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***Comparison of High-Pass and Low-Pass Filters –
Laboratory Report***

Electrical Principles (ACMA4031)

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1 Abstract

This report investigates the behaviour of low-pass and high-pass RC filters. The cutoff frequencies were calculated theoretically and compared with values obtained from simulation and experimental measurements. Attenuation was measured over a range of frequencies and used to generate frequency response graphs. The results showed close agreement between theoretical and simulated values, with some variance in experimental results due to non-ideal factors.

2 Introduction

2.1 Low-Pass and High-Pass Filter Circuits and Applications

Low-pass and high-pass filters are electronic circuits designed to selectively allow or attenuate specific frequencies from an electrical signal [1]. The difference between a low-pass and high-pass filter is that a low-pass filter will allow signals below a cutoff frequency to pass, whilst a high-pass filter will allow signals above a certain frequency to pass [2]. A low-pass filter consists of a resistor in series with the input signal, and a capacitor connected between the resistor and output to ground as shown in figure 1. The output is taken across the capacitor [3]. A high-pass filter is similar in structure, with the only difference in configuration being that the positions of the resistor and capacitor are swapped.

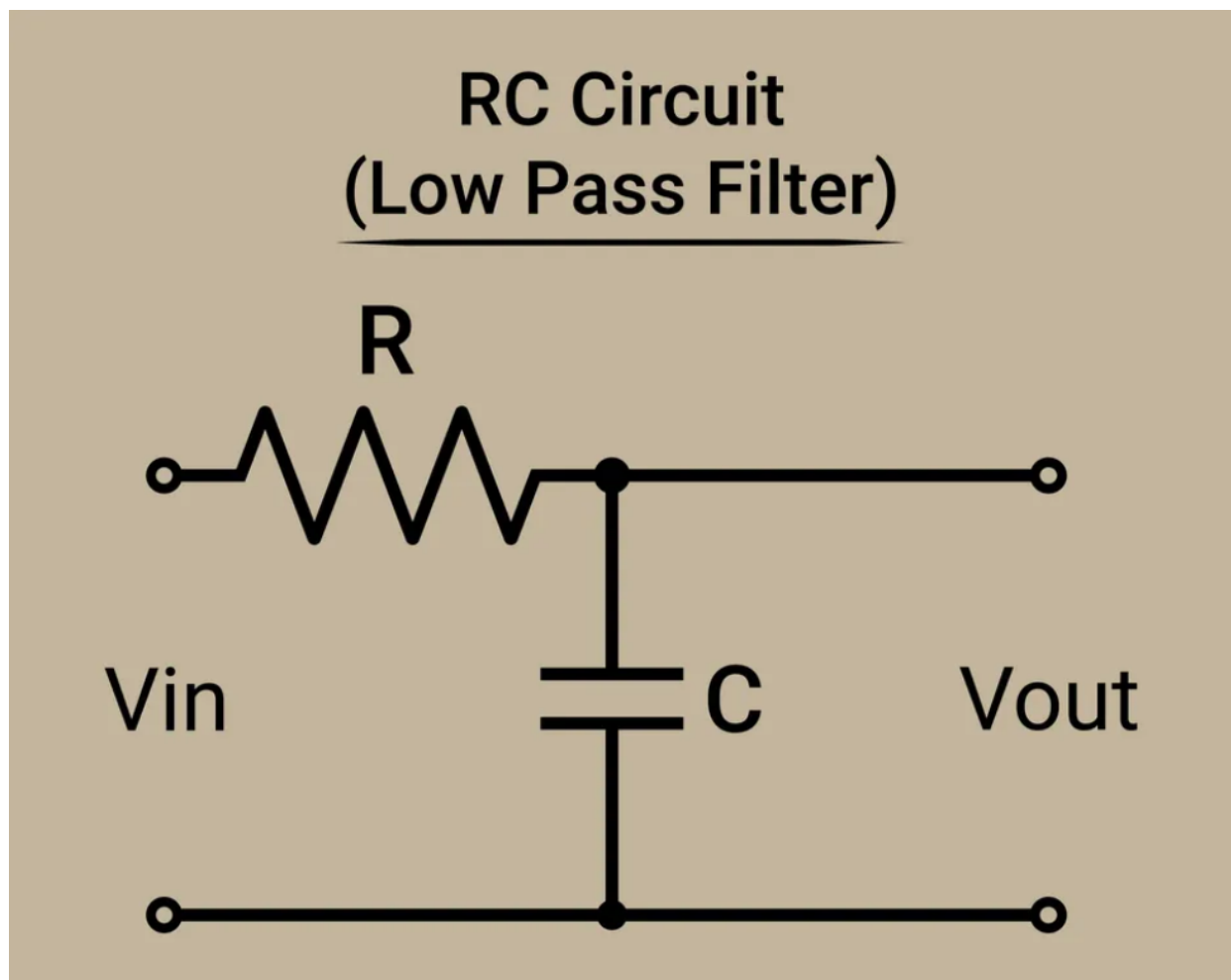


Figure 1: Low-pass RC filter circuit [3]

Their ease of design, compact size, and stable performance make them well suited for low-frequency applications such as audio processing, noise reduction, signal smoothing, and basic signal conditioning in analog systems [4].

2.2 Theory of Low and High Pass Filters

RC filters are passive electrical circuits composed of resistors and capacitors that are used to control the frequency content of a signal. How they behave depends on the frequency-dependent properties of the capacitor, whose impedance changes with frequency, and the resistance in the circuit. At low frequencies, the capacitor has a high impedance, meaning that it resists the flow of current. At high frequencies, the capacitor has a low impedance, allowing current to flow more easily through the circuit.

In a low-pass filter, the resistor is connected in series with the input signal, and the capacitor is connected to ground at the output. At low frequencies, the capacitor's high impedance means very little current flows through it, so most of the input voltage appears across the output and the signal is passed. At high frequencies, the capacitor's impedance decreases, allowing more current to flow to ground. This reduces the output voltage, resulting in attenuation of the signal.

In a high-pass filter, the capacitor is connected in series with the input signal, and the resistor is connected to ground. At low frequencies, the capacitor has a high impedance and restricts current flow, leading to a small output voltage. As the frequency increases, the capacitor's impedance decreases, allowing more current to pass through the circuit. This increases the output voltage, meaning high-frequency signals are transmitted while low-frequency signals are attenuated [3].

2.3 Mathematical Theory

The performance of high-pass and low-pass filters is described using the cutoff frequency, which defines the point at which the output signal begins to be significantly attenuated. The cutoff frequency is defined as the frequency at which the output voltage falls to approximately 70.7% of the input voltage. This corresponds to a reduction of -3 dB in signal amplitude and provides a reference point for analysing filter circuits. The cutoff frequency or “-3 dB breakpoint” is calculated by using the formula [5]:

$$f_c = \frac{1}{2\pi RC}$$

This shows that the cutoff frequency is inversely proportional to both resistance and capacitance.

Attenuation describes the reduction in signal amplitude as it passes through the filter and is measured in decibels (dB). It is calculated using the ratio of output voltage to input voltage in the formula:

$$A = 20 \log_{10}\left(\frac{V_{out}}{V_{in}}\right)$$

At the cutoff frequency, the attenuation is equal to –3 dB. This relationship allows the cutoff frequency to be determined experimentally by identifying the point at which the attenuation reaches –3 dB on a graph of attenuation against frequency.

2.4 Aim of the Report

The aim of this report is to determine and compare the theoretical, simulated and experimental cutoff frequencies of low-pass and high-pass RC filters.

3 Circuits and Parameters

3.1 Low-Pass Filter

The low-pass filter that will be investigated in this report will be a simple RC filter consisting of a signal generator, a 10 k Ω resistor connected in series with the generator, a 560 pF capacitor connected between the resistor and ground with an oscilloscope used to measure input and output voltages, and to monitor signal frequency. To determine simulated and experimental results, this circuit will be built in Proteus (Figure 2) and constructed using the corresponding components on a breadboard (Figure 3).

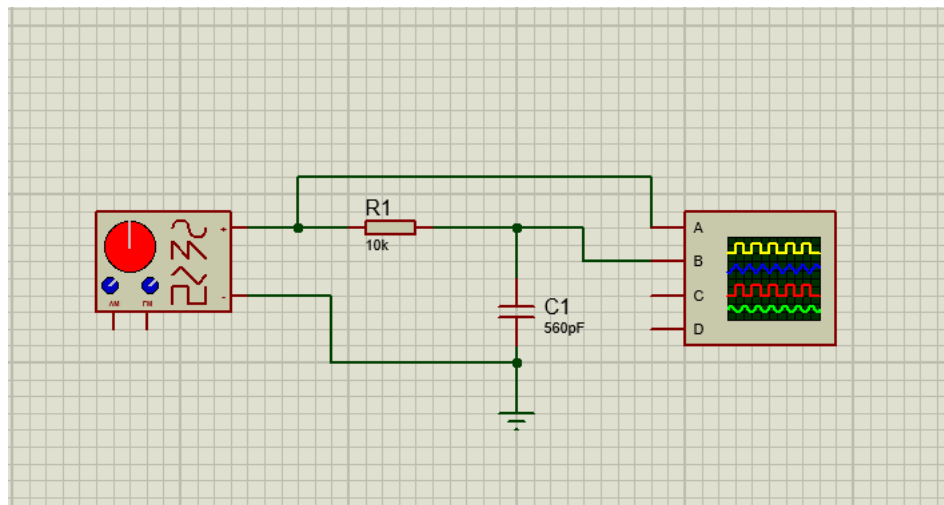


Figure 2: Low-pass filter built in Proteus

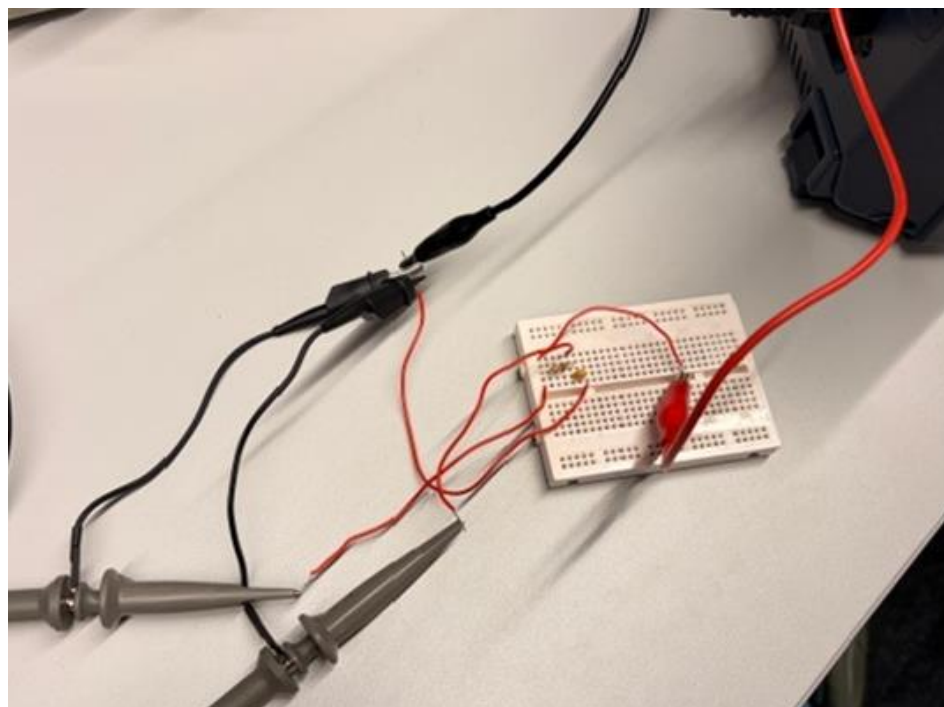


Figure 3: Low-pass filter made using a breadboard

3.2 High-Pass Filter

The high-pass filter that will be investigated in this report will be a simple RC filter made up of a signal generator, a 15 nF capacitor connected in series with the generator, a 10 k Ω resistor connected between the capacitor and ground with an oscilloscope used to measure input and output voltages, and to monitor signal frequency. To determine simulated and experimental results, this circuit will be built in Proteus (Figure 4) and physically with the corresponding components on a breadboard (Figure 5).

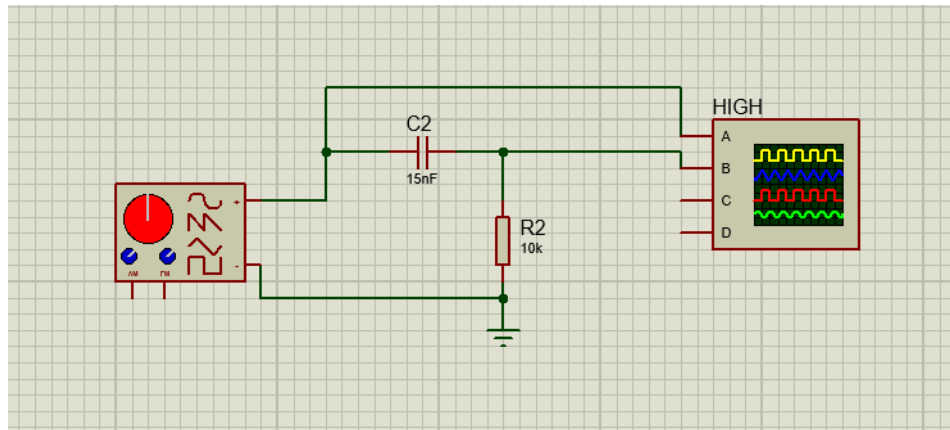


Figure 4: High-pass filter built in Proteus

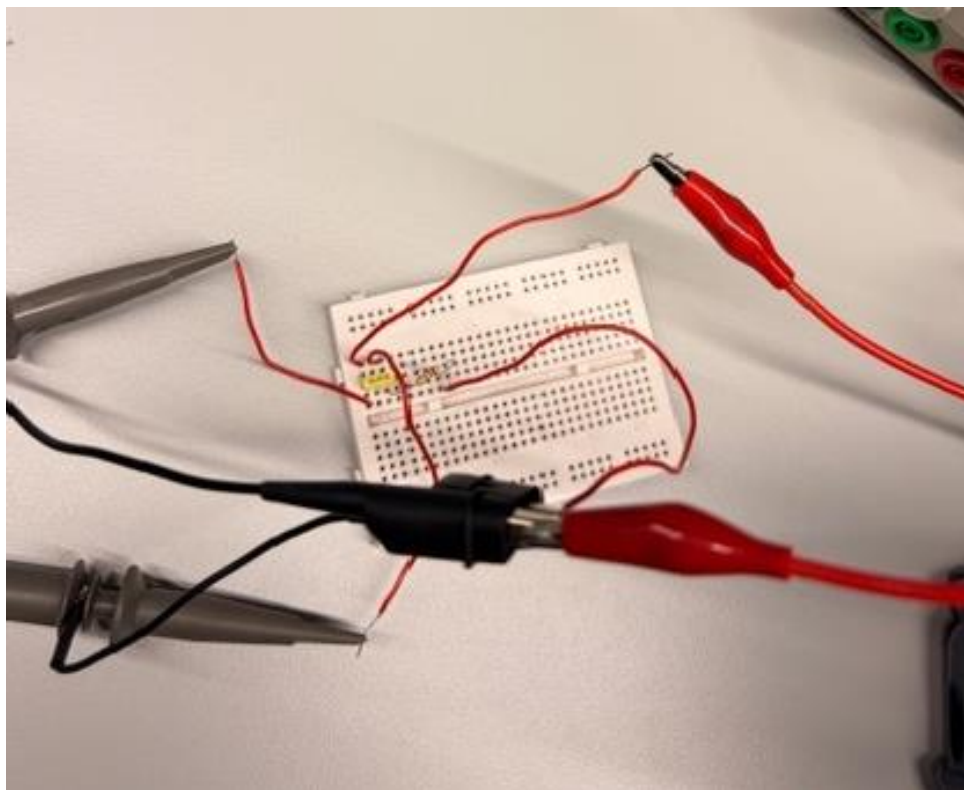


Figure 5: High-pass filter built with a breadboard

3.3 Measurement Parameters

For both the low-pass and high-pass filters, measurements of signal frequency, input voltage, and output voltage will be recorded. These values will be used to calculate attenuation and determine the cutoff frequency for each circuit.

Measurements will be taken over a frequency range of 100 Hz to 300 kHz, with closely spaced readings taken around the -3 dB cutoff region to improve the accuracy of the results.

The input signal will be maintained at a constant amplitude of 4 V peak-to-peak throughout all measurements.

4 Results

4.1 Low-Pass Filter

The theoretical cutoff frequency for the low-pass filter was calculated as 28.42 kHz (to 2 d.p) using the formula:

$$f_c = \frac{1}{2\pi RC}$$

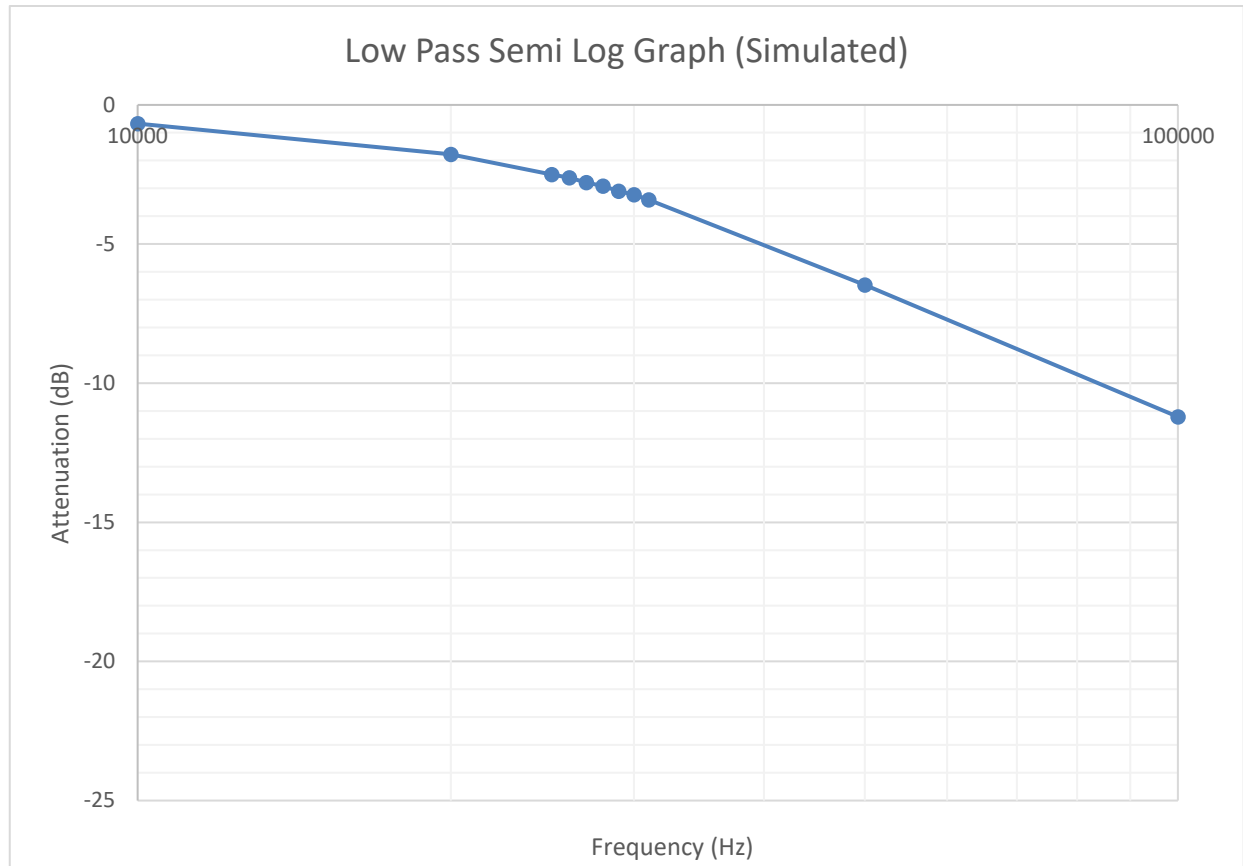


Figure 6: Simulated low-pass filter attenuation vs frequency

Figure 6 shows minimal attenuation at low frequencies. As the frequency increases, the attenuation becomes more negative. The cutoff frequency, identified at approximately -3 dB, is around 28.5 kHz. Closely spaced measurements around this region allow for a more accurate estimation.

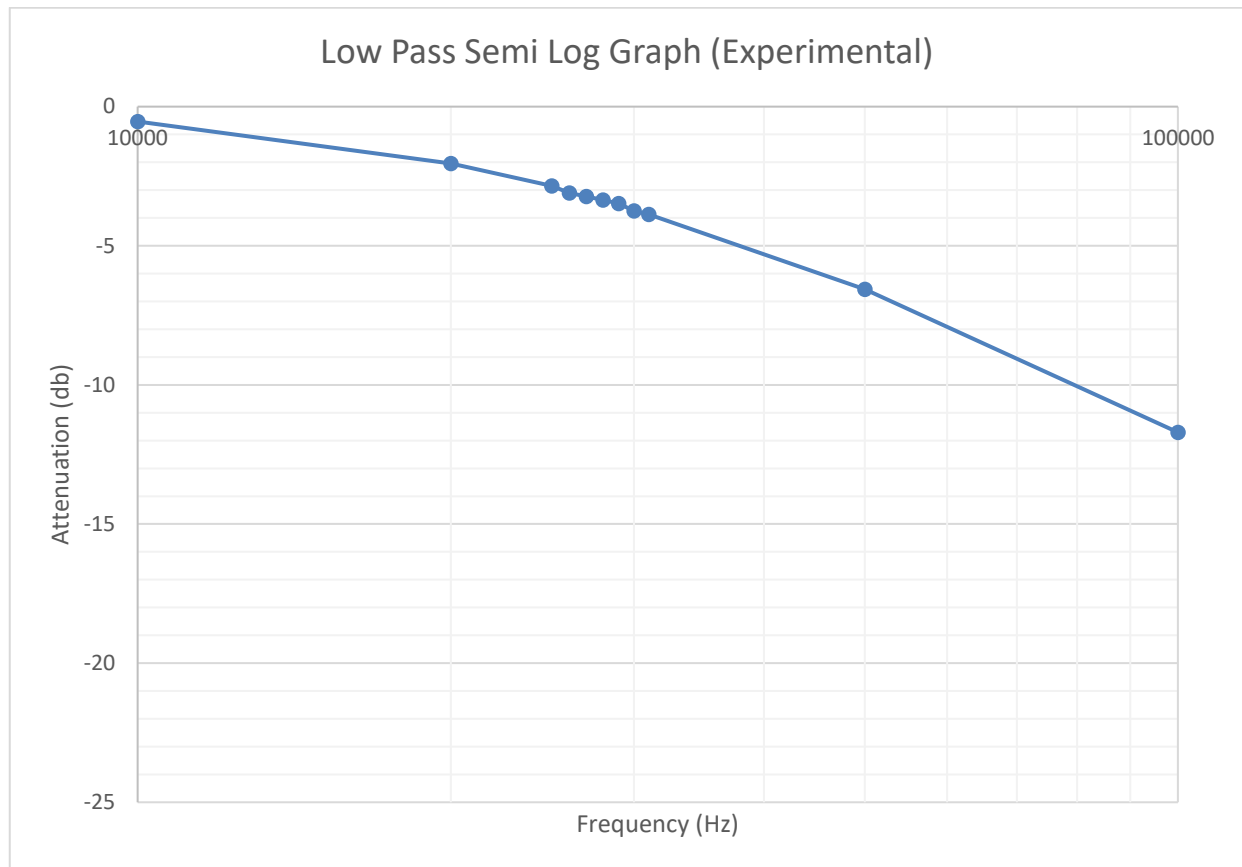


Figure 7: Experimental low-pass filter attenuation vs frequency

Figure 7 shows a similar trend, with minimal attenuation at low frequencies and increasing attenuation as frequency increases. The cutoff frequency is estimated to be approximately 25.5 kHz. The simulated and experimental results show similar behaviour, with a small variation in the measured cutoff frequency.

4.2 High-Pass Filter

The theoretical cutoff frequency for the high-pass filter was calculated as 1061.03 Hz (to 2 d.p) using the formula:

$$f_c = \frac{1}{2\pi RC}$$

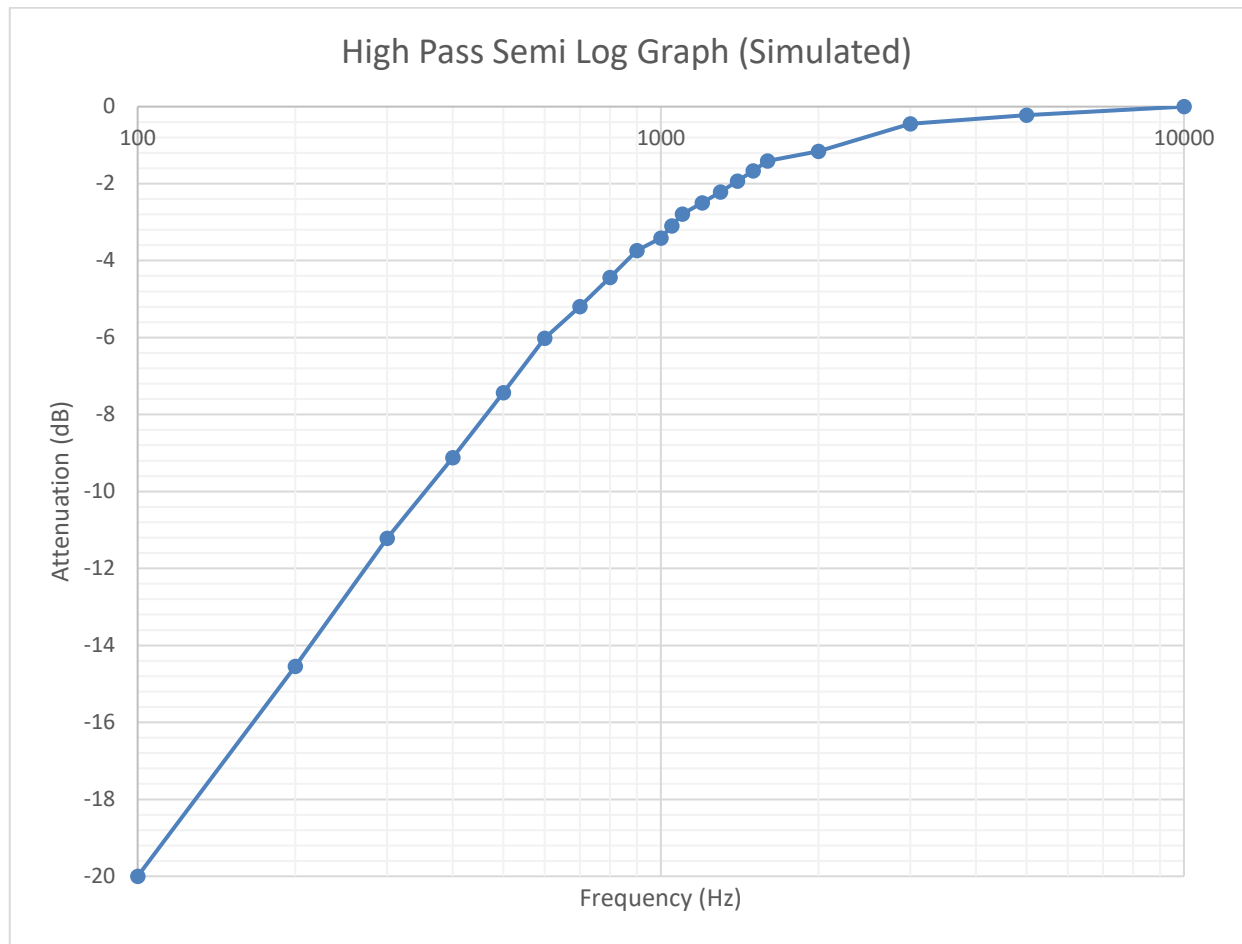


Figure 8: Simulated high-pass filter attenuation vs frequency

Figure 8 shows high attenuation at low frequencies. As the frequency increases, the attenuation becomes less negative. The cutoff frequency, identified at the approximate -3 dB point, is ≈ 1075 Hz. Closely spaced measurements around this region improve the accuracy of the cutoff frequency estimation.

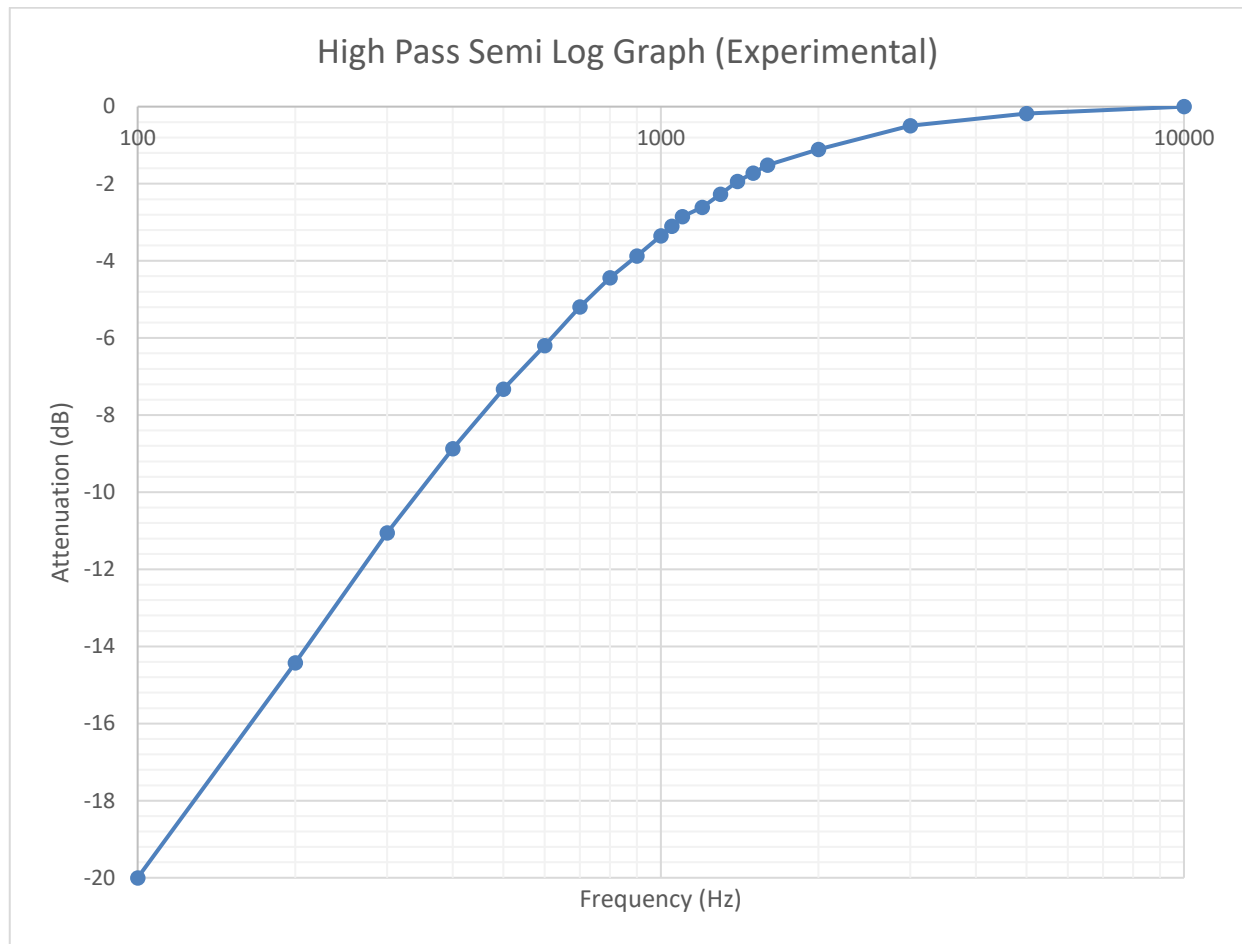


Figure 9: Experimental high-pass filter attenuation vs frequency

Figure 9 follows the trend of Figure 8, with high attenuation at low frequencies. Attenuation then becomes less as the frequency increases. The cutoff frequency is again estimated to be 1075 Hz. The simulated and experimental results show very close agreement, with both producing nearly identical cutoff frequencies.

5 Analysis Discussion

5.1 Low-Pass Filter Performance

For the low-pass filter, the theoretical cutoff frequency was calculated as 28.42 kHz. The simulated cutoff frequency of ≈ 28.5 kHz showed excellent agreement, indicating the simulation closely replicated an ideal low-pass filter circuit. The experimentally determined cutoff frequency was approximately 25.5 kHz, around 10% lower than the theoretical value. This variation likely comes from component tolerances, especially in the capacitor in this case, and parasitic capacitance throughout the circuit. Although it doesn't match the theoretical value as well as the simulated circuit did, the attenuation vs frequency trend on the graph closely follows the expected trend.

5.2 High-Pass Filter Performance

The theoretical cutoff frequency for the high-pass filter was worked out as 1061.03 Hz. In this case, both the simulated and experimental cutoff frequencies were found to be approximately 1075 Hz. This nearly mirrors the theoretical estimation, indicating the simulation closely reflected the expected behaviour and the experimental error was minimal to none. The attenuation trends are also as expected with high attenuation at low frequencies and decreasing attenuation as frequency increased. The improved agreement compared to the low-pass filter likely comes from the influence of component tolerance.

5.3 Overall Comparison and Analysis

In both the low-pass and high-pass filters, the estimated cutoff frequencies closely matched the theoretical numbers, with attenuation at the cutoff being around -3 db. The trends of each attenuation-frequency graph also highlighted the gradual transition around the cutoff point, opposed to harsh and abrupt changes. The use of closely spaced measurements around the cutoff region improved the accuracy of identifying this point in both simulated and experimental data.

Overall, the simulation results showed excellent agreement with theoretical predictions for both filters, while the experimental results showed slightly greater deviation, particularly in the low-pass filter. This difference highlights the influence of real-world factors that aren't accounted for in theory such as component tolerances, stray capacitance and measurement uncertainties.

6 Conclusion

In this experiment, the cutoff frequencies of low-pass and high-pass RC filters were successfully determined using theoretical calculations, simulation, and practical measurements. The theoretical values, calculated by common electrical theory, provided a reliable baseline for comparison.

The simulated results showed strong agreement with theoretical cutoffs for both filters, confirming the accuracy of the simulation models. The experimental results also demonstrated good agreement, although the low-pass filter presented a small deviation from the theoretical value, likely due to non-ideal circuit behaviour.

The use of attenuation measurements enabled the cutoff frequency to be identified at the -3 dB point, demonstrating the relationship between frequency and signal reduction in low-pass and high-pass filters. Overall, the results confirm the expected behaviour of both filter types and highlight the impact of real-world factors on practical circuit performance.

7 References

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[5] P. Horowitz and W. Hill, *The Art of Electronics*, 3rd ed. Cambridge, UK: Cambridge University Press, 2015. Available: [The Art of Electronics \(3rd edition\)](#)