

Transducers and signal conditioning assignment

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Transducers and signal conditioning

Course work

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Abstract

The task set out for this assignment was to create a temperature sensor which produces more voltage the hotter it got between -50°C and +100°C. The output would be 0V at -50°C and 5V at 100°C. In order to solve this problem, knowledge on how different filters such as Chebyshev, Bessel and Butterworth is required to accurately give a circuit that would work without error.

Introduction

The problem here involves designing a signal conditioning circuit for a temperature sensor that outputs $68\mu\text{V}/^\circ\text{C}$. The temperature sensor must measure temperature in the range of -50°C and +100°C. the circuit must also output the correct voltage based on the temperature input. Also the output voltage is contaminated with a 120mVpk-pk 50Hz mains interference. The circuit should include the following: Over voltage protection, filtering, gain and level shift. The first stage is the over voltage protection. This allows the circuit to work within its designed voltage range by blocking out any voltage exceeding. This works by putting Zener diodes in revers bias without conducting, since the voltage is too low. When the voltage exceeds the circuits range the Zener diodes conduct in revers and sends it to ground, protecting the circuit from being damaged [2]. Next up is the filtering stage to deal with the 50HZ interference. A low pass is an ideal solution for this project. A low pass filter only allows

signals below its cutoff frequency whilst also attenuating all signals above its frequency. Using a low pass filter ensures there won't be any outputs above our frequency which helps in giving a more accurate output of results [3]. Next in the circuit is the gain. Gain is the ratio of the output compared to the input. The gain is calculated by the difference in resistors. The gain of a circuit must be carefully calculated to give precise outputs as a small difference can completely change the output of the circuit [4]. The last stage of the circuit is the level shifting stage. Level shifting is the process of converting voltage levels from one domain to another. This is required as the sensors output at -50°C would be negative, the correct amount of level shifting is required to bring it up to the desired value [5].

Background information

Signal conditioning is very important for preparing raw sensor or input signals to be used by the rest of the circuit. These sensors require the signal to be conditioned before you can accurately measure the signal. Signal conditioning can be used to amplify weak signals to a reasonable level. This happens because many sensors produce very low outputs that require boosting for accurate readings. Signal conditioning is also used to remove unnecessary noise from interfering with the output. It is often used as a low pass filter which blocks out the high frequency signals being the noise and leaves you with only your desired low frequency signals [1]. There are typically two types of sensors: active or passive. Most of the time an active sensor is used, these are inserted into a bias network. On the other hand, passive sensors provide a signal generated through the values of other components on the circuit. An offset adjustment might be needed if a signal has a bias or offset that needs adjusting to align with the correct range. Isolating certain components is another feature that signal conditioning can do. this protects the circuit from high voltage surges and can reduce the noise from ground potential. Some benefits of signal conditioning include, protecting sensitive components through isolation, simplifying signal integrations into systems and ensuring compatibility between different components [2].

Method

When designing the signal conditioning circuit for the project, careful consideration was given to the design choices when working out the best: over voltage protection, filtering, gain and level shifting to use. The chosen parameters were used to meet the project requirements. The cut off frequency of the filter is a crucial parameter as it determines which frequencies get read and which ones are attenuated. For this project the main focus was to suppress the 50Hz mains interference which would be contaminating the signal. A low pass filter was therefore ideal for this circuit, as to avoid the 50Hz mains. Using a low pass filter is the best choice for this as it is a simple concept that can attenuate all frequencies higher than the cutoff point. At 50Hz this filter provides enough attenuation as to not have any interference with the output signal [3]. The filter order can determine how sharp the attenuation takes effect. A Chebyshev filter was chosen for this project due to its characteristics of achieving a quicker and steeper roll than a Butterworth. The steep roll off that the Chebyshev has gives effective attenuation of the 50Hz signal with a lower order filter. For this project a second order filter was deemed sufficient to allow quick attenuation. Whilst a third order would have provided better results it was deemed too complicated a circuit for the project given. The extra roll off in attenuation would not have been sufficient enough to warrant the extra sensitivity given to parts values, complexity of circuit and price of the circuit. With the second order filter the attenuation at 50Hz is brought to levels that are negligible in the output. This will keep the integrity of the signal output without adding any

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unnecessary complexity [4]. The next part of the circuit is the gain. The gain works by using an op-amp and changing the value of resistors to change the value of gain depending on what is needed. For this circuit a non-inverting op amp was used. A non-inverting op amp is when the output voltage is in phase with the input voltage [5]. Gain can change how much voltage is outputted compared to the input voltage. In the case of this project a range of -3.4mV to +6.8mV was used as an input, therefore a lot of gain would be required to meet the expected outcome [6]. The last part of the circuit is the level shifting. Level shifting uses an offset to bring the desired output value to be true. In the case of this circuit, a positive offset is required to bring the starting temperature up to 0V. The level shifting stage uses high precision to secure stability and high accuracy [7].

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Design

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Figure 1 features an over voltage protection. This ovp has been configured by placing two Zener diodes. This is an extremely effective method for over voltage protection. This approach allows all voltage up to a certain point, in this circuit bring 5V to flow freely. However, any more than 5V and the ovp kicks in by pushing all the voltage to ground effectively deleting it. This works since both the Zener diodes are connected in opposite polarity covering all ranges positive and negative. There are many advantages of this configuration including, low component count. Since its only using two Zener diodes and ground it is extremely easy to set up with minimal component count and a cost-effective solution. Zener diodes also react very quickly to voltage spikes allowing for more maximum protection for the circuit. They also offer customizable voltage protection levels. By using two Zener diodes clamping the circuit at an appropriate voltage is very simple [8]. Figure 2 shows a fourth order Chebyshev low pass filter. The low pass is designed to limit how high the signal can be read before it attenuates. By using this filter below 50Hz it ensures the mains frequency gets attenuated and there will be no interference with the rest of the circuit allowing for more accurate results to be provided. A fourth order was the perfect balance between attenuation and ripple for this project as anymore ripple would've made the results harder to read. Also, by going with a fourth order it not only limits component count allowing for an easier build design, but it also allows the components to be less restrictive allowing for a cheaper solution to the project. The Chebyshev filter is based on Chebyshev polynomials, which introduce controlled ripples in the passband. Fourth order Chebyshev filters are widely used in signal processing and instrumentation where minimizing interference and noise from other frequencies is important. In this circuit it is also useful as it suppresses the mains frequency, giving another layer of protection allowing for accurate results from the output. This type of filter has a nice balance of circuit design complexity and performance [9]. Figure 3 shows how the gain is produced for the circuit. By using the formula $1+(R3/R4)$ the gain can be worked out for the circuit. For this circuit a gain of 254.3 was required. The reason for going with those particular values for resistors is because 100ohm is widely used and wont have any affects a high resistance resistor may have such as getting very hot which could have detrimental effects to the circuit such as burning, but it can also interfere with the results as that extra noise would not have been accounted for. A 25.33K resistor is also readily available to buy as to why that resistor got chose. It is possible to get a more exact value resistor but that would involve using multiple resistors in series which in turn increases the complexity of the circuit and not worth the slightly higher accuracy as this resistor is already accurate enough [10].

Results

The time domain analysis shows how the circuit should respond over a set period of time. The graph shows a smooth block line for the change in input. Shortly after the input change the change in output voltage is clearly shown on the graph followed by the ripples from the Chebyshev filter. The frequency domain analysis shows the circuit's ability to attenuate and amplify specific frequencies as stated earlier. The point in which the temperature changes on the input is visible with outputs all dropping following the drop in voltage. This shows that the attenuation is working properly as it follows the voltage levels throughout the graph. The two graphs show clear values from the circuit by using a 1 second time period allowing a higher quality graph to be created as it is more spread out. This allows the reader to get a better understanding of when key moments happen.

Discussion

The graphs in figure 4 and 5 represent the results of the project through using a fourth order Chebyshev filter. The Chebyshev filter is a widely used in processing signals, due to its characteristics of a ripple response and a sharp cut-off. This ensures no unwanted frequencies are detected allowing for an accurate reading. Figure 4 broadcasts a simple view of the filter's response. The red wave shows the oscillation behaviour with the filter. This also highlights the attenuation levels of the circuit as it flows with the change in voltage input. This graph also highlights some of Chebyshev's behaviour such as a sudden steep roll off with its quick changes. Figure 5 depicts a more detailed look at the filter's response. This is done by using the smallest time possible on the graph, being 1 second. By doing this it allows the reader to easily read key information such as, peak to peak voltage, ensuring it hits the correct high and low for the project given. The ripples commonly created by a Chebyshev filter are clearly shown in this graph, further proving that the filter is effectively working as intended. Although the ripple could be less, this is key into having an enhanced roll off rate and making sure no unwanted signals or frequencies are detected which could influence the final display of results. After the cut-off frequency, the filter displays a steep decline in response, whilst this could have been improved to be steeper, by using a sixth order or higher Chebyshev filter, it felt unnecessary in complicating the circuit as it would not only add more components but also be much more sensitive to work. This would mean changing values of other components to be more specific which could significantly increase the cost and complexity of the filter. The transition band on the graph is thin, once again highlighting how precise this filter is at being able to determine desired and undesired frequencies. The filter also demonstrates its capability to suppress interference and noise efficiently. Some key characteristics of this Chebyshev filter include a sharp roll-off and stopband suppression. The steep roll-off in the graphs shows the filter's high selectivity. This is also helped by using a fourth order filter compared to a second order which would not have had as steep a roll off. In the stopband, the circuit provides very high attenuation of frequencies. This makes sure no external frequencies or signals are interfering with the results. However, the downside to using this filter must be considered. The ripple behaviour that the Chebyshev is known for, may not be acceptable in all scenarios, specifically those that require accurate readings throughout the circuit and not looking for a single point. As this was project was using a peak to peak this did not become a problem, but could've become one, if there were more signals throughout the graph to be considered. However, throughout this project, the Chebyshev is believed to have been sufficient as it provided an accurate peak to peak voltage of +10V and -5V. This was however only for a short time and if needed to read the results for longer to enhance clarity, a different filter would have been more beneficial.

Conclusion

To conclude, the project's objective of designing a circuit that outputs a voltage proportional to the input temperature, ranging from 0V at -50°C to 5V at +100°C, were successfully shown throughout the report. The circuit effectively suppresses mains interference to ensure accurate readings, whilst also outputting key, accurate results. The accurate results shown throughout highlight the importance of carefully thought out component choices and values to ensure an accurate circuit using as little components as possible to reduce cost and complexity. The circuit's success hinged on several key design stages: overvoltage protection, filtering, gain, and level shifting. The overvoltage protection was created by putting 2 Zener diodes in reverse to each other. This is the most simple and effective method of ovp as it only contains two components. The filtering stage used a fourth order Chebyshev filter. This low pass filter is able to provide steep roll off and accurate attenuation to ensure no unwanted signals are recorded. The gain stage utilized a non-inverting op-amp configuration to amplify the sensor's output signal from a range of -3.4mV to +6.8mV to a usable level. The chosen resistor values ensured accurate and stable gain while minimizing heat generation and noise. By going with a 100ohm resistor it ensured the other resistor would not be too big to cause any problems. This stage highlighted the importance of precise calculations. Level shifting is also a crucial aspect of the circuit, allowing the voltage to be increased allowing it to fit perfectly with the correct outputs required for the project. High precision was needed for this to ensure the peak to peak sat at +10V and -5V. Any minor adjustments could have an effect on the final output and therefore this value was carefully selected. The results show evidence of the Chebyshev filter working properly due to it outputting key values a normal Chebyshev filter would such as, the rippling effect and a high drop off.

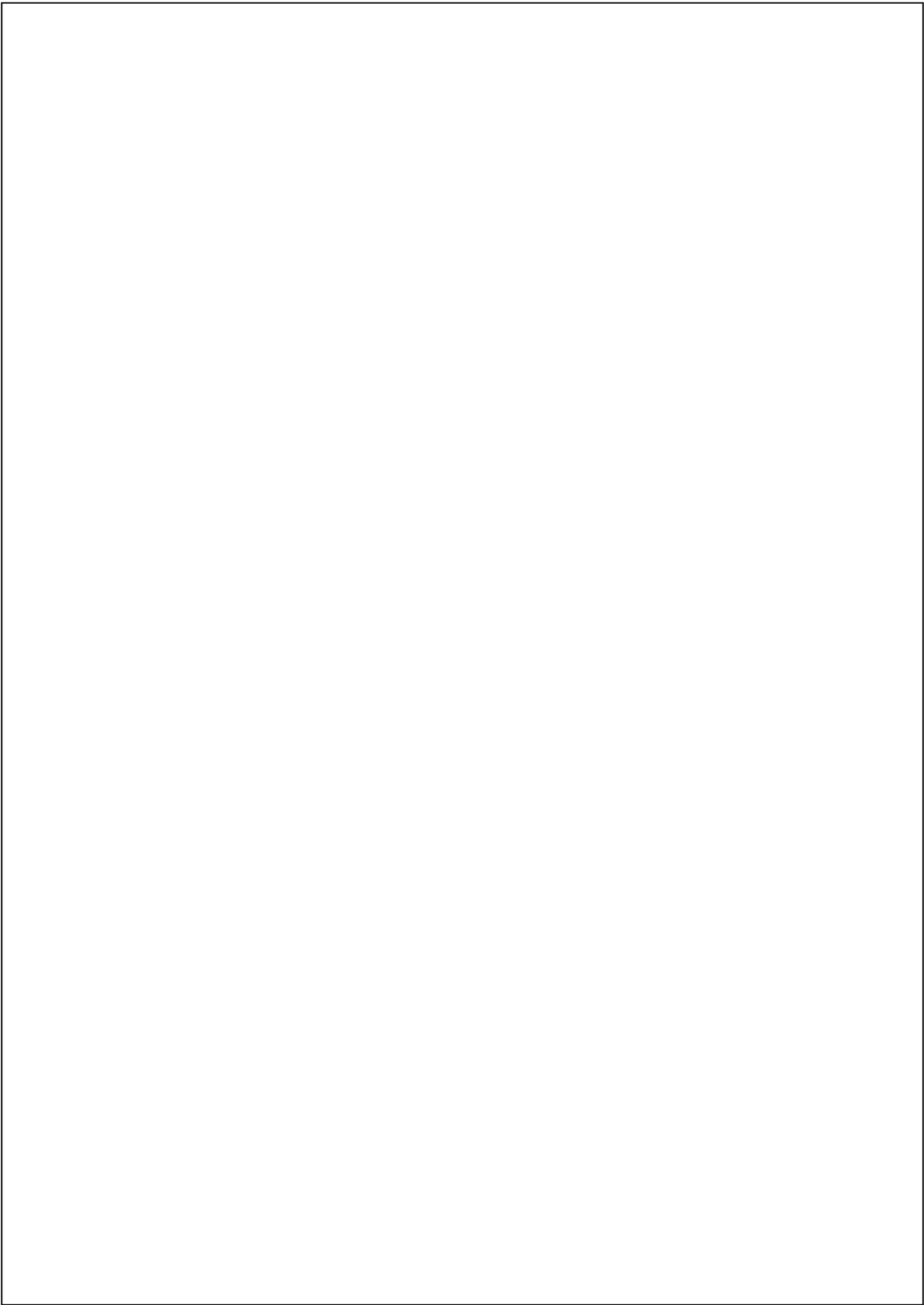
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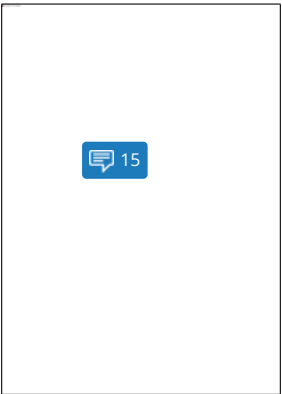


Figure 1 ovp

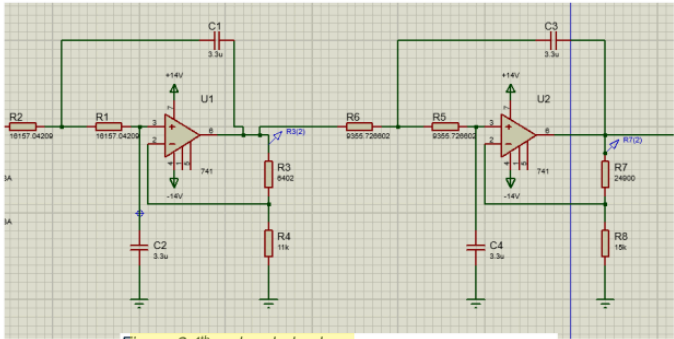


Figure 2 4th order chebyshev

16

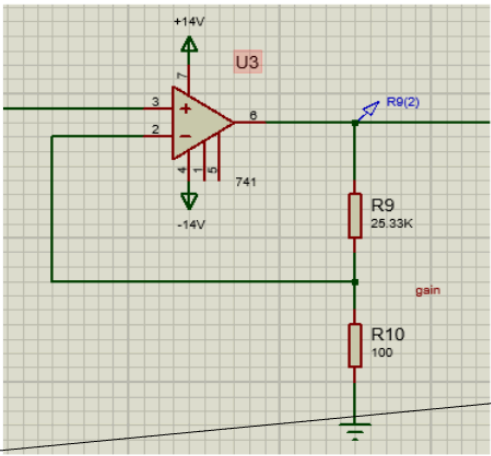


Figure 3 gain

17

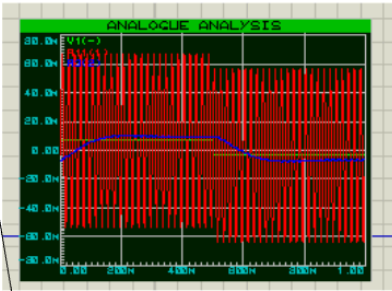


Figure 4 frequency response

18

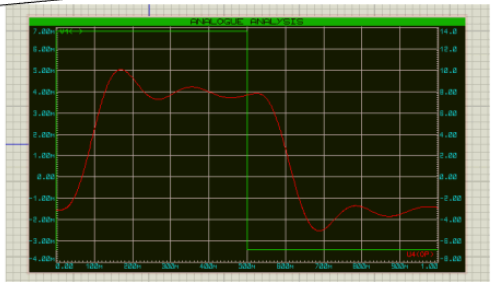


Figure 5 magnitude response

Transducers and signal conditioning assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

37 /100

PAGE 1



Comment 1

You were asked to create a signal conditioning circuit, not a temperature sensor.



Cap. Error

Capitalization



Comment 2

Your abstract should contain the following:

1. What you did
2. Why is this important?
3. How you did it
4. What you found
5. Why are your findings important?



Comment 3

Why is this first? You need to explain this protects the rest of the circuit from high voltages.



Sp.

Spelling error

Additional Comment

too



Sp.

Spelling error

Additional Comment

reverse



Comment 4

reference [1] should always come first.



Comment 5

Hz not HZ

PAGE 2



Comment 6

I thought you were talking about sensors here, not filters.



Comment 7

But you have shown a 4th order filter below.

PAGE 3



Comment 8

A block diagram may have helped here.



Comment 9

But you have not presented this part of the circuit. Why not?



Comment 10

You have not stated your cutoff frequency for the filter, or included ANY calculations whatsoever. These are essential in the design process as allow you to specify the circuit operation you require, and they prove to me your understanding of the topic.

You have not justified ANY design choices, nor have you presented a complete design.



Comment 11

High value resistors do not get hot. Resistors generally get hot due to high currents flowing through them. If the resistance is high, then the current will be low. $I = V/R$



Comment 12

I'm not sure they are. You should check supplier websites.

PAGE 4



Comment 13

There is no frequency domain plot included in your report.

**Comment 14**

This is a reference list, not a bibliography.

**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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**Comment 15**

Missing image

**Comment 16**

While a Chebyshev filter may seem like a good option as it gives a steep roll-off in the frequency domain, this has the side-effect of causing overshoot and ringing in the time domain. Evident in the red trace of figure 5 below.

**Comment 17**

These should all be near the text of your report where you discuss them, not all at the end.

**Comment 18**

This graph is not the frequency response.



Comment 19

It looks as though you have too much gain in your circuit, and your output does not go to zero.

GRADING FORM: SMU GENERIC_SMOSEY

RHYS JONES

36.70

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.

2.95

KNOWLEDGE & UNDERSTANDING

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



Gaps in knowledge, with only superficial understanding. Some significant inaccuracies.

10.5

You have not sourced an appropriate sensor, as requested in the assignment brief.

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 some attempts to synthesise, albeit with some weaknesses.

Some evidence to support findings/ views, but evidence not consistently interpreted.

Some relevant conclusions and recommendations, where relevant

You have not measured the response time of your circuit.

12

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Rudimentary application of methods, materials, tools and/or techniques but without consideration and competence. Flawed appreciation of the context of the application.

You have not presented ANY design justifications or calculations (other than for the gain stage), or a complete design. You have not included any information on the level shifting circuit.

9

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