Requirements for Installation in Zone 0 and Division 1

In addition to the named requirements for Zone 1, the following requirements must be complied with for Zone 0 / Division 1.

Apparatus rated for level of protection ia is required in accordance with IEC/EN 60079-11 and other national standards, including ANSI/UL 60079-11 and ANSI/UL 913.

Circuits with more than one associated apparatus are not permitted in Zone 0, unless they are certified as such by a third-party agency and clearly allowed by way of the issued certificate or control drawing. Normally, such circuits can only reach a maximum ib level of protection, even if each individual associated apparatus is rated for the level of protection ia.

Galvanic isolation of intrinsically safe and non-intrinsically safe circuits in associated apparatus is preferable. If using associated apparatus without galvanic isolation (i. e., a Zener diode barrier) then the impedance between the connection point to the grounding point of the high voltage current system (TN-S network) must be less than 1 Ω and an additional isolation transformer for mains-supplied apparatus is required.

The manufacturer’s installation documents or safety-relevant control drawings (if provided) must be followed for any intrinsically safe or associated apparatus. Additional safety-related installation requirements may also be contained within the actual certificate from the third-party certification agency.

Intrinsically Safe Circuits and Simple Apparatus

Intrinsically safe circuits may also contain apparatus that does not have special certification for use in explosion-hazardous areas and that is not marked accordingly. The following section provides information about the characteristics of such “simple apparatus” that is sufficient for most applications.

What is Simple Apparatus?

According to IEC/EN 60079-11, or ANSI/UL 60079-11, simple apparatus is a simple electrical component (or a combination) with clearly defined technical data that does not impair the intrinsic safety of a circuit.

Examples

Essentially, three groups of components fall under this definition:
- Passive components such as resistors, simple semiconductors, plugs, terminals, etc.
- Energy storage components, i. e., inductors and capacitors
- Sources of energy, such as thermocouples, provided they do not exceed the limit values 1.5 V, 100 mA, and 25 mW

In practice, terminal compartments of intrinsically safe apparatus, Pt100, or similar components are often operated based on this definition. Even though these are simple apparatus, the designer or user must take them into account in the evaluation process.

Assessing Spark Ignition

The definition of an intrinsically safe circuit refers to ignition by sparks and hot surfaces. This makes it easy to assess group 1 apparatus. Components such as terminals, connectors, or resistance thermometers contain no lumped inductances or capacitances and thus have no influence on the energy of generated sparks. Even if L_i or C_i are to be included, these can be taken into account as described in the section “Verification of Intrinsic Safety,” page 13.

Assessment of Thermal Ignition

It is more difficult to assess how simple apparatus heats up. IEC/EN 60079-14 sets out conditions for a number of components of the conditions, under which a simple apparatus can be assigned to temperature class T6, T5, or T4.

Components in which no power is being applied can be classified as T6, such as terminals, electro-mechanical switches, or connectors. These components must fulfill two requirements:
- The components are operated within their rated values.
- The components are operated up to a maximum ambient temperature of 40 °C.

This is easy to assess because the rated values can be taken from the respective datasheet, and the plant operator or designer is aware of the ambient temperature.

Classification as T5 is omitted at this point, since so far we are not aware of any material that falls into this temperature class.

As T4, a component is most easily assessed in accordance with IEC/EN 60079-14, section 16.4

Total surface area of a simple apparatus (excluding lead wires)	P_o: Simple apparatus (ambient temperature at the point of installation)
< 20 mm²	$T_{surface} \leq 275$ °C
≥ 20 mm² ... ≤ 1000 mm²	$T_{surface} \leq 200$ °C
≥ 20 mm²	$P_o \leq 1.3$ W at 40 °C $P_o \leq 1.25$ W at 50 °C $P_o \leq 1.2$ W at 60 °C $P_o \leq 1.1$ W at 70 °C $P_o \leq 1.0$ W at 80 °C

Table 2. Classification as T4 according to IEC/EN 60079-14, section 16.4

In this case, the third row of the table can be used without having to undertake much effort to carry out measurements. T4 can be used as a basis under the following conditions without further calculation or measurement:
- The surface of the simple apparatus without supply lines is at least 20 mm²
- The maximum output power (P_o) of the associated apparatus is, at an operating temperature of ≤ 80 °C at the installation location, a maximum of 1.0 W

As soon as a higher operating temperature is present or one of the temperature classes T1 ... T3 is required, there are no further bases for assessment. Then a calculation must be done that takes into account the thermal resistance of the simple apparatus.

It is important to realize that the surface area of concern is that of the power dissipating element, which may be different than the outer housing of a device. For example, some potentiometers have an outer housing around the inner adjustable element. The surface of concern is the inner element. Also in the case of potentiometers and other variable devices, it is important to realize that the total surface of the element may not be where the total fault power is dissipated. Therefore, it is important to understand the circuit, where maximum power transfer will happen, and to properly assess the power dissipation in this condition.

Type of Protection "Intrinsic Safety" for Use in Fieldbus Systems

Introduction

Reduced production costs, increased product quality, higher plant availability, and the demand for continuous data flow have brought fieldbus technology to the forefront. Digital communication allows extensive information about the status of a production plant and its environment to be communicated quickly. This also allows functionalities to be outsourced from the central control panel to decentralized field devices and allows for simpler cabling.

In addition to digital communication, the main advantage of fieldbus is the design flexibility that it allows. The digitally available diagnostics and process data also simplify plant maintenance. Bus diagnostics makes the physical layer measurable for each segment and each field device, and simplifies commissioning. By integrating bus diagnostics in supply technology, it is possible to monitor plants not just sporadically, but continuously, which makes it possible to identify deteriorating conditions during ongoing operation.

The output of the diagnostics information is carried out in accordance with the categories of the NAMUR recommendation 107 "Self-monitoring and diagnostics of field devices." By default, all devices deliver the same structured diagnostic information and so ensure a quick and easy system overview. Additional detailed information allows device replacement and repair to be scheduled and plant down times to be avoided.

If the fieldbus systems are to be used in explosion-hazardous areas, they must be free of sources of ignition. The type of protection "intrinsic safety" has the advantage in the case of a fieldbus system that the nodes can be connected or disconnected from the transmission line during operation. If the fieldbus is designed based on the type of protection "intrinsic safety," the verification of intrinsic safety must be carried out.

System Structure

In process automation, fieldbuses digitalize information from the control room to the field device. Compared to analog 4 mA … 20 mA-control, digital communication with fieldbus is a step forward for control technology. As with analog measured value transmission, the fieldbus transmits the process information and power supply via a shielded twisted-pair cable. Up to 32 nodes can be connected to a fieldbus cable. Various types of protection are used when installing in the explosion-hazardous area. The fieldbus infrastructure consists of a power supply, cables, and fieldbus junction boxes. Trunks lead from the control room to the fieldbus junction boxes. The field devices are connected to these trunks via spurs.

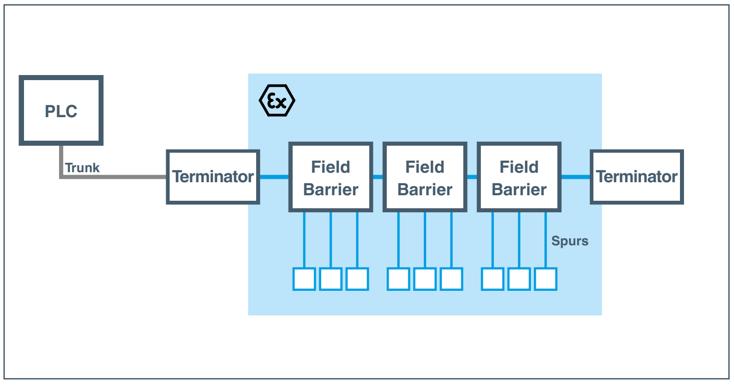


Figure 14. Illustration of intrinsically safe fieldbus

Verification of Intrinsic Safety

The interconnection of several devices from different manufacturers to a fieldbus makes it more difficult to verify intrinsic safety.

While classic 4 mA … 20 mA technology usually concerns point-to-point connections that are easy to calculate, with a fieldbus system many devices are connected in parallel to a cable. Therefore, this would result in a costly and complex verification of intrinsic safety for each individual intrinsically safe circuit.

To make a fieldbus system with its components, power supply, cables, fieldbus junction boxes, field devices, displays, etc., intrinsically safe, the operator responsible would need to carry out a time-consuming, repetitive calculation procedure. The individual devices with their summated ignition curves would have to be connected to a system with a total ignition curve and assessed regarding critical values. Any subsequent change through extending the plant or replacing a device, for example, would mean that the entire process would need to be repeated.

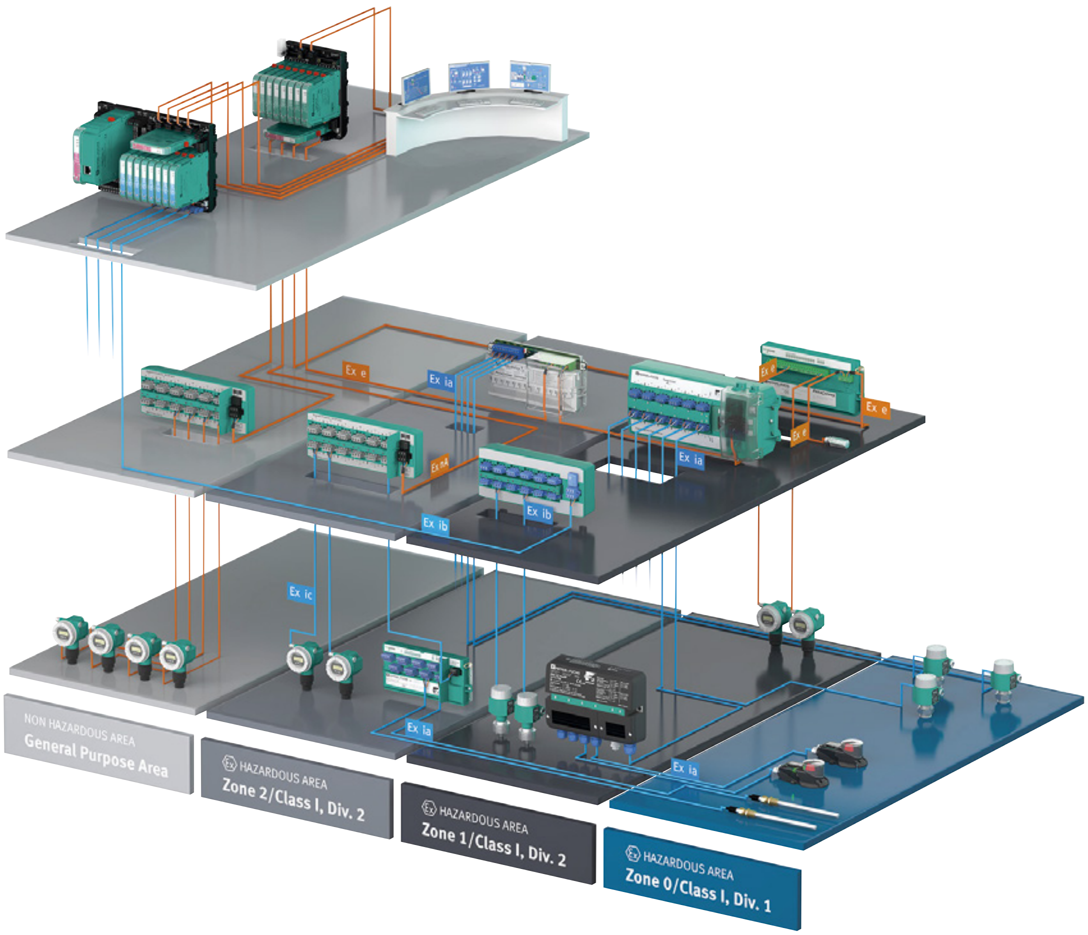


Figure 15. Illustration of process control system, fully digital down to each single field device

There are therefore two different models for verifying intrinsic safety for fieldbus systems:
- FISCO
- Entity

National provisions govern which of the two models should be applied. FISCO is almost exclusively used in Europe; Entity is mainly used in North America, but the FISCO approach is also allowed. The process fieldbuses PROFIBUS MBP-IS (PROFIBUS PA) or FOUNDATION Fieldbus H1 are typically used in explosion-hazardous areas.

Both process fieldbuses use the IEC/EN 61158-2 physical layer with the type of protection “intrinsic safety.” The advantage of the physical layer is the power supply to the field devices from the transmission line.

Power supplies or power repeaters deliver the necessary supply current for FOUNDATION Fieldbus H1. In the case of PROFIBUS MBP-IS as the intrinsically safe variant of PROFIBUS MBP, Segment Couplers deliver the supply current.

FISCO

FISCO was developed by the National Metrology Institute of Germany (PTB) and published in the report PTB-W-53 “Investigations into Intrinsic Safety for Fieldbus Systems.”

FISCO stands for Fieldbus Intrinsically Safe COncept and describes a conceptual procedure for easy implementation of explosion protection in the case of fieldbus installations with the type of protection “intrinsic safety.” “Simple implementation” refers to the process of planning and approval of a new intrinsically safe fieldbus installation and for interventions or subsequent changes and extensions.

From a technical point of view, FISCO is based on detailed ignition tests by PTB that describe the integration of a power supply with the corresponding bus cable and the connected field devices (sensors/actuators).

As a result, these test series proved that the reactances, i. e., the non-ohmic components of an impedance of the cable in a segment, do not influence the intrinsic safety of the fieldbus network type under investigation. This specifically means for the area under investigation and for cable within certain parameters that: depending on the type of cable, a cable length of up to 1000 m is permitted despite the intrinsic safety requirement.

This has a positive effect on the possible plant topology. At the same time, the minimum ignition curve for ohmic circuits instead of for inductive circuits can be used to determine the permissible limit values. This enables a higher current from the power supply and thus allows more devices on the fieldbus. However, the number of field devices in the available power supplies remains below the maximum permissible limit of 32 devices per segment as provided by IEC/EN 61158-2 for signaling reasons.

In practice, intrinsically safe power supplies usually provide approx. 100 mA output current. Depending on the power requirement of the field devices, 4 ... 8 nodes can be connected to a fieldbus. The limited number of field devices has led to the development of the “high-power trunk concept.”

FISCO was created for use in explosion-hazardous areas in process automation. At an international level, FISCO is specified in the IEC/EN 60079-11: Explosive atmospheres - Part 11: Equipment Protection by Intrinsic Safety “i”. As noted, the requirements for FISCO are also documented in the North American standard ANSI/UL 60079-11.

Notes on the FISCO cables and leads can be found in the annex of the harmonized standard DIN EN 60079-14, which is available at an international and European level as IEC/EN 60079-14.

Information relating specifically to FISCO is not located in the National Electrical Code (NEC) or Canadian Electrical Code (CE Code). However, information relevant to a FISCO installation would be contained on a manufacturer’s control drawing. The control drawing is a critical safety document that must be followed for a FISCO installation in North America.

The PROFIBUS MBP-IS and FOUNDATION Fieldbus H1 bus systems use the physical aspect of the harmonized standard to transfer the energy and the digital data DIN EN 61158-2 which is available at an international and European level as IEC/EN 61158-2.

MBP-IS transmission technology (Manchester Coded – Bus Powered and Intrinsically Safe) implements the concurrent power supply of the connected nodes and the transmission of data. The transfer rate is 31.25 kBit/s.

Manchester encoding is line coding that receives the clock signal when encrypting. In relation to the clock signal, the edges of the signal carry the information. Each bit is encoded as a level change. In the code definition, a falling edge means a logical 1; a rising edge means a logical 0. A level change takes place between the bit times.

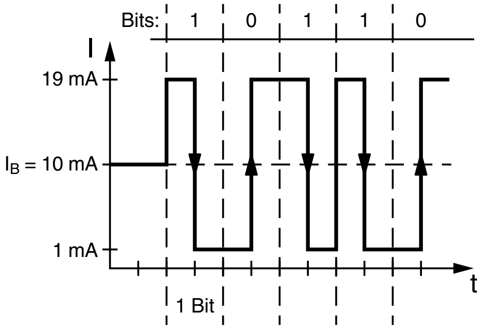


Figure 16. Current modulation (Manchester II coding)

Manchester encoding refers to a synchronous transmission. The bit pulse is obtained directly from the signal and thus each bit is re-synchronized. This means it is possible to transmit a telegram without transmitting additional synchronization signals. Each node receives a basic current of at least 10 mA for modulation purposes. This enables the device power supply. The communication signals are generated by the sending device through modulation of +/- 9 mA on the average current. As each bit always consists of a ratio of positive and negative signal, the average of this signal is always constant. This average is now used to power the devices. Hence the name MBP (Manchester Coded — Bus Powered).

Should a field device require more than 10 mA for the internal power supply, the number of devices that can be connected to the fieldbus reduces.

FISCO can be used to develop, install, modify, and extend intrinsically safe fieldbus installations in a simplified manner, provided the following points are taken into account:

- Only one active source is permitted on a segment (power supply, Power Hub, Segment Coupler). All other nodes act as passive power drains.
- All other nodes (field devices, bus masters, handheld) act as passive power drains. No power is supplied when a node is being transmitted.
- Each node constantly receives at least 10 mA DC.
- For each node:
    - Maximum permissible input voltage $U_i \geq$ maximum output voltage U_o of the power supply
    - Maximum permissible input current $I_i \geq$ maximum output current I_o of the power supply
    - Maximum permissible input power $P_i \geq$ maximum output power P_o of the power supply
- The effective internal inductances L_i and capacitances C_i of the nodes are negligibly small in terms of intrinsic safety and are limited to the following values:
  $L_i < 10\ \mu H$
  $C_i < 5\ nF$
- The maximum permissible total cable length for intrinsically safe ia IIC (Groups A/B)-circuits is 1000 m.
- The maximum permissible cable length per spur from the fieldbus junction box to the field device for intrinsically safe ia IIC-circuits is 60 m.

- The transmission line must comply with the following cable parameters:
  Resistance: 15 Ω/km < R' < 150 Ω/km
  Inductance: 0.4 mH/km < L' < 1 mH/km
  Capacitance: 45 nF/km < C' < 200 nF/km (including the shield)
- Taking account of the shield, capacitance per unit length is calculated as follows:
  $C' = C'_{wire/wire} + 0.5 \times C'_{wire/shield}$ if the bus cable is free of potential or
  $C' = C'_{wire/wire} + C'_{wire/shield}$ if the shield is connected to the power supply by a pole
- The segment must have a terminator at both ends of the cable. The terminator must comply with the following limit values:
  90 Ω < R < 100 Ω
  0 µF < c < 2.2 µF

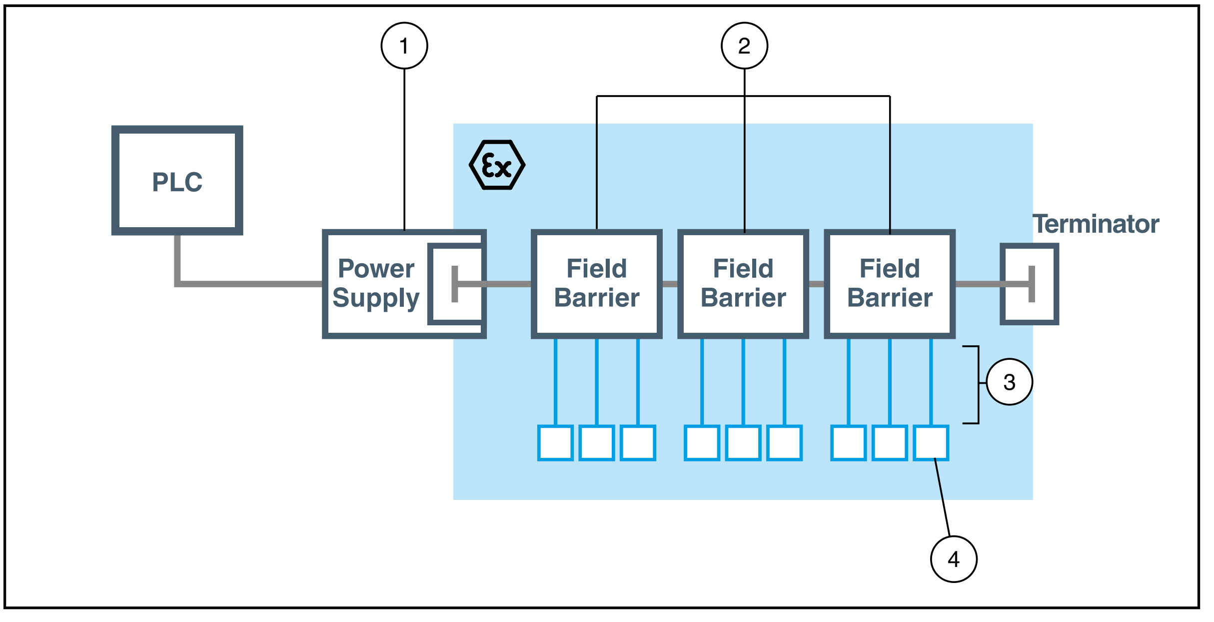


Figure 17. Requirements for a FISCO fieldbus:

1 Only one active segment at the device.

2 All participants act as a passive current drain.

3 Constant average current of the field devices ≥ 10 mA.

4 During transmission of a participant, no power is fed into the circuit. C_o and L_o can be neglected.

Simple Apparatus

Simple apparatus to be used in an intrinsically safe system must comply with IEC/EN 60079-11. In addition, total inductance and total capacitance of each individual piece of simple electrical apparatus in a FISCO system must not be larger than 10 µH or 5 nF (L_i and C_i, respectively).

If simple apparatus is to be operated in a system with "ia" or "ib" levels of protection, this apparatus should be carefully categorized according to a temperature class or to a maximum surface temperature because the maximum available power can reach 5.32 W. Systems with "ic" levels of protection are categorized according to a temperature class during uninterrupted operation.

Marking

To be suitable for use in a FISCO system, apparatus must be labeled with “FISCO,” followed by an indication of its function, i. e., power supply, field device, or terminator. In addition, marking must include the name and address of the manufacturer.

Apparatus can be dual-marked, i. e., can be used in a FISCO system or in a conventional intrinsically safe system. Marking distinguishes between FISCO marking and the marking requirements for the conventional intrinsically safe system.

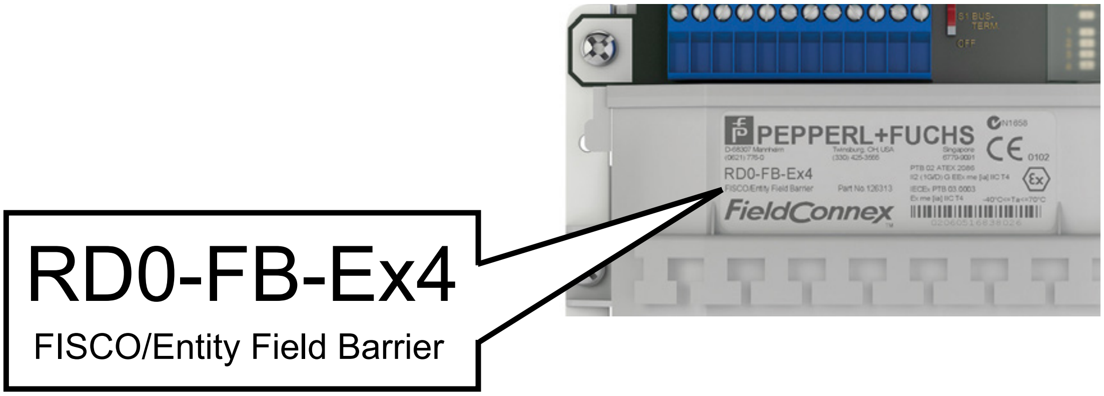


Figure 18. Marking of a FieldBarrier

Design of FISCO Systems according to IEC/EN 60079-25

The following section gives a brief insight on the design of systems according to FISCO in accordance with IEC/EN 60079-25. If IEC/EN 60079-25 is not in force given the location of the plant or due to local code requirements, additional installation information will be contained within the certification or on the approval control drawing. As noted above, the IEC/EN 60079 series of standards are good guides to use as the basis for any explosion hazardous-location installation.

System Requirements

- The cable used in the system must have properties in accordance with FISCO. The maximum length of each trunk including the length of all spurs is 1 km for explosion group IIC and 5 km for explosion groups I, IIB, and IIIC.
- If cables are used that comply with these specifications, it is not necessary to take any further note of cable characteristic values.
- A FISCO system can be considered as safe when it is made up of a power supply, a number of up to 32 field devices and up to 2 line terminators which comply with all requirements of IEC/EN 60079-25 and which use a cable in accordance with the above specification.

The requirements from IEC/EN 60079-25 are as follows:

- All apparatus used in a FISCO system must be of the same apparatus group I, II, or III. The system must be assigned to the level of protection “ia”, “ib,” or “ic,” determined by the least favorable level of protection used in the system. The assigned level of protection should be specified in the safety documentation.
- Subsystems of the system can have different levels of protection. For example, an “ia” spur can be connected to an “ib” trunk by inserting a suitable, certified interface.
- The line terminators must be attached at the ends of the trunk. The power supply must not be more than 60 m from one end of the trunk. If the power supply is connected via a spur, its length is limited to 60 m.
- The number of field devices that can be connected to a spur is limited to a maximum of 32 devices due to operational restrictions.
- Connection devices or switches can be added to a system, without having to amend verification of intrinsic safety. Other types of simple apparatus, which comply with the requirements of IEC/EN 60079-11, can be connected to a FISCO system.
  The prerequisite is that the total inductance and capacitance of each piece of simple apparatus is not greater than 10 μH and 5 nF. Taken together, all simple apparatus including field devices must not exceed a total of 32 items.
- The system description document can be in the form of a simple “apparatus list” and filed together with documentation relating to the devices being used. The document should clearly specify the level of protection of each system component.
- For group II systems, the apparatus group of the power supply determines the apparatus group of the system.
- The temperature class or, if applicable, the highest surface temperature of any apparatus must be defined and recorded in the documentation. It is also necessary to confirm that the specification of the permissible ambient temperature for each piece of apparatus is suitable for the respective intended operating location.

Additional Requirements for “ic” FISCO Systems

Some apparatus can be used in an “ic” FISCO system despite them not meeting FISCO apparatus requirements.

The prerequisite for this is that the apparatus complies with the following parameters:

Input characteristic value:
$U_i \geq 17.5$ V

Operating characteristic value:
$L_i \leq 20$ µH
$C_i \leq 5$ nF

This includes field devices, line terminators, and auxiliary equipment that comply with intrinsic safety requirements and are to be used with a FISCO power supply.

It also includes apparatus that has been designed in accordance with the requirements of IEC/EN 60079-15 for limited-energy apparatus of the type of protection (nL).

Until 2008, standardization included the Fieldbus Non-Incendive Concept (FNICO), which defined the requirements for approving apparatus. Devices in accordance with FNICO are still on the market. Now, according to the FNICO requirements of IEC/EN 60079-27:2005, approved or confirmed apparatus can be used in an “ic” FISCO system.

If FNICO, intrinsically safe, or limited-energy apparatus is being used in an “ic” FISCO system, this should be pointed out at the site where the apparatus has been installed. Marking a plant as an “ic” FISCO system is an acceptable way of fulfilling this requirement.

FISCO power supply		FISCO field device
U_o is defined as ≤ 17.5 V	≤	U_i is defined as ≥ 17.5 V
I_o must not exceed 380 mA	≤	U_i is defined as ≥ 380 mA
P_o is defined as ≤ 5.32 W	≤	U_i is defined as ≥ 5.32 W

Table 3. FISCO requirements and power supplies and field devices

Entity

Entity is based on the observation that the cable has a lumped inductance and a lumped capacitance, unlike FISCO, where the cable is defined as having a distributed inductance and a distributed capacitance. Compared with FISCO, Entity allows less electrical energy to be transmitted into the explosion-hazardous area. Typical values of an Entity power supply are 10.6 V and 70 mA. Therefore, this means fewer nodes can be operated on a segment and the permitted cable lengths are shorter than with FISCO.

All requirements specified for FISCO apply to Entity, except the following:

- Internal inductance of a field device < 20 µH
- Internal capacitance of a field device < 5 nF

To verify intrinsic safety in accordance with Entity, in addition to comparing voltages, currents and power, it must also be determined whether the connected inductances and capacitances do not exceed the maximum permitted value L_o and C_o. The following applies:

- $L_o > L_{cable}$ + total L_i
- $C_o > C_{cable}$ + total C_i

High-Power Trunk Concept

The high-power trunk with FISCO spurs has become common for operating a fieldbus in explosion-hazardous areas. The type of protection “intrinsic safety” is well-suited when using fieldbus in processing plants where it is necessary to intervene during operation, e. g., for maintenance, servicing, or replacing a device. In other areas of the plant, at the trunk and at the fieldbus junction boxes, this maintenance activity is usually not required. The type of protection “increased safety (e)” or Division 2 wiring/installation techniques are used here. The high-power trunk concept allows for long cable runs, as well as more connectable field devices, and is now the industry standard.

The mixed approach of the types of protection “increased safety (e)”/Division 2 wiring/installation techniques and “intrinsic safety (i)” are implemented for the PROFIBUS MBP with the help of Segment Couplers and FieldBarriers for Zone 1/Division 2 applications and Segment Couplers and Segment Protectors for Zone 2/Division 2 applications. A Power Hub is used for the FOUNDATION Fieldbus H1 instead of a Segment Coupler.

FieldBarriers and Segment Protectors are coupler devices used to connect intrinsically safe field devices. These coupler devices supply the connected field devices and limit the short-circuit current at each output. The lengths of the cable to an output can be up to 120 m and are operated without a terminator. The trunk that is used for connecting to the fieldbus is not intrinsically safe. Using additional terminals, the fieldbus trunk can be connected to several FieldBarriers or Segment Protectors (cascading).

The FieldBarrier spur outputs are intrinsically safe “ia” for connecting field devices in Zone 0 and 1 / Division 1 and 2. The trunk connection is type of protection “increased safety (e)” or Division 2 wiring/ installation techniques are implemented.

Similarly, Segment Protectors are used in Zone 2/Division 2 instead of FieldBarriers. The trunk connection is type of protection “non-sparking (nA)” or employs Division 2 wiring methods. The outputs are energy-limited “ic,” “nL,” or “non-incendive.”

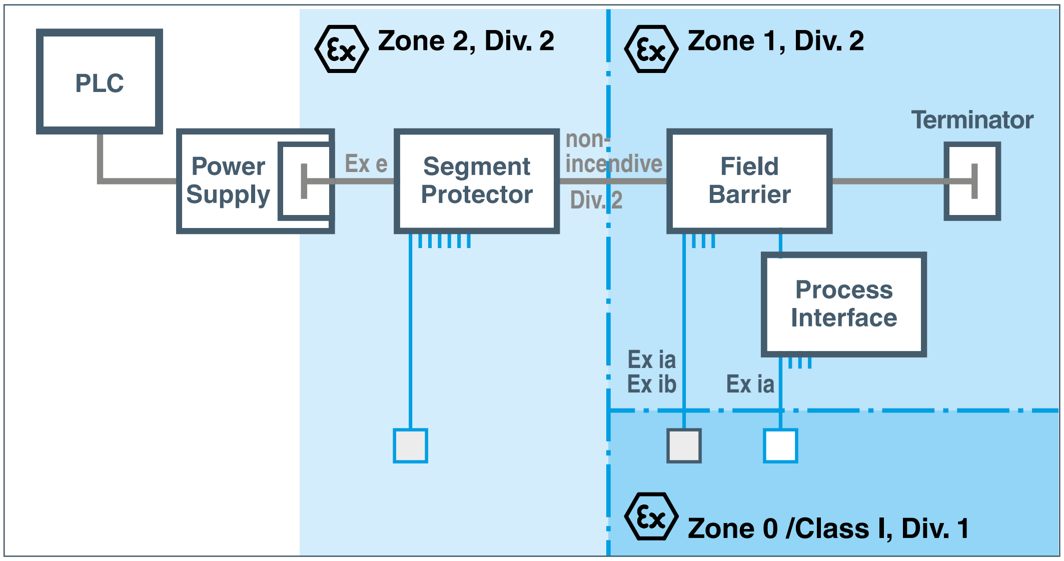


Figure 19. High-power trunk concept

Intrinsically safe MBP-IS transmission technology is limited to the field devices in the explosion-hazardous area of a plant, which are then connected to the control system and engineering devices in the control room via Segment Couplers and PROFIBUS, for example.

The Segment Couplers adjust the PROFIBUS-RS-485 transmission to the PROFIBUS MBP signal level and vice versa. From the point of view of the bus protocol, they are transparent.

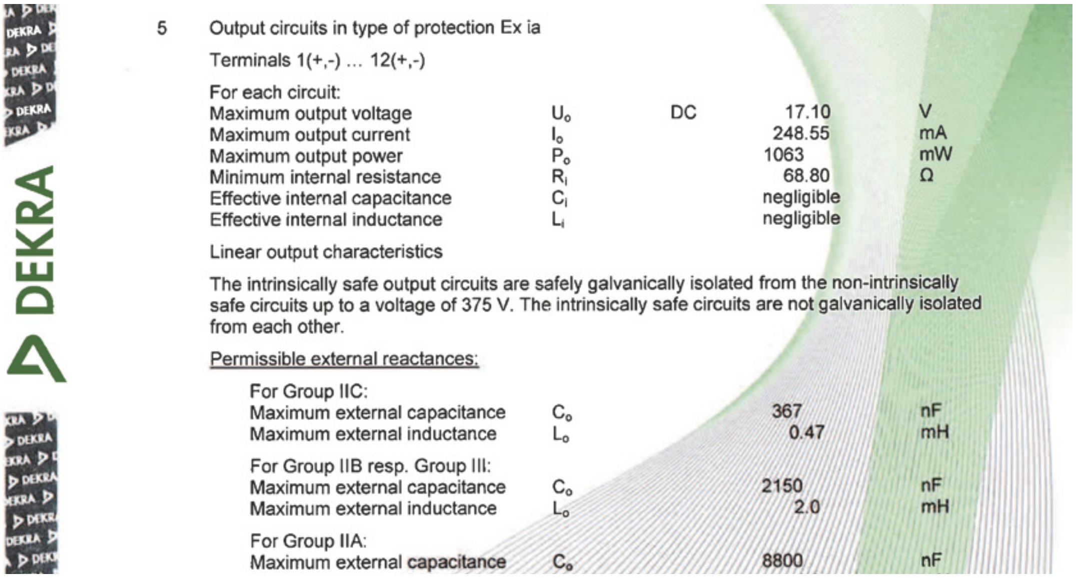
The free Segment Checker planning software should be used to design and calculate segments. The software is available at www.segmentchecker.com. This software can be used to check the electrical function of a segment prior to installation work. Planning and checking options extend to the permitted length of cable and the number of connectable nodes per segment. This planning step protects against subsequent, cost-intensive modifications to the installation. The result is a diagram of the segment, fully checked for efficient use of the fieldbus. The overview diagram combined with a comprehensive project report and the parts list forms a solid basis for detailed planning.

Verification of Intrinsic Safety with FISCO

The supply source (power supply, Segment Couplers, Power Hub) and all nodes (FieldBarriers, Segment Protectors, field devices) must be certified according to FISCO so that verification of intrinsic safety can be carried out in accordance with FISCO. The explosion protection characteristic value should be taken from the respective (EU type) examination certificates, or the locally valid installation documents or control drawings. The cable must comply with the requirements of FISCO.

In practice, verification of intrinsic safety is considerably simplified by FISCO because it can be limited to reviewing performance and cable lengths, if certified devices and corresponding cables are used.

There is no need to carry out a complicated calculation. Instead, you can simply list the FISCO-certified apparatus, e. g., in the form of a table, and refer to the corresponding EU type examination certificates or other locally valid certification documents. Temperature class, equipment category, gas group, and ambient temperature must therefore be taken into account.



5 Output circuits in type of protection Ex ia

Terminals 1(+,-) ... 12(+,-)

For each circuit:

Maximum output voltage	U_o	DC	17.10	V
Maximum output current	I_o		248.55	mA
Maximum output power	P_o		1063	mW
Minimum internal resistance	R_i		68.80	Ω
Effective internal capacitance	C_i		negligible	
Effective internal inductance	L_i		negligible	

Linear output characteristics

The intrinsically safe output circuits are safely galvanically isolated from the non-intrinsically safe circuits up to a voltage of 375 V. The intrinsically safe circuits are not galvanically isolated from each other.

Permissible external reactances:

For Group IIC:			
Maximum external capacitance	C_o	367	nF
Maximum external inductance	L_o	0.47	mH
For Group IIB resp. Group III:			
Maximum external capacitance	C_o	2150	nF
Maximum external inductance	L_o	2.0	mH
For Group IIA:			
Maximum external capacitance	C_o	8800	nF

Figure 20. Section of an EU-type examination certificate for a FISCO FieldBarrier

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