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Design of Filter Circuit

Electrical Principles (ACMA 4031)

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2. Abstract

This report presents a structured analysis of a Low-Pass Filter (LPF) and High-Pass Filter (HPF) which are designed and simulated in proteus along with the creation on breadboards, to understand the cut-off frequency of both circuits comparing theoretical (formula), simulation (Proteus) and experimental (Breadboards). Both circuits have a signal generator set to 4V peak-peak, with frequency changing from 100hz to 300kHz. The LPF has a resistance of 10k Ω and a capacitance of 560pF. The HPF has a resistance of 10k Ω and a capacitance of 15nF. For the LPF, the theoretical cut-off frequency ($1/2\pi R_c$) is 28.4 kHz, the simulated cut off frequency is 27.7kHz and an experimental cut off frequency of 24.3 kHz. The HPF has a theoretical cut off frequency of 1.06 kHz, a simulated cut off frequency of 1.06 kHz and an experimental cut off frequency of 1.10 kHz.

3. Introduction

3.1 Principles of Low Pass Filters and High Pass Filters

An electrical filter is a circuit that allows specific signals within a certain frequency range to pass while attenuating anything outside of that range. The two filters used are the low-pass filter (LPF), which allows frequencies below the cut-off frequency to pass. Also explained in *It allows only low-frequency signals to pass through and blocks other frequencies* (Fu, Li and Zhuo, 2023). In the high-pass filter (HPF), most of the input voltage drops across the resistor, meaning high frequency signals can pass with small attenuation. To test these filters a signal generator was used to generate a sin wave of 4V peak-to-peak. With frequencies ranging from 100Hz to 300kHz. An Oscilloscope is also used to measure the input and output voltage for both circuits, with proteus using virtual components, to help gather more accurate results.

3.2 Real World Applications

Filters are widely used an example is in medical electronics, high-pass and low-pass filters are used to ensure accurate results within electrocardiograms (ECG): *High-pass and low-pass filters applied to 12-lead Electrocardiograms (ECG) are fundamental to avoid artifacts, but an inappropriate use may lead to misdiagnosis. Parola, F. and García Niebla, J. (2017)*. Additionally, Filters are also used in audio crossover networks. As a typical audio signal contains both low (bass) and high (treble) frequencies. Sending low frequencies to a small tweeter can cause damage. Whereas, sending high frequencies to a woofer can cause a problem with clarity and sound quality. Filters are used to solve this issue by separating the frequencies. A low pass filter will direct the bass to the subwoofer, and a high pass filter will direct the treble to the tweeter. This ensures no damage is caused to either component or the audio is optimal. RC filters would be used for this scenario under specific circumstances. It would only be used during active cross over, frequencies split before the signal is amplified, or in line-level inputs of powered subwoofers. RC filters also widely used as they are simple and reliable. *'Passive RC filters, known for their simplicity and reliability, are particularly useful in low-frequency applications, such as subwoofer systems, where low frequency signals need to be isolated from higher frequencies'* (Sogbey, 2025)

3.3 Theoretical Foundation

The cut-off frequency is when the output voltage drops to approximately 70.7% of the input voltage and when an attenuation of -3db is obtained. The cut-off frequencies theoretical formula is $1/2\pi RC$. This is used to obtain a theoretical cut-off frequency, the cut off frequency without any other resistance, human error or other factors that may affect the result. The low pass filter ($R = 10 \text{ k}\Omega$, $C = 560 \text{ pF}$) has a theoretical cut off frequency of 28.4 kHz ($1/2\pi(10\text{k})(560\text{p})$). The high pass filter ($R = 10 \text{ k}\Omega$, $C = 15 \text{ nF}$) has a theoretical cut off frequency of 1.06 kHz ($1/2\pi(10\text{k})(15\text{n})$). The attenuation in decibels is found using the formula $A = 20\log_{10}(V_{\text{out}}/V_{\text{in}})$.

3.3 Remainder of the Report

The remainder of this report will consist of: Section 3 (Circuit Descriptions) which will provide descriptions of the circuits created along with the components in the circuit and their roles. The testing parameters and experimental procedures that were used including the criteria of the signal generator setting (4V peak to peak sin wave), initial frequency and frequency change (100 Hz to 300 kHz), and the excel spreadsheet used to record the input voltage output voltage and the attenuation. Section 4 (Results) this will include tables of data and attenuation graphs plotted on a logarithmic frequency axis. The data tables will include all cut off frequencies for both filters. Section 5 (Discussion) Using graphs, tables and relevant data sets to compare the theoretical, simulated and

experimental data. Comparing the difference and identifying potential causes. Section 6 (Conclusion) state the technical findings, Section 7 lists all the references used in this report in Harvard style.

4. Circuit Descriptors

4.1 Low Pass Filter - Simulation (Proteus)

The low-pass filter consists of a 10 k Ω resistor and a 560-pF capacitor.

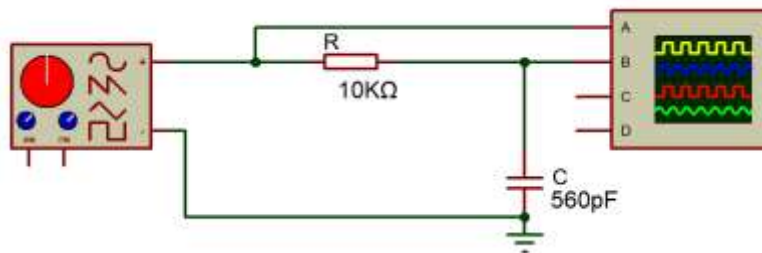


Figure 1 Proteus Circuit-LPF

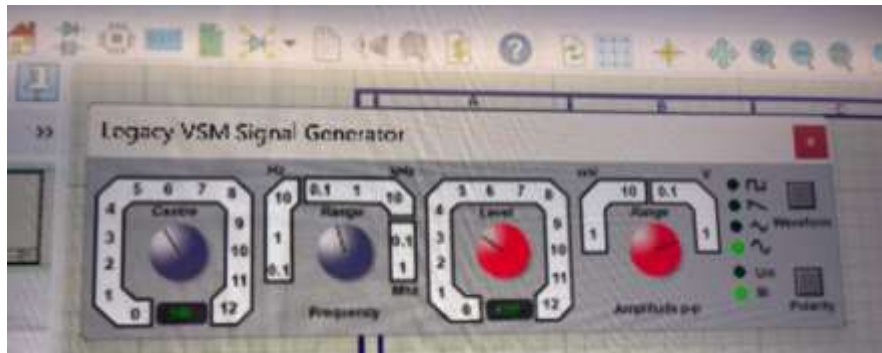


Figure 2 Proteus Signal Generator (4V peak-peak sin wave)-LPF

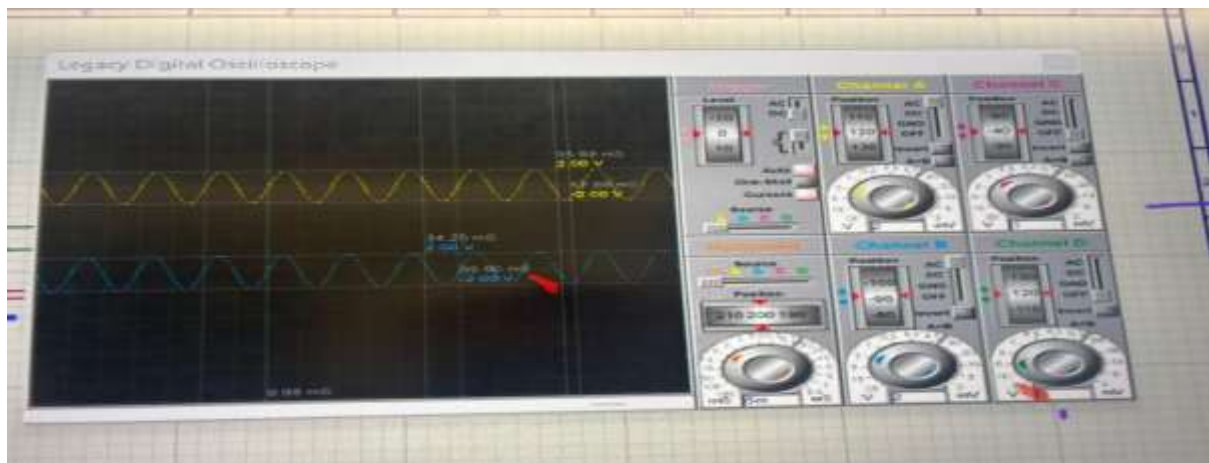


Figure 3 Proteus Oscilloscope-LPF

4.2 Low Pass Filter - Experimental Circuit

This low pass filter circuit is built on a breadboard using a 10 k Ω resistor and a 560-pF capacitor

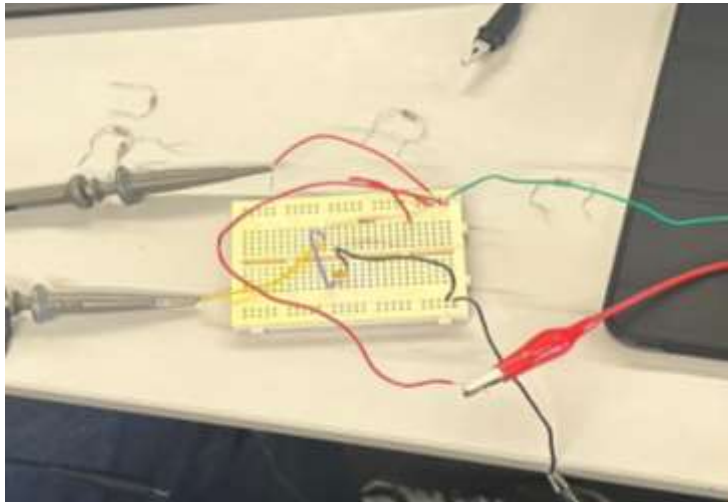


Figure 4 Low Pass Filter Circuit on Breadboard



Figure 5 Signal Generator (4V peak-peak sin wave)-LPF

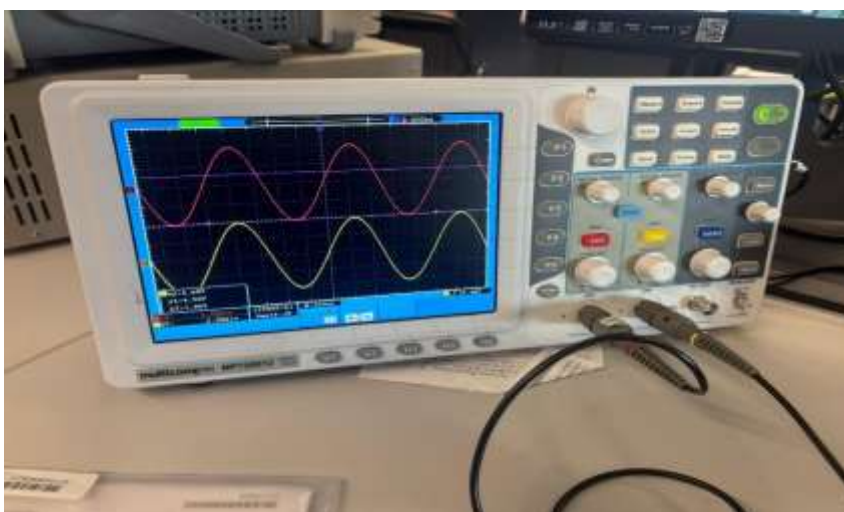


Figure 6 Oscilloscope (Input waveform 4V peak-peak)-LPF

The input of the low pass filter is connected to the signal generator. The output is connected to the oscilloscope. A common ground is shared between the circuit. The signal generator and the oscilloscope

4.3 High Pass Filter – Simulation (Proteus)

The high pass filter consists of a 10 kΩ resistor and a 15 nF capacitor built on the Proteus software

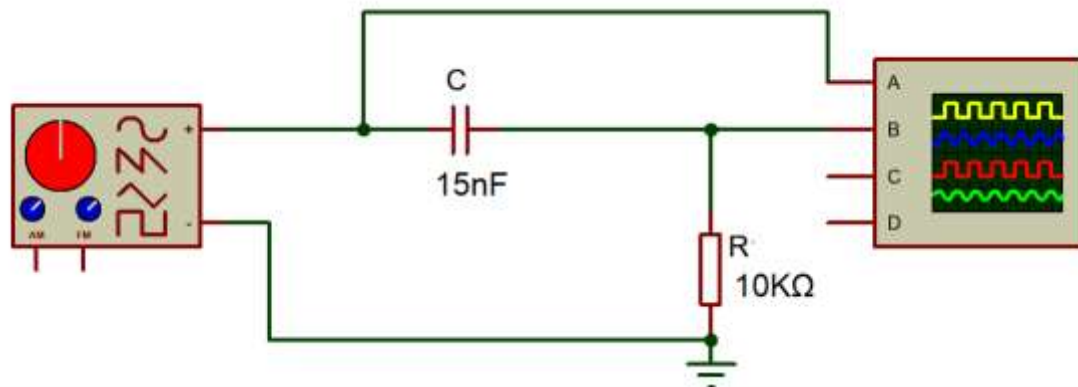


Figure 7 Proteus Circuit – HPF

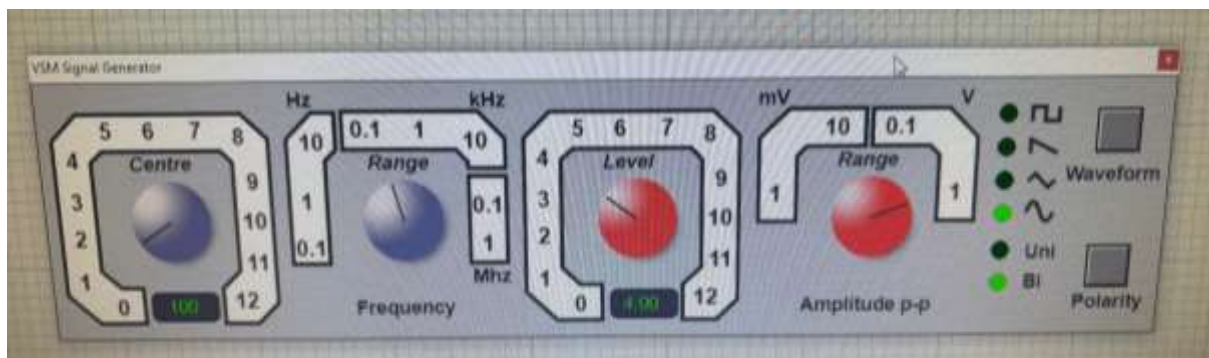


Figure 8 Proteus Signal Generator (4V peak-peak sin wave)-HPF

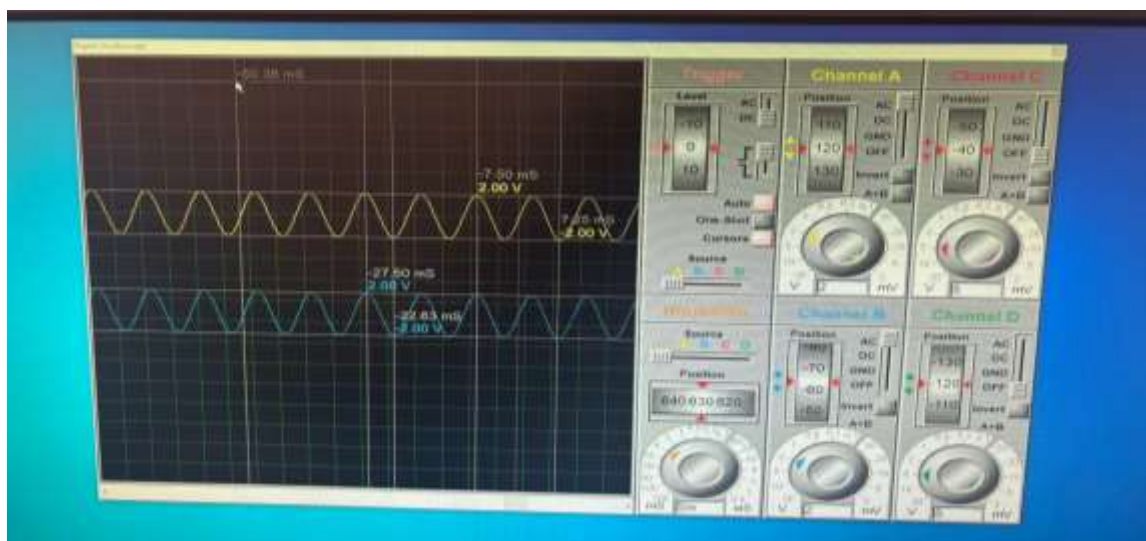


Figure 9 Proteus Oscilloscope-HPF

4.4 High Pass Filter – Experimental Circuit

The experimental circuit is built on a breadboard using a 10 k Ω resistor and a 15 nF capacitor.

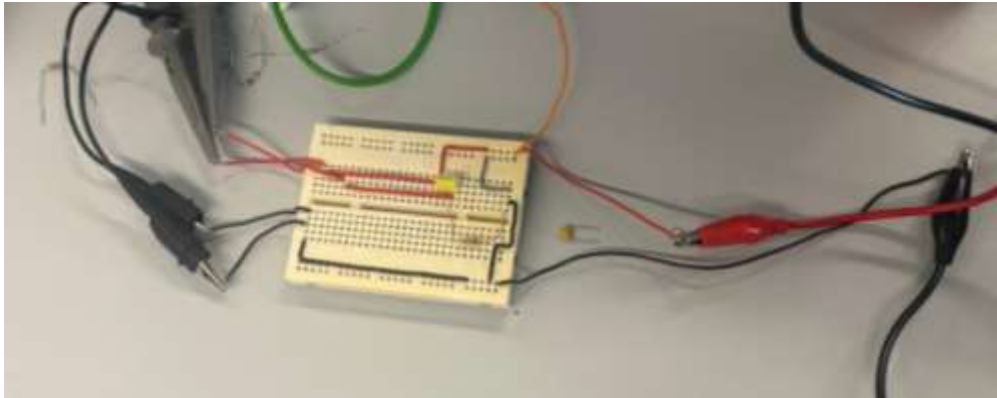


Figure 10 High Pass Filter Circuit on Breadboard

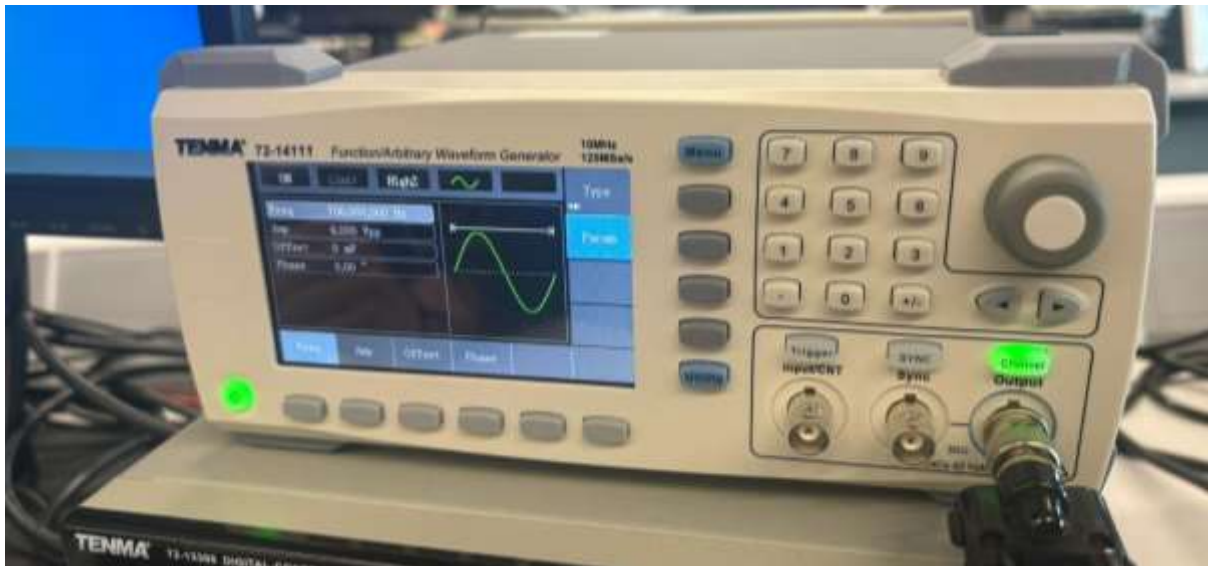


Figure 11 Signal Generator (4V peak-peak sin wave)-HPF

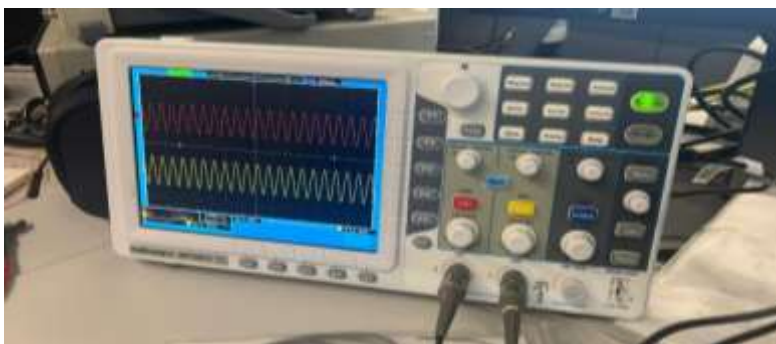


Figure 12 Oscilloscope (Input waveform 4V peak-peak)-HPF

The input of the HPF is connected to the same signal generator and the output is connected to the same oscilloscope as the LPF, with common ground. This was done to ensure similar conditions.

4.5 Test Parameters (Common to Both Filters)

The signal generator is set to 4V peak-peak sin wave, this was also checked in Proteus and in the experimental circuits which can be seen in figures above. The frequency started at 100 Hz and gradually increased to 300 kHz, going up in closer increments towards the cut-off region. The oscilloscope is used to measure the input voltage (V_{in}) and the output voltage (V_{out}) peak-peak at each frequency.

5 Results

5.1 Low Pass Filter

The figures below highlight the attenuation is 0dB at frequencies below 1000 Hz for the simulation LPF and at -0.2 dB at frequencies below 1000 Hz for the experimental circuit. As the frequency increases above 10 kHz the attenuation begins to decrease at a faster rate. The -3dB (cut-off frequency) occurs at 27.7 kHz for the simulated circuit. This is further highlighted in figure 13 below where it is stated that the attenuation of -3dB lies between 27 kHz and 28 kHz. Additionally, the cut off frequency in the experimental circuit occurs at 24.3 kHz.

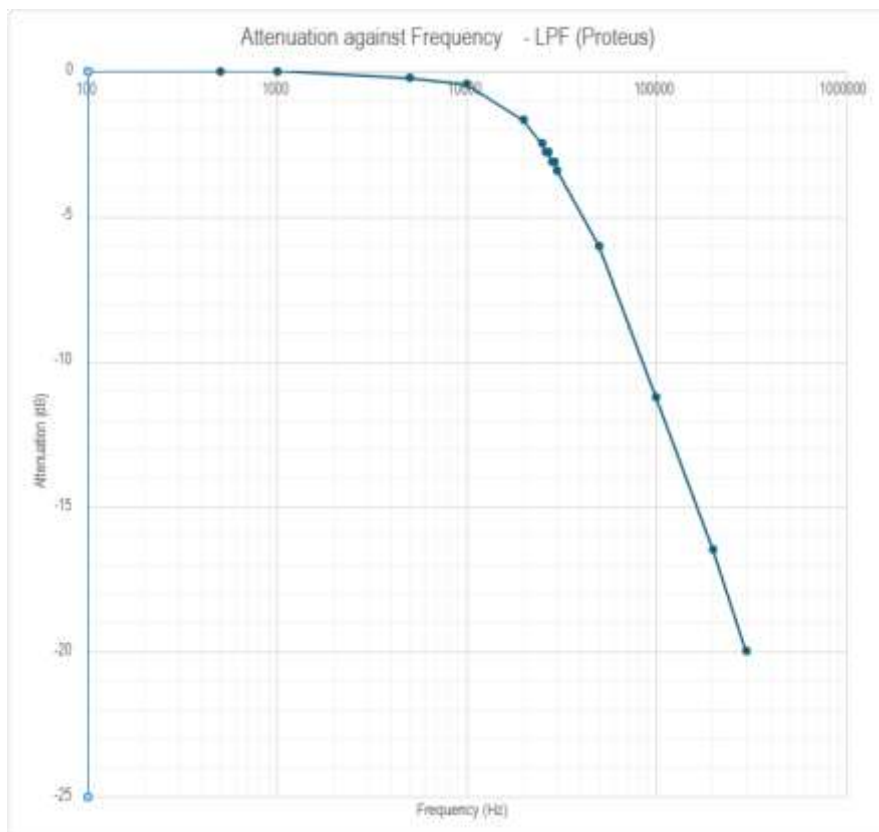


Figure 13 Attenuation against Frequency Graph - LPF (Simulation)

Low pass Filter (Proteus)			
F (Hz)	Vin	Vout	A
100	4	4	0
500	4	4	0
1000	4	4	0
5000	4	3.9	-0.219907686
10000	4	3.8	-0.445527894
20000	4	3.3	-1.670921029
25000	4	3	-2.498774732
26000	4	2.9	-2.793239869
27000	4	2.9	-2.793239869
28000	4	2.8	-3.0980392
29000	4	2.8	-3.0980392
30000	4	2.7	-3.413924543
50000	4	2	-6.020599913
100000	4	1.1	-11.21334612
200000	4	0.6	-16.47817482
300000	4	0.4	-20

Figure 14 Tabulated data from Proteus Simulation (Input voltage, output voltage & calculated attenuation – LPF

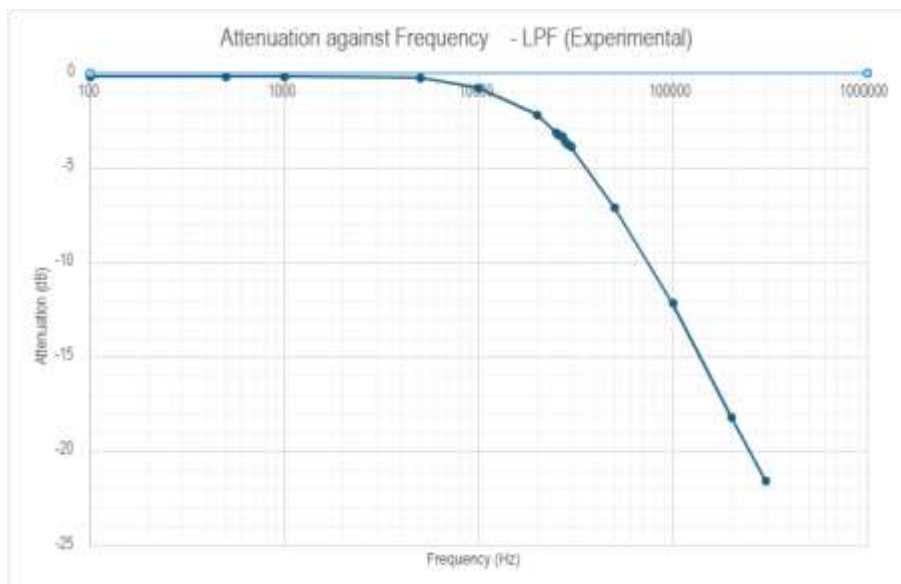


Figure 15 Attenuation against Frequency Graph - LPF (Experimental)

Low pass Filter (Experimental)			
F (Hz)	Vin	Vout	A
100	4.08	4	-0.172003435
500	4.08	4	-0.172003435
1000	4.08	4	-0.172003435
5000	4.08	3.96	-0.259299543
10000	4.08	3.72	-0.802344464
20000	4.08	3.16	-2.219461609
25000	4.08	2.84	-3.146836461
26000	4.08	2.8	-3.270042635
27000	4.08	2.76	-3.39502162
28000	4.08	2.68	-3.650507381
29000	4.08	2.64	-3.781124724
30000	4.08	2.6	-3.913736302
50000	4.08	1.8	-7.10775316
100000	4.08	1	-12.21320326
200000	4.08	0.5	-18.23380318
300000	4.08	0.34	-21.58362492

Figure 16 Tabulated data from Experimental Circuit (Input voltage, output voltage & calculated attenuation – LPF

5.2 High Pass Filter

The figures below highlight that the attenuation approaches 0dB at high frequencies (above 10 kHz) for both data sets. Below 1 kHz, the attenuation increases sharply. The simulated cut-off frequency is at 1.06 kHz, and the experimental cut-off frequency is at 1.1 kHz. This is further highlighted in figure 18 and 20 below where it is stated that the attenuation of -3db lies between 1.1 kHz and 1.15 kHz for experimental and between 1.05 kHz and 1.1 kHz for the simulated circuit.

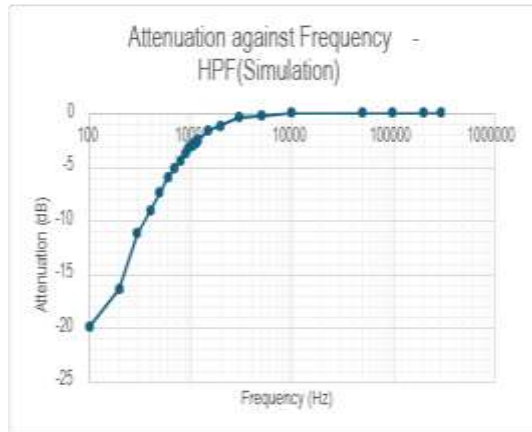


Figure 17 Attenuation against Frequency Graph - HPF (Simulation)

F (Hz)	High pass Filter		(Simulation)
	Vin	Vout	A
100	4	0.4	-20
200	4	0.6	-16.47817482
300	4	1.1	-11.21334612
400	4	1.4	-9.118639113
500	4	1.7	-7.432221399
600	4	2	-6.020599913
700	4	2.2	-5.19274621
800	4	2.4	-4.436974992
900	4	2.6	-3.741732867
950	4	2.7	-3.413924543
1000	4	2.8	-3.0980392
1050	4	2.8	-3.0980392
1100	4	2.9	-2.793239869
1150	4	2.9	-2.793239869
1200	4	3	-2.498774732
1500	4	3.3	-1.670921029
2000	4	3.5	-1.15983894
3000	4	3.8	-0.445527894
5000	4	3.9	-0.219907686
10000	4	4	0
50000	4	4	0
100000	4	4	0
200000	4	4	0
300000	4	4	0

Figure 18 Tabulated data from Proteus Simulation (Input voltage, output voltage & calculated attenuation – HPF

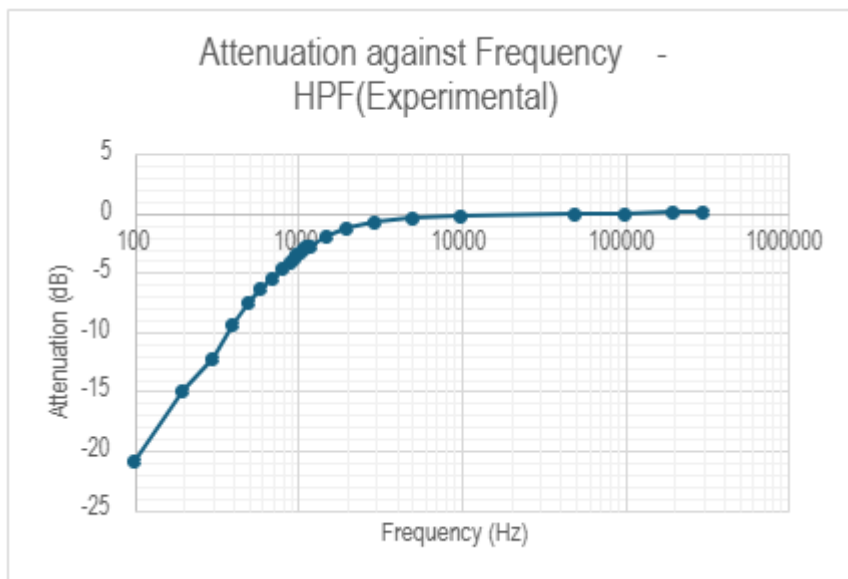


Figure 19 Attenuation against Frequency Graph - HPF (Experimental)

F (Hz)	High pass Filter		(Experimental)
	Vin	Vout	A
100	4.08	0.37	-20.84916878
200	4.08	0.73	-14.94674606
300	4.08	1	-12.21320326
400	4.08	1.4	-9.290642548
500	4.08	1.72	-7.502634324
600	4.08	1.96	-6.368081835
700	4.08	2.16	-5.524128239
800	4.08	2.4	-4.608978428
900	4.08	2.56	-4.048403956
950	4.08	2.64	-3.781124724
1000	4.08	2.72	-3.521825181
1050	4.08	2.8	-3.270042635
1100	4.08	2.88	-3.025353507
1150	4.08	2.96	-2.787369041
1200	4.08	2.96	-2.787369041
1500	4.08	3.28	-1.895726388
2000	4.08	3.52	-1.282349992
3000	4.08	3.76	-0.709446363
5000	4.08	3.92	-0.347481921
10000	4.08	4	-0.172003435
50000	4.08	4.08	0
100000	4.08	4.08	0
200000	4.08	4.16	0.168663351
300000	4.08	4.16	0.168663351

Figure 20 Tabulated data from Experimental Circuit (Input voltage, output voltage & calculated attenuation – HPF

6 Discussion

6.1 Comparison of Results

The LPF has a theoretical cut off frequency of 28.4 kHz, the simulated (Proteus) value is 27.7 kHz, and the experimental cut off frequency is 24.3 kHz. The simulations cut off frequency is within a 2.5% difference of the theoretical (formula) value. The experimental value is 15.56% lower than the theoretical value and 13.08% lower than the simulated value. This highlights that the experimental circuit has factors that affected results and that it attenuates high frequencies earlier than expected.

The HPF has a theoretical cut off frequency of 1.06 kHz, a simulated value of 1.06 kHz, and an experimental value of 1.10 kHz. The theoretical value and simulated value have no difference.

Indicating, that for the HPF the simulated circuit performed as expected. The experimental value is 3.70% higher than both – a smaller deviation in comparison to the experimental low pass filter. This means the experimental circuit attenuates low frequency signals earlier than expected.

6.2 Reasons for Discrepancies

There are many factors that could affect the results, below are some relevant factors that may affect them.

Component tolerances cause discrepancies to result. This is due to the components having a typical tolerance that may not be exactly the resistance or capacitance that needs to be applied. For example, a resistor usually has a tolerance of $\pm 5\%$. The 560-pF capacitor (LPF) usually has a tolerance of $\pm 10\%$ and the 15 nF capacitor has a tolerance of $\pm 5-10\%$. Having a higher resistance or capacitance will cause a lower cut off frequency. This could explain the 15.56 % and 13.08% difference for the experimental LPF. The smaller difference in the HPF of 3.70% suggests that the components have figures closer to their suggested values.

The next factor that could affect results is the resistivity of the wires and breadboard. Both components add an amount of resistivity to the circuit. This is more noticeable when looking at figures 10 and 4 where the HPF does not have excess wire unlike the LPF. The less organised wire connection could affect the overall resistivity of the circuits affecting the cut off frequency and the accuracy of the results.

Measurement uncertainty is also a factor in accuracy of results. For example, trying to find the overall voltage output in Proteus involves using a cursor to find the peak-to-peak value, reading this wrong could lead to inaccurate results. Furthermore, the oscilloscope typically has a tolerance of $\pm 2-3\%$, this could explain the anomaly's found in the HPF at 200 kHz and 300 kHz in the experimental circuit where numbers other than 0 are recorded.

7 Conclusion

In this experiment, the -3 dB for the LPF is 28.4 kHz (theoretical), 27.7 kHz (simulated) and 24.3 kHz (experimental). The experimental value is 15.56% lower than the theoretical value and 13.08% lower than the simulated value. The HPF has a cut off frequency of 1.06 kHz (theoretical and simulated) and 1.10 kHz (experimental). The experimental value is 3.70% higher than both values.

It is concluded that the simulation reliably predicts ideal scenarios. Practical circuits have a higher chance of inaccurate results due to discrepancies that have been stated above. These include, component tolerances and human error with the LPF being affected more due to this.

7. References

Parola, F. and García Niebla, J. (2017). Use of High-Pass and Low-Pass Electrocardiographic Filters in an International Cardiological Community and Possible Clinical Effects. *Advanced Journal of Vascular Medicine*, [online] vol. 2, no. 1. Available at: <https://sedici.unlp.edu.ar/handle/10915/118090>.

Fu, H., Li, Y. and Zhuo, Q. (2023). *Research on the Passive and Active Low Pass Filters*. [online] MCEE. Available at: https://d1wqtxts1xzle7.cloudfront.net/108454730/7497-libre.pdf?1701876308=&response-content-disposition=inline%3B+filename%3DResearch_on_the_Passive_and_Active_Low_P.pdf&Expires=1777391310&Signature=O2zWvyoOyMbhfSslg8Qnoe3BaNgdSE~Nrn5llaKuKtsLcTQkQ7xplkFWHLqdWS1e cmsdXuGXU6MY6fCKIETYFbUARgOYRu41wH60rMFyc8r5aBXajDIHjG7VuHPcQ3MdahuAT25zRAuWaE0n66iBuMQ4vuOdWlV8w-gmiaKfdhdehsUHqMowU9HBQ52aZEca7nOOIR7MGUaNrmOMGgQXF3dkpEH2ijMkwVERmh69wMbQGxdLYSNw2YskfbPRvHemdl5F8-zl9S7e3vybMlg8slhGumw~-HE95gpHlwp7ijBqpdddoGuqHsw6TWK8Koqupe3M5X21Ex-1hziY09JCOA__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA [Accessed 28 Apr. 2026].

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