Introduction to RTD measurement circuits

TI Precision Labs – ADCs

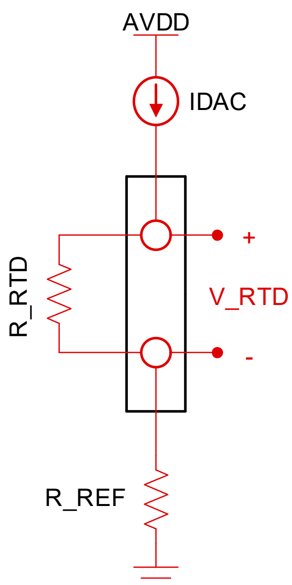
Created by Bryan Lizon

Presented by Josh Brown

TEXAS INSTRUMENTS

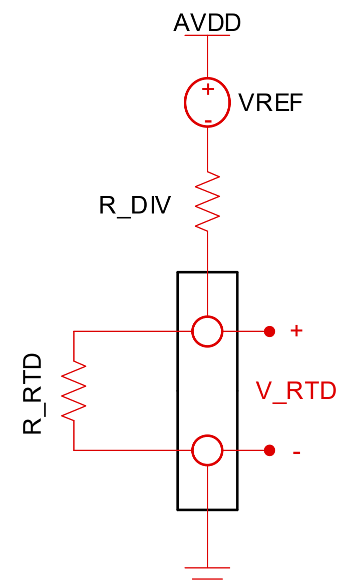
RTD biasing schemes

Constant current



$$V\_RTD = IDAC * R\_RTD$$ → linear equation

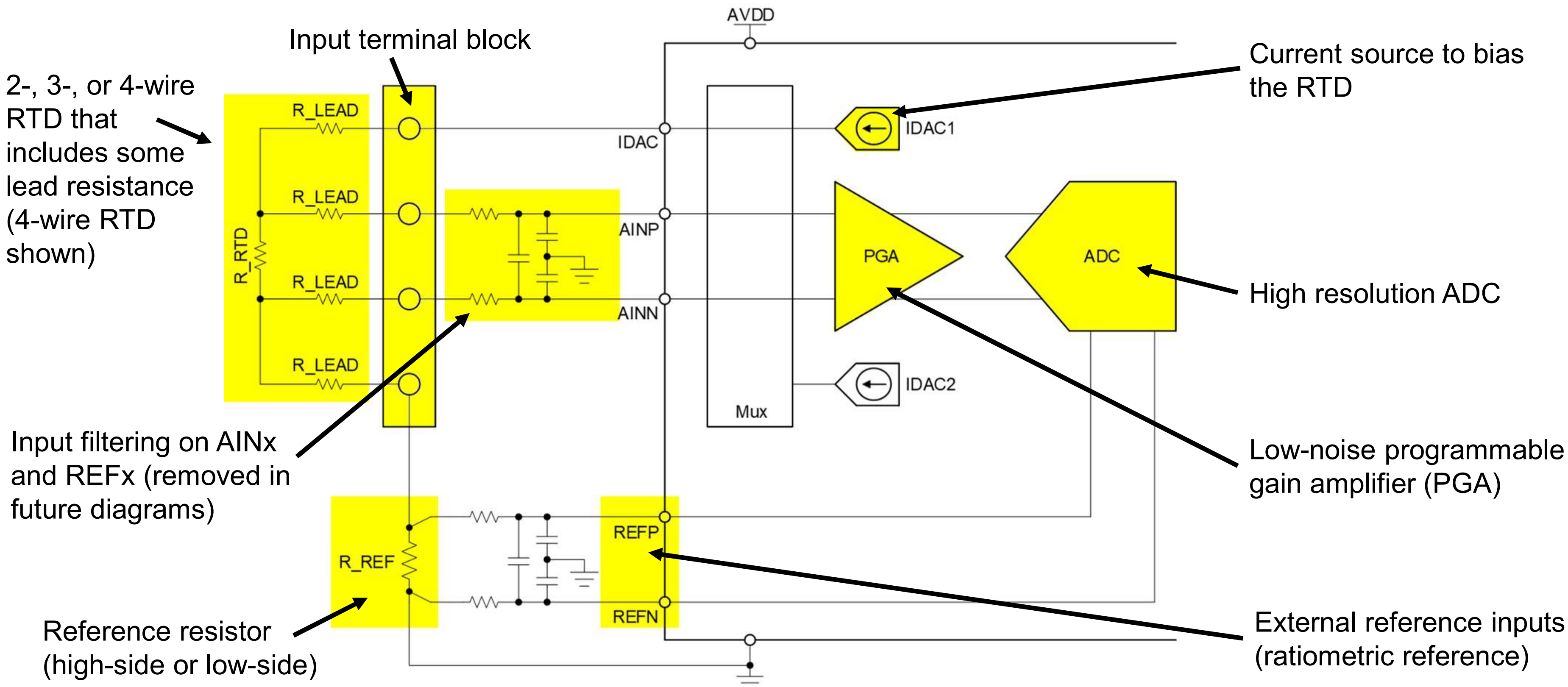
Constant voltage



$$V\_RTD = VREF \frac{R\_RTD}{R\_RTD + R\_DIV}$$ → Nonlinear equation due to the R_RTD term in the denominator

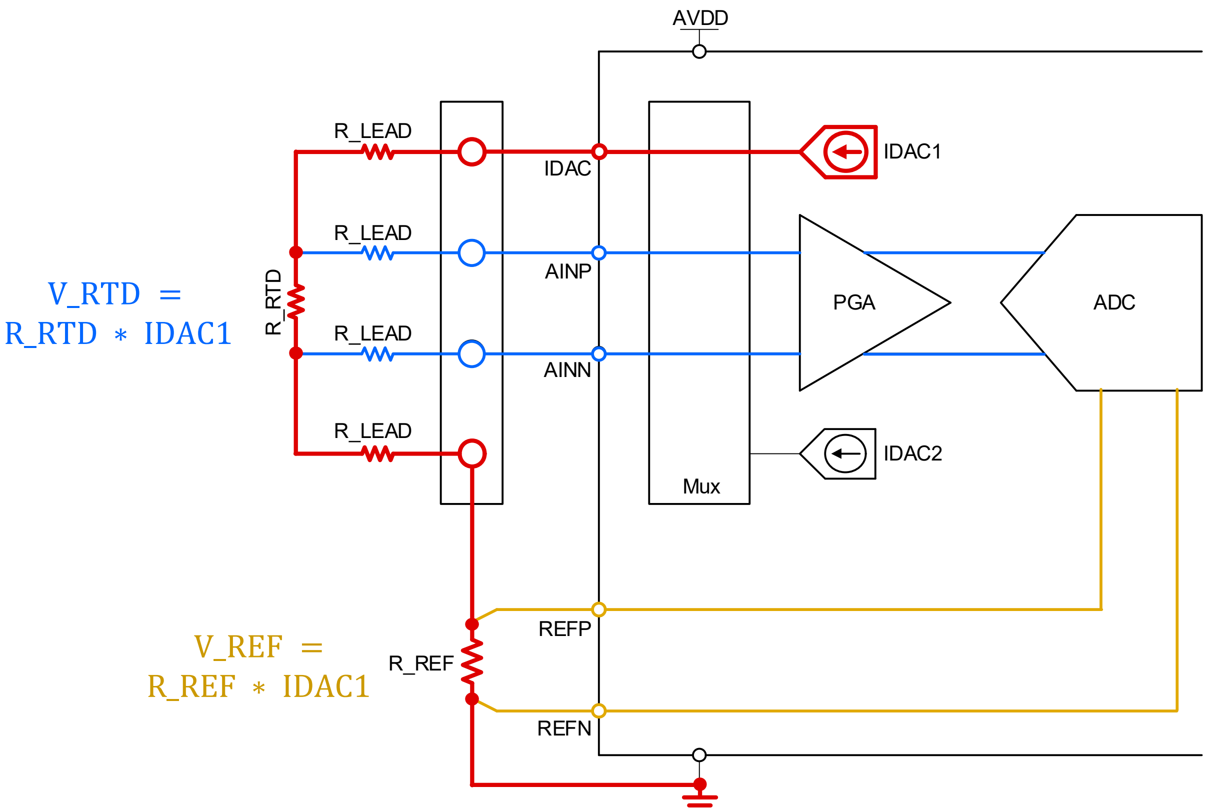
RTD measurement circuit basics

Basic 4-wire RTD measurement system using a low-side R_REF



IDAC biasing & ratiometric measurements

Basic 4-wire RTD measurement system using a low-side R_REF



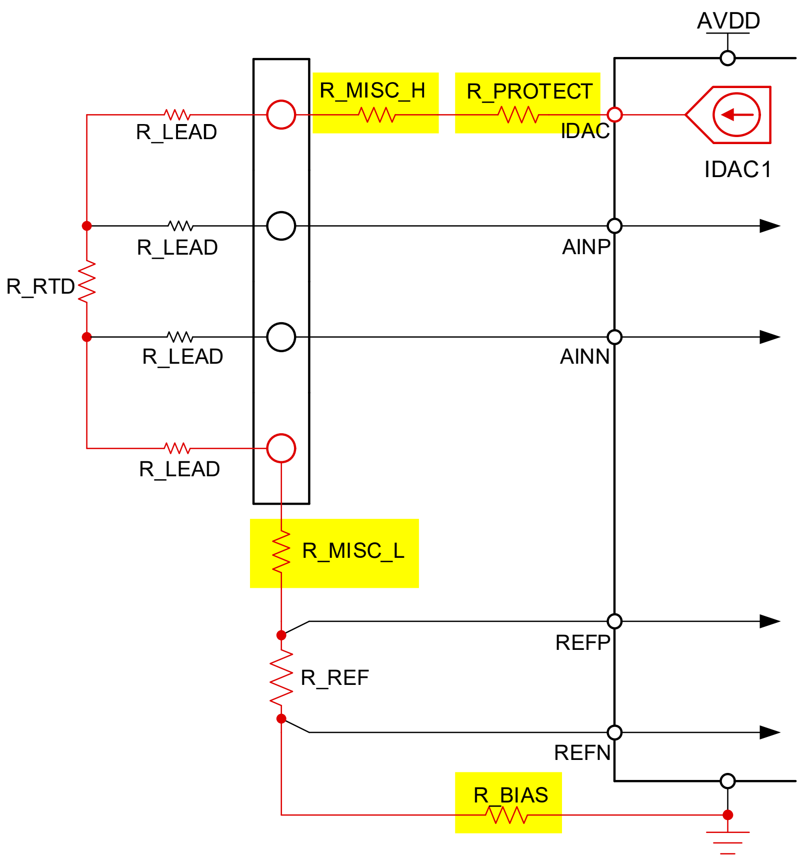
$$\text{ADC Code} \propto \frac{V\_RTD}{V\_REF}$$

$$\frac{V\_RTD}{V\_REF} = \frac{R\_RTD * IDAC1}{R\_REF * IDAC1}$$

$$= \frac{R\_RTD}{R\_REF}$$

Output code is independent of IDAC1 value = ratiometric

Total circuit resistance (R_TOTAL)



Additional sources of circuit resistance

Resistance	Description
R_PROTECT	Limits current into IDAC pin in case of an overvoltage event due to miswiring
R_MISC_H	Any additional miscellaneous resistance in the circuit *before* the RTD e.g. multiplexer R_{ON}
R_MISC_L	Any additional miscellaneous resistance in the circuit *after* the RTD e.g. multiplexer R_{ON}
R_BIAS	Bias resistor helps shift the input signal into the common-mode range of the integrated PGA

$$R\_TOTAL = R\_PROTECT + R\_MISC\_H + 2 * R\_LEAD + R\_RTD + R\_MISC\_L + R\_REF + R\_BIAS$$

Why is R_TOTAL important?

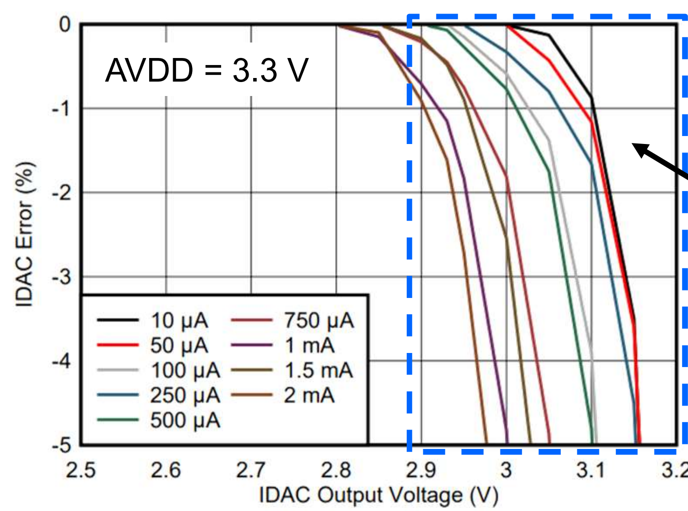
IDAC compliance voltage

<u>Compliance voltage</u>:

- Headroom required between IDAC output and AVDD to maintain constant current
- Voltage at IDAC output pin = R_TOTAL * IDAC
- Typically specified to 0.1% deviation
- May depend on the selected IDAC current

ADS124S08 IDAC Accuracy vs Compliance Voltage

Parameter	Condition	MIN	TYP	MAX	Unit
Current settings			10, 50, 100, 250, 500, 750, 1000, 1500, 2000		µA
Compliance voltage	10 µA to 750 µA, 0.1% deviation	AVSS		AVDD – 0.4	V
	1 mA to 2 mA, 0.1% deviation	AVSS		AVDD – 0.6	



IDAC error increases (IDAC magnitude decreases) significantly beyond the compliance voltage

Code to RTD resistance to temperature

$$\text{ADC code} = 2^{N} * \text{Gain}\frac{V_{RTD}}{A * V_{REF}}$$

$$\frac{V_{RTD}}{V_{REF}} = \frac{IDAC * R_{RTD}}{IDAC * R_{REF}}$$

$$\text{ADC code} = 2^{N} * \text{Gain}\frac{R_{RTD}}{A * R_{REF}}$$

$$R_{RTD} = \frac{\text{ADC code} * A * R_{REF}}{2^{N} * \text{Gain}}$$

- N = ADC resolution
- A = constant → for example:
  - A = 4 if FSR = ±2 * VREF / gain
  - A = 2 if FSR = ±VREF / gain

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:

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

R_{RTD} look-up table (LUT)

	Temperature in °C									
°C	0	1	2	3	4	5	6	7	8	9
	Resistance in Ω									
-50	80.31									
-40	84.27	83.87	83.48	83.08	82.69	82.29	81.89	81.50	81.10	80.70
-30	88.22	87.83	87.43	87.04	86.64	86.25	85.85	85.46	85.06	84.67
-20	92.16	91.77	91.37	90.98	90.59	90.19	89.80	89.40	89.01	88.62
-10	96.09	95.69	95.30	94.91	94.52	94.12	93.73	93.34	92.95	92.55
0	100.00	99.61	99.22	98.83	98.44	98.04	97.65	97.26	96.87	96.48
0	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51
10	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40
20	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.29
30	111.67	112.06	112.45	112.83	113.22	113.61	114.00	114.38	114.77	115.15
40	115.54	115.93	116.31	116.70	117.08	117.47	117.86	118.24	118.63	119.01
50	119.40	119.78	120.17	120.55	120.94	121.32	121.71	122.09	122.47	122.86
60	123.24	123.63	124.01	124.39	124.78	125.16	125.54	125.93	126.31	126.69
70	127.08	127.46	127.84	128.22	128.61	128.99	129.37	129.75	130.13	130.52
80	130.90	131.28	131.66	132.04	132.42	132.80	133.18	133.57	133.95	134.33
90	134.71	135.09	135.47	135.85	136.23	136.61	136.99	137.37	137.75	138.13
100	138.51	138.88	139.26	139.64	140.02	140.40	140.78	141.16	141.54	141.91

**assumes RTD response is linear

LUT linear interpolation

R_{RTD} look-up table (LUT)

°C	Temperature in °C									
	0	1	2	3	4	5	6	7	8	9
	Resistance in Ω									
-50	80.31									
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-20	92.16	91.77	91.37	90.98	90.59	90.19	89.80	89.40	89.01	88.62
-10	96.09	95.69	95.30	94.91	94.52	94.12	93.73	93.34	92.95	92.55
0	100.00	99.61	99.22	98.83	98.44	98.04	97.65	97.26	96.87	96.48
0	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51
10	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40
20	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.29
30	111.67	112.06	112.45	112.83	113.22	113.61	114.00	114.38	114.77	115.15
40	115.54	115.93	116.31	116.70	117.08	117.47	117.86	118.24	118.63	119.01
50	119.40	119.78	120.17	120.55	120.94	121.32	121.71	122.09	122.47	122.86
60	123.24	123.63	124.01	124.39	124.78	125.16	125.54	125.93	126.31	126.69
70	127.08	127.46	127.84	128.22	128.61	128.99	129.37	129.75	130.13	130.52
80	130.90	131.28	131.66	132.04	132.42	132.80	133.18	133.57	133.95	134.33
90	134.71	135.09	135.47	135.85	136.23	136.61	136.99	137.37	137.75	138.13
100	138.51	138.88	139.26	139.64	140.02	140.40	140.78	141.16	141.54	141.91

- Computationally simple
- Assumes linear response between two points

$\mathrm{R1} = 131.28\ \Omega$ < $\mathrm{R_{MEAS}} = 131.5\ \Omega$ < $\mathrm{R2} = 131.66\ \Omega$

$(\mathrm{T1} = 81°\mathrm{C})$ $(\mathrm{T_{MEAS}} = ?)$ $(\mathrm{T2} = 82°\mathrm{C})$

Equation of a line**: $T_x = M * R_x + B$

Calculate the slope:

$$M = \frac{\mathrm{T2} - \mathrm{T1}}{\mathrm{R2} - \mathrm{R1}} = \frac{82 - 81}{131.66 - 131.28} = 2.632 \frac{°\mathrm{C}}{\Omega}$$

Calculate y-intercept:

$$B = T_x - M * R_x = 81°\mathrm{C} - 2.632 \frac{°\mathrm{C}}{\Omega} * 131.28\ \Omega = -264.474°\mathrm{C}$$

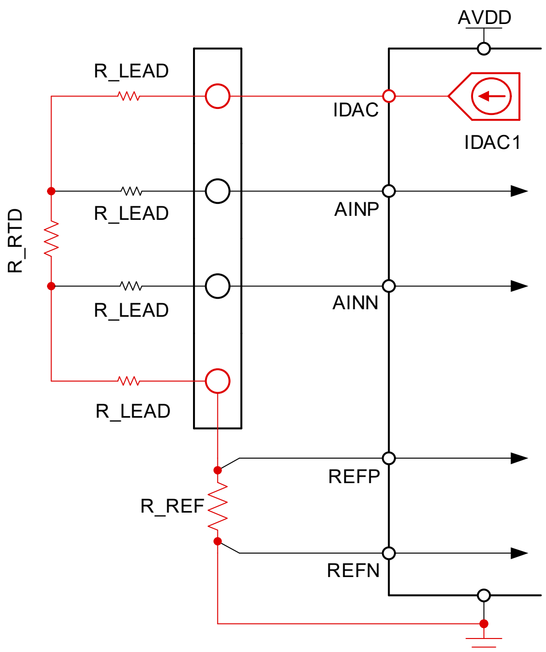
Calculate T_{MEAS}:

$$T_{MEAS} = 2.632 \frac{°\mathrm{C}}{\Omega} * R_{MEAS} - 264.474°\mathrm{C}$$

$$= 81.585°\mathrm{C}$$

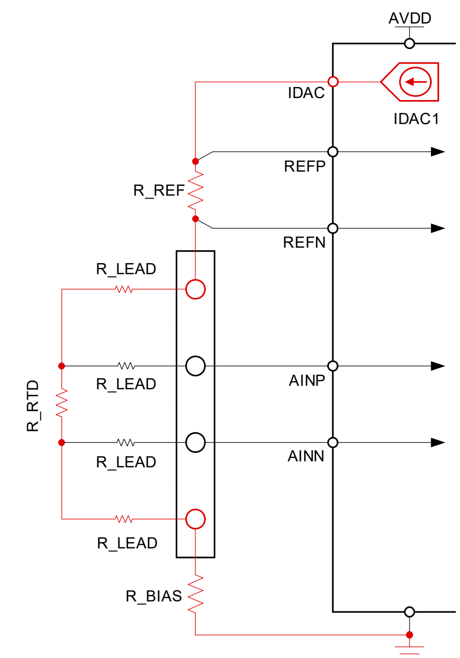
Low-side versus high-side reference resistor

Low-side R_REF (4-wire RTD)



- ✓ No bias resistor required
- × No inherent IDAC protection

High-side R_REF (4-wire RTD)

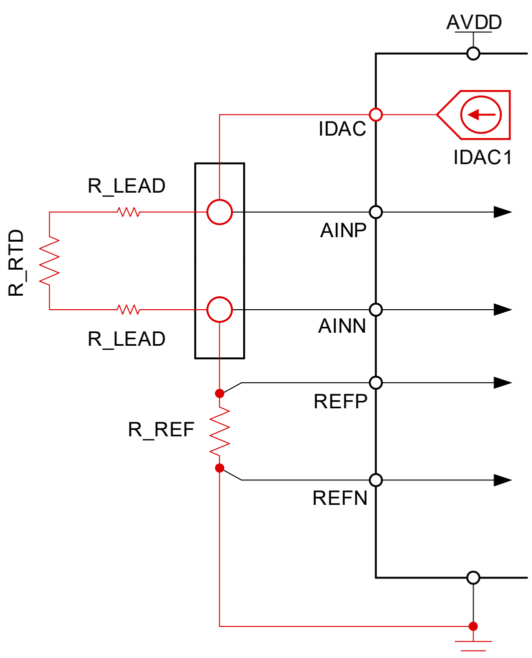


- ✓ R_REF limits current into IDAC pin
- × Can require extra bias resistor

**Low-side R_REF shown; high-side R_REF is possible

2-, 3-, and 4-wire RTD wiring configurations**

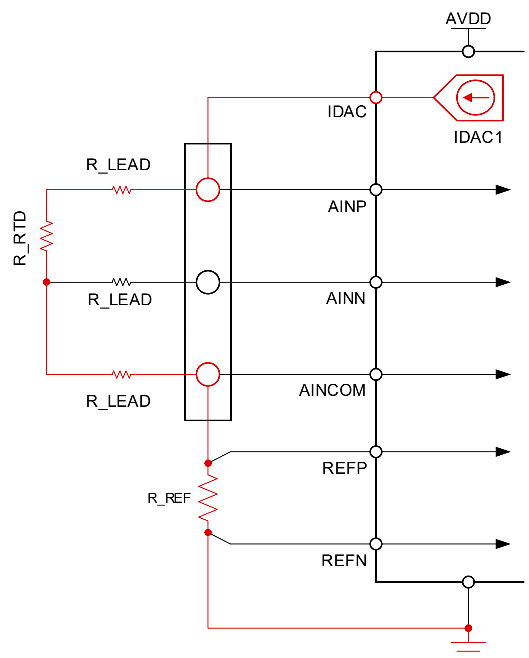
2-wire RTD



✓ Lowest cost

× No lead resistance cancellation

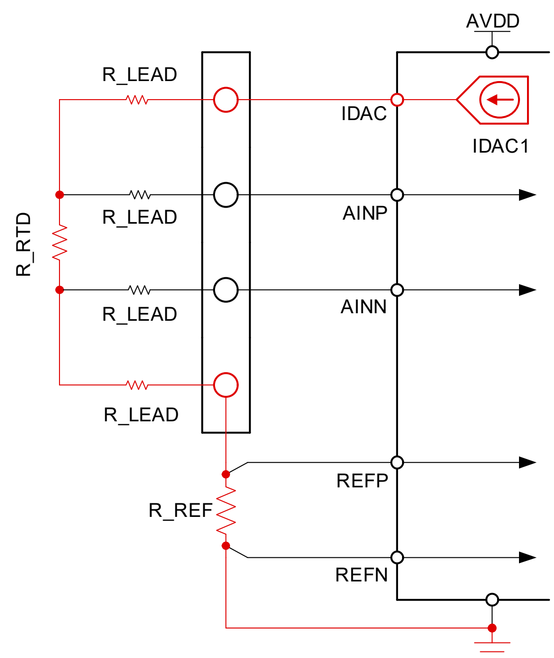
3-wire RTD



✓ Balances accuracy & cost

× IDAC mismatch error

4-wire RTD



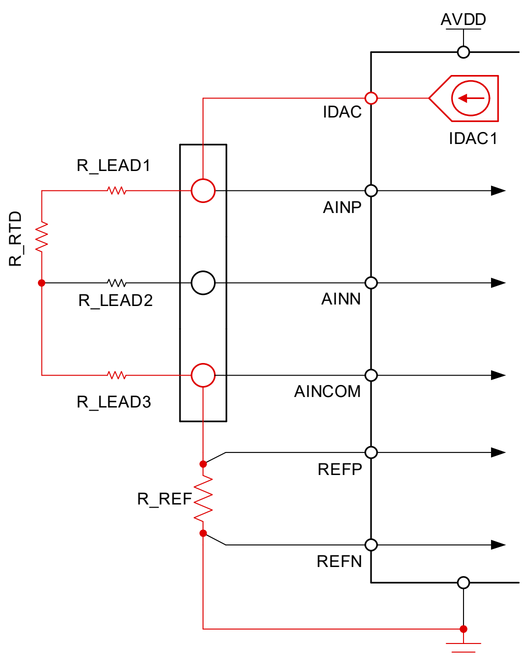
✓ Highest accuracy

× Most expensive

**Low-side R_REF shown; high-side R_REF is possible

1x IDAC versus 2x IDACs for 3-wire RTDs

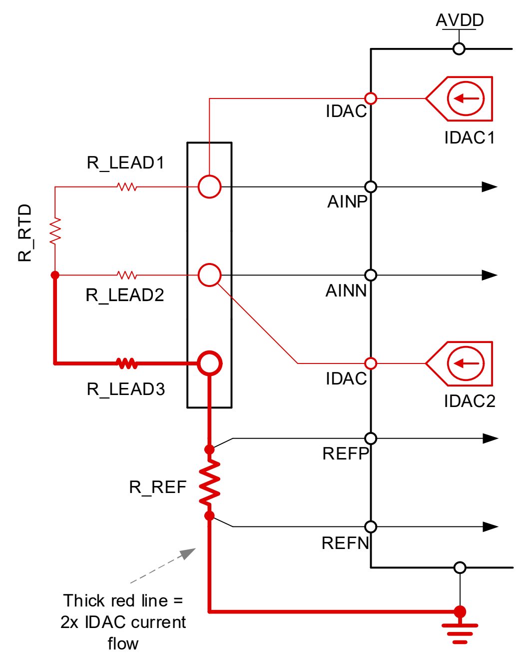
3-wire RTD using 1x IDAC**



✓ No IDAC mismatch errors

× Requires 2x measurements

3-wire RTD using 2x IDACs**



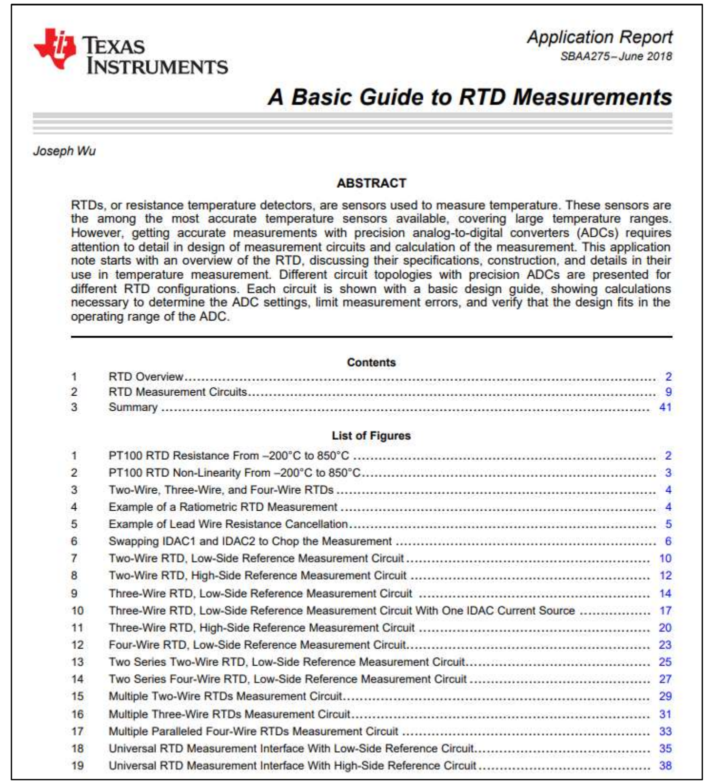
✓ Automatic lead resistance cancellation

× IDAC mismatch causes additional error

Additional information

RTD Design Guide = more detailed analysis of all RTD circuit configurations:

- 2-wire RTD w/ low-side R_REF
- 2-wire RTD w/ high-side R_REF
- 3-wire RTD w/ low-side R_REF and 1x IDAC
- 3-wire RTD w/ high-side R_REF and 1x IDAC
- 3-wire RTD w/ low-side R_REF and 2x IDACs
- 3-wire RTD w/ high-side R_REF and 2x IDACs
- 4-wire RTD w/ low-side R_REF
- 4-wire RTD w/ high-side R_R
- Multi-RTD systems


TEXAS INSTRUMENTS

Application Report
SBAA275–June 2018

A Basic Guide to RTD Measurements

Joseph Wu

ABSTRACT

RTDs, or resistance temperature detectors, are sensors used to measure temperature. These sensors are the among the most accurate temperature sensors available, covering large temperature ranges. However, getting accurate measurements with precision analog-to-digital converters (ADCs) requires attention to detail in design of measurement circuits and calculation of the measurement. This application note starts with an overview of the RTD, discussing their specifications, construction, and details in their use in temperature measurement. Different circuit topologies with precision ADCs are presented for different RTD configurations. Each circuit is shown with a basic design guide, showing calculations necessary to determine the ADC settings, limit measurement errors, and verify that the design fits in the operating range of the ADC.

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For more detailed information, review TI's app note on RTD measurement circuits (SBAA275)

Thanks for your time!
Please try the quiz.

Quiz: Introduction to RTD measurement circuits

1. What does the IDAC compliance voltage specification indicate?
   a) It provides the voltage range at the IDAC output pin over which the IDAC can maintain constant current, within some defined deviation
   b) It shows that the IDAC is compliant with IEC test standards for electrical overstress
   c) It indicates the range of current that the IDAC is capable of outputting
   d) It is an indicator of how much temperature drift to expect in the IDAC

2. (T/F) The reference resistor (R_REF) does not need to have good accuracy as the ratiometric properties of the reference eliminates initial tolerance errors
   a) True
   b) False

Quiz: Introduction to RTD measurement circuits

3. One advantage of a high side reference resistor is that it can offer some protection against electrical overstress. What is a disadvantage to this method?
   a) Input filter capacitors may be required for this method
   b) An extra bias resistor can be required to keep the input in the proper common mode range
   c) The common mode rejection of the ADC is impacted by this resistor
   d) The voltage coefficient of this resistor can cause nonlinearity

4. (True/False) When using a ratiometric reference, errors in the biasing current cancel out because the RTD output and reference scale proportionately.
   a) True
   b) False

Thanks for your time!