# Sensor-Emulator-EVM
## System Reference Guide

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High-Precision Linear Products

**TEXAS INSTRUMENTS**

# Sensor-Emulator-EVM

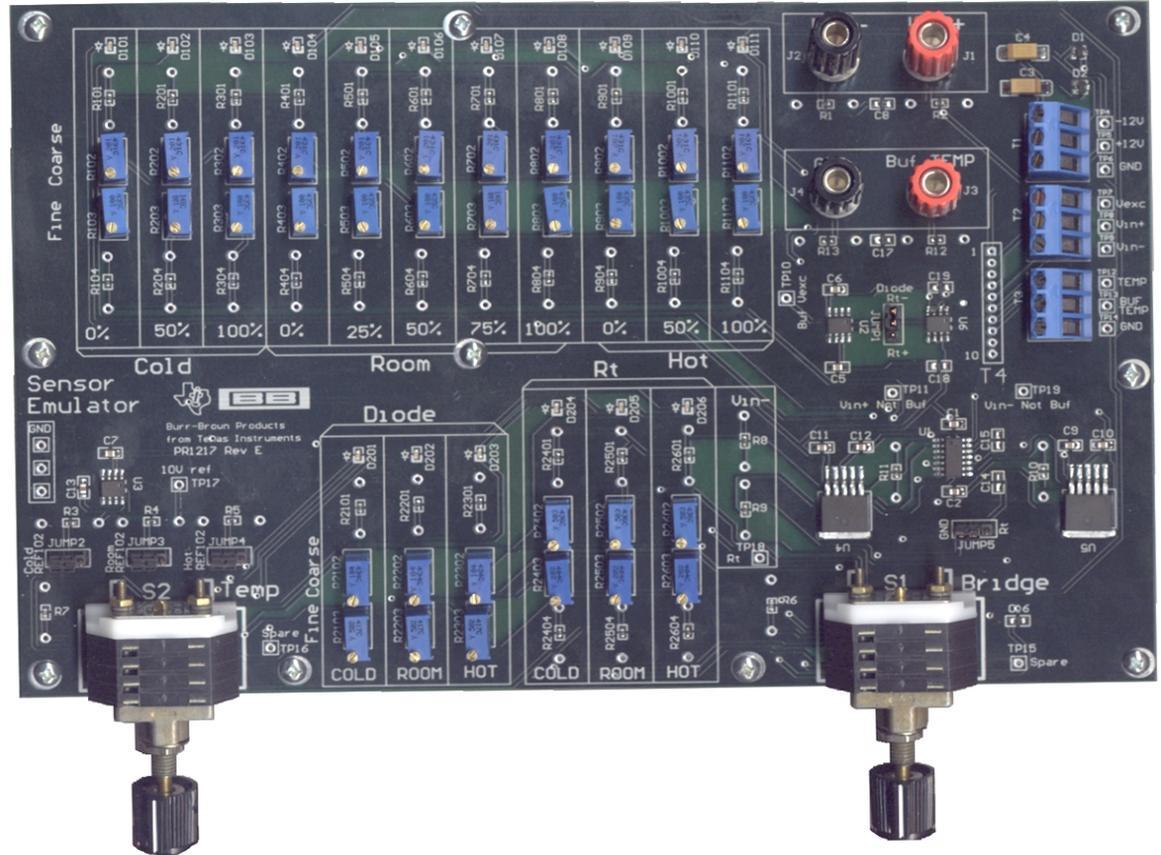**TEXAS INSTRUMENTS**

- Simplifies Development of Voltage Excited Bridge Sensor Signal Conditioning Systems

- Provides Eleven Different Emulated Sensor Output Conditions

- Provides Three Different Emulated Temperature Signals for Diode or Series Resistor Methods of Bridge Sensor Temperature Monitoring

- Emulates Bridge Outputs

  - Cold Temp: 0%, 50%, 100%

  - Room Temp: 0%, 25%, 50%, 75%, 100%

  - Hot Temp: 0%, 50%, 100%

- LED Indicators for Emulation at a Glance

# Sensor Emulator EVM

**Texas Instruments**

## Table of Contents                                                    Pages

Note: Some sections of this user's guide reference use of the PGA309EVM.  This is done for ease of documenting features available on the Sensor-Emulator-EVM which will work with any bridge sensor signal conditioning chip which uses voltage bridge excitation.

# 1.0 Introduction to
# The Sensor Emulator

**Q:    *What is the sensor emulator?***

A:    The sensor emulator is a design that uses rotary switches and potentiometers to emulate the operation of a resistive bridge sensor at discrete operating points, for voltage excitation applications.

**Q:    *Why use the sensor emulator?***

A:    Once the sensor emulator has been programmed, it allows the user to cycle through a set of sensor output conditions very quickly.  Doing this with a real sensor can be extremely time consuming because it can take several hours to cycle through various temperatures.  Also, some sensors have non-repeatability issues.  For example, pressure sensors can have pressure hysteresis and temperature hysteresis.  The emulator does not have non-repeatability issues (repeatability errors are typically less then 0.03%).  This approach allows the user to program the sensor signal conditioning chip many different ways to quickly and easily assess the optimal calibration settings for a given application.

# 1.0 Introduction to The Sensor Emulator

**Q:     Why not just use a precision voltage source to emulate a sensor?**

A:     A precision voltage source is not affected by changing sensor excitation.  Many sensor signal conditioning chips modulate the sensor excitation to compensate for sensor nonlinearity.  In this case (and in the case of a ratiometric system), a precision voltage source would not work.  Also, it is much more convenient to have all the different sensor conditions pre-programmed so that you can quickly transition from one condition to another without having to reprogram the source at each different condition.

# 2.0 Overview of Hardware Emulation of a Real World Sensor

- Description of real world bridge sensors
  - Temperature Drift and Nonlinearity versus applied stimulus
  - Measurement of the sensor temperature

- Description of how Sensor-Emulator-EVM circuitry produces signals equivalent to real world sensors
  - Emulates four different real world configurations

# Bridge Sensor Output
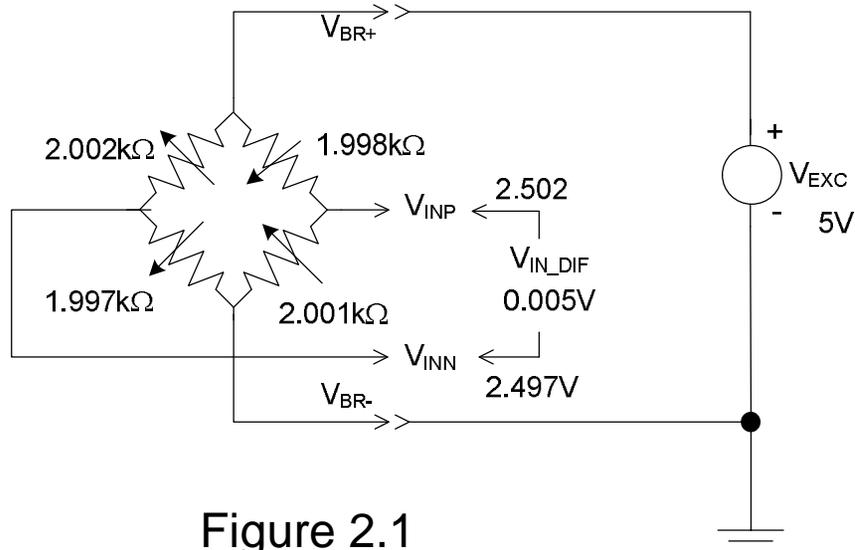
Output With No Stimulus Applied (Offset)

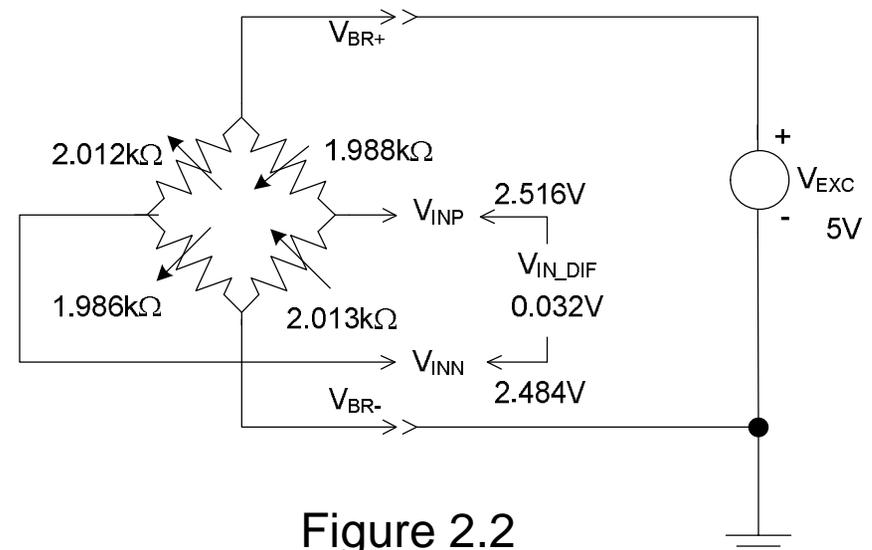Output With Full Scale Stimulus Applied



Figure 2.1



Figure 2.2

Figure 2.1 is an example of a typical resistive bridge sensor with no applied stimulus.   With no stimulus applied, the resistors ideally would be perfectly matched and the sensors' output ($V_{IN\_DIF}$ ) would be zero.  Most practical sensors, however, will have some output resulting from resistor mismatch.  The output signal with no applied stimulus is called *offset*. Figure 2.2 is an example of a typical resistive bridge sensor with full scale stimulus applied. For the example sensor, the offset is 5mV (Figure 2.1) and the full scale output is 32mV (Figure 2.2).  Span is defined as the difference between the full scale stimulus and the offset (Span = Full Scale Output – Offset).
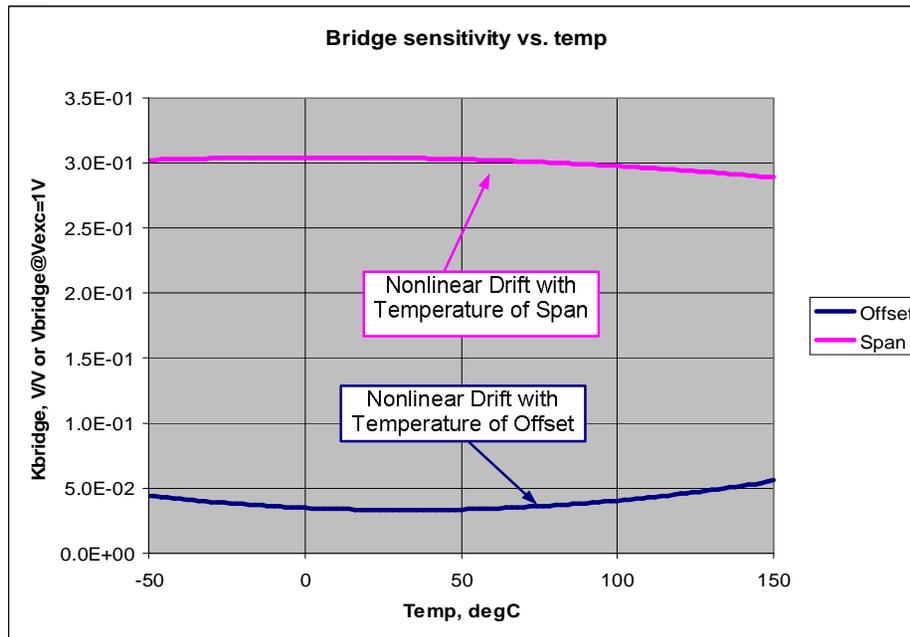
# Drift and Nonlinearity with a Bridge Sensor

**Bridge sensitivity vs. temp**

Nonlinear Drift with Temperature of Span

Nonlinear Drift with Temperature of Offset

Offset
Span

Figure 2.3

**Kbridge vs. pressure @Troom**

Practical Bridges May Have Nonlinear Output with Applied Stimulus (Nonlinear Line)

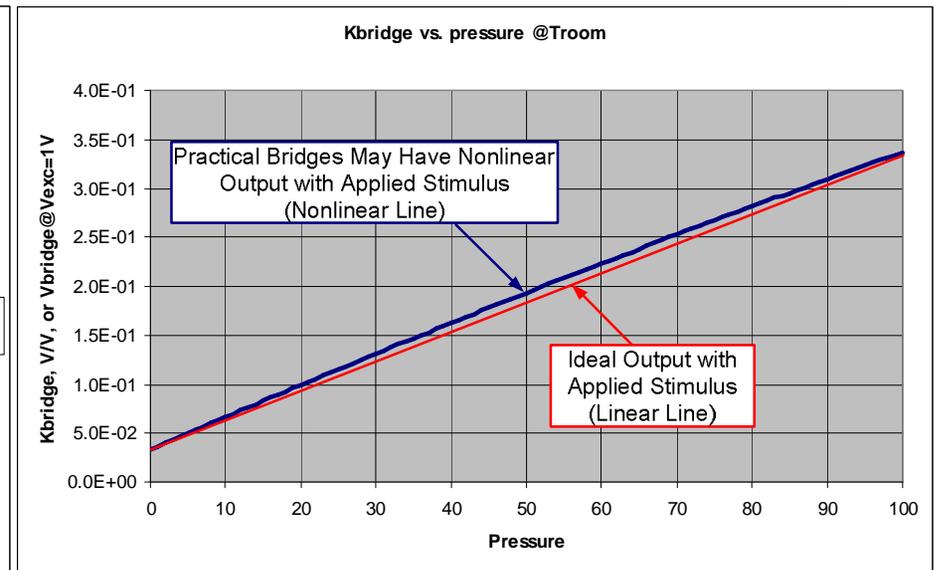Ideal Output with Applied Stimulus (Linear Line)

Figure 2.4

An important aspect of pressure sensors is how they drift with temperature. Figure 2.3 is an example of span and offset drift with temperature for a typical resistive bridge sensor. Note that the drift is fairly large and nonlinear. Figure 2.4 is an example of how a bridge sensor can be nonlinear with applied stimulus (in this example the stimulus is pressure). The sensor emulator can be configured to reproduce these characteristics for most sensors. Note that the graphs are shown in a normalized format. The normalized format allows the graph to be easily scaled by multiplying by the bridge excitation voltage.

# Emulating Bridge Sensor Outputs

This is a simplified diagram of how the sensor emulator generates a bridge output voltage. The potentiometer R102 is adjusted to set the output voltage of the emulated bridge ($V_{in+}$ with respect to $V_{in-}$). The potentiometer R103 is used to make fine adjustments in the output value. R8 and R9 set a common mode voltage for the other leg of the bridge. R101 and R104 set the adjustable output range of the emulated bridge. For the configuration shown, the output range is -25mV to +26mV ($V_{dif} = V_{in-} - V_{in+}$). Selecting a different value for R101 and R104 can expand this range. On the Sensor-Emulator-EVM, 11 channels like this one are selectable using a rotary switch.
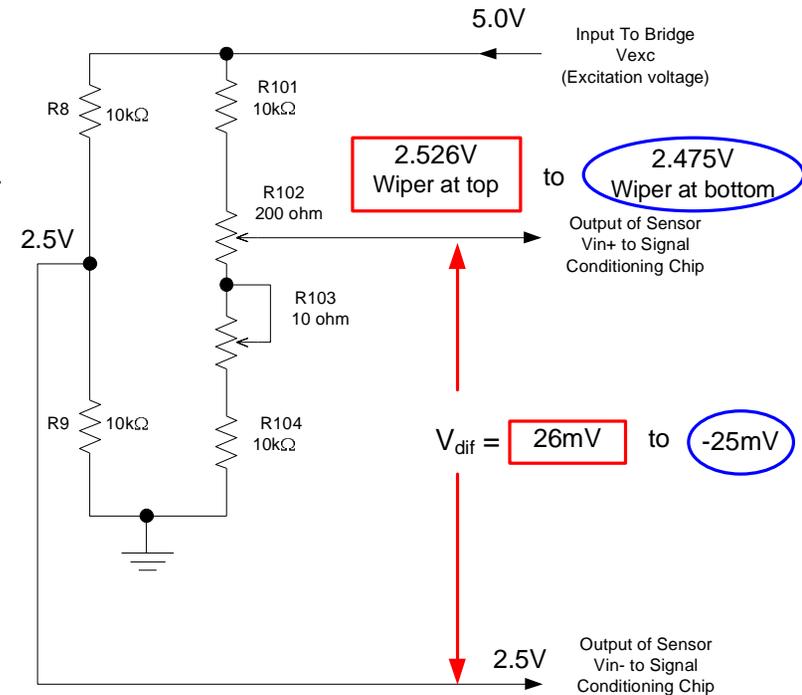


Figure 2.5

| Positive full scale of the emulator | Negative full scale of the emulator |
|---|---|
| $V_{exc} := 5 \quad R_{104} := 10 \cdot 10^3 \quad R_{102} := 200 \quad R_{101} := 10 \cdot 10^3$ | $V_{exc} := 5 \quad R_{104} := 10 \cdot 10^3 \quad R_{102} := 200 \quad R_{101} := 10 \cdot 10^3$ |
| $R_{102a} := 200$    Wiper position at top of POT | $R_{102a} := 0$    Wiper position at bottom of POT |
| $R_{103} := 10$    Pot set to maximum Resistance | $R_{103} := 0$    Pot set to Minimum Resistance |
| $V_{dif} := \dfrac{V_{exc} \cdot (R_{104} + R_{103} + R_{102a})}{R_{101} + R_{104} + R_{103} + R_{102}} - \dfrac{V_{exc}}{2}$ | $V_{dif} := \dfrac{V_{exc} \cdot (R_{104} + R_{103} + R_{102a})}{R_{101} + R_{104} + R_{103} + R_{102}} - \dfrac{V_{exc}}{2}$ |
| $V_{dif} = 0.026$    Positive full scale output of emulator | $V_{dif} = -0.025$    Negative full scale output of emulator |

# Emulating a Temperature Sensor with a Series Bridge Resistor

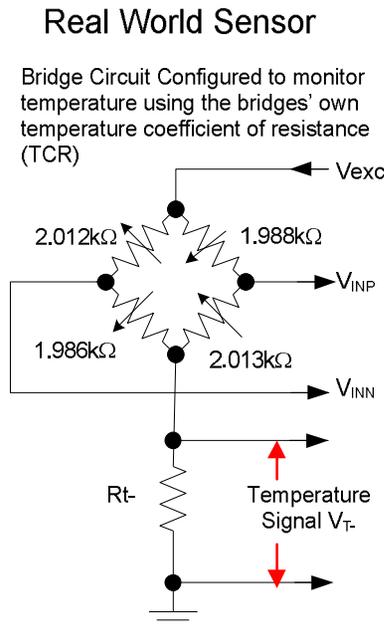**(R$_{t-}$ connected to the bottom of the bridge)**

### Real World Sensor

Bridge Circuit Configured to monitor temperature using the bridges' own temperature coefficient of resistance (TCR)

Vexc

2.012kΩ   1.988kΩ

V$_{INP}$

1.986kΩ   2.013kΩ

V$_{INN}$

Rt-   Temperature Signal V$_{T-}$

**Figure 2.6**

### Simplified Real World Sensor

Vexc

R$_{Bridge}$   The bridge is equivalent to a resistor with a strong temperature coeficient

Rt-

$$V_T = \frac{V_{exc} \cdot R_T}{R_T + R_{Bridge}}$$

**Figure 2.7**

### Sensor Emulator Circuit

Vexc

10kΩ

2kΩ

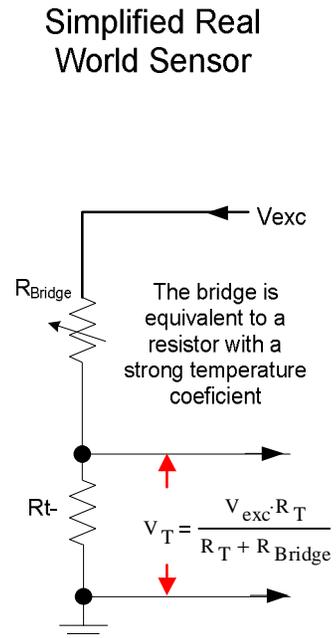Equivalent to R$_{Bridge}$
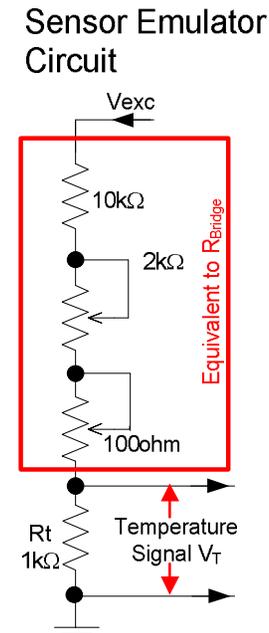
100ohm

Rt 1kΩ   Temperature Signal V$_T$

**Figure 2.8**

Figure 2.6 illustrates one method for monitoring the temperature of a real world bridge sensor. In this type of circuit the resistance of the bridge has a strong temperature coefficient. The bridge resistance generates a bridge current with a strong temperature coefficient, which generates a voltage across the temperature sensing resistor (Rt). Rt is typically located remotely from the bridge and should not have a strong temperature coefficient. Note that Rt can be connected to the top or bottom of the bridge. This diagram illustrates the case where it is connected to the bottom of the bridge. The sensor emulator circuit has three channels to emulate the Rt temperature signal that are selectable through a rotary switch.

An important aspect of the Rt method of temperature sensing is the reduction of the excitation voltage across the bridge by the series Rt resistance. For example, if Vt = 1V and Vexc = 5V, then only 4V remains for the bridge excitation. This phenomena is modeled by the sensor emulator and the detail of how this works are described in Figure 2.15.

# Emulating a Temperature Sensor with a Series Bridge Resistor

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($R_{t+}$ connected to the top of the bridge)

**Real World Sensor**

Bridge Circuit Configured to monitor temperature using the bridges' own temperature coefficient of resistance (TCR)

Vexc

Temperature Signal $V_{T-}$   $V_{INP}$

Rt+

Vout = Vexc – $V_T$

**Figure 2.9**

**Simplified Real World Sensor**

Simplified Equivalent Circuit

Vexc

$$V_T = \frac{V_{exc} \cdot R_T}{R_T + R_{Bridge}}$$

Rt+

Vout = Vexc – $V_T$

$R_{Bridge}$

The bridge is equivalent to a resistor with a strong temperature coeficient

**Figure 2.10**

**Sensor Emulator Circuit**

Sensor Emulator Circuit

Vexc

10kΩ

2kΩ

Equivalent to $R_{Bridge}$

100ohm

Vout = Vexc – $V_T$

+

INA

Rt

Temperature Signal $V_T$

1kΩ
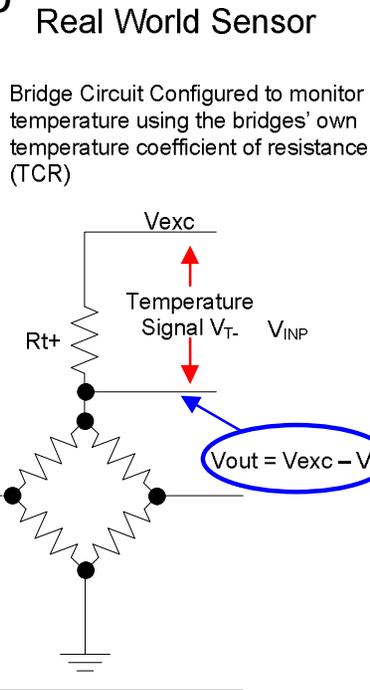
2

–

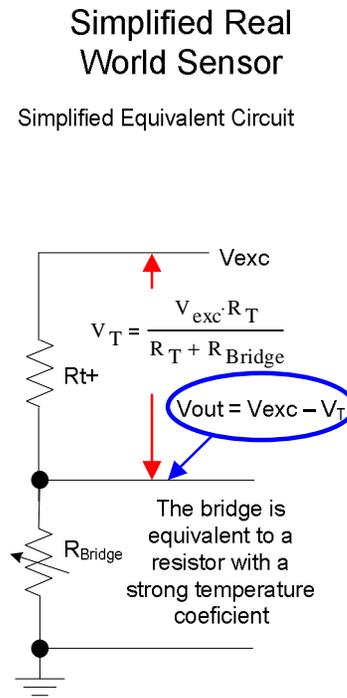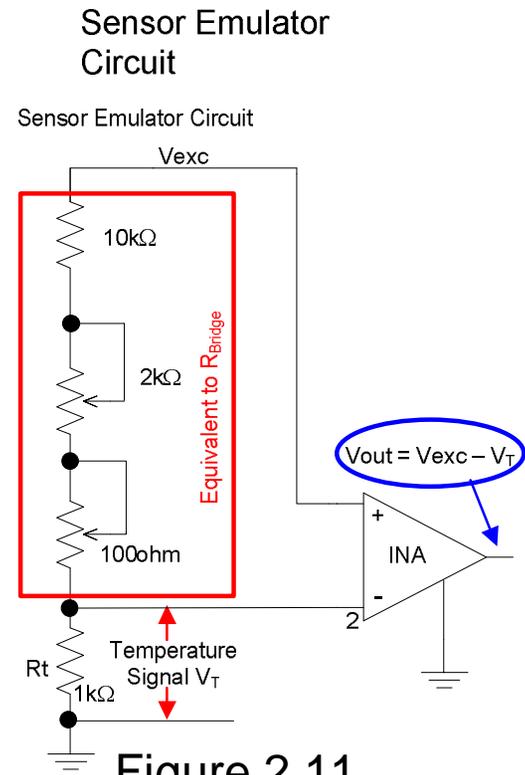**Figure 2.11**

The sensor emulator circuit can also emulate the case where the temperature sense resistor is connected to the top of the bridge. This is done using an instrumentation amplifier to translate the voltage signal to be referenced to Vexc rather then ground. This mode of operation is selected by a jumper (JUMP1). This circuit also feeds the temperature signal back to the bridge emulator to adjust the excitation across the bridge, as in the real world case. The details of how this feedback works are described in Figure 2.15.

# Diode Temperature Sensor Emulator
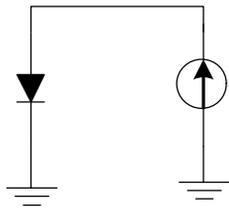
**Real World Sensor**
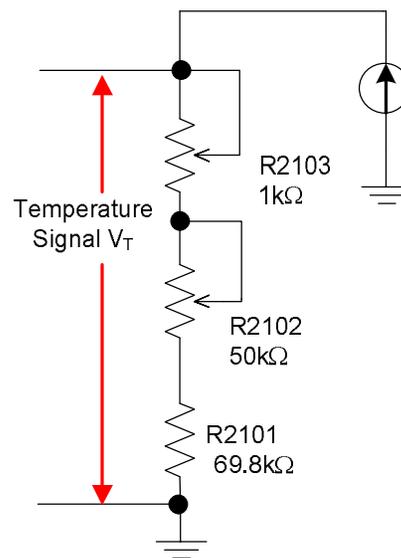
Figure 2.12

**Sensor Emulator with External I_exc**

Temperature Signal $V_T$

R2103 1kΩ

R2102 50kΩ

R2101 69.8kΩ

Figure 2.13

**Sensor Emulator with Onboard Reference**

15V

1.2MΩ

10V Vref

R3

Temperature Signal $V_T$

R2103 1kΩ
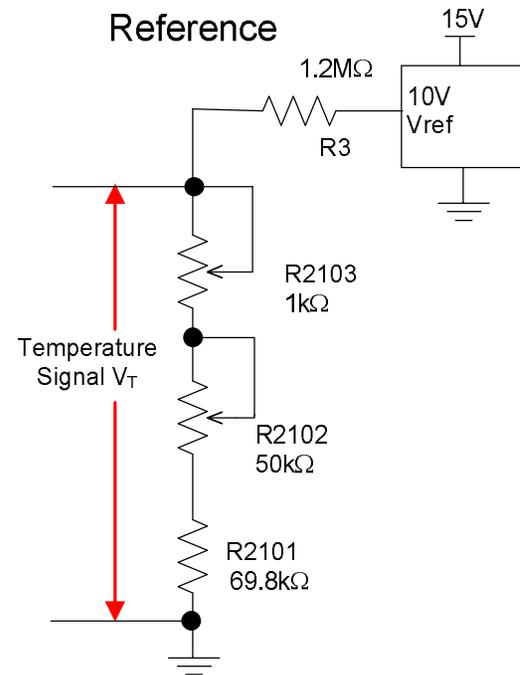
R2102 50kΩ

R2101 69.8kΩ

Figure 2.14

Figure 2.12 illustrates another method for monitoring the temperature of a real world sensor. In this type of circuit a diode is placed in close thermal contact with the bridge and a constant current is driven through the diode. The diode voltage is a reasonably linear function with temperature (the slope is approximately -2mV / °C). The emulator circuit shown in Figure 2.13 uses resistors to develop a voltage equivalent to the diode voltage. Figure 2.14 shows how the emulator can be used to develop an equivalent diode drop if an external current source is not available.

# Emulation Case 1: Rt-
# (Resistance in the Bottom of The Bridge)



Figure 2.15

This diagram illustrates how the emulator generates the bridge output and temperature signals for the circuit where the sense resistor is connected to the bottom of the bridge. Note how the output voltage of the temperature emulator (0.415V) is fed back to the bottom of the bridge emulator via the buffer circuit (U5 and U1c), to emulate the bridge excitation change due to Rt in series with the bridge in the real world.

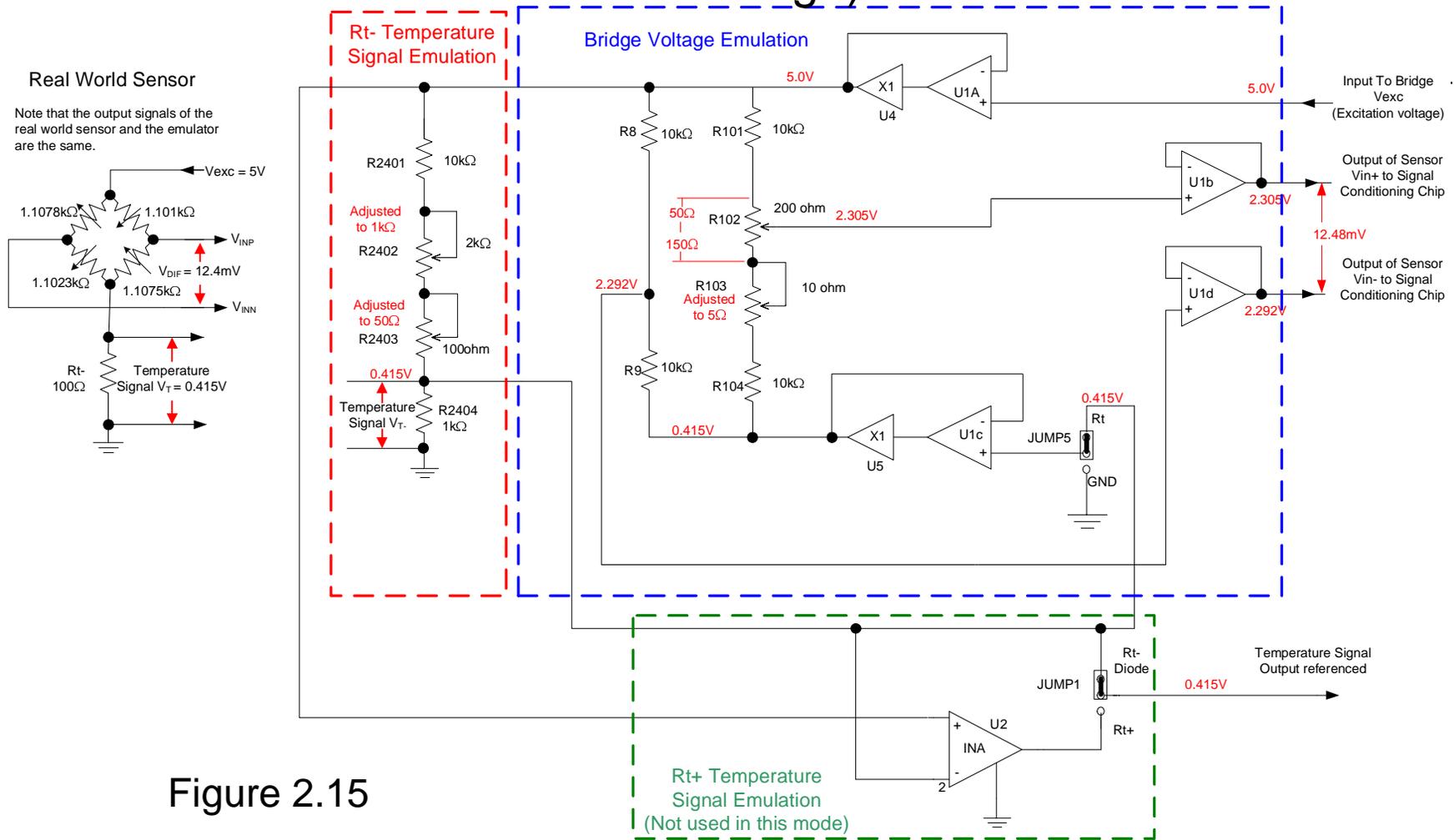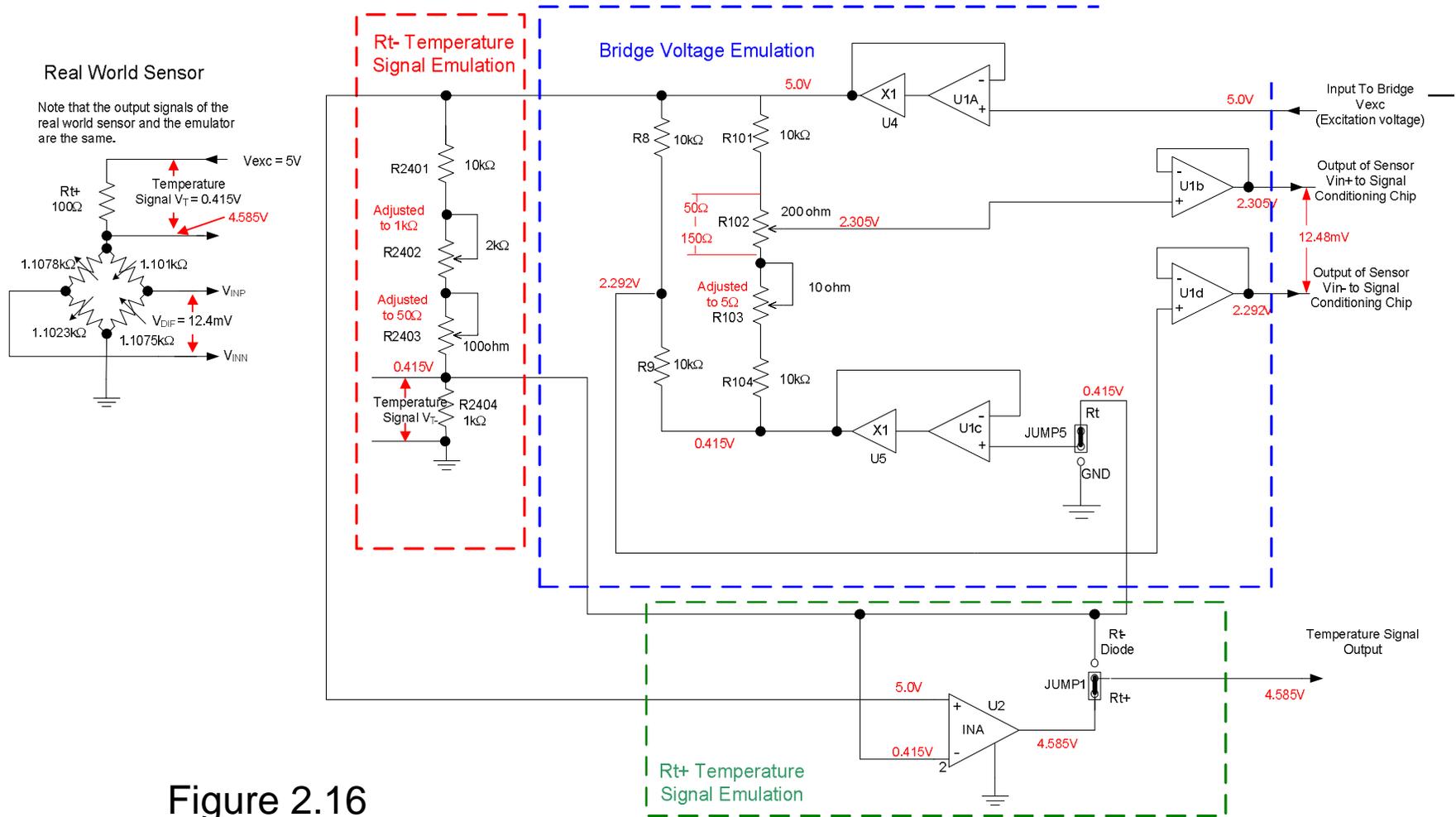# Emulation Case 2: Rt+ (Resistance in the Top of The Bridge)



Figure 2.16

This diagram illustrates how the emulator generates the bridge output and temperature signal for the circuit where the sense resistor is connected to the top of the bridge. Note how the output voltage of the temperature emulator (0.415V) is fed back to the bottom of the bridge emulator via the buffer circuit (U5 and U1c) to emulate the bridge excitation change due to Rt in series with the bridge in the real world. Also, note how the instrumentation amplifier (U2) is used to translate the temperature signal voltage so that it is referenced to the excitation voltage (Vexc).

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# Emulation Case 3:  Diode Temperature Sensor with External Current Source

Real World Sensor

Note that the output signals of the real world sensor and the emulator are the same.

Bridge Voltage Emulation

Diode Voltage set by External Current Source

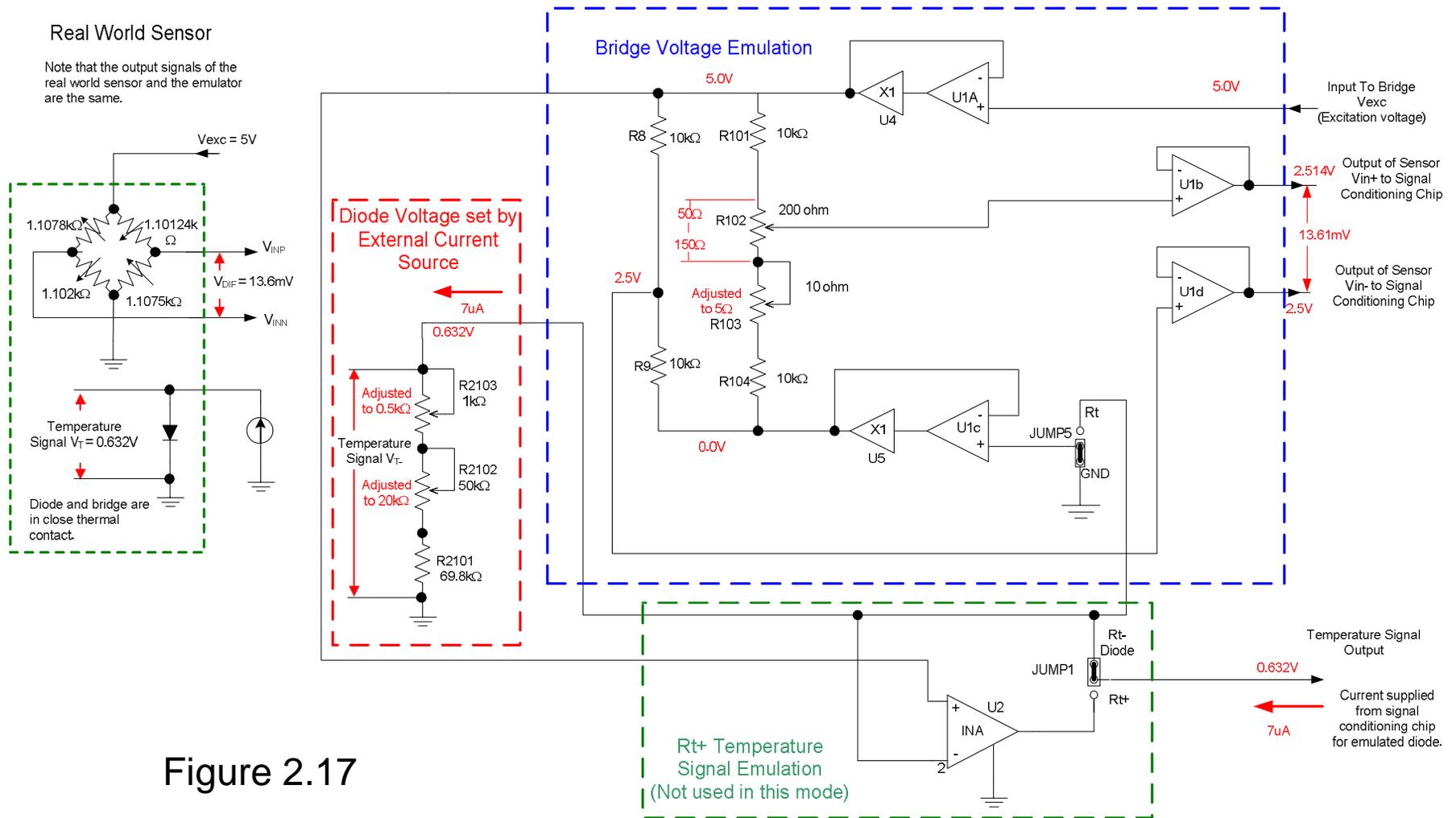Rt+ Temperature Signal Emulation
(Not used in this mode)

Figure 2.17

This diagram illustrates how the emulator generates the bridge output and temperature signal for the diode temperature measurement.  Note that in this case JUMP1 is set so that the bottom of the bridge emulator is at ground potential. Also note that this configuration requires an external current source to operate (in this example, 7μA).

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# Emulation Case 4:  Diode Temperature Sensor with On-Board Voltage Reference



**Bridge Voltage Emulation**

Real World Sensor

Note that the output signals of the real world sensor and the emulator are the same.

$V_{exc} = 5V$

1.1078k$\Omega$   1.10124k$\Omega$

$V_{INP}$

1.102k$\Omega$   1.1075k$\Omega$

$V_{DIF} = 13.6mV$

$V_{INN}$

Temperature Signal $V_T = 0.70V$

Diode and bridge are in close thermal contact.

**Diode voltage set by on board Vref.**

JUMP2   REF102   R3 1.2M$\Omega$   15V 10V Vref REF102

0.70V

Adjusted to 0.5k$\Omega$   R2103 1k$\Omega$

Temperature Signal $V_{T-}$

Adjusted to 20k$\Omega$   R2102 50k$\Omega$

R2101 69.8k$\Omega$

5.0V   X1   U4   U1A

R8 10k$\Omega$   R101 10k$\Omega$

50$\Omega$   R102   200 ohm

150$\Omega$

2.5V   Adjusted to 5$\Omega$   R103   10 ohm

R9 10k$\Omega$   R104 10k$\Omega$

0.0V   X1   U1c   U5   JUMP5   Rt   GND

Input To Bridge Vexc (Excitation voltage)   5.0V

U1b   2.514V Output of Sensor Vin+ to Signal Conditioning Chip

13.61mV

U1d   Output of Sensor Vin- to Signal Conditioning Chip   2.5V

**Rt+ Temperature Signal Emulation (Not used in this mode)**

U2   INA   2

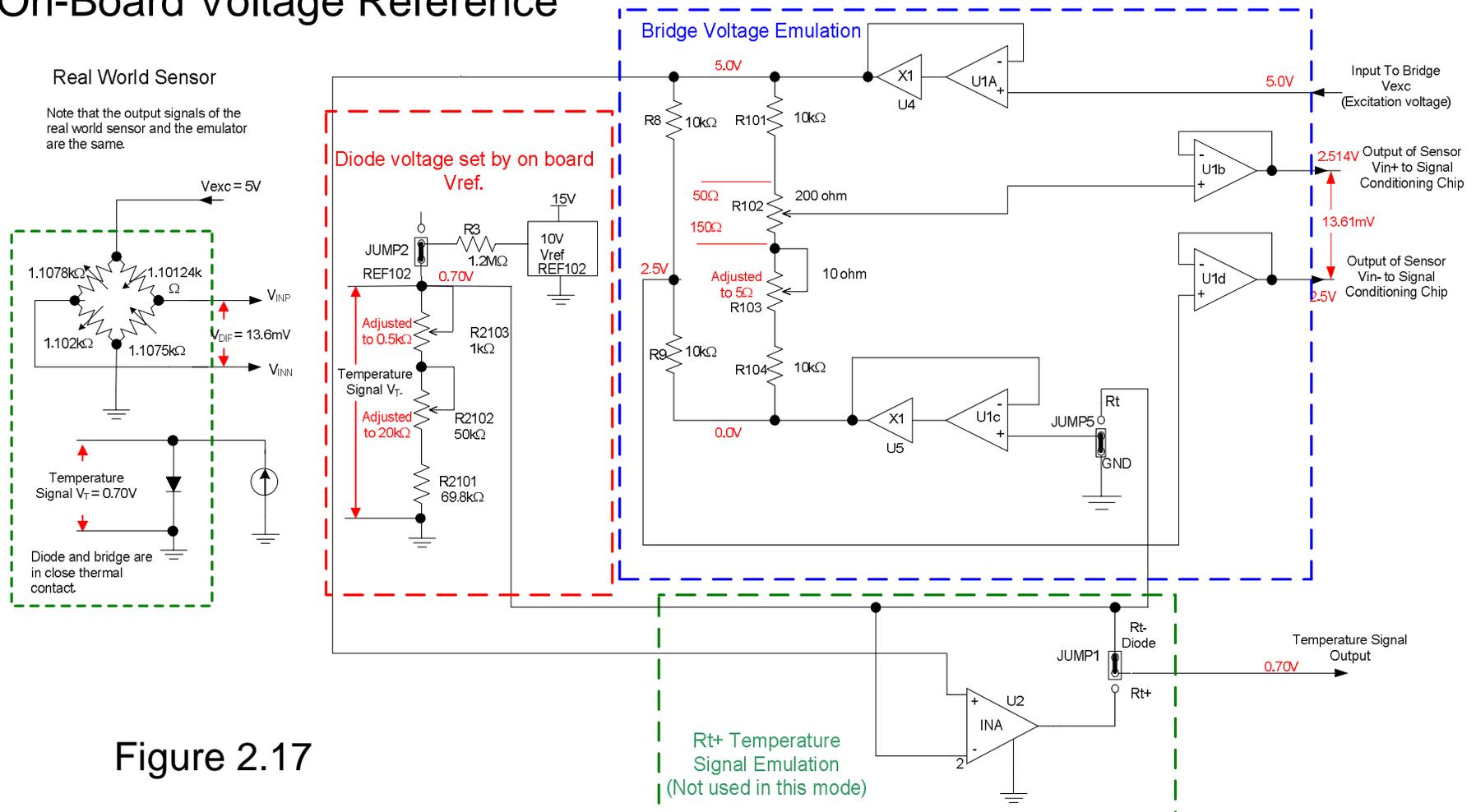JUMP1   Rt-Diode   Rt+

Temperature Signal Output   0.70V

Figure 2.17

This diagram illustrates how the emulator generates the bridge output and temperature signal for the diode temperature measurement.  Note that in this case JUMP1 is set so that the bottom of the bridge emulator is at ground potential. Also note that this uses an on-board voltage reference (REF102) to set the diode voltage (JUMP2 selects this option).

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# 3.0 Changing the Programmable Range of the Emulator

Figure 3.1 illustrates how the range of the bridge emulator can be adjusted by putting a resistor in parallel with R101 and R104. This needs to be done for each channel of the emulator (11 channels x 2 resistors = 22 resistors total). The examples illustrates how the range is increased using a 1kΩ parallel resistor. In general, it is best to select a parallel resistance value that scales your range so that the full scale output of the emulator is slightly larger than what is required for your emulator. Scaling the emulator in this manner will provide the optimal resolution and lowest noise. Note that holes are provided for a parallel through-hole resistor to simplify the process of adjusting the emulator scale.
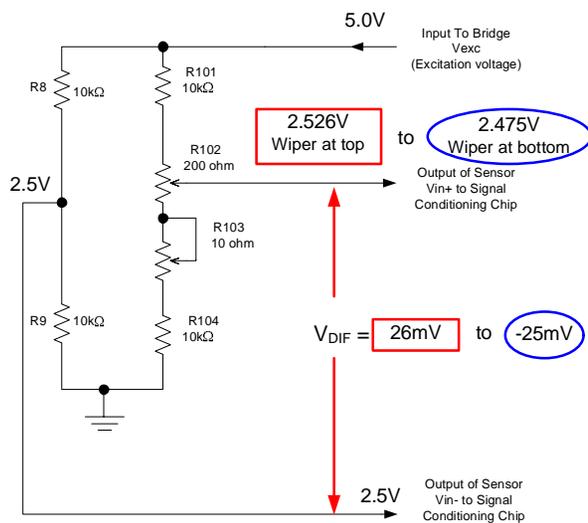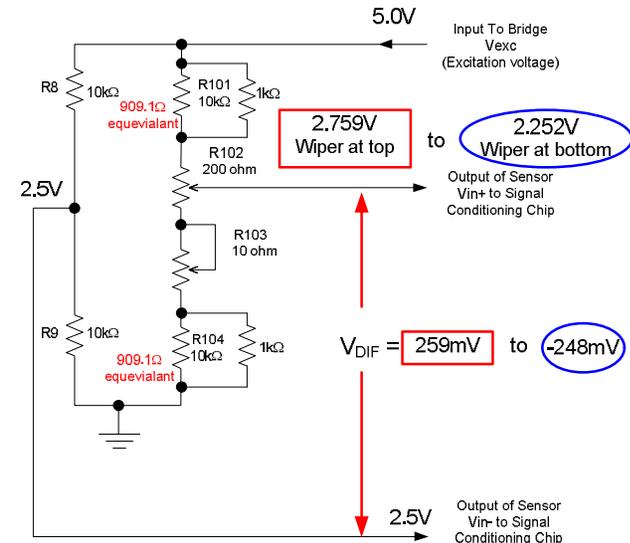


Figure 3.0: Default Range



Figure 3.1: Adjusted Range

| Positive full scale of the emulator | Negative full scale of the emulator |
|---|---|
| $V_{exc} := 5 \quad R_{104} := 10 \cdot 10^3 \quad R_{102} := 200 \quad R_{101} := 10 \cdot 10^3$ | $V_{exc} := 5 \quad R_{104} := 10 \cdot 10^3 \quad R_{102} := 200 \quad R_{101} := 10 \cdot 10^3$ |
| $R_{102a} := 200$    Wiper position at top of POT | $R_{102a} := 0$    Wiper position at bottom of POT |
| $R_{103} := 10$    Pot set to maximum Resistance | $R_{103} := 0$    Pot set to Minimum Resistance |
| $V_{dif} := \dfrac{V_{exc} \cdot (R_{104} + R_{103} + R_{102a})}{R_{101} + R_{104} + R_{103} + R_{102}} - \dfrac{V_{exc}}{2}$ | $V_{dif} := \dfrac{V_{exc} \cdot (R_{104} + R_{103} + R_{102a})}{R_{101} + R_{104} + R_{103} + R_{102}} - \dfrac{V_{exc}}{2}$ |
| $V_{dif} = 0.026$    Positive full scale output of emulator | $V_{dif} = -0.025$    Positive full scale output of emulator |

| Positive full scale of the emulator | Negative full scale of the emulator |
|---|---|
| $V_{exc} := 5 \quad R_{104} := 909.1 \quad R_{102} := 200 \quad R_{101} := 909.1$ | $V_{exc} := 5 \quad R_{104} := 909.1 \quad R_{102} := 200 \quad R_{101} := 909.1$ |
| $R_{102a} := 200$    Wiper position at top of POT | $R_{102a} := 0$    Wiper position at bottom of POT |
| $R_{103} := 10$    Pot set to maximum Resistance | $R_{103} := 0$    Pot set to Minimum Resistance |
| $V_{dif} := \dfrac{V_{exc} \cdot (R_{104} + R_{103} + R_{102a})}{R_{101} + R_{104} + R_{103} + R_{102}} - \dfrac{V_{exc}}{2}$ | $V_{dif} := \dfrac{V_{exc} \cdot (R_{104} + R_{103} + R_{102a})}{R_{101} + R_{104} + R_{103} + R_{102}} - \dfrac{V_{exc}}{2}$ |
| $V_{dif} = 0.259$    Positive full scale output of emulator | $V_{dif} = -0.248$    Negative full scale output of emulator |

# 4.0 Required Electrical Connections to Sensor-Emulator-EVM
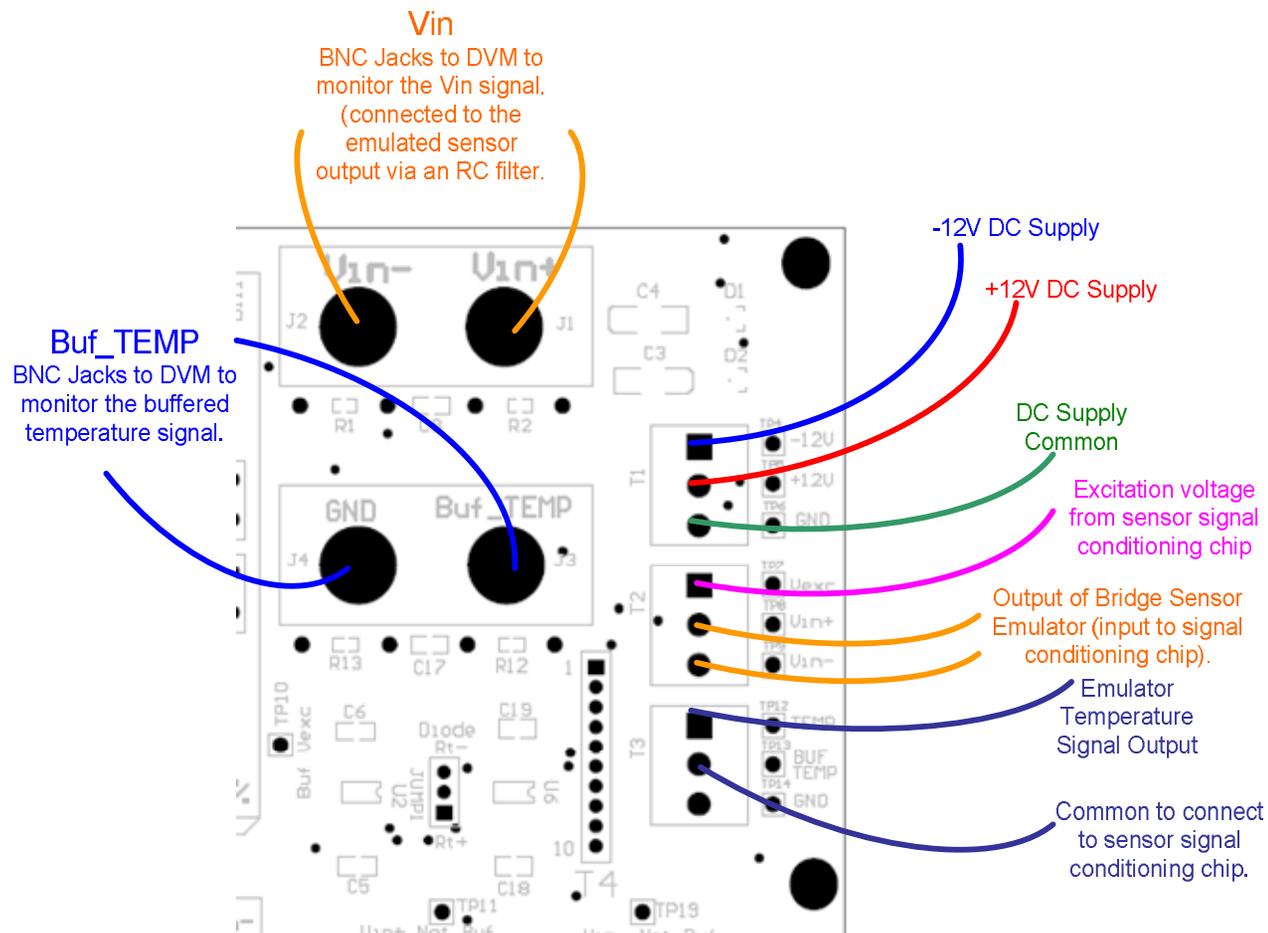
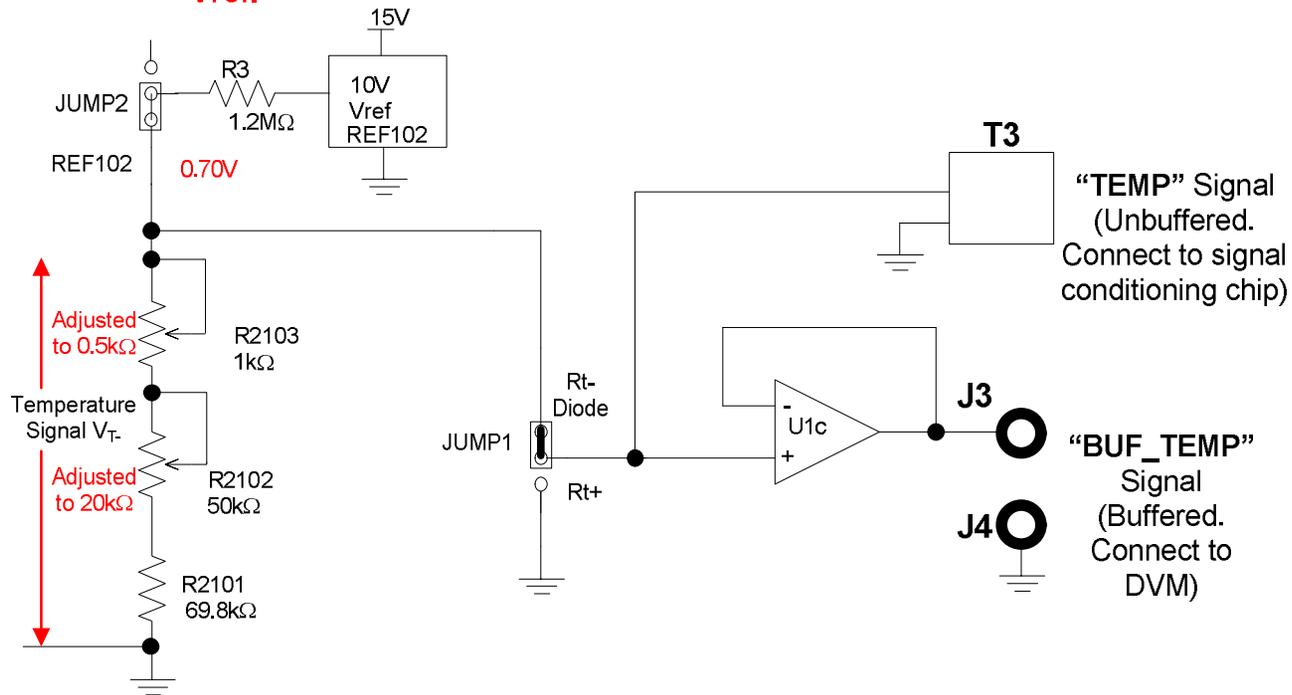# Example of a Typical Engineering Bench Setup Using the Sensor Emulator
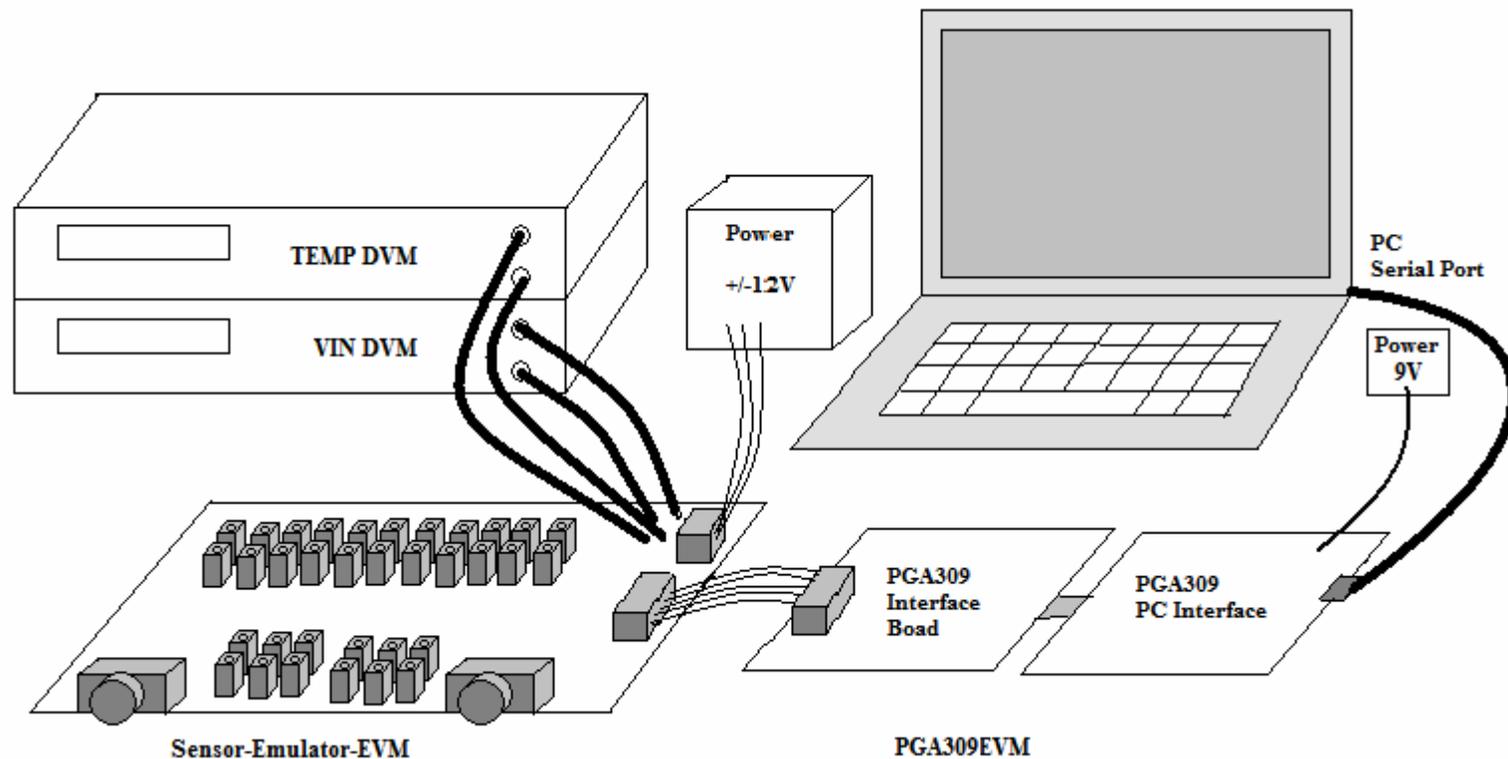
This diagram illustrates an example of how the sensor emulator would be used in an engineering bench setup. The PGA309 is a programmable sensor signal conditioning chip. The Sensor-Emulator-EVM can be used in conjunction with the PGA309EVM to facilitate the development of a PGA309 application.

# Note on the Buf_Temp Banana Jacks

The Buf_Temp banana jacks are used to monitor the temperature signal with a DVM.  It is important to monitor temperature at this point because the non-buffered temperature signal is a high impedance output, and the DVM can load this output.
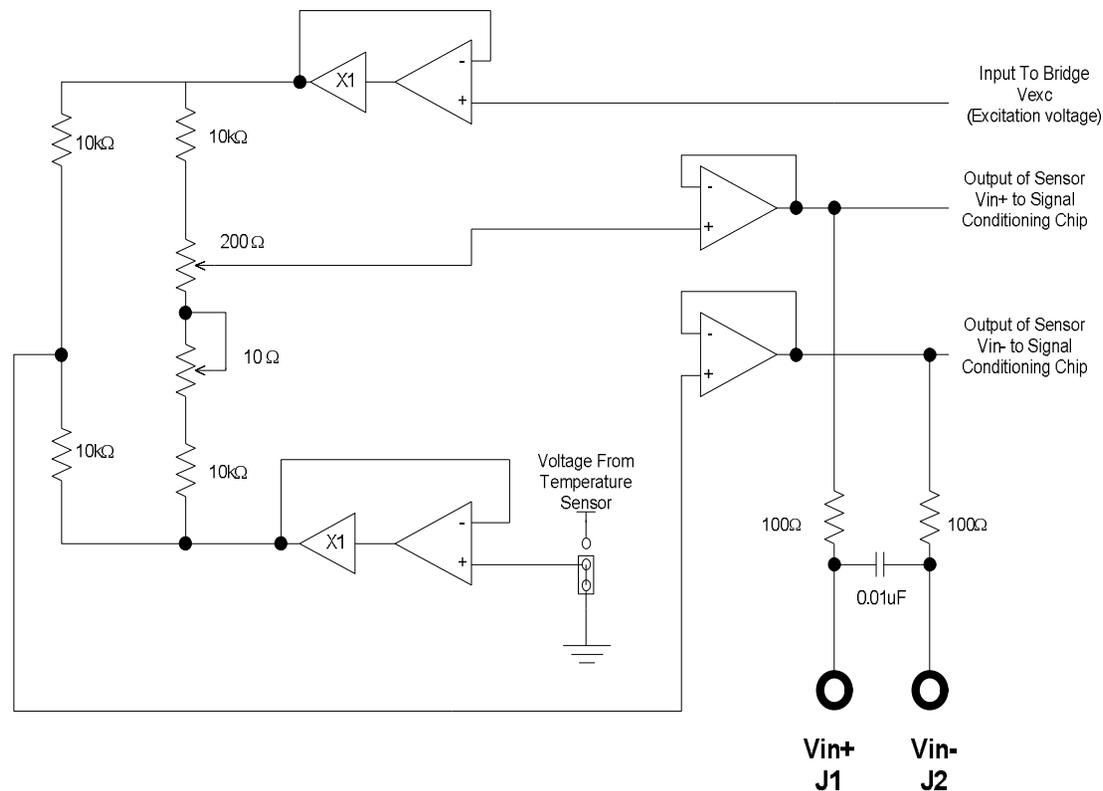


Diode voltage set by on board Vref.

15V

R3 1.2MΩ

10V Vref REF102

JUMP2

REF102    0.70V

T3

"TEMP" Signal (Unbuffered. Connect to signal conditioning chip)

Adjusted to 0.5kΩ

R2103 1kΩ

Temperature Signal $V_{T-}$

Rt-Diode

JUMP1

Adjusted to 20kΩ

R2102 50kΩ

Rt+

U1c

J3

"BUF_TEMP" Signal (Buffered. Connect to DVM)
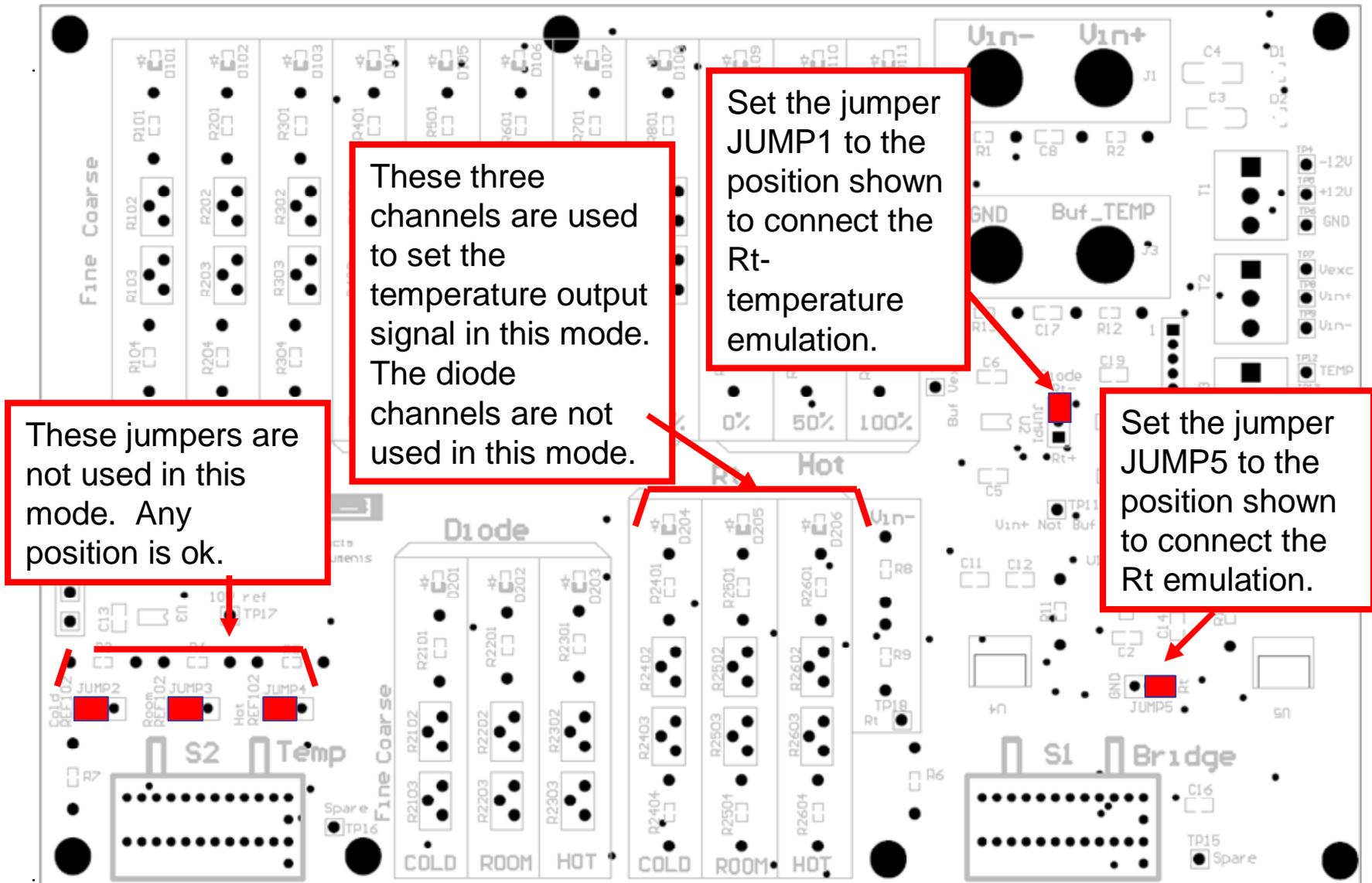
J4

R2101 69.8kΩ
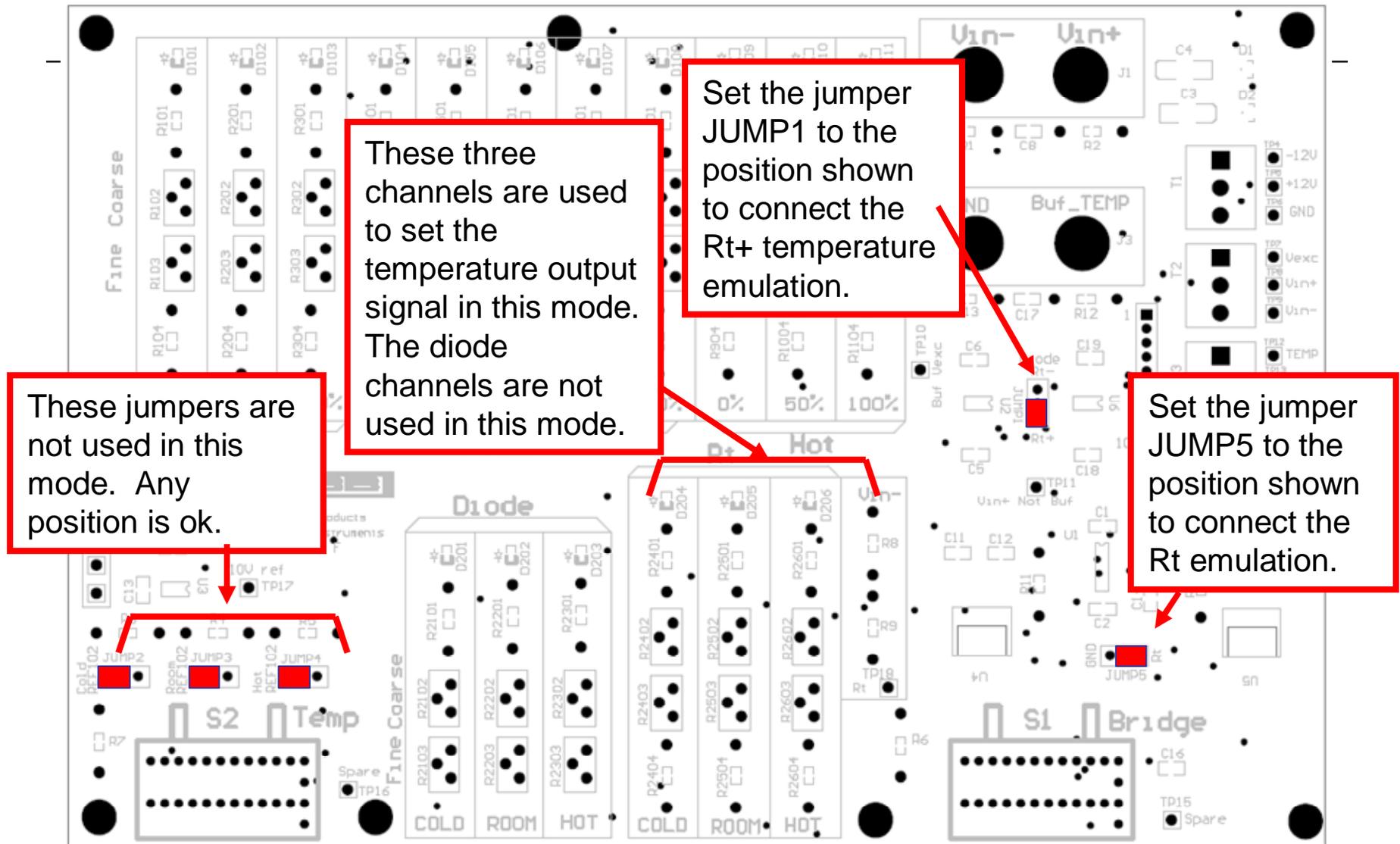
# Note on the Vin- and Vin+ Banana Jacks

The Vin- and Vin+ banana jacks are used to monitor the sensor output signal with a DVM. The Vin banana jacks are connected to the Vin signal through a standard RC filter. This filter helps to reduce the coupling of noise (from ground loops) into the sensor output circuit, and into high gain sensor signal conditioner inputs.
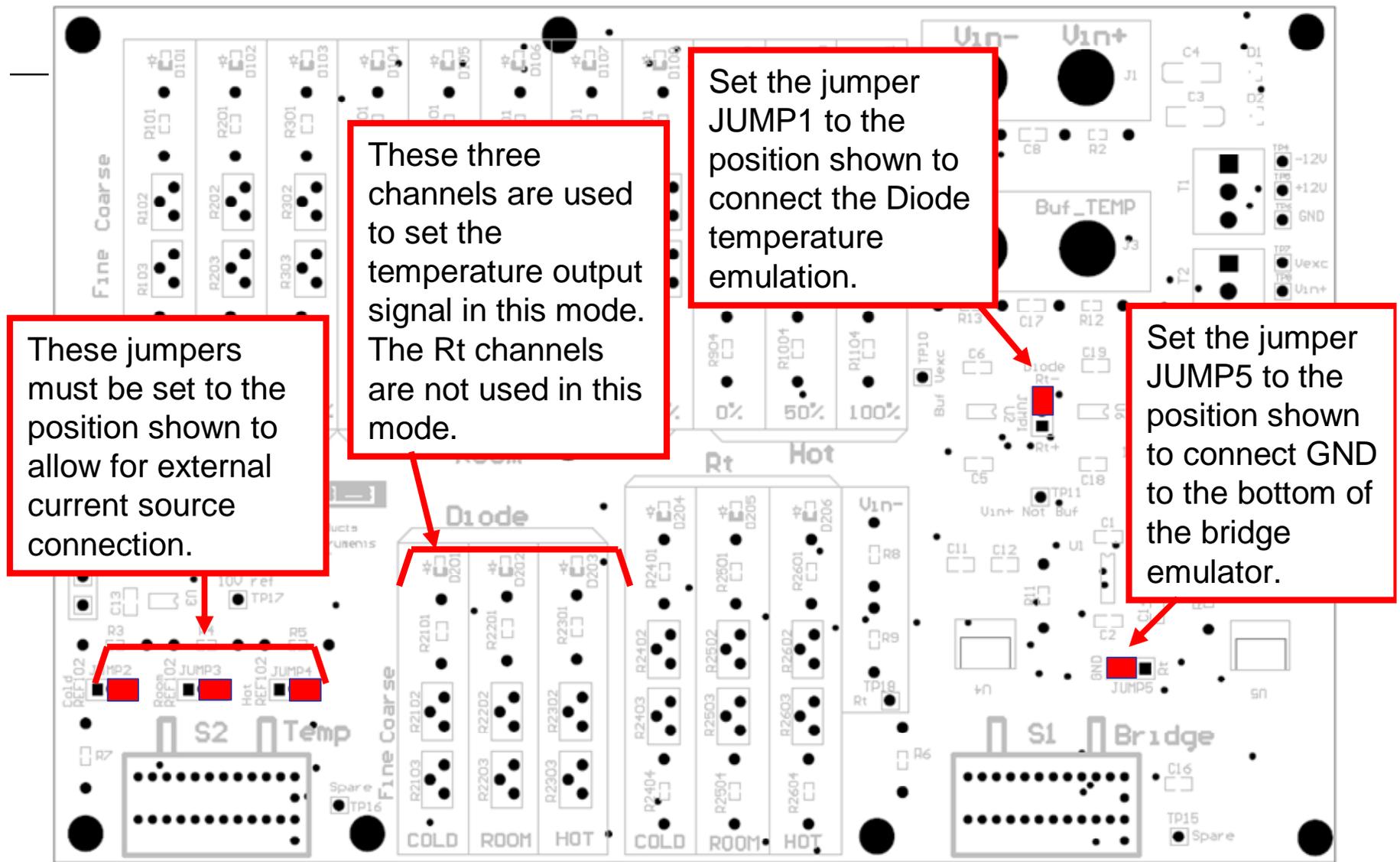
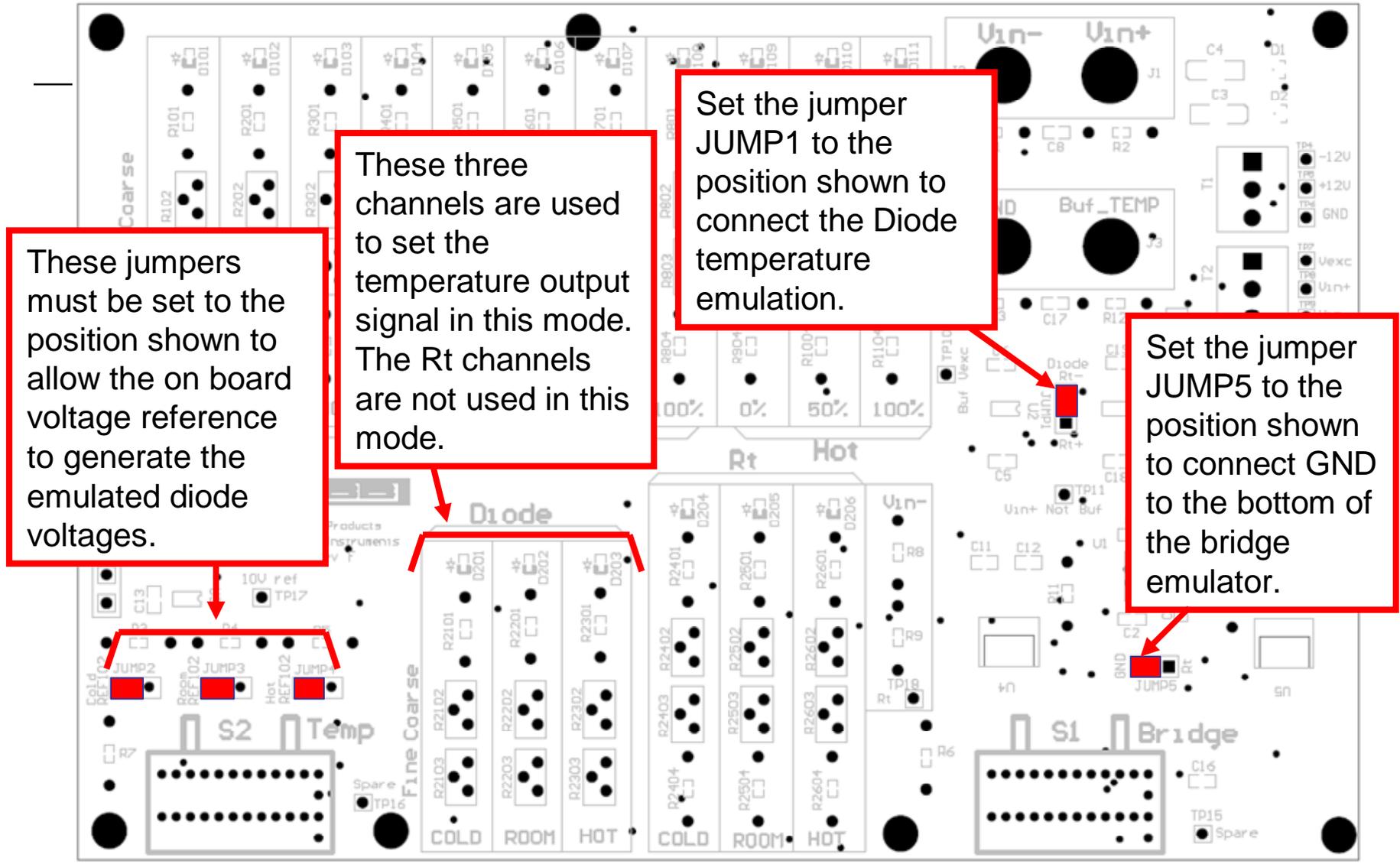# Emulation Case 1: Resistance in the Bottom of the Bridge Rt-



Set the jumper JUMP1 to the position shown to connect the Rt-temperature emulation.

These three channels are used to set the temperature output signal in this mode. The diode channels are not used in this mode.

Set the jumper JUMP5 to the position shown to connect the Rt emulation.

These jumpers are not used in this mode. Any position is ok.

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# Emulation Case 2: Resistance in the Top of the Bridge Rt+



These three channels are used to set the temperature output signal in this mode. The diode channels are not used in this mode.

Set the jumper JUMP1 to the position shown to connect the Rt+ temperature emulation.

These jumpers are not used in this mode. Any position is ok.

Set the jumper JUMP5 to the position shown to connect the Rt emulation.

# Emulation Case 3: Diode Temperature Sensor with External Current Source



These jumpers must be set to the position shown to allow for external current source connection.

These three channels are used to set the temperature output signal in this mode. The Rt channels are not used in this mode.

Set the jumper JUMP1 to the position shown to connect the Diode temperature emulation.

Set the jumper JUMP5 to the position shown to connect GND to the bottom of the bridge emulator.

# Emulation Case 4: Diode Temperature Sensor with Onboard Voltage Reference



Set the jumper JUMP1 to the position shown to connect the Diode temperature emulation.

These three channels are used to set the temperature output signal in this mode. The Rt channels are not used in this mode.

These jumpers must be set to the position shown to allow the on board voltage reference to generate the emulated diode voltages.

Set the jumper JUMP5 to the position shown to connect GND to the bottom of the bridge emulator.

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# 5.0 Configuring the Sensor-Emulator-EVM to Emulate a Real World Sensor

If the raw output of the sensor is not known, the *generate_emu_values.xls* spreadsheet (SBOC065, available for download at www.ti.com) can be used to translate the specifications of your bridge sensor and temperature sensor to system voltage levels. The spreadsheet contains five sections:

1.  Offset and Span:  Generates the bridge output voltages.

2.  Diode Vo: Generates the temperature sensor output voltages for the diode method.

3.  Rt-: Generates the temperature sensor voltages for the Rt- method.

4.  Rt+: Generates the temperature sensor voltages for the Rt- method.

5.  PGA309_Error:  Allows you to read the PGA309 via the ADS1100.
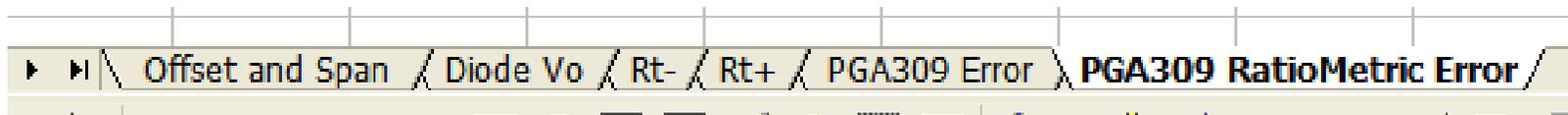
# Offset and Span:  Generates the bridge output voltages from sensor specifications

All the areas shown in light blue are either sensor specifications or system requirements.  Enter these values and the spreadsheet will generate output voltage settings for each channel on the sensor emulator.  The next several pages will show how the voltages listed in the spreadsheet are used to program the sensor emulator.

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Temp range: | degC | | | | | | | | |
| 2 | Tmin= | -45.00 | | Precalibration Sensor Simulator Settings (LinDac = 0) | | | | | | |
| 3 | Tmax= | 90.00 | | | | Cold | | | | |
| 4 | Troom= | 22.50 | | Pressure Input | | 0% | 50% | 100% | | |
| 5 | | | | Sensor Output (mV) | | -0.215 | 5.379 | 11.939 | | |
| 6 | Vexc (V) | 3.400E+00 | | | | | | | | |
| 7 | | | | | | Room | | | | |
| 8 | Span (V/V) | 3.509E-03 | | Pressure Input | | 0% | 25% | 50% | 75% | 100% |
| 9 | Offset (V/V) | -2.945E-04 | | Sensor Output (mV) | | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |
| 10 | | | | | | | | | | |
| 11 | | | | | | Hot | | | | |
| 12 | | | | Pressure Input | | 0% | 50% | 100% | | |
| 13 | NonlinSpanDrift (% of Span) | -5.031E-02 | | Sensor Output (mV) | | -1.053 | 4.887 | 11.855 | | |
| 14 | NonlinOffsetDrift (% of Span) | -3.077E-02 | | | | | | | | |
| 15 | PressureNonlin (% of Span) | -3.976E-02 | | | | | | | | |
| 16 | | | | | | | | | | |
| 17 | GainTC1 (% of Span/C) | 4.682E-04 | | | | | | | | |
| 18 | OffsetTC1 (% of Span/C) | -5.205E-04 | | | | | | | | |
| 19 | GainTCNonlin(TC2) (% of Span/C$^2$) | -1.104E-05 | | | | | | | | |
| 20 | OffsetTCNonlin(TC2) (% of Span/C$^2$) | -6.753E-06 | | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | Note: % of Span is represented as a decimal number | | | | | | | | | |
| 23 | i.e. OffsetTC1 (% of Span) = 0.1  is 10% | | | | | | | | | |
| 24 | | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | | | | | | | | | | |

**Precalibration Sensor Simulator Settings (LinDac = 0)**

| | Cold | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -0.257 | 5.332 | 11.887 | | |
| | | | | | |
| | Room | | | | |
| Pressure Input | 0% | 25% | 50% | 75% | 100% |
| Sensor Output (mV) | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |
| | | | | | |
| | Hot | | | | |
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -1.041 | 4.927 | 11.926 | | |

The sensor output at cold temperature and 0% of applied stimulus is emulated by this channel. The rotary switch S1 is used to select this channel. When the channel is selected, LED D101 will light to indicate that the correct channel is selected.
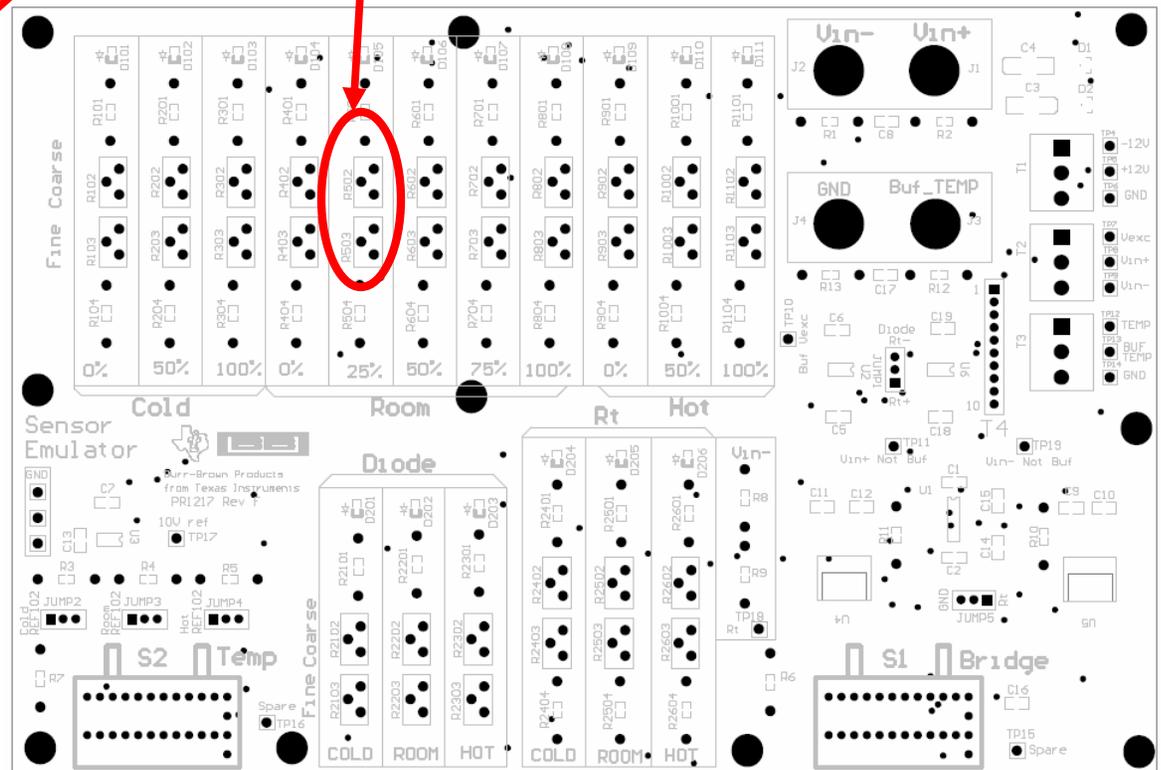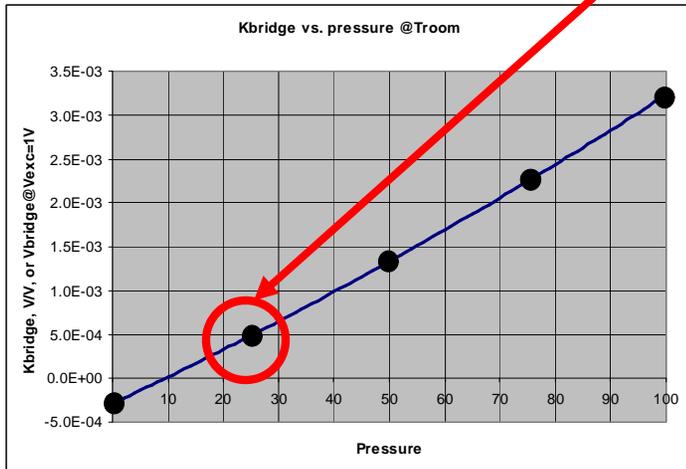


Bridge Sensitivity vs Temp

**Precalibration Sensor Simulator Settings (LinDac = 0)**

| Cold | | | |
|---|---|---|---|
| Pressure Input | 0% | 50% | 100% |
| Sensor Output (mV) | -0.257 | 5.323 | 11.867 |

| Room | | | | |
|---|---|---|---|---|
| Pressure Input | 0% | 25% | 50% | 75% | 100% |
| Sensor Output (mV) | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |

| Hot | | | |
|---|---|---|---|
| Pressure Input | 0% | 50% | 100% |
| Sensor Output (mV) | -1.041 | 4.927 | 11.926 |

The sensor output at cold temperature and 100% of applied stimulus is emulated by this channel. The rotary switch S1 is used to select this channel. When the channel is selected, LED D103 will light to indicate that the correct channel is selected.



Bridge Sensitivity vs Temp

**Precalibration Sensor Simulator Settings (LinDac = 0)**

| | Cold | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -0.257 | 5.323 | 11.867 | | |
| | | | | | |
| | Room | | | | |
| Pressure Input | 0% | 25% | 50% | 75% | 100% |
| Sensor Output (mV) | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |
| | | | | | |
| | Hot | | | | |
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -1.041 | 4.927 | 11.926 | | |

The sensor output at room temperature and 0% of applied stimulus is emulated by this channel. The rotary switch S1 is used to select this channel. When the channel is selected, LED D104 will light to indicate that the correct channel is selected.
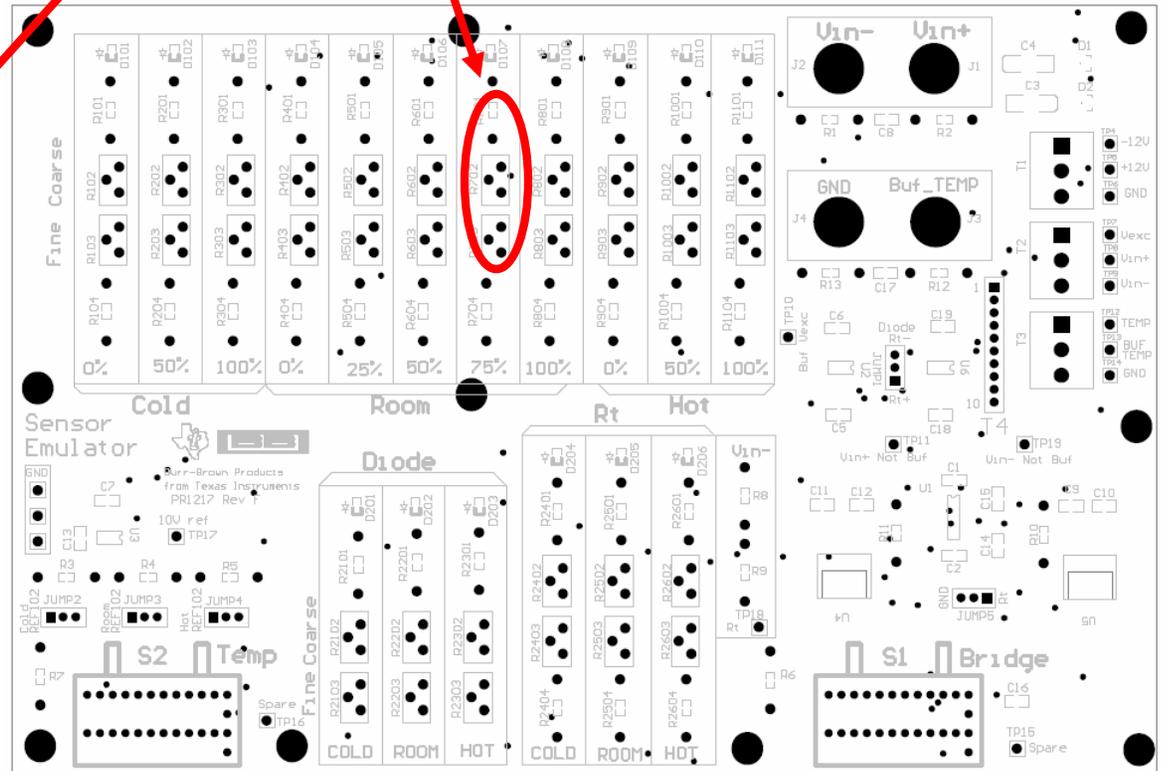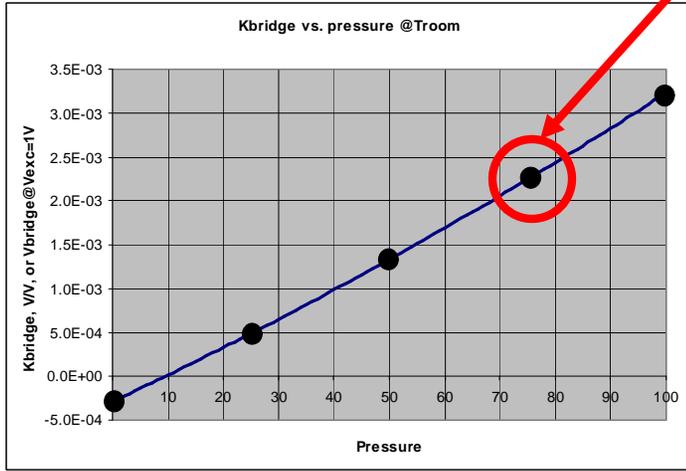


**Kbridge vs. pressure @Troom**
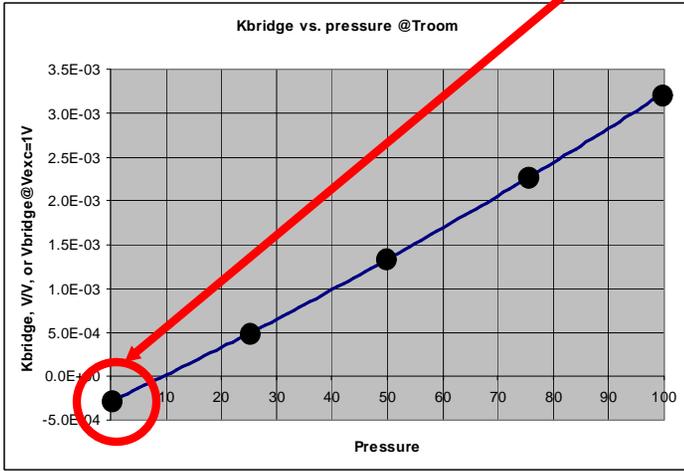
Emulate the nonlinearity of the curve at room temperature for four points.

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**Precalibration Sensor Simulator Settings (LinDac = 0)**

| | Cold | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -0.257 | 5.323 | 11.867 | | |

| | Room | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 25% | 50% | 75% | 100% |
| Sensor Output (mV) | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |

| | Hot | | |
|---|---|---|---|
| Pressure Input | 0% | 50% | 100% |
| Sensor Output (mV) | -1.041 | 4.927 | 11.926 |

The sensor output at room temperature and 25% of applied stimulus is emulated by this channel. The rotary switch S1 is used to select this channel. When the channel is selected, LED D105 will light to indicate that the correct channel is selected.
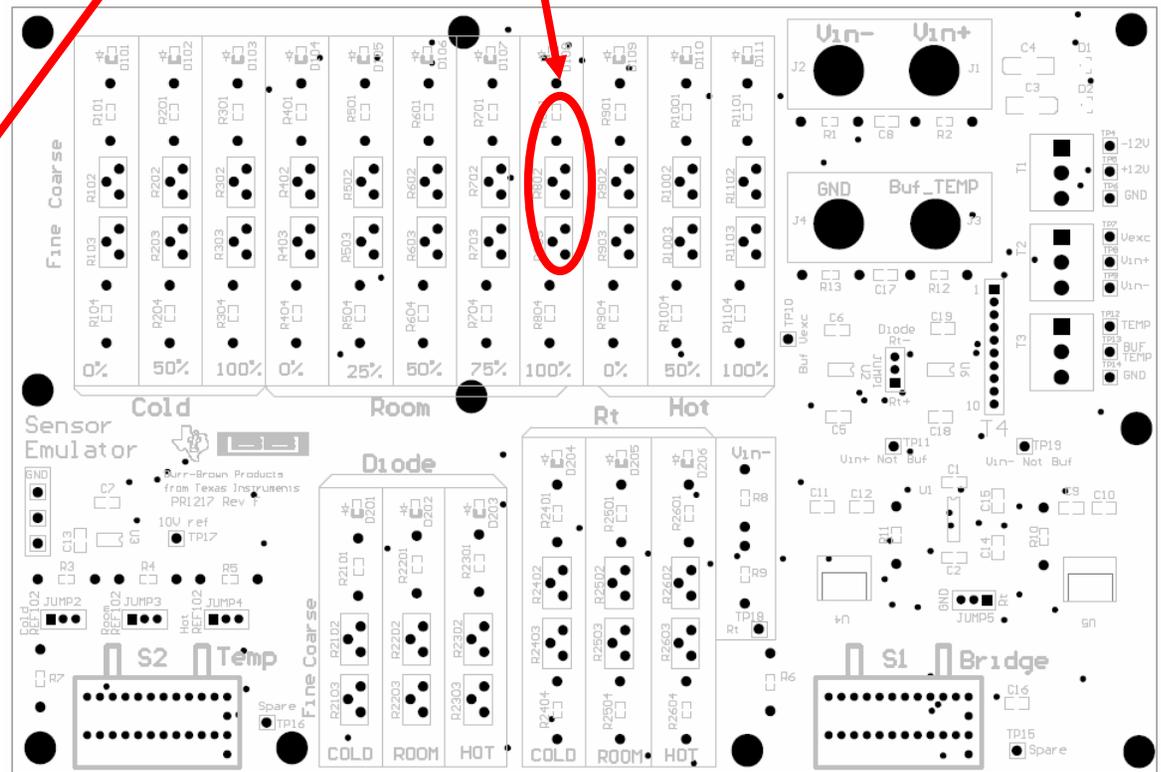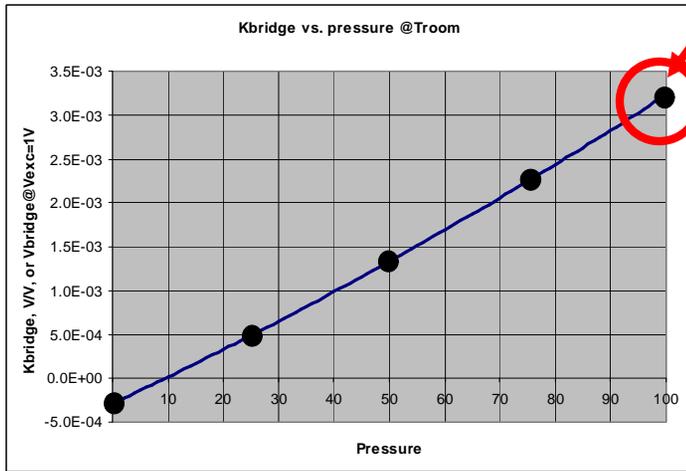


Kbridge vs. pressure @Troom

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**Precalibration Sensor Simulator Settings (LinDac = 0)**

| | Cold | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -0.257 | 5.323 | 11.867 | | |

| | Room | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 25% | 50% | 75% | 100% |
| Sensor Output (mV) | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |

| | Hot | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -1.041 | 4.927 | 11.926 | | |

The sensor output at room temperature and 50% of applied stimulus is emulated by this channel. The rotary switch S1 is used to select this channel. When the channel is selected, LED D106 will light to indicate that the correct channel is selected.



Kbridge vs. pressure @Troom

**Precalibration Sensor Simulator Settings (LinDac = 0)**

| | Cold | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -0.257 | 5.323 | 11.867 | | |

| | Room | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 25% | 50% | 75% | 100% |
| Sensor Output (mV) | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |

| | Hot | | |
|---|---|---|---|
| Pressure Input | 0% | 50% | 100% |
| Sensor Output (mV) | -1.041 | 4.927 | 11.926 |

The sensor output at room temperature and 75% of applied stimulus is emulated by this channel. The rotary switch S1 is used to select this channel. When the channel is selected, LED D107 will light to indicate that the correct channel is selected.



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**Precalibration Sensor Simulator Settings (LinDac = 0)**

| | Cold | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -0.257 | 5.323 | 11.867 | | |
| | | | | | |
| | Room | | | | |
| Pressure Input | 0% | 25% | 50% | 75% | 100% |
| Sensor Output (mV) | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |
| | | | | | |
| | Hot | | | | |
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -1.041 | 4.927 | 11.926 | | |

The sensor output at room temperature and 100% of applied stimulus is emulated by this channel. The rotary switch S1 is used to select this channel. When the channel is selected, LED D108 will light to indicate that the correct channel is selected.



Kbridge vs. pressure @Troom



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**Precalibration Sensor Simulator Settings (LinDac = 0)**

| | Cold | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -0.257 | 5.323 | 11.867 | | |

| | Room | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 25% | 50% | 75% | 100% |
| Sensor Output (mV) | -1.001 | 1.626 | 4.490 | 7.591 | 10.929 |

| | Hot | | | | |
|---|---|---|---|---|---|
| Pressure Input | 0% | 50% | 100% | | |
| Sensor Output (mV) | -1.041 | 4.927 | 11.926 | | |

The other channels are set in a similar manner and selected using S1.
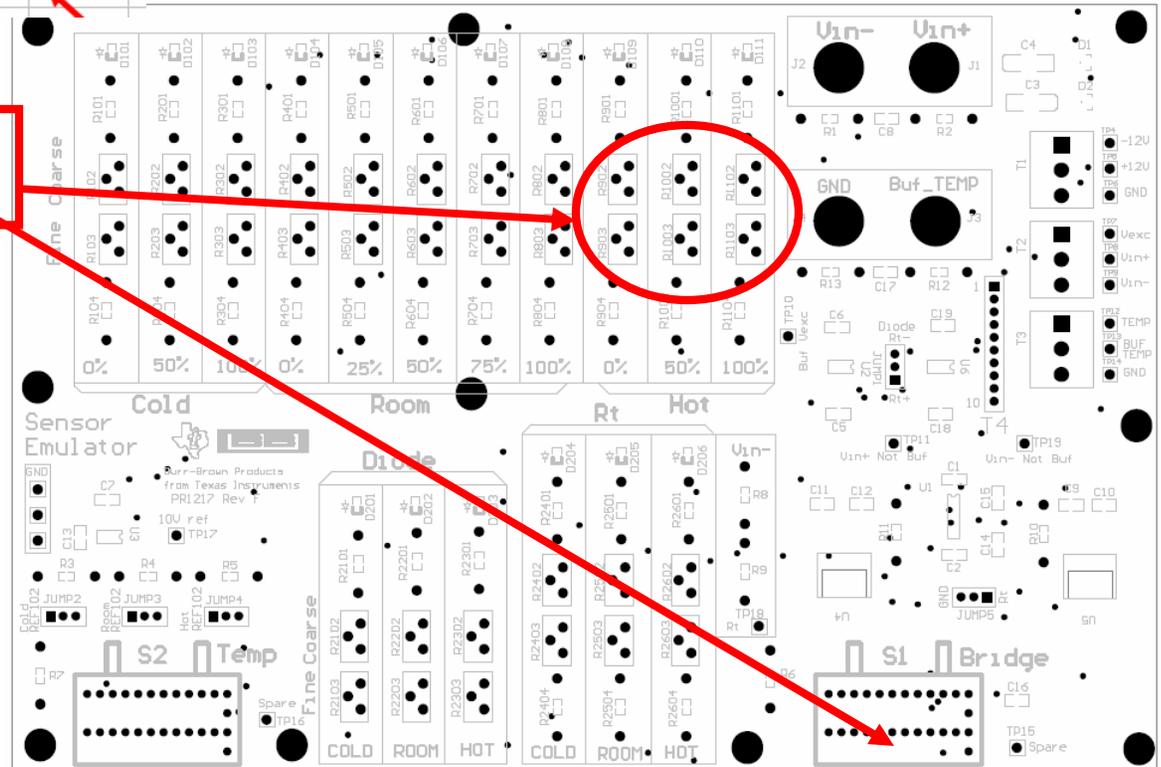
# Diode Vo: Generate Diode Voltages based on Operating Temperature Range

The second tab in the spreadsheet allows the user to enter the temperature range and room temperature diode voltage (light blue areas). The spreadsheet calculates the diode voltages and displays the results in the yellow areas. Note that the Temp ADC area is specific to the PGA309 sensor signal conditioning chip. The Temp ADC values will be used in the computation of the *Counts* for the temp ADC. The next several pages will show how the diode voltages are used to program the sensor emulator.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 10 | | | | | | |
| 11 | Temp range: | degC | | Temp(degC) | Diode Vbe (V) | Counts |
| 12 | Tmin= | -45.00 | | -45.00 | 0.75 | 24000 |
| 13 | Troom= | 20.00 | | 20.00 | 0.62 | 19840 |
| 14 | Tmax= | 90.00 | | 90.00 | 0.48 | 15360 |
| 15 | | | | | | |
| 16 | Diode | Volts | | | | |
| 17 | Room Temp Vbe= | 0.62 | | | | |
| 18 | | | | | | |
| 19 | Temp ADC | | | | | |
| 20 | Vref (in V) = | 4.096 | | | | |
| 21 | Numb Bits | 16 | | | | |
| 22 | Gain= | 4 | | | | |
| 23 | | | | | | |
| 24 | | | | | | |
| 25 | | | | | | |
| 26 | | | | | | |
| 27 | | | | | | |

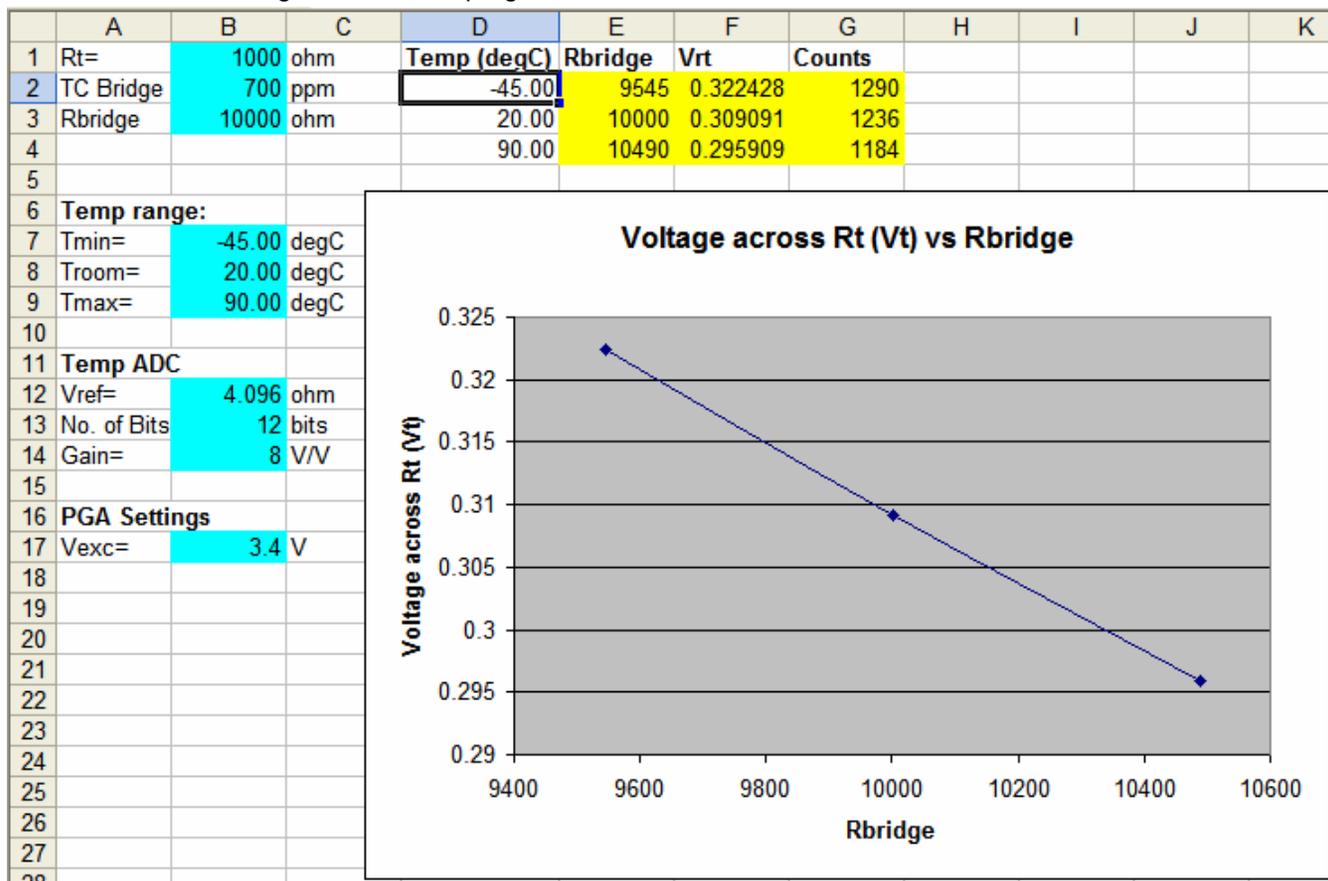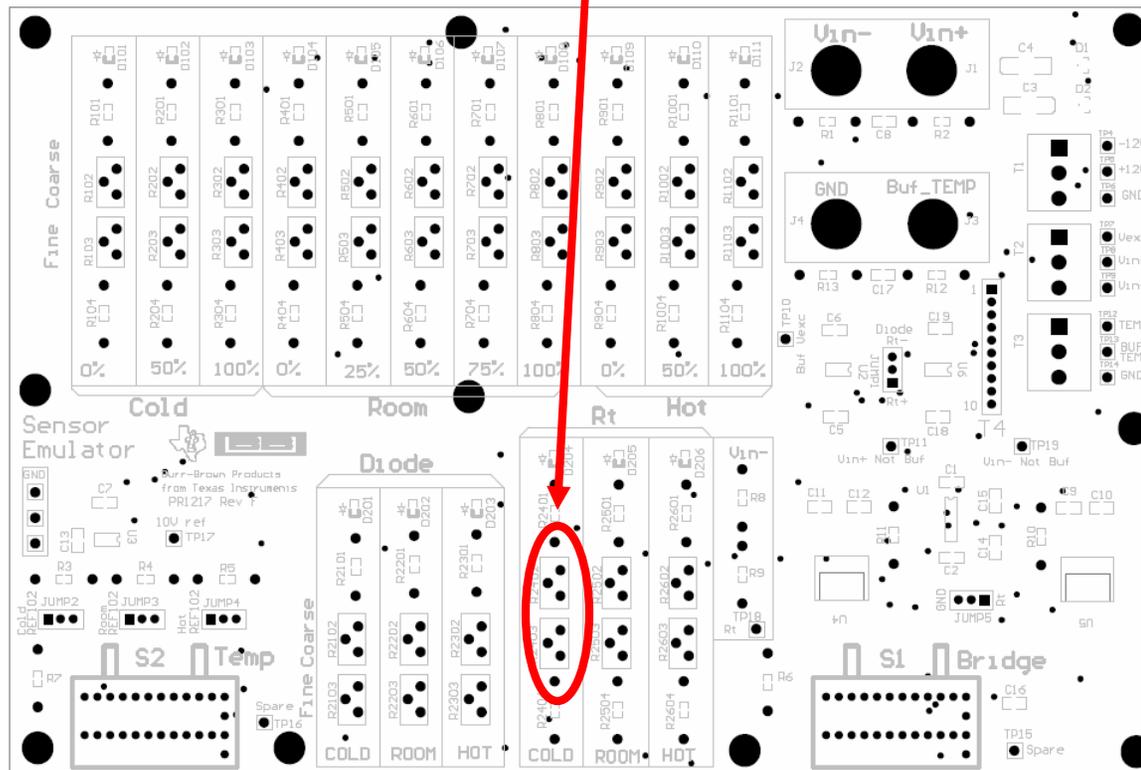| Temp(degC) | Diode Vbe (V) | Counts |
|---|---|---|
| -45.00 | 0.81 | 25920 |
| 20.00 | 0.68 | 21760 |
| 90.00 | 0.54 | 17280 |

The temperature output signal at cold temperature (-45°C) is emulated by this channel.  The rotary switch S2 is used to select this channel.  When the channel is selected, LED D201 will light to indicate that the correct channel is selected.
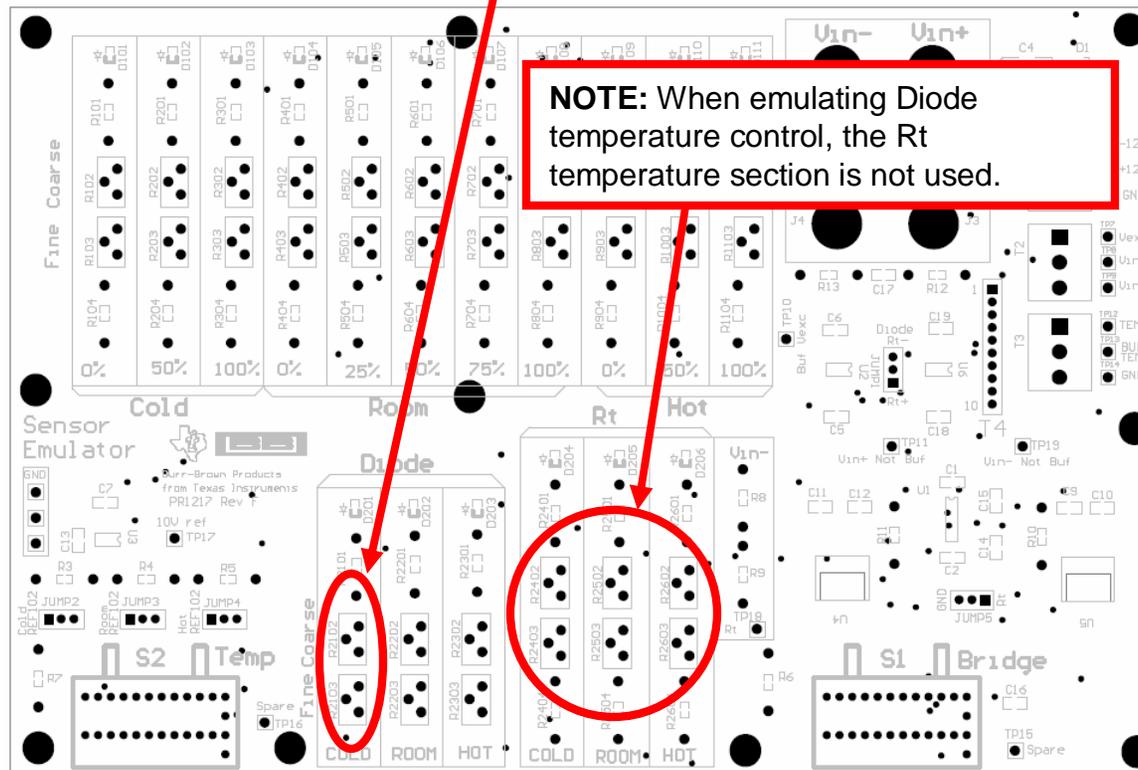
**NOTE:** When emulating Diode temperature control, the Rt temperature section is not used.

| Temp(degC) | Diode Vbe (V) | Counts |
|---|---|---|
| -45.00 | 0.81 | 25920 |
| 20.00 | 0.68 | 21760 |
| 90.00 | 0.54 | 17280 |

The temperature output signal at room temperature (25°C) is emulated by this channel. The rotary switch S2 is used to select this channel. When the channel is selected, LED D202 will light to indicate that the correct channel is selected.
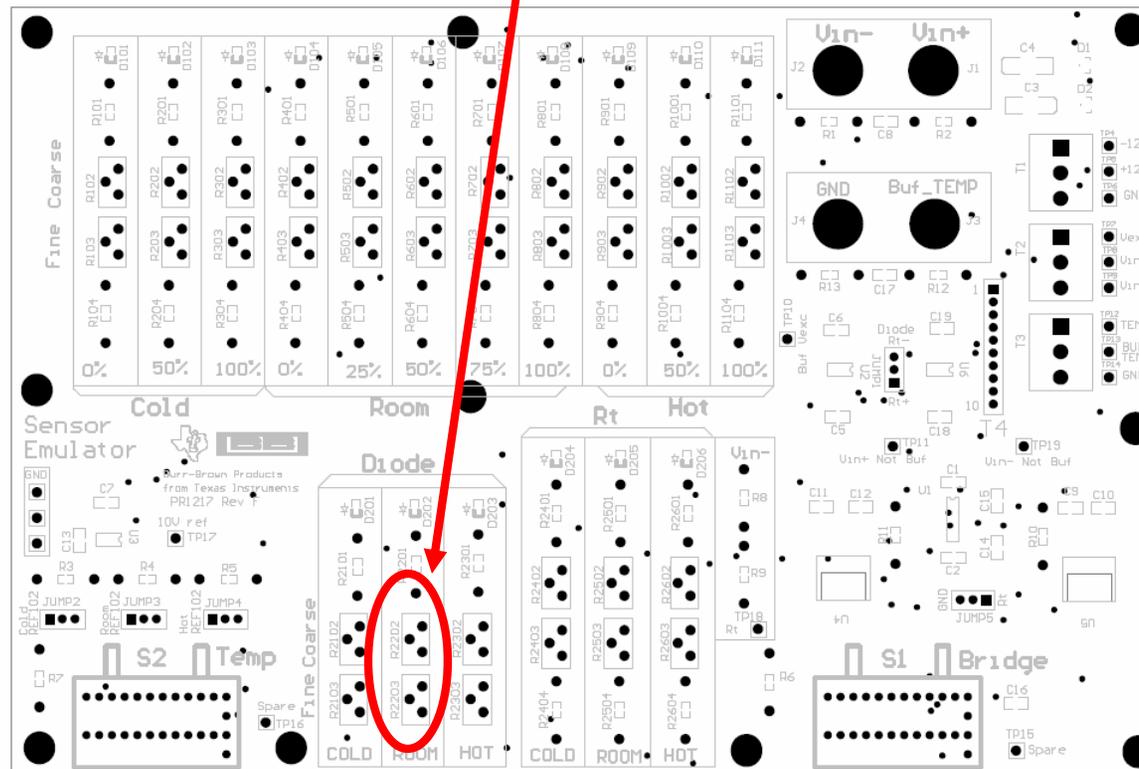
| Temp(degC) | Diode Vbe (V) | Counts |
|---|---|---|
| -45.00 | 0.81 | 25920 |
| 20.00 | 0.68 | 21760 |
| 90.00 | 0.54 | 17280 |

The temperature output signal at hot temperature (85°C) is emulated by this channel. The rotary switch S2 is used to select this channel. When the channel is selected, LED D203 will light to indicate that the correct channel is selected.
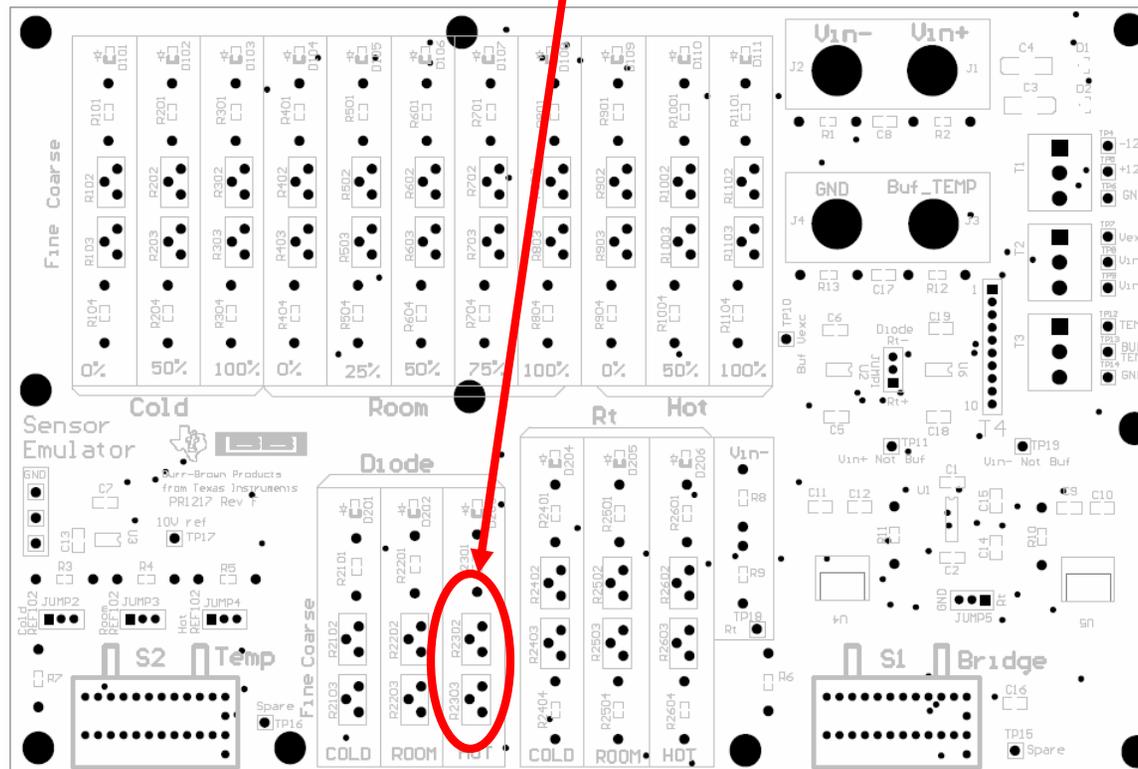
# Generate Rt Voltages based on Operating Temperature Range and System Parameters

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The third tab in the spreadsheet allows the user to enter the temperature range and other system parameters in the light blue areas. The spreadsheet calculates the voltage level of the temperature signal and displays this in the yellow areas. Note that the Temp ADC area is specific to the PGA309 sensor signal conditioning chip. The Temp ADC values will be used in the computation of the *Counts* for the Temp ADC. The next several pages will show how the Rt voltages are used to program the sensor emulator.

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Rt= | 1000 | ohm | Temp (degC) | Rbridge | Vrt | Counts | | | | |
| 2 | TC Bridge | 700 | ppm | -45.00 | 9545 | 0.322428 | 1290 | | | | |
| 3 | Rbridge | 10000 | ohm | 20.00 | 10000 | 0.309091 | 1236 | | | | |
| 4 | | | | 90.00 | 10490 | 0.295909 | 1184 | | | | |
| 5 | | | | | | | | | | | |
| 6 | Temp range: | | | | | | | | | | |
| 7 | Tmin= | -45.00 | degC | | | | | | | | |
| 8 | Troom= | 20.00 | degC | | | | | | | | |
| 9 | Tmax= | 90.00 | degC | | | | | | | | |
| 10 | | | | | | | | | | | |
| 11 | Temp ADC | | | | | | | | | | |
| 12 | Vref= | 4.096 | ohm | | | | | | | | |
| 13 | No. of Bits | 12 | bits | | | | | | | | |
| 14 | Gain= | 8 | V/V | | | | | | | | |
| 15 | | | | | | | | | | | |
| 16 | PGA Settings | | | | | | | | | | |
| 17 | Vexc= | 3.4 | V | | | | | | | | |
| 18 | | | | | | | | | | | |
| 19 | | | | | | | | | | | |
| 20 | | | | | | | | | | | |
| 21 | | | | | | | | | | | |
| 22 | | | | | | | | | | | |
| 23 | | | | | | | | | | | |
| 24 | | | | | | | | | | | |
| 25 | | | | | | | | | | | |
| 26 | | | | | | | | | | | |
| 27 | | | | | | | | | | | |
| 28 | | | | | | | | | | | |

**Voltage across Rt (Vt) vs Rbridge**

| D | E | F | G |
|---|---|---|---|
| Temp (degC) | Rbridge | Vrt | Counts |
| -45.00 | 9545 | 0.322428 | 1290 |
| 20.00 | 10000 | 0.309091 | 1236 |
| 90.00 | 10490 | 0.295909 | 1184 |

The temperature output signal at cold temperature (-45°C) is emulated by this channel. The rotary switch S2 is used to select this channel. When the channel is selected, LED D204 will light to indicate that the correct channel is selected.

| D | E | F | G |
|---|---|---|---|
| Temp (degC) | Rbridge | Vrt | Counts |
| -45.00 | 9545 | 0.322428 | 1290 |
| 20.00 | 10000 | 0.309091 | 1236 |
| 90.00 | 10490 | 0.295909 | 1184 |

The temperature output signal at room temperature (20°C) is emulated by this channel. The rotary switch S2 is used to select this channel. When the channel is selected, LED D204 will light to indicate that the correct channel is selected.
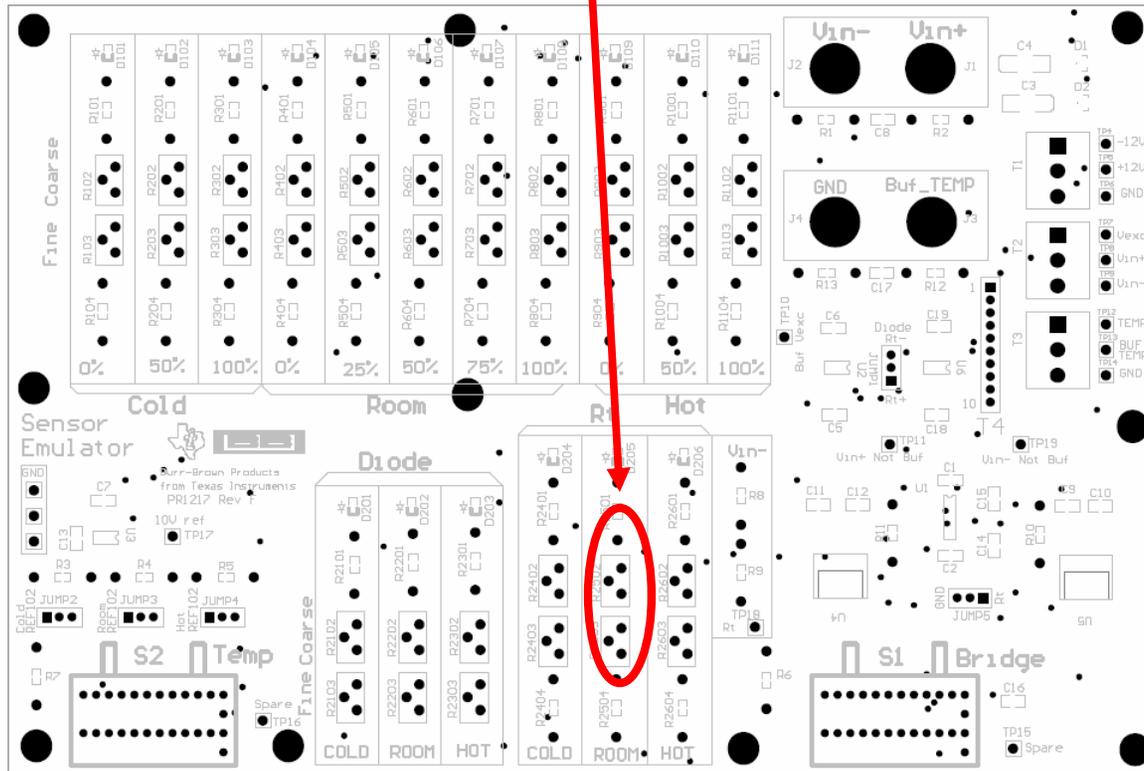
| D | E | F | G |
|---|---|---|---|
| Temp (degC) | Rbridge | Vrt | Counts |
| -45.00 | 9545 | 0.322428 | 1290 |
| 20.00 | 10000 | 0.309091 | 1236 |
| 90.00 | 10490 | 0.295909 | 1184 |

The temperature output signal at hot temperature (90°C) is emulated by this channel. The rotary switch S2 is used to select this channel. When the channel is selected, LED D204 will light to indicate that the correct channel is selected.
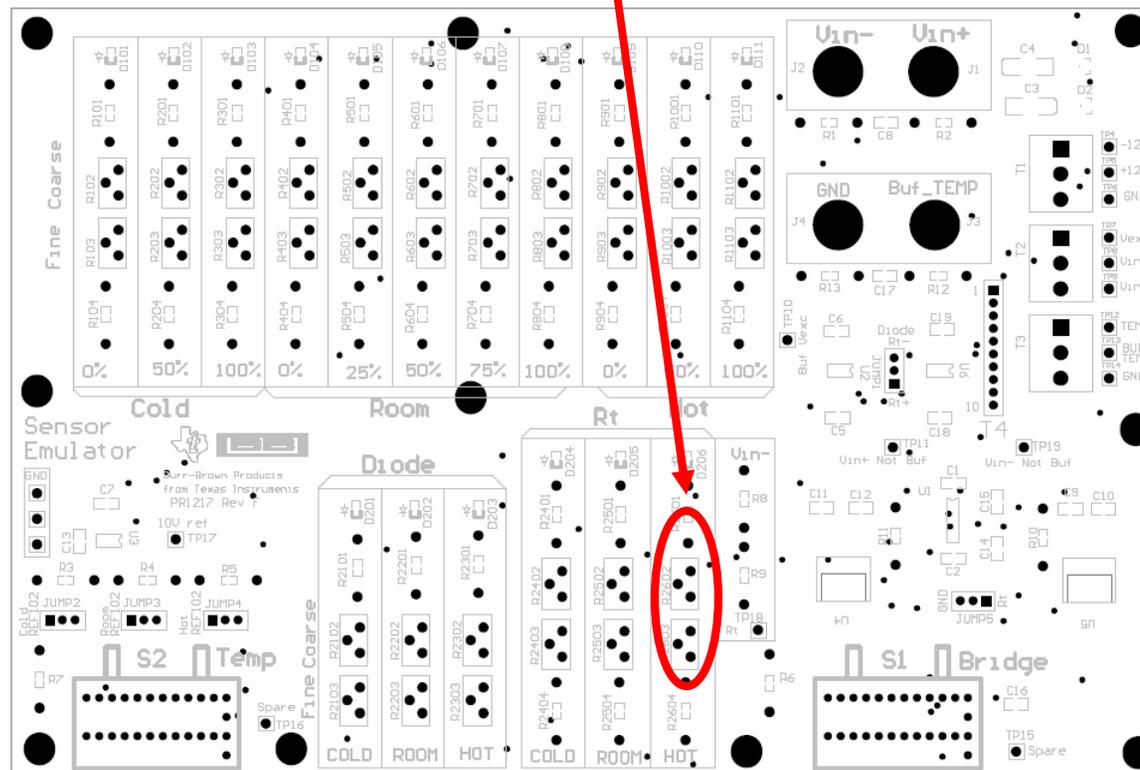
# 6.0 Schematic
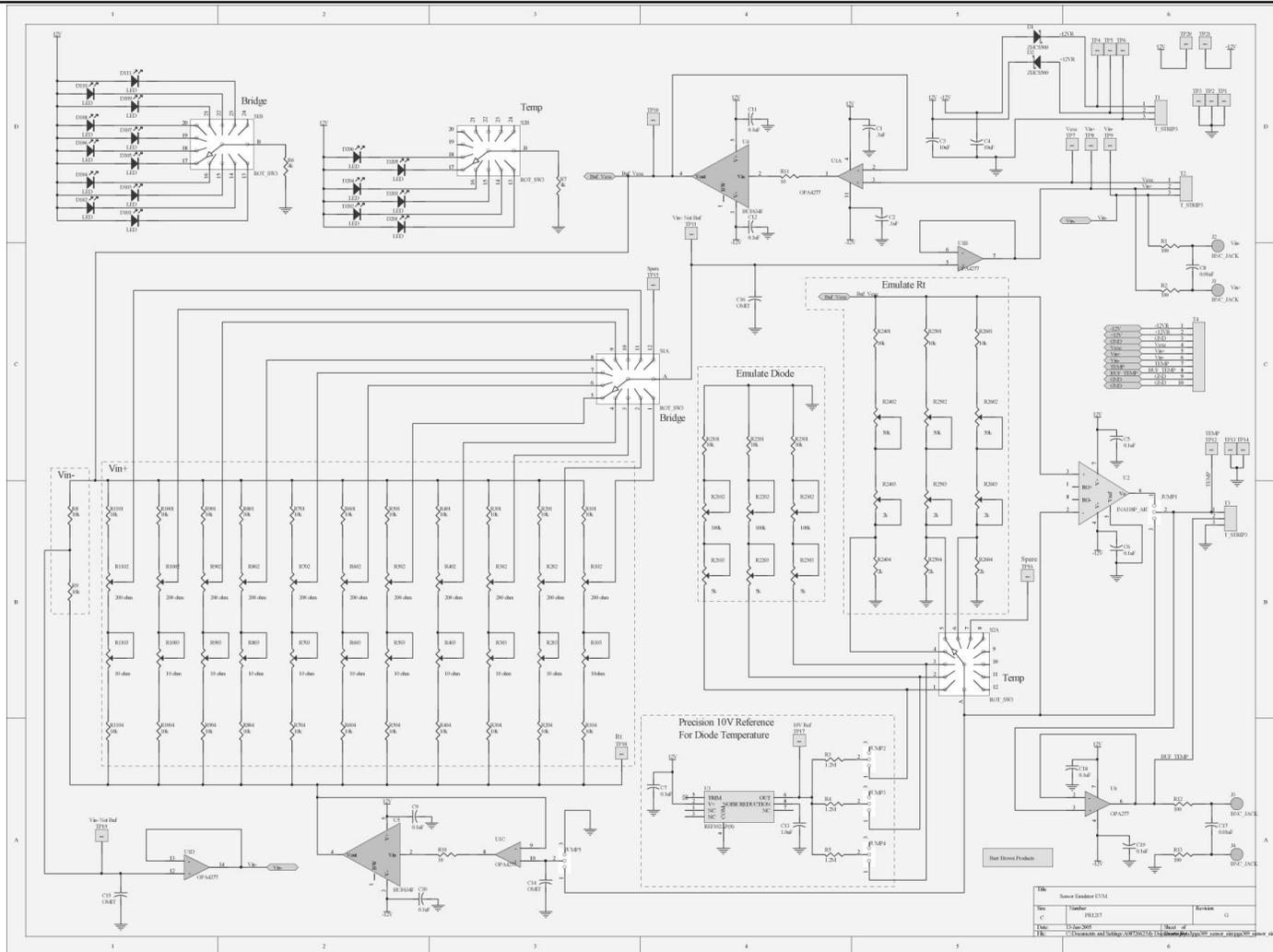
# 7.0 Parts List

**Sensor Emulator Board Parts List**                    **Matches PR1217 Rev G**

| Qty/EVM | Ref Des | Description | Part No. | Mfr. | Disti | Disti Part No. |
|---|---|---|---|---|---|---|
| 2 | J1, J3 | POST BINDING INSUL GROUNDED RED | 111-0702-001 | Johnson Components | Digikey | 111-0702-001-ND |
| 2 | J2, J4 | POST BINDING INSUL GROUNDED BLACK | 111-0703-001 | Johnson Components | Digikey | 111-0703-001-ND |
| 3 | T1-T3 | 3-Position Terminal Strip, Cage Clamp, 45º, 15A, Dove-tailed | ED300/3 | On-Shore Technology Inc | Digikey | ED1620-ND |
| 11 | C1, C2, C5, C6, C7, C9, C10, C11, C12, C18, C19 | CAP .1UF 25V CERAMIC X7R 0805 | ECJ-2VB1E104K | Yageo America | Digikey | PCC1828CT-ND |
| 2 | C8, C17 | CAP 0.01uF 50V CERAMIC X7R 0805 | C0805C103K5RACTU | Kemet | Digikey | 399-1158-1-ND |
| 1 | C13 | CAP CERAMIC 1UF 25V X5R 0805 | ECJ-2FB1E105K | Panasonic - ECG | Digikey | PCC2319CT-ND |
| 2 | C3, C4 | CAPACITOR TANT 10UF 20V 10% SMD Size C | T491C106K020AS | Kemet | Digikey | 399-1614-1-ND |
| 2 | C14, C15, C16 | **OMIT (LEAVE BLANK ON PCB)** | | | | |
| 11 | R103, R203, R303,R403, R503, R603, R703, R803, R903, R1003, R1103 | 10ohm 25turn pot | 3296Y-1-100 | Bourns Inc | Digikey | 3296Y-100-ND |
| 11 | R102, R202, R302, R402, R502, R602, R702, R802, R902, R1002, R1102 | 200ohm 25turn pot | 3296Y-1-201 | Bourns Inc | Digikey | 3296Y-201-ND |
| 3 | R2102, R2202, R2302 | 100k 25 turn pot | 3296Y-1-104 | Bourns Inc | Digikey | 3296Y-104-ND |
| 3 | R2103, R2203, R2303 | 5k 25 turn pot | 3296Y-1-502 | Bourns Inc | Digikey | 3296Y-502-ND |
| 3 | R2403, R2503, R2603 | 2k 25 turn pot | 3296Y-1-202 | Bourns Inc | Digikey | 3296Y-202-ND |
| 3 | R2402, R2502, R2602 | 50k 25 turn pot | 3296Y-1-503 | Bourns Inc | Digikey | 3296Y-503-ND |
| 30 | R101, R201, R301, R401, R501, R601, R701, R801, R901, R1001, R1101, R104, R204, R304, R404, R504, R604, R704, R804, R904, R1004, R1104, R8, R9, R2401, R2501, R2601, R2101, R2201, R2301 | RES 10K OHM 1/16W .1% 0603 SMD | ERA-3YEB103V | Panasonic - ECG | Digikey | P10KYCT-ND |
| 3 | R2404, R2504, R2604 | RES 2.0K OHM 1/16W .1% 0603 SMD | ERA-3YEB202V | Panasonic - ECG | Digikey | P2.0KYCT-ND |
| 2 | R6,R7 | 4.02k 1/16W 1% 0603 SMD | 9C06031A4021FKHFT | Yageo America | Digikey | 311-4.02KHCT-ND |
| 2 | R10, R11 | RES 10.0 OHM 1/16W .1% 0603 SMD | ERJ-3EKF10R0V | Yageo America | Digikey | P10.0HCT-ND |
| 4 | R1, R2, R12, R13 | RES 100 OHM 1/16W .1% 0603 SMD | ERA-3YEB101V | Panasonic - ECG | Digikey | P100YCT-ND |
| 3 | R3, R4, R5 | RESISTOR 1.20M OHM 1/16W 1% 0603 | ERJ-3EKF1204V | Panasonic - ECG | Digikey | P1.20MHCT-ND |
| 2 | S1-S2 | SWITCH ROTARY DP-12POS ENCLOSED | C3P0212N-A | Bourns Inc | Digikey | 451-1007-ND |
| 5 | JUMP1-JUMP5 | 3-Position Pin Strip Header | PEG03SS-GBR | Crane Connectors | Bisco Industries | |
| 5 | Jumpers for JUMP1-JUMP5 | Jumper Shorting Units | 881545-2 | Amp | Digikey | A26242-ND |
| 17 | D101, D102, D103, D104, D105, D106, D107, D108, D109, D110, D201, D202, D203, D204, D205, D206 | Ultra Bright Red Diffused LED, 0603 pkg | LNJ208R8ARA | Panasonic | Digikey | P524CT-ND |

# Parts List, *cont'd*

**Sensor Emulator Board Parts List**                                                                                    **Matches PR1217 Rev G**

| Qty/EVM | Ref Des | Description | Part No. | Mfr. | Disti | Disti Part No. |
|---|---|---|---|---|---|---|
| 2 | D1, D2 | DIODE SCHOTTKY 40V 0.5A SOT-23 | ZHCS500TA | Zetex Inc | Digikey | ZHCS500CT-ND |
| 1 | U1 | OPA4277UA | OPA4277UA | Texas Instruments | Digikey | OPA4277UA-ND |
| 1 | U2 | INA118U | INA118U | Texas Instruments | Digikey | INA118U-ND |
| 1 | U3 | REF102AU | REF102AU | Texas Instruments | Digikey | REF102AU-ND |
| 2 | U4 - U5 | BUF634F | BUF634FKTTT | Texas Instruments | Digikey | 296-15904-1-ND |
| 1 | U6 | OPA277UA -- IC PRECISION OPAMP SO-8 | OPA277UA | Texas Instruments | Digikey | OPA277UA-ND |
| 10 | | 4-40 hex standoffs,Threaded, 0.500" length, 0.250" OD, Aluminum Iridite Finish | 2203 | Keystone | Digikey | 2203K-ND |
| 10 | | 4-40x3/8" Philips PanHead Machine Screw, Steel, Zinc Plated | PMS 440 0038 PH | Building Fasteners | Digikey | H781-ND |
| 2 | | KNOB INSTRUM SGL BAR RND .5"DIA | 8567 | Keystone Electronics | Digikey | 8567K-ND |

**IMPORTANT NOTICE**