

Lab Notebook TM (2415958)

by Tamsin McKerrow

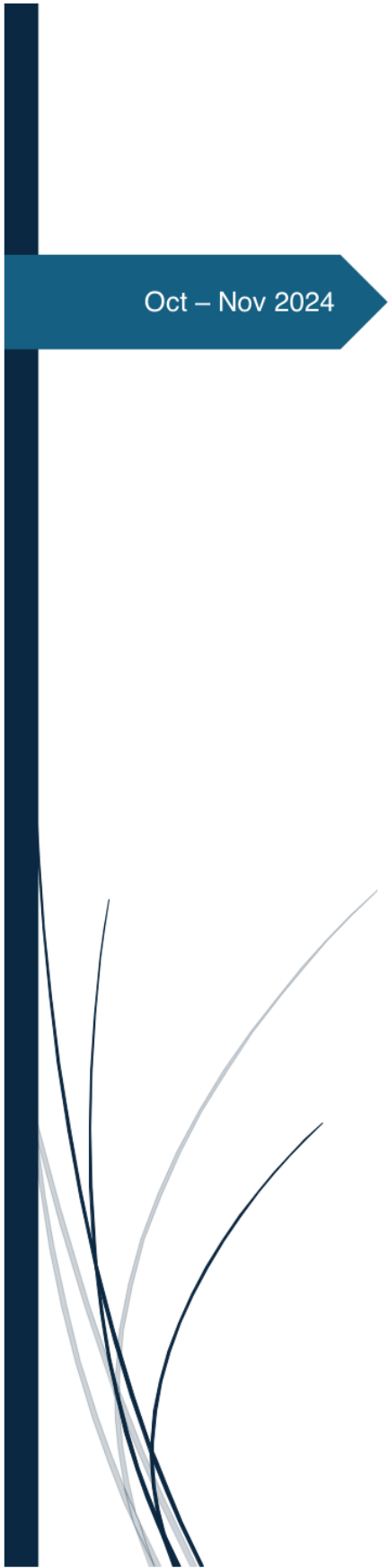
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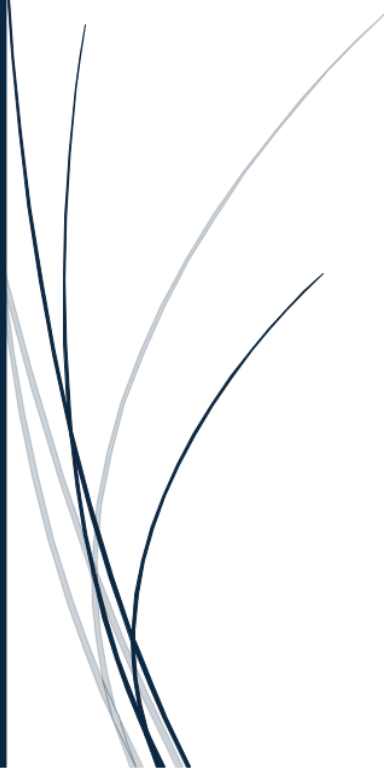
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Oct – Nov 2024

Lab Notebook

Op-Amp Design & Build

An abstract line drawing consisting of several thin, curved lines in dark blue and light grey, originating from the bottom left and extending upwards and to the right.

Tamsin McKerrow (2415958)

WORKSHOP SKILLS FOR ELECTRONICS – ACDA4022
BEng Embedded Electronic Systems

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Introduction

I have been tasked to reproduce and test a non-inverting amplifier circuit with a gain of 3. The circuit diagram reproduced is shown in [Appendix 1](#).

This notebook depicts the creation of a schematic and PCB layout, as well as the construction and testing of the breadboarded design and the printed circuit board.

The circuit uses a 741 operational amplifier, and their typical application is shown in figure 1.

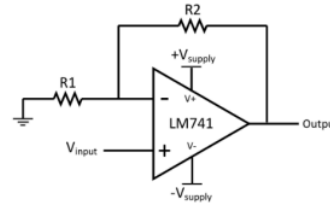


Figure 1: 741 Typical Application [1]

Schematic

Below is the schematic diagram drawn using Proteus. According to the 741 datasheet [1], R4 and R3 are used to calculate the gain: $\text{Gain} = 1 + (R4/R3)$.

For the circuit below the gain can be calculated as $1 + (20000/10000) = 3$.

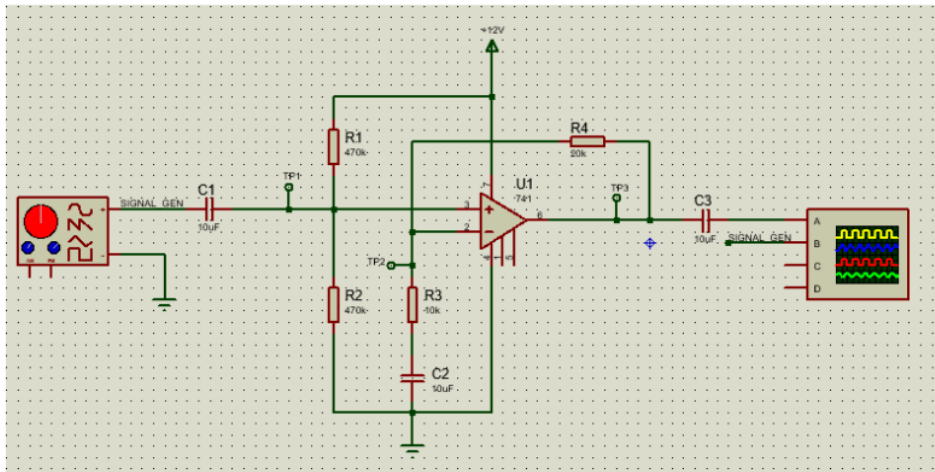


Figure 2: Proteus Schematic

R1 and R2 create a voltage divider – where $V_{out} = (R2 \times V_{in}) / (R1 + R2)$. Meaning that the output voltage going into pin 3 of the op-amp = $(470k \times 12V) / (470k + 470k) = 6V$.

R4 is the feedback resistor – this takes a small part of the output voltage signal and applies it to the inverting input terminal of the op-amp, which produces negative feedback [2].

The circuit is a non-inverting amplifier because the input signal is applied to the positive input of the op-amp. This means that the output signal will be in-phase with the input signal [2].

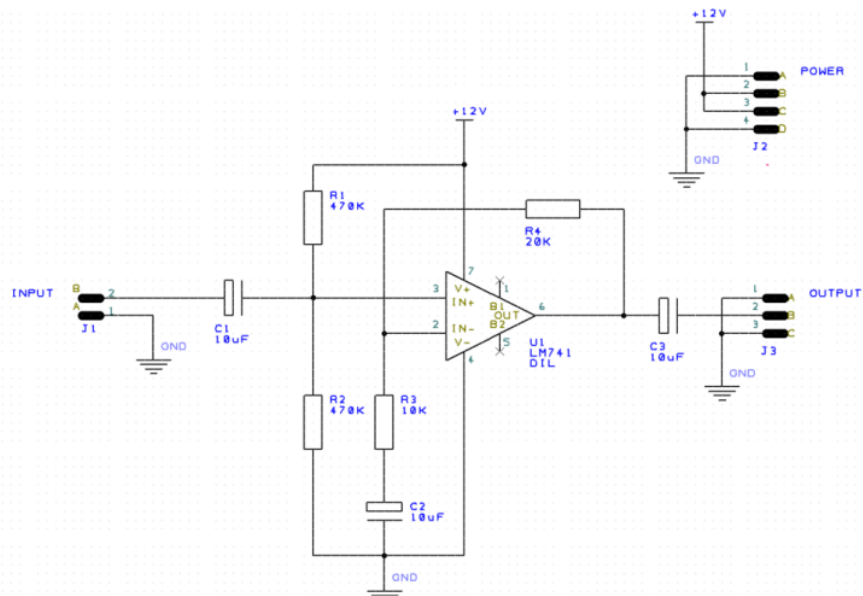


Figure 3: Easy PC Schematic

The schematic shown in figure 3 is the replication of figure 2 with the addition of connectors so testing the PCB will be easier. Also, the schematic had to be redrawn in Easy-PC to be able to create the PCB layout.

Simulation in Proteus

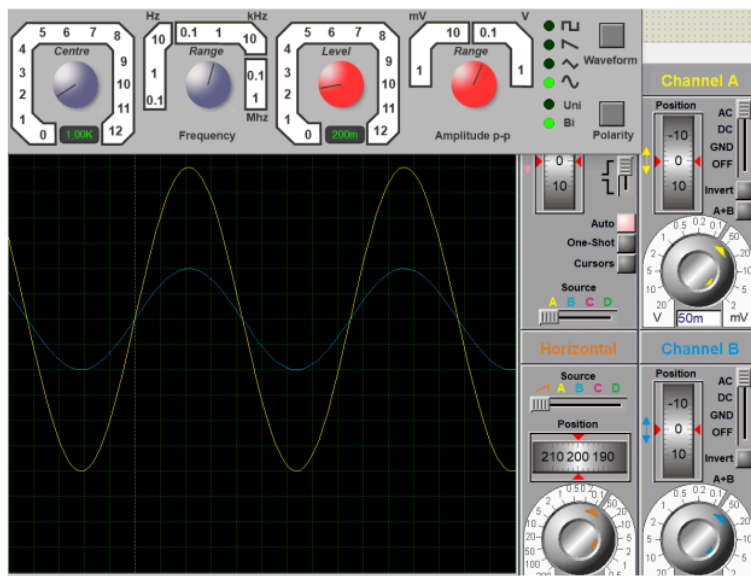


Figure 4: Simulation Results at 1kHz, 200mV input

Channel A shows the output waveform and channel B shows the input waveform.

Table 1: Simulation Results

Frequency (Hz)	Vout (V)	Gain (dB)	Voltage Gain (Av)	Frequency (Hz)	Vout (V)	Gain (dB)	Voltage Gain (Av)
----------------	----------	-----------	-------------------	----------------	----------	-----------	-------------------

Lower -3dB Frequency	1	0.355	4.98396714 8	1.775	18000	0.6	9.542425094	3
	1.5	0.4325	6.69912232 3	2.1625	19000	0.6	9.542425094	3
	2	0.485	7.69423485 9	2.425	20000	0.6	9.542425094	3
	5	0.575	9.17275698 1	2.875	25000	0.595	9.469739401	2.975
	10	0.5925	9.43316718	2.9625	30000	0.5925	9.43316718	2.9625
	20	0.5925	9.43316718	2.9625	35000	0.5975	9.506158279	2.9875
	50	0.6	9.54242509 4	3	40000	0.5925	9.43316718	2.9625
	100	0.6	9.54242509 4	3	45000	0.595	9.469739401	2.975
	200	0.6	9.54242509 4	3	50000	0.593	9.440493954	2.965
	300	0.6	9.54242509 4	3	55000	0.593	9.440493954	2.965
	400	0.6	9.54242509 4	3	60000	0.59	9.39644032	2.95
	500	0.6	9.54242509 4	3	65000	0.5875	9.359557506	2.9375
	750	0.6	9.54242509 4	3	70000	0.5875	9.359557506	2.9375
	1000	0.6	9.54242509 4	3	75000	0.585	9.322517408	2.925
	2000	0.6	9.54242509 4	3	80000	0.5825	9.285318681	2.9125
	3000	0.6	9.54242509 4	3	85000	0.5825	9.285318681	2.9125
	4000	0.6	9.54242509 4	3	90000	0.5775	9.210439858	2.8875
	5000	0.6	9.54242509 4	3	95000	0.5775	9.210439858	2.8875
	6000	0.6	9.54242509 4	3	100000	0.575	9.172756981	2.875
	7000	0.6	9.54242509 4	3	200000	0.515	8.215544668	2.575
	8000	0.6	9.54242509 4	3	300000	0.4425	6.897665587	2.2125
	9000	0.6	9.54242509 4	3	320000	0.425	6.547178688	2.125
	10000	0.6	9.54242509 4	3	350000	0.405	6.128500551	2.025
	11000	0.6	9.54242509 4	3	400000	0.375	5.460025441	1.875
	12000	0.6	9.54242509 4	3	500000	0.32	4.082399653	1.6
	13000	0.6	9.54242509 4	3	600000	0.2775	2.844659836	1.3875
	14000	0.6	9.54242509 4	3	700000	0.245	1.762721774	1.225
	15000	0.6	9.54242509 4	3	800000	0.216	0.66847511	1.08
	16000	0.6	9.54242509 4	3	900000	0.194	-0.264565315	0.97
	17000	0.6	9.54242509 4	3	1000000	0.177	-1.061134586	0.885

The gain in dB was calculated using the following formula: $20\log_{10}\left[\frac{V_{OUT}}{V_{IN}}\right]$. Where $V_{IN} = 0.2V$.

The voltage gain (A_v) was calculated using the following formula: $A_v = \frac{V_{OUT}}{V_{IN}}$

Bandwidth = 320000 – 1.5 = 319998.5Hz

Gain Bandwidth Product = $A_v \times \text{Bandwidth} = 3 \times 319998.5 = \underline{959995.5Hz}$

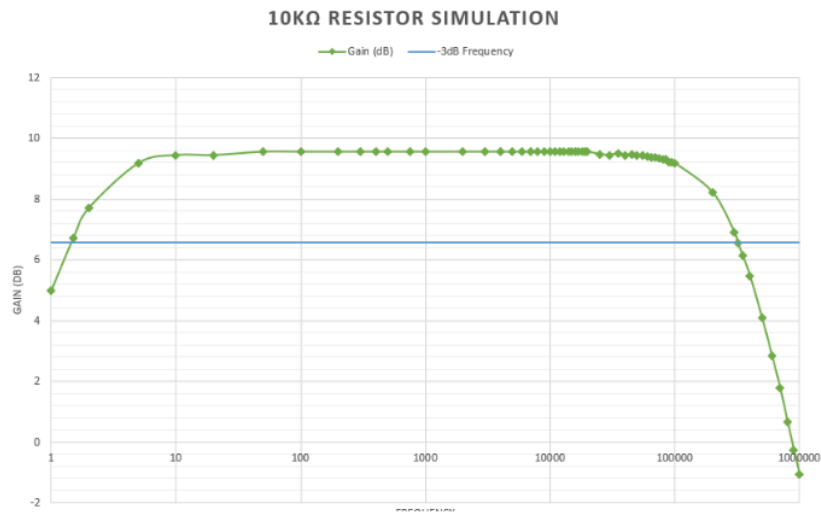


Figure 5: 10kR Resistor Simulation

PCB Layout

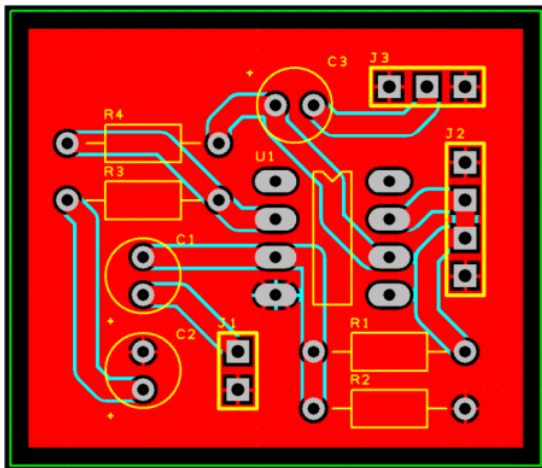


Figure 6: PCB Layout Top Layer

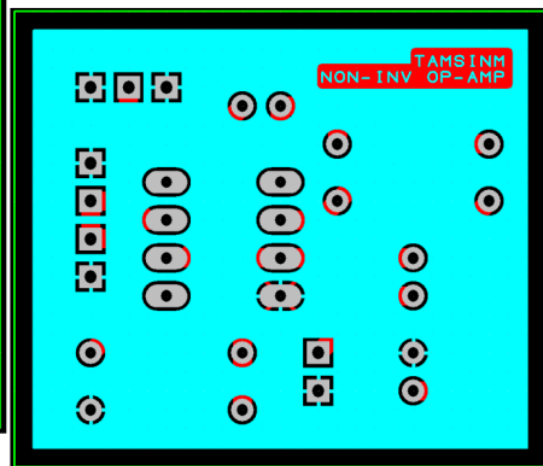


Figure 7: PCB Layout Bottom Layer

This is the second revision of the PCB as it was too big to begin with. I added a ground plan on both the top and bottom layers.

Table 2: Breadboard Results

	Frequency (Hz)	Vout (V)	Gain (dB)	Voltage Gain (Av)	Frequency (Hz)	Vout (V)	Gain (dB)	Voltage Gain (Av)	
	1	2.4	1.411621486	1.176470588	30000	6.08	9.485468237	2.980392157	
Lower -3dB Frequency	2	4.24	6.354713783	2.078431373	35000	6.12	9.542425094	3	
	5	5.72	8.955317227	2.803921569	40000	6.12	9.542425094	3	
	10	6.04	9.428135424	2.960784314	41000	6.08	9.485468237	2.980392157	
	20	6.12	9.542425094	3	45000	6.04	9.428135424	2.960784314	
	50	6.12	9.542425094	3	50000	5.96	9.312321846	2.921568627	
	100	6.12	9.542425094	3	55000	5.72	8.955317227	2.803921569	Upper -3dB Frequency
	200	6.12	9.542425094	3	60000	5.4	8.455271848	2.647058824	
	300	6.12	9.542425094	3	65000	5.08	7.924670897	2.490196078	
	400	6.12	9.542425094	3	70000	4.76	7.359535706	2.333333333	
	500	6.12	9.542425094	3	75000	4.48	6.832956931	2.196078431	
	750	6.12	9.542425094	3	80000	4.2	6.272382459	2.058823529	
	1000	6.12	9.542425094	3	85000	3.96	5.76130037	1.941176471	
	2000	6.12	9.542425094	3	90000	3.76	5.31115355	1.843137255	
	3000	6.12	9.542425094	3	95000	3.56	4.836396611	1.745098039	
	4000	6.12	9.542425094	3	100000	3.4	4.436974992	1.666666667	
	5000	6.12	9.542425094	3	150000	2.28	0.966093591	1.117647059	
	6000	6.12	9.542425094	3	175000	1.96	-0.347481921	0.960784314	
	7000	6.12	9.542425094	3	200000	1.72	-1.48203441	0.843137255	
	8000	6.12	9.542425094	3	240000	1.44	-3.025353507	0.705882353	
	9000	6.12	9.542425094	3	250000	1.4	-3.270042635	0.68627451	
	10000	6.12	9.542425094	3	300000	1.16	-4.903443564	0.568627451	
	11000	6.12	9.542425094	3	400000	0.92	-6.916846802	0.450980392	
	12000	6.12	9.542425094	3	500000	0.72	-9.04595342	0.352941176	
	13000	6.12	9.542425094	3	600000	0.64	-10.06900387	0.31372549	
	14000	6.12	9.542425094	3	700000	0.52	-11.87253648	0.254901961	
	15000	6.12	9.542425094	3	800000	0.44	-13.32354982	0.215686275	
	20000	6.12	9.542425094	3	900000	0.4	-14.15140352	0.196078431	
	25000	6.12	9.542425094	3	1000000	0.36	-15.06655333	0.176470588	

Bandwidth $\approx 75000 - 2 = 74998\text{Hz}$

Gain Bandwidth Product = $A_v \times \text{Bandwidth} = 3 \times 74998 = 224994\text{Hz}$

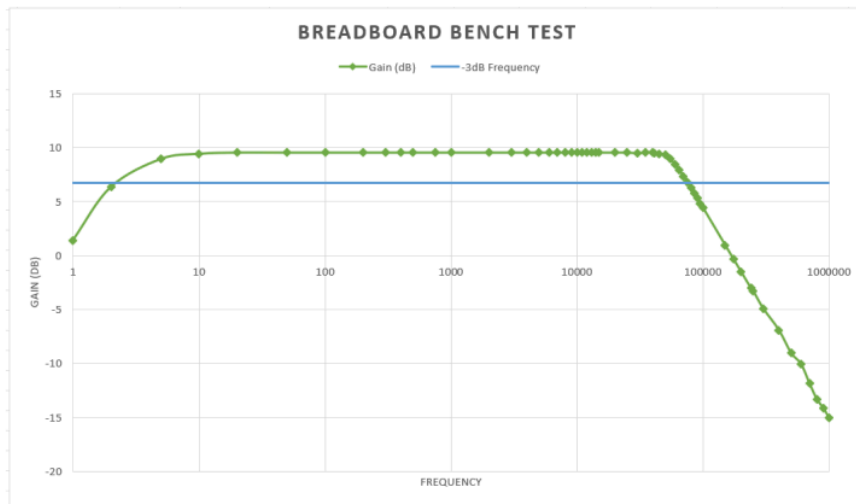


Figure 11: Breadboard Bench Test Results

Comparison



Figure 12: Comparison of Simulation and Breadboard

The cut-off frequency on the breadboard circuit is a lot lower than the simulated circuit. This could be due to various factors – which include, poor connections, component tolerances and temperature. The simulation does not consider any of these factors and the results of this are usually the 'ideal' value.

PCB Population

Build

For all the solder joints, I first put the soldering iron on the pad to ensure that the pad and component leg is slightly heated up. Then I added the solder and kept the iron on the pad for a few seconds so that I could be sure a good connection was made.

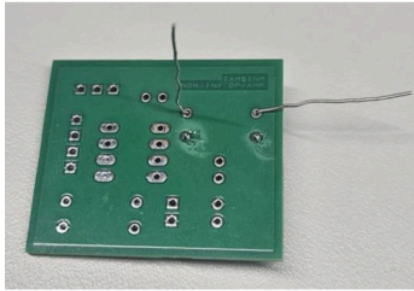


Figure 13: PCB - Soldering TH Resistors

For all the resistors and capacitors, I bent one leg down to secure the component, then I soldered the straight leg. I then double checked that the component was flush with the board and straight. After this I bent the other leg straight then soldered this.

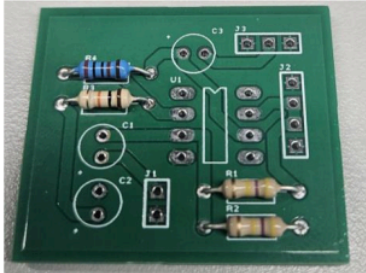


Figure 16: PCB - Soldered Resistors

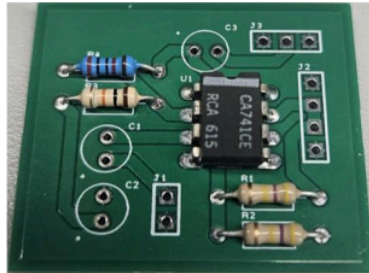


Figure 15: PCB - Added IC

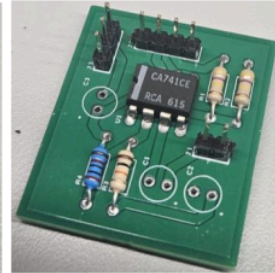


Figure 14: PCB - Added Headers

I soldered the components in order of height.

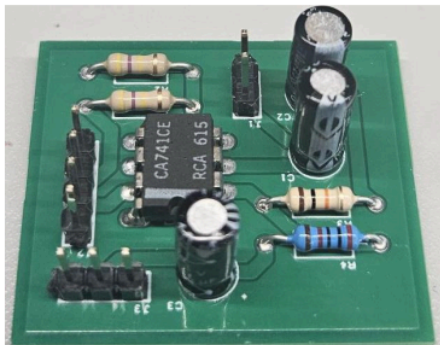


Figure 17: Finished PCB - Top



Figure 18: Finished PCB - Bottom

Testing

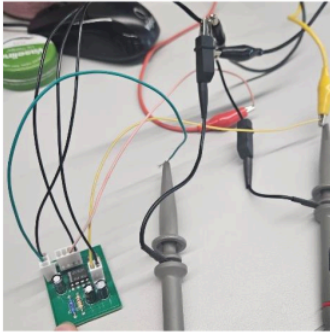


Figure 19: Finished PCB Testing

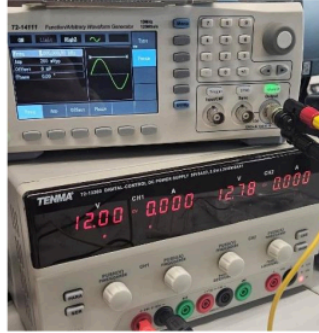


Figure 20: Test Setup for PCB

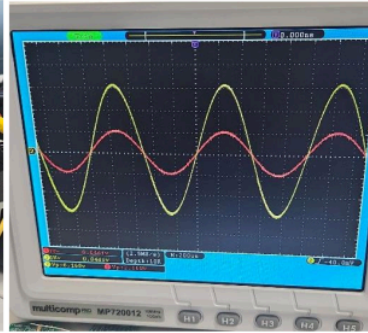


Figure 21: Oscilloscope Results

The input voltage from the signal generator was 0.2V and the supply voltage was 12V.

Table 3: PCB Test Results

	Frequency (Hz)	Vout (V)	Gain (dB)	Voltage Gain (Av)	Frequency (Hz)	Vout (V)	Gain (dB)	Voltage Gain (Av)	
Lower -3dB Frequency	1	2.52	1.501293597	1.188679245	25000	6.08	9.151354367	2.867924528	
	2	4.2	5.938268589	1.981132075	30000	6.08	9.151354367	2.867924528	
	2.25	4.52	6.576051478	2.132075472	35000	6.08	9.151354367	2.867924528	
	2.5	4.84	7.170190014	2.283018868	40000	6.08	9.151354367	2.867924528	
	3	5.12	7.658682001	2.41509434	41000	6.08	9.151354367	2.867924528	
	5	5.84	8.801539724	2.754716981	45000	6.08	9.151354367	2.867924528	
	10	6.12	9.208311224	2.886792453	50000	6.08	9.151354367	2.867924528	
	20	6.16	9.264897025	2.905660377	55000	6.08	9.151354367	2.867924528	
	50	6.16	9.264897025	2.905660377	60000	6.08	9.151354367	2.867924528	
	100	6.16	9.264897025	2.905660377	65000	6.12	9.208311224	2.886792453	
Upper -3dB Frequency	200	6.16	9.264897025	2.905660377	70000	6.12	9.208311224	2.886792453	
	300	6.16	9.264897025	2.905660377	75000	6.08	9.151354367	2.867924528	
	400	6.16	9.264897025	2.905660377	80000	6.12	9.208311224	2.886792453	
	500	6.24	9.376974575	2.943396226	85000	6.08	9.151354367	2.867924528	
	750	6.24	9.376974575	2.943396226	90000	6	9.036307789	2.830188679	
	1000	6.2	9.321116571	2.924528302	95000	6	9.036307789	2.830188679	
	2000	6.2	9.321116571	2.924528302	100000	6.12	9.208311224	2.886792453	
	3000	6.2	9.321116571	2.924528302	150000	5.96	8.978207976	2.811320755	
	4000	6.2	9.321116571	2.924528302	175000	5.84	8.801539724	2.754716981	
	5000	6.2	9.321116571	2.924528302	200000	5.68	8.560249496	2.679245283	
	6000	6.2	9.321116571	2.924528302	240000	5.44	8.185260775	2.566037736	
	7000	6.2	9.321116571	2.924528302	250000	5.36	8.056578575	2.528301887	

8000	6.16	9.26489702 5	2.90566037 7	300000	5	7.452682868	2.35849056 6
9000	6.16	9.26489702 5	2.90566037 7	350000	4.38	6.302764992	2.06603773 6
10000	6.16	9.26489702 5	2.90566037 7	400000	4.28	6.102158162	2.01886792 5
11000	6.16	9.26489702 5	2.90566037 7	500000	3.64	4.695310454	1.71698113 2
12000	6.16	9.26489702 5	2.90566037 7	600000	3.2	3.576282348	1.50943396 2
13000	6.16	9.26489702 5	2.90566037 7	700000	2.76	2.291464423	1.30188679 2
14000	6.16	9.26489702 5	2.90566037 7	800000	2.44	1.221079308	1.15094339 6
15000	6.16	9.26489702 5	2.90566037 7	900000	2.14	0.081558248	1.00943396 2
20000	6.12	9.20831122 4	2.88679245 3	1000000	1.92	-0.860692645	0.90566037 7

Bandwidth $\approx 350000 - 2.25 = 349997.75\text{Hz}$

Gain Bandwidth Product = $A_v \times \text{Bandwidth} = 2.94 \times 349997.75 = 1030182.06\text{Hz}$

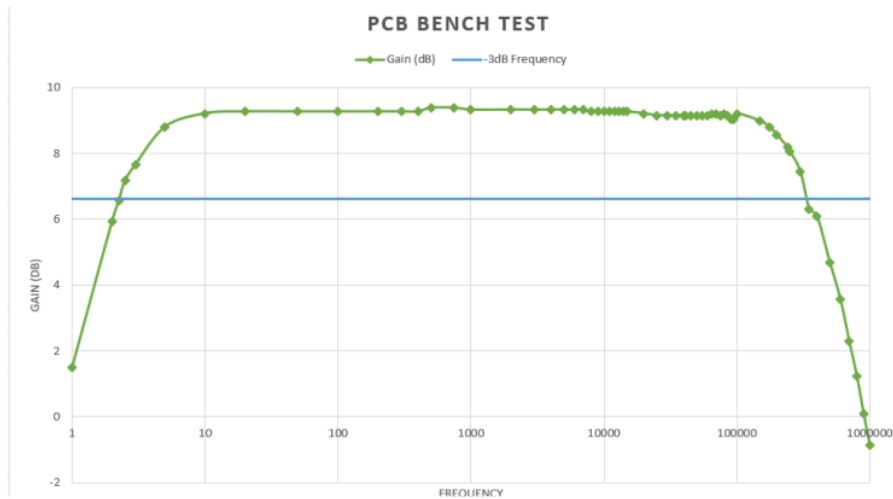


Figure 22: PCB Bench Test Results

Comparison

I took the -3dB point of each of the tests and plotted the average (mean). The -3dB point is essentially the half-power point or the cut-off frequencies.

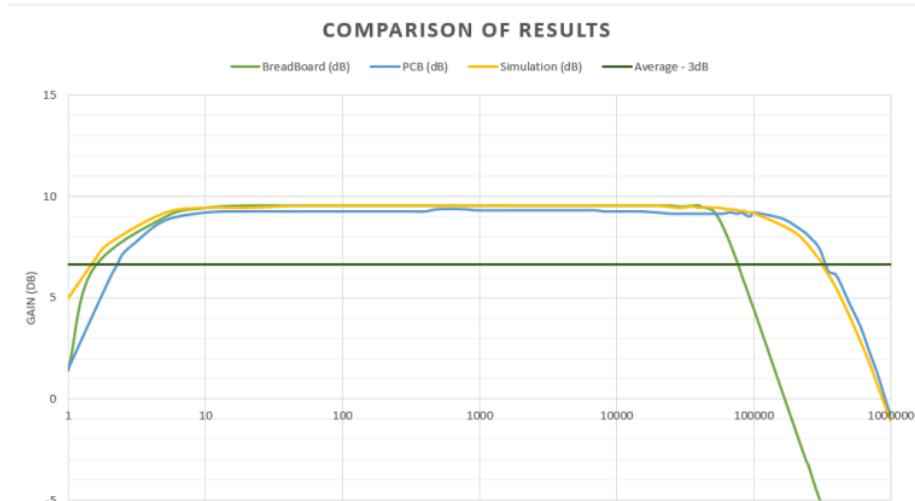


Figure 23: Comparison of All Results

The PCB results match the simulation a lot better than the breadboard results. This indicates that the issue may be with poor connections or human error as the same components were used for the breadboard and the PCB. The lower cut-off point of all the tests are quite similar.

Suggested Improvements

If a second revision of the PCB was created – I would make the designators a bit bigger and put the components closer together so the board can be smaller.

I could also change to traces to the bottom of the PCB so it is easier to see what connects to what.

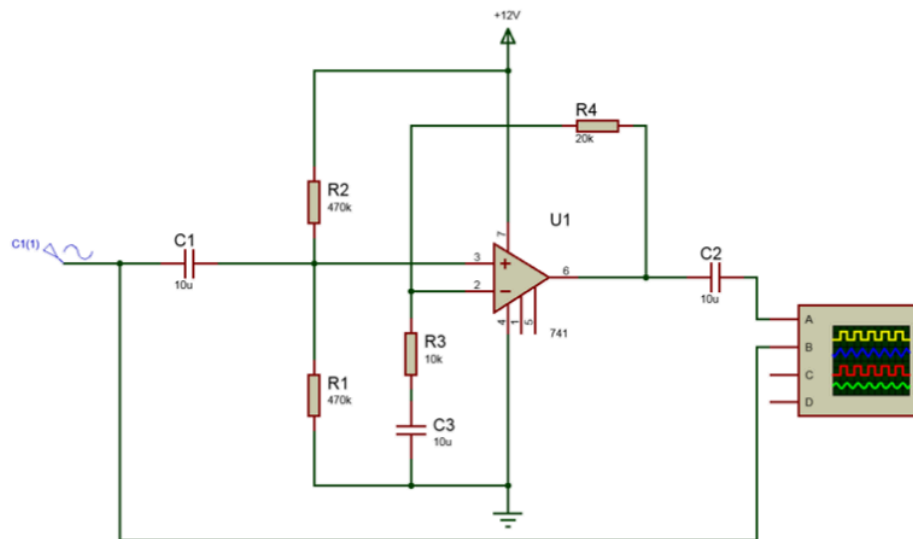
I would also re-do the breadboard test to see why the results were so different to the simulation and PCB.

References

- [1] Texas Instruments, "LM741 Operational Amplifier Datasheet," October 2015. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm741.pdf?ts=1732536694956&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FLM741. [Accessed 26 November 2024].
- [2] W. Storr, "Non-inverting operational amplifier - the non-inverting op-amp," Electronics Tutorials, 04 August 2022. [Online]. Available: https://www.electronicstutorials.ws/opamp/opamp_3.html. [Accessed 26 November 2024].

Appendices

1: Circuit to Reproduce



This schematic was taken from the assignment specification and is a non-inverting amplifier with a gain of 3.

Lab Notebook TM (2415958)

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

83/100

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TAMSIN MCKERROW

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ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



There are no marks available for this section

0

KNOWLEDGE & UNDERSTANDING

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



Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.

30

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.



There are no marks available for this section

0

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Soldering 100% - Excellent soldering
Layout 100% - Excellent layout
Populating 100% - All components fitted flush to PCB with no gaps beneath.
Functioning 70% - PCB functions poorly (signal clipped) due to C1 connected with reverse polarity.
 $(100+100+100+70)/10=37\%$

37

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 with an exceptionally high level of professionalism.
Work is exceptionally coherent, very fluent and is presented professionally.

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