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Design of Filter circuit

Electrical Principles (ACMA4031)

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April 2026

Table of Contents

1. Abstract	2
2. Introduction	3
3. Circuit descriptions	5
4. Results	7
4.1 Theoretical Experiment	7
4.2 Simulation Experiment (Proteus software).....	9
4.3 Practical Experiment (Breadboard connections).....	13
5. Discussion	17
5.1 Cutoff frequency comparison	17
5.2 Low-pass filter discussion	18
5.3 High-pass filter discussion	18
5.4 Overall filter behaviour	18
6. Conclusion	19
7. References	20

1. Abstract

The experiment examined the frequency response of RC low-pass and high-pass filters. Each circuit used a 10kΩ resistor with a 560pF capacitor for the low-pass filter and a 15nF capacitor for the high-pass filter, driven by a constant 4V input. Input and output peak-to-peak voltages were recorded across frequencies from 100 Hz to 300 kHz. The investigation was carried out theoretically, through Proteus simulation software and practically using breadboard circuits in the electrical laboratory. These results were then plotted in a table and attenuation measurements taken to each of these values using the attenuation (dB) formula below:

$$A = 20 \times \log_{10} \frac{V_{out}}{V_{in}}$$

These results were then used to create a '*Frequency (f) vs Attenuation (dB)*' graph for both the low-pass and high-pass circuits.

The low-pass filter demonstrated attenuation at high frequencies with a cut off frequency measured at approximately 28,420Hz. Conversely, the high-pass filter demonstrated attenuation at lower frequencies, with a cut off frequency measured at approximately 1,061Hz.

In both cases, the cut-off region at -3dB closely matched the theoretical predictions, thus confirming the expected filter behaviour.

2. Introduction

This report presents the findings of theoretical, practical and simulated experiments, each of which assessing the frequency response of both Low and High pass filter RC circuits. As described in the previous section, each circuit consisted of a $10\text{k}\Omega$ resistor and a 560pF capacitor in the low-pass circuit and a 15nF capacitor in the high-pass circuit with a constant 4V input signal applied to both circuits. The following sections of the report will look in greater detail at circuit descriptions, results from the experiments carried out, a discussion giving the explanation of the results, a conclusion section which will give a statement of the findings and end the report with a relevant reference section.

Filters are fundamental circuits which are used to control the frequency content of electrical signals. Both Low and High pass filter RC circuits are commonly used in audio electronics, communication systems, instrumentation and signal conditioning applications. Signals will often contain unwanted frequencies, as such filters serve to allow engineers to control signal behaviour.

An ideal filter is a network that allows signals of only certain frequencies to pass while blocking all others. Depending on the region of frequencies that are allowed through or not, filters are characterized as low-pass, high-pass, band-pass, band-reject and all-pass. There are many needs for electric filters, some of the more common being those used in radio and television sets, which allow tuning into a certain channel by passing its band of frequencies while filtering out those of other channels. (Kolawole et al. 2015)

Low pass filters serve the purpose of allowing low frequencies to pass whilst attenuating higher frequencies. Conversely, High pass frequencies serve to do the opposite function, allowing high frequencies to pass.

The experiment task description asks to take several closely spaced measurements around the cutoff region (the -3 dB point) to determine the cutoff and half-amplitude points accurately. The cutoff frequency of a filter is the frequency at which the output signal has dropped to 70.7% of the input amplitude. This corresponds to -3 dB attenuation as

$$A = 20 \times \log_{10} \frac{V_{out}}{V_{In}}$$

These cutoff frequencies of both filter sets will be compared between theoretical cutoff frequencies, simulated cutoff frequencies (using Proteus simulation software) and experimental cutoff frequencies (using a practical breadboard setup in the Electrical laboratory).

Attenuation is used to describe how much a circuit reduces the amplitude of a signal as it passes through it, this is expressed in decibels (dB). Attenuation values will be recorded for both low and high pass filter circuits for each of the experiments: theoretical, simulated and experimental. These values will then be compared and the differences explained in greater detail.

3. Circuit descriptions

The concept structure of a simple RC low-pass filter circuit in the experiment consists of a signal generator, 10 k Ω resistor, 560pF capacitor and an oscilloscope used for signal visualisation and measuring key metrics such as the peak-to-peak amplitude and the output taken across the capacitor.

In contrast, the concept structure of a simple RC high-pass filter circuit in the experiment consists of a signal generator, 10 k Ω resistor, 15nF capacitor and an oscilloscope, again used for measuring the same key metrics as the low-pass filter circuit.

Across both circuit sets constant 4V input signal remained constant with incremental range of frequencies from initially 100Hz up to 300kHz.

Examples of both the low-pass filter circuit and high-pass filter circuit configurations are shown in *Figure 1* and *Figure 2* below.

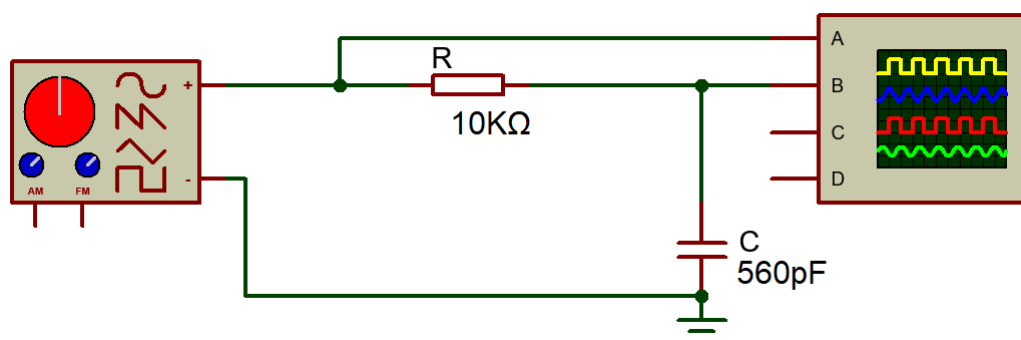


Figure 1: Low-pass filter circuit configuration

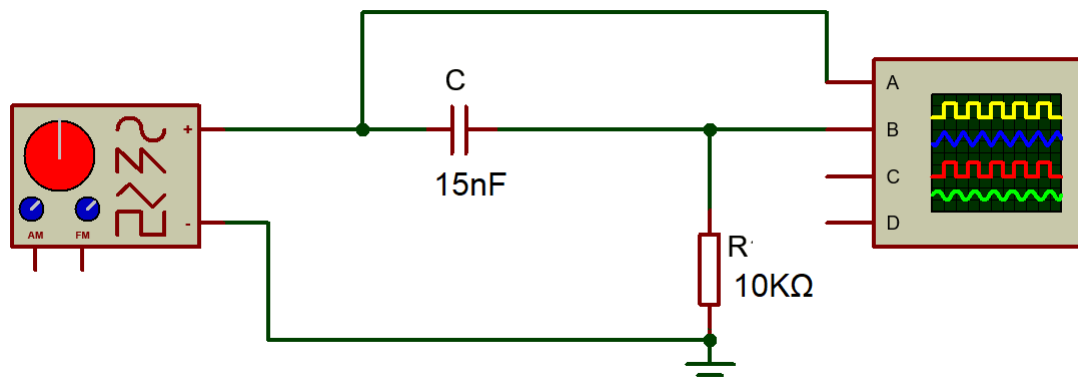


Figure 2: High-pass filter circuit configuration

The concept structure of the both the low-pass and high-pass filter circuit was replicated theoretically, simulated (using Proteus software) and experimental (using breadboard connections in the Electrical laboratory).

4. Results

4.1 Theoretical Experiment

Below is the tabulated results of the theoretical experiment from both the low-pass filter and the high pass filter. These results were achieved by firstly solving the value for Vout (Output voltage) using the formula: $V_{out} = V_{in} (1 / \sqrt{1+(2\pi fRC)^2})$. When the Vout values have been achieved, the formula to find the attenuation can be carried out, this formula is:

$$A = 20 \times \log_{10} \frac{V_{out}}{V_{in}}$$

Both the Vout and the Attenuation values of the low-pass filter circuit are displayed in the table of results below in *Figure 3*.

<i>Low Pass Filter (Theoretical)</i>				(Theoretical)	
F (Hz)	Low pass Filter		Attenuation (dB)		
	Vin	Vout			
100	4	4	0		
500	4	4	0		
1000	4	4	0		
5000	4	3.999	-0.002171744		
10000	4	3.995	-0.010864154		
20000	4	3.958	-0.091684029		
25000	4	3.889	-0.244440964		
26000	4	3.869	-0.289225232		
26500	4	3.858	-0.31395536		
27000	4	3.846	-0.341014229	Take close readings across this as	
27500	4	3.833	-0.370423441		
28000	4	3.82	-0.399932568		
28500	4	3.806	-0.431824148		
29000	4	3.791	-0.466124138		
29500	4	3.776	-0.500560114		
30000	4	3.76	-0.537442928		
50000	4	2.894	-2.811229291		
100000	4	1.497	-8.53676382		
200000	4	0.748	-14.56316787		
300000	4	0.499	-18.07918891		
Cutoff frequency is $F_c = 1/2\pi RC$, therefore the cutoff frequency = 28,420Hz					

Figure 3: Theoretical experimental results (low-pass filter)

These Attenuation dB values were plotted against the Frequency Hz values to demonstrate the cutoff frequency of **28,420Hz** at the -3 dB value point, see *Figure 4* below. The formula used to determine the cutoff frequency was:

$$F_c = 1/(2\pi RC)$$

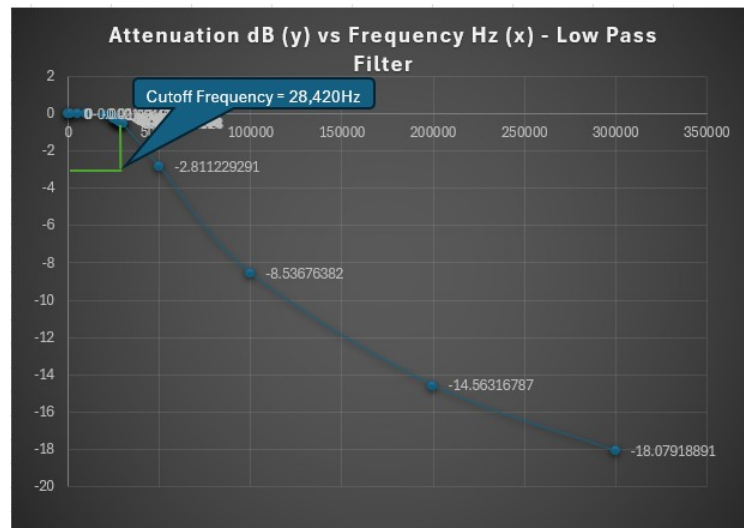


Figure 4: Attenuation vs Frequency Graph – Low Pass Filter

Both the Vout and the Attenuation values of the high-pass filter circuit are displayed in the table of results below in *Figure 5*.

High Pass Filter (Theoretical)

F (Hz)	High pass Filter			Attenuation	(Theoretical)		
	Vin	Vout					
100	4	0.377		-20.51437282			
200	4	0.74		-14.65656543			
300	4	1.09		-11.29266987			
400	4	1.41		-9.056817573			
500	4	1.7		-7.432221399			
600	4	1.97		-6.151875303			
700	4	2.2		-5.19274621			
800	4	2.41		-4.400858975			
900	4	2.59		-3.775204545			
950	4	2.67		-3.510974599			
1000	4	2.74		-3.28618857			
1050	4	2.82		-3.03621766			
1100	4	2.88		-2.853350071			
1150	4	2.94		-2.674253218			
1200	4	3		-2.498774732			
1500	4	3.26		-1.776847825			
2000	4	3.53		-1.085705719			
3000	4	3.77		-0.514372822			
5000	4	3.91		-0.197664679			
10000	4	3.98		-0.043538385			
50000	4	4		0			
100000	4	4		0			
200000	4	4		0			
300000	4	4		0			

Cutoff frequency is $F_c = 1/2\pi RC$, therefore the cutoff frequency = 1,061Hz

Figure 5: Theoretical experimental results (high-pass filter)

These Attenuation dB values were plotted against the Frequency Hz values to demonstrate the cutoff frequency of **1,061Hz** at the -3 dB value point, see *Figure 6* below. The formula used to determine the cutoff frequency was:

$$F_c = 1/(2\pi RC)$$

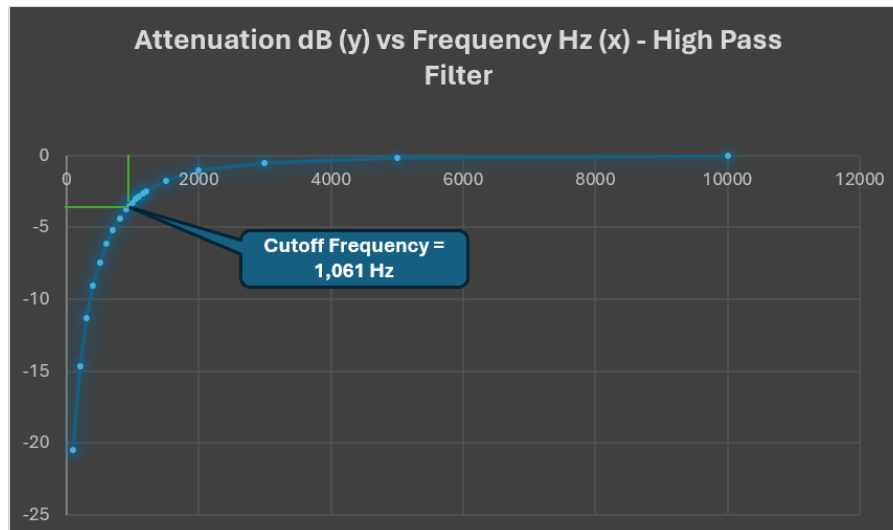


Figure 6: Attenuation vs Frequency Graph – High Pass Filter

4.2 Simulation Experiment (Proteus software)

The next stage of the task was to assess how the circuits perform using circuit simulation software (Proteus). Below are the results of both the low and high pass filter circuits including snapshots of the both circuits within the Proteus circuit simulation software, see Figures 7 - 14 below.

Low Pass Filter (Simulation – Proteus Software)

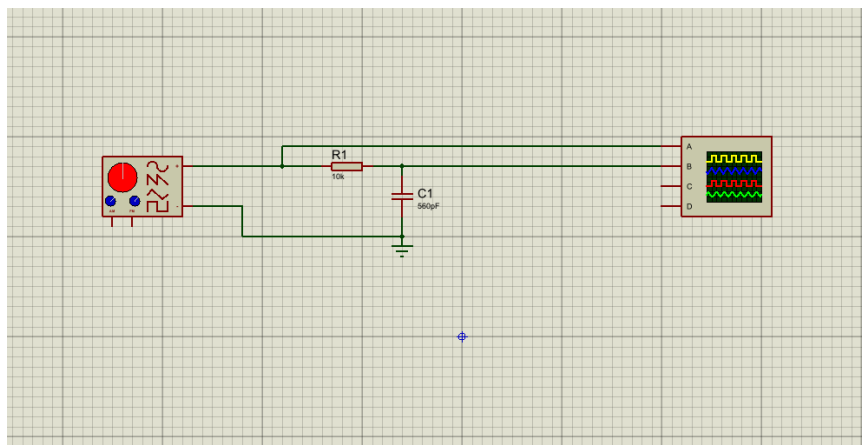


Figure 7 – Snapshot of Low Pass Filter circuit arrangement

Low Pass Filter – VSM Oscilloscope (Simulation – Proteus Software)

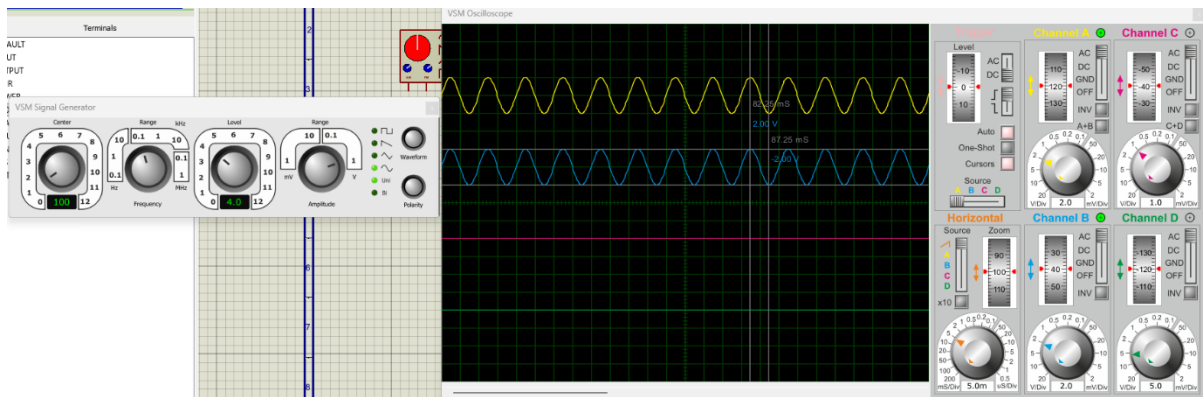


Figure 8 – Snapshot of VSM Oscilloscope at 4v pk-pk at 100Hz

Again, the constant 4V input signal applied to both circuits and data was retrieved from the VSM Oscilloscope display. See Figure 9 below, the tabulated results from the simulated low pass filter.

Low pass Filter				Simulation (Proteus Software)			
F (Hz)	Vin	Vout	Attenuation (dB)				
100	4	4	0				
500	4	4	0				
1000	4	4	0				
5000	4	4	0				
10000	4	3.8	-0.445527894				
20000	4	3.2	-1.93820026				
25000	4	3	-2.498774732				
26000	4	3	-2.498774732				
26500	4	3	-2.498774732				
27000	4	2.8	-3.0980392				
27500	4	2.8	-3.0980392				
28000	4	2.8	-3.0980392				
28500	4	2.8	-3.0980392				
29000	4	2.8	-3.0980392				
29500	4	2.8	-3.0980392				
30000	4	2.8	-3.0980392				
50000	4	2	-6.020599913				
100000	4	1	-12.04119983				
200000	4	0.6	-16.47817482				
300000	4	0.4	-20				

Figure 9: Simulation experimental results (low-pass filter)

These Attenuation dB values were plotted against the Frequency Hz values to demonstrate the cutoff frequency of **27,000Hz** at the -3 dB value point, see Figure 10 below.

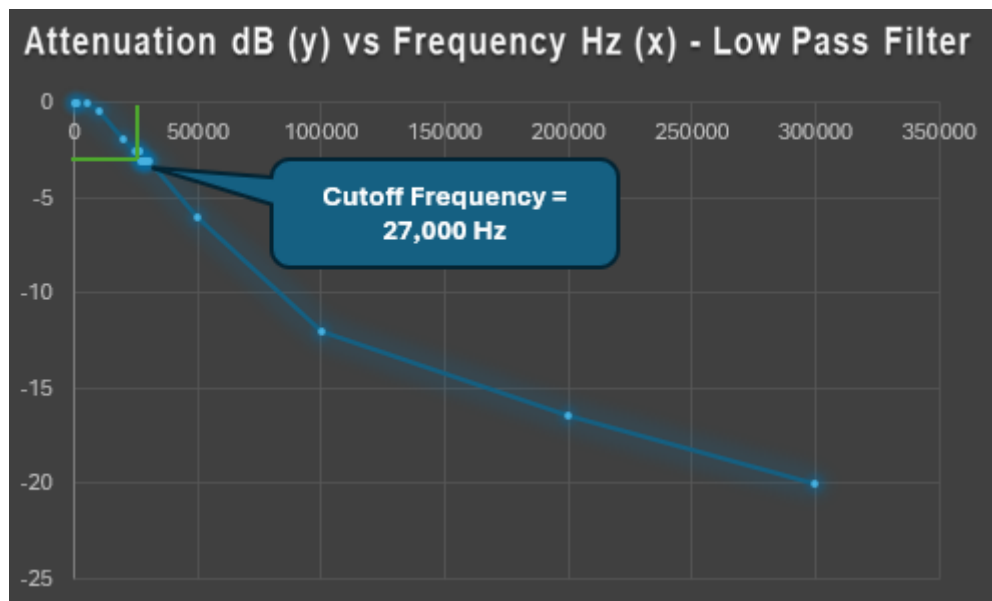


Figure 10: Attenuation vs Frequency Graph – Low Pass Filter

The simulation circuit was rearranged to the High Pass filter arrangement, as shown in Figure 11 below. The data retrieved was tabulated and shown in Figure 13.

High Pass Filter (Simulation – Proteus Software)

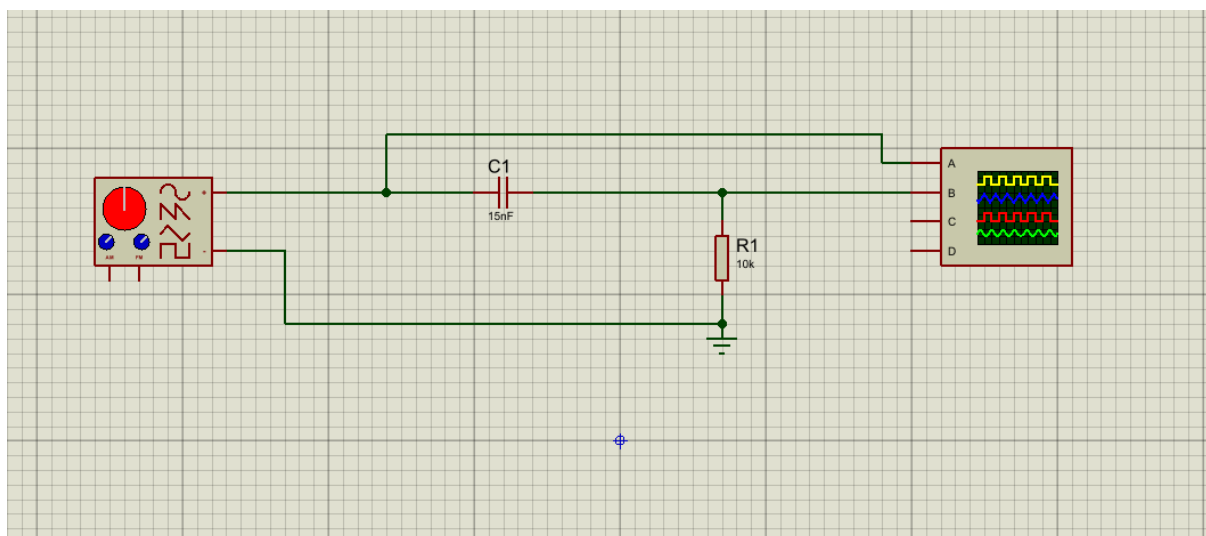


Figure 11 – Snapshot of High Pass Filter circuit arrangement

High Pass Filter – VSM Oscilloscope (Simulation – Proteus Software)

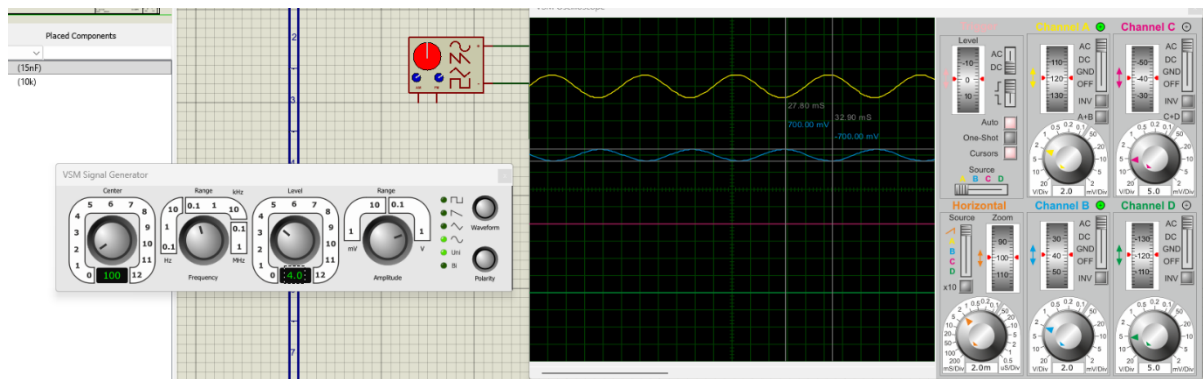


Figure 12 – Snapshot of VSM Oscilloscope at 4v pk-pk at 100Hz

See Figure 13 below, the tabulated results from the simulated low pass filter.

High pass Filter				(Simulation - Proteus Software)			
F (Hz)	Vin	Vout	Attenuation				
100	4	0.4	-20				
200	4	0.75	-14.53997456				
300	4	1.1	-11.21334612				
400	4	1.4	-9.118639113				
500	4	1.7	-7.432221399				
600	4	1.95	-6.240507599				
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	2.7	-3.413924543				
1050	4	2.9	-2.793239869				
1100	4	2.9	-2.793239869				
1150	4	3	-2.498774732				
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	4	0				
10000	4	4	0				
50000	4	4	0				
100000	4	4	0				
200000	4	4	0				
300000	4	4	0				

Figure 13: Simulation experimental results (high-pass filter)

These Attenuation dB values were plotted against the Frequency Hz values to demonstrate the cutoff frequency of **1,000Hz** at the -3 dB value point, see Figure 14 below.

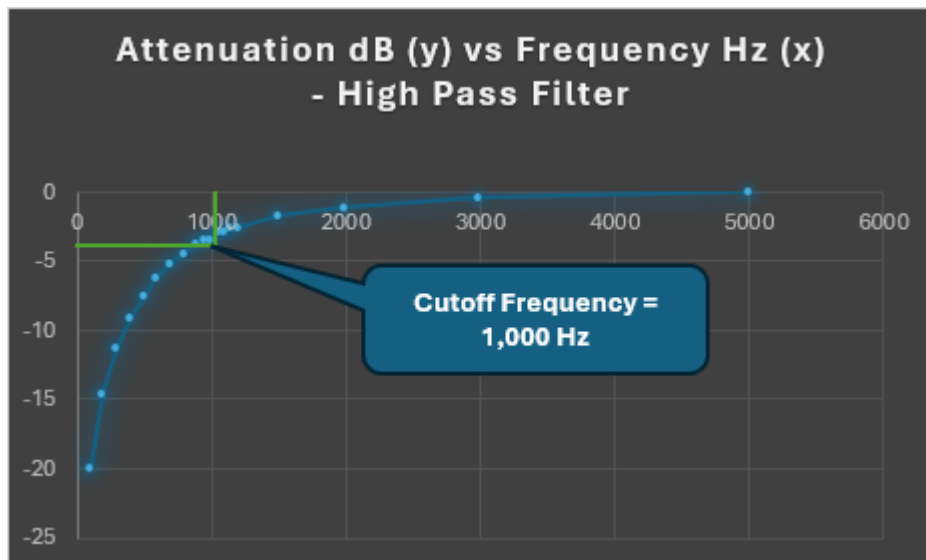


Figure 14: Attenuation vs Frequency Graph – High Pass Filter

4.3 Practical Experiment (Breadboard connections)

The next stage of the task was to assess how the circuits perform practically using breadboard connections. Below are the results of both the low and high pass filter circuits including snapshots of the both circuits within the breadboard connection experiment, see Figures 15 – 21 below.

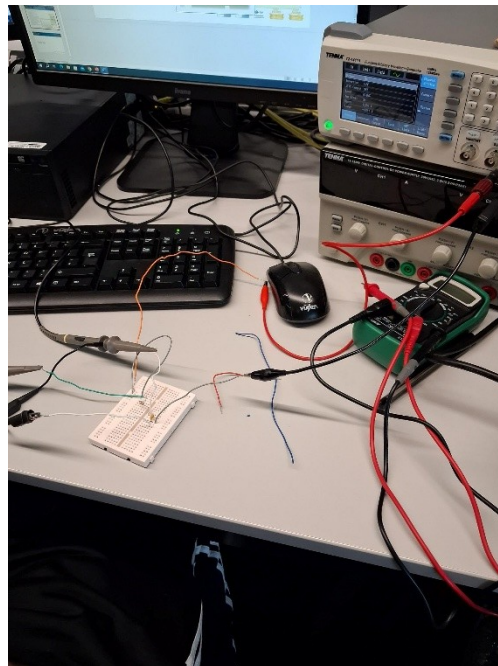


Figure 15 – Snapshot of Low Pass Filter circuit breadboard arrangement

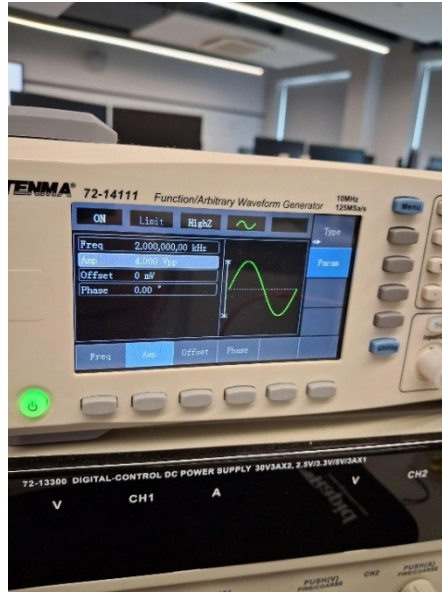


Figure 16 – Snapshot of waveform generator used for practical breadboard connection experiment

The constant 4V input signal applied to both circuits and data was retrieved from the Oscilloscope display. See Figure 17 below, the tabulated results from the breadboard connection low pass filter.

F (Hz)	Low pass Filter			Attenuation (dB)	Practical breadboard connections			
	Vin	Vout						
100	4	4		0				
500	4	4		0				
1000	4	4		0				
5000	4	4		0				
10000	4	3.6		-0.915149811				
20000	4	3.12		-2.158107946				
25000	4	2.88		-2.853350071				
26000	4	2.8		-3.0980392				
26500	4	2.8		-3.0980392				
27000	4	2.8		-3.0980392				
27500	4	2.72		-3.349821746				
28000	4	2.72		-3.349821746				
28500	4	2.72		-3.349821746				
29000	4	2.64		-3.609121289				
29500	4	2.64		-3.609121289				
30000	4	2.56		-3.87640052				
50000	4	0.48		-18.41637508				
100000	4	0.48		-18.41637508				
200000	4	0.48		-18.41637508				
300000	4	0.48		-18.41637508				
Cutoff frequency is calculated as: 26,300 Hz								

Figure 17 – Tabulated results of breadboard connections (Low pass filter)

These Attenuation dB values were plotted against the Frequency Hz values to demonstrate the cutoff frequency of **26,300Hz** at the -3 dB value point, see *Figure 18* below.

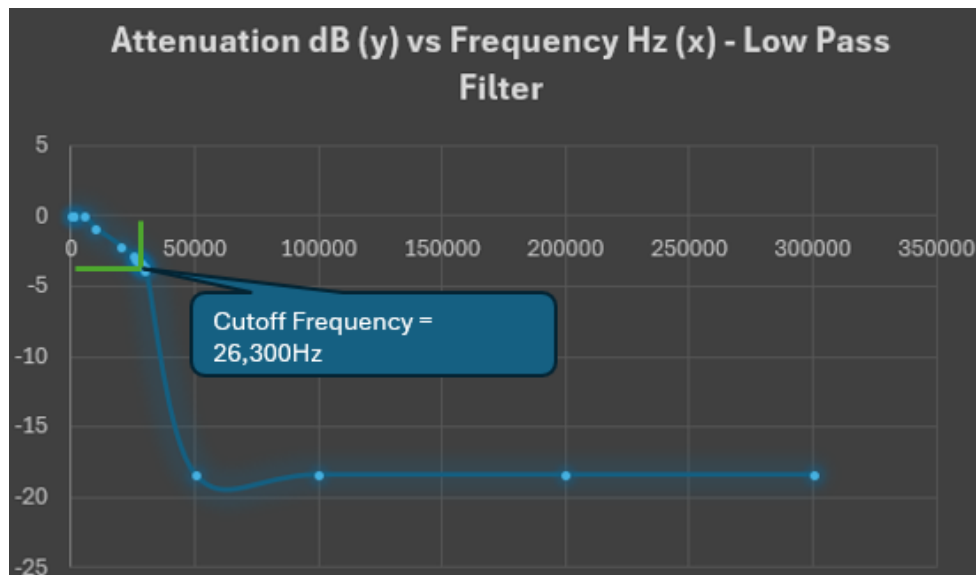


Figure 18 - *Attenuation vs Frequency Graph (Low pass filter)*

The breadboard circuit was rearranged to the High Pass filter arrangement, as shown in Figure 19 below. The data retrieved was tabulated and shown in Figure 20.

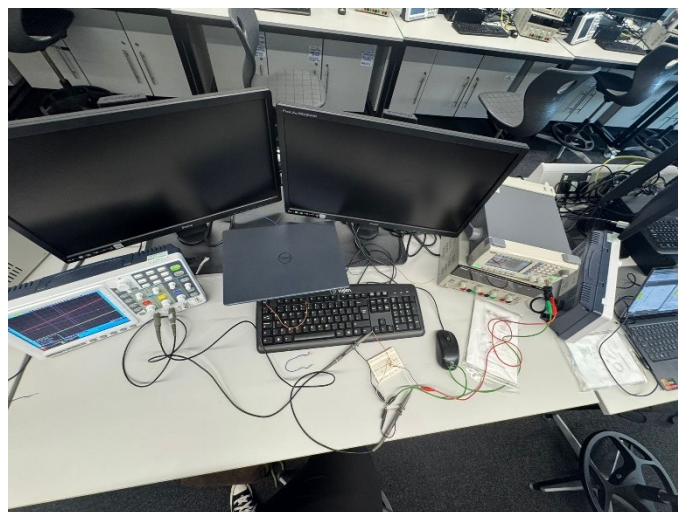


Figure 19 – *Snapshot of High Pass Filter circuit breadboard arrangement*

F (Hz)	Vin	Vout	High Pass Filter	Practical breadboard connections			
			Attenuation Db				
100	4	0.48	-18.41637508				
200	4	0.8	-13.97940005				
300	4	1.12	-11.05683937				
400	4	1.44	-8.873949985				
500	4	1.76	-7.13094647				
600	4	2	-6.020599913				
700	4	2.24	-5.03623946				
800	4	2.4	-4.436974992				
900	4	2.56	-3.87640052				
950	4	2.64	-3.609121289				
1000	4	2.72	-3.349821746				
1050	4	2.8	-3.0980392				
1100	4	2.88	-2.853350071				
1150	4	2.96	-2.615365605				
1200	4	2.96	-2.615365605				
1500	4	3.28	-1.723722952				
2000	4	3.52	-1.110346557				
3000	4	3.76	-0.537442928				
5000	4	4	0				
10000	4	4	0				
50000	4	4	0				
100000	4	4	0				
200000	4	4	0				
300000	4	4	0				

Figure 20 – Tabulated results of breadboard connections (High pass filter)

These Attenuation dB values were plotted against the Frequency Hz values to demonstrate the cutoff frequency of **1,070 Hz** at the -3 dB value point, see Figure 21 below.

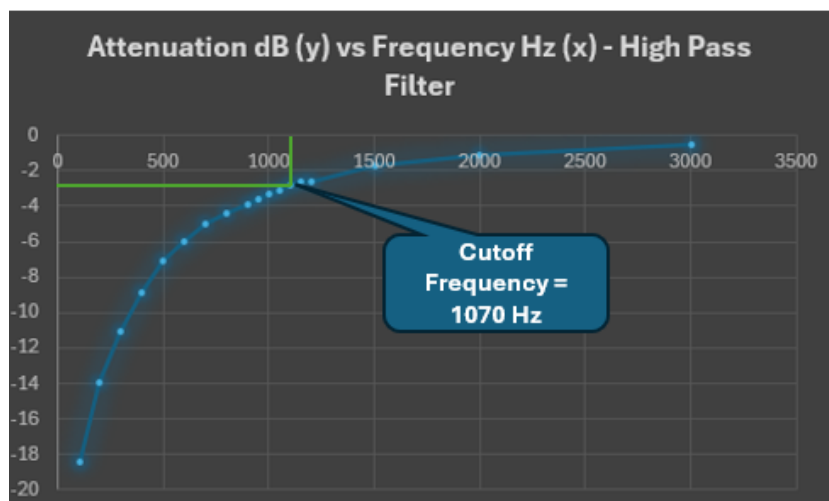


Figure 21 - Attenuation vs Frequency Graph (High pass filter)

5. Discussion

In this section I will evaluate the results of the low and high pass RC circuit experiments for each version of the experiment, i.e: Theoretical, Simulation and Practical. I will discuss the cutoff frequencies and attenuation characteristics obtained from each of the experiments and assess and compare similarities and differences between each of the experiments.

5.1 Cutoff frequency comparison

Below is a comparison table of the cutoff frequencies obtained from each version of the experiment:

Filter type	Theoretical Fc	Simulation Fc	Practical Fc	Notes
Low-Pass (10 kΩ, 560pF)	28,420 Hz	27,000 Hz	26,300 Hz	Similar set of results with a total difference of 2,120 Hz between the highest and lowest value
High-Pass (10 kΩ, 15nF)	1,061 Hz	1,000 Hz	1,070 Hz	Lowest range of values with a total difference of 70 Hz between the highest and lowest value

This table highlights that both filters behaved as expected with both simulated and practical experiments closely aligning with the theoretical values.

The low-pass filter circuit demonstrated the greatest range between the highest and lowest value (2,120 Hz). The high-pass filter circuit was more consistent, with a smaller range between the highest and lowest value (1,070 Hz).

5.2 Low-pass filter discussion

The low-pass filter experiments demonstrated the expected high-frequency attenuation. The measured cut-off frequencies: 28,420 Hz, 27,000 Hz and 26,300 Hz were closely grouped, with differences likely due to internal resistance, capacitor behaviour and component tolerances. This filter showed the widest cut-off variation in Section 5.1, yet the attenuation curve still followed the expected pattern of minimal loss at low frequencies and increasing attenuation beyond the cutoff region.

5.3 High-pass filter discussion

The high-pass filter experiments performed as expected, attenuating low frequencies whilst passing higher ones. The measured cut-off frequencies: 1,061 Hz, 1,000 Hz and 1,070 Hz were even more closely grouped, indicating strong consistency and minimal influence from practical imperfections. As shown in Section 5.1, this filter exhibited the smallest cutoff variation. The attenuation curve still shows the expected increase in amplitude with rising frequency despite minor imperfections.

5.4 Overall filter behaviour

Overall, both filter types behaved as expected: the low pass filter attenuated high frequencies with a clear -3dB region near the predicted cutoff and conversely the high-pass filter attenuated low frequencies with a similarly accurate cut off point.

Across the theoretical, simulated and practical results, the attenuation curves maintained the characteristic RC shape with clearly identifiable -3dB cutoff regions. Deviations between practical and ideal responses can be attributed to connection imperfections, however the core filter behaviour remained consistent throughout.

6. Conclusion

This investigation demonstrated the expected frequency responses of RC low-pass and high-pass filters across theoretical, simulated and practical testing. Theoretical cut-off frequencies (28,420 Hz for the low-pass and 1,061 Hz for the high pass) were closely matched by the simulation results (27,000 Hz and 1,000 Hz) and by practical measurements (26,400 Hz and 1,070 Hz).

The attenuation curves and -3dB regions also aligned with predicted behaviour. Overall the results confirm that simple RC filters operate in a consistent, predictable manner, thus reinforcing their reliability in real-world applications.

An extract from 'The development of a fully balanced active RC high-pass filter' (Thitapars et al.) 2025, describes the following:

In terms of practical application, the results can be used to design high-pass filters for various applications, particularly in communication systems, audio signal processing, and medical devices. This filter can effectively reduce noise and improve the quality of transmitted signals, such as enhancing audio quality in consumer electronics or signal conditioning in diagnostic medical instruments. Furthermore, reducing the resistance and capacitance values (C) can increase the operating frequency (f_0), which allows for fine-tuning the filter to meet specific technical requirements, such as the ability to operate at high or low frequencies as needed. (Thitapars et al.)

Thus, reaffirming the importance and real-world applicability of RC filter circuits.

7. References

- Kolawole, Emmanuel S., et al. "Design and Implementation of Low-Pass, High-Pass and Band-Pass Finite Impulse Response (FIR) Filters Using FPGA." *Circuits and Systems*, vol. 06, no. 02, 2015, pp. 30–48, <https://doi.org/10.4236/cs.2015.62004>. Accessed 27 Mar. 2026.
- Thitapars, Sarayut, et al. "The Development of a Fully Balanced Active-RC High-Pass Filter." *EUREKA: Physics and Engineering*, no. 1, 31 Jan. 2025, pp. 84–92, <https://doi.org/10.21303/2461-4262.2025.003645>. Accessed 3 Apr. 2026.