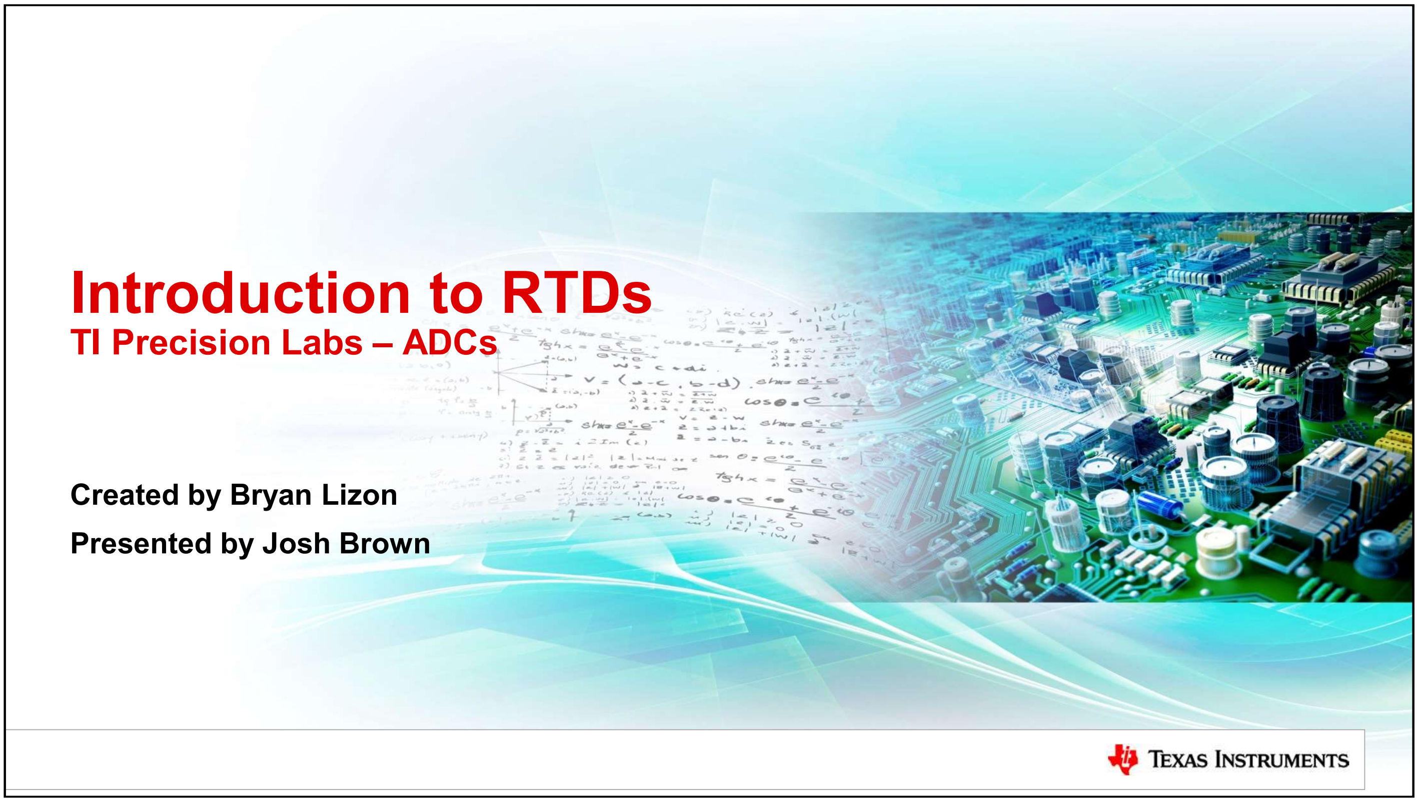
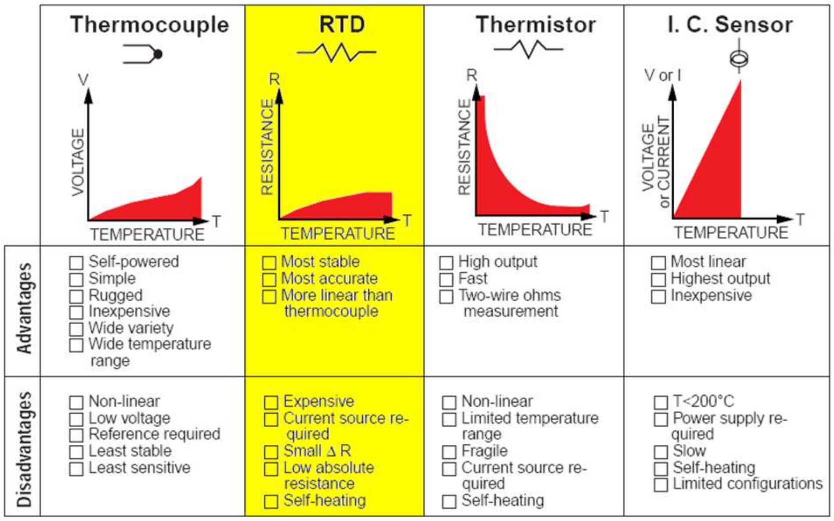


Hello, and welcome to the TI Precision Lab module introducing resistance temperature detectors, or RTDs. The goal of this module is to understand the important characteristics of RTDs. This information will be used throughout the subsequent RTD training curriculum and is important to understanding RTD circuits and how to measure them.

Temperature sensor comparison



- Resistive Temperature Detector
- Sensor with a predictable resistance vs. temperature
- Measure the resistance and calculate temperature based on the resistance vs. temperature characteristics of the RTD material

TEXAS INSTRUMENTS 2

Shown here is an overview of the characteristics of some of the most common temperature sensors. These sensors include thermocouples, RTDs, thermistors, and discrete analog or digital temperature ICs.

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As stated on the previous slide, this presentation focuses on resistive temperature detectors, or RTDs. Some of the benefits of an RTD is that they are the most stable and accurate temperature sensor. These two qualities enable RTDs to be used in many precision applications. RTDs are also highly-linear, providing the user with a predictable relationship between sensor resistance and measured temperature.

RTDs also have some disadvantages, such as requiring an external source to bias the sensor. Another challenge is that the change in RTD resistance is relatively small, resulting in a small output voltage. These challenges are discussed in more detail in subsequent Precision Labs modules.

Now that we understand some of the benefits and challenges of an RTD, let's consider how an RTD works

How does an RTD work?

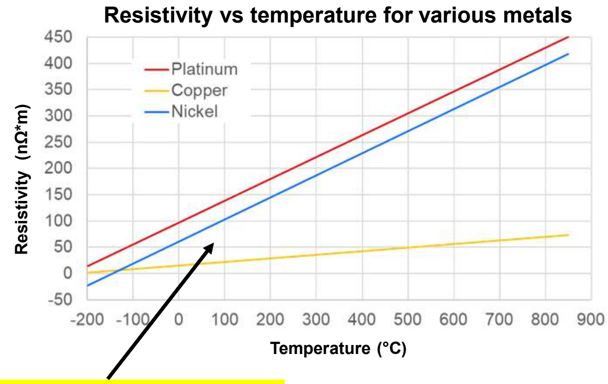
$$\text{Resistance} = \text{R} = \frac{\rho * \text{L}}{\text{A}}$$

Resistivity (ρ) characteristics:

- Property of a material
- Temperature dependence approximated by:

$$\rho(\text{T}) = \rho_0 * [1 + \alpha * (T - T_0)]$$

- α = temperature coefficient, derived empirically
- ρ_0, T_0 = initial conditions



Resistivity increases over temperature

To understand how an RTD works, it is helpful to recall the equation for resistance. As shown at the top left of this slide, the resistance of a material is equal to its resistivity multiplied by the ratio of its length, L, to its cross-sectional area, A.

<click>

As an example, a wire is shown in the top right that has a length, L, and an area, A, both of which are well defined and easy to apply to the resistance equation. However, the third term, resistivity, is the key to understanding how RTDs behave

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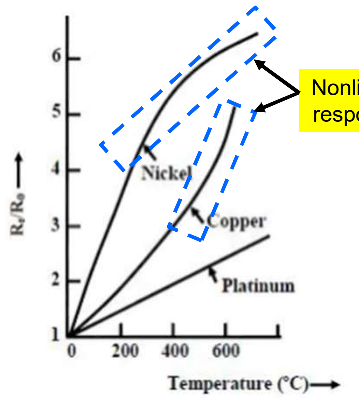
Resistivity is a material property that has a temperature dependence approximated by the equation shown here. Note that the alpha term in this equation is a temperature coefficient that is derived empirically. Additionally, some initial conditions are required.

<click>

Plotting resistivity as a function of temperature, T, for certain metals produces graphs that are highly linear as shown. Assuming the resistivity approximation is valid across the given temperature range, the resistance will also be linear relative to the wire length or area. Note that not all materials follow this approximation, but it is generally valid for the three metals used in the plot: platinum, copper, and nickel. As a result, these metals are the most widely-used materials for all RTD types.

Common RTD types & characteristics

RTD temperature vs resistance curve



Summary of RTD characteristics

RTD Material	Nominal Resistance* @ 0°C (Ω)	Typical Temperature Range**
Nickel (Ni)	100, 120, 1000	-60°C to +260°C
Copper (Cu)	10, 50, 100	-100°C to +260°C
Nickel-Iron (Ni-Fe)	640	-100°C to +204°C
Platinum (Pt)	10,100, 200, 500, 1000	-200°C to +850°C

*Additional resistances are possible
**Ranges can change for different α values

- Most common
- Linear response over wide temp range

As stated on the previous slide, platinum, copper, and nickel are the metals most commonly-used for RTD construction. These metals are used because they all have a highly linear temperature dependence according to the resistivity approximation.

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However, the approximation does not hold across the entire temperature range for real sensors, which can result in nonlinear portions of the temperature versus resistance curve as shown on the left. Therefore, the useful temperature measurement range can vary for different RTD types

<click>

Shown in the table on the right are the characteristics of the most common RTDs. Each RTD has a nominal resistance, or the expected resistance at 0 degrees Celsius. Different nominal resistances are available within each RTD type, which can be useful for different applications. Moreover, the nominal resistance is used in conjunction with the RTD material to identify the different RTD types. For example, a platinum RTD whose nominal resistance is 200 ohms at 0 degrees Celsius would be referred to as a Pt200.

Each RTD type also has a typical temperature range that corresponds to the portion of the temperature curve where the sensor resistance is most linear. Nickel and copper RTDs tend to have the smallest operating temperature range because of the increased nonlinearity shown in the curves on the left

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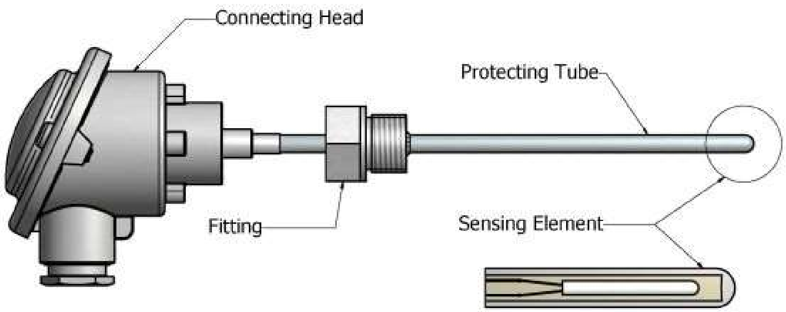
Comparatively, platinum RTDs are the most common because they offer a linear response over the widest temperature range. This behavior makes platinum RTDs highly desirable for a wide range of industrial applications, some of which are discussed on the next slide.

Where are RTDs used?

Example RTD probe



Temperature transmitter

- Thermal controllers
- Thermal ovens
- PLC analog input modules

Shown on the left is the mechanical housing of a typical RTD probe. The sensing element is inserted into a protecting tube to keep it from getting damaged. This protecting tube is attached to the connecting head. The connecting head allows the RTD housing to be held in place such that the sensing element can be inserted into the measurement media, usually a liquid. The sensor wires, which are not shown in this image, extend from the bottom of the connecting head to the measurement system.

Common measurement systems are shown on the right side. For example, an RTD probe might connect to the inputs of a temperature transmitter to be used as part of an industrial control loop. Other factory automation end equipment that commonly use RTDs are listed on the bottom right, and include thermal controllers, thermal ovens, and analog input modules for PLC systems. RTDs can be used in medical, automotive, and aerospace applications as well.

In all cases, the ADC measures the analog temperature reading and converts it to a digital output code. The system controller then converts this output code to a temperature. The next slide discusses two methods for converting a measured RTD resistance to temperature

Converting a measured resistance to a temperature

Callendar-Van Dusen equation

For T < 0°C:

$$R_{RTD} = R_0 * (1 + (A * T) + (B * T^2) + [(C * T^3) * (T - 100)])$$

For T > 0°C:

$$R_{RTD} = R_0 * [1 + (A * T) + (B * T^2)]$$

For a Pt100 RTD (α = 0.00385):

$R_0 = 100\ \Omega$ $\quad B = -5.775 * 10^{-7}$

$A = 3.9083 * 10^{-3}$ $\quad C = -4.183 * 10^{-12}$

✓ More accurate results

× Can be difficult to calculate

Look-up table (LUT)

°C ITS-90	0	1	2	3	4	5	6	7	8	9	10
-200	18.52										
-190	22.83	22.40	21.97	21.54	21.11	20.68	20.25	19.82	19.38	18.95	18.52
-180	27.10	26.67	26.24	25.82	25.39	24.97	24.54	24.11	23.68	23.25	22.83
-170	31.34	30.91	30.49	30.07	29.64	29.22	28.80	28.37	27.95	27.52	27.10
-160	35.54	35.12	34.70	34.28	33.86	33.44	33.02	32.60	32.18	31.76	31.34
-150	39.72	39.31	38.89	38.47	38.05	37.64	37.22	36.80	36.38	35.96	35.54
-140	43.88	43.46	43.05	42.63	42.22	41.80	41.39	40.97	40.56	40.14	39.72
-130	48.00	47.59	47.18	46.77	46.36	45.94	45.53	45.12	44.70	44.29	43.88
-120	52.11	51.70	51.29	50.88	50.47	50.06	49.65	49.24	48.83	48.42	48.00
-110	56.19	55.79	55.38	54.97	54.56	54.15	53.75	53.34	52.93	52.52	52.11
-100	60.26	59.85	59.44	59.04	58.63	58.23	57.82	57.41	57.01	56.60	56.19
-90	64.30	63.90	63.49	63.09	62.68	62.28	61.88	61.47	61.07	60.66	60.26
-80	68.33	67.92	67.52	67.12	66.72	66.31	65.91	65.51	65.11	64.70	64.30
-70	72.33	71.93	71.53	71.13	70.73	70.33	69.93	69.53	69.13	68.73	68.33
-60	76.33	75.93	75.53	75.13	74.73	74.33	73.93	73.53	73.13	72.73	72.33
-50	80.31	79.91	79.51	79.11	78.72	78.32	77.92	77.52	77.12	76.73	76.33
-40	84.27	83.87	83.48	83.08	82.69	82.29	81.89	81.50	81.10	80.70	80.31
-30	88.22	87.83	87.43	87.04	86.64	86.25	85.85	85.46	85.06	84.67	84.27
-20	92.16	91.77	91.37	90.98	90.59	90.19	89.80	89.40	89.01	88.62	88.22
-10	96.09	95.69	95.30	94.91	94.52	94.12	93.73	93.34	92.95	92.55	92.16
0	100.00	99.61	99.22	98.83	98.44	98.04	97.65	97.26	96.87	96.48	96.09
0	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51	103.90
10	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40	107.79
20	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.29	111.67
30	111.67	112.06	112.45	112.83	113.22	113.61	114.00	114.38	114.77	115.15	115.54
40	115.54	115.93	116.31	116.70	117.08	117.47	117.86	118.24	118.63	119.01	119.40
50	119.40	119.78	120.17	120.55	120.94	121.32	121.71	122.09	122.47	122.86	123.24

✓ Find values quickly & easily

× Accuracy limited by table step size

There are two common methods to derive the measured temperature from the RTD resistance

<click>

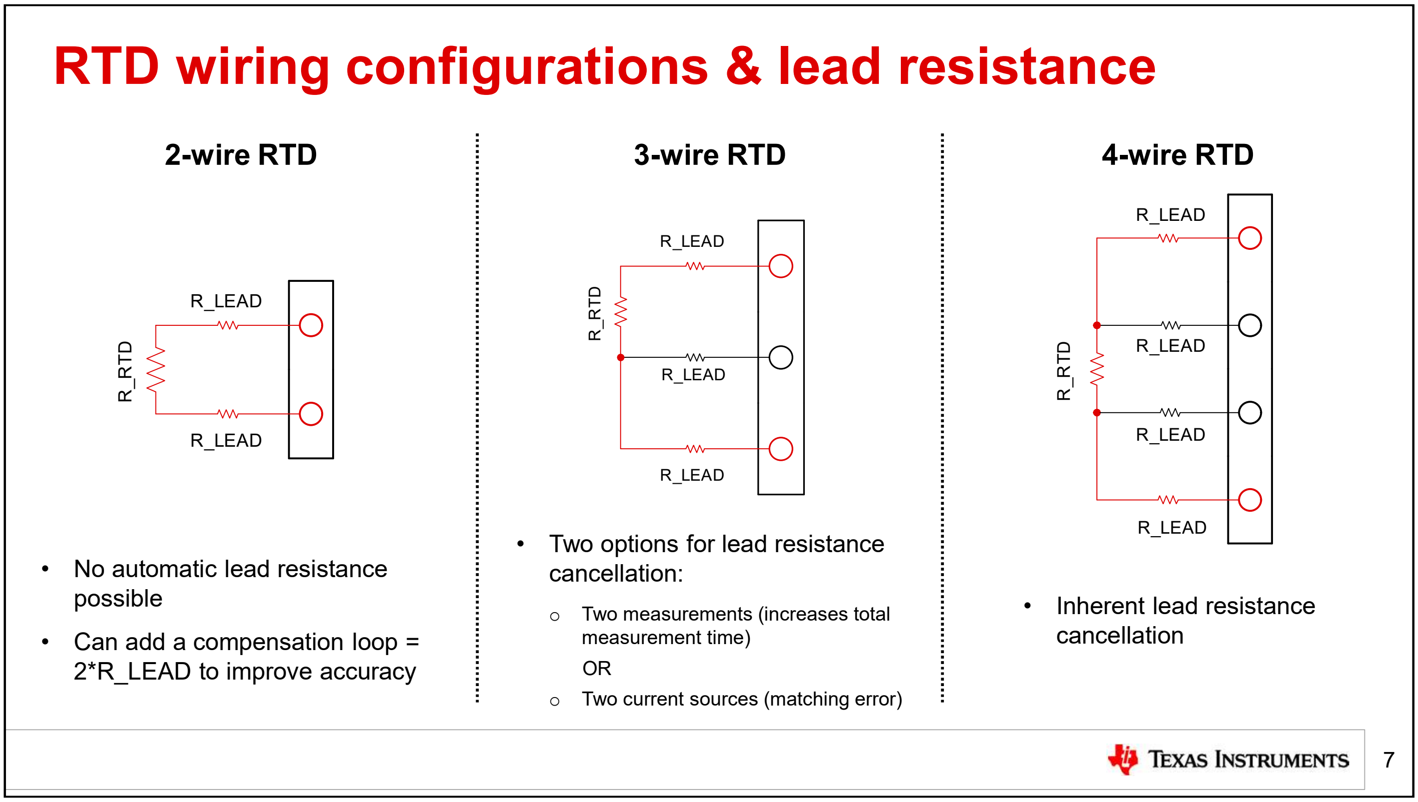
The first method uses a polynomial equation to correlate temperature to RTD resistance. The most common equation is referred to as the Callendar-Van Dusen equation, which is named for the two scientists that first identified this relationship. Note that the equation is separated into two parts, with one equation for temperature below 0 degrees Celsius and a separate equation for temperatures greater than 0 degrees Celsius. Both equations have constants A, B, or C that are empirically derived and are specific to platinum RTDs. Example values for a Pt100 with an alpha value of 0.00385 are shown on the left.

Different polynomial equations have been derived for other RTD types such as nickel or copper. Additionally, higher-order polynomials are also available to calculate platinum RTD resistance across a wider temperature range. These equations can provide very accurate results, but they can be computationally intensive. Moreover, an RTD system measures a resistance that must be correlated to a temperature, while each of these equations outputs a resistance from the corresponding measured temperature. Therefore, the user must first calculate the inverse of each equation before it is possible to convert the measured resistance to a temperature

<click>

The second method to convert a measured resistance to a temperature is a look-up table, or LUT, which is shown on the right. A look up table uses the aforementioned equations to generate fixed RTD resistance values across a specific temperature range. A look up table is beneficial because it is a large dataset of static values that does not require any computation. The challenge with a look-up table is limited accuracy due to a typical temperature step size of one degree Celsius. Identifying temperatures within this standard increment requires an interpolation function, though this is usually a simple computation.

Now that we know how RTDs work, where they are used, and how to convert resistance to temperature, let's shift focus to basic circuit analysis for the different RTD wiring options



There are three common RTD configurations

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The first, and simplest, RTD wiring configuration is the 2-wire RTD shown on the left. One important characteristic of an RTD is that each RTD wire has some lead resistance, R_LEAD. When the RTD is biased, current flows through the sensor along the path in red. In the case of a 2-wire RTD, both lead resistances are part of the measured input and cannot be automatically removed. While this lead resistance is typically negligible when the RTD wire length is short, some applications can require very long leads. In such an application, very long RTD sensors can have significant lead wire resistance compared to the RTD resistance. As a result, 2-wire RTDs are typically used for lower-accuracy systems. It is also possible to add a compensation loop to the circuit whose resistance is equal to two times R_LEAD. This method is not shown on this slide

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The next type of RTD wiring configuration is a 3-wire RTD, shown in the middle of this slide. Similar to a 2-wire RTD, each wire has some lead resistance, R_LEAD. As the RTD is biased, current flows through the sensor along the path in red. Unlike a 2-wire RTD, the measured input only includes one R_LEAD, which can be automatically removed from the measurement using two different methods. The first method involves taking two separate measurements, at the cost of increased measurement time. The second option for lead resistance cancellation uses two biasing sources. This method does not increase measurement time but can reduce accuracy due to bias source matching error. Both of these options are discussed in more detail in a subsequent precision Labs module.

<click>

The final RTD wiring option is a 4-wire RTD, shown on the right. Like 2- and 3-wire RTDs, each wire in a 4-wire RTD has some lead resistance. However, the bias current only passes through R_LEAD in the top and bottom legs, which enables direct measurement of the RTD resistance without any influence from R_LEAD. In other words, a 4-wire RTD provides inherent lead wire resistance cancellation.

Subsequent Precision Labs modules expand upon this basic circuit analysis and cover topics including how to measure each RTD type, measuring multiple RTDs, measurement system errors, calibration, selecting components for a design, and RTD wire break detection.

Thanks for your time!
Please try the quiz.

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That concludes this video. Thank you for watching. Please try the quiz to check your understanding of this video's content.

Quiz: Introduction to RTDs

1. An RTD is designated as Pt100. What does this nomenclature mean?
   a) It has a nominal temperature of 100°C
   b) It is made of platinum and designed for a 100°C temperature range
   c) It will output 100 mV at 0°C
   d) It is made of platinum and reads 100 Ω at 0°C

2. (T/F) The Callendar-Van Dusen equation and associated coefficients can accurately translate temperature into RTD resistance using a polynomial. This method can be challenging for microcontroller systems because it is computationally intensive.
   a) True
   b) False

TEXAS INSTRUMENTS

Question 1. An RTD is designated as PT100. What does this nomenclature mean?

<pause>

The correct answer is D, It is made of platinum and reads 100 ohms at 0 degrees C.

Question 2, true or false. The Callendar-Van Dusen equation and associated coefficients can accurately translate temperature into RTD resistance using a polynomial. This method can be challenging for microcontroller systems because it is computationally intensive.

<pause>

The correct answer is A, true

Quiz: Introduction to RTDs

3. (True/False) The main benefit of a 4 wire RTD over a 2 wire RTD is that the additional wires provide redundancy in harsh environments.
   a) True
   b) False

4. (True/False) An RTD outputs a voltage proportional to temperature without external excitation. The voltage is normally in the millivolt level and is the result of the Seebeck effect.
   a) True
   b) False

Texas Instruments

Question 3, true or false. The main benefit of a 4 wire RTD over a 2 wire RTD is that the additional wires provide redundancy in hash environments.

<pause>

The correct answer is B, false. The main benefit of a 4-wire RTD is higher accuracy that results from automatic lead resistance cancellation

Question 4, true or false. An RTD outputs a voltage proportional to temperature without external excitation. The voltage in normally in the millivolt level and is the result of the Seebeck effect

<pause>

The correct answer is B, false. An RTD requires external excitation, and the Seebeck effect describes the behavior of a thermocouple

Thanks for your time!

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That’s all for todays video. Thanks for watching.