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Passive RC Filter Networks

Electrical & Electronic Principles

ACDB4002

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1 Abstract

This essay explores the accuracy of theoretical estimates in relation to simple RC filters, in comparison to their respective physical counterparts.

The filters, constructed on breadboards, are accurately powered by a variable signal generator, and the outputs measured by a multi-channel oscilloscope. Simulation software is used to create a virtual replica for comparison.

A wide sweep of data points was collected, and attenuation was inferred for each of these, allowing semi-log graphs of attenuation over frequency to be generated.

Slight discrepancies were found, mainly for the low pass filter. This is largely attributed to unavoidable factors, namely stray capacitance from using breadboards, and lower tolerances for common components.

The findings confirm that the theory behind it is solid although minor imperfections in the real-world lead to slight differences in results.

2 Introduction

Filters are essential components in modern electronics (Burrel, 2024). Seemingly simple filters can selectively block or allow specific frequencies. They are used in a variety of applications, from audio equipment and equalizing to communication systems such as radios and even smoothing out noise in signals going into sensitive electronics. Without filters, isolating radio stations, mastering audio, or powering devices could be nigh impossible.

Two types of filters will be focused on, low pass and high pass filters.

Low pass filters allow low frequencies to pass unperturbed, whilst blocking higher frequencies.

High pass filters do the opposite, allowing high frequencies through, whilst blocking low frequencies.

Simple low and high pass filters can be built using resistor-capacitor (RC) circuits. Although simple, these filters are the foundation for more complex active filters.

The cut-off frequency of a filter is extremely important. It is defined as the point where a filter begins to significantly attenuate the signal. It is defined as the point where the power is reduced to half of its original value, or -3dB. In terms of voltage, it corresponds to a drop of 29.3% from the original voltage.

To work out the cut-off frequency for a simple RC filter, this formula may be used:

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

Where:

f_c is the cutoff frequency in Hertz (Hz)

R is the resistance in Ohms (Ω)

C is the capacitance in farads (F)

This project aims to compare the attenuation behaviour of a physical RC filter to a virtual simulation of one, created in Proteus. The aim is to examine the accuracy the theoretical formulas hold against real world examples.

3 Circuit Descriptions

3.1 Low-Pass Filter

Resistor: 10kΩ

Capacitor: 560pF

Input Voltage: 5V Peak to Peak

A low pass filter is constructed by placing a resistor and capacitor in series, with the output voltage measured across the capacitor.

At low frequencies, the capacitor's reactive impedance is high, resisting the flow of current. The voltage remains the same, as little to no current is flowing through the circuit and into the ground.

As the frequency increases, the reactive impedance of the capacitor decreases, allowing more current to bypass the load and flow straight into the ground, dropping the voltage across the capacitor. At a high enough frequency, all current flows will exhibit this behaviour.

This results in a filter that allows low frequencies through and gradually attenuates higher frequencies.

Theoretical Cutoff Frequency:

$$f_c = \frac{1}{2\pi(10000)(560 \times 10^{-12})} \approx 28.4kHz$$

3.2 High-Pass Filter

Resistor: 10kΩ

Capacitor: 15nF

Input Voltage: 5V Peak to Peak

The high pas filter has a reversed low pass filter layout. The capacitor is placed first, with a resistor after it, the output voltage is taken across the resistor.

At low frequencies, the capacitor's high reactive impedance prevents current flow through the entire circuit. Voltages measured at low enough frequencies will be zero, as no current flows through the circuit. As frequency increases, the capacitor's reactive impedance decreases, and gradually current flow increases, resulting in an increase in output voltage. At a high enough frequency, the current will be entirely unimpeded, and the output voltage will match or be very close to the input voltage.

Theoretical Cutoff Frequency:

$$f_c = \frac{1}{2\pi(10000)(15 \times 10^{-9})} \approx 1.06 \text{ kHz}$$

3.3 Methodology

3.3.1 Physical Setup

The practical requires:

- A signal generator
- Resistors
- Capacitors
- A Breadboard
- An Oscilloscope



Figure 1, Signal Generator

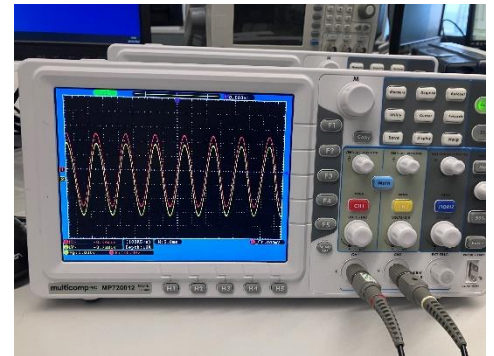


Figure 2, Oscilloscope

For both the low and high pass filters the signal generator was set to a static voltage of 5 Volts, peak to peak. The test range is 100Hz to 300,000Hz, and frequencies are incremented until either the frequency reaches 300,000Hz, or the output voltage matches the input voltage.

To collect reliable data, estimates for where the cut off frequencies are expected are calculated, and smaller increments are used near that range.

The filters are assembled on a breadboard, with care taken to ensure the correct capacitors and resistors are selected, and that everything is wired properly.

Input and Output voltages are taken to the oscilloscope to ensure accurate results. The input voltage is double checked on the oscillator to ensure it reads 5 Volts peak to peak.

Photographs of the setups and of the experiment process were taken and are present in this chapter.

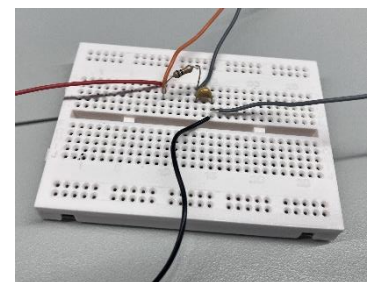


Figure 3, Physical Low Pass Filter

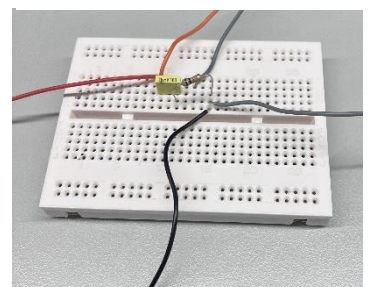


Figure 4, Physical High Pass Filter

3.3.2 Virtual Setup

The virtual simulation is present in Proteus. With a low and high pass filter file, the process is not dissimilar to the practical's bar physical equipment. Screenshots are included in this chapter also.

3.3.3 Data Processing

All results were recorded into a spreadsheet file, split into separate sheets for each of the four experiments. Frequency and Voltage were recorded, and attenuation was calculated at each data point using the following formula:

$$a = 20 \log \left(\frac{V_{out}}{V_{in}} \right)$$

Where:

V_{out} is the Voltage output in Volts (V)

V_{in} is the voltage input in Volts (V)

a is the resulting attenuation in decibels (dB)

The attenuation values are plotted against frequency on a semi-logarithmic graph, allowing for easy visualization of the attenuation.

Linear interpolation is used to estimate the cut off frequency with a higher degree of accuracy, this is expanded upon in the discussion.

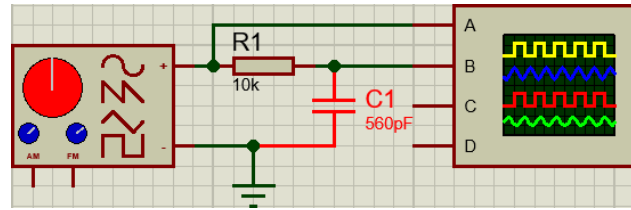


Figure 5, Virtual Low Pass Filter

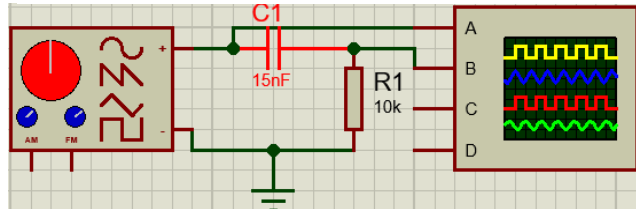


Figure 6, Virtual High Pass Filter

4 Results

4.1 Low Pass Filter

The attenuation curve for the low pass filter practical follows the theoretical example similarly. Both exhibit a reduction in voltage of 10% at around 13,000Hz, and both reach an attenuation of -3dB within a few thousand Hertz of each other. As frequency increases, attenuation decreases at an accelerated rate and seems to decrease linearly after the cut off frequency. The accuracy of graphs begins to falter as the frequency increases, however, as the cut off frequency is the focus, it is of less importance.

Figures 7 and 8 (left) show the practical and theoretical attenuation plots, both sets exhibit similar slopes and cutoffs.

To accurately determine the cut off frequency linear interpolation is used between the two data sets closest to -3dB.

Given:

f_1 , the frequency for the reading taken just before -3dB, is 24,000 Hz

f_2 , the frequency for the reading taken just after -3dB, is 25,000 Hz

dB_1 , the attenuation for the reading taken just before -3dB, is -2.9 dB

dB_2 , the attenuation for the reading taken just after -3dB, is -3.05 dB

And using the formula:

$$f_{cutoff} = f_1 + \left(\frac{-3 - dB_1}{dB_2 - dB_1} \right) \times (f_2 - f_1)$$

Substituting:

$$f_{cutoff} = 24000 + \left(\frac{-3 - -2.9}{-3.05 - -2.9} \right) \times (25000 - 24000)$$

$$f_{cutoff} = 24000 + 0.6667 \times 1000$$

$$f_{cutoff} = 24667 \text{ Hz}$$

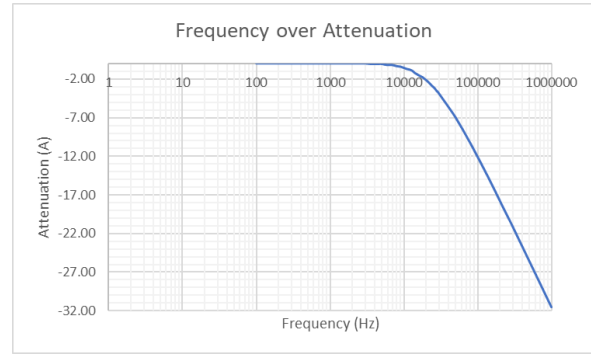


Figure 7, Low Pass Frequency over Attenuation Practical Graph

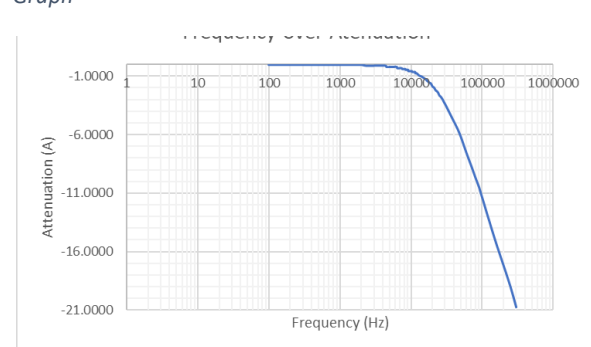


Figure 8, Low Pass Frequency over Attenuation Virtual Graph

This is ~13% lower than the theoretical prediction of 28,420.55 Hz.

In professional settings, an error lower than 10% is desired. Considering the filters were built with common inexpensive components, on breadboards, which are known to add parasitic or stray capacitance to the circuit. A sub 15% error remains within acceptable levels, given the circumstances.

4.2 High Pass Filter

The high pass filter attenuation curve behaves exactly as the theoretical one. Attenuation begins at its highest and decreases linearly, once past the cut off frequency, the rate at which attenuation decreases accelerates until attenuation reaches zero.

Figures 9 and 10 (right) show the practical and theoretical graphs.

Once again, linear interpolation is used to determine the cut-off frequency.

Given:

f_1 is 1050 Hz

f_2 1060 Hz

dB_1 is 2.999 dB

dB_2 is 3.046 dB

Substituting:

$$f_{cutoff} = 1050 + \left(\frac{-3 - -2.999}{-3.046 - -2.999} \right) \times (1060 - 1050)$$

$$f_{cutoff} = 1050 + 0.021 \times 10$$

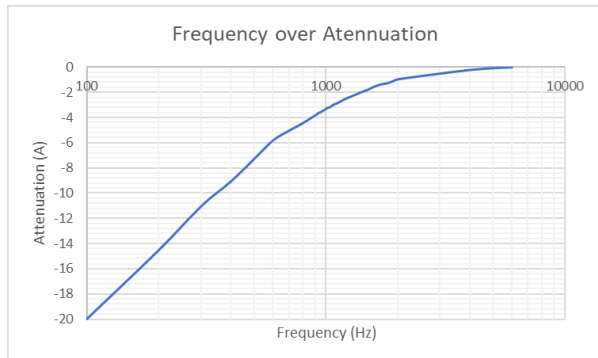


Figure 9, High Pass Frequency over Attenuation Practical Graph

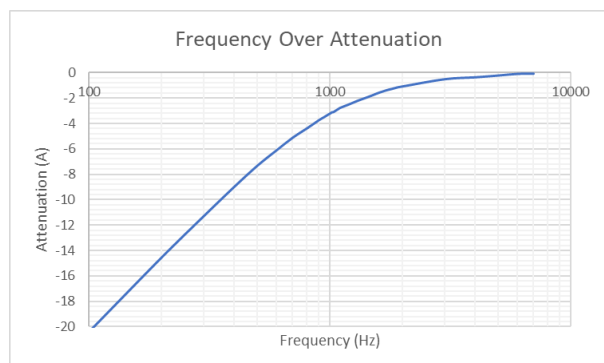


Figure 10, High Pass Frequency over Attenuation Virtual Graph

Figure 3, High Pass Filter Virtual Results

Figure 4, High Pass Filter Practical Results

$$f_{cutoff} = 1050.21 \text{ Hz}$$

The theoretical cut off point is calculated as 1061.03 Hz, the practical result deviates by around 1%.

Perhaps this is due to less stray capacitance at lower frequencies, this is supported by the graphs for the low pass filters showing growing inaccuracies as the frequency increased.

5 Discussion

The results show a strong correlation between the expected behaviour of these circuits, and their behaviour in a practical setting, implying that the theory behind it is solid.

To determine the cut off frequency more accurately, linear interpolation is used for the data points taken before and after the -3dB attenuation point. Using the following formula:

$$f_{cutoff} = f_1 + \left(\frac{-3 - dB_1}{dB_2 - dB_1} \right) \times (f_2 - f_1)$$

Where:

f_1 is the frequency for the reading taken just before -3dB

f_2 is the frequency for the reading taken just after -3dB

dB_1 is the attenuation for the reading taken just before -3dB

dB_2 is the attenuation for the reading taken just after -3dB

5.1 Low Pass Filter

The low pass filter's theoretical cut off point is 28,420.55 Hz. The cut off frequency from the practical results is:

$$f_{cutoff} = 24000 + \left(\frac{-3 - -2.9}{3.05 - 2.9} \right) \times (25000 - 24000)$$

Totalling around 24,667 Hz, although lower than the estimation, it only equals a ~13% error.

Considering the practical low pass filter was built on a breadboard with common components a sub 15% error is completely acceptable.

Utilizing higher quality components with higher tolerances should negate uncontrollable variables like stray capacitance, which can be a significant source of inaccuracy (Glisson, 2011).

5.2 High pass Filter

The high pass filter's theoretical cut off point is 1,061.03Hz. The cut off frequency from the practical result is:

$$f_{cutoff} = -1050 + \left(\frac{-3 - 2.999}{3.046 - 2.999} \right) \times (1060 - 1050)$$

Totalling around 1050.21 Hz. An error of 1.02% which is within the margins.

6 Conclusion

In this experiment, the behaviour of simple low and high pass RC filters was examined by building physical circuits and simulating their virtual counterparts. The theoretical cut-off frequencies, calculated using the standard formula

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

Were compared against real-world measurements from the physical circuits.

Both filters had cut-off frequencies within an acceptable range, compared to the theoretical predictions. The low-pass filter displayed a larger deviation, still within a reasonable error margin, which was expected to happen due to stray capacitance from the breadboard.

Despite these deviations, the reliability of the mathematical models behind the virtual calculations was proven to be accurate, even outside of ideal conditions.

Ultimately, the experiment confirmed the predictability and reliability of simple RC filters.

7 References

- Burrell, S. (2024) *Understanding the basics: What is an RC low pass filter and how does it work?*, Wray Castle. Available at: https://wraycastle.com/blogs/knowledge-base/understanding-the-basics-what-is-an-rc-low-pass-filter-and-how-does-it-work?utm_source=chatgpt.com (Accessed: April 2025).
- Fernandes, J. (2025) *Figures 1-10*.
- Glisson, T.H. (2011) ‘Stray and Parasitic Capacitance; Capacitive Coupling’, in *Introduction to Circuit Analysis and Design*, pp. 255–255. Springer