Low-Cost, Single-Chip, Differential Temperature Measurement Solution Using Precision Delta-Sigma ADCs

TEXAS INSTRUMENTS

Introduction

Various commercial and industrial end-equipment require differential temperature measurements (DTM) to operate, including thermal mass flow meters, integral tunable laser assemblies (ITLA), and heat meters, such as the one shown in Figure 1 below.

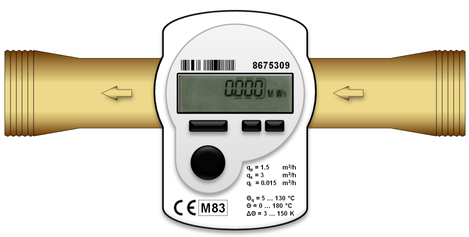

Figure 1. Heat Meter using DTM

Many of these end-equipment are battery-powered systems with extremely limited PCB space, requiring small, low-power solutions that also provide high resolution. Texas Instruments' ADS1220 offers a single-chip solution with an excellent balance between power consumption, size, and performance for many DTM applications.

Circuit Implementation

Typical DTM implementations use two 2- or 4-wire resistance temperature detectors (RTDs). Figure 2 shows two 4-wire RTDs attached to the ADS1220, a 24-bit, low-power ADC operating down to 2.3 V and offered in a 3.5 mm x 3.5 mm QFN package.

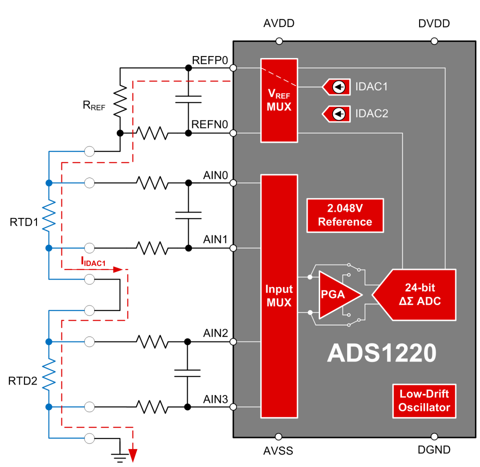

Figure 2. ADS1220 DTM Connection Diagram

Key characteristics of this circuit include:

- *Integrated RTD excitation* – uses one of ADS1220's integrated current sources (IDAC1) to excite both RTDs
- *Ratiometric measurement* – reference voltage ($V_{REF} = I_{IDAC1} \cdot R_{REF}$) and input signal ($V_{RTD} = I_{IDAC1} \cdot R_{RTD}$) are proportional to the excitation current (I_{IDAC1}) such that measurements do not rely on the exact value of I_{IDAC1}
- *RTDs in series* – offers faster settling time when multiplexing between RTD measurements since both RTDs are always excited
- *Anti-aliasing RC filters* – reduce aliasing and provide overvoltage protection
- *PGA bypass* – avoids integrated INA common-mode voltage limitations while still offering gains of 1, 2 and 4 V/V

Selecting Component Values and ADC Settings

The specific end-equipment defines the component selection and ADC settings for the system shown in Figure 2. As an example, Table 1 lists common DTM requirements in heat meter applications using two PT-500 RTDs.

Table 1. System Specifications

Parameter	Unit	Value
Temperature Sensors		PT-500
Temperature Measurement Range (Θ)	°C	0—180
Differential Temperature Range (ΔΘ)	K	3—100
Differential Temperature Resolution	mK	10
Measurement Cycle	s	1
Power Supply Voltage	V	3

Using these heat-meter-specific parameters, select component values and settings for the ADS1220 as outlined below:

1. R_{REF} – select the value of R_{REF} to be 1x, 2x, or 4x the largest expected RTD resistance (highest temperature), including some margin
2. *IDAC current* – select the largest available value that still meets the IDAC's compliance voltage
3. *Gain* – select the same factor chosen in "R_{REF}"
4. *Output data rate (ODR)* – select the fastest available data rate that still meets the system's resolution requirements

Optimizing **R_{REF}**, **IDAC current**, and **gain** increases the ADC's input signal and maximizes the measurement resolution as much as possible. Similarly, maximizing the ADC's **ODR** enables efficient device power cycling in order to minimize ADC on-time (power consumption) during each measurement cycle.

Designers must also consider ADC startup time, as this may hinder efficient power cycling. To mitigate this challenge, the ADS1220 offers a startup time of only 50 µs. This fast startup time allows complete ADC power-down for more of the measurement cycle, enabling additional power savings compared to other solutions.

To meet the requirements outlined in the previous sections (specifically Table 1), Table 2 lists optimal ADC settings and system component values.

Table 2. Component Values & ADC Settings

Parameter	Value
R_{REF}	3.84 kΩ
I_{IDAC}	250 µA
Gain	4 V/V
Output Data Rate	90 SPS
Sampling Mode	Turbo

Table 3 lists the necessary register settings to implement the configuration shown in Figure 2 and enable the parameters from Table 2.

Table 3. Register Settings for Values in Table 2

Register	Setting	RTD1	RTD2
00h	RTD1 = AIN0/1, RTD2 = AIN2/3, Gain = 4, PGA Bypass	05h	55h
01h	90 SPS, Turbo Mode, Single-Shot Conversion	30h	30h
02h	Ext. VREF, IDAC = 250 µA	44h	44h
03h	IDAC1 routed to REFP0	A0h	A0h

With these settings, the system achieves a DTM resolution better than 10 mK. Additionally, the system can measure each RTD and still power down the ADC for approximately 98% of the 1 second measurement cycle. During the RTD measurements, the ADS1220 consumes approximately 965 µA while operating at the settings shown in Figure 2.

System Tradeoffs

In most DTM applications, designers typically optimize between measurement resolution and power consumption. Changing the ADC's ODR offers a direct way to balance these two parameters. Table 4 summarizes the system tradeoffs associated with changing the ADC's ODR.

Table 4. Effect of Changing ADC ODR on Resolution, ADC On-Time, and Power Consumption

ODR	ADC On-Time	Resolution	Power
Increases	Decreases	Decreases	Decreases
Decreases	Increases	Increases	Increases

Converting Code to Temperature

As stated in the "Circuit Implementation" section, the diagram in Figure 2 employs a ratiometric measurement such that the voltage across the RTD and reference voltage are both proportional to the IDAC current. Therefore, calculating the RTD temperature only requires the ADC's output code and resolution (N) as well as the user-defined values for gain and R_{REF}:

$$(V_{RTD} \cdot \text{Gain}) / (2 \cdot V_{REF}) = \text{Code} / 2^N \quad (1)$$

$$(R_{RTD} \cdot I_{IDAC} \cdot \text{Gain}) / (2 \cdot R_{REF} \cdot I_{IDAC}) = \text{Code} / 2^N \quad (2)$$

$$(R_{RTD} \cdot \text{Gain}) / (2 \cdot R_{REF}) = \text{Code} / 2^N \quad (3)$$

$$R_{RTD} = (\text{Code} \cdot R_{REF}) / (\text{Gain} \cdot 2^{N-1}) \quad (4)$$

Diagnostic Features for DTM

The ADS1220 includes two additional features that provide useful diagnostics in DTM applications:

- *Voltage reference monitoring* – helps determine if the ADC's reference voltage is valid. A reference voltage across R_{REF} close to 0 V may indicate a disconnected RTD
- *Sensor burnout current sources (BOCS)* – can detect an open sense line of a 4-wire RTD

Alternative Device Recommendations

Texas Instruments offers additional precision ADCs other than the ADS1220 that can be used for DTM. The solutions listed in Table 5 optimize for specific parameters such as cost, size or performance.

Table 5. Alternative Device Recommendations

Device	Optimized Parameter	Performance Trade-Off
ADS1120	Lower cost	16-bit resolution
ADS122C04	I2C Interface	Slower data communication
ADS122U04	UART Interface	
ADS124S06	Higher resolution	5 mm x 5 mm QFN

Conclusion

Many industrial end-equipment that employ DTM require highly-integrated, low power, high-resolution ADCs, all in a small form factor. Texas Instrument's ADS1220 offers an excellent balance of performance, size, and current consumption to accurately and efficiently measure two 2- or 4-wire RTDs for DTM.