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Electronic Design®

Measure RTD Sensors without a Precision Current Source

You can achieve accurate resistance-temperature-detector sensor measurements without having to resort to using a precision current source.

Traditionally, resistance-temperature-detector (RTD) sensor resistance is measured by applying a precision current source and measuring the developed voltage. This approach usually requires a precision voltage reference to create then current source, followed by a high-quality analog-to-digital converter (ADC) to measure the voltage.

This isn't difficult to achieve at room temperature, but when you consider that the temperature of your measuring system can be in the range of –40 to +55 C°, the task becomes more daunting.

A brute-force approach to this problem would be to use an expensive temperature-stable voltage reference, ADC, and other components combined with software calibration to compensate for the temperature drift of parameters. This approach is complex and will fail to achieve the high precision that borderlines the sensor accuracy.

A better approach was discovered using 5 ppm/°C ultra-stable resistors with 0.1% accuracy as a reference for RTD measurements. This approach requires two onboard ultra-stable resistors for calibration (1k and 2k) to achieve high RTD precision. Those resistors are used to calibrate the RTD reading and compensate for temperature-drift errors.

The design uses the Q1-Q3 transistors in combination with the R1 resistor to form a constant-current source that sources about 1 mA using a 2.5-V ADC voltage reference *(see figure)*. Calibration resistors R4 and R5 along with the RT1 and RT2 RTD sensors can sink this current when the corresponding GPIO pin is driven low. When not used, the GPIO pins are tri-stated. The voltage is measured at the ADC output.

For calibration, we will need to read two resistors and calculate the constant-current source value and combined errors, which we call V_{Offset}. The calibrated I_{cc} and V_{Offset} values are used to convert RTD temperature readings.

The calibration results *(see table)* are applied using following formula:

$$R_{RTD} = (V_{ADC} - V_{Offset})/I_{CC} \qquad (1)$$

where:

- R_{RTD} is the measured RTD resistance.
- V_{ADC} is the ADC voltage reading.
- I_{CC} is a somewhat constant-current source.

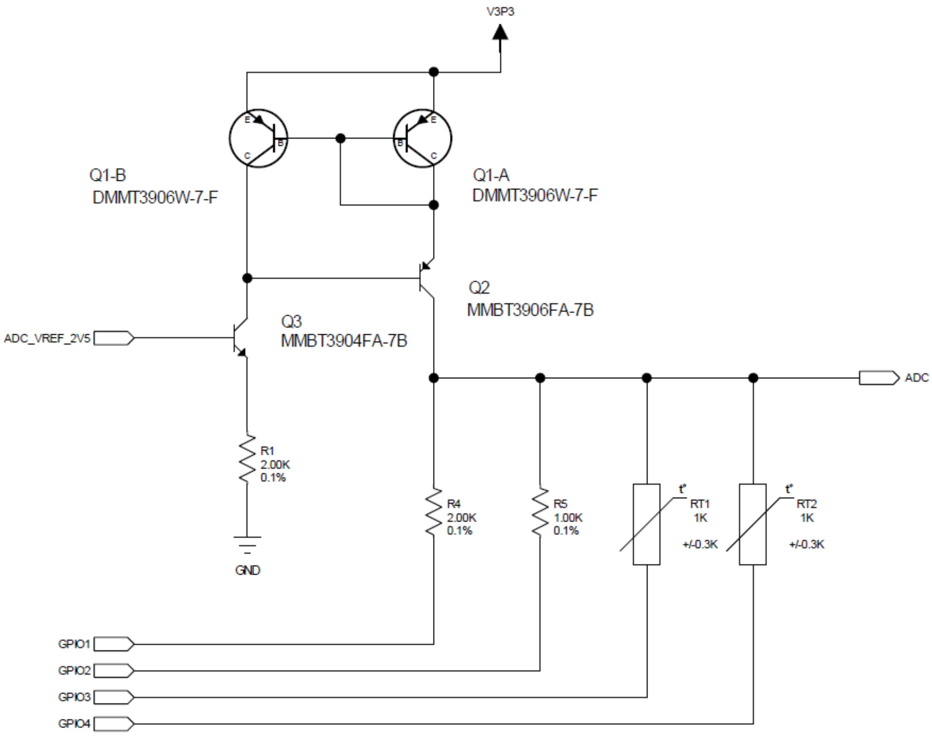
V_{Offset} is the voltage offset of cumulative errors. Note that this variable is a combination of multiple error voltage sources. Therefore, it might be beneficial (though not necessary) to split into its components to get better precision.

To calculate V_{Offset} and I_{CC}, we need to make a few assumptions to derive the formula below:

- *First assumption:* Calibration resistors are ideal and have 1,000- and 2,000-Ω values, respectively.
- *Second assumption:* The I_{CC} current source is stable for the duration of measurements.
- *Third assumption:* ADC conversion results are perfect.

Following those assumptions, we can write that:

Sample	VCAL_1K	VCAL_2K	RTD 1			RTD 2			Calibration Values	
	ADC Volts	ADC Volts	ADC Volts	R ohms	Temp C°	ADC Volts	R ohms	Temp C°	V_{offset}	Icc
1	1.208	2.353	1.350	1123.94	31.90	1.315	1092.96	23.90	0.06445	0.00114
2	1.208	2.353	1.347	1121.13	31.10	1.315	1092.96	23.90	0.06445	0.00114
3	1.196	2.349	1.331	1117.32	30.20	1.321	1108.94	28.00	0.04189	0.00115
4	1.196	2.349	1.350	1134.08	34.50	1.321	1108.94	28.00	0.04189	0.00115
5	1.196	2.349	1.334	1120.11	30.90	1.321	1108.94	28.00	0.04189	0.00115



The Q1-Q3 transistors and R1 resistor form a constant-current source that sources about 1 mA using a 2.5-V ADC voltage reference.

$$I_{CC} * 1000 + V_{Offset} = VCAL_{1K} \qquad (2)$$
$$I_{CC} * 2000 + V_{Offset} = VCAL_{2K}$$

In Equation 2, $VCAL_{1K}$ and $VCAL_{2K}$ represent voltages developed on calibration resistors when I_{CC} current is applied.

By solving those equations for I_{CC} and V_{Offset}, we get the following equations:

$$V_{Offset} = \frac{VCAL_{1K}*2000 - VCAL_{2K}*1000}{1000} \qquad (3)$$

$$I_{CC} = \frac{VCAL_{2K} - V_{Offset}}{2000} \qquad (4)$$

Experimental Setup Measurements

The experimental setup has two calibration resistors and two RTDs mounted on different locations. We used an ADC with 10-bit resolution and surface-mount RTDs rated 1k at room temperature. Notice how the calibration values change when board temperature changes between sample 2 and 3 in the *table*.

To gather the data, the software followed these steps:

1. Read ADC voltage levels on calibration resistors and RTDs.
2. Calculate V_{offset} using Equation 3.
3. Calculate I_{CC} with Equation 4.
4. Determine RTD resistance utilizing Equation 1.
5. Convert RTD resistance values to temperature with the table lookup and piecewise interpolation.

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