

Temperature Sensing NTC Circuit With MSP430™ Smart Analog Combo

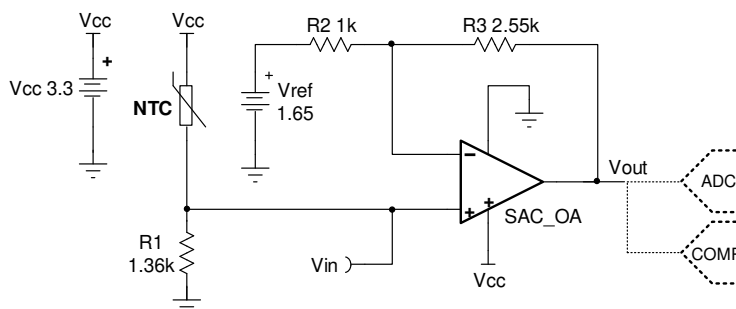
Design Goals

Temperature		Output Voltage		Supply		
T_{Min}	T_{Max}	V_{outMin}	V_{outMax}	V_{CC}	V_{EE}	V_{ref}
25°C	50°C	0.2 V	3.1 V	3.3 V	0 V	1.65 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 NTC Circuit Design Files](#).

This temperature sensing circuit uses a resistor in series with a negative-temperature-coefficient (NTC) 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 gain 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 negative temperature coefficient output voltage. To measure the output voltage of a PTC thermistor, switch the position of R_1 and the thermistor.
- V_{ref} can be generated using one of 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 will influence 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 of approximately 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

$$V_{out} = V_{cc} \times \frac{R_1}{R_{NTC} + R_1} \times \frac{R_2 + R_3}{R_2} - \frac{R_3}{R_2} \times V_{ref}$$

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

$$R_{NTC_max} = R_{NTC} @ 25^\circ\text{C} = 2.252 \text{ k}\Omega, \quad R_{NTC_min} = R_{NTC} @ 50^\circ\text{C} = 819.7 \Omega$$

$$R_1 = \sqrt{R_{NTC} @ 25^\circ\text{C} \times R_{NTC} @ 50^\circ\text{C}} = \sqrt{2.252 \text{ k}\Omega \times 819.7 \Omega} = 1.359 \text{ k}\Omega \approx 1.36 \text{ k}\Omega$$

2. Calculate the input voltage range.

$$V_{inMin} = V_{cc} \times \frac{R_1}{R_{NTC_max} + R_1} = 3.3 \text{ V} \times \frac{1.36 \text{ k}\Omega}{2.252 \text{ k}\Omega + 1.36 \text{ k}\Omega} = 1.2418 \text{ V}$$

$$V_{inMax} = V_{cc} \times \frac{R_1}{R_{NTC_min} + R_1} = 3.3 \text{ V} \times \frac{1.36 \text{ k}\Omega}{819.7 \Omega + 1.36 \text{ k}\Omega} = 2.0582 \text{ V}$$

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

$$G_{ideal} = \frac{V_{outMax} - V_{outMin}}{V_{inMax} - V_{inMin}} = \frac{3.1 \text{ V} - 0.2 \text{ V}}{2.0582 \text{ V} - 1.2418 \text{ V}} = 3.5519 \frac{\text{V}}{\text{V}}$$

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

$$\text{Gain} = \frac{R_2 + R_3}{R_2}$$

$$R_2 = 1 \text{ k}\Omega \text{ (Standard value)}$$

$$R_3 = R_2 \times (G_{ideal} - 1) = 1 \text{ k}\Omega \times (3.5519 \frac{\text{V}}{\text{V}} - 1) = 2.5519 \text{ k}\Omega$$

$$\text{Choose } R_3 = 2.55 \text{ k}\Omega$$

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

$$G_{actual} = \frac{R_2 + R_3}{R_2} = \frac{1 \text{ k}\Omega + 2.55 \text{ k}\Omega}{1 \text{ k}\Omega} = 3.55 \frac{\text{V}}{\text{V}}$$

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

$$V_{out_swing} = (V_{inMax} - V_{inMin}) \times G_{actual} = (2.0582 \text{ V} - 1.2418 \text{ V}) \times 3.55 \frac{\text{V}}{\text{V}} = 2.9 \text{ V}$$

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

$$V_{outMax} = V_{mid-supply} + \frac{V_{out_swing}}{2} = \frac{V_{cc} - V_{ee}}{2} + \frac{V_{out_swing}}{2} = \frac{3.3 \text{ V} - 0 \text{ V}}{2} + \frac{2.9 \text{ V}}{2} = 3.1 \text{ V}$$

8. Calculate the reference voltage.

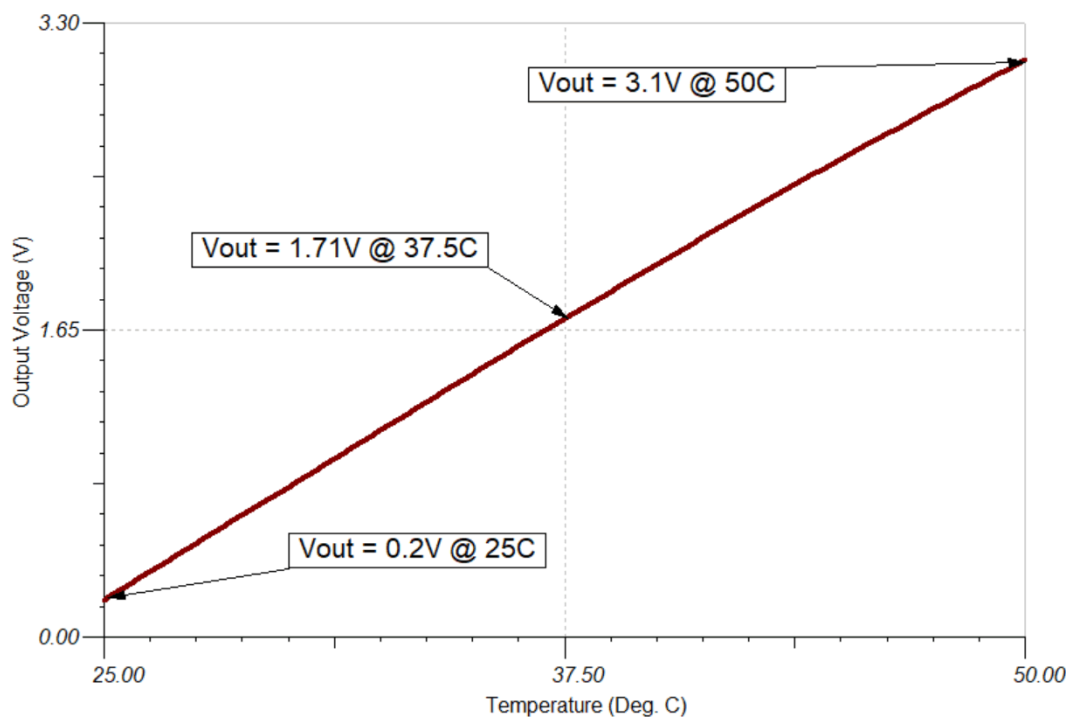
$$V_{outMax} = V_{inMax} \times G_{actual} - \frac{R_3}{R_2} \times V_{ref}$$

$$3.1 \text{ V} = 2.0582 \text{ V} \times 3.55 \frac{\text{V}}{\text{V}} - \frac{2.55 \text{ k}\Omega}{1 \text{ k}\Omega} \times V_{ref}$$

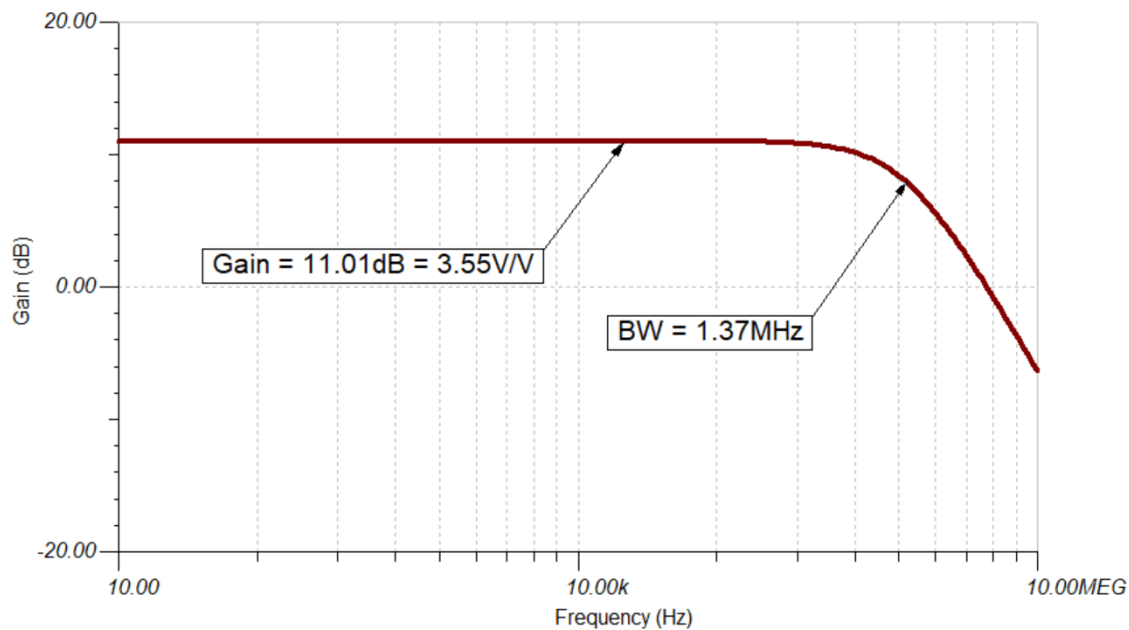
$$V_{ref} = \frac{2.0582 \text{ V} \times 3.55 \frac{\text{V}}{\text{V}} - 3.1 \text{ V}}{\frac{2.55 \text{ k}\Omega}{1 \text{ k}\Omega}} = 1.65 \text{ V}$$

Design Simulations

DC Transfer Results



AC Simulation Results



Target Applications

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

References

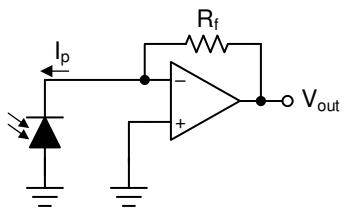
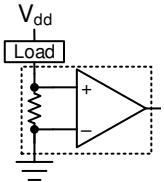
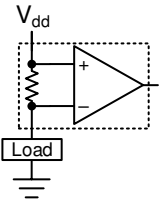
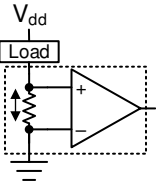
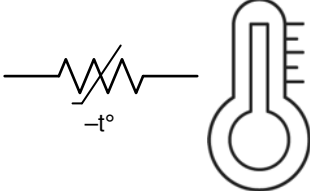
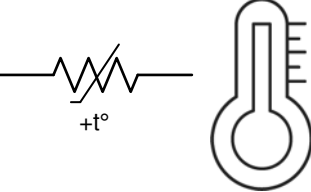
1. [MSP430 MCUs Smart Analog Combo Training](#)
2. [Analog Engineer's Circuit Cookbooks](#)
3. [MSP430FR2311 TINA-TI Spice Model](#)
4. [MSP430 Temp Sense NTC Circuit Code Examples and SPICE Simulation File](#)

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	

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

Revision History

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

Changes from October 19, 2019 to March 9, 2020 Page

- Added *Related MSP430 Circuits* section..... 5

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