

Assignment 1

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Assignment 1 ACDA5006
Signal Conditioning
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1.0 Abstract

A temperature sensor with an output sensitivity of $68\mu\text{V}/^\circ\text{C}$ and a range of -50°C to 100°C , contaminated with 120mv Pk-Pk 50Hz AC noise, requires a signal conditioning circuit to give a 0-5V output with $-50^\circ\text{C} = 0\text{V}$. The circuit designed will utilise an active, multipole, multi order low pass filter. The signal will be amplified using a non-inverting op-amp circuit and level shifted to provide the output signal with a differential mode. A step input is fed to the circuit, from this, the response time of the system can be analysed. The frequency response can be generated to confirm the correct noise attenuation and gain of the circuit.

2.0 Introduction

Temperature measurement is one of the most important and commonly measured parameters within industrial process'. There are many methods to measure temperature based on the physical properties that it can change. Various types of active and passive instruments can be used to measure temperature, some examples of these include [1],

- Thermoelectric sensors (Thermocouples)
- Resistive temperature devices (RTD'S), where a change in resistance indicates a change in temperature
- Semiconductor devices
- Thermistors

Thermocouples make up a majority of temperature measuring devices within industrial processes, where the change in temperature is directly converted to an emf. Thermocouples produce this emf via the Seebeck effect, when two different metals are connected together at a hot and cold(reference) junction a current will flow [2].

From the specifications given, a device that generates a $68\mu\text{V}/^\circ\text{C}$ EMF is a Chromel-constantan thermocouple (Type E). This is a very high sensitivity device with good linearity, a total inaccuracy of $\pm 0.5^\circ\text{C}$ and a measuring range of -200°C to 900°C as stated in *Measurement and Instrumentation* [1]. This sensitivity can also be obtained through standard thermocouple charts [3] as follows,

Type E @ $-270^\circ\text{C} = -9.385\text{mV}$

Type E @ $1000^\circ\text{C} = 76.373\text{mV}$

$$\frac{V}{^\circ\text{C}} = \frac{76.373 \times 10^{-3} - (-9.385 \times 10^{-3})}{1000 - (-270)}$$

$\frac{V}{^\circ\text{C}} = 67.88 \frac{\mu\text{V}}{^\circ\text{C}}$

Caption required

As the output voltage is extremely small, noise can have a large effect on the transducer output signal. The sensor signal is contaminated with a 50Hz, 60mV Pk signal. Common sources of mains frequency interference occur due to inductive coupling from power cables near the signal carrying conductors. Through mutual inductance, significant noise voltage levels can become present on a desired signal [4].

Signal conditioning operations modify the transducer signal to represent it in such a way that it can be used for other processes. These include, filtering, amplification, level shifting or sensitivity adjustments [5]. In this report, the transducer signal has been filtered, using multiple order active filters, amplified and level shifted to give a linear, 0-5V signal proportional to the temperature range. A higher voltage output now allows the signal to be post processed by an analogue to digital converter, PLC input or process controller.  4

3.0 Circuit Design

3.1 Design Criteria

In this section, the design choices made to successfully condition the signal from the sensor are discussed. The elements required to achieve a clean proportional output of 0 – 5V for transmission include:

- Overvoltage protection
- Noise filtering
- Amplification
- Level shifting

3.1.1 Sensor Signal Characteristics

From the specification of the signal to be conditioned, the sensitivity of the temperature sensor is defined as $68\mu V/^{\circ}C$, and is required to measure between $-50^{\circ}C$ and $100^{\circ}C$, with $0V = 0^{\circ}C$. From this information, the output voltage range of the sensor can be calculated as follows:

- *Sensor output at $-50^{\circ}C$:*

$$V_{out} = -50^{\circ}C \times 68 \times 10^{-6}V$$

$$V_{out} = -3.4 \times 10^{-3}V$$

$$V_{out} = -3.4mV$$

Equation 5

- *Sensor output at $100^{\circ}C$:*

$$V_{out} = 100^{\circ}C \times 68 \times 10^{-6}V$$

$$V_{out} = 6.8 \times 10^{-3}V$$

$$V_{out} = 6.8mV$$

Equation 6

Therefore, the sensor output voltage range is.

- *Sensor Output voltage range:*

$$V_{sens} = |V_{out@-50^{\circ}C}| + |V_{out@100^{\circ}C}|$$

$$V_{sens} = |3.4| + |6.8|$$

$$V_{sens} = 10.2mV$$

Equation 7

3.1.2 Noise Implications

In order to avoid large temperature output reading swings due to the high signal to noise ratio, the 50Hz noise will need to be attenuated using a low pass filter. As the signal from the sensor contains no other AC components, as well as being a slow changing temperature signal, the cut-off frequency of the filter can be set well below 50Hz in order to attenuate most of the noise.

The attenuation required from this filter can be determined from the acceptable error in the output signal. For this design, a minimum inaccuracy of $\pm 0.5^\circ\text{C}$ has been chosen. This is the typical accuracy of a standard Type-E thermocouple [3]. Therefore, the acceptable noise voltage is:

$$\text{Noise Error} = 0.5^\circ\text{C} \cdot 68 \times 10^{-6}\text{V}$$

$$\text{Noise Error} = 34 \times 10^{-6}\text{V}$$

Equation 3

The total attenuation of the noise signal by the filter can now be calculated from this error voltage and the total noise voltage, expressed in dB:

$$\text{Noise Attenuation(dB)} = 20 \log_{10} \left(\frac{\text{Error Tolerance(V)}}{\text{Signal Noise(V)}} \right)$$

$$\text{Noise Attenuation(dB)} = 20 \log_{10} \left(\frac{34 \times 10^{-6}}{120 \times 10^{-3}} \right)$$

$$\text{Noise Attenuation(dB)} = -70.95 \text{ dB}$$

Equation 4

3.1.3 Amplification Requirements

To produce a 0 – 5V signal proportional to temperature, an amount of gain must be present in the system to amplify the sensor signal to the required level. The total system gain is the ratio of output voltage range to input voltage range as follows:

$$A_v = \frac{V_{out}}{V_{in}}$$

$$A_v = \frac{5}{10.2 \times 10^{-3}}$$

$$A_v = 490.196$$

Equation 5

This can be expressed in dB for analysis on a bode plot:

$$\text{Gain}(dB) = 20 \log_{10}(A_V)$$

$$\text{Gain}(dB) = 20 \log_{10}(490.196)$$

$$\text{Gain}(dB) = 53.807dB$$

Equation 6

From Equations 6 and 7 the amplification stage of the circuit requires a voltage gain of 490.196 or 53.807dB, to provide a maximum 5V signal from the system.

3.2 Circuit Design Elements

3.2.1 Over Voltage Protection

In order to protect the sensitive components, overvoltage protection needs to be applied to the input stage of the signal conditioning circuit. For this, a pair of 1N4733A, 5.1V Zener diodes have been chosen. Zener diodes are classified with respect to their reverse breakdown voltage, or 'Zener voltage' [6]. This is exhibited as a sharp reverse breakdown characteristic at relatively low voltages. This makes them suitable as voltage regulators or reference voltage devices. Provided the device is operating within its limits, a fixed output voltage will appear across it [7]. This characteristic allows them to be used in overvoltage protection circuits. If the voltage at the input of the circuit rises above the reverse breakdown voltage of the Zener diode, it conducts to ground, clamping its output voltage. By placing two opposing Zener diodes, overvoltage protection has been provided for positive and negative voltage transients. The 100Ω resistor serves to limit the current flowing through the diodes. Figure 1 displays the overvoltage protection stage of the circuit.

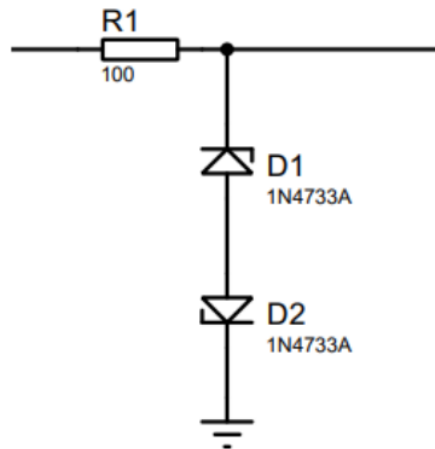


Figure 1 – Opposing Zener diodes forming an overvoltage clamp

3.2.2 Filter Design

From equation 5, the total stop band attenuation required is -70.95dB. As the sensor outputs a DC voltage, there are no other harmonics present to filter out in the passband, this allows the cut off frequency of the filter to be set well below the noise frequency for maximum attenuation. A cut off frequency, or -3dB point of 5Hz has been chosen to allow for any rapid changes in temperature seen by the sensor.

For this application cascaded 2 pole active filters have been used in a Sallen-and-Key topology, utilising an LM741 op-amp. Here, the cut-off frequency of the filter is determined by the passive R and C filter components at the input to an amplifier [8]. The ratio of the remaining resistors at the non-inverting amplifier output provides some voltage gain for the filter [9]. By cascading multiple filter stages, the attenuation in the stop band can be increased due to a higher roll off rate after the cut-off frequency.

3.2.3 Filter Response Characteristics

For this design, a Bessel filter response was chosen. The Bessel filter exhibits the following desirable features:

- Relatively flat passband
- Good rise time
- Constant group delay

This provides a linear phase response, translating to minimum distortion to the output waveform. The filter exhibits low overshoot and ringing artefacts [10] [11]. Low distortion of the signal makes amplification and level shifting to achieve an accurate 0-5V output far simpler as oscillations will translate into temperature swings at the output of the signal conditioner.

The compromise for using a Bessel filter is the slow rate of attenuation after the cut-off frequency, adding more stages does not significantly improve this [9]. From table 6.1 in The Art of Electronics, to achieve minimum amount of overshoot, good rise time and the correct amount of attenuation an 8 pole Bessel filter is required. A 6 pole could have been used; however, this has a larger amount of overshoot, therefore distortion of the signal. Table 1 displays the time domain performance for a Bessel filter.

Type	f_{3dB} (Hz)	Poles	Step risetime (0 – 90%) (s)	Over- shoot (%)	Settling time		Stopband attenuation	
					to 1% (s)	to 0.1% (s)	$f=2f_c$ (dB)	$f=10f_c$ (dB)
Bessel	1.0	2	0.4	0.4	0.6	1.1	10	36
(-3dB at $f_c = 1\text{Hz}$)	1.0	4	0.5	0.8	0.7	1.2	13	66
	1.0	6	0.6	0.6	0.7	1.2	14	92
	1.0	8	0.7	0.3	0.8	1.2	14	114

Table 1 – Table 6.1 taken from Art of Electronics displaying time domain performance of Bessel Low Pass Filters [9]

3.2.4 Filter Component Calculations

Standard components used in filter applications should be of a high tolerance, 1% (E96 series) for resistors, and minimum 5% E12 series capacitors [12]. Resistances should be in the range of thousands of Ohms [9].

The cut off frequency or -3dB point of the filter is set to 5Hz.

$$f_c = \frac{1}{2\pi RC}$$

Equation 7 – Cut off frequency

The product of R and C determines this frequency. To determine the value of C, capacitive reactance is set at $X_C = 20\text{k}\Omega$.

$$X_C = \frac{1}{2\pi f_c C}$$

$$C = \frac{1}{2\pi f_c X_C}$$

$$C = \frac{1}{2\pi(5)(20 \times 10^3)}$$

$$C = 1.59\mu\text{F}$$

$$C = 1.5\mu\text{F (E12 Standard)}$$

Equation 8

To calculate the value of the resistors for the passive filter elements of each active stage for a Bessel filter, a table of values is used that contains a normalising factor, K , This shown in equation 10.

$$RC = \frac{1}{2\pi c_n f_c}$$

Equation 9

Table 6.2 from Horowitz and Hill 'The Art of Electronics' these normalising factors, along with the gain factors for each stage are given. Table 2 displays these values.

8 Pole Bessel	
Cn	Av
1.781	1.204
1.835	1.213
1.956	1.593
2.192	2.184

Table 2 - Values of Cn and K taken from table 6.2 The Art of Electronics to create a Bessel filter response [9]

From the values in table 2, and equation 10, resistor values for each filter stage can be calculated.

1st stage active filter resistor values

$$f_c = \frac{1}{2\pi c_n RC}$$

Were, $c_n = 1.781$

$$R = \frac{1}{2\pi c_n f_c C}$$

$$R = \frac{1}{2\pi(1.781)(5)(1.5 \times 10^{-6})}$$

$$R = 11915.02\Omega$$

$$R = 11.8K\Omega \text{ (E96 1\%)}$$

2nd stage active filter resistor values

$$f_c = \frac{1}{2\pi c_n RC}$$

Were, $c_n = 1.835$

$$R = \frac{1}{2\pi c_n f_c C}$$

$$R = \frac{1}{2\pi(1.835)(5)(1.5 \times 10^{-6})}$$

$$R = 11564.39\Omega$$

$$R = 11.5K\Omega \text{ (E96 1\%)}$$

3rd stage active filter resistor values

$$f_c = \frac{1}{2\pi c_n RC}$$

Were, $c_n = 1.956$

$$R = \frac{1}{2\pi c_n f_c C}$$

$$R = \frac{1}{2\pi(1.956)(5)(1.5 \times 10^{-6})}$$

$$R = 10849 \Omega$$

$$R = 10.7K\Omega \text{ (E96 1\%)}$$

4th stage active filter resistor values

$$f_c = \frac{1}{2\pi c_n RC}$$

Were, $c_n = 2.192$

$$R = \frac{1}{2\pi c_n f_c C}$$

$$R = \frac{1}{2\pi(2.192)(5)(1.5 \times 10^{-6})}$$

$$R = 9680.95 \Omega$$

$$R = 9.76K\Omega \text{ (E96 1\%)}$$

The Sallen-Key active filter gain is set by the ratio of the resistors feeding back from the output to the non-inverting input. The gain factor for each stage is shown in table 2. The non-inverting amplifier gain equation can be used to find the resistor values for each stage. Equation 11 shows non-inverting amplifier gain. For simplicity and to minimise the variety of components, in each stage, $R1=20K\Omega$.

$$A_V = 1 + \frac{R2}{R1}$$

Equation 10 – Non-Inverting Amplifier Gain [13]

1st stage gain resistor values

Allow $R1 = 20k\Omega$ and from Table 2, where $A_V = 1.024$,

$$A_V = 1 + \frac{R2}{R1}$$

$$\therefore R2 = R1(A_V - 1)$$

$$R2 = 20 \times 10^3(1.024 - 1)$$

$$R2 = 480\Omega$$

$$R2 = 475\Omega \text{ (E96 1\%)}$$

2nd stage gain resistor values

Allow $R_1 = 20\text{k}\Omega$ and from Table 2, where $A_V = 1.213$

$$A_V = 1 + \frac{R_2}{R_1}$$

$$\therefore R_2 = R_1(A_V - 1)$$

$$R_2 = 20 \times 10^3(1.213 - 1)$$

$$R_2 = 4260\Omega$$

$$\mathbf{R_2 = 4.22K\Omega (E96 1\%)}$$

3rd stage gain resistor values

Allow $R_1 = 20\text{k}\Omega$ and from Table 2, where $A_V = 1.593$

$$A_V = 1 + \frac{R_2}{R_1}$$

$$\therefore R_2 = R_1(A_V - 1)$$

$$R_2 = 20 \times 10^3(1.593 - 1)$$

$$R_2 = 11860\Omega$$

$$\mathbf{R_2 = 11.8K\Omega (E96 1\%)}$$

4th stage gain resistor values

Allow $R_1 = 20\text{k}\Omega$ and from Table 2, where $A_V = 2.184$

$$A_V = 1 + \frac{R_2}{R_1}$$

$$\therefore R_2 = R_1(A_V - 1)$$

$$R_2 = 20 \times 10^3(2.184 - 1)$$

$$R_2 = 23680\Omega$$

$$\mathbf{R_2 = 23.7K\Omega (E96 1\%)}$$

From these values it is possible to construct the circuit. Figures 2 – 5 show each multipole filter stage.

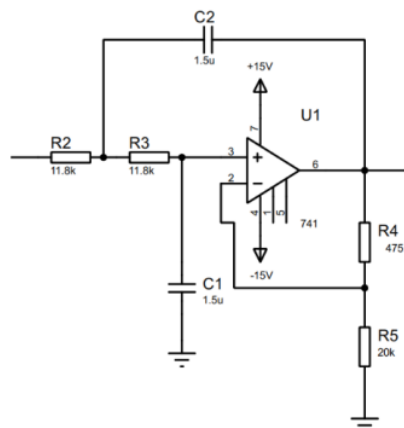


Figure 2 - 1st stage 2 pole active filter

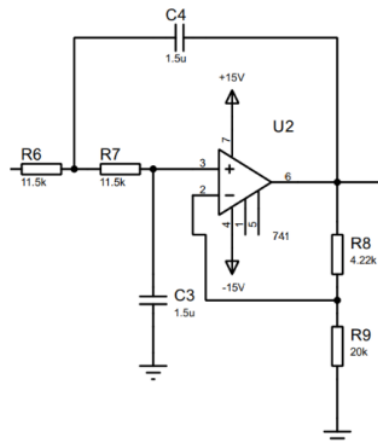


Figure 3 - 2nd stage 2 pole active filter

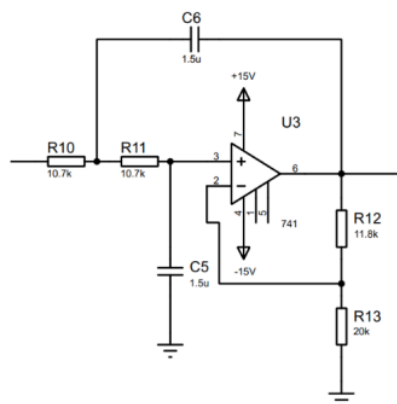


Figure 4 - 3rd stage 2 pole active filter

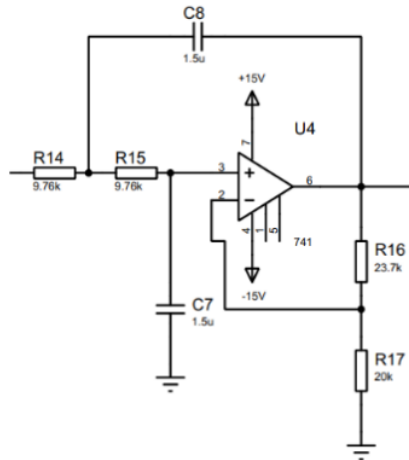


Figure 5 - 4th stage 2 pole active filter

By using standard resistor and capacitor values, the actual gain from each stage may differ. In order to know the gain required from the signal conditioner amplifier section, the total gain from the filter must be calculated.

From equation 11,

$$A_V = 1 + \frac{R2}{R1}$$

$$A_{Vstage\ 1} = 1 + \frac{475}{20 \times 10^3}$$

$$A_{Vstage\ 1} = 1.024$$

$$A_{Vstage\ 2} = 1 + \frac{4.22 \times 10^3}{20 \times 10^3}$$

$$A_{Vstage\ 2} = 1.211$$

$$A_{Vstage\ 3} = 1 + \frac{11.8 \times 10^3}{20 \times 10^3}$$

$$A_{Vstage\ 3} = 1.590$$

$$A_{Vstage\ 4} = 1 + \frac{23.7 \times 10^3}{20 \times 10^3}$$

$$A_{Vstage\ 4} = 2.185$$

$$A_{Vtotal} = A_{Vstage\ 1} \times A_{Vstage\ 2} \times A_{Vstage\ 3} \times A_{Vstage\ 4}$$

$$A_{Vtotal} = 4.308$$

$$Gain(dB) = 20 \log_{10}(A_V)$$

$$Filter\ Gain(dB) = 20 \log_{10}(4.308)$$

$$Filter\ Gain = 12.685\ dB$$

3.2.5 Amplifier Stage Requirements

From equation 7 in section 3.1.3, the total gain required for the system is 53.807dB. From section 3.2.4, the total gain from the filter is 12.685dB, these values can be used to calculate the remaining gain required from a non-inverting amplifier stage.

$$\text{Required gain (dB)} = \text{Total gain required} - \text{Gain from filter}$$

$$\text{Required gain (dB)} = 53.807 - 12.685$$

$$\text{Required gain (dB)} = 41.122$$

Expressing amplifier requirements as a voltage gain ratio,

$$\text{Gain(dB)} = 20 \log_{10} \left(\frac{V_{out}}{V_{in}} \right)$$

$$\frac{V_{out}}{V_{in}} = 10^{\frac{41.122}{20}}$$

$$A_v = \frac{V_{out}}{V_{in}} = 113.789$$

Setting the resistor ratio of the output to non-inverting input using equation 11, setting R1 = 1KΩ.

Non-inverting amplifier gain

$$A_v = 1 + \frac{R2}{R1}$$

Allow R1 = 1kΩ

$$R2 = R1(A_v - 1)$$

$$R2 = 1 \times 10^3 (113.789 - 1)$$

$$R2 = 112789\Omega$$

$$R2 = 113 \text{ K}\Omega \text{ (E96 1\%)}$$

Figure 6 shows the non-inverting amplifier stage of the circuit.

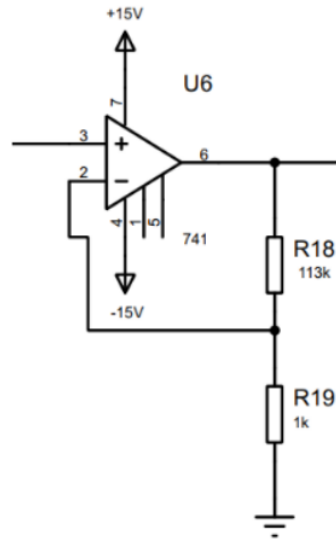


Figure 6 - non-inverting amplifier circuit stage

3.2.6 Level Shifting Circuit Requirements

The sensor outputs a negative voltage at -50°C , the resulting amplified output signal will be below zero, specification requires $-50^{\circ}\text{C} = 0\text{V}$ at the output. A differential amplifier is used to offset the difference in input voltage by supplying a fixed voltage reference to the non-inverting input to the op-amp. Equation 12 shows the general equation for a differential amplifier.

$$V_{out} = V_2 \left(\frac{R_4}{R_3 + R_4} \right) \left(1 + \frac{R_2}{R_1} \right) - V_1 \left(\frac{R_2}{R_1} \right)$$

Equation 11 Differential amplifier equation [14]

By setting all resistor values equal, this equation reduces to

$$V_{out} = V_2 - V_1$$

Equation 12

Calculating the fixed offset voltage required for V_1 , non-inverting amplifier input as follows using the total system voltage gain and the sensor output at -50°C

$$\text{Level Shift} = A_v \cdot V_{low}$$

$$\text{Level Shift} = 490.196 \cdot (-3.4 \times 10^{-3})$$

$$\text{Level Shift} = -1.66667\text{V}$$

Equation 13

From equation 14, the voltage supplied to the non-inverting input is -1.66667V, from equation 13 this now gives an output voltage of

$$V_{out} = V_2 - (-1.66667)$$

$$V_{out} = V_2 + 1.66667$$

Equation 14

This will Level shift the amplified signal output to achieve a 0 – 5V signal between -50°C and 100°C. Figure 7 displays the difference amplifier level shifting stage with all resistors set to 10KΩ to satisfy equation 15.

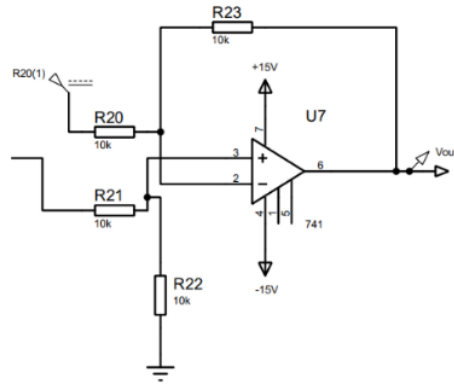


Figure 7 – Difference amplifier acting as a level shifting circuit

Figure 8 displays the full signal conditioning circuit.

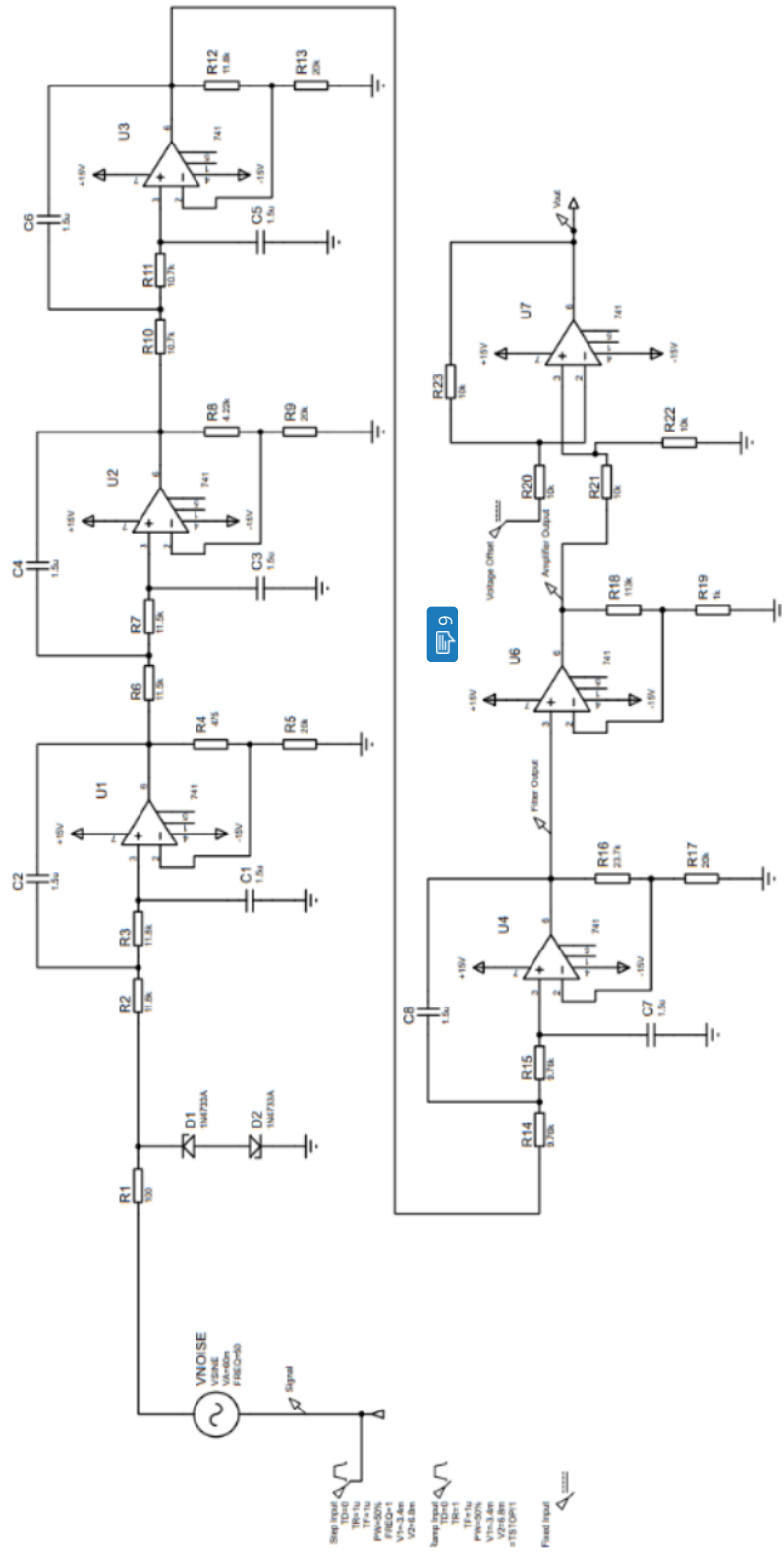


Figure 8 - Full signal conditioning circuit including overvoltage protection, filter stages, amplification and level shifting circuits

4.0 Circuit Simulation

This section outlines the simulation methods for analysing the circuit. These simulation parameters include

- Sensor output signal representation being input to the circuit as a step input
- Noise signal simulation
- Filter frequency response to step input (attenuation and cut off frequency)
- Response to ramp input
- Conditioned signal output measurements and accuracy confirmation

4.1 Sensor Output Signal Representation

Step Input

To simulate the sensor output within Proteus, a step input was fed into the circuit, rising from -3.4mV to 6.8mV (values from equations 1 and 2). Starting at $t = 0$, with a rise and fall time of $1\mu\text{s}$ for a total of 1 cycle. Figure 9 displays the step input dialogue box, also shown is the feed to the circuit input and a voltage probe to graph the signal.

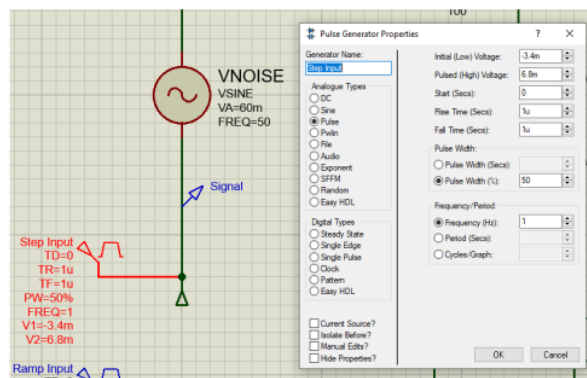


Figure 9 - Step input dialogue box setting voltage range from -3.4mV to 6.8mV

From the step input, system response characteristics can be obtained. These include

- Rise time
- Overshoot
- Passband and stopband ripple
- Output voltage offset
- System delay time
- Settling time to 1% of final value.

Ramp Input

As a temperature signal is seldom seen as a step change between minimum and maximum temperatures, a ramped input was simulated to rise from -3.4mV to 6.8mV over 10 seconds. This is held for 1 second before a 1 second fall time. Figure 10 shows the dialogue box for these settings.

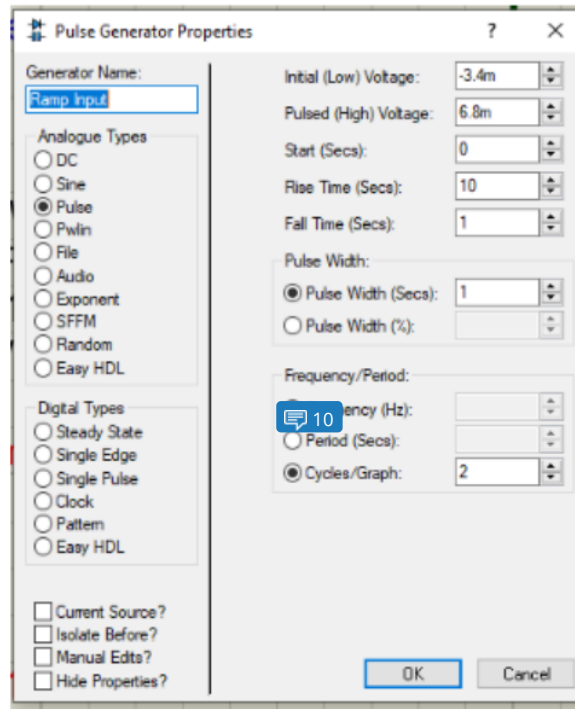


Figure 10 Ramp input simulation settings

4.2 Noise Signal Simulation

To simulate the 50Hz – 60mV peak AC noise signal a sinusoidal voltage input labelled V-noise, is placed in series with the input sensor signal. This creates a step input modulated by an AC interference. The dialogue box can be seen in figure 11.

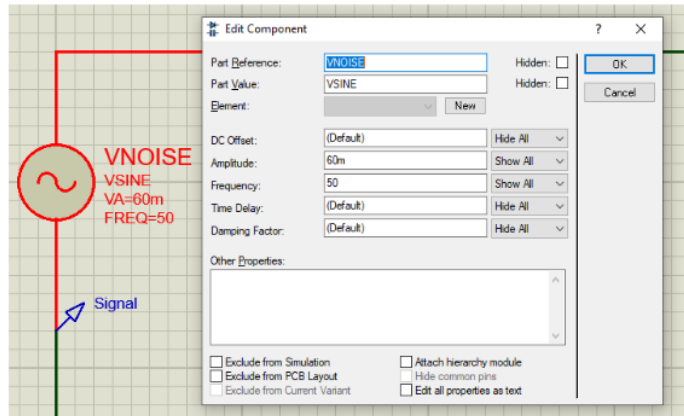


Figure 11 - AC noise signal simulation set to 50Hz - 60mV -Pk

4.3 Level Shifting Voltage Simulation

From equation 14, the voltage reference to be added to the differential amplifier stage was calculated as -1.66667V. This is fed to the inverting input of the op-amp via a fixed DC voltage source. Figure 12 displays the dialogue box and terminal placement.

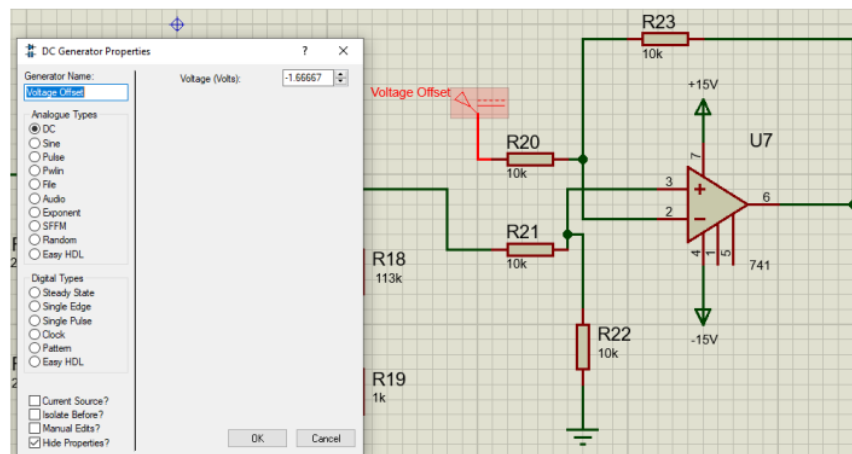


Figure 12 - Voltage offset placed into inverting input of the differential amplifier for level shifting.

4.4 Measurement Points

In order to obtain simulation results, voltage probes are placed at significant points on the circuit. These include,

- Signal before the noise element
- Filter output
- Amplifier output
- Final □□□□ after level shifting.

These probe locations can be seen in figure 8. These probe points allow time domain and frequency response graphs to be created showing the circuit response.

4.5 Graph settings

An analogue graph window was used to display the time domain response of the circuit, starting at $t = 0$ to $t = 1$ second. Figure 13 shows the dialogue box for this.

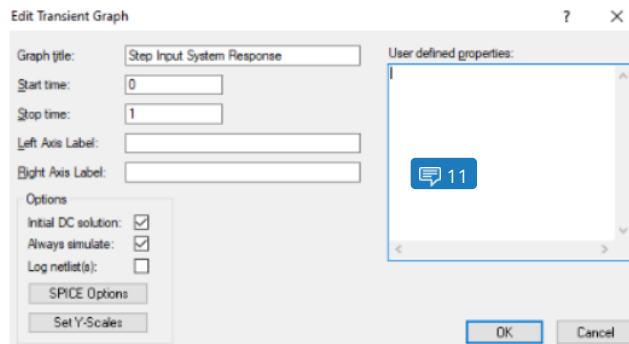


Figure 13 - Time domain response analogue graph settings

To measure the frequency response of the circuit, a frequency chart feature was used. This is set to measure between 1Hz and end at 100Hz. The reference signal is set to the step input with V-out being the measured quantity. Figure 14 displays the dialogue box for this graph.

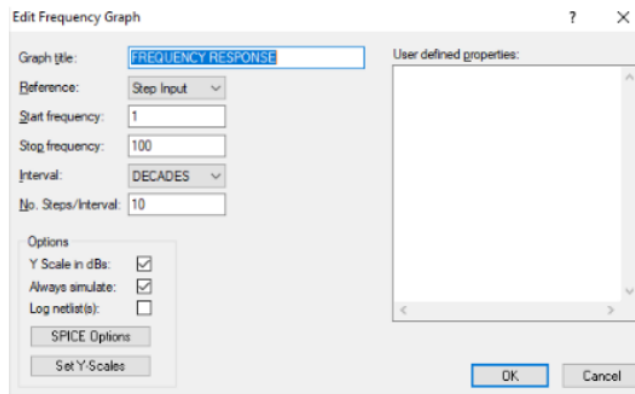


Figure 14 - Frequency response graph settings within Proteus

5.0 Simulation Results

5.1 Step Response

Figure 15 displays the step response of the signal conditioning circuit.

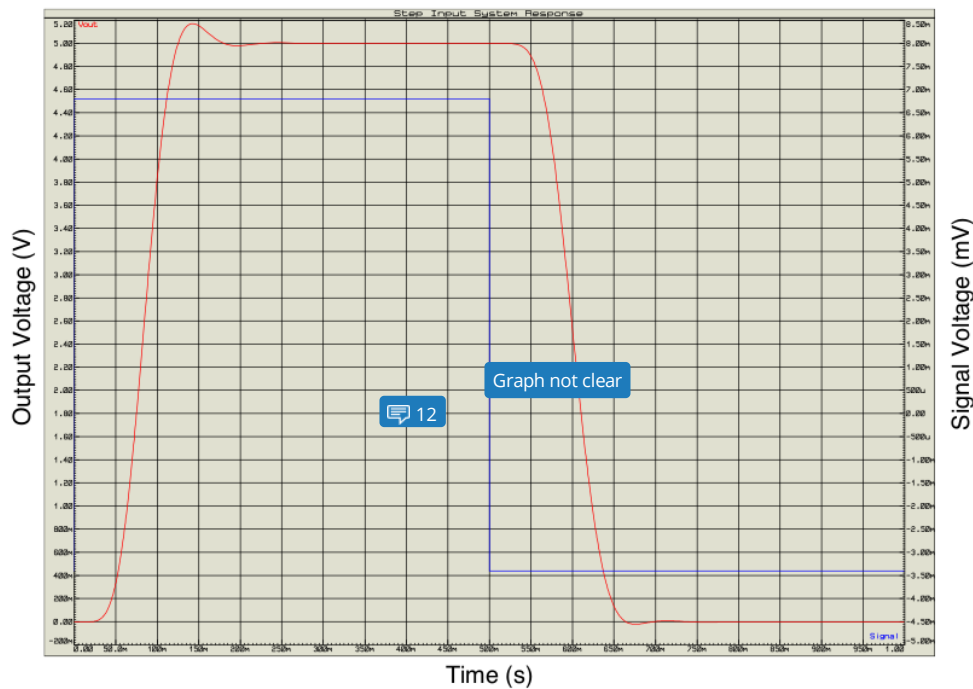


Figure 15 - Graph of signal conditioning circuit step response output

From figure 15, some minor overshoot can be seen, this settles to exactly 5V after approximately 250mS. When the step input falls to -3.4mV, there is minimum undershoot and rapid settling of the output to 0V.

5.2 Frequency Response

Figure 16 displays the frequency response of the signal conditioning circuit.

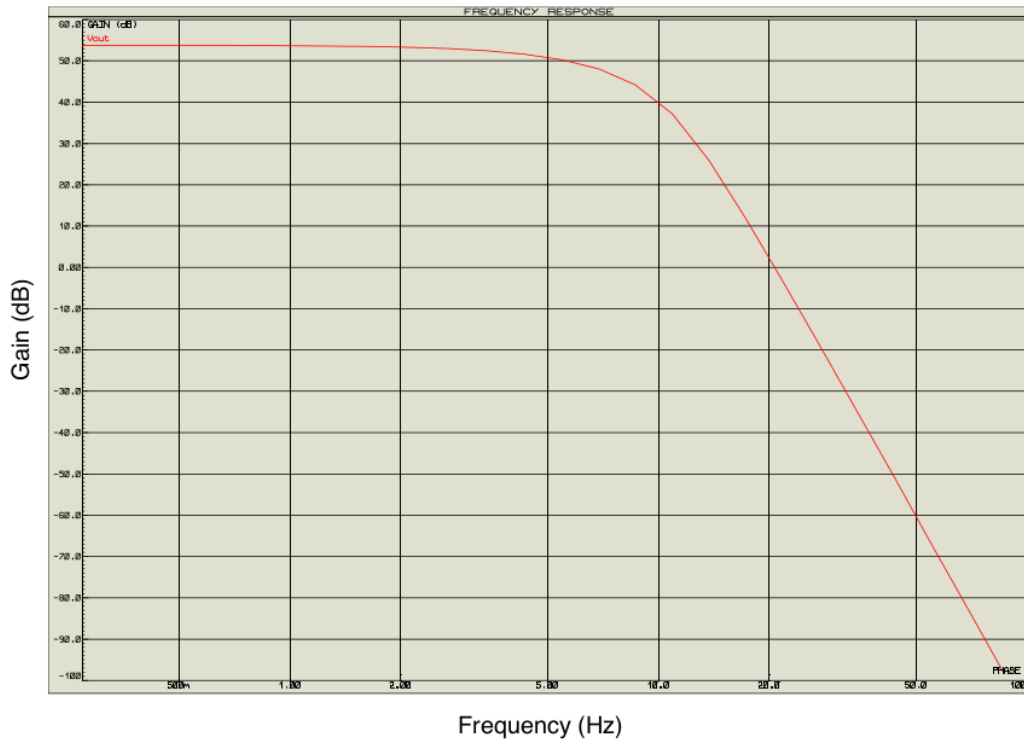


Figure 16 - Frequency response of signal conditioning circuit

From figure 16 the -3dB point can be seen at 5Hz, beginning the roll off into the stop band.

5.3 Ramp Input Response

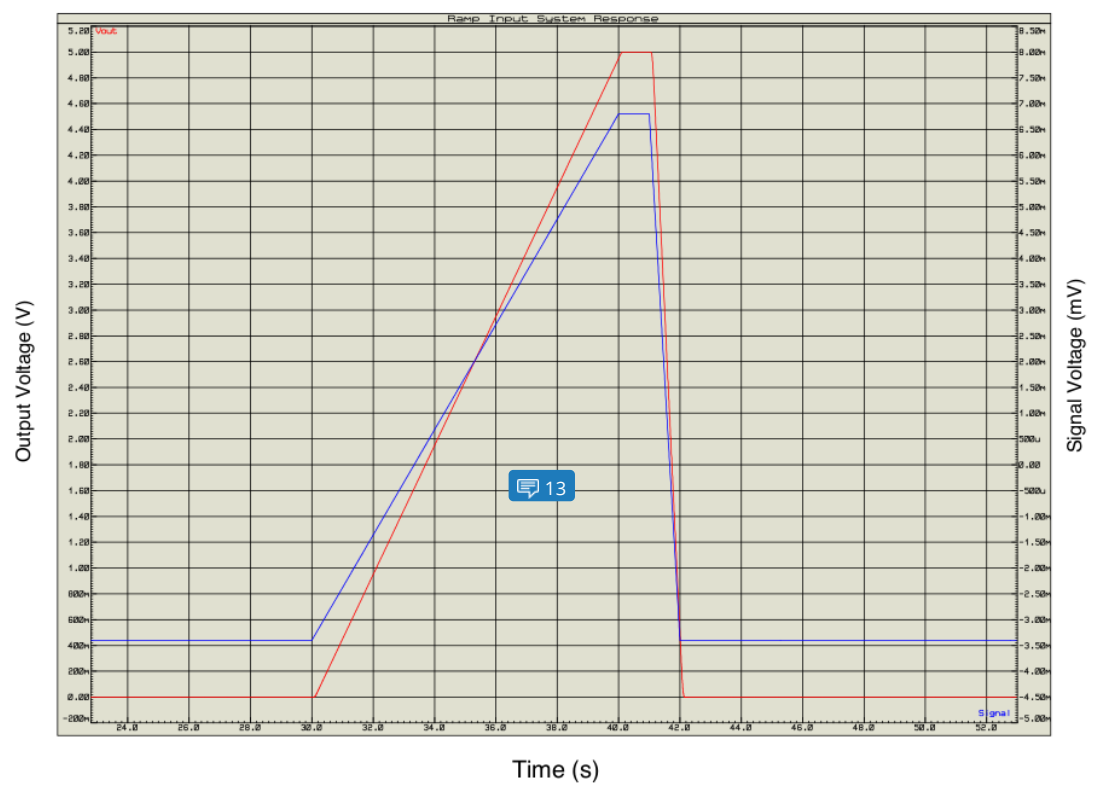


Figure 17 - Ramp input response

6.0 Analysis of Results

6.1 Time Domain Analysis

Using the cursors on the graph windows within Proteus, accurate measurements can be taken of the output waveform. Time domain properties that have been measured include [11],

- System time delay
- Rise time
- Overshoot
- Settling time to 1% of final value
- Output voltage offset/Level shift (accuracy analysis).

System time delay

The time delay of the system is the time taken for the signal to reach 50% of its final value. Using the cursor feature on the step response graph, the time taken for the signal to reach 2.5V is 83.386mS. Typical response times for a mineral insulated thermocouple of 2mm diameter is around 400mS when taken from 20°C air into boiling water [15]. Therefore, the response time of the signal conditioner would be adequate for this application.

Rise Time

The rise time of a system is the time taken to reach 90% of final value from 10% of final value. From the graph in figure 15, this equates to,

$$t_{10\%} = 54.5mS @ 0.5V$$

$$t_{90\%} = 111.1mS @ 4.5V$$

$$t_r = t_{90\%} - t_{10\%}$$

$$t_r = 111.1 - 54.5$$

$$t_r = 56.6mS$$

Equation 15

Overshoot

From the time domain analysis of the step input in figure 14, there is a small amount of overshoot on the output waveform. Using the cursors, the output overshoots to a maximum voltage of 5.17V, equating to a 3.4% of final value. This overshoot is significantly less than that of a Butterworth or Chebyshev response [9].

Settling Time

The settling time for the output to reach 1% of its final value and remain there was measured as 168mS

Level Shift and Output Accuracy

From equation 14, the voltage to be fed into the difference amplifier to bring the signal to 0-5V was -1.66667V. Using an amplitude response graph in proteus, the signal can be shown pre and post level shifting. Figure 18 displays this

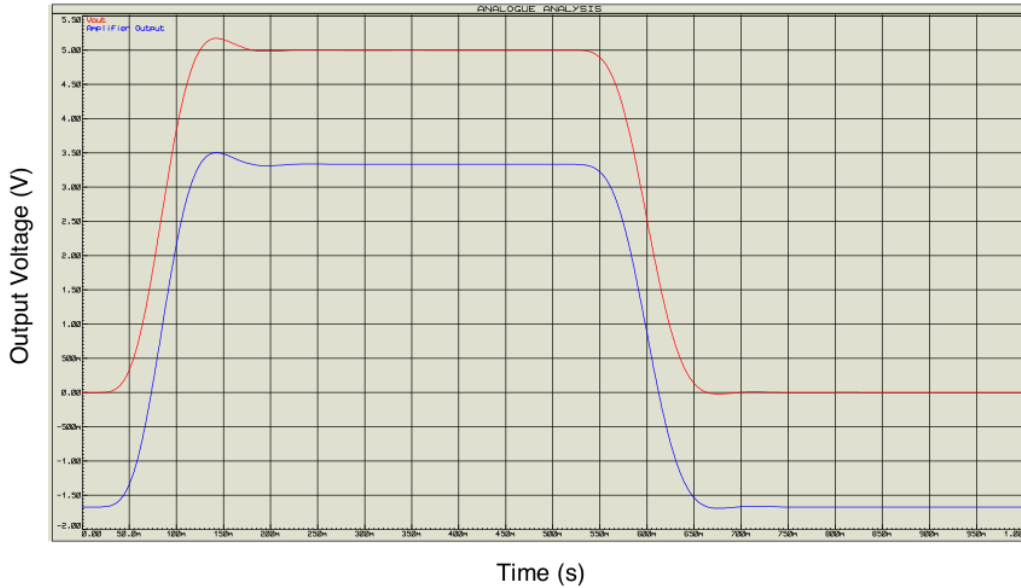


Figure 18 - Graph of the amplifier output signal and the final shifted output

Taking measurements from these graphs it is shown that the calculated level shifting voltage was correct as the output waveform sits exactly at 0V and 5V.

The output sensitivity is calculated as

$$Sens_{out} = \frac{V_{out}}{Range}$$

$$Sens_{out} = \frac{5V}{150^{\circ}C}$$

$$Sens_{out} = 0.03 \frac{V}{^{\circ}C}$$

Equation 16

In order to achieve an output temperature accuracy of $\pm 0.5^{\circ}C$, the voltage at $-50^{\circ}C$ and $100^{\circ}C$ cannot deviate more than $\pm 15mV$. From the graph in figure 14, the voltage at full scale settles to exactly 5V with no deviation. The voltage then drops to 0V, deviating no more than $\pm 1mV$ after settling from the undershoot. Therefore, the signal conditioner output accuracy falls within specification.

6.2 Frequency Response Analysis

From the frequency response graph, the gain of the total system and the -3dB point can be measured. From figure 16 the total gain is measured as 53.8dB, this matches the calculated gain from section 3.1.3, equation 6. The -3dB point at 50.8dB corresponds with the specified cut off frequency of 5Hz. From figure 15, there is a total measured attenuation to 50Hz of -114dB, this correlates with the figures for an 8 pole Bessel filter from table 1, where the attenuation is $10 \log_{10} 114 \approx -20.57$ dB. This total attenuation exceeds the specified -70.95dB 50Hz ripple in section 3.1.2.

7.0 Conclusion

From this report, the circuit designed has successfully conditioned the output signal of the temperature sensor to give an accurate, linear 0-5V signal between -50°C and 100°C. The Temperature sensor has been chosen as a Type E Chromel – constantan thermocouple. The response time of the system is adequate to provide stable, accurate temperature reading changing over time.

The results of the simulations are as follows,

- Time Delay = 83.386mS
- Rise Time from 10% to 90% = 56.6mS
- Overshoot = 5.17V, equating to 3.4% of final value.
- Settling time to 1% of final value = 168mS
- Total System gain of 53.8dB, simulation measurement matches calculated
- 8 pole Bessel filter provides -114dB of noise attenuation – Exceeds calculated requirement of -70.95dB
- Output signal achieves 0 – 5V with less than $\pm 0.5^\circ\text{C}$ error.

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Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

85 / 100

PAGE 1

PAGE 2



Comment 1

These terms mean the same thing



Abstract - results

Good abstract, although you should include a statement of your results.



Comment 2

Good. Well found



Caption required

You should always include a caption on figures, equations and tables to allow you to refer to them in your text.

e.g. An illustration of this can be seen in figure 2. The relationship of the variables is shown in equation 2. Table 1 shows the results of the first experiment where the control variable, temperature in degrees celsius is shown in the first column....



Comment 3

Good explanation with accurate example

PAGE 3



Comment 4

Good examples

PAGE 4



Comment 5

calculated using equations 1 to 3.

Use captions to refer to equations and figures etc.



Comment 6

Equation 1

PAGE 5

PAGE 6



Comment 7

What about the forward voltage of the other diode?

The actual voltage will be:

$$V_{ov} = V_f + V_r$$

$$V_{ov} = 0.7 + 5.1 = 5.8V$$

PAGE 7

PAGE 8



Comment 8

Should this be high or low? Maybe "resistors with a small tolerance" may have been less ambiguous.

PAGE 9

PAGE 10

PAGE 11

PAGE 12



Comment 9

Excellent



Comment 10

While the reader is supposed to be able to repeat your work from what you've written, you are not writing an instruction manual so you don't need to include screenshots of dialog boxes like this one.



Comment 11

You're not writing an instruction manual. You can just state the simulation parameters in your text without a screenshot of the dialog box



Graph not clear

Graph is not clear.

Tip: make graphs smaller on screen before copying them, this will make the text larger and the information on them clearer.



Comment 12

Excellent data, although the graph is not very clear



Comment 13

Excellent - well done for using a more realistic stimulus.

PAGE 25

PAGE 26



Comment 14

Your circuit performs well and satisfies the specifications. Well done

PAGE 27

PAGE 28

GRADING FORM: SMU GENERIC_SMOSEY

NIALL REES

84.50

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Outstanding knowledge of research-informed literature embedded in the work. Outstanding selection of relevant and credible sources. High-level referencing skills consistently and professionally applied.

4.5

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Highly detailed knowledge and understanding of the main theories/concepts, and a critical awareness of the ambiguities and limitations of knowledge.

25.5

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



Exceptional work; judiciously selected and evaluated evidence. Very high quality analysis, developed independently. Ability to investigate contradictory information and identify reasons for contradictions. Highly persuasive conclusions

27

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Outstanding levels of application and deployment skills. Assimilation and development of cutting edge processes and techniques.

24

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate professionally and, confidently in a suitable format. Work is coherent, very fluent

3.5

and is presented professionally