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High-Pass, Low-Pass Filters
Electrical and Electronic Principles

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1 Abstract

This report looks at the output voltage through high and low pass filters, from an input voltage of 5V, at a variety of frequencies. These frequencies were recorded and compared to equations representing the circuit's behaviour in theory. The study found that the recorded data was very close to the expected results, and thus demonstrated the relationship that the experiment hoped to replicate well. However, unaccounted resistances in the circuit meant that the recorded voltage didn't line up perfectly with the theoretical equations. The maximum difference in these numbers was $\approx 0.2V$.

Despite this, the experiment was very successful in its' outlined goals of looking at these filters and their behaviour. The most important information was that the data closely followed the expected trend and peaked/troughed at the same frequencies.

2 Introduction

Circuits are used in everything from house-hold appliances, major engineering applications, and hand-held electronics. They are distinguished from batteries, and have advantages such as high-power density, and quick charging/discharge rates (D. Pech et al, 2010). The underlying principles of capacitors are the same throughout all electrical applications, big or small.

2.1 Aims

This laboratory investigation aims to look into the properties and effect of the output voltage from high and low pass frequency filters when an alternating current (AC) is applied across them. From this, the study also aims to briefly discuss the applications of these filters. The experiment will look to measure the relationship between the frequency of the AC and the resultant 'output' voltage from across the filter, and calculate its attenuation, in order to look at how and when the voltage is blocked or allowed to pass. The relationship found by this experiment will be analysed in the wider context of mathematical predictions, and other information sources on the topic. Any possible anomalies found in the data, will be cross compared in order to confirm the data collected here, and reveal any possible discrepancies.

2.2 Objectives

In order to achieve this, two circuits will have a, 5V peak (10Vpp), alternating current passed across them. These circuits will be high and low-pass filters respectively. This study will look at a range of frequencies, from 80Hz to 315KHz with 36 increments on a logarithmic scale. The output voltage will be measured at each increment of frequency using an oscilloscope. For each frequency, the capacitive resistance will be calculated (X_c) along with predicted values for output voltage. Finally, three readings of the actual voltage will be measured at each increment and an average calculated to help remove error.

After this, the data gathered here will be compared to other information around the topic and looked at from a wider angle. This is to determine what these readings show and how they might, or might not, meet the overall goal of the project.

3 Circuit Descriptions

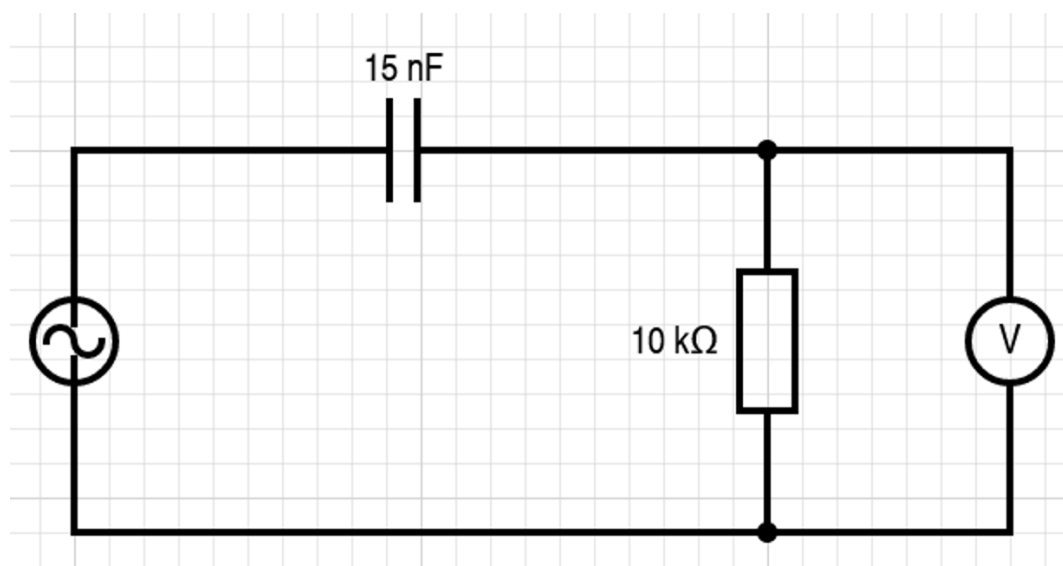
This experiment will be testing two different circuit layouts, one a high-pass filter and the other a low-pass filter. The components in these circuits have been chosen to guarantee clear readings with available instrumentation, along with data values which will best illustrate the relationship which this experiment aims to demonstrate. Both of these filters use the property of 'capacitive resistance' (X_c). This property is a function of when a capacitor is placed in parallel in an AC circuit, and is the effective resistance of the capacitor against alternating current. The capacitive resistance can be described as inversely proportional to the frequency of the current.

$$X_c = 1/2\pi fC$$

Capacitive resistance is based on how capacitors interact with AC. At low frequencies, charge builds up very slowly on the capacitor's plates, linked to the current building up and then dropping off in each direction. When voltages are removed in the discharging stage, when the current begins to change direction, mobile ions stop being built up and voltage begins to stop moving (Zhao, Zhou, Xu, & Zhao, 2023). As current can only flow across the capacitor when the charge has built on the plates sufficiently, at low frequencies the effective resistance of the capacitor, (capacitive resistance) is very high. As the frequency increases however, the reverse happens. As the current is building charge more regularly, the capacitor increasingly allows current to flow within the same time period. This brings the capacitive resistance down and eventually near to zero, allowing almost all the voltage the pass through the capacitor.

3.1 High-Pass

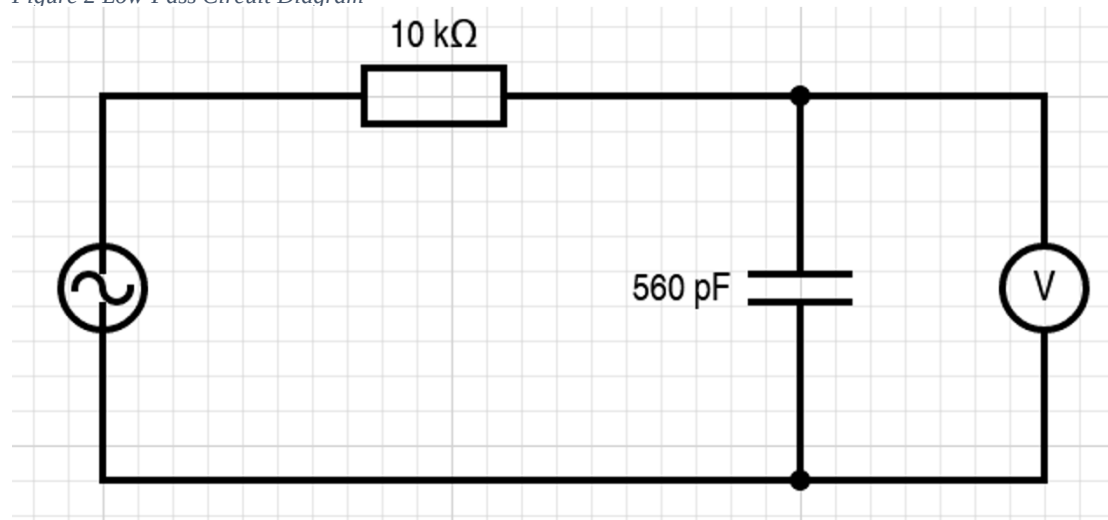
Figure 1 High-Pass Circuit Diagram



As shown in the above figure, (figure 1) in the high-pass filter layout a 15nF capacitor will be placed in series between the input and output voltage. Additionally, a 10K Ω resistor is placed in parallel between V_{in} and V_{out} . In this circuit, all the current must pass through the capacitor in order to complete the circuit, and so the circuit experiences higher resistances at low frequencies. This is due to the way that a capacitor reacts to AC in series as described above.

3.2 Low-Pass

Figure 2 Low-Pass Circuit Diagram



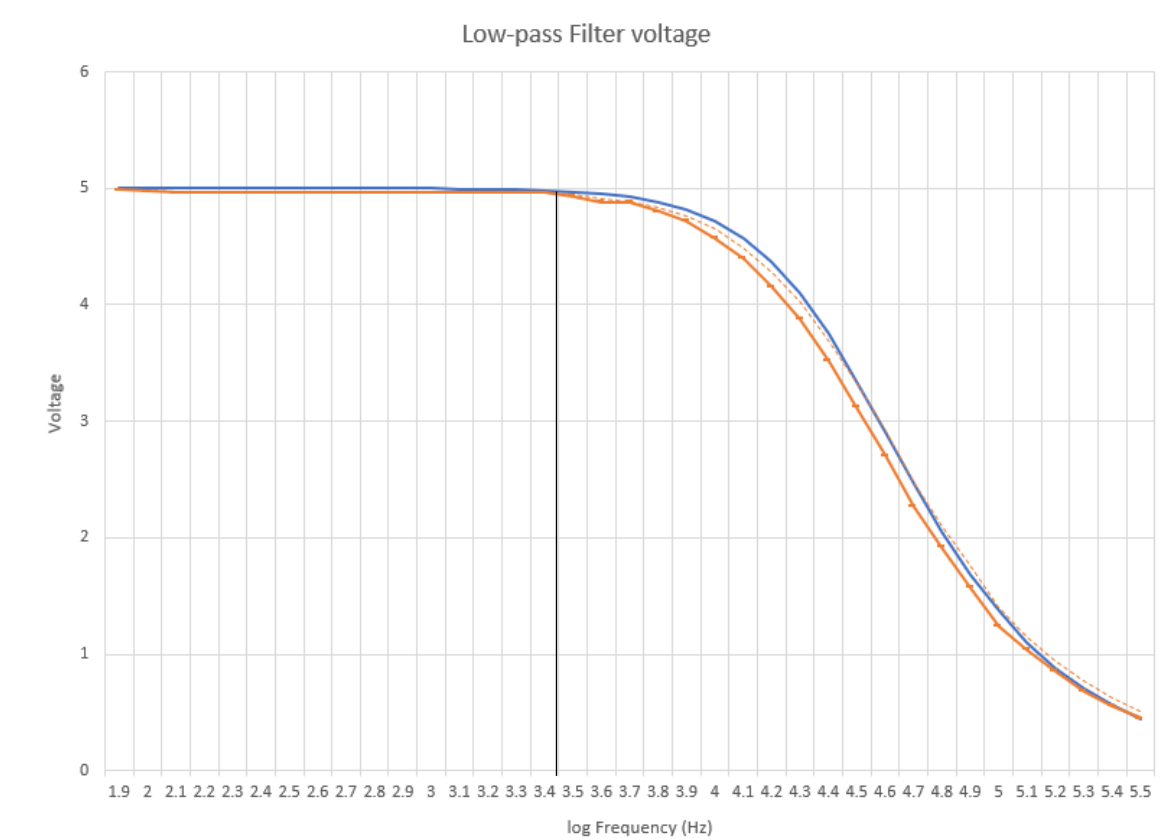
A traditional low pass filter consists of a resistor and capacitor (Khushwant Sehra et al, 2016), similar to the high pass. The low pass filter circuit, as shown above, is very similar to the high-pass but the positions of the components have been swapped around. The capacitor is now in parallel with V_{in} / V_{out} and the resistor is in series. Additionally, the capacitance of the capacitor has changed to 560pF. Otherwise, the circuit is unchanged with AC and 10Vpp. In this configuration, the capacitor blocks the shorter route the current could take at lower frequencies and so the current must travel through V_{out} . When the frequency increases however, and the capacitive resistance is reduced more and more, eventually almost all the current can take the shorter route through the capacitor and so the current eventually stops flowing through V_{out} .

4 Results

Both Low and High pass circuits clearly demonstrated the relationship that the experiment set out to illustrate.

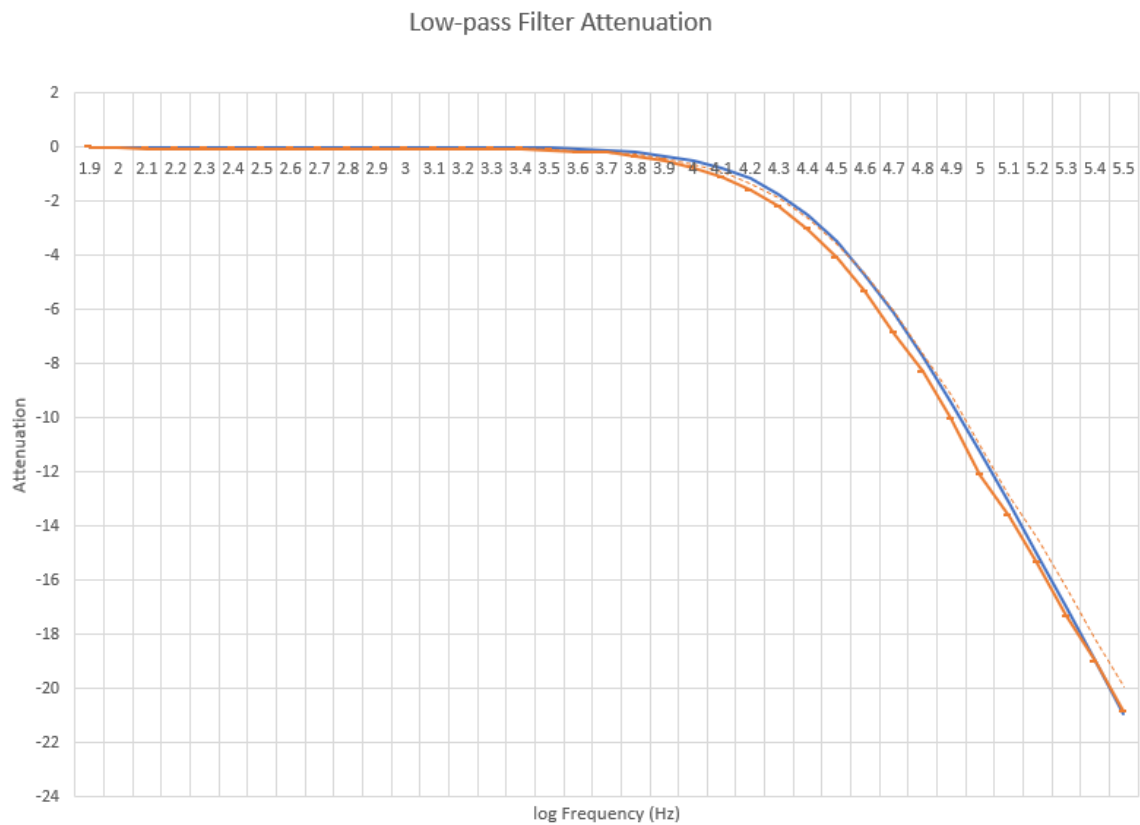
4.1 Low-Pass Results

Figure 3 Low-Pass Voltage Graph



For the low-pass, when the frequency was low at $< \sim 10^{3.4}\text{Hz}$, the output voltage was consistently near the full 5V. However, during the experiment when the difference between each measurement was very slight, the equipment was unable to provide the definition needed to measure the differences in voltage near input voltage or zero. As the frequency increased, as shown in figure 3, the voltage began to drop off rapidly after $10^{3.4}\text{Hz}$. During this decrease in voltage across the output, the current is starting to pass through the capacitor, and we see this as a drop in peak voltage. Shown in blue is the predicted curve that the voltage would follow in a theoretical circuit. The measured values (in orange) follow the predicted profile very closely. However, the voltage dropped slightly below what was expected. This is likely due to resistances in the circuit that couldn't be accounted for in the circuit or possibly manufacturing tolerances in the given values of the components.

Figure 4 Low-Pass Attenuation Graph



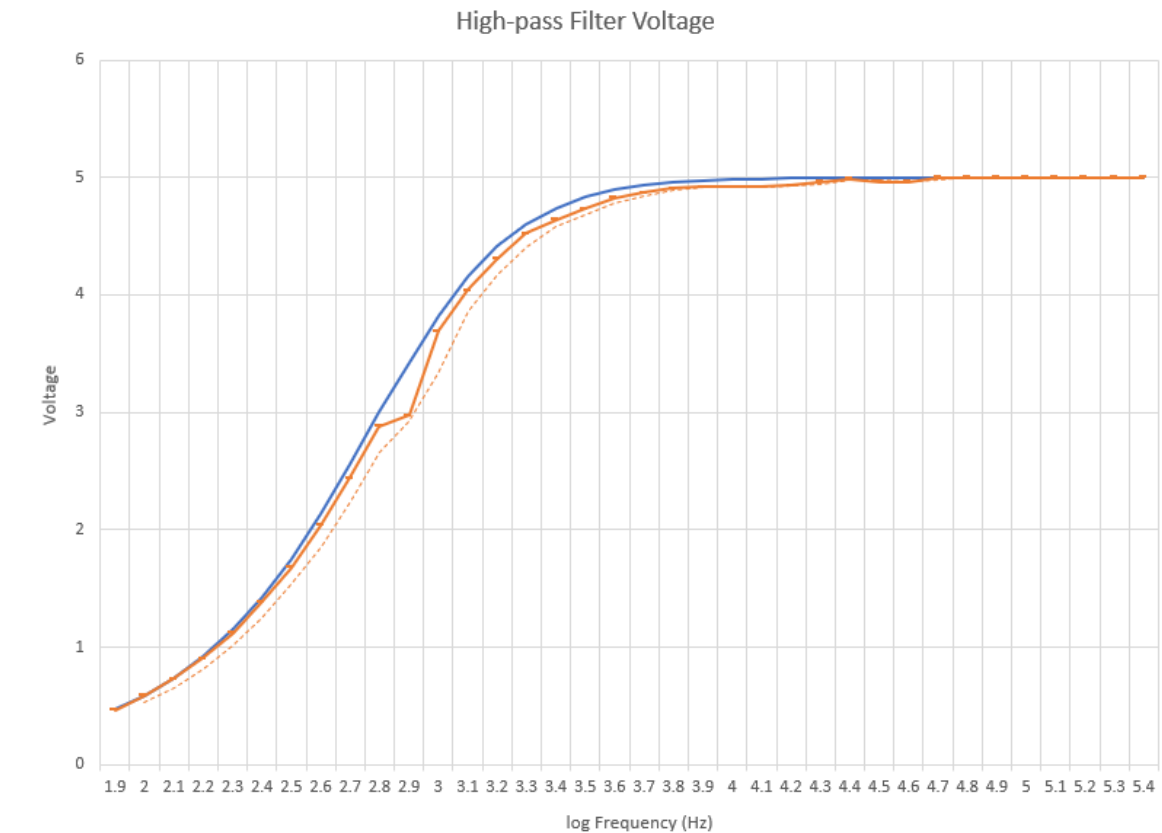
Similarly, as shown in figure 4, the calculated attenuation drops at this same point. Attenuation here is calculated using the formula:

$$A = 20 * \log(V_{out}/V_{in})$$

This metric shows the diminishing strength of the voltage passing across the output. The attenuation shows that the voltage drops exponentially, as the X-axis is logarithmic, and matches the predicted attenuation in blue. This confirms the relationship that this experiment was looking at, and the variation in the middle of the graph is explained by the excess resistance, as in the previous graph.

4.2 High-Pass Results

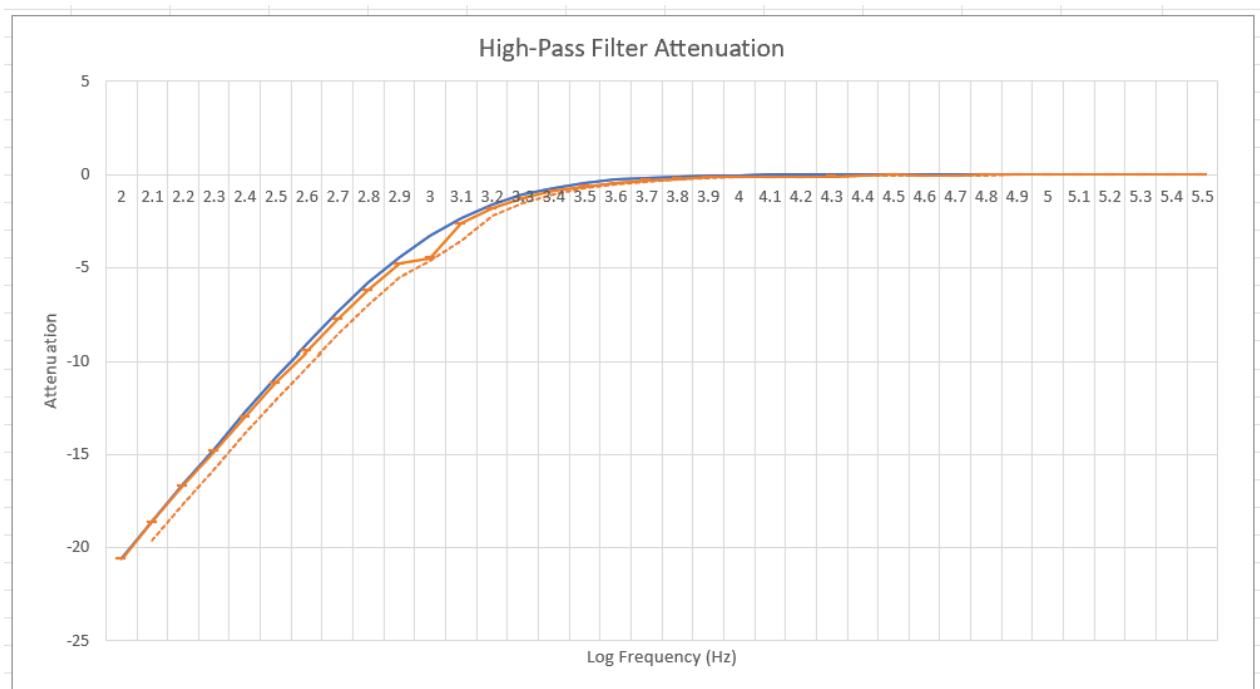
Figure 5 High-Pass Voltage Graph



The high-pass filter shows the reverse relationship between voltage and frequency. Starting at the same frequency as the low-pass, the voltage as above, is far below the input. Yet unlike the low-pass, this circuit never reached zero volts, but started at 0.48V. This is a potential way to improve the method with which the experiment was carried out. In successive experiments, it would be beneficial to measure the output voltage at lower frequencies or to change the component value of the capacitor used in order to provide results that match the observed frequency range.

The measured voltage rises rapidly from the first measurement until $10^{3.2}\text{Hz}$, and has completely flattened out by $10^{3.9}\text{Hz}$, where it reaches near 5V. At this point the measuring equipment wasn't sensitive enough to pick up the small differences in voltage and many of the results were repeated values.

Figure 6 High-Pass Attenuation Graph



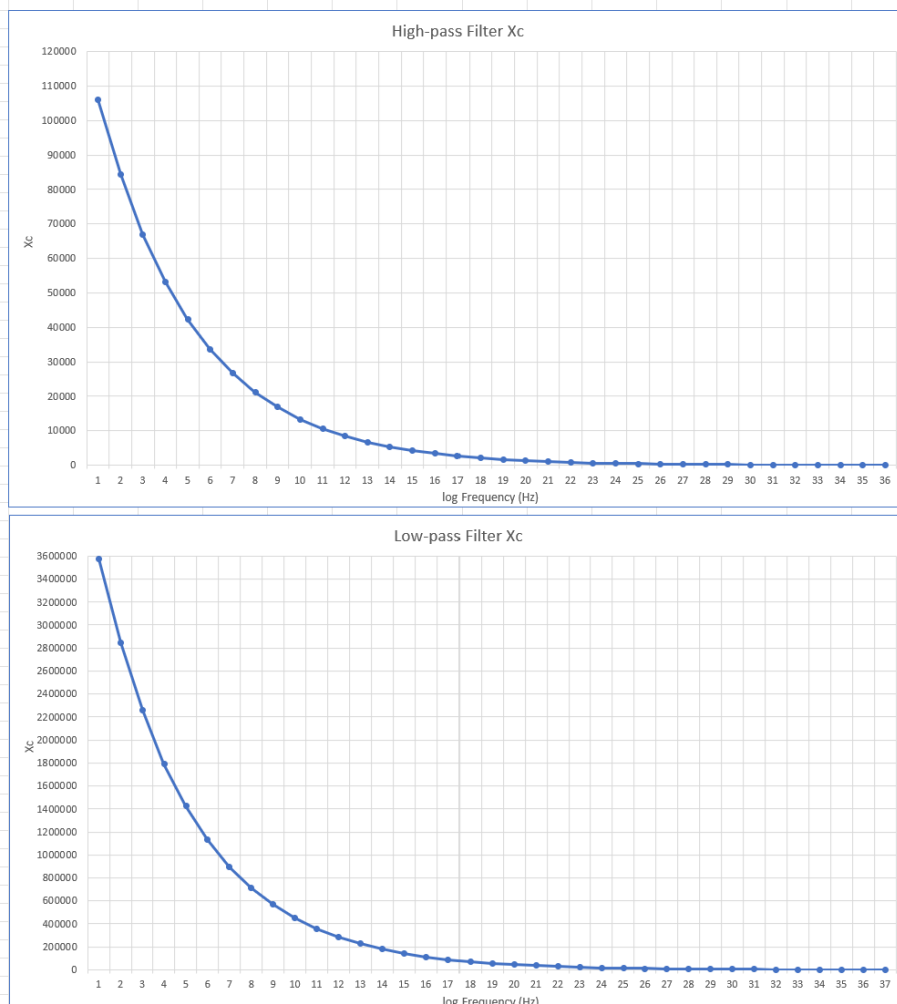
The attenuation of the high-pass circuit mostly matched the predicted values. However, there was one significant outlier in the data set at 10^3 Hz as shown in both graphs. This has been caused by an anomalous reading of 2.28V when the other two of those three were both 3.32V. This could have been caused by a variety of problems and the reading can largely be discounted due to the other two values which line up more readily with other data points. Additionally, similar to the low-pass filter, the measured voltage was consistently slightly lower than expected. This also can most likely be explained by the same phenomenon.

5 Discussion

This experiment has successfully demonstrated the relationship which it set out to explore at the beginning of the experiment. This being a set of results that are matched by both other studies and the calculated predictions. This circuit has been shown to perform filtering actions by attenuating the lower frequencies and passing the high frequencies for high-pass filters, or the reverse for low-pass (Khushwant Sehra et al, 2016).

For the high-pass filter, this relationship was an increase of measured output voltage connected to the frequency of the AC passing through the circuit. This correlation would continue until the voltage became very near to the input 5V. The low-pass filter was seen, as predicted, to start at low frequencies to be at the full 5V. After reaching a specific frequency, the voltage began to drop and eventually reached close to nothing. Yet, this experiment failed to measure low enough frequencies to show the behaviour of the high-pass filter when all the voltage is being blocked. Also, there were some unexpected anomalies and differing results. Mainly some variances in capacitance and resistance values, which meant that the measured voltages dropped off faster than expected by the calculated values. Alternatively, these variations in the measured voltage could be caused by resistances in the measuring equipment not accounted for in the theory of the experiment. When this happens a portion of the electric energy is transformed into heat (A. d'Entremont L. P., 2014).

Figure 7 High-Low Pass Capacitive Resistance Graph



Another important point is the capacitive resistance (X_c) graphs in the above figure. of the two circuits were very similar. Both showed an exponential decay of the capacitive resistance. This is due to the fact that the only thing changing the circuit was the location of the capacitors and the resistors, and the behaviour of the capacitors themselves was unchanged. The difference between the two circuits was how this behaviour was utilised. This being because capacitors prevent continuous current flow as the two plates are separated by a non-conductive material and are passive components (Hickman., 1999). When exploring there use, it is important to know how the individual components are behaving.

More Broadly, these filters are an important and fundamental component of many modern electronics, on a large scale being in household, and grid level electronics which deal with alternating current. These applications may only be functional within specific frequencies, and filtering out others might be beneficial. Alternatively, these might be applied if specific frequencies of an input signal were trying to be isolated.

6 Conclusions

Through the course of this experiment, it has been found that the high and low pass filters studied here follow the expected behaviour that was originally calculated. It was also found that these circuits don't behave in an ideal way, and there were consistent deviations from the predicted behaviours that can be accounted for through variations in the circuit and imperfections inherent to working on real circuits based on simulated or calculated behaviours.

7 References

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