



WORKSHOP SKILLS LOGBOOK

Planning, Simulating, and building a 3 Gain Non-
Inverting Operational Amplifier

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Introduction

The following report details and outlines the processes behind the simulation, prototyping, PCB Design, and assembly, of a 3 Gain Non-Inverting Operational Amplifier, as shown in the figure below.

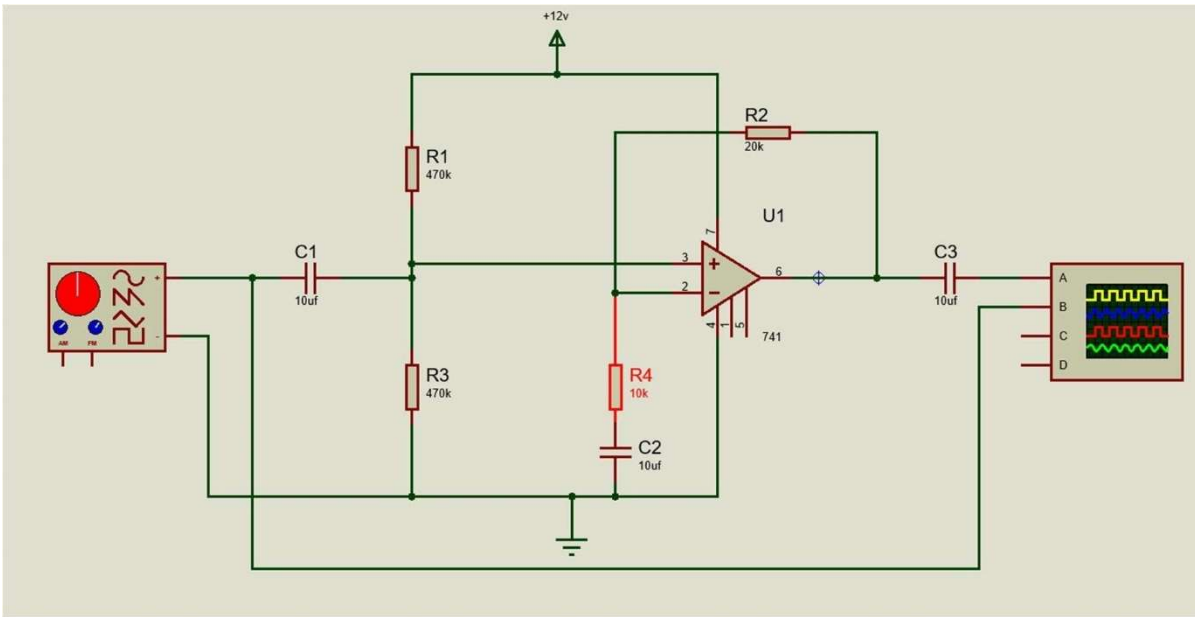


Figure 1: Simulated Proteus diagram of the Operational Amplifier circuit as specified in the Lab instructions.

The circuit works by amplifying the voltage difference between the two input pins, the gain of the amplifier can be calculated through the formula:

$$A = \frac{V_{Out}}{V_{In}}$$

The gain of the system is determined by the feedback resistor and the input resistor, and as such the theoretical gain of the circuit can be found through the formula:

$$Gain = 1 + \frac{R2}{R4}$$

Amplifier Circuit Simulation

When the circuit shown in figure 1 is simulated within the proteus design software, the following table of results is can be obtained, showing the effects of the frequency, and how the gain is impacted at various intensities.

From this table of results, it is possible to conclude that as the frequency increases, at a certain point there will be a degree of decay visible in the gain, eventually causing the OpAmp to output at negative gain, meaning that the output signal would be lower or weaker than the input signal.

It is shown in table 1 that the OpAmp has a minimum frequency of 50Hz in order to operate at the desired gain, lower frequencies yield a lower gain. As higher frequencies are reached a degree of loss can be observed at approximately 50KHz where the gain then begins to fall off, this trend continues to a greater degree at higher frequencies.

f	Vin	Vout	Gain(dB)		f	Vin	Vout	Gain(dB)
0	0	0	0		1000	2	6	9.54
1	2	3.54	4.96		2000	2	6	9.54
2	2	4.84	7.68		5000	2	6	9.54
5	2	5.72	9.13		10000	2	6	9.54
10	2	5.92	9.43		20000	2	6	9.54
20	2	5.98	9.51		50000	2	5.78	9.22
50	2	6	9.54		100000	2	3.26	4.24
100	2	6	9.54		200000	2	1.65	-1.67
200	2	6	9.54		500000	2	0.65	-9.76
500	2	6	9.54		1000000	2	0.34	-15.39

Table 1: Showing the simulated results from within proteus, where the gain build up and fall off can be observed at either end of the results.

Simulated Circuit Gain vs Frequency Graphs

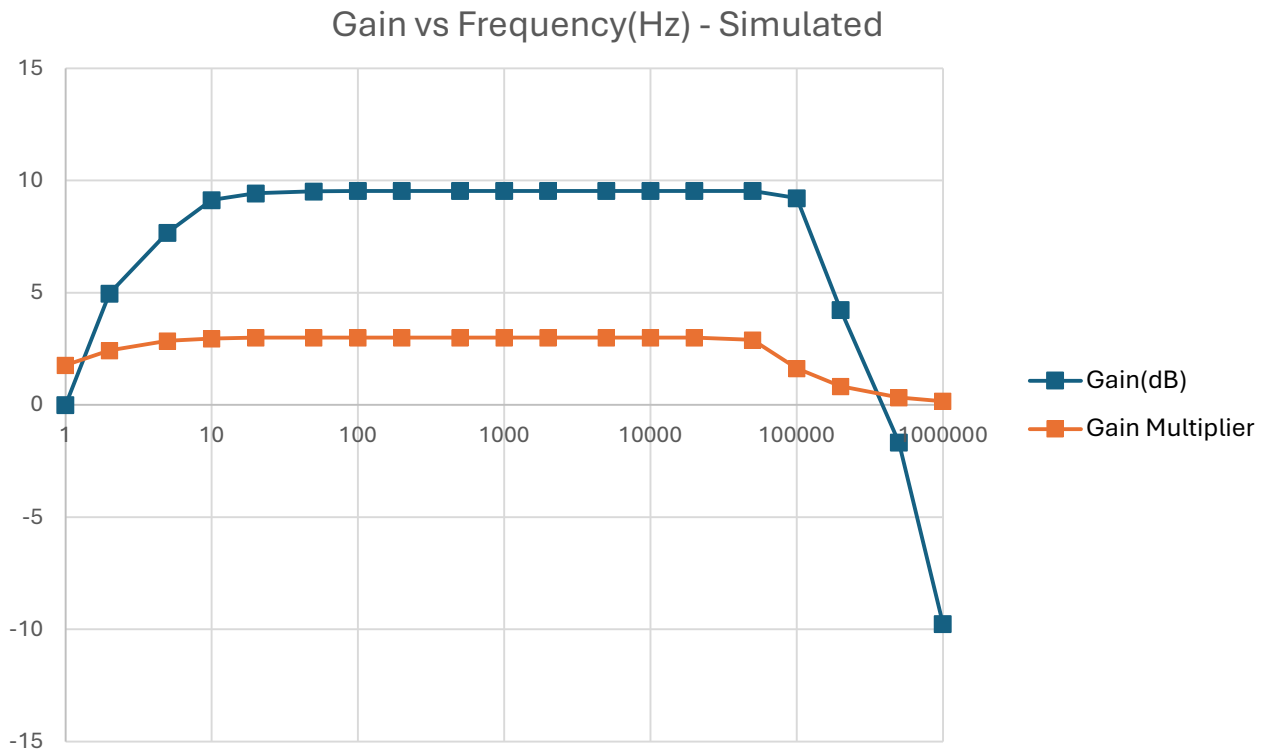


Figure 2: A Graph showing the relationship between the gain and the frequency within the operational amplifier.

The graph above shows the relationship between the frequency of the input waveform and the gain, where it can be concluded that as the operational amplifier reaches the maximum operating frequency the gain reduces and eventually reaches a point where the voltage of the output waveform is less than the voltage of the input waveform.

As this data is simulated, it is expected to receive similar, but not exact, results through the breadboard testing and later the assembled printed circuit assembly.

From the simulated results it was also possible to calculate the expected Gain Bandwidth Product (GBP), by measuring the frequency at 70% of the maximum output at either end of the scale and calculating the result based on the higher result (FH) minus the lower result (FL). Within the context of the simulation the FH is 66kHz and the FL is 1.9hz. Thus, it can be concluded that the simulated GBP is 65,998.08Hz, for simplicity's sake this can be expressed as 66kHz due to the difference between the FL and FH being so minor, comparable results are to be expected through the later stages of testing.

Breadboard Testing of the Amplifier Circuit

Following the simulations the circuit was then prototyped using a breadboard and the necessary components, as detailed below.

Assembled Breadboard

Following the results of the simulations confirming that the desired components would results in the desired output gain, the components were then assembled onto a breadboard. This method allows for the circuit to be tested using physical components without the need for any permanent soldering, allowing for the components to be swapped and replaced in the event that components were found to be faulty, or resulted in an unwanted output.

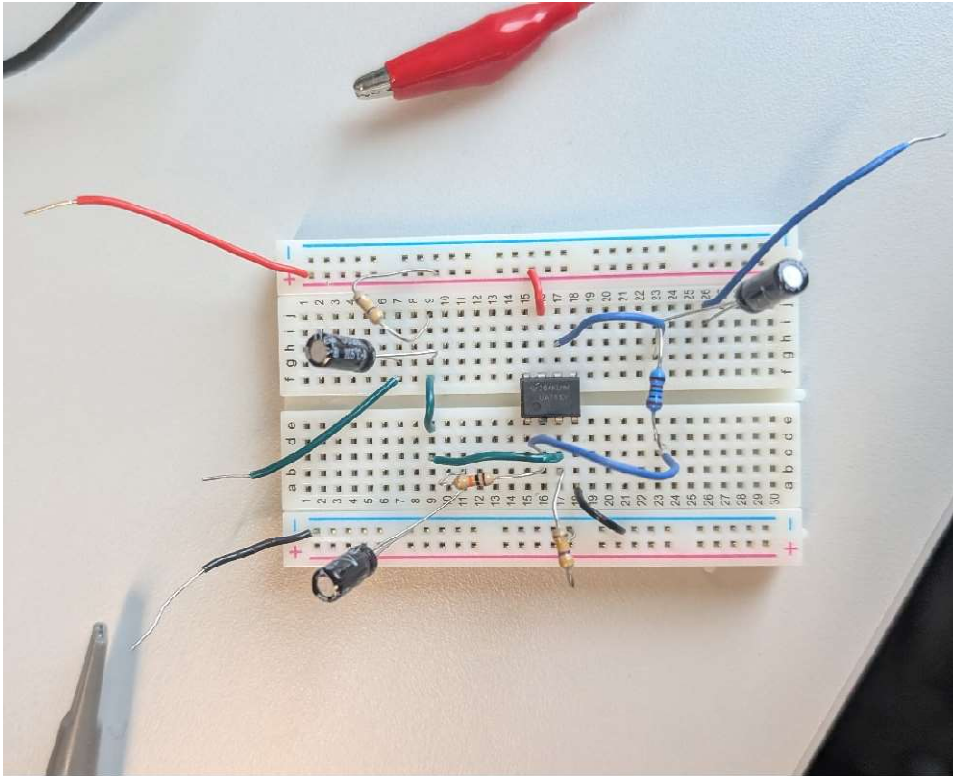


Figure 3: The Amplifier circuit assembled onto a breadboard

Fortunately the circuit was assembled with no issues beyond wire routing, and was colour coded to show the positive feed on the red connections, the feed to ground on the black connections, the green connections leading to the signal input, and the blue connections leading to the signal output, this was to allow for easier testing later. The ground connection was given a larger contact area, to allow for all the test equipment to be connected to the same ground pin. The components used were as follows:

- 2x 470k Ω Resistors
- 1x 10k Ω Resistor
- 1x 20k Ω Resistor
- 3x 10 μ f Capacitors
- 1x UA741 Operational Amplifier

Assessing the Breadboard Circuit

When testing the breadboard circuit, as shown in figure 3, the input was connected to a signal generator to allow for the frequency to be freely and accurately adjusted to the desired value. Also connected to the input connection was an oscilloscope probe, allowing for the signal to be compared and shown against the output signal proving the effectiveness of the amplifier. Another oscilloscope probe was connected to allow for the measurement of the output waveform. Supply was then connected to a 12V DC power supply, and the ground connection was connected as such.

Initial testing showed that everything was performing as expected, allowing for the recording of actual results to take place, the results are recorded below.

Breadboard Circuit Results and Graphs

f	Vin	Vout	Gain(dB)		f	Vin	Vout	Gain(dB)
0	0	0	0		1000	2.04	6.08	9.485468
1	1.4	2.6	5.376906		2000	2.04	6.08	9.485468
2	1.8	4.4	7.763603		5000	2.04	6.08	9.485468
5	2.04	5.76	9.015846		10000	2.04	6.08	9.485468
10	2.04	6.04	9.428135		20000	2.04	6.08	9.485468
20	2.04	6.08	9.485468		50000	2.04	4.52	6.910165
50	2.04	6.08	9.485468		100000	2.12	2.28	0.63198
100	2.04	6.08	9.485468		200000	2.12	1.16	-5.23756
200	2.04	6.08	9.485468		500000	2.12	0.52	-12.2067
500	2.04	6.08	9.485468		1000000	2.12	0.28	-17.5836

Table 2: This shows the results of the breadboard circuit and how the circuit behaved at various frequencies.

From the results shown in Table 2 it can be concluded that the physical components vary slightly from their simulated counterparts shown in Table 1. A key indicator of this is how the physical components achieve their peak operating frequency at a much lower point than in the simulations, as this is reached somewhere between 10-20Hz, as opposed to the 50Hz in the simulation. Similarly, it can be seen that physical components begin to fall off at a much lower frequency vs the simulated data.

This difference in results could be due to the condition of the components, or potentially due to an error in manufacture, as the simulation would show the ideal result against the manufacturers specifications whereas the physical products could vary from this.

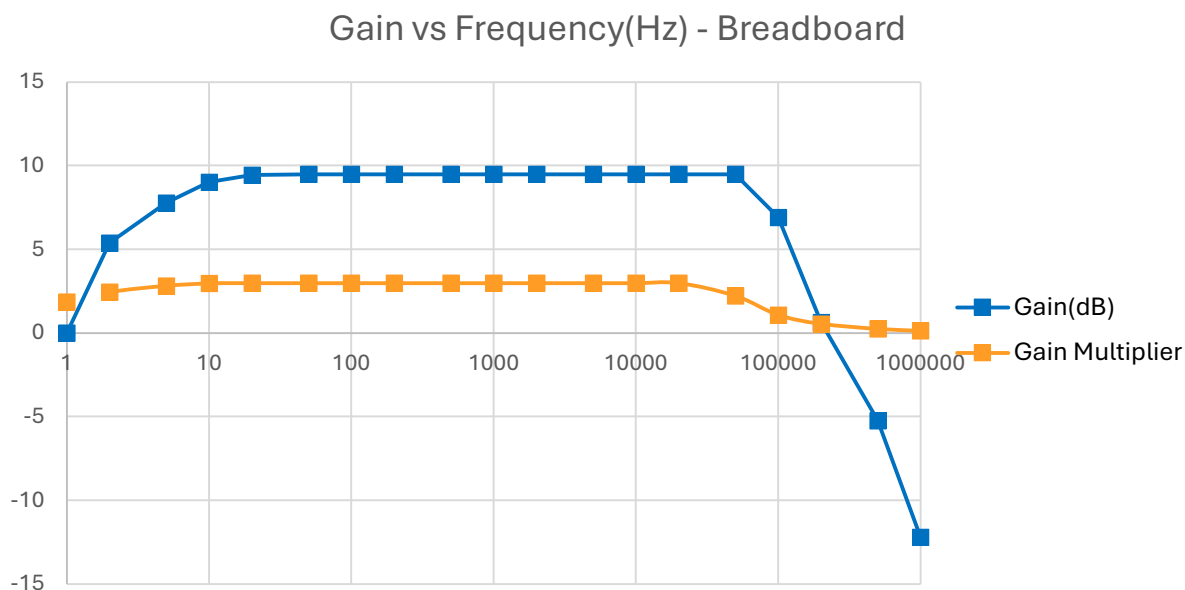


Figure 4: This graph shows the behaviour of the Gain vs Frequency on the breadboard circuit

Amplifier PCB Design and Assembly

Designing the PCB

The circuit diagram shows an LM741 op-amp configured as a summing amplifier. The non-inverting input (V+) is connected to a +12V supply through a 4.7k resistor (R1) and to the output through a feedback resistor (R2). The inverting input (V-) is connected to the three 4-bit digital inputs (A, B, C) through 4.7k resistors (R3, R4, R5) and to the output through a feedback resistor (R6). The output is connected to a 10uF capacitor (C1) and a 10k resistor (R7). The circuit is powered by a +12V supply and ground.

The addition of a dedicated supply/ground header also allowed for the components that required a direct supply/ground to be connected directly as such within the PCB, this enabled for a much cleaner PCB design, with fewer overlapping traces, as the supply was able to connect directly through PL3 and a dedicated copper ground plane was able to be poured to connect all necessary pins to ground.

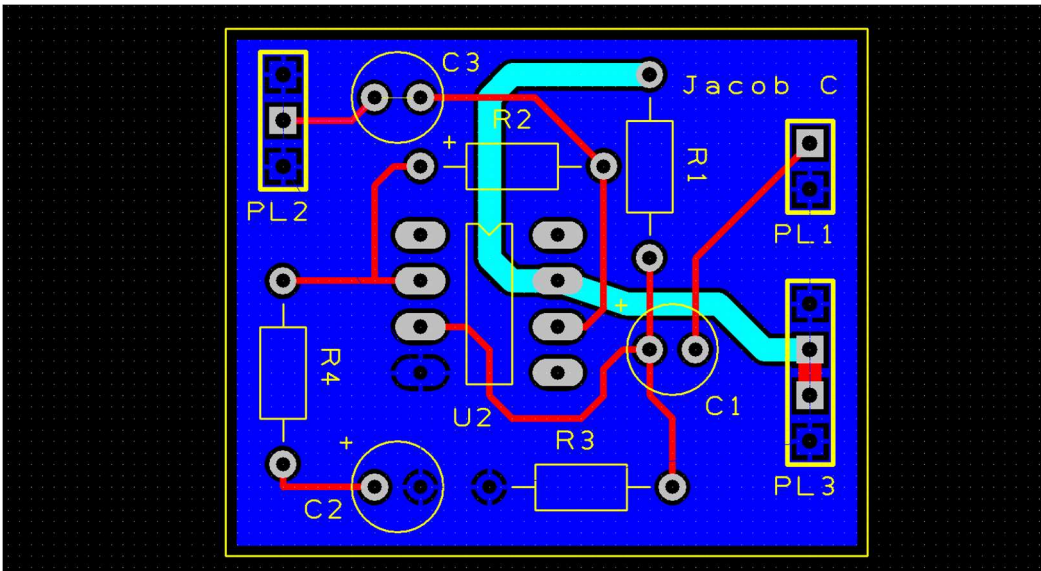


Figure 6: The PCB Design layout as shown in Easy-PC

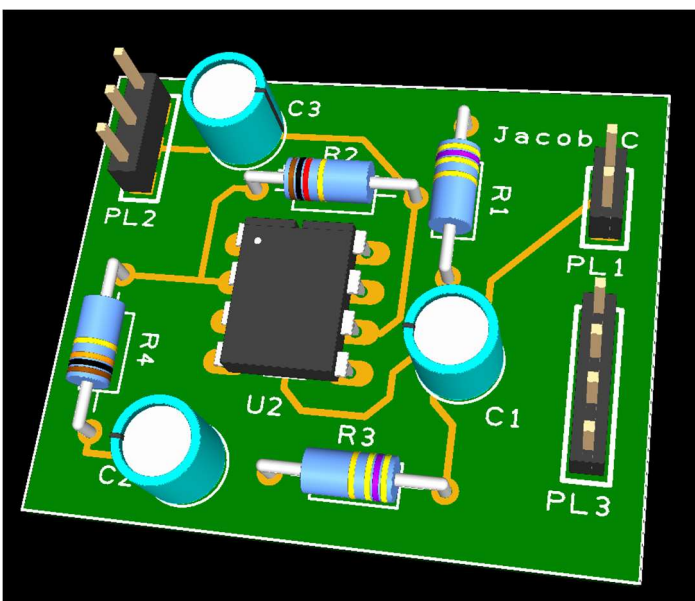


Figure 7: A 3D Render of the PCB Design layout

Figures 6 and 7 show the design layout as well as a 3D Render of the amplifier, combining the two functions allowed for any potential clearance issues to be resolved before the PCB is sent off for production, preventing issues before they can arise.

It can also be seen in figure 6 how the addition of PL1, PL2, and PL3 influenced the design of the board as it enabled the use of a copper pour to act as a ground plane enabling all of the components within the circuit that required a ground source to be connected through a single point, in this case being PL3.

PCB Assembly

Following from the design phase, the assembly and testing phase follows the steps taken when assembling and testing the final Printed Circuit Assembly (PCA).

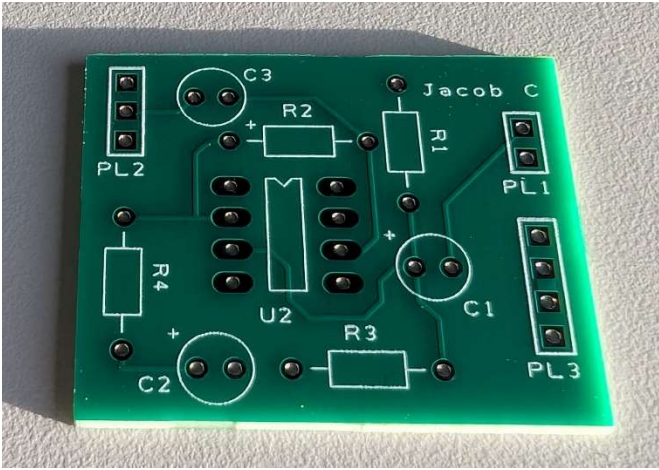


Figure 8: The PCB as detailed in figures 6 and 7.

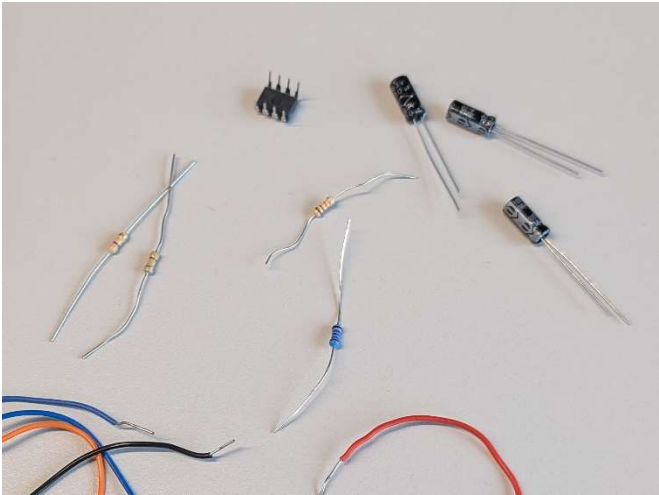


Figure 9: The collected inventory of the components to be used in the final construction of the amplifier

Prior to the construction of the final product, it is necessary to take inventory of all of the components that will be necessary to the build. Prepared were 4 resistors of the required values, 3 capacitors, and the UA741 Op-Amp. Alongside these components were also a series of wires prepared in order to cover any potential problems that may arise within the circuit, i.e.; an incorrectly pathed trace, leading to a fault within the circuit. Fortunately, the wires were unnecessary within the finished product, as shown below in figure 10.

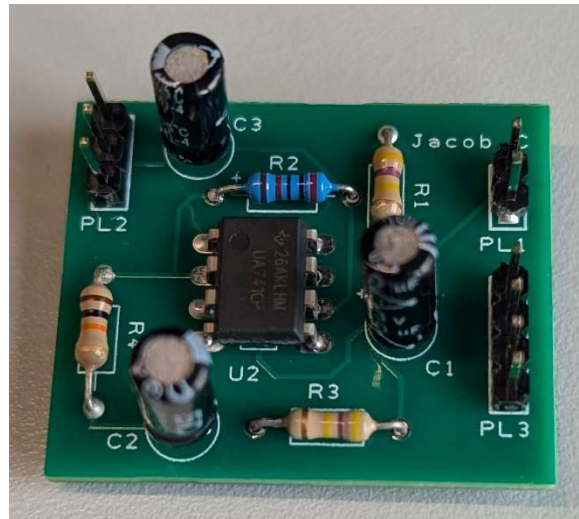


Figure 10: The finished PCA

Assembled Circuit Testing

Following the successful construction of the circuit, it was necessary to test the circuit to ensure it was operating as intended. Similarly to the breadboard circuit, this was completed using various testing equipment to simulate use in practice. A signal generator was connected through PL1, as this was the input with an oscilloscope probe connected to capture the input waveform, and an oscilloscope was connected through PL2 in order to capture the output waveform, supply and ground were connected through PL3. The expected output waveform was expected to be 6v with a 2v input.

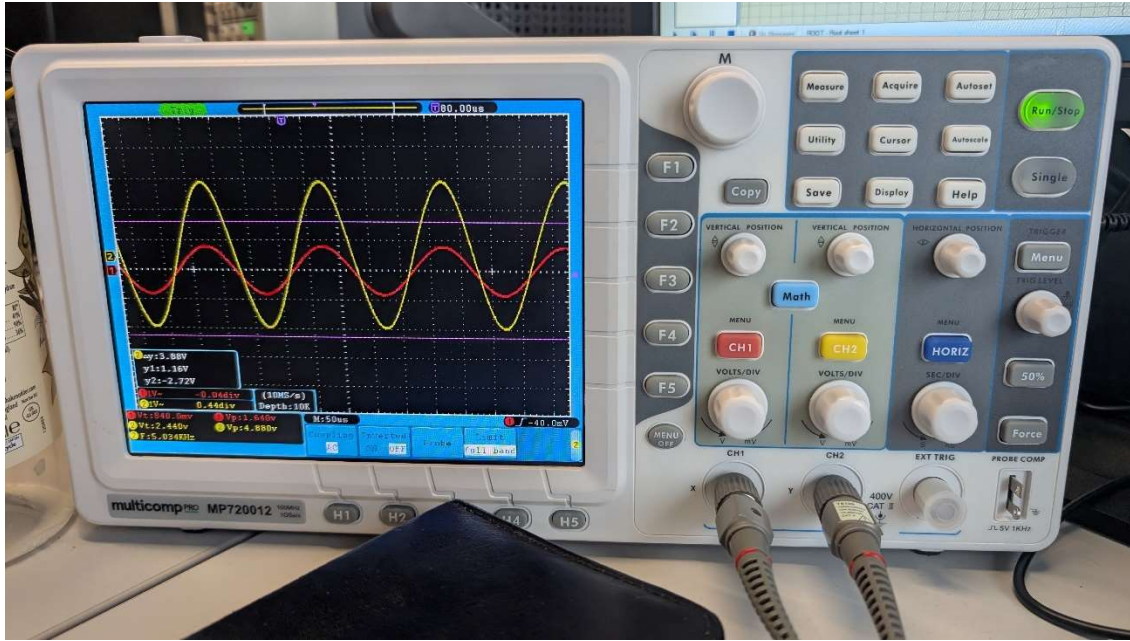


Figure 11: The finished product measured with an oscilloscope. Red = Input - Yellow = Output

As shown in figure 11, a voltage of 1.64v was captured on the input with a voltage of 4.88v captured on the output, resulting in an overall gain of approximately 2.97, which is not a gain of 3. However as shown in the table of below this could have been due to the frequency of the input signal not being high enough to push a full gain of 3, as the results show that at lower frequencies the amplifier is not able to operate at its desired capacity.

f	Vin	Vout	Gain(dB)	f	Vin	Vout	Gain(dB)
0	0	0	0	1000	2.08	6.04	9.259472
1	1.4	2.4	4.681664	2000	2.08	6.04	9.259472
2	1.72	3.8	6.885103	5000	2.08	6.04	9.259472
5	2	5.6	8.943161	10000	2.08	6.04	9.259472
10	2.08	5.96	9.143658	20000	2.08	6.04	9.259472
20	2.08	6.04	9.259472	50000	2.08	4.56	6.81803
50	2.08	6.04	9.259472	100000	2.1	2.32	0.865374
100	2.08	6.04	9.259472	200000	2.1	1.08	-5.77591
200	2.08	6.04	9.259472	500000	2.1	0.51	-12.293
500	2.08	6.04	9.259472	1000000	2.12	0.29	-17.2788

Table 3: This shows the results and performance of the completed circuit.

From these results it is possible to conclude that the conclusions drawn from the initial simulations and prototyping were correct in the fact that the operational amplifier has an upper and lower limit where the amplifier will perform at its peak effectiveness. In order to achieve better performance, it would be necessary to either use newer components in potentially better condition, or to use different components such as a different operational amplifier in order to have a larger gain bandwidth.

When measured, the FL and FH were found to be 1.86Hz and 53000Hz respectively, resulting in an overall GBP of 52,998.14 Hz, which as before can be expressed as 53000 due to the negligible difference between the initial figures.

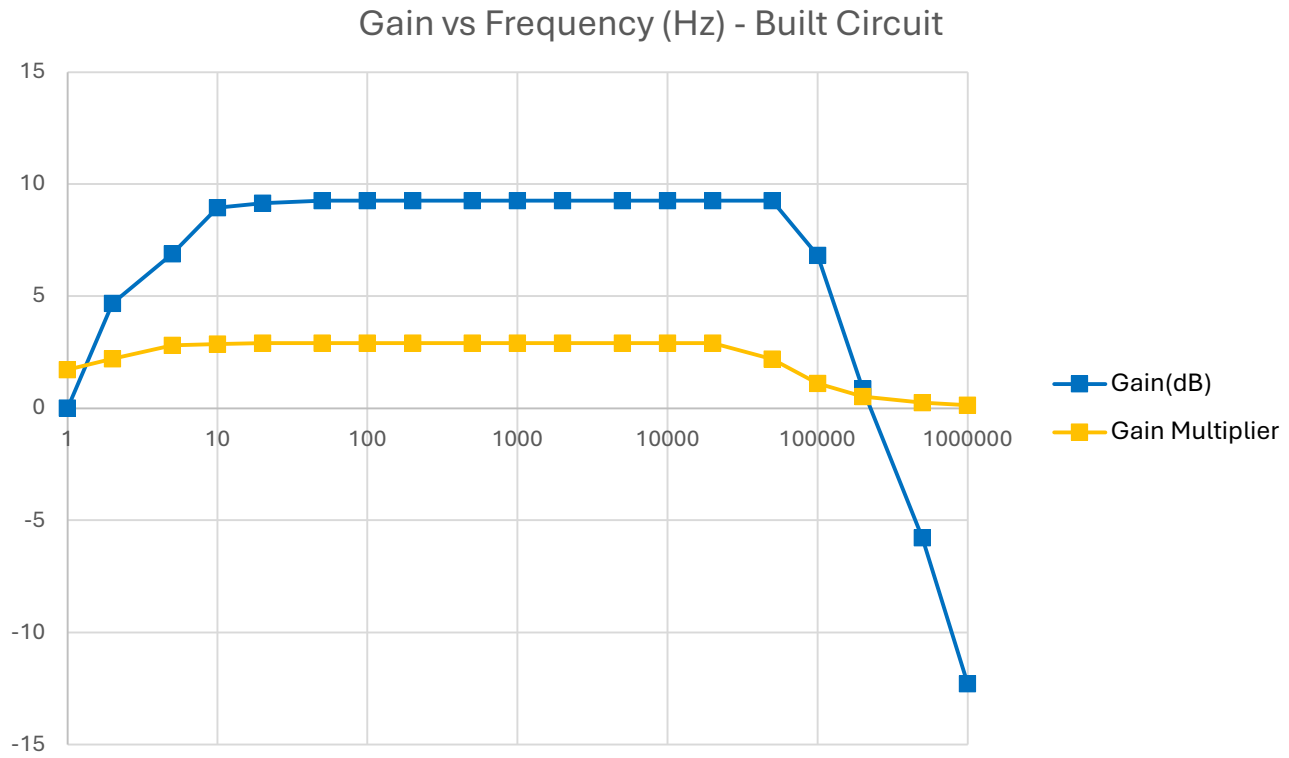


Figure 12: A graph showing the final results of the built circuit shown on a graph.

The results from the graph shown in figure 12 demonstrate that the results captured in the initial simulation and testing were accurate in showing the trend in results where the amplifier is recorded to have a ramping period at the opposing ends of the graph, leading to the conclusion that the amplifier will only perform at its peak for a certain period, anything beyond or below that would damage the output leading to undesirable results.