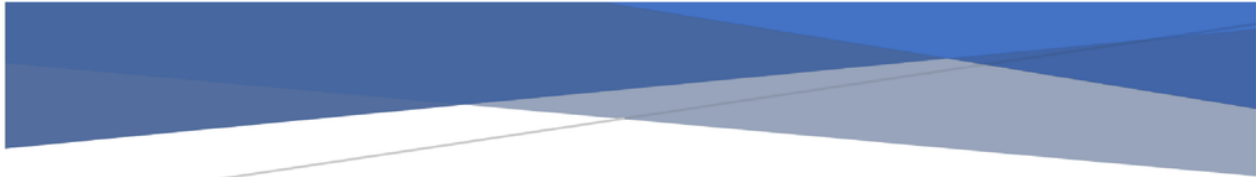


Lv 5 signal conditioning

by James Denning

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SIGNAL CONDITIONING

Abstract

[Draw your reader in with an engaging abstract. It is typically a short summary of the document.]



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1. INTRODUCTION.

With a signal generator acting as a thermocouple sensor, producing a constant “direct current” (D.C) signal, at a value of 120uV (milli-Volts) per Celsius detected, signal conditioning circuits and methods will be applied to isolate contaminated analogue signal (A.C) from thermocouple sensor output.

The temperature sensor has a minimum voltage range of 0 volts, that represent -80c, and a maximum range of 0.00216V's (2.16mV's), that represents 100c.

Both the D.C and A.C signals are passed through the voltage protection circuit (unit) to prevent large voltages passing through.

The following circuit after is a filtering unit, which will remove the A.C signal from interfering with further circuits.

After filtering out other signals, a level shifter will be applied to alter the voltage level to range from 0 volts up to 5 volts.

The following chapters will give detail on the signal conditioning techniques and each circuit will be justification on why they were applied for the requested applications.

2. SIMULATION ARCHITECTURE

The overall project consists of the circuits/units stated before in the introduction.

<u>Circuit & Signal title</u>	<u>Description</u>
(TC2) thermocouple sensor	Generates a range of signal values that represents the temperature.
(A.C) Contaminating Analogue signal.	With a peak voltage 1.2V pk-pk (0.6 pk), oscillating at a frequency of 50HZ mains hum.
Over voltage protection unit.	Prevents large voltages passing through (voltage level dependent on circuit's element specification).
Filtering unit.	Op-Amp arranged in Butter-worth configuration to remove noise received by signal conditioning circuits.
Operational Amplifier unit (Op-Amp).	Controls the gain and level shifting. which will consist of multiple Op-Amps.

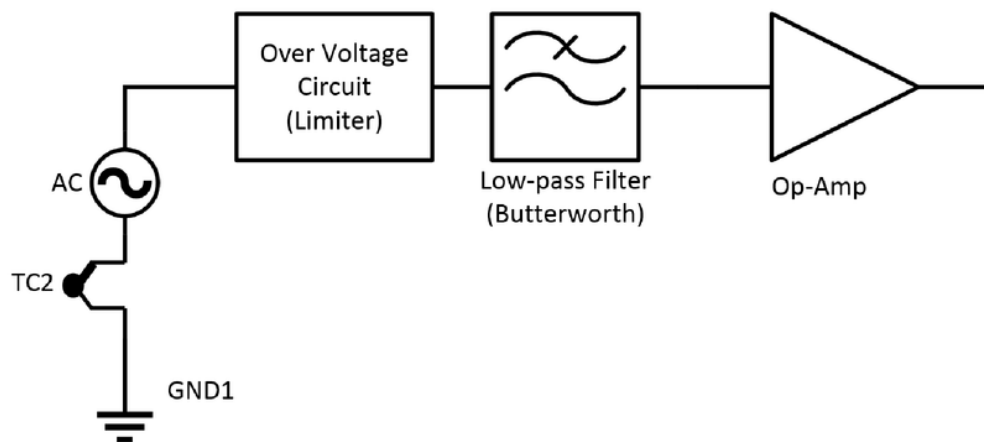


Figure 0: Block diagram of signal conditioning system.

3. THERMISTOR SENSOR/ VOLTAGE SUPPLY

To analyse the temperature in an enclosed environment, a signal generator acting as a thermocouple sensor is used to measure and in response produce a voltage level that will be interpreted by a microcontroller in the units of measurement of “Celsius”.

The measurement of the electrical element ranges from 0 volts (interpreted as -80°C), to 21.6 Milli-Volts (interpreted as 100°C).

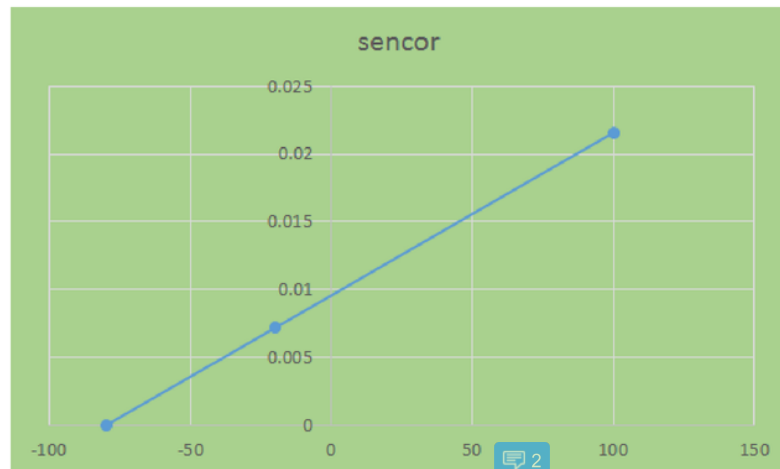


Figure 1.1: Excel graph depicting the thermocouple's voltage range

Despite the sensors lowest potential, the minimum temperature that is required for this project is -20°C , which is gained from the sensor producing of 7.1.mV. The voltage range of interest would be 7.1.Milli-volts (represents -20°C), to 2.16 Mille-volts (represents 100°C).

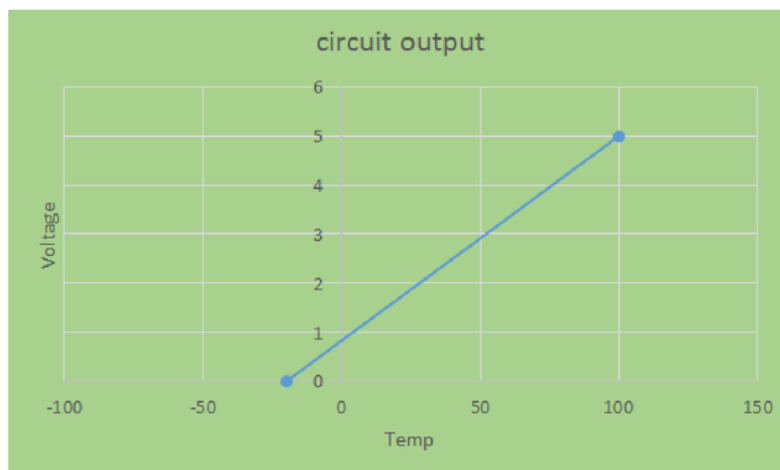


Figure 1.2: Excel graph depicting ideal voltage range.

As the thermocouple sensor generates a voltage level, this “Direct-Current” (DC) signal is corrupted by an oscillating signal.

This unwanted signal has a voltage Amplitude (Pk-Pk) of 2.1volts and oscillates at a frequency of 50 Hz, which is considered as noise and will need to be isolated with signal conditioning methods.

On Proteus, the Temperature sensors output will be represented by a Pulse-Generator (Pulse-Gen) with a Sine-wave-Generator creating the noise. As the pulse – Gen produce a square pulse, ranging from 7.1.mV to 2.16 mV, the signal will be under the influence of the noise, distorting the main signal.

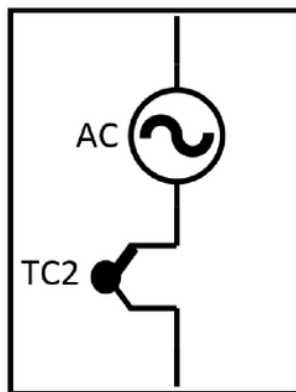


Figure 2.1: block diagram of thermocouple sensor and sine-wave (Noise) generator.

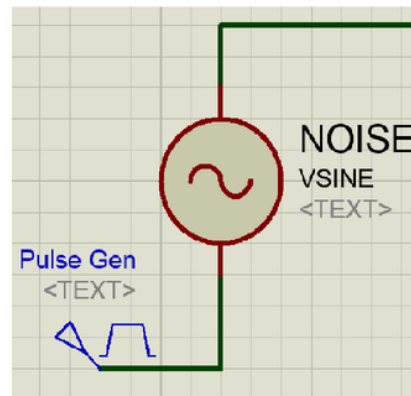


Figure 2.2: Proteus components of pulse generator and sine- wave generator.

4. VOLTAGE PROTECTION UNIT

As both D.C and A.C signals are emitted from the temperature sensor, the signals will first come in to contact with “Over voltage protection unit”.

To prevent large voltages passing through, the unit is comprised of only two components. A Resistor, which will restrict the flow of current and a Zener diode, that that will prevent the voltage exciting to a higher level.

The Zener diode is placed in “reverse-bias” to regulate voltage and connected to ground to re-direct voltage. Although conventional diodes are connected in “forward-bias” to operate, this diode must be arranged in this manner to prevent exciting voltage.

As small voltages are passing through the resistor (affected by potential division), the voltage is applied to the node, directing voltage to the next circuit and to the Zener diode in reverse-bias, while no current or voltage is conduct though the diode. For there to be voltage over the diode, the voltage received must reach its breakdown voltage. [1] [2]

To achieve breakdown voltage, the applied voltage would need to meet the diodes pre-determined (voltage) value and when reached, the diode will conduct, allowing voltage to be redirected. [1]

If equal or greater voltage is applied to this circuit, it will not exceed the predetermined voltage and stay at that regulated voltage until otherwise. [2]

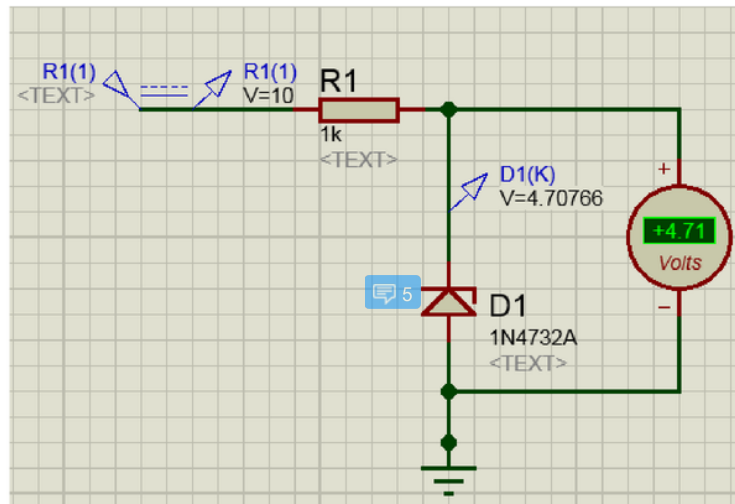


Figure 3: Proteus circuit of isolated voltage protection unit in operation.

To show the operation of the circuit, a 10 volt source has been applied. As detail, the voltage will not exceed over the pre-determined voltage, estimated to be approximately 5 volts.

4.1. OP-AMP BUFFER (UNITY BUFFER)

Before creating a filter, a circuit must be applied before, to avoid over loading the circuit in series. If a hypothetical filter (filter A) connected to another filter (filter B) we have a series of filters.

The first circuit, “filter A” has little impedance applied to its input pin, whereas “filter B” has greater impedance than the first filter.

If a current source was applied to this series of filters, the current source drawn would be large due to the load value of “filter B” being great do to the due to the filters greater impedance value.

As this accurse, large value of current is passed though filter A, and is unable to tolerate the over loading of current, resulting in to large amount and the possibility of overheating.

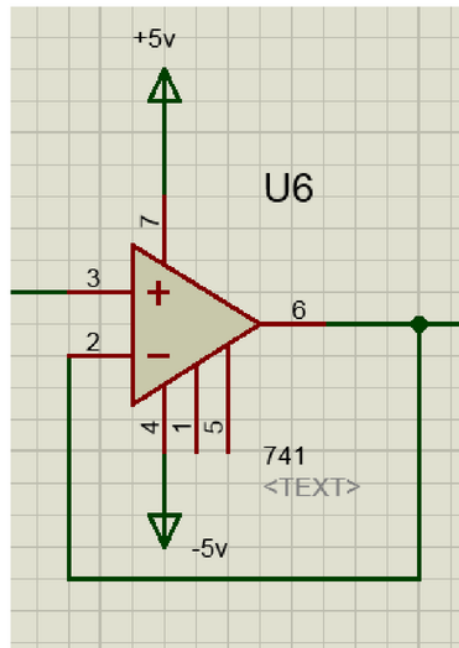


Figure 3.1 Proteus circuit of buffer Op-Amp.

[3]

A buffer is applied to the start of the filter to prevent this action due to the buffers high impedance value and therefore reducing the current flow entering the circuit.

This buffer is just a single Op-Amp with a gain of 1 so that no amplification of the signal is applied

5. OP-AMP FILTER (BUTTERWORTH INTRODUCTION).

An analogue signal is corrupting the direct current signal generated by the thermistor and will interfere with voltage levels analysed by a microcontroller. To isolate the unwanted signal (noise), filtering methods must be applied.

The characteristics of the noise are as follows...

- Peak voltage 1.2V pk-pk (0.6 V pk)
- Oscillating at a frequency of 50Hz mains hum.

With the noise oscillating at 50 Hz, a filter could be a "resistor and capacitor" (R.C) "Low-pass filter" to remove the signal.

The selected signal conditioning circuit is a Butterworth filter that consists of an Operational-Amplifier (Op-Amp) that will be connected with low-pass filters.

The Butterworth filter is defined by establishing a flat frequency response of the pass-band area.

Stated by ; Electronic project focus. [4]

"- The Butterworth filter has frequency response as flat as mathematically possible; hence it is also called as a maximally flat magnitude filter". [4]

If this function can be obtained, the ideal saturation can be obtained with the series of low frequencies.

With the selected value of the capacitors and resistors applied, the frequency response should produce a slope that gradually declines in respect to decibels.

If the Butterworth filter design increases, then filter would increase and also the create a brick wall response and should resemble the image above as shown in [the above figure](#).



5.1 OP-AMP FILTER (CUT-OFF FREQUENCY / R.C LOW-PASS-FILTER CALCULATION).

The values for the filter's electrical elements were obtained by selecting a common resistor value, (10 kilo-Ohms) and then rearranging the "Cut-off frequency" expression to estimate the product "C" in capacitance.

Note: with earlier tests, noise was still present on the filter's output at 50Hz cut-off point. The Cut-off frequency was decreased to 30 Hz.

With the selected resistor, the expression for Cut-off frequency is rearranged to make "C" the subject.

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

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

$$C = \frac{1}{2 \cdot \pi \cdot (10 \times 10^3)(30)}$$

$$C = \frac{1}{2 \cdot \pi \cdot (300,000)}$$

$$C = \frac{1}{(1,884,955.592)}$$

$$C = 530.516 \text{ nF } (10^{-9})$$

To determine the "Cut-off frequency" the following expression is used with the component values of from the low pass filter. Whereas R = 10 kilo-Ohms, and C = 318.31 nano-farads.

Note: component values have not been altered to standard E-series values.

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

$$F_c = \frac{1}{2 \cdot \pi \cdot (10 \times 10^3)(318.31 \times 10^{-9})}$$

$$F_c = \frac{1}{2 \cdot \pi \cdot (5.31 \times 10^{-3})}$$

$$F_c = \frac{1}{(0.334)}$$

$$F_c \approx 29.97$$

5.2 OP-AMP FILTER ("FIRST-ORDER" FILTER)

With the R.C low-pass-filter values obtain, the Low-pass filter can be assembled and produce filtering functionality.

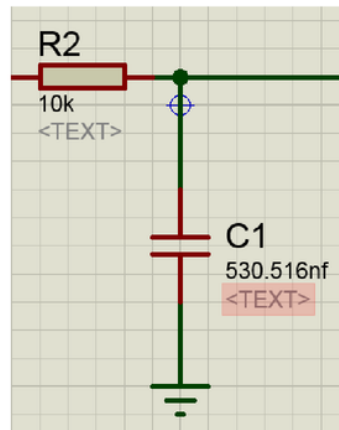


Figure 4: Proteus circuit of R.C Low-pass-filter.

Cut-off point (29.97 Hz)

This R.C filter depicted in Figure 4 is considered a R.C network and therefore, can be defined as a "First-order" filter.

With another RC networks applied, the two R.C networks would be considered as one unit and defined as a "Second-order" filter, increasing the downfall of the slope.

Individually, each network would be classed as a "stage", but as one unit they are define by the number of networks, hence either a first, second or third order.

When applying multiple orders in series, the orders are considered to be cascading. If there are multiple cascading orders, the slope of the frequency response will become steeper, decreasing the pass band area and establishing a new curve response defined as a brick wall response.

Increasing the number of orders (filter networks), will also increase the total impedance of the unit, coursing high circuit resistance, signal phase distortion and affect frequency response.

The first-order filter response dose attenuates the noise by several decibels, but still the noise is large enough by 300 Milli-volts to course some distortion to the thermocouple sensor signal. An expansion to this filter must be made to full noise attenuation.

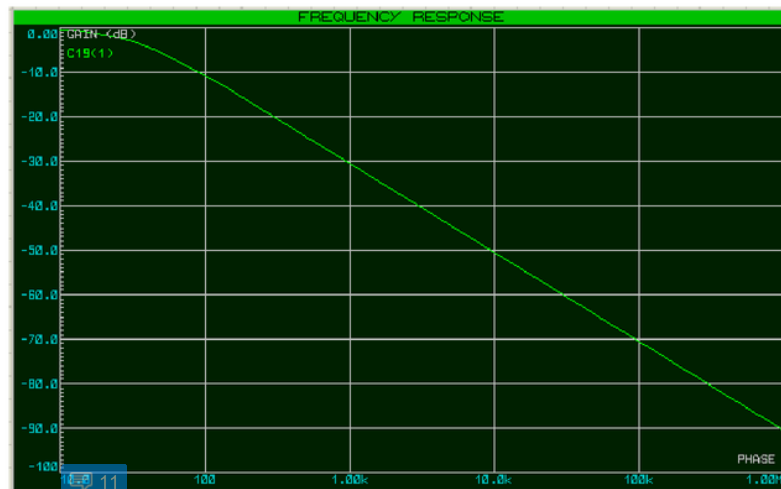


Figure 5.1: Proteus Low-pass-filter response graph (respect to decibels)

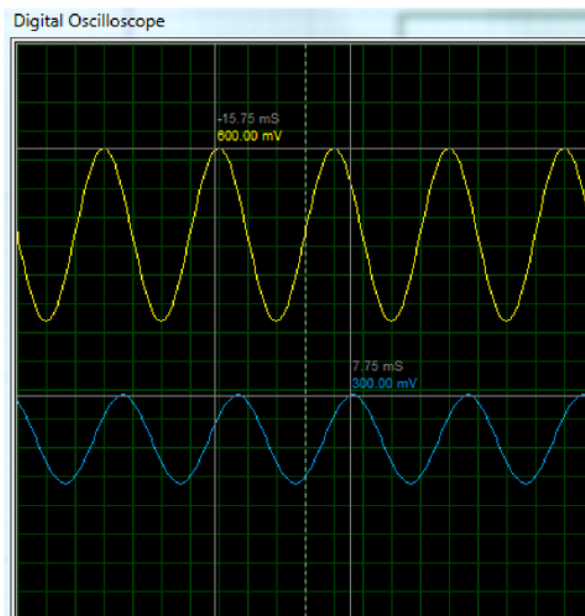


Figure 5.2: Proteus Low-pass-filter, oscilloscope display.

5.3 OP-AMP FILTER (BUTTERWORTH/SALLEN AND KEY CONFIGURATION).

With A “Second order” filter assembled, the slope has become narrower and the temperature signal has reduced in size with little swing.

To improve on the signal size, an Operational-Amplifier must be applied to the Second-order filter to amplify the signal.

When applying the Op-Amp to the two networks, the circuit architecture established is considered to be a Butterworth filter using “Sallen and Key” topology.

This filter is now assembled and is comprised of Op-Amp that in a salon-and-key configuration that produces a Butterworth frequency response.

The gain of the Op-Amp will also increase the output signal to avoid signal size reduction.

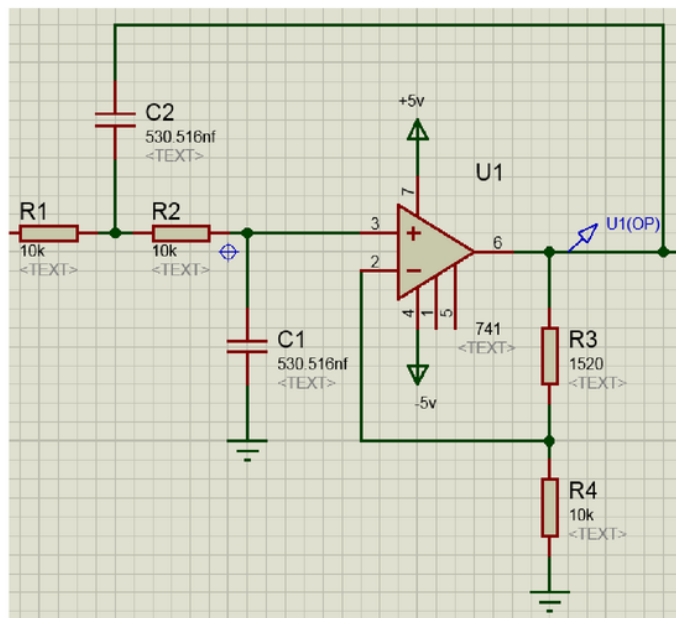


Figure 6: Proteus circuit Butterworth filter with "Sallen and Key" topology

With a single “Second order” filter with “Sallen-and key configuration, the frequency response curve has become steeper, establishing a shorter pass-band regen.

Analysing the output the “Sallen and Key” filter, noise is still present and interfering with the temperature sensor signal. Further development of the filtering system must be made to produce a clear signal.

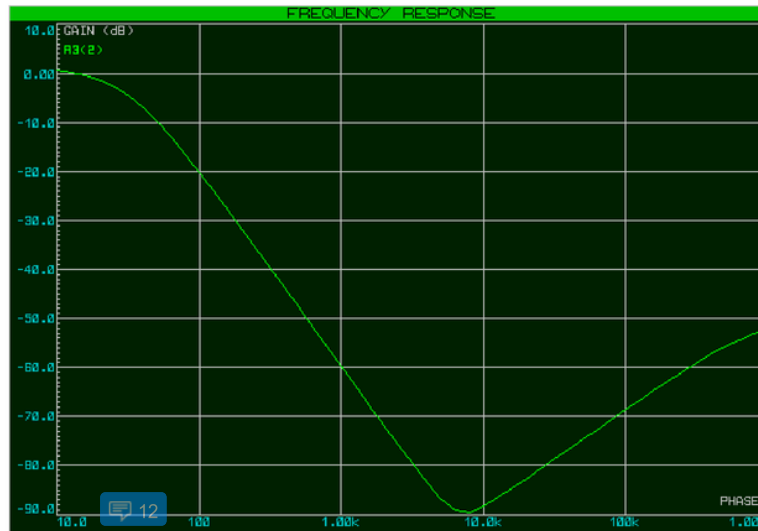


Figure 7: Proteus Butterworth filter with "Sallen and Key" topology response graph
(respective to decibels).

It is clear that one “Sallen and key” filter with a “Second-order” network will not be adequate to remove the corrupting signal.

To improve on this issue, three Stages of R.C networks with “Sallen and Key” topology have been connected together to establish a cascade of filters, now defined as an “Eighth-order”.

With the combination of the four stages, each one will cascade with the next, creating a greater filter design to remove the noise.

An “Eighth-order” Butterworth filter has been established, which has again decreased the pass-band and created a steeper slope than the “Second-order” Butterworth filter.

The presents of the analogue signal has reduced to a point where the thermocouple sensor signal is just visible with clear phase deviation, yet the noise is still influencing the Pulse- gen signal, that the “envelope” (the top of the wave form) is distorted. Additional stages may need to be applied to improve the pulse-gen signal.

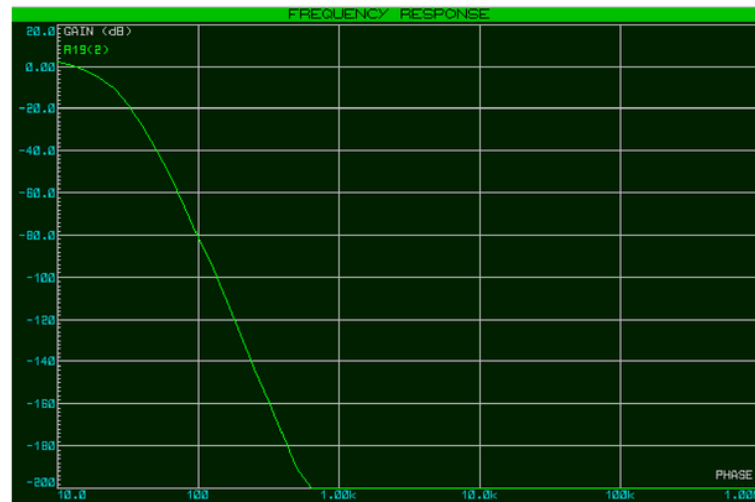


Figure 8.1: Proteus "Eighth-order" Butterworth filter response graph.

(Respected to decibels)

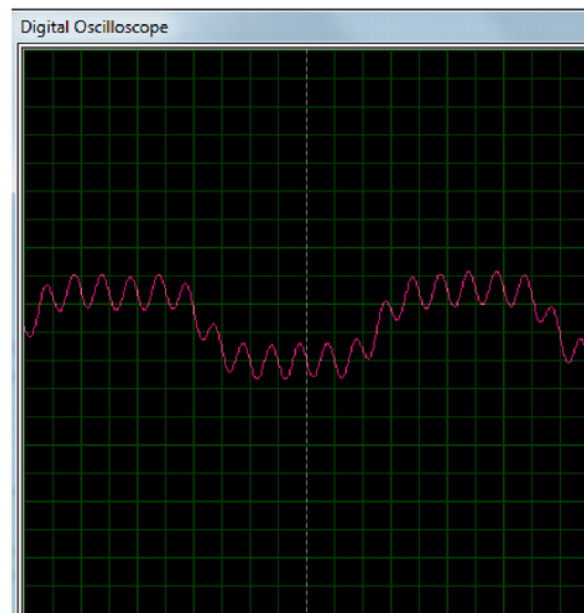


Figure 8.2: Proteus "Eighth-order" Butterworth filter, oscilloscope display

To determine the gain for each amplifier in each stage the following expression is used to determine the resistor value to establish the correct gain ratio.

Referring to book "the Art of electronics" each stage would have to have the same gain ratio. For an "Eighth-order" filter, a gain of 1.038 would be used. [3]

Note: from calibrating the filter, the attempt to alter the values would create an unstable output.

$$(k - 1)R$$

$$(1.038 - 1) 10 \cdot 10^3$$

$$(0.038) 10 \cdot 10^3$$

Feedback resistor value = 380 ohms.

To ensure the value is current, the Non-inverting op-amp formula (expression) is used.

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

$$A = 1 + \frac{380}{10,000}$$

$$A = 1 + 0.038$$

$$A = 1.038$$

With no improvement on removing noise with an “Eighth-order” Butterworth filter, an addition of four stages were applied to the filter to produce a “Sixteenth-order” Butter worth filter.

With the addition of the new stages, the noise is now attenuated to the point that the pulse-gen signal is no longer under influence of the analogue signal. With the gain of each stage, the pulse-gen signal has increase to 60mVs.

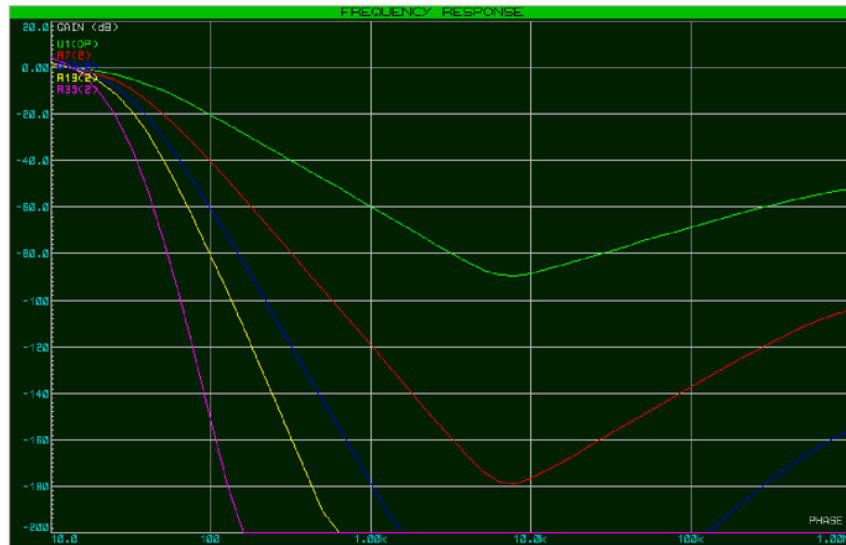


Figure 9.2: Proteus Butterworth filter response graph.

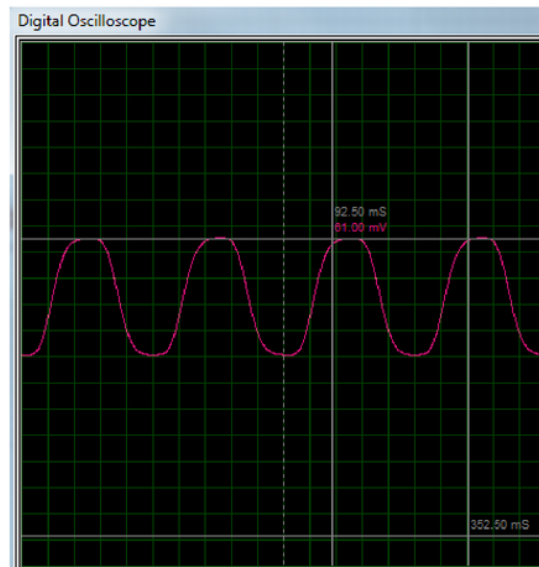


Figure 9.2: Proteus Butterworth filter, oscilloscope display.

With the “Sixteenth-order” Butterworth filter (with “Sallen and Key” topology) now completed. A level shifter can now be constructed and applied to the out but of this filter.

6 .OP-AMP LEVEL SHIFTER

When a clear signal has travelled to the level shifter, the voltage range should alter to the levels in which the pin of a microcontroller can operate, ranging from 0 to 5 volts.

With 7.1.mV is applied to the level shifter, the voltage should alter to 0 volts and when 2.16mV is applied, the voltage level should alter to 5 volts. Other signals applied should change within the range 7.1.mV to 2.16mV to produce a range of 0 to 5 volts.

Displayed below is an isolated circuit, which is being calibrated to be set as a level-shifter. As a signal is applied to the Op-Amp, the output signal should be shifted to a level higher than its earlier counterpart.

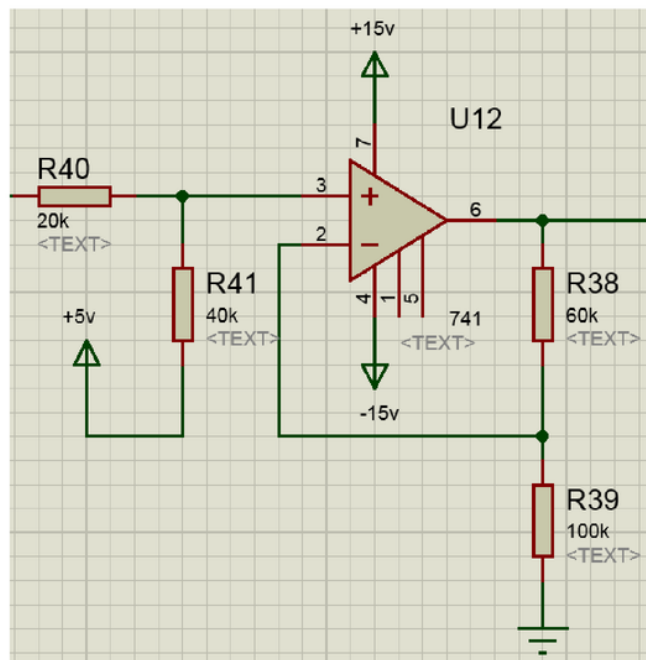


Figure 10: Proteus circuit of isolated "Level shifter"

To test the circuit's operation, an analogue signal with a Peak of 2.5 volts, is applied to the "Level-shifter" to move the signal higher in level.

The level shifting of the circuit is controlled by two resistors (R40 and R41) set at the Non-inverting input and are connected to one node. One resistor (R41) is connected to a power terminal of 5 volts that is applying an additional of 3.3 volts. From here, the voltage applied from the power terminal, can be altered to change the level of the input signal.

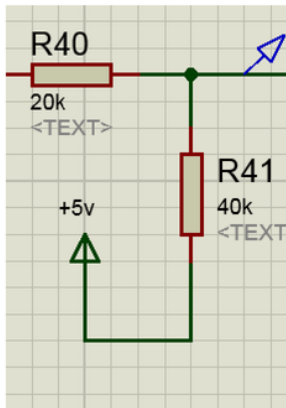


Figure 11.1: Proteus circuit "Level-shift" input resistors.

The other two resistors connected to the output and looped back to the Inverting input; control the gain of the Op-Amp. If the size of the signal is too small, the peak of the signal can be manipulated by recalibrating the values of the resistors (R38 and R39).



Figure11.2: Proteus circuit "Level-shift" gain controlled resistors

Monitoring the oscilloscope of the “Level-shifter”, the applied Analogue signal is displayed with a peak of 2.5 volts (indicated in yellow).

The new level shifted signal, identified by as the green waveform, has been produced by the Op-Amp and raised by 2.5 volts, which now oscillates between 5.35 volts to 0 volts.

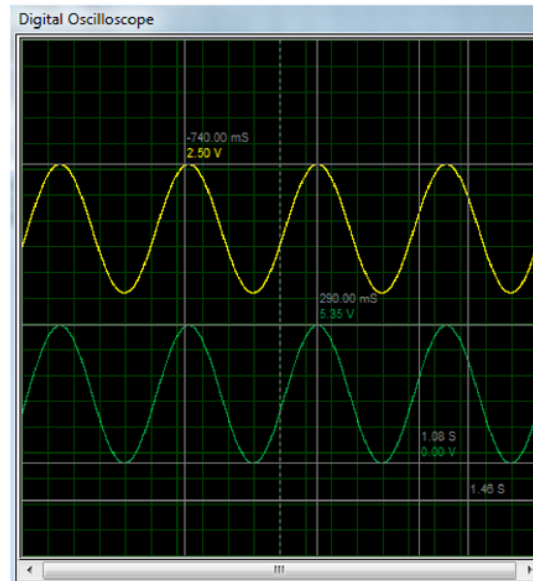


Figure 12: Proteus "Level-shifter", oscilloscope display.

With the “Level-shifter” now considered operational, the circuit can now be applied to the output of the signal conditioning system.

With the Level shifter applied to the Butterworth's output, the value of the resistor should be recalibrated to shift the signal higher to oscillate between 0 to 5 volts.

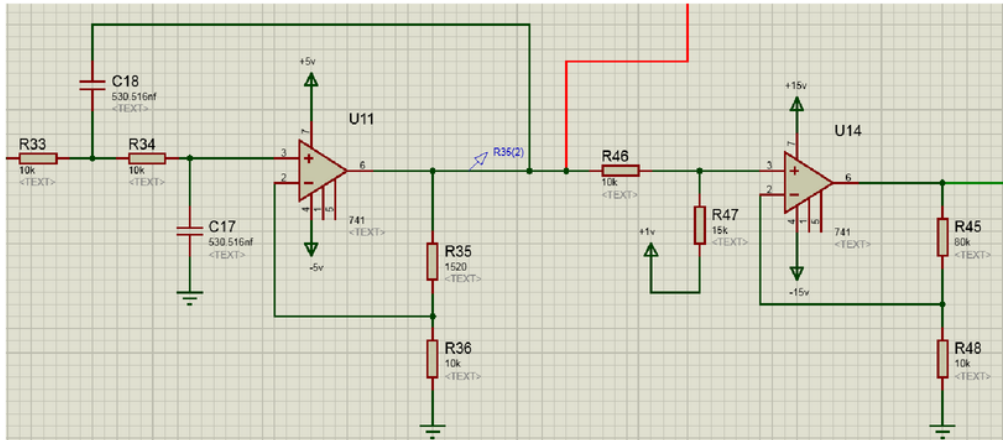


Figure 13.1: Proteus circuit of "Butterworth" output and "Level-shifter" conjoined.

As the resistor's values are altered to increase the height and size of the signal, the signal does not appear to respond to the recalibration.

As the resistors, connected to the Non-inverting output are altered, the signal dose increase in voltage level. However, attempting to increase the swing (amplitude) of the signal appears to also increase the voltage level of the signal.

The circuit appears to be unable to correctly level shift with no explanation given.

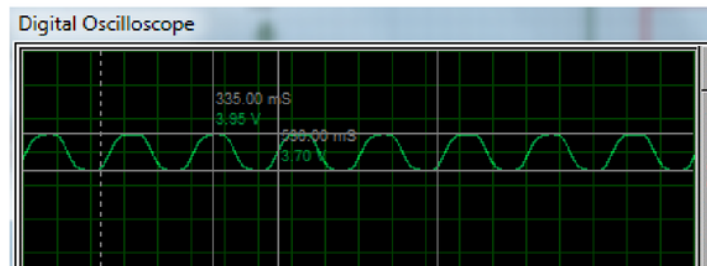


Figure13.2: Proteus Final signal output, oscilloscope display.

7. TIME DELAY

With the signal received, the delay can be determined by monitoring the original signal produced for the Pulse-gen and the signal received from the signal condition system.

Note: the signal originating from the Pulse Generator is indicated as a blue wave form and the signal altered by the signal conditioning system is displayed as a green wave form.

Monitor the signals simultaneously, both signals appear to be out of synchronisation. This is most likely due to the high collective impedance of the Butterworth filter comprised of multiple “Second-order networks.

Measuring the response of green wave form, the signal seems to respond after 125 Milliseconds. This delay reaction does not affect the operation of the system greatly and can be considered be ignored.

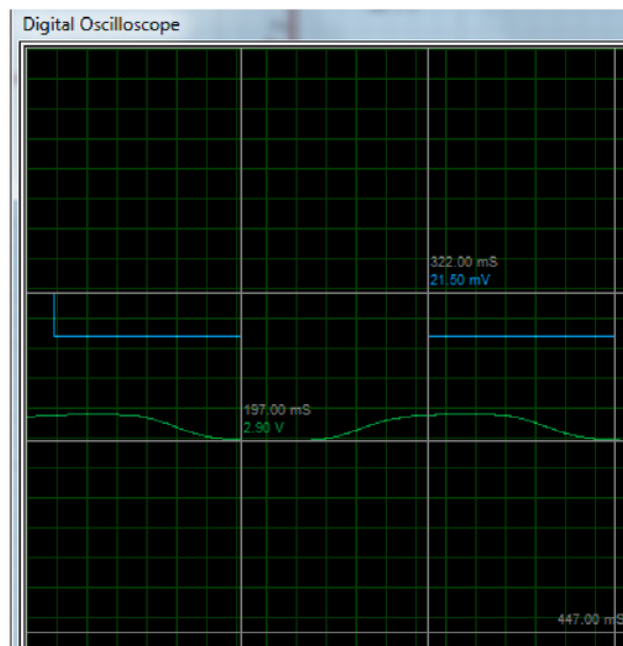


Figure 14

8. CONCLUSION

The full operation of the signal conditioning system was unfortunately was not obtained.

The voltage protection could manage to prevent high voltage from being applied, Although the operation of the first unit was functional, the butter worth filter required a larger number of “second order” filters to remove the unwanted signal corrupting the pulse-gen signal.

In future, a circuit similar to a demodulator could be applied at the “Eighth-order” filter to clear the top or envelope of the signal to reduce the number of orders/stages.

With the “Level-shifter”, the circuit appeared to worth well. As a signal was applied to the circuit, the unit would increase the voltage level and amplifier the signal, giving it greater swing.

When the “Level-shifter” was applied to the rest of the signal conditioning system, the signal would not increase in amplitude although the gain factor was constantly changed.

There was no explanation for the error that could have been identified and therefore could not be resolved.

If the goal of this project was to create just a filtering system with no level shift and could tolerate the large sixteenth-order Butterworth filter, then the project has met its goal and milestone.

Unfortunately the level shift does not work, giving a small voltage range.

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Lv 5 signal conditioning

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

63/100

PAGE 1



Comment 1

Is this part of the template you've used, or is this your abstract?

PAGE 2

PAGE 3

PAGE 4

PAGE 5



Comment 2

Axis titles?

Units?

PAGE 6



Comment 3

1.2V pk-pk



Comment 4

removed

PAGE 7



Comment 5

Good, but if another zener diode were included, connected in reverse polarity to the one shown, then you could protect against negative voltages too.

PAGE 8



Comment 6

Not sure that this would be the result.

More likely would be the signal reducing in amplitude due to the effect of the input and output impedances of the amplifiers combining to form potential dividers.



Comment 7

buffer's - apostrophe to show ownership

PAGE 9



Comment 8

Which figure?

The above figure shows a unity gain buffer.

PAGE 10

PAGE 11



Comment 9

1st order PASSIVE filter



Comment 10

gradient?

PAGE 12



Comment 11

It would have been nice to see this graph start closer to DC. Maybe at 0.1Hz

PAGE 13

PAGE 14



Comment 12

Would have been nice to see what happens between 0.1 Hz and 10 Hz



Comment 13

Shouldn't this be four 2nd order stages to make an 8th order filter?

PAGE 15

PAGE 16



Comment 14

The Art of Electronics?

PAGE 17

PAGE 18

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PAGE 24

GRADING FORM: SMU GENERIC_SMOSEY

JAMES DENNING

63.45

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



You have used a number of sources and followed the required referencing standard. Some of the references you have used may not be reputable.

2.9

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.

20.4

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 & significance of evidence. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions

18.9

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A very good application of a range of techniques. Very good consideration of the context of the application. 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 well, confidently and consistently in a suitable format. Can work very well as part of a team, with very good contribution to group activities. Work is coherent and fluent and is well structured and organised. "

3.25