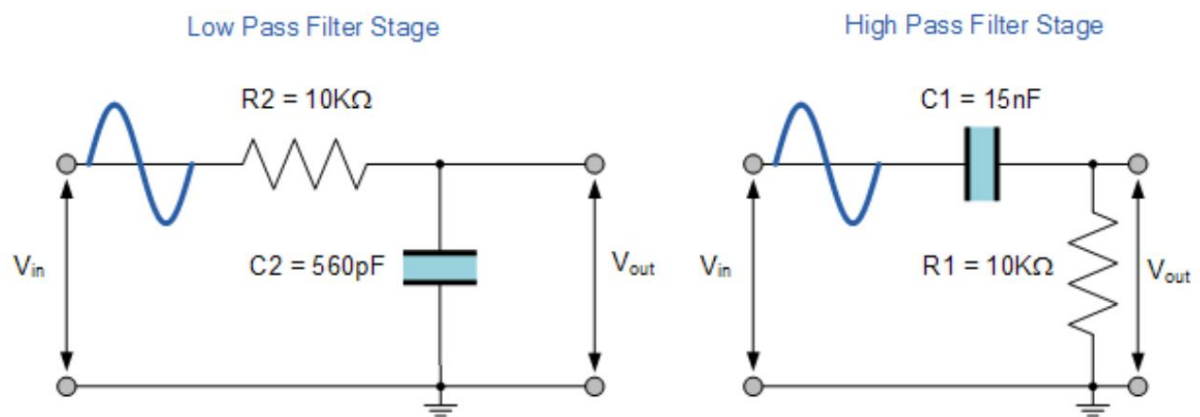


University of Wales Trinity Saint David

School of Engineering



Passive RC Filter Network

Electrical & Electronic Principles ACBD4002

Shea Whitehead

2212438

April 2023

## Contents

|     |                                       |    |
|-----|---------------------------------------|----|
| 1   | Abstract.....                         | 1  |
| 2   | Introduction .....                    | 2  |
| 3   | Circuit descriptions .....            | 3  |
| 3.1 | Lowpass Filter Circuit .....          | 3  |
| 3.2 | High Pass Filter Circuit .....        | 4  |
| 4   | Results.....                          | 4  |
| 4.1 | Calculated Results And Formulae. .... | 4  |
| 4.2 | Measured Results.....                 | 6  |
| 4.3 | Low Pass Filter Results. ....         | 6  |
| 4.4 | High Pass Filter Results .....        | 8  |
| 5   | Discussion.....                       | 11 |
| 6   | Conclusion.....                       | 13 |
| 7   | References .....                      | 13 |

# 1 Abstract

This report describes how the laboratory exercise analyses the effects of both a high and low pass filters on an electrical circuit.

Two separate circuits built using breadboards, resistors and capacitors creating a first order RC low pass and a high pass filter. Using the signal generator, the same input voltage of 5V pk-pk at 100Hz is set for both circuits. Several measurements are taken at a range of frequencies between 100Hz to 300kHz using the oscilloscope.

The measurements taken are consistent within a tolerance of that calculated. By plotting graphs, the function of each filter is clear. Both pass bands and stop bands can be seen. Showing each filters effect at varying frequencies on each circuit.

The report also shows how tolerances of each component can affect results.

## 2 Introduction

The aim of the laboratory exercise is to build and analyse two separate circuits and to compare the results after using two different filter setups. A high pass filter and a low pass filter with the same input voltage of 5V pk-pk sine wave with zero offset and zero phase input signal will be used for both circuits throughout. Several measurements of output voltage ( $V_{out}$ ) will be taken at multiple ranges of frequency between 100Hz and 300 kHz. The results taken are entered into a spread sheet where they are then used to plot scatter graphs to determine the -3dB cut off frequencies. The aim is to see what effect the varying frequencies have on output voltage and attenuation.

Both high and low pass filters can commonly be found in audio equipment such as amplifiers, microphones, headphones and speakers.

“Passive filters are made up of passive components such as resistors, capacitors and inductors and have no amplifying elements (transistors, op-amps, etc) so have no signal gain, therefore their output level is always less than the input.” (Electronic-Tutorials, n.d.)

A low pass filter is designed to allow signals below a cut-off frequency to pass through and modify or reject signals after this cut-off frequency. The unwanted frequency is often referred to as noise. The filter allows this noise to be altered or blocked depending on which frequency is applied. Often used in Bass speakers or sub woofers where low frequency is used.

A high pass filter unlike the low pass filter, allows signals above its specified cut-off frequency to pass and all signals below are attenuated. High pass filters are often found in tweeter speakers where high frequencies are use and a low frequency needs to be reduced.

### 3 Circuit descriptions

#### 3.1 Lowpass Filter Circuit

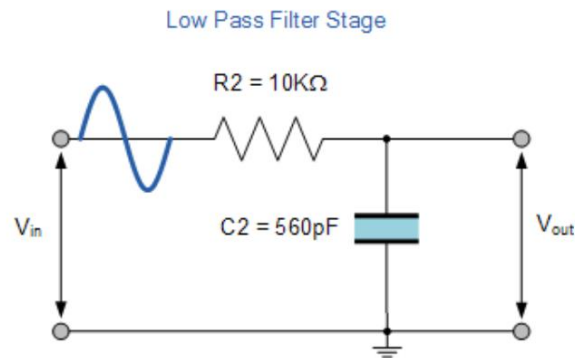


Figure 1- Low Pass Filter Circuit Diagram.

During the exercise the low pass filter has been constructed on a single breadboard, using a  $10K\Omega$  resistor and a  $560pF$  capacitor and laid in series as shown above in figure 1. This is known as a First order filter because the circuit only has a single reactive component within it which is capacitor. Using a function generator set at 5V Pk-PK for the input voltage ( $V_{in}$ ) sine wave, this input remains constant throughout the exercise. Measurements of output voltage ( $V_{out}$ ) are then taken using the oscilloscope between the resistor and the capacitor as shown below in figure 2. The first measurement is taken with a frequency set on the function generator of 100Hz. Several more measurements are taken up to final frequency of 300kHz.

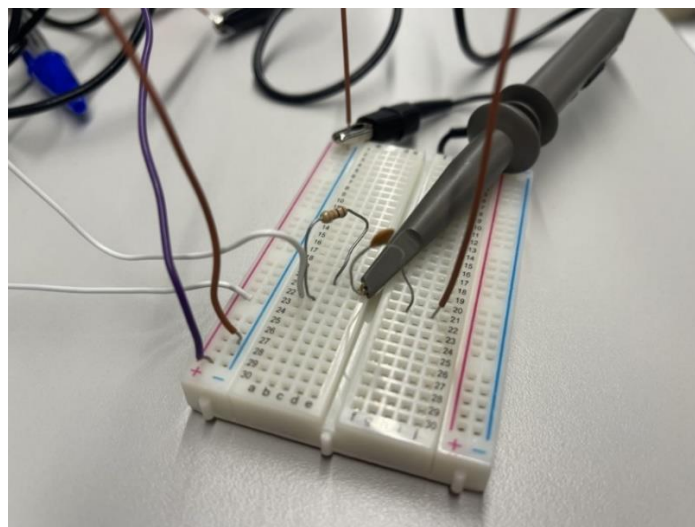


Figure 2-Image of circuit built in laboratory exercise.

## 3.2 High Pass Filter Circuit

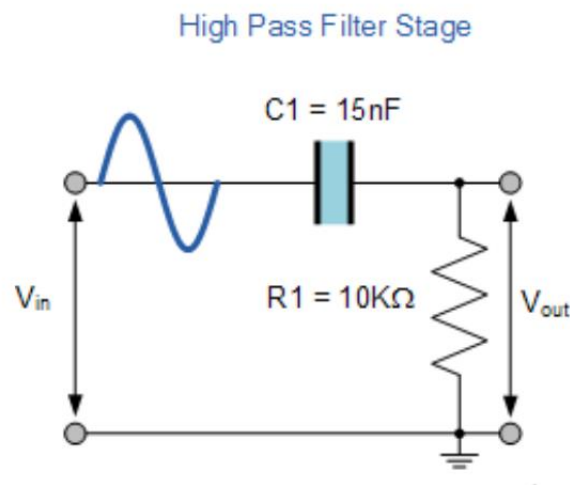


Figure 3- High Pass Filter Circuit diagram.

The second circuit constructed is the high pass filter using a  $10\text{k}\Omega$  resistor and a  $15\text{nF}$  capacitor. However, the layout has changed as can be seen in figure 3. The positioning of the capacitor and resistor have swapped. Now the output signal is being measured from across the resistor. Using the same input voltage as the low pass filter of  $5\text{V}$  Pk-Pk sine. Measurements again taking at the same frequency ranges as previous filter.

## 4 Results

### 4.1 Calculated Results And Formulae.

To calculate Voltage output ( $V_{out}$ ), first it is required to calculate the capacitive reactance in Ohms and the impedance. Capacitive reactance has the electrical symbol " $X_c$ " as shown in figure 4.

$X_c$  = Capacitive reactance in Ohms,  $f$  = Frequency in Hertz (Hz),  $C$  = Capacitance in Farads(F)

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

Equation 1-Capacitive Reactance Formula.

To calculate Impedance in a circuit using a single resistor and capacitor in series the formula below in figure 5 is used.

Z=Impedance, R=Resistance, X<sub>c</sub>= Capacitive reactance.

$$Z = \sqrt{R^2 + X_C^2}$$

*Equation 2- Impedance Formula.*

Now that impedance and capacitive reactance is known, the output Voltage can be calculate using the formula below in Figure 6. X<sub>c</sub>= Capacitive reactance, R= Resistance, Z=Impedance.

$$V_{out} = V_{in} \times \frac{X_C}{\sqrt{R^2 + X_C^2}} = V_{in} \frac{X_C}{Z}$$

*Equation 3-Voltage Output Formula.*

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{R}{Z}$$

at low  $f$ :  $X_C \rightarrow \infty$ ,  $V_{out} = 0$

at high  $f$ :  $X_C \rightarrow 0$ ,  $V_{out} = V_{in}$

*Equation 4-AC Potential Divider Equation*

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

*Equation 5- Frequency Cut Off Equation*

## 4.2 Measured Results.

Voltage output measurements taken from the laboratory using the oscilloscope from range 100Hz to 300kHz have been populated into Table 1 below.

Now that the measured voltage is known. Attenuation(dB) can be calculated using the formula below in equation 5. A=Attenuation(dB)

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

*Equation 5-Attenuation Formula.*

## 4.3 Low Pass Filter Results.

Below in Table 1 the results of both measured and calculated values have been inputted along with all the relevant formulae as mentioned above in Results 4.1 and 4.2.

Table 1-Low Pass Filter Calculated And Measured.

| Resistor        | 10000          |               |                     |                   |                 |                  |
|-----------------|----------------|---------------|---------------------|-------------------|-----------------|------------------|
| Capacitor       | 5.6E-10        |               |                     |                   |                 |                  |
| Vin             | 5              |               |                     |                   |                 |                  |
| LOW PASS FILTER |                |               |                     |                   |                 |                  |
| Frequency(Hz)   | Xc( $\Omega$ ) | Z( $\Omega$ ) | Vout calculated (V) | A (dB) Calculated | A (dB) Measured | Measured Vout(V) |
| 100             | 2842052.555    | 2842070.148   | 5.000               | 0.000             | -0.070          | 4.960            |
| 500             | 568410.511     | 568498.469    | 4.999               | -0.001            | -0.070          | 4.960            |
| 1000            | 284205.256     | 284381.130    | 4.997               | -0.005            | -0.070          | 4.960            |
| 5000            | 56841.051      | 57713.994     | 4.924               | -0.132            | -0.282          | 4.840            |
| 10000           | 28420.526      | 30128.496     | 4.717               | -0.507            | -0.724          | 4.600            |
| 15000           | 18947.017      | 21424.039     | 4.422               | -1.067            | -1.351          | 4.280            |
| 16000           | 17762.828      | 20384.260     | 4.357               | -1.196            | -1.432          | 4.240            |
| 17000           | 16717.956      | 19480.505     | 4.291               | -1.328            | -1.598          | 4.160            |
| 18000           | 15789.181      | 18689.522     | 4.224               | -1.465            | -1.766          | 4.080            |
| 19000           | 14958.171      | 17992.968     | 4.157               | -1.604            | -1.938          | 4.000            |
| 20000           | 14210.263      | 17376.178     | 4.089               | -1.747            | -2.158          | 3.900            |
| 30000           | 9473.509       | 13774.882     | 3.439               | -3.252            | -3.768          | 3.240            |
| 40000           | 7105.131       | 12267.147     | 2.896               | -4.743            | -5.161          | 2.760            |
| 50000           | 5684.105       | 11502.567     | 2.471               | -6.123            | -6.670          | 2.320            |
| 60000           | 4736.754       | 11065.118     | 2.140               | -7.370            | -7.959          | 2.000            |
| 70000           | 4060.075       | 10792.785     | 1.881               | -8.492            | -8.874          | 1.800            |
| 80000           | 3552.566       | 10612.291     | 1.674               | -9.505            | -10.117         | 1.560            |
| 90000           | 3157.836       | 10486.750     | 1.506               | -10.425           | -10.812         | 1.440            |
| 100000          | 2842.053       | 10396.021     | 1.367               | -11.265           | -11.568         | 1.320            |
| 110000          | 2583.684       | 10328.380     | 1.251               | -12.036           | -12.396         | 1.200            |
| 120000          | 2368.377       | 10276.634     | 1.152               | -12.748           | -12.995         | 1.120            |
| 130000          | 2186.194       | 10236.183     | 1.068               | -13.409           | -13.639         | 1.040            |
| 140000          | 2030.038       | 10203.972     | 0.995               | -14.025           | -14.334         | 0.960            |
| 150000          | 1894.702       | 10177.912     | 0.931               | -14.602           | -15.090         | 0.880            |
| 160000          | 1776.283       | 10156.534     | 0.874               | -15.145           | -15.494         | 0.840            |
| 170000          | 1671.796       | 10138.782     | 0.824               | -15.656           | -15.918         | 0.800            |
| 180000          | 1578.918       | 10123.882     | 0.780               | -16.140           | -16.363         | 0.760            |
| 190000          | 1495.817       | 10111.255     | 0.740               | -16.599           | -16.833         | 0.720            |
| 200000          | 1421.026       | 10100.461     | 0.703               | -17.035           | -17.329         | 0.680            |
| 210000          | 1353.358       | 10091.163     | 0.671               | -17.451           | -17.329         | 0.680            |
| 220000          | 1291.842       | 10083.098     | 0.641               | -17.848           | -17.856         | 0.640            |
| 230000          | 1235.675       | 10076.055     | 0.613               | -18.228           | -18.416         | 0.600            |
| 240000          | 1184.189       | 10069.871     | 0.588               | -18.592           | -18.416         | 0.600            |
| 250000          | 1136.821       | 10064.411     | 0.565               | -18.942           | -19.016         | 0.560            |
| 260000          | 1093.097       | 10059.566     | 0.543               | -19.278           | -19.659         | 0.520            |
| 270000          | 1052.612       | 10055.247     | 0.523               | -19.602           | -19.659         | 0.520            |
| 280000          | 1015.019       | 10051.381     | 0.505               | -19.915           | -19.659         | 0.520            |
| 290000          | 980.018        | 10047.907     | 0.488               | -20.217           | -19.659         | 0.520            |
| 300000          | 947.351        | 10044.773     | 0.472               | -20.509           | -20.355         | 0.480            |

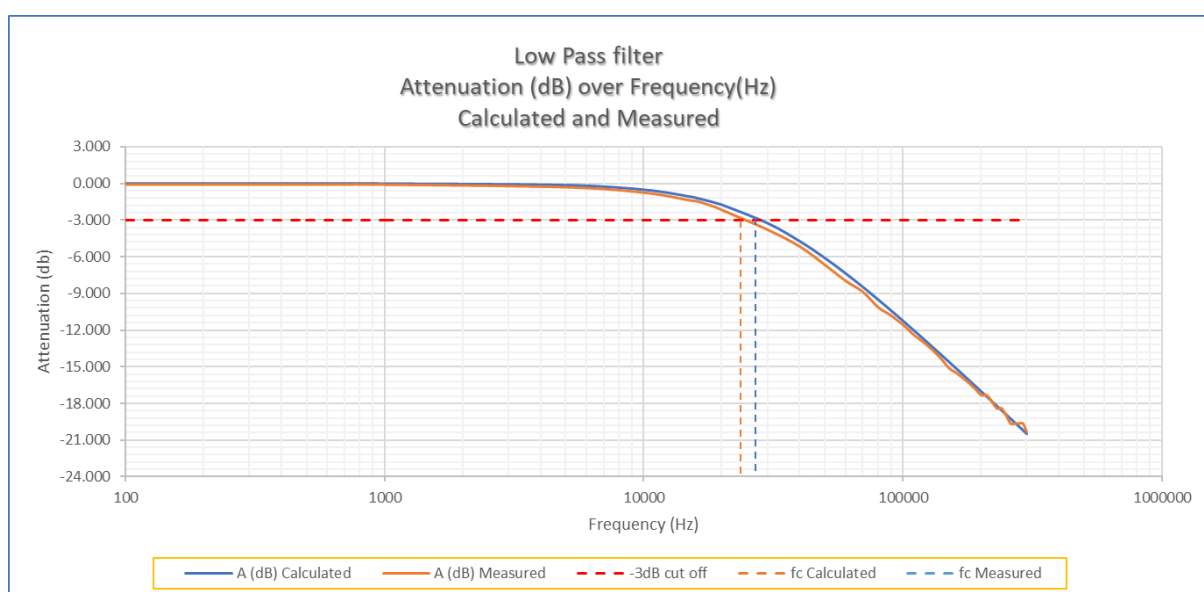


Figure 4-Low Pass Filter Attenuation Graph

Figure 4 shows that the attenuation remains at 0dB and begins to drop at approximately 6kHz. The -3dB cut off frequency can be seen between approximately 24kHz-28kHz for measured and calculated, after this point there is a noticeable drop off for both results through the stop band. The calculated frequency cut-off using equation 5 as follows.

$$f_c = \frac{1}{(2\pi \cdot 10000 \cdot 560 \cdot 10^{-12})} = 28420.56\text{Hz}$$

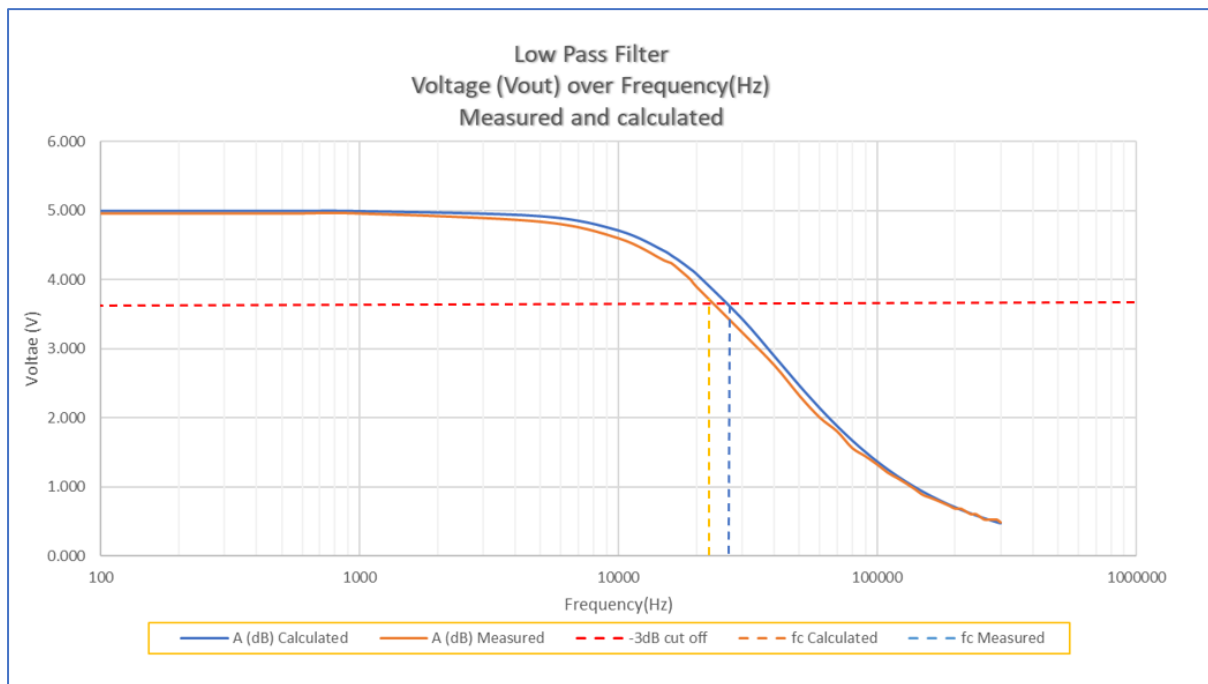


Figure 5-Low Pass Filter Voltage over Frequency Graph

The results in Figure 5 show the effects of frequency increase on voltage output on a low pass filter circuit. The Estimated -3dB cut has been entered into Figure 5 to find output voltage, like the attenuation results, voltage remains constant until the frequency is increased where the voltage is an estimated 3.7V at the cut-off point. The significant decline in voltage can be seen as the frequency increases and moves into the stop band.

#### 4.4 High Pass Filter Results

Below in Table 2 the results of both measured and calculated values have been inputted along with all the relevant formulae as mentioned above in Results 4.1 and 4.2.

Table 2-High Pass Filter Calculated And Measured.

| Resistor      | 10000      |            | HIGH PASS FILTER |              |                 |                  |
|---------------|------------|------------|------------------|--------------|-----------------|------------------|
| Capacitor     | 1.5E-08    |            |                  |              |                 |                  |
| Vin           | 5          |            |                  |              |                 |                  |
| Frequency(Hz) | Xc(Ω)      | Z(Ω)       | Vout (V)         | A (dB)       | A (dB) Measured | Measured Vout(V) |
| 100           | 106103.295 | 106573.492 | 0.469159815      | -20.55298396 | -20.35457534    | 0.48             |
| 250           | 42441.3182 | 43603.5032 | 1.146696857      | -12.79042765 | -12.99503963    | 1.12             |
| 500           | 21220.6591 | 23458.8229 | 2.13139424       | -7.406124331 | -7.618133387    | 2.08             |
| 750           | 14147.1061 | 17324.5667 | 2.886075075      | -4.773247604 | -4.791550332    | 2.88             |
| 1000          | 10610.3295 | 14580.0924 | 3.42933356       | -3.275205496 | -3.452614539    | 3.36             |
| 1250          | 8488.26363 | 13116.8068 | 3.811903379      | -2.356562407 | -2.662443713    | 3.68             |
| 1500          | 7073.55303 | 12248.8837 | 4.082004625      | -1.761930238 | -1.93820026     | 4                |
| 1750          | 6063.04545 | 11694.4654 | 4.275526794      | -1.359607439 | -1.597533474    | 4.16             |
| 2000          | 5305.16477 | 11320.1048 | 4.41692023       | -1.077008969 | -1.26972515     | 4.32             |
| 3000          | 3536.77651 | 10607.016  | 4.713861096      | -0.511864467 | -0.649040476    | 4.64             |
| 4000          | 2652.58238 | 10345.8298 | 4.832865143      | -0.295306552 | -0.354575339    | 4.8              |
| 5000          | 2122.06591 | 10222.6789 | 4.891085843      | -0.191294384 | -0.354575339    | 4.8              |
| 6000          | 1768.38826 | 10155.1562 | 4.923607192      | -0.133732139 | -0.354575339    | 4.8              |
| 7000          | 1515.76136 | 10114.2243 | 4.943532859      | -0.098651583 | -0.069766557    | 4.96             |
| 8000          | 1326.29119 | 10087.569  | 4.956595588      | -0.075730367 | -0.069766557    | 4.96             |
| 9000          | 1178.9255  | 10069.2535 | 4.96561142       | -0.059945463 | -0.069766557    | 4.96             |
| 10000         | 1061.03295 | 10056.132  | 4.972090658      | -0.048619314 | -0.069766557    | 4.96             |
| 15000         | 707.355303 | 10024.9864 | 4.987537958      | -0.021675808 | -0.069766557    | 4.96             |
| 16000         | 663.145596 | 10021.964  | 4.989042076      | -0.019056753 | -0.069766557    | 4.96             |
| 17000         | 624.137032 | 10019.4584 | 4.990289685      | -0.016884947 | -0.069766557    | 4.96             |
| 18000         | 589.462752 | 10017.3583 | 4.991335914      | -0.015064115 | -0.069766557    | 4.96             |
| 19000         | 558.438397 | 10015.5805 | 4.992221852      | -0.013522549 | -0.069766557    | 4.96             |
| 20000         | 530.516477 | 10014.0625 | 4.992978624      | -0.012205951 | -0.069766557    | 4.96             |
| 30000         | 353.677651 | 10006.2524 | 4.996875734      | -0.005429103 | -0.069766557    | 4.96             |
| 40000         | 265.258238 | 10003.5175 | 4.998241879      | -0.003054705 | -0.069766557    | 4.96             |
| 50000         | 212.206591 | 10002.2513 | 4.998874589      | -0.001955259 | -0.069766557    | 4.96             |
| 60000         | 176.838826 | 10001.5635 | 4.999218384      | -0.001357912 | -0.069766557    | 4.96             |
| 70000         | 151.576136 | 10001.1487 | 4.999425716      | -0.000997691 | -0.069766557    | 4.96             |
| 80000         | 132.629119 | 10000.8795 | 4.999560296      | -0.000763878 | -0.069766557    | 4.96             |
| 90000         | 117.89255  | 10000.6949 | 4.99965257       | -0.000603569 | -0.069766557    | 4.96             |
| 100000        | 106.103295 | 10000.5629 | 4.999718576      | -0.000488897 | -0.069766557    | 4.96             |
| 110000        | 96.4575413 | 10000.4652 | 4.999767415      | -0.000404051 | -0.069766557    | 4.96             |
| 120000        | 88.4194128 | 10000.3909 | 4.999804562      | -0.000339518 | -0.069766557    | 4.96             |
| 130000        | 81.6179195 | 10000.3331 | 4.999833471      | -0.000289295 | -0.069766557    | 4.96             |
| 140000        | 75.7880681 | 10000.2872 | 4.99985641       | -0.000249444 | -0.069766557    | 4.96             |
| 150000        | 70.7355303 | 10000.2502 | 4.999874917      | -0.000217294 | -0.069766557    | 4.96             |
| 160000        | 66.3145596 | 10000.2199 | 4.999890063      | -0.000190982 | -0.069766557    | 4.96             |
| 170000        | 62.4137032 | 10000.1948 | 4.999902616      | -0.000169175 | -0.069766557    | 4.96             |
| 180000        | 58.9462752 | 10000.1737 | 4.999913136      | -0.0001509   | -0.069766557    | 4.96             |
| 190000        | 55.8438397 | 10000.1559 | 4.999922038      | -0.000135434 | -0.069766557    | 4.96             |
| 200000        | 53.0516477 | 10000.1407 | 4.99992964       | -0.000122229 | -0.069766557    | 4.96             |
| 210000        | 50.5253788 | 10000.1276 | 4.999936181      | -0.000110866 | -0.069766557    | 4.96             |
| 220000        | 48.2287706 | 10000.1163 | 4.999941851      | -0.000101016 | -0.069766557    | 4.96             |
| 230000        | 46.1318676 | 10000.1064 | 4.999946797      | -9.24234E-05 | -0.069766557    | 4.96             |
| 240000        | 44.2097064 | 10000.0977 | 4.999951138      | -8.48819E-05 | -0.069766557    | 4.96             |
| 250000        | 42.4413182 | 10000.0901 | 4.999954969      | -7.82273E-05 | -0.069766557    | 4.96             |
| 260000        | 40.8089598 | 10000.0833 | 4.999958366      | -7.23255E-05 | -0.069766557    | 4.96             |
| 270000        | 39.2975168 | 10000.0772 | 4.999961393      | -6.70674E-05 | -0.069766557    | 4.96             |
| 280000        | 37.8940341 | 10000.0718 | 4.999964101      | -6.23624E-05 | -0.069766557    | 4.96             |
| 290000        | 36.5873432 | 10000.0669 | 4.999966534      | -5.81357E-05 | -0.069766557    | 4.96             |
| 300000        | 35.3677651 | 10000.0625 | 4.999968728      | -5.43246E-05 | -0.069766557    | 4.96             |

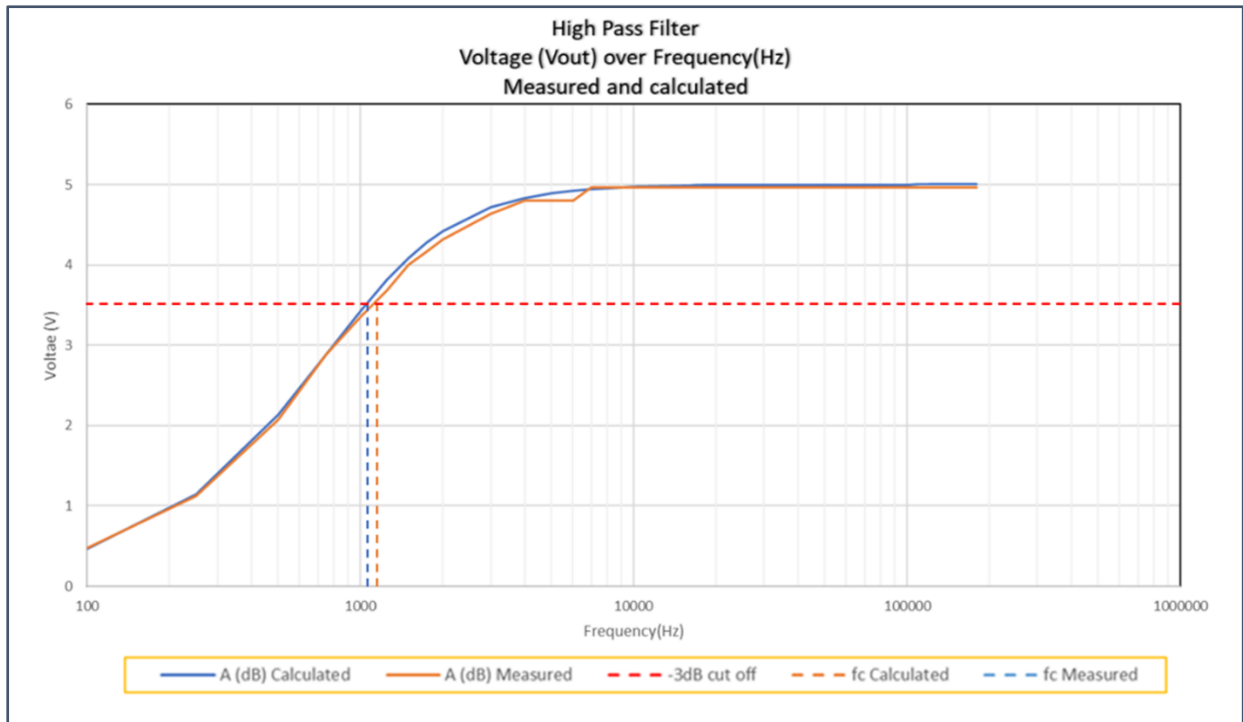


Figure 6- High Pass Filter, Voltage Over Frequency

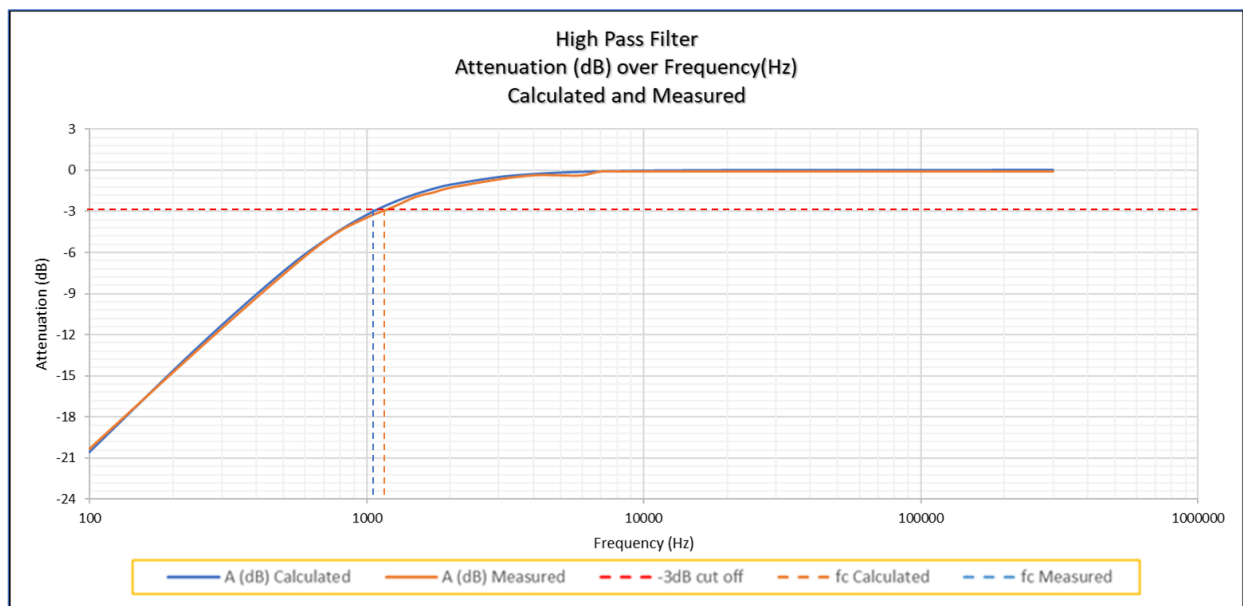


Figure 7- High Pass Filter, Attenuation Over Frequency.

The result shown in Table 2, Figure 6 and Figure 7 of the high pass filter circuit all show the effect of the high pass filter circuit. The -3dB cut off, as the frequency is increased to approximately 1kHz the attenuation begins to stabilize and remains at a constant 0dB when at approximately 4kHz as the frequency comes out of the stop band and into the pass band. The Estimated -3dB has been entered into figure 6 and shows an estimated voltage output of 3.6V.

Using equation 5 as follows for the calculated frequency, 1061.03Hz showing the measured.

$$f_c = \frac{1}{(2\pi * 10000 * 15 * 10^{-9})} = 1061.03\text{Hz}$$

## 5 Discussion

The results show the intended function of each circuit. Where the low pass filter is allowing a band of frequency to pass through without being altered as can be seen in Figure 4. There is a stable 0dB attenuation along the X axis before the corner frequency/cut off frequency is reached which is know as the pass band this also represents the filters Bandwidth. Beyond this point the frequency response is in the stop band and the response decreases at a slope of -20dB/Decade.

This Capacitive reactance is the impedance of a capacitor. Evidence of this is shown in each graph. This value will change depending on the frequency which is applied. Capacitive Reactance varies with the applied frequency. The resistance however remains the same because it obeys ohms law.

The voltage output shown in Figure 5 begins to decline at a steady slow rate. At approximately 2kHz is where a significant change in rate of decline. The effect of the low pass filter is clear when the cut-off frequency is reached with the voltage rapidly decreasing when entering the stop band at approximately 3.7V. Another example can be seen in Figure 8. Capacitive Reactance is the complex impedance of a capacitor. This value will change depending on the frequency is applied.

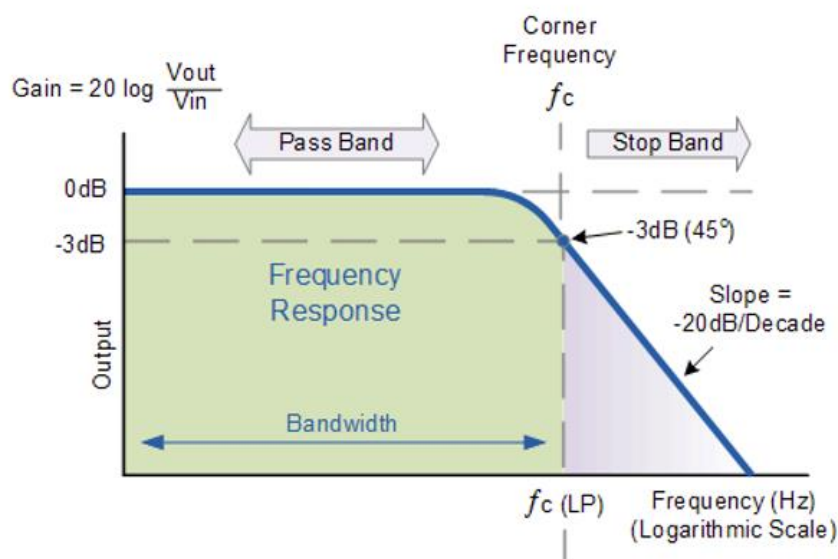


Figure 8- Frequency Response Of A 1st-Order Low Pass Filter (Electronic-Tutorials, n.d.)

The high pass filter works in opposite to the low pass filter. At low frequency when in the stop band of the filter a sharp rise in attenuation can be seen. As the frequency is increase and passes through the filter the attenuation levels out at 0dB as it enters the passband. The estimated voltage at the cut 3.6V. Example show in Figure 10.

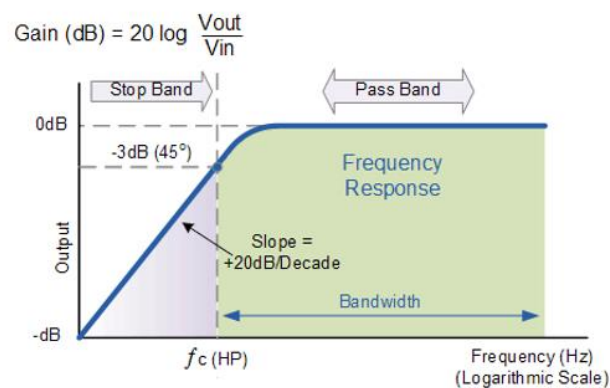


Figure 9-Frequency Response Of A 1st-Order High Pass Filter (Electronic-Tutorials, n.d.)

The voltage of corner frequency/cut-off frequency for both is between 3.6V and 3.7V showing that the opposite function of each filter.

Although not the same there are condition that could have an impact on results. Such as equipment used. For example. Function generator calibration and capacitors used. The resistors used in the exercise have a 5%+/- tolerance which can skew the results. As the exercise was carried out over two sessions it could not be guaranteed that all equipment used was the same for each circuit built. All components used will have manufacturing tolerances which need to be considered. This shows the measured results against the calculated results using theory/equations listed above.

Should the exercise be repeated to get more accurate results. The calculations could be made before the measurements were taken. As the calculated frequencies for the -3dB could then set directly into the function generate to give a more accurate result.

## 6 Conclusion

In this laboratory exercise, it has been determined that the High and low pass filter's functions are opposite. The graphs above show each filter's function clearly with varying frequency which is caused by the capacitor's reactance for each of the frequency values. The measured results although not identical to the calculated results follow the theory applied. Considering component tolerances used to create the circuit it can confidently show the exercise has been successful in proving calculations, equations and theory used.

## 7 References

Electronic-Tutorials, n.d. *Electronic-Tutorials*. [Online]

Available at: [https://www.electronics-tutorials.ws/filter/filter\\_2.html](https://www.electronics-tutorials.ws/filter/filter_2.html)

[Accessed 12 April 2023].