

University of Wales Trinity Saint David

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Mathematical, Simulatory and Experimental

Testing of Low/High-pass circuits

Electrical Principles (ACMA4031)

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Abstract

This paper outlines the completion of an experiment to determine the cutoff frequencies of a high-pass filter and a low-pass filter mathematically, via simulation and experimentally before comparing the results. It was determined that while mathematical modelling and simulation modelling produce near identical results there are not a perfect representation of the results achieved experimentally due to unaccounted factors and assumptions made in the mathematics.

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Introduction

Electrical filters work based on frequency dependant impedance from inductors or capacitors in order to lower the energy of unwanted frequencies whilst maintaining the energy of wanted frequencies [1]. Capacitive impedance is inversely proportional to frequency as shown:

$$Z_c = \frac{1}{2\pi fC}$$

This means any circuit connected in series to it shall experience a high potential difference at high frequencies and any circuit connected in parallel shall experience a low potential difference at high frequencies and vice versa [2]. Inductive impedance is proportional to frequency as shown:

$$Z_L = 2\pi fL$$

This means any circuit connected in series to it shall experience a low potential difference at high frequencies and any circuit connected in parallel shall experience a high potential difference at high frequencies and vice versa [2]. These properties can be used to make passive filters (Filters that do not require external power other than the source [3]) for circuits. The components can be combined with each other as well as resistors to create high-pass, low pass or banded pass filters. Filters have a wide range of uses in industry such as telecommunication where filters are used to separate frequencies. They have uses in music and sound where they are used to attenuate unwanted frequencies, as well as in scientific measurement where filters are used for clearing noise from a measurement [1].

A capacitor can be paired with a resistor in a resistive capacitive (RC) circuit in order to create low-pass and high-pass filters when arranged in a potential divider configuration [4] as seen in figure 1 and figure 2 respectively. The total impedance for an RC circuit can be calculated by

$$Z_T = \sqrt{Z_c^2 + R^2}$$

In a potential divider application this gives the equation for output voltage as

$$V_{out} = V_{in} \times \frac{Z_c}{Z_T}$$

For low pass filters and

$$V_{out} = V_{in} \times \frac{R}{Z_T}$$

For high pass filters [1]

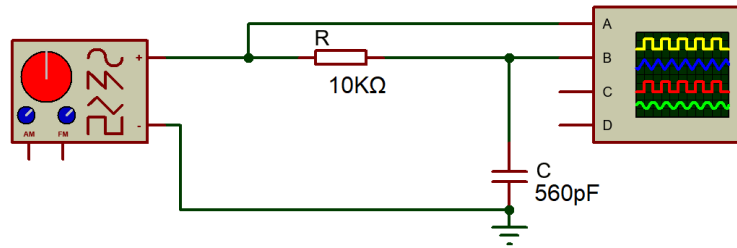


Fig 1: Low-pass filter circuit

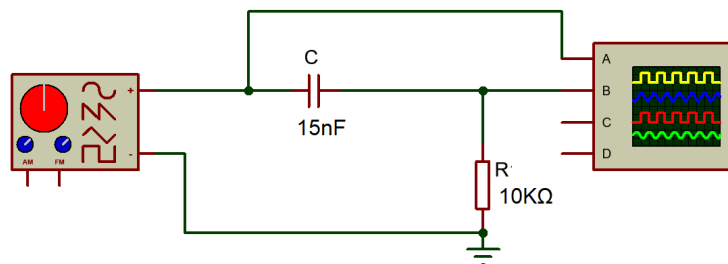


Fig 2: High-pass filter circuit

The cutoff frequency of a filter is considered the frequency where the power drops by half, known as the half power point. This is equivalent to $\frac{1}{\sqrt{2}}$ (≈ 0.707) of the maximum voltage. This also equates to an attenuation of -3dB which can be calculated via [5]:

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

Using this and the above equations the equation for cutoff frequency can be calculated as

$$f_{cutoff} = \frac{1}{2\pi CR}$$

Note the same equation is used for both circuits with different cutoff directions.

This report aims to perform a series of experiments on the circuits figure 1 and figure 2 in order to determine their cutoff frequencies mathematically, experimentally and in simulation. The results of this will then be compared to one another and any differences will be discussed.

Circuit Descriptions

The two circuits being tested are the low pass filter and the high pass filter, figure 1 and figure 2 respectively (repeated below for convenience). The low pass circuit contains a 560pF capacitor in series with a 10K Ω resistor and the oscilloscope or load connected in parallel to the capacitor. The high pass circuit contains a 15nF capacitor in series with a 10K Ω resistor and the oscilloscope or load connected in parallel to the resistor. Both circuits are powered by a function generator

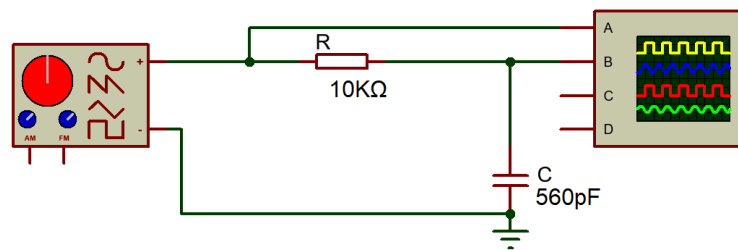


Fig 1: Low-pass filter circuit

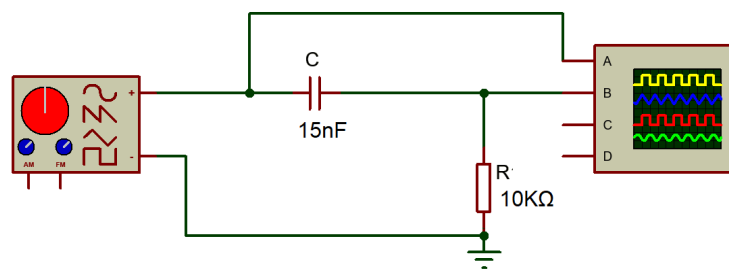


Fig 2: High-pass filter circuit

Each circuit is being tested on Proteus 8 in simulation as well as experimentally. Figure 3 and figure 4 show the physical circuits.

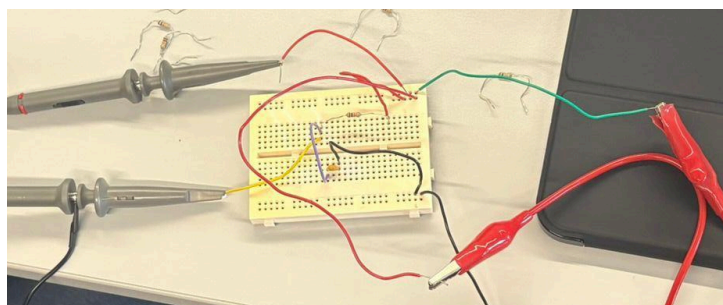


Fig 3: Low-pass filter

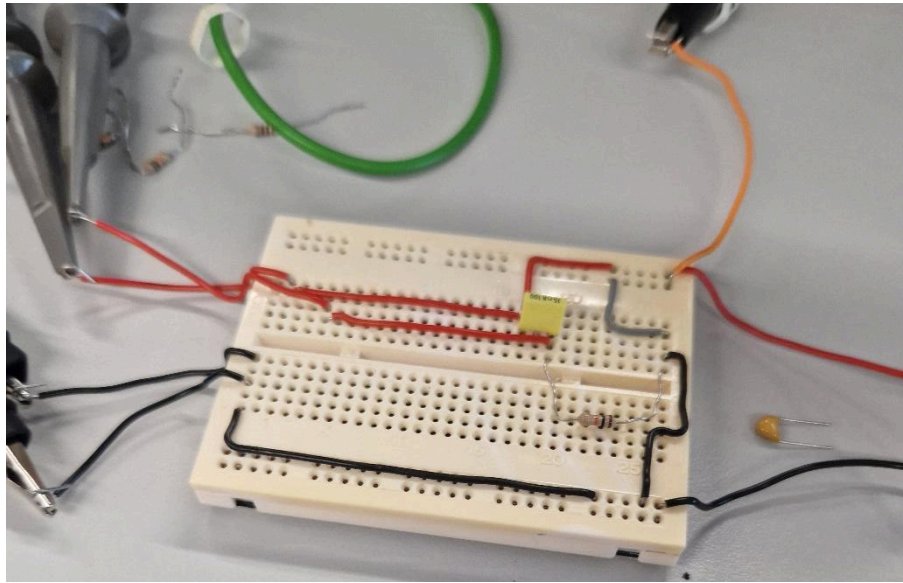


Fig 4: High-pass filter

The low pass filter is being powered by a 4 volt peak-to-peak sinusoidal wave with the frequency being changed. On each change the input and output voltage are measured on the oscilloscope via pins A and B respectively in figure 1. The frequencies that are being used are: 100, 500, 1000, 5000, 10000, 20000, 25000, 26000, 27000, 28000, 29000, 30000, 50000, 100000, 200000 and 300000 Hz.

The high pass filter is being powered by a 4 volt peak-to-peak sinusoidal wave with the frequency being changed. On each change the input and output voltage are measured on the oscilloscope via pins A and B respectively in figure 2. The frequencies that are being used are: 100, 200, 300, 400, 500, 600, 700, 800, 900, 950, 1000, 1050, 1100, 1150, 1200, 1500, 2000, 3000, 5000, 10000, 50000, 100000, 200000 and 300000 Hz.

Results

Low Pass Filter

Mathematical

The equation for cutoff frequency, as stated previously, is:

$$f_{cutoff} = \frac{1}{2\pi CR}$$

To get the idea mathematical cutoff frequency the numbers from the low pass filter is applied.

$$\frac{1}{2\pi \times 560 \times 10^{-12} \times 10 \times 10^{-3}} = 28,421 \text{ Hz}$$

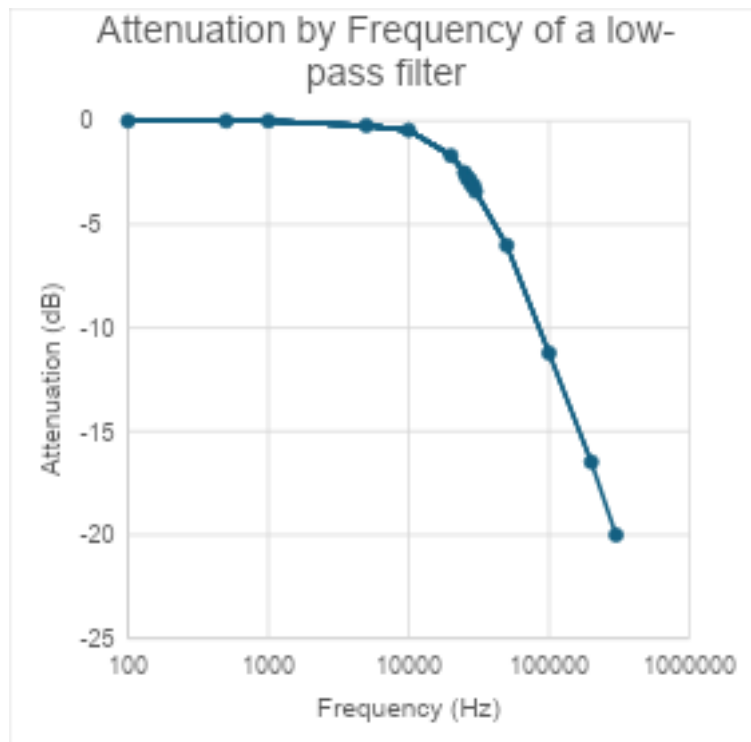
Simulated

The simulation of the experiment in proteus 8 produced the results displayed in Table 1.

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
10000			
0	4	1.1	-11.21334612
20000			
0	4	0.6	-16.47817482
30000			
0	4	0.4	-20

Table 1 – Low-pass Proteus

From Table 1, Graph 1 was produced.



Graph 1 – Low-pass Proteus

From graph 1 a result can be read off at Attenuation = -3dB in order to get a cutoff frequency off 27500 Hz.

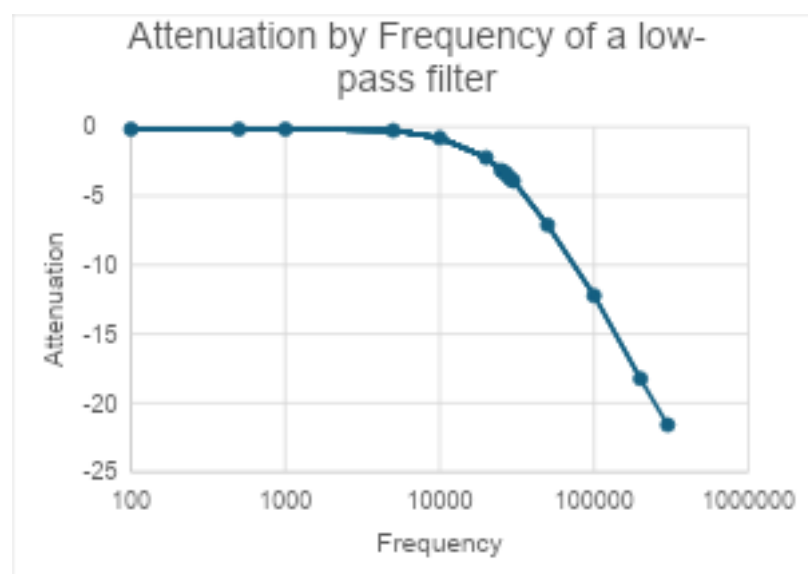
Experimental

The performance of the experiment produced the results displayed in Table 2.

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	0	1	-12.21320326
200000	0	0.5	-18.23380318
300000	0	0.34	-21.58362492

Table 2 – Low-pass Experimental

From Table 2, Graph 2 was produced.



Graph 2 – Low-pass Experimental

From graph 2 a result can be read off at Attenuation = -3dB in order to get a cutoff frequency of 22500 Hz.

High Pass Filter

Mathematical

The equation for cutoff frequency, as stated previously, is:

$$f_{cutoff} = \frac{1}{2\pi CR}$$

To get the ideal mathematical cutoff frequency the numbers from the high pass filter are applied.

$$\frac{1}{2\pi \times 15 \times 10^{-9} \times 10 \times 10^3} = 1061 \text{ Hz}$$

Simulated

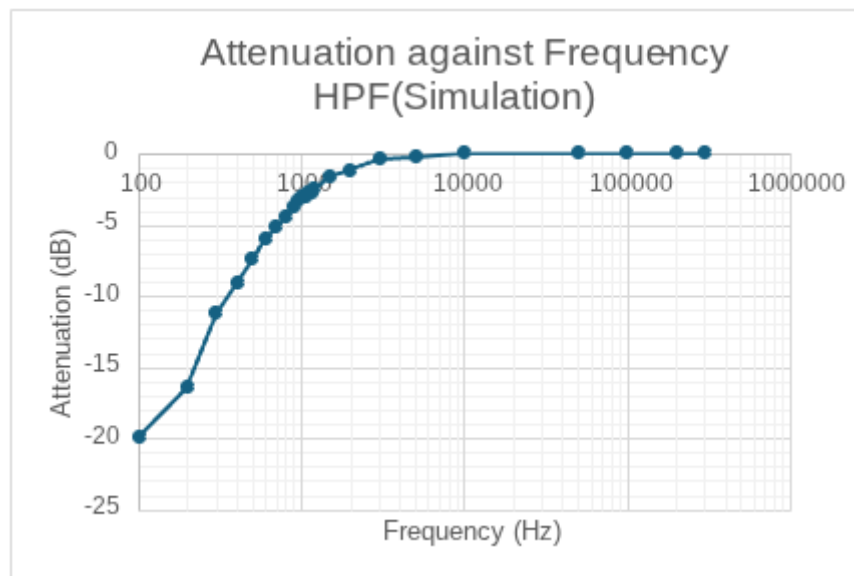
The simulation of the experiment in proteus 8 produced the results displayed in Table 3.

F (Hz)	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

Table 3 – High-pass Proteus

From Table 3, Graph 3 was produced.



Graph 3 – High-pass Proteus

From graph 3 a result can be read off at Attenuation = -3dB in order to get a cutoff frequency of 1075 Hz.

Experimental

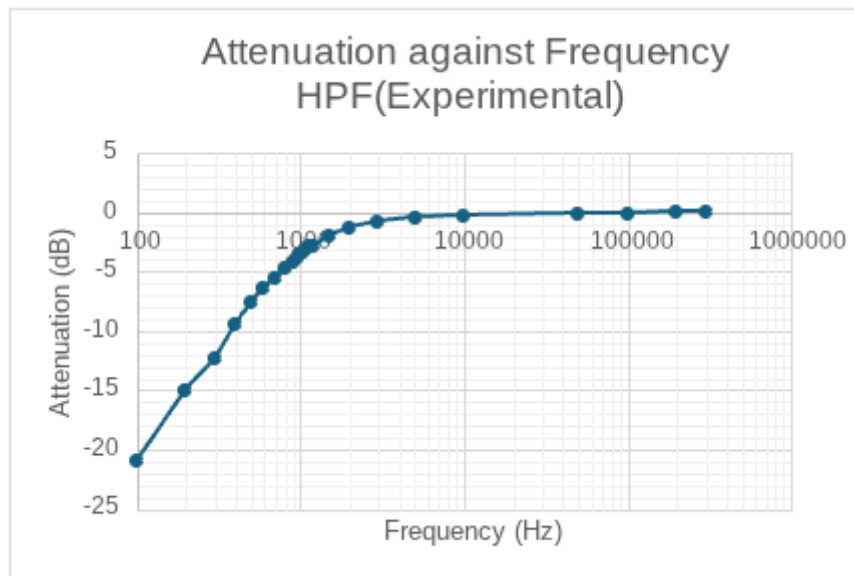
The performance of the experiment produced the results displayed in Table 4.

F (Hz)	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

Table 4 – High-pass Experimental

From Table 4, Graph 4 was produced.



Graph 2 – Low-pass Experimental

From graph 4 a result can be read off at Attenuation = -3dB in order to get a cutoff frequency of 1175 Hz.

The experimental output voltage goes above the input voltage by 0.08 V_{PP}.

Discussion

In both the high-pass and the low-pass filters the mathematical and simulation results differ greatly from the experimental results while there is a small difference in the mathematical and simulation results. The small difference between these two results is likely due to the reading of the simulation results being done via a graph. The reading from the graph causes a small error as it relies on human skill which is inherently inaccurate. The difference larger between mathematical and experimental results is likely due to a number of factors that can't be controlled in the experiment. External signals of the same frequency as tested from nearby sources as well as radio stations and background noise can cause the oscilloscope to read a higher voltage than the simulated results. In the experiment the wires had a resistance unlike the perfect wires assumed mathematically. This could cause higher or lower readings on both circuits depending on where the extra resistance was applied on

the circuit. The mathematical models also assume that component properties are exact values which is not the case in the real world due to manufacturing inaccuracies causing components to have a small range of values instead of one accurate one. Finally in the high pass filter experimental results show a higher maximum output voltage than maximum input voltage. This further proves that some external signals were being transmitted into the wire. Therefore, the mathematical and simulatory models can be considered representative of the trends of these circuits but cannot be considered exact models due to outside factors that have not been accounted for as well as assumptions that mathematical models make.

Conclusion

In conclusion the mathematical and simulatory approaches provide a general model and understanding to real life circuits but cannot be considered exact due to the inaccuracies of real life circuits as well as inherent assumptions of mathematical models.

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