

Finalsubmission

by Max Ladner

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ACDA5006 Transducers & Signal Conditioning Assignment

Max Ladner

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General Business

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Abstract

The problem solved in this project is the design of a signal conditioning circuit for a temperature sensor with the given output parameters of 0V for a temperature of -50°C and 5V for 100°C. Which rejects interference.



This problem has been solved through the implementation of Proteus software circuit design. By creating an adequate design for a circuit that filters and levels shifts the signal to meet the required voltage range and attenuates noise interference, the temperature sensor signal can be appropriately analysed.

The resulting time delay for the designed circuit in this report is of 52 milliseconds.

Introduction

The project brief specifies the need for signal conditioning of output readings taken from a temperature sensor. Conditioning is required for multiple purposes – amplifying the signal, reducing noise – through galvanic isolation, and filtering [1]. The resulting benefits from a circuit that achieves the listed purposes allow for an output signal that is useful for analysis of the sensors output, in this instance the relevant temperature of an atmosphere or material within a process operation – which by monitoring can prevent over/under heating, in turn protecting the process and the operators working within it.



In order to complete a design for the signal conditioning circuit, which will produce a signal of 0V for a temperature of -50°C and 5V for 100°C, and rejects signal interference, a necessity of individually designed components, namely, over voltage protection, filtering, gain and level shifting circuits, is required for the circuit design, which will create a readable output signal – comparative to the temperature sensor. Each of the individual components have benefits necessary to signal conditioning, listed as follows:

- Over voltage protection - electronic circuits found on circuit boards, motherboards, network cards, and similar components; like temperature sensors, are unable to handle extra peaks in current and voltage. In the absence of proper protection, an overvoltage could damage delicate electronic components within the circuits of connected devices. [2] By adding over voltage protection to the designed circuit, the risk of damage to the components from voltage spikes can be mitigated, insuring longevity in its functionality.
- Filtering – Signal filtering is used for the reasons of reducing and smoothing out high-frequency noises attributed to measurements taken of variables such as flow, pressure, level or, temperature. [3] It is important in ensuring readings taken from the sensor are simple to read and interpret the results for use in monitoring.
- Gain – Signal gain controls the amplification factor of the signal, whilst it can seem best to amplify the signal as much as possible, if the output voltage overtakes the supply voltage, the amplifier may become saturated. [4] By adding a gain to the results, the readings become simpler to translate for use in control and monitoring systems.
- Level shifting - level shifters are used for signals that cross voltage levels, without level shifting they may not be correctly sampled. [5] This could therefore create issues when interpreting results if a level shifting device is not present.

The circuit will have an architecture of sensor, over voltage protection, filtering, gain, level shift, and then output/ This will ensure the best resultant readings are given, in line with the desired attenuation

Background information

Signal conditioning refers to an electronic circuit that modifies a signal to make it suitable for subsequent processing stages. Numerous data acquisition applications involve environmental or mechanical measurements obtained from sensors, including vibration and temperature. Prior to effective and precise measurement by a data acquisition device, these signals produced by sensors require signal conditioning to occur. [6] There are various types of signal conditioning devices available, each designed to achieve different results. Among these are amplification, which serves to increase the signal amplitude; attenuation, utilised to decrease the amplitude; and filtering, which effectively removes unwanted noise within a specific frequency range. [7]

The relevant types of signal conditioning that need to be considered for use in the applied circuit containing a temperature sensor are both amplification and filtering. Amplification is required as in many instances where a temperature sensor is applied, due to low-level nonlinear outputs, it is necessary to adequately condition and amplify the sensor output prior to any further processing. [8] Filtering is also required, as is in many instrumentation applications; filters are implemented to remove noise and interference from measurement signals. For instance, an electronic thermometer might utilize a low-pass filter to eliminate high-frequency noise from the output of the temperature sensor. [9] Therefore, an important consideration within this brief's design would be the inclusion of both an amplifier, to ensure an appropriate output signal level, and a low-pass filter, to reduce high frequency noise; making the output signal easier to read and interpret.

Method

Throughout the design process of the circuit, certain values had to be carefully considered and calculated to achieve a result that worked within the project briefs specification. The following explanations highlight each consideration and why those choices were decided upon.

A cut off frequency of 6.5Hz was chosen to filter out any noise interference signal of 50Hz, as stated in the brief, to ensure the results are easy to read and true to the sensors output. As the output of sensor is proportional to temperature, it will be of relatively low frequency in most scenarios, the 6.5Hz cut off will ensure that the frequencies omitted by the sensor will remain unaffected by filtering. Whilst by not setting cut off lower, the risk of attenuating parts of the sensors signals, or causing phase distortion, is avoided. The capacitive reactance could then be selected based on the cut-off frequency, a range of values from 5-10kΩ was chosen and 7.5kΩ resulted in a reasonable capacitor value that could be applied to the design.

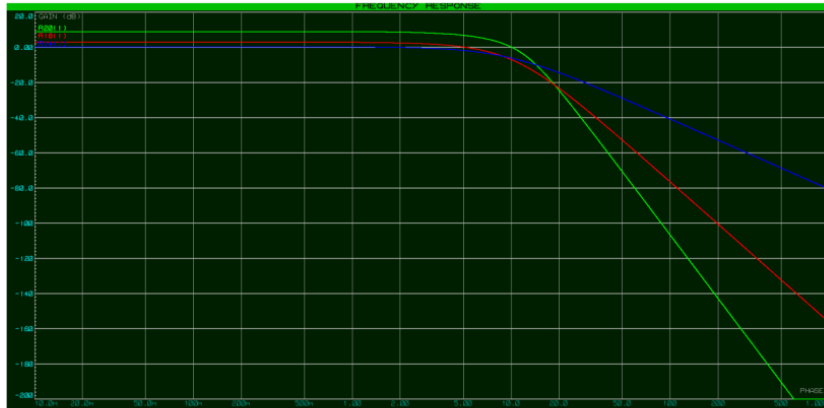


Figure 1: Resultant frequency response curves for each stage of filtering

The choice of 6th order for the low pass Bessel filter was made for achieving a sharp attenuation of the 50Hz mains noise. As the 6th order Bessel provides a good level of steepness of roll-off, whilst remaining reasonable simple to achieve in design. The difference in amplitude-frequency curves of a 2nd, 4th and 6th order Bessel filter can be seen in figure 1. Another benefit of a Bessel filter is minimal phase distortion it provides. The high noise can be attenuated while phase distortion can be kept at a minimal, this is important in temperature sensing as the signals magnitude and phase both need to be preserved.

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

Equation 1: For finding resistor values in relation to filtering.

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

Equation 2: For finding Capacitor values required in the filter.

$$R_2 = R_1(K - 1)$$

Equation 3: For finding resistor R_2 values.

The resistor values attributed to the filter design require calculating using equation 1, where F_c is the cut off frequency, C is capacitor value and C_n is a preset value based on order and filter type. To apply equation 1, C must be calculated first using equation 2, where X_c is reactive capacitance.

From equation 2 we obtain a capacitor value of $0.326\mu\text{F}$ which can be substituted for a real-world capacitor of value, $0.33\mu\text{F}$, this can then be applied to the capacitors within the circuit design as well as used to calculate the R values, alongside the C_n values found for 6 pole Bessel filters in figure 2, for the circuit for each of the three stages: giving 46171Ω , 43852Ω , and 3887Ω for stages 1, 2, and 3, respectively. These values can also be given real-world substitutes of $47\text{k}\Omega$, $43.2\text{k}\Omega$, and $39\text{k}\Omega$, respectively. These real resistor values were obtained from an online table [10]. These values can also be applied to the design.

Pole	Butterworth		Bessel		Chebyshev (0.5dB)		Chebyshev (2dB)	
	K		C_n	K	C_n	K	C_n	K
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 2: Table of figures used for calculations of resistors in filtering [11]

Using equation 3, and values of K from figure 2, solutions for R_2 values can be obtained. Setting R_1 for each stage as $10\text{k}\Omega$, the resulting R_2 values are: 400Ω , $3.64\text{k}\Omega$, and $10.2\text{k}\Omega$, these can again be converted to real resistor values of 390Ω , $3.65\text{k}\Omega$, and $10.2\text{k}\Omega$. Which can be applied to the circuit.

With the filter resistor and capacitor values applied a resulting graph of the output voltage compared to the input voltage can be used to find the value of required gain from equation 4. When V_{out} is set at the desired 5V output voltage specified in the brief, and V_{in} is determined by the range of voltage derived from the graph shown in figure 3.

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

Equation 4: Equation for gain respective of input and output voltages.

This equation achieves a gain value of 173, which can be further applied to equation 5 to find the resistor values needed in the op-amp to achieve appropriate gain.

$$R_1 = R_2 \times (G - 1)$$

Equation 5: Resistor R_1 Value for gain op-amp

Setting R_2 to value 470Ω , the achieved value of R_1 of 80840Ω , which can be replaced by an $81k\Omega$ resistor. With the values of R_1 and R_2 applied to the op-amp, the graph previously used can be simulated again and a reading can be taken for the level shifting off-set, which in this design is a voltage of $8.08mV$, which was found within the resultant output shown in figure 3. Once all the calculations are applied to the circuit simulation, design results can be taken.

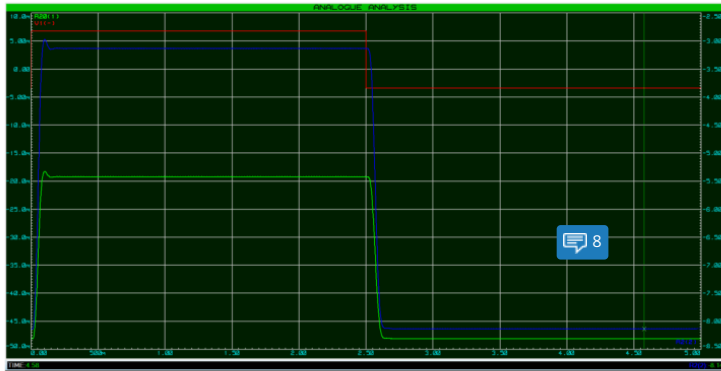


Figure 3: Graph used to find results for gain and level shift values. The green line depicts output from after filtering, whilst the blue line depicts output after gain op-amp.

Design

This design section includes figures and descriptions relevant to the circuit and its component parts, the values and calculations of which have been previously mentioned in the method section.

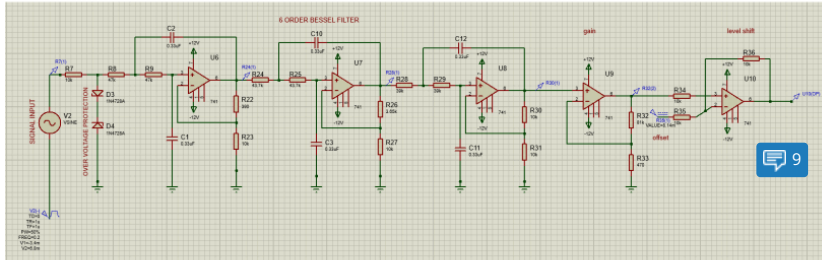


Figure 4: Complete circuit diagram

Figure 4 shows the circuit diagram with each circuit component labelled, and each component value. The final design takes the architecture of; signal generator; to simulate the temperature sensor, over voltage protection, a 6th order Bessel filter, an op-amp; to supply the circuit gain, and the level shift; to provide the final output signal.

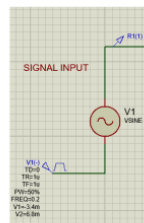


Figure 5: Input signal generator.

Figure 5 displays the signal generation used for simulating the input signal which would be provided from the temperature sensor. Using the same parameters as highlighted in the project brief for the temperature sensor within the sine generator, the output results can be the same as would be expected from the sensor.

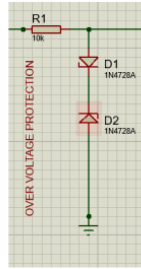


Figure 6: OVP

Figure 6 highlights the circuits over voltage protection, OVP. Two Zener diodes in series, of opposite polarities and set at the same voltages can act as a waveform clipper to prevent spikes from harming the circuit connected to the supply [12], in this instance the signal voltage produced. By using OVP, the voltage range that goes into the Bessel filter can be conditioned into an appropriate level, that is unlikely to damage circuit components. The voltage of the Zener diodes in this circuit are: 3.3V

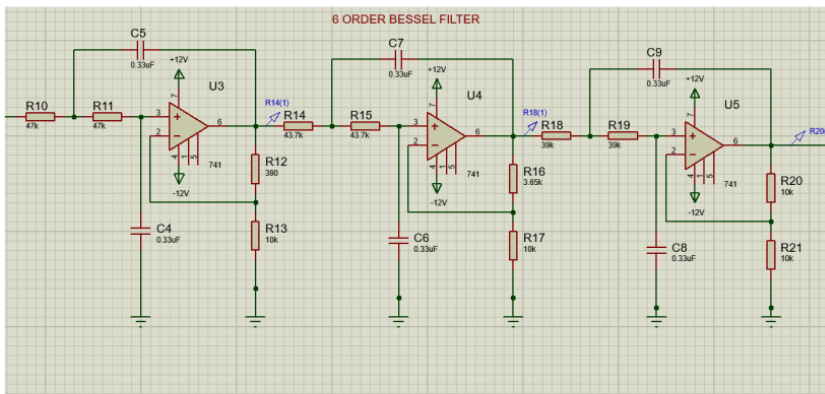


Figure 7: 6th order Bessel filter.

Figure 7 illustrates the 6th order low pass Bessel filter chosen for this circuit design. A Bessel filter has been chosen for a few reasons; an improvement in time-delay responses, less abrupt frequency characteristics in relation to phase shift and time-delay compared to Chebyshev and Butterworth filters, and the likelihood of the other two types of filters exhibiting waveform distortion and overshoot when powered by pulse signals, due to poor time-delay performances of said filters. In contrast, the resultant negatives for the Bessel's dependency in time delay values are, is an amplitude response with less steepness compared to that of the Butterworth or Chebyshev in the transition region between passband and stopband [13].

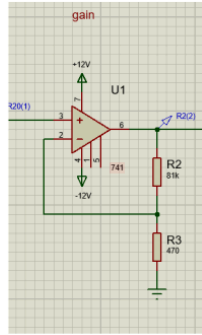


Figure 8: Op-Amp to account for circuit gain.

Figure 8 shows the implementation of a non-inverting op-amp for applying the circuit gain required after filtering, this is used to move the input voltage to its desired output level, in the instance of the circuit designed, the desired output is 5 volts. The gain value achieved can be used to calculate the resistor values needed to achieve the appropriate voltage.

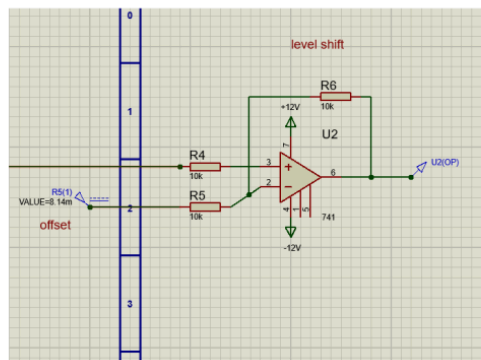


Figure 9: Circuit level shift and final output

Figure 9 includes the level shift section of the circuit and its final output voltage probe (U2(OP)). Level shifting is required to ensure that the desired output voltage range is achieved for the purposes of integrating the circuit with devices used in reading and interpreting the results, further down to process line. The offset voltage is determined by the circuit and is used to balance the input into the op-amp.

Results

From the completed circuit the results graph of time against voltage, shown is figure 10, was achieved. From this graph the results for the time delay could be taken, which for this graph is 0.052 seconds, or 52 milliseconds. The result is obtained from taking the difference in response times for the input and output, at 50% of the range.

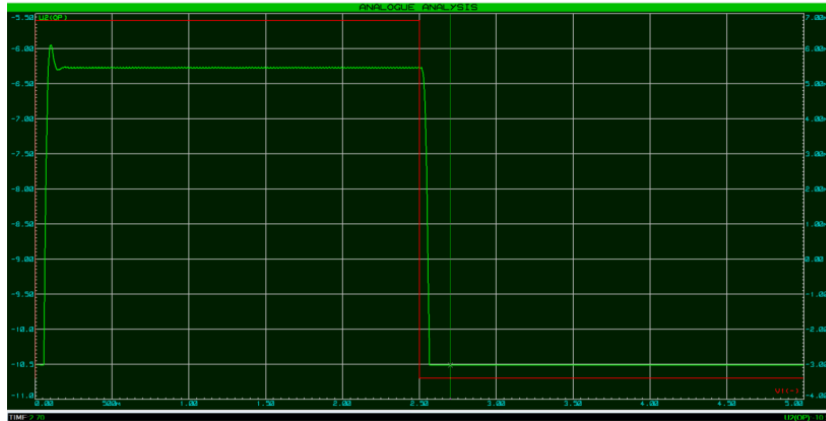


Figure 10: The resulting graph from designed circuit simulation.

Discussion

The time delay response of 52 milliseconds shows a successful factor for the designed circuit as it shows a very short delay in temperature readings being taken from the sensor, to having been filtered and level shifted, ready for interpretation. This is a benefit for this type of circuit due to the potential nature of constantly shifting temperatures in certain operations. One factor in the design that can be attributed to this low time delay is the low filter order (6th order), once a filter is applied, a time delay can be observed in the data [14]. By keeping the filter order to a minimal, a prevention in a greater delay can be achieved.

As required by the brief a potential temperature sensor for the specification of producing $68\mu\text{V}/^\circ\text{C}$ with $0\text{V} = 0^\circ\text{C}$, is LM35 sensor by Texas Instruments [15], this sensor has an operating range of -55°C to 150°C , with the brief requiring a range of -50°C to 100°C . However, as it produces $10\text{mV}/^\circ\text{C}$, some scaling would need to be applied with a further gain stage to achieve the desired $68\mu\text{V}/^\circ\text{C}$.

Conclusion

In the above report a signal conditioning circuit that can process the output of a temperature sensor contaminated by a mains interference, that can accurately measure temperatures in the range -50°C to 100°C whilst rejecting a noise of 50Hz. This has been achieved by incorporating circuit stages of over voltage protection, filtering, gain, and level shifting. Each of which provide the following functions to the circuit:

- Over voltage protection – ensures the output from the sensor is protected against sudden voltage spikes and remains within safe voltage limits.
- Filtering – effectively attenuates the 50Hz mains interference.
- Gain – amplifies the signal, ensuring the range spans from 0V to 5V
- Level shifting – adjusts the output voltages to align with the desired range.

The response time of the circuit had been considered in the design to allow the temperature sensors output readings are constantly updated in as close to real-time as possible. This has been achieved by considering whether the filtering stage could potentially introduce a significant response delay.

Overall, the signal conditioning circuit meets the functional requirements of the brief, by providing accurate and stable temperature measurements and rejects interference, making it suitable of applying in real-world settings.

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

56/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4



Comment 1

Good abstract



Comment 2

Your circuit is not performing galvanic isolation though. This is where parts of a circuit are electrically isolated from each other to prevent leakage currents.



Comment 3

It is impossible for this situation to happen. In practice, the output voltage cannot exceed the supply voltage,



Comment 4

A block diagram would have helped with this description.

PAGE 5

PAGE 6



Comment 5

Why did you choose this frequency? Why not 2Hz or 10Hz?



Comment 6

How can you present results before you have presented the design?

This should be in your results section

When you present a graph like this, you should state what each curve relates to.



Comment 7

Why a 6th order filter? Why Bessel over butterworth or Chebyshev?

You need to justify your choices

PAGE 7

PAGE 8



Comment 8

This should be in your results section.

PAGE 9



Comment 9

This diagram may have been better after the description of each section.



Comment 10

Do you mean non-inverting amplifier?

There are lots of op-amps in this design.



Comment 11

The parameters from the project brief were the sensitivity and offset, not absolute values of voltage for a given temperature. How did you determine these voltages?

PAGE 10

PAGE 11

PAGE 12



Comment 12

Good



Comment 13

This is not the correct sensor. The LM35 has a sensitivity of 1mV/C not 68uV/C. The correct sensor was a type E Thermocouple

PAGE 13



Comment 14

What level of attenuation did you achieve at 50Hz? This is an important factor as it allows you to calculate the noise level in your signal and hence your precision.

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

Additional Comment

What was the URL?

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MAX LADNER

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ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



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

4

KNOWLEDGE & UNDERSTANDING

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



Knowledge is extensive. Exhibits understanding of the breadth and depth of established views.

18

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. Valid conclusions and recommendations, where relevant
Your analysis does not go much further than observations of the results. You need to look deeper and explain what they mean and the consequences of them.

15

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.
"

16.5

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 could be better structured.

2.25

results presented before the design, complete design before each subcircuit etc.