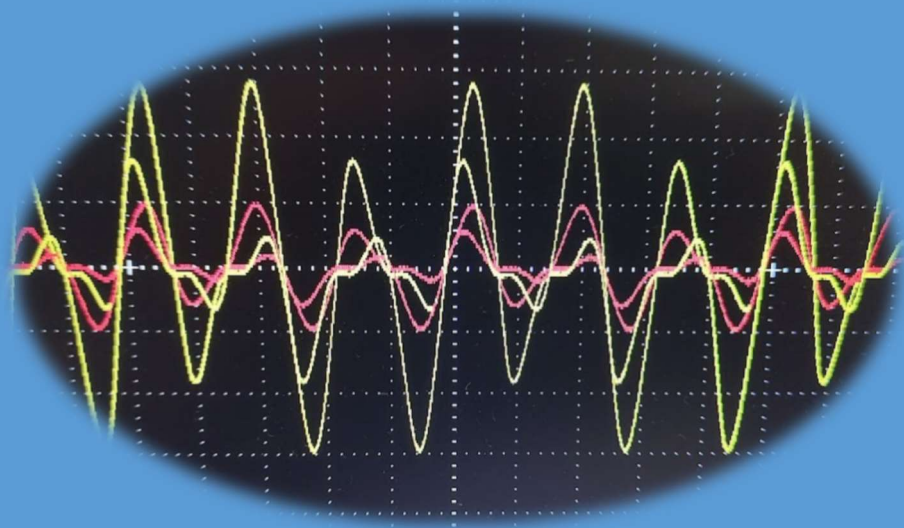


EMBEDDED ELECTRONICS WORKSHOP SKILLS LOGBOOK



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Contents

Introduction	2
Initial Circuit Design & Simulation	3
Circuit Breadboard & Testing.....	5
PCB Design, construction & Testing.....	9
Reflections and Conclusion.....	13
Appendix:	13

Introduction

The aim of this project is to develop and apply practical workshop skills essential for the professional electrical engineer. This includes understanding various components, the design of a functioning circuit demonstrating an understanding using general principles of electrical physics. Simulation of the circuit model through appropriate software, in this case Proteus, followed by EasyPC, for the PCB Design. On top of simulation and design, practical skills are to be developed. This includes making use of physical prototyping through a breadboard, soldering practice, test and evaluation equipment, component testing and PCB assembly with these activities conducted in a safe workshop manner.

Whilst not dealing with any high risk hazards, items, equipment or processes during the activities carried out through the making of this logbook, the author believed it to be suitable to conduct a general safety summary for good practice to follow moving forwards.

Key safety points:

- Everybody is responsible for safety in the workshop/Lab.
- If unsure how to use equipment such as a soldering iron, ask how.
- Ensure good housekeeping and a clean, organised and clear workspace at all times.
- Wear suitable clothing and secure loose hair/clothing if required.
- Make use of correct PPE, namely fume extractors for soldering.
- Use equipment and materials in the correct way, do not try to put extreme current/voltage through equipment that is not rated for such activity.
- Be familiar with the specific risks posed by electric shocks and how to deal with a casualty.



Figure 1: Electrical hazard warning sign.
Credit: [rsdelivers Electrical-hazard-warning-sign-english](#)

Initial Circuit Design & Simulation

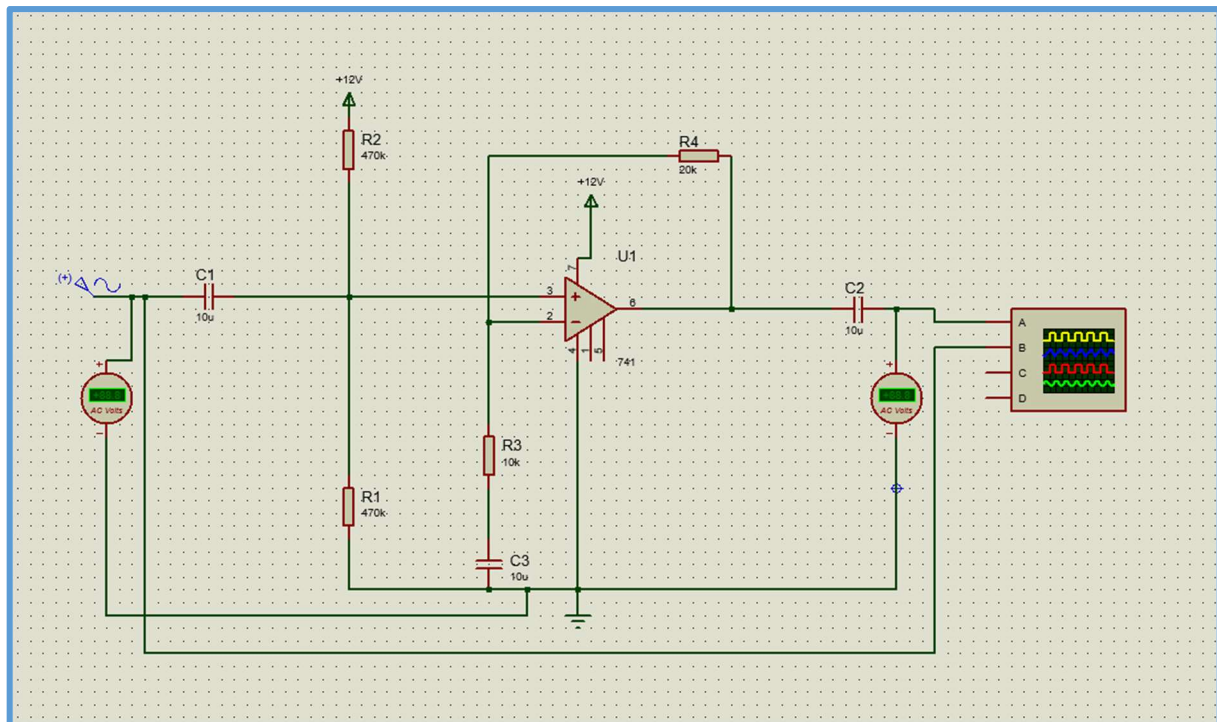


Figure 2: The concept circuit designed in Proteus, using the 741 OpAmp

The first stage of this process was to build a circuit schematic in Proteus for a non-inverting Operational amplifier (OpAmp). The specified gain aimed for voltage amplification is, $A_v = 3\text{dB}$ in this case. It is determined by the following equation.

$$A_v = \frac{V_o}{V_i} \{1.0\}$$

Where A_v is the voltage gain, V_{in} is voltage into the circuit and V_{out} is the measured amplified voltage.

Coming from the input sine waveform, we have one connection to the oscilloscope via channel B and another to the capacitor $C1 = 10\mu\text{F}$, serving as a filter being that this is the input into the OpAmp on pin 3. The resistors $R1$ and $R2$ have a value of 470Ω , with $R3 = 10\text{k}\Omega$ connected to ground, and $R4 = 20\text{k}\Omega$ on the feedback loop. The capacitor $C2 = 10\mu$, acting as a filter before going into the amplification/feedback loop. Finally we have the output from pin 6 going through a final filter capacitor before hitting channel A on the oscilloscope. For the 741 OpAmp pins number 2 and 3 are inputs, pin number 6 is the output, pin number 7 is the positive power supply, pin number 4 is the ground. The AC voltmeters served as a sanity check, to see if numbers seemed sensible before needing to dial in the oscilloscope.

The values of the required resistors are the key in achieving the desired 3dB amplification. From the circuit we can determine equation {2}.

$$V_o = V_i + \frac{V_i R_4}{R_3} \{2.0\}, \text{ need to } \div \text{ by } V_i \text{ to get gain eqn } \{1.0\}$$

$$A_v = \frac{V_o}{V_i} = 1 + \frac{R_4}{R_3} \{2.1\}$$

$R4 = 20\text{K}$ and $R3 = 10\text{K}$ our idealised gain is:

$$A_v = \frac{V_o}{V_i} = 1 + \frac{20\text{k}\Omega}{10\text{k}\Omega} = 1 + 2 = 3\text{dB} \{2.2\}$$

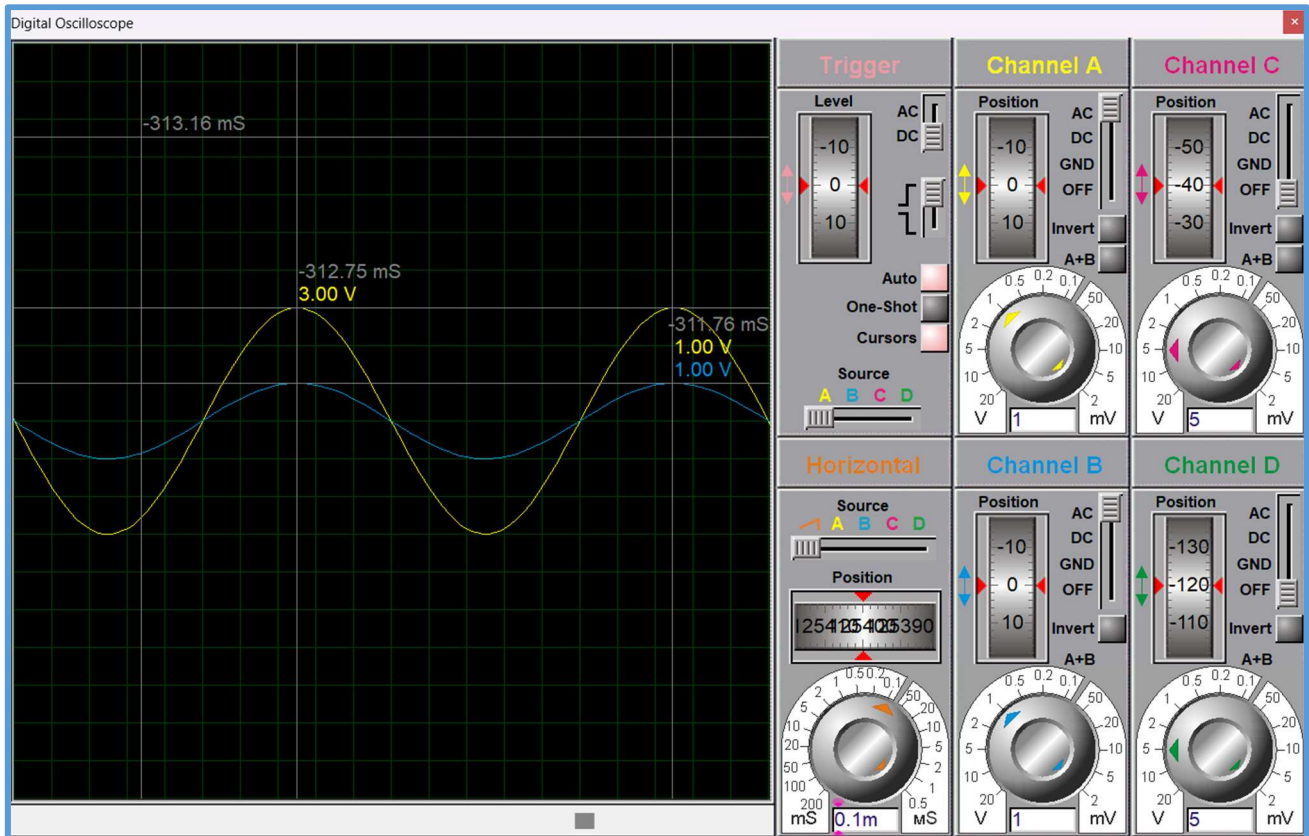


Figure 3: A promising first measurement, the yellow being the output channel and blue being the input signal. The input voltage is amplified 3 times and so our OpAmp has a gain of 3dB as calculated.

Frequency (Hz)	Output V_o (V)	Input V_i (V)	Gain A (dB)
1.00E-01	0.28	0.48	0.58
5.00E-01	1.25	0.90	1.39
1.00E+00	1.77	0.98	1.82
5.00E+00	2.85	0.98	2.92
1.00E+01	2.92	0.98	2.99
5.00E+01	2.95	1.00	2.95
1.00E+02	3.00	1.00	3.00
5.00E+02	2.90	0.93	3.14
1.00E+03	2.98	1.02	2.92
5.00E+03	3.00	1.00	3.00
1.00E+04	2.95	0.99	2.98
5.00E+04	2.85	1.00	2.85
1.00E+05	1.65	1.00	1.65
5.00E+05	0.38	0.98	0.38
1.00E+06	0.20	0.98	0.21

Table 1: Simulated results using Proteus as shown in figure:2

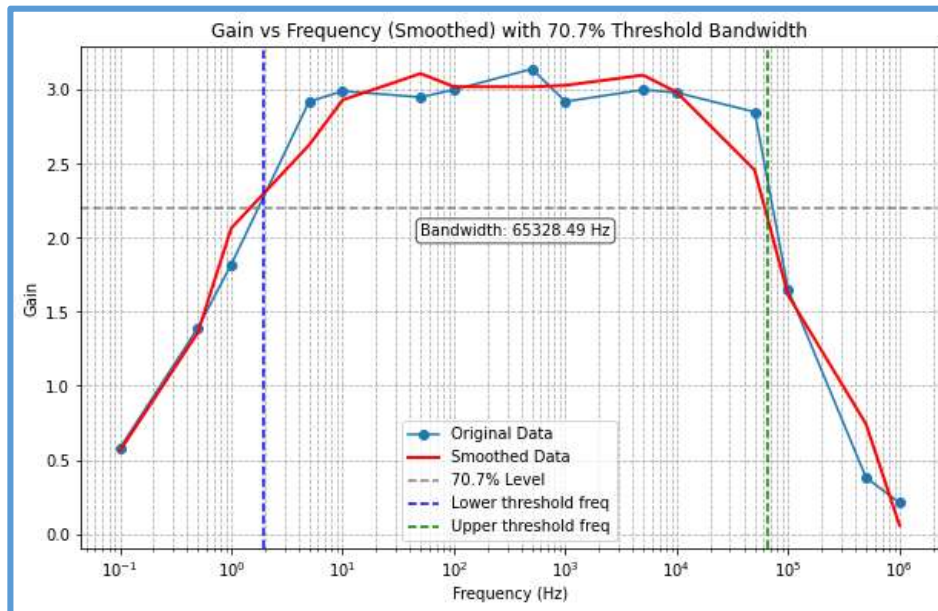


Figure 4: Graph showing results of Table: 1, bandwidth for the simulation is approximately 65kHz, the data is plotted on a logarithmic scale.

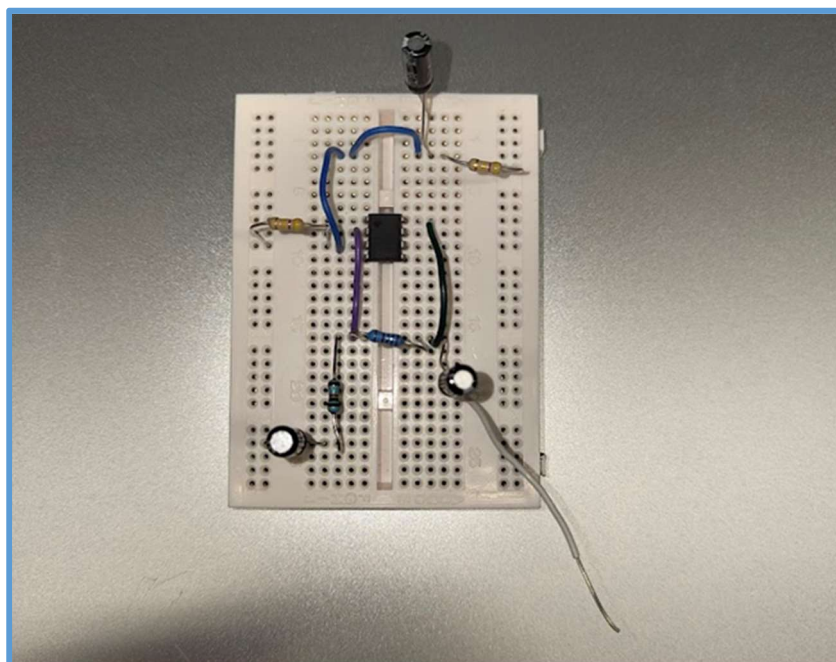
From the graph, lower intercept: (Freq=1.95 Hz, Gain=2.20) Upper Intercept: (Freq=65330.44 Hz, Gain=2.20) therefore our gain band width product GBWP is:

$$\begin{aligned} GBWP &= \text{Bandwidth} \times \text{Max (Smoothed)Gain} \{3.0\} \\ GBWP &= 65328.49 \times 3.11 \{3.1\} \\ GBWP &= 203109.38 \{3.2\} \end{aligned}$$

So for the simulation the bandwidth is around 65kHz at a gain threshold of 2.2, and the GBWP is ≈200kHz.

Circuit Breadboard & Testing

Following from the simulation some live prototyping followed, using a breadboard. Initially a breadboard design was completed on paper, however a learning opportunity presented itself, as being on top of general housekeeping in the lab, not only benefits safety but also productivity and efficiency. Having lost the original breadboard diagram some improvisation was required. Upon testing the improvised



breadboard the circuit was giving no output, this was eventually overcome, with several iterations and outside assistance to get a clean signal from the breadboard. This was highlighted, as in an engineering environment, especially when working within time constrained projects setbacks caused by lack of organisation such as breadboard noticeably missing key components such as power into the system. This had an adverse effect on the functionality of the OpAmp.

this are easily avoidable.

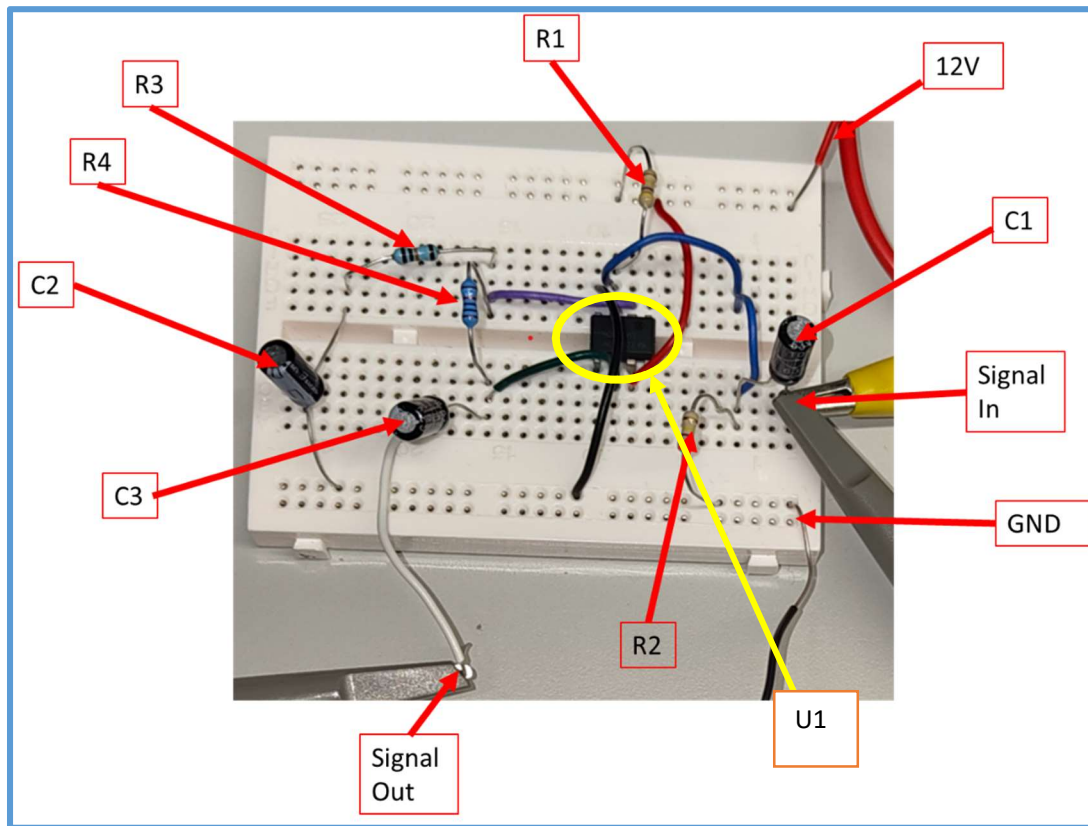


Figure 6: The final iteration of the breadboard, with signal probes and now power/ground attached, this improved performance.

Component No.	Component
R1	470k Ω Resistor
R2	470k Ω Resistor
R3	10 k Ω Resistor
R4	20 k Ω Resistor
C1	10 μ F capacitor
C2	10 μ F capacitor
C3	10 μ F capacitor
U1	741 OpAmp

Table 2: Component legend for parts present and connected to the breadboard.

The breadboard testing largely followed the same procedure as the simulation that was previously conducted. With the voltage in set to 2V and the frequency of the AC signal swept from 0.05Hz to 1MHz.

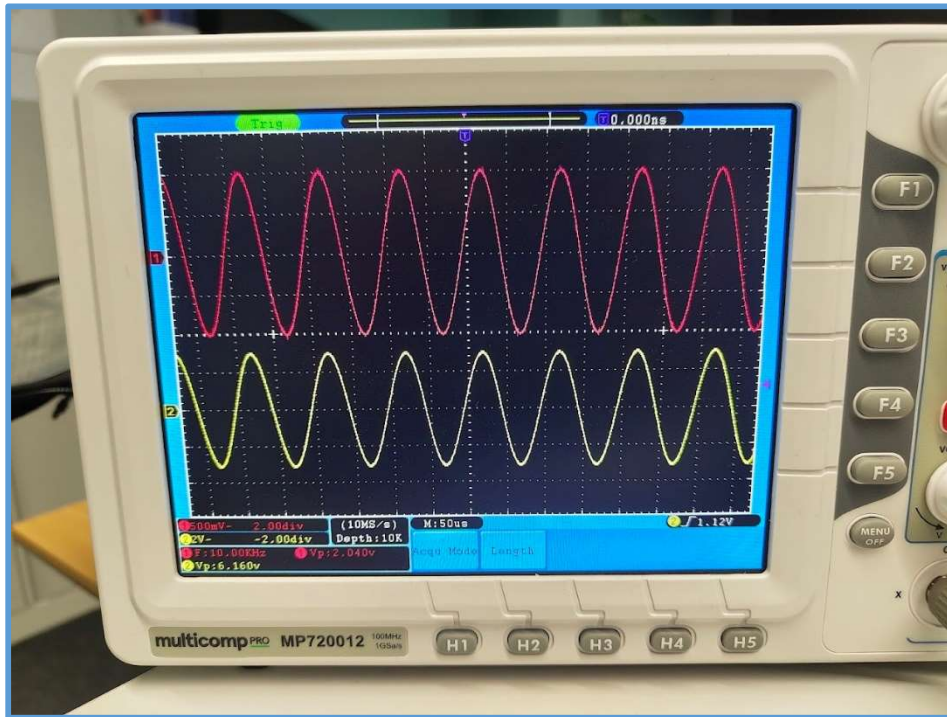


Figure 7: Example of output from the breadboard at 2.040V (red) in we have an amplified output (yellow) of 6.160V.

Frequency (Hz)	Output V_o (V)	Input V_i (V)	Gain A (dB)
5.00E-02	0.148	0.200	0.740
1.00E-01	0.420	0.520	0.808
5.00E-01	1.720	1.840	0.935
1.00E+00	3.200	2.100	1.524
1.00E+02	6.080	2.080	2.923
2.00E+03	6.120	2.080	2.942
5.00E+03	6.120	2.080	2.942
1.00E+04	6.160	2.100	2.933
2.00E+04	6.160	2.080	2.962
3.00E+04	6.080	2.060	2.951
4.00E+04	5.680	2.060	2.757
5.00E+04	4.800	2.020	2.376
1.00E+05	2.400	2.060	1.165
1.50E+05	1.600	2.100	0.762
2.00E+05	1.220	2.060	0.592
3.00E+05	0.808	2.100	0.385
4.00E+05	0.616	2.080	0.296
5.00E+05	0.496	2.060	0.241
1.00E+06	0.256	2.080	0.123

Table 3:
Results from breadboard giving promising results. Whilst not identical in where the gain ramps up to the simulation they are within the same order of magnitude.

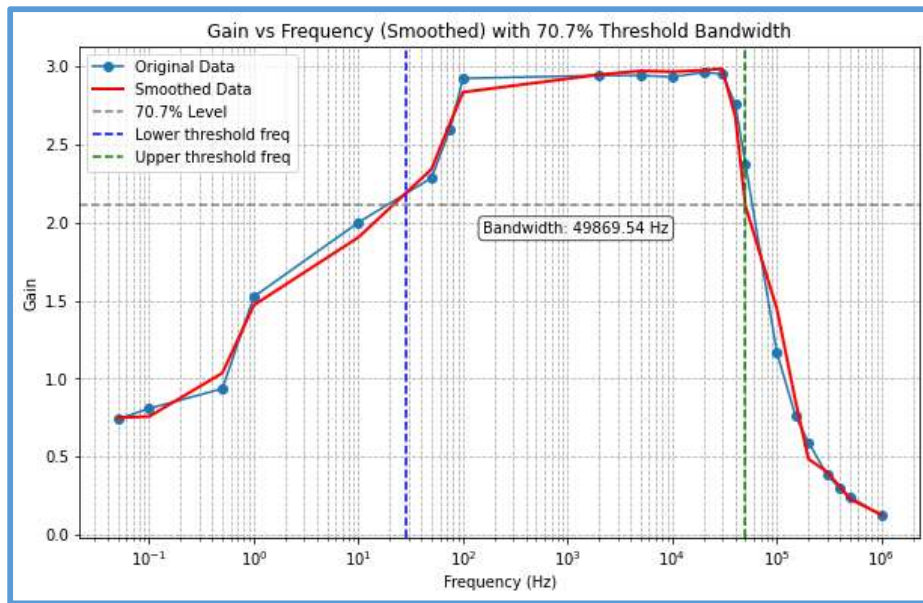


Figure 8: Graph showing results of Table: 3, similar shape but a bit dog legged but within the same order of magnitude as the simulation.

Calculated as before, Results for Bread Board Data:

Max Gain: 2.98

Lower Intercept: (Freq=28.79 Hz, Gain=2.11)

Upper Intercept: (Freq=49898.33 Hz, Gain=2.11)

70.7% Bandwidth: 49869.54 Hz

GBWP (70.7%): 148858.20

PCB Design, construction & Testing

Soldering is a critical skill for any electronic engineer, being proficient in producing reliable connections to components and boards is not only important for electronic connectivity but also the mechanical strength the items being soldered. Poorly soldered components/equipment are likely to have poor reliability and a higher likelihood of failure, both being physically broken and electrical malfunctions. Below are practice pieces used to hone soldering ability before assembling the main PCB for this project.

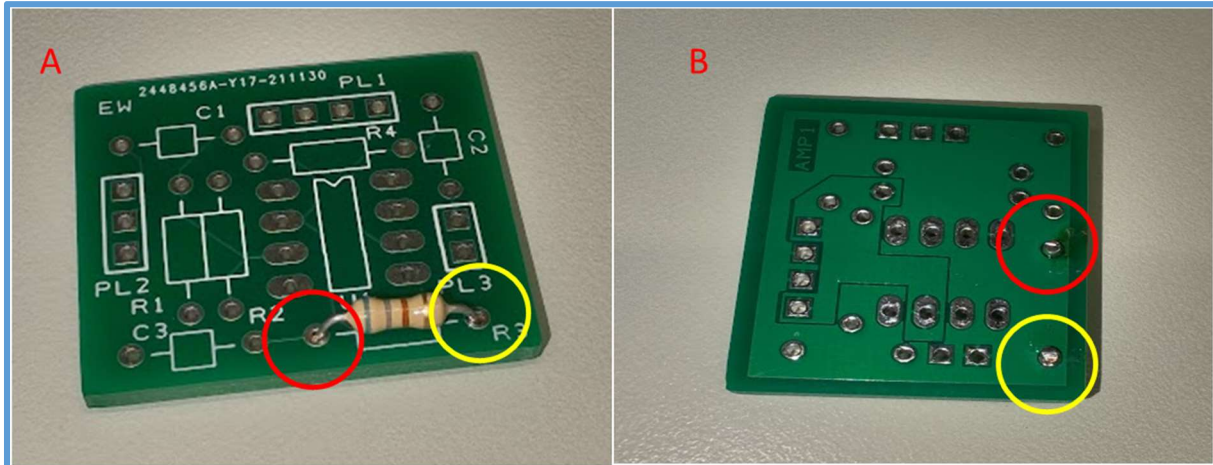


Figure 9: First attempt at soldering a resistor, a small excess of solder added to the board that was later cut too short which generally reduces the mechanical strength of the joint. On (A) red circle, solder has not flowed fully into the joint which again is likely to reduce the quality of connection.

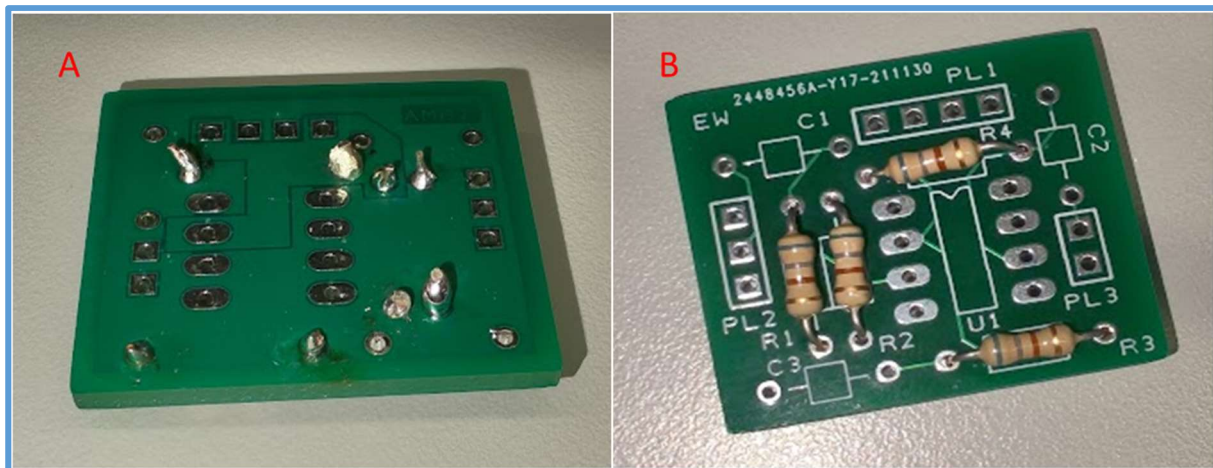


Figure 10: Some more practice, with wildly varying quality of solder joints some burning of flux and formation of amorphous blobs. Overall this practice was a fantastic learning opportunity for the author to develop the practical skills needed in an electronics workshop environment.

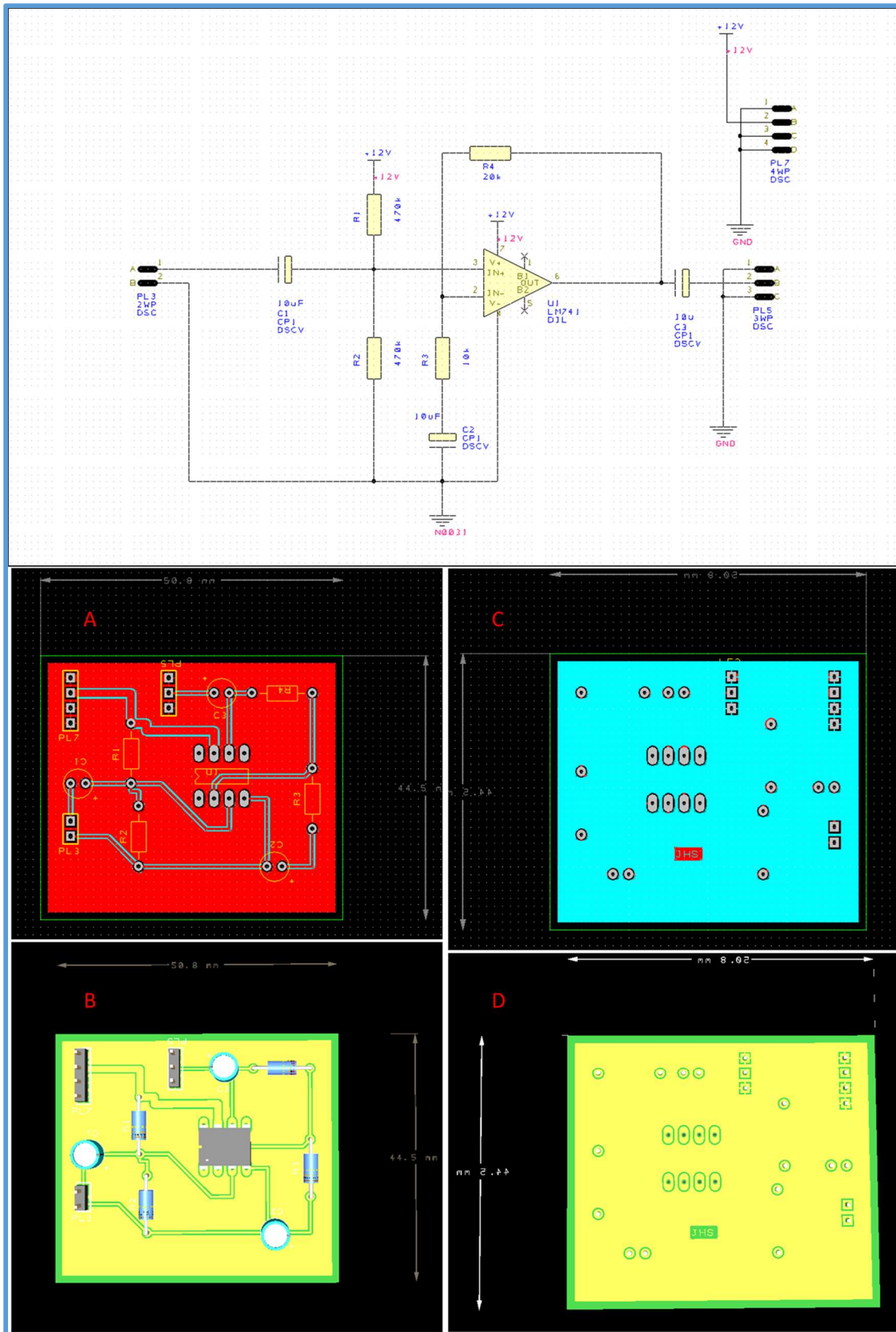


Figure 11: Schematics of PCB made using Easy-PC. On top is the circuit schematic similar to what we have in Proteus, in A and B have the top of the circuit in PCB schematic and 3D render respectively. C and D following in the same form but viewing the reverse side of the PCB.

In the schematics above and then carried out into the assembly of the PCB a slight mistake has been made. On Easy PC the selected OpAmp was the LM741 whereas the OpAmp meant for use is simply the 741. Whilst very similar they have slightly different pin locations, this likely was the cause of some unusual results to be discussed shortly as the PCB schematic was wired up for the LM741. Whilst not as catastrophic an oversight as the Mars Climate Orbiter, it highlights the importance of having a “measure twice cut once” frame of mind. In all science and engineering it is the details matter, in this case it’s a relatively benign mistake it serves a reminder that, like the Mars Orbiter, the next mistake could be far more costly.

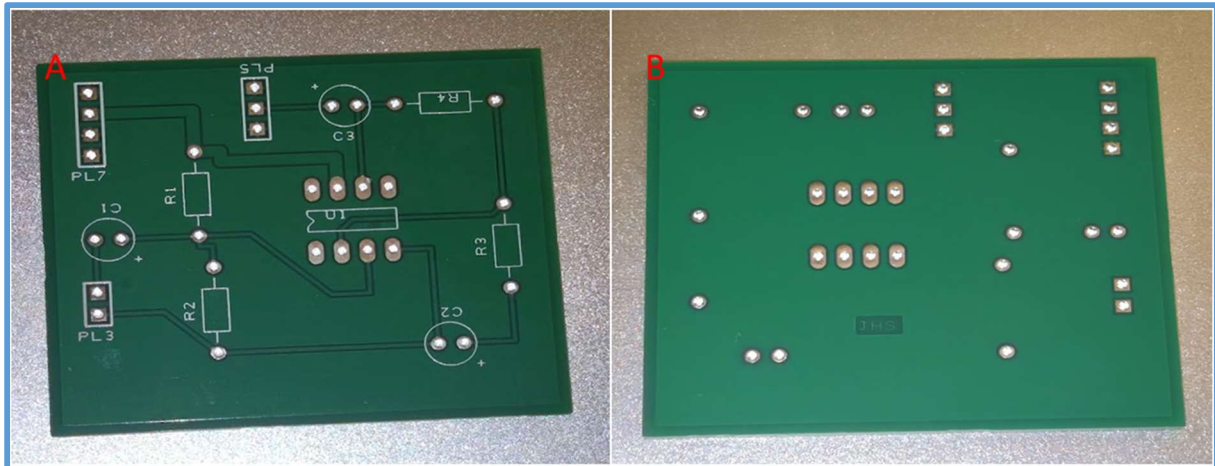


Figure 12: The PCB factory fresh, trace looks as designed in Easy-PC.

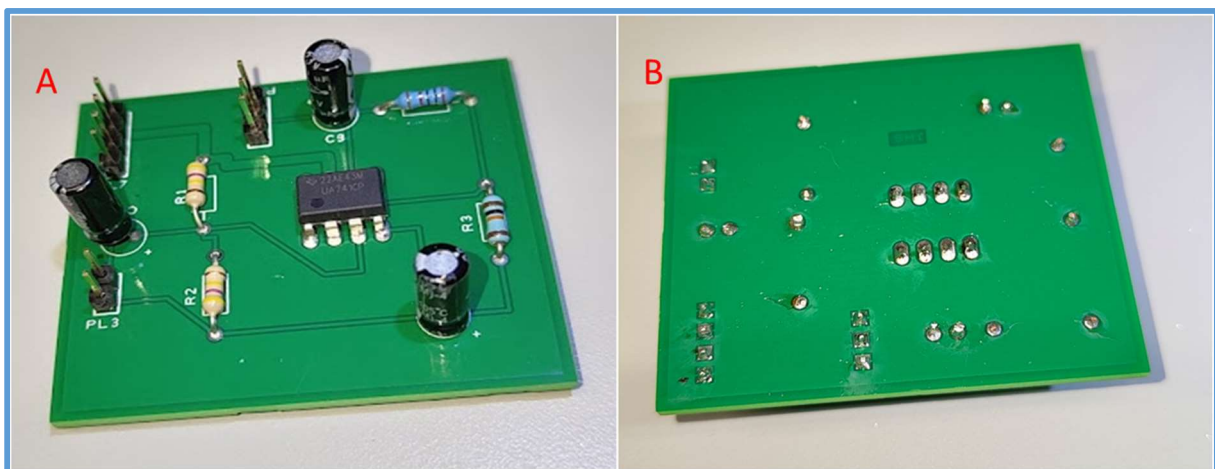


Figure 13: Despite the LM741/741 mix up, the final board is looking clean and well connected. There is a marked improvement of soldering quality than that seen in Figure: 10. Much less scuffed/burnt flux on the back plate of the PCB and clear solid connections top and bottom. Larger and higher resolution images of Figure:13 A and B can be seen in the appendix.

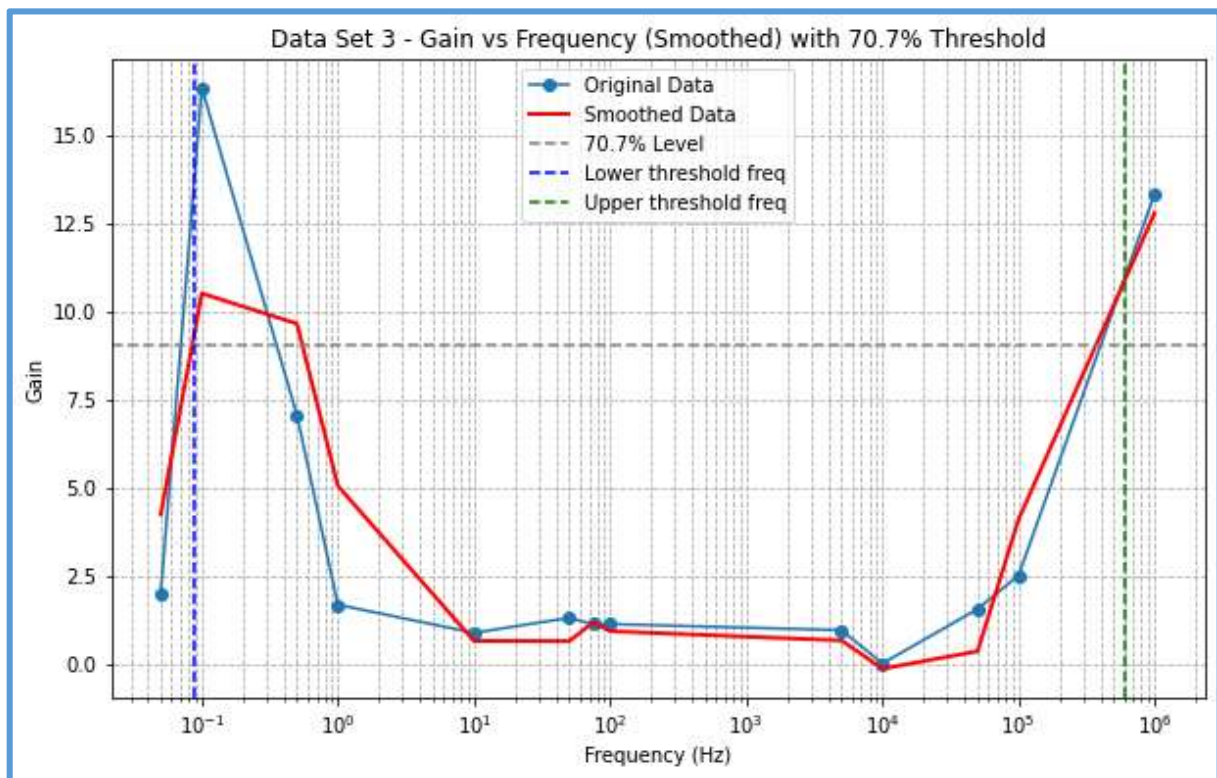


Figure 14: Graph of gain vs frequency for the PCB, there appears to be an issue.

Compared to the results for the simulation and breadboard the PCB values are a departure from what was expected and possibly suggest an advancement in amplification procedure new to science. Unfortunately, and more likely is that the botched pinout from doing the traces for the wrong OpAmp is causing problems. Although if the graph were mirrored it would follow a similar shape to the bread board and simulation results.

Results for Data PCB:

Max Gain: 12.79

Lower Intercept: (Freq=0.09 Hz, Gain=9.04)

Upper Intercept: (Freq=612322.06 Hz, Gain=9.04)

70.7% Bandwidth: 612321.97 Hz

GBWP (70.7%): 7829134.44

Whilst confidently presented there is without doubt, a high degree of uncertainty in these numbers.

Reflections and Conclusion

Despite some setbacks and comically erroneous values for gain on the PCB this logbook was ultimately meant to follow a learning experience, rather than a work of literature a Nobel laureate would be proud of (Give it time you never know). With that in mind it is the author's view that the stated aims have been met:

- Designed a functioning circuit (well 2/3 worked)
- Used Proteus and Easy-PC to get a PCB
- Had a working bread board prototype
- Improved soldering and evaluation skills
- Successfully soldered a (questionable) PCB
- Safely – no burns, shocks, fires or injuries

Overall, great success for what was set out to be achieved, even if the numerical results could have been improved.

Appendix:

