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Temperature sensor signal
conditioning circuit
design & report
ACDA5006

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Abstract - results

This report showcases the design and implementation of a signal conditioning circuit for a temperature sensor with mains interference. The temperature sensor, which outputs $68\mu\text{V}/^\circ\text{C}$ with 0V corresponding to 0°C , is contaminated with 120mV peak-to-peak 50Hz mains interference. The goal is to design a circuit that produces a 0V output for -50°C and a 5V output for 100°C , while rejecting the interference. The design involves four key stages: overvoltage protection, filtering, amplification and level shifting. After calculating the necessary resistor and capacitor values and designing each stage, the circuit meets the required specifications with some adjustments made due to some unprecedented circumstances, including the need for a level shift due to a lower gain than expected.

Introduction

Signal conditioning is the process of modifying and manipulating signals from inputs to make them suitable for further processing or measurement. Sensors such as temperature sensors, pressure sensors and other types of sensors are widely used in both industrial and residential scenarios in order to monitor environmental conditions. Temperature sensing and control plays a particularly important role in industries such as steelworks, automotive and healthcare, where precise and accurate measurements are necessary for safe and efficient operations. [1]

One problem that is faced when it comes to temperature sensing is the fact that many sensors produce low-voltage analogue outputs that are susceptible to noise and interference. One common source of interference is mains frequency of 50Hz (in many countries, including the UK [2]), which can significantly affect the accuracy of temperature measurements. For accurate results, the signal needs to be processed to remove noise, amplified, and properly scaled in order to meet the required voltage range. Therefore a signal conditioning circuit is required to ensure that the signal remains intact and can be used in a measurement instrument reliably.

The temperature sensor in this design has a sensitivity of $68\mu\text{V}/^\circ\text{C}$, with 0V being the equivalent of 0°C . This sensor's output must be conditioned to produce a voltage range of 0V at -50°C and 5V at 100°C , meaning that the total range is 150°C over 0-5V. This will require a gain stage to amplify the sensor's output and a level-shifting circuit to adjust the voltage range.

The sensor's output is contaminated by 120mV peak-to-peak mains interference. This interference originates from the power supply; if not properly filtered it can introduce significant noise, making it difficult to distinguish actual temperature signal from the noise.

Circuit design

The design will be based on the following stages:

1. Over voltage protection

This stage will protect the circuit from any accidental voltage spikes that may exceed the tolerance of the components used. A few zener diodes will be used in this stage to clamp the voltage and protect the components.

2. Filtering

A low-pass filter will be designed to minimise the 50Hz mains interference while allowing the temperature signal to pass through unaltered. A Butterworth filter is a good choice because it provides a smooth response and minimal distortion of the signal, which is crucial for accurate temperature measurements. The simple design, stability and predictable behaviour make it a practical choice, balancing performance and use complexity. [3]

3. Gain stage

The gain stage will amplify the sensor's output to span the required voltage range of 0V to 5V. Given the temperature sensor's sensitivity, the gain required will be calculated to provide a 5V output at 100 degrees celsius.

4. Level shifting

The level-shifting stage will ensure that the output voltage starts at 0V at -50 degrees celsius, which is the minimum value of the temperature range. This is necessary because the sensor's output at 0 degrees celsius is 0V, and the amplified signal must be shifted to the correct starting voltage. This can be achieved by using a differential amplifier. [4]

Over-voltage protection is an important stage in the signal conditioning circuit, as the sensor's output may experience voltage spikes that could damage the rest of the components.

A common method for over-voltage protection is the use of a Zener diode. They are designed to allow current to flow in the reverse direction when the voltage exceeds a certain breakdown voltage. By choosing a Zener diode with a breakdown voltage slightly higher than the sensor's maximum output, we can ensure any voltage spikes above this threshold are clamped, protecting the circuit. [5]

For example, two Zener diodes with a breakdown voltage of around 6.8V would be appropriate, as this is above the sensor's maximum output voltage but still safe for the circuit. The diodes will be facing each other in order to protect the circuit from both positive and negative over-voltage conditions.



Figure 1: Zener diodes used in the circuit

The mains interference at 50Hz must be filtered out to avoid contamination of the temperature signal. A low-pass filter is the simplest and most effective way to achieve this. A fourth-order Butterworth filter is chosen for this application due to its smooth and maximally flat frequency response and sharp attenuation of frequencies above the cutoff.

To design the filter, a cutoff frequency must first be chosen. Since the mains interference is at 50Hz, we want to set the cutoff frequency slightly higher to ensure the adequate filtering of the noise. A cutoff frequency of around 60Hz is selected, which will allow the temperature signal (which changes relatively slowly) to pass through the filter while filtering out the 50Hz interference.

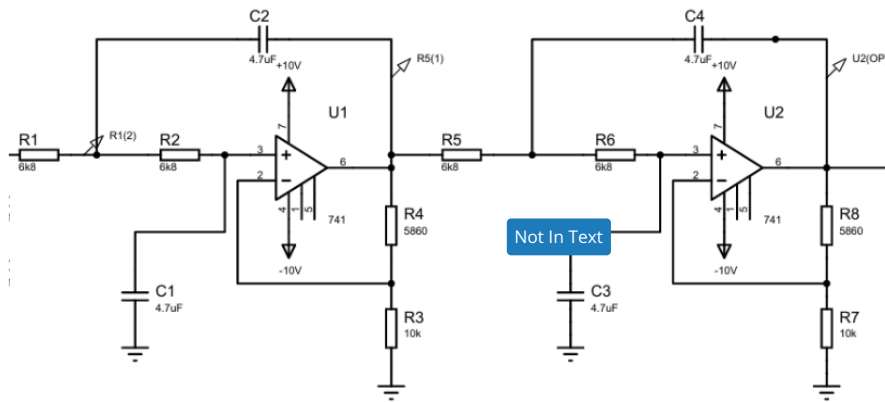


Figure 2: Butterworth filter.

The sensor's output has a slope of $68\mu\text{V}/^\circ\text{C}$, so for a temperature range from -50 degrees celsius to 100 , the voltage change will be:

$$V_{\square} = (100 - (-50)) \times 68\mu\text{V} = 10.2\text{mV}$$

A non-inverting amplifier can be used to **achieve the required gain**. The gain of a non-inverting amplifier is determined by the ratio of the feedback resistor R_f and the input resistor R_{in} :

$$\text{Gain} = 1 + \frac{R_f}{R_{in}}$$

By selecting the appropriate resistor values, the required gain of 370 can be achieved.

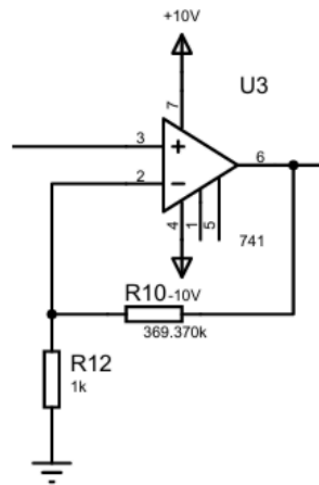


Figure 3: Amplification stage

The temperature sensor's output is zero at 0 degrees celsius, but after amplification, the output voltage is still near zero. To shift the voltage range to start at 0V for -50 degrees celsius, a level-shifting circuit is required. This can be achieved by using a differential amplifier, which adds a reference voltage to the amplified signal, effectively shifting the output to the desired range. [6]

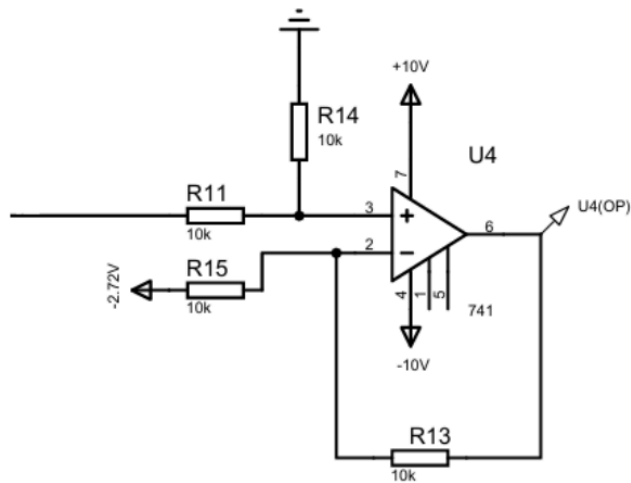


Figure 4: Level shifting stage



The signal conditioning circuit was simulated using Proteus to verify behaviour. It involved using a DC oscilloscope voltage source from -3.4mV to 2mV, as well as a DC since voltage source with 120mV peak-to-peak and 50Hz noise.

A non-inverting amplifier with a gain of 370 was modeled using 1k and 369k Ohm resistors.

8

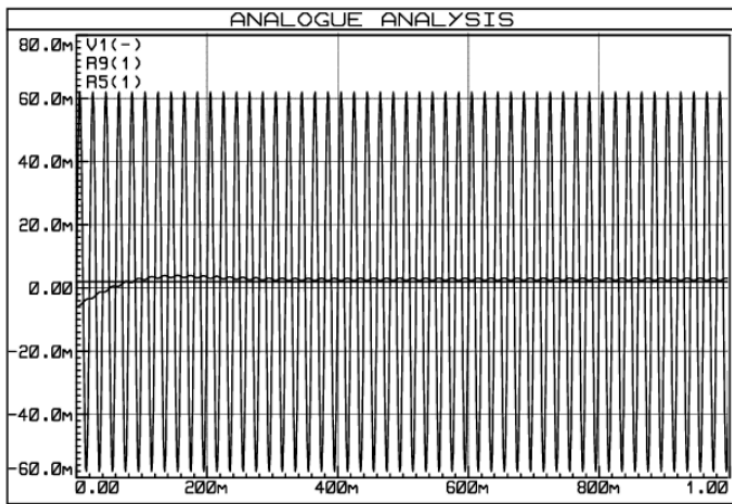


Figure 6: Voltage values just before low-pass filtering

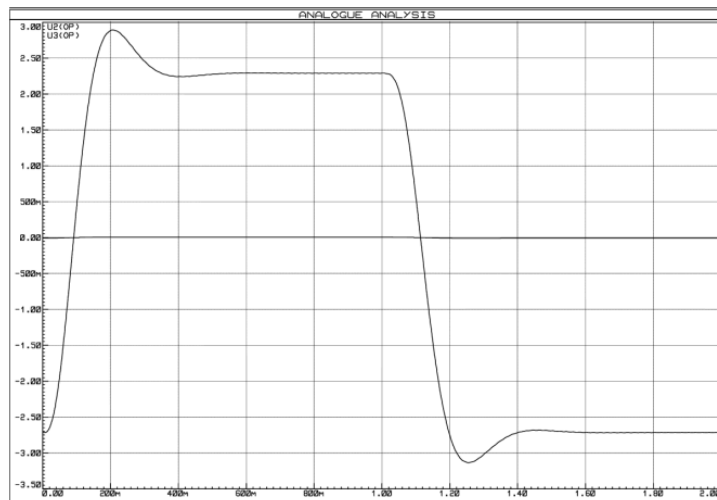


Figure 7: Voltage gain stage

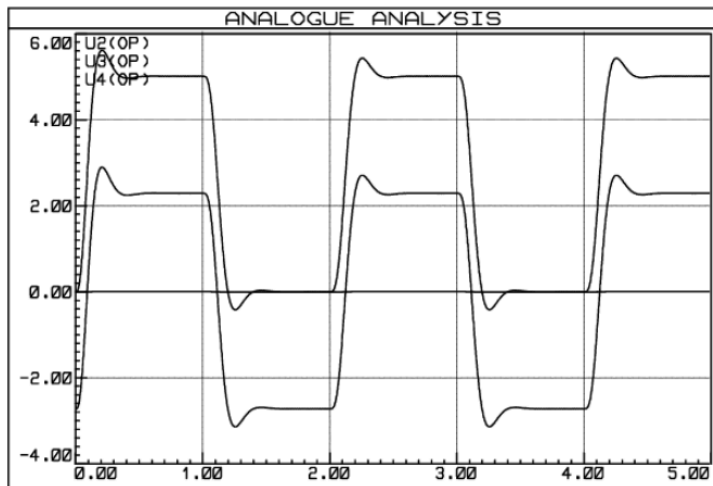


Figure 8: Voltage shifting stage

The required reference voltage for the level shifting was -2.71V . Also, the voltage overshoots and undershoots before settling to the desired output.

Discussion

As seen in the graph in figure 8, the output voltage is overshooting and undershooting, due to the fact that generally speaking, filters have a non-ideal frequency response, especially near the cut-off frequency. When the filter is exposed to a sudden change in input, the circuit overshoots/undershoots the target value before settling. [7]

4. Butterworth filters, being maximally flat, minimise ripple in the passband but can have significant transient responses when exposed to sharp changes or high-frequency signals. [8] The order of the filter also affects the degree of overshoot. Higher-order filters tend to output more pronounced overshoot because they have more reactive components (e.g. capacitors), which cause them to respond aggressively to changes in the input signal.

Furthermore, when a step input is applied to the filtering stages, as they contain capacitors, the capacitors will charge and discharge towards the new voltage, but they won't reach the steady-state value instantly. Instead, they will have an exponential rise or fall. Also, if the input change is significant, the capacitors may temporarily over and undershoot the target voltage before eventually stabilising.

Conclusion

In this project, a signal conditioning circuit was successfully designed and simulated for a temperature sensor with mains interference. The design included stages for overvoltage protection, filtering, amplification and level shifting. The final circuit met the required specifications, with the output voltage correctly corresponding to the temperature range from -50°C to 100°C after filtering and amplification. Despite some setbacks, the circuit performs as intended and can be used for further applications.



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PAGE 1

PAGE 2

PAGE 3

QM

Abstract - results

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

PAGE 4

PAGE 5

QM

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.



Comment 1

If you are using a low pass filter, and you set the cutoff frequency above 50Hz, then the filter will not remove the 50Hz noise from the signal.

your filter circuit below has a cutoff of 5Hz, not 60Hz

PAGE 6

QM

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.



Comment 2

But you don't know the output level from the filter. The filter will provide an amount of gain.



Comment 3

The terms DC and oscillating contradict each other. Instead I would describe it as pulsing.



Comment 4

Good. the passband ripple you mention is in the frequency domain, not the time domain.



Comment 5

Which leads to the response time of the circuit...

but you have not measured it.



Comment 6

It would have been nice to see the frequency response of your circuit. This would allow you to prove the filtering capability of your circuit,



Comment 7

You have not measured the response time of your circuit, or sourced a suitable sensor - as requested in the assignment brief.



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.



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.

GRADING FORM: SMU GENERIC_SMOSEY

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



"Inclusion of a wide range of research-informed literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied."

3**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.

19.5

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 synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging awareness of different stances and ability to use

17.4

evidence to support the argument.
Valid conclusions and recommendations, where relevant

You have not measured the response time of your circuit.

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.

19.5

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 professionally and, confidently in a suitable format.
Work is coherent, very fluent and is presented professionally.

3.5