

Temperature Sensing PTC Circuit With MSP430™ Smart Analog Combo

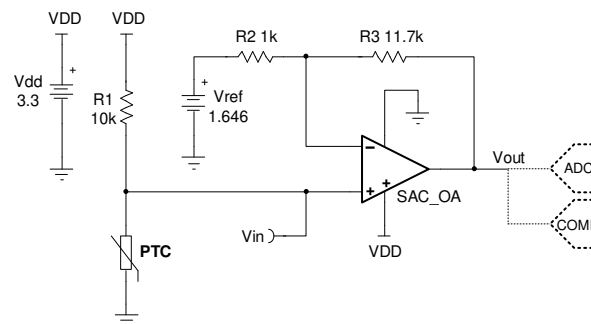
Design Goals

Temperature		Output voltage		Supply		
T_{Min}	T_{Max}	V_{outMin}	V_{outMax}	V_{dd}	V_{ee}	V_{ref}
0°C	50°C	0.15 V	3.15 V	3.3 V	0 V	1.646 V

Design Description

Some MSP430™ microcontrollers (MCUs) contain configurable integrated signal chain elements such as op-amps, DACs, and programmable gain stages. These elements make up a peripheral called the Smart Analog Combo (SAC). For information on the different types of SACs and how to leverage their configurable analog signal chain capabilities, visit [MSP430 MCUs Smart Analog Combo Training](#). To get started with your design, download the [Temperature Sensing PTC Circuit Design Files](#).

This temperature sensing circuit uses a resistor in series with a positive-temperature-coefficient (PTC) thermistor to form a voltage divider, which produces an output voltage that is linear over temperature. The circuit uses the [MSP430FR2311](#) SAC_L1 op-amp in a noninverting amplifier configuration with inverting reference to offset and amplify the signal, which helps to use the full ADC resolution and increase measurement accuracy. (Note: The [MSP430FR2355](#) features four SAC_L3 peripherals which each contain a built-in DAC and PGA, providing a single-chip solution for generating V_{ref} and measuring the thermistor circuit.) The output of the integrated SAC op-amp can be sampled directly by the on-board ADC or monitored by the on-board comparator for further processing inside the MCU.



Design Notes

- The connection, V_{in} , is a positive temperature coefficient output voltage. To measure the output voltage of a negative-temperature-coefficient (NTC) thermistor, switch the position of R_1 and the PTC resistor.
- V_{ref} can be generated by the integrated SAC_L3 DACs in the MSP430FR2355 or a voltage divider. If a voltage divider is used, the equivalent resistance of the voltage divider affects the gain of the circuit.
- Using high-value resistors can degrade the phase margin of the amplifier and introduce additional noise in the circuit. It is recommended to use resistor values around 10 k Ω or less.
- If the solution is implemented using the MSP430FR2311, the SAC_L1 op-amp is configured in general purpose mode to measure the thermistor circuit.
- If the solution is implemented using the MSP430FR2355, one SAC_L3 peripheral is configured in DAC mode to generate the reference voltage and another is configured in general purpose mode to measure the thermistor circuit.

Design Steps

$$V_{out} = V_{dd} \times \frac{R_{PTC}}{R_{PTC} + R_1} \times \frac{R_2 + R_3}{R_2} - \frac{R_3}{R_2} \times V_{ref} \quad (1)$$

1. Calculate the value of R_1 to produce a linear output voltage. Use the minimum and maximum values of the PTC to obtain a range of values for R_1 .

$$\begin{aligned} R_{PTC_Max} &= R_{PTC @ 50^\circ C} = 11.611 \text{ k}\Omega \\ R_{PTC_Min} &= R_{PTC @ 0^\circ C} = 8.525 \text{ k}\Omega \\ R_1 &= \sqrt{R_{PTC @ 0^\circ C} \times R_{PTC @ 50^\circ C}} = \sqrt{8.525 \text{ k}\Omega \times 11.611 \text{ k}\Omega} = 9.95 \text{ k}\Omega \approx 10 \text{ k}\Omega \end{aligned} \quad (2)$$

2. Calculate the input voltage range.

$$\begin{aligned} V_{inMin} &= V_{dd} \times \frac{R_{PTC_Min}}{R_{PTC_Min} + R_1} = 3.3 \text{ V} \times \frac{8.525 \text{ k}\Omega}{8.525 \text{ k}\Omega + 10 \text{ k}\Omega} = 1.519 \text{ V} \\ V_{inMax} &= V_{dd} \times \frac{R_{PTC_Max}}{R_{PTC_Max} + R_1} = 3.3 \text{ V} \times \frac{11.611 \text{ k}\Omega}{11.611 \text{ k}\Omega + 10 \text{ k}\Omega} = 1.773 \text{ V} \end{aligned} \quad (3)$$

3. Calculate the gain required to produce the maximum output swing.

$$G_{ideal} = \frac{V_{outMax} - V_{outMin}}{V_{inMax} - V_{inMin}} = \frac{3.15 \text{ V} - 0.15 \text{ V}}{1.773 \text{ V} - 1.519 \text{ V}} = 11.811 \frac{\text{V}}{\text{V}} \quad (4)$$

4. Select R_2 and calculate R_3 to set the gain calculated in Step 3.

$$\begin{aligned} \text{Gain} &= \frac{R_2 + R_3}{R_2} \\ R_2 &= 1 \text{ k}\Omega \\ R_3 &= R_2 \times (G_{ideal} - 1) = 1 \text{ k}\Omega \times (11.811 - 1) = 10.811 \text{ k}\Omega \\ \text{Choose } R_3 &= 10.7 \text{ k}\Omega \text{ (Standard value)} \end{aligned} \quad (5)$$

5. Calculate the actual gain based on standard values of R_2 and R_3 .

$$G_{actual} = \frac{R_2 + R_3}{R_2} = \frac{1 \text{ k}\Omega + 10.7 \text{ k}\Omega}{1 \text{ k}\Omega} = 11.7 \frac{\text{V}}{\text{V}} \quad (6)$$

6. Calculate the output voltage swing based on the actual gain.

$$V_{out_swing} = (V_{inMax} - V_{inMin}) \times G_{actual} = (1.773 \text{ V} - 1.519 \text{ V}) \times 11.7 \frac{\text{V}}{\text{V}} = 2.9718 \text{ V} \quad (7)$$

7. Calculate the maximum output voltage when the output voltage is symmetrical around mid-supply.

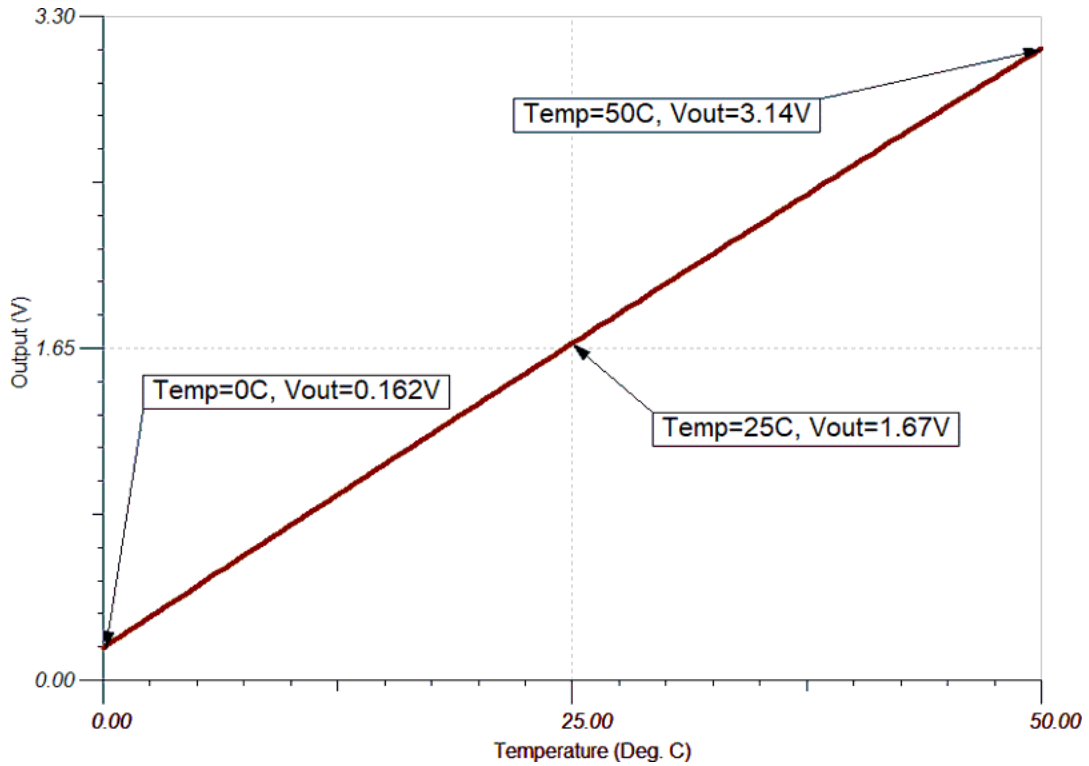
$$V_{outMax} = V_{mid-supply} + \frac{V_{out_swing}}{2} = \frac{V_{dd} - V_{ee}}{2} + \frac{V_{out_swing}}{2} = \frac{3.3 \text{ V} - 0 \text{ V}}{2} + \frac{2.9718 \text{ V}}{2} = 3.136 \text{ V} \quad (8)$$

8. Calculate the reference voltage.

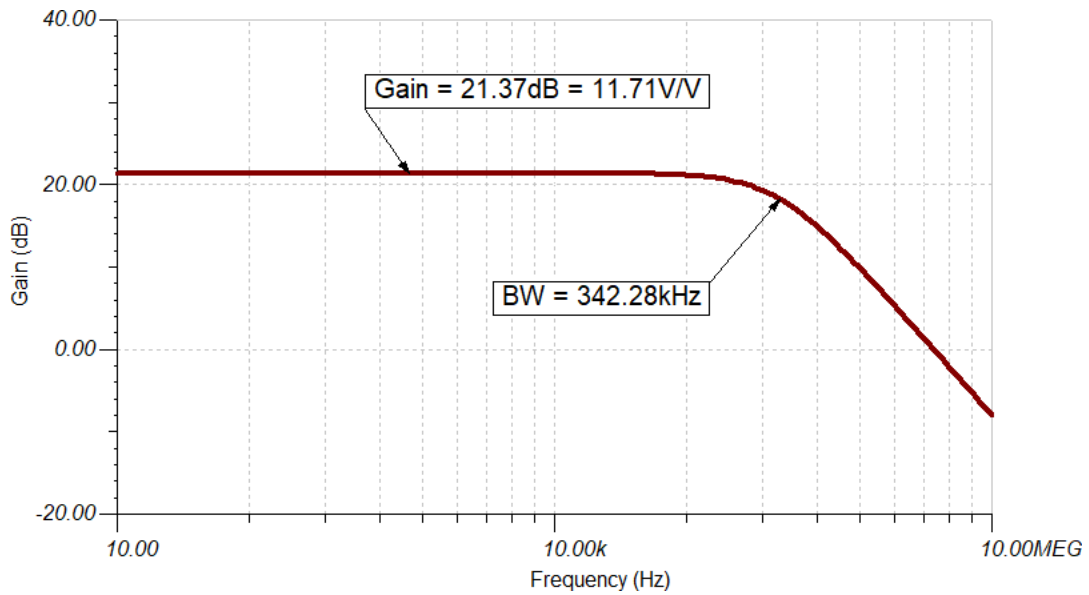
$$\begin{aligned} V_{outMax} &= V_{inMax} \times G_{actual} - \frac{R_3}{R_2} \times V_{ref} \\ 3.136 \text{ V} &= 1.773 \text{ V} \times 11.7 \frac{\text{V}}{\text{V}} - \frac{10.7 \text{ k}\Omega}{1 \text{ k}\Omega} \times V_{ref} \\ V_{ref} &= \frac{1.773 \text{ V} \times 11.7 \frac{\text{V}}{\text{V}} - 3.136 \text{ V}}{\frac{10.7 \text{ k}\Omega}{1 \text{ k}\Omega}} = 1.646 \text{ V} \end{aligned} \quad (9)$$

Design Simulations

DC Transfer Results



AC Simulation Results



Target Applications

- [Field temperature transmitters](#)
- [Thermostats](#)
- [Thermometers](#)
- Thermistor probes
- System temperature monitor

References

1. [MSP430 MCUs Smart Analog Combo Training](#)
2. [Analog Engineer's Circuit Cookbooks](#)
3. [MSP430FR2311 TINA-TI Spice Model](#)
4. [MSP430 Temp Sense PTC Circuit Code Examples and SPICE Simulation File](#)

Design Featured Op Amp

MSP430FRxx Smart Analog Combo		
	MSP430FR2311 SAC_L1	MSP430FR2355 SAC_L3
V_{CC}	2.0 V to 3.6 V	
V_{CM}	-0.1 V to $V_{CC} + 0.1$ V	
V_{out}	Rail-to-rail	
V_{os}	± 5 mV	
A_{OL}	100 dB	
I_q	350 μ A (high-speed mode)	
	120 μ A (low-power mode)	
I_b	50 pA	
UGBW	4 MHz (high-speed mode)	2.8 MHz (high-speed mode)
	1.4 MHz (low-power mode)	1 MHz (low-power mode)
SR	3 V/ μ s (high-speed mode)	
	1 V/ μ s (low-power mode)	
Number of channels	1	4
http://www.ti.com/product/MSP430FR2311		
http://www.ti.com/product/MSP430FR2355		



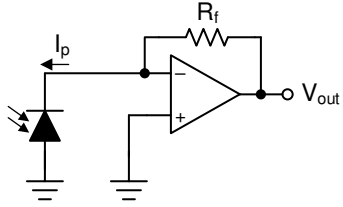
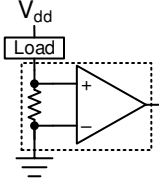
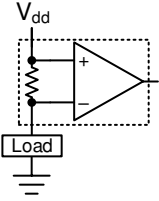
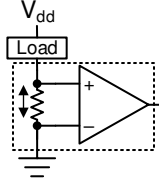

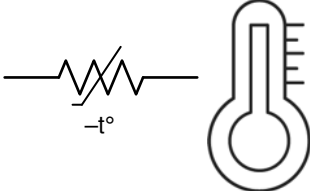
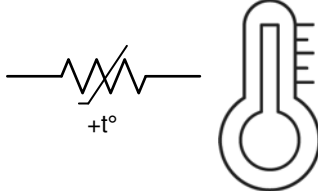
Design Alternate Op Amp

MSP430FR2311 Transimpedance Amplifier	
V_{CC}	2.0 V to 3.6 V
V_{CM}	-0.1 V to $V_{CC}/2$ V
V_{out}	Rail-to-rail
V_{os}	± 5 mV
A_{OL}	100 dB
I_q	350 μ A (high-speed mode)
	120 μ A (low-power mode)
I_b	5 pA (TSSOP-16 with OA-dedicated pin input)
	50 pA (TSSOP-20 and VQFN-16)
UGBW	5 MHz (high-speed mode)
	1.8 MHz (low-power mode)
SR	4 V/ μ s (high-speed mode)
	1 V/ μ s (low-power mode)
Number of channels	1
http://www.ti.com/product/MSP430FR2311	

Design Featured Thermistor

TMP61	
V_{CC}	Up to 5.5 V
R₂₅	10 kΩ
R_{TOL}	1%
I_{SNS}	400 μA
Operating temperature range	-40°C to 125°C
http://www.ti.com/product/TMP61	

Related MSP430 Circuits

<p>Low-noise and long-range PIR sensor conditioner circuit</p> 	<p>Bridge amplifier circuit</p> 	<p>Transimpedance amplifier circuit</p> 
<p>Single-supply, low-side, unidirectional current-sensing circuit</p> 	<p>High-side current sensing with discrete difference amplifier circuit</p> 	<p>Low-side, bidirectional current-sensing circuit</p> 
<p>Half-wave rectifier circuit</p> 	<p>Temperature sensing with NTC thermistor circuit</p> 	<p>Temperature sensing with PTC thermistor circuit</p> 

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from October 19, 2019 to March 6, 2020

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- Added *Related MSP430 Circuits* section..... 6
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