

Transducers Assignment 1

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2022

Transducers and Signal Conditioning

ASSIGNMENT 1
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SAFRAN SEATS GB |

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Abstract

The following document will outline the process of designing a temperature sensor for the given parameters in the specification.

This will outline the steps taken to design the sensor, from voltage protection, filtering, gain, and level shifting to achieve the desired specification.

Within this document, it will **outline** the various methodology for designing the various aspects of the sensor, and will show the reason for getting the values for the design.

This document also showcases the circuit being simulated using Proteus, and will detail what those simulations showed and why we can be confident the design of the circuit functions and is correct.

Abstract - results

Introduction

The brief outlines the requirements of the temperature sensor.

Designing the circuit for the temperature sensor will require 4 sections. Those sections include:

- Over Voltage Protection
- Filtering
- Gain/Amplification
- Level Shift

Over Voltage Protection

Over voltage protection circuits are designed to prevent any potentially dangerous voltages from creeping through the rest of the circuit, and potentially damaging components within the circuit. This can be achieved through Zener diodes. Most power supplies will use an over voltage protection circuit to prevent damage to other electrical components within the circuit being powered. A threshold will be set by the values of the zener diodes, where if the supply voltage exceeds this threshold, the zener diodes will 'open' allowing current to flow through.

Filtering

Filtering circuits are designed to filter out any unwanted noise in the circuit. A common type of filter used in various applications is a low pass filter. This type of filter will allow frequencies **on the low** end through but will prevent higher frequencies from passing through. These types of filters are commonly used in loudspeakers.

Butterworth Filter

The Butterworth low pass filter will provide a maximally flat response, with a moderate amount of distortion. This filter will have a small amount of overshooting but should be relatively flat with an almost critically damped effect on the output signal.

Chebyshev Filter

The Chebyshev filter will allow for more overshooting and ripples within the passband. This filter will also have a steeper roll off at the frequency cut off that'll be designed into the filter parameters. However, the downside to this filter compared to the Butterworth filter, is that it has a poor transient response.

Bessel Filter

The Bessel filter will allow for less distortion compared to that of the Butterworth filter, however, will have an increase in response time that will be determined by a certain time constant. The output waveform will have some overshoot and ringing due to the component frequencies of the square waves will shift in time with each other.

[1]Below, the general characteristics of each filter can be seen.

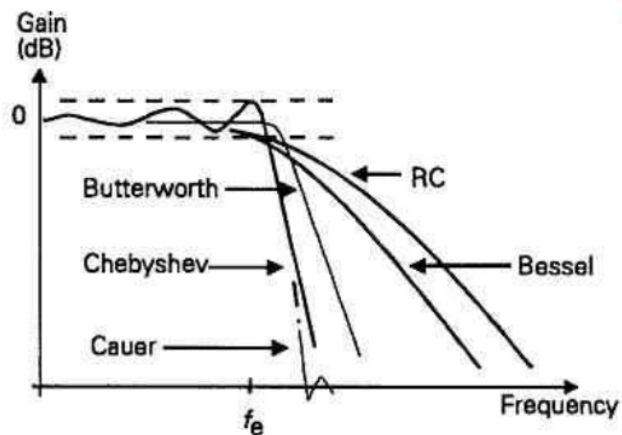


Figure 1- Different Low Pass Filter Characteristics Citation Needed

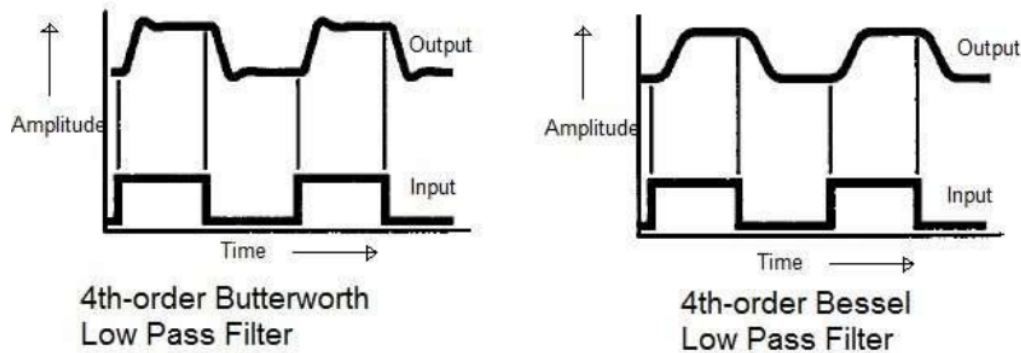


Figure 2- Butterworth VS Bessel Citation Needed

Amplification

Amplification circuit increase the signal voltage to a suitable level. For most systems, this will range from 0-10V, depending on the requirements of the system. In most cases, amplification will take place before level shifting, to provide more accuracy for level shifting to take place.

Level Shifting

Level shift circuits are used to bring the signal voltage into the correct range for the processor. To achieve this, a DC voltage signal will be applied to bring the signal voltage into the required range for the system. [2]However, by doing this, it may introduce **Contraction** into the system, which can affect the response time of the circuit. This is something that'll have to be taken into consideration when designing the circuit. Direction is important when level shifting. By applying the incorrect direction when applying the DC voltage, it will cause the level shift to occur in the wrong direction. If level shifting is required from 3.3V to 5V and the wrong direction is applied, it will instead level shift down to 1.6V. This is also something that'll need to be considered when designing the circuit.

Circuit Design

Various circuits have been designed to achieve the requirements of the temperature sensor. These various circuits are as follows:

- Over Voltage Protection Circuit
- 4th Order Butterworth Low Pass Filter
- Level Shift Circuit – Difference Amplifier
- Op-Amp Gain Circuit – Non-Inverting Amplifier

Input Voltage Signals

A pulse generator was used to supply the circuit with an initial voltage. This was calculated by multiplying the sensitivity of the sensor by the range of the temperature sensor. As the range of the temperature sensor is -50 degrees Celsius to 100 degrees Celsius, the initial voltage was calculated by the following equation.

$$LV = 68\mu V \times -50 = -3.4mV \quad \text{Caption required}$$

The pulsed (high) voltage was calculated by the following equation.

$$HV = 68\mu V \times 100 = 6.8mV \quad \text{Caption required}$$

A sine generator was also used to apply the frequency of our input signal, which was outline in the brief of being 50Hz of interference. This will add 50Hz of noise to the input signal, that'll need to be filtered out of the signal before amplifying.

Over Voltage Protection

To prevent dangerous voltages from entering into the system, two Zener diodes will be used as the over voltage protection circuit. This will be used to cut off the supply voltage to the circuit if it exceeds the voltage set by the over voltage protection circuit. In this circuit, the over voltage protection is set to 5.1V as our circuit doesn't require any more than 5V. If the supply voltage exceeds 5.1V, the Zener diodes will 'open' and allow current to flow through.

4th Order Butterworth Low Pass Filter

This low pass filter is used to filter out any of the higher frequencies that aren't wanted in our signal. The 4th order low pass filter will provide a steeper drop off than what a standard 1st order low pass filter. With an acceptance of 0.5°C, the accepted level of noise was 34μV. To go lower and more accurate than this, it would require a 6th order filter, however, with the application of this sensor, it isn't feasible or needed to go any more accurate than this. With a frequency cut off of 5Hz, the maximum amount of attenuation we can achieve with a 4th order filter is -72.9db but would roughly require -75db of attenuation to reduce the noise in the system.

The level of attenuation required can be calculated by the following equation.

$$20 \times \log_{10} \frac{(34 \times 10^{-6})}{(120 \times 10^{-3})} = -70.954dB \quad \text{Caption required}$$

A frequency cut off of 5Hz was selected as to allow for a low enough drop off at 50Hz.

Calculating the value of the capacitor required for the circuit, the following equation needed to be calculated:

$$X_c = \frac{1}{2\pi FC} \quad \text{Caption required}$$

The capacitive resistance was determined as $15K\Omega$, which was design choice of this circuit. This can then be used to calculate the capacitor value.

$$15K = \frac{1}{2\pi \times 5 \times C}$$

This calculation gave a capacitor value of $2.12\mu F$. The closest retail capacitor is $2.2\mu F$.

The gain resistors of the filter also need to be calculated. To calculate this, the table shown below will need to be followed to determine the values of the resistors. [3]

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 2.235	1.432 1.606	1.084 1.759	0.597 1.031	1.582 2.660	0.471 0.964	1.924 2.782	
6	1.068 1.586 2.483	1.607 1.692 1.908	1.040 1.364 2.023	0.396 0.768 1.011	1.537 2.448 2.846	0.316 0.730 0.983	1.891 2.648 2.904	
8	1.038 1.337 1.889 2.610	1.781 1.835 1.956 2.192	1.024 1.213 1.593 2.184	0.297 0.599 0.861 1.006	1.522 2.379 2.711 2.913	0.238 0.572 0.842 0.990	1.879 2.605 2.821 2.946	

4

Citation Needed

Figure 3- Gain Resistor Table

The table shows the gain values of each stage of the filter, from which we can calculate the resistor values.

$$1.152 = 1 + \frac{R1}{R2}$$

Caption required

With $R1$ equalling $10K\Omega$ (design choice), when put into the equation above, the value for $R2$ came out as 1520Ω . The closest retail resistor value to this is $1.5K\Omega$.

The same is done for the second stage of the filter. Using the value given from the table above, the following equation will calculate the gain resistor values.

$$2.235 = 1 + \frac{R1}{R2}$$

Caption required

Again, with $R1$ equalling $10K\Omega$ (design choice), when put into the equation above, the value for the $R2$ came out as 12350Ω , with the closest retail resistor value being $12K\Omega$.

Op-Amp Gain Circuit

The op-amp gain circuit will amplify the input signal voltage to achieve the desired output. This is done before level shifting as it is more accurate after amplification has taken place. The gain of the circuit is determined by the resistors, which is determined by the following equation:

$$ACL = 1 + (R1/R2)$$

Caption required

By altering $R1$ and $R2$ will determine the gain. This is required when the amplified output signal needs to be in phase with the input signal. To calculate the values of $R1$ and $R2$ we need to know how much gain is required to achieve the desired output. This can be determined by dividing the range of the input voltages by the range of the output voltage. This equation is shown below.

$$\text{Gain} = \frac{5}{0.0102} = 490.1961$$

This value was calculated using an Excel spreadsheet, to determine all values within this circuit.

$$10^{45.474} = \frac{V_{out}}{V_{in}} = 193.807$$

This value can then be used to calculate the resistor value of R2 for the gain circuit.

$$193.807 = 1 + \frac{R1}{R2}$$

Where R1 equals 100Ω, R2 equals $192.807 \times 100 = 19280\Omega$. The closest retail resistor would be 19.5KΩ.

Level Shift Circuit

The level shift circuit will amplify the difference between the input voltages. By changing one of the input voltages, will alter the output voltage which will shift the output to the required direction. This circuit can also be used to solve equations if the difference between two input voltages needs to be known.

To calculate the level shift voltage required for the system, the circuit was simulated with no level shift voltage applied to the circuit. From reading the graph simulated, it identified the required voltage to shift the output to its desired range.

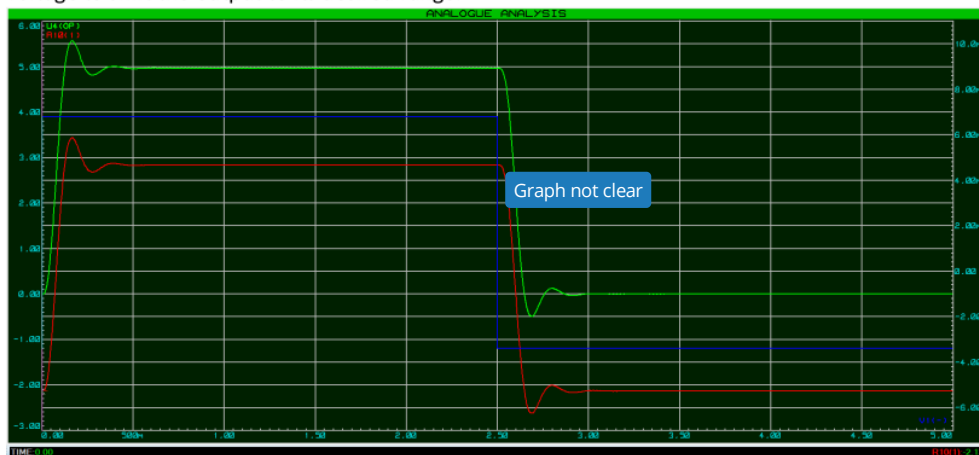


Figure 4- Level Shift Graph

From the graph above, the red line is showcasing the voltage signal before level shifting has taken place. From pointing at the start point of the graph, we can see that -2.13V needs to be applied to the signal so the signal will start at 0V and peak at 5V. This can be seen by the green line, which is showcasing the output signal once level shifting has occurred.

Simulation Setups
Overall Circuit Diagram

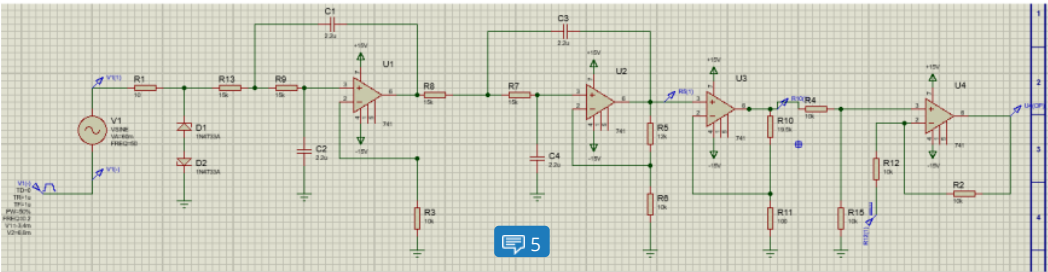


Figure 5- Overall Circuit Diagram

Over Voltage Protection Circuit

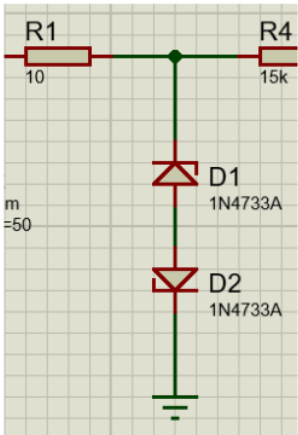


Figure 6- Over Voltage Protection Circuit

Filtering Circuit

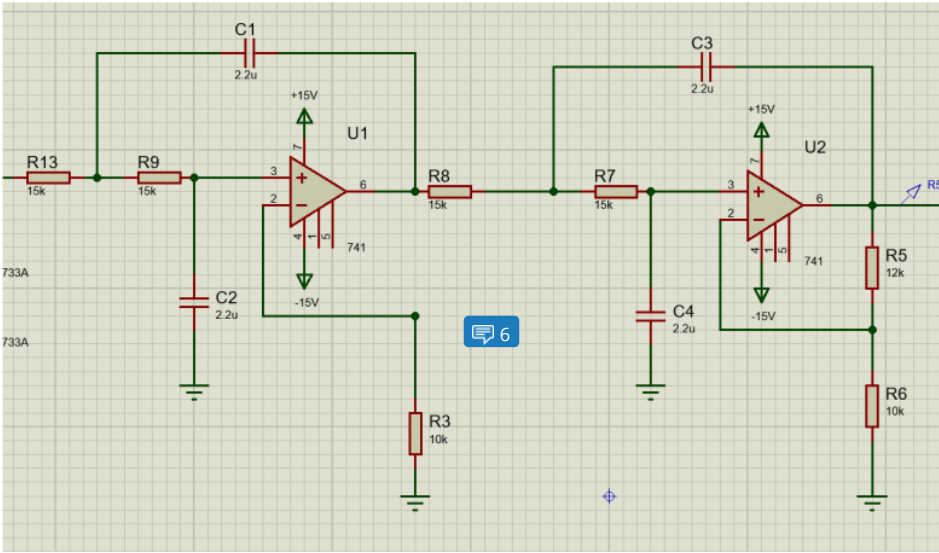


Figure 7- 4th Order Butterworth Filter

Amplifying Circuit

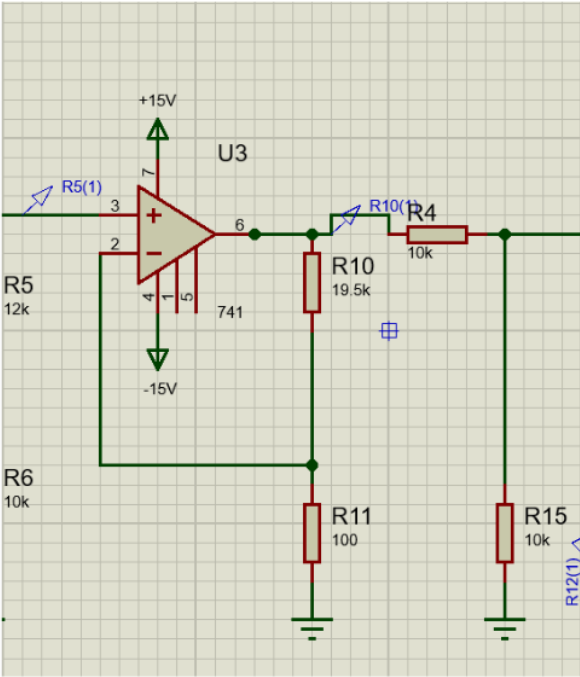


Figure 8- Amplifying Circuit

Level Shifting Circuit

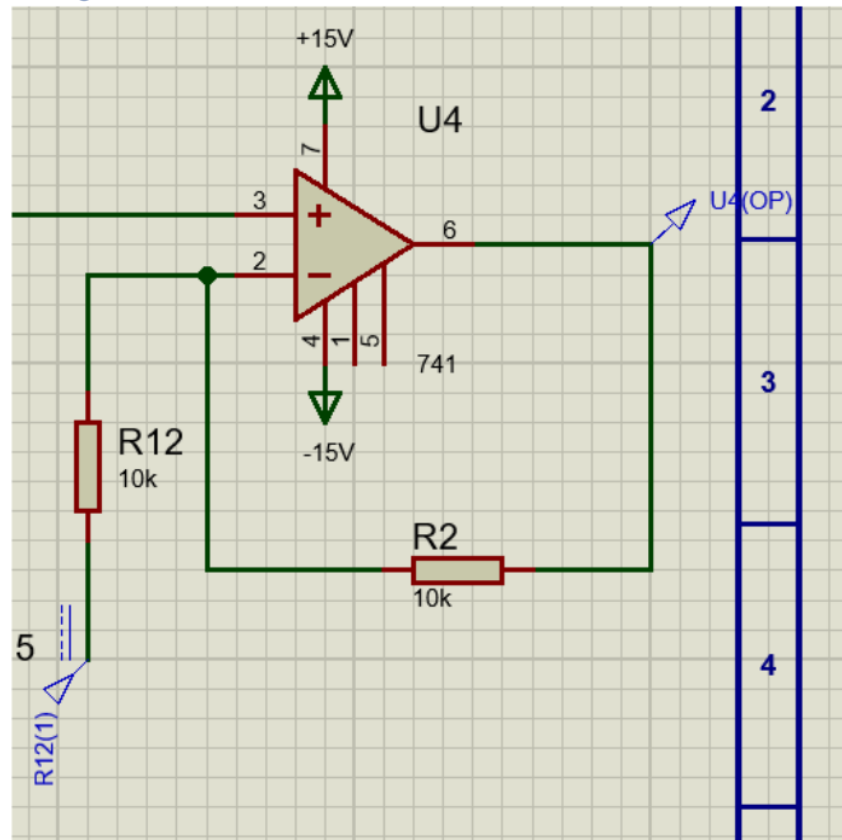


Figure 9- Level Shift Circuit

Figure 10- Frequency Response Graph

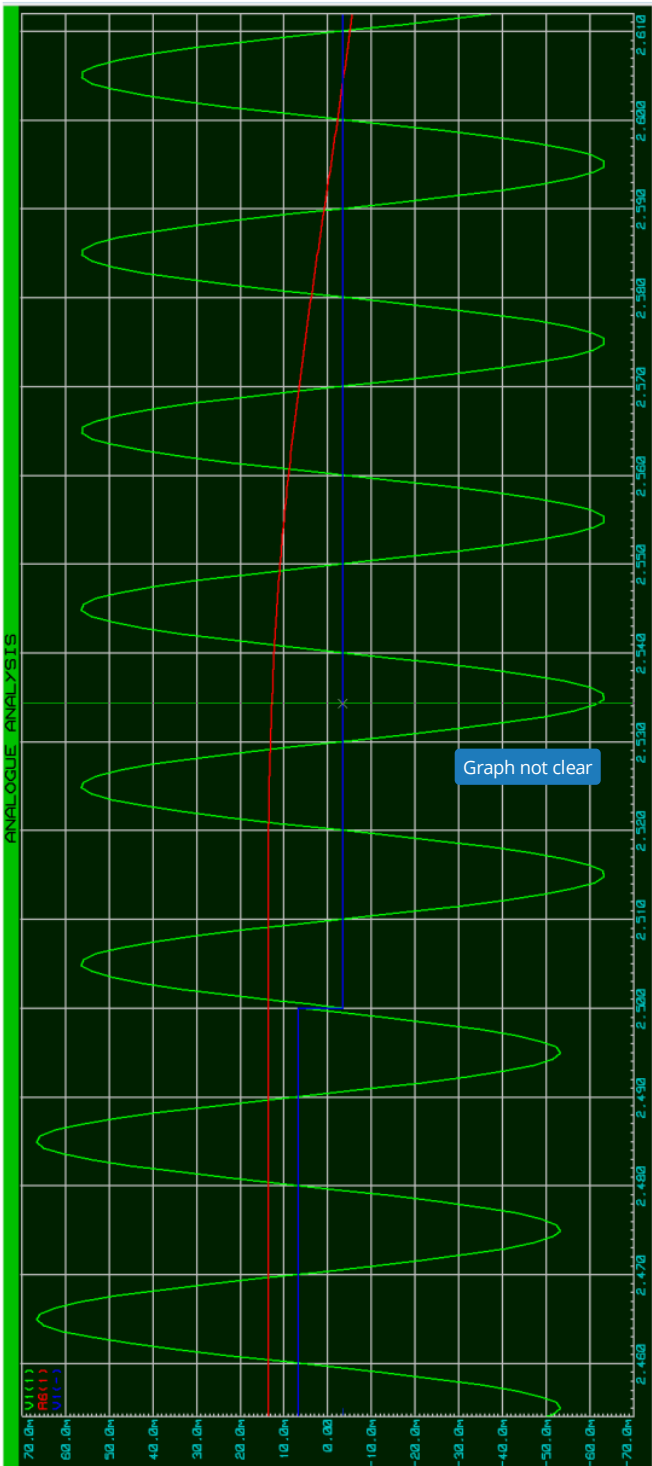


Figure 11- Analogue Graph Showing Noise

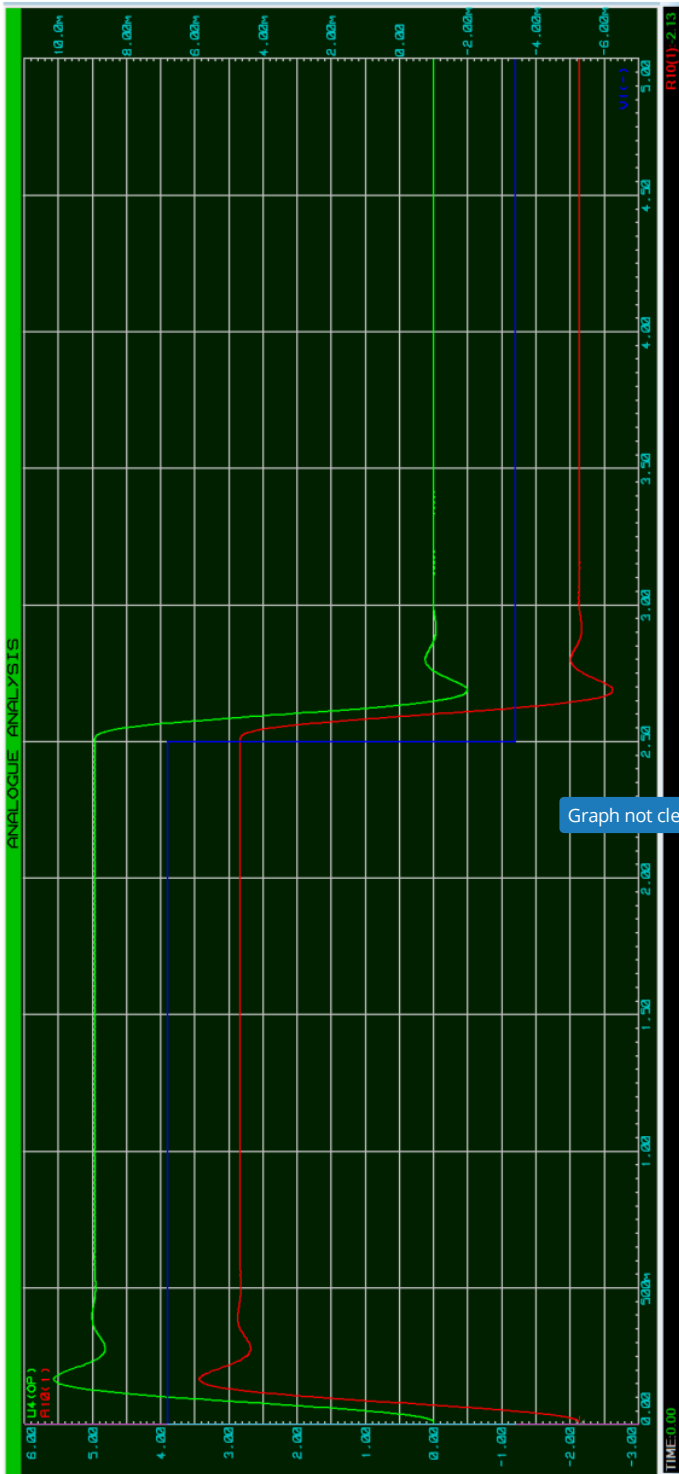


Figure 12- Analogue Graph with Level Shift

Discussion

From simulating the circuit on proteus, we can see from various graphs exactly what our circuit is doing, which will validate our workings.

Figure 10- Frequency Response Graph shows the frequency cut off of our signal. From the graph, we can see that the frequency cuts off at 5Hz, which is what we designed it to do. This graph shows the filtered input signal, and also the filtered amplified signal. This also confirms our workings within the excel spreadsheet used to calculate the gain required in the circuit. From this graph we can also see that the signal is maximally flat with a fairly steep drop off at the 5Hz frequency cut off. This drop off could've been made steeper with a 6th order filter, or a Chebyshev filter, but would have an increased response time with more oscillations and overshooting as a result. The graph also shows the two signals being completely in phase with each other.

Figure 11- Analogue Graph Showing Noise is showcasing the input signal with noise, our unfiltered input signal with no noise and our filtered signal. This showcases that the filter has been effective, as nearly all of the noise has been filtered out of our signal before being amplified.

Figure 12- Analogue Graph with Level Shift is showcasing the unfiltered input signal, the filtered amplified signal and the filtered amplified signal with level shifting taking place. From this graph, we can determine the response time of our circuit. From this graph, we can determine that the response time is roughly 500ms, which is more than sufficient for a temperature sensor, as temperature gradually increases and doesn't tend to spike. This graph also shows us there is some over shooting from our output signal and takes roughly 375ms from it over shooting to settle. This could be improved by implementing damping onto the level shift circuit. However, by doing so, the overshooting issue is solved, but the response time of the system is increased as there is more resistance in the circuit. The response time from 5V to 0V is virtually the same the response time from 0V to 5V of around 500ms.

This graph also showcases and proves the level shifting has taken place. We can see that the output signal ranges from 0-5V, as described in the brief. Therefore, at -50°C, the output voltage is 0V and at 100°C, the output voltage is 5V.

Sourced Temperature Sensor

After confirming the circuit designed functions as intended, a temperature sensor fitting the parameters of the circuit designed was found. The sensor sourced is a type E thermocouple, meaning that it has a sensitivity of $68\mu\text{V}/^\circ\text{C}$, the same as the circuit designed above. This particular sensor also meets the temperature range required, with a range from -50°C to 200°C. The datasheet for this sensor can be found below in the reference list. [4]



Conclusion

To conclude, there are a few point we can take away from this experiment. The first point to take away is that the design of the circuit functions as intended. The output voltage of the circuit has been shifted so that at -50°C , the output voltage is 0V and at 100°C the output voltage is 5V.

From simulating the circuit, the response time can be determined. From looking at the simulation graphs, the response time of the circuit was roughly 500ms. This is more than fast enough for measuring temperature as temperature tends to not 'spike' and is more of a gradual increase.

Finally, a temperature sensor that meets the parameters of our circuit was found. Therefore, if this circuit was required in a real world application, then the sensor sourced would be most likely be used.

References

- [1] S. Mosey, *Passive and Active Filters*, UWTSD, 2016.
- [2] "Arrow," [Online]. Available: <https://www.arrow.com/en/research-and-events/articles/using-a-level-shifter-to-integrate-different-voltage-signals>. [Accessed 30 November 2022].
- [3] H. & Hill, in *Art of Electronics*, p. 408. Refs missing info
- [4] "Farnell," [Online]. Available: <https://www.farnell.com/datasheets/2340219.pdf>. [Accessed 29 November 2022].

Ref Qty

Transducers Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

59 / 100

PAGE 1

PAGE 2

PAGE 3



Comment 1

You've used *outline* three times in three sentences.

QM

Abstract - results

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

PAGE 4

QM

Colloquialism

You should not use colloquialisms in formal writing.

PAGE 5

QM

Citation Needed

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QM

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Contraction

In formal academic writing, you should avoid using contractions like "aren't" "can't" "don't" etc. instead you should use the full form of the words. "Are not" "Can not", "Do not".

PAGE 6



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....



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....



Comment 2

input signal voltage, not [power] supply voltage



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....



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 7



Comment 3

If this reference relates to the table, then it should be in the caption for the table



Citation Needed

Cite Source:

Please use the link below to find links to information regarding specific citation styles:

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Comment 4

Table not Figure



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....



Caption required

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Caption required

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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....



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.

PAGE 9



Comment 5

Good circuit diagram, although it is not very clear. Splitting it into smaller chunks may have helped this.

PAGE 10



Comment 6

There is a resistor missing from the top of R3 to the output of U1

PAGE 11

PAGE 12



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.

PAGE 13



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.

PAGE 14



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.

PAGE 15



Comment 7

I think you need to come up with some more verbs. Consider:

Shows
Highlights
Indicates
Suggests
Exhibits
Displays
Conveys
Communicates



Comment 8

...or by using a Bessel filter



Comment 9

Excellent, well identified

PAGE 16



Comment 10

...almost

PAGE 17

QM

Refs missing info

Some of your references are missing information. To understand what information should be included, see the university IEEE referencing handbook on the library website.

https://uwtsd.ac.uk/media/uwtsd-website/content-assets/documents/library-and-learning-resources/infoskills/IEEE-eng_v.1.2.pdf

QM

Ref Qty

I was hoping for more references

RYAN STAPLETON

58.75

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



References to a limited range of mostly relevant sources. Some omissions and minor errors. Referencing conventions evident though not always applied consistently.

2.25

KNOWLEDGE & UNDERSTANDING

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



Knowledge is accurate with a good understanding of the field of study.

16.8

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.



Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments, and to review the reliability, validity and significance of evidence. Ability to communicate ideas and evidence accurately and

19.2

convincingly. Sound, convincing conclusions / recommendations

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A very good application of a range of methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive use of examples, where relevant. Evidence of some innovation and creativity.

18

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 effectively in a suitable format, but may have minor errors. Mostly coherent work and is in a suitable structure.

2.5