



# Analog signal transmission in the field of MCR technology

User manual

# User manual

## Analog signal transmission in the field of MCR technology

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# 1 Introduction

## 1.1 Motivation and target groups for this user manual

Interference-free transmission of signals plays a central role in the field of MCR technology (measurement, control, regulation). However, signal transmission is affected by increasingly electrical environments. This holds especially true for the weak signals emitted by the measuring sensors.

If the measuring signals are low voltages or electric currents that must be securely transmitted, carefully conditioned or evaluated, then there is an increase in the electromagnetic and high-frequency interference they are exposed to. This is due to the following reasons:

- The increasing number of electrically operated components in all performance classes, especially motors operated via frequency inverters and other actuators
- The increasing miniaturization and packing density of device components
- The growing number of wireless communication and control equipment
- The ever-increasing performance of digital systems working with higher transmission frequencies

Insufficient attention given to the above disturbance variables, incorrect adjustments or lack of planning, can all affect interference-free signal transmission.

As a precautionary measure, the control signals sent to the active components of technical systems are provided in an “electrically more robust” way. In general, however, they are subjected to the same disturbance variables, implementation and planning risks.

This user manual is an introduction to the technical and practical basics of analog data transmission that are essential for automation and process control technology. In addition, this user manual points out the risks to functional safety and draws attention to frequent mistakes that are made during the planning or installation phase or found when troubleshooting the systems. This user manual is intended for all interested parties, in particular for trainees and technicians who want to become familiar with analog data transmission in the field of automation and process control technology.

## 1.2 What type of signals are involved?

This user manual focuses on analog electrical voltage and current signals, collectively referred to as “analog signals”. If signals vary smoothly between a minimum and maximum value, they are referred to as “analog” or “continuous-valued” signals. The value range is very large and almost infinitely large regarding the measuring accuracy.

Analog signals, for example, are generated using a sensor that records states and state changes of physical variables and converts them into an electrical signal. Typically, the following variables are measured in system and process technology:

- Temperature
- Pressure
- Fill level
- Flow rate
- Vibration
- Deformation with regard to load measurement

- Humidity
- Gas concentration
- Electrophysical variables such as voltage, current, field strength, etc.

Electrical conductors are used to transmit analog signals from the signal source to the destination device. Using a sensor signal, various options are available for the destination device:

- A display device (e.g., fill level indicator in vehicles)
- A control system (e.g., for temperature control of a heating circuit)
- A signal converter (e.g., amplifier for a microphone signal)

A measuring transducer can be connected downstream of the sensor in order to convert the analog measuring signal into a so-called standard signal, thus enabling further signal processing via additional standardized, electrical modules. The measuring transducer may already be integrated in the sensor housing.

Compared to continuous-valued, analog signals, the situation is quite different when binary signals are considered. They can have only two possible values used to signalize the states “ON” and “OFF” or “1” and “0” respectively. Binary signals are often equated with “digital” signals. This is due to the fact that digital signals are usually binary coded. Signals that can take on a limited number of values in steps, and that are referred to as “discrete-valued” signals are to be classified between the analog and binary signals.

Continuous-valued (analog) and discrete-valued signals can be measured continuously by means of sampling and quantization, in this way becoming digital signals. In general, digital signals are binary coded and further processed in digital computer systems. It is also typical to reconvert digital signals into analog signals. The devices used for these conversion processes are referred to as A/D converters and D/A converters.

Conversions between “analog” and “digital” can be performed either by installing converters specially provided for this purpose or in a hidden way within processing components. The digitized signal type offers advantages with regard to transmission, storage, lossless copying and automatic correctability of signals. However, the conversion has some disadvantages:

- Device costs increase.
- Time response may be too slow if there is any need for rapid reactions.
- There are system-related errors (e.g., the resolution may be insufficient for specific applications).

In the field of MCR technology, analog signals are often only evaluated binarily for a control system. This is the case, for example, when monitoring a temperature that should initiate countermeasures when exceeding a limit value. The currently measured temperature, for example, can only be used for comparison purposes to determine whether the temperature will exceed or fall below the limit value.

The transmission of analog signals in the area of telecommunications or the transmission of analog useful signals through modulation of a significantly higher-frequency carrier signal is outside the scope of this user manual.

## 2 Basics

### 2.1 Signal conditioning in MCR technology

#### 2.1.1 Measuring signals

In the field of MCR technology, an analog measuring signal generally passes through the following stations:

1. A **sensor** reacts to a physical variable and converts it to an electrically evaluable signal. Either the sensor generates a voltage in the circuit or changes the circuit to which it is connected and that is supplied by a source of current or it changes the voltage drop along the electrical circuit fed with constant current. Sensors converting physical variables to electrical variables for measurement reasons are often referred to as **measuring transducers** or **transmitters**.

Sensors are typically used to measure the following physical variables:

- Temperature
  - Pressure
  - Substance concentrations
  - Frequency (e.g., speed, flow rate)
  - Electromagnetic and electrical properties (e.g., light, high-energy radiation, conductivity)
2. In general, the sensor is connected to an **interface module** used for signal conditioning. It is an electronic module which can have one or several of the following functions:
    - Electrical **amplification, filtering** and **standardization** of the measuring signal
    - **Electrical isolation** of the measuring circuit from the device output circuit
    - **Electrical power supply** of the sensor, if required
    - The sensor and the interface module can be installed together in one housing. A device integrated in this way is sometimes referred to as **transmitter**.
  3. The conditioned measuring signal is transmitted to a device or system which evaluates and further processes the measuring information. This can either be a display device or a control system with a very simple or highly complex structure. Depending on the characteristics, the following designations are commonly used for control systems:
    - **PLC** (Programmable Logic Controller)
    - **DDC** (Direct Digital Control)
    - **DCS** (Distributed Control System/process control system)

In simple MCR systems, it is possible to combine interface blocks and the control system in one device. The sensor may also be added, if required.

4. In industrial control systems, information is usually transmitted using communication bus systems. These systems enable a variety of information to be transmitted using only a limited number of electrical cable connections. An analog sensor signal needs to be conditioned for its transmission on a bus system. Conditioning takes place in an interface module and generally covers the following points:
  - **Digitization** of the analog signal
  - Signal integration into the bus access protocol (including addressing)
5. **Transmission** on the bus to the control system. In more extensive bus systems, several subsections can be used, if required. These are provided with repeater modules to compensate signal losses.

## Analog signal transmission in the field of MCR technology

The electrosensory acquisition, conditioning and evaluation of status data referring to the environment or an industrial system are considered to be the fundamental and core areas in the field of MCR technology. Figure 2-1 provides a schematic view of these three areas:

- The signal acquisition in the "field", as the monitored area to be controlled is called.
- Signal "conditioning" by means of electronic components for amplification, conversion and protection from interferences on the signal path.
- Analog and/or digital signal processing in an evaluation and control unit.

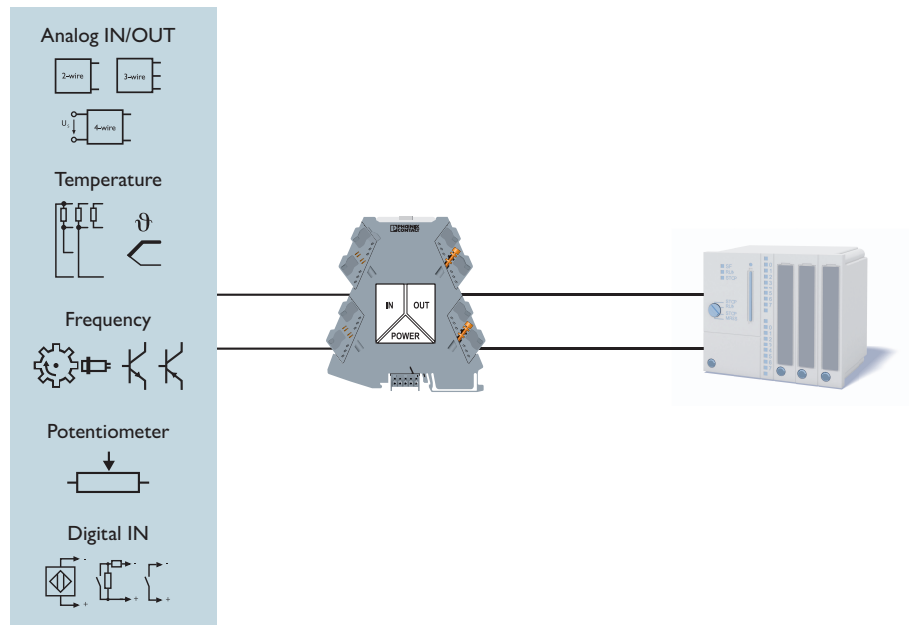


Figure 2-1 Analog signal from the sensor to the control unit

## 2.1.2 Control signals

Control systems evaluate information provided by the sensors and generate control signals in order to control actuators, producing effects either electromechanically or by other means. Actuators typically used in MCR systems are as follows:

- Relays
- Valves
- Electrically operated motors and further electrokinetic actuators
- Heating and cooling equipment

In the field of MCR technology, a control signal generally passes through the following stations:

- Interface block for converting the control logic signal to the **access protocol** for the communication bus.
- **Transmission** on the bus to the actuator. If required, several subsections can be used when connected via repeaters.
- Interface block for converting the bus signal to an analog or digital signal, enabling the addressed **actuator** to be accessed and operated. If necessary, this conversion may be carried out separately for the control logic and the electrical operation of the actuator. In the same way as with the modules used to condition measuring signals, the interface blocks may, in addition to the conversion function, have one or more of the following functions: amplification, filtering, standardization, electrical isolation, electrical supply.

## 2.2 Event acquisition, pulse and frequency measurement

Switches or buttons are used to acquire and record events that occur rarely, occasionally or in a slow sequence. In machine building, for example, microswitches are used to determine positions or directions of motion. These are operated mechanically via switching nubs on moving machine parts. If any contact should be avoided, electromagnetic encoders can fulfill the same function (Hall sensors, slot-type initiators, etc.).

Non-contact methods are mainly used for the acquisition of fast pulse sequences (e.g., to determine the flow volume via an impeller or to measure the motor speed). Each rotation will be acquired electromagnetically by an impulse encoder.

Switches, buttons and pulse encoders that are connected to a circuit provide a binary signal. If required, this signal can be further adapted with a suitable module and evaluated by the display or control unit. Depending on the application, the signal can be used in different ways:

- Triggering an action
- Measuring the event duration
- Counting the events
- Measuring the frequency

Converter modules are available for frequency display or frequency evaluation in any other way, which convert the frequency to a proportional current signal.

To monitor the correct measuring function, the “Switched on” and “Switched off” states should be distinguishable from a short circuit or cable interrupt being present in the measuring circuit. To this end, resistors are added to the measuring circuit, as shown in Figure 2-2.

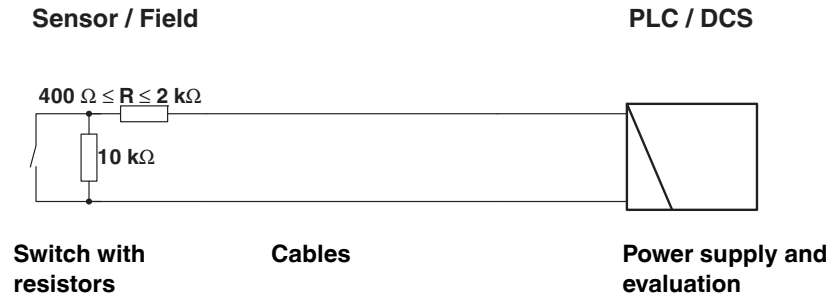


Figure 2-2 Switch connection with resistors added to the circuit for cable monitoring

- 400 Ω ... 2 kΩ: Resistance for maximum current when the switch is closed (short-circuit current is higher)
- 10 kΩ: Resistance for the quiescent current when the switch is opened (in case of cable break the current is equal to 0)

Dimensioning of the resistors needs to be adapted to the measuring circuit in a way that the evaluation unit is able to reliably differentiate between the four states:

- Short circuit
- Switch closed
- Switch opened
- Cable interrupted

Good interface modules have the wiring with resistors and further diagnostic functions already integrated. Depending on an adjustable analog output value, they indicate an error in two ways: on connection modules specially provided for this purpose (line fault detection/fault monitoring terminal blocks) and in an optical way by means of LEDs located on the modules.

## 2.3 Temperature measurement

Temperature measurement methods using resistance thermometers and thermocouples have become well established in industrial applications.

### 2.3.1 Resistance thermometers

In resistance thermometers, a temperature-dependent resistor is used as a sensor which is supplied with a constant current. The current must be kept as low as possible in the order of 1 mA, thus preventing the undesired heating of the resistor. The voltage difference is measured at the resistor, the so-called voltage drop. The measured voltage is proportional to the resistance. Therefore, the signal only needs to be adapted to the evaluating device and used as the measure of the temperature.

Resistance thermometers are often referred to as RTDs, the abbreviation for “Resistance Temperature Detector”.

Depending on the application purpose and the measuring accuracy required, resistance thermometers can be connected to the evaluating devices in different ways.

**2-wire connection**

For less accurate measurements, the resistance thermometer can be connected using the 2-wire connection method.



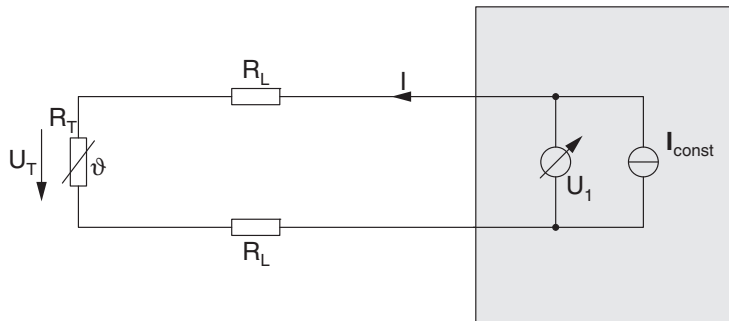
Since the connecting cable resistances will falsify the measurement result, the connecting cables should be as short as possible and each cable should not be longer than 10 m.

The cable resistances can be determined for increased accuracy and, with many measuring transducers, be subtracted from the measured resistance. Using a 1 mm<sup>2</sup> copper cable, the resistance is approximately 0.17 Ω for every 10 m.

Using a Pt 100 resistance thermometer, 0.385 Ω corresponds to a temperature change of approximately 1°K.

$$U_T = U_1 - (2 I_{const} R_L)$$

$$R_T = U_T / I_{const}$$



**Resistance thermometers      Cables      Power supply and evaluation**

Figure 2-3 Resistance thermometer with 2-wire connection

- U<sub>1</sub>: Total voltage drop determined with voltage measuring device
- U<sub>T</sub>: Voltage drop at shunt
- R<sub>T</sub>: Shunt resistance
- R<sub>L</sub>: Cable resistance between voltage measuring device and shunt resistor
- I<sub>const</sub>: Constant current source (with electronically controlled current output)



When connecting the shunt resistor using the 2-wire connection method, a change in the cable resistances as a result of a changed ambient temperature will not be considered and thus falsify the measurement result.

For greater cable lengths and more accurate measurements, the resistance thermometer should be connected using the 3 or 4-wire connection method.

### 3-wire connection

The 3-wire connection method is suitable for cables between sensor and measuring transducer with more than 10 m. An additional third cable is used here to connect the shunt to the evaluation unit. According to the wiring shown in Figure 2-4, the measuring current will not pass through this cable. Thus, it is possible to measure and consider the resistance and its temperature-dependent change on one of the cables through which current is flowing.



In this case, however, the resistances of the two cables through which current is flowing must be the same. This is generally the case when using a 3-wire cable. Accordingly, the 3-wire connection method is most frequently used.

$$U_1 = I_{\text{const}} R_T + I_{\text{const}} R_L$$

$$U_2 = I_{\text{const}} R_L$$

$$U_T = U_1 - U_2$$

$$R_T = U_T / I_{\text{const}}$$

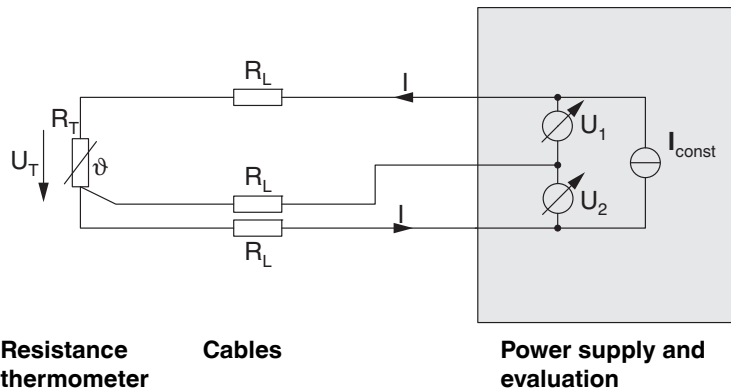


Figure 2-4 Resistance thermometer with 3-wire connection

- $U_1$ : Voltage drop at  $R_T$  and  $R_L$  determined with voltage measuring device 1
- $U_2$ : Voltage drop at  $R_L$  determined with voltage measuring device 2
- $U_T$ : Voltage drop at shunt
- $R_T$ : Shunt resistance
- $R_L$ : Cable resistance between voltage measuring device and shunt (must be the same for the two cables through which current is flowing)
- $I_{\text{const}}$ : Constant current source (with electronically controlled current output)



In addition to the wiring shown in Figure 2-4, there is a variant 3-wire connection option with two current sources, as implemented with the MACX MCR-T-UI-UP signal conditioner with ADC<sup>1</sup>. Advantage: Voltage needs to be measured only once.

<sup>1</sup> Analog-to-digital converter

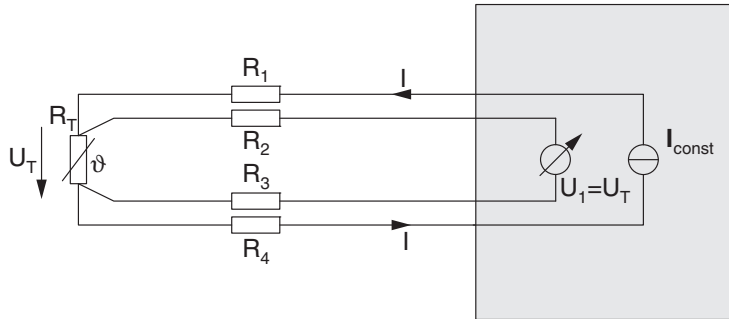
**4-wire connection**

The 4-wire connection method is suitable for cables between sensor and measuring transducer with more than 10 m. Using the 4-wire connection method, two measuring cables are connected to the shunt, without any measuring current flowing through them.



Cable resistance values and differences are thus irrelevant here. When using resistance thermometers, the 4-wire connection method allows for the most precise measurements.

$$R_T = U_T / I_{const}$$



**Resistance thermometer      Cables      Power supply and evaluation**

Figure 2-5 Resistance thermometer with 4-wire connection

- $U_1$ : Voltage drop at  $R_T$  determined with a voltage measuring device
- $U_T$ : Voltage drop at shunt
- $R_T$ : Shunt resistance
- $R_{1...4}$ : Cable resistances between voltage measuring device and shunt (may be different for all cables:  $R_1 \neq R_2 \neq R_3 \neq R_4$ )
- $I_{const}$ : Constant current source (with electronically controlled current output)



To provide a good CMV<sup>1</sup> suppression of the measuring transducer, it is useful if  $R_2$  and  $R_3$  are identical.

<sup>1</sup> Common Mode Voltage

## 2.4 Thermocouples

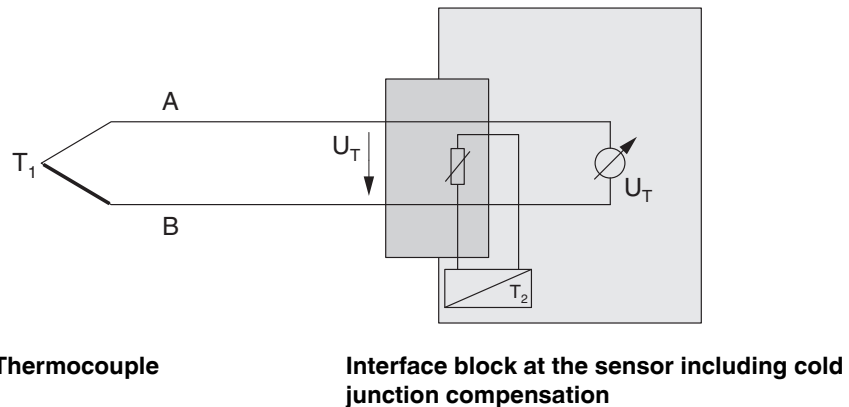
Thermocouples consist of two conductors connected with each other on one side. The conductors consisting of different metals with different thermoelectric properties are exposed to a temperature gradient and, therefore, will convert heat flow to electrical voltage. Electrical voltage is measured at both thermocouple connections.

### Cold junction compensation

In a thermocouple, however, voltage will not only be generated at the contact point of the connected conductors, but also at both connection points of the measuring transducer, as each of these points together with the connected thermocouple cable will form another thermocouple.

In order to be able to calculate the absolute measurement point temperature value from this voltage difference, and thus also temperature difference, the temperature of the connection points must be the same and known. For this purpose, the connection points are artificially maintained at a known temperature: for laboratory measurements, for example, at 0°C using ice water, in industrial applications with thermostatically controlled heating and cooling. When considering the connection point temperature, this is referred to as cold junction compensation. It can also be implemented with a separate temperature measurement at the connection points. Interface modules are available for the connection of thermocouples, in which cold junction compensation is already integrated. Interface modules of this type are also signal transformers with cable connections to the evaluation unit.

Thermocouples are often referred to with the abbreviation TC.



**Thermocouple**                      **Interface block at the sensor including cold junction compensation**

Figure 2-6 Thermocouple connection

- $T_1$ : Temperature at the measurement point
- $T_2$ : Temperature at the connection point
- $U_T$ : Voltage generated between the measurement point and the connection point. Indicates the absolute temperature  $T_1$  at the measurement point by considering the connection point temperature  $T_2$ .

## 2.4.1 Summary tables

Table 2-1 Widely used temperature measurement methods

Features	Sensor type	
	Resistance thermometer, RTD	Thermocouple, TC
<b>Measured quantity</b>	Resistance (measured via voltage drop, depends on the absolute temperature)	Temperature difference (generates a voltage)
<b>Temperature range</b>	Relatively limited in the upper value: -200°C ... +850°C	-250°C ... +3000°C
<b>Accuracy</b>	Very good	Good
<b>Response times</b>	Long	Short
<b>Cold junction</b>	Not required	Required (Reference measurement/cold junction compensation)
<b>Sensor material</b>	Platinum, copper or nickel	Pairs of different metals
<b>Robustness</b>	Good	Very good
<b>Resistance to vibration</b>	Very sensitive (non-encapsulated)	Very robust
<b>Long-term stability</b>	Very good	Satisfactory
<b>Self-heating</b>	Needs to be considered	None
<b>Surface temperature measurement</b>	Limited suitability	Suitable
<b>Sensor dimensions/ Measurement point</b>	Relatively large/ Shunt length	Very small sensors can be produced, punctiform
<b>Characteristic</b>	Widely linear	Non-linear
<b>Electrical signal strength</b>	Low (approx. 0.4 mV per degree K at 1 mA measuring current, Pt 100)	Very low (some $\mu$ V per degree temperature difference)
<b>Measuring current supply</b>	Required	Not required
<b>Connecting cables</b>	Copper instrumentation cable	Thermal material or compensating line (less expensive)
<b>Price</b>	Relatively expensive	Rather inexpensive (except for Pt alloys)

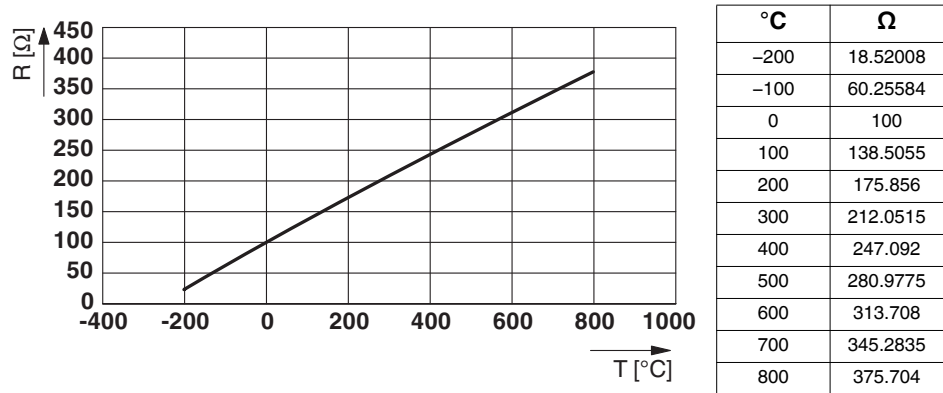
Table 2-2 Types of resistance thermometers

Type	Standardization	Temperature range [°C]
Pt 100	IEC751 / GOST 6651 $\lambda = 0.00385$	-200 ... +850
Pt 200	IEC751 / GOST 6651 $\lambda = 0.00385$	-200 ... +850
Pt 500	IEC751 / GOST 6651 $\lambda = 0.00385$	-200 ... +850
Pt 1000	IEC751 / GOST 6651 $\lambda = 0.00385$	-200 ... +850
Pt 100	GOST 6651 $\lambda = 0.00391$	-200 ... +850
Pt 100	GOST 6651 $\lambda = 0.00391$	-200 ... +850
Pt 100	JIS C1604-1997	-200 ... +850
Pt 1000	JIS C1604-1997	-200 ... +850
Ni 100	DIN 43760	-60 ... +250
Ni 1000	DIN 43760	-60 ... +250
Cu 50	GOST 6651 $\lambda = 0.00428$	-180 ... +200
Cu 100	GOST 6651 $\lambda = 0.00428$	-180 ... +200
Cu 53	GOST 6651 $\lambda = 0.00426$	-50 ... +180

The following three tables provide examples of characteristic curves for commonly used resistance thermometers. The X-axis represents the temperature in °C, the Y-axis the resistance in  $\Omega$ .

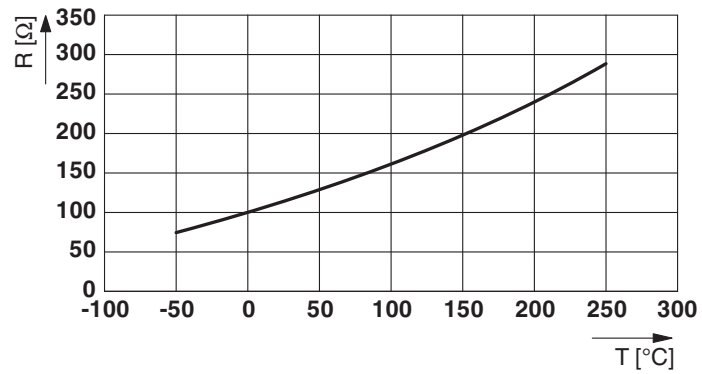
**Characteristic curve  
Pt 100**

Table 2-3 Characteristic curve Pt 100 (IEC 751)



**Characteristic curve  
Ni 100**

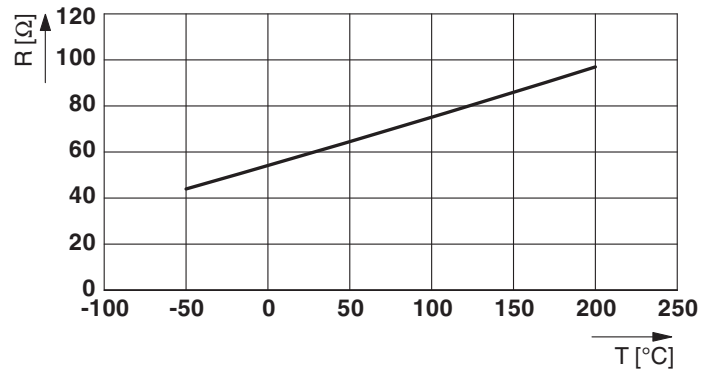
Table 2-4 Characteristic curve Ni 100 (DIN 43760)



°C	Ω
-50	74.255
0	100
50	129.105
100	161.7785
150	198.63475
200	240.66
250	289.15625

**Characteristic curve  
Cu 53**





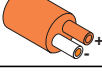

Table 2-5 Characteristic curve Cu 53 (GOST 6651  $\alpha = 0.00426$ )



°C	Ω
-50	41.7100002
0	53.0001339
50	64.2897102
100	75.5787289

Thermocouple types

Table 2-6 Thermocouple types

Type	Standardization	Temperature range [°C]	IEC <sup>1</sup> color code
B	IEC584	+500 ... +1820	Not defined
E	IEC584	-230 ... +1000	
J	IEC584	-210 ... +1200	
K	IEC584	-250 ... +1372	
N	IEC584	-200 ... +1300	
R	IEC584	-50 ... +1768	
S	IEC584	-50 ... +1768	Not defined
T	IEC584	-200 ... +400	
L	DIN 43710	-200 ... +900	-
U	DIN 43710	-200 ... +600	-
A-1	GOST 8.585	0 ... +2500	-
A-2	GOST 8.585	0 ... +1800	-
A-3	GOST 8.585	0 ... +1800	-
M	GOST 8.585	-200 ... +100	-
L	GOST 8.585	-200 ... +800	-

<sup>1</sup> International Electrotechnical Commission

Characteristic curves of thermocouples

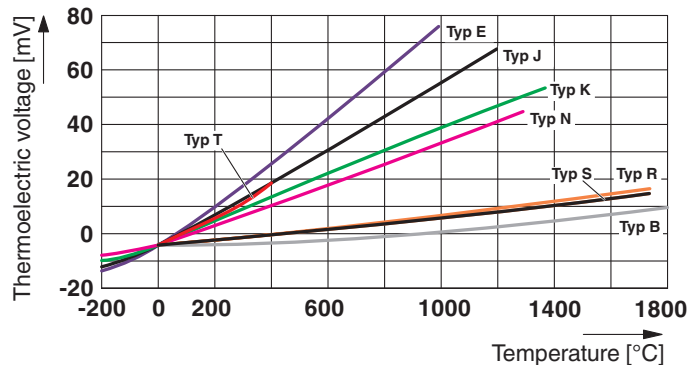


Figure 2-7 Characteristic curves of thermocouples

## 2.5 Proximity sensors according to NAMUR<sup>1</sup> standard

### NAMUR sensors

NAMUR sensors are proximity sensors that are widely used in the fields of process technology and machine building. Depending on the different application purposes, they are available as optoelectronic, magneto-inductive, capacitive and inductive sensors.

Sensors according to NAMUR standard have standardized electrical properties and measuring characteristics (IEC 60947-5-6: Control circuit devices and switching elements - DC interface for proximity sensors and switching amplifiers). They can therefore be used interchangeably regardless of their manufacturer. NAMUR sensors are short-circuit-proof. Short circuits and cable breaks can be detected by the evaluating unit. There is no separate power supply required for the NAMUR sensor; it is supplied via the measuring circuit.

Figure 2-8 shows the measurement behavior of two NAMUR sensor types. Their essential properties are explained in the following:

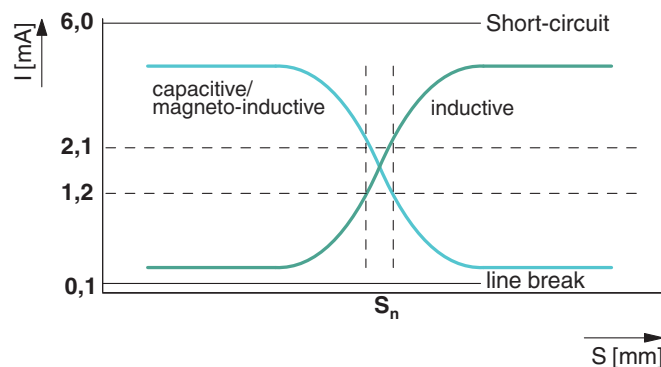


Figure 2-8 NAMUR sensor characteristic (without optoelectronic variant)

$I_{[mA]}$ : Sensor output current measured in mA

$S_{[mm]}$ : Distance between object and sensor in mm

$S_n$ : Distance between the two switching points that correspond to the associated current values and to which the switching behavior of the evaluating unit should be adapted.

Using capacitive and magneto-inductive sensor variants, the measured sensor output current will decrease when the object moves away from the sensor. In comparison, the output current will increase when using inductive sensor variants.

### Hysteresis

The dashed lines are used to indicate the switching points to which the evaluating unit should be set. The lines are drawn in pairs to indicate the offset (hysteresis) that needs to be taken into account for the setting of the two switching points. This enables chatter to be avoided between switching on and off, when only one switching point is set and both the object and sensor will move in proximity of this switching point.

<sup>1</sup> The acronym "NAMUR" is based on the former German association name "Normenarbeitsgemeinschaft für Mess- und Regeltechnik in der chemischen Industrie" (standards working group for measurement and control engineering in the chemical industry). The acronym was kept.

### Example

Using a capacitive sensor, a measured current of 1.2 mA should be used as an off signal by the evaluation unit, if the object moves away from the sensor. If the object approaches the sensor again, the switching on process, however, should only take place at a measured current of 2.1 mA.

If the evaluating unit measures a sensor output current of 6 mA or higher, there will be a short current in the sensor or between the two connecting cables.

If the evaluating unit measures a sensor output current of 0.1 mA or lower, the sensor circuit or the connecting cables will be broken.

## 2.6 Standard signals

In the field of MCR technology, standard signals according to DIN IEC 60381 are electrical signals with the following basic characteristics:

- Defined value range with the following electrical specifications:

#### **Standard current signal** (DIN IEC 60381-1)

0 mA ... 20 mA

4 mA ... 20 mA (life zero)

#### **Standard voltage signal** (DIN IEC 60381-2)

0 V ... 10 V

0 V ... 5 V

1 V ... 5 V (life zero)

-10 V ... +10 V (life zero)

- Basis for electrical components with simplified signal processing that are standardized and interchangeable regardless of the manufacturer.

Depending on the measuring task, analog sensor signals can be converted into one of the standard signals in an interface module. The conversion result should be closely proportional to the measured input value, in order to avoid a distortion of the measurement results.

If the lower limit value for the standard signal value range is set to 1/-10 V or 4 mA, it will then be possible to detect a break in the measurement circuit when the value 0 (V or mA) is detected by the evaluating component.

When setting the lower limit value of the value range to 0 (V or mA), the evaluating component is not able to differentiate whether the lowest value has been measured or a cable break occurred when the value of these so-called "true zero signals" is 0.



In almost all industrial applications, "life zero signals" are used where the zero point of the measurement is represented by 1/-10 V or 4 mA.

### Advantages of the standard current signal

The standard current signal of 0/4 mA ... 20 mA is less sensitive to electromagnetic disturbances than the standard voltage signal and largely immune to the disadvantages of long cable paths between the signal source and the evaluating component. It fulfills the high accuracy requirements made on a wide range of applications in the field of process automation.

The standard voltage signal is less robust and more strongly affected by voltage losses of long cables. It is thus more suitable for use in building and factory automation where accuracy requirements are far less stringent than in the field of process automation. In addition, the standard voltage signal is more susceptible to electromagnetic interference (EMI).

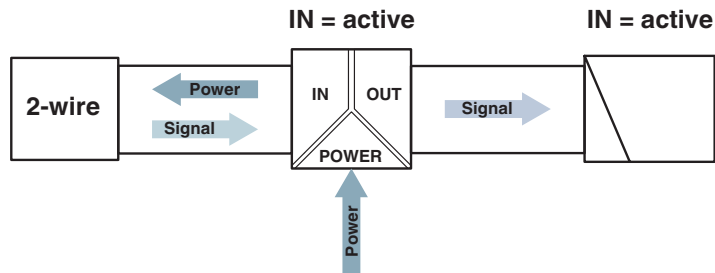


Figure 2-9 Interface block with sensor supply and standard signal output

- The sensor is supplied by an interface module and provides a measuring signal.
- The interface block converts the measuring signal into a standard signal (standard voltage or current signal).
- The standard signal is fed to a component for evaluation.

**Transmitter**

If the sensor and the interface module are located in the same housing, this unit is also referred to as a transmitter.

If a standard voltage signal is present, but a standard current signal is required, then standard voltage-to-current signal converters are available for this purpose. There are also standard current-to-voltage signal converters available for the reverse case.

Apart from the above-mentioned standard signals used in the field of MCR technology, unipolar and bipolar signals are used in the following areas:

- 50 mV ... 100 V
- 1 mA ... 100 mA

**2.6.1 Standard signals 1 ... 5 V, 0 ... 10 V**

Transmission errors of 0.1% (at 50 Ω cable resistance and 10 kΩ input resistance of the evaluating unit) are typical for standard voltage signals.

**2.6.2 Standard current signals according to DIN IEC 60381-1**

With regard to the standard current signal, a distinction must be made between the active current output (current source) and the passive current output (current sink).

**Active current output (current source)**

A sensor or signal converter with **active** current output delivers current proportional to the measured value. It has its own voltage source that can either be built in or connected as a separate supply, by means of additional cables from the evaluating component, if required. When using a sensor or signal converter with active current output, the maximum permissible ohmic load must be considered for its connection (as specified in the device data sheets). The measuring signal will be falsified in the event of an ohmic overload.

An active current output can not only be used for the standardization of measuring signals, but also for the control of actuators. For example, the current source is able to control a valve that controls the flow rate proportionally to the delivered current strength between 0% and 100%.

### **Passive current output (current sink)**

A sensor or signal converter with **passive** current output changes its internal resistance proportionally to the measured value and therefore the current in the conductor loop of the measuring circuit. The sensor or signal converter is supplied by the evaluating component via the two measuring cables and requires a part of the supply voltage for its functioning. When using a passive current output, the maximum permissible voltage value needs to be considered, as specified in the device data sheets. If the voltage is too high, the measuring signal may be falsified and the device destroyed.

## 3 Applications

### 3.1 Signal conditioners

As briefly described in the previous section, interface blocks may have different functions with regard to signal conditioning:

- Amplification
- Standardization
- Filtering
- Electrical isolation
- Electrical supply of connected components
- Cable monitoring

The electronic components used for these tasks are summarized under the term “signal conditioner” or “signal isolator” and are available with different functions:

- With one or several of these functions
- Adjustable for different input and output signals
- Adjustable via switches located on the device or remote configuration using the control system

Depending on the input signal types, signal conditioners can be divided into the following groups:

- Signal conditioners for binary signals (switching amplifiers with relay or contactor function, frequency converters for acquisition of speed and direction of rotation)
- Signal conditioners for proportional analog signals (sensor supply devices, measuring transducers with standard signal output, limit sensors)

Manufacturers of automation and process control technology offer a wide variety of signal conditioners from universally applicable to highly specialized types.

- Signal conditioners offering only one, a few or all basic properties that can be individually switched on or off
- Converter and interface modules with additional functions (see “Additional functions of signal conditioners” on page 31)
- Combinations of these properties
- Multi-channel signal conditioners converting an input signal into several output signals or combining several modules in one housing

In the following, the basic properties of signal conditioners are explained by means of wiring examples.

#### 3.1.1 Signal amplification

Signal amplification is always required if a signal is too weak and its acquisition by the evaluation unit will only be falsified or attenuated. This may be due to the following factors, either individually or in combination:

- Long cable paths, high cable resistances
- High input resistance of the evaluation unit or high total resistance of several signal “consumers” connected in series

## Analog signal transmission in the field of MCR technology

- Signals of voltage-generating sensors or transmitters with weak power output due to their construction type.

In electrotechnical parlance, the following clear diagnostics is made with regard to these incorrect adjustments: Either the sensor or the signal is not able to drive the connected, excessive load. The maximum permissible load for a signal output is indicated as resistance value in the data sheets for electrical MCR components.

### Problem

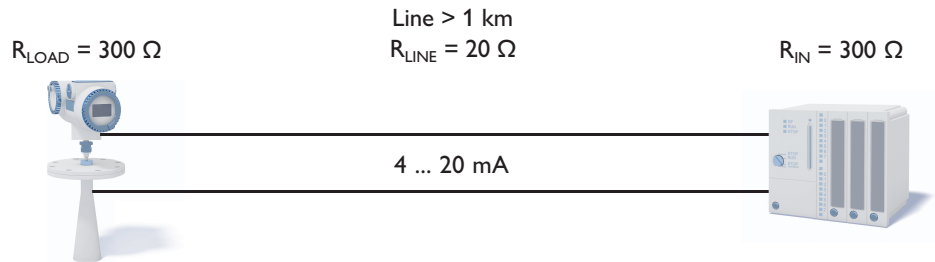


Figure 3-1 Incorrect adjustment owing to high cable and terminal resistances

- Sum of resistances of the measuring signal cables and the evaluation unit input:  
20 Ω + 300 Ω = 320 Ω



The load connected to the measuring sensor is 320 Ω and thus exceeds its maximum permissible load of 300 Ω.

The measuring sensor is not able to drive this load, leading to a falsified measuring signal.

### Solution

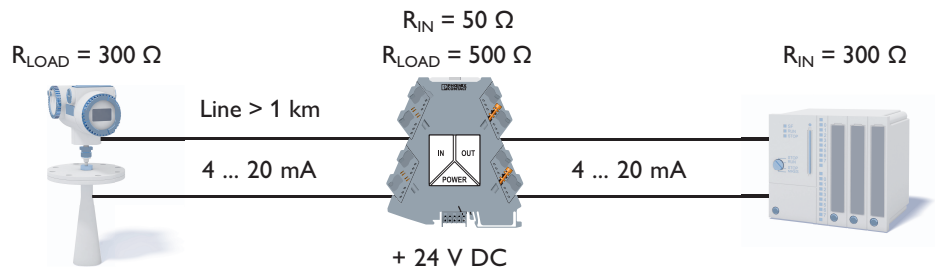


Figure 3-2 Signal amplification to correct the error in the adjustment

- Adding an amplifier for analog signals to the connecting cables for the measuring signal.
- Sum of resistances of the measuring signal cables and the amplifier input:  
20 Ω + 50 Ω = 70 Ω



The load connected to the measuring sensor is 70 Ω and thus lower than the maximum permissible load of 300 Ω. Furthermore, the input resistance of the evaluation unit of 300 Ω does not overload the amplifier output, as it is intended to drive a load of up to 500 Ω.

The measuring signal will not be falsified.

### 3.1.2 Conversion to a standard signal

In the signal amplification example, the transmitter used for pressure measurement already provides a standard signal of 4 mA ... 20 mA. A sensor and a signal amplifier which provides the standard signal are integrated into the transmitter.

The measuring transducer integrated in the transmitter usually consists of a piezoelectric element on the surface from which charges are generated due to the pressure. They can be measured as a voltage drop via the element. The signal amplifier has a power supply which aids in amplifying the measuring signal and converts it to the standard signal that will be provided by the transmitter at its measuring signal connections on the output side.

Depending on the application purpose, measuring transducers without any amplification function may be integrated into transmitters. For example, a voltage converter can be used for the measurement of higher alternating voltages. Its input is directly connected to the voltage to be measured and provides a standard voltage signal at the output side.

The Section "Standard signals" on page 20 shows in a general way how to connect an interface module with standard signal output. The use of a standard signal converter is shown in Figure 3-3.

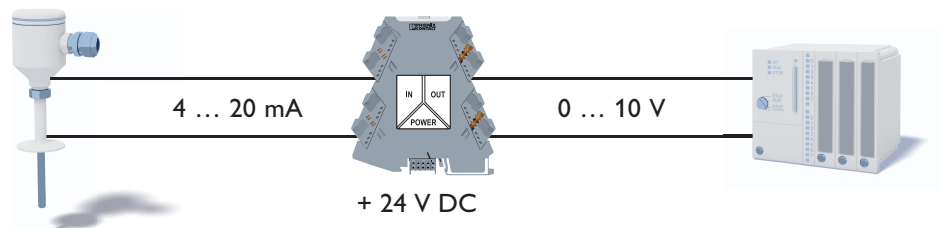


Figure 3-3 Standard signal converter

#### Problem

- The sensor or transmitter provides a standard signal of 4 mA ... 20 mA. The evaluation unit requires a signal of 0 V ... 10 V.

#### Solution

- The standard signal converter connected between the transmitter and the evaluation unit makes the required adjustment.

### 3.1.3 Filtering

Signal conditioners with filtering function are able to detect and suppress interference voltages within a wide frequency spectrum. To avoid interference resulting from the above-mentioned causes, the voltage signal should be converted into a current signal.

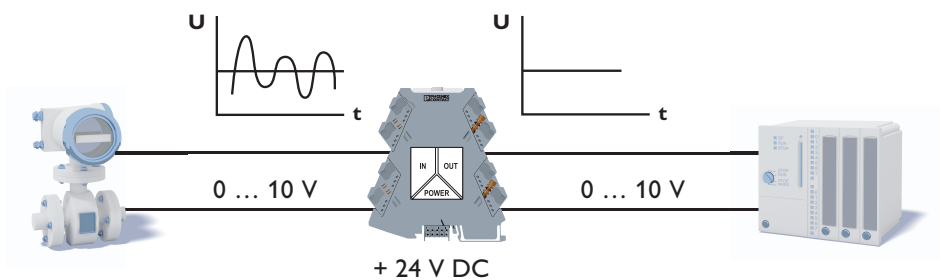


Figure 3-4 Signal filtering

### Problem

Interference voltages may occur in cables used for measured-value transmission.

- Owing to electromagnetic induction caused by currents in electrical cables which are installed in nearby locations (see Figure 3-4)
- Owing to the impact of high-frequency signals caused by electrical devices in the industrial environment, e.g., frequency inverters

### Solution

Interference is particularly strong if voltage signals are affected. Depending on the cables used, signal transmission can be protected against such interference to a certain extent.

- Twisted pairs reduce interference through voltages induced in the cable.



The conductive sheaths of shielded cables reflect and absorb the electrical fields, to which the cables are exposed.

### 3.1.4 Electrical isolation

There are different reasons to electrically isolate the circuit in which the sensor or transmitter is installed from the circuit in which the evaluating unit is located.

- To interrupt and avoid compensating currents between potential differences as well as electromagnetic interference in measuring technology, data transmission and electro-acoustic systems
- To increase safety and protect electrical devices and systems from hazardous voltages and voltage pulses

Depending on the application, the electrical isolation - also referred to as galvanic decoupling or separation - can be achieved in different ways:

- Inductively by means of transformers (for alternating voltages and pulses)
- Capacitively by means of capacitors (for high-frequency signals)
- Optically by means of optocouplers or fiber optic paths (for all types of information)
- Mechanically by means of relays and pneumatic elements (for transmission of electro-mechanical/pneumatic switching states and pulses)

Each one of these methods has its advantages and disadvantages. Optocouplers, for example, have a high dielectric strength. However, they do not allow energy to be transmitted and are subjected to undesired aging processes. Conventional transformers allow for energy transmission, but they are large and expensive. Microcoils embedded in the semiconductor material of integrated circuits (“coreless transformers”) do not have this disadvantage but usually suffer the loss of the energy transmission function (except for digital signal transmitters, e.g., of ADuM5421 type).



An electrically isolated signal connection is referred to as floating connection because there are no compensating currents flowing between potential differences.

In plant and process technology, the electrical isolation of field circuits from system control circuits has gained acceptance. In this context, „field“ is the technical term that summarizes all sensors, transmitters and actuators within the controlled system. In addition, circuits are often electrically isolated within the field.

## Problem

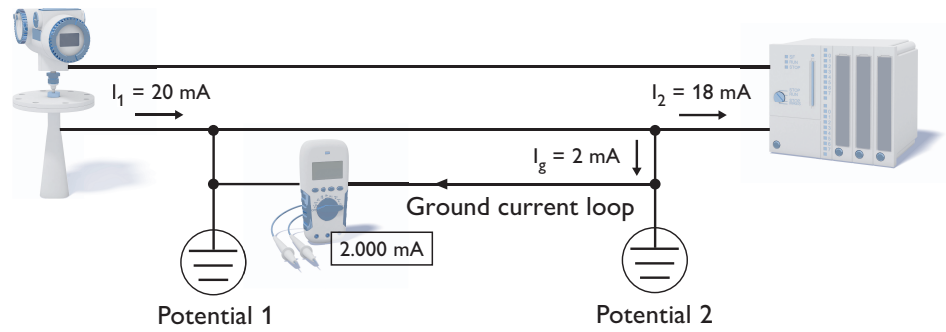


Figure 3-5 Ground current loop

- The transmitter and evaluation unit are grounded, but they have different ground potentials. A compensating current  $I_g$  is flowing through one of the connecting cables for the measuring signal  $I_1$  and leads to its falsification.
- Signal  $I_2$  deviating from the measuring signal  $I_1$  is measured.

## Solution

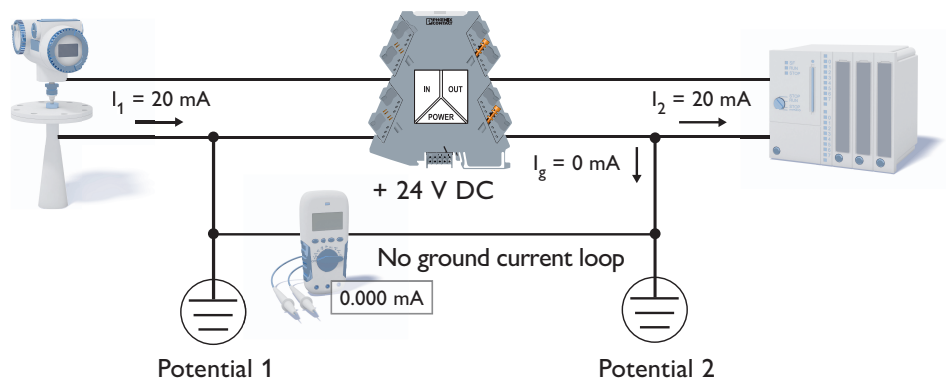


Figure 3-6 Electrical isolation to break ground current loops

- Integrating a galvanic signal isolator, e.g., a transmitter, into the connecting cables for the measuring signal.
- The compensating current  $I_g$  is no longer flowing.  $I_2$  which is identical with the measuring signal  $I_1$  is measured.

### 3.1.5 Electrical supply and isolation of signal paths

Depending on whether the connected sensor or transmitter has its own power supply or is supplied via sensor signal cables, there is a difference made between a passive and active input at the input terminals of a signal conditioner or evaluation unit.

#### Passive input

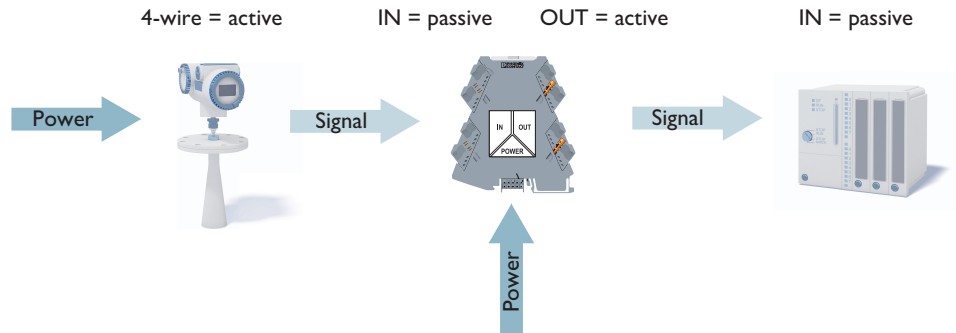


Figure 3-7 Examples for a passive signal input

- The only function of the signal input is to receive the signal. In the example, the signal conditioner and the evaluation unit have passive inputs.
- The active sensor/transmitter (with four connections) supplies the passive input of the signal conditioner.
- The active output of the signal conditioner supplies the passive input of the evaluation unit.

#### Active input

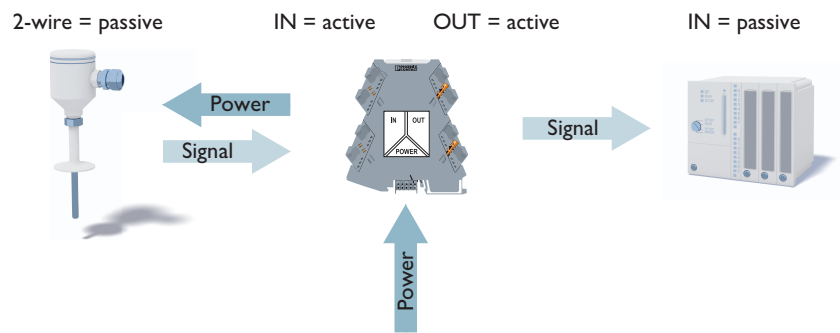


Figure 3-8 Example for an active signal input

The signal input has two functions:

1. Signal receipt
  2. Power supply of the sensor
- In the example, the signal conditioner has an active input. It supplies the 2 or 3-wire sensor/transmitter. The active output of the signal conditioner supplies the passive input of the evaluation unit (as in the previous example).
  - Components that need an electric power source can be supplied with separate power supplies or via the signal lines.

Table 3-1 Supply paths for signal isolators: advantages and disadvantages

Power supply	Advantages	Disadvantages
<b>Separate</b>	– Electrical isolation of the supply circuit from the signal circuits	– Extra expense in material and costs
<b>Via signal lines</b>	– Material and cost savings	– Not possible for all applications – Increased risk of interference

**Passive isolation (input loop-powered)**

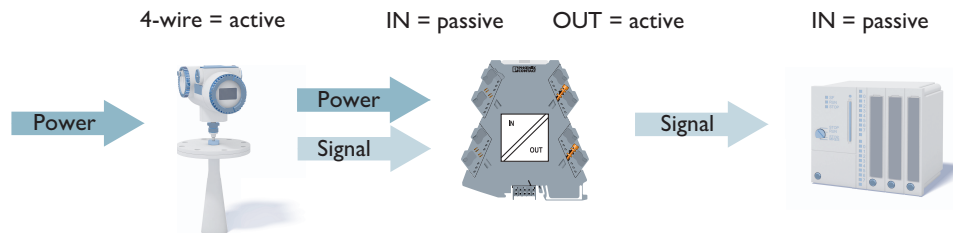


Figure 3-9 Example 1 for passive isolation (input loop-powered)

**Signal conditioner supply via its signal input using a transmitter (input loop-powered)**

- The signal paths between the active (4-wire connection) sensor/transmitter and the signal conditioner are not electrically isolated from the transmitter supply.



The sensor/transmitter needs to drive the total load of the signal conditioner and the evaluation unit input.

**Passive isolation (output loop-powered)**

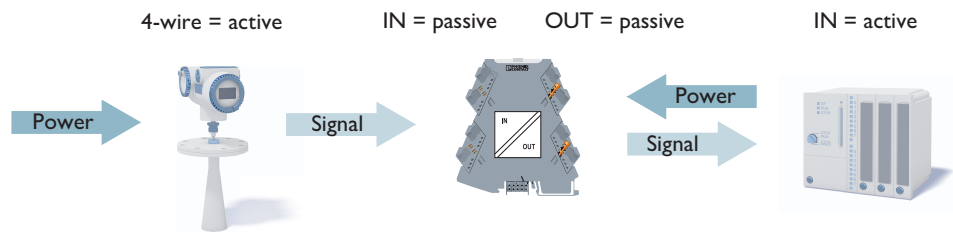


Figure 3-10 Example 2 for passive isolation (output loop-powered)

**Signal conditioner supply via its signal output using the evaluation unit (output loop-powered)**

- The signal path between the sensor/transmitter and the signal conditioner is electrically isolated from the transmitter supply.
- The signal path between signal conditioner and evaluation unit is not electrically isolated from the supply for the evaluation unit.



Only the output signal of 4 mA ... 20 mA is suitable for this purpose.

### 3.1.6 Cable monitoring

With regard to connecting a switch to an evaluation unit, Figure 2-2 on page 10 has already shown how, using two resistors, a simple monitoring function for cable interrupts and short circuits can be implemented for a 2-wire cable.

This monitoring function is specified in greater detail in the NE 21 Recommendation provided by the User Association of Automation Technology in Process Industries.

Special interface modules are available for cable monitoring which do not have any other monitoring functions.

Cable monitoring is integrated in many interface blocks as an additional function. Errors will be indicated here at separate terminal blocks and displayed on the modules via LEDs.

The following figure shows schematically how cable monitoring can be used for the total signal transmission path from the sensor to the evaluation unit.

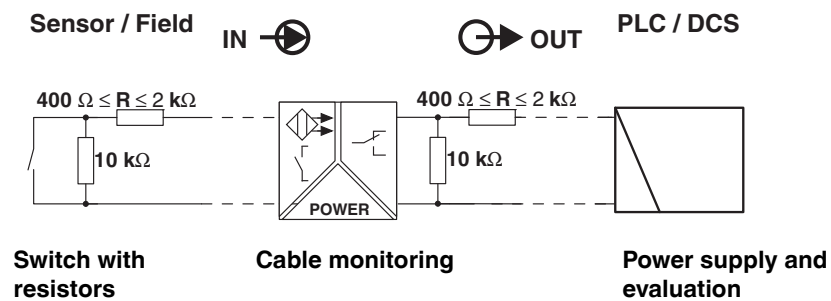


Figure 3-11 Cable monitoring

### 3.1.7 Additional functions of signal conditioners

Apart from the basic functions of signal conditioners, a wide range of additional functions is available for interface modules within the field of MCR technology. The modules may have a single channel, multiple channels or, together with other functions, be integrated in one housing.

- Switching amplifier with relay function for high loads
- Configurable limit sensors, comparators
- Measuring transducers specially designed for temperature sensors
- Amplifiers for the connection of strain gauges
- Frequency-analog measuring transducers, analog-frequency measuring transducers
- Configurable converters for measuring values (e.g., in the event of an irregularly shaped tank, to linearize fill level values which are not proportional to the filling quantity)
- HART-transparent interface modules

Series MINI Analog Pro signal conditioners with bus and network connections combine the benefits of electrical isolation with those of digital communication. Plug-in gateways bundle up to eight channels quickly and without errors in just one network cable. This ensures electrical isolation up to the CPU and eliminates the need for signal-specific input cards.

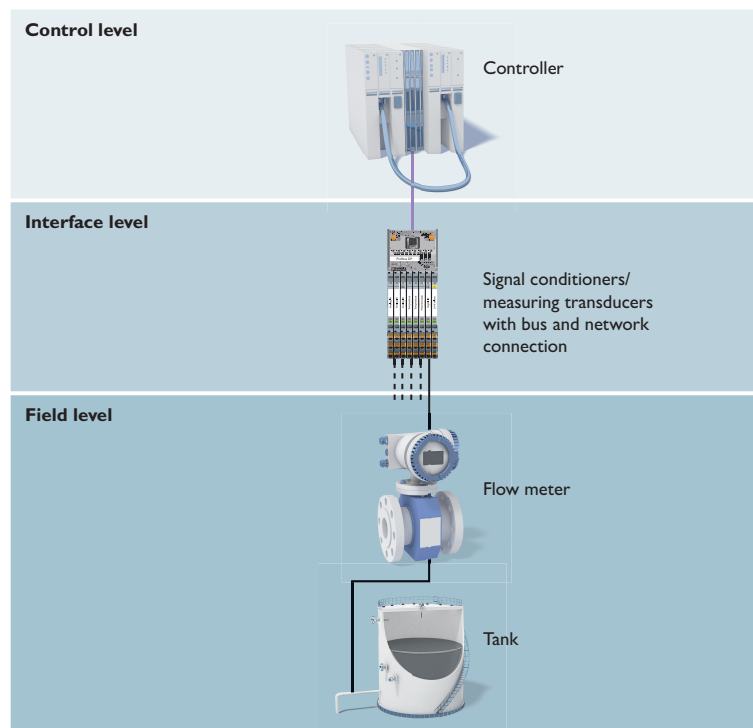


Figure 3-12 Safely isolated from the field to the network, thanks to plug-in gateways

### 3.1.8 Analog and digital signal inputs and outputs

The function and application of an interface module determine how its inputs and outputs are to be “wired” which means what other electrical components can be usefully connected. Interface blocks are therefore mainly categorized by their value ranges for inputs and outputs. In addition, they can be categorized by information regarding the power supply, further electrophysical properties, type and dimensions.

Basically, they can be classified by indicating whether their signal inputs and outputs are used to process analog or digital signals. (See “What type of signals are involved?” on page 5 for analog and digital signal differentiation.)

The interface module types indicated below are primarily used in automation and process control technology. They can have a single or several channels, combine several types in one module and/or be intended for use in potentially explosive areas.

Table 3-2 Interface modules with analog and digital signal inputs (IN) and outputs (OUT)

IN	OUT	Type	Examples
Analog	Analog	Signal conditioner	<ul style="list-style-type: none"> <li>– Universal signal conditioner</li> <li>– Input isolator (for electrical isolation of sensors in the field from the control system)</li> <li>– Power supply isolators (with energy supply for the sensor)</li> <li>– Signal duplicator</li> <li>– Output isolator (for electrical isolation of actuators in the field from the control system, with or without HART transparency)</li> </ul> <p>Output can be configured proportionally to the input or with a different characteristic.</p>
		Temperature transducer	See “Temperature measurement” on page 10 for RTD and TC signals.
Analog	Digital	Limit and threshold adjuster	For analog signals from potentiometers, temperature sensors, etc.; several outputs possible; with relay or transistor output, several outputs possible
Digital	Digital	Signal conditioner	<ul style="list-style-type: none"> <li>– For switch contacts</li> <li>– NAMUR signal conditioner for proximity sensors (capacitive/magneto-inductive, inductive, optical); see “Proximity sensors according to NAMUR standard” on page 19</li> <li>– Digital solenoid drivers</li> </ul> <p>With relay or transistor output, several outputs possible</p>
Digital	Analog	Frequency transducer	D/A converter with an analog output that is proportional to the frequency or configurable with a different characteristic



The following section provides application examples for the four types listed above.

## 3.2 Application examples

The following examples show typical applications of signal conditioners. The corresponding applications are briefly explained and a circuit diagram shows how to connect the sensor and the evaluation unit (e.g., the control system).

In the descriptive texts for the application examples, the term “signal conditioner” always refers to active signal conditioners with their own electrical supply. Passive signal conditioners without their own separate power supply are referred to as “passive signal conditioners”.

### 3.2.1 Analog IN/Analog OUT

#### Measuring the current consumption of a DC electric motor using a shunt

For current measurements in low and medium power ranges, a low-ohmic (shunt) resistor is used within the circuit which is connected in series with the consumer. An electric voltage drop takes place across the resistor, proportional to the current flowing through it. The voltage is measured and, based on this value, the strength of the electric current flowing across the resistor to the consumer is calculated according to Ohm's law.

- The active sensor supplies a voltage signal, which is proportional to the motor current consumption, to the passive signal conditioner input.
- The signal conditioner supplies an active current output signal, which is analog to the input signal, to a passive input of the evaluation unit.

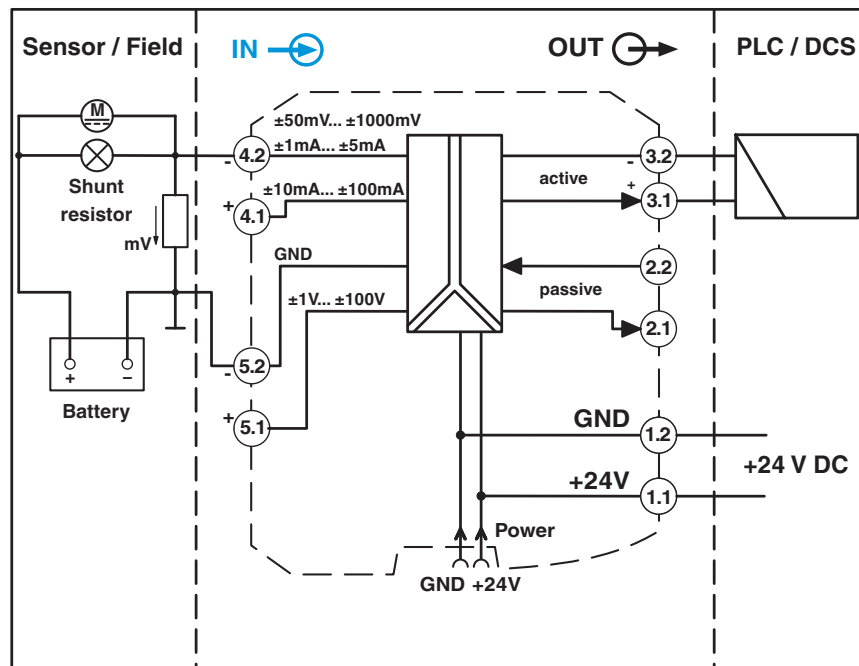


Figure 3-13 Current measurement using a shunt

**Pressure measurement in an explosion-protected area**

- The passive 2-wire sensor supplies a current signal, which is proportional to the pressure, to the active signal conditioner input.
- The signal conditioner supplies an active current output signal, which is proportional to the input signal, to a passive evaluation unit input.

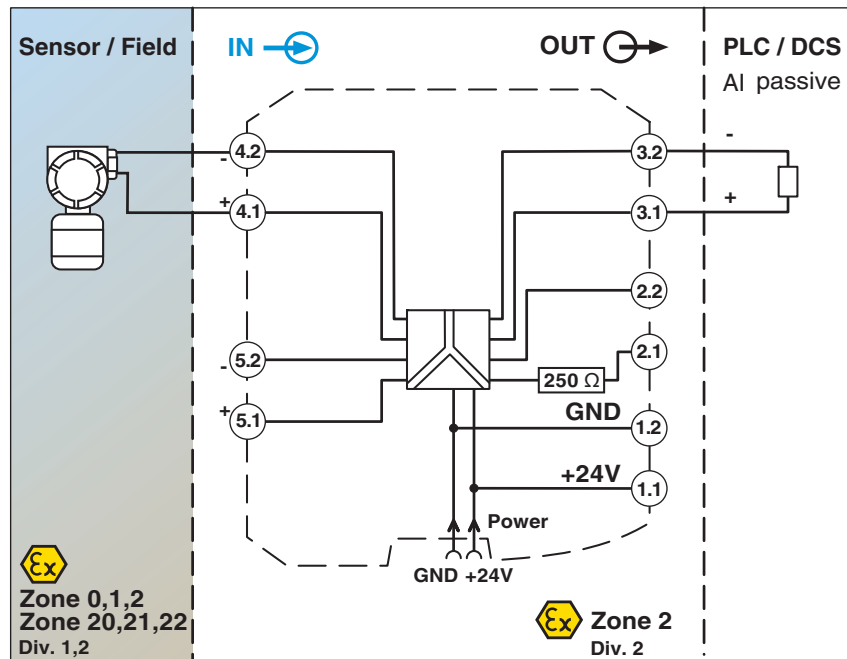


Figure 3-14 Pressure measurement in an explosion-protected area using the MACX MCR-EX-SL-RPSSI-I repeater power supply

### Flow measurement in an explosion-protected area

- The active 4-wire sensor supplies a current signal, which is proportional to the flow rate, to the passive signal conditioner input.
- The signal conditioner supplies a passive current output signal, which is proportional to the input signal, to an active evaluation unit input.

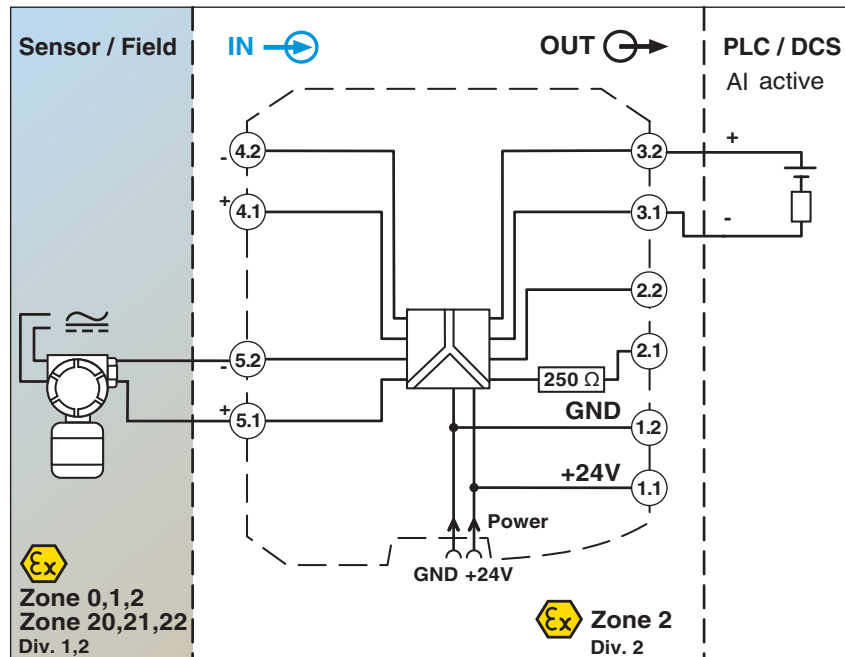


Figure 3-15 Flow measurement in an explosion-protected area using the MACX MCR-EX-SL-RPSSI-I repeater power supply

**Control valve activation in an explosion-protected area**

- The active output of the control unit supplies an analog current signal to the passive signal conditioner (output isolator) input.
- The signal conditioner supplies an active current output signal, which is proportional to the input signal, to the control valve. This signal is used for operating the control valve.

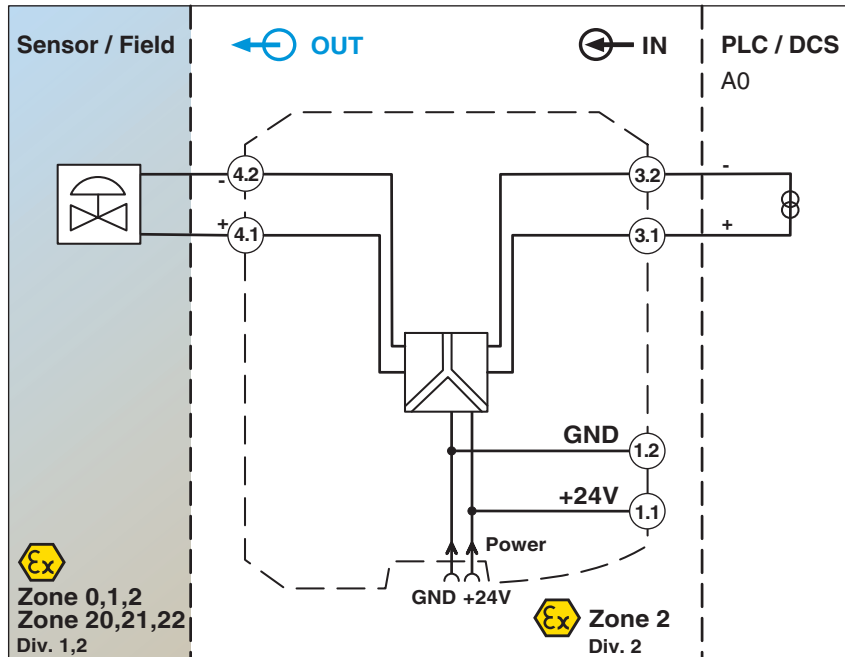


Figure 3-16 Control valve activation in an explosion-protected area using the MACX MCR-SL-IDSI-I signal conditioner

**Lifting platform control using a potentiometric sensor**

- The passive potentiometric sensor supplies an analog actual-value signal to the active signal conditioner input.
- The signal conditioner supplies an active voltage output signal, which is analog to the input signal, to a passive actual-value input of the closed-loop controller.
- The control system supplies an analog voltage signal to the setpoint input of the closed-loop controller. The closed-loop controller compares the actual value and the setpoint and controls the motor until the actual value has reached the setpoint.

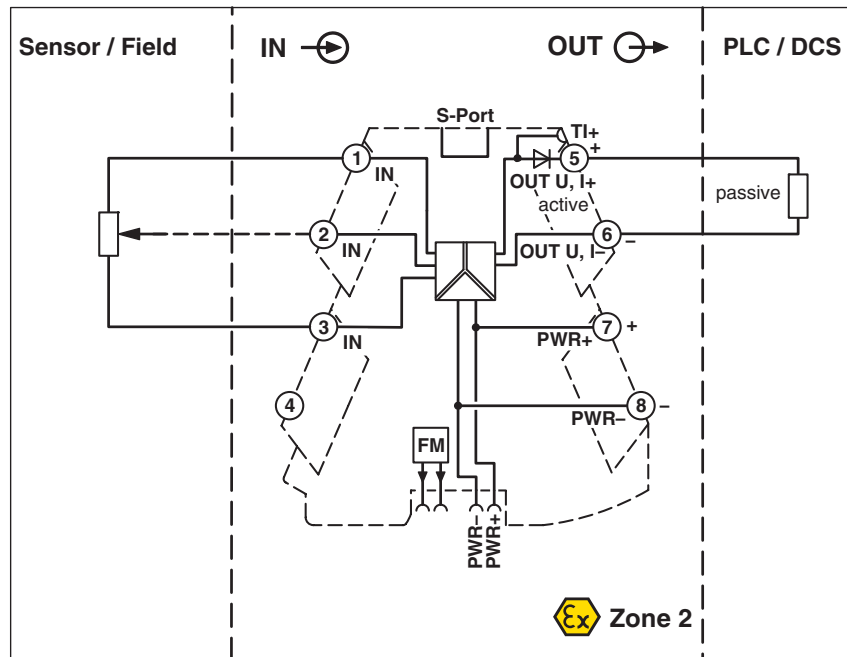


Figure 3-17 Lifting platform control using a potentiometric sensor and the MINI MCR-2-POT-UI(-PT)(-C) signal conditioner

**Flow measurement using a passive isolator**

- The active 4-wire sensor supplies a current signal, which is analog to the flow rate, to the passive input of the input loop-powered passive isolator (signal conditioner without its own, separate power supply; it is supplied by the sensor).
- The passive isolator supplies an active current output signal, which is analog to the input signal, to a passive evaluation unit input.

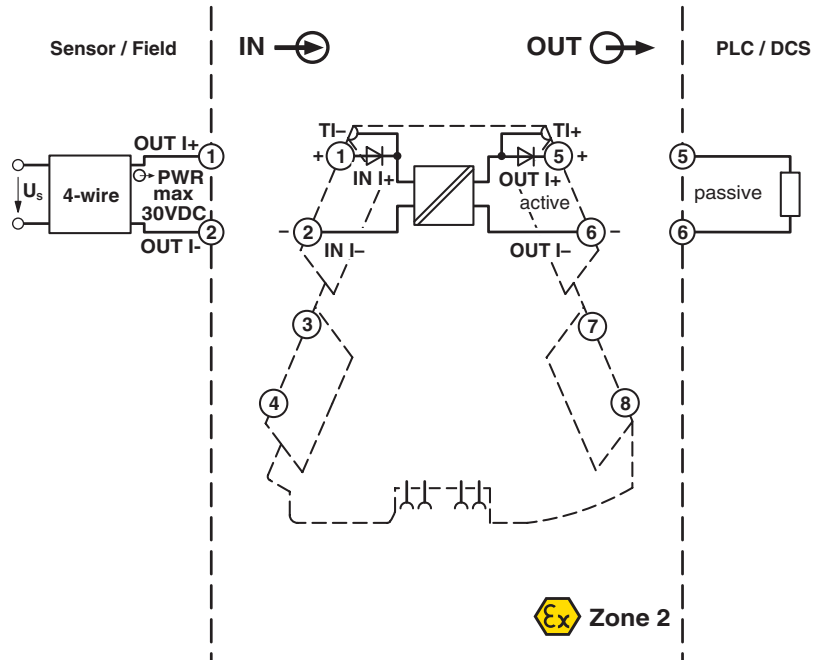


Figure 3-18 Flow measurement using a passive isolator, e.g., with a signal conditioner of the MINI Analog Pro series



When using a passive isolator, the voltage provided by the measuring transducer must be high enough to drive the total load with the maximum current of 20 mA.

**Using an output loop-powered passive isolator**

- The (active 4-wire) sensor provides an analog voltage signal to the passive input of the output loop-powered passive isolator (see also “Electrical supply and isolation of signal paths” on page 28).
- The passive isolator supplies a passive current output signal, which is analog to the input signal, to an active evaluation unit input.

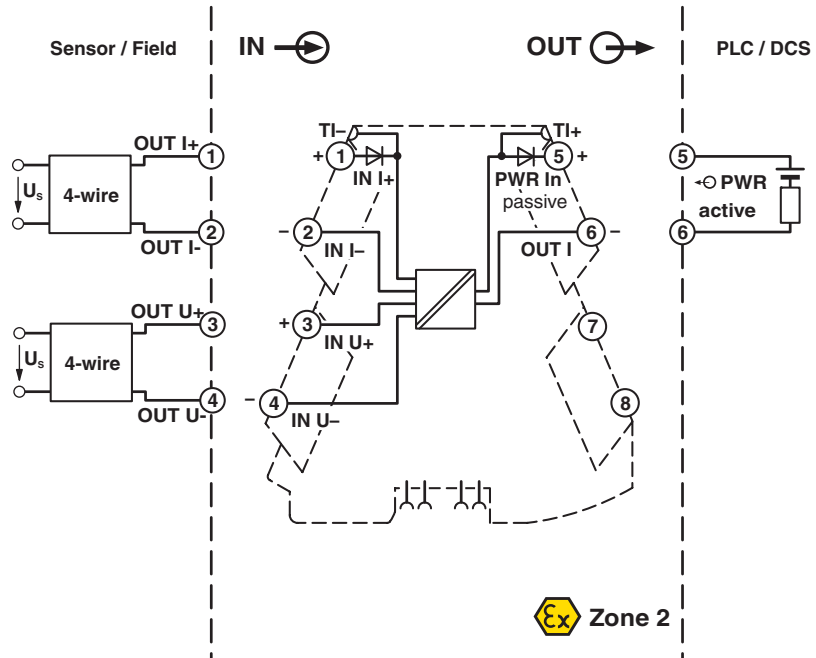


Figure 3-19 Using an output loop-powered passive isolator, e.g., with a signal conditioner of the MINI Analog Pro series

### 3.2.2 Analog IN, Digital OUT

#### Potentiometric position measurement with digital signal outputs

- The passive position sensor (potentiometer) supplies an analog signal to the active input of the signal conditioner.
- The signal conditioner supplies a digital output signal, which is dependent on the input signal, to three digital inputs of the evaluation unit(s).
- The three output signals can be configured independently of one another to certain input signal values (measured positions).
- In addition to the three digital outputs, the signal conditioner has an active analog current output or an active analog voltage output.

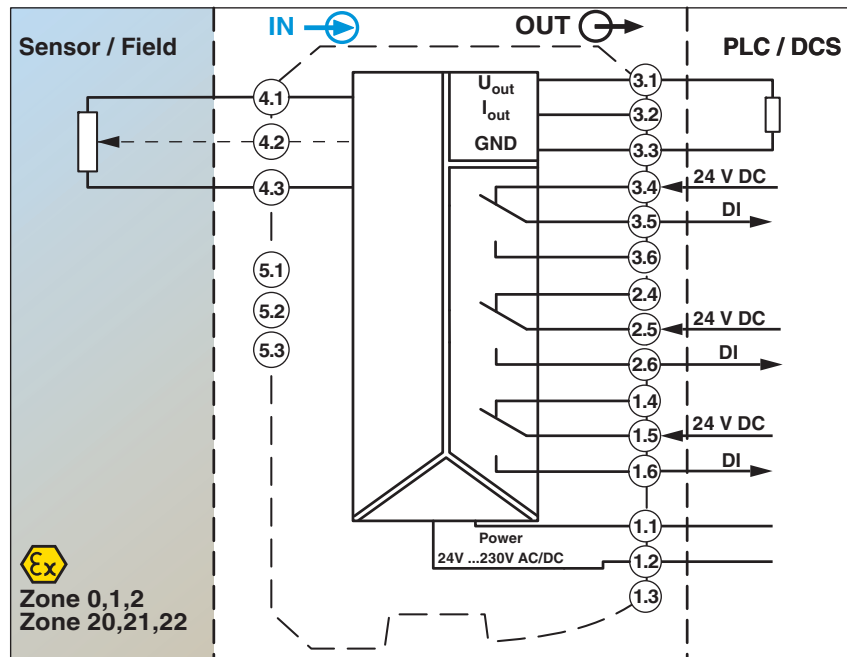


Figure 3-20 Potentiometric position measurement with digital signal outputs, e.g., with a signal conditioner of the MACX ... T-UIREL series

### Temperature measurement with digital signal outputs

- The passive temperature sensor (RTD with 4-wire connection) supplies a resistance-dependent voltage signal to the active signal conditioner input.
- The signal conditioner supplies a digital output signal, which is dependent on the input signal, to two digital inputs of the evaluation unit(s).
- The two output signals can be configured independently of each other to certain input signal values (measured temperatures).
- As shown below, the two digital outputs (relay outputs as N/C contacts) 2 and 3 can be connected in series and used as redundant signals to be evaluated by the control unit (e.g., for switching off a system due to increased safety requirements).
- In addition to the two digital outputs, the signal conditioner has an active analog current output or an active analog voltage output.

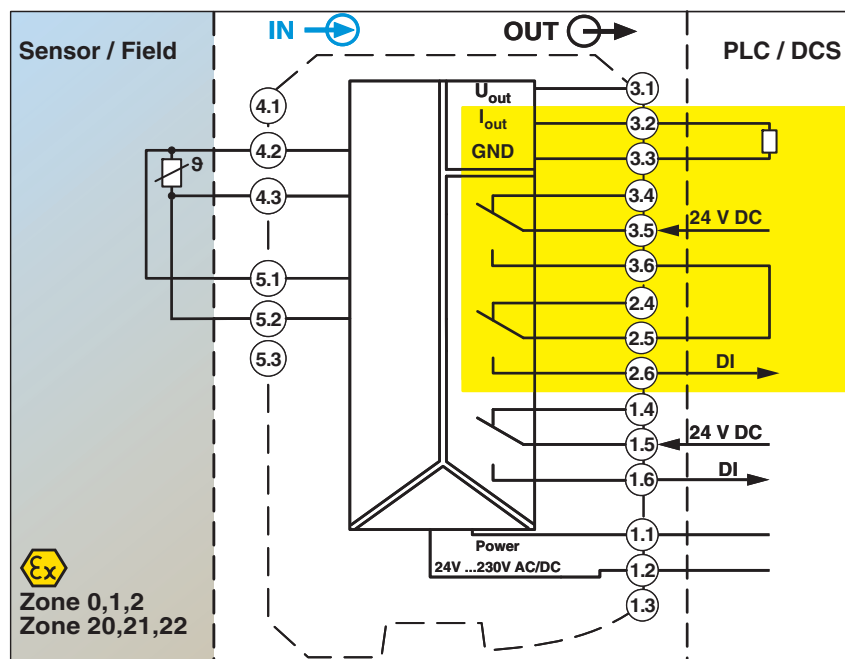


Figure 3-21 Temperature measurement with digital signal outputs

### 3.2.3 Digital IN, Digital OUT

#### Digital conditioning of a switch signal

- The passive sensor (switch, proximity sensor) supplies a digital pulse/frequency signal to the active signal conditioner input.
- The signal conditioner supplies a digital output signal, which is dependent on the input signal, to a digital evaluation unit input.
- The characteristic used to convert the input signal into the output signal can be configured.
- Wiring the sensor/switch with resistors enables measuring cable interrupts and sensor/switch failures to be detected (see also “Event acquisition, pulse and frequency measurement” on page 9). With regard to NAMUR proximity sensors, these resistors are already integrated in the sensor housing.
- The second digital output of the signal conditioner can be used just as the first one to control another digital input (signal duplication) or as an error message output. The different options can be set.

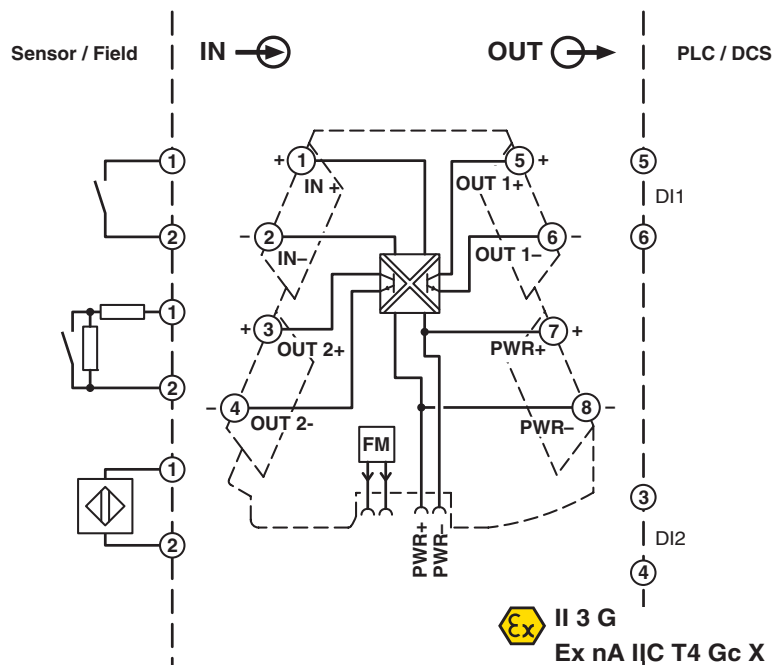


Figure 3-22 Digital conditioning of a switch signal

### Two-channel digital conditioning of proximity switch signals

- Each of the two passive NAMUR sensors (proximity sensors) supplies a digital pulse/frequency signal to an active signal conditioner input.
- The signal conditioner supplies a digital output signal, which is dependent on the input signal, to a digital input of the evaluation unit.
- The characteristic used to convert the input signal into the output signal can be configured.

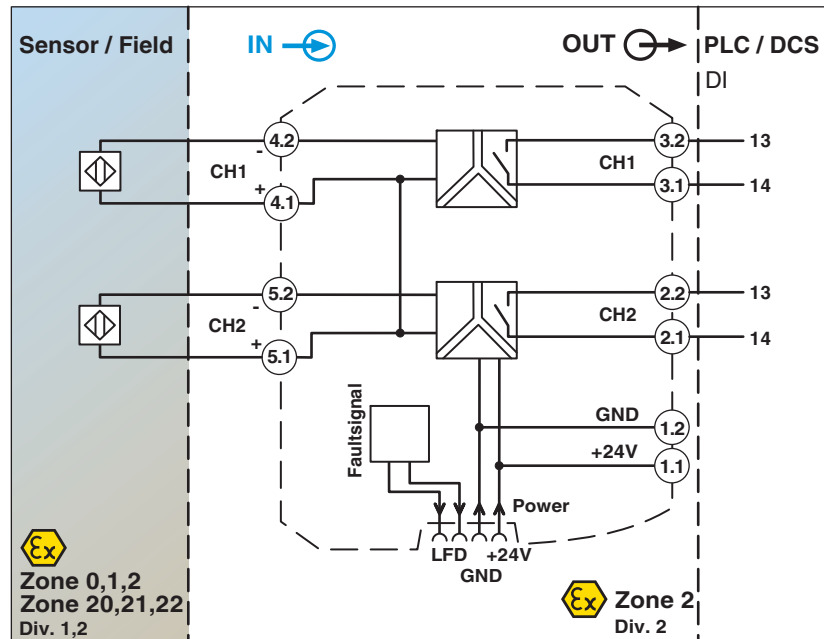


Figure 3-23 Two-channel digital conditioning of proximity switch signals



Since the resistors for detecting measuring cable interrupts and sensor failures are already integrated in the NAMUR proximity sensors, this error information is provided in the form of signals at both LFD connections of the signal conditioner (line fault detection). The LFD signals are routed to the provided cables in the signal conditioner supply rail and can be evaluated by the control unit.

### Digital valve control in an explosion-protected area

- The output of the control unit supplies a digital signal to the signal conditioner (output isolator) input.
- The signal conditioner supplies a digital signal, which is dependent on the input signal, to the control valve being operated by this signal (opened or closed).

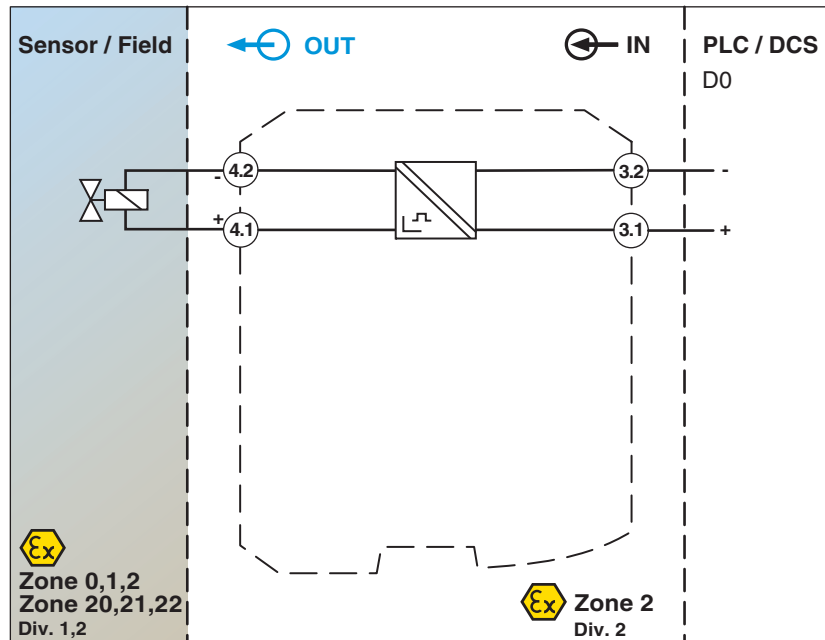


Figure 3-24 Digital valve control in an explosion-protected area (only with signal conditioners of the MACX ... EX series)

### 3.2.4 Digital IN, Analog OUT

#### Converting frequencies to analog values

- The passive NAMUR sensor supplies a frequency signal to the active signal conditioner input.
- The signal conditioner supplies an active output signal, which is dependent on the frequency, to a passive evaluation unit input.
- The characteristic used to convert the input signal into the output signal can be configured.

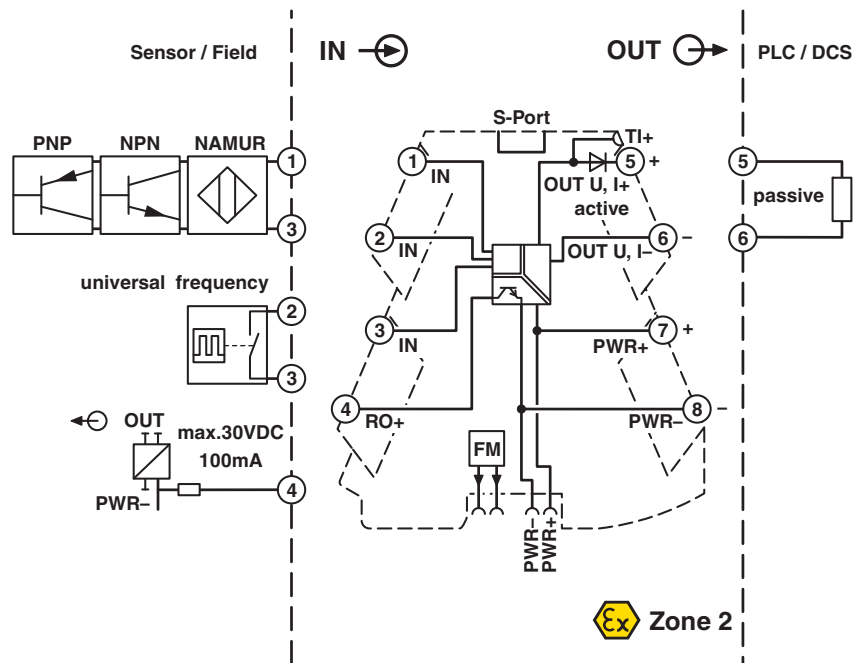


Figure 3-25 Converting frequencies to analog values



## 4 Digital fieldbuses

In systems using automation and process control equipment, two areas need to be connected by means of electric cables:

- Field devices, i.e. the sensing devices (sensors), and actuating elements (actuators) in the system
- Evaluation and control unit(s)

To eliminate the need to connect each field device to the control unit by means of separate connecting cables, the first digital fieldbuses were developed and put in use in the 1980s. They enabled multiple field devices to be connected to the control unit via collectively used bus cabling, thus replacing multicore cable harnesses which had separate conductors for each field device:

- Each field device can be connected, at nearly any position, to the fieldbus cabling by means of an interface block.
- A digital bus protocol allows for communication between the field devices and the control unit, with the interface modules interpreting the sensor and control information sent and received by the field devices.



Since 1999, fieldbuses have been internationally standardized according to **IEC 61158** (Digital data communication for measurement and control – Fieldbus for use in industrial control systems).

Today, most of the first generation fieldbuses are being amended or replaced by Ethernet. Ethernet is the protocol for connecting computers in a Local Area Network (LAN) which is most prevalent in the business world and in administration and science. Realtime-capable Ethernet has been developed for the requirements of industrial automation.

### ISO/OSI reference model

In 1979, the International Organization for Standardization (ISO) developed a model for structuring and standardizing the world of data communication and networks. It is called the OSI reference model (Open Systems Interconnection). ISO was aiming at developing a reference model for the communication of two systems (computers, for instance).

According to the ISO/OSI reference model, a system A can communicate with a system B (two systems by different manufacturers). The ISO/OSI reference model consists of seven layers:

- Layer 1: Physical Layer
- Layer 2: Data Link Layer
- Layer 3: Network Layer
- Layer 4: Transport Layer
- Layer 5: Session Layer
- Layer 6: Presentation Layer
- Layer 7: Application Layer

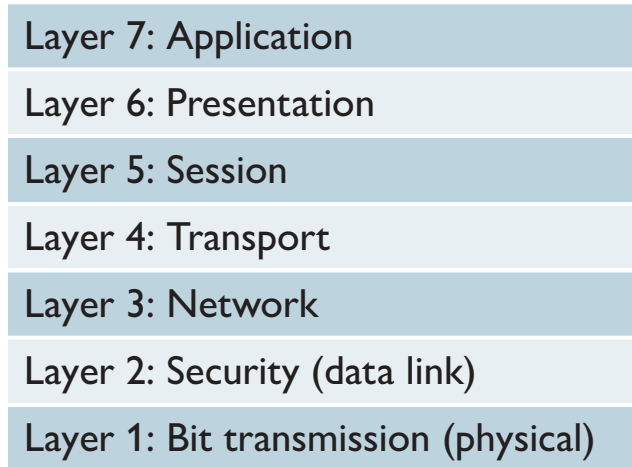


Figure 4-1 ISO/OSI reference model

For most fieldbus systems, and in accordance with IEC standardizations, only the following layers of the ISO/OSI reference model are specified for communication protocols in computer networks:

- Layer 7: Application Layer
- Layer 2: Data Link Layer
- Layer 1: Physical Layer

In connection with the list of key advantages and disadvantages of the use of digital fieldbuses, four concepts of digital fieldbuses will be looked at more closely, as an example of numerous trends and products:

- The HART fieldbus standard and WirelessHART
- The group of Fieldbus Foundation (FF) protocols
- The group of PROFIBUS protocols
- Ethernet-based systems

**Advantages**

- Relatively low cabling effort (savings in material and time during planning and installation)
- Improved signal availability, thanks to short signal paths especially for analog signals
- Standards facilitate the replacement of components made by different manufacturers
- Relatively high flexibility in terms of modification and extension
- Parameterization, status requests, etc. can be done from the control room

**Disadvantages**

- These relatively complex systems require qualified personnel for planning, installation, maintenance, and troubleshooting. Initial cost savings may therefore be canceled out.
- Higher prices for components and smallest replaceable units
- Slightly higher response times
- Connecting a bus centrally results in broader consequences in the case of a malfunction, and may require a redundant design of the bus.
- Higher and partially complex requirements for the wiring and the grounding concept of systems



## 4.1 HART®

HART (Highway Addressable Remote Transducer) is an open fieldbus standard, whose technology is supported by the HART Communication Foundation (HCF), an independent non-profit organization.

The HART protocol is mainly characterized by the fact that, as opposed to other digital fieldbus systems, it is used in addition to conventional analog standard signals. Consequently, it does not replace point-to-point wiring, but enables the integration of intelligent field devices.

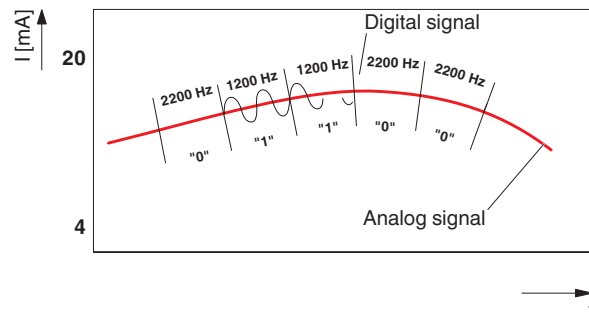


Figure 4-2 HART modulation of an analog current standard signal

### Basics

Using the FSK (Frequency Shift Keying) method, a higher-frequency oscillation with an amplitude of  $\pm 0.5$  mA is modulated to the low-frequency 4 ... 20 mA standard signal, to simultaneously transmit digital and analog information (see Figure 4-2). In this process, a digital 1 is signaled and detected as a frequency of 1.2 kHz, and a digital 0 is signaled and detected as a frequency of 2.2 kHz.

In a flow meter, for example, it would thus be possible to transmit information about the current status of the device in addition to the 4 ... 20 mA proportional analog value of the flow rate, and to transmit new configuration data to the device.

### Characteristics

Essential properties of the HART standard are the following:

- Tried and tested, easy to install, to maintain, and to use
- Open de-facto standard freely available to any manufacturer or user; manufacturer-specific adjustments and extensions
- Retention of the cabling used for communication via the 4 ... 20 mA standard signal, which is prevalent throughout the industries
- HART allows for bidirectional digital communication between multiple HART field devices in addition to the continuing transmission of the analog current standard signal.
- The field devices used must be equipped with HART microprocessor technology, which is why they are often called “SMART” devices.
- Standardized in CPF9 (Communication Profile Family in accordance with IEC 61784)
- According to relevant equipment approvals: use of “intrinsically safe” circuits with limited current flow and protection against incendive sparks (suitable for the potentially explosive areas Ex zones 0 and 1)
- Optional use of two operator panels: the engineering panel in the control unit, and a secondary, usually mobile operator panel (laptop or control unit in the form of a hand-held terminal)
- Optional looping-in of HART displays, for on-site diagnostics

### Topology

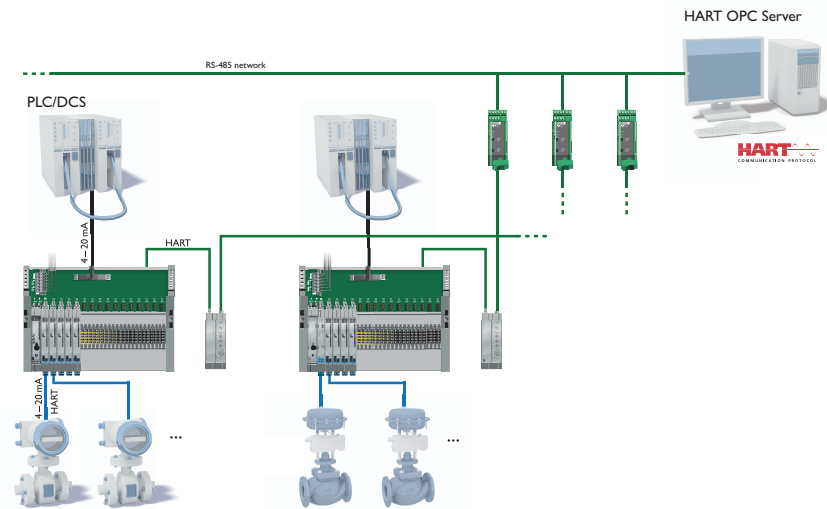


Figure 4-3 HART topology

### Field of application

Usually, HART signals are used when implementing the following communication functions:

- Extension of existing systems with HART components, and transmission of information about status, diagnostics, configuration, and control.
- Subsequent or temporary installation of field devices, e.g., transportable interoperable devices for implementing measurements and configurations.



For the HART communication to work between the HART components, it must not be blocked by signal isolators or other interface modules.

Therefore, different interface modules are available for HART communication:

- Interface modules that let HART signals pass through unmodified. (HART-transparent modules)
- Interface modules that block HART signals, for instance in order to disconnect certain parts of a system from HART communication because it might cause malfunctions there.
- Interface modules that can be adjusted either to forward or to block HART signals

### Advantages

All in all, arguments in favor of using HART technology are the following:

- Easy construction of a robust digital communication network, thanks to the use of existing 4 to 20 mA wiring
- Efficient field device configuration and status diagnostics, thanks to online access
- Increased system availability, thanks to preventive detection of deviations and errors
- Error-free bidirectional data exchange with HART-transparent signal conditioners – electrically isolated, even for intrinsically safe circuits
- Long distances covered and inexpensive retrofitting of system parts – with WirelessHART devices

### 4.1.1 HART multiplexer

HART multiplexers allow HART information to be integrated into engineering and management systems which are operated separately from evaluation and control unit(s).

The connections between HART field devices and the controller are brought together on a HART multiplexer connection board. There, in an electrically isolated way, the HART information is either transmitted to the multiplexer, or received by it.

The multiplexer stores the process variables, configuration data, and diagnostic data of all connected HART-compatible field devices, communicating with the engineering and management system via one single connection.

#### Advantages

Arguments in favor of using HART multiplexers are the following:

- Bundling of many HART channels on a single cable (usually 32 channels per multiplexer)
- Bundling of many HART multiplexers on a single controller interface (usually 128 multiplexers on one PC interface)
- Minimal space requirements, especially important for retrofittings in control cabinets with little space left for additional components
- Simple additional usage of information so far unused, and of functions of HART-compatible field devices

## WirelessHART

### 4.1.2 WirelessHART

Bypassing of connections between field devices and control unit, which are not suitable for HART communication, can be done by means of wireless communication (WirelessHART). Specific wireless modules for connection to the field devices and the control unit are available.



Like HART, WirelessHART is an open industrial standard, which was established in 2010 by IEC (International Electrotechnical Commission) as the international standard **IEC 62591**.

- Coverage of distances from 30 m to 250 m, depending on the building density
- Mesh-shaped layout (meshed network), in which each of the HART wireless modules simultaneously serves as a router and repeater
- Usage of installed tools and procedures for configuration, maintenance, and diagnostics

### Topology

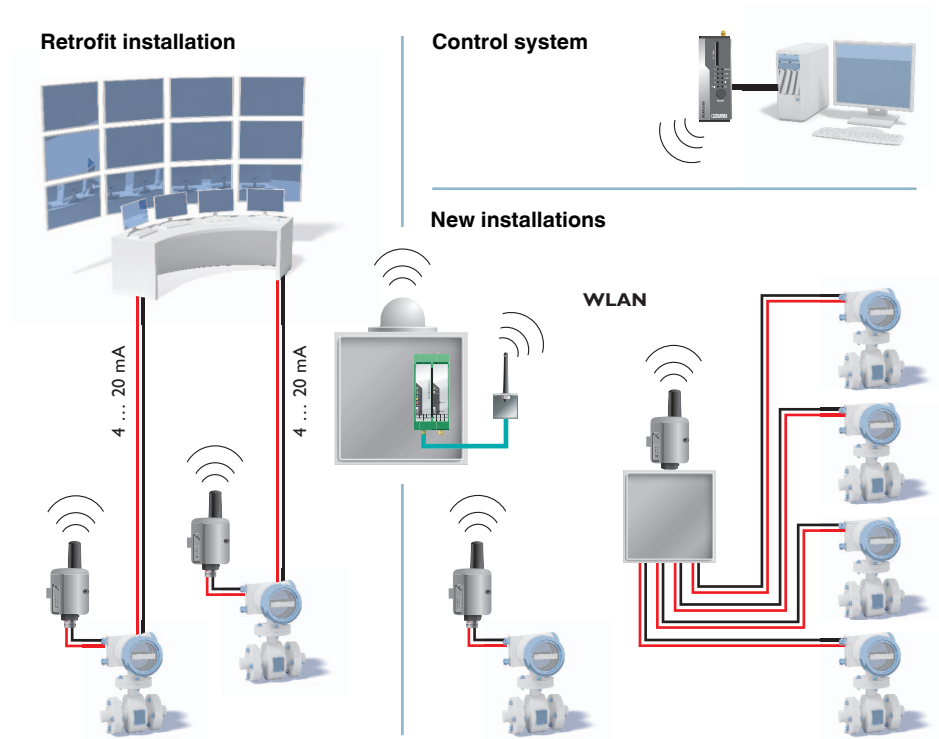


Figure 4-4 WirelessHART topology

### Advantages

- Can be used when connections between field devices and control unit are not HART-compatible
- Better mobility and flexibility during system changes and extension
- Increased data throughput by means of simultaneous usage of multiple communication paths
- Compensation for transmission errors by means of automatic redirection of wireless signals around sources of interference



## 4.2 FOUNDATION Fieldbus

The Fieldbus Foundation, established in 1994 in the U.S., is a consortium consisting of several companies that develop and produce fieldbus systems and fieldbus components. It aims at establishing common standards.

FOUNDATION Fieldbus can be implemented in two different ways so as to meet the various requirements of process automation.

FOUNDATION Fieldbus H1 uses the MBP (Manchester Coded Bus Powered) transmission technology with a transmission speed of 31.25 kbps. Data transmission and the supply of the connected devices are usually realized by means of a twisted two-wire cable. The wiring effort resulting from connecting field devices can thus be reduced significantly.

Thanks to an option for limiting energy to the field, FOUNDATION Fieldbus is also suitable for use in potentially explosive areas (ATEX zones 0 and 1).

Additionally, the HSE (High Speed Ethernet) standard was established. It allows for a maximum transmission speed of 100 Mbps on the basis of Ethernet technology. HSE serves as a higher communication level to control systems such as DCS systems (Distributed Control Systems).

### Characteristics

- Prevalent in America and Asia
- Application focus: process automation
- Support of system management (asset management) and predictive maintenance
- Topology: line or tree
- Individual “intelligent” field devices can perform automation tasks. These devices no longer act as simple sensors or actuators, but offer additional functions (decentralized processing)
- Standardized in CPF1 according to **IEC 61784**

### Topology

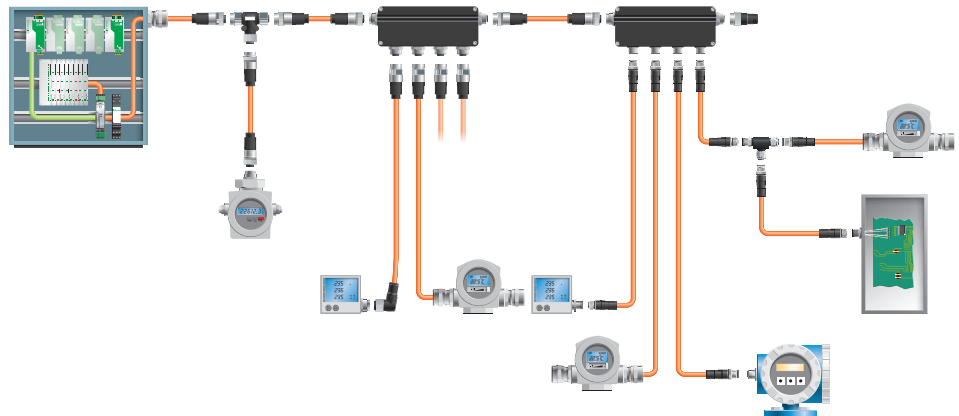


Figure 4-5 FOUNDATION Fieldbus topology

### Variants

#### H1 (up to 31.25 kbps)

- Centralized communication control by means of clocked and unclocked data transmission, thanks to the Link Active Scheduler (LSA)
- Data exchange and active energy supply via twisted 2-wire cables
- Maximum total length of a bus segment: 1900 m (up to 9500 m max. with four repeaters)
- Suitable for the potentially explosive areas Ex zones 0 and 1
- Maximum number of field devices in a safe area: 32
- Bus termination on both sides by means of termination resistors (terminators)

#### HSE (up to 100 Mbps)

- Use of high-speed Ethernet
- Data exchange via twisted 2-wire cables and/or fiber optics

### Advantages

- Tailored installation thanks to the modular structure
- High level of safety: approved for potentially explosive areas up to zone 0



## 4.3 PROFIBUS

PROFIBUS (**Process Field Bus**) is the result of an initiative started by several companies and institutes in 1987 in Germany, which aims at the development of standardized technical concepts for production and process automation.

PROFIBUS is a multi-master-capable bus system that transfers a so-called token during authorization for establishing communication between the masters. Connected devices can be divided into master and slave devices. Masters are usually automation or engineering systems. Automation systems, such as PLCs, are called class 1 masters. An example for an engineering system is a PC that is connected to the bus for startup. Such systems are called class 2 masters.

Slaves are field devices able to communicate only if they are requested to do so by the master.

PROFIBUS offers different options for data exchange:

cyclical data exchange for process data, and acyclical data exchange for parameterization data

### Characteristics

- Mostly used in Europe, initially
- Can be used both in production automation and in process automation
- Bit-serial data transmission
- Topology: line or tree
- Multi-master-capable communication
- Controlled access to the bus by combination of master/slave and token passing methods
- Standardized in CPF3 according to **IEC 61784**

## Topology

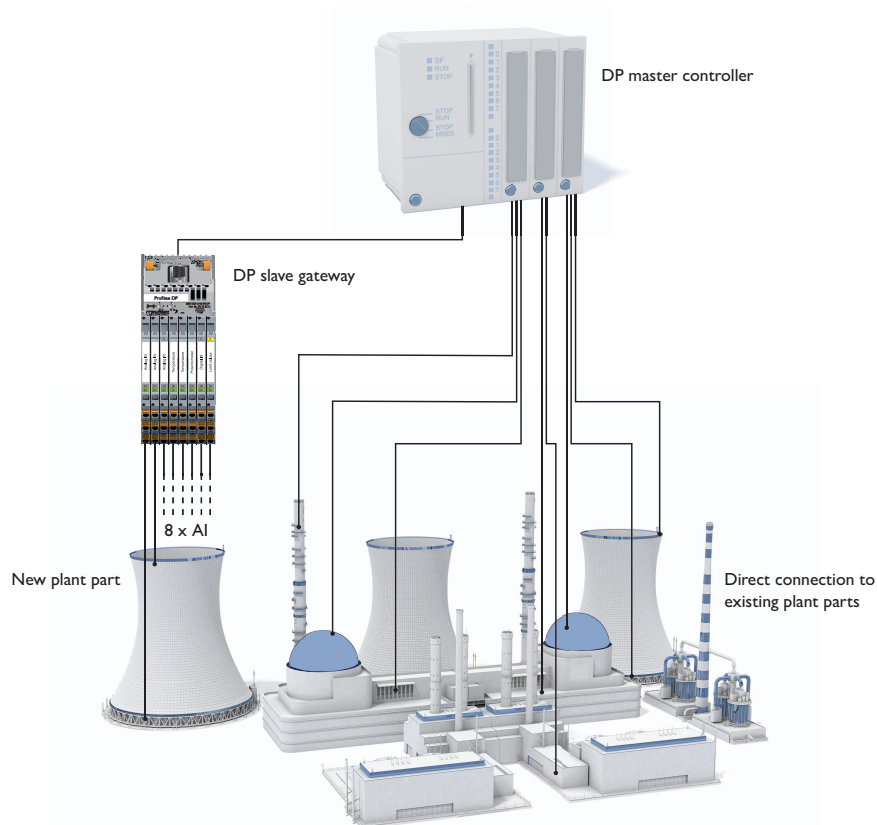


Figure 4-6 PROFIBUS topology

## Variants

**DP** (distributed periphery)

- Distributed management of I/O devices (sensors, actuators) used in production; multi-master-capable
- Standardized diagnostic functions
- Interconnection of several controllers (similar to the FSM variant)
- Data exchange via twisted 2-wire cables and/or fiber optics
- Data transmission rate up to 12 Mbps

**PA** (process automation)

- Communication in process control and process engineering
- Data exchange and energy supply via twisted 2-wire cables
- Relatively slow data transmission rate of up to 31.25 kbps
- Digital alternative to classical, analog communication (4 ... 20 mA equipment)
- Suitable for the potentially explosive areas Ex zones 0 and 1

**FMS** (Fieldbus Message Specification)

- Designed for use in complex machines and systems
- Replaced by the DP variant according to the standardization

## Analog signal transmission in the field of MCR technology

### Advantages

- Worldwide leading fieldbus system – thanks to 25 years of proven technology and widespread use in all sectors of industrial automation
- Internationally standardized according to **IEC 61158**
- Future-proof – ongoing technological development by the PROFIBUS User Organization

## 4.4 Ethernet-based systems

For some years now, the portion of Ethernet-based fieldbus systems (Industrial Ethernet) has been becoming more and more important in the field of automation technology. Especially on the management level, but also on control level, Industrial Ethernet is almost state of the art today. This is partly due to its advantages well known from applications in the office environment.

The best-known Industrial Ethernet communication systems are:

- PROFINET, especially in Europe;
- Modbus/TCP and EtherNet/IP™ in North America.

### Characteristics

- Described in the IEEE 802 standards
- Line, ring, or star topology
- Transmission speeds of 10 and 100 Mbps in industrial networks
- Medium access by means of the CSMA/CD method

### Topology

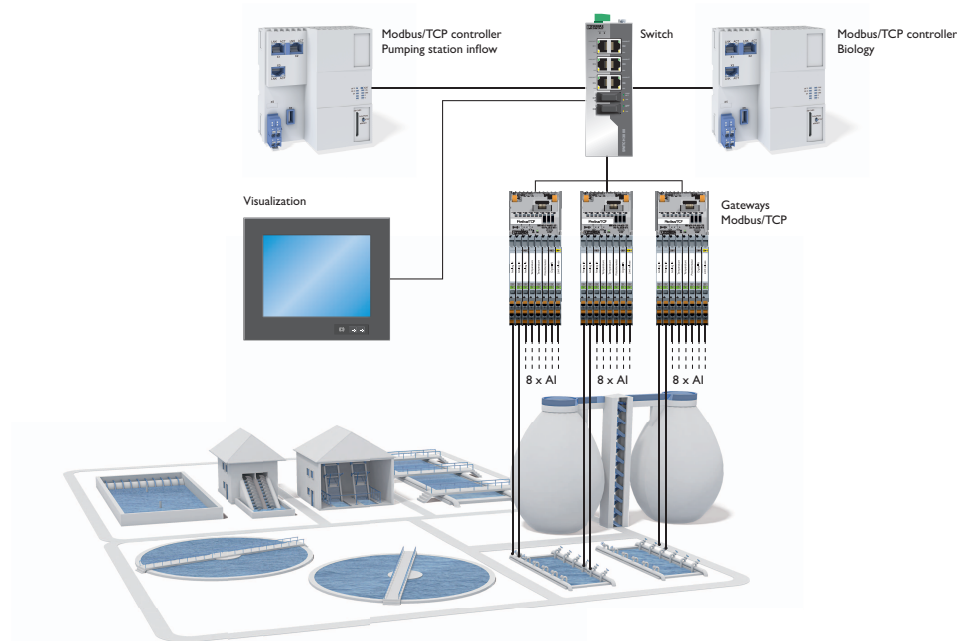


Figure 4-7 Topology of Ethernet-based systems

**Variants****PROFINET IO**

- **Process Field Network**
- Based on the PROFIBUS DP function model
- Standardized diagnostic functions
- Designed for fast transmission of I/O data
- Interconnection of multiple controllers

**Modbus/TCP**

- Developed by Schneider Electric and IDA
- Usage of the TCP/IP transmission technology, while retaining the established Modbus services
- TCP/IP-based client/server communication

**EtherNet/IP™**

- Developed by ODVA and Rockwell Automation
- Especially prevalent on the American continent
- Uses “Common Industrial Protocol” (CIP), the application protocol well known from DeviceNet™ and ControlNet™

**Advantages**

- Options for transferring large quantities of data
- Usage of switches enables setup of large networks
- Almost unlimited number of devices with an equal priority
- Options for the usage of various transmission media (copper, FO, wireless technologies)
- Vertical and horizontal communication in a system via one transmission medium
- Works with almost every network topology



## 5 Basics of functional safety

### 5.1 Functional safety according to the safety integrity level (SIL)

The safety integrity level (SIL) is based on the following standards for the process industry:

Table 5-1 SIL standards for process industry

Name		Target group
<b>IEC/EN 61508</b>	Functional safety of electrical/electronic/programmable electronic safety-related systems	Device and system manufacturers
<b>IEC/EN 61511</b>	Functional safety - Safety instrumented systems for the process industry sector	Planners, installers, and operators of systems

Special standards are available for the functional safety of machines.

The following objectives are aimed at assessing the SIL and designing the devices and systems:

- Assessment regarding the probability of failure and reliability of safety functions
- Traceable measurability and quantification of the probability of failure or risk reduction
- Use of safety-related design principles to minimize the desired low level of malfunctions to an acceptable residual risk
- Finally, the protection of life, health, environment and goods

In the so-called hazard assessment of systems used in order to determine their SIL two factors are taken into consideration:

- Reliability and probability of failure of the system
- Hazard potential of the system

According to the above-mentioned standard, there are four SILs ranging from level 1 (low) to level 4 (high). Systems with a low hazard potential can be operated with a low SIL. Systems with SIL 1 and 2 can be assessed by manufacturers at their own responsibility. Systems with a high hazard potential need a high SIL. Systems with SIL 3 and 4 need to be assessed and certified by independent third parties.

SIL assessment, however, cannot not be restricted to individual modules and safety equipment, as the standard requirements refer to safety circuits, or essentially the interconnection of equipment such as sensors, actuators, control elements, etc.

If subsystems are assigned to different SILs, the overall system will have the lowest SIL of the subsystems. In order to increase the SIL of a subsystem, it is possible, for example, to use components that are set up in order to ensure redundancy. In process industry, measuring circuits are most often assigned to SIL 2 or occasionally to SIL 3 which usually occurs when the subsystems are set up to be redundant.

### 5.1.1 SIL inspection

The following process sequence is subject to SIL standards, whereby the “four eyes principle” (double checking) is required with regard to all steps of assessment, planning and verification.

1. Risk analysis: Determining the required risk reduction (specification of SIL requirement)
2. Implementing the risk reduction (implementation and SIL assessment of safety equipment)

#### 1. Risk analysis

- a. Identifying all risks (using a risk identification method)
- b. Determining the reduction requirement for each risk
- c. Quantifying the required risk reduction for each risk (using a risk assessment method from which the SIL requirement may be derived as a result)

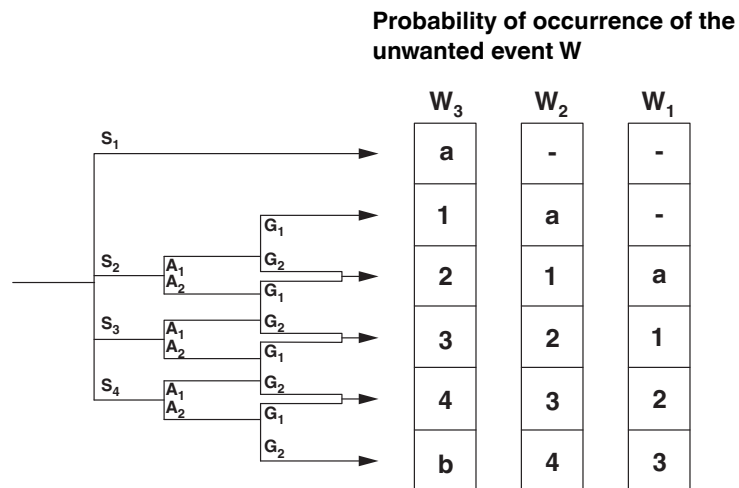
Risk identification and risk assessment are often carried out using software. Commonly used methods:

#### Risk identification methods

- Hazard and operability study (HAZOP)
- Event tree analysis (ETA)
- Fault tree analysis (FTA)

#### Risk assessment and quantification methods

- Risk graph (see Figure 5-1)
- Layer of protection analysis (LOPA)
- Risk matrix (see Figure 5-2)



- 1, 2, 3, 4 Safety integrity level (SIL)
- Tolerable risk, no safety requirements
- a No special safety requirements
- b A single E/E/PE system will not suffice

Figure 5-1 Example of a risk graph

**Risk parameters**

<b>Severity of impact (injury and damage)</b>	<p><b>S<sub>1</sub></b> Slight injury or damage</p> <p><b>S<sub>2</sub></b> Serious, irreversible injury or death of a person, temporary serious damage</p> <p><b>S<sub>3</sub></b> Death of several people, long-term damage</p> <p><b>S<sub>4</sub></b> Many deaths, catastrophic consequences</p>
<b>Frequency/duration of stay</b>	<p><b>A<sub>1</sub></b> Seldom to frequent stay in the danger zone</p> <p><b>A<sub>2</sub></b> Frequent to permanent stay in the danger zone</p>
<b>Avoidance of danger</b>	<p><b>G<sub>1</sub></b> Possible</p> <p><b>G<sub>2</sub></b> Not possible, scarcely possible</p>
<b>Probability of occurrence of the unwanted event</b>	<p><b>W<sub>1</sub></b> Very low, scarcely</p> <p><b>W<sub>2</sub></b> Low</p> <p><b>W<sub>3</sub></b> High, frequent</p>

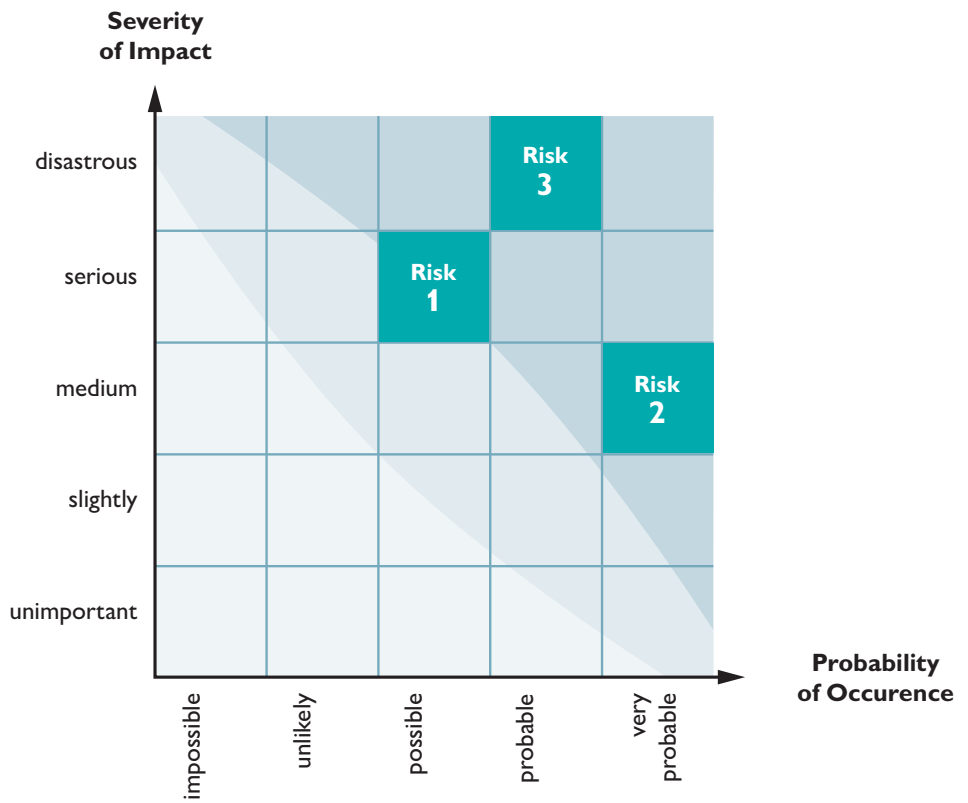


Figure 5-2 Example for a risk matrix

### 2. Risk reduction

The operational control equipment of a system enables normal operation and, in general, already includes safety functions. However, these functions can rarely cover all avoidable risks up to the acceptable residual risk. For this reason, additional operational control and safety equipment is used that is only activated in the event of malfunctions.

The design of operational control and safety equipment may prevent incidents or limit consequences/damages and must be adapted to the risk.

- The tolerable residual risk must be sufficiently low.
- The expense with regard to planning, installation and operation must be reasonable.

The objective is thus to achieve that the operational control and safety equipment fulfills the required risk reduction (SIL requirement) as precisely as possible:

- Instructions for the design of the safety equipment can be found in the **IEC/EN 61508** and **IEC/EN 61511** standards (see above) and the **VDI/VDE 2180** directive “Safe-guarding of industrial process plants by means of process control engineering (PCE)”.
- It is necessary to examine whether a possible safety equipment failure would be due to random or systematic reasons, how likely it is that it will occur and if it can be avoided or not.
- The practical implementation of the safety equipment should cover the following three aspects:
  - a) **Fault avoidance** using an FSM (Functional Safety Management) system
  - b) **Fault control** by means of redundancy, diagnostic coverage, safe states in the event of a fault
  - c) Quantification of **probability of failure** due to random errors (PFD/PFH calculation, see below)

### 5.1.2 SIL-relevant parameters

The SIL-relevant safety parameters are provided by the device manufacturers in the device documentation in order to help the planners and users with the SIL classification of measuring chains in which the devices will be used.

The abbreviations used in the following two examples are explained from page 64 onwards.

Example taken from a data sheet

#### Safety integrity requirements

##### Error rates

- Type B device (according to EN 61508-2)
- Safety integrity level (SIL) 2
- HFT = 0
- 1oo1 architecture

$\lambda_{sd}$	$\lambda_{su}$	$\lambda_{dd}$	$\lambda_{du}$	SFF	DC <sub>D</sub>	HFT
4.61 * 10 <sup>-7</sup>	1.50 * 10 <sup>-7</sup>	3.18 * 10 <sup>-8</sup>	3.23 * 10 <sup>-7</sup>	91.3%	90.2%	0

The total failure rate is: 9.62 \* 10<sup>-7</sup>

MTTF (Mean Time To Failure) is: 119 years

The probability of a dangerous failure per hour for “continuous demand” mode and the average probability of failure of the specified function for “low demand” mode are determined based on the error rates:

##### PFD<sub>avg</sub> values

T[PROOF] =	1 year	2 years	3 years	5 years	7 years	8 years
PFD <sub>avg</sub> =	1.3 * 10 <sup>-4</sup>	2.6 * 10 <sup>-4</sup>	3.91 * 10 <sup>-4</sup>	6.51 * 10 <sup>-4</sup>	9.11 * 10 <sup>-4</sup>	1.04 * 10 <sup>-3</sup>

PFH\* = 3.23 \* 10<sup>-8</sup>/h

The calculation is performed assuming a checking interval of one year and a repair time of eight hours.

On the basis of the value determined for the average probability of failure PFD<sub>avg</sub>, the checking interval can be increased to up to seven years.

Example of an FMEDA table

Table 5-2 FMEDA<sup>1</sup> table taken from a TÜV<sup>2</sup> approval for a device

SFF	Type A subsystems			Type B subsystem		
	Hardware fault tolerance (HFT)			Hardware fault tolerance (HFT)		
Safe failure fraction	0	1	2	0	1	2
< 60%	SIL 1	SIL 2	SIL 3	Not permitted	SIL 1	SIL 3
60% - < 90%	SIL 2	SIL 3	SIL 4	SIL 1	SIL 2	SIL 4
90% - < 99%	SIL 3	SIL 4	SIL 4	SIL 2	SIL 3	SIL 4
≥ 99%	SIL 3	SIL 4	SIL 4	SIL 3	SIL 4	SIL 4
Safety integrity level (SIL)	<b>Operating mode with low requirement level</b> (average probability of failure on demand of a safety function = PFD)					
4	≥ 10 <sup>-5</sup> to 10 <sup>-4</sup>					
3	≥ 10 <sup>-4</sup> to 10 <sup>-3</sup>					
2	≥ 10 <sup>-3</sup> to 10 <sup>-2</sup>					
1	≥ 10 <sup>-2</sup> to 10 <sup>-1</sup>					

<sup>1</sup> FMEDA = Failure Mode Effect and Diagnostic Analysis

<sup>2</sup> TÜV = German abbreviation for Technischer Überwachungsverein, English: technical inspection association

**Explanation of the abbreviations used in the examples (data sheet, FMEDA table)**

**PFD<sub>avg</sub>**

**Average probability of failure on demand**

- Average probability of dangerous failure on demand of a safety function
- Determined for operating modes with a “low demand rate”. Protection systems of process technology systems for the chemical industry usually operate with a low demand rate.
  - a) The safety function is only used in case of danger, in order to transfer the system to be monitored into the defined safe state.
  - b) The safety function is demanded less than once a year.

**PFH**

**Probability of a dangerous failure per hour**

- Probability of failure per hour for the safety function
- Determined for operating modes with a “high demand rate” or essentially if it is required to permanently keep the system to be monitored in its normal safe state (e.g., for speed monitoring on machines)

**SFF**

**Safe failure fraction**

- Safe failure fraction:  
Proportion of failures without the potential to set the safety-related system to a dangerous or impermissible function state
- For example, a value of 91.3% implies that, on average, 91.3 of 100 failures are not critical for the safety function.

**HFT**

**Hardware fault tolerance**

- Hardware fault tolerance:  
Ability of a function unit to continue with the execution of a demanded function despite existing faults or deviations.
- The value 0 indicates that there is “no hardware redundancy”. A fault (hardware failure) will result in the loss of the safety function. Value 1 (simple redundancy) means that at least two faults are required to cause a loss of the safety function.

**Type A/B**

**Type A devices**

- Simple devices for which the failure behavior of the components can be completely described (e.g., repeater power supply 4 mA ... 20 mA)

**Type B devices**

- Complex devices for which the failure behavior is not fully known (e.g., microprocessor software and device firmware)

$\lambda_d, \lambda_{dd}, \lambda_{du}, \lambda_s$

$\lambda_d$	Rate of dangerous failures	Proportion of dangerous failures per hour
$\lambda_{dd}$	Rate of dangerous detected failures	Proportion of detected dangerous failures per hour
$\lambda_{du}$	Rate of dangerous undetected failures	Proportion of undetected dangerous failures per hour
$\lambda_s$	Rate of safe failures	Proportion of safe failures per hour

**5.2 Safety in potentially explosive areas**



Explosion protection is a subfield of safety technology and plays a particularly important role with regard to design and operation of technical systems in the following sectors:

- Chemical industry
- Mining industry, oil and natural gas production
- Wood-processing and textile industry
- Food industry
- Coating technology

Explosion protection must also be taken into account in fields which, at first glance, seem not to be affected (e.g., for chocolate production):

- Cocoa powder in connection with atmospheric oxygen may constitute the danger of a dust explosion.
- High-proof alcoholic solutions that are used to clean mixing vessels and pipes can form explosive gas mixtures.

Explosion protection needs to be technically implemented wherever flammable substances in the form of gas, vapor, mist or dust can react with oxygen if source of ignition is present. Depending on the propagation velocity of this chemical reaction, the following rough classification is made which goes beyond the combustion process:

- Deflagration [cm/s]
- Explosion [m/s]
- Detonation [km/s]

**Sources of ignition**

The following table provides an overview of ignition sources.

Table 5-3 Sources of ignition

Source of ignition	Examples of causes
Sparks	Mechanically created sparks (e.g., caused by friction, impact or abrasion processes), electric sparks
Arcs	Short circuit, switching operations
Hot surfaces	Heater, metal-cutting production, heating up during operation
Flames and hot gases	Combustion reactions, flying sparks during welding
Electrical systems	Opening/closing of contacts, loose contact A PELV (U < 50 V) is not an explosion protection measure. Low voltages can still generate sufficient energy to ignite a potentially explosive atmosphere.
Static electricity	Discharge of charged, separately arranged conductive parts, as with many plastics, for example
Electrical compensating currents, cathodic corrosion protection	Reverse currents from generators, short circuit to exposed conductive part/ground fault in case of errors, induction
Electromagnetic waves in the range of $3 \times 10^{11} \dots 3 \times 10^{15}$ Hz	Laser beam for distance measurement, especially for focusing
High frequency $10^4 \dots 3 \times 10^{12}$ Hz	Wireless signals, industrial high-frequency generators for heating, drying or cutting, etc.
Lightning strike	Atmospheric weather disturbances
Ionizing radiation	X-ray apparatus, radioactive material, absorption of energy leads to heating up
Ultrasound	Absorption of energy in solid/liquid materials leads to heating up
Adiabatic compression and shock waves	Sudden opening of valves
Exothermal reactions	Chemical reaction leads to heating up

**Gas concentration**

The concentration of gases in the gas/air mixture determines whether or not an explosion can take place. The mixture can only be ignited if the concentration of the material is between the lower explosive level (LEL) and the upper explosive limit (UEL). \*

**Examples of gases under normal pressure**

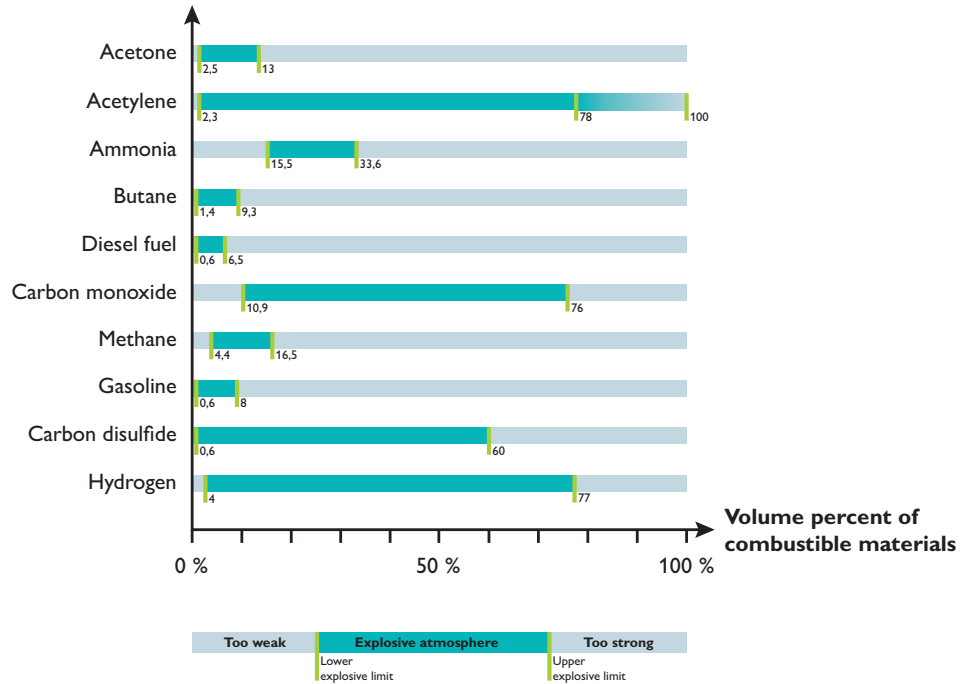


Figure 5-3 Examples for flammable gas concentrations in the air with normal pressure

The table is based on normal pressure and room temperature. The explosive range of a material expands as the pressure and temperature rise.

**Dust concentration**

Similar specifications as those defined for gases can also be made for dust even though the explosive limits do not have the same meaning here. Clouds of dust are generally heterogeneous and the concentration within the same cloud fluctuates strongly. A lower flammability limit (of approx. 20 g/m<sup>3</sup> ... 60 g/m<sup>3</sup>) and an upper flammability limit (of approx. 2 kg/m<sup>3</sup> ... 6 kg/m<sup>3</sup>) can be determined for dust.

\*Some chemically non-resistant materials (e.g., acetylene, ethylene oxide) can also undergo exothermal reactions without oxygen through self-decomposition. The upper explosive limit (UEL) then changes to 100 percent by volume.

**Procedures**

Explosion protection procedures are classified as follows:

1. Primary explosion protection: **Avoidance of explosive atmospheres**  
Replacement, dilution, passivation of explosive substances, e.g., by adding nitrogen or carbon dioxide
2. Secondary explosion protection: **Avoidance of effective ignition sources**  
Avoidance of all ignition sources, reducing the expansion of the potentially explosive area
3. Tertiary explosion protection: **Constructive explosion protection**  
Explosion suppression by means of extinguishing devices, pressure-resistant and pressure shock-resistant design of devices and buildings, automated sealing and pressure relief systems

The integrated explosion protection considers all classes of procedures in their sequence indicated above with regard to priority and order.

**5.2.1 Directives, standards, and regulations**

**ATEX directives**

In Europe, explosion protection is specified by ATEX directives:

- ATEX Product Directive 2014/34/EU (also known as ATEX 114) applies to manufacturers of devices and equipment carrying a risk of ignition.
- ATEX Operational Directive 1999/92/EC (also known as ATEX 118a or ATEX 137) applies to system operators.

**Equipment group, equipment category**

In the ATEX directives, equipment is divided into groups and categories. Details are shown in the following table:

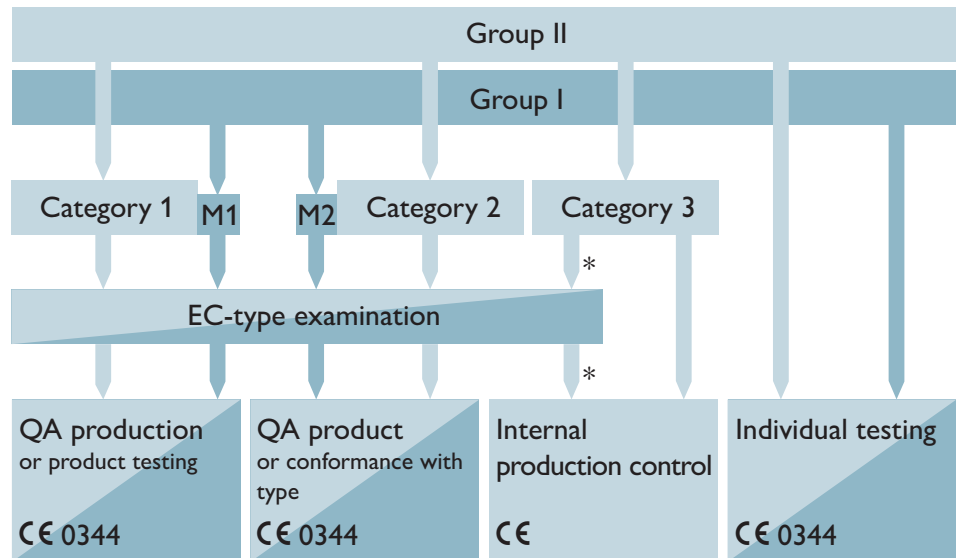
- Equipment group I (mines) with categories M1 and M2
- Equipment group II (other equipment) with categories 1, 2, 3

Table 5-4 Equipment groups and categories according to ATEX directives

Equipment group	Category	Degree of protection	Protection guarantee	Operating conditions
I	M1	Very high degree of safety	Two independent protective measures Safe if two errors occur independently of one another	For reasons of safety, it must be possible to continue operating a device even if the atmosphere is potentially explosive
I	M2	High degree of safety	In normal operation, protective measures remain effective even under difficult conditions	It must be possible to switch off these devices if a potentially explosive atmosphere occurs
II	1	Very high	Two independent protective measures Safe if two errors occur independently of one another	Devices can still be used in Zones 0, 1, 2 (G), and 20, 21, 22 (D) and continue to be operated
II	2	High	Safe in normal operation and if common errors occur	Devices can still be used in Zones 1, 2 (G), and 21, 22 (D) and continue to be operated
II	3	Normal	Safe in normal operation	Devices can still be used in Zones 2 (G) and 22 (D) and continue to be operated

**Conformity assessment**

Depending on the assignment of a device to the equipment group and category and if used for its intended purpose, the method of conformity assessment is determined according to Figure 5-4:



\* Possible as an option, similar procedure

Figure 5-4 Determining the conformity assessment method

The ATEX directives specify the basic requirements for health and safety that are to be implemented in the so-called harmonized standards or in manufacturer's and operator's own standards and guidelines.

- The equipment conformity with the standards and guidelines needs to be examined and certified by a "notified body" ("CE 0344" indicated as an example in Figure 5-4 refers to the DNV KEMA testing and certification body situated in the Netherlands with subsidiaries in more than 30 countries) or
- Conformity is attested by the manufacturer himself, as the equipment is not subject to production monitoring (in Figure 5-4, "CE" without four-digit testing and certification body indication)

With regard to the different norms and standards for different applications, the following fields of application can be differentiated: In general, there are correlations between the European (EN), international (IEC), US (NEC, FM, UL) and Canadian (CSA) regulations:

- Electrical equipment in areas with a danger of gas explosions
- Electrical equipment in areas with a danger of dust explosions
- Non-electrical equipment in potentially explosive areas
- Operation of process technology systems

### 5.2.2 Zone classification

The areas in which an explosive atmosphere may arise are divided into zones. The probability that a danger will arise serves as the main classification criterion. If there are doubts about how the zones are to be divided, the protection measures must be based on the highest possible probability of occurrence of a hazardous, potentially explosive atmosphere.

Table 5-5 Requirements for electrical equipment in Ex zones

Zone	Approval of electrical equipment
0	Explicit approval for zone 0 and examination certificate of a recognized testing body
1	Examination certificate of a recognized testing body
2	Requirements according to VDE 0165/9.83, Clause 6.3

The zone classification in prevailing European standards is based on the following dependencies:

- Separation between hazardous areas with a danger of gas or dust explosions
- According to type of danger
- According to equipment category (see Table 5-4)

Table 5-6 Zones for areas with a danger of gas explosions according to EN 60079-10-1

Zones	Type of danger
Zone 0	Continuous, long periods, frequent
Zone 1	Occasional
Zone 2	Not usually present, short periods only

Table 5-7 Zones for areas with a danger of dust explosions according to EN 60079-10-2

Classification in Germany prior to ATEX	Classification according to ATEX	Type of danger
Zone 10	Zone 20	Continuous, long periods, frequent
	Zone 21	Occasional
Zone 11	Zone 22	Not usually present, short periods only

Table 5-8 Assignment of zones and equipment categories according to 1999/92/EC Operator Directive

Zone	Equipment category
0, 20	1
1, 21	1, 2
2, 22	1, 2, 3

### 5.2.3 Protection types

The types of protection define design principles to be used in the different areas in order to provide protection from explosions. Details are described in EN/IEC standards. The following four tables provide information on protection type standards for electrical equipment.

Furthermore, there are protection type standards available for non-electrical equipment (e.g. gears, pneumatic pumps, conveyor belts).

Table 5-9 Protection types for electrical equipment in gas atmospheres

Protection type		Protection principle	EN/IEC	Zone	Application
Ex ia, ib, ic	Intrinsic safety	Intrinsic safety, intrinsically safe systems, intrinsically safe (FISCO <sup>1</sup> ) and non-sparking (FNICO <sup>2</sup> ) fieldbus systems	60079-11, 60079-25, 60079-27	0, 1, 2	Measurement and control technology, sensors, actuators, instrumentation
Ex d	Flameproof enclosure	Flameproof enclosure	60079-1	1, 2	Switching, command, and signaling devices, controllers, motors, power electronics
Ex e	Increased safety	Increased safety	60079-7	1, 2	Branch and connection boxes, housing, motors, terminal blocks
Ex px, py, pz	Pressurized enclosure	Pressurized enclosure	60079-2	1, 2	Control cabinets, motors, measuring and analysis devices, computers
Ex o	Oil immersion	Oil immersion	60079-6	1, 2	Transformers, relays, startup controls, switching devices
Ex ma, mb, mc	Molded encapsulation	Exclusion of an explosive atmosphere	60079-18	1, 2	Coils of relays and motors, electronics, solenoid valves, connection systems
Ex q	Sand encapsulation	Sand encapsulation	60079-5	1, 2	Transformers, relays, capacitors
Ex nA, nC, nL, nR, nP	Protection type for Zone 2	Different	60079-15	2	Zone 2 only
Ex op is, op pr, op sh	Optical radiation	Limiting or preventing the transmission of energy from optical radiation	60079-28	1, 2	Optoelectronic devices

<sup>1</sup> Fieldbus Intrinsically Safe Concept

<sup>2</sup> Fieldbus Non-Incendive Concept

#### Intrinsic safety Ex i

Main characteristics of the “intrinsic safety” protection type:

- Applies to the entire circuit in which the electrical equipment is operated
- Voltage limitation reduces the ignition spark energy
- Current limitation reduces surface temperatures
- Limitation of energy stored in the circuit (in capacitances and inductances)
- Separation of intrinsically safe circuits from non-intrinsically safe ones by wiring resistors and Zener diodes or via electrical isolation

## Analog signal transmission in the field of MCR technology

With regard to intrinsic safety, the EN/IEC 60079-11 differentiates between three protection levels:

Table 5-10 Protection levels for the “intrinsic safety” protection type

Protection level	Approved for Ex zone	Fault tolerance	
ia	0 <sup>1</sup> , 1, 2	Double fault safety	The occurrence of a fault or any combination of two faults cannot cause ignition in normal operation (e.g., by the wiring of three redundant Zener diodes <sup>2</sup> ).
ib	1, 2	Single fault safety	The occurrence of a fault cannot cause ignition in normal operation (e.g., by the wiring of two redundant Zener diodes <sup>2</sup> ).
ic	2	None	The device cannot cause ignition during normal operation.

<sup>1</sup> In Ex zone 0, the IEC/EN 60079-14 recommends electrical isolation in addition to Ex ia.

<sup>2</sup> Zener diodes used for voltage limitation are semi-conductor components, classed as being susceptible to interference and need to be protected through redundant elements. Film or wire wound resistors for current limitation are classed as components that are not susceptible to interference. In the event of a fault, they change to the high-impedance state and can be operated without redundancy.

### Protection type Ex n

Main characteristics of the “Ex n” protection type:

- Improved industrial quality for normal operation
- Without error analysis (as, for example, with Ex i)
- Can only be used for equipment group II in Zone 2
- Closely follows the US standard NI with deviations regarding Ex nC

Table 5-11 Sub-division of the “n” protection type for electrical equipment in gas atmospheres

Protection type		Comparable to ...	Protection principle
Ex nA	Non-sparking	Ex e	Occurrence of arcs, sparks or hot surfaces is minimized
Ex nC	Sparking equipment	To some extent, Ex d, Ex m	Enclosed switching device, nonflammable components, hermetically sealed, sealed or encapsulated installations
Ex nR	Restricted breathing enclosure	---	Ingress of explosive gases is limited
Ex nL	Energy limited (replaced by Ex ic according to EN/IEC 60079-11)	Ex i	Energy limitation so that neither sparks nor thermal effects cause an ignition
Ex nP	Simplified pressurized enclosure	Ex p	Ingress of explosive gases is prevented by overpressure, monitoring without disconnection

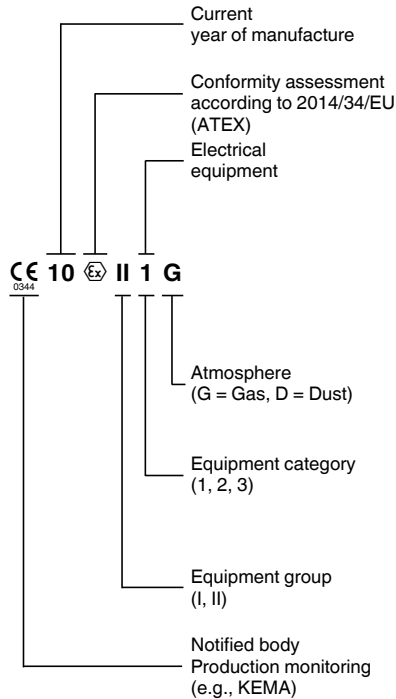
Table 5-12 Protection types for electrical equipment in dust atmospheres

Protection type	Protection principle	EN/IEC	Zone	Application
Ex pD New: P	Pressurized enclosure	61241-4 New: 60079-2	21, 22	Control cabinets, motors, measuring and analysis devices
Ex iD New: ia, ib, ic	Intrinsic safety	61241-11 New: 60079-11	20, 21, 22	Measurement and control technology, sensors, actuators, instrumentation
Ex mD New: ma, mb, mc	Molded enclosure	61241-18 New: 60079-18	20, 21, 22	Coils of relays and motors, electronics, and connection systems
Ex tD New: ta, tb, tc	Protection provided by enclosure	61241-1/ New: 60079-31	21, 22	Switching, command, and signaling devices, lamps, branch and connection boxes, enclosures

## 5.2.4 Labeling of Ex products

### 5.2.4.1 ATEX directive and EN 60079-0

Labeling according to ATEX directive



Labeling according to EN 60079-0:2009

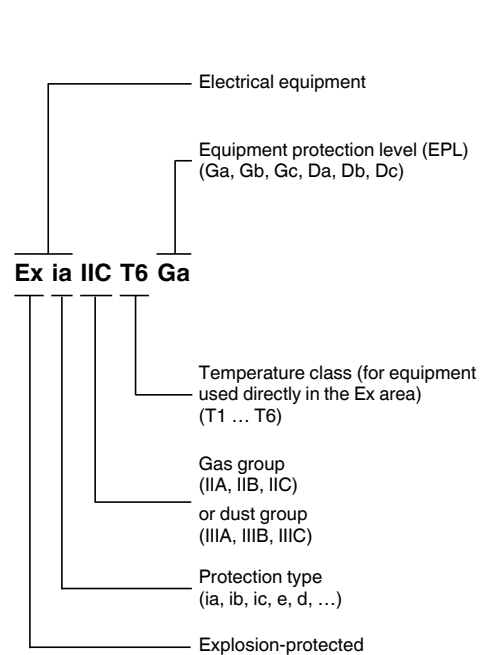


Figure 5-5 Labeling of Ex products

## Analog signal transmission in the field of MCR technology

**ATEX category, EN-60079 protection level** The following table shows the assignment of the equipment category according to ATEX and the equipment protection level according to EN 60079-0:2009:

Table 5-13 Assignment of equipment category according to ATEX and equipment protection level according to EN 60079-0:2009

	Equipment category according to ATEX Directive 2014/34/EU	Equipment protection level (EPL)	Zone	Type of danger
<b>Gas</b>	1G	Ga		Continuous, long periods, frequent
	2G	Gb	1	Occasional
	3G	Gc	2	Not usually present, short periods only
<b>Dust</b>	1D	Da	20	Continuous, long periods, frequent
	2D	Db	21	Occasional
	3D	Dc	22	Not usually present, short periods only
<b>Mining</b>	M1	Ma		Continuous, long periods, frequent
	M2	Mb		Occasional

### 5.2.4.2 EC-type examination

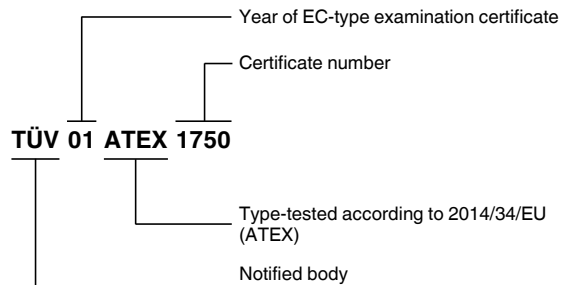


Figure 5-6 Information provided in an EC-type examination certificate



For further information about explosion protection please refer to the brochure „Explosion protection – Theory and practice“ (MNR 5149416).

## 6 The basics of surge protection

**i** Webcode: #0144

### 6.1 Basic knowledge

#### Risk assessment

Systems and buildings are evaluated by a risk assessment in accordance with IEC/EN 62305. The aim is to avoid and/or minimize possible personal injury and damage to property as well as operational downtimes. At the end of the assessment and following the implementation of measures there should only be a small, known residual risk that is covered or insured. Lightning and surge protection also represents an important part of the assessment. Valuable evaluation points can be scored here in the risk calculation with comparatively little expenditure. Furthermore, lightning and surge protection is no longer deemed optional by many insurance companies, it is actually mandatory. In accordance with the generally recognized technical regulations and corresponding standards, industrial plants must be equipped with technical systems with lightning and surge protection. This is the only way to ensure a high level of system safety and availability.

#### Lightning protection zone concept

Part 4 of IEC/EN 62305 shows the principles according to which this type of basic concept for lightning and surge protection can be implemented. To this end, the entire system should be divided into lightning protection zones (LPZs). The area outside of the building envelope is referred to as Zone 0. This zone is then further subdivided into Zone 0A and Zone 0B. In Zone 0A, the threat is due to direct lightning strikes and the resulting full electromagnetic field. However in Zone 0B, due to external lightning protection, the probability of a direct strike, except to the lightning rods, is very low. Nevertheless, in the event of a lightning strike a full electromagnetic field is created.

The area inside the building envelope is subdivided into “nested” zones. In the different zones, varying threat values can be expected with regard to conducted transient surge voltages and electromagnetic fields. Due to the cascaded design of the protection zones, the level of threat gradually decreases. The disturbance variables that occur on the electrical equipment within the individual lightning protection zones are still so small that no damage is caused as a result. Accordingly, the best protection is provided in the innermost zone.

**LPZ:**  
Lightning protection zone

**SPD:**  
Surge protective device

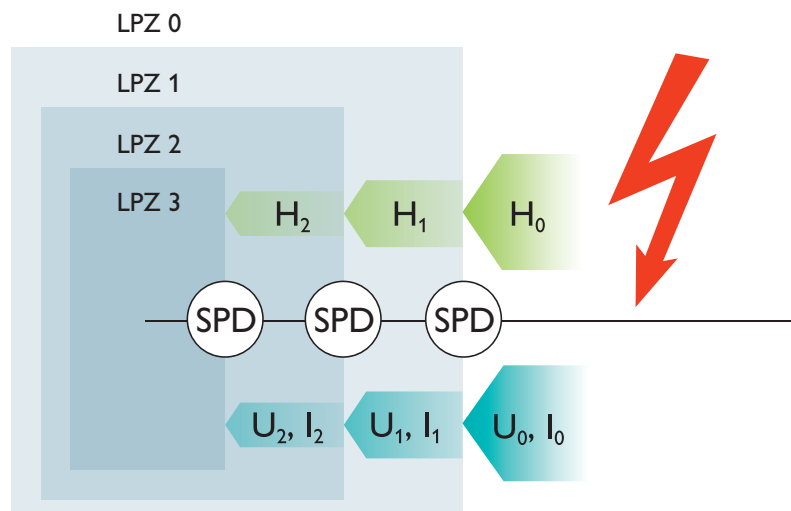


Figure 6-1 EMC-compliant lightning protection zone concept

With regard to the electromagnetic fields, the nested arrangement of the various forms of room shielding results in progressive attenuation. In industrial buildings, the steel constructions, reinforcing elements in concrete floors and walls, and other metal components such as facade cladding can be used for room shielding if they can be connected together electroconductively. In new buildings, clever planning and effective coordination between trades can mean that good room shielding can be provided by structural elements that are already planned, with relatively little additional expenditure. In existing buildings, the attenuation behavior of the LPZ can be improved by retrofitting ring feeders and reinforcing elements. For example, LPZ 3 can be implemented quite easily if the electrical modules are installed in metal control cabinets. Here the control cabinet itself represents the envelope around the zone. Electrical equipotential bonding and grounding using the best available technology should always be taken into consideration.

The internal lightning and surge protection is also incorporated in several stages with the aim of limiting transient surge voltages on electrical cables. Ideally, a surge protective device (SPD) is installed at every zone transition.

 **Webcode: #0143**

## 6.2 Surge protection for power supply systems

To protect power supply systems, a type 1 lightning arrester is designed for the transition from Zone 0 to Zone 1. In accordance with the standard, this arrester should be placed directly at the entry point. This is the best way to avoid couplings in parallel routed cables inside the building.

In practice, type 1 arresters are often used for main current distribution.

Type 2 arresters are designed for the transition from Zone 1 to 2. In practice, they are used in intermediate distributors.

Type 3 arresters offer a particularly good voltage protection level with very low residual voltage values. They are installed upstream of particularly sensitive electronic devices. The distance between the protective device and the device to be protected should therefore be as short as possible.

The technical properties of the arresters differ greatly. They can be combined so as to provide optimum protection in the overall system.

Type 1 arresters can discharge very high discharge currents of up to 100 kA to ground. This high discharge capacity ensures that even very high lightning currents of 200 kA do not cause damage when they encounter the external lightning protection system. A portion of the power pulse current reaches the inside of the building via the galvanic connection to the building's equipotential bonding. With respect to the rating of the discharge capacity of lightning arresters, it is assumed that the lightning current is split 50:50.

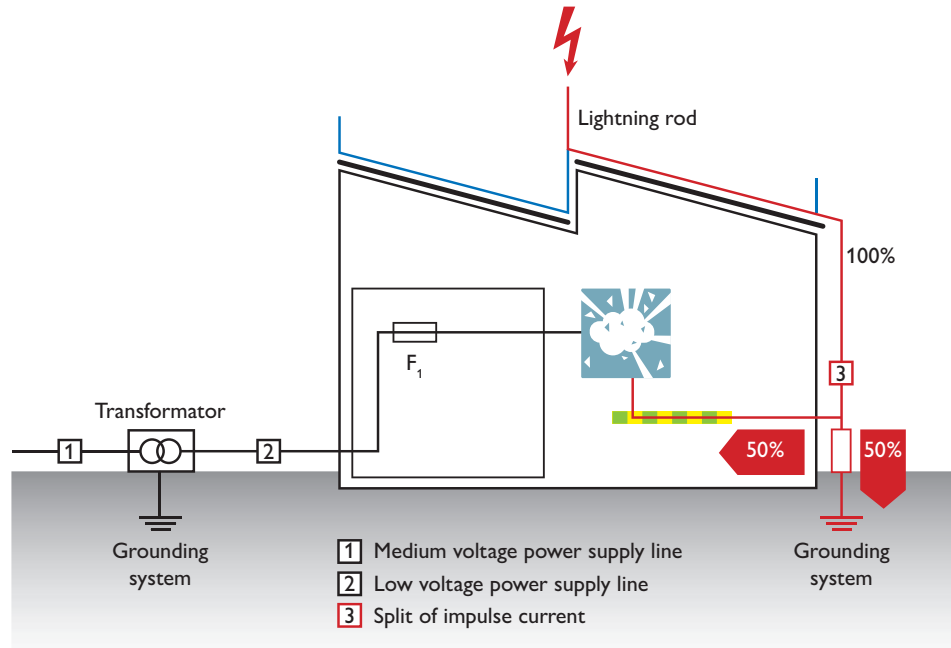


Figure 6-2 Effects of lightning current distribution

The effect of the surge voltage then also continues to other buildings or system parts via cables in the building or via the equipotential bonding network. Here too the power pulse current is split at every branch and is ultimately led to ground via various points.

Due to the remaining residual voltage via the type 1 lightning arrester, two additional protection stages should be installed in the inner LPZs. Type 2 and type 3 arresters are required here.

The type of network present should be taken into consideration when selecting surge protective devices. Specific cable lengths, typically 10 m between the individual protection stages, ensure that the coordinated response behavior of the individual arrester types works in the overall system. In the case of modern products in a system from the same manufacturer, the products can also be coordinated without a minimum cable length since the technology is already optimally coordinated and features high-quality trigger electronics.

The newest generation of products operate with virtually no line follow current. When the SPD discharges a transient pulse, there is a very low-impedance state between the energy-carrying conductors and ground. In this case, modern SPDs limit the current from the power supply network, which then also flows via the arrester, to a minimum. The SPD and the entire system are spared, which in turn has a bearing on the durability of the installation and uninterrupted operation, even in the event of frequent surge voltages.

### 6.3 Indirect couplings

There are other forms of coupling in addition to the direct galvanic coupling of a surge voltage.

In the event of a lightning strike, an electromagnetic field is created around the lightning channel due to the lightning surge current. This induces a high voltage in cables installed in the affected area. The induced surge voltages reach all connected end devices via the cables. Similar effects occur when power cables conduct the lightning surge current into the building and transmit the current to parallel routed signal lines.

Capacitive coupling primarily occurs via the electric field between two points with a large potential difference. A high potential occurs via the down conductor of a lightning arrester due to a lightning strike. An electric field is created between the down conductor and the cables for power supply and signal transmission. The charge is transferred through the electric field, causing surge voltages in the affected cables.

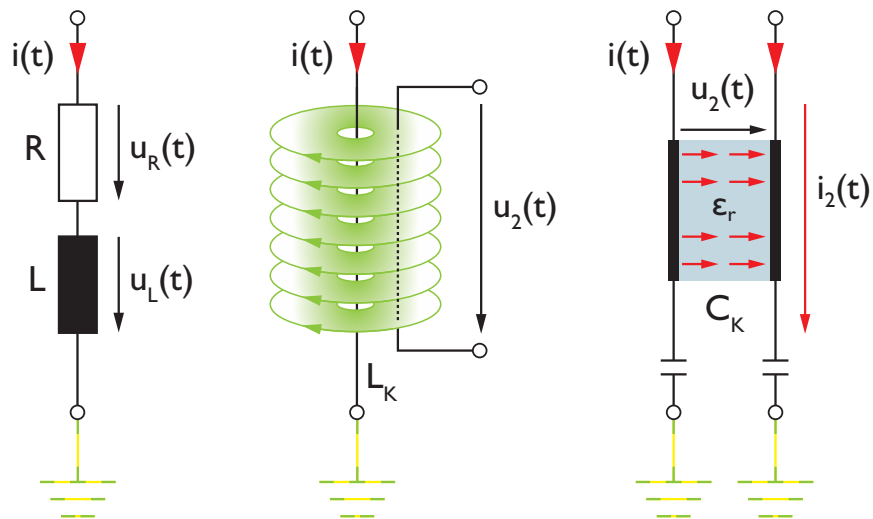


Figure 6-3 Possible forms of coupling surge voltages, from the left: galvanic or direct, inductive, and capacitive coupling

Transient surge voltages also occur as a result of switching operations at large loads or in low-voltage and medium-voltage networks. It is not always possible in practice to find the ideal isolation distances and shielded cables to limit interference. However, suitable protective devices are available for all situations and these can be used to create an effective surge protection solution.

## 6.4 Surge protection for MCR equipment as well as data technology

Modern protective devices for signal interfaces feature a combination of fast-responding and highly resilient components so as to combine both features in one product. It is extremely difficult to disconnect cables for MCR circuits and data technology at the lightning protection zone transitions. This is why in practice a protection stage is often not installed at every transition as per the standard. The protective devices are installed as close as possible to the device that is to be protected. Shielded cables are used in order to reduce the risk of crosstalk and couplings. It should be noted that it is often not just the device that is located centrally that is worth protecting, but also the field device. In such cases, protective devices should be included at both ends of the cable. The dielectric strength of an electrical device is determined in accordance with IEC/EN 61000-4-5, for example. The immunity of the device itself is described.

A distinction is made between:

1. The dielectric strength between the signal wires and ground. Typical values are 1.5 kV for waveforms (1.2/50)  $\mu\text{s}$  or (8/20)  $\mu\text{s}$ .
2. The electric strength. This describes the maximum pulse voltage which may occur between the signal wires without destroying the device. Since this usually affects the device electronics directly, the value is considerably lower. The electric strength is typically below 100 V. Suitable protective devices limit surge voltages between core and ground and between core and core.

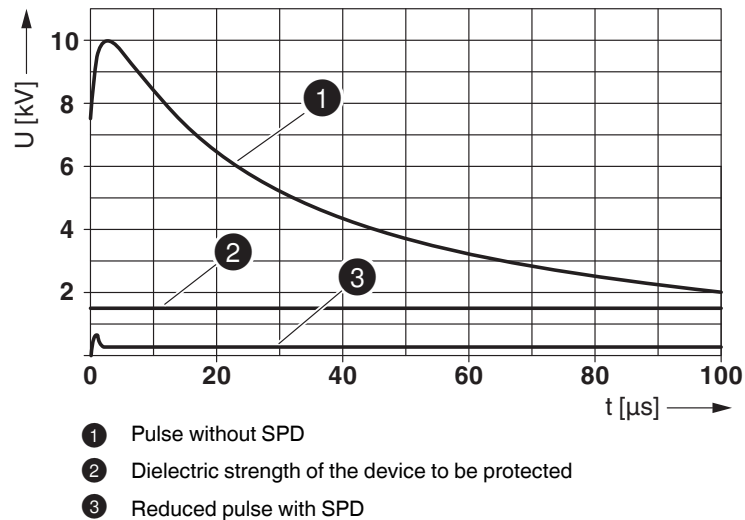


Figure 6-4 Voltage pulse in the core-ground direction of action and voltage limitation by using a surge protective device

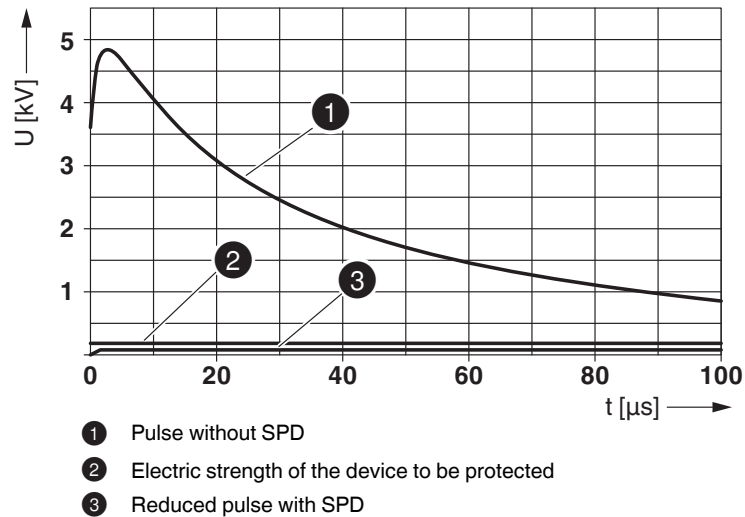


Figure 6-5 Voltage pulse in the core-core direction of action and voltage limitation by using a surge protective device

### 6.4.1 Special considerations for MCR and data technology protection

There are various protective circuits to suit the special protection requirements of electronics modules. When it comes to selection, you need to know whether you are dealing with isolated signals or a common reference potential. The reference potential can be floating or connected to ground. Selection guides make it easier to find the right product.

In the central control cabinets, protective devices are mounted on the DIN rail. With modern protective devices, the reference potential of the protective circuit is on a contact foot that is resistant to surge currents. Surge currents from surge voltage couplings are therefore directly discharged to ground via the DIN rail. It must be ensured that the DIN rail is integrated in the equipotential bonding system and a standard-compliant connection to ground exists.

In the field, protective devices are also used as DIN rail modules in small distribution boards. Special versions are available for mounting on the threaded screw connections of measuring transducers.

Cable shielding can also be connected to the majority of protective devices. With regard to electrical and magnetic fields, effective protection is ensured if the shield is grounded directly at both terminals. In practice, there may be local potential differences between the grounding points. Protective devices should therefore be equipped with an additional gas discharge tube in order to ground the shield indirectly. The insulation protection for the cables is therefore maintained, but possible interference currents are prevented.

## 6.5 Surge protection for data technology and field-buses

Suitable protective devices are also available for the special requirements of data technology and fieldbuses. They handle high data rates without distorting or attenuating signals. In addition, the physical interface is already taken into consideration, enabling system-compliant connection. Suitable product versions are available for PROFIBUS, Modbus, FOUNDATION Fieldbus, Ethernet up to 10GBASE-T, and many more systems.

## 6.6 Surge protection in the explosion-proof area

The IEC/EN 60079 series of standards contains various references indicating that surge protection is also mandatory in this sensitive area. The type of protection for the signal circuit and installation location are key factors when selecting suitable protective devices.

If pressure-encapsulated housings are used in Ex zones, each component installed must be assessed by the planner or system integrator with respect to the resulting overall solution. The self-heating of components is a factor here. These values are comparably low for protective devices. Protective devices with Ex approval in accordance with Ex n protection can be installed in Zone 2 without additional encapsulation.

Systems often contain signal circuits with Ex i protection (intrinsic safety) in accordance with IEC/EN 60079-11. Protective devices with the appropriate approval rating must be used for these applications. Products for this intended use have Ex i certification in accordance with ATEX Directive 2014/34/EC. IECEx and UL approvals are also available for the American market. Protective devices with Ex i approval are suitable for installation in Zone 1, whereby the protected cables can be led up to Zone 0. If Ex i protection is selected, the capacitances and inductances of the protective devices must be taken into consideration in the overall calculation to ensure intrinsic safety.

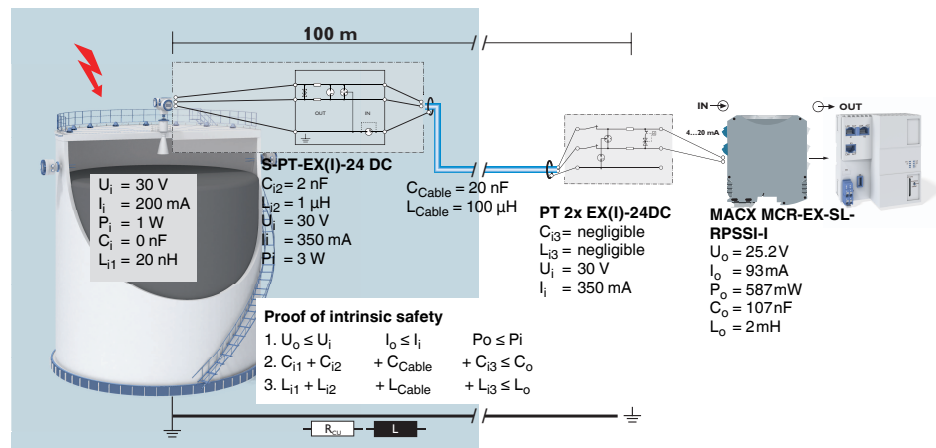


Figure 6-6 Protection provided by SURGETRAB S-PT-EX(I)-24DC in through wiring and TTC-6P-1X2-M-EX-24DC-UT-I

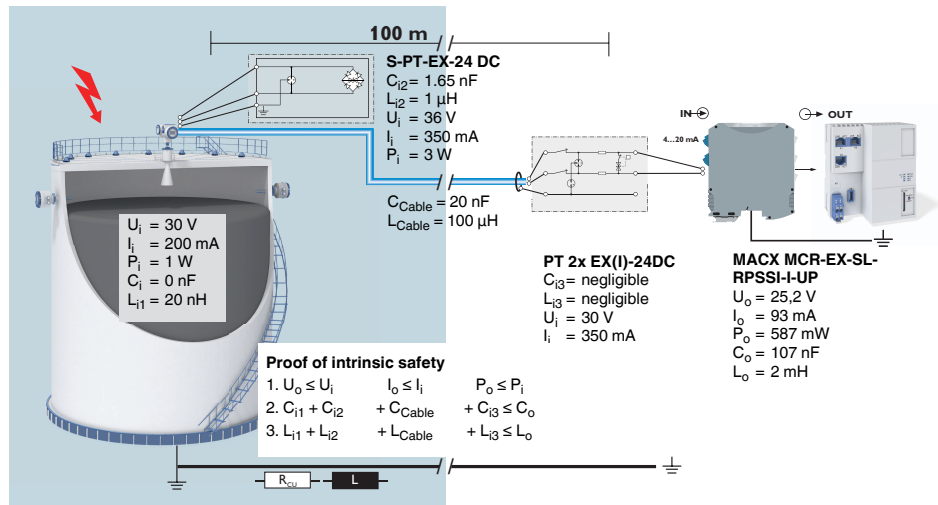


Figure 6-7 Protection provided by SURGETRAB S-PT-EX-24DC in parallel wiring and TTC-6P-1X2-M-EX-24DC-UT-I

## 6.7 Surge protection in connection with safety applications

In accordance with IEC 61508, surge protection is regarded as a type A subsystem. Protective devices are therefore simple systems whose possible errors are 100% known. In order that system planners can perform an overall assessment in safety circuits that also takes surge protection into account, the determined error rates of products must be provided. The planner can verify which safety integrity level will be achieved based on the implementation of the safety circuit structure and inclusion of a time frame for maintenance intervals. In addition, it must be ensured that possible state changes of components in the protective device do not result in an undetected dangerous signal state, such as End of Life mode.

## 6.8 Predictive monitoring of surge protection modules

Testing the technical functional capability of important system components is a constant challenge for operators. Cost pressure has meant that operators are increasingly having to economize when it comes to maintenance, and maintenance intervals for testing are not always being observed. This can also include the inspection and examination of protective devices which must be carried out in accordance with both international and company standards. There is a growing trend to actively monitor important technical components and to send the status to the central control room. The ultimate aim is to increase system availability. This standard has also become established in surge protection and many products feature the option of remote signaling. However the current benchmark goes a step further. Internal “wear” to surge protection products caused by frequent discharge is measured and evaluated in the product. When a defined stress limit is reached, the protective device indicates this. The warning is sent before a real malfunction can occur. The information is sent to the control room and targeted maintenance work can therefore be scheduled through predictive monitoring. Concepts of this kind enable operators to make optimum use of the budget for maintenance and servicing.

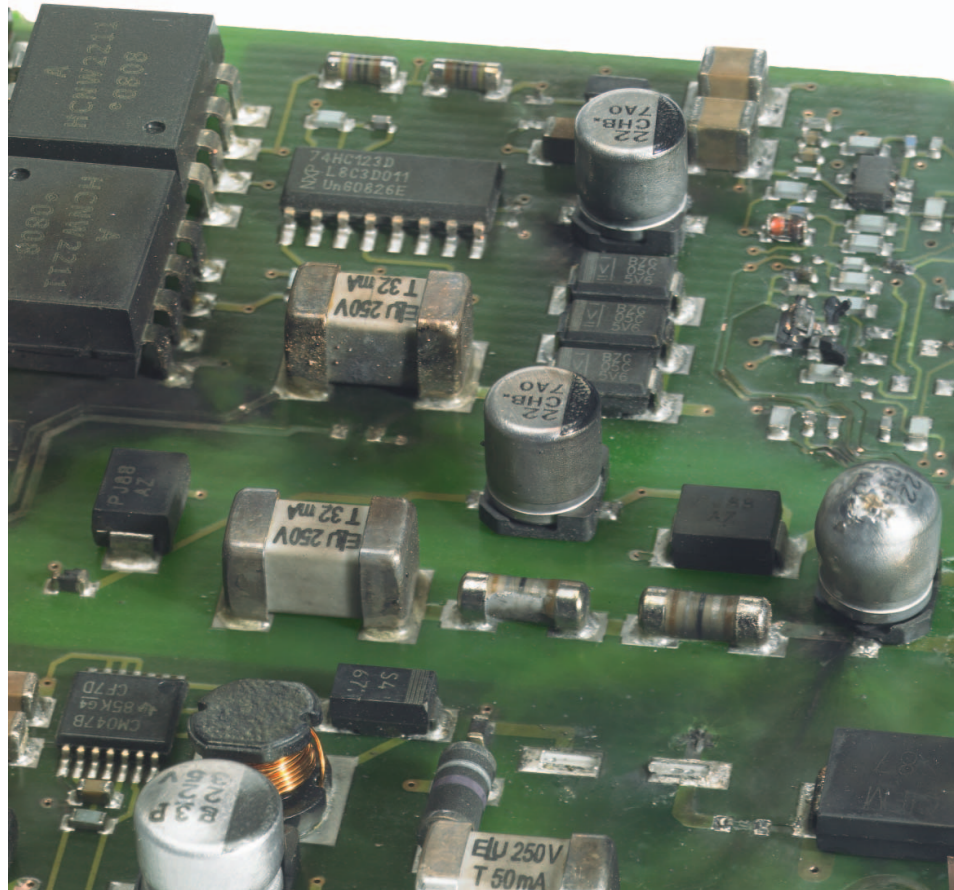


Figure 6-8 Damage caused by surge voltages on an electronic module

## 6.9 Application examples

Application examples are very useful when it comes to selecting adequate surge protection for an application. In addition to specifications for suitable surge protection, installation instructions are also provided. By means of these two sources of information, the surge protection concept can be improved.

### 6.9.1 Protection of an analog measurement

#### PT-IQ

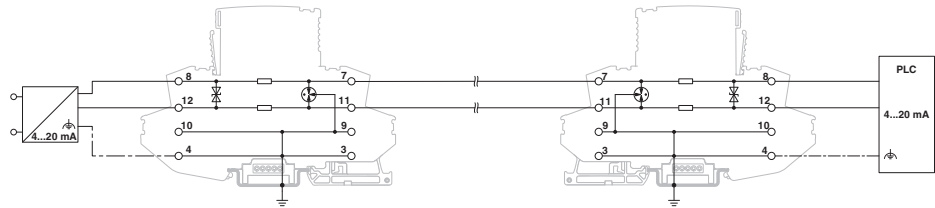


Figure 6-9 Protection of an analog measurement with PT-IQ

#### TERMITRAB

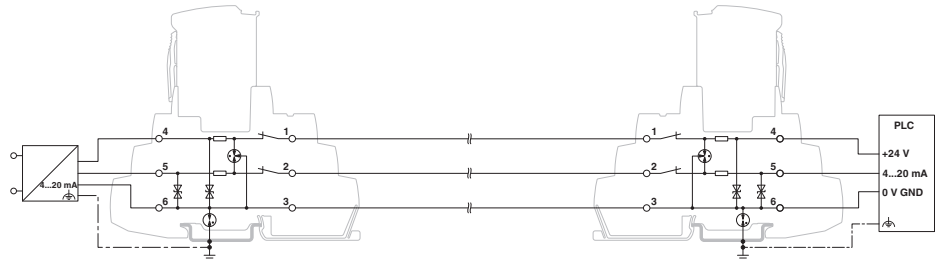


Figure 6-10 Protection of an analog measurement with TERMITRAB

### 6.9.2 Protection of an analog measurement; intrinsically safe circuit

#### SURGETRAB/TERMITRAB

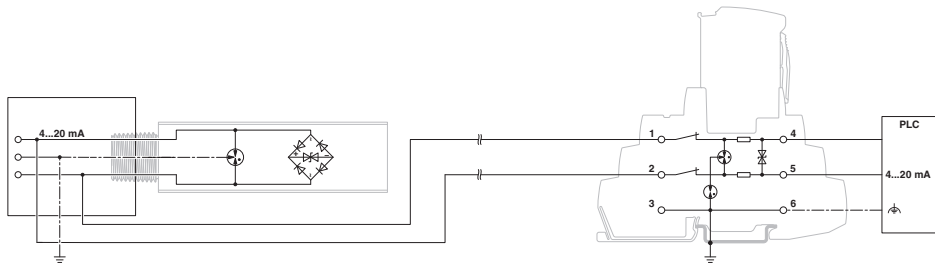


Figure 6-11 Protection of an analog measurement with SURGETRAB/TERMITRAB

### 6.9.3 Protection of a 4-wire measurement

PT 4

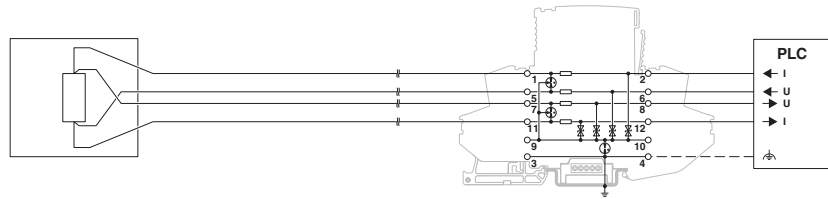


Figure 6-12 Protection of a 4-wire measurement with PT 4

### 6.9.4 Protection of an Ethernet interface (including PoE)

DT-LAN-CAT.6+

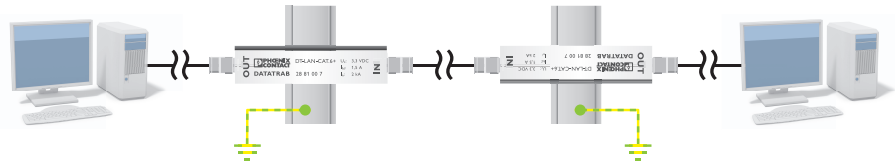


Figure 6-13 Protection of an Ethernet interface with DT-LAN-CAT.6+

### 6.9.5 Protection of PROFIBUS

PT-IQ and PT 5HF

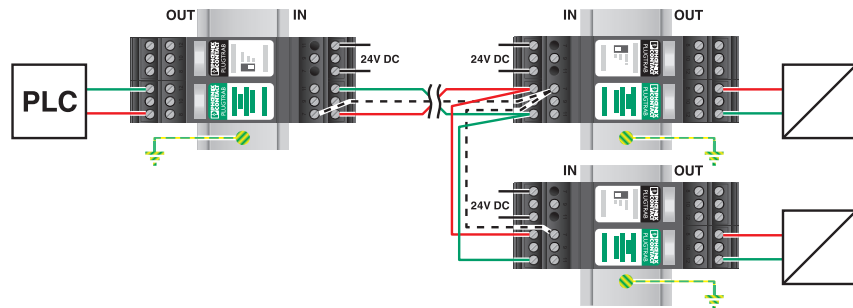


Figure 6-14 Protection of PROFIBUS with PT-IQ and PT 5HF



# A Technical appendix

## A 1 Products for measurement and control technology

### Reliable signal transmission

The modular analog converters for measurement and control technology prevent analog signals from being distorted by disturbance variables. With accurate conversion, isolation, filtering or amplification of analog signals, they secure and increase transmission quality and therefore the quality of closed-loop control circuits.

Phoenix Contact offers the following product ranges for this purpose:

### MINI Analog Pro

#### Highly compact signal conditioners with plug-in connection technology

Easy-to-handle in confined spaces

The highly compact MINI Analog Pro signal conditioners are easy to install and start up in a confined space. The new gateway enable you to integrate up to eight field signals that can be freely combined in industrial networks without any interference.

 Webcode: #0492

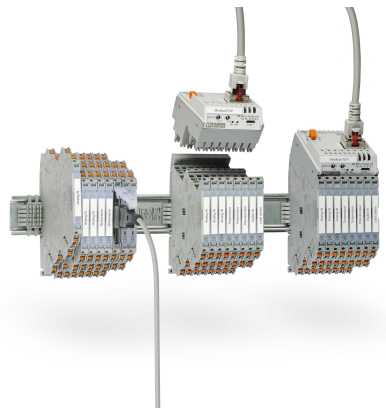


Figure A-1 MINI Analog Pro

- Easy installation, thanks to easily accessible terminal points, power bridging, and plug-in connection terminal blocks
- Easy startup and servicing: measure signals without disconnecting current loops, plus optional disconnect function
- Space-saving network integration of freely combinable signal conditioners by means of compact gateways for Modbus RTU/TCP, PROFIBUS and EtherNet/IP™
- Numerous parameterization options: easy configuration via DIP switches as well as extended configuration via software or smartphone app without additional accessories
- Easy to maintain, thanks to large-surface marking areas, status LEDs in every signal conditioner, and group error message
- Wiring with screw connection or fast and tool-free push-in technology
- Optimum signal quality, thanks to the latest switching technology and safe electrical isolation between input, output, and supply

### MACX signal conditioners **Signal conditioner with SIL functional safety**

A solution for every type of signal

Safely isolate, adjust, filter, and amplify: MACX signal conditioners offer comprehensive solutions for analog signal processing.

Save planning and operating costs by combining high signal flexibility with safe isolation and SIL evaluation.

**i** Webcode: #1143



Figure A-2 MACX signal conditioners

- Functional Safety and reliability with consistent SIL certification according to IEC 61508
- Precise, interference-free signal transmission, thanks to a patented transmission concept with safe electrical isolation and low self-heating
- Convenient configuration and monitoring: via DIP switches and operator interface or with software for extended functionality and monitoring
- Fast and secure installation, thanks to plug-in terminal blocks with screw connection or push-in connection technology
- Flexible energy supply: versions with wide-range input or easy power bridging with the DIN rail connector for 24 V versions
- Maximum explosion protection for all Ex zones and gas groups with 1-channel and 2-channel signal isolators for intrinsically safe circuits in the Ex area
- Integrate analog signals easily into the safety chain according to the Machinery Directive with signal conditioners with performance level

## Termination Carrier

### System cabling for signal conditioners

Termination Carriers from Phoenix Contact are Plug and Play solutions for fast and error-free connection of a large number of signals from the field to your automation system. Select the appropriate standard DIN rail devices for signal conditioning and equip your Termination Carriers accordingly.

 **Webcode: #1138**



Figure A-3 Termination Carrier for MINI Analog Pro and MACX signal conditioners

- Space-saving, thanks to the compact design; the radius of the system cables does not protrude beyond the modules
- DIN rail bracket with integrated end bracket, enabling several Termination Carriers to be mounted side by side
- High system availability, thanks to the robust housing in combination with a vibration-resistant aluminum profile, and mechanically decoupled termination PCB
- Simplified documentation and startup, thanks to the service-friendly Termination Carrier concept
- Quick and safe connection to the Termination Carrier PCB with plug-in and coded cable sets
- Use of standard DIN rail devices only; special devices are not required
- Quick and error-free controller connection by means of pre-assembled VARIOFACE system cabling

### Field Analog

### Process indicators and field devices

Record, monitor, control

The Field Analog process indicators allow you to monitor and display analog and temperature signals as well as control them via digital and analog outputs. The head-mounted transducers can be used to record temperatures directly on site and convert them into standard analog signals.

 **Webcode: #1140**



Figure A-4 Process indicators and field devices Field Analog

- Easy configuration of process indicators via front keypad or FDT/DTM software
- Everything at a glance: backlit display with bar graph and color change in the event of an error
- Can be used internationally, thanks to UL and CSA approvals
- Also for intrinsically safe circuits in the Ex area: versions with ATEX, CSA, and FM approval
- Record temperatures locally and convert them using loop-powered head-mounted transmitters or measuring transducers for the DIN rail
- Universal use: process indicators for field and control panel installation with universal input for current, voltage, RTD, and TC
- Monitoring of up to four additional process values via process indicators with HART master function

**PLUGTRAB PT-IQ****Forward-looking surge protection system**

PLUGTRAB PT-IQ is a system comprising a supply and fault signaling module as well as the actual surge protection. The supply and fault signaling module supplies power to the protective devices, and provides the group remote signaling for up to 28 protective modules.

A particularly interesting feature is the multi-stage signaling and remote signaling of the protective devices. Each voltage-limiting component of the protective circuit is intelligently monitored.

A yellow status signal indicates that as a result of frequent surge voltages, the performance limit has been reached. The arresters continue to function and your system is still protected. A replacement is, however, recommended in order to avoid unnecessary service operations.

**Special protection for potentially explosive areas**

Potentially explosive areas: Install PT-IQ Ex directly in Ex zone 2

With PLUGTRAB PT-IQ Ex, surge protective devices are available for the first time with an auxiliary voltage supply for the “intrinsic safety” protection type which can be installed directly in Ex zone 2.

PT-IQ Ex permanently monitors intrinsically safe circuits up to Ex zone 0. Protective devices with pre-existing damage are also directly detected and reported.

Approvals according to ATEX and IECEx enable global use.

**i** Webcode: #0144



Figure A-5 PLUGTRAB PT-IQ product range

- Service can be planned thanks to self-monitoring protective devices with status indicator
- Vibration-resistant installation – the new locking mechanism provides secure fixing even for installations in harsh environments.
- Space-saving installation: up to five signal wires can be protected on an overall width of just 17.5 mm
- Energy efficient, as the green LEDs on all protection modules can be switched off centrally at the supply and fault signaling module

## Analog signal transmission in the field of MCR technology

- Variable connection technology: choose between conventional screw connection or convenient push-in connection technology

### TERMITRAB complete

#### Protection in the terminal block

The multi-stage surge protective devices for protecting a double wire serve as fine and medium protection between the signal wires and as coarse protection between the signal wires and the ground. With screw or push in connection and as version with disconnect knives or for the Ex area.

**i** Webcode: #0292



Figure A-6 TERMITRAB product range

### SURGETRAB

#### Protection directly at the measuring head

The screw-on modules are available for all common standard signals. The extremely robust housing made from V4A stainless steel protects against unwanted outages even in rough industrial environments and is ready to be used in the Ex area.



Figure A-7 SURGETRAB product range

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PHOENIX CONTACT GmbH & Co. KG

Flachsmarktstraße 8

32825 Blomberg

GERMANY

PHOENIX CONTACT Development and Manufacturing, Inc.

586 Fulling Mill Road

Middletown, PA 17057

USA

Should you have any suggestions or recommendations for improvement of the contents and layout of our manuals, please send your comments to:

[tecdoc@phoenixcontact.com](mailto:tecdoc@phoenixcontact.com)



PHOENIX CONTACT GmbH & Co. KG  
Flachmarktstraße 8  
32825 Blomberg, Germany  
Phone: +49 5235 3-00  
Fax: +49 5235 3-41200  
E-mail: [info@phoenixcontact.com](mailto:info@phoenixcontact.com)  
[phoenixcontact.com](http://phoenixcontact.com)