

Signal Conditioning - Gareth Davies

by Gareth Davies

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Transducers and Signal Conditioning



[12]

Level 5 Assignment
Submitted By
Gareth Davies (2218705)

Abstract

A thermocouple's output was being corrupted by 120mV pk-pk, 50Hz mains interference. A circuit design was required to eliminate this interference and produce an output signal operating within given parameters. This project set out to do just that.

To achieve this, the design was split into small function specific sections for overvoltage protection, signal filtration, amplification, and level shifting.

This paper will show how each section was designed through electrical theory, track the evolution of the input signal through simulation analysis, and highlight how the output signal now meets the system specifications.

[Abstract - results](#)

Table of Contents

Abstract.....	2
Introduction	4
Circuit Design.....	5
Circuit Specifications:	5
Overvoltage Protection:	7
Filter Design:	8
Amplification:	16
Level Shifting:	18
Final Circuit Design - Simulation	20
Conclusion	21
Bibliography	22

Introduction

Signal conditioning is the process of manipulating an input signal in a manner that prepares it for the next stage of processing [1]. It is often used within a sensory system to produce an accurate, noise free output signal proportional to its input. This output signal is then fed into some form of controller that analyses the information and adjusts processes accordingly.

Using operational amplifier and active filter theory, this project will look to create multiple signal conditioning circuits specifically designed for a single process within the system. These processes will include overvoltage protection, signal filtering, amplification, and level shifting.

Once tested and operating correctly, these circuits will be cascaded together to create a fully functional signal conditioning system.

Circuit Design

Circuit Specifications:

From the project brief, the following system specification can be extracted:

Input Signal:

- Thermocouple will produce $68\mu V$ per $^{\circ}C$.
- At $0^{\circ}C$ the sensor will produce $0V$.
- This input signal is contaminated with $120mV$ pk-pk $50Hz$ interference.

Desired Output Signal:

- Output signal should range between $0 - 5V$.
- At $-50^{\circ}C$ the voltage must equal $0V$.
- At $100^{\circ}C$ the voltage must equal $5V$.
- Input noise must be removed.

It is clear from this specification that the conditioning circuit will be required to amplify the input signal to operate between the $0-5V$ range. To calculate this gain, the following calculation can be used:

$$\text{Maximum Amplitude @ } 100^{\circ}C = 68\mu V \times 100 = \mathbf{6.8mV}$$

$$\text{Minimum Amplitude @ } -50^{\circ}C = 68\mu V \times (-50) = \mathbf{-3.4mV}$$

$$\text{Input Voltage Range} = \frac{6.8mV - (-3.4mV)}{1} = 0.0102V$$

$$\text{Output Voltage Range} = 5V$$

When using simulation software later in this project, this minimum and maximum amplitude range of -3.4 to $6.8V$ will be used to set the input signal.



$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{5V}{0.0102V} = \mathbf{490.1961}$$

$$\text{dB Gain} = 20 \times \log_{10}(490.1961) = \mathbf{53.81 dB}$$

When designing a signal conditioning circuit, it is also important to select an acceptable operating tolerance.

Through research, it was found that the sensor described in the project brief is a type-E thermocouple (Nickel-Chromium/Constantan) [2]. These thermocouples operate within a temperature range of -200 to 900°C and produce a high sensitivity output of 68µV per °C measured, the exact specification required for this circuit.

In practice, a thermocouple such as the OMEGA SA2F-E-120 could be integrated into this design [3] [4].

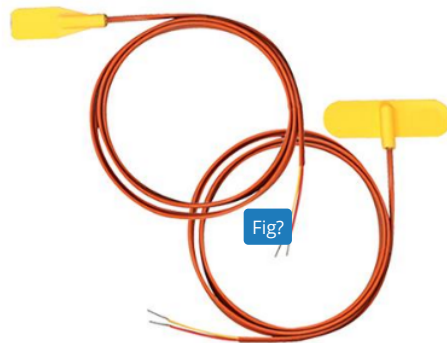


Figure 1 - OMEGA SA2F-E-120

Additional research into type-E thermocouples found that they have a standard accepted tolerance of +/- 1.7°C or +/- 0.5% depending on whichever value is greater [5].

This systems temperature range of 150°C would equate to a 0.5% tolerance of +/- 0.75°C.

As a result, the larger standard tolerance of +/- 1.7°C has been selected for this circuit.

$$\text{Input Voltage Tolerance} = 1.7^{\circ}\text{C} \times 68\mu\text{V} = \mathbf{115.6\mu\text{V}}$$

$$\text{Required Attenuation} = 20 \times \log_{10}\left(\frac{115.6\mu\text{V}}{68\mu\text{V}}\right) = \mathbf{4.61\text{ dB}}$$

Caption required

$$\text{Output Sensitivity} = \frac{\text{Output Voltage Range}}{\text{Temperature Range}} = \frac{5\text{V}}{150^{\circ}\text{C}} = \mathbf{0.03\text{V per }^{\circ}\text{C}}$$

$$\therefore \text{Output Tolerance} = 0.03\text{V} \times 1.7^{\circ}\text{C} = \mathbf{51\text{mV}}$$

Overvoltage Protection:

To prevent transient voltages from interfering with, or potentially damaging this system, an overvoltage protection circuit will be used. For this system, a voltage protection of 5V will be sufficient.

To achieve this, two 5.1V Zener diodes will be connected back-to-back and placed in parallel with the circuit. A small value resistor will also be placed in series with the signal.

If a voltage larger than 5.1V is present within this circuit, one of the Zener diodes will begin to conduct depending on voltage polarity. Transient voltages will then be passed through the diode and dropped across the small resistor. The Zener itself will only allow a voltage drop of 5.1V per design. As a result, Kirchhoff's voltage law states that the voltage dropped across parallel components will be equal [6]. Hence, the circuit voltage is protected from voltages exceeding 5.1V.

Using Proteus 8 software, this circuit could be simulated and its effect on the input signal analysed.

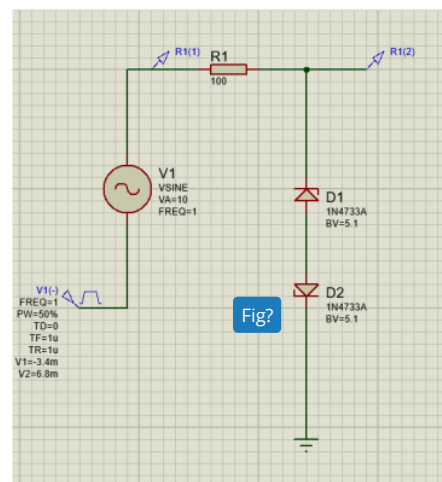


Figure 2 - Voltage Protection Circuit

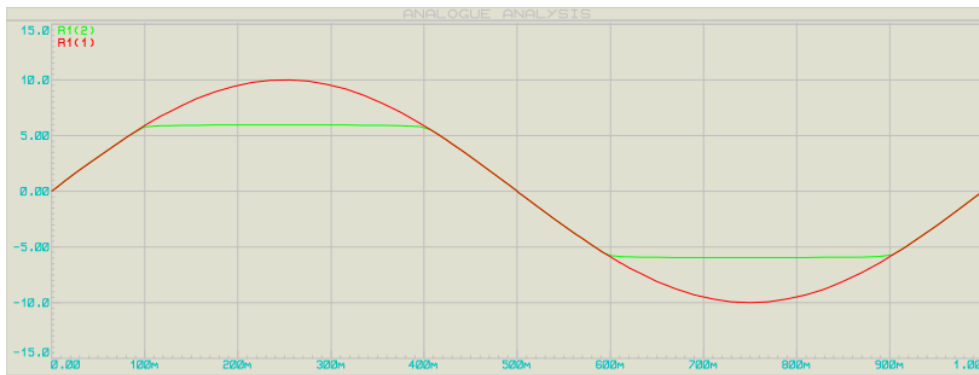


Figure 3 - Voltage Protection Example

To prove operation, an input signal (R1(1)) was supplied to the circuit with an amplitude of 10V. It can be seen that the output signal (R1(2)) has been clipped at approximately 6V providing overvoltage protection to the remaining circuit.

As with all silicone diodes, Zener diodes require an initial voltage of 0.7V to operate hence the amplitude measures closer to 6V.

Filter Design:

To remove the 120mV pk-pk, 50Hz noise from the input signal, an active low pass filter can be used.

An active filter consists of both passive RC components, as well as an active component such as an operational amplifier (Op-amp). The values selected for the RC components will set the cut off frequency (F_c) of the filter whilst the addition of an Op-amp will provide several benefits:

- Active filters are unaffected by their load impedance, meaning a stable output signal will always be produced. [7]
- OP-Amps provide gain to the filter, removing the unwanted attenuation suffered by passive filters.
- By varying this gain, it is possible to easily manipulate the signal response of a filter.
- Very high input impedances allow multiple Op-amps to be cascaded together, creating higher performing systems. [8]

For this specific design, an active low pass filter will be used. This will allow frequencies below the cut off to pass, whilst blocking all higher frequencies. To eliminate as much noise as possible, a relatively low cut off frequency of 5Hz has been selected.

Filter Selection:

As mentioned previously, it is possible to manipulate the signal response of an active filter. Depending on the conditions being monitored and the desired output response, different types of active filters have been designed. The four most common variants of these filters are the Butterworth, Bessel, Chebyshev, and Elliptic filters. [9]

Each of these filters can provide beneficial response characteristics and are selected depending on application. For this project, a Bessel design has been chosen.

Bessel Filter:

Bessel filters have an incredibly linear relationship between  phase and frequency response. This characteristic is referred to as having a maximally flat group delay. Due to this, Bessel filters are optimised for a quick transient response whilst possessing a relatively poor frequency response. Overshoot and ringing are significantly reduced as a result of this linear group delay [10].

Generally, the transient response properties of Bessel filters are not required for temperature sensing operations due to its slow rate in change. The reason for selecting the Bessel filter for this application is due to the system sensitivity.

With a relatively high sensitivity of $68\mu\text{V}$ per $^{\circ}\text{C}$, the rate of voltage change in type-E thermocouples can be far greater than other thermocouple types. The quicker transient response of Bessel filters will therefore be more beneficial for these devices, even if not being objectively required.

The major benefit from using a Bessel filter is the near elimination of overshoot and ringing in the output signal. As calculated previously, the output sensitivity of this system will be 0.03V per $^{\circ}\text{C}$, therefore, small changes in the output signal (i.e., overshoot and ringing), will equate to large fluctuations in temperature measurements. The properties of a Bessel filter will minimise this effect and increase overall system accuracy.

To ensure sufficient attenuation can be achieved, a higher order  Bessel filter will be required due to their poor frequency response. For this design, a 6th Order Bessel filter has been selected and created by cascading three 2nd order Bessel filters together. This may also be referred to as a 6-pole filter.

Filter Design:

12

The diagram below shows the basic construction of a 2nd order low pass filter or a 2-pole section of a higher order low pass filter.

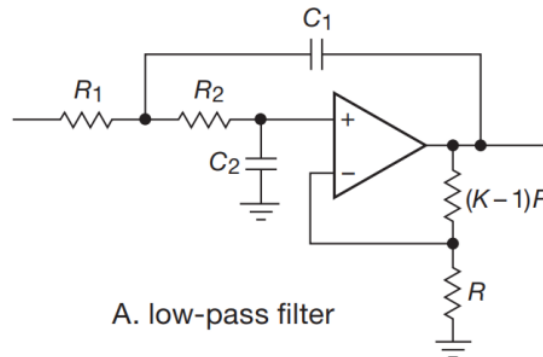


Figure 4 - 2nd Order Low Pass Filter with Amplification [8, p. 407]

(For continuity with calculations within this paper, component $(K-1)R$ will hereby be defined as R_F .)

An understanding of each component within this configuration is fundamental to the design of this circuit. A brief overview is given below.

OP-Amp:

OP-amps are essentially voltage amplifying devices that produce an output signal proportional to the difference between their two input terminals. These two terminals are known as the inverting and non-inverting inputs. Depending on the terminal being fed, the output will either be 180° out of phase or in phase with the original signal.

The use of feedback loops from the output back to these input terminals will determine the overall operation of the OP-amp.

Gain:

Components R_F and R in figure 4, are resistors used to control the overall gain of the amplifier. A negative feedback loop is created by feeding the output signal back into the inverting input via resistor R_F . Component R is then used to create a voltage divider.

By changing the values of these resistors, the voltage fed back to the inverting input will change. As a result, a proportional gain will be created through the OP-amp. To calculate the gain of a non-inverting amplifier, the following calculation can be used.

$$Gain = 1 + \frac{R_F}{R}$$

Caption required

Filter:

Components R1, R2, C1 and C2 combine to create a 2nd order filter. As capacitors are connected across the output of the Op-amp, this configuration will create a low pass filter.

Capacitor theory states that as signal frequency increases, capacitive reactance reduces [11]. This essentially diverts higher frequencies back through the capacitors preventing them from appearing in the output signal.

The values of these RC components will set the cut-off frequency of the filter. This can be calculated using the following formula.

$$F_c = \frac{1}{2\pi R C}$$

Caption required

Referring back to figure 4, for this to be defined as a Bessel filter, several conditions must be met:

- 1. In each section, R1 = R2 = R and C1 = C2 = C.
- 2. RC products in each section must be scaled by a normalising factor (C_n).
- 3. The gain within each section must be set to a specified value (K) [8, p. 408]

The normalisation factor and gain values required for an active low pass filter (LPF) design can be found in the table below

Poles	Butterworth		Bessel		Chebyshev (0.5dB)		Chebyshev (2dB)	
	K	c _n	K	c _n	K	c _n	K	c _n
2	1.586	1.272	1.268	1.231	1.842	0.907	2.114	
4	1.152	1.432	1.084	0.597	1.582	0.471	1.924	
	2.235	1.606	1.759	1.031	2.660	0.964	2.782	
6	1.068	1.607	1.040	0.396	1.537	0.316	1.891	
	1.586	1.692	1.364	0.768	2.448	0.730	2.648	
	2.483	1.908	2.023	1.011	2.846	0.983	2.904	
8	1.038	1.781	1.024	0.297	1.522	0.238	1.879	
	1.337	1.835	1.213	0.599	2.379	0.572	2.605	
	1.889	1.956	1.593	0.861	2.711	0.842	2.821	
	2.610	2.192	2.184	1.006	2.913	0.990	2.946	

Figure 5 - Normalising Factor and Gain Values for Active LPF Design [8, p. 408]

Using these values and the selected cut off frequency of 5Hz, all three stages of the required 6th order Bessel filter was designed using the calculations shown.

Stage One:

$$F_c = 5\text{Hz} \quad C_n = 1.607 \quad K = 1.040 \quad \text{Let } C = 1.5\mu\text{F}$$

Filter Components:

$$F_c = \frac{1}{2\pi RC C_n} = \frac{1}{2\pi \times R \times 1.5\mu\text{F} \times 1.607}$$

$$R = \frac{1}{2\pi \times 1.5\mu\text{F} \times 5\text{Hz} \times 1.607} = 13205.14\Omega$$

Nearest Standard Size = 13kΩ

Gain Components:

$$\text{Gain} = 1 + \frac{R_F}{R}$$

$$\text{Let } R = 22\text{k}\Omega$$

$$\therefore 1.040 = 1 + \frac{R_F}{22\text{k}\Omega}$$

$$R_F = 0.040 \times 22\text{k}\Omega = 880\Omega$$

Nearest Standard Size = 910Ω

Stage Two:

$$F_c = 5\text{Hz} \quad C_n = 1.692 \quad K = 1.364 \quad \text{Let } C = 1.5\mu\text{F}$$

Filter Components:

$$F_c = \frac{1}{2\pi RC C_n} = \frac{1}{2\pi \times R \times 1.5\mu\text{F} \times 1.692}$$

$$R = \frac{1}{2\pi \times 1.5\mu F \times 5Hz \times 1.692} = 12541.76\Omega$$

Nearest Standard Size = 13k Ω

Gain Components:

$$\text{Let } R = 22k\Omega$$

$$\therefore 1.364 = 1 + \frac{R_F}{22k\Omega}$$

$$R_F = 0.364 \times 22 k\Omega = 8008\Omega$$

Nearest Standard Size = 8.2k Ω

Stage Three:

$$F_C = 5Hz \quad C_n = 1.908 \quad K = 2.023 \quad \text{Let } C = 1.5\mu F$$

Filter Components:

$$F_C = \frac{1}{2\pi RC C_n} = \frac{1}{2\pi \times R \times 1.5\mu F \times 1.908}$$

$$R = \frac{1}{2\pi \times 1.5\mu F \times 5Hz \times 1.908} = 11121.93\Omega$$

Nearest Standard Size = 11k Ω

Gain Components:

$$\text{Let } R = 22k\Omega$$

$$\therefore 2.023 = 1 + \frac{R_F}{22k\Omega}$$

$$R_F = 1.023 \times 22 k\Omega = 22506.0\Omega$$

Nearest Standard Size = 22k Ω

Using the values calculated for each section, the following 6th order Bessel filter was designed and simulated using Proteus 8 software.

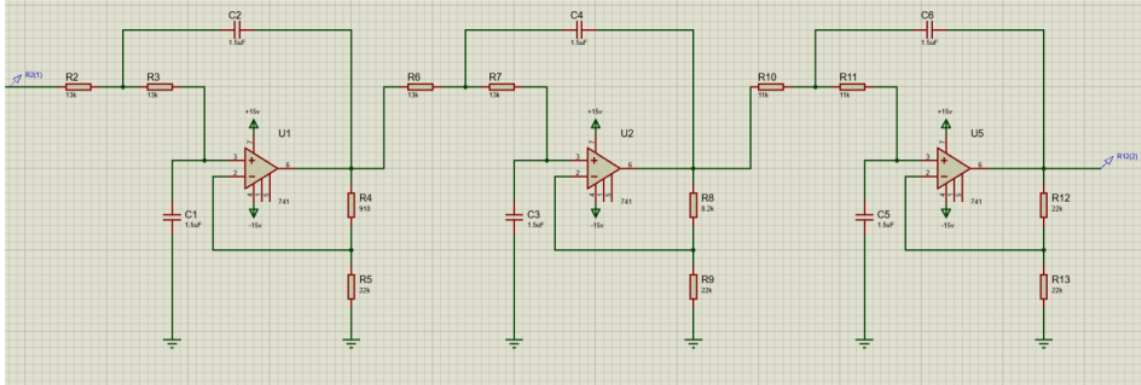


Figure 6 - 6th Order Bessel Filter Simulation

To ensure this filter operates as required, Proteus was used to plot the input signal (R2(1)) against the output signal (R12(2)) over a period of one second.

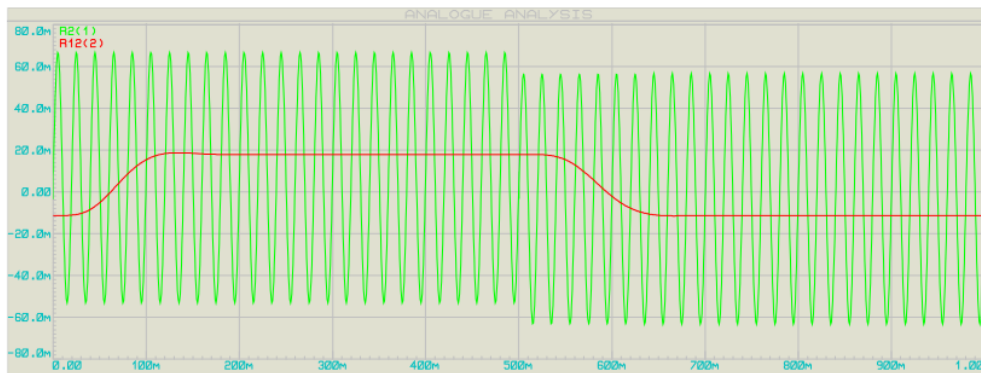


Figure 7 - Analogue Analysis of Filter Operation

This graphical analysis clearly shows that the 50Hz noise has been removed from the output signal that now has a period of 16ms. The 120mV pk-pk noise has also significantly decreased to 29.27mV. This makes sense if you consider the following equations for a type-E thermocouple and the total filter gain:

$$Pk - Pk \text{ Voltage} = \text{Thermocouple Sensitivity} \times \text{Temperature Range}$$

$$Pk - Pk \text{ Voltage} = 68\mu\text{V} \times 150^\circ\text{C} = 10.2\text{mV}$$

$$\text{Bessel Filter Gain} = K1 \times K2 \times K3 = 1.040 \times 1.364 \times 2.023 = 2.87$$

$$\text{Output Singal Pk - Pk Voltage} = 10.2\text{mV} \times 2.87 = \mathbf{29.274\text{mV as shown}}$$

The Proteus software can also be used to plot the frequency response of the designed filter as shown in figure 8.

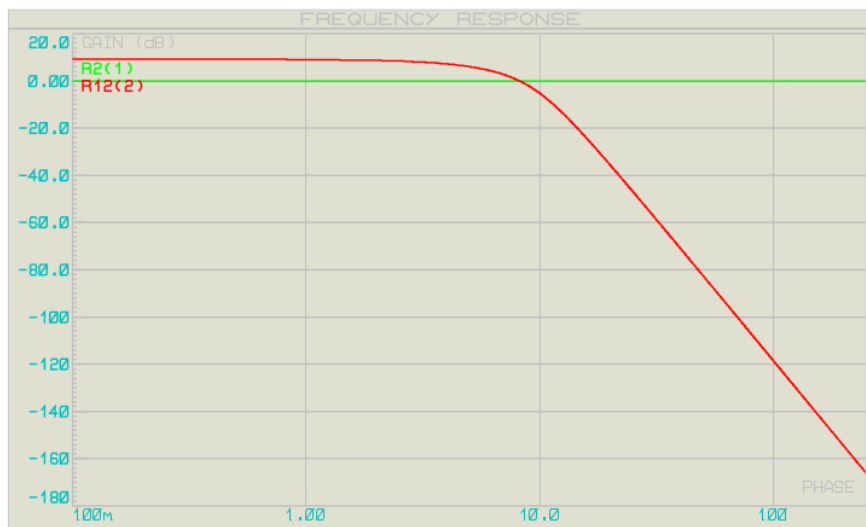


Figure 8 - Frequency Response of the Bessel Filter Design

The first thing to note from this frequency response plot is that the output signal has obtained a dB gain of 9.12. Again, this was expected due to the gain properties of active filters.

By interacting with the Proteus software, an exact magnitude of 6.05dB was measured at the desired cut off frequency of 5Hz. In a theoretically perfect filter, this value would measure 6.12dB, i.e., exactly -3dB from the maximum amplitude. This minor deviation in values simply occurs due to standard size RC components being used within the filter instead of the exact RC values calculated. Standard size components are simply used to reduce component requirements, size, and cost of a physical model.

This analysis shows the exact cut-off frequency for this Bessel filter to be 4.92Hz, that more than satisfies the requirements of this system.

With the noise successfully removed from the input, the remaining signal now needs to be amplified to operate within a desired range of 5V.

Amplification:

Within the circuit specification, it was calculated that a total gain of 53.81dB was required for this circuit design. During the filter stage, a gain of 9.12dB has already been acquired. Using these values, the remaining gain requirement can be calculated.

$$dB \text{ Gain Required} = 53.81dB - 9.12dB = 44.69dB$$

$$\therefore 44.69dB = 20 \times \log_{10}(\text{Gain})$$

$$\frac{44.69dB}{20} = \log_{10}(\text{Gain})$$

$$\text{Gain} = 10^{\frac{44.69dB}{20}} = 171.593$$

To produce this gain, another Op-amp will be used in a non-inverting configuration. To determine the resistor values required for this, the following calculation are used.

$$\text{Gain} = 1 + \frac{R_2}{R_1}$$

$$\text{Let } R = 160 \Omega$$

$$\therefore R_F = 160\Omega \times 171.593 = 27454.88\Omega$$

$$\text{Closest Standard Size} = 27k\Omega$$

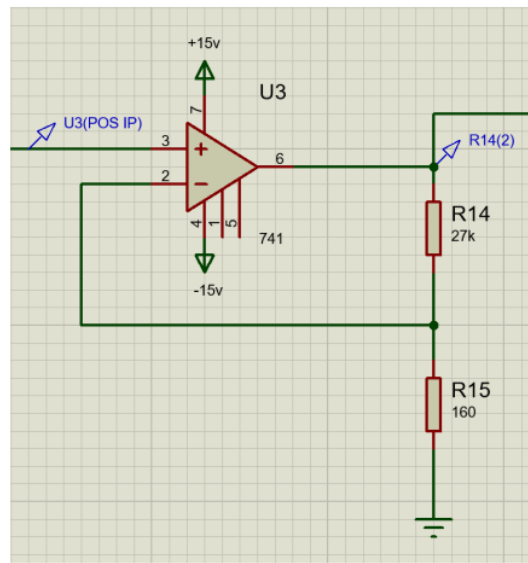


Figure 9 - Non-Inverting Amplifier - Gain of 171.593

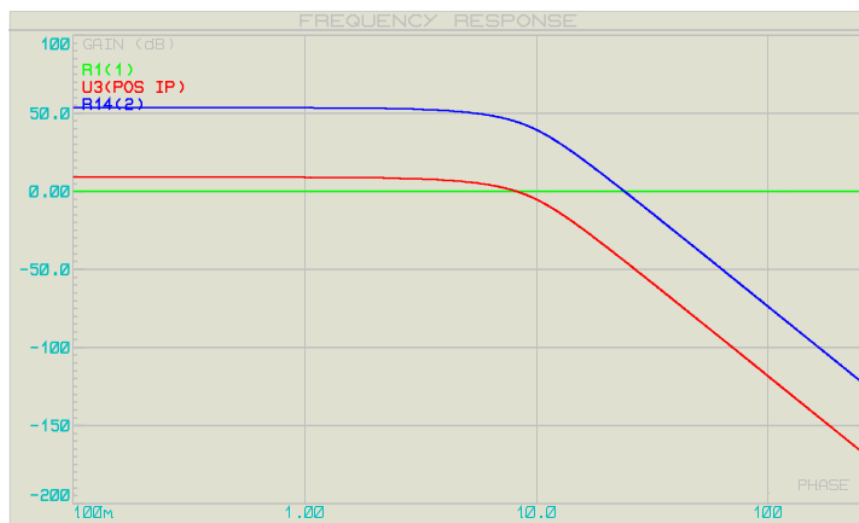


Figure 10 - Frequency Response Post Amplification

Post amplification, the output signal R14(2) has obtained a gain of 53.7dB. This is very close to the desired system gain of 53.81dB calculated within the circuit specification. As within the filter stage, this small deviation is due to the use of standard size RC components. If a precise gain was required, a variable resistor may be used within the voltage divider.

From this frequency response, it can also be seen that an attenuation to -38.0dB has been achieved within the transition band of this filter, i.e., between 5 and 50Hz. This shows a far larger attenuation than the required 4.61dB calculated previously, suggesting a lower order filter may have been used for this application.

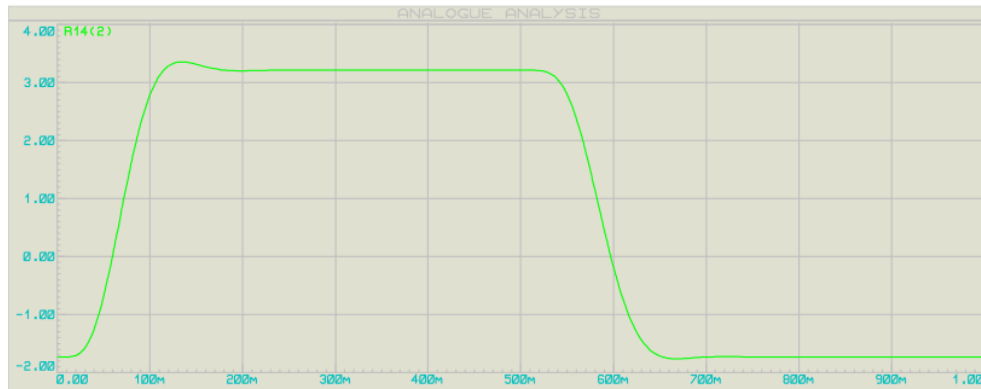


Figure 11 - Analogue Analysis Post Amplification

The output signal has now been amplified to a pk-pk amplitude of 4.94V. Assuming the upper and lower voltage tolerance of 51mV, it is clear this signal operates to the desired accuracy.

Even with the use of a Bessel filter, the output signal does contain a small amount of overshoot. Despite this, the signal has a short settling time relative to the practical rate of change in temperature. This should therefore create minimal, if any, issues for this application.

Whilst the accuracy and range of this signal are now produced within system parameters, it is currently cycling between -1.73V and 2.21V. This signal now needs level shifting to operate between 0 and 5V, per the circuit specification.

Level Shifting:

Using an Op-amp purely as a differential amplifier, a level shifting of the output signal can occur without any amplification. To do this, the gain of the OP-amp needs to be set to one, i.e., all resistive value must be equal. A separate voltage, proportional to the level shift required, will then be fed into the unused input of the Op-amp.

For this design, a resistive value of 10kΩ has been selected.

To keep the output in phase with the system signal, it will be fed into the non-inverting input of the OP-amp. As a result, a negative voltage will be required into the inverting input.

When determining the level shift required, it is intuitive to use the -1.73V minimum voltage measure in figure 11 to set the minimum amplitude to 0V. This however, would only shift the maximum amplitude to 4.94V, 9mV outside of the 51mV allowable tolerance.

Instead, using a voltage of -1.76V will shift the minimum amplitude to 0.03V and the maximum to 4.97V. This will now allow the system to operate within tolerance.

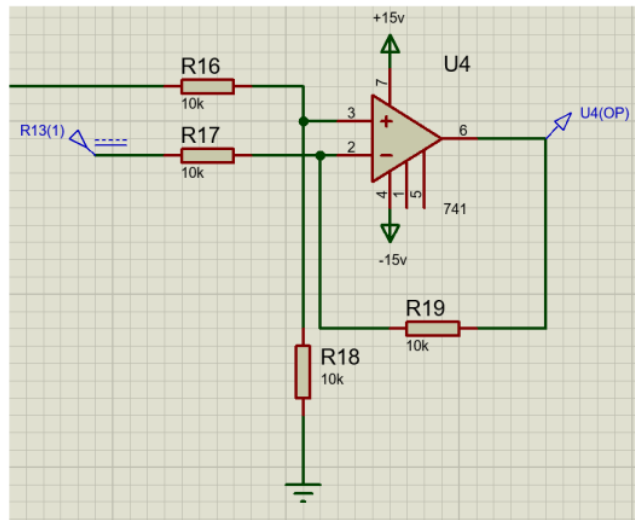


Figure 12 - Level Shifting Circuit

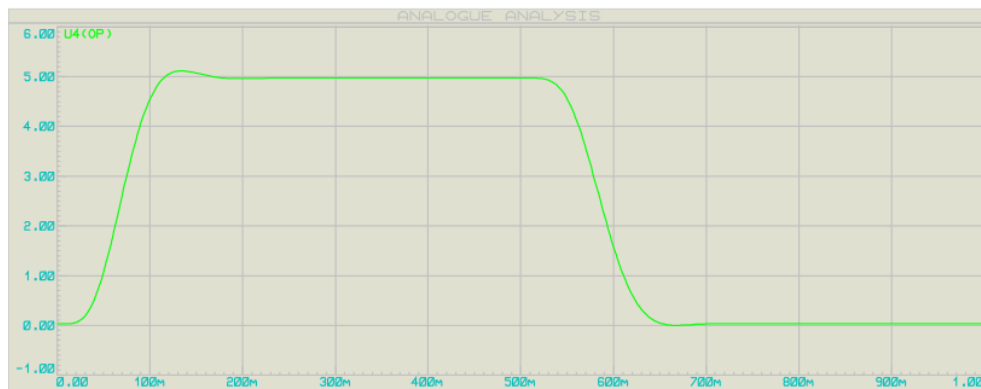


Figure 13 - Final Output Signal

After the level shifting process the final output signal has been produced. The pk-pk amplitude as expected cycles between 0.03V and 4.97V satisfying the system tolerance of 51mV per °C.

This outputted signal now satisfies all design specifications for the system.

Final Circuit Design - Simulation

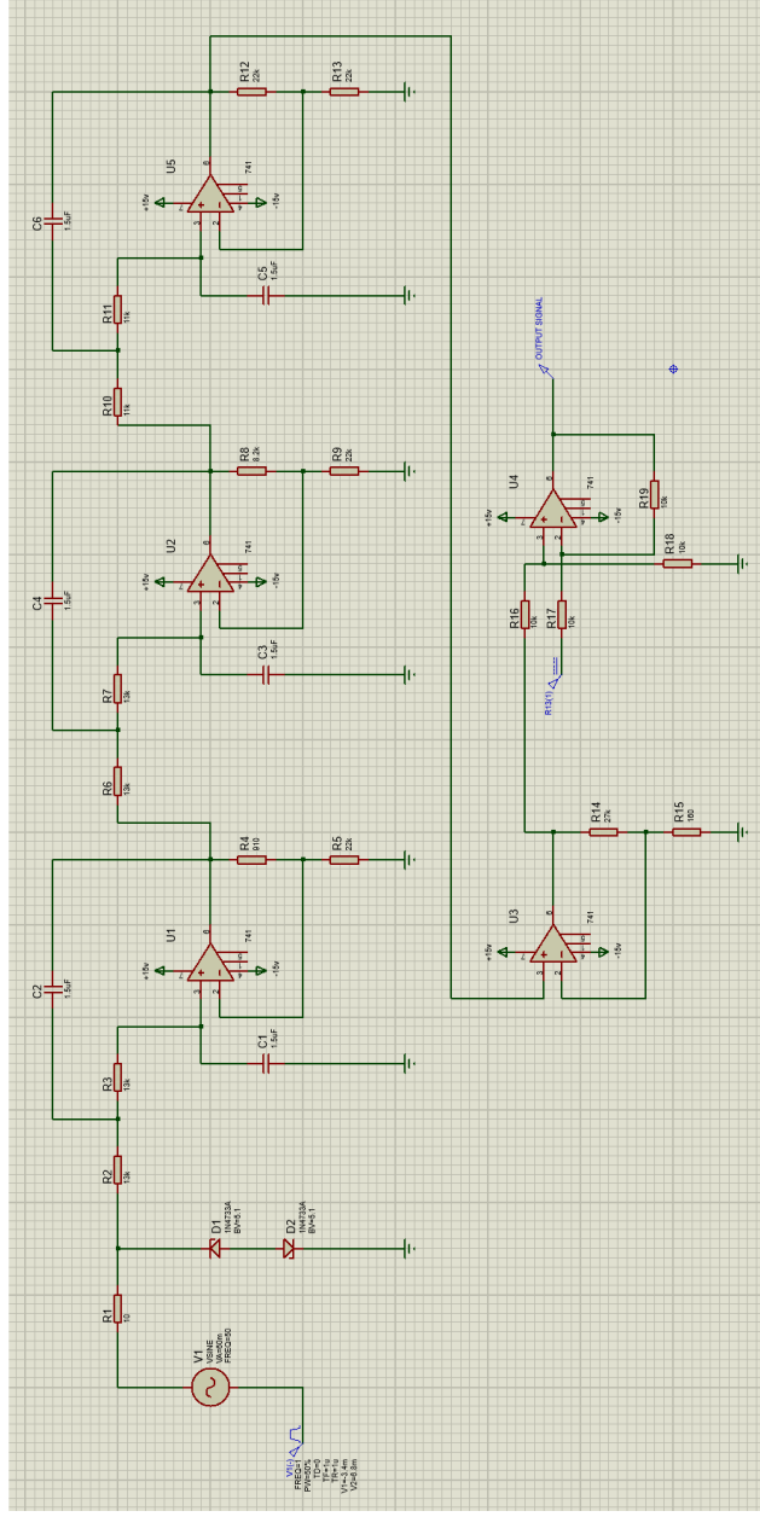


Figure 14 - Simulation of Complete Signal Conditioning Circuit

Conclusion

Through this design process, it has been shown how through the use of operational amplifiers and basic RC components, relatively complex signal conditioning circuits can be created.

The output signal produced shows no signs of external noise and operates within the design parameters required. Minimal overshoot is still present within the signal, however a relatively fast settling time and the practical rate of temperature change, will result in no application error.

The frequency response of this signal shows a much greater attenuation than that required for this circuit application. Initially, a 6th order filter was selected to overcome the poor attenuation characteristic of Bessel filters. This does not appear to have been required. A smaller, cheaper, and less complex 4th order Bessel filter would probably have been sufficient for this task.

Overall, the circuit fulfils all design requirements and would function within a real-world application.

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Signal Conditioning - Gareth Davies

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

76/100

PAGE 1

PAGE 2

QM

Abstract - results

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

PAGE 3

PAGE 4

PAGE 5

QM

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 1

Do you mean mV



Comment 2

What do these equations relate to? You should always caption equations, images, tables etc. so you can point the reader to them when you discuss that object in your text.

I'm assuming the 0.0102V relates to the span of the input signal. You should indicate this more clearly.

PAGE 6



Comment 3

Good. I was looking for the specific type of thermocouple, which you have shown. Well done.



Comment 4

as shown in figure 1



Fig?

Figure not mentioned in text.



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 5

Good introduction, but you need to "join the dots" a bit more clearly. You've shown the equations you've used to determine key specifications and operating characteristics, but not described them in your text.

PAGE 7



Comment 6

...as shown in figure 2



Comment 7

It would actually be the zener voltage plus the forward voltage so...

$$5.1 + 0.7 = 5.8 \text{ V}$$

So any input greater than 5.8V would allow the zener diodes to conduct, reducing the voltage seen by the op amps.

What would an input of 5.8V give as an output? How would the rest of the circuit react to this over-voltage?



Fig?

Figure not mentioned in text.

PAGE 8



Comment 8

Good - see comment on previous page



Comment 9

Why 5 Hz? Why not 1 Hz or 10 Hz?

PAGE 9



Comment 10

Is phase of importance?

The thermocouple gives a DC signal proportional to temperature.



Comment 11

Very good reasoning for choosing a Bessel filter.

PAGE 10



Comment 12

in figure 4



Caption required

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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....

PAGE 11



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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 13

...found in table 1



Comment 14

Table 1

PAGE 12

PAGE 13



Comment 15

As these calculations are essentially repeated for each filter stage, they may have been better presented as one set of equations and a table of calculated results

PAGE 14



Comment 16

Why does this signal have a period of 1 second? (period is measured in seconds, frequency is measured in Hz)

PAGE 15



Comment 17

Good observation

PAGE 16



Comment 18

as shown in equation X. I had to go looking to find this calculation.



Comment 19

What effect will using standard component values have on the sensitivity of the output signal?

PAGE 17

PAGE 18



Comment 20

But this is only a range of 4.94V. What does the missing 60mV of range correspond to in terms of temperature, and is this significant?

PAGE 19

PAGE 20

PAGE 21



Comment 21

What was the response time for the circuit?

PAGE 22



Comment 22

Good range of references, but be careful when using websites. Always check your sources for credibility. You should always try to use peer reviewed articles or academic writings such as textbooks.

PAGE 23

GRADING FORM: SMU GENERIC_SMOSEY

GARETH DAVIES

76

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



A comprehensive range of research informed literature embedded in the work. Excellent

3.75

selection of relevant and credible sources. High-level referencing skills, consistently applied

KNOWLEDGE & UNDERSTANDING

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



Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.

22.5

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.



Thoroughly logical work, supported by evaluated evidence. High quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Strong, persuasive, conclusions, justifiable recommendations.

22.5

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 well, confidently and consistently in a suitable format. Work is coherent and fluent and is well structured and organised. Use captions to direct the reader to the things you want them to see - figures, equations, tables, etc.. - and refer to them in your text by their caption. "...as shown in figure 3..." "... calculated with equation 4..." "These results are shown in table 2."

3.25