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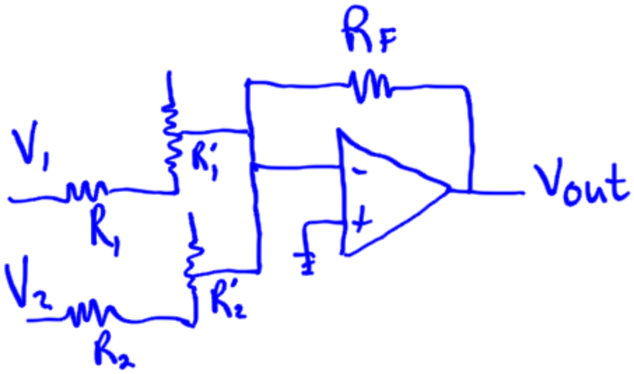
Lab 16

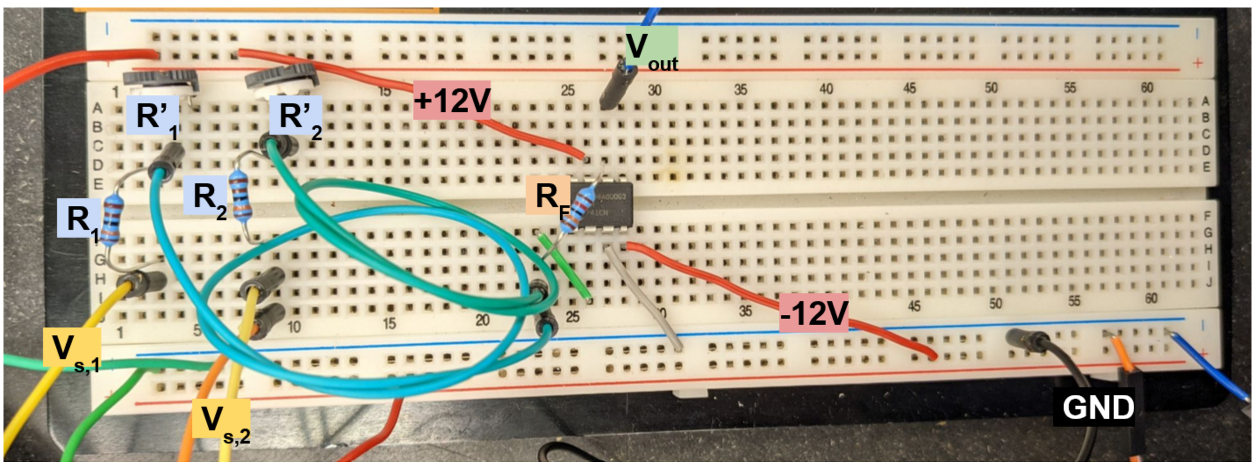
Figure 1. Summing circuit diagram for 2-input audio mixer with variable gain



$$R_{g1} = R_1 + R_1'$$

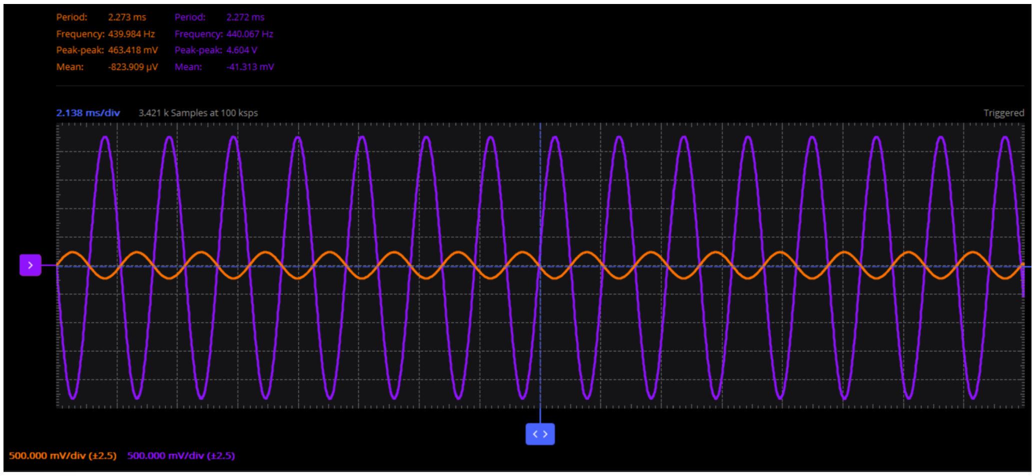
$$R_{g2} = R_2 + R_2'$$

Figure 2. Built summing circuit with variable gains between 2 and 10.



$R_{g1} = R_{g2} = R_1 + R'_1 = R_2 + R'_2 \cong$ 1.25kΩ + up to 5kΩ variable resistance; **$R_F \cong$ 12.5kΩ**

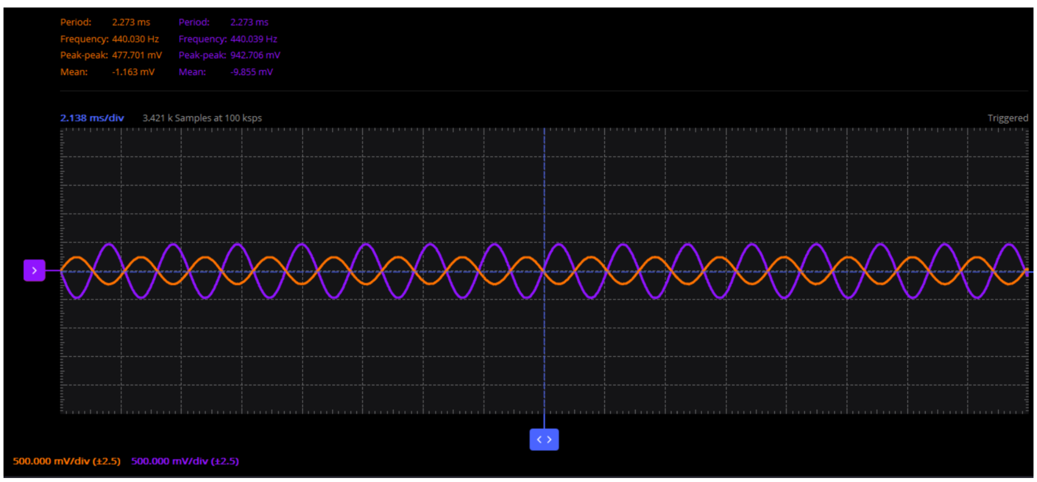
Figure 3. Channel 1 V_S (orange) and V_{out} (purple) over time. Maximum gain.



$V_{s,1}$ = 0.5V p-p sine wave with frequency 440Hz

Gain = 4.604V / 0.463418V = 9.93
This is close to the desired gain of 10.

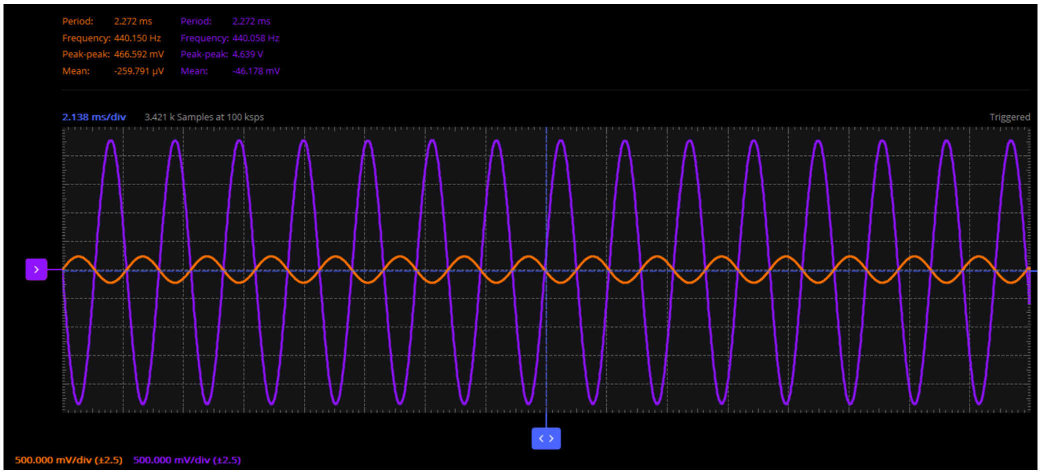
Figure 4. Channel 1 V_S (orange) and V_{out} (purple) over time. Minimum gain.



$V_{s,1}$ = 0.5V p-p sine wave with frequency 440Hz

Gain = 942.766mV / 477.701mV = 1.97
This is close to the desired gain of 2.

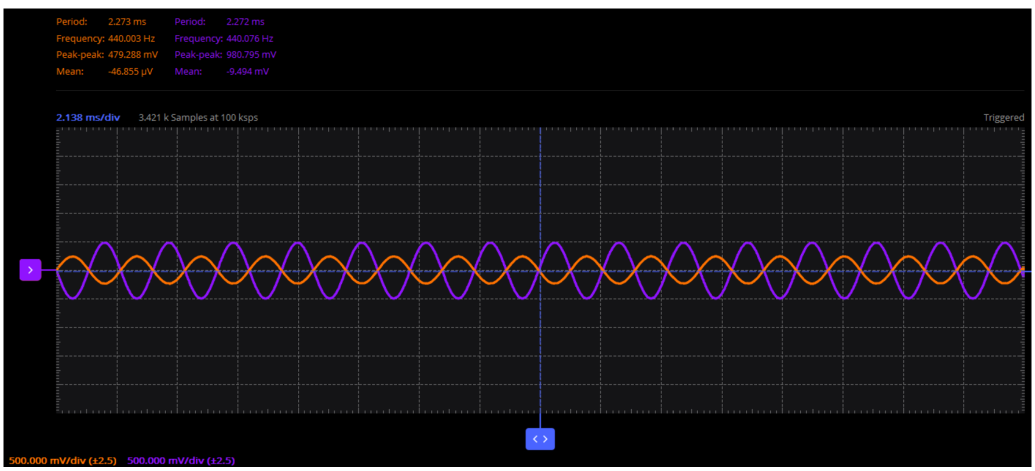
Figure 5. Channel 2 V_S (orange) and V_{out} (purple) over time. Maximum gain.



$V_{s,2}$ = 0.5V p-p sine wave with frequency 349.23Hz

Gain = 4.639V / 0.466592V = 9.94
This is close to the expected gain of 10.

Figure 6. Channel 2 V_S (orange) and V_{out} (purple) over time. Minimum gain.



$V_{s,2}$ = 0.5V p-p sine wave with frequency 349.23Hz

Gain = 980.795mV / 479.288mV = 2.04
This is close to the expected gain of 2.

Figure 7. Gain results.

Channel	Minimum gain	Maximum gain
1 (440Hz)	1.97	9.93
2 (349.23Hz)	2.04	9.94

Figure 8. Channel 2 V_S (orange) and V_{out} (purple) over time. Minimum gain; two inputs

$V_{s,1}$ = 0.5V p-p sine wave with frequency 440Hz
$V_{s,2}$ = 0.5V p-p sine wave with frequency 349.23Hz

The circuit can be used to drive a speaker. Scopy provided two 50mV p-p sine waves with frequencies of 440Hz (an A) and 349.23Hz (an F). Adjusting the gain on each input impacted the relative strength of each pitch in the final output, as demonstrated in this video: https://youtu.be/F1JNsCs0zvs

As demonstrated in this video, adding different filters changes the quality of sound produced by the op-amp circuit: https://youtu.be/rcsf_iVbMKQ

A low-pass filter can be added to the circuit to filter out high-frequency components of a signal. To determine f_c for a RC low-pass filter in the inverting op-amp circuit, use R_F in the formula $2\pi f_c = 1/RC$. This is because the capacitor is in parallel with R_F.

Figure 9. Circuit diagram for adding a low-pass filter.

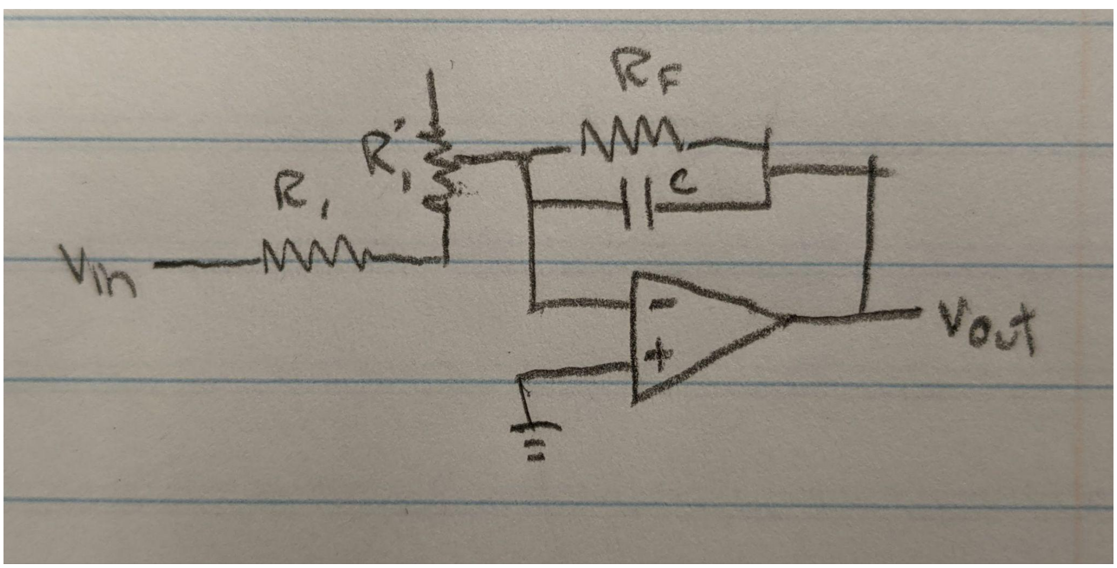
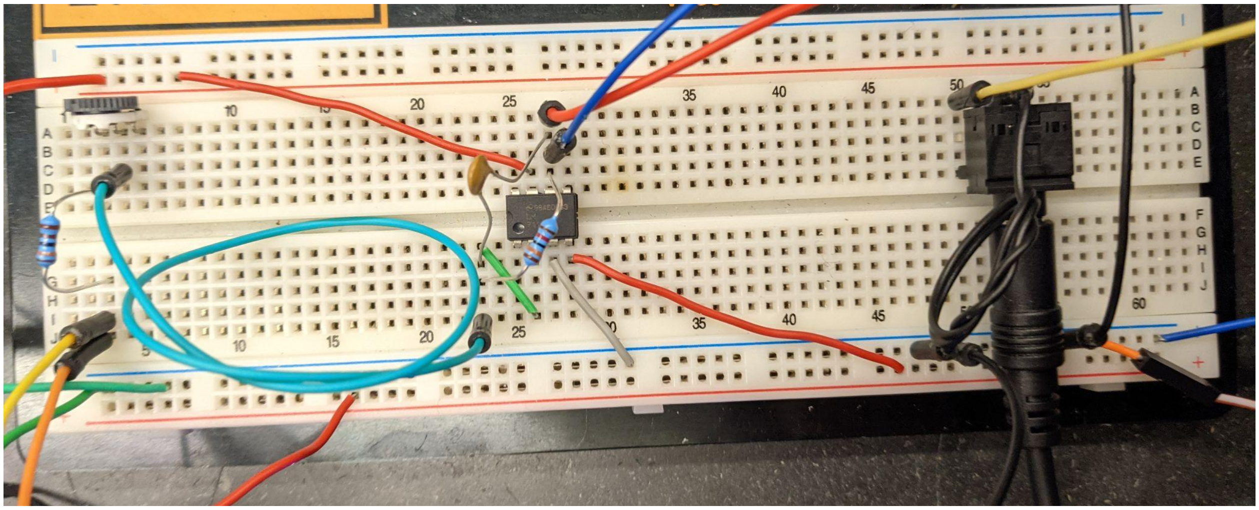


Figure 10. Built circuit with a low-pass filter.



For a critical frequency of about 2500Hz:

$f_c = 1 / 2\pi R_F C$

$C = 1 / f_c 2\pi R_F$

$C = 1 / (2500Hz)(2\pi)(12500\Omega)$ → **$C = 5000pF$**

A high-pass filter can be added to the circuit to filter out low-frequency components of a signal. To determine f_c for a RC high-pass filter in the inverting op-amp circuit, use R_G in the formula $2\pi f_c = 1/RC$. This is because the capacitor is in series with R_G.

Figure 11. Circuit diagram for adding a high-pass filter.

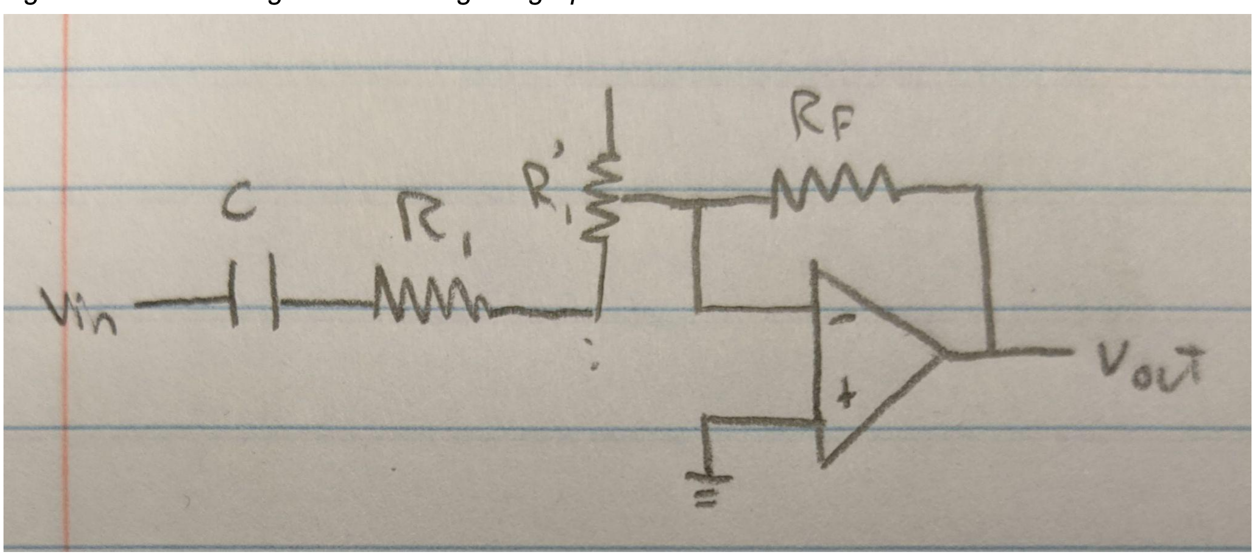
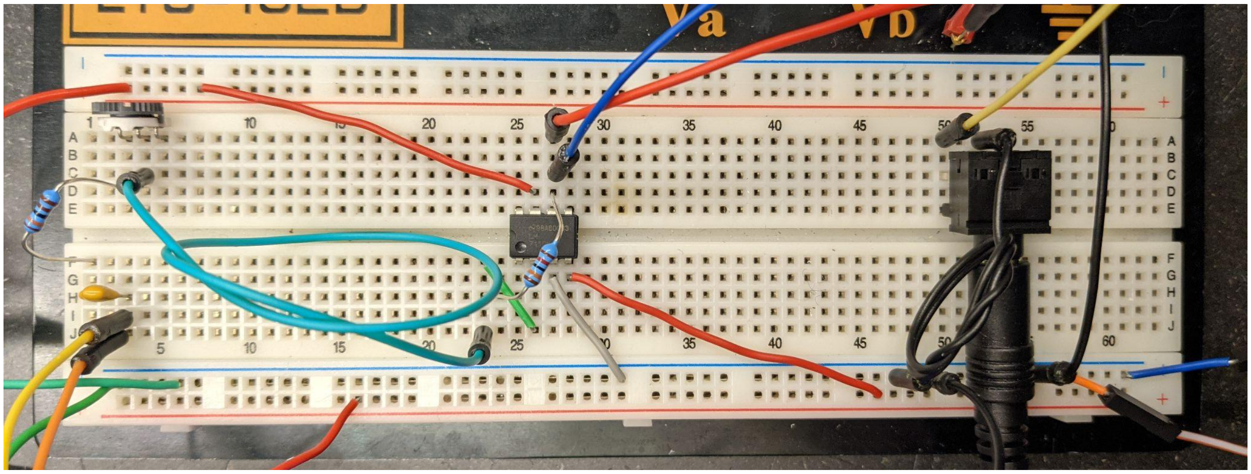


Figure 12. Built circuit with a high-pass filter.



For a critical frequency of about 250Hz.

$f_c = 1 / 2\pi R_G C$

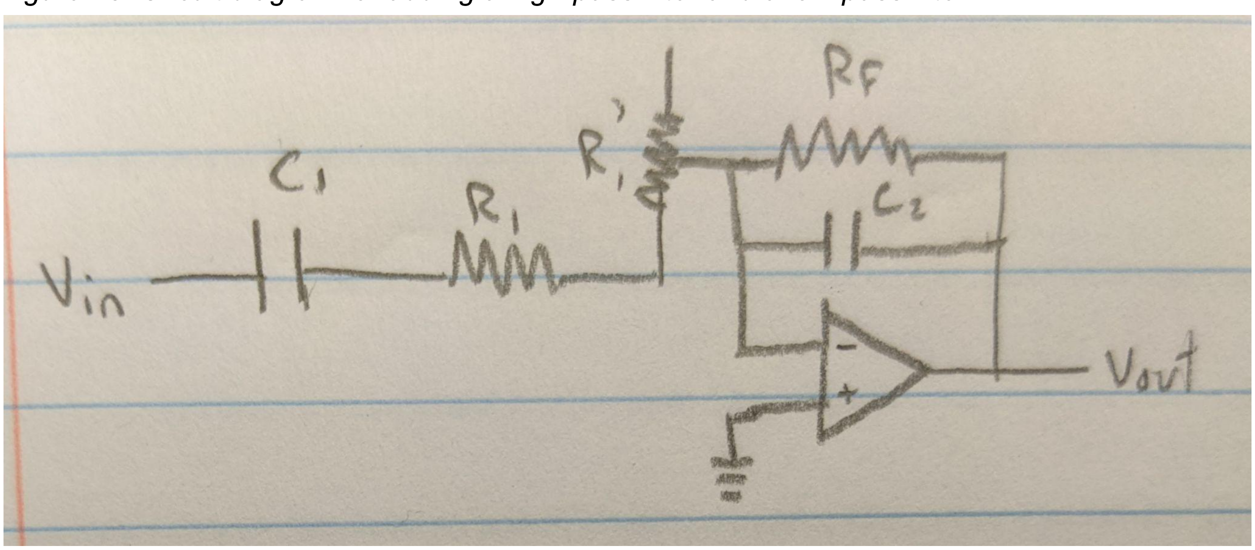
$C = 1 / f_c 2\pi R_G$

$C = 1 / (250\text{Hz})(2\pi)(1250\Omega) \rightarrow \mathbf{C = 0.5\mu F}$

Due to available components, a 0.47μF capacitor was used for the high-pass filter. Calculations were made under the assumption that the variable resistor would be set to its minimum resistance value, so $R_G = 1250\Omega$.

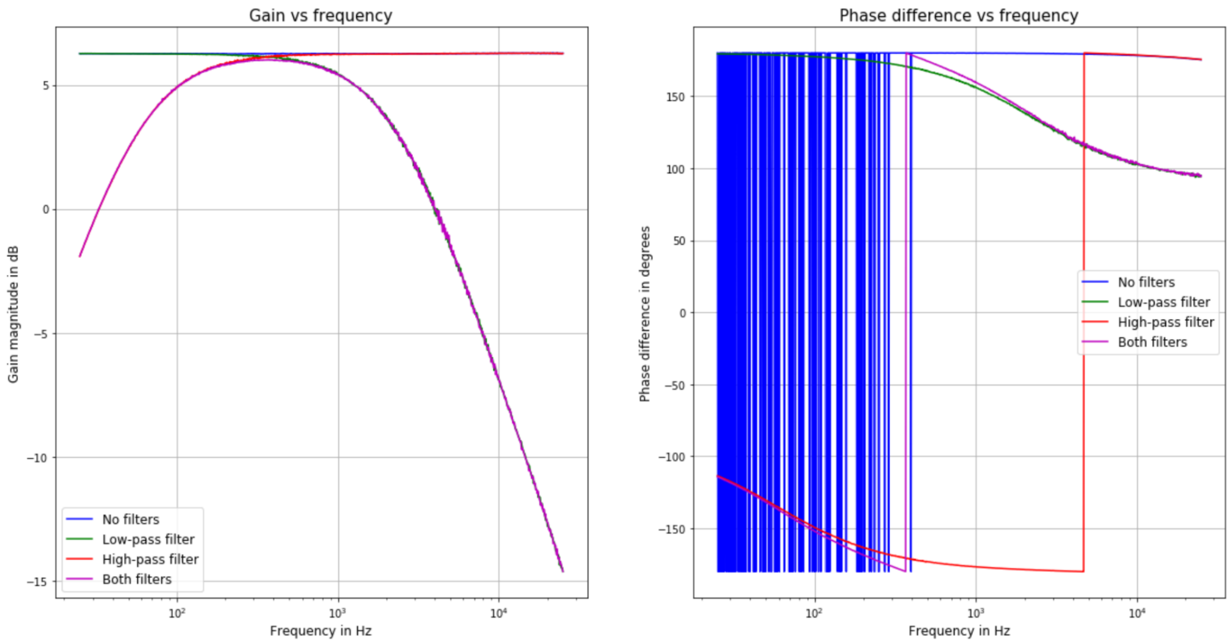
Both filters can also be included in the circuit at once, filtering out both high and low frequencies.

Figure 13. Circuit diagram for adding a high-pass filter and a low-pass filter.



Scopy's network analyzer was used to gather data on the gain and phase difference for a range of frequencies between 25Hz and 25kHz for the circuit with no filters, a low-pass filter, a high-pass filter, and both filters. The data was then exported and plotted in Python.

Figure 13. Gain and phase difference vs frequency for various combinations of filters.

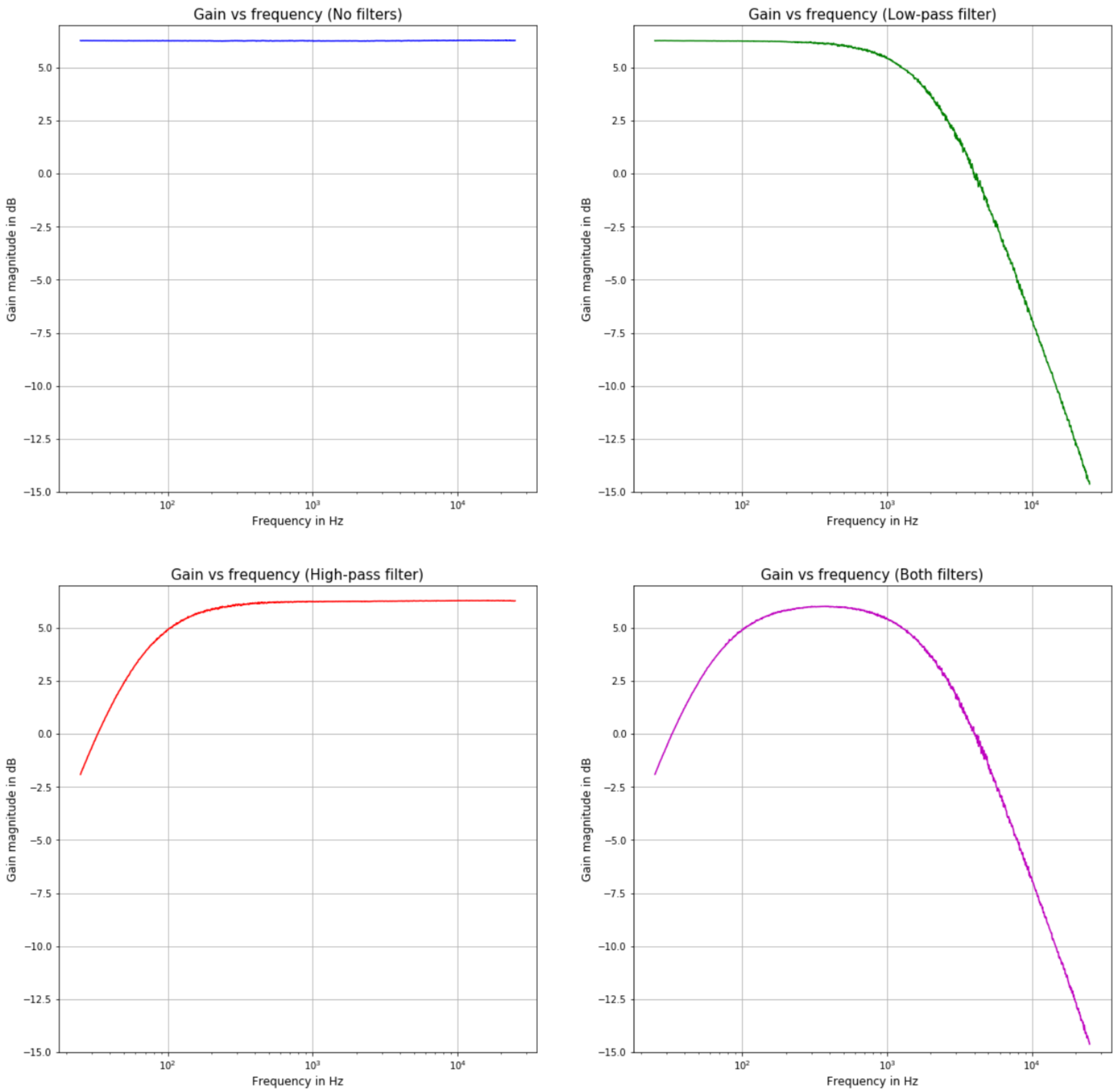


It is difficult to tell which filters correspond to which curves when they are all plotted over each other, so the subplot function was used to plot each case for comparison (see figure on next page).

It revealed that the circuit with no filter had a constant gain of between 6 and 7 for the entire range of plotted frequencies. The circuit with the low-pass filter exhibited constant gain at the same value for lower frequencies, but displayed significant decreases in gain for higher frequencies. The circuit with the high-pass filter exhibited low gains at low frequencies that increased to the same constant value as in the other circuits and remained constant for higher frequencies. The circuit with both filters kept the regions of increase and decrease from each filter, and only had a constant gain between 6 and 7 for a narrow mid-range of frequencies.

This is as expected. Lower gain means that components at that frequency aren't as strong in the output. So the high-pass filter has lower gain for lower frequencies, but lets higher frequencies "pass" through with relatively unchanged gain. The low-pass filter has lower gain for higher frequencies, but lets lower frequencies "pass" through with relatively unchanged gain. And with both filters in the circuit, only frequencies that are between the two filters' respective critical frequencies pass through with unchanged gain.

Figure 14. Gain vs frequency for various combinations of filters.

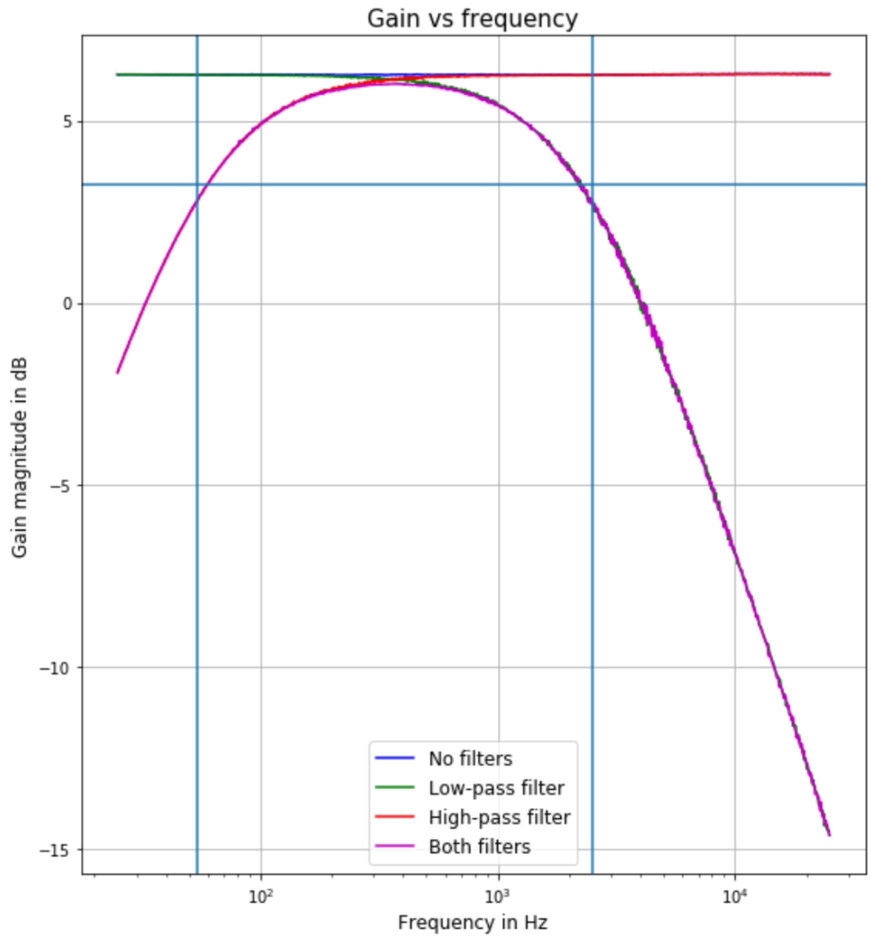


When checking whether my critical frequencies were as expected, I noticed that my critical frequency for the high-pass filter was NOT what I expected. I expected it to be around 250Hz, but visually looking at these plots, I noticed that it was less than 100Hz. I realized that I had done my calculations as if the variable resistor was at its minimum value, but that I had taken my data with it at its maximum value. This means that the value of R_G was in fact 5kΩ higher than in my calculations. With a more accurate idea of R_G, I recalculated f_c for the high-pass filter:

$f_c = 1 / 2\pi R_G C$
$f_c = 1 / (2\pi)(1250\Omega)(0.47\mu F) \rightarrow$ $\mathbf{f_c = 54Hz}$

To check my critical frequencies, I plotted vertical lines at 54Hz and 2500Hz on my gain plot.

Figure 15. Gain vs frequency for various combinations of filters. Vertical lines at predicted critical frequencies 54Hz and 2500Hz. Horizontal line at 3dB below flat max gain of the circuit.



Since all four circuits have approximately the same gain in their flat region, I took the average of the constant gain plotted for the circuit with no filters. I plotted a horizontal line at a gain 3dB below that. The actual critical frequencies are the points at which the horizontal line intersects the plotted gain vs frequency curves for the filters.

The critical frequencies that I expected (after re-calculating for the high-pass filter) seem fairly close to the actual critical frequencies of the circuits. The critical frequency expected for the high-pass filter (54Hz) is a little bit lower than the actual critical frequency, but visually is close. The critical frequency expected for the low-pass filter (2500 Hz) is a little bit higher than the actual critical frequency, but is visually close.