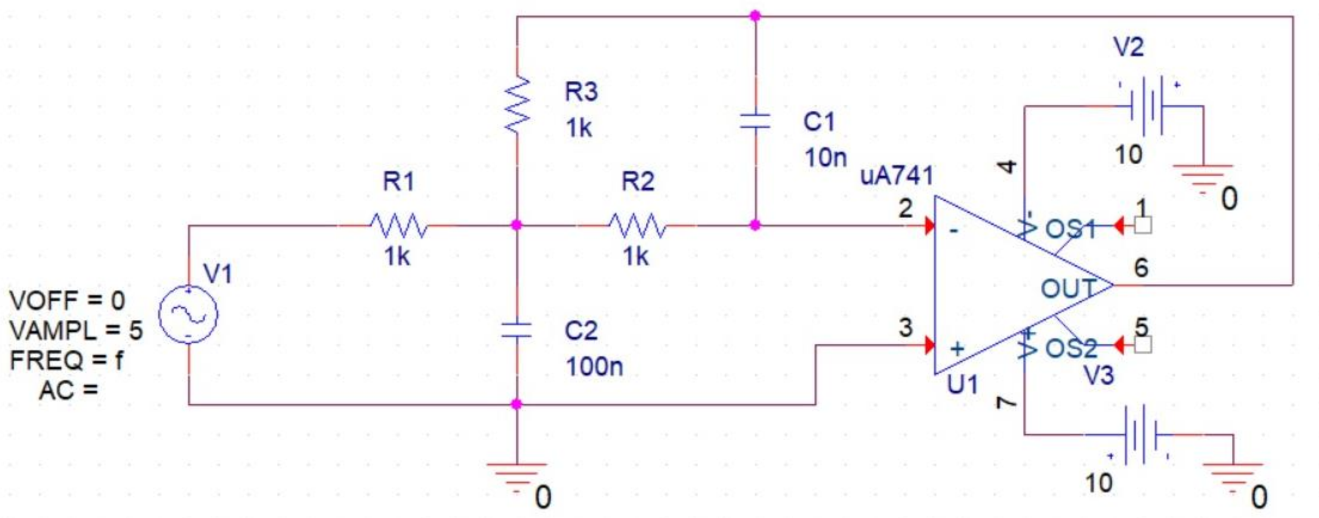
ECE 2101L Lab #6

Frequency Response of Linear Active Circuits



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Objective

The objective of the experiment six is to explore and analyze the frequency response of a linear active operational amplifier circuit to find the 3dB frequency and see the general behavior of its response.

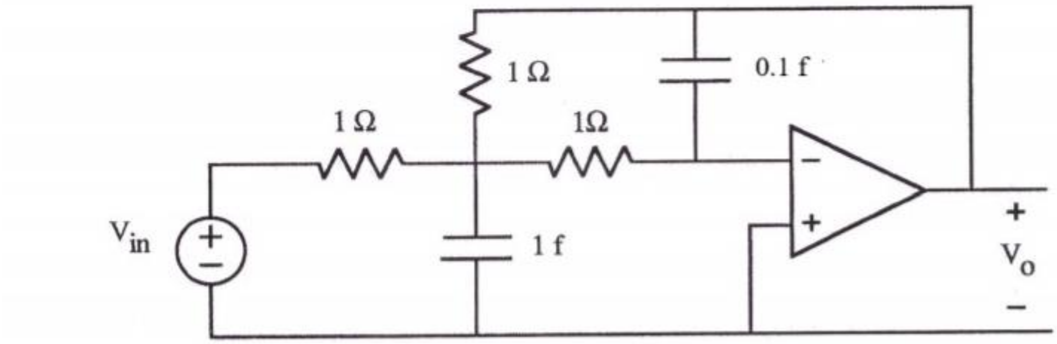
Materials

The necessary equipment needed for the lab are as follows

1. Breadboard
2. 4 BNC Clip Connectors
3. Clip Leads
4. 100nF and 10nF Nonpolar Capacitors
5. 3 1kΩ Resistors
6. 741 Op Amp
7. LCR Meter
8. Digital Multimeter
9. Oscilloscope
10. Function Generator

Pre-Lab

1. Given the following op amp circuit

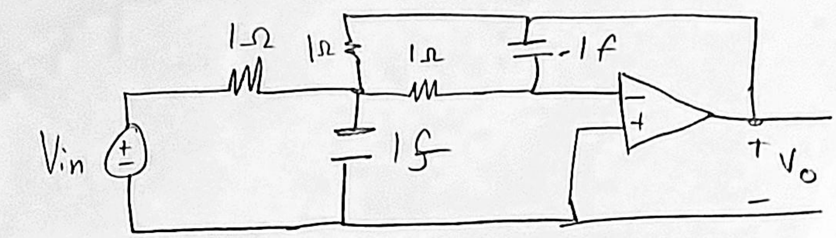


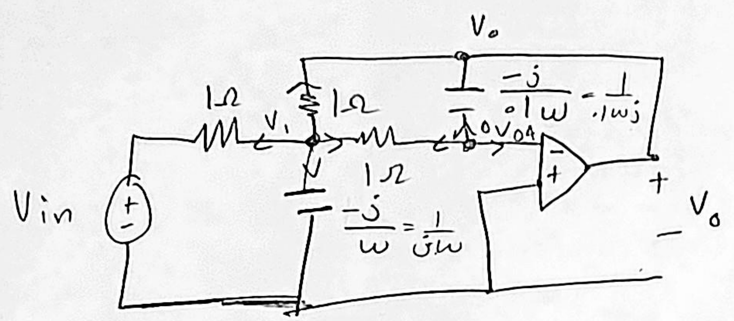
a. Draw the phasor network
b. Write and put in matrix form the node equations
c. Show that

$$G(j\omega) = \frac{V_o(j\omega)}{V_{in}} = -\frac{1}{1 - 0.1\omega^2 + j0.3\omega}$$

d. Use any plotting program to obtain a graph of $|G(j\omega)|$ from $\omega = 0.01$ to $\omega = 100$ on a log scale

1.





① $\frac{V_1 - V_{in}}{R_1} + \frac{V_1 - V_o}{R_1} + \frac{V_1}{R_1} + \frac{V_1}{\frac{1}{j\omega C_1}} = 0$

① $\frac{V_1}{R} - \frac{V_{in}}{R_1} + \frac{V_1}{R} - \frac{V_o}{R_1} + \frac{V_1}{R} + V_1(j\omega C_1) = 0 = V_1\left(\frac{3}{R} + j\omega C_1\right) - \frac{V_{in}}{R} - \frac{V_o}{R}$

② $\frac{-V_1}{R} + \frac{-V_o}{\frac{1}{C_2\omega j}} = 0$

$$\begin{bmatrix} (3+C_1R\omega j) & (-1) \\ (1) & (RC_2\omega j) \end{bmatrix} \begin{bmatrix} V_1 \\ V_o \end{bmatrix} = \begin{bmatrix} V_{in} \\ 0 \end{bmatrix}$$

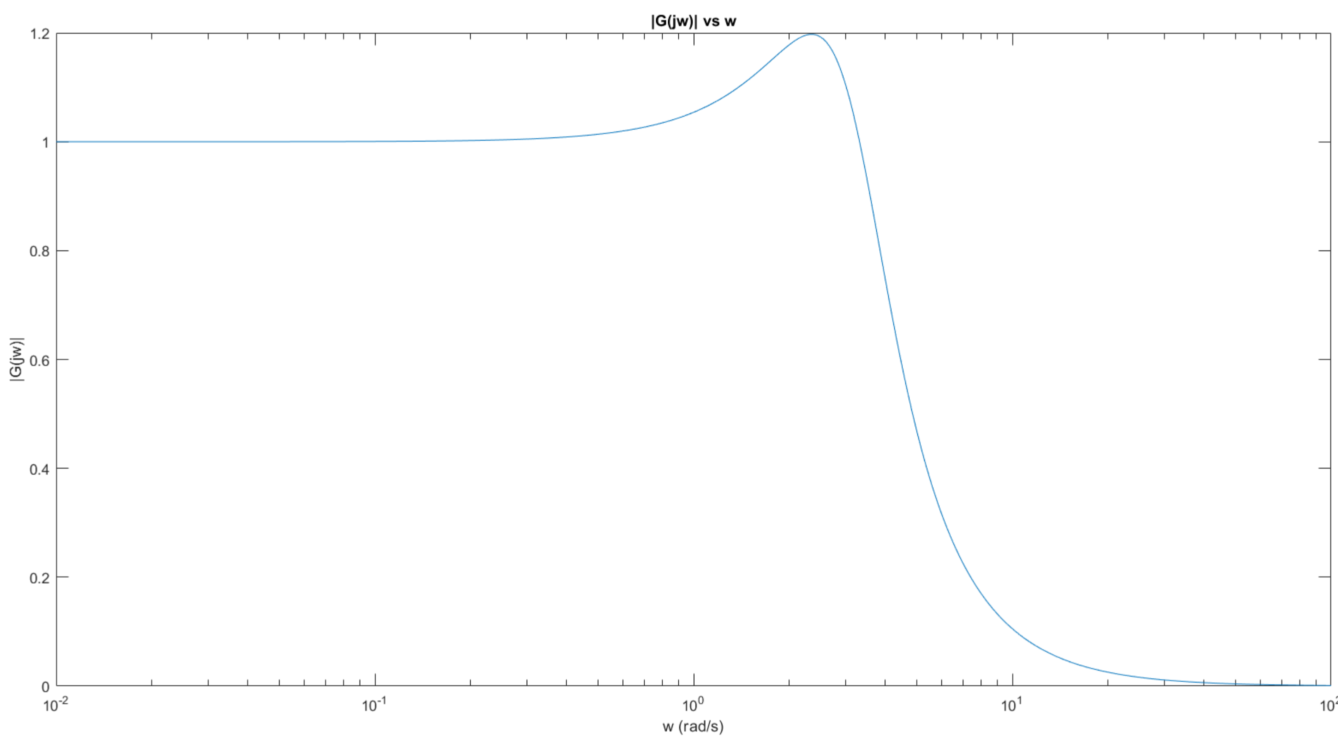
② $\cancel{R} - V_o(C_2\omega j) = V_1\cancel{/R}$

$-V_o R^2(C_2\omega j)\left(\frac{3}{\cancel{R}} + j\omega C_1\right) - \frac{V_o}{\cancel{R}} = \frac{V_{in}}{\cancel{R}}$

$-V_o R C_2 \omega j\, 3 + V_o R^2 \omega^2 C_1 C_2 - V_o = V_{in}$

$$G(j\omega) = \frac{V_o}{V_{in}} = \frac{-1}{1 - R^2 C_1 C_2 \omega^2 + 3RC_2\omega j}\Bigg|_{\substack{R=1 \\ C_1=1 \\ C_2=.1}} = \frac{-1}{1 - .1\omega^2 + .3\omega}$$

$$|G(j\omega)| = \left|\frac{V_o}{V_{in}}\right| = \frac{1}{\sqrt{(1-.1\omega^2)^2 + (.3\omega)^2}}$$



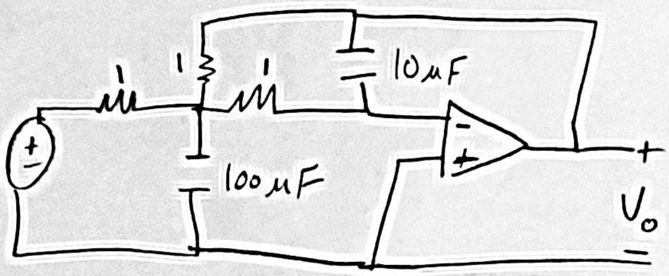
Graph 1: Pre-lab Plot of |G(jw)| using MATLAB

2. Frequency scale your circuit by $\omega_o = 10^4$

a. Draw the result circuit
b. Find the transfer function
c. Sketch the corresponding frequency response

2. Frequency Scale of $W_o = 10^4$

$R' = R$, $C' = C/W_o$



b.

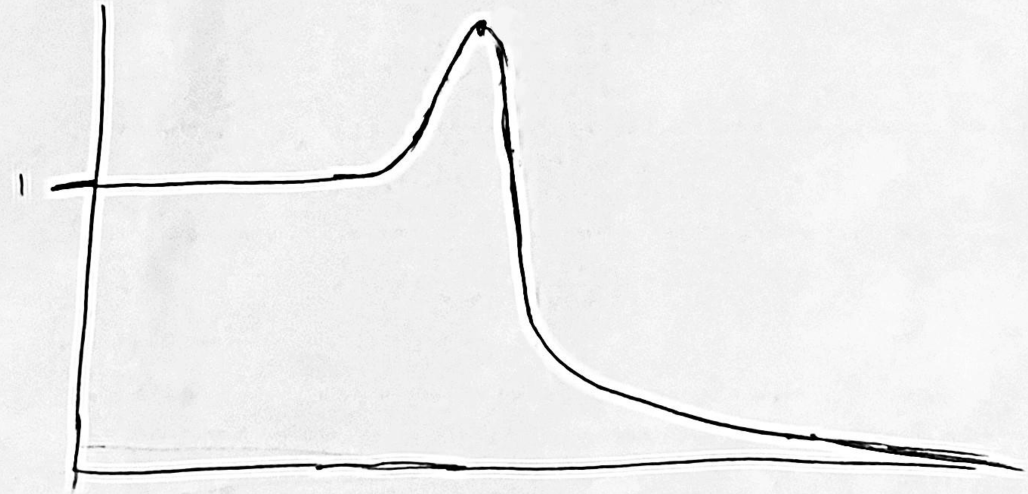
$$G(jw) = \frac{-1}{1 - R^2 C_1 C_2 W^2 + 3RC_2 W j}$$

$R = 1$
$C_1 = 100\mu F$
$C_2 = 10\mu F$

$$G(jw) = \frac{-1}{1 - 1\times10^{-9} w^2 + 30\times10^{-6} w j}$$

$$|G(jw)| = \frac{1}{\sqrt{(1-10^{-9}w^2)^2 + (30\times10^{-6} w)^2}}$$

c.



3. Magnitude scale your circuit (2) by $R_o = 10^3$

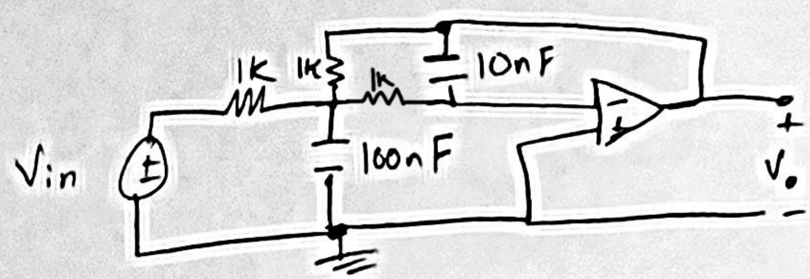
a. Draw the result circuit

b. Find the transfer function

c. Use any plotting program to obtain a graph of $|G(j\omega)|$ from $\omega = 10^2$ to $\omega = 10^6$ on a log scale.

d. Obtain the 3dB frequency from your graph

3. Magnitude Scale by $R_o = 10^3$ $\quad R' = R \cdot R_o \quad C' = C/R_o$

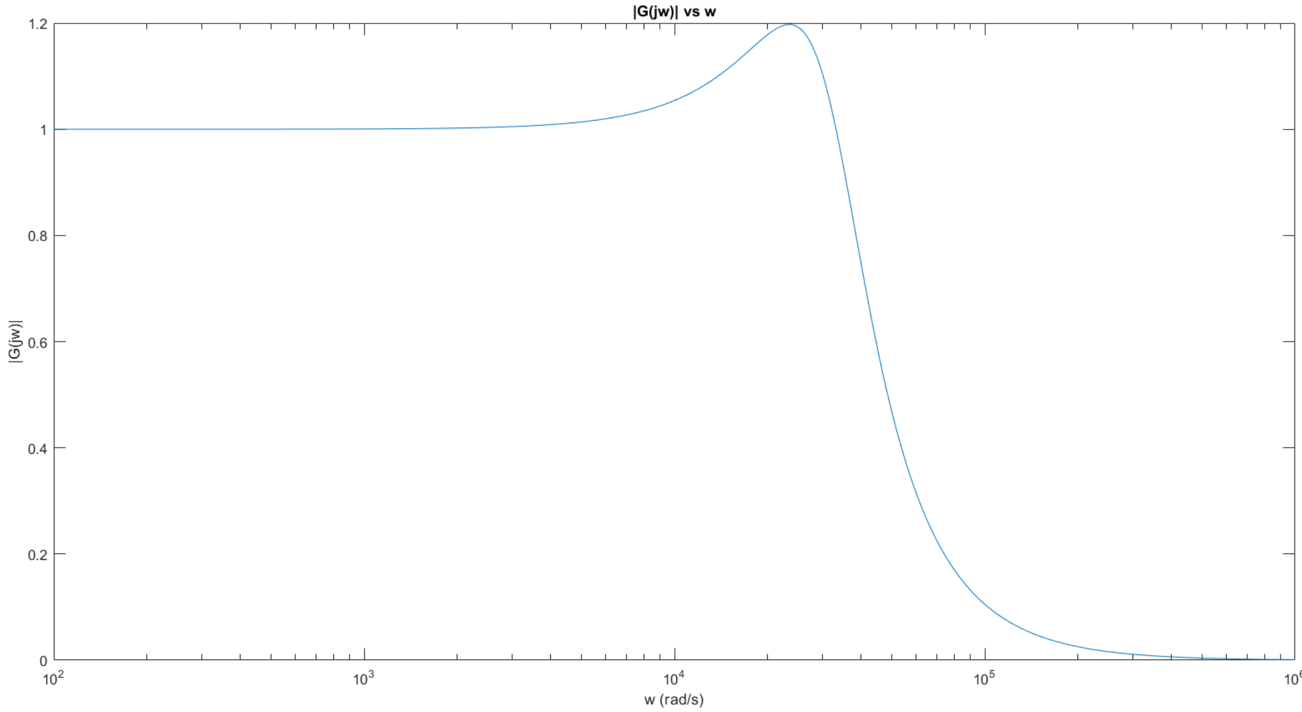


b. $$G(j\omega) = \frac{-1}{1 - R^2 C_1 C_2 \omega^2 + 3 R C_2 \omega j}$$

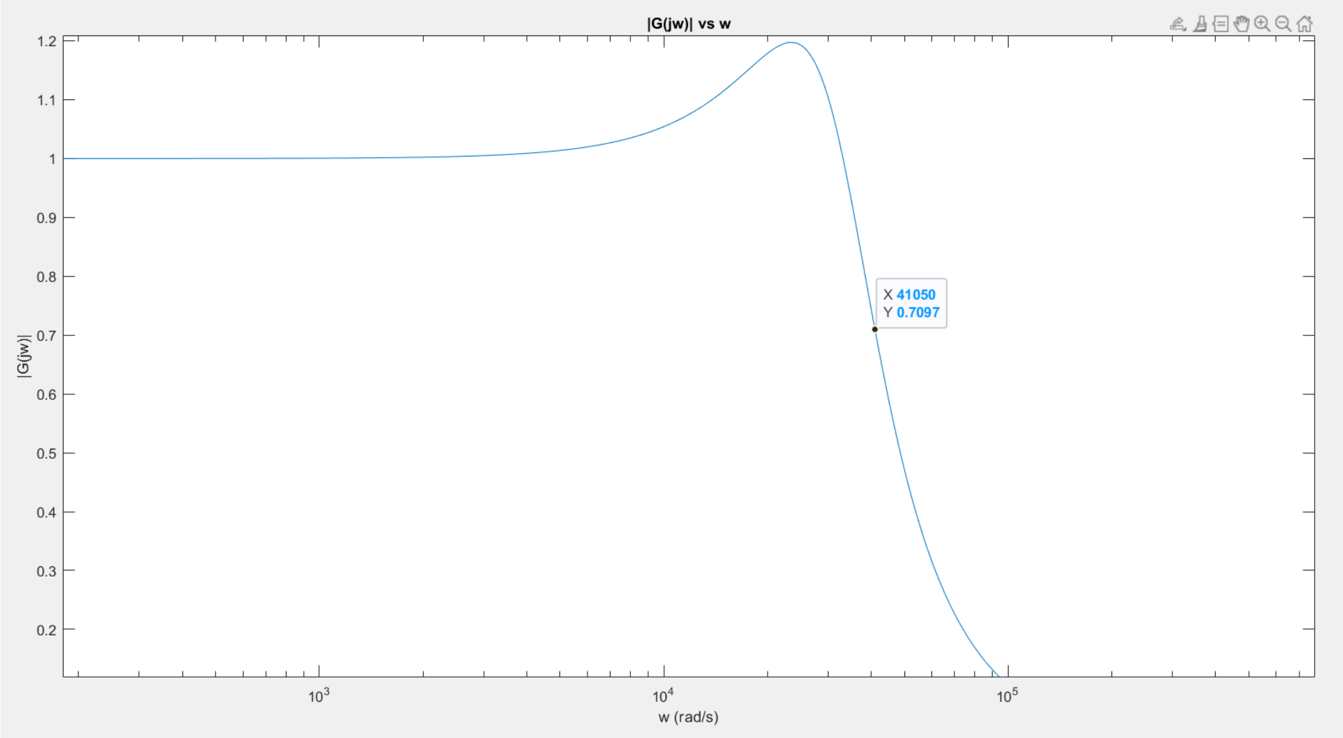
$R = 1K$
$C_1 = 100nF$
$C_2 = 10nF$

$$G(j\omega) = \frac{-1}{1 - 10^{-9}\omega^2 + 30 \cdot 10^{-6}\omega j}$$

$$|G(j\omega)| = \frac{1}{\sqrt{(1 - 10^{-9}\omega^2)^2 + (30 \cdot 10^{-6}\omega)^2}}$$



Graph 2: Pre-lab Plot of |G(jw)| using MATLAB



Graph 3: 3dB Frequency Estimation using MATLAB Plot

By using the graph, the 3dB frequency can be estimated at approximately 41050 rads/s however this can be more accurate if the equation is solved for the frequency at 3dB. By solving the equation, the 3dB frequency is found to be 41125 rads/s. The difference is due to MATLAB skipping over points in the plot which causes 41050 rads/s to be the closest point. However, we will be using the angular frequency 41125 rads/s as our 3dB frequency due to the increased accuracy.

Procedure

We started the lab by creating the circuit shown in figure 1 and measuring the amplitude of the voltage response of the output of the op amp. We used a input voltage source with a amplitude of 5V and we used the Vcc of the operational amplkifer to be +10V and -10V respectivly.

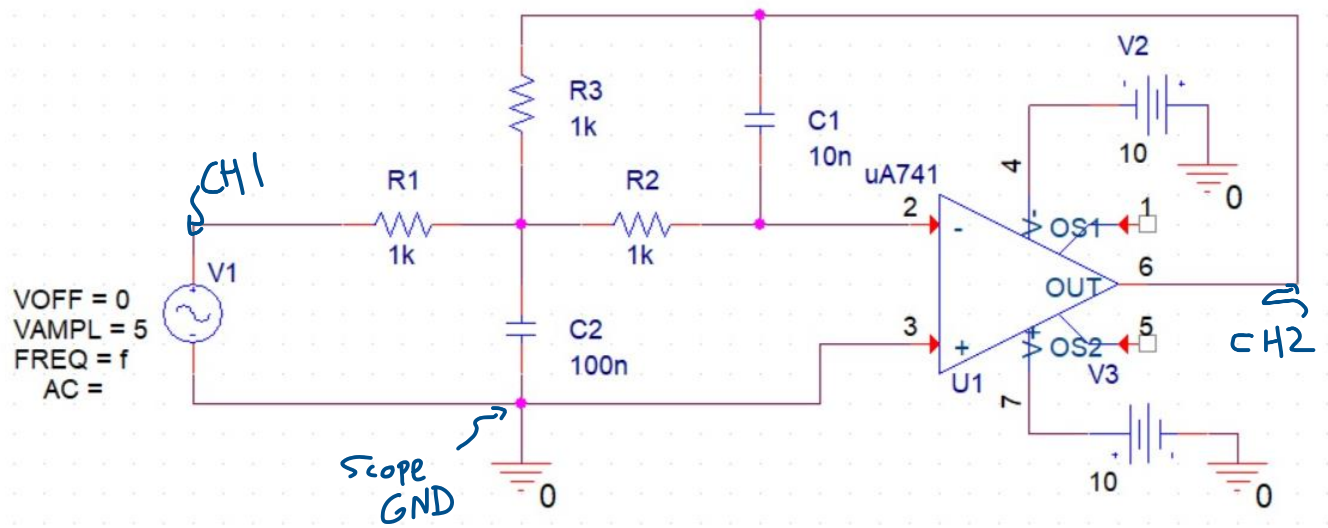


Figure 1: PSPICE Circuit Diagram

Results

When $\omega = 10^2$, or f = 15.9155 Hz

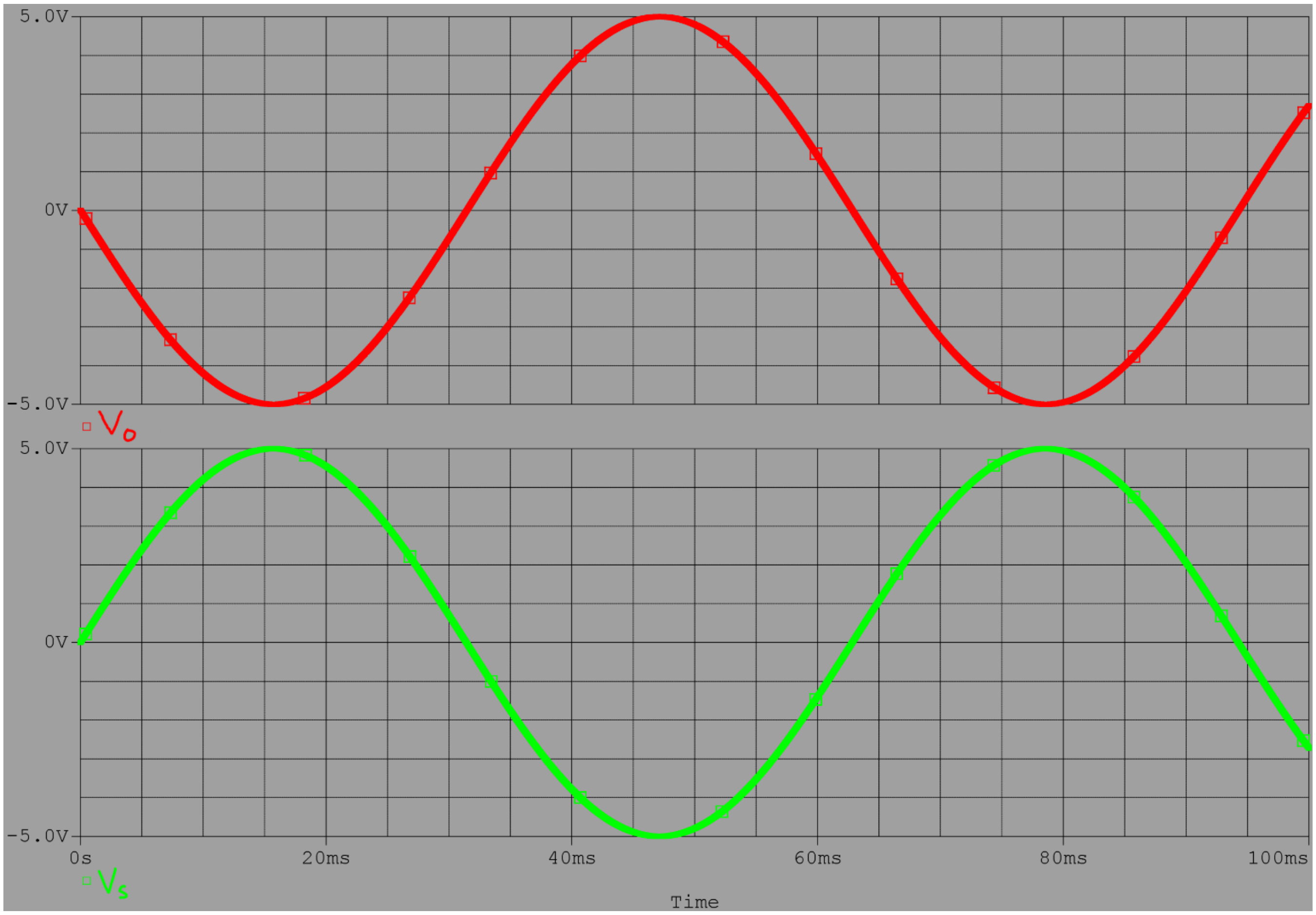


Figure 2: PSPICE Output When f = 15.9155Hz

Measurement	Value
1/Period(V(R1:1))	15.91550
MAX(V(R1:1))	5.00000
MAX(V(R3:2))	5.00025
abs(MAX(V(R3:2)))/(abs(MAX(V(R1:1))))	1.00005

Figure 3:PSPICE Measurement Output When f = 15.91550 Hz

When $\omega = 10^3$, or f = 159.1549 Hz

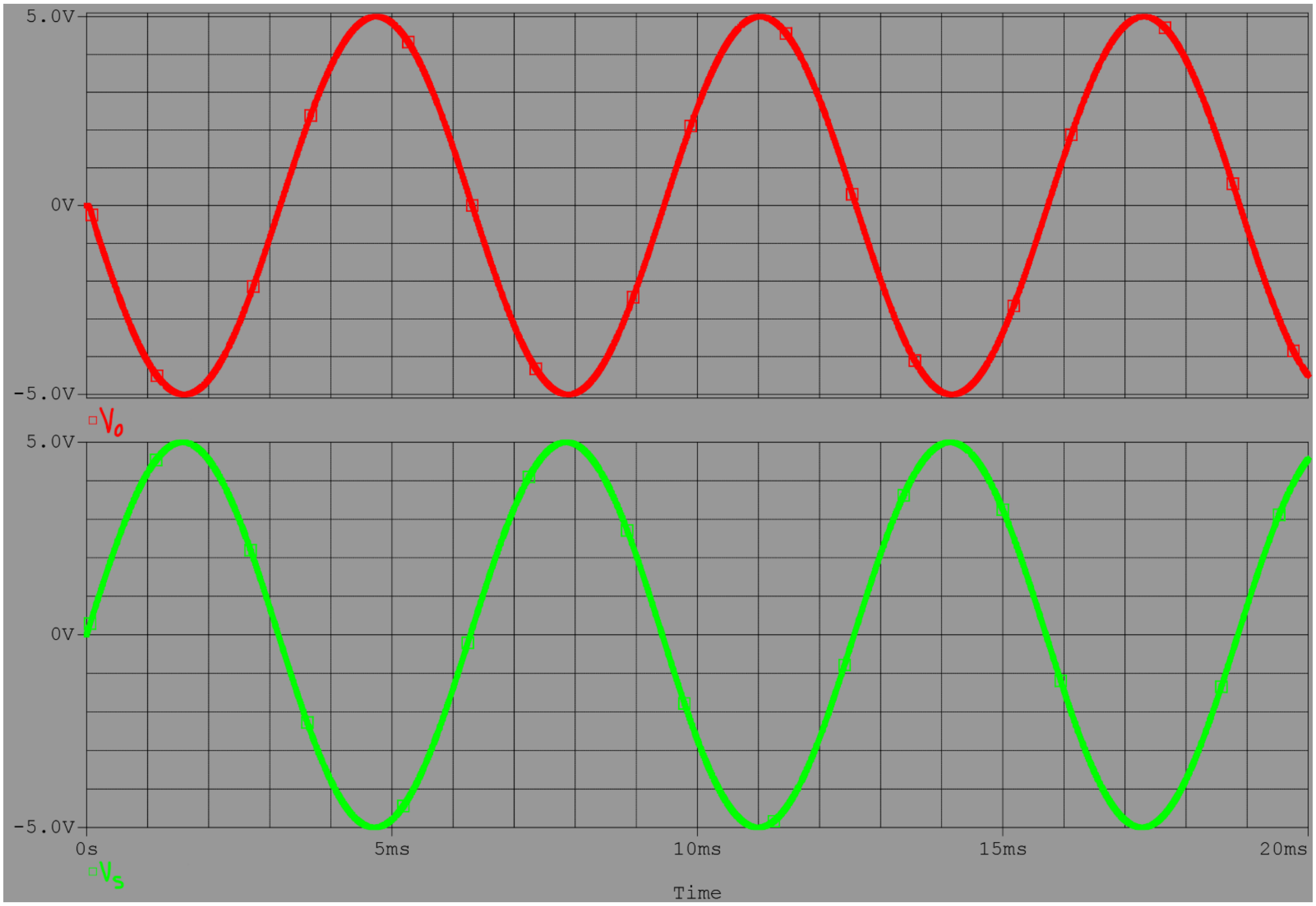


Figure 4: PSPICE Output When f = 159.1549Hz

Measurement	Value
1/Period(V(R1:1))	159.15490
MAX(V(R1:1))	5.00000
MAX(V(R3:2))	5.00303
abs(MAX(V(R3:2)))/(abs(MAX(V(R1:1))))	1.00061

Figure 5:PSPICE Measurement Output When f = 159.1549 Hz

When $\omega = 10^4$, or f = 1.5915kHz

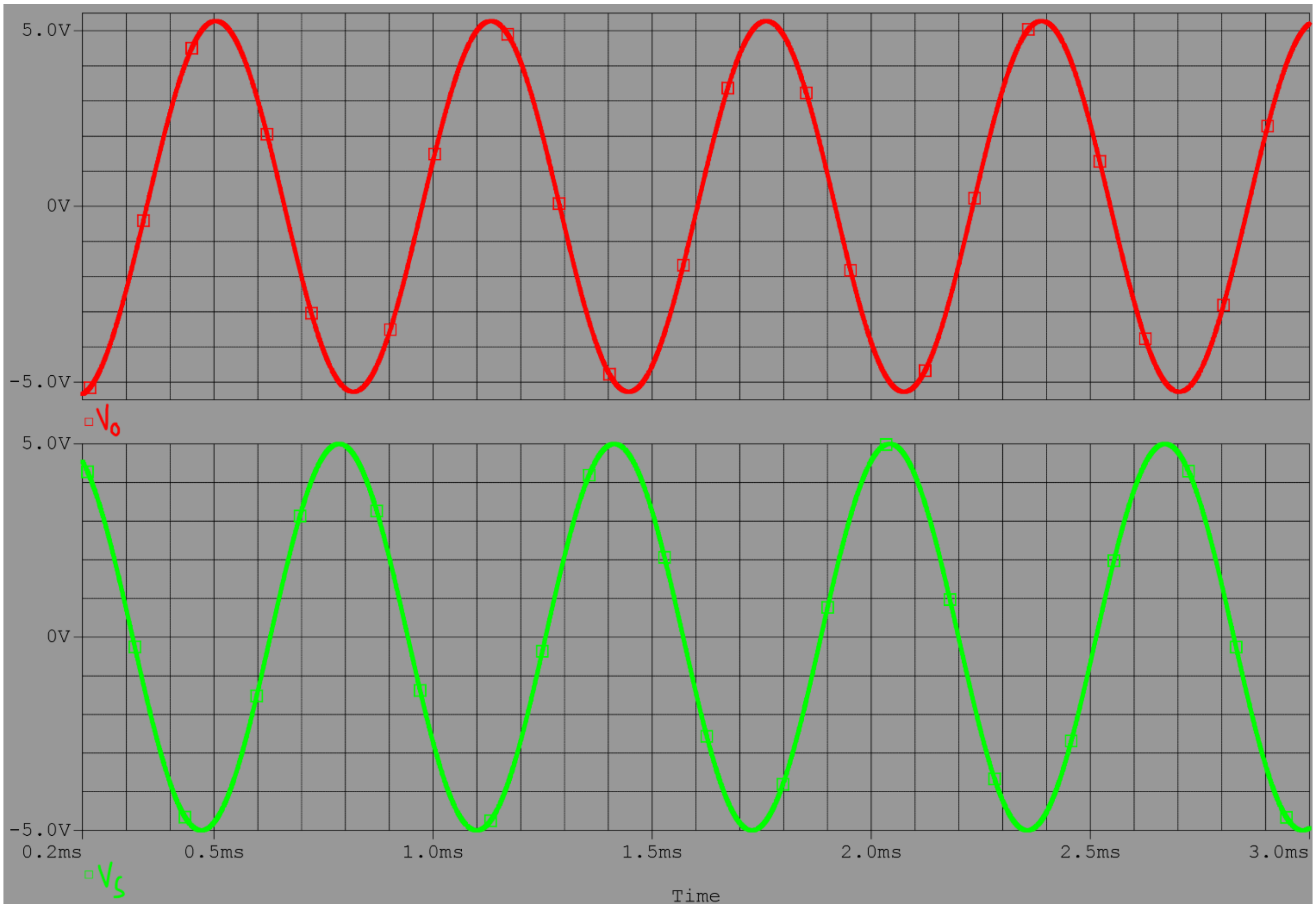


Figure 6: PSPICE Output When f = 1.5915kHz

Measurement	Value
1/Period(V(R1:1))	1.59150k
abs(MAX(V(R3:2)))/(abs(MAX(V(R1:...	1.05541
MAX(V(R1:1))	5.00000
MAX(V(R3:2))	5.27703

Figure 7: PSPICE Measurement Output When f = 1.5915kHz

When $\omega = 2.4 \times 10^4$, or f = 3.8197kHz

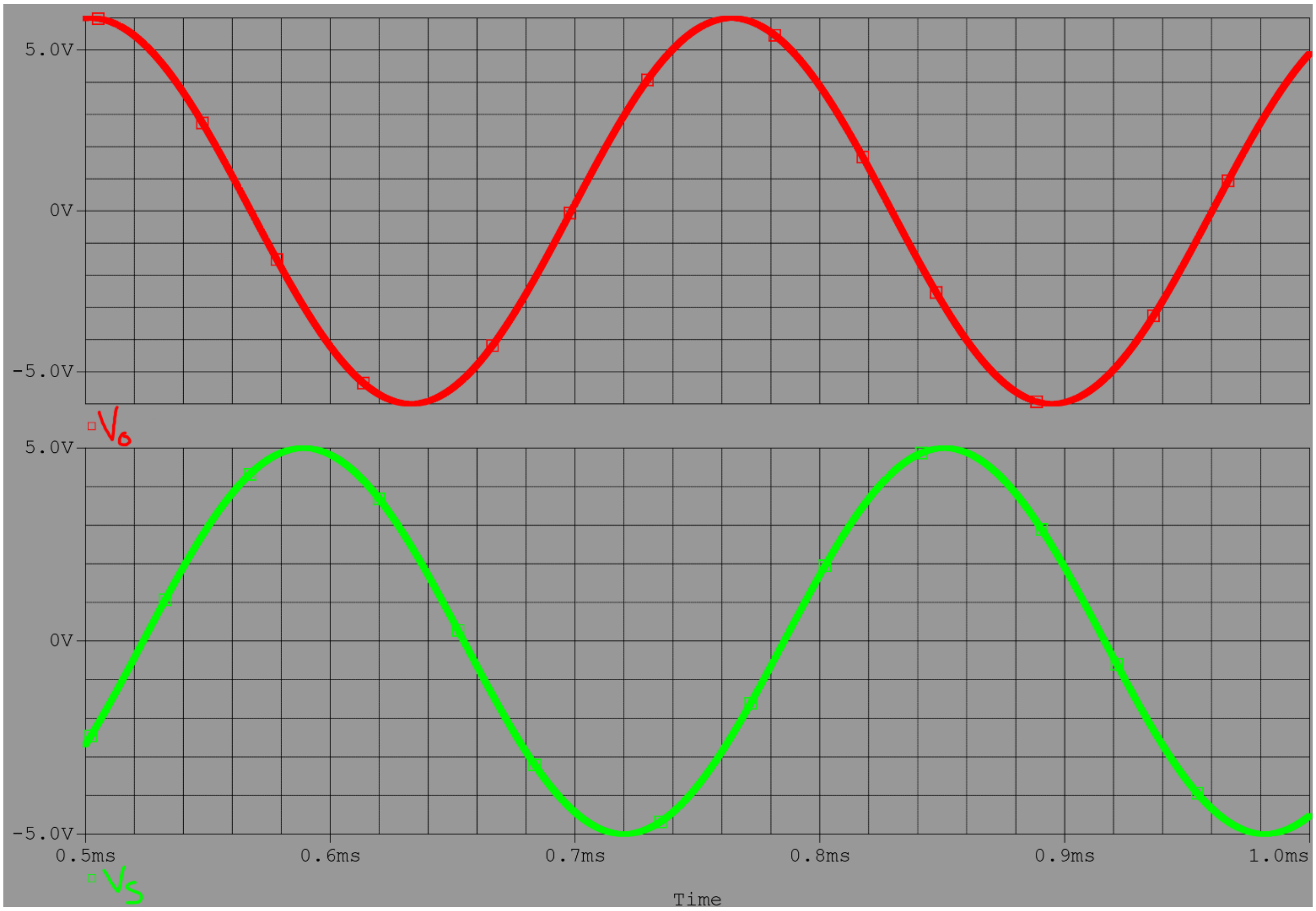


Figure 8: PSPICE Output When f = 3.8197kHz

Measurement	Value
1/Period(V(R1:1))	3.81970k
abs(MAX(V(R3:2)))/(abs(MAX(V(R1:1))))	1.19928
MAX(V(R1:1))	5.00000
MAX(V(R3:2))	5.99638

Figure 9: PSPICE Measurement Output When f = 3.8197kHz

When $\omega = 4.084 \times 10^4$, or f = 6.5kHz

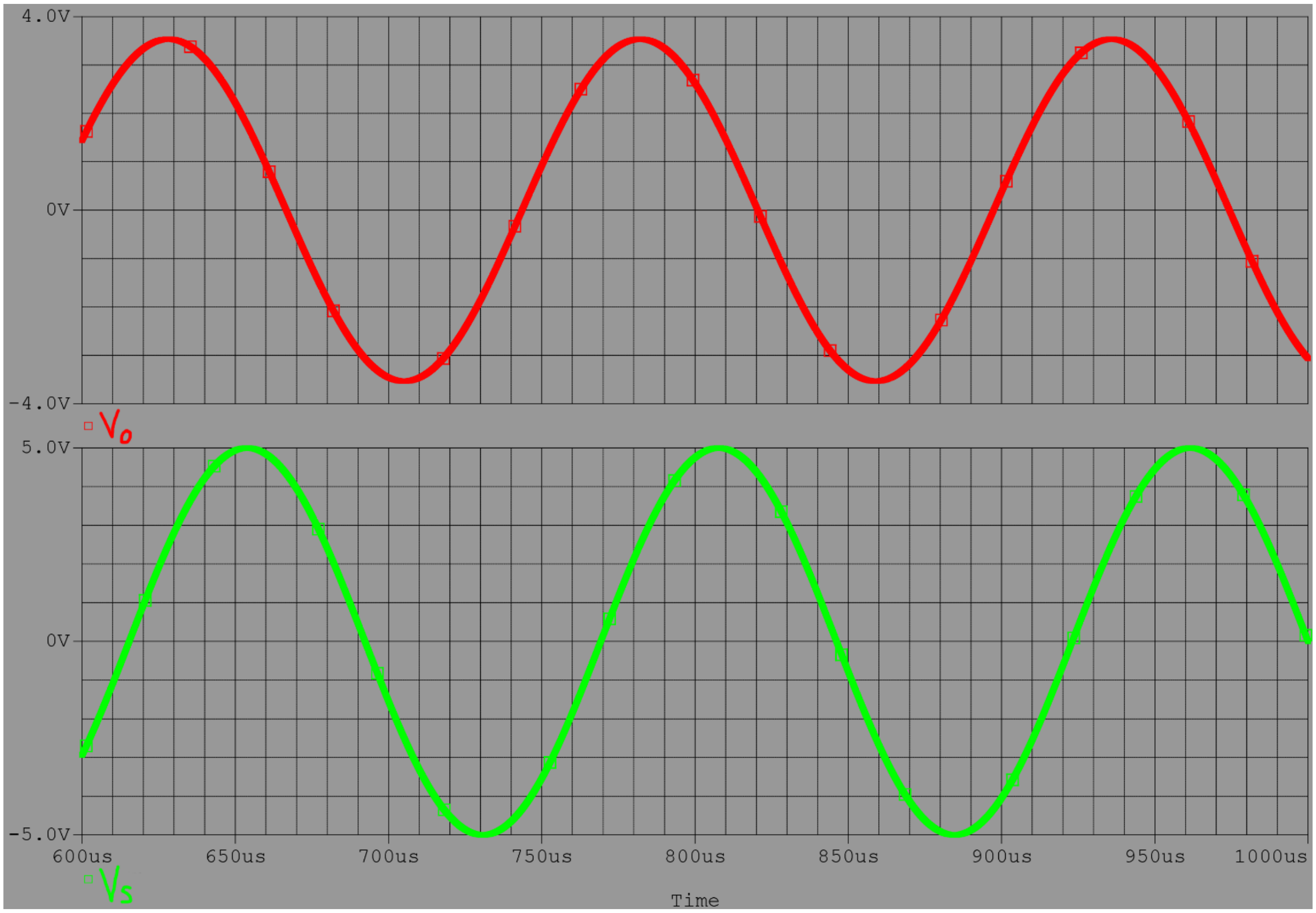


Figure 10: PSPICE Output When f = 6.5kHz

Measurement	Value
1/Period(V(R1:1))	6.50000k
abs(MAX(V(R3:2)))/(abs(MAX(V(R1:...	707.24930m
MAX(V(R1:1))	5.00000
MAX(V(R3:2))	3.53625

Figure 11: PSPICE Measurement Output When f = 6.5kHz

When $\omega = 10^5$, or f = 15.9155kHz

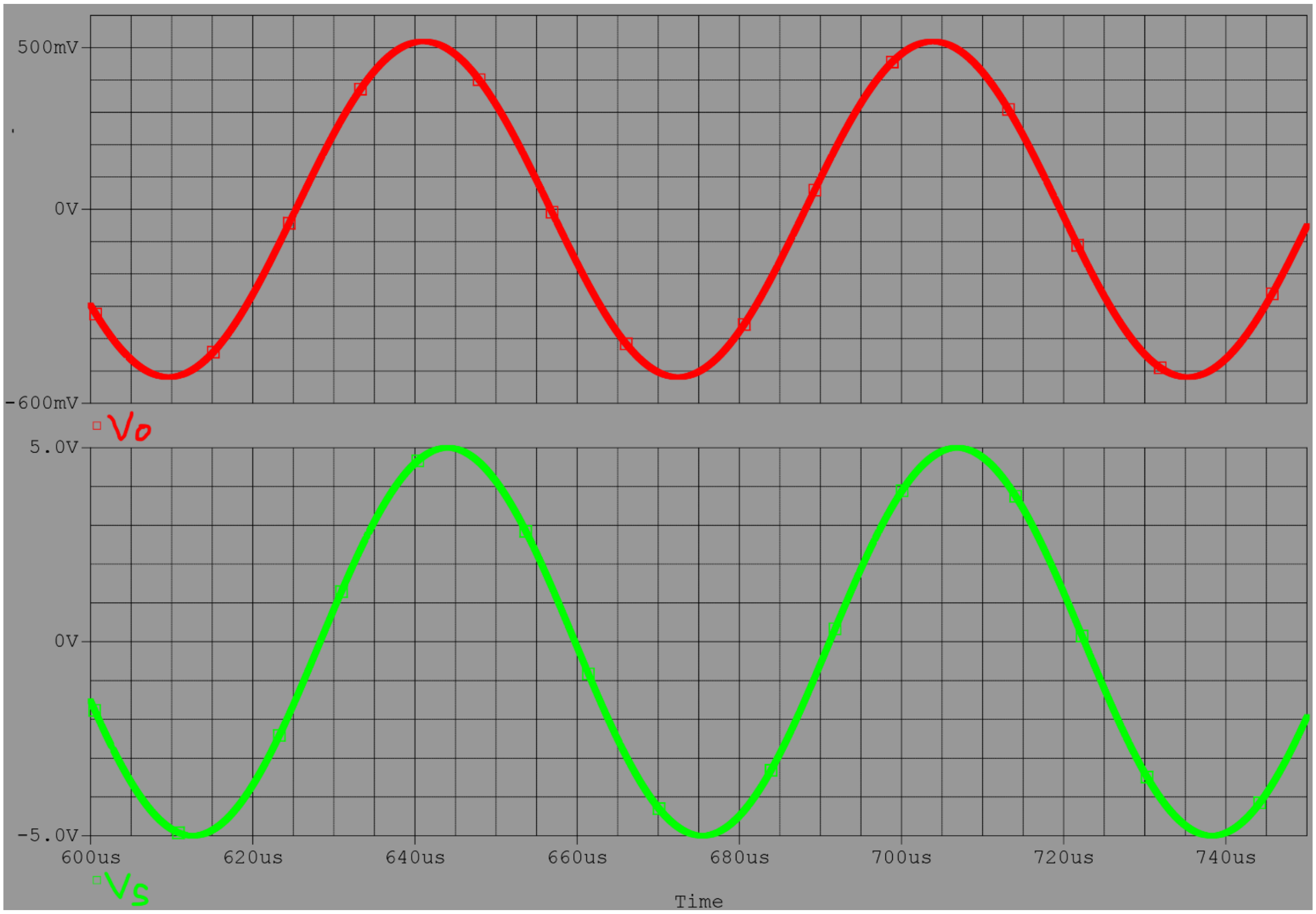


Figure 12: PSPICE Output When f = 15.9155kHz

Measurement	Value
MAX(V(R3:2))	519.45585m
MAX(V(R1:1))	5.00000
abs(MAX(V(R3:2)))/(abs(MAX(V(R1:...	103.89117m
1/Period(V(R1:1))	15.91550k

Figure 13: PSPICE Measurement Output When f = 15.9155kHz

When $\omega = 10^6$, or f = 159.155kHz

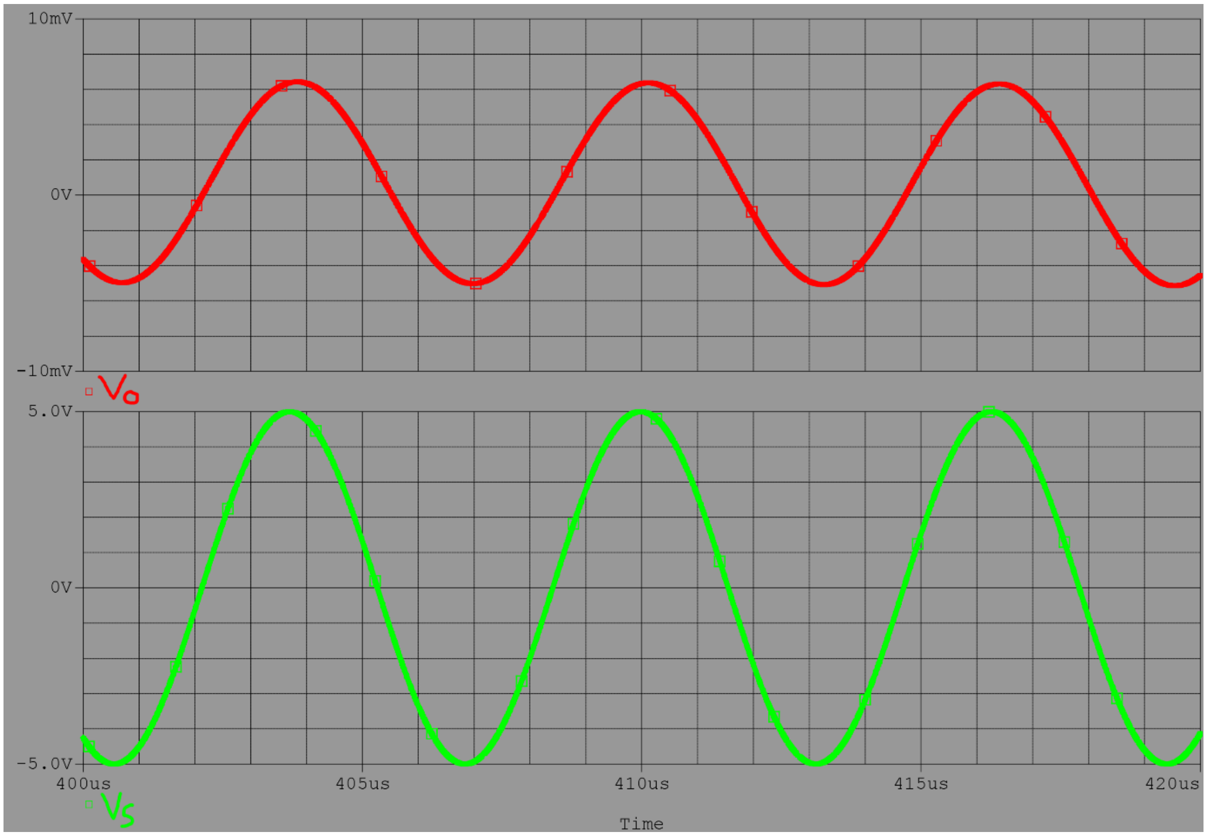


Figure 14: PSPICE Output When f = 159.155kHz

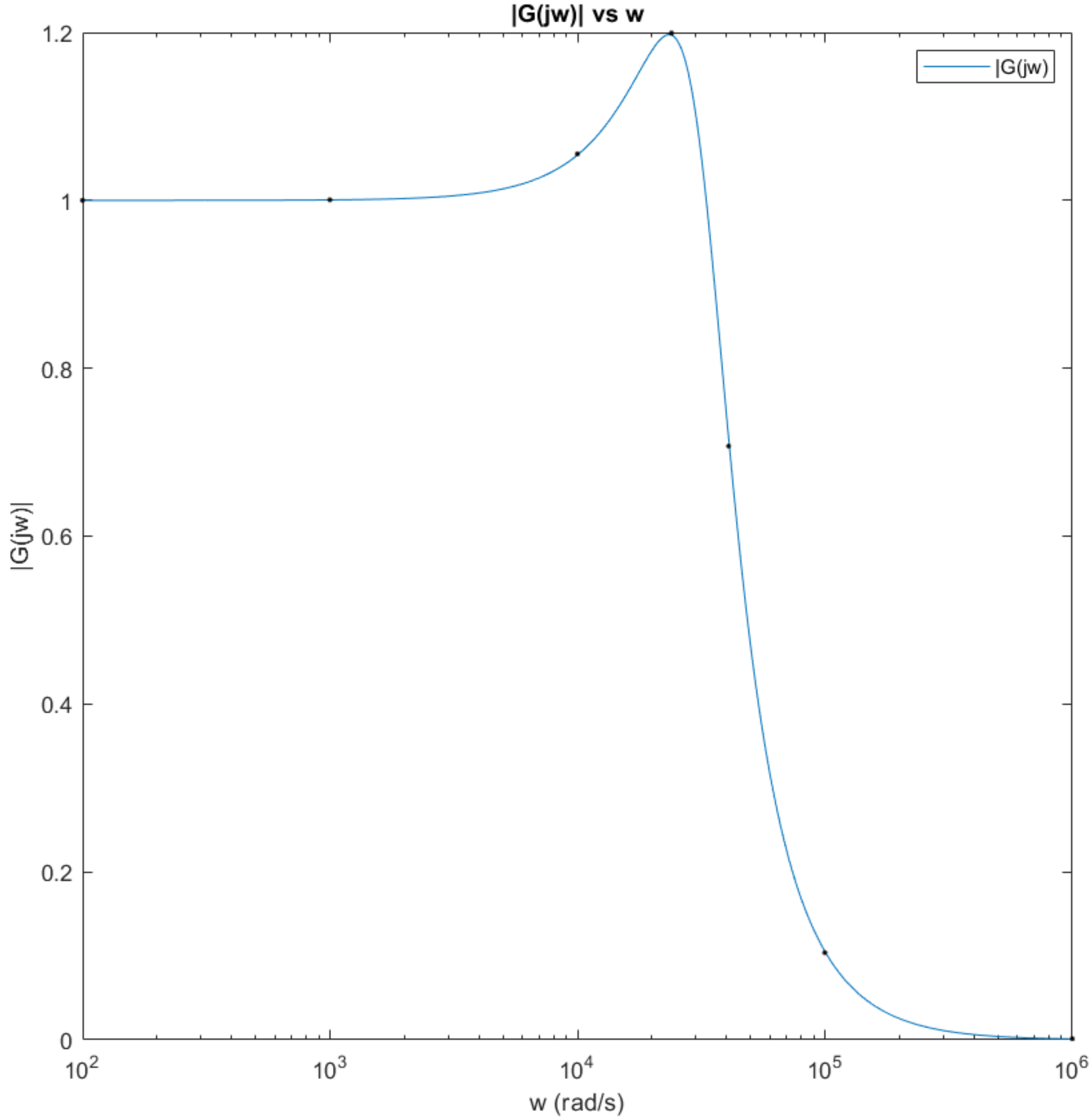
Measurement	Value
1/Period(V(R1:1))	159.15500k
abs(MAX(V(R3:2)))/(abs(MAX(V(R1:1))))	1.28655m
MAX(V(R1:1))	5.00000
MAX(V(R3:2))	6.43276m

Figure 15: PSPICE Measurement Output When f = 159.155kHz

Table Compiling All Data

f [Hz]	$\|V_S\|$ [V]	$\|V_O\|$ [V]	|G(jw)|
15.9155	5	5.00025	1.00005
159.1549	5	5.00303	1.00061
1.5915k	5	5.27703	1.05541
3.8197k	5	5.99638	1.19928
6.5k	5	3.53625	.707249
15.9155k	5	.519456	.103891
159.155k	5	.006433	.001287

Table 1: Table Compiling All Results



Graph 4: MATLAB Plot With Lab Data In Black

3dB Frequency

The gain at f = 6.5kHz is incredibly close at .707249 and was used as our 3dB frequency for out PSPICE simulation.

General Analysis

When comparing our collected data to the plot on MATLAB, we could see there was a slight percent error. The error is not significant and would be reasonable under situations of rounding. This is expected for a PSPICE simulation since it is based on theorical calculations.

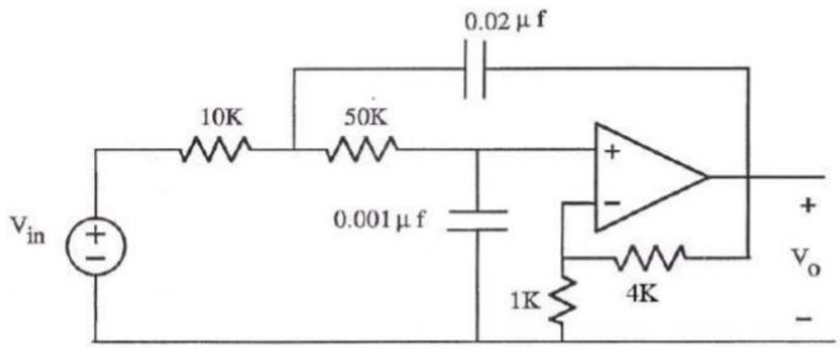
Problems

1. Compare calculated and measured 3dB frequencies.

    In the prelab we found that the 3dB frequency was about 6.545kHz and throughout the course of the lab, we determined it to be about 6.5kHz. This results in a percent difference of 0.69%. The low percent difference as mentioned before, is due to the use of PSPICE which is based heavily on theorical calculations.

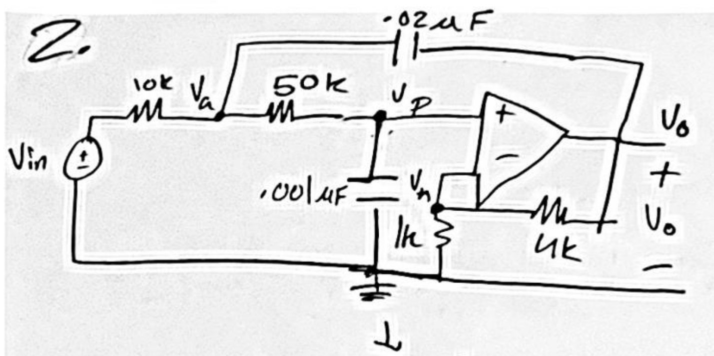
2.

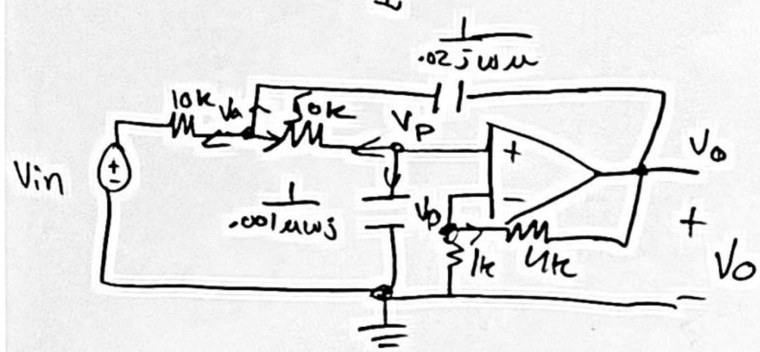
2. Write and put in matrix form the node equations of the circuit



2.

$V_P = V_n$





① $\left(\frac{V_a - V_{in}}{10k} + \frac{V_a - V_P}{50k} + \frac{V_a - V_o}{\frac{1}{.02\mu j\omega}}\right) 50k = 0$

$$5V_a - 5v_{in} + V_a - V_p + (V_a - V_o)(.001j\omega) = 0$$

① $$(6 + .001j\omega)V_a + (-1)V_p + (-.001j\omega)V_o = 5v_{in}$$

② $$\left(\frac{V_p - V_a}{50k} + \frac{V_p}{\frac{1}{.001\mu\omega j}}\right)50k = 0$$

$$V_p - V_a + (.00005\omega j)V_p = 0$$

② $$(-1)V_a + (1 + 5\times10^{-5}\omega j)V_p + (0)V_o = 0$$

③ $$\left(\frac{V_p}{1k} + \frac{V_p - V_o}{4k}\right)4k = 0$$

$$4V_p + V_p - V_o = 0$$

$$5V_p - V_o = 0$$

③ $$(0)V_a + (5)V_p + (-1)V_o = 0$$

$$\begin{bmatrix} (6 + .001j\omega) & (-1) & (-.001j\omega) \\ (-1) & (1 + 5\times10^{-5}\omega j) & (0) \\ (0) & (5) & (-1) \end{bmatrix} \begin{bmatrix} V_a \\ V_p \\ V_o \end{bmatrix} = \begin{bmatrix} 5v_{in} \\ 0 \\ 0 \end{bmatrix}$$