Analog Engineer's Circuit

Single-Supply Strain Gauge Bridge Amplifier Circuit with MSP430™ Smart Analog Combo

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Design Goals

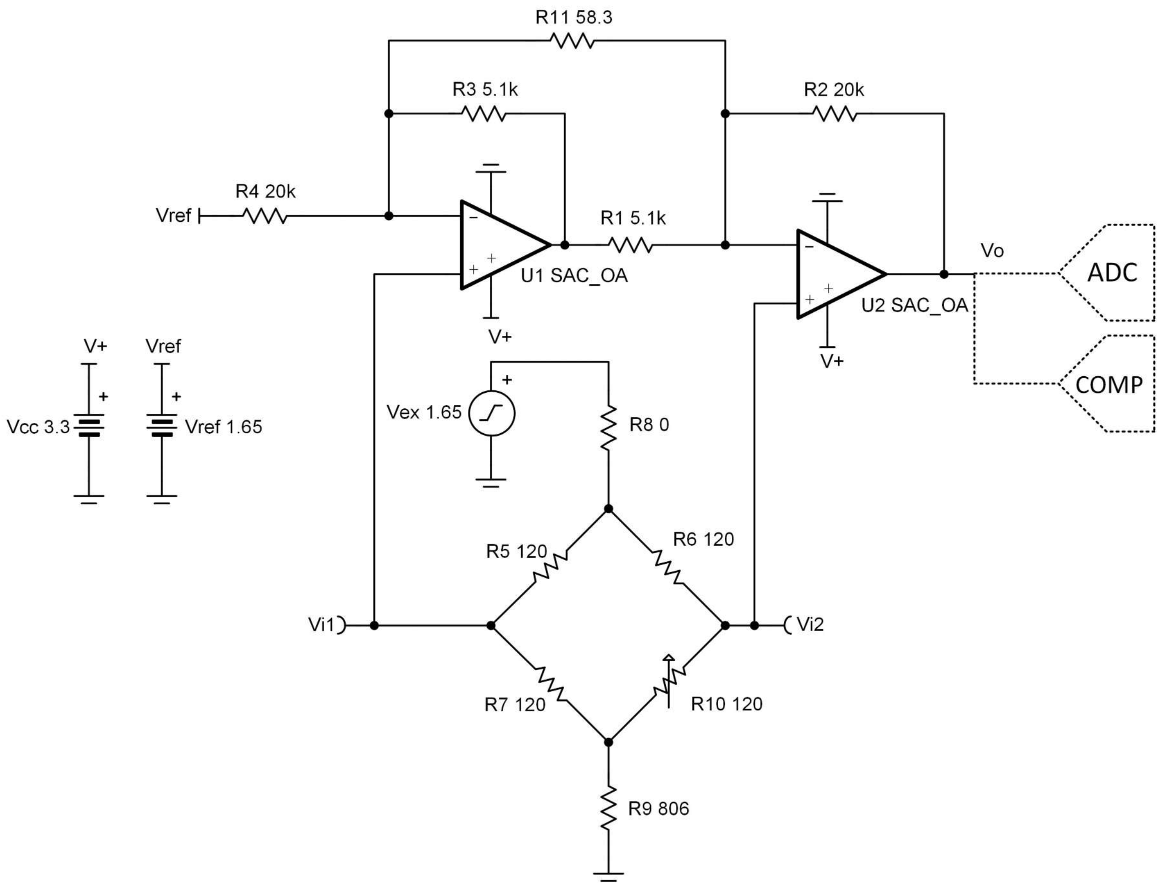
Input V_{iDiff} ($V_{i2} – V_{i1}$)		Output		Supply		
V_{iDiff_Min}	V_{iDiff_Max}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
–2.22mV	2.27mV	0.1V	3.2V	3.3V	0V	1.65V

Strain Gauge Resistance Variation (R_{10})	V_{cm}	Gain
115Ω to 125Ω	1.34V	690V/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 configurable analog signal chain capabilities, visit MSP430 MCUs Smart Analog Combo Training. To get started with your design, download the Strain Gauge Bridge Amplifier Circuit Design Files.

A strain gauge is a sensor whose resistance varies with applied force. The change in resistance is directly proportional to how much strain the sensor is experiencing due to the force applied. This pressure sensing circuit uses a strain gauge placed in a bridge configuration to measure the variation in resistance. This design leverages all four of the built-in op-amp blocks (SACs) in the MSP430FR2355. Two SAC_L3 peripherals are configured in general-purpose mode to amplify a differential signal created by the change in resistance of a strain gauge while the other two are configured in DAC mode to supply the reference voltage (Vref) and the excitation voltage (Vex). By varying R_{10}, a small differential voltage is created at the output of the Wheatstone bridge which is fed to the 2 SAC op-amp instrumentation amplifier inputs. The linearity of the instrumentation amplifier is based on the input common-mode and output-swing ranges of the MSP430 SAC op-amp, which can be found in the specification chart at the end of this document. The output of the second stage 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

- Resistors R_5, R_6, and R_7 of the Wheatstone bridge must match the stain gauge nominal resistance and must be equal to avoid creating a bridge offset voltage.
- Low tolerance resistors must be used to minimize the offset and gain errors due to the bridge resistors.
- V_{ex} sets the excitation voltage of the bridge and the common-mode voltage V_{cm}.
- V_{ref} biases the output voltage of the MSP430 SAC-based instrumentation amplifier to mid-supply to allow differential measurements in the positive and negative directions.
- R_{11} sets the gain of the instrumentation amplifier circuit.
- R_8 and R_9 set the common-mode voltage of the instrumentation amplifier and limits the current through the bridge. This current determines the differential signal produced by the bridge. However, there are limitations on the current through the bridge due to self-heating effects of the bridge resistors and strain gauge.
- Establish that $R_1 = R_3$ and $R_2 = R_4$ and that ratios of R_2/R_1 and R_4/R_3 are matched to set the V_{ref} gain to 1V/V and maintain high DC CMRR of the instrumentation amplifier.
- Using high-value resistors can degrade the phase margin of the circuit and introduce additional noise in the circuit.
- If the fix is implemented using the MSP430FR2311, the instrumentation amplifier would need to consist of one SAC_L1 op-amp and one Transimpedance Amplifier (TIA) op-amp. The excitation and reference voltages, Vex and Vref, would need to be supplied externally (for example, voltage divider).
- The *Strain Gauge Bridge Amplifier Circuit Design Files* include code examples showing how to properly initialize the SAC peripherals.

Design Steps

1. Select R_5, R_6, and R_7 to match the stain gauge nominal resistance

$$R_{gauge} = R_5 = R_6 = R_7 = 120\Omega$$

2. Choose R_9 to set the common mode voltage of the instrumentation amplifier at 1.34V.

$$V_{cm} = \frac{\frac{R_{bridge}}{2} + R_9}{R_{bridge} + R_8 + R_9} \times V_{ex}$$

Where

$$R_{bridge} = total\ resistance\ of\ the\ bridge$$

To allow maximum current through the bridge, choose

$$R_8 = 0\Omega$$

$$V_{cm} = \frac{\frac{120\Omega \times 4}{2} + R_9}{(120\Omega \times 4) + 0\Omega + R_9} \times 1.65V = 1.34V$$

$$\frac{240 + R_9}{480 + 0\Omega + R_9} = \frac{1.34V}{1.65V} = 0.812$$

$$0.188R_9 = 149.82 \rightarrow R_9 = \frac{149.82}{0.188} = 797.42\Omega \rightarrow R_9 = 806\Omega\ (Standard\ value)$$

3. Calculate the gain required to produce the desired output voltage swing

$$\mathrm{G} = \frac{\mathrm{V_{oMax} - V_{oMin}}}{\mathrm{V_{iDiff\_Min} - V_{iDiff\_Min}}} = \frac{3.2\ \mathrm{V} - 0.1\mathrm{V}}{0.00222\mathrm{V} - (-0.00227\mathrm{V})} = 690.42\frac{\mathrm{V}}{\mathrm{V}}$$

4. Select R_1, R_2, R_3 and R_4. To set the V_{ref} gain at 1V/V and avoid degrading the instrumentation amplifier's CMRR, R_1 must equal R_3 and R_2 equal R_4. Choose

$$\mathrm{R_1 = R_3 = 5.1k\ \Omega}$$

and

$$R_3 = R_4 = 20k\Omega\ (Standard\ value)$$

5. Calculate R_{11} to meet the required gain

$$\mathrm{G} = 1 + \frac{\mathrm{R_4}}{\mathrm{R_3}} + \frac{2 \times \mathrm{R_2}}{\mathrm{R_{11}}} = 690.42\frac{\mathrm{V}}{\mathrm{V}}$$

$$\mathrm{G} = 1 + \frac{20\mathrm{k}\Omega}{5.1\mathrm{k}\Omega} + \frac{2 \times \mathrm{R_2}}{\mathrm{R_{11}}} = 690.42\frac{\mathrm{V}}{\mathrm{V}} \rightarrow 4.92 + \frac{40\mathrm{k}\Omega}{\mathrm{R_{11}}} = 690.42\frac{\mathrm{V}}{\mathrm{V}} \rightarrow \frac{40\mathrm{k}\Omega}{\mathrm{R_{11}}} = 685.5 \rightarrow \mathrm{R_{11}} = \frac{40\mathrm{k}\Omega}{685.5} = 58.35\Omega \rightarrow \mathrm{R_{11}} = 58.3\Omega\ \left(\text{Standard Value}\right)$$

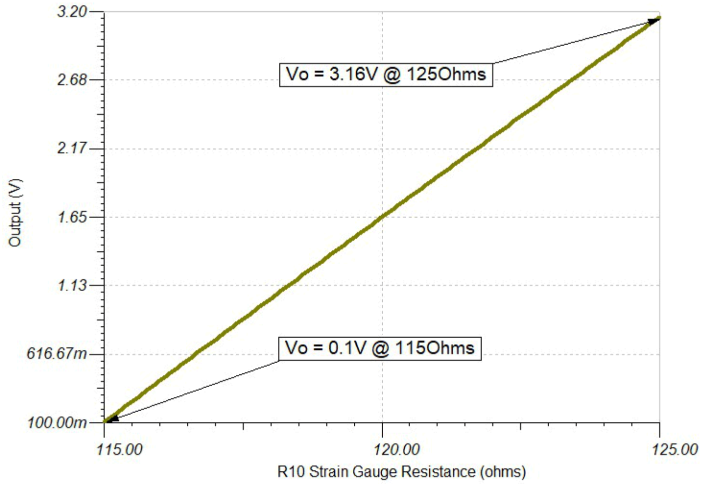
6. Calculate the current through the bridge

$$\mathrm{I_{bridge}} = \frac{\mathrm{V_{ex}}}{\mathrm{R_8 + R_9 + R_{bridge}}} = \frac{1.65\mathrm{V}}{0\Omega + 806\Omega + 120\Omega \times 4}$$

$$\mathrm{I_{bridge}} = \frac{1.65\mathrm{V}}{806\Omega + 480\Omega} \rightarrow \mathrm{I_{bridge}} = 1.28\mathrm{mA}$$

Design Simulations

DC Simulation Results



Target Applications

- *Pressure transmitter*
- *Weigh scale*

References

1. Texas Instruments, *MSP430 Strain Gauge Bridge Amplifier Circuit*, code examples and SPICE simulation file
2. Texas Instruments, *16MHz Integrated Analog Microcontroller with 3.75KB Fram, OpAmp, Tia, Comparator with Dac, 10-bit ADC*, product page
3. Texas Instruments, *MSP430 MCUs Smart Analog Combo*, training video

Design Featured Op Amp

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

Design Alternate Op Amp

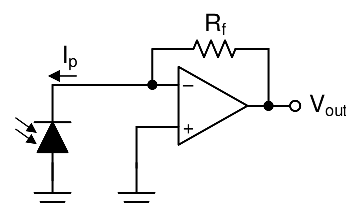
MSP430FR2311 Transimpedance Amplifier	
V_{cc}	2.0V to 3.6V
V_{CM}	-0.1V to V_{CC}/2V
V_{out}	Rail-to-rail
V_{os}	±5mV
A_{OL}	100dB
I_q	350µA (high-speed mode)
	120µA (low-power mode)
I_b	5pA (TSSOP-16 with OA-dedicated pin input)
	50pA (TSSOP-20 and VQFN-16)
UGBW	5MHz (high-speed mode)
	1.8MHz (low-power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

Related MSP430 Circuits

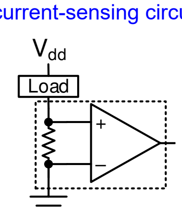
Low-noise and long-range PIR sensor conditioner circuit

Bridge amplifier circuit

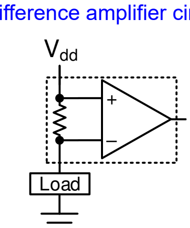
Transimpedance amplifier circuit



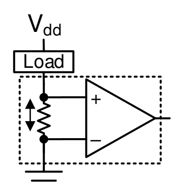
Single-supply, low-side, unidirectional current-sensing circuit



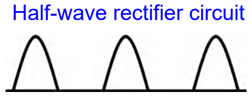
High-side current sensing with discrete difference amplifier circuit



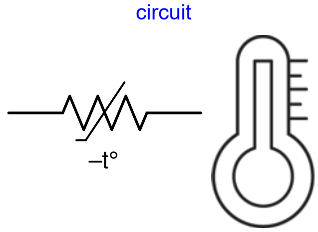
Low-side, bidirectional current-sensing circuit



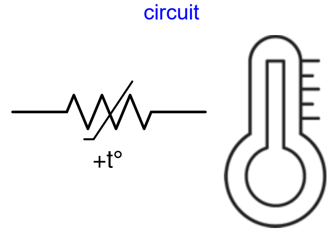
Half-wave rectifier circuit



Temperature sensing with NTC thermistor circuit



Temperature sensing with PTC thermistor circuit



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Revision History

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

Changes from Revision A (March 2020) to Revision B (October 2024)	Page
• Updated the format for tables, figures, and cross-references throughout the document	1

Changes from Revision * (December 2019) to Revision A (March 2020)	Page
• Added *Related MSP430 Circuits* section	1

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