Single-supply strain gauge bridge amplifier circuit

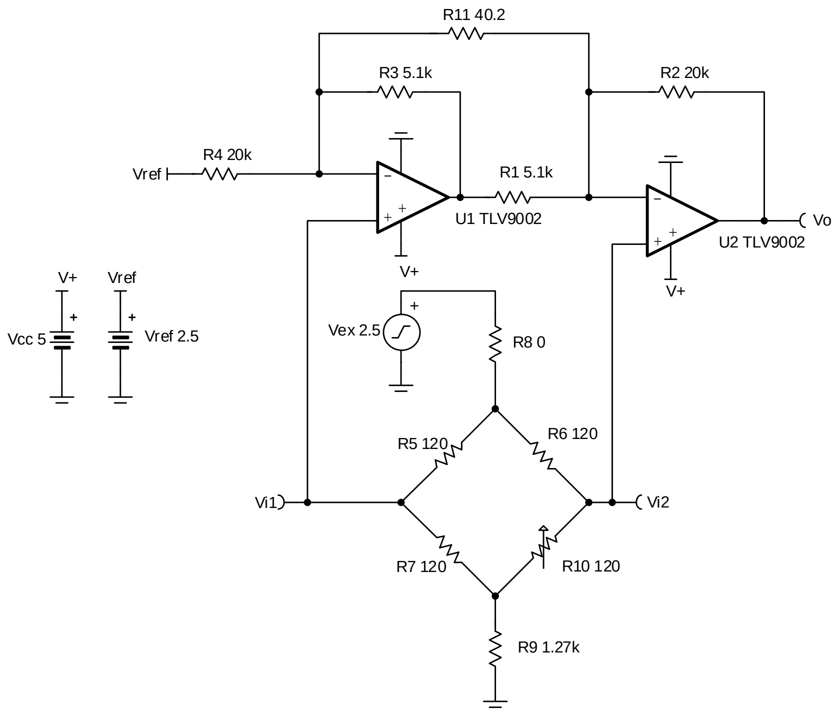
Design Goals

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	225mV	4.72V	5V	0V	2.5V

Strain Gauge Resistance Variation (R_{10})	V_{cm}	Gain
115Ω – 125Ω	2.15V	1001V/V

Design Description

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. To measure the variation in resistance, the strain gauge is placed in a bridge configuration. This design uses a 2 op amp instrumentation circuit to amplify a differential signal created by the change in resistance of a strain gauge. By varying R_{10}, a small differential voltage is created at the output of the Wheatstone bridge which is fed to the 2 op amp instrumentation amplifier input. Linear operation of an instrumentation amplifier depends upon the linear operation of its primary building block: op amps. An op amp operates linearly when the input and output signals are within the device’s input common–mode and output-swing ranges, respectively. The supply voltages used to power the op amps define these ranges.



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Design Notes:

1. 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.
2. Low tolerance resistors must be used to minimize the offset and gain errors due to the bridge resistors.
3. V_{ex} sets the excitation voltage of the bridge and the common–mode voltage V_{cm}.
4. V_{ref} biases the output voltage of the instrumentation amplifier to mid–supply to allow differential measurements in the positive and negative directions.
5. R_{11} sets the gain of the instrumentation amplifier circuit.
6. 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.
7. Ensure 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.
8. Linear operation is contingent upon the input common–mode and the output swing ranges of the op amps used. The linear output swing ranges are specified under the A_{ol} test conditions in the op amps datasheets.
9. Using high–value resistors can degrade the phase margin of the circuit and introduce additional noise in the circuit.

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 2.15V

$$V_{cm} = \frac{\frac{R_{bridge}}{2} + R_5}{R_{bridge} + R_8 + R_9} \times V_{ex}$$

Where R_{bridge} = total resistance of the bridge

Choose $R_8 = 0\,\Omega$ to allow maximum current through the bridge

$$V_{cm} = \frac{\frac{120\Omega \times 4}{2} + R_9}{120\Omega \times 4 + 0\Omega + R_9} \times 2.5\,V = 2.15\,V$$

$$\frac{240 + R_9}{480 + 0\Omega + R_9} = \frac{2.15V}{2.5V} = 0.86$$

$$0.14\,R_9 = 172.8 \rightarrow R_9 = \frac{172.8}{0.14} = 1.23\,k\Omega \rightarrow R_9 = 1.27\,k\Omega \text{ (Standard value)}$$

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

$$G = \frac{V_{oMax} - V_{oMin}}{V_{iDiff\_Min} - V_{iDiff\_Min}} = \frac{4.72V - 0.225V}{0.00222V - (-0.00227V)} = 1001\frac{V}{V}$$

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 $R_1 = R_3 = 5.1k\,\Omega$ and $R_3 = R_4 = 20\,k\,\Omega$ (Standard value)

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

$$G = 1 + \frac{R_4}{R_3} + \frac{2 \times R_2}{R_{11}} = 1001\frac{V}{V}$$

$$G = 1 + \frac{20k\Omega}{5.1k\Omega} + \frac{2 \times R_2}{R_{11}} = 1001\frac{V}{V} \rightarrow 4.92 + \frac{40k\Omega}{R_{11}} = 1001\frac{V}{V} \rightarrow \frac{40k\Omega}{R_{11}} = 996.1 \rightarrow R_{11} = \frac{40k\Omega}{996.1} = 40.15\,\Omega \rightarrow R_{11} = 40.2\Omega \text{ (Standard Value)}$$

6. Calculate the current through the bridge

$$I_{bridge} = \frac{V_{ex}}{R_8 + R_9 + R_{bridge}} = \frac{2.5V}{0\Omega + 1.27k\Omega + 120\Omega \times 4}$$

$$I_{bridge} = \frac{2.5V}{1.27k\Omega + 480\Omega} \rightarrow I_{bridge} = 1.42mA$$

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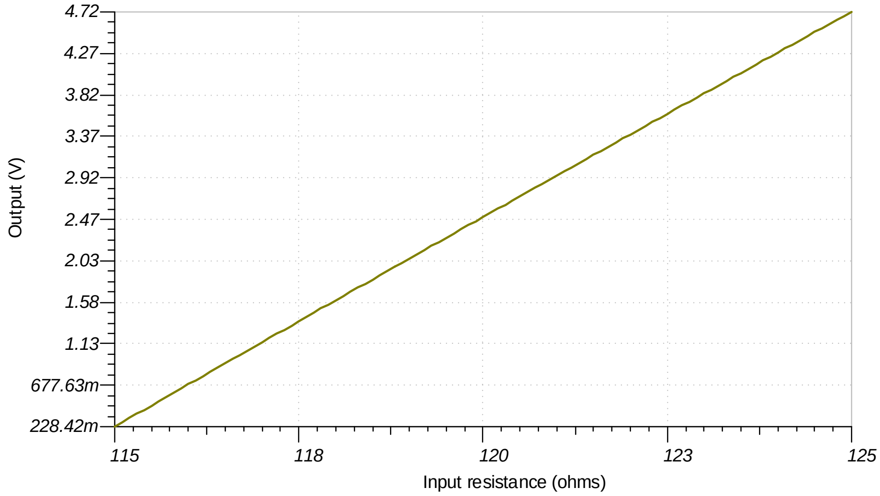
Design Simulations:

DC Simulation Results



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References:

1. Analog Engineer's Circuit Cookbooks
2. SPICE Simulation File SBOMAU4
3. TI Precision Designs TIPD170
4. TI Precision Labs
5. V_{CM} vs. V_{OUT} plots for instrumentation amplifiers with two op amps

Design Featured Op Amp:

TLV9002	
V_{ss}	1.8V to 5.5V
V_{inCM}	Rail–to–rail
V_{out}	Rail–to–Rail
V_{os}	0.4mV
I_q	0.06mA
I_b	5pA
UGBW	1MHz
SR	2V/µs
#Channels	1,2,4
www.ti.com/product/tlv9002	

Design Alternate Op Amp:

OPA376	
V_{ss}	2.2V to 5.5V
V_{inCM}	(V_{ee}–0.1V) to (V_{cc}–1.3V)
V_{out}	Rail–to–Rail
V_{os}	0.005mV
I_q	0.76mA
I_b	0.2pA
UGBW	5.5MHz
SR	2V/µs
#Channels	1,2,4
www.ti.com/product/opa376	

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