Theory and Facts

TEMPERATURE TRANSMITTERS

Temperature transmitters

This section will describe the following basic facts about temperature transmitters:
What is a temperature transmitter?
Why using temperature transmitters?
Why using isolated transmitters?
Where to mount the transmitters?

What is a temperature transmitter?

A temperature transmitter is generally recognized as a device, which on the input side is connected to some sort of temperature sensor and on the output side generates a signal that is amplified and treated in different ways. Normally the output signal is directly proportional to the measured temperature within a defined measurement range. Many additional features can be added depending on the type of transmitter being used.
The features of the temperature transmitters are often described by using different terms with respect to technology, mounting method, functions etc.
The following is a short summary of the terms used.

Technology

Analog transmitters
These transmitters are designed on analog circuit technology. They normally offer basic functions such as temperature linearization and sensor break detection. Sometimes they are adjustable for different measuring ranges.

Digital transmitters
This transmitter type is microprocessor based. They are often called *intelligent* transmitters, because they normally offer many extra features, which are not possible to realize in analog transmitters.
Read more about these features in the product descriptions for the IPAQ and MESO transmitters.

Mounting method

In-head transmitters
In-head transmitters are designed for mounting in the connection heads of temperature sensors. All Inor's in-head transmitters fit into DIN B heads or larger. Special care has to be devoted to the ruggedness because of the harsh conditions that sometimes exist.

DIN rail transmitters
Din rail transmitters are designed to be snapped onto a DIN rail. The Inor transmitters fit on a 35 mm rail according to DIN EN 50022.

Input type

RTD transmitters
RTD transmitters are used only for RTD sensors (Pt100, Pt1000, Ni100 etc.). Normally they can handle only one RTD type. Inor's RTD transmitters are designed for Pt100 input and are either fix-ranged or adjustable. They all have a temperature linear output.

Thermocouple (T/C) transmitters
A T/C transmitter measures a mV-signal from the T/C and compensates for the temperature of the cold junction. The cold junction compensation (CJC) is normally made by measuring the terminal temperature. Alternatively some transmitters can be adjusted to compensate for an external fixed cold junction temperature. Pure T/C transmitters are often not temperature linearized because of the complicated unlinearity of the T/Cs.

Universal transmitters
Universal transmitters are normally of the intelligent (microprocessor based) type. They are programmable for different input types and ranges and have an accurate temperature linearization. The Inor transmitters in the IPAQ and MESO families are all universal with input types such as RTDs, T/Cs, resistance, voltage and current. For details, see the product descriptions.

Output type

Analog output
The output signal is a current, e.g. 0-20 or 4-20 mA or a voltage, e.g. 0-10 V. The signal is normally proportional to the measured value within a defined measurement range (temperature linear).
This is still the absolute dominating technique used for temperature transmitters.

Digital output
The measured value (temperature) is presented as a binary coded message. So called Fieldbus transmitters use this technique. The Fieldbus transmitters on the market today use different standards for the communication thus creating some problems when integrating them with other instrumentation.
Examples of standards available are: Profibus, Interbus, Foundation Fieldbus, LonWorks and CAN-bus.

Analog and digital output
The HART transmitters (see description under the MESO transmitters) have an analog output with a superimposed digital signal on the same wires. Typically the analog signal is used for normal measurements and the digital signal only for temporary measurements because of the low communication speed. The digital signal is mainly used for configuration and status information.

Output / power supply connection

(See also under part 2-, 3- and 4-wire transmitters)

2-wire transmitters:
Totally two leads are used in common for power supply and output signal.
3-wire transmitters:
Totally three leads are used for power supply and output signal. One lead is common.

4-wire transmitters*:*
Totally four leads are used, two for the power supply and two for the output signal.

Isolation

Non-isolated transmitters
These transmitters have leading connections between for instance input and output circuits. They should be used with care.

Isolated transmitters
Isolated transmitters have no leading connections between circuits that are isolated from each other. The isolation effectively eliminates the risk for circulating currents and facilitates the connection of transmitters to control systems with grounded inputs.
Read more under "Why using isolated transmitters?"

Why using temperature transmitters?

The following part gives some important reasons for using temperature transmitters in temperature measurements.

To convert the low-level sensor output to an amplified signal.

The amplified signal is much less sensitive to electrical disturbances. This is particularly important if the sensor is located far away from the receiving instrumentation. Long cables and low signal levels increase the risk for significant disturbances in the measurement.

To convert the unlinear sensor output to a temperature linear standard signal.

Typical standard signals are 0-20 or 4-20 mA, 0-5 or 1-5 V and 0-10 or 2-10 V. Thanks to the standard signals, which are proportional to the temperatures, it is possible to use standard instruments for indication, recording etc. and standard input modules in PLCs or DCSs. This greatly simplifies the plant engineering.

To reduce the costs for cables and other instrumentation.

If field mounted transmitters are used, the cable costs can be reduced. Only two leads are required, if a 2-wire transmitter is used, compared to three or four for RTDs.
Standard signal cables can be used instead of more expensive compensation or extension cables for T/Cs.
Normally all the connected instrumentation is less expensive if using standard input signals like for instance 4-20 mA.

To improve the safety of the temperature measurement.

The safety can be improved by letting the transmitter supervise the sensor leads. The *Sensor Break Protection* will indicate broken sensor leads and force the output to a user defined level.

To improve the accuracy of the temperature measurement.

The accuracy can be improved by letting the transmitter compensate for sensor errors *(Sensor Error Correction)* or errors in connected instrumentation *(System Error Correction)*.
See section Software / IPRO 4.

Measuring errors due to reduced isolation in the sensor or between the sensor leads can be avoided with the *SmartSense* function. This function is a standard feature in most of the Inor intelligent transmitters. ***See the description of SmartSense later in this section.***

To improve the functionality of the temperature measurement.

Useful functions can be included together with the measurement, especially when using the intelligent IPAQ and MESO transmitters.
Some examples are:
Dampening function to reduce instabilities of the measuring value.
Loop calibration output. The transmitter generates an accurate output signal that is used to calibrate or check other instruments in the measurement loop.
On-screen real time presentation of measured values (in °C or °F) and output signal. The presentation can be in numericals, as bar graphs or as a line recorder.

Why using isolated transmitters?

Measurements with thermocouples

Figure 1 shows a typical situation, when using T/Cs connected to a PLC or DCS over a non-isolated transmitter.

The isolation to ground R_{ISO} is sometimes rather low, e.g. at high temperatures and/or small dimensions of the T/C.

An undesired "ground current" I_{Err} of variable magnitude, depending on the actual situation, will arise. The ground current will flow through the T/C and cause voltage drops over the resistances R_{L1} and R_{L2} in the T/C leads. These voltage drops will interact with the EMF generated by the T/C and can cause significant measuring errors.

It is sometimes hard to foresee and calculate these errors, but it is not unusual that they can reach 5-10 % of the measuring range.

If the transmitter is galvanically isolated between the input and output circuit, the ground loop will be cut off, and the ground current will be stopped. No errors will arise due to a low isolation between T/C and ground.

Fig.1

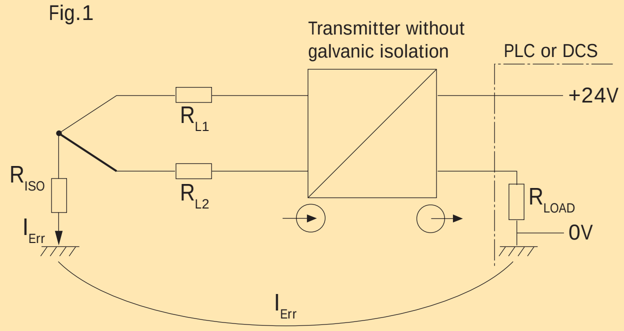
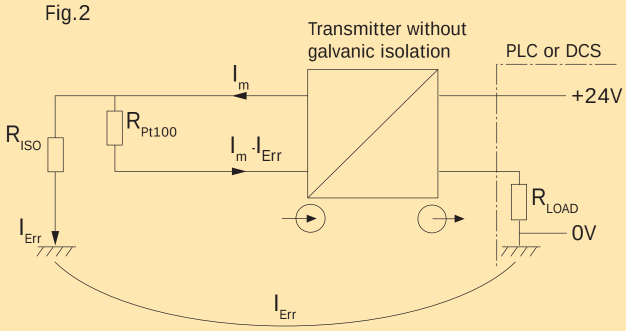


Fig.2



Measurements with RTDs

Figure 2 shows an RTD sensor connected to a PLC or DCS over a non-isolated transmitter.

The isolation to ground R_{ISO} is normally very high in a "healthy" RTD, typically 50 to 500 MΩ. However, under certain conditions it happens that the internal isolation of an RTD can be significantly reduced. Reasons might be wear or damage causing moisture to penetrate into the RTD.

Depending of the value of R_{ISO} a certain portion I_{Err} of the measuring current I_m will pass through the ground and not through the RTD sensor. This will cause a measuring error.

If the transmitter is galvanically isolated between the input and output circuit, the ground loop will be cut off, and the ground current will be stopped. No errors will arise due to a low isolation between RTD and ground.

Conclusion

To be sure about a good measuring result, use isolated transmitters!

Where to mount the transmitters?

In an industrial plant, where there are normally long distances between the measuring points and the receiving instrumentation, some important aspects regarding the location of the transmitters can be mentioned.
There are basically three different locations for the mounting of the temperature transmitters:

- ***In-head mounting - inside the connection head of the temperature sensors.***
- ***Field mounting – close to the temperature sensors.***
- ***Central mounting - in the vicinity of the control room.***

In-head mounting

The transmitters are mounted directly inside the connection head and are normally replacing the terminal block. All Inor's In-head transmitters fit in a DIN B head or larger. They are designed and tested for the harsh conditions that In-head transmitters will often meet.
This way of mounting normally offers the biggest advantages. It is however necessary to be aware of the environmental influence (mainly the temperature) on the measurement accuracy.

Advantages

- *Maximum safety in the signal transmission. The amplified signal, e.g. 4-20 mA, is very insensitive to electrical disturbances being induced along the transmission cable.*
- *Cost savings for the transmission cables. Only two leads are required if a 2-wire transmitter is used.*
- *Cost savings for installation. No extra connection points because of the transmitter.*
- *Cost and space savings. No extra housings or cubicles are needed.*
- *Field instruments, e.g. indicators, can easily be installed, also at a later stage without redesigning the measuring circuits. For instance, if using the Inor IPAQ-H^{PLUS} or IPAQ-HX^{PLUS} transmitters, an Inor digital display can be connected, or loop powered indicators can be installed in the 4-20 mA loop.*

Disadvantages

- *The ambient temperatures can be outside the allowed limits for the transmitters.*
- *The ambient temperature influence on the measuring accuracy has to be considered. If the temperatures are expected to deviate strongly from normal room temperature, and if the highest possible accuracy is required, we recommend using Inor's high-performance transmitters IPAQ-H^{PLUS} or IPAQ-HX^{PLUS} because of their extreme temperature stability.*
- *Extreme vibrations might cause malfunction of the transmitters.*
- *The location of the temperature sensor can give maintenance problems.*

Field mounting

The transmitters are either mounted directly beside the temperature sensors or in the vicinity of the sensors. Often more than one transmitter is mounted in the same field box.
This method is more expensive than In-head mounting, but otherwise a good alternative offering most of the advantages of In-head mounting without the disadvantages mentioned above.

Advantages

- *High safety in the signal transmission. The main part of the signal transmission is made with an amplified signal.*
- *No extreme temperatures or vibrations exist. This facilitates accurate and safe measurements.*
- *Cost savings for transmission cables (See above).*
- *A wider selection of transmitters is available. DIN rail transmitters can also be used.*
- *Field instruments can often be installed easily (See above).*
- *Maintenance can normally be carried out without problems.*

Disadvantages

- *Higher installation costs compared to In-head mounting.*
- *Costs and space requirements for transmitter boxes or cubicles.*

Central mounting

In this case, the transmitters are placed in the vicinity of the control room or in another central part of the plant They are often mounted inside cubicles, and/or closed rooms. The ambient conditions are normally very good and stable.
This method offers the most convenient conditions for maintenance and the best possible environment for the transmitters. There are on the other hand some disadvantages that should be considered.

Advantages

- *Convenient conditions for installation, commissioning and maintenance.*
- *Minimum risk for environmental influences (e.g. temperature influence).*

Disadvantages

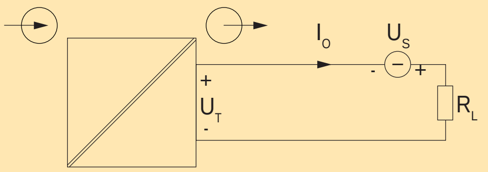
- *Reduced safety in the signal transmission. The low-level sensor signal is rather sensitive to electrical disturbances being induced along the transmission cable.*
- *Relatively high costs for cabling. T/C measurements require compensation or extension cables all the way to the transmitters. RTD measurements with high accuracy should be done in 4-wire connection to get rid of the lead resistance influence (See section Transmitter Connections).*
- *Costs and space requirements for cubicles or frames.*
- *Rather complicated and expensive to connect field instruments, e.g. indicators.*

2-, 3- and 4-wire transmitters

This part describes three transmitter groups with respect to output and power supply connections:

- **2-wire transmitters:**
  Totally two leads are used in common for power supply and output signal.
- **3-wire transmitters:**
  Totally three leads are used for power supply and output signal. One lead is common.
- **4-wire transmitters:**
  Totally four leads are used, two for the power supply and two for the output signal.

Fig.3 2-wire transmitter



2-wire transmitters

This is the most frequently used transmitter type today, especially for field mounted transmitters and transmitters in hazardous locations.

Fig. 3 shows the principal diagram.

The power supply U_S and the output signal I_O are using the same pair of leads.

The power supply is a DC voltage, which is allowed to vary according to the transmitter specifications, e.g. 6.5 to 36 VDC for IPAQ-H.

The output signal is standardized to 4-20 mA, but intermediate and reversed values occur too.

The maximum load R_L is depending on the supply voltage and the minimum voltage over the transmitter U_T and is specified separately for all 2-wire transmitters in a Load Diagram. For calculation of the maximum load, the formula can be used:

$$R_{L\,max} = \frac{U_S - U_T}{I_{max}}$$

Advantages of 2-wire transmitters:

- *Reduced cable and installation costs with only two leads.*
- *Reduced dimensions, heat losses and costs since a mains transformer is not needed.*
- *Direct connection to PLC or DCS using active inputs (using the system's internal transmitter supply).*
- *Allow for big variations in the supply voltage.*
- *Simple and cost effective Intrinsically Safe installations in hazardous locations.*
- *Well-established technique makes the 2-wire transmitters compatible with other instrumentation.*

Disadvantages of 2-wire transmitters:

- *Output signal limited to 4-20 mA (or intermediate values).*
- *Because of the low power supplied to the 2-wire transmitters (can be as low as 25 mW), power consuming functions (alarm relays etc.) can not be included.*
- *Since the power supply is galvanically connected to the output signal, special caution is necessary when using power supplies that are grounded and/or common for a number of transmitters.*

3-wire transmitters

This transmitter type is rarely used for industrial applications, probably because it is a mixture of the 2- and 4-wire technique, not offering the full advantages of any of them. For the time being, Inor is not manufacturing 3-wire transmitters.

Fig. 4 shows the principal diagram.

The 3-wire transmitter has one power supply circuit and one output circuit. Because these circuits have one point in common, it is enough to use only three leads between transmitter and power supply / load.

The supply voltage U_S is typically 12-36 VDC, but other voltages such as 24 VAC can be found.

The output signal I_O or U_O can be a DC current or DC voltage, e.g. 0/4-20 mA, 0/1-5 V or 0/2-10 V.

The minimum and maximum load R_L depend on supply voltage and type of output.

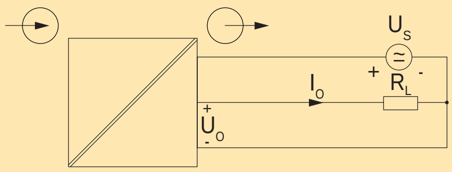
Advantages of 3-wire transmitters:

- *Reduced cable costs compared to 4-wire transmitters.*
- *Accept AC and DC supply voltage.*
- *Big variety of output signals.*

Disadvantages of 3-wire transmitters:

- *Since the power supply is galvanically connected to the output signal, special caution is necessary when using power supplies that are grounded and/or common for a number of transmitters.*
- *3-wire transmitters are normally not designed for Intrinsically Safe installations.*

Fig.4 3-wire transmitter



4-wire transmitters

The 4-wire transmitters are used, when it is preferred to have the output and power supply isolated from each other, or when the transmitter functions (e.g. relays, lighted display etc.) require more power than what is available for 2-wire transmitters.

Fig. 5 shows the principal diagram.

In the 4-wire transmitters, the power supply U_S and the output signal I_O or U_O are separated and normally isolated from each other.

The supply voltage can vary from 12 VDC to 230 VAC.

The output signal I_O or U_O can be a DC current or DC voltage, e.g. 0/4-20 mA, 0/1-5 V or 0/2-10 V.

The minimum and maximum load R_L depend on supply voltage and type of output.

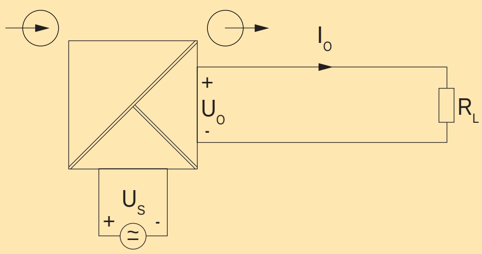
Advantages of 4-wire transmitters:

- *Accept DC and AC (up to 230 V) supply voltage.*
- *Since the power supply is galvanically isolated from the output signal, there are no problems using power supplies that are grounded and/or common for a number of transmitters.*
- *Can handle more power consuming functions like relays, displays, sensor excitations etc.*

Disadvantages of 4-wire transmitters:

- *Higher cable and installation costs when field mounted (compared to 2-wire transmitters).*
- *Increased dimensions, heat losses and costs due to built-in mains transformer (compared to 2-wire transmitters).*
- *Normally have to be mounted outside the hazardous locations.*

Fig.5 4-wire transmitter



2-, 3- and 4-wire connection for RTD sensors

This part describes three connection types used for RTD:

- **2-wire connection*:***
  Two leads connect sensor and transmitter.
- **3-wire connection*:***
  Three leads connect sensor and transmitter.
- **4-wire connection*:***
  Four leads connect sensor and transmitter.

Fig.6 2-wire connection

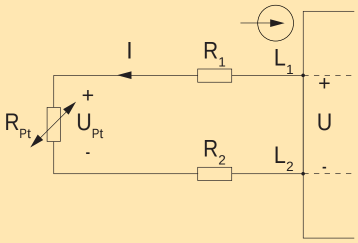
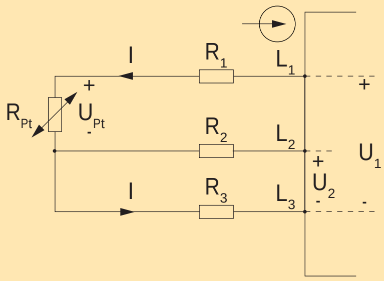


Fig.7 3-wire connection



In the following part, the pros and cons of the different connection types are explained. Things to observe and the effects of wrong connections are also mentioned.
The examples below are given for RTD's (e.g. Pt100 sensors), but in principle they apply to all resistance sensors.
The grouping is based on the transmitter design or configuration and not on the number of leads actually used between sensor and transmitter.

2-wire connection

This connection is seldom used in industrial measurements, because of the accuracy problems involved.
Fig. 6 shows the input wiring.
The transmitter sends out a constant measuring current I, which generates a voltage U measured by the transmitter.
The voltage is $\mathbf{U=I^*(R_{Pt}+R_1+R_2)}$.
The correct value would be the voltage over the sensor resistance R_{Pt} only, i.e. $\mathbf{U_{Pt}=I^*R_{Pt}}$. Thus the lead resistances R_1 and R_2 create a measuring error.
As a rule of thumb, the error due to the lead resistance (R_1+R_2) is approximately 2.6 °C (4.7 °F) per ohm for a Pt100 sensor and 10 times less for a Pt1000 sensor.
If the lead resistance is known, the transmitter can be manually adjusted to compensate for the lead resistance.
Since this is a fixed compensation, changes in the lead resistance, due to temperature variations, will not be taken care of.

Advantages of 2-wire connection:

- *Reduced cable costs (depends on distance).*

Disadvantages of 2-wire connection:

- *Considerable measuring errors can occur without compensation for lead resistance.*
- *Time-consuming compensation for lead resistance.*
- *Errors due to variation in the cable temperature can never be eliminated.*

3-wire connection

The 3-wire connection is today the dominating technique for connection of RTD sensors, especially in industrial use. The reason is the combination of automatic compensation for the lead resistance and reasonable cable costs.
Fig. 7 shows the input wiring.
In principal, most transmitters for 3-wire connection work in the same way. A constant measuring current I is sent through lead L_1, the sensor element and lead L_2, generating a voltage U_1, which is U_1=I*(R_{Pt}+R_1+R_2).
To get rid of the influence of R_1 and R_2, an extra lead L_3 is connected to one side of the sensor element. No current is flowing in this lead because of a very high input impedance, so the voltage U_2 is U_2=I*R_2.
Assuming that the lead resistances are identical, R_1=R_2=R_L, and

letting the transmitter calculate a voltage U, which is $U=U_1-2*U_2$, the result will be:

$$U=I*R_{Pt}+2*I*R_L-2*I*R_L \text{ or:}$$

$$\mathbf{U=I*R_{Pt}=U_{Pt}}$$

Thus we have an expression, which vary directly with the sensor resistance and without influence of the lead resistances.

Note:

It is very important that lead L_1 and L_2 have equal resistance. To avoid the risk of mixing up the leads, always keep all 3 lead resistances as equal as possible.

For practical reasons, all transmitters have an upper limit for the lead resistances of typically 15-25 ohm per lead (see Specifications).

Table 1 *shows examples of the errors in a 3-wire connection for Pt100 and Pt1000 caused by a difference in resistances, R_{diff}, between L_1 and L_2.*

Examples of "unclean" connections

For different reasons, the user might connect sensors with only two leads or with four leads to transmitters for 3-wire connection.

Two sensor leads together with transmitter for 3-wire connection

*A typical connection can be as shown in **fig. 8.***

It is important to note that, even if all three terminals of the transmitter are used, the automatic compensation for lead resistance is not working.

The error due to the lead resistance is the same as described above for 2-wire connection, i.e. approximately 2.6 °C (4.7 °F) per ohm total lead resistance (R_1+R_2). Manual (fixed) compensation can normally be performed.

Four sensor leads together with transmitter for 3-wire connection

*Sometimes the four sensor leads are connected as shown in **fig. 9.***

Because the three lead resistances, as seen from the transmitter, are not equal, the automatic compensation for lead resistance is not working properly. The measuring error depends on the difference in lead resistance, as described above.

Solution: Use only three of the sensor leads.

Conclusion

With two leads to the sensor, the 3-wire connection will neither improve the accuracy nor make it worse compared to the 2-wire connection.

With four leads to the sensor, the 3-wire connection will not compensate the lead resistance properly.

Advantages of 3-wire connection:

- *Automatic compensation for the resistance in the leads connecting sensor and transmitter.*
- *Reduced cable costs compared to 4-wire connection.*

Disadvantages of 3-wire connection:

- *An unbalance in the resistance of the three sensor leads might cause considerable measuring errors.*
- *Poor connections, i.e. corroded or loose terminals, can cause measuring errors due to extra and unequal resistances.*

Table 1

	Resistance difference, Rdiff	
	0.1 ohm	1.0 ohm
Pt 100	0.26 °C/0.47 °F	2.6 °C/4.7 °F
Pt 1000	0.03 °C/0.05 °F	0.26 °C/0.47 °F

Fig.8 "Unclean" connection

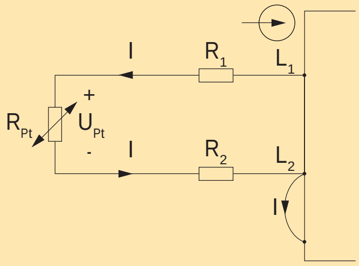


Fig.9 "Unclean" connection

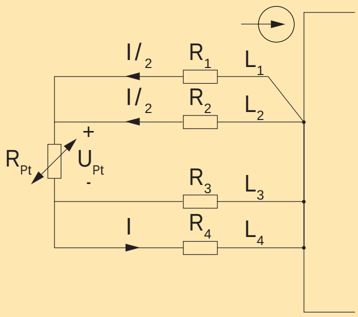


Fig.10   4-wire connection

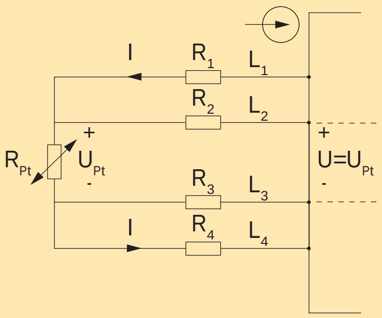


Fig.11   "Unclean" connection

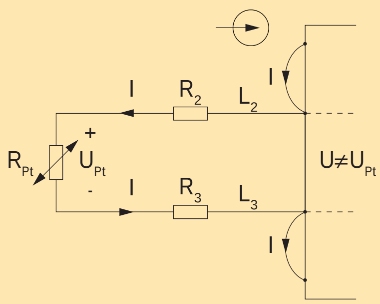
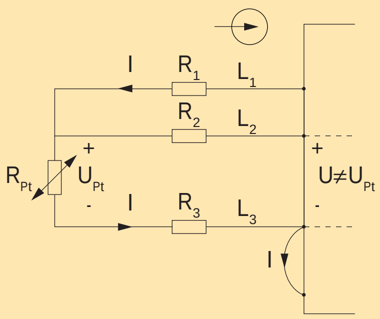


Fig.12   "Unclean" connection



4-wire connection

The 4-wire connection of RTD sensors is used when the highest accuracy is required, e.g. in research laboratories and for critical industrial measurements. With the 4-wire connection, the influence of the lead resistances is fully eliminated. Even resistances due to poor connections will have no influence.

Fig. 10 shows the input wiring.

A constant measuring current I is sent through lead L_1, the sensor element and lead L_4, generating a voltage U_{Pt} over the sensor element, which is $U_{Pt}=I*R_{Pt}$. This voltage is measured by connecting two leads, L_2 andL_3, from the sensor to a high impedance input of the transmitter. Practically no current is flowing in L_2 and L_3, so there is only a negligible voltage drop over these leads, and the transmitter will directly measure the voltage:

$$U=I^*R_{Pt}=U_{Pt}$$

the sensor resistance and that was reached without any reservations for the lead resistances.

For practical reasons, all transmitters have an upper limit for the lead resistance of typically 15-25 ohm per lead (see Specifications).

Examples of "unclean" connections

For different reasons, the user might connect sensors with only two leads or with three leads to transmitters for 4-wire connection.

Two sensor leads together with transmitter for 4-wire connection

A typical connection can be as shown in ***fig. 11.***

Please note that, even if all four terminals of the transmitter are used, the lead resistances R2 and R3 will directly create a measuring error.

The voltage seen from the transmitter is

$$U=I^*(R_{Pt}+R_2+R_3)\neq U_{Pt}$$

The error due to the lead resistance is the same as described above for 2-wire connection, i.e. approximately 2.6 °C (4.7 °F) per ohm total lead resistance (R_2+R_3). Manual (fixed) compensation can normally be performed.

Three sensor leads together with transmitter for 4-wire connection

A typical connection can be as shown in ***fig. 12.***

Even if all four terminals of the transmitter are used, in this example the lead resistance R3 will directly create a measuring error.

The voltage seen from the transmitter is

$$U=I^*(R_{Pt}+R_3)\neq U_{Pt}$$

The error due to the lead resistance is approximately 1.3 °C (2.3 °F) per ohm of the resistance in each lead (R_1, R_2 or R_3). Manual (fixed) compensation can normally be performed.

Conclusion

With two leads to the sensor, the 4-wire connection will neither improve the accuracy nor make it worse compared to the 2-wire connection.

With three leads to the sensor, the 4-wire connection will make the accuracy worse compared to the 3-wire connection.

Advantages of 4-wire connection:

- *High accuracy because the resistances in the leads connecting sensor and transmitter have no influence.*
- *Poor connections, i.e. corroded or loose terminals, will not influence the accuracy in most cases.*

Disadvantages of 4-wire connection:

- *Increased cable costs compared to 2-wire and 3-wire connection.*

EMC – Electromagnetic Compatibility

The Electromagnetic Compatibility or EMC is a feature that has become more and more important for electronic products.

The EMC covers two main areas, namely:

- ***A product's immunity to electromagnetic interferences***
- ***A product's emission of electromagnetic interferences***

Regulations

Today it is mandatory for all electronic products, which are placed on the market within the EC countries, to fulfill the requirements of the ***EMC Directives 89/336/EEC and 93/68/EEC.***

The following generic standards specify the general requirements and the criteria for approval:

EN 50081, Electromagnetic Compatibility – Generic Emission Standard

EN 50082, Electromagnetic Compatibility – Generic Immunity Standard

These generic standards refer to ***Basic standards,*** where the different EMC tests are described in detail.

CE-marking

If an electronic product for industrial use complies with the relevant standards like EN 50081-2 and EN 50082-2 and thus fulfills the EMC Directives mentioned above, the manufacturer has the right to put the "CE" mark on the product.

For all products, which carry the CE mark, a ***"Declaration of Conformity"*** must be available on request.

EMC-compliance and CE-marking of the Inor products

All Inor's electronic products like Temperature transmitters, Signal conditioners, Isolators, Indicators, etc. comply with the following EMC standards:

- *EN 50081-2, Emission, Industrial Environment*
- *EN 50082-2, Immunity, Industrial Environment*

Consequently all Inor products are approved to carry the CE mark.

Test specifications for the Inor products

Emission, EN 50081-2, Industrial Environment

Basic standard	Test	Specifications	Results
EN 55011	Radiated interference	30-230 MHz, 30 dB (mV/m), 30 m 230-1000 MHz, 37 dB (mV/m), 30 m	Complies

Immunity, EN 50082-2, Industrial Environment

Basic standard	Test	Specifications	Results
EN 61000-4-2	Electrostatic discharge (ESD)	Contact: ±4 kV Air discharge: ±8 kV	Criterion B
ENV 50140 ENV 50204	RFI influence, air borne	80-1000 MHz, 80 %AM, 1kHz, 10 V/m 900±5 MHz, pulse modulation (GSM), 10V/m	Criterion A
EN 61000-4-4	Fast transients on leads	±1 kV, ±2 kV, ±4 kV 2 minutes Capacitively coupled	Criterion B
ENV 50141	RFI influence, injection on leads	0.15-80 MHz, 80 %AM, 1 kHz, 10 V Coupled via 150 Ω	Criterion A

Criterion A:
The influence of the apparatus during the test is limited to the values of the Specifications for the apparatus.

Criterion B:
The apparatus resumes the values of the Specifications for the apparatus directly after the test.

SmartSense – *Sensor Isolation Monitoring*

This section describes how the isolation influences the measurements with RTDs and Thermocouples - independent of manufacturer - and how to get an early warning regarding errors due to low isolation.

Fig.1

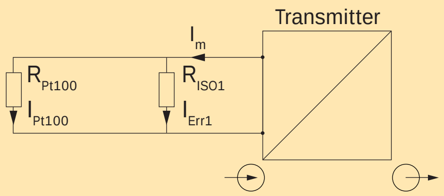


Fig.2

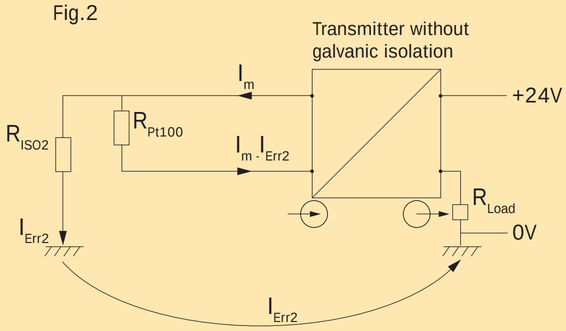
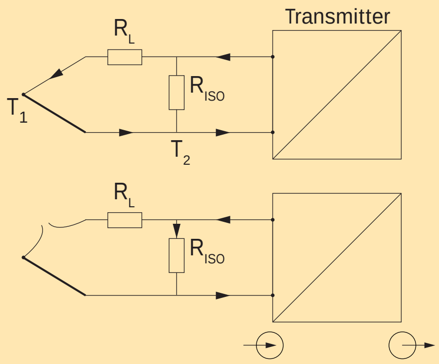


Fig.3



The structures of Pt100 and thermocouple thermometers have properties, which can lead to erroneous measurements. This is independent of brand and type. One of these often neglected sources of error is the isolation in the thermometer, which, if too low, can give a serious degradation of the measurement. Heat, vibration, physical or chemical influence or radioactive influence can lower the isolation. This section will give an explanation to the necessity of keeping an eye on the isolation resistance and how to make this.

The effect of low isolation

Pt100

The Pt100 element is a low-resistance sensor, and a too low isolation resistance will influence the measurement. ***Figure 1*** shows the electrical schematic for a Pt100 sensor in 2-wire connection with a temperature transmitter. The isolation resistance between the sensor leads is symbolized by R_{ISO1}. ***See Figure 1.***

The measuring current I_m shall go through the Pt100 element, but a negligible fraction I_{Err1} is normally passing through the high isolation resistance R_{ISO1}. When the isolation is lowered, a greater fraction of the current will pass through the isolation resistance. As a result of this, the measured voltage over the combined resistance of Pt100 and isolation resistance will be lower than if the isolation resistance was sufficiently high. This will give a too low measured temperature value, and this is not dependent on whether the transmitter is isolated or not.

If the transmitter is without galvanic isolation between input and output, a low isolation resistance between sensor and earth R_{ISO2} can carry a significant part I_{Err2} of the measuring current. This so called "ground current" will also cause a too low indicated temperature. With an isolated transmitter, this will not happen, because the isolation will cut off the loop, where the ground current is flowing.
See Figure 2.

Thermocouples

Low isolation in thermocouple sensors will give other errors. The EMF from a thermocouple is not particularly sensitive for low isolation. The problem is rather that a low isolation will give a new measuring point in the location of the low isolation. If this location is near the real measuring point, the error will be negligible.

Figure 3 shows a thermocouple connected to a temperature transmitter. If the low isolation R_{ISO} is in a location where the temperature T_2 differs from the temperature in the measuring point T_1 there is a possibility of a significant error. The measured temperature will correspond to an intermediate value of T_1 and T_2.

Low isolation in thermocouple sensors can also make the sensor break detection to fail, because the monitoring current can still pass through R_{ISO}.
See Figure 3.

Isolation monitoring with *SmartSense*

The transmitters in the IPAQ family from Inor are microcontroller based and do a couple of measurements and controls beyond the standard measurements. One of these controls (not included in IPAQ-L) is to monitor the isolation resistance of the sensor and the sensor leads. This function, named ***SmartSense***, is available for Pt100 and thermo couple sensors. To accomplish the monitoring, the sensor must be furnished with an extra conductor. Under certain circumstances there is a possibility of using the cable shield. See Sensor solution below.

When the isolation resistance is too low, the IPAQ transmitter will signal this with a flashing LED in the front, and the output signal will go to a pre-programmed value.

Pt100

For Pt100 the detection limit for “low isolation” is adjustable between 50 kΩ and 500 kΩ. The error due to the isolation value R_{ISO} has to be added to other measurement errors. By 400 °C/752 °F the added error is 0.4 °C/0.7 °F for 500 kΩ and 3.1°C/5.6°F for 50 kΩ isolation. ***See Fig. 4.***

Thermocouples

For thermocouples the detection limit for “low isolation” is adjustable between 20 kΩ and 200 kΩ. The added error depends on the relation between the lead resistance R_L and the isolation resistance R_{ISO}. The error is also dependent on the temperature difference between the measuring point and the location of the low isolation. Under the following circumstances: measuring temperature 1000 °C/1832 °F, ambient temperature 25 °C/77 °F and R_L 50 Ω there will be an error of 1% if the isolation resistance is 5 kΩ. This equals 10 °C. It is assumed that the low isolation is in the ambient temperature area.

Sensor solution

The SmartSense function in the IPAQ transmitters is applicable for Pt100 in 3-wire connection and thermocouples. For a correct usage of the SmartSense, the sensor must have an extra conductor. This conductor will have a separate terminal and go through the sensor all the way to the sensor element. ***See Figure 5.***

Mineral isolated Pt100 sensors and thermocouples will use an unconnected conductor.
N.B. Due to the normally low isolation in mineral isolated thermocouples at high temperatures, it is not useful to monitor the high temperature end, above ~600 °C/1100 °F depending on application. Instead, it is important to monitor connections and cables from the sensor to the transmitter. It is not recommended to use the sheath of the sensor or a cable shieldas the monitoring conductor. One task of the sheath is to keep interference outside the measurements. Connecting the sheath to the SmartSense terminal can lead to erroneous measurements. This is also applicable to the shield of cable sensors. ***See Figure 6.***

Conclusion: Full control over sensor and connection

A too low isolation resistance in temperature sensors can give erroneous measurements independent of brand and type. SmartSense gives the possibility of substituting Pt100 (3-wire connected) and thermocouple sensors with a low isolation resistance in time. SmartSense does not only monitor the sensor but also the conductors from the sensor terminals to the transmitter terminals. This gives a full control on the condition of the measuring chain from measuring point to transmitter.

Causes of low isolation:

- *Contamination*
- *Physical influence (wear, jamming)*
- *Chemical influence (corrosion)*
- *Vibration*
- *Radioactive radiation*

Fig.4

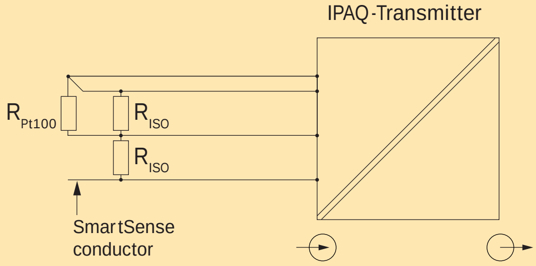


Fig.5

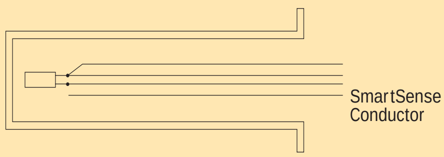
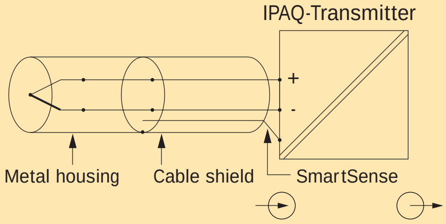


Fig.6



Examples of errors

Pt100 by 400°C / 752°F

Isolation R_{ISO}	Error
500 kΩ	0.4 °C / 0.7 °F
100 kΩ	1.6 °C / 2.9 °F
50 kΩ	3.1 °C / 5.6 °F
10 kΩ	15 °C / 27 °F

Thermocouple type K by 1000°C / 1832°F, R_L=50 Ω, T_{AMB} = 25°C / 77°F

Isolation R_{ISO}	Error
50 kΩ	1 °C / 1.8 °F
20 kΩ	3 °C / 5.4 °F
5 kΩ	10 °C / 18 °F

Temperature sensors

Two dominating sensor types are used for industrial temperature measurement applications:

- ***Resistance Temperature Devices, "RTDs"***
- ***Thermocouples, "T/Cs"***

Resistance Temperature Devices - RTDs

The RTD is a temperature sensor containing a temperature sensitive element of resistive type. The resistance of the element is changing with the temperature.
The resistance versus temperature characteristics are well defined and standardized according to different international standards.
Mainly two types of RTD sensors are used, namely the Platinum (Pt) and the Nickel (Ni) sensors.

Platinum sensors

The most commonly used RTD sensors are the Platinum sensors, which are distinguished by their high accuracy and stability. Today's manufacturing technology has reduced the costs and made it possible to produce vibration resistant Platinum sensors also with small dimensions.

Platinum sensor types
The dominating Platinum sensor type is the Pt100, which has a resistance of 100.0 Ω at 0 °C. The resistance/temperature characteristics are exactly defined in equations, which differs slightly between different standards.
Other types of Platinum sensors are for instance Pt250, Pt500 and Pt1000. These types have exactly the same characteristics as the Pt100, but the resistance values are 2.5, 5 and 10 times the Pt100-values for the same temperatures.

Standards
The Platinum sensors are manufactured according to different standards, where the European standard IEC 751 has become the most used. Other standards are the Japanese JIS 1604 and some American ANSI standards.

Tolerances
The standards mentioned above also define the allowed tolerances. IEC 751 has two tolerance classes for Platinum sensors: Class A and Class B, where Class A is the more accurate (with smaller tolerances).

Alpha-value
One parameter that is commonly used to describe the characteristics of a Platinum sensor is the temperature coefficient α (alpha). The α-value differs from one standard to another.
The α-value is defined as:

$$\alpha = \frac{R_{100} - R_0}{100 \cdot R_0}$$

where R_{100} is the resistance at 100 °C
R_0 is the resistance at 0 °C

The α-value according to IEC 751 is 0.00385055 °C^{-1}, normally rounded to α = 0.00385 °C^{-1}.
Other α-values also exist, for instance according to American standards.
A Pt100 sensor according to IEC 751 is often described as "Pt100, α=0.00385" and according to JIS 1604 as "Pt100, α=0.003916".

Nickel sensors

Compared to the Platinum sensors, the Nickel sensors are a less expensive, less accurate and not so stable. One small advantage could be that the resistance increases faster with the temperature, which makes it easier to design measuring instruments for Nickel sensors compared to Platinum sensors.
The Nickel sensors are mainly produced in two types: Ni 100 and Ni1000, having a resistance of 100 and 1000 Ω respectively at 0 °C.
The Nickel sensors are normally manufactured according to the European standard DIN 43760. They are standardized in the temperature range –60 to +180 °C, and only one tolerance class is being used.

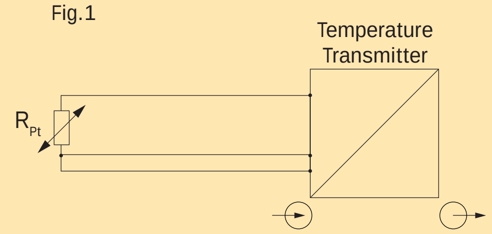
Resistance/temperature and tolerance tables

For practical reasons, the resistance/temperature equations are often converted to tables stating the approximate resistance values at different temperatures.
The tolerances for Pt100 and Ni100 sensors are also presented in tables.
See section " Tables" at the end of this catalog.

Connections to measuring instruments

The RTDs are connected to instruments such as temperature transmitters with two, three or four leads.
For more information, see the part "2, 3- and 4-wire connection for RTD sensors". ***See Figure 1.***

Fig.1



Example of a Platinum RTD in 3-wire connection with a transmitter.

Thermocouples – T/Cs

A T/C is a temperature sensor consisting of two leads in different material. The two leads are connected in one end, the Hot Junction, which is also the measuring point of the T/C. The other end of the leads, the Cold Junction, is normally connected to a temperature transmitter or some other type of measuring instrument. ***See Figure 2.***

The output from the T/C is a mV signal, also called EMF (Electromotive Force). The EMF is a function of the difference in temperature between the Hot Junction (T_1) and the Cold Junction (T_2). The relation between EMF and temperature difference depends on the materials in the two T/C leads.

Because we want the T/C to measure the temperature T_1, and it is normally not possible to keep the temperature T_2 at 0 °C, it is necessary to compensate for the deviation from 0 °C. This so called Cold Junction Compensation (CJC) can be made in a temperature transmitter. The transmitter measures the terminal temperature and performs the compensation automatically.
Besides the CJC, the temperature transmitter will measure the EMF, and create an output signal which is proportional to the temperature T_1.

Connections to measuring instruments

If a T/C is not connected directly to a measuring instrument, e.g. a temperature transmitter, the T/C has to be "extended" up to the transmitter by means of a Extension or Compensation cable.
These cables have the same effect, as if the T/C was reaching all the way to the transmitter, which means that the Cold Junction is transferred to the terminals of the transmitter, where the Cold Junction Compensation is performed. ***See Figure 3.***

Extension and Compensation cables

Extension cables
Extension cables are made from the same materials as the T/C and can be regarded as a direct extension of the T/C with a very small influence on the accuracy.
Compensation cables
Compensation cables are used together with T/Cs of more expensive materials such as Pt and Rh. The characteristics of the compensation cables are very similar to the corresponding T/C. The tolerances are higher, so the compensation cables should not be used over certain temperatures, typically 200 °C.

T/C types

There are a number of standardized T/C types available on the market. They all have different properties, which make them more or less suitable for different applications.
The following T/C types are well known and standardized according to the European standard IEC 584-1 (some also acc. to American standards):

- *Type B, Pt30%Rh-Pt6%Rh*
- *Type E, NiCr-CuNi*
- *Type J, Fe-CuNi*
- *Type K, NiCr-Ni*
- *Type N, NiCrSi-NiSi*
- *Type T, Cu-CuNi*
- *Type R, Pt13%Rh-Pt*
- *Type S, Pt10%Rh-Pt*

The mV/temperature characteristics and the tolerances for the different T/C types can be found at the end of this catalog.
See section "Tables".

Fig.2

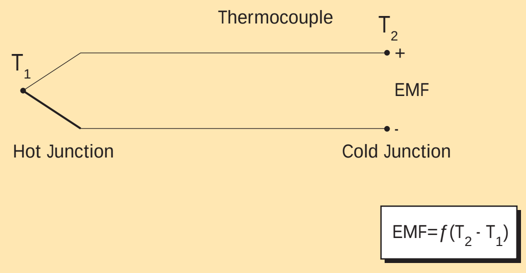


Fig.3