Tim Claycomb

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Single-Supply Strain Gauge in a Bridge Configuration Reference Design

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Design Resources

TIPD170	All Design files
TINA-TI™	SPICE Simulator
INA333	Product Folder
REF5025	Product Folder

Circuit Description

This strain gauge reference design accurately measures the resistance of a strain gauge placed in a bridge configuration. Changes in the strain gauge resistance create a differential voltage that is amplified by an instrumentation amplifier. The bridge excitation voltage and instrumentation amplifier reference voltage are supplied using the REF5025.

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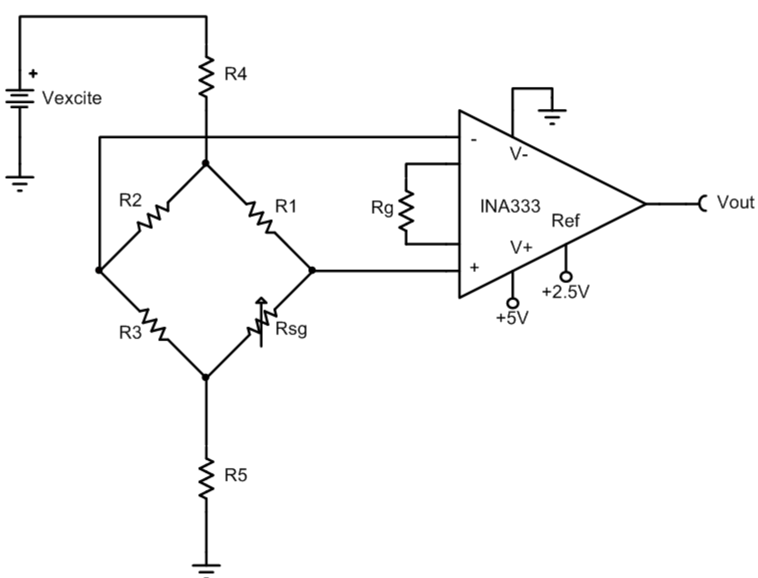

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1 Design Summary

The design requirements are as follows:

- Supply Voltage: 5 V
- Bridge Excitation Voltage: 2.5 V
- Strain Gauge Nominal Resistance: 120 Ω
- Strain Gauge Resistance Variation: 115 Ω - 125 Ω
- Reference Voltage: 2.5 V
- Output Voltage: 225 mV to 4.72 V

The design goals and performance are summarized in Table 1. Figure 1 depicts the measured transfer function of the design.

Table 1. Comparison of Design Goals, Simulation, and Measured Performance

Specification	Goal	Calculated (max)	Calculated (typ)	Measured
Total Uncalibrated Error (%FSR)	<1.5%	1.833%	0.688%	-0.953%
Total Calibrated Error (%FSR)	<0.01%	0.0072%	0.0042%	-0.0154%

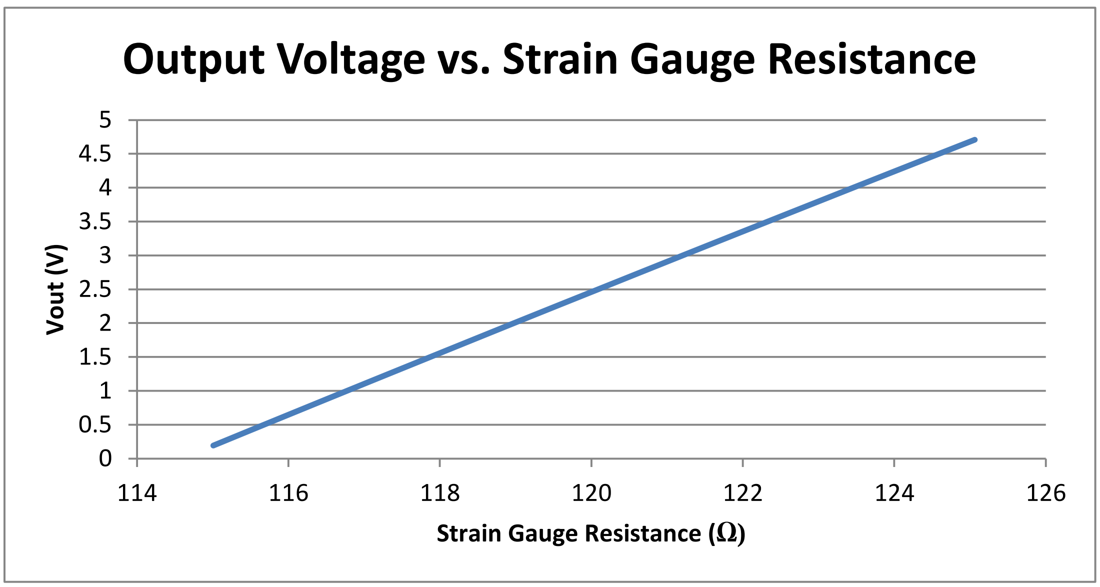

Figure 1: Measured Output Voltage vs. Strain Gauge Resistance

2 Theory of Operation

2.1 Strain Gauge Measurement Topology

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 as shown in Figure 2.

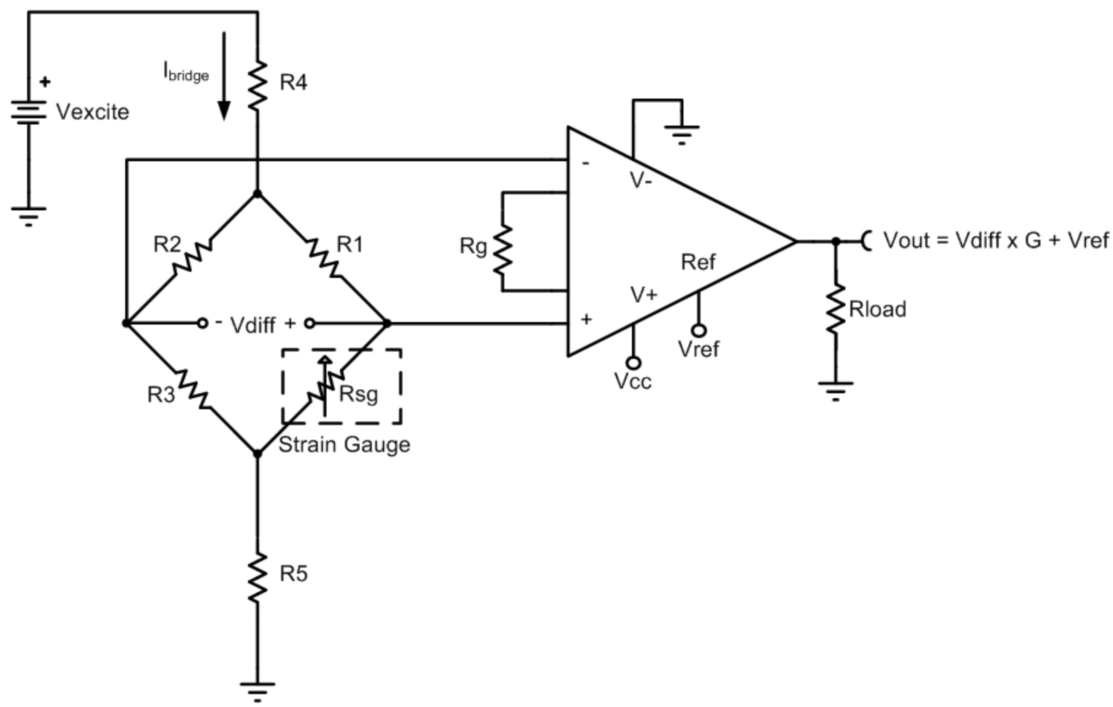

Figure 2: Strain Gauge Measurement Topology

Equation (**1**) shows the transfer function for the circuit show in Figure 2.

$$V_{out} = V_{diff} \times G + V_{ref} \quad (1)$$

Where:

V_{ref} = the reference voltage of the instrumentation amplifier.

G = the gain of the instrumentation amplifier.

As the strain gauge resistance varies from its nominal value, a differential voltage, V_{diff}, is produced across the bridge. Equation (**2**) calculates the differential voltage across the bridge.

$$V_{diff} = \frac{R_3 R_1 - R_{sg} R_2}{-R_1 R_2 - R_3 R_1 - R_5 R_1 - R_5 R_2 - R_5 R_3 - R_{sg} R_2 - R_{sg} R_3 - R_{sg} R_5} \times V_{excite} \quad (2)$$

Typically, resistors, R_1, R_2, and R_3, are set equal to the strain gauge nominal resistance so that a 0 V differential voltage is produced across the bridge when the strain gauge is not experiencing strain. With R_1=R_2=R_3, the differential voltage across the bridge can be simplified to Equation (**3**).

$$V_{diff\_simple} = \frac{R_1^{\ 2} - R_{sg} R_1}{-2R_1^{\ 2} - 3R_5 R_1 - 3R_4 R_1 - 2R_{sg} R_1 - R_{sg} R_4 - R_{sg} R_5} \times V_{excite} \quad (3)$$

2.2 Measuring the Differential Bridge Voltage

An instrumentation amplifier is typically used to amplify the differential bridge voltage. Instrumentation amplifiers have very high input impedance and therefore introduce negligible error with respect to the bridge resistance. The output voltage (V_{out}) of the instrumentation amplifier can be calculated using Equation (1).

A reference voltage must be supplied to the instrumentation amplifier because strain gauge can increase and decrease in resistance which produces a positive and negative differential bridge voltage. The reference voltage should be one-half of the supply voltage. A reference voltage at mid-supply biases the output voltage of the instrumentation amplifier to allow differential measurements in the positive and negative direction.

2.3 Common Mode Resistors

The common mode resistors, R_4 and R_5, have two main functions; limit the current through the bridge and set the common mode of the instrumentation amplifier. The current through the bridge determines how large of a differential signal will be 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. There is also typically a maximum current specification for the strain gauge that cannot be exceeded without damaging the strain gauge. The current through the bridge can be calculated using Equation **(4)**.

$$I_{bridge} = \frac{3R_1 + R_{sg}}{2R_1^{\,2} + 3R_5R_1 + 2R_{sg}R_1 + R_{sg}R_5 + 3R_4R_1 + R_{sg}R_4} \times V_{excite} \quad (4)$$

Equation (4) can be simplified to Equation (5).

$$I_{bridge} = \frac{V_{excite}}{R_4 + R_5 + R_{bridge}} \quad (5)$$

Where:

R_{bridge} = the total resistance of the bridge.

To ensure the instrumentation amplifier can produce the maximum output voltage swing, the common mode of the instrumentation amplifier must be set correctly. The input common mode voltage (V_{cm}) can be calculated using Equation (6).

$$V_{cm} = \frac{3R_5R_1 + 2R_{sg}R_1 + R_{sg}R_5}{2R_1^{\,2} + 3R_5R_1 + 2R_{sg}R_1 + R_{sg}R_5 + 3R_4R_1 + R_{sg}R_4} \times V_{excite} \quad (6)$$

Equation (6) can be simplified to Equation (7).

$$V_{cm} = \frac{\frac{R_{bridge}}{2} + R_5}{R_{bridge} + R_4 + R_5} \times V_{excite} \quad (7)$$

3 Component Selection

3.1 *Bridge Resistors (R_1, R_2, and R_3)*

The bridge resistors R_1, R_2, and R_3 are chosen to be 120 Ω to match the resistance of the stain gauge nominal resistance. Matching the bridge resistors with the strain gauge resistance produces a 0 V differential bridge voltage when the strain gauge resistance is at its nominal value. The tolerances of the resistors were chosen to be 0.05% to minimize the offset and gain errors due to the bridge resistors.

3.2 *Instrumentation Amplifier*

The instrumentation amplifier chosen for this design is the INA333 for its low input offset, low input offset voltage drift, low input bias current, and rail-to-rail output voltage swing.

3.3 *Common Mode Resistors (R_4 and R_5)*

R_4 was chosen to be 0 Ω to allow for the maximum current through the bridge and ultimately the maximum differential bridge voltage. R_5 is chosen to be 1.27 kΩ to place the input common mode voltage of the INA333 at approximately 2.4 V. Having a common mode of 2.4 V allows for the maximum output swing of the instrumentation amplifier. Figure 3 shows the output voltage vs. common mode voltage plot of the INA333; notice a common mode voltage of 1.5 V to 3.5 V produces the largest possible output voltage swing. The tool used to create Figure 3 can be downloaded here.

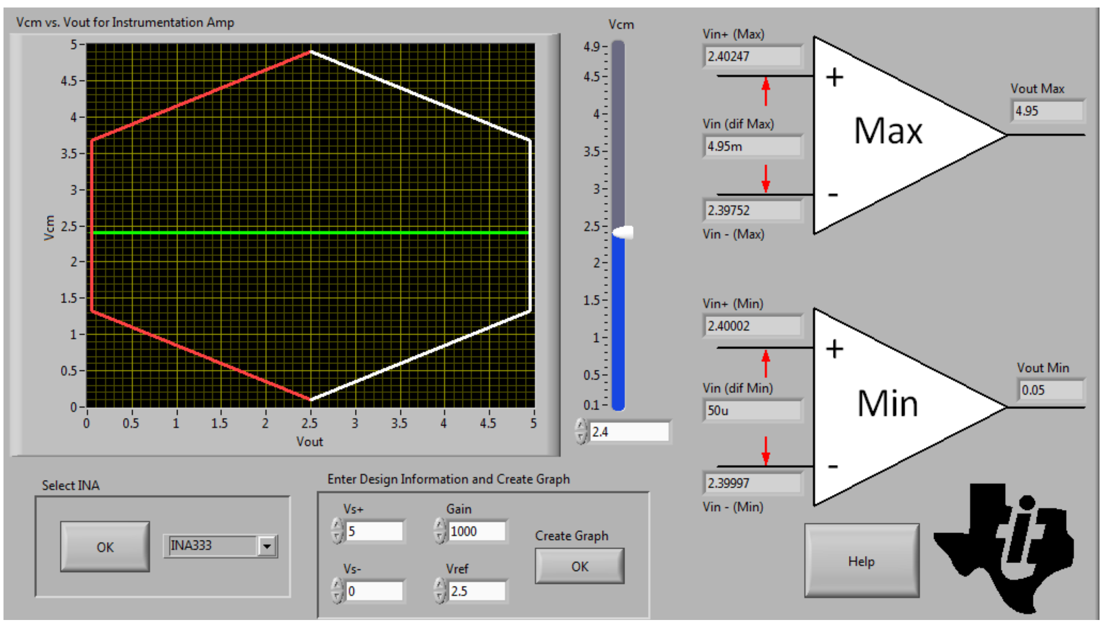

Figure 3: Vcm vs. Vout of INA333

3.4 *Instrumentation Amplifier Gain*

The gain of the instrumentation amplifier is set to 1000V/V by choosing the gain-setting resistor, R_g, to be 100 Ω. A tolerance of 0.01% was chosen to minimize the gain error due to resistor tolerance. Equation **(8)** calculates the gain of the instrumentation amplifier.

$$G = \frac{V_{out\_max} - V_{out\_min}}{V_{diff\_max} - V_{diff\_min}} = \frac{4.72V - 225mV}{2.22mV - (-2.27mV)} = 1001V/V \quad (8)$$

3.5 Bridge Excitation Voltage/Amplifier Reference Voltage

The REF5025 was chosen to supply the bridge excitation voltage and INA333 reference voltage because of its high initial accuracy, low noise, and low drift performance. Using a 2.5 V reference voltage for the INA333 biases the output voltage to mid-supply when a 0 V differential voltage is measured.

4 Simulation and Error Calculations

4.1 Simulation

Figure 4 shows the TINA-TI circuit used for simulation.

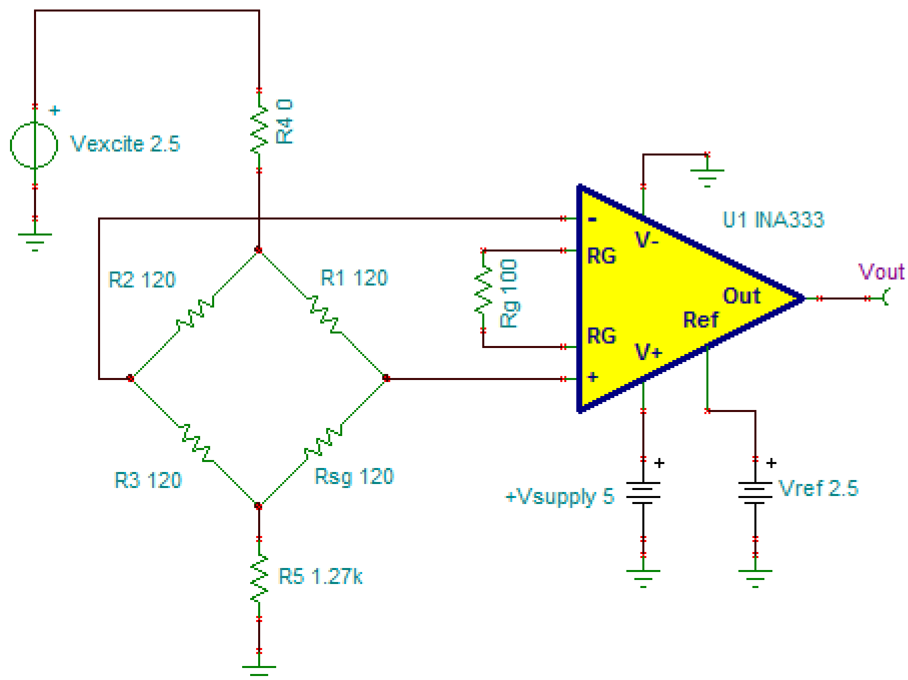

Figure 4: TINA-TI simulation circuit

Figure 5 displays the simulated output voltage for a strain gauge resistance from 115 Ω to 125 Ω. Notice when the strain gauge has a resistance of 120 Ω, equal to the bridge resistors, the output voltage is equal to the reference voltage of 2.5 V. When the strain gauge resistance is above 120 Ω, the output voltage is above 2.5 V and when the strain gauge resistance is below 120 Ω, the output voltage is below 2.5 V.

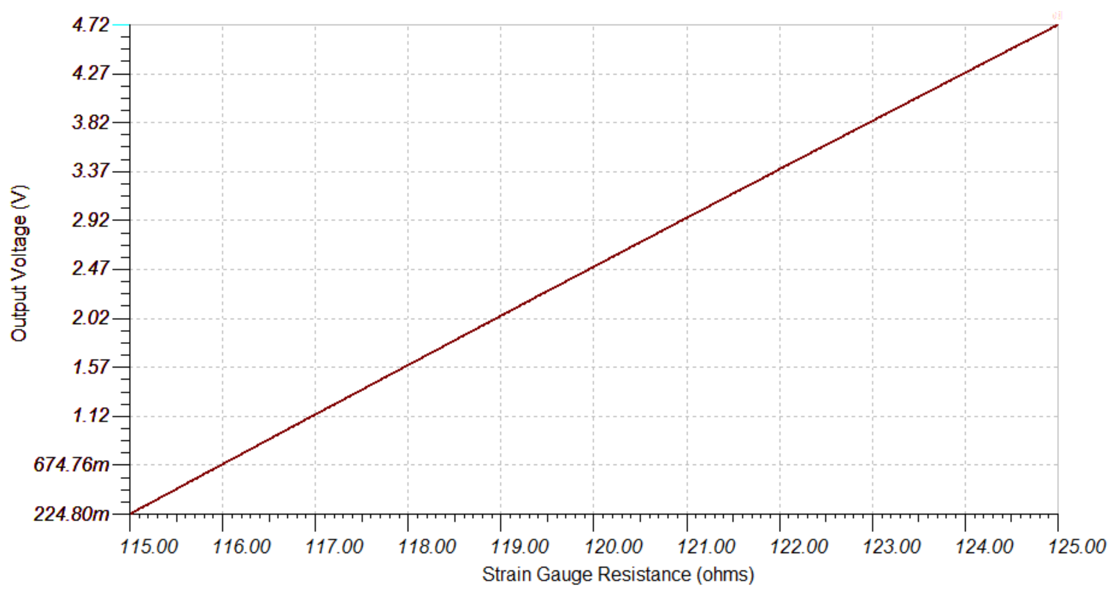

Figure 5: Simulation Results

4.2 Error Calculations

4.2.1 Errors Due to Bridge and Common Mode Resistors

The tolerance of the bridge resistors, R_1, R_2, and R_3, and common mode resistor, R_5, create both an offset and gain error. The majority of the offset error is due to the bridge resistors tolerance and the majority of the gain error is due to the common mode resistor tolerance. Equation (**9**) calculates the bridge differential voltage (V_{diff_bridge}). Setting R_1 and R_3 with a negative tolerance and R_2 with a positive tolerance gives the worst-case offset error due to the bridge resistors. Setting R_5 to have a negative tolerance gives the worst-case gain error due to the common mode resistors. The offset error (V_{offset_error}) is calculated using Equation (**10**). The gain error in the positive ($V_{gain\_errror\_pos}$) and negative ($V_{gain\_errror\_neg}$) direction is calculated using Equation (**11**) and Equation (**12**), respectively. The worst case offset and gain error referred to the input (RTI) due to the bridge and common mode resistors is calculated to be 81.02 µV and -2.95 µV, respectively.

$$V_{diff\_bridge} = \frac{R_3 R_1 - R_{sg} R_2}{-R_1 R_2 - R_3 R_1 - R_5 R_1 - R_5 R_2 - R_5 R_3 - R_{sg} R_2 - R_{sg} R_3 - R_{sg} R_5} \times V_{excite} \quad (9)$$

$$V_{offset\_error} = V_{diff\_tolerance@120\Omega} - V_{diff\_ideal@120\Omega} \quad (10)$$

$$V_{gain\_error\_pos} = (V_{diff\_tolerance@125\Omega} - V_{diff\_ideal@125\Omega}) - (V_{diff\_tolerance@120\Omega} - V_{diff\_ideal@120\Omega}) \quad (11)$$

$$V_{gain\_error\_neg} = (V_{diff\_tolerance@115\Omega} - V_{diff\_ideal@115\Omega}) - (V_{diff\_tolerance@120\Omega} - V_{diff\_ideal@120\Omega}) \quad (12)$$

Where:

$V_{diff\_tolerance@120\Omega}$ = the bridge differential voltage with the bridge resistors maximum tolerance at a strain gauge resistance of 120 Ω.

$V_{diff\_ideal@120\Omega}$ = the ideal bridge differential voltage with a strain gauge resistance of 120 Ω.

$V_{diff\_tolerance@125\Omega}$ = the bridge differential voltage with the bridge resistors maximum tolerance at a strain gauge resistance of 125 Ω.

$V_{diff\_ideal@125\Omega}$ = the ideal bridge differential voltage with a strain gauge resistance of 125 Ω.

$V_{diff\_tolerance@115\Omega}$ = the bridge differential voltage with the bridge resistors maximum tolerance at a strain gauge resistance of 115 Ω.

$V_{diff\_ideal@115\Omega}$ = the ideal bridge differential voltage with a strain gauge resistance of 115 Ω.

4.2.2 Errors Due to INA333

The errors associated with the INA333 are due to input offset voltage, common mode rejection ratio (CMRR), gain error, and gain non-linearity. These errors are listed in Table 2.

Table 2: INA333 Performance Specifications

INA333 Specification	Typical Value
Input Offset Voltage (µV)	± 10 ± 25/G
Common Mode Rejection Ratio (dB)	115
Gain Error (%FSR)	0.25
Gain Non-Linearity (ppm)	10

The input offset voltage RTI ($V_{os\_\mu V}$) of the INA333 is calculated using Equation (**13**) and has the units of microvolts.

$$V_{os\_\mu V} = \pm 10 \pm \frac{25}{G} = 10 + \frac{25}{1000} = 10.025\mu V \quad (13)$$

The CMRR of the INA is specified in the product datasheet (PDS) as 115 dB, Equation (14) converts the CMRR specification into units of V/V.

$$V_{os\_CMRR(V/V)} = 10^{CMRR\_dB/20} = 10^{115/20} = 562341.3252V/V \quad (14)$$

The offset voltage due to CMRR of the INA333 RTI (V_{os_CMRR}) is calculated using Equation (15).

$$V_{os\_CMRR(V)} = (V_{cm\_spec} - V_{cm\_system})/V_{os\_CMRR(V/V)} = \frac{(2.5V - 2.4V)}{562341.3252V/V} = 178.498nV \quad (15)$$

The gain error of the INA333 ($V_{GE(\%FSR)}$) is specified as 0.25 %FSR. Equation (16) converts the INA333 gain error specification into units of volts.

$$V_{GE(V)} = \frac{V_{GE(\%FSR)} \times FSR_{input}}{100} = \frac{0.25 \times 0.0045V}{100} = 10.8\mu V \quad (16)$$

Where:

FSR_{input} = the full-scale range of the input to the INA333.

The gain non-linearity specification of the INA333 is specified in parts per million (ppm). Equation (17) and Equation (18) converts the linearity specification from ppm to volts.

$$V_{os\_linearity(\%)} = \frac{V_{os\_linearity(ppm)}}{10000} = \frac{10}{10000} = 0.001\% \quad (17)$$

$$V_{os\_linearity(V)} = \frac{V_{os\_linearity(\%)} \times FSR_{input\_\max}}{100} = \frac{0.001 \times 0.0055}{100} = 55nV \quad (18)$$

4.2.3 Total Uncalibrated Error

The total input referred error is calculated by taking the root sum square (RSS) of all errors associated with the bridge and INA333. Equation (19) calculates the total error of the system in units of volts. Equation (20) converts the total error to a percentage of the full scale range. The total RTI error of the system is calculated to be 1.833 %FSR. The total RTI error calculated in Equation (20) assumes a worst case scenario for the bridge resistors tolerance. However, this is unlikely to occur. Using typical tolerance values the total RTI error is calculated to be 0.688 %FSR. The majority of the total error is due to the offset error of the bridge.

$$V_{Total\_Error(V)} = \sqrt{V_{offset\_error}^2 + V_{gain\_error\_pos}^2 + V_{os\_\mu V}^2 + V_{os\_CMRR(V)}^2 + V_{GE(V)}^2 + V_{os\_linearity(V)}^2} \quad (19)$$

$$V_{Total\_Error(\%FSR)} = \frac{V_{Total\_Error(V)} \times 100}{FSR_{input}} = \frac{82.4603\mu V \times 100}{0.0045V} = 1.833\%FSR \quad (20)$$

4.2.4 Total Calibrated Error

The total calibrated error is calculated by taking the RSS of errors associated with the CMRR and gain non-linearity of the INA333. Equation (21) calculates the total calibrated error in units of volts. Equation (22) converts the total calibrated error to a percentage of the full scale range. The total RTI calibrated error of the system is calculated to be 0.004 %FSR.

$$V_{Total\_Cal\_Error(V)} = \sqrt{V_{os\_CMRR(V)}^2 + V_{os\_linearity(V)}^2} = \sqrt{178.498nV^2 + 55nV^2} = 186.779nV \quad (21)$$

$$V_{Total\_Cal\_Error(\%FSR)} = \frac{V_{Total\_Cal\_Error(V)} \times 100}{FSR_{input}} = \frac{186.779nV \times 100}{0.0045V} = 0.0042\%FSR \quad (22)$$

5 PCB Design

The PCB schematic and bill of materials can be found in Appendix A.

5.1 PCB Layout

Figure 6 shows the PCB layout for the design. The traces for the bridge and common mode resistors were kept as short and balanced as possible to minimize the possibility of a differential voltage in the signal chain due to trace impedance mismatch. The terminal block, J1, was placed on the bottom of the PCB to allow for a close connection of R_4 and R_5. Finally, the gain setting resistor, R_g, was placed as close to the pins of U1 as possible to minimize stray capacitance and trace impedance. General layout guidelines, such as, placing decoupling capacitors close to the devices as possible and pouring a solid ground plane, were also used.

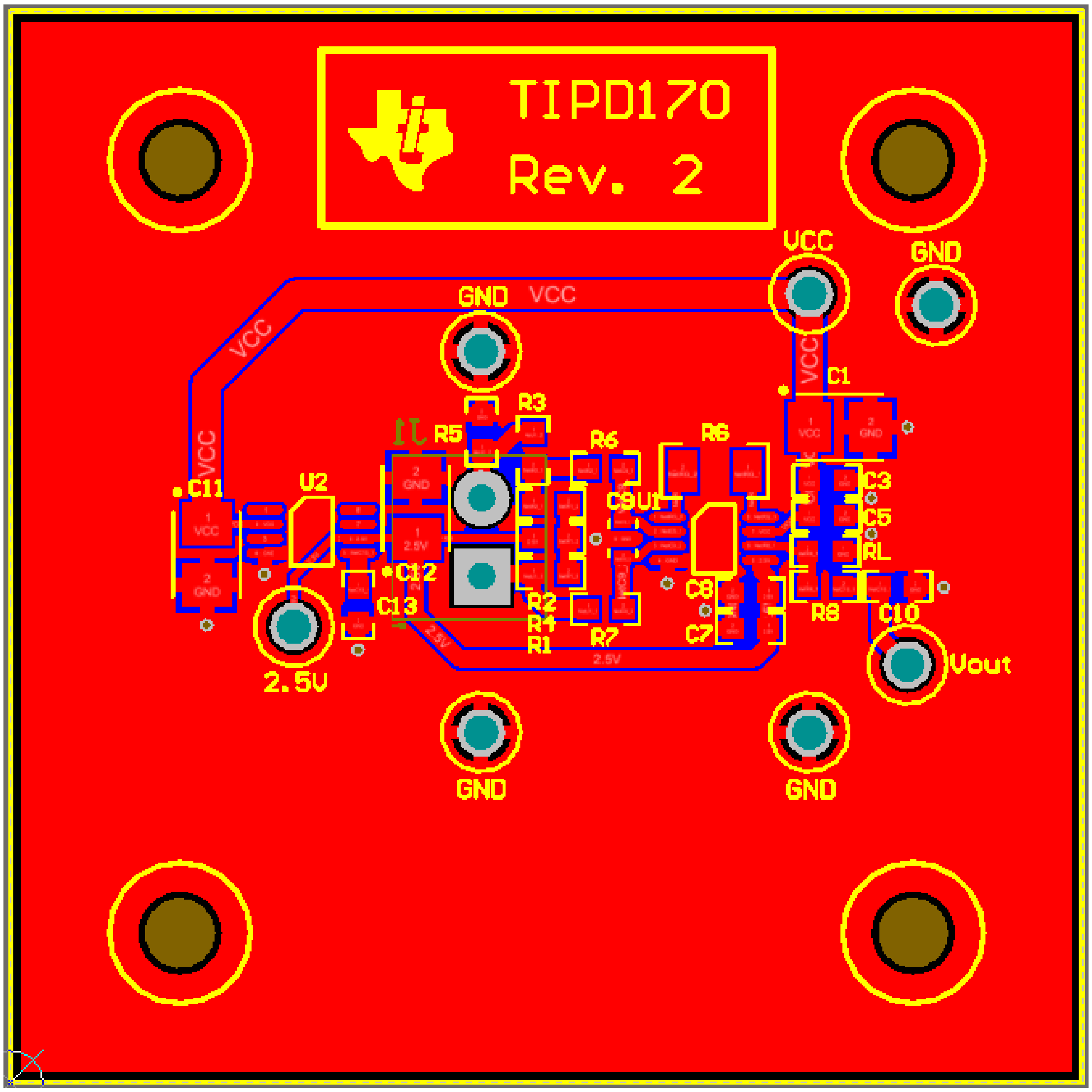

Figure 6: PCB Layout

6 Verification & Measured Performance

6.1 Output Voltage vs. Strain Gauge Resistance

Figure 7 shows the measured output voltage of the INA333 vs. strain gauge resistance. The data was collected by placing different values of resistors in the terminal block, J1, to represent the strain gauge resistance. Each resistor used was accurately measured before being placed in the terminal block. High accurate low drift resistors were used to prevent a change in resistance due to heating while handling the resistors when placing them into the terminal block or from self-heating due to the bridge current.

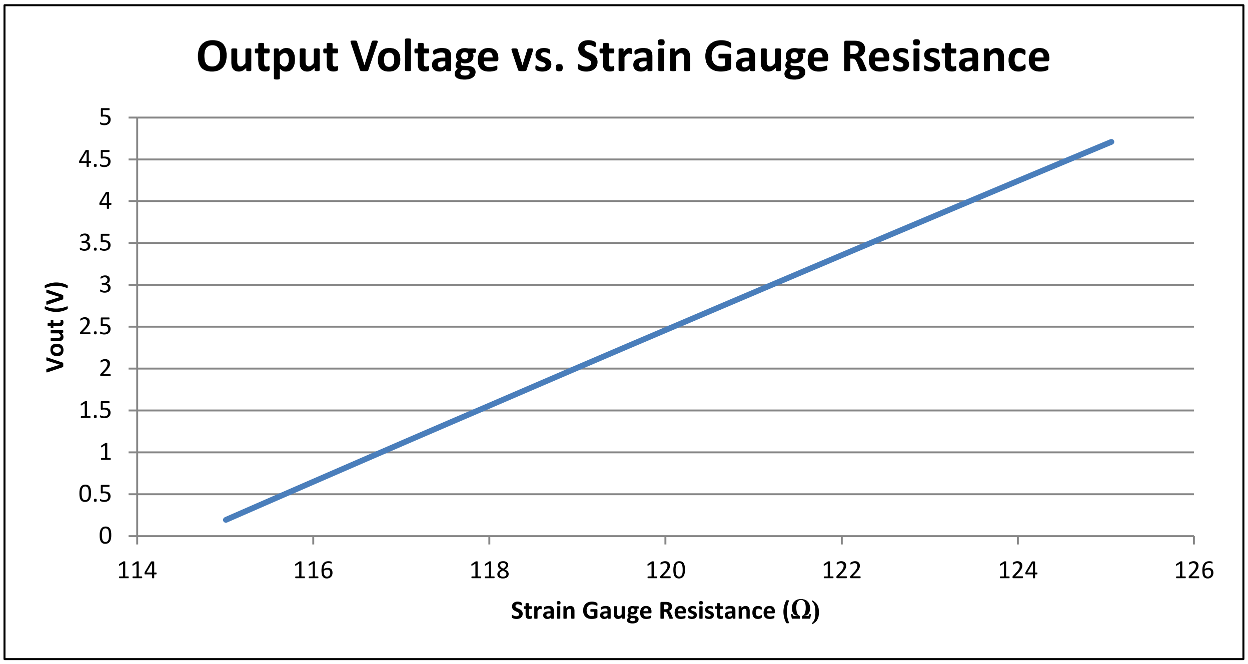

Figure 7: Output Voltage vs. Strain Gauge Resistance

6.2 Uncalibrated Error

The total full scale uncalibrated error is calculated using Equation (**23**).

$$Error_{\%FSR} = \frac{V_{out\_measured} - V_{out\_ideal}}{FSR_{output}} \times 100 \quad (23)$$

Where:

V_{out_ideal} = the ideal output voltage

$V_{out\_measured}$ = the measured output voltage

FSR_{output} = the ideal full scale output voltage range

To calculate the ideal output voltage, the resistor used to simulate the strain gauge resistance was measured, recorded, and then used to calculate the ideal differential bridge voltage. The ideal values for the bridge resistors and common mode resistors were used. The ideal differential bridge voltage is calculated using Equation (**3**). Equation (**1**) is used to calculate the ideal output voltage.

Figure 8 shows the total full scale uncalibrated error. Notice the majority of the error is an offset error caused from the resistors in the bridge.

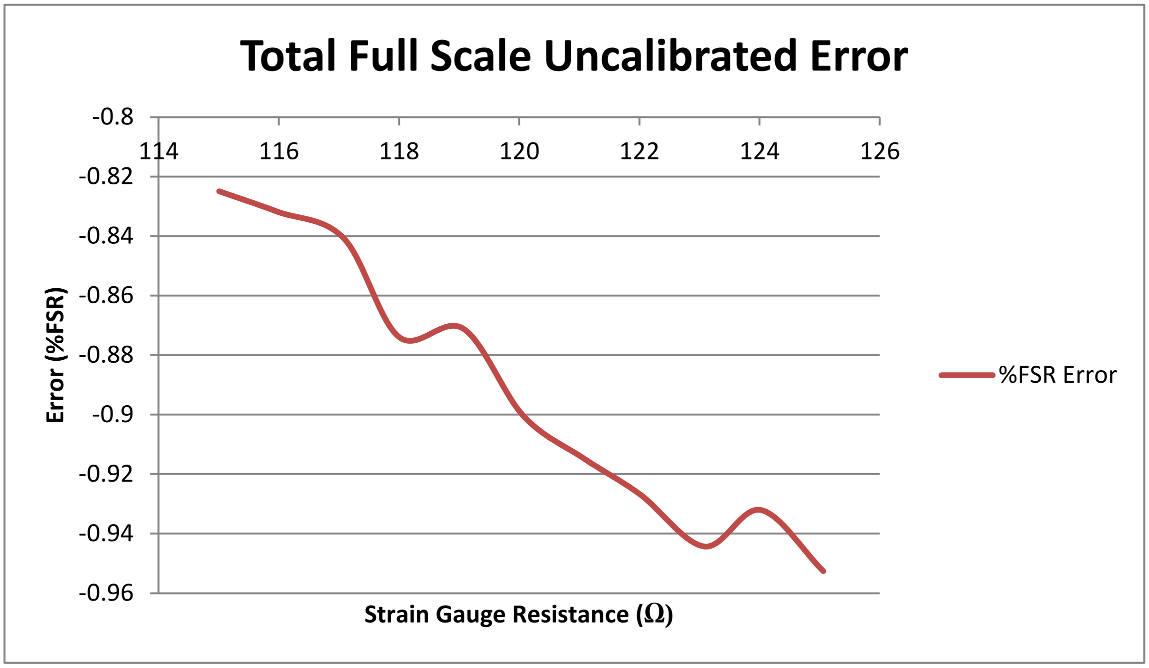

Figure 8: Total Full Scale Uncalibrated Error

6.3 Calibration

A 2-point calibration was performed to remove errors due to offset voltage, gain error, component tolerance, etc. The data points chosen for calibration were with a maximum and minimum strain gauge resistance of 115 Ω and 125 Ω, respectively. To perform a calibration, a gain correction factor, α, and an offset correction factor, β, must first be calculated using Equation (**24**) and Equation (**25**), respectively. Table 2 displays the data points used for calibration.

Table 3: Data Points for Calibration

	Strain Gauge Resistance = 115 Ω		Strain Gauge Resistance = 125 Ω	
	Measured	**Ideal**	**Measured**	**Ideal**
Vout	0.1924346 V	0.229689358 V	4.708435 V	4.751455036 V

$$\alpha = \frac{V_{out\_ideal@125\Omega} - V_{out\_ideal@115\Omega}}{V_{out\_measured@125\Omega} - V_{out\_measured@115\Omega}} \quad (24)$$

$$\beta = \left(\alpha \times V_{out\_measured@115\Omega}\right) - V_{out\_ideal@115\Omega} \quad (25)$$

Using Equation (**24**) and Equation (**25**), α is calculated to be 1.001277, and β is calculated to be -0.03701.

Equation (**26**) was used to calculate the calibrated output voltage.

$$V_{out\_calibrated} = (V_{out\_measured} - \beta) \times \alpha \quad (26)$$

Figure 8 shows the total full-scale error after calibration. The non-linearity shown in Figure 9 is greater than the non-linearity specification of the INA333; some of this error can be attributed to noise in the system. Assuming a best-case scenario and using the input voltage noise specification in the INA333 datasheet of 50 nV/√Hz at 10 Hz, the output noise peak-to-peak is calculated to be 1.31 mVpp which is 0.029 %FSR of the output. Equation (27) calculates the output noise peak-to-peak. Equation (28) converts the peak-to-peak output noise to a percentage of the full-scale range.

$$V_{noise\_pp} = 6.6 \times G \times V_{noise} \times \sqrt{BW_n \times 1.57} = 6.6 \times 1000 \frac{V}{V} \times 50 \frac{nV}{\sqrt{Hz}} \times \sqrt{10Hz \times 1.57} = 1.31mVpp \quad (27)$$

$$V_{noise\_\%FSR} = \frac{V_{noise\_pp} \times 100}{FSR_{output}} = \frac{1.31mVpp \times 100}{4.5V} = 0.029\%FSR \quad (28)$$

Where:

V_{noise} = the input voltage noise of the INA333.

BW_n = bandwidth of the INA333.

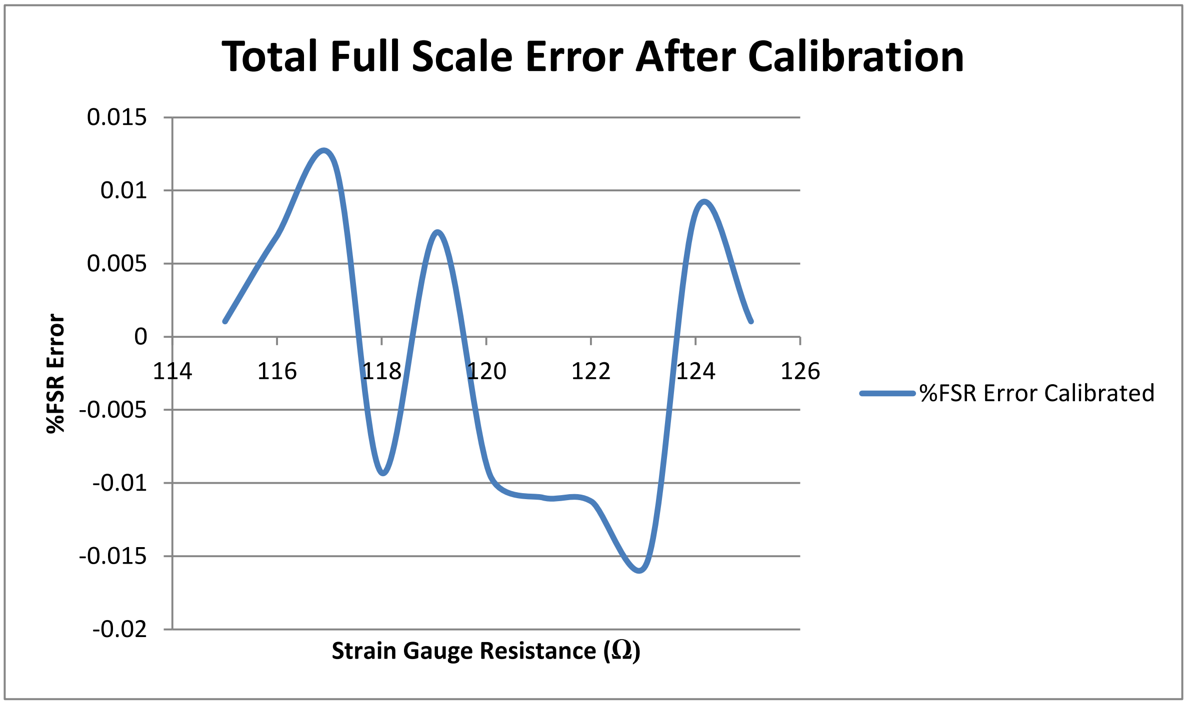

Figure 9: Total Full Scale Error After Calibration

7 Modifications

7.1 Strain Gauge

A strain gauge with a different nominal resistance can be used, typical strain gauge nominal resistances are, 120 Ω, 350 Ω, 1000 Ω, and 3000 Ω. If a different nominal resistance is used, the bridge resistors must be chosen to match the nominal resistance of the strain gauge.

7.2 Common Mode Resistors

The common mode resistors, R_4 and R_5, can be increased to reduce the current consumption of the circuit, or decreased to create a larger differential bridge voltage. If a larger differential bridge voltage is present, the gain of the instrumentation amplifier must be adjusted such that the output voltage does not exceed the output voltage swing of the device. Furthermore, R_4 and R_5, must be adjusted such that the common mode voltage of the device is not violated and the maximum strain gauge current is not exceeded.

7.3 Amplifier

Other instrumentation amplifiers can be used to measure the differential bridge voltage, such as, the INA188 for a low drift solution, the INA827 for applications that require a higher bandwidth or the INA122 for a lower power solution with higher gain.

8 About the Author

Timothy Claycomb is an Analog Applications Engineer in the Precision Linear group at Texas Instruments. He earned his B.S. in Electrical Engineering from Michigan State University in 2013.

9 Acknowledgements & References

1. *A. Kay, Operational Amplifier Noise: Techniques and Tips for Analyzing and Reducing Noise. Elsevier, 2012.*

2. *The Strain Gauge. Available: http://www.omega.com/literature/transactions/volume3/strain2.html*

3. *Bridge Measurement Systems Section 5 (SLYP163)*

The author would like to thank Collin Wells for his technical contribution during this design.

Appendix A.

A.1 Electrical Schematic

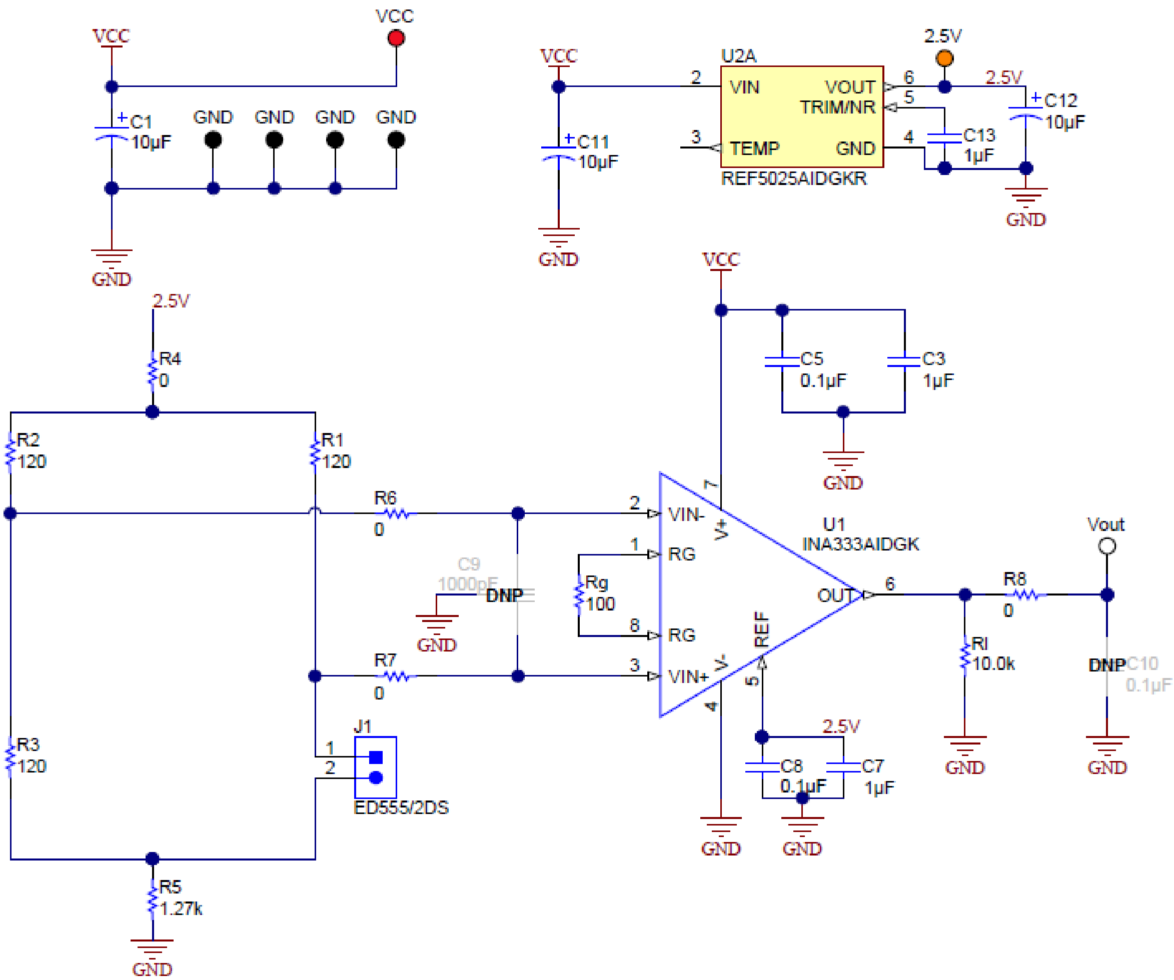

Figure A-1: Electrical Schematic

A.2 Bill of Materials

TEXAS INSTRUMENTS

Bill of Materials

TI DESIGNS

TIPD170: Strain Gauge in a Bridge Configuration Refere

Item #	Quantity	Designator	Value	PartNumber	Manufacturer	Description	DigiKey Part Number
1	3	C1, C11, C12	10uF	TPSB106M020R1000	AVX	CAP, TANT, 10uF, 20V, +/-20%, 1 ohm, 3528-21 SMD	478-4087-1-ND
2	3	C3, C7, C13	1uF	GRM188R71E105KA12D	MuRata	CAP, CERM, 1uF, 25V, +/-10%, X7R, 0603	490-5307-1-ND
3	2	C5, C8	0.1uF	0603YC104JAT2A	AVX	CAP, CERM, 0.1uF, 16V, +/-5%, X7R, 0603	478-3726-1-ND
4	1	J1		ED555/2DS	On-Shore Technology	Terminal Block, 6A, 3.5mm Pitch, 2-Pos, TH	ED1514-ND
5	3	R1, R2, R3	120	RG1608N-121-W-T1	Susumu	RES, 120, 0.05%, 1/10 W, 0603	RG16P120BCT-ND
6	4	R4, R6, R7, R8	0	CRCW06030000Z0EA	Vishay-Dale	RES, 0, 5%, 0.1 W, 0603	541-0.0GCT-ND
7	1	R5	1.27k	ERA-3AEB1271V	Panasonic Electronic Components	RES, 1.27K OHM, 1/10W, 0.1%, 0603, SMD	541-1.27KHCT-ND
8	1	Rg	100	RNCF1206TKY100R	Stackpole Electronics Inc.	RES 100 OHM 1/4W 0.01% 1206	311-100HRCT-ND
9	1	TP1	Red	5005	Keystone	Test Point, TH, Compact, Red	5005K-ND
10	4	TP2, TP4, TP5, TP6	Black	5006	Keystone	Test Point, TH, Compact, Black	5006K-ND
11	1	TP7	Orange	5008	Keystone	Test Point, Compact, Orange, TH	5008K-ND
12	1	TP8	White	5007	Keystone	Test Point, Compact, White, TH	5007K-ND
13	1	U1		INA333AIDGK	Texas Instruments	Micro-Power, Zerø-Drift, Rail-to-Rail Out Instrumentation Amplifier	296-23564-1-ND
14	1	U2		REF5025AIDGKR	Texas Instruments	Low Noise, Very Low Drift, Precision Voltage Reference,	REF5025AIDGKR-ND
15	4	U90, U91, U92, U93		2205	Keystone	STANDOFF HEX 4-40THR ALUM 1"L	2205K-ND
16	4	U94, U95, U96, U97		PMSSS 440 0025 PH	B&F Fastener Supply	MACHINE SCREW PAN PHILLIPS 4-40	H703-ND
17	1	RI	10.0k	CRCW060310K0FKEA	Vishay-Dale	RES, 10.0k ohm, 1%, 0.1W, 0603	
18	0	C9	1000pF	CX0603MRX7R0BB102	Yageo America	CAP, CERM, 1000 pF, 100 V, +/- 20%, X7R, 0603	
19	0	C10	0.1uF	0603YC104JAT2A	AVX	CAP, CERM, 0.1uF, 16V, +/-5%, X7R, 0603	

Figure A-2: Bill of Materials

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