Application Note

Designing Temperature Monitoring Systems with NTC and RTD

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ABSTRACT

Temperature measuring and monitoring is widely used in medical equipment and industries. In MRI equipment, there needs to be several NTC to monitor liquid-helium temperature. In a ventilator, engineers need to monitor temperature of air and make sure the temperature of air is comfortable for the patient. In a CT system, the engineer needs to monitor temperature of DAS system for get best SNR and then high imaging quality. In an IVD system, engineers also need to monitor temperature of samples. In a hospital, the doctor also needs to monitor the temperature of the patient during surgical operations since this is a key parameter of humans. There are several methods based on different principles to measure temperature. However, most medical equipment prefers to use NTC or RTD for temperature measure since high precision, easy mounting, and inexpensive. This application note shows several designs to measure or monitor temperature with sensor of NTC or RTD. The methods proposed in this application note can also be used in other industry systems.

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1 Temperature Measure

Temperature is an important parameter for several medical systems and industry producing. In MRI equipment, there needs to be several NTC to monitor liquid-helium temperature. In a ventilator, engineers need to monitor temperature of air and make temperature of air is comfortable for patient. In a CT system, engineer need monitor temperature of DAS system for get best SNR and then high imaging quality. In an IVD system, engineers also need to monitor temperature of samples. In hospital, doctor also need monitor temperature of patient during surgical operations since this is a key parameter of humans. There are several methods based on different principles to measure or monitor temperature. This application note mainly focuses on NTC and RTD methods. The document proposes several designs to interface with NTC and RTD since NTC and RTD is ease of mounting, inexpensive, high-sensitive, high precision and then was widely used in medical systems and industry systems.

2 Key Challenge to Design a Temperature Monitor

As previously mentioned, NTC and RTD was widely used in medical system and industry system for temperature measure and monitor. However, both NTC and RTD are passive elements and needs external source to excite. There mainly has two method to excite the NTC and RTD: DC voltage or DC current. the resistor vary with temperature is quite small in generally for NTC and RTD. This is especially truth for RTD. So, designer need to use big voltage or current to excite NTC and RTD for get measurable output voltage. Also, the excite current can not too big in case heating the sensor. For example, 1℃ temperature vary can cause approximately 0.39Ω resistor vary for a 100Ω at 0℃ RTD. With 0.1mA drive current, the vary voltage is approximately 0.039mV and much less than 1LSB of 12bit-ADC with 3.3V full range. While the common voltage is 10mV. So, the maximum gain is 330 for a 3.3V system. But the gain can be need approximately 1000 if engineer require 0.2℃ resolution. for defeat this challenge, TI propose several designs to help customer easy the design and get the expected result.

3 Proposed Designs for Temperature Monitor Based NTC or RTD

3.1 Voltage Excitation

Traditionally, bridge circuit was used with RTD and NTC temperature sensor for remove the bias voltage or common voltage and just sampling difference voltage by an instrumentation amplifier. The function between output of bridge and sensor resistor varies is non-linearity. Bridge amplifier can solve this issue. The bridge amplifier as dash block shown in Figure 3-1. Assume the reference voltage is V_R and output of amplifier is Vo, then it is easy to receive Equation 1.

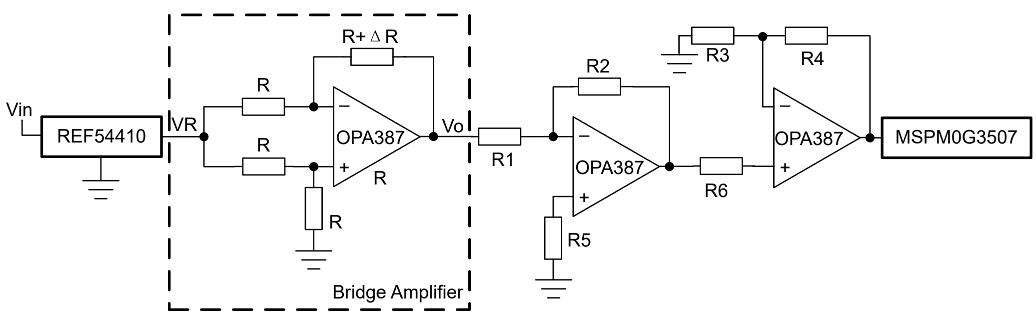

Figure 3-1. Discrete RTD Signal Conditions Circuit

$$V_o = -\frac{V_R}{2R} \times \Delta R \tag{1}$$

From Equation 1, the designer can see that the output voltage is linear with resistor varies. Assume the reference is 4.096V and resistor of RTD is 1000Ω under 0℃, the output can be approximately 7.9872mV for 1℃ temperature rise under approximately 2mA excite current. in actually design, the excite current can need less than 1mA for avoid self-heating and then the output voltage can small than 7.9872mV for 1℃ temperature rises. For get better resolution and precise, there need a post-amplifier to amplify the signals from bridge amplifier.

Note, from Equation 1, the output voltage is inverting with varied resistor. So, first stage amplifier potential needs dual-power supply in case function abnormal.

Since the signals is quite small, for improved system precision, the key requirements for bridge amplifier is low offset and low offset drift. OPA387 is a very low offset amplifier and can meet this application. Maximum 2uV offset voltage can work to improve system precision. The second amplifier was used to inverter output of bridge amplifier to non-inverter and amplify the signals again. The third amplifier is optional in case the need to amplify further in actual design. Also, good idea if customer inserts the filter between amplifier circuits for reduced system noise and improve SNR of system.

Performance of reference is another factor which can potentially impact system precision according Equation 1. For getting best precision, REF54410 was proposed for exciting the sensor. The 0.02% precision and 0.8ppm/C drift can help to improve system precision. REF54410 is one parts of REF54 series reference with 4.096V output voltage. Customer can select other parts with different output voltage to meet specific requirements.

3.2 Current Excitation

Another way to remove the common voltage for RTD and NTC application is to use two exactly the same current source to excite RTD and NTC and an auxiliary offset resistor. The value of auxiliary offset resistor can be equal the value of RTD and NTC resistor at start point temperature. TI: REF200 includes two exactly same constant current source and can meet this application. The typical application circuit is shown as Figure 3-2.

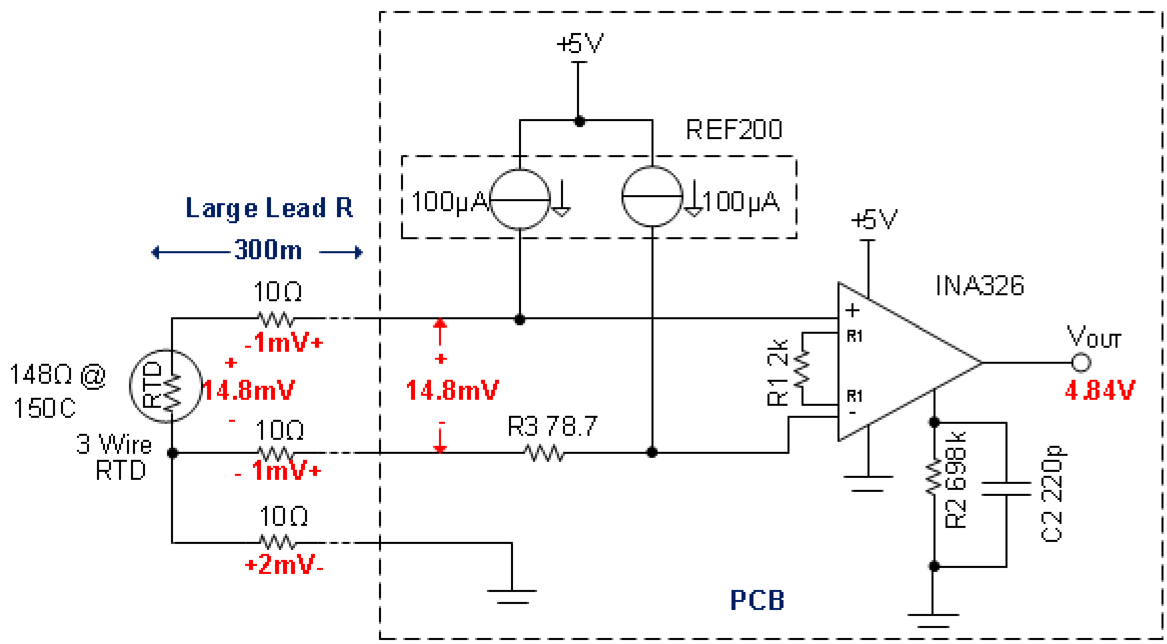

Figure 3-2. RTD Signal Conditioning Circuit Based Constant Current Source

In Figure 3-2, R3 is auxiliary offset resistor for remove common voltage of RTD under approximately-54℃ since the application measure temperature in range of -50℃approximately150℃ with a 100Ω RTD sensor. In -54℃, the RTD resistor is 78.7Ω, then 100uA excitation current can produce the common voltage of 7.87mV. this common voltage can be removed by instrument amplifier INA326. The function between RTD resistor vary with output voltage as shown in Equation 2.

$$V_{out} = \Delta R_{RTD} \times 100\mu A \times Gain \tag{2}$$

Equation 2 shows that the output voltage is linear with resistor varies. The gain can be adjusted according to specific application. The temperature can be deduced by the output voltage.

3.3 Ratio Measure

TI also developed specific IC to meet NTC and RTD signal conditioning application. Such IC generally had integrated two adjustable constant current sources to excite NTC and RTD sensor. The IC also integrated high resolution ADC and associated PGA for signal conditioning. For multichannel application, the IC also integrated a MUX. The miscellaneous user interface for meeting varies requirements. A typical IC is ADS124S08. Figure 3-3 shows a typical configuration for ADS124S08 to measure temperature with a 3-wire RTD.

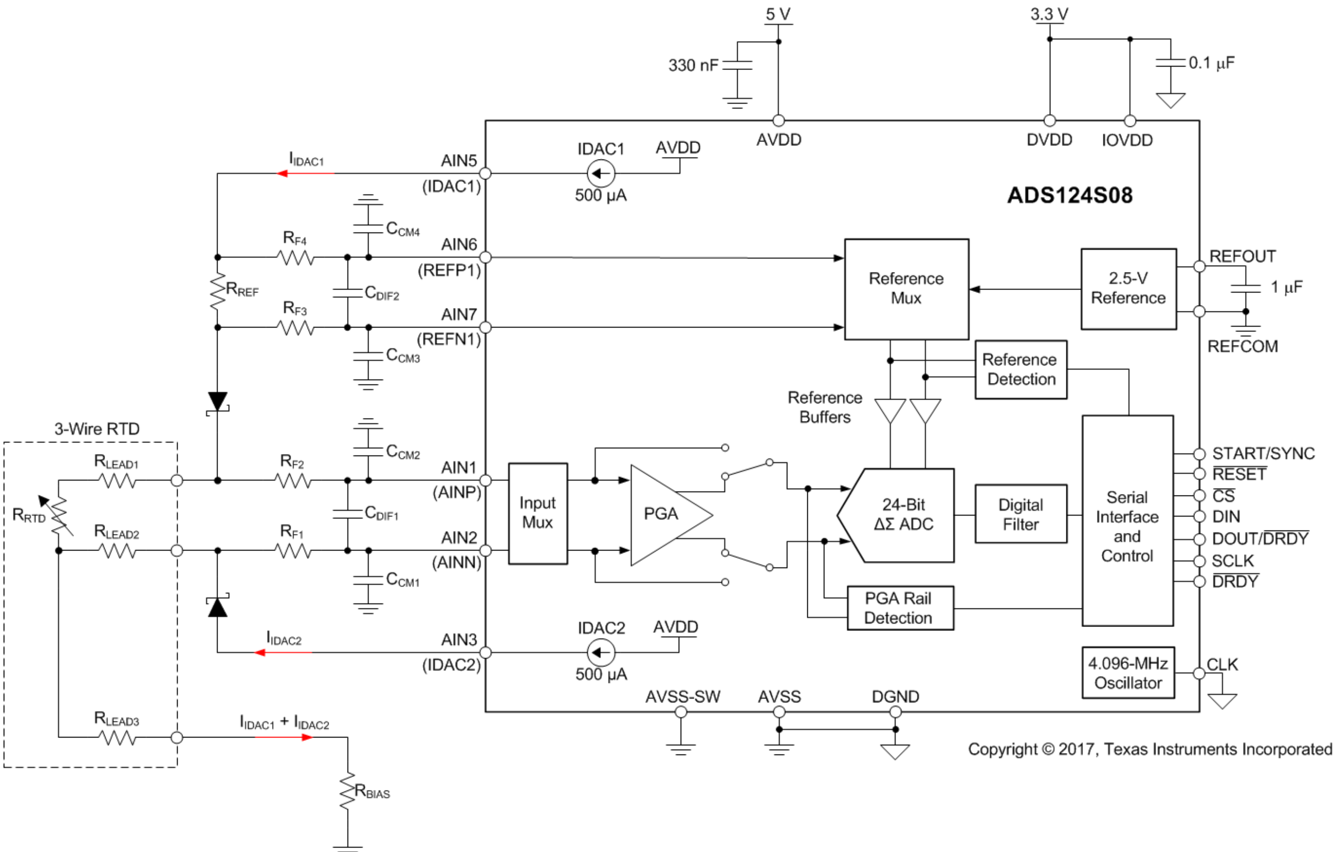

Figure 3-3. Integrated RTD Signal Conditioning Circuit Based ADS124S08

The internal adjustable constant current source 1 of ADS124S08 flow out reference resistor R_{REF}, diode, R_{lead1}, RTD, R_{lead3} and R_{bias} then back to ground. The internal adjustable constant current source 2 also flow out ADS124S08, diode, R_{lead2}, R_{lead3} and R_{bias} then back to ground. Here R_{lead1}, R_{lead2} and R_{lead3} are resistor of wire of RTD and has equal resistor. The impact of lead resistor was removed since the voltage produced by excited current are exactly the same under exactly same excite current and canceled. Assume the value of constant current source is I, PGA gain is G, then ADC input voltage can be: $I \times R_{RTD} \times G$. ADC reference can be equal voltage of R_{REF}. So, the ADC result can be:

$$D = \frac{V_{ADC}}{V_{REF}} = \frac{I \times R_{RTD} \times G}{I \times R_{REF}} = \frac{R_{RTD} \times G}{R_{REF}} \tag{3}$$

Equation 3 shows that ADC result has no function with precision of constant current source. The result is only associated with reference resistor and gain of amplifier. The customer can directly get the resistor value of RTD/NTC from ADC result. Then to deduce the temperature.

The *ADS124S0x Low-Power, Low-Noise, Highly Integrated, 6- and 12-Channel, 4-kSPS, 24-Bit, Delta-Sigma ADC with PGA and Voltage Reference* data sheet and *A Basic Guide to RTD Measurements* application note show how to remove the impact of resistor of lead and error of adjustable constant current source to get better precision. Refer to the data sheet and application note for more detailed information.

3.4 Integrated Designs

In an actual temperature measure design, some customers need to do calibration, remove offset error, compensate linearity. An MCU always is necessary in modern temperature measure system. MSPM0G3507 is a Cortex-M0+ MCU and integrated two zero-draft-precision amplifiers, precision reference, and a two 12bit-4MSPS ADCs with 17 external channels. With hardware averaging, the ADC resolution is potentially improved to 14bits with 250Ksps rate.

The designer can implement 2.1 descriptive discrete designs with MSPM0G3507 single chip for temperature signal conditioning. Also, the designer needs to keep ΔR<0 in all conditions since MSPM0G3507 can power supply with a single positive power supply. With ΔR<0, according to Equation 1, the output can be a positive output. The designer does not need to power internal amplifier with dual supply.

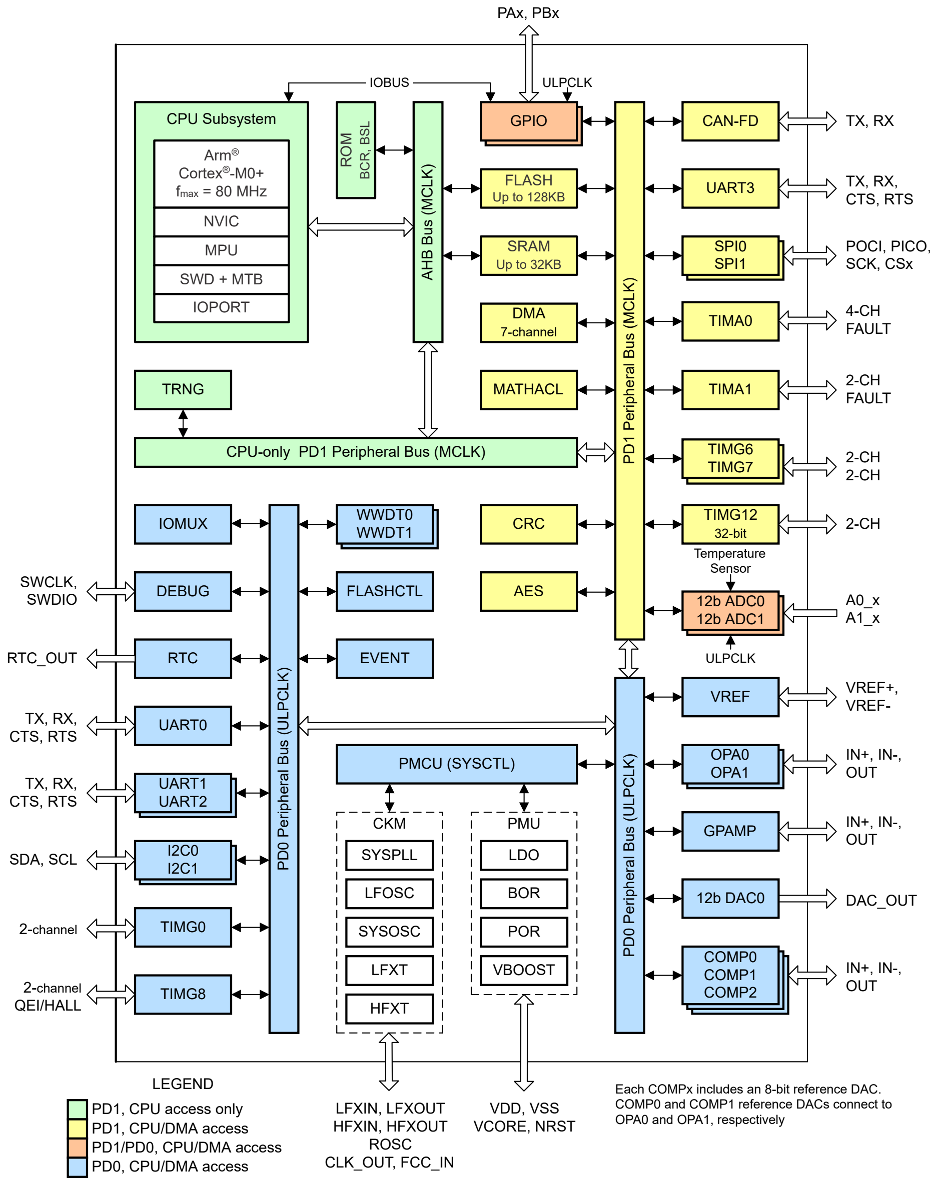

Figure 3-4. Single Chip MCU Block Figure for RTD Signal Conditioning

PGA900 sensor conditioning chip is another integrated design for temperature measure. TI: PGA900 is a resistor sensor signal conditioning chip with an ARM Cortex-M0+ integrated. the block figure as Figure 3-5 shows. With integrate adjustable constant current, PGA, ADC and MCU make PGA900 is a single chip design for temperature measure too. Wide power supply character (3.3 approximately 30V) and miscellaneous output format is potential to meet miscellaneous industry application.

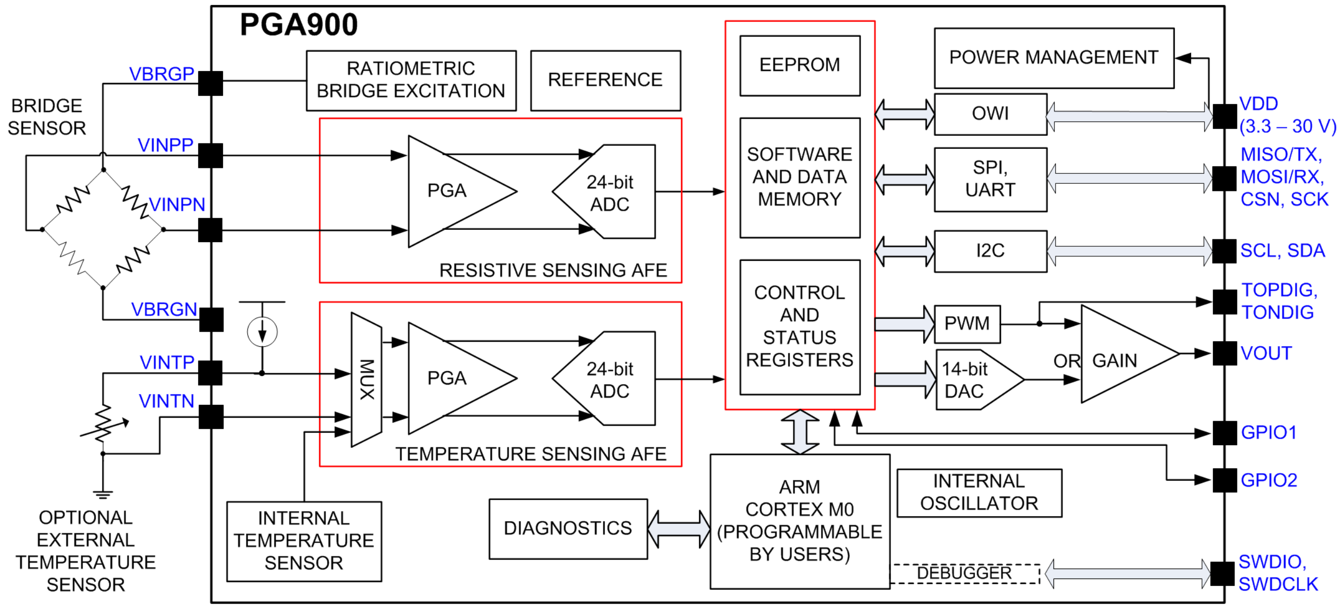

Figure 3-5. ASIC for RTD Signal Conditioning

The customer can interface NTC and RTD to resistive sensing AFE channel (main channel) or temperature sensing AFE channel (aux channel). The output voltage of main channel is non-linear for a single sensor since it is excited by a precision internal voltage reference. This is not an issue for an MCU system, MCU can calculate the relationship between sampling voltage and varied resistor. Aux channel is excited by an adjustable constant current, so the output voltage is linearity with varied resistor and potentially have an offset voltage.

4 Summary

This application note discussed several designs for RTD/NTC sensor signal conditioning. The potential was used for other resistor-based sensor signal conditioning such as PTC, optic-sensing resistor, magnetic-sensing resistor and so on. There are several articles and products from TI that can help customer to design a resistor-based temperature signal conditioning circuit. Consult your FAE, TI.com for detailed information, support, and help. For easy to select best designs for a specific application, Table 4-1 shows the difference between these designs.

Table 4-1. Comparison Between Proposed Signal Conditioning Designs

Item	Voltage-excite	Current-excite	ratio	MSPM0G3507	PGA900
Performance	best	best	better	good	better
Lead Compensation	better	best	best	better	good
Flexibility	best	best	better	good	Better
Design	difficult	middle	easy	middle	middle
PCB area	large	large	small	smallest	smallest
Cost	High cost	High cost	Middle cost	Low cost	Middle cost

5 References

1. Texas Instruments, *A Basic Guide to RTD Measurements*, application note.
2. Texas Instruments, *REF200 Dual Current Source and Current Sink* data sheet.
3. Texas Instruments, *ADS124S0x Low-Power, Low-Noise, Highly Integrated, 6- and 12-Channel, 4-kSPS, 24-Bit, Delta-Sigma ADC with PGA and Voltage Reference* data sheet.
4. Texas Instruments, *PGA900 Programmable Resistive Sensing Conditioner With Digital and Analog Outputs* data sheet.

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