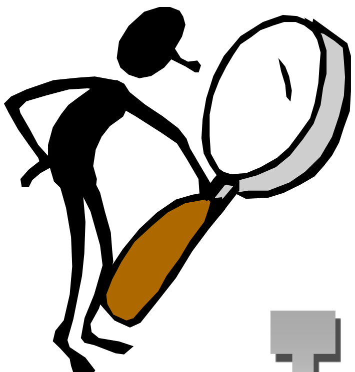
Level 1
Fundamental Training



Temperature

Contents

Why measure temperature?

- **Because temperature affects:**
  - ***rate of reaction***
  - ***viscosity***
  - ***state of a matter***
  - ***strength of materials***
  - ***quality & taste of food***
  - ***safety of a process***

- **Temperature is critical to the following process:**
  - ***Pulp & Paper***
  - ***Food Industry Pasteurisation***
  - ***Vacuum Packaging***
  - ***Chemical Industry***

Why measure temperature?
4 Common Reasons

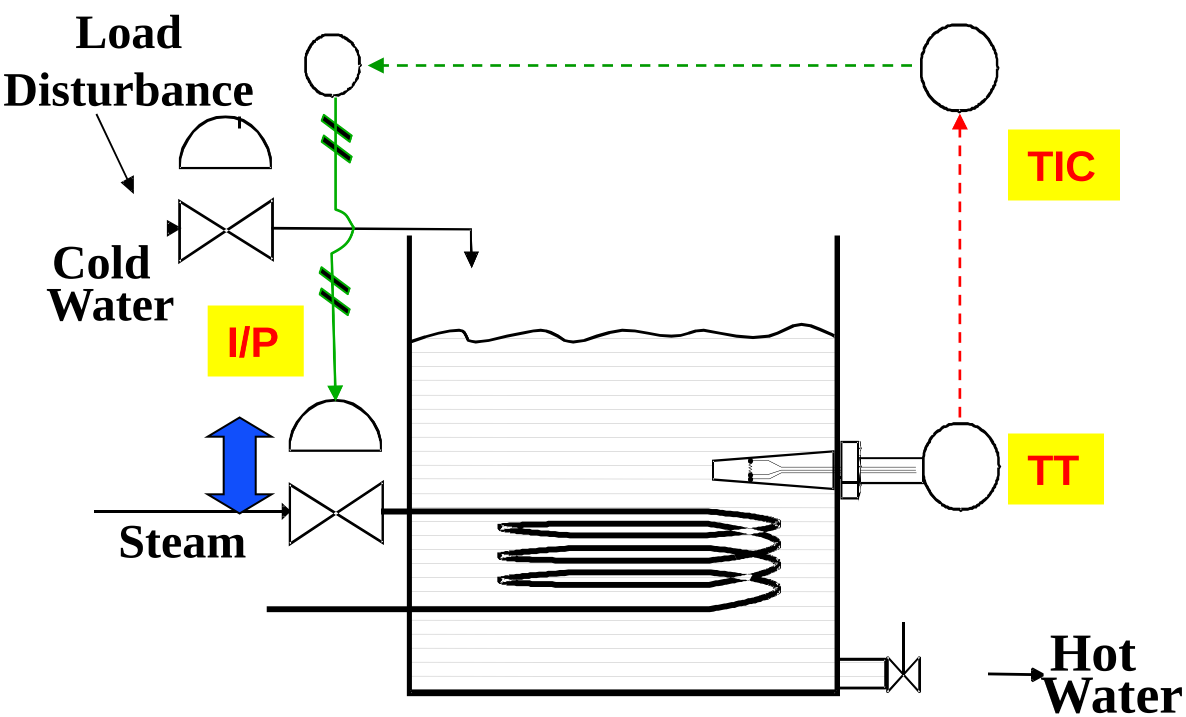
- **Safety**
  - **to prevent explosion as a result of excessive temperature**
- **Efficiency**
  - **example:- Air -Conditioning**
    - » accurate temperature measurement prevent the supplier from overcooling the air, which saves energy and increases efficiency
- **Product Quality & Yield**
  - **variation from optimum temperature result in**
    - » very little production of the desired product
    - » creation of waste product
  - **precise temperature measurement ensures efective separation of products in**
    - » distillation column
    - » catalytic cracking processes

Why measure temperature?
4 Common Reasons

- **Custody Transfer**
  - **amount of material that is bought & sold**
  - **extremely important to know exact temperature when determining volumetric flow rate of gas**
  - **amount of material contained in a specific volume of gas**
    - » decreases with rising temperatures
    - » increases with falling temperatures
  - **inaccurate temperature measurement result in**
    - » over or under-charging customers during custody transfer

Temperature terminology
Temperature Control Loop

- **Temperature Loop Issues:**
  - Fluid response slowly to change in input heat
  - Requires advanced control strategies
    - **Feedforward Control**



Temperature terminology

Temperature Measurement Scales

	KELVIN	CELSIUS	RANKINE	FAHRENHEIT
BOILING POINT OF WATER	373	100°	672	212°
ICE POINT	273	0°	492	32°
ABSOLUTE ZERO	0	-273°	0	-460°

Kelvin & Rankine are absolute scales

°C = 5/9 (°F - 32)

°F = 9/5 (°C) + 32

K = 273 +°C

R = 460 + °F

Temperature terminology

Temperature Measurement Scales

Example #1

20°C = 20 + 273 = 293K

20°C = 9/5(20) +32 = 68°F*

Differential Temperature

°C = 5/9 °F

°F = 9/5 °C

K = °C

°R = °F

Example: 2 points in a process differ in temperature by 100 °C. These 2 points differ by 180 °F

i.e. 180 = 9/5(100)

Whereas, they also differ by 100K

METALS change in VOLUME in response to change in TEMPERATURE & DISSIMILAR METAL STRIPS having different COEFFICIENT of VOLUME CHANGE.

Example: ***Bimetallic Thermometer***
Thermocouple *(discussed later)*

Bimetallic Thermometer

The degree of deflection of 2 dissimilar metals is proportional to the change in temperature.

One end of the spiral (wounded from a long strip of material) is immersed in the process fluid and the other end attached to a pointer.

Expansion & Contraction of FILLED THERMAL FLUIDS

Example: Vapour Pressure Thermometer

A bulb connected to a small bore capillary which is connected to an indicating device.

Indicating device consist of a spiral bourdon gauge attached to a pointer.

The bulb is filled with a volatile liquid and the entire mechanism is gas tight and filled with gas or liquid under pressure.

Basically the system converts pressure at constant volume to a mechanical movement.

Change in RESONANT FREQUENCY of crystal in response to change in TEMPERATURE

Example: Quartz Crystal Thermometers

Quartz crystal hermetically sealed in a stainless steel cylinder, similar to a thermocouple or RTD sheath but , larger.

Quartz crystal converts temperature into a frequency.

They provide good accuracy and response time with excellent stability.

Hence, this technology is expensive.

Collection of THERMAL RADIATION from an object subjected to HEAT

Example: Radiation Pyrometry

Infers temperature by collecting thermal radiation from process and focusing it on a photon detector sensor.

The sensor produces and output signal as radiant energy striking it releases electrical charges.

Change in RESISTANCE with response to change in TEMPERATURE

Example: ***Thermistors***

RTD *(discussed later)*

Thermistors

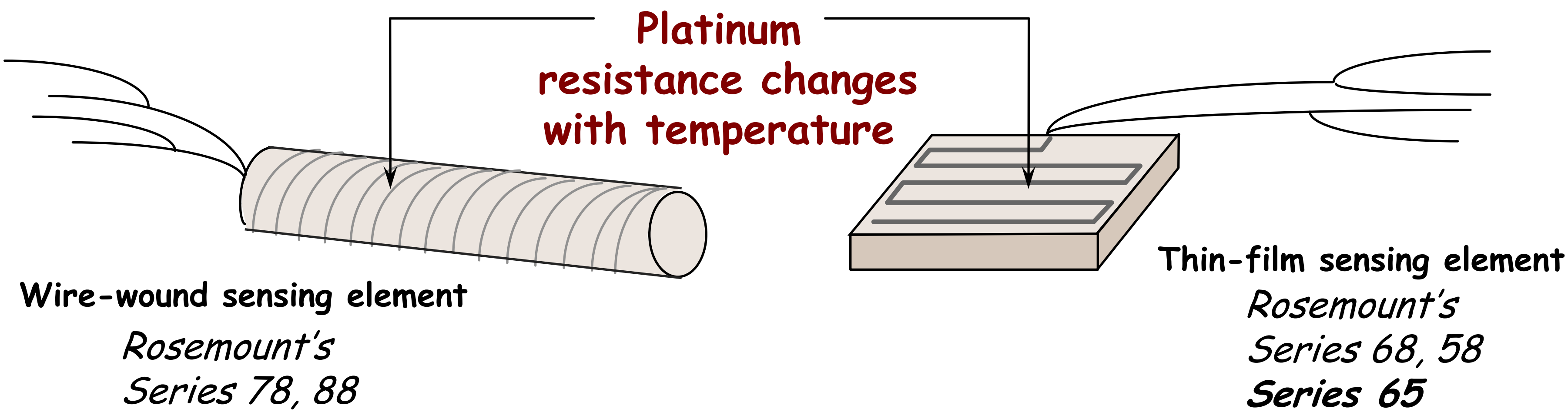
Semi-conductors made from specific mixtures of pure oxides of nickel, manganese, copper, cobalt, and other metals sintered at very high temperature.

Used with Wheatstone Bridge which amplifies small change in resistance - in a simple circuit with a battery and a micro-ammeter.

- *Stability* - **Moderate**
- *Linearity* - **Poor (Logarithmic)**
- *Slope of Output* - **Negative**

What is an RTD ?

- **Resistance Temperature Detector**
  - » ***Operation depends on inherent characteristic of metal (Platinum usually): electrical resistance to current flow changes when a metal undergoes a change in temperature.***
  - » ***If we can measure the resistance in the metal, we know the temperature!***



Two common types of RTD elements:

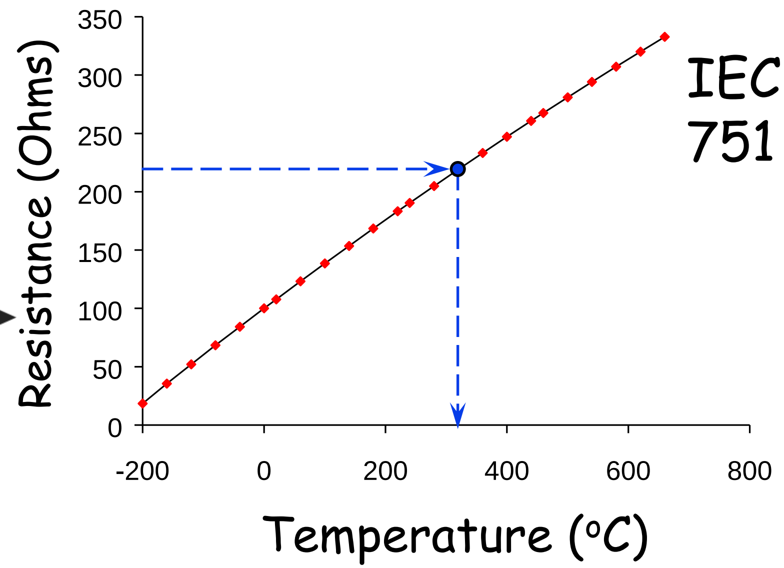
How does a RTD works?

- Resistance changes are Repeatable
- The resistance changes of the platinum wiring can be approximated by an ideal curve -- the IEC 751

International Resistance vs. Temperature Chart:

°C	Ohms
0	100.00
10	103.90
20	107.79
30	111.67

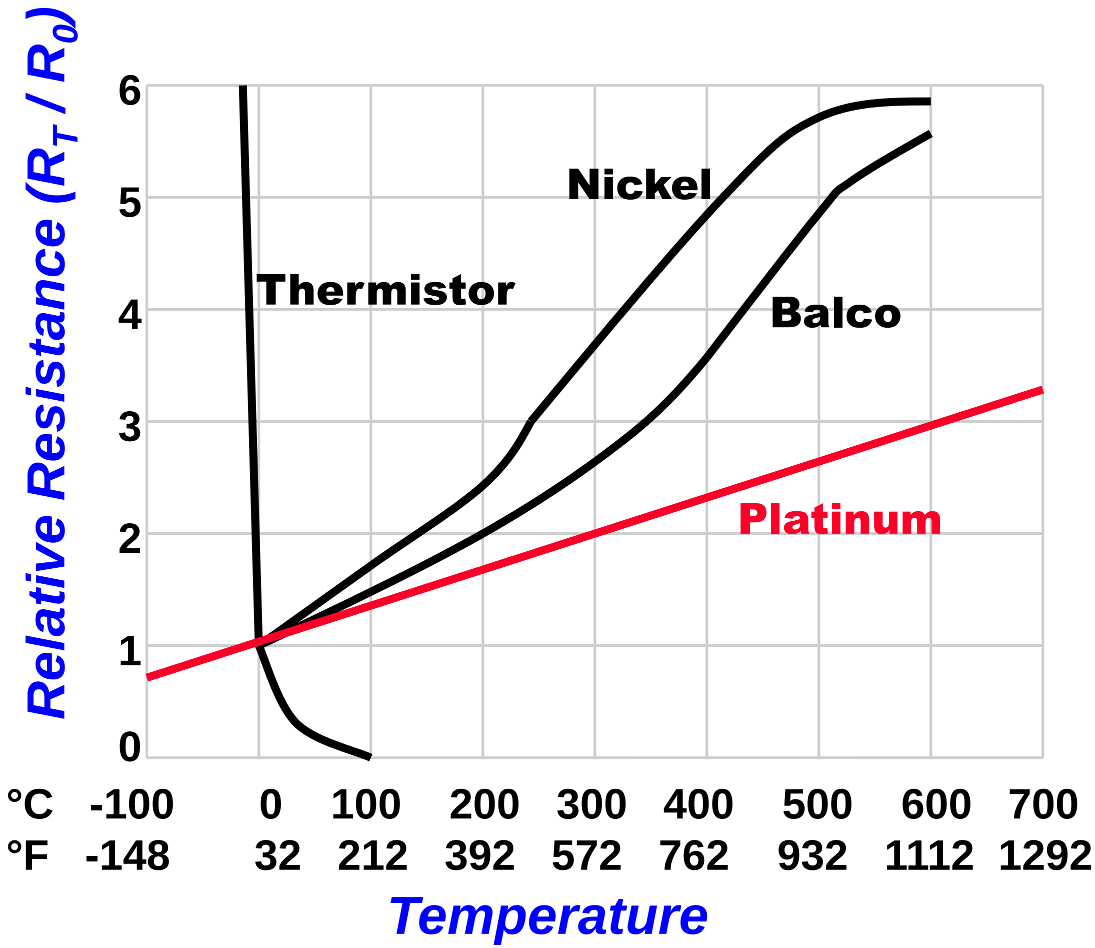
IEC 751



IEC 751 Constants are :- A = 0.0039083, B = - 5.775 x 10 $^{-7}$,
If t>=0°C, C=0, If t<0, C = - 4.183 x 10 $^{-12}$

Example: $$R_T = R_0 [1 + At + Bt^2 + C(t-100)t^3] = 103.90$$

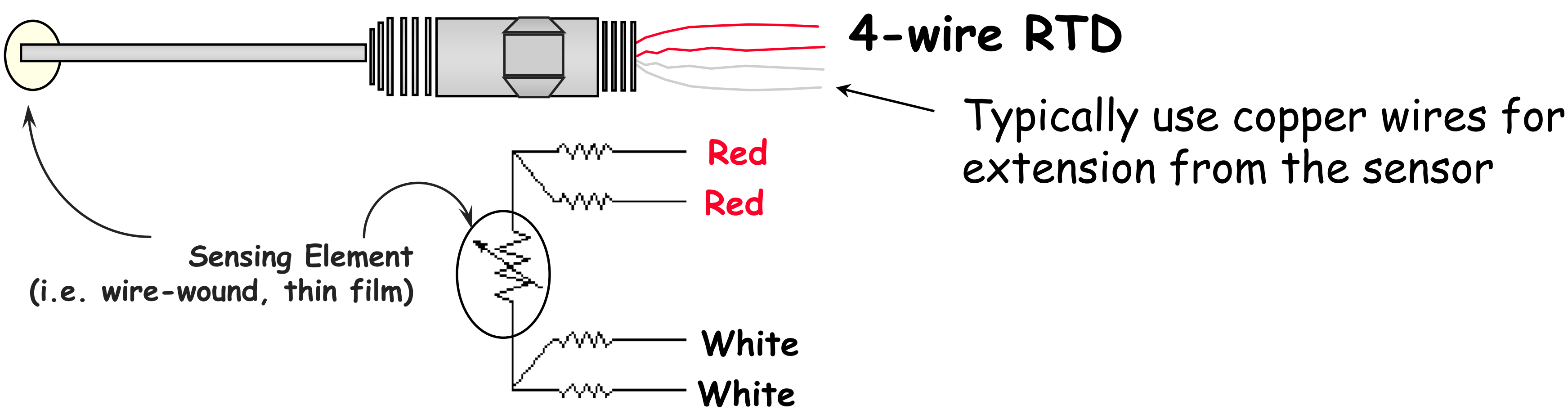
Platinum vs other RTD materials



- *Most linear*
- *Most Repeatable*
- *Most Stable*
- *Positive Slope*

Why use a 2-, 3-, or 4- wire RTD?

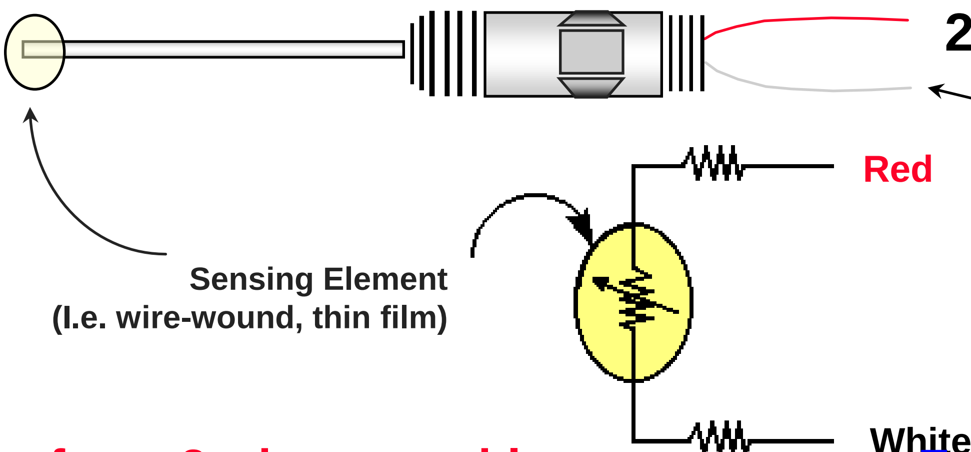
- **2-wire:** *Lowest cost -- rarely used due to high error from lead wire resistance*
- **3-wire:** *Good balance of cost and performance. Good lead wire compensation.*
- **4-wire:** *Theoretically the best lead wire compensation method (fully compensates); the most accurate solution. Highest cost.*



Temperature Sensors
RTDs

2-wire or 4-wire RTD ?

- **If the sensing element is at 20°C,**
  - What would be the temperature measured at the end of the extension wire using a 2-wire assembly
  - What would be the temperature measured at the end of the extension wire using a 4-wire assembly



2-wire RTD

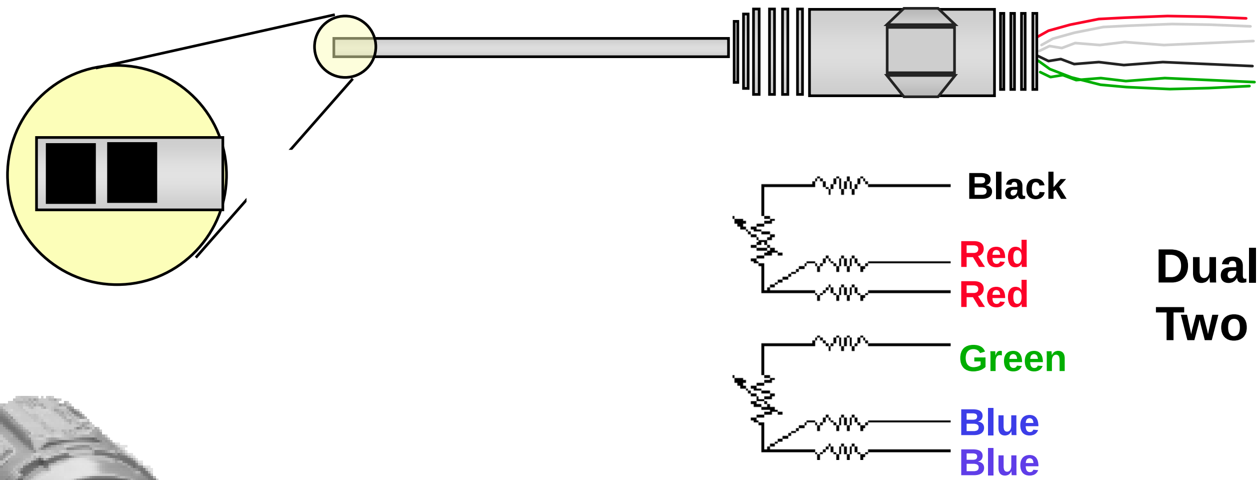
6 metres of copper extension wire, lead resistance = 0.06 ohms/metre

(1 ohm = 2.5 deg C approx)

Error for a 2 wire assembly
0.06 x 6 x 2 = 0.72 ohms or 1.8Deg C
This means that the temperature measured at the end of the cable would be 21.8 Deg C

Error for a 4 wire assembly
As the lead resistances can be accounted for the temperature measured at the end of the cable would be 20.0 Deg C

Dual Element RTDs available

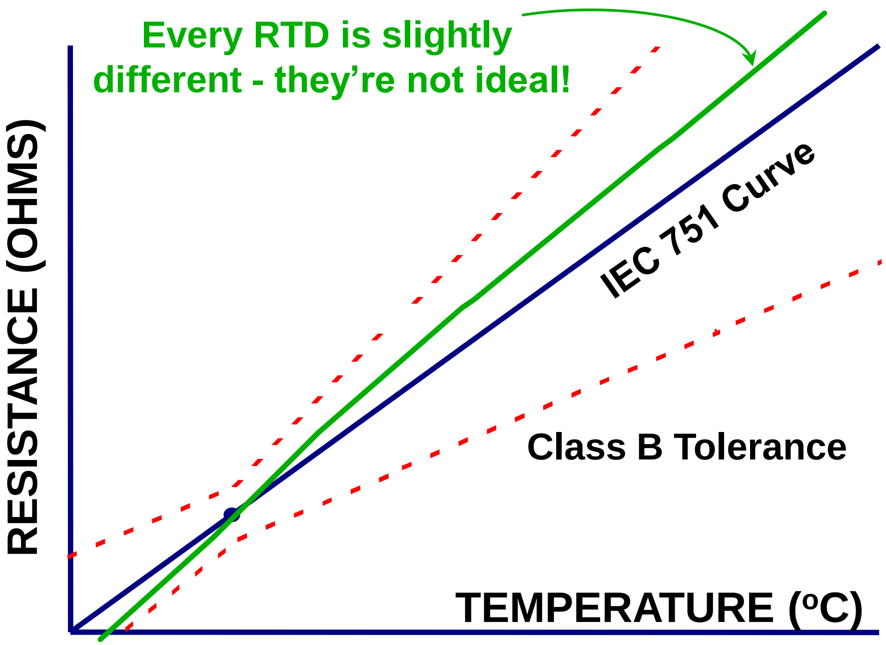


Dual Element:
Two 3-wire RTDs

- Supports Hot Backup capability
- Dual element adds only $5 over single element RTD
  - » *Reduce the risk of a temperature point failure*
- Supports Differential Temperature Measurement

Temperature Sensors
RTDs

The IEC 751 standard curve (programmed into all our transmitters) describes an IDEAL Resistance vs Temperature relationship for Pt100 α = 0.00385 RTDs.



Standard IEC 751 Curve
Class B Tolerance

- ± **0.8ºC at -100ºC**
- ± **0.3ºC at 0ºC**
- ± **0.8ºC at 100ºC**
- ± **1.3ºC at 200ºC**
- ± **1.8ºC at 300ºC**
- ± **2.3ºC at 400ºC**

(Sensor Interchangeability Error)

The goal is to find out what the real RTD curve looks like, and reprogram the transmitter to use the "real" curve!

- **EN 60751 Tolerances**
  - – Pt 100, $\alpha = 0.00385$

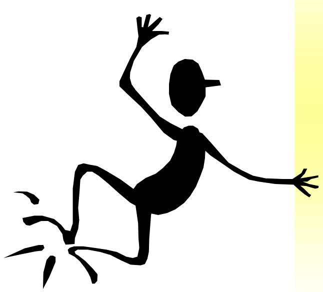
Temperature °C	Resistance Ohms	Accuracy			
		Grade A ± °C	Grade A ± Ohms	Grade B ± °C	Grade B ± Ohms
-200	18.52	0.55	0.24	1.3	0.56
-100	60.26	0.35	0.14	0.8	0.32
0	100.00	0.15	0.06	0.3	0.12
100	138.51	0.35	0.13	0.8	0.30
200	175.85	0.55	0.2	1.3	0.48
300	212.05	0.75	0.27	1.8	0.64
400	247.09	0.95	0.33	2.3	0.79
500	280.98	1.15	0.38	2.8	0.93
600	313.71	1.35	0.43	3.3	1.06

Temperature Sensors
RTDs

Quiz: - Find the Interchangeability Error

Your customer is operating a process at *100°C* and is using a Platinum RTD...

What is the maximum error that will be introduced into the temperature measurement from Sensor Interchangeability?



+/-0.35 deg C for Class A,
+/-0.8 deg C for Class B
Fortunately, Sensor Interchangeability Error can be reduced or eliminated by Sensor Matching!

What is RTD Calibration?

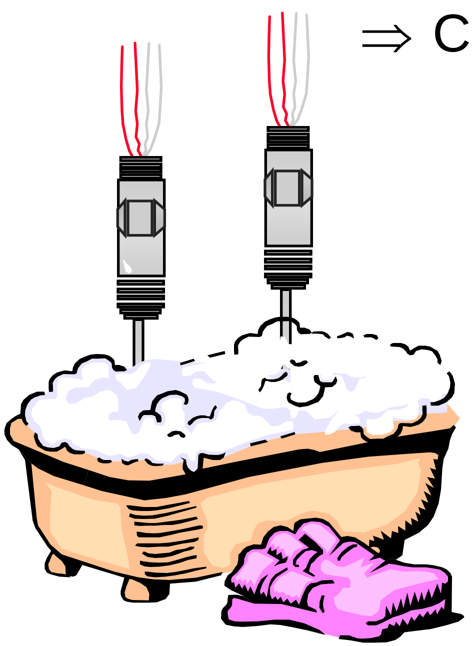
– The real RTD curve is found by “characterizing” an RTD over a specific temperature range or point.

» ***Temperature Range Characterization***

⇒ Calibration certificate provided with sensor

» ***Temperature Point Characterization***

⇒ Calibration certificate provided with sensor



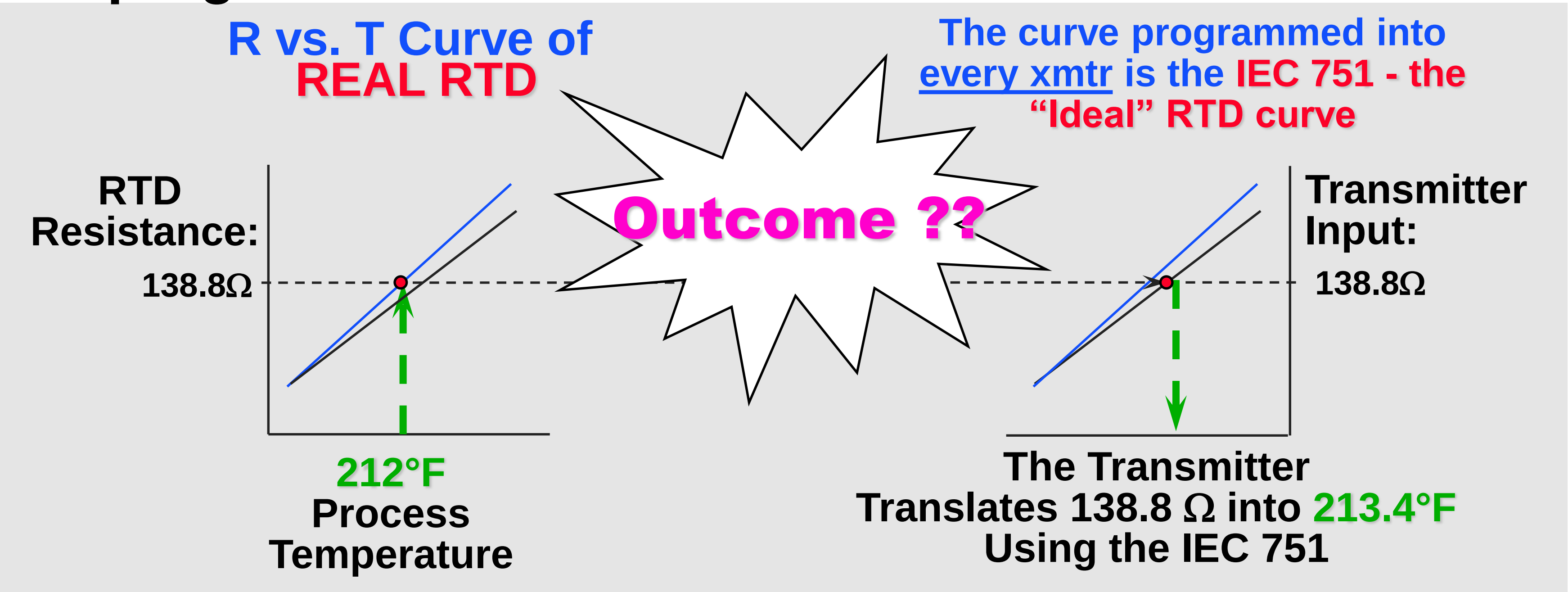
Data generated
(RTD “characterized”)

Temperature Bath
- One temperature
- Multiple temperatures

Customer Receives RTD-specific Resistance vs. Temperature Chart:

°C	Ohms
0.0	99.997
1.0	100.38
2.0	100.77
3.0	101.16

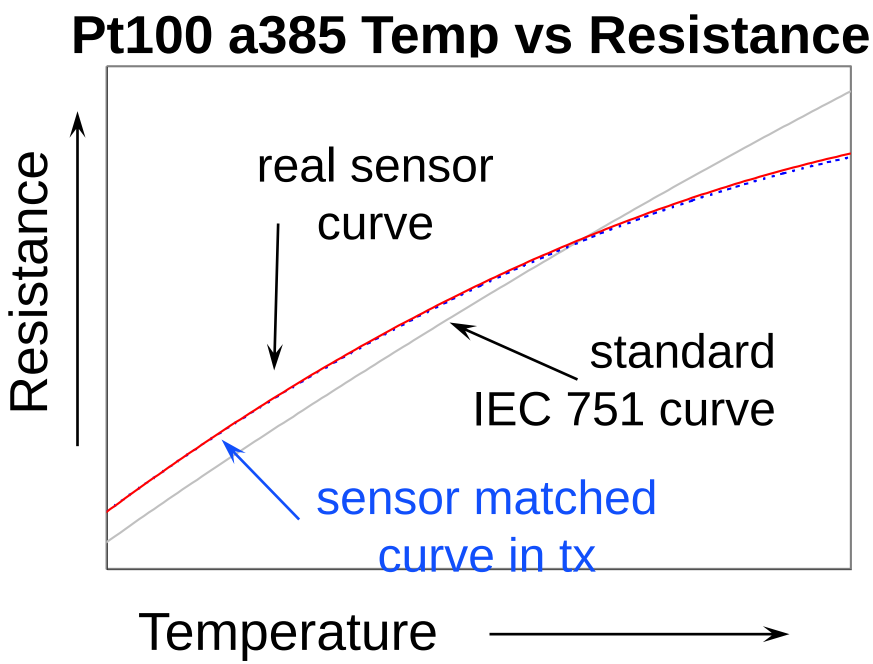
With a Real RTD, the Resistance vs. Temperature relationship of the sensor is NOT the same curve that is programmed into the transmitter

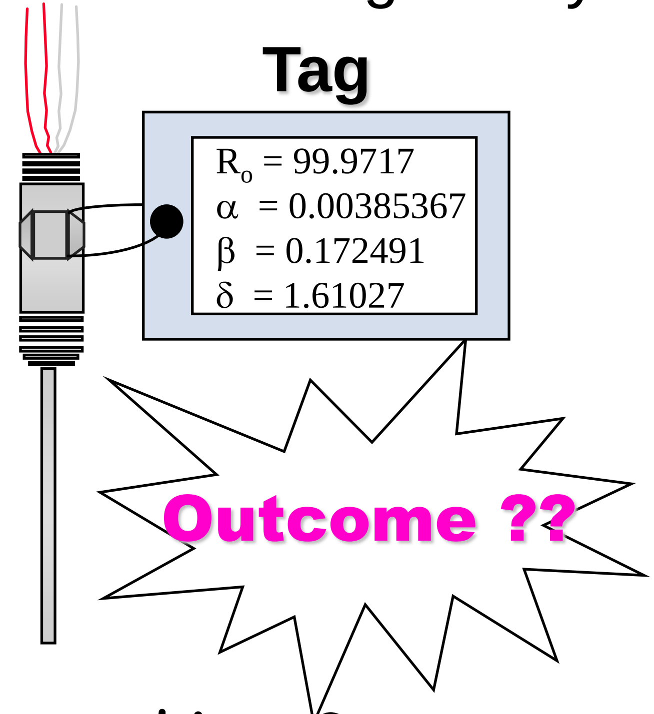


- Transmitter curve does NOT match RTD curve.
- Transmitter reading does NOT equal process temperature.

If we could tell the transmitter the shape of the "Real" RTD curve, we could eliminate the interchangeability error!

Sensor Matching - eliminates sensor interchangeability error

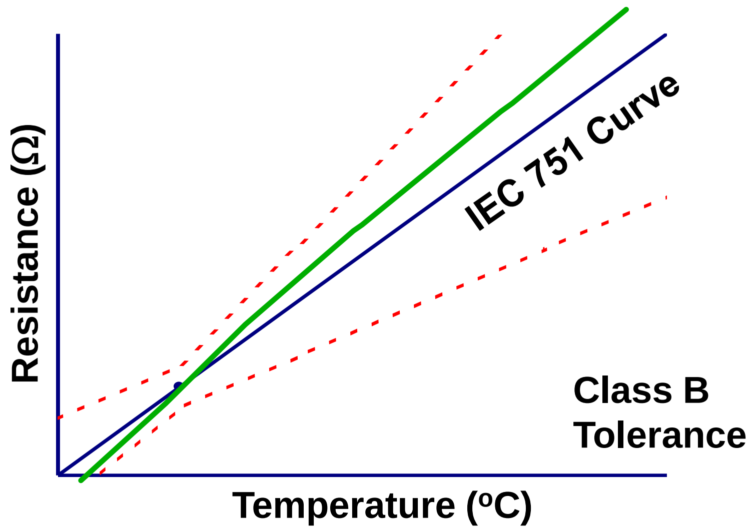




A fourth order equation can be programmed into Smart Transmitters to follow non-ideal sensor curvature; simply enter four constants using 275.

- **Transmitter curve is perfectly matched to "ideal" RTD curve**
- **Transmitter reading equals process temperature**

Sensor Matching - Mapping the Real RTD Curve



- The transmitter does not use the IEC 751 standard curve.
- Instead, the Callendar-Van Dusen constants can be used in the equation below to create the true sensor curve.
- Or, the actual IEC 751 constants A,B, and C can be used in the IEC 751 equation if known.

$$R_t = R_o + R_o\alpha[t-\delta(0.01t-1)(0.01t)-\beta(0.01t-1)(0.01t)^3]$$

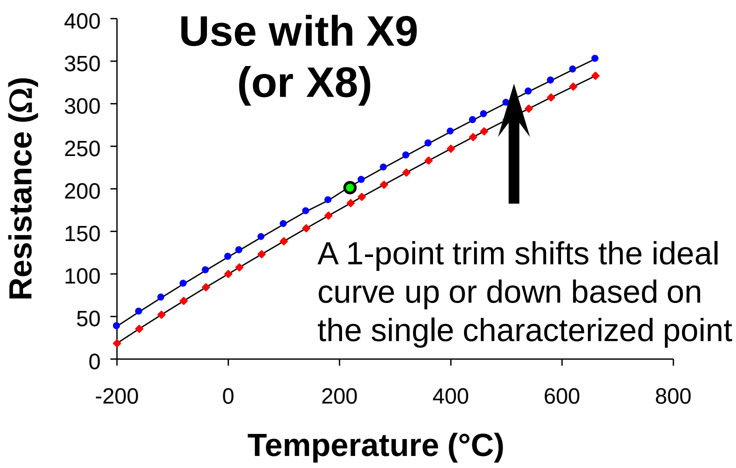
4th Order Callendar-Van Dusen Equation

R_t = Resistance at Temperature t (°C)
R_o = Sensor-Specific Constant (Resistance at t = 0°C)
α = Sensor-Specific Constant
δ = Sensor-Specific Constant
β = Sensor-Specific Constant (If t >=0°C, then $\beta = 0$)

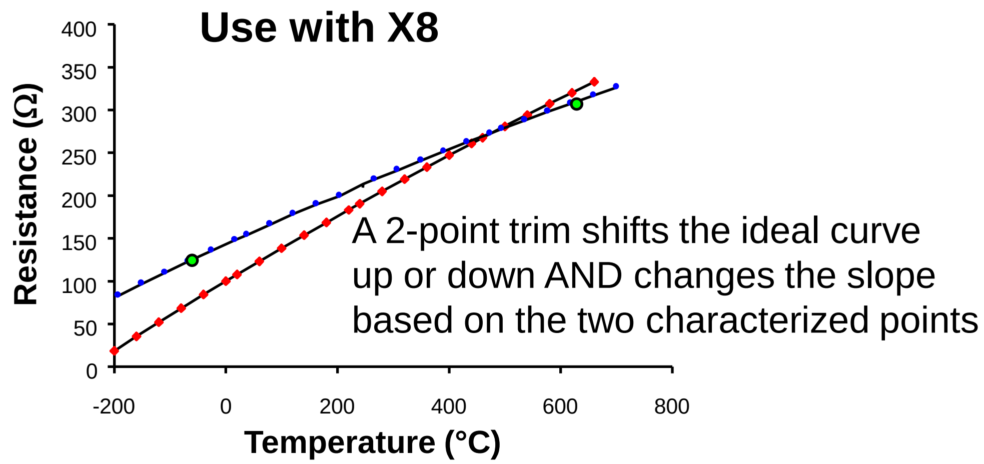
Sensor Trimming

- Data from the resistance vs. temp. chart can be used to reduce sensor interchangeability error
- Use one or two points to trim the sensor to a transmitter

One Point Trim

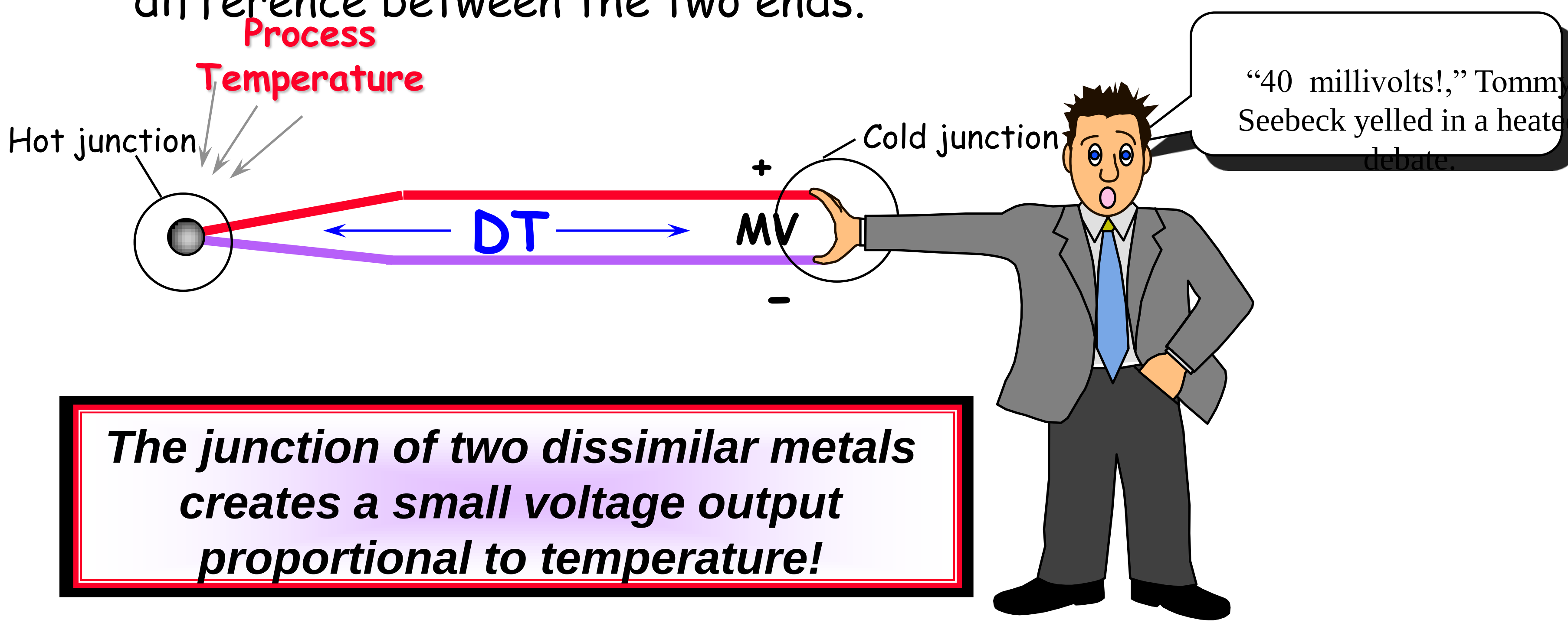


Two Point Trim



What is a Thermocouple ?

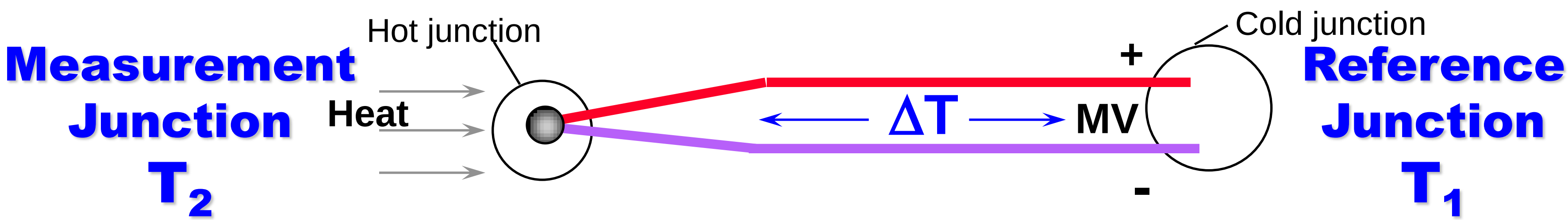
- Two dissimilar metals joined at a "Hot" junction
- The wires are connected to an instrument (voltmeter) that measures the potential created by the temperature difference between the two ends.



The junction of two dissimilar metals creates a small voltage output proportional to temperature!

How does a Thermocouple work ?

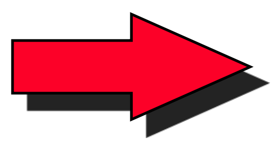
– The measured voltage is proportional to the temperature difference between the hot and cold junction! $(T_2 - T_1) = \Delta T$.

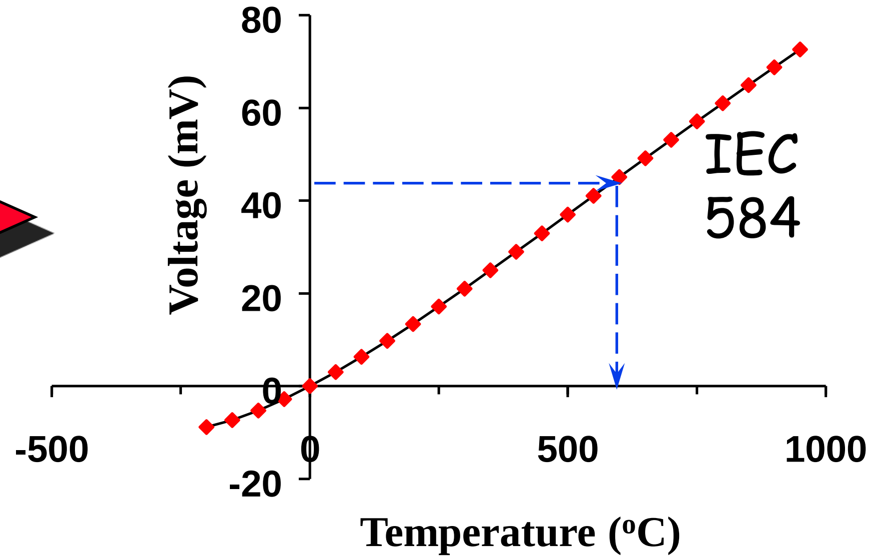


Thermoelectric Voltage vs. Temperature Chart:

°C	Millivolts
0	0.000
10	0.591
20	1.192
30	1.801

TYPE E THERMOCOUPLE

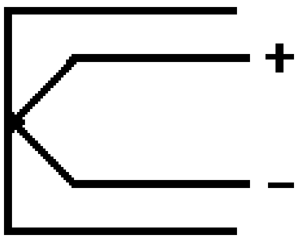




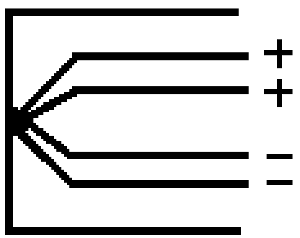
Hot-Junction Configurations

– ***Grounded***

- improved thermal conductivity
- quickest response times
- susceptible to electrical noise



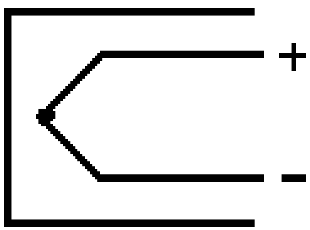
Single Grounded



Dual Grounded

– ***Ungrounded***

- slightly slower response time
- not susceptible to electrical noise

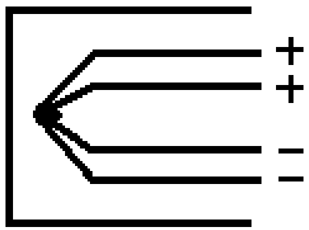


Single Ungrounded

Hot-Junction Configurations

– ***Unisolated***

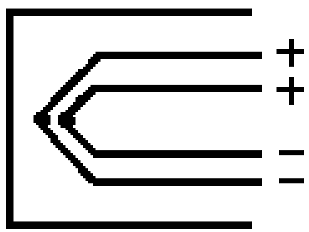
- junctions at the same temperature
- both junctions will typically fail at the same time



Dual Ungrounded, Un-isolated

– ***Isolated***

- junctions may/may not be at the same temperature
- increased reliability for each junction
- failure of one junction does not affect the other



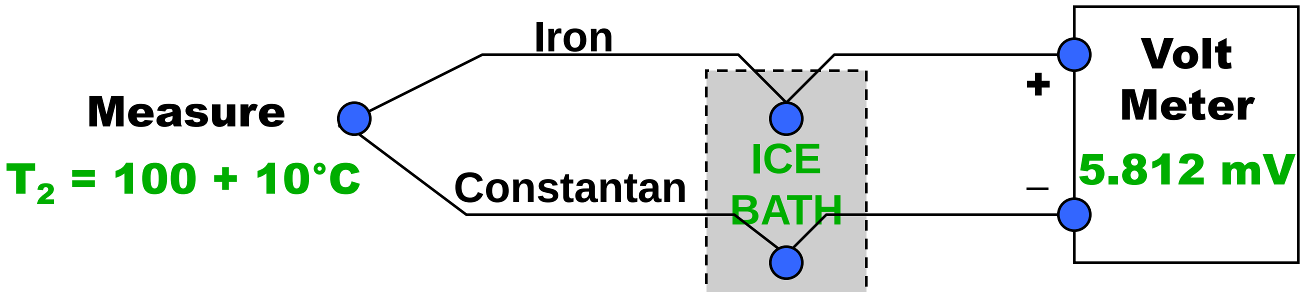
Dual Ungrounded, Isolated

Why is Cold Junction Compensation needed?

– Reference Junction must be kept constant.

» ***2 Methods used to accomplished this :***

- **Place Reference Junction in Ice Bath**



Reference

T_1 = 0°C

Δ T = 110°C

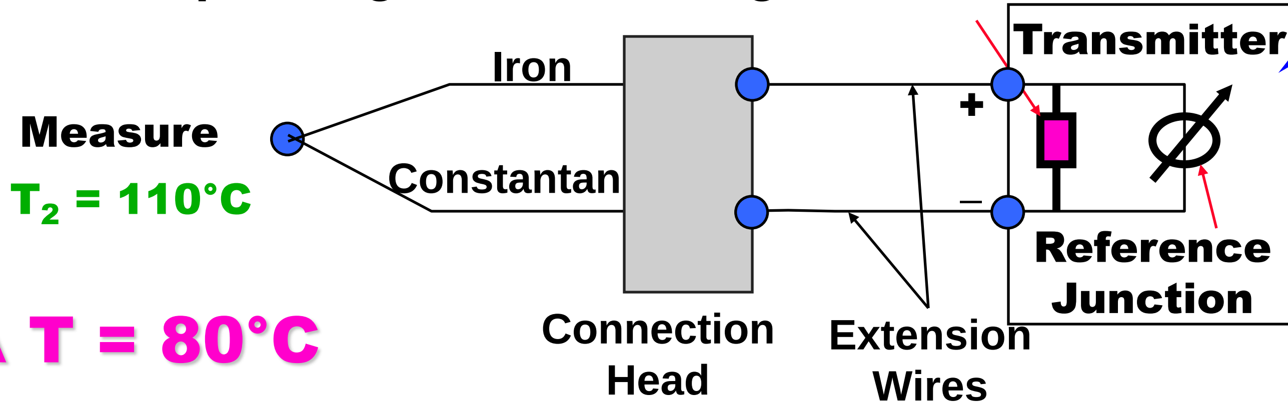
°C	-100	-0	+0	100
	MILLIVOLTS			
0	-4.632	0.000	0.000	5.268
2	-4.550	-0.995	1.019	5.376
6	-4.876	-0.301	0.303	5.594
10	-5.036	-0.501	0.507	5.812
14	-5.194	-0.699	0.711	6.031

NOT Practical !

What is Cold Junction Compensation

– Electronic Circuitry

» passing current through a Thermistor



Example:
Ambient Temp = 30°C

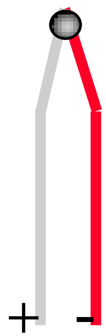
4.186 mV
+
1.536 mV
= 5.722 mV
» 110°C

Δ T = 80°C

Common Practise !

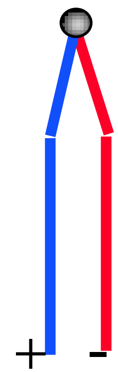
°C	-100	-0	+0	100
	MILLIVOLTS			
0	-4.632	0.000	0.000	5.268
10	-5.036	-0.501	0.507	5.812
30	-5.801	-1.481	1.536	6.907
60	-6.821	-2.892	3.115	8.560
80	-7.402	-3.785	4.186	9.667

Types of Thermocouple



- **Type J**
  - Iron / Constantan
    - White, Red
    - 0 to 760 °C
    - *Least Expensive*

- **Type K**
  - Chromel / Alumel
    - » Yellow, Red
    - » 0 to 1150 °C
    - » *Most Linear*

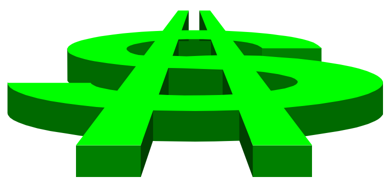


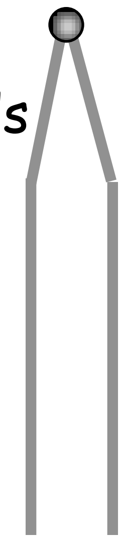
- **Type T**
  - Copper / Constantan
    - » Blue, Red
    - » -180 to 371 °C
    - » *Highly resistant to corrosion from moisture*

Temperature Sensors
Thermocouples

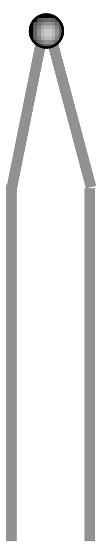
Other Types

- High temperature range
- Industrial/ laboratory standards
- *LOW* EMF output!
  (Not very sensitive)
- **Expensive!**

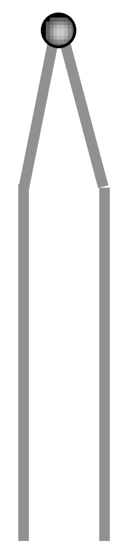




☞ **Type R**
- Pt, 13% Rh / Pt
  - » **-50 to 1540 °C**



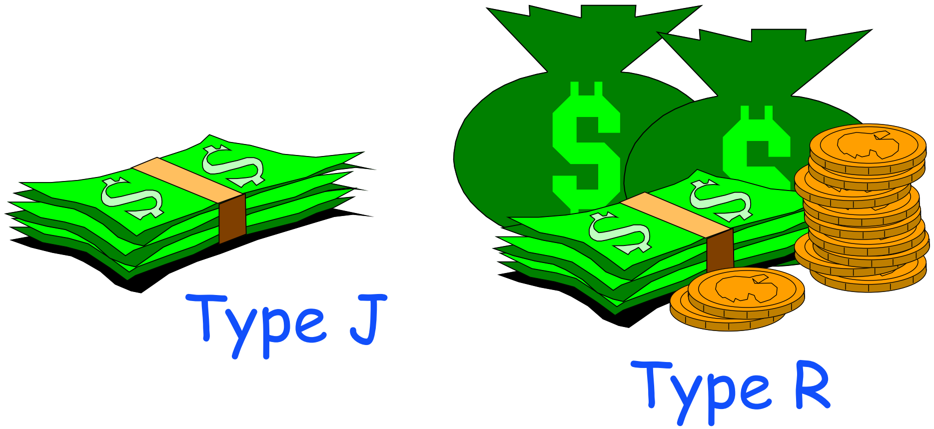
☞ **Type B**
- Pt, 6% Rh / Pt, 30% Rh
  - » **38 to 1800 °C**

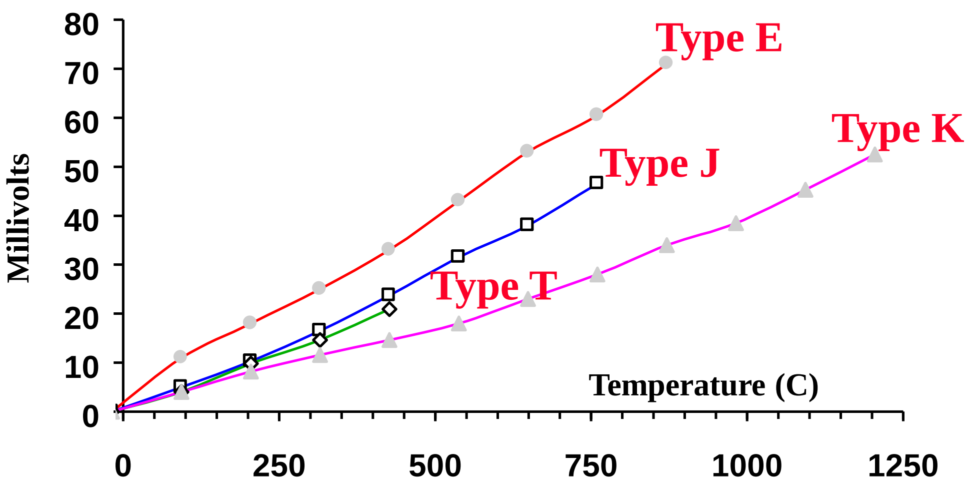


☞ **Type S**
- Pt, 10% Rh / Pt
  - » **-50 to 1540°C**

Why use one type over another ?

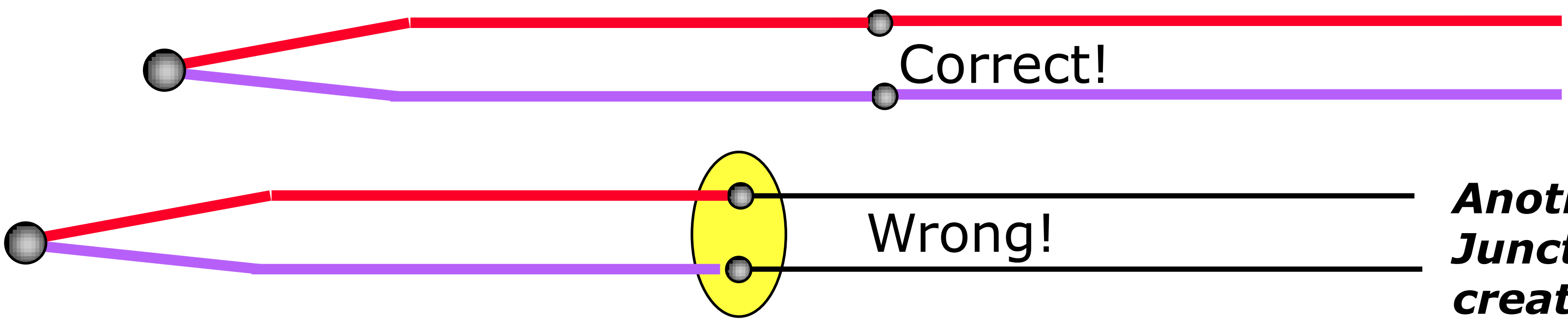
- ***Temperature range***
- ***Cost***





- ***Signal level***
- ***Linearity of the range***

All thermocouple lead wire extensions MUST be with the same type of wire!



Another Hot Junction is created... not good!

Cannot use copper wire for extensions! T/C wire is more expensive to run and much harder to install!

Why choose RTD over Thermocouple ?

Better Accuracy & Repeatability

- RTD signal less susceptible to noise
- Better linearity
- RTD can be "matched" to transmitter (Interchangeability error eliminated)
- CJC error inherent with T/C's; RTD's lead wire resistance errors can be eliminated

Better Stability

- T/C drift is erratic and unpredictable; RTD's drift predictably
- T/C's cannot be re-calibrated

Greater Flexibility

- Special extension wires not needed
- Don't need to be careful with cold junctions

Why choose thermocouple over RTD ?

Applications for Higher Temperatures

- Above 1100°F

Lower Element Cost

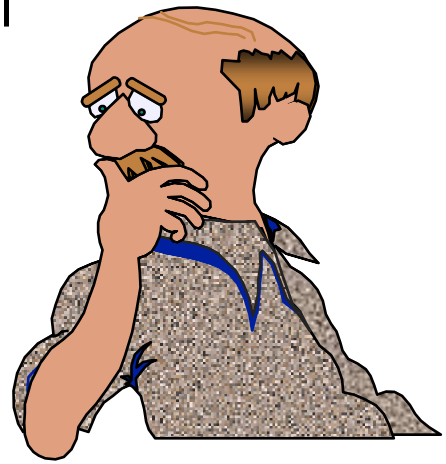
- Cost is the same when considering temperature point performance requirements

Faster response time

- Insignificant compared to response time for T-Well and process

Perceived as more rugged

- Rosemount construction techniques produce extremely rugged RTD



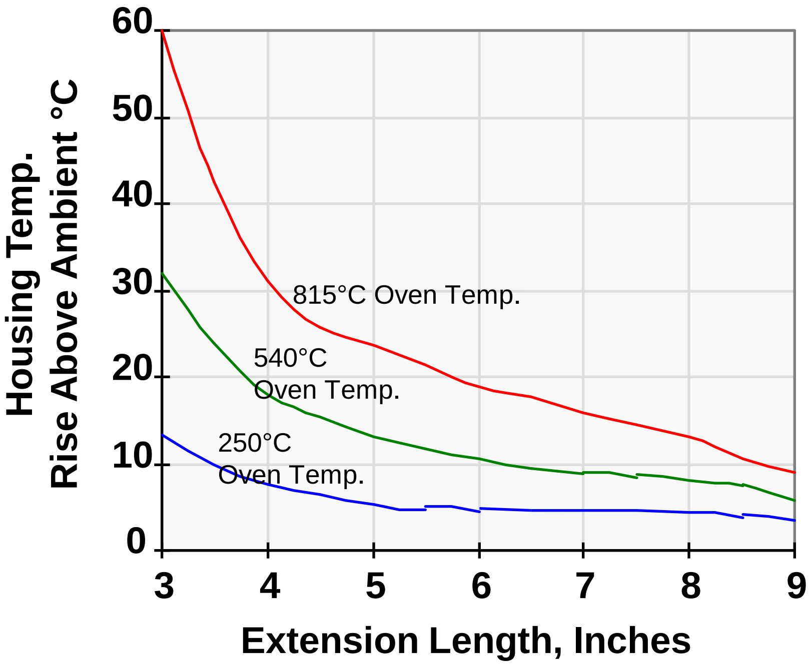
Temperature Sensors
Comparison

RANGE	OFFER
-200 to 500º C	**RTD**
500 to 1100º C	**Thermocouple** Type K
>1100º C	Special **Thermocouple** R, S or B

Sensor accessories
Extension Fittings

- **Extension fittings are used for a number of reasons :**
  - **Heat dissipation from the process to the transmitter**
  - **Extend sensor through tank jacket or pipe insulation**
  - **Ease of accessibility through mounting in hard to reach areas**
  - **Disconnect sensor from process without full disassembly (Union)**
  - **Two types of Assembly**
    - Coupling and nipple assembly
    - Union and nipple assembly

Transmitter Housing Temperature Rise vs.Extension Length for a test Installation



Example of Application

- ***Example #1***
  - **4 inch**

32°C + 30°C

62°C Ceiling

- ***Example #2***
  - **6 inch**

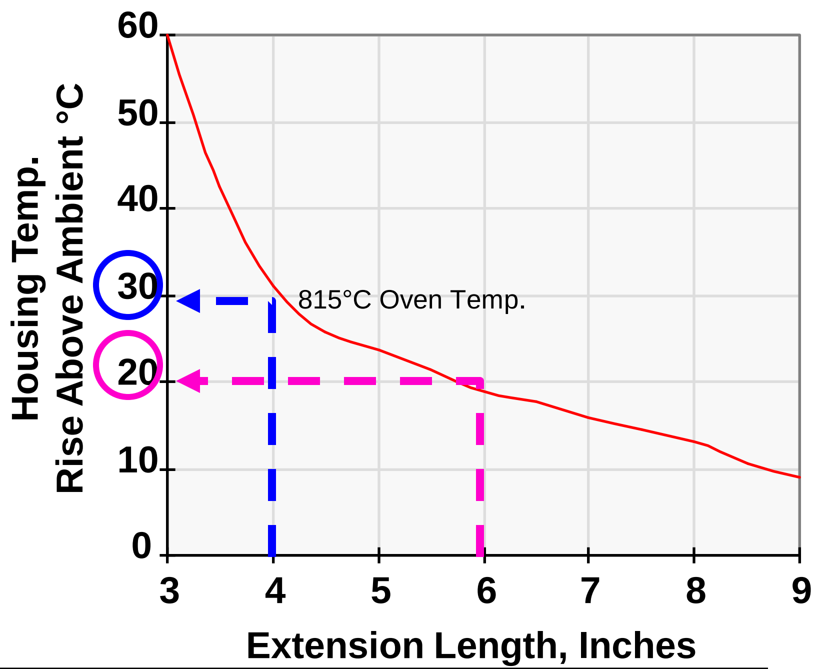
32°C + 20°C

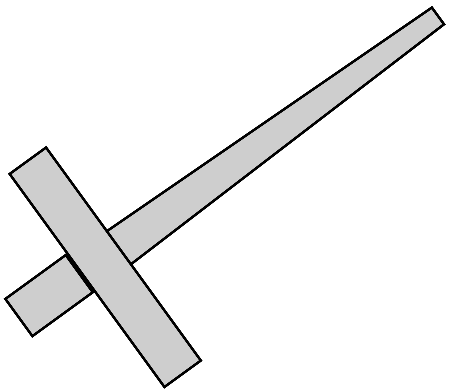
52°C Ceiling

Lets say:

Temp Limit of Transmitter is 70°C
Amb. Temp is 32°C

Transmitter Housing Temperature Rise vs.Extension Length for a test Installation





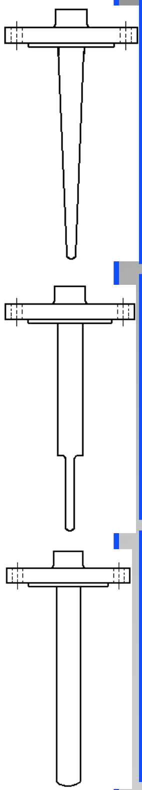
What is a thermowell (T-well) ?

- A unit that protects a sensor from process flow, pressure, vibrations, and corrosion
- Allows for sensor removal without process shutdown
- Slows response time (by 5 times)

Why are there different material types ?

- *To handle different corrosive environments*
- *To handle different temperature and pressure limits*

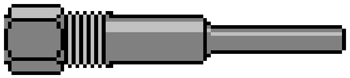
Thermowell Design Styles - *Comparison Table*



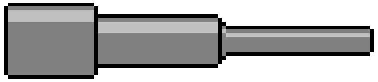
Rating: 1= Best	Process Pressure	Time Response	Wake Frequency	Price	Drag Force
Tapered	1	2	1 or 2	3	2
Stepped	1	1	3	1	1
Straight	1	3	1 or 2	1	2

Thermowell Mounting Styles

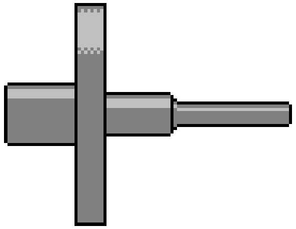
- Threaded
  - *Most common*
  - *Easy to remove and install*



- Welded
  - *Non-removable*
  - *Used in high velocity, temperature and pressure fluids*
  - *Used in non-leak applications*



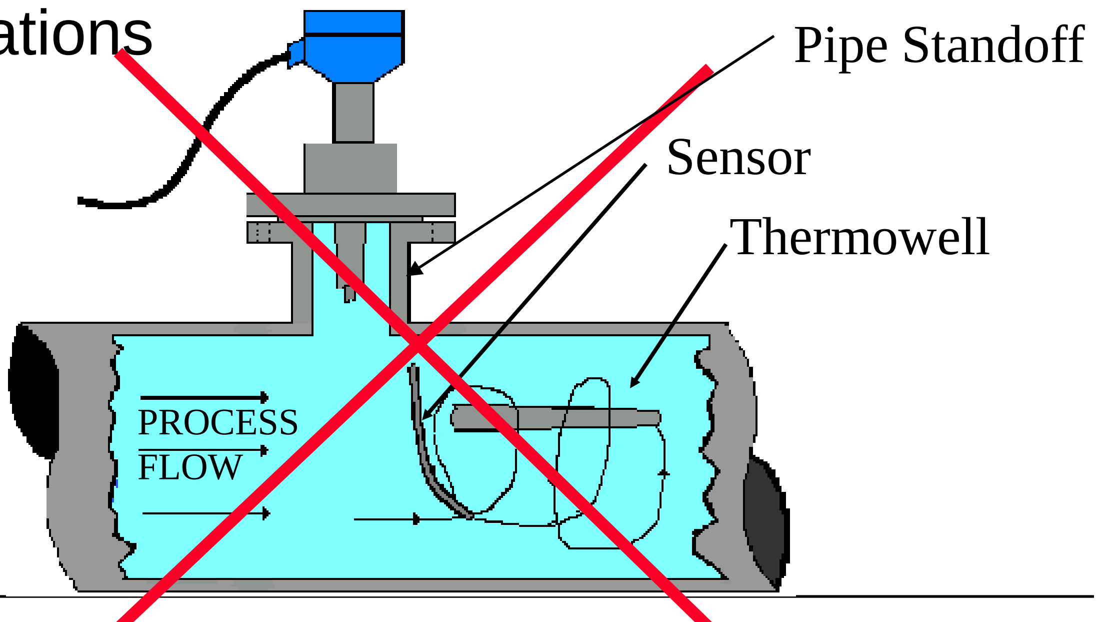
- Flanged
  - *Used in corrosive environments*
  - *Used in high velocity, and high temperatures*



What is thermowell analysis ?

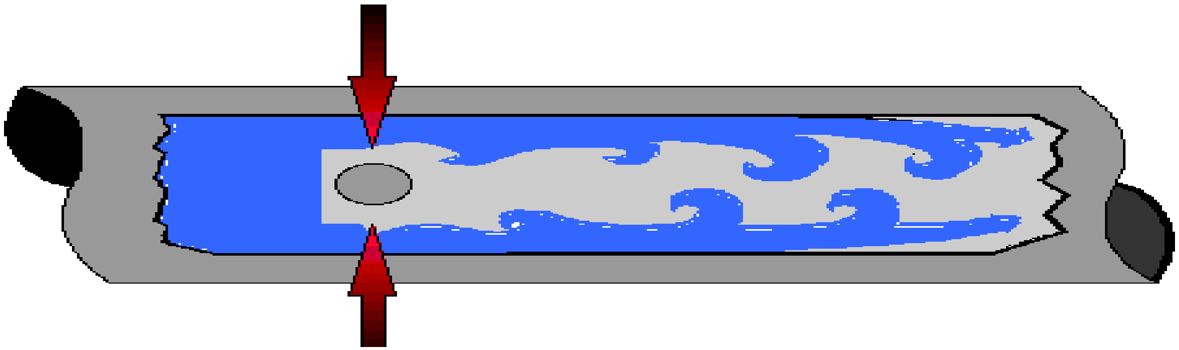
- A method used to determine if a thermowell is physically capable of withstanding the process conditions.
- It includes wake frequency, resonance, or Murdock calculations.
- Stress calculations.
- Pressure calculations

What we do not want is damage to the customer's Plant



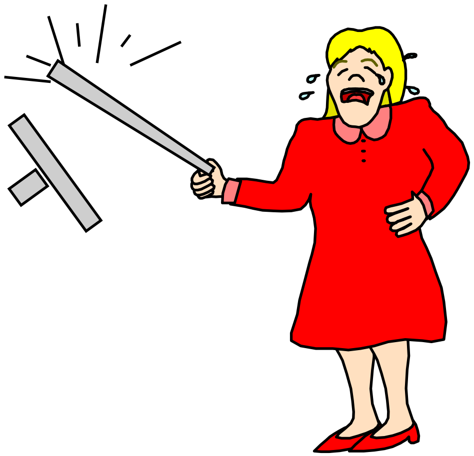
Thermowell Failures

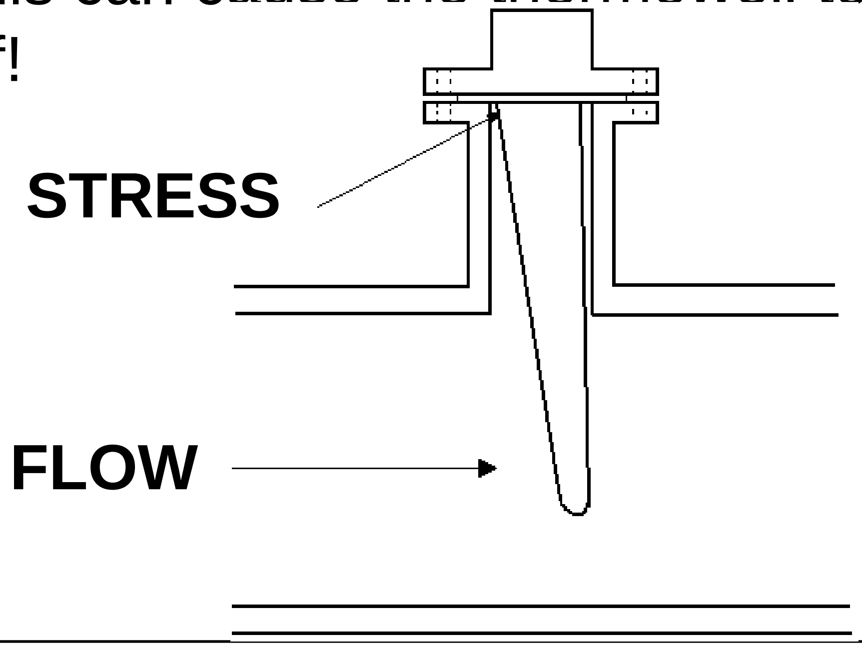
- T-wells can fail under certain conditions
- Fluid flowing around the T-well forms a turbulent wake called the Von Karman trail
- The wake alternates from side to side at a specific frequency dependent on many variables
- If that frequency exceeds 80% of the T-well's natural frequency, the T-well can fail!



Stress Failure

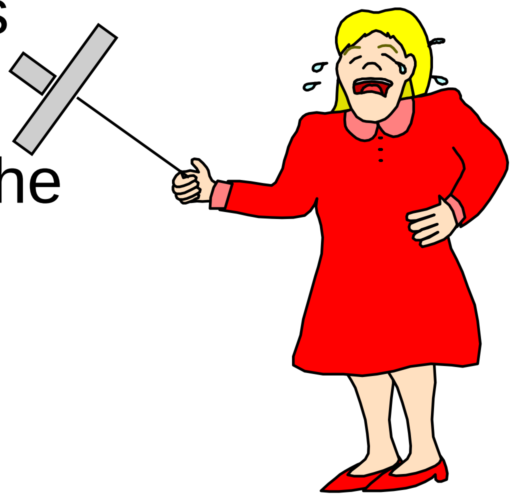
- T-wells can fail under stress conditions
- Fluid flowing past the T-well creates a stress on the thermowell where it is attached to the pipe
- This can cause the thermowell to snap off!

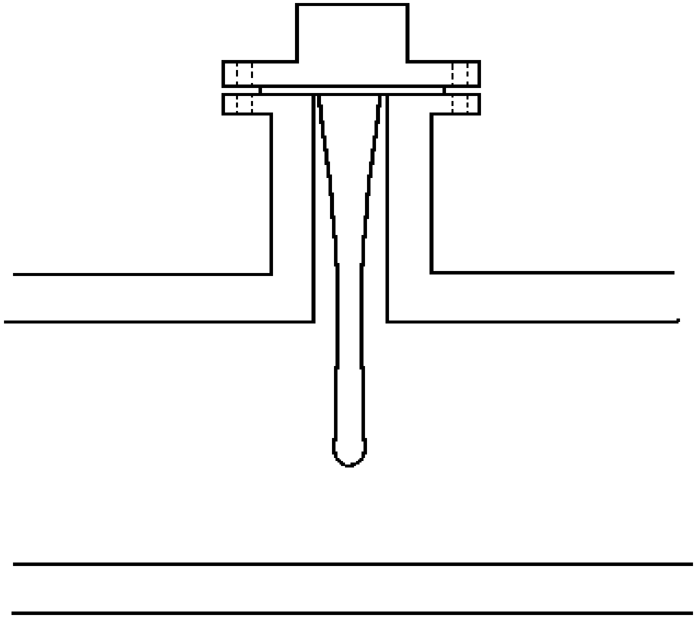




Static Pressure Failure

- T-wells can fail due to excess process pressure
- Excess process pressure can cause the thermowell to collapse!





Checking For Thermowell Suitability

– Thermowell calculations can be carried out provided we have information on the following:

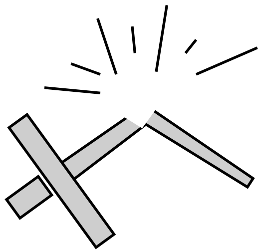
- **Thermowell Style**
- **Thermowell Material**
- **Thermowell Dimensions**
- **Fluid Velocity or Flow Rate**
- **Process Pressure**
- **Process Temperature**
- **Fluid Density**
- **Fluid Viscosity**
- **Various Process Pipe Dimensions**
- **T-well calculations can be carried out by Rosemount Temperature Applications Groups**

Look on the back of your Sensor PDS!

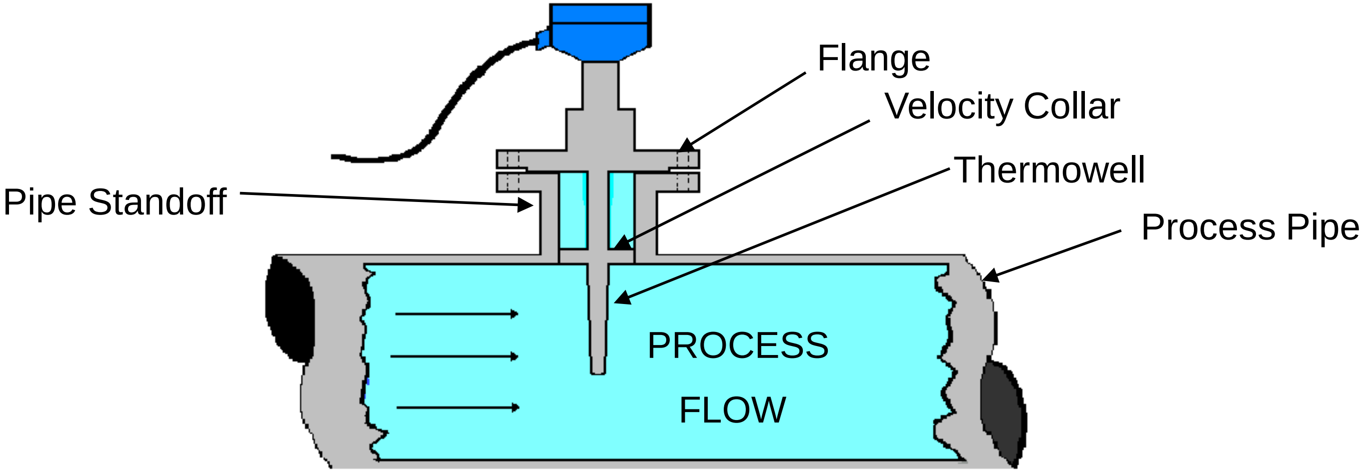
Why do we need all this information???

1. To calculate the natural frequency
2. To calculate the wake frequency
3. To calculate the fluid velocity
4. To calculate the stress on the T/Well
5. To calculate the maximum pressure

Sensor accessories
Thermowells



- **What can we do if the Thermowell fails???**
  - We can redesign the Thermowell by:-
    - » Changing the style of Thermowell.
    - » Changing the length of the Thermowell.
    - » Changing the diameter of the Thermowell.
    - » Changing the Thermowell material.
    - » If all else fails, we can use a velocity collar.



Temperature transmitter

What does a Transmitter do & Why use Transmitter?

Transmitter converts temperature sensor's signal from resistance or voltage into a common digital or analog 4-20 mA control signal

- Converts a noise susceptible signal to a standard, more robust 4-20 mA signal
- Provides local indication of temperature measurement
- **Smart transmitter** provides ⇒ *remote communication & diagnostics*
  ⇒ *improved accuracy & stability*
  ⇒ *reduced plant inventory*

Temperature transmitter
Wire Direct vs. Transmitter

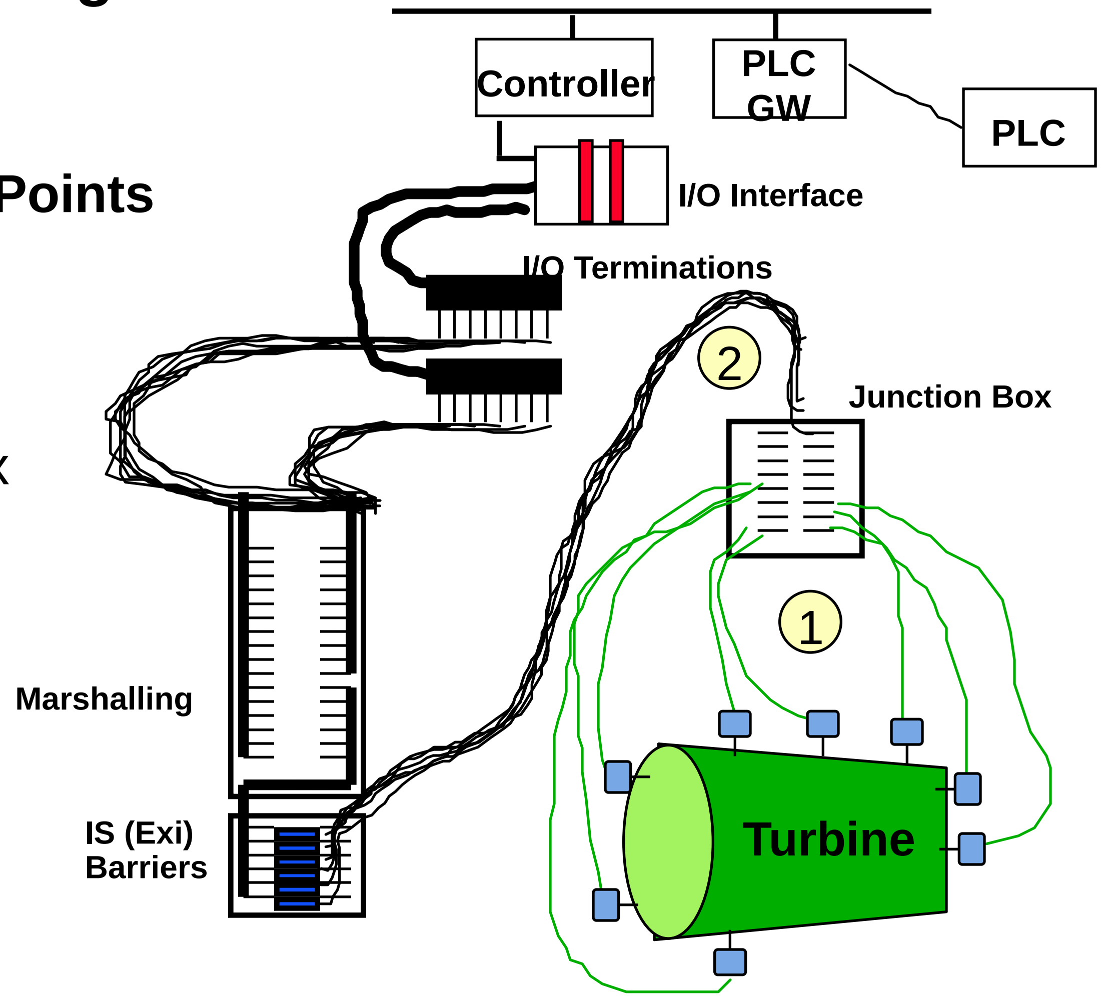
The alternative to using a transmitter

Example

8 Temp. Measurement Points

(1) "Spur": Length of T/C wire run from process to Junction Box

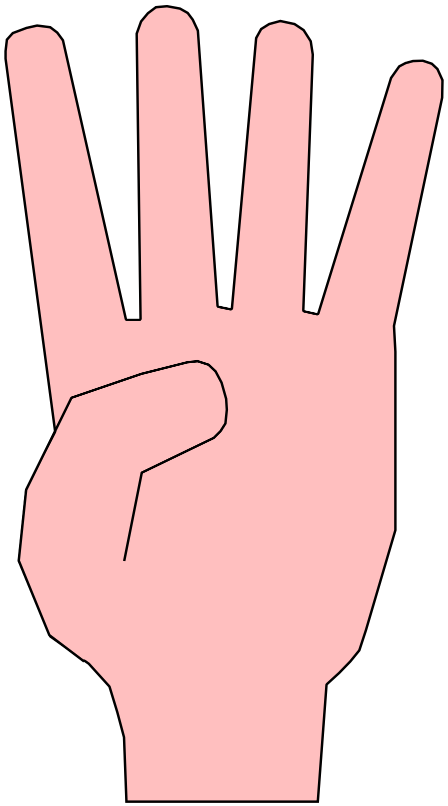
(2) "Trunk": Length of Bundled cable from Junction Box to Marshalling Panel



Temperature transmitter
Transmitter Mounting Styles

4 main transmitter mounting styles

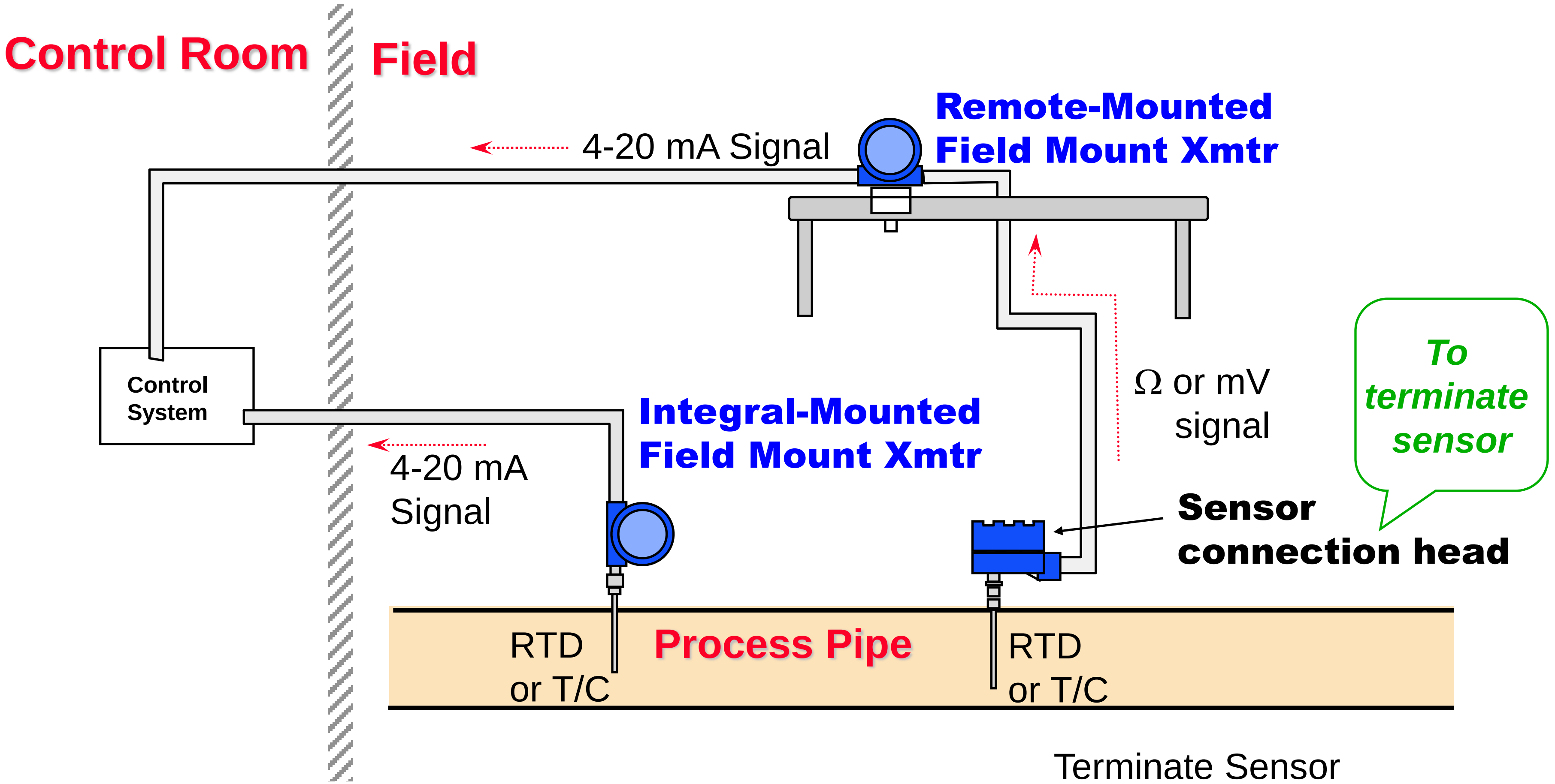
- **Head-Mount**
- **Rail-Mount**
- **Field-Mount**
- **Rack-Mount**



Temperature transmitter

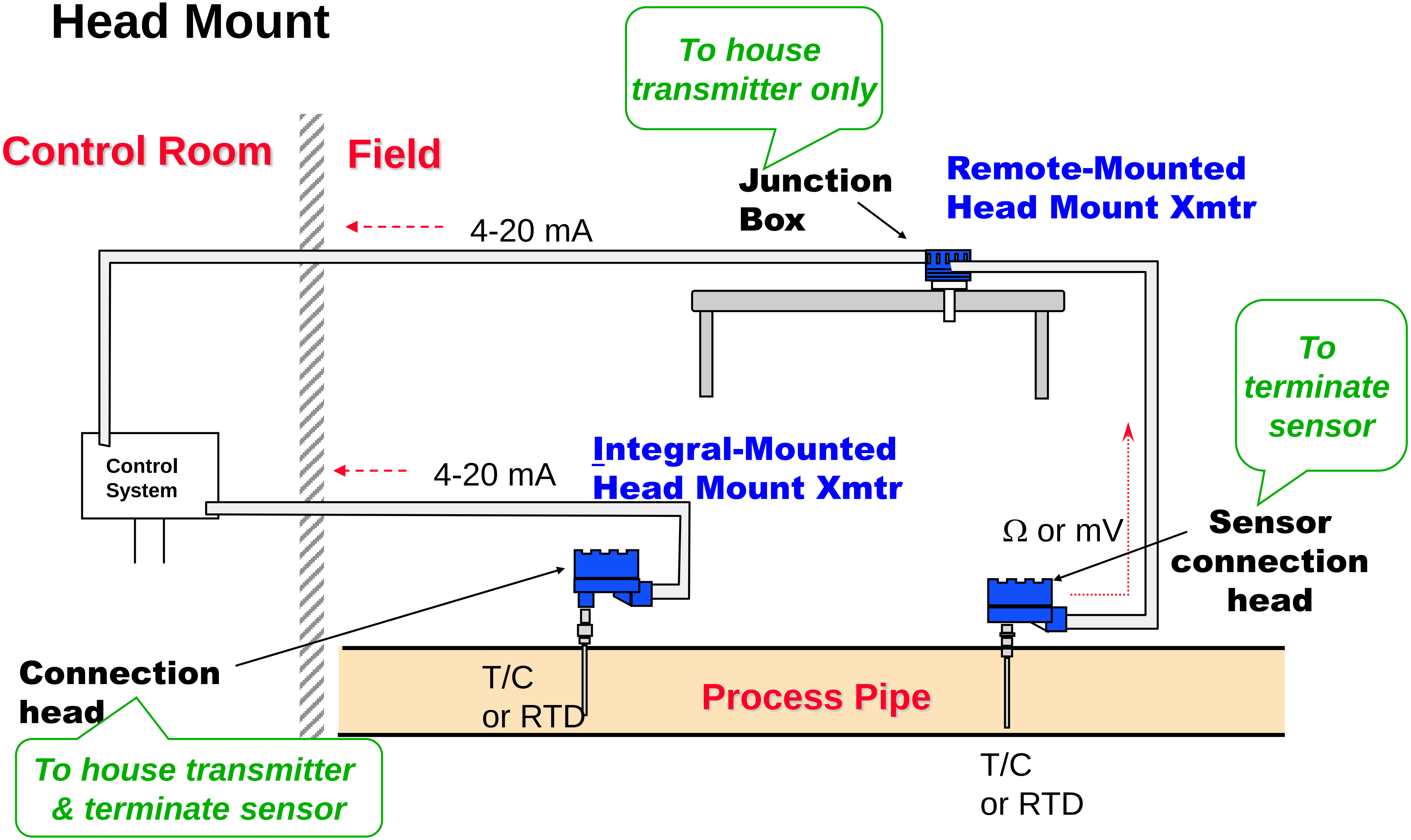
Transmitter Mounting Styles

Field Mount



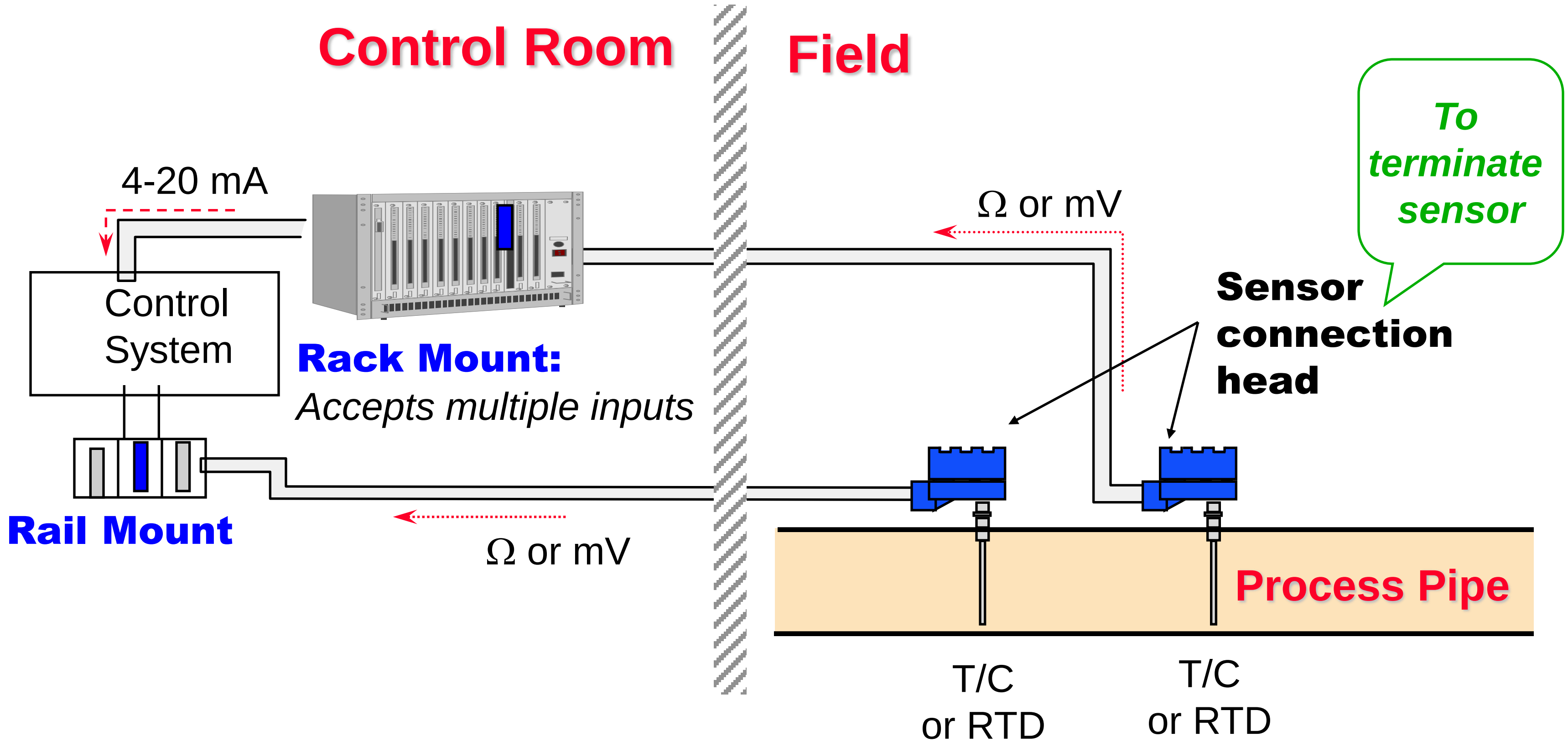
Terminate Sensor

Head Mount



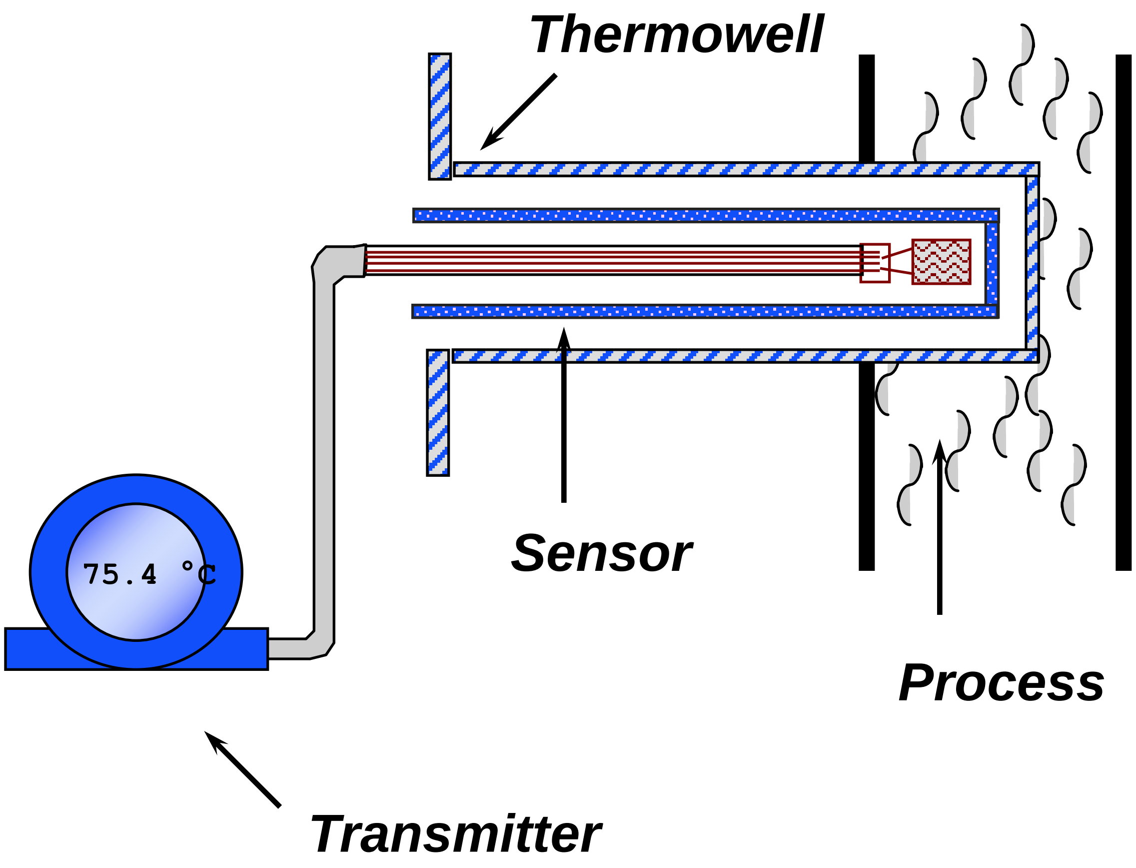
To house transmitter only
Control Room
Field
Junction Box
Remote-Mounted Head Mount Xmtr
4-20 mA
To terminate sensor
Control System
4-20 mA
Integral-Mounted Head Mount Xmtr
Ω or mV
Sensor connection head
Connection head
T/C or RTD
Process Pipe
To house transmitter & terminate sensor
T/C or RTD

Rail & Rack Mount - Remote-Mounting Configurations



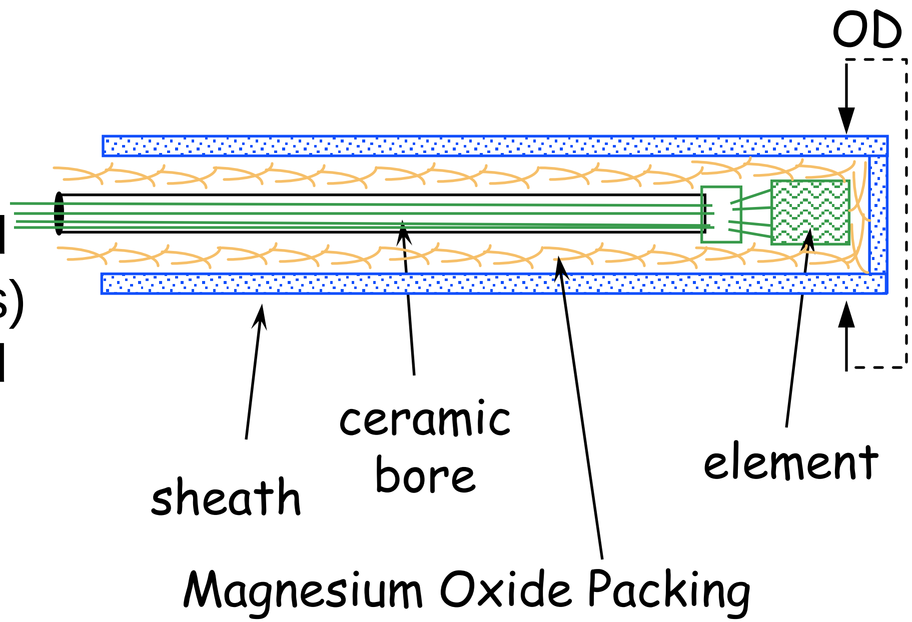
Temperature transmitter
Factors Affecting Response Time

- **Sensor**
- **Thermowell**
- **Transmitter**
- **Process**



Temperature transmitter
Factors Affecting Response Time

- **Type of element**
  - Thin-film has slightly faster response time than wirewound
  - Thermocouples do not vary significantly
- **Element packaging**
  - Rosemount RTD’s are packed in magnesium oxide to provide optimum thermal conduction within the sheath
  - Grounded thermocouples are twice as fast as ungrounded
- **Sheath thickness and material**
  - Rosemount uses 316SST and Inconel (for high temperatures) for sheath; both are very good thermal conductors



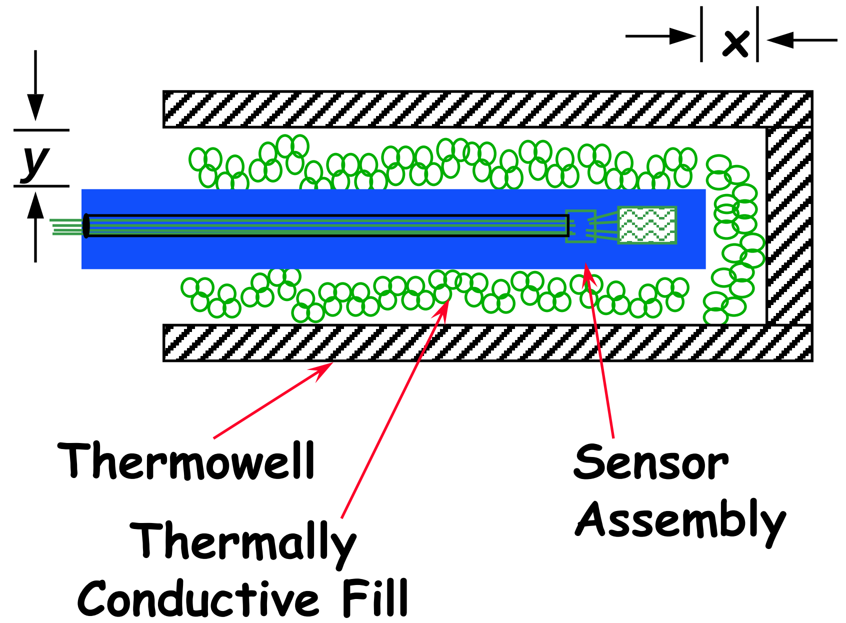
Temperature transmitter
Factors Affecting Response Time

- **Thermowell design style (thickness at tip)**
  - Stepped is the fastest
- **Contact between sensor sheath and thermowell (x and y)**
  - Spring loaded sensor ensures contact at the tip (x=0)
  - Industry practice suggests using thermally conductive fill can significantly reduce time lag

Tapered thermowell = 26 seconds

Stepped thermowell = 22 seconds

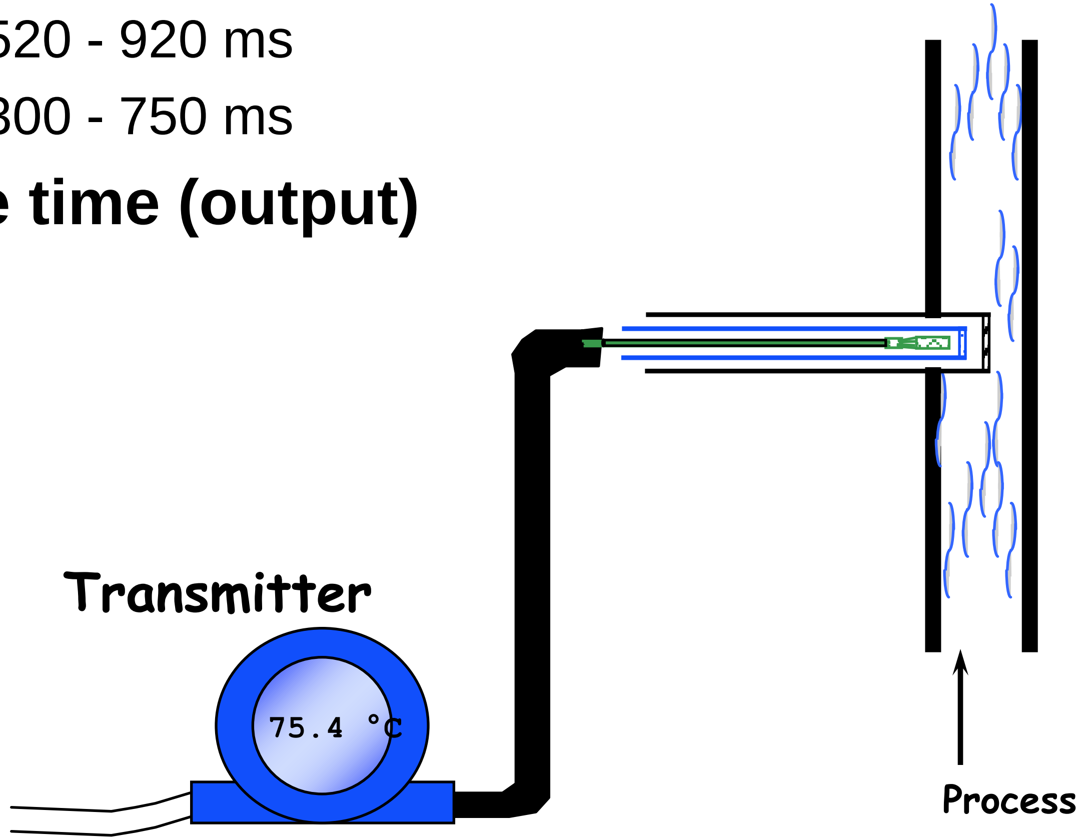
Industry data shows stepped t-well with fill = 11 seconds



Temperature transmitter

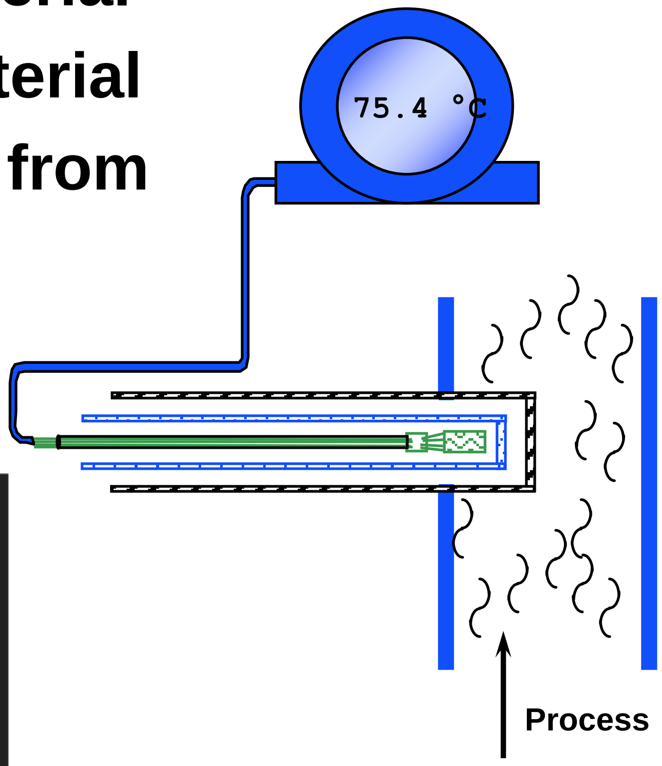
Factors Affecting Response Time

- **Time response depends on element (complexity of calculation)**
  - 2-wire RTD 440 - 760 ms
  - 3 & 4-wire RTD 520 - 920 ms
  - Thermocouples 300 - 750 ms
- **Transmitter update time (output) every 1/2 second**



Temperature transmitter
Factors Affecting Response Time

- **Velocity of the material**
- **Thermal conductivity of the material**
- **Density and viscosity of the material**
- **Process time constants can be from seconds to hours:**



Water @ 3 fps t = 1 min

Air at 50 fps, 40-80°C = 11 minutes

Oil agitated in a bath: t = 13 minutes

Oil not agitated: t = >45 minutes

Temperature transmitter
Factors Affecting Response Time

Sensor	< 7 to 10 sec
Sensor in Thermowell	60 to 120 sec
Transmitter	.5 to .9 sec
Process	Seconds to Hours

- Thermowells and process material/conditions have the greatest effect on temperature point response time

Exercise

A 4-20 mA transmitter is spanned 50 to 150°C. Express the span in the following units:

1. [ ] to [ ] °F

2. [ ] to [ ] K

3. What is the temperature reading if the above transmitter outputs 10 mA? [°C]

4. An old differential temperature indicator with a scale of 0 - 100°F is reading 60°F. What is that reading in °C? [°C]

5. An Pt 100 RTD has the following C.V.D constants R_0 =100.00Ω, α = 0.003842, δ =1.415, β = 0.11. If the temperature being measured is 30°C, What will be the resistance value? [Ω]

Exercise

Identify the characteristics for RTD & Thermocouple & indicate them by entering a "R" or a "T" respectively.

6. High accuracy. [ ]

7. Can handle wider temperature range. [ ]

8. CJC is not required. [ ]

9. Can be matched to transmitter. [ ]

10. Faster response time. [ ]

Identify which the sensor or thermowell design that provide faster response time.

11. A. Thin-film RTD
    B. Wire Wounded RTD [ ]

Exercise

12. A. Thin-film RTD
    B. Wire Wounded RTD [ ]

13. A. Straight Thermoell
    B. Tapered Thermowell
    C. Stepped Thermowell [ ]

14. A. Grounded Thermocouple
    B. Un-grounded Thermocouple [ ]

15. Which Thermowell mounting style can be used in high velocity and high temperature corrosive environment.

    A. Threaded
    B. Welded
    C. Flanged [ ]