

Curtis Rees 2003711

by Curtis Rees

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Curtis Rees

2003711

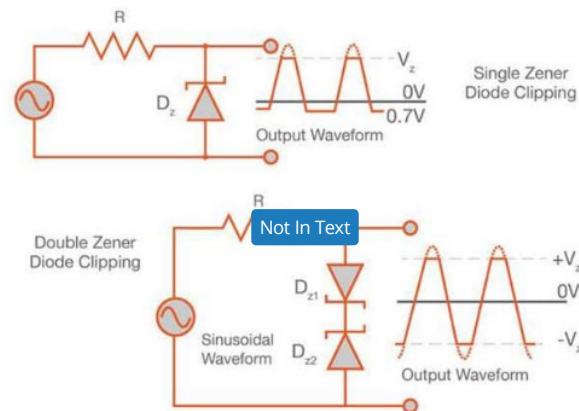
Transducers and Signal Conditioning

Abstract

This report contains a design for a signal conditioning circuit that will produce a signal of 0V for a temperature of 50°C and 5V for 100°C. The temperature sensor used produces $68\mu\text{V}/^\circ\text{C}$ with $0\text{V} = 0^\circ\text{C}$. However, in my circuit design I am going to need to design an appropriate filter in order to remove the contamination of the output voltage with a 120mVpk-pk 50Hz mains interference. It was important to design my circuit with different stages such as over voltage protection, filtering, gain and level shifting. In addition to this I will be determining the response time for my design and sourcing a temperature sensor that matches the specifications given.

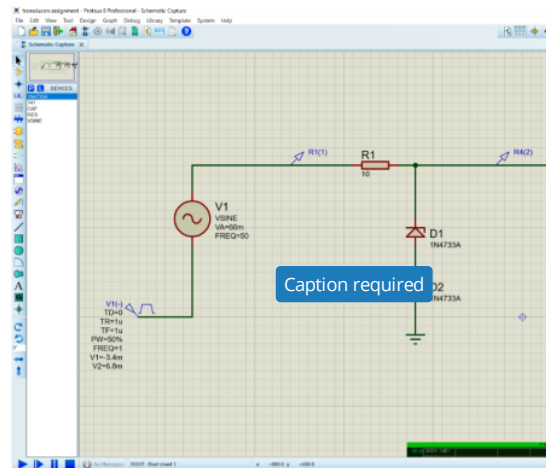
Circuit design and general background information

The first stage of the circuit design is over voltage protection. Overvoltage protection ensures that the system runs undamaged despite potential changes in the external conditions, specifically those that cause overvoltage and power surges. [1] The main component we use to achieve over voltage protection is a Zener diode. These have a well-defined reverse breakdown voltage, which means that it starts conducting current and continues operating continuously in the reverse bias mode without getting damaged. In addition to this, the voltage drop across the diode remains constant over a wide range of voltages therefore, making it suitable to be used in voltage regulation.

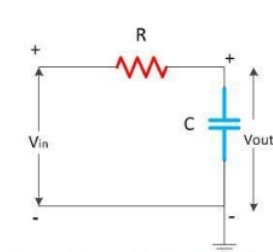


Some applications of the Zener diode clipping circuit (over voltage protection) shown in figure 1, could be power supplies, where it's important to keep the voltage within a specific region to prevent damaging any parts. As well as power supplies, diode clipping circuits can be used to eliminate excess ripples in signals that exceed a particular noise level. For example in FM transmitters, where it's important to have a voltage regulator to reduce unwanted noise therefore, improving sound quality. Another application of figure 1 is to adjust existing waveforms and create new ones. For example the waveform can be adjustable in different types of ways, it can be in the shape of a Sine wave, which is the most efficient waveform and is used in musical tones etc. Or even adjusted to be a square wave which is useful as timing references in microprocessors. [2]

My over voltage protection design on proteus is shown below:



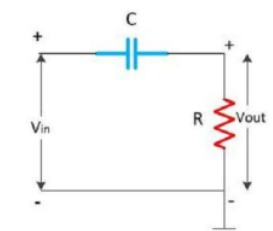
The second design stage of the circuit is the signal filtering. There are four main types of filters and these include low-pass filters, high-pass filters, band-pass filters and finally a notch filter which can all be used in different ways to allow certain parts of the signal through while blocking parts. A low pass



Low-Pass R-C Circuit

Figure 2 [8]

RC filter passes low-frequency signals blocks or impedes high frequency signals. In figure 2 you can see that if high-frequency signal enters the low pass RC filter circuit then the capacitor will allow it to pass and it will be passed to ground. Therefore, meaning the output voltage obtained is zero as the entire voltage is passed to ground. On the other hand if low frequency signal enters the low pass filter circuit then it will generate the output, because the resistance will offer the same obstruction as in the case of high frequency however, the capacitor will provide infinite resistance. Low pass filters are often used in digital to analogy converters.



High-Pass R-C Circuit

Figure 3 [8]

Another useful filter could be a high-pass filter which attenuates the low-frequency signal and allows only high-frequency signal to pass through it. This is the direct opposite to a low-pass filter. As figure 3 shows the components of a high pass filter is just the opposite way around, having the capacitor before the resistor. An application of a high-pass filter is in stereo systems where a capacitor connected in series with the treble speaker will serve as a high pass filter. It imposes a high impedance to low frequency bass signals, therefore making it more efficient by preventing the power from being wasted on a speaker inefficient for reproducing such sounds. [3]

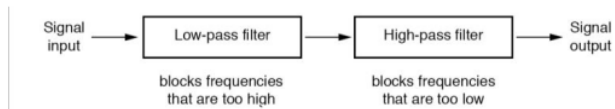


Figure 4 [9]

Caption - description

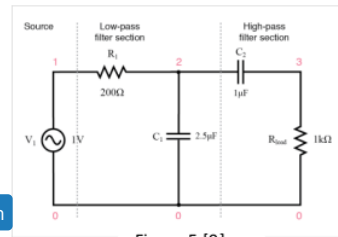


Figure 5 [9]

Another filter which is used regularly is a band-pass filter which is a device that passes frequencies within a certain range and attenuates (rejects) frequencies outside that range. It contrasts both a high-pass filter which allows through frequencies above a specific frequency, with a low pass filter which allows frequencies below a specific frequency. One downside to using a bandpass filter is that it does not attenuate all frequencies outside the desired frequency range completely. You can experience filter roll off which is the region just outside the intended band pass where frequencies are attenuated but not rejected, this could cause problems. Sometimes it is necessary to only pass a certain range of frequencies and this filter allows you to do so, that's why they are often used in audio amplifier applications or circuits such as in loudspeaker crossover filters or pre-amplifier tone controls. [4]

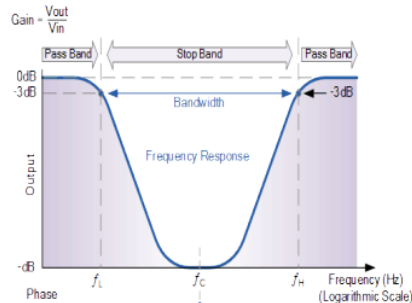


Figure 6 [10]

Final main type of filter for signal processing is a notch filter (band-stop filter) which is a filter that passes most frequencies unaltered but attenuates a specific range while leaving a low level of high frequencies. It is the direct opposite of a band-pass filter which I previously just talked about. These filters are highly selective, high Q-factor, form of the band stop filter which is used to reject a very small band of frequencies. For example this type of filter is useful to attenuate or reject a specific frequency such as a mains hum, which has been induced into a circuit from inductive loads such as motors or ballast lighting.

Use of 1st Person

In addition to these filters, there are Butterworth responses, Chebyshev responses and elliptic responses that can be chosen for my signal design. A Butterworth filter is designed to have as flat of a frequency response as possible, with no ripples in the pass-band and zero roll off response in the stop-band. However, a Chebyshev response will see a faster roll-off by allowing ripple in the frequency response in either the stop-band or pass-band. Finally an elliptic response is for situations where very fast transitions are required between both the passband and stopband. [5]

For the filtering stage of the circuit I have designed two low pass Butterworth filter designs in series with the function of removing noise and attenuation and allowing for a clean signal to be produced. The signal is shown later in the simulation setups.

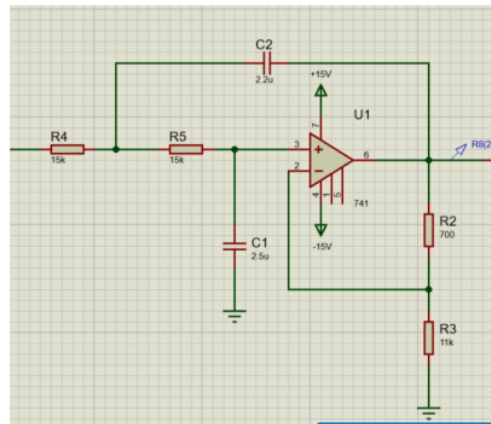


Figure 7

Caption - description

Figure 7 shows the first low pass Butterworth filter that I have incorporated into my circuit design. The gain of the op amp is shown below as well as the calculations for the resistor values.

Amp 1 gain =

$$1 + R2 / R1$$

$$1 + 700 / 11000$$

$$= 16.714 \text{ 3d.p}$$

$$R1 = 11k \Omega$$

$$R2 = 0.000063636 \times R1$$

$$R2 = 0.000063636 \times 11k$$

$$R2 = 700 \Omega$$

Next part of the low pass filtering design stage is the second low pass filter. Shown later in the simulation setup, the signal after just one low pass filter is not steep enough, meaning the stop band was too gentle. When designing the circuit, I aimed for the circuit to be as square edged as possible while maintaining the 0v-5v range. By adding the second low pass Butterworth filter this helped me do so.

Figure 8 below shows my design of the second low pass filter with the calculations for the gain along with the resistor values that were used to smoothen out the ripples.

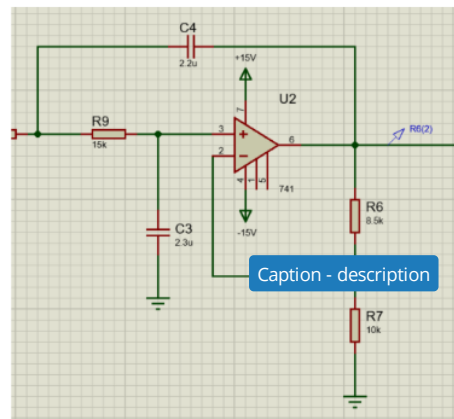


Figure 8

Amp 2 gain =

$$1 + R2 / R1$$

$$1 + 8.5k / 10k$$

$$= 1.176 \text{ 3d.p}$$

$$R1 = 10k \Omega \quad \text{Caption required}$$

$$R2 = 0.85 \times R1$$

$$R2 = 0.85 \times 10k$$

$$R2 = 8.5k \Omega$$

4th Order

$$F_c = 50\text{Hz}$$

$$X_c = 15k\Omega$$

$$\text{Caption required}$$

$$15000 = 1 / (2\pi \times 50 \times C)$$

$$C = 1 / (2\pi \times 50 \times 15k) = 2.12\mu\text{F}$$

Therefore use 2.2μF Capacitor

Next stage of the design process for the circuit is for amplifying. An amplifier is an electronic device that increases the voltage, current or power of a signal. The use of an amplifier in my circuit is very important as it amplifies the signal from the sensor while amplifying the input voltage. By using an amplifier circuit, it makes it much easier for me to perform analogue-to-digital conversions, which are needed for the temperature sensor to give appropriate readings.

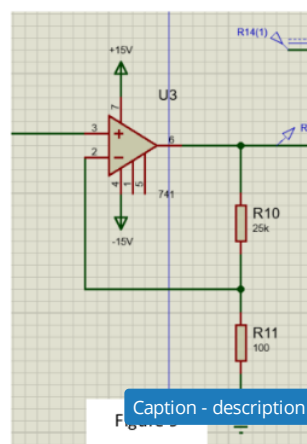


Figure 9

Use of 1st Person Voice

More specifically I used a non-inverting amplifier which produces an output signal that is in phase with the input signal, whereas an inverting amplifier's circuit is out of phase. Both inverting and non-inverting op amps can be constructed from one op amp and two resistors, just connected in different configurations. [6]

Use of 1st Person Voice

Use of 1st Person Voice

Figure 9 shows my circuit design within my circuit. I've got the op-amp connected to both +15V power supply as well as a -15V power supply. Later in the results I will show the effect this has on the signal.

Use of 1st Person Voice

Use of 1st Person Voice

Use of 1st Person Voice

Use of 1st Person Voice

My final design stage for my circuit was level shifting. The reason I have decided to incorporate a level shifting circuit is because of the multiple gain stages used in the op-amp. The function of the level shifting is to shift the level at the output of the intermediate stage down to zero. The reason why level shifting is the last stage of my circuit is because it improves the final output signal accuracy and makes more sense to set the voltage to zero at the final stage. The DC generator 'R14(1)' was set to -2.2V and R12 was altered from 10k to 9.88k as this helped achieve as close to zero offset as possible.

Figure 10 shows the level shifting stage in my circuit design.

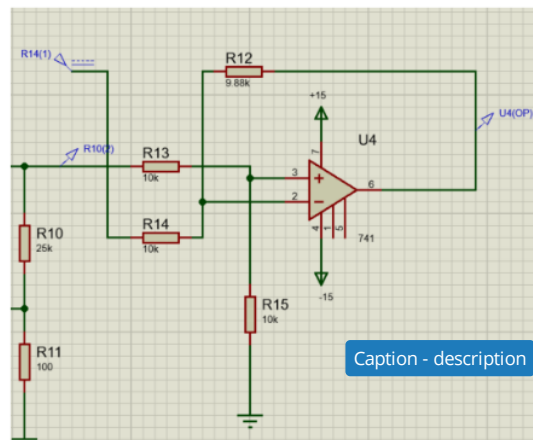


Figure 10

Additionally, when the circuit was designed I calculated an acceptable noise output of 0.5°C.

$0.5 \times 68\mu$ Caption required

$$20 \times \log_{10} (34 \times 10^6 / 120 \times 10^{-3}) = -70.95\text{dB}$$

Simulation setup

Use of 1st Person Voice

Use of 1st Person Voice

Now that I have designed and constructed my circuit on proteus, I now need to simulate the circuit to gather data and have greater understand on what the circuit is doing. By simulating the circuit it helps finds any problems or design issues that have previously been made, such as resister values or capacitor values or even incorrect connections between the components.

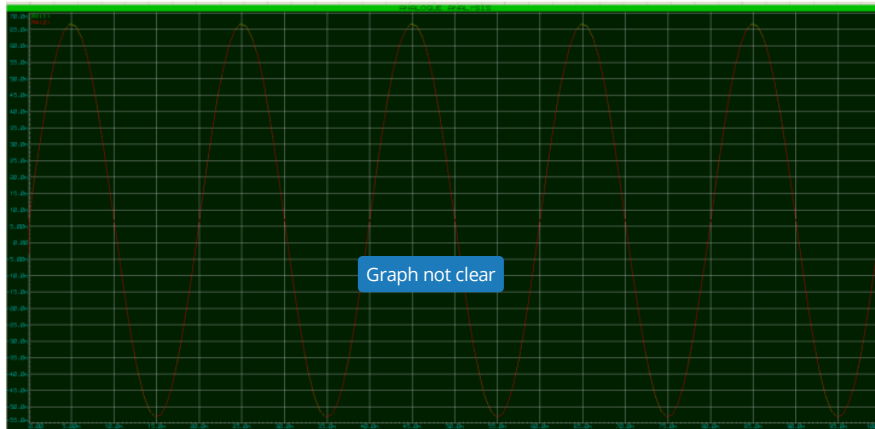


Figure 11

Caption - description

So the first step was to place two voltage probes either side of my voltage protection circuit. From the results in Figure 11 I can see that there is a clear sine wave which peaks from +60V to -60V and this is probe showcasing the signal before the over voltage protection. However, looking at the green tracer I see that its no longer a sine wave and that the signal is capped at 5.1V. The reason its capped at 5.1V is because the two Zener diodes which have been designed to do so to protect the circuit.

Use of 1st Person Voice

Use of 1st Person Voice

Next step is to simulate the filtering process. The circuit consists of two low pass butterworth filters which are used to remove ripples and noise from the signal and to attenuate the contamination.

9



Figure 12

Caption - description

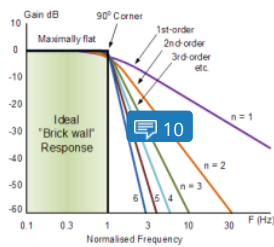


Figure 13 [11]

Caption - description

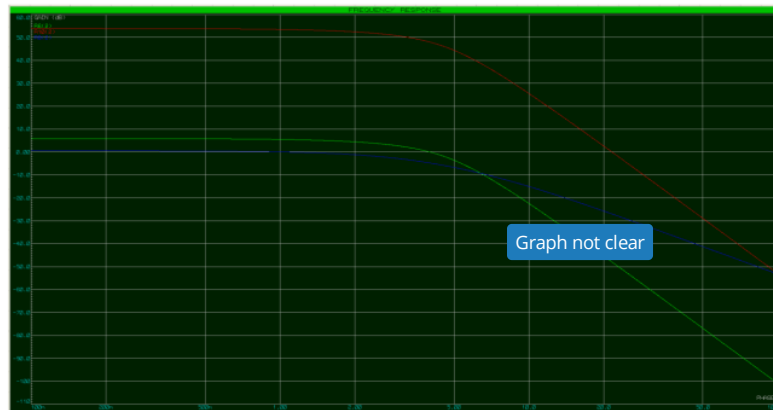


Figure 14

Caption - description

Next step of the simulation is to amplify the 2nd order low pass Butterworth filter which can be seen in figure 14. Like I've previously mentioned, the importance of an amplifier is to amplify the voltage making it easier to read. The green trace line shows before the gain and the red trace line shows after the gain.

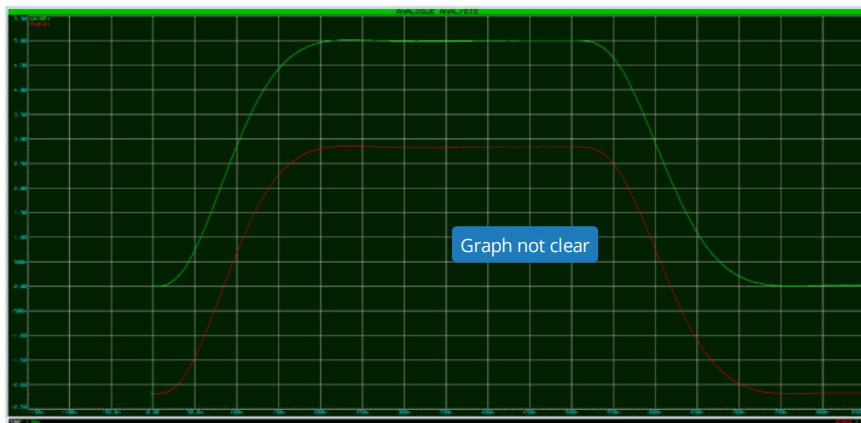


Figure 15

Caption - description

Figure 15 shows the analogue analysis graph showing the simulation of the level shifting circuit design. The yellow trace line is the measurement after the amplifier stage (before the level shifting) and has an offset voltage of 2.1V. We want the offset voltage to be as close to zero as possible and this is why we shift and change its position. The green trace line is the result of the level shifting circuit and you can see that its very close to zero offset voltage.

Results

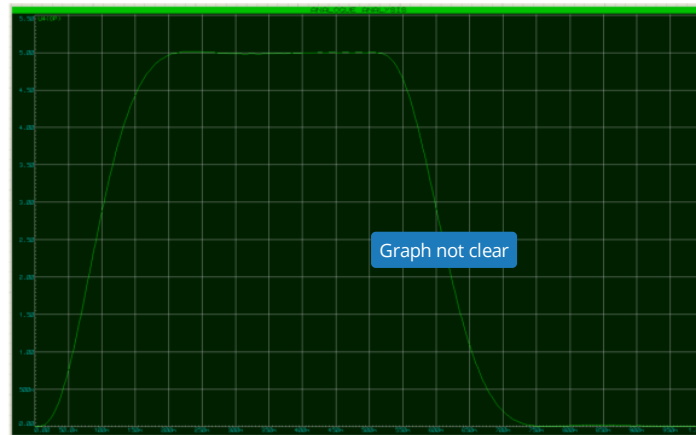


Figure 16 Caption - description

Figure 16 is the final output voltage after all the stages of the circuit. From the graph you can see a very smooth square-like signal which is what I expected to see from the circuit. It's got an offset voltage of 6.64mV and rises fairly quickly to the peak voltage of 5.01V. Despite trying to minimise the ripple voltage as much as possible I've still got a very small ripple. From the graph, the ripple rises to 5.01V, slightly drops down to 4.98V before levelling off at 5V.

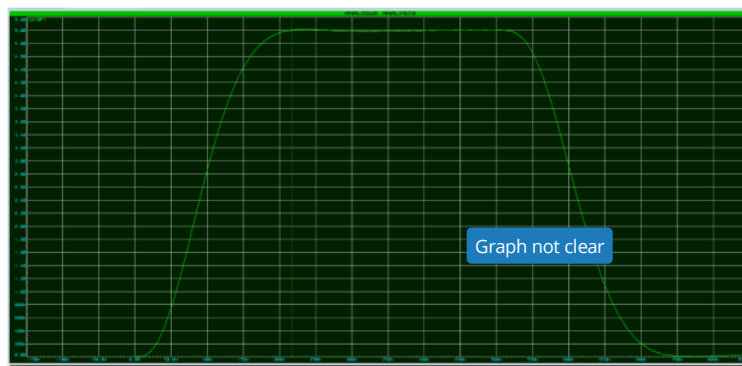


Figure 17 Caption - description

To calculate the response time for the design I used a previous measure tool which I placed at 5V at the peak voltage and read the X axis results of '216m'. Therefore, the response time for my

14

design is 0.216 seconds. Before reading my result /made sure the signal started as close to 0V and 0ms as possible.

Use of 1st Person Voice

Temperature sensor that matches the specification

RS PRO Type K Thermocouple
1m Length, 1/0.2mm Diameter
→ +250°C

RS Stock No.: 363-0250



Figure 19

Caption - description

Figure 19 is a thermocouple temperature sensor that meets my specification costing £7.08. When selecting an appropriate thermocouple there are a few factors that needed to be considered. When searching for one I made sure that it would be compatible with the temperature range of -50°C - 100°C. Data sheet for this thermocouple states that it is a type K and has a temperature range of -75°C to +250°C which meets the specification. It does not state the response time but is said to have a fast response time so again meets my specification.

DM-508

RTD Sensor, Thin Film, Class A, 2x5mm, -50 °C, +400 °C, 100 ohm, DM Series



Despite finding a temperature sensor that meets the specification, I found a RTD temperature probe that meets the specification for a fraction of the price at £3.67. Data sheet states that its capable for use from -50°C to +500°C, which meets the specification. Another benefit of using this this is the high level accuracy, +-0.05% stability. It also states the thermal response time of 0.1s and with my circuit having a response time of 0.216s it meets the specification.

Conclusion

In conclusion I have used the different over voltage protection, filtering, gain and level shifting circuits in order to condition the signal so its suitable for my chosen RTD temperature measuring probe. Voltage probes throughout the circuit design show how the different stages effected the signal and also how the ratio between the resisters can alter the peak voltage . Additionally, the capacitors are used in smoothening out of the signal and removing the ripple.

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]

FINAL GRADE

GENERAL COMMENTS

Instructor

53/100

PAGE 1

PAGE 2



Use of 1st Person Voice

When writing technical reports, do not use first person voice. Instead, use the third person passive voice.

You should not use words like "I", "you", "we" etc..



Abstract - results

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



Not In Text

You have included a figure without mentioning it in the text. You should refer to the figure in the text, otherwise it is not worth including as the reader will not know what it relates to.

PAGE 3



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

You should avoid using words like "you" in academic writing.

In figure 2 it can be seen that...

PAGE 4

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Caption - description

Caption should include a description

QM

Use of 1st Person Voice

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PAGE 5



Comment 2

Although it has two amplifiers, it is only one filter. It is a 4th order Butterworth filter made from two 2nd order VCVS filter sections.

QM

Caption - description

Caption should include a description

QM

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Comment 3

How did you decide what the gain should be? To get a specific filter response the amplifier gains must be set accurately .



Comment 4

These equations seem to go round and round back to where you started.

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 5

No, the stop band attenuation is not enough

PAGE 6

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Caption - description

Caption should include a description

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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....

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Caption - description

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PAGE 7

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Comment 6

No. It places the signal range at the correct values. In the assignment brief I asked for $-50^{\circ}\text{C} = 0\text{V}$ and $100^{\circ}\text{C} = 5\text{V}$. You cannot achieve this without level shifting.



Comment 7

Is 9.88K a preferred value for a resistor?



Comment 8

But what did it do to the sensitivity of the circuit?

QM

Caption - description

Caption should include a description

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Caption required

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PAGE 8

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QM

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.

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Comment 9

two 2nd order filter SECTIONS making ONE FILTER



Graph not clear

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



Caption - description

Caption should include a description

PAGE 9



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Comment 10

Needs to be bigger. Text in image is unclear



Caption - description

Caption should include a description



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.



Caption - description

Caption should include a description



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Comment 11

Figure 14 shows the frequency response of the 4th order Butterworth filter, not the filter itself - as you have written it.



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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.



Caption - description

Caption should include a description



Comment 12

Who is "we"?

Do not use first person voice



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Additional Comment

From the graph is can be seen that....



Comment 13

What do these offsets translate to as error in temperature reading?

QM

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.

QM

Caption - description

Caption should include a description

QM

Use of 1st Person Voice

When writing technical reports, do not use first person voice. Instead, use the third person passive voice.

You should not use words like "I", "you", "we" etc..

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PAGE 11



Comment 14

Excellent.



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Caption - description

Caption should include a description



Comment 15

type K thermocouples do not have a sensitivity of $68\mu\text{V}/\text{degC}$ and therefore would NOT be suitable for this signal conditioning circuit



Comment 16

RTD probes would not work with this circuit as they do not produce a voltage - they produce a change in resistance

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PAGE 13



Ref Qual

You should try to use more high quality reference sources, such as textbooks from reputable academic publishers and articles from peer reviewed journals.



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PAGE 14

CURTIS REES

53.30

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Inclusion of a range of research-informed literature, including sources retrieved independently. Referencing conventions mostly consistently applied. You need to use higher quality sources

2.75

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.

16.5

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.



Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging awareness of different stances and ability to use evidence to support the argument. Conclusions are a bit sparse

16.2

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A good and appropriate application of standard methods, materials, tools and/or techniques. Good appreciation of the context of the application, with some use of examples, where relevant.

15.6

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 in a suitable format but with some room for improvement. Work lacks coherence in places and could be better structured.

2.25