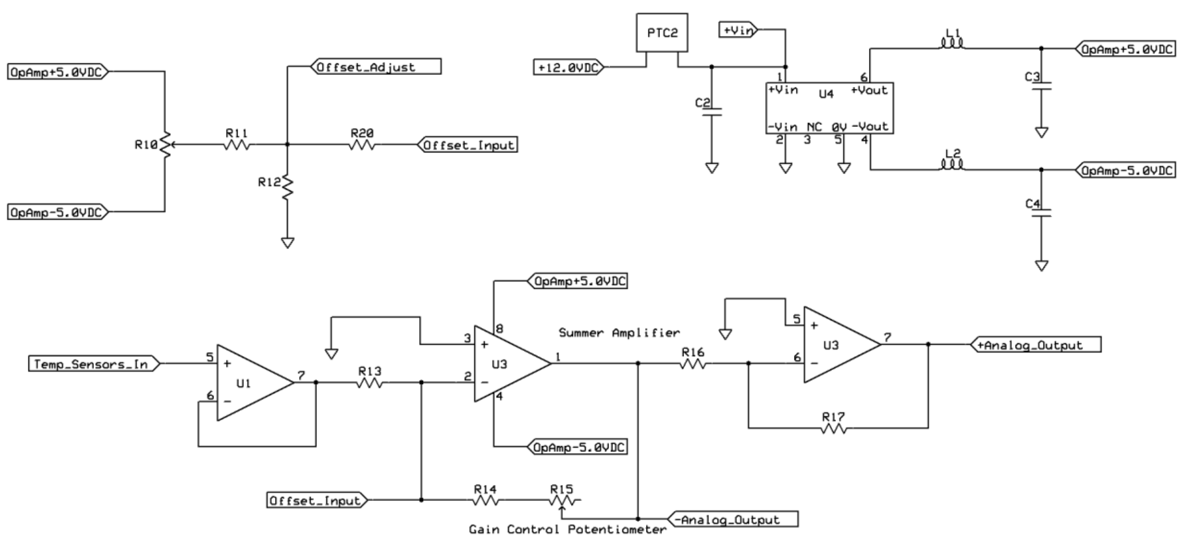
Lesson 3: Op Amp Signal Conditioning Using the LM335Z Temperature Sensor

Introduction:

The purpose of this lesson is to demonstrate the ability of the op amp inverting amplifier circuitry contained on the Temperature Sensor/Fan Controller Board to condition the signal produced by the LM335Z solid state precision temperature sensor. A schematic diagram of this op amp circuitry is shown in Figure 3-1. (Note this figure is identical to Figure 2-1 in Leeson 2 of this series.) Review the introductory section of lesson 2 as necessary to regain familiarity with the design and function of the op amp circuitry contained on the Temperature Sensor/Fan Controller Board. Also return to Mouser.com and enter the part number **LM335Z/NOPB** in the **Part # / Keyword** box to access the product detail page for the 926-LM335Z/NOPB and the LM335Z/NOPB Datasheet link. Review the datasheet as necessary to regain familiarity with this family of precision temperature sensors. As indicated in the Description on page 1 of the datasheet, the temperature sensing range for the LM335Z extends from -40°C to +100°C. A strong advantage of the LM335Z is the linear response it exhibits within this temperature range, producing a 10mV change in voltage per °C.

In this lesson, the op amp circuitry on the Temperature Sensor/Fan Controller Board will be adjusted such that a hypothetical change in temperature from 0°C to +50°C would produce a 0V to +3.0V swing at the board's +Analog_Output. This is a very wide range in temperature, equivalent to a span of nearly 32°F to 122°F. (Continue to study Equations 3-1, 3-2, and 3-3 as necessary to gain proficiency converting between degrees Kelvin and Celsius, as well as degrees Celsius and Fahrenheit.)



Op Amp Summer Amplifier Circuitry

Figure 3-1

Suggested Materials:

- Temperature Sensor/Fan Controller Board
- TSFC Ancillary Kit (for Temperature Sensor/Fan Controller Board)
- +12VDC Wall Adapter with 2.1mm/5.5mm center-positive connector (In the United States: Mouser part number 709-GST25U12-P1JW (manufactured by Mean Well). In the United Kingdom: 418-TR70MA12001E02VI (manufactured by Cincon) and compatible power cord 693-6044.0215 (manufactured by Schurter).
- Digital Multimeter (B&K 2704C or equivalent)
- Jeweler's Slotted Screwdriver (with 1.0mm or 1.2mm blade width)
- Compact Hair Dryer (CONAIR 1875 or equivalent)
- Infrared (IR) Non-contact Digital Thermometer (Etekcity Lasergrip 1080 or equivalent)
- Scientific Calculator (TI-30Xa or equivalent)

Objectives:

Upon completion of the following procedure, the student should be able to:

1) Explain how an op amp summer amplifier could serve as the signal conditioning circuitry for a precision temperature sensor.

2) Calculate and adjust the offset and gain requirements for a summer amplifier serving as the signal conditioning circuitry for a precision temperature sensor.

3) Adjust the gain and offset trimmer pots on the Temperature Sensor/Fan Controller Board as necessary to achieve the desired output span for the summer amplifier serving as the signal conditioning circuitry for a precision temperature sensor.

4) Approximate the environmental temperature being measured, given the output voltage of a summer amplifier serving as the signal conditioning circuitry for a precision temperature sensor.

5) Predict the approximate output voltage of a summer amplifier serving as the signal conditioning circuitry for a precision temperature, given an environmental temperature.

Equations:

Equation 3-1 (Converting Celsius to Kelvin):

$$°\mathbf{K} = \mathbf{273.15°} + °\mathbf{C}$$

Equation 3-2 (Converting Celsius to Fahrenheit):

$$°\mathbf{F} = (°\mathbf{C} \times \mathbf{1.8}) + \mathbf{32°}$$

Equation 3-3 (Converting Fahrenheit to Celsius):

$$°\mathbf{C} = (°\mathbf{F} - \mathbf{32°}) \times \frac{\mathbf{5}}{\mathbf{9}}$$

Procedure:

Part 1: Determining the minimum and maximum values of the Temp_Sensors_In voltage

1) Using Equation 3-1, convert the minimum temperature of the given range (0°C) to degrees Kelvin. Record its value in the space provided:

$°K_{(min)}$ = ___________________°

2) Again, using this Equation 3-1, convert the maximum temperature of the given range (+50°C) to degrees Kelvin. Record its value in the space provided:

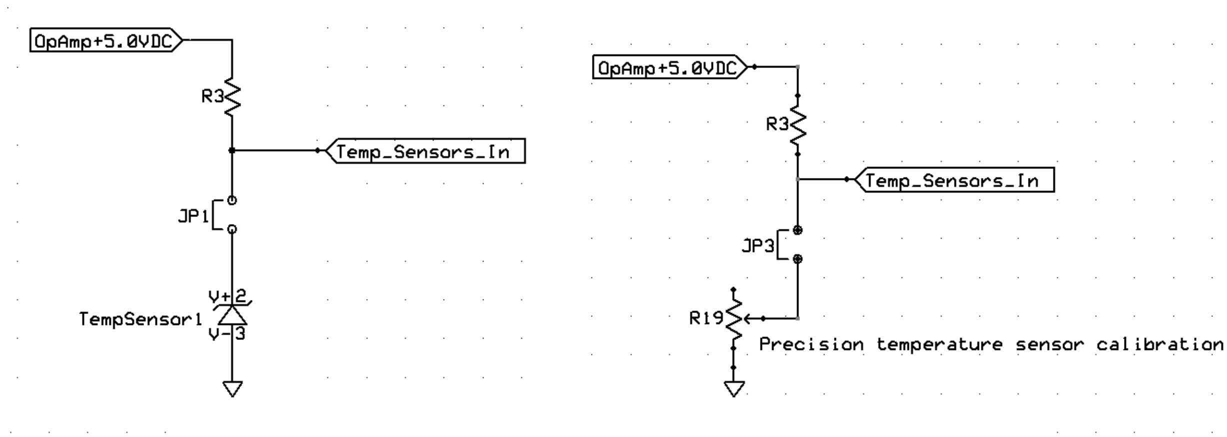
$°K_{(max)}$ = ___________________°

3) Refer back to Lesson 1 of this coursebook and review Equation 1-2 of that document. Using the value of $°K_{(min)}$ calculated in step1 of this procedure, determine the value of Vout that should be present at the Temp_Sensors point in Figure 3-2. Record its value in the space provided:

$Vout_{(min)}$ = ___________________

4) Again, applying Equation 1-2 of Lesson 1, use the value of $°K_{(max)}$ calculated in step 2 to determine the value of Vout that should be present at the Temp_Sensors point in Figure 3-2. Record its value in the space provided:

$Vout_{(max)}$ = ___________________



TempSensor1 Voltage Divider and Calibration Components

Figure 3-2

Part 2: Setting the minimum and maximum amplitudes of the ±Analog_Output signals

As in Lesson 2, we will use trimmer pot R19 and R3 to form a voltage divider, the output of which will be accessed at TP2. Again, R19 will be adjusted to represent the voltage levels developed over TempSensor1 at the minimum and maximum values of temperature being monitored.

1) Referring to Figures 3-2 and 3-4, locate and remove jumper JP2. (This action removes thermistor RT1 and resistor R6 from the circuit.) Next, ensure that jumper JP1 is also removed from the board. (This action isolates the LM335Z (TempSensor1) from the op amp circuitry during calibration.) Insert a shorting jumper into the JP3 position. (This allows trimmer potentiometer R19 and resistor R3 to form a simple voltage divider during calibration.) Referring to step 2 of Part 3 of Lesson 1 and Figure 1-7, ensure that a 1/4W 2KΩ resistor (red, black, red, and gold bands) is present in the R3 position.

NOTE: Before proceeding to the test procedure, please review the illustration below, which shows the recommended method for connecting test equipment to test points on a circuit module. Using the jumper leads as shown here avoids "wear and tear" on the test point header pins. (A set of jumper leads is provided with the TSFC Ancillary Kit.)

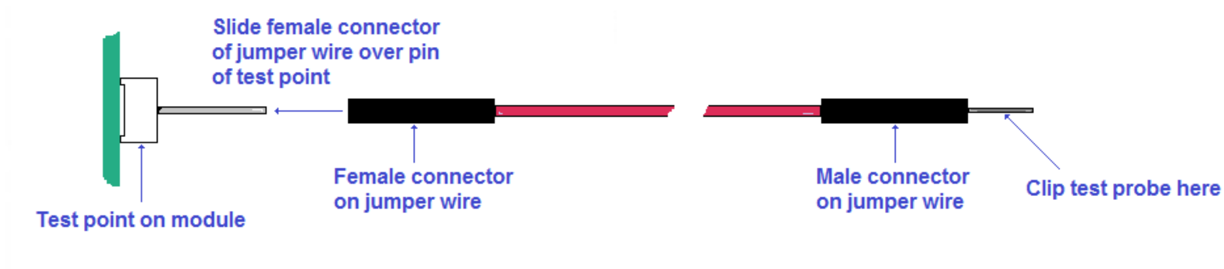
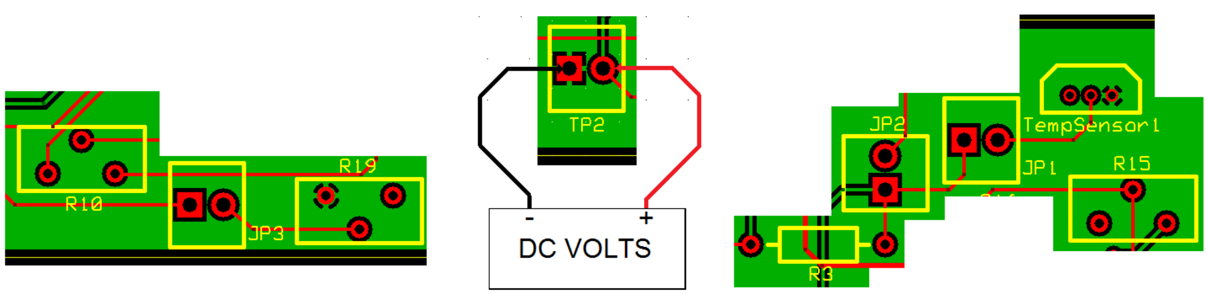


Figure 3-3

2) Adjust the multimeter to measure DC voltage and connect it to TP2 as shown in Figure 3-4.

3) If using the +12VDC Wall Adapter, connect it to DC power jack J2 on the Temperature Sensor/Fan Controller Board. Then plug the wall adapter into a de-energized power strip. If using a benchtop power supply, proceed to step 5.



Location of Trimmer Potentiometer R10, JP3 and Trimmer Potentiometer R19

Measuring Calibration Voltage Divider Output

Locations of Temperature Sensor LM335Z, JP1, JP2, R3, and Gain Control Trimmer R15

Figure 3-4

4) Energize the power strip and verify that +12VDC indicator LED2 illuminates. If LED2 turns on, and LED1 is off then begin reading the Op Amp Summing Amplifier Theory of Operation prior to performing step 7. If both LED1 and LED2 turn on when the board is energized, begin reading the rotate the wiper of potentiometer R2 counterclockwise until LED1 turns off. Then proceed to step 7.

5) If using a benchtop power supply rather than a wall adapter, adjust its output to +12VDC prior to connecting it to the circuit board. Next, switch off the power supply and connect two short pieces of hookup wire (red and black) to Euro block connector J5 as represented in Figure 3-5. Secure the wire pieces to the connector by tightening the two jack screws.

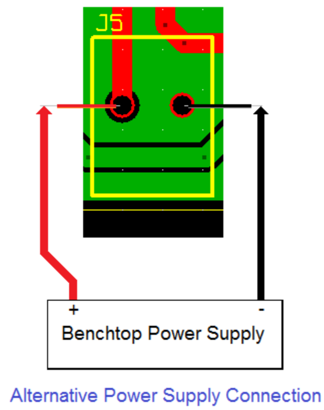


Figure 3-5

CAUTION: Reversing the polarity of the power supply voltage could damage or destroy the circuit board.

6) After ensuring the polarity of the benchtop power leads is correct (as shown if Figure3- 5) apply power to the circuit board and verify that +12VDC indicator LED2 illuminates. If LED2 turns on, and LED1 is off then begin reading the Op Amp Summing Amplifier Theory of Operation prior to performing step 7. proceed to step 7. If both LED1 and LED2 turn on when the board is energized, rotate the wiper of potentiometer R2 counterclockwise until LED1 turns off, then begin reading the following theory of operation.

Op Amp Summing Amplifier Theory of Operation:

The purpose of the remaining steps of this lesson is to gain further experience working with op amp signal conditioning circuitry. Our objective is to allow the +Analog_Output signal to swing between 0.0VDC and +3.0VDC as temperature fluctuates between 0°C and 50°C. In step 2 of the first part of this lesson we determined the Temp_Sensors_In signal should equal nearly +2. 732VDC at 0°C. As represented graphically in Figure 3-6, the +Analog_Output signal should equal 0.0VDC with this input condition. We also determined Temp_Sensors_In signal should equal nearly +3.232VDC at 50°C. As represented graphically in Figure 3-6, the +Analog_Output signal should equal +3.0VDC with this input condition. The input voltage swing (that of Temp_Sensors_In) is shown in gray, while the output voltage swing (that of +Analog_Output) is shown in blue.

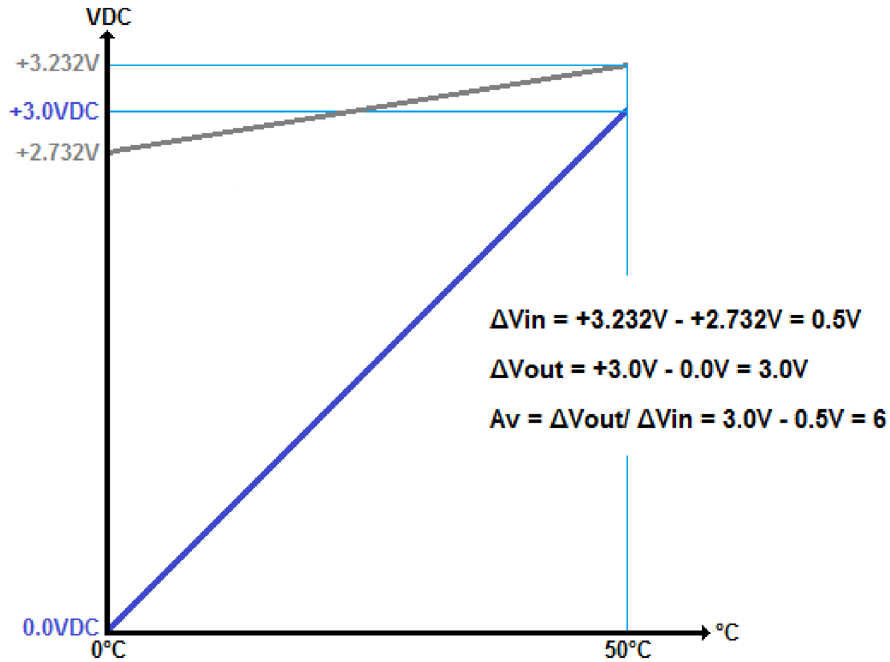


Figure 3-6

7) Referring to Figure 3-4, reduce the voltage gain of the first inverting amplifier stage to its minimum level by rotating the wiper of gain control pot R15 fully clockwise.

8) Again, referring to Figure 3-4, use the alignment tool to rotate the wiper of R19 while observing the multimeter. Adjust R19 as necessary to bring the Temp_Sensors_In voltage level to the value calculated in step 3 of Part 1 of this procedure.

9) Using Figure 3-7 as a guide, locate test point TP3 on the right-hand side of the circuit board. Remove the multimeter from the TP2 position and connect the positive (red) lead to pin 2 of TP3, as represented by the solid red positive test lead. (The black lead can remain connected to pin 1 of TP2 or connect to pin 4 of TP3.)

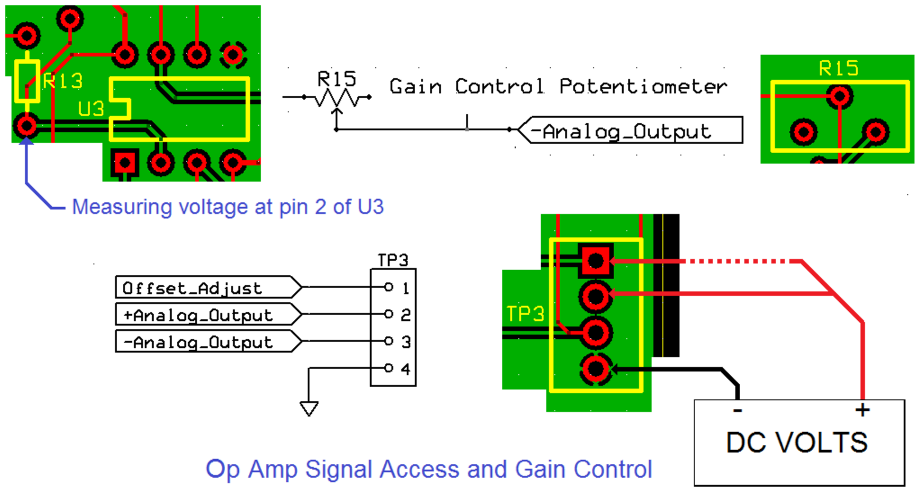


Figure 3-7

10) Refer back to Figure 3-4 to locate level shifting trim pot R10. Using the alignment tool, rotate the wiper of R10 while observing the multimeter. Adjust R10 as necessary to bring the +Analog_Output signal as close as possible to 0VDC.

NOTE: The purpose of steps 7 through 10 is to simulate a condition where the LM335Z temperature approaches 0°C and the +Analog_Output signal level approaches 0VDC. With this condition, the Offset_Input voltage should nearly equal the negative equivalent of the Temp_Sensors_In voltage. Thus, during step 10, we should have set the Offset_Adjust input to nearly -2. 732VDC.

11) Connect the positive lead of the multimeter to the Offset_Adjust test point (pin 1 of TP3), as represented by the broken red line in Figure 3-7. Record the measured voltage in the space provided**:**

Offset_Adjust at 0°C = ___________________ VDC

Is the measured Offset_Adjust voltage nearly equal and opposite to the Temp_Sensors_In voltage?

(Yes/No)

12) Remove the multimeter from TP3 and reconnect it to TP2 as shown in Figure 3-4.

13) Using the alignment tool, rotate the wiper of R19 while observing the multimeter. Adjust R19 as necessary to bring the Temp_Sensors_In voltage to its maximum level of 3.232VDC.

14) Again, remove the multimeter from TP2 and connect it to pin 2 of TP3, as indicated by the solid red test lead in Figure 3-7. (The black lead can remain connected to pin 1 of TP2 or connect to pin 4 of TP3.)

15) Refer again to Figure 3-4 to locate gain control trim pot R15. Using the alignment tool, rotate the wiper of R15 while observing the multimeter. Adjust the wiper of R15 as necessary to bring the +Analog_Output signal as close as possible to +3.0VDC.

16) Referring to Figure 3-7, move the positive lead of the multimeter to pin 3 of TP3 and measure the voltage present at the -Analog_Output. Record its value in the space provided:

-Analog_Output = __________________VDC

Is the -Analog_Output voltage equal and opposite to the adjusted level of the +Analog_Output signal?

(Yes/No)

NOTE: We have just increased the ohmic value of Gain Control Potentiometer R15 as necessary to bring the +Analog_Output level to +3.0VDC when the LM335Z temperature attains 50°C. We will now perform a second adjustment of the Offset_Input, as necessary, to minimize any residual offset error in the Op Amp circuitry.

17) Again, adjust the multimeter to measure DC voltage and connect it to TP2 as shown in Figure 3-4.

18) As in step 8, use the alignment tool to rotate the wiper of R19 while observing the multimeter. Adjust R19 as necessary to again bring the Temp_Sensors_In voltage to the minimum input level of +2.732VDC.

19) Using Figure 3-7 as a guide, locate test point TP3 on the right-hand side of the circuit board. Remove the multimeter from the TP2 position and connect the positive (red) lead to pin 2 of TP3, as represented by the solid red positive test lead in Figure 2-7. (The black lead can remain connected to pin 1 of TP2 or connect to pin 4 of TP3.)

NOTE: Ideally, the +Analog_Output output signal should still equal 0.0VDC. However, by adjusting R15 to achieve the desired gain, we could have introduced a slight offset error. Performance of the following step should minimize this error.

20) As in step 10, refer to Figure 3-4 to locate Offset_Adjust trim pot R10. Using the alignment tool, rotate the wiper of R10 as necessary to bring the +Analog_Output signal as close as possible to 0VDC.

21) Connect the positive lead of the multimeter to the Offset_Adjust test point (pin 1 of TP3), as represented by the broken red line in Figure 3-7. Record the measured voltage in the space provided**:**

Offset_Adjust at 0°C = ___________________ VDC

Is the measured Offset_Adjust voltage nearly equal to that measured in step 11?

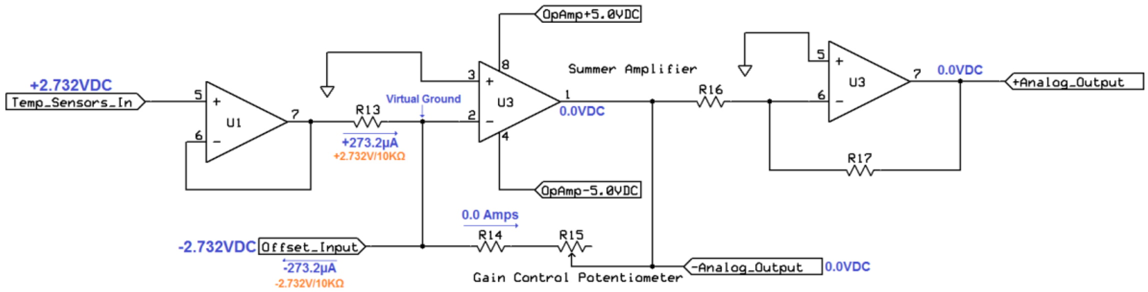
(Yes/No)

NOTE: It might have been necessary to either increase or decrease the value of R10 slightly to align the span of the op amp summer amplifier from 0.0V to +3.0V. Performing this adjustment will have minimized offset error and thus increased system accuracy.

Op Amp Summer Amplifier Operation at Minimum and Maximum Voltage Input Conditions:

Recall the purpose of steps 7 through 10 was to simulate a condition where the +Analog_Output would approach 0V as the temperature approached 0°C. During steps 13 through 15, we adjusted the R15 such that an increase of temperature to 50°C would cause the +Analog_Output level to approach +3.0VDC. Note that, with the +Analog_Output level approaching +3.0VDC, the -Analog_Output equaled nearly -3.0VDC, verifying the inverting action of the first amplifier stage. Thus, we have produced an amplifier condition where an input voltage swing of 0.5V (from +2.732 to +3.232VDC) would produce an output voltage swing of 0 to +3.0VDC at the +Analog_Output and a symmetrical 0 to -3.0VDC swing at the -Analog_Output. We will now perform an in-depth analysis of the op amp circuitry, referring to Figures 3-8 and 3-9 for clarification. For the sake of simplicity, the following circuit analysis is based on the concept of the ideal op amp.

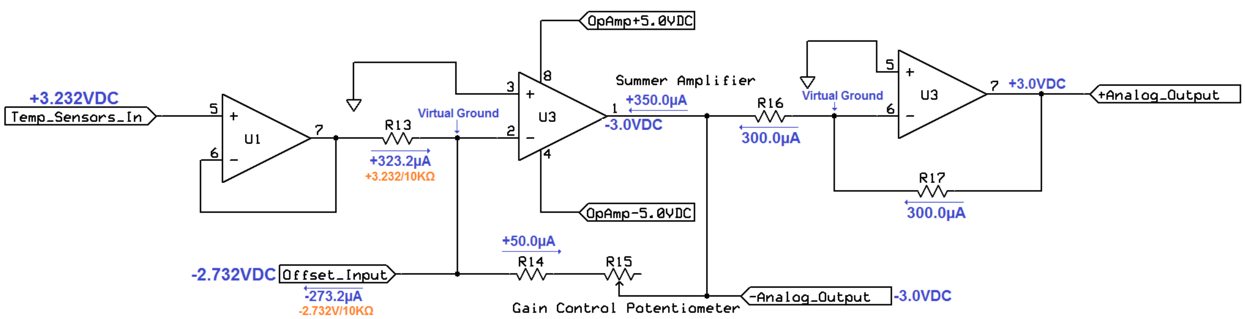
Figure 3-8 represents the circuit condition when the LM335Z temperature equals 0°C. Assuming ideal operation for the voltage follower stage, pin 7 of U1 equals exactly +2.732VDC. Assuming ideal operation of the op amp inverting amplifier stage, the virtual ground point (pin 2 of U3) equals exactly 0.0VDC and the op amp input impedance is infinite. Thus, with the Offset_Input at -2.732VDC the current flowing away from the virtual ground node is equal and opposite that flowing through R13. With this condition, there is no current flow through resistors R14, R15, R16, and R17 and the +Analog_Output voltage is 0.0VDC. (Note the arrows in Figures 3-8 and 3-9 represent conventional current flow, from positive to negative.)



Summer Amplifier Voltage and Current Conditions at 0°C

Figure 3-8

Figure 3-9 represents the ideal circuit condition when LM335Z temperature equals 50°C. Assuming pin 7 of U1 to equal exactly +3.232VDC, current flow from the voltage follower to the virtual ground equals 323.2µA, while the Offset_Input current remains at 273.2µA. The algebraic sum of these two currents now becomes the feedback current for the first stage of the summer amplifier. We previously adjusted R15 to allow this feedback current (now at 50µA) to bring the -Analog_Output voltage to -3.0VDC. With R16 and R17 both equaling 10KΩ, the gain for the second inverting amplifier stage becomes -1, causing the +Analog_Output to equal +3.0VDC.



Summer Amplifier Voltage and Current Conditions at 50°C

Figure 3-9