Lab 3 Report
ECE1212 Electronic Circuits Design Lab
Lab Due Date: February 26, 2018

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August 15, 2020

Introduction

Operational amplifiers (op-amps) can also be used in filtering circuits due to their tune-able 3dB bandwidth. Voltages within a certain range of frequencies will pass and be amplified, while those outside will be blocked, or filtered out.

In experiment 3, the use of op-amps in filters will be explored, including the designing, building and testing of a Wien-bridge oscillator and three active filters (two low pass and one band pass). Theoretical predictions were made using mathematical analysis and MATLAB programming to observe system properties, such as poleszeroes, transfer functions, and magnitude responses.

Procedure

Part A: Low Pass Filters

(1) In the prelab, the following circuit in 1 was designed for both sets of conditions:

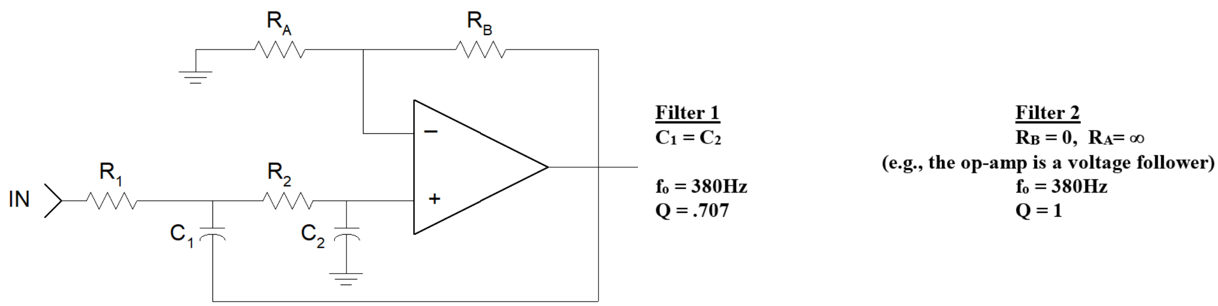

Figure 1: Circuit and 2 target sets of conditions

Additionally, an analysis and derivation of the transfer functions were carried out.

(2) The circuit was built, and the gains and magnitude frequency response of each low pass filter was measured using Labview sweeps. Additionally, the magnitude frequency response of filter 1 was remeasured with R_B increased 15%.

Part B: Band Pass Filters

(1) In the prelab, a Sallen-Key bandpass filter (see Figure **??** with center frequency f_o = 620Hz and quality factor Q = 7 was designed.

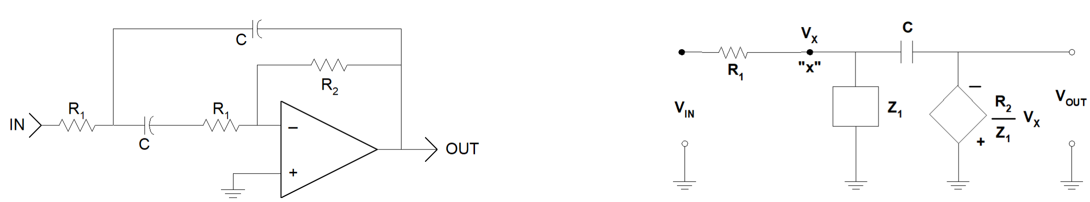

Figure 2: Circuit and pi-model equivalent

(2) The circuit was built and the magnitude-frequency response was measured once again using Labview's sweep function. The feedback resistor R_2 was varied ±10% and re-measured.

Part C: Oscillators

(1) In the prelab, a Wien-bridge oscillator was designed according to the Barkhausen criterion.

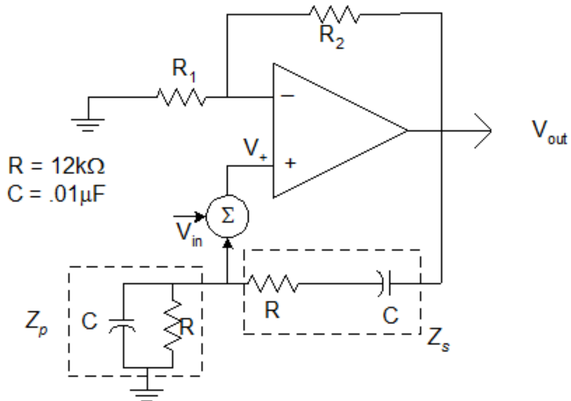

Figure 3: Wien bridgecircuit

(2) Next, the circuit was tested and the input resistance R_1 was tuned to find the point where oscillations started to occur and where the gain was high enough to cause a square wave.

(3) Step 2 was repeated with the addition of a lamp diode grounding the input resistance

Results

The following section reports the results of the experiments performed in this lab. For this report, figures will consist of oscilloscope outputs, magnitude frequency response plots, and other measured and calculated data. Each figure will either be preceded or followed by a short description. Each figure will also have a caption beneath it.

Part A: Low Pass Filters

(1) The following values were used for the two filter designs determined in the prelab:

$R_A = 1k\Omega$
$R_B = 587\Omega$ utilizing a decade box
$R_1 = 12k\Omega + 680\Omega = 12680\Omega$
$R_2 = 12k\Omega + 680\Omega = 12680\Omega$
$C_1 = 0.033\mu F$
$C_2 = 0.033\mu F$

$R_A = \infty$
$R_B = 0\Omega$
$R_1 = 8.2k\Omega + 180\Omega = 8380\Omega$
$R_2 = 8.2k\Omega + 180\Omega = 8380\Omega$
$C_1 = 0.1\mu F$
$C_2 = 0.022\mu F||1nF||1nF||1nF = 0.025\mu F$

Figure 4: Left: Filter 1 Design & Right: Filter 2 Design

Figure 4 shows several combinations of resistors and capacitors. This was a design constraint - choosing values that could be made with a reasonable number of components.

(2) Below in Figure 5, the scope output for Filter 1 is shown on the left and the scope output for Filter 2 is shown on the right.

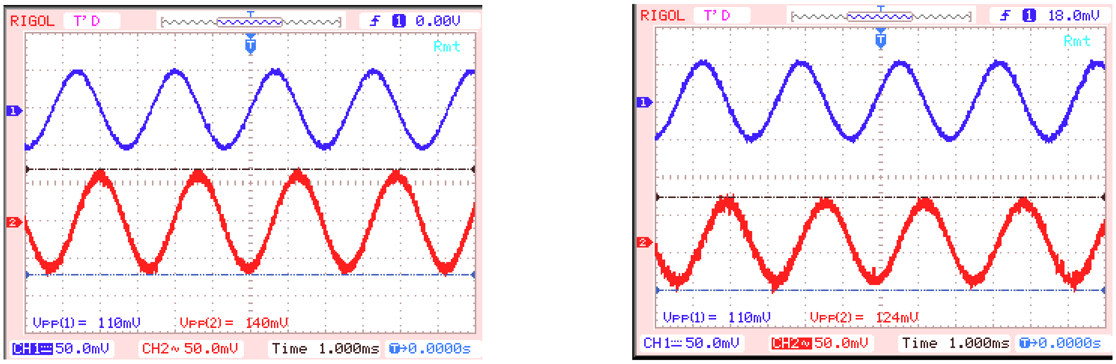

Figure 5: Left: Filter 1 gain & Right: Filter 2 gain

As seen in the scope displays above, the gain of Filter 1 is $\frac{0.140V}{0.110V} = 1.273$ V/V. The gain of Filter 2 is $\frac{0.124V}{0.110V} = 1.127$ V/V.

(3) Below are the frequency responses of Filter 1 and 2:

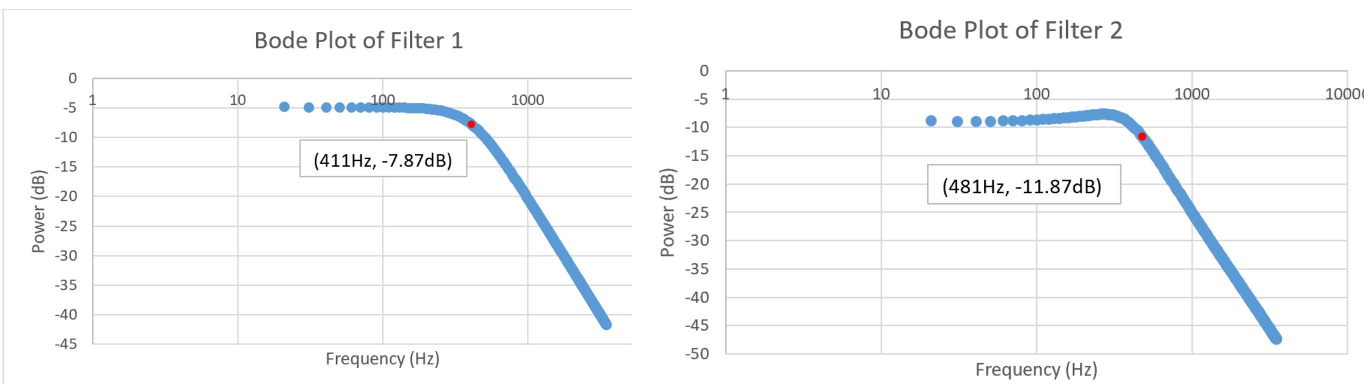

Figure 6: Left: Condition 1 frequency response & Right: Condition 2 frequency response

In Figure 6 above, the plots look fairly similar. The differences are due to the increase in quality factor Q. Most notably is the upward slope before the peak in filter 2.

Below is the result when raising R_B of filter 1 15%:

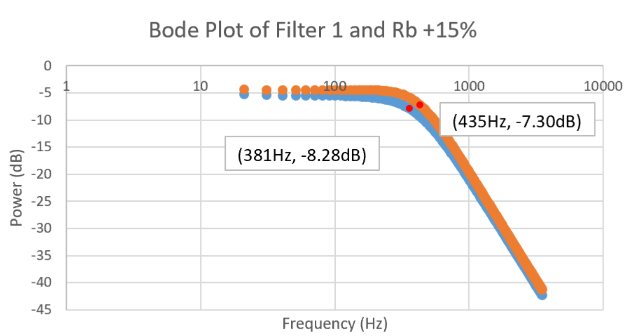

Figure 7: Blue: $R_B = 499\Omega$ (original) and Orange: $R_B = 573\Omega$ (+15%)

Figure 7 above shows the effect of increasing the feedback resistance R_B. There is a slightly higher overall power and there seems to be a slight inherent increase in quality factor.

Part B: Band Pass Filters

(1) The following values were used for the design for the band pass filter determined in the prelab:

$$Q = 7$$
$$\omega_o = 1240\pi Hz$$
$$R_1 = 370.420\Omega(270\Omega + 100\Omega)$$
$$R_2 = 163k\Omega(160k\Omega + 3k\Omega)$$
$$C = 33nF$$

$$Center frequency = \omega_o = \sqrt{\frac{1}{C^2(R_1R_2 + R_1^2)}} = 1240\pi Hz$$
$$Bandwidth = \frac{3}{C(R_1 + R_2)} = 556.46Hz$$

Figure 8: Left: Band Pass Filter Design & Right: Calculation of center frequency and bandwidth

(2) Figure 9 below shows the frequency response of the designed band pass filter:

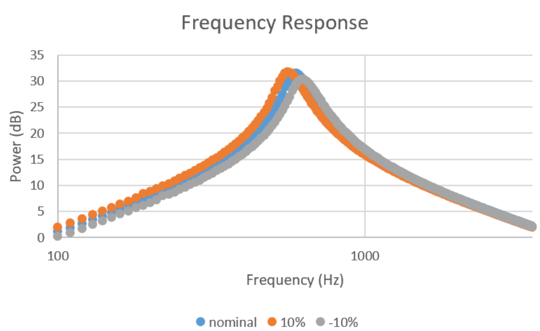

Figure 9: Frequency responses of designed band pass filter

Part C: Oscillators

(1) In the prelab, the frequency of oscillation was calculated to be $F_o = 1326.3$ Hz. Also, the value of $\frac{R_2}{R_1}$ was calculated to be equal to 2. R_2 was nominally set to 2.4kΩ while R_1 was nominally set to 1.2kΩ to satisfy this condition.

(2) Below in Figure 10, the output scope images for the oscilloscope test are provided.

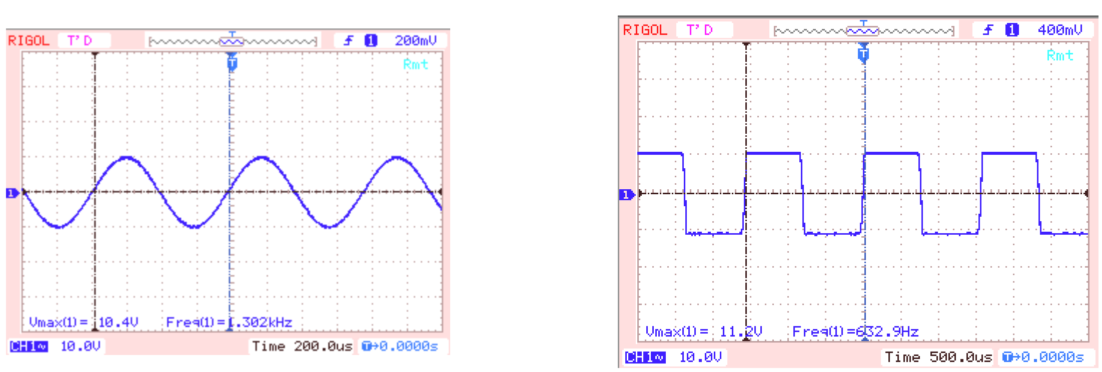

Figure 10: Left: Minimum input resistance for oscillations & Right: Minimum input resistance for square wave representation

The figure on the left displays the scope output when oscillations are just met. The parameters of this wave and circuit were:

$$f = 1.302kHz$$
$$V_{max} = 10.4V$$
$$R_1 = 1.179k\Omega$$
$$R_2 = 2.376k\Omega$$
$$Potentiometer = 25\Omega$$
$$\pm V = \pm 12$$

The figure on the right displays the generation of a square wave due to oscillations with a high gain circuit. The parameters of this wave and circuit were:

$$f = 639.2Hz$$
$$V_{max} = 11.2V$$
$$R_1 = 1.179k\Omega$$
$$R_2 = 2.376k\Omega$$
$$Potentiometer = 10.496k\Omega$$
$$\pm V = \pm 12$$

(3) For the last part of Part C in the lab, a lamp was used to determine the lamp ranges that were able to still produce a stable sine wave oscillation and then the ranges that clipped without a lamp in the cicruit. The results are as follows:

Lamp ranges that are produce a stable sine wave:

$$V_{min} = 6V, f = 1.316kHz$$
$$V_{max} = 10.4V, f = 1.316kHz$$

Non lamp sine wave ranges before clipping:

$$V_{min} = 10.4V, f = 1.282kHz$$
$$V_{max} = 10.8V, f = 1.282kHz$$

Discussion

Part A: Low Pass Filters

(1) One of the largest challenges for this section was component selection. After values were solved for, the simplest combinations of available resistors had to be determined, and what level of precision was necessary. For instance, being off 5Ω on a 1000Ω value was negligible, while being 3nF off of a 0.22μF value could not be ignored.

If higher Q values were necessary, component selection would be significantly more difficult, as the values of standard components are less continuous as the values get higher.

(2) The Bode plots of thee filters reveal the effect of quality factor Q and gain G on the system. Q results in an increased peak just before the power drop-off (Figure 6, and G increases the overall power of the filter in its pass region (Figure 7. While these trends and characteristics matched those on the predicted with MatLab, the 3dB frequency was significantly lower than modelled, which occurred an order of magnitude higher at ≈ 1250Hz.

The gain for filter 1 was calculated to be G = 1.27V/V, which was expected. Using the basic gain formula for non-inverting op amps G = 1+ $\frac{R_B}{R_A}$, the gain was predicted to be 1.587V/V, which is 19% of the experimental value. Filter 2 was much closer. The design was unity gain, and its gain was G = 1.13V/V, 13% off.

Part B: Band Pass Filters

(1) The values were determined through analysis of the transfer function of the system. Deriving the general form of the equation helped show the relation between different factors and the output on the system (direct/inverse proportionality). Additionally, the poles and zeros could be found to create a root-locus plot, describing system stability and response time.

(2) Maximum gain could not be realized due real system limitations such as powering voltage to the op amp. Also, the maximum expected gain was determined under ideal op-amp conditions. While in correct operating conditions, the output can produce accurate approximations, however under less ideal conditions, the practical and ideal values can quickly diverge.

Altering the feedback resistance R_B did not seem to alter frequency bandwidth much, if not at all. However, the center frequency seems to be inversely proportional to R_B. This makes sense as R_B itself is directly proportional gain, and the lower the system gain, the higher the system 3dB bandwidth.

Part C: Oscillators

(1) Based on the results from part C, the frequency in which the oscillations began to occur was 1.302kHz. Compared to the calculated value of 1.326kHz, this produced a 1.8% error. Therefore, the oscillation frequency measured confirmed expected results.

The actual resistances needed to produce this result are listed below Figure 10 and are R_1 = 1.179kΩ, R_2 = 2.376kΩ and R_{pot} = 25Ω with the potentiometer in series with R_2. The expected ratio for oscillation to occur from the prolab was 2. Based on the acutal values, the ratio of $\frac{R_2}{R_1} = \frac{2.376k+25}{1.179k} = 2.04$ which provides 2% error from the expected value. Therefore, the results again confirmed expectations.

(2) When keeping the two resistors constant and increasing the potentiometer to 10.496kΩ, the square wave shown in the right image in Figure 10 was the output. This happened because the increase in potentiometer resistance greatly increased the gain of the op amp circuit. Therefore, the small oscillations in the oscillator circuit now we're clipping due to the high gain. This resulted in the square wave shown in the figure. Shown in the results as well, the frequency did change. The frequency dropped from 1.302kHz down to 639.2Hz in this case when square waves were observed. A possible explanation for this is that with the high gain, the higher frequency noise oscillation is filtered out resulting in a lower frequency square wave.

(3) As seen in the data in part C of the lab, adding a lamp to the circuit stabilizes the circuit allowing for a larger range on voltage values to produce a sine wave oscillatory output without clipping. With the lamp the voltage range was (6V, 10.4V). Without the lamp the voltage range was (10.4V, 10.8V).

This circuit stabilizes the oscillator because the lamp prevents the op-amp from saturating. Therefore, there is a larger range of voltage values that can be reached without clipping. Because the lamps resistance is nonlinear, as the output increases, the resistance increases which decreases the gain and keeps the op-amp from saturating. Without the lamp in the circuit the oscillator would drive the op amp into clipping, causing increased distortion.

Conclusion

The purpose of lab 3 was to experimentally test the active filter and oscillator applications of operational amplifiers. The experiments of the lab included low pass filters (2 different designs), an active band pass filter, and an oscillator circuit. Specifically, quality factor, Q, bandwidth, center frequency, and oscillation frequency and characteristics were explored in the lab.

Results accurately reflected what was expected and taught in lecture. Key takeaways were learning the diversity of uses the operational amplifier has, from filtering to generating a stable oscillation circuit simply from noise. This experiment also demonstrated the importance of deriving theoretical models to predict behaviour, and the differences that can arise between theoretical and practical responses.

References

[1] Experiment 3 – Active Filters and Oscillators Lecture Notes

[2] Rigol DM3058 User's Guide. https://www.csulb.edu/sites/default/files/groups/college-of-engineering/About/rigol-dm3058-digital-multimeter-user-guide.pdf

[3] LM741 Operational Amplifier. http://www.ti.com/lit/ds/symlink/lm741.pdf

[4] Professor Li

[5] TA's Yanhao Du and Qirui Wang