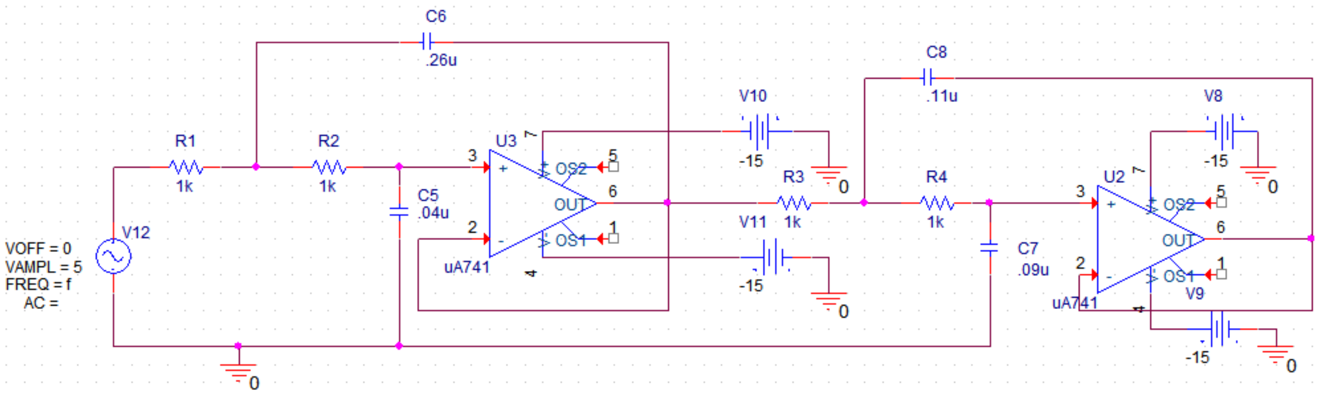
ECE 2101L Lab #7

Cascaded 2nd Order Sections



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Objective

The objective of the lab is to be able to calculate and analyze the frequency response of a cascaded 2nd order active circuit and find characteristics such as the 3dB frequency. Finally, the circuit's functionality must be demonstrated using simulation or other means.

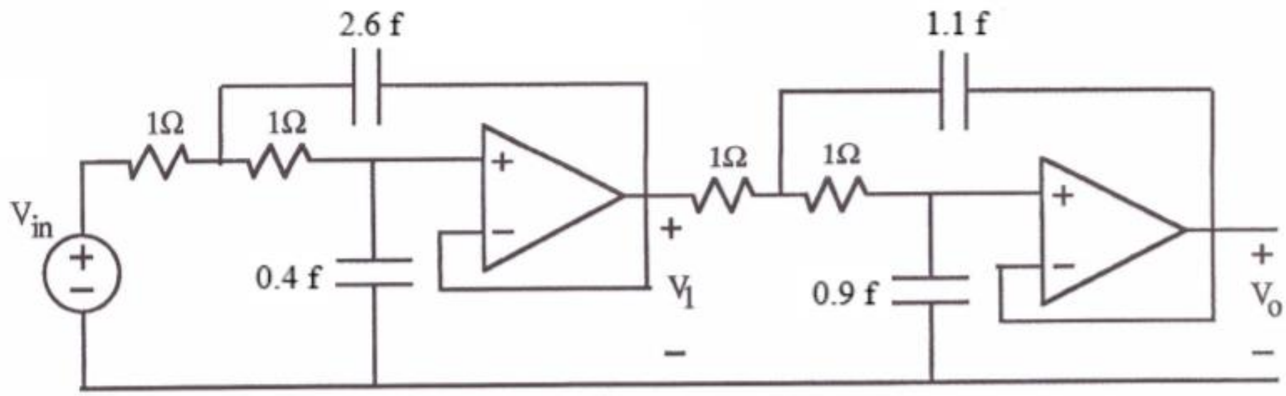
Materials

The necessary equipment needed for the lab are as follows

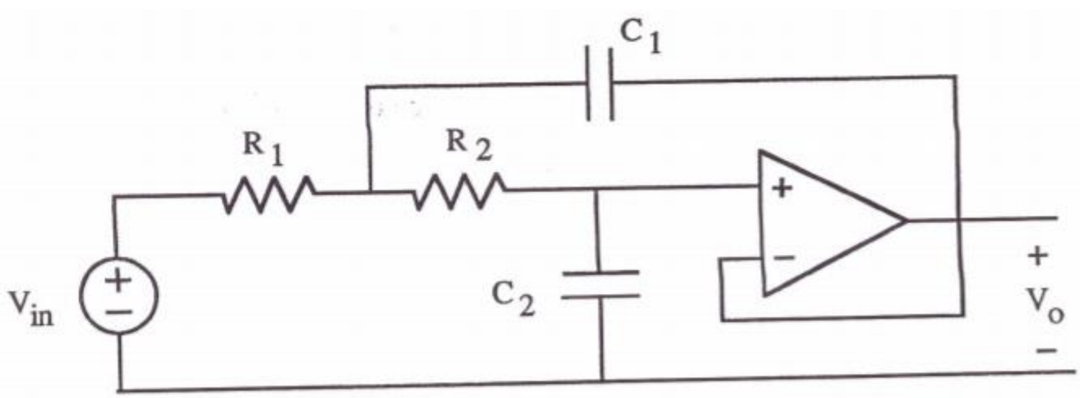
1. Breadboard
2. 4 BNC Clip Connectors
3. Clip Leads
4. .26µF, .04µF, .11µF, .09µF Nonpolar Capacitors
5. 4 1kΩ Resistors
6. 2 741 Op Amp
7. LCR Meter
8. Digital Multimeter
9. Oscilloscope
10. Function Generator

<u>Pre-Lab</u>

1. To design the cascaded circuit to be built in the lab – which with normalized elements is



a. Make use of the fact that the gain of each of the sections



is

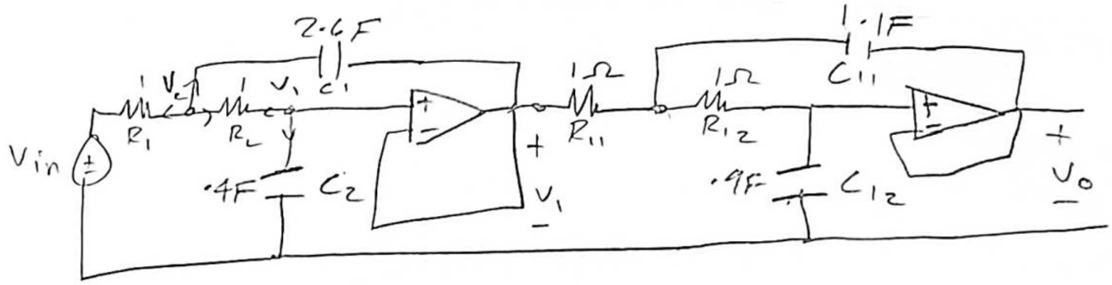
$$G(j\omega) = \frac{\dfrac{1}{R_1 R_2 C_1 C_2}}{\dfrac{1}{R_1 R_2 C_1 C_2} - \omega^2 + j\omega\left(\dfrac{1}{R_1 C_1} + \dfrac{1}{R_2 C_1}\right)}$$

to find the transfer functions

(i) $G_1(j\omega) = V_1(j\omega) / V_{in}$

(ii) $G_2(j\omega) = V_o(j\omega) / V_1(j\omega)$

(iii) $G_o(j\omega) = G_1(j\omega) * G_2(j\omega) = V_o(j\omega) / V_{in}$



1.

(1) $$\frac{V_1 - V_2}{R_2} + \frac{V_1}{\frac{1}{j\omega C_2}} = 0 = \frac{V_1}{R_2} - \frac{V_2}{R_2} + V_1(j\omega C_2) = 0$$

(1) $$(1 + R_2 \omega C_2 j)V_1 + (-1)V_2 = 0$$

(2) $$\frac{V_2 - V_{in}}{R_1} + \frac{V_2 - V_1}{R_2} + \frac{V_2 - V_1}{\frac{1}{j\omega C_1}} = 0$$

(2) $$R_2 V_2 - R_2 V_{in} + R_1 V_2 - R_1 V_1 + R_2 R_1 j\omega C_1 (V_2 - V_1) = 0$$

(2) $$(-R_1 - R_2 R_1 j\omega C_1)V_1 + (R_2 + R_1 + R_2 R_1 j\omega C_1)V_2 = R_2 V_{in}$$

$$(-R_1 - R_2 R_1 j\omega C_1)V_1 + (R_2 + R_1 + R_2 R_1 j\omega C_1)(1 + R_2 \omega C_2 j)V_1 = R_2 V_{in}$$

$$G_1(j\omega) = \frac{R_2}{(-R_1 - R_2 R_1 j\omega C_1) + (R_2 + R_2^2 \omega C_2 j + R_1 + R_1 R_2 \omega C_2 j + R_2 R_1 j\omega C_1 + R_2^2 R_1 j^2 \omega^2 C_1 C_2}$$

$$= \frac{R_2}{\cancel{-R_1} - \cancel{R_2 R_1 j\omega C_1} + R_2 + R_2^2 \omega C_2 j + \cancel{R_1} + R_1 R_2 \omega C_2 j + \cancel{R_2 R_1 j\omega C_1} - R_2^2 R_1 \omega^2 C_1 C_2}$$

$$= \frac{1}{1 + R_2 \omega C_2 j + R_1 \omega C_2 j - R_2 R_1 \omega^2 C_1 C_2}$$

$$= \frac{1}{(1 - R_2 R_1 \omega^2 C_1 C_2) + j\omega(R_2 C_2 + R_1 C_2)} \cdot \frac{\frac{1}{R_1 R_2 C_1 C_2}}{\frac{1}{R_1 R_2 C_1 C_2}}$$

$$G(j\omega) = \frac{\frac{1}{R_1 R_2 C_1 C_2}}{\frac{1}{R_1 R_2 C_1 C_2} - \omega^2 + j\omega\left(\frac{1}{R_1 C_1} + \frac{1}{R_2 C_2}\right)}$$

$$G_1(j\omega) = \frac{.9615}{.9615 - \omega^2 + j\omega(.7692)}$$

$$G_2(j\omega) = \frac{1.0101}{1.0101 - \omega^2 + j\omega(1.8182)}$$

$$G_0(j\omega) = \frac{.9615}{(.9615 - \omega^2 + j\omega \cdot .7692)} \cdot \frac{1.0101}{(1.0101 - \omega^2 + j\omega \cdot 1.8182)}$$

$$G_0(j\omega) = \frac{.9712}{(.9712 - .9615\omega^2 + j\omega 1.748) + (1.0101 - \omega^2) + \omega^4 - j\omega^3 1.8182}$$

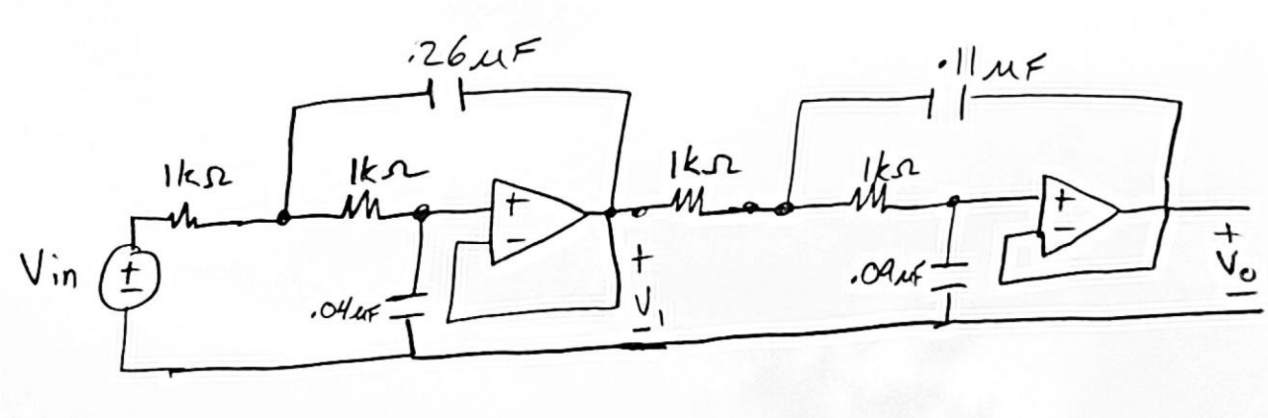
Cont ↓

$$j\omega .777 - .7692 j\omega^3 - \omega^2 1.399$$

$$G_0(j\omega) = \frac{.9712}{\omega^4 - 3.37\omega^2 + .9712 + j(-2.5874\omega^3 + 2.526\omega)}$$

b. Then frequency scale by $\omega_o = 10^4$ and magnitude scale by $R_o = 10^3$ the elements in the circuit. Draw the final circuit.

Component	Scale $W_o = 10^4$	Scale $R_o = 10^3$
R_1	1	1k
R_2	1	1k
R_{11}	1	1k
R_{12}	1	1k
C_1	260 µF	.26 µF
C_2	40 µF	.04 µF
C_{11}	110 µF	.11 µF
C_{12}	90 µF	.09 µF



2. Obtain a single graph containing the magnitudes of all three of the transfer functions $|G_1(j\omega)|$, $|G_2(j\omega)|$ and $|G_o(j\omega)|$ of your scaled circuit. Calculate the 3dB frequency for the first section $|G_1(j\omega)|$ and the overall $|G_o(j\omega)|$, and include them on the graph.

Scaled Circuit Gain

$$G_1(j\omega) = \frac{9.615 \times 10^7}{9.615 \times 10^7 - \omega^2 + j\omega(7.69 \times 10^3)}$$

$$|G_1(j\omega)| = \frac{9.615 \times 10^7}{\sqrt{(9.615 \times 10^7 - \omega^2)^2 + (\omega \cdot 7.69 \times 10^3)^2}}$$

$$|G_2(j\omega)| = \frac{1.0101 \times 10^8}{\sqrt{(1.0101 \times 10^8 - \omega^2)^2 + (\omega \cdot 1.8181 \times 10^4)^2}}$$

$$|G_o j\omega| = \frac{9.712 \times 10^{15}}{\sqrt{((1.01 \times 10^8 - \omega^2)^2 + (\omega \cdot 8181 \times 10^4)^2)((9.615 \times 10^7 - \omega^2)^2 + (\omega \cdot 7.69 \times 10^3)^2)}}$$

Solving For 3dB in MATLAB

$$\frac{1}{\sqrt{2}} = |G_1(j\omega)|, \quad \omega = 13547.5 \text{ rad/s}$$

$$\frac{1}{\sqrt{2}} = |G_o(j\omega)|, = \omega = 9909.2 \text{ rad/s}$$

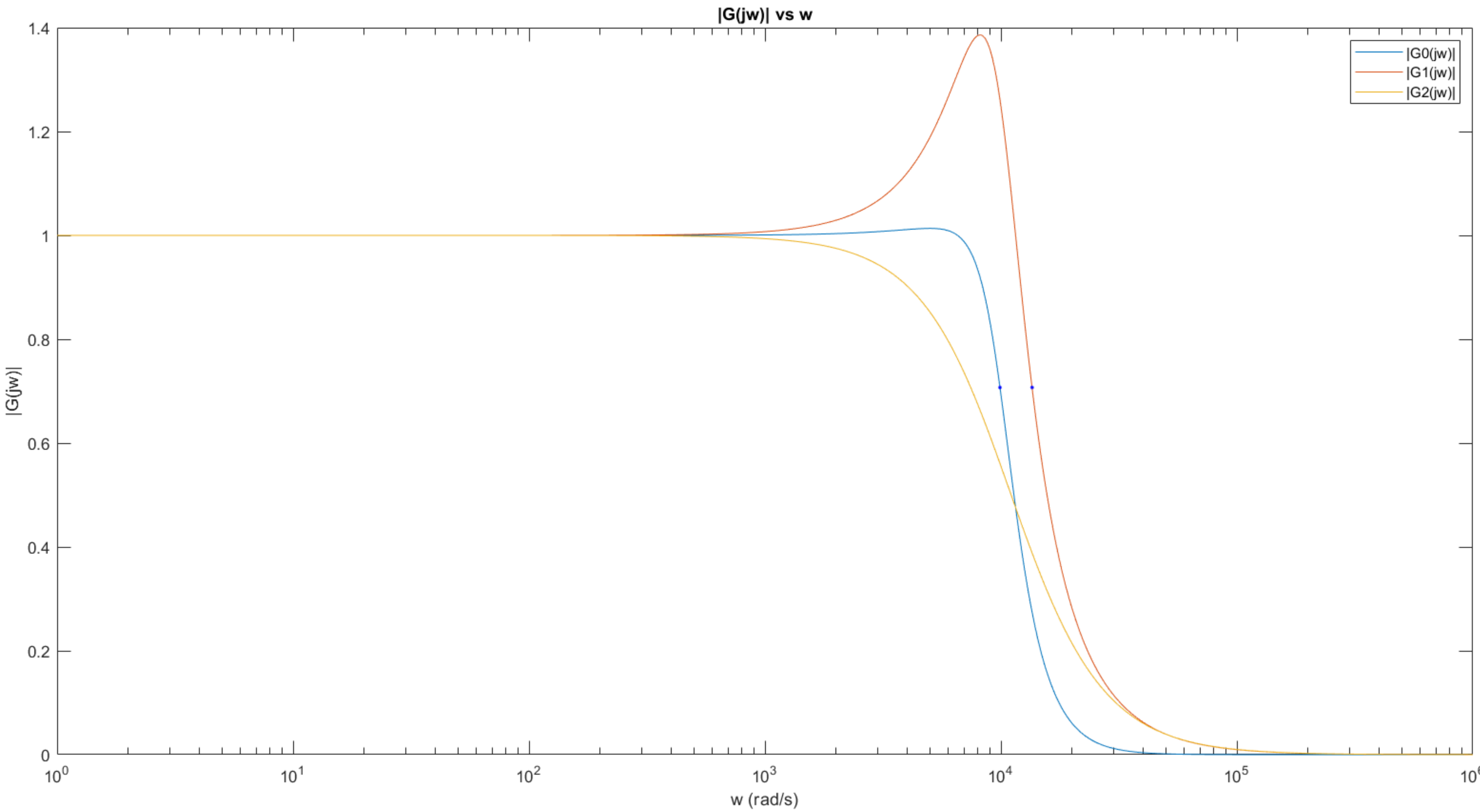


Figure 1: MATLAB Plot For Gain: 3dB Points Marked In Dark Blue

<u>Procedure</u>

To begin the lab, we constructed the circuit shown in figure 2 in PSPICE for simulation. To emulate data collection in lab, the data was taking with a channel 2 scope probe at both the output of the first and second Op Amp. After collecting our data, we then plotted it onto the MATLAB plot from the pre-lab.

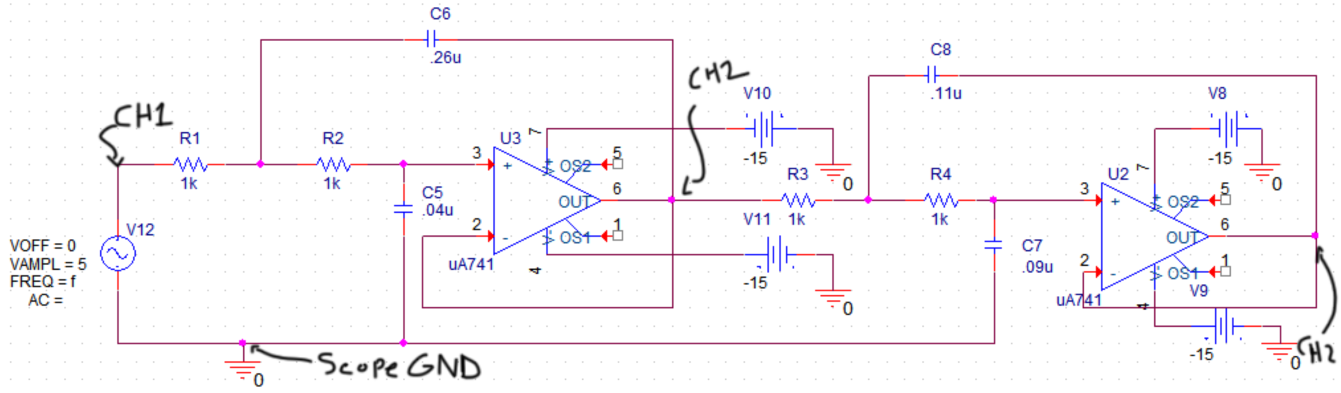


Figure 2: PSPICE Circuit

Results

When f = 15.915 Hz

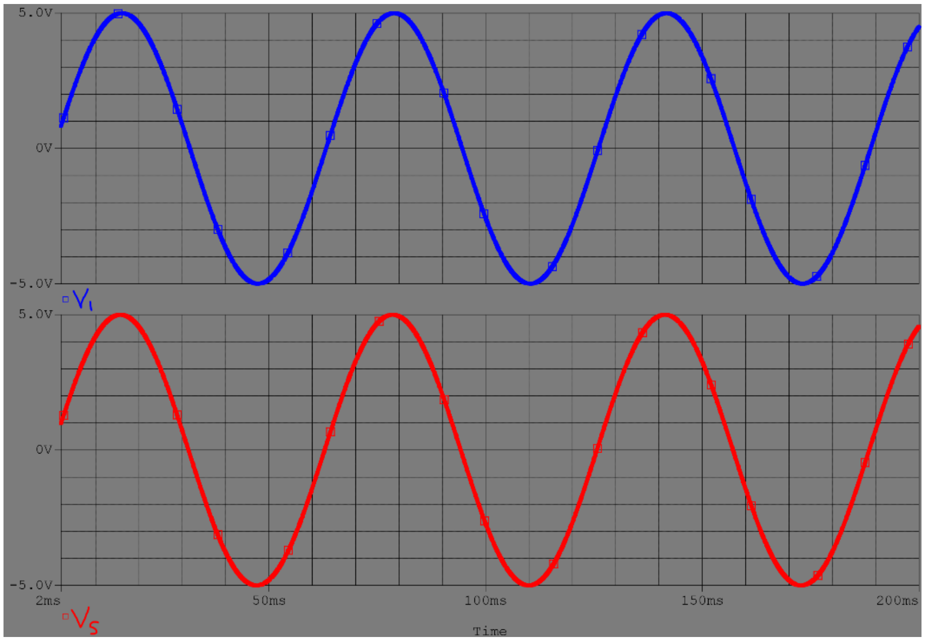


Figure 3: Output of V1, and Vs From PSPICE When f =15.915Hz

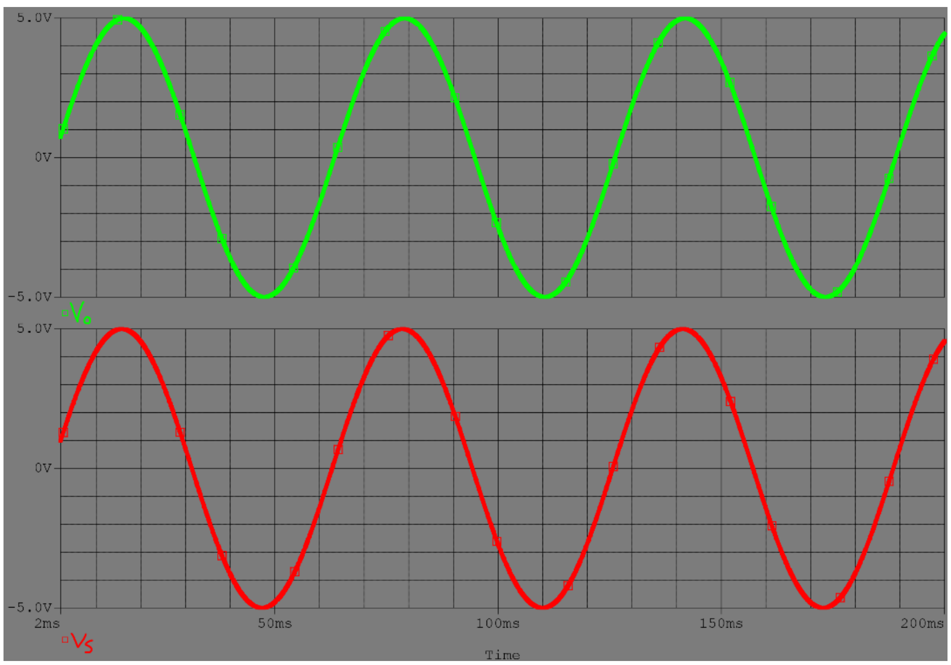


Figure 4: Output of V0, and Vs From PSPICE When f =15.915Hz

Measurement	Value
Max_XRange(V(U2:-),2m,200m)	4.99667
Max_XRange(V(R3:1),2m,200m)	4.99731
Max_XRange(V(R1:1),2m,200m)	5.00000
1/Period_XRange(V(R3:1),2m,200m)	15.91500

Figure 5: PSPICE Measurement Results When f = 15.915Hz

When f = 159.15 Hz

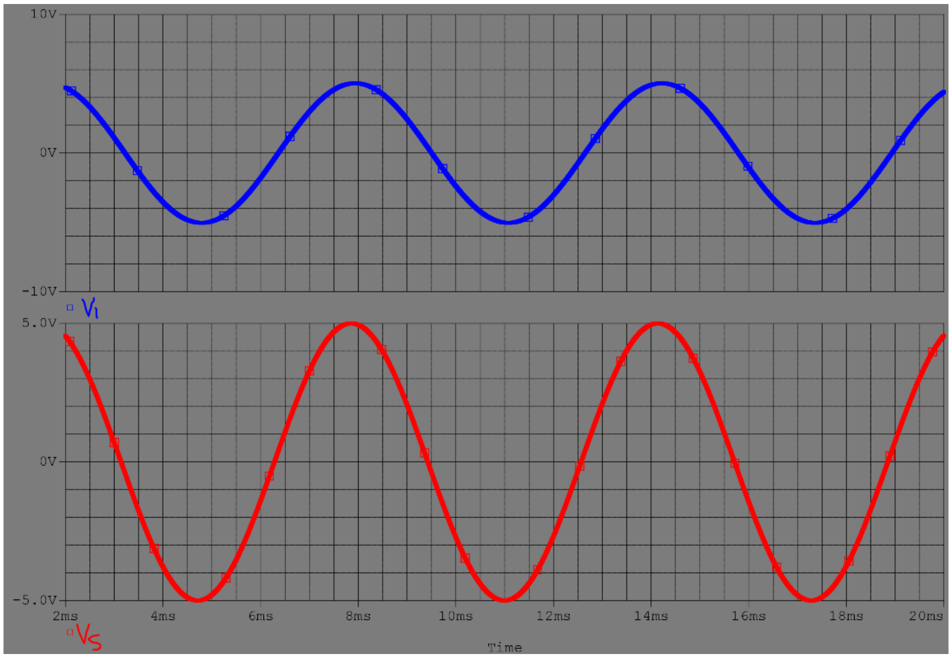


Figure 6: Output of V1, and Vs From PSPICE When f =159.15Hz

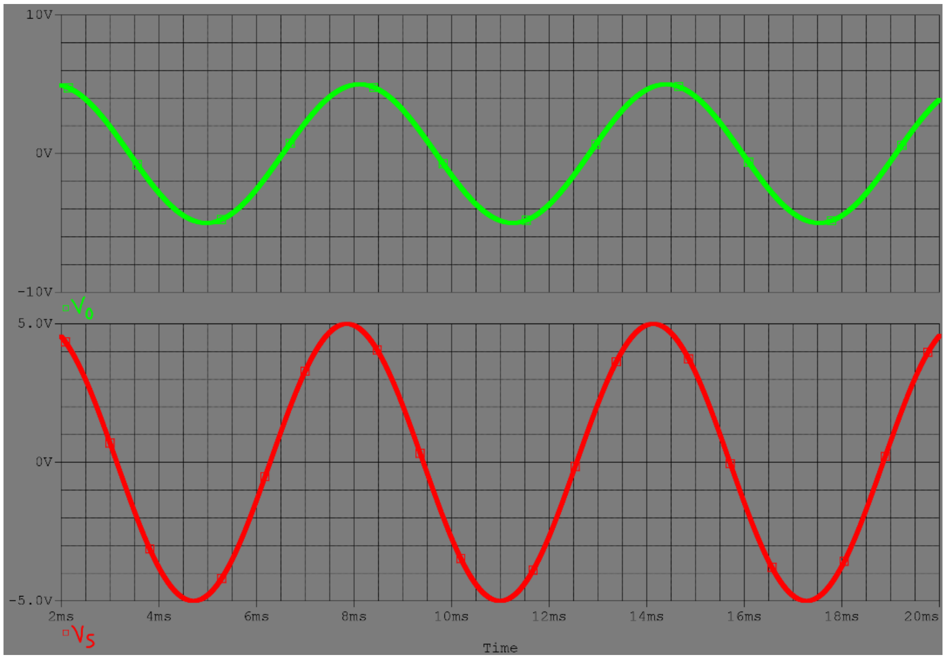


Figure 7: Output of V0, and Vs From PSPICE When f =159.15Hz

Measurement	Value
Max_XRange(V(U2:-),2m,20m)	5.00408
Max_XRange(V(R3:1),2m,20m)	5.03599
Max_XRange(V(R1:1),2m,20m)	5.00000
1/Period_XRange(V(R3:1),2m,20m)	159.15000

Figure 8: PSPICE Measurement Results When f = 159.15Hz

When f = 1.577 kHz

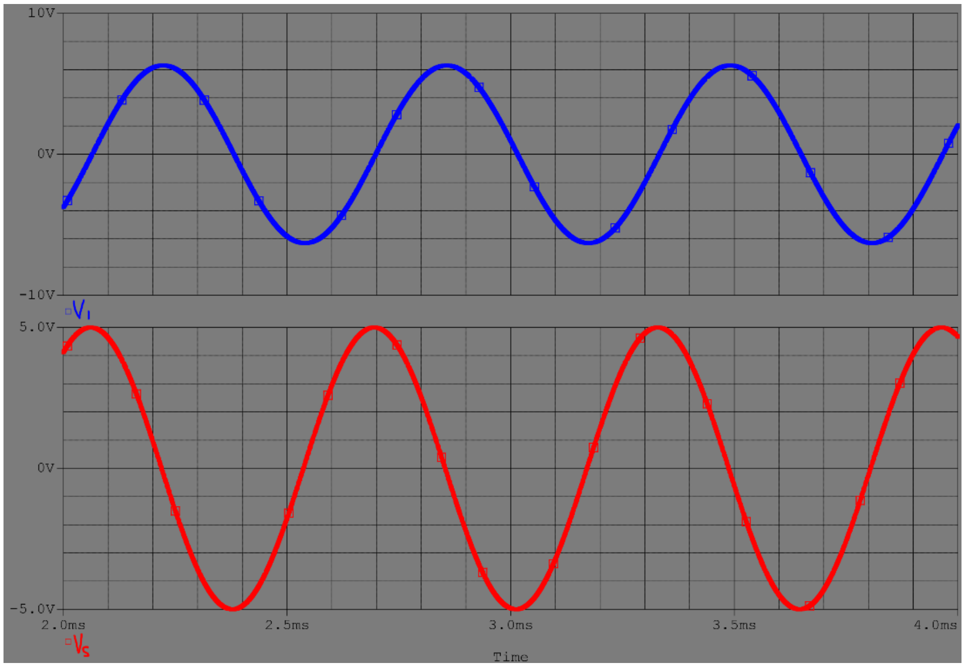


Figure 9: Output of V1, and Vs From PSPICE When f =1.577kHz

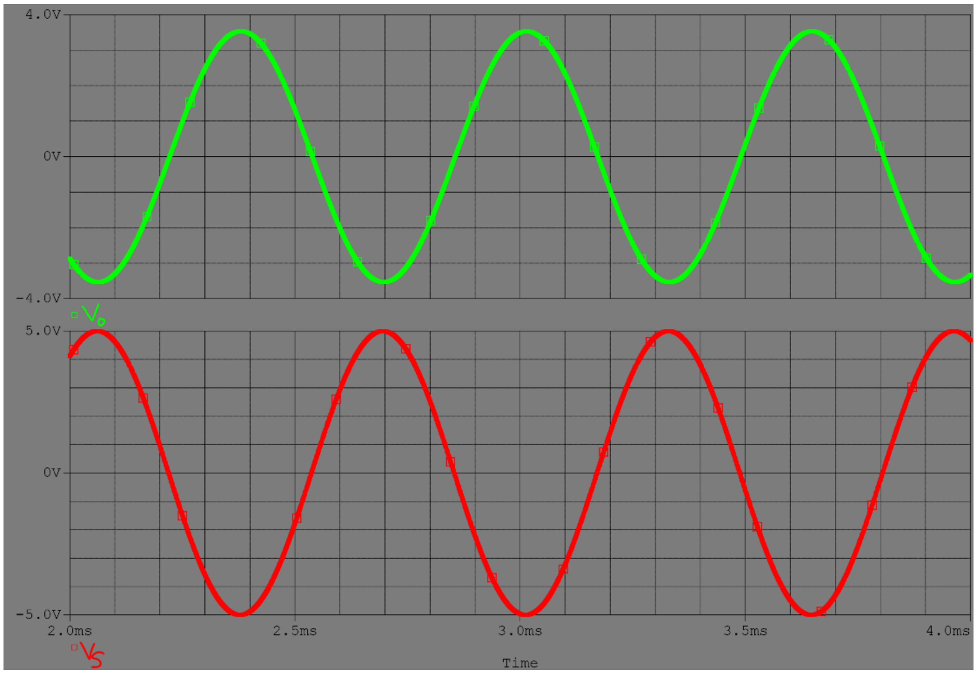


Figure 10: Output of V0, and Vs From PSPICE When f =1.577kHz

Measurement	Value
Max_XRange(V(U2:-),2m,4m)	3.53468
Max_XRange(V(R3:1),2m,4m)	6.30556
Max_XRange(V(R1:1),2m,4m)	5.00000
1/Period_XRange(V(R3:1),2m,4m)	1.57692k

Figure 11: PSPICE Measurement Results When f = 1.57692 kHz

When f = 1.5915kHz

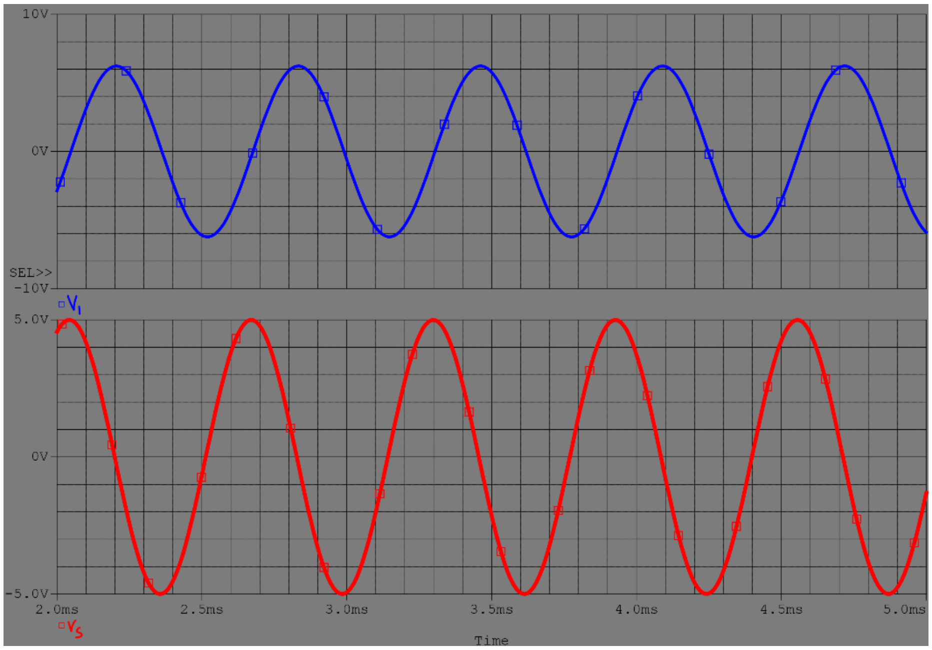


Figure 12: Output of V1, and Vs From PSPICE When f =1.5915kHz

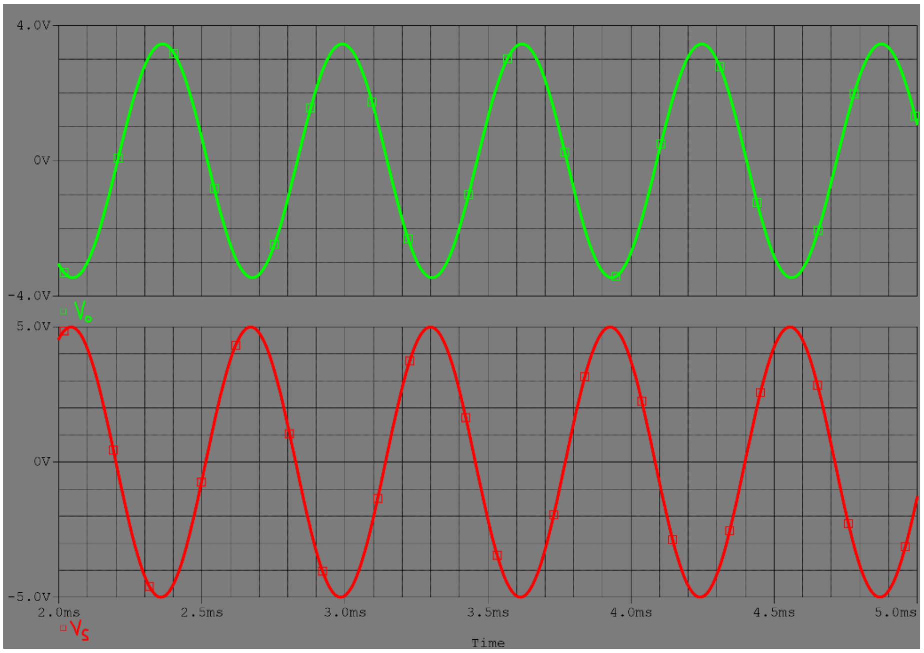


Figure 13: Output of V0, and Vs From PSPICE When f =1.5915kHz

Measurement	Value
Max_XRange(V(R1:1),2m,5m)	4.99998
Max_XRange(V(R3:1),2m,5m)	6.23466
Max_XRange(V(U2:-),2m,5m)	3.45978
1/Period_XRange(V(R3:1),2m,5m)	1.59145k

Figure 14: PSPICE Measurement Results When f = 1.5915 kHz

When f = 2.15599kHz

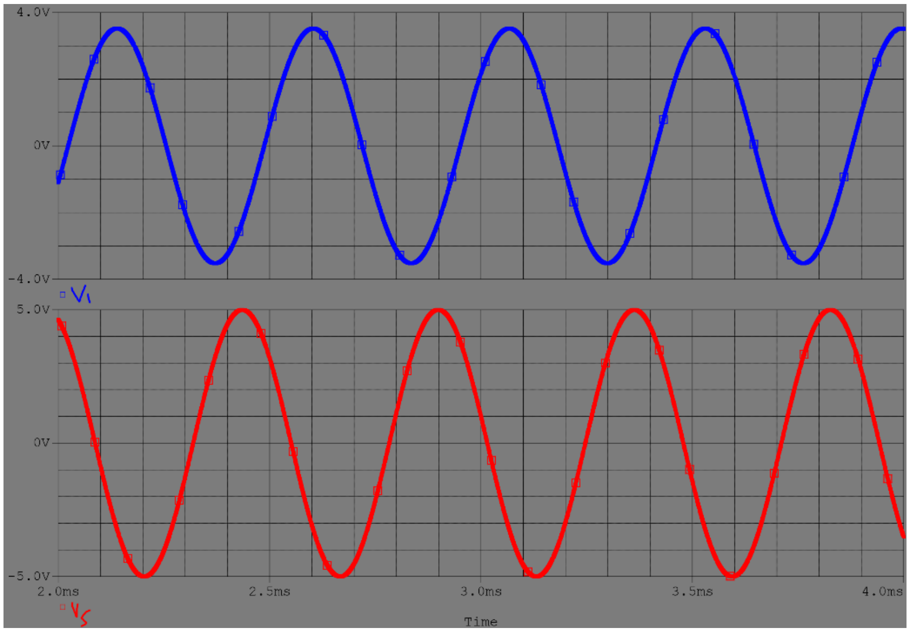


Figure 15: Output of V1, and Vs From PSPICE When f =2.1599kHz

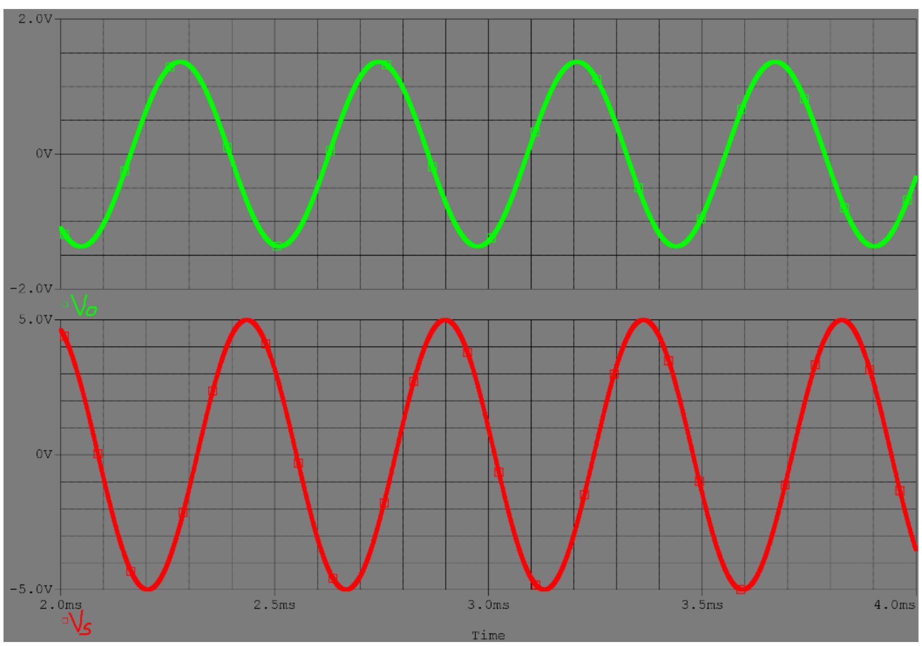


Figure 16: Output of V0, and Vs From PSPICE When f =2.1599kHz

Measurement	Value
Max_XRange(V(U2:-),2m,20m)	1.36889
Max_XRange(V(R3:1),2m,20m)	3.52312
Max_XRange(V(R1:1),2m,20m)	5.00000
1/Period_XRange(V(R3:1),2m,20m)	2.15599k

Figure 17: PSPICE Measurement Results When f = 2.1599kHz

When f = 15.915kHz

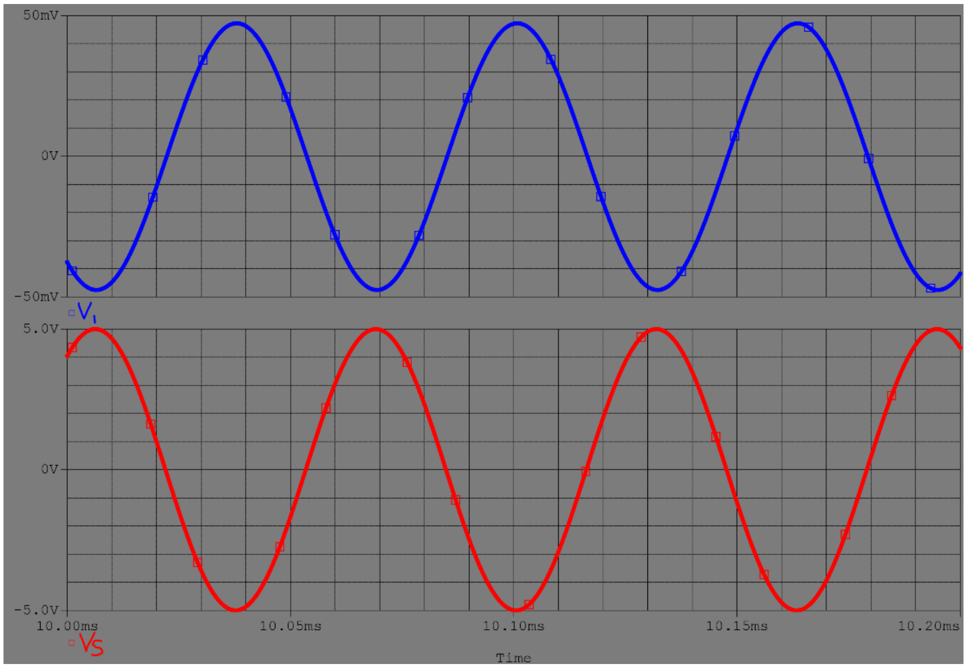


Figure 18: Output of V1, and Vs From PSPICE When f =15.915kHz

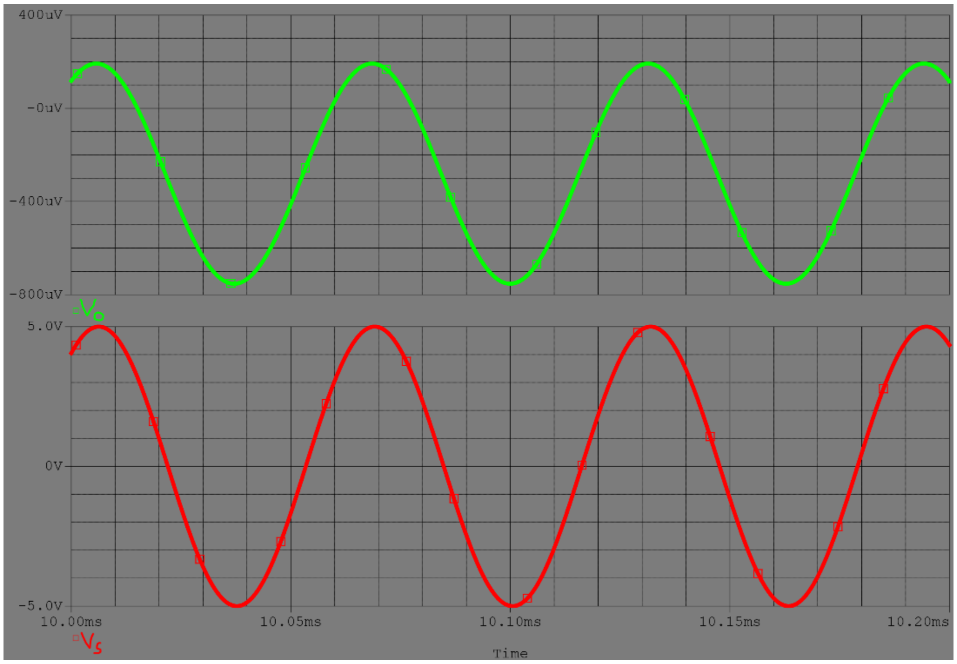


Figure 19: Output of V0, and Vs From PSPICE When f =15.915kHz

Measurement	Value
1/Period_XRange(V(R3:1),10m,10.2m)	15.91500k
Max_XRange(V(R1:1),10m, 10.2m)	5.00000
Max_XRange(V(R3:1),10m,10.2m)	47.25727m
(Max_XRange(V(U2:-),10m,10.2m) - Min_XRange(V(U2:-),10m,10.2m))/2	472.62065u

Figure 20: PSPICE Measurement Results When f = 15.915kHz

When f = 159.15kHz

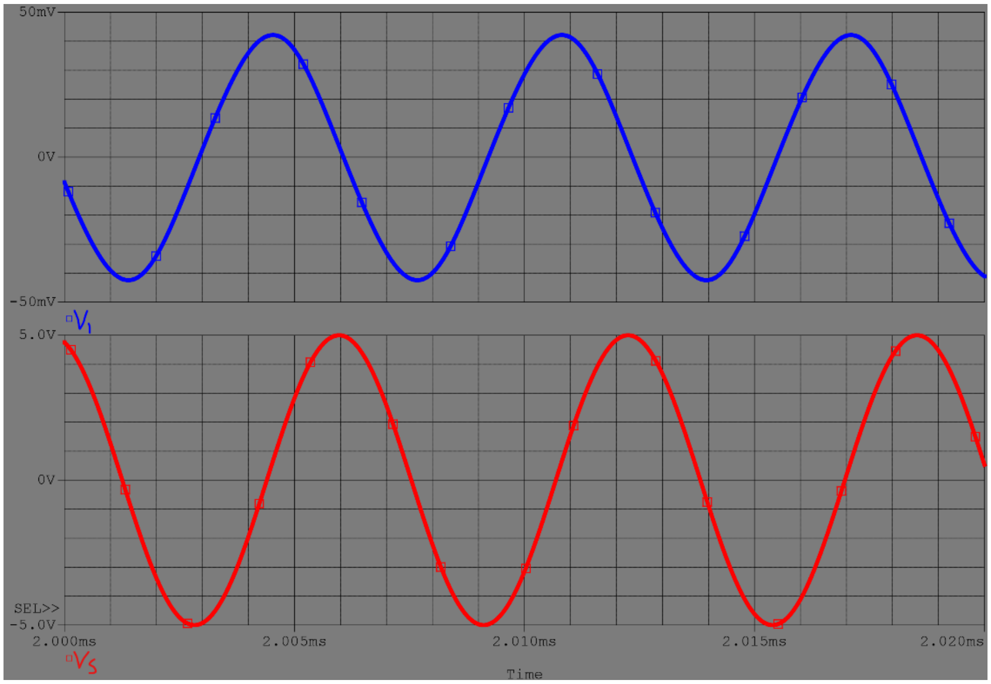


Figure 21: Output of V1, and Vs From PSPICE When f =159.15kHz

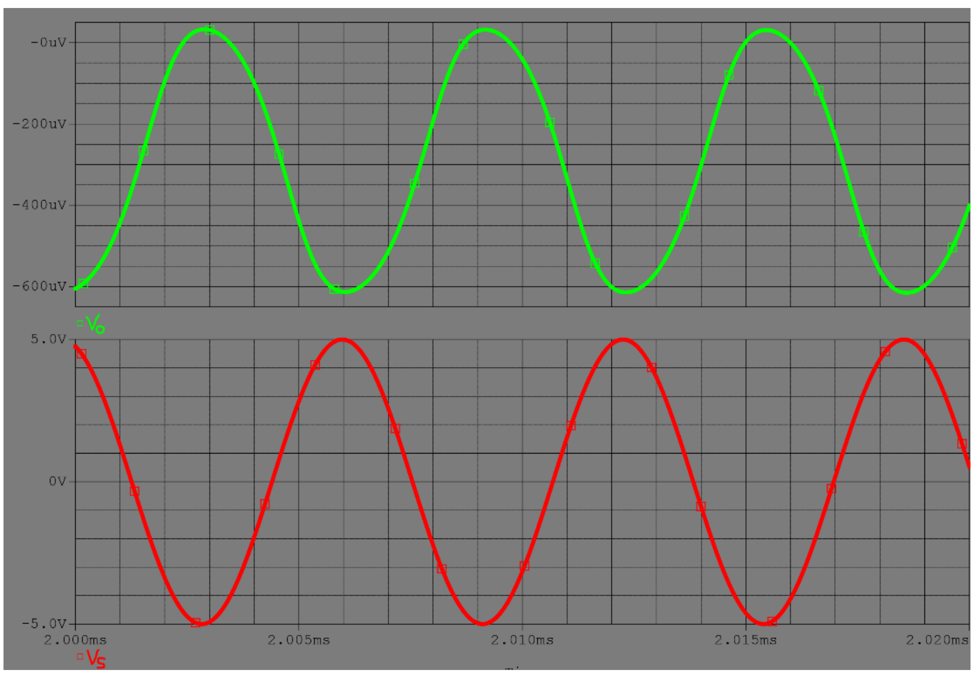


Figure 22: Output of V0, and Vs From PSPICE When f =159.15kHz

Measurement	Value
Max_XRange(V(R3:1),2m,2.20m)	42.13389m
Max_XRange(V(R1:1),2m, 2.02m)	5.00000
1/Period_XRange(V(R3:1),2m,2.02m)	159.15088k
(Max_XRange(V(U2:-),2m,2.02m) - Min_XRange(V(U2:-),2m,2.02m))/2	324.11052u

Figure 23: PSPICE Measurement Results When f = 159.15kHz

Table Compiling All Data

f [Hz]	ω [rad/s]	Vs [V]	V1 [V]	V0 [V]	G1	G0
15.915	10^2	5	4.99731	4.99667	.9995	.9993
159.15	10^3	5	5.03599	5.00408	1.0072	1.0008
1.57692k	9908.1	5	6.30556	3.53468	1.2611	0.7069
1.59145k	10^4	4.99998	6.23466	3.45978	1.2469	0.6920
2.156k	13546.5	5	3.52312	1.36889	0.7046	0.2738
15.915k	10^5	5	47.257m	472.621μ	9.4514m	94.5242μ
159.15k	10^6	5	42.133m	324.11μ	8.4266m	64.822μ

Graph From Pre-Lab With Data

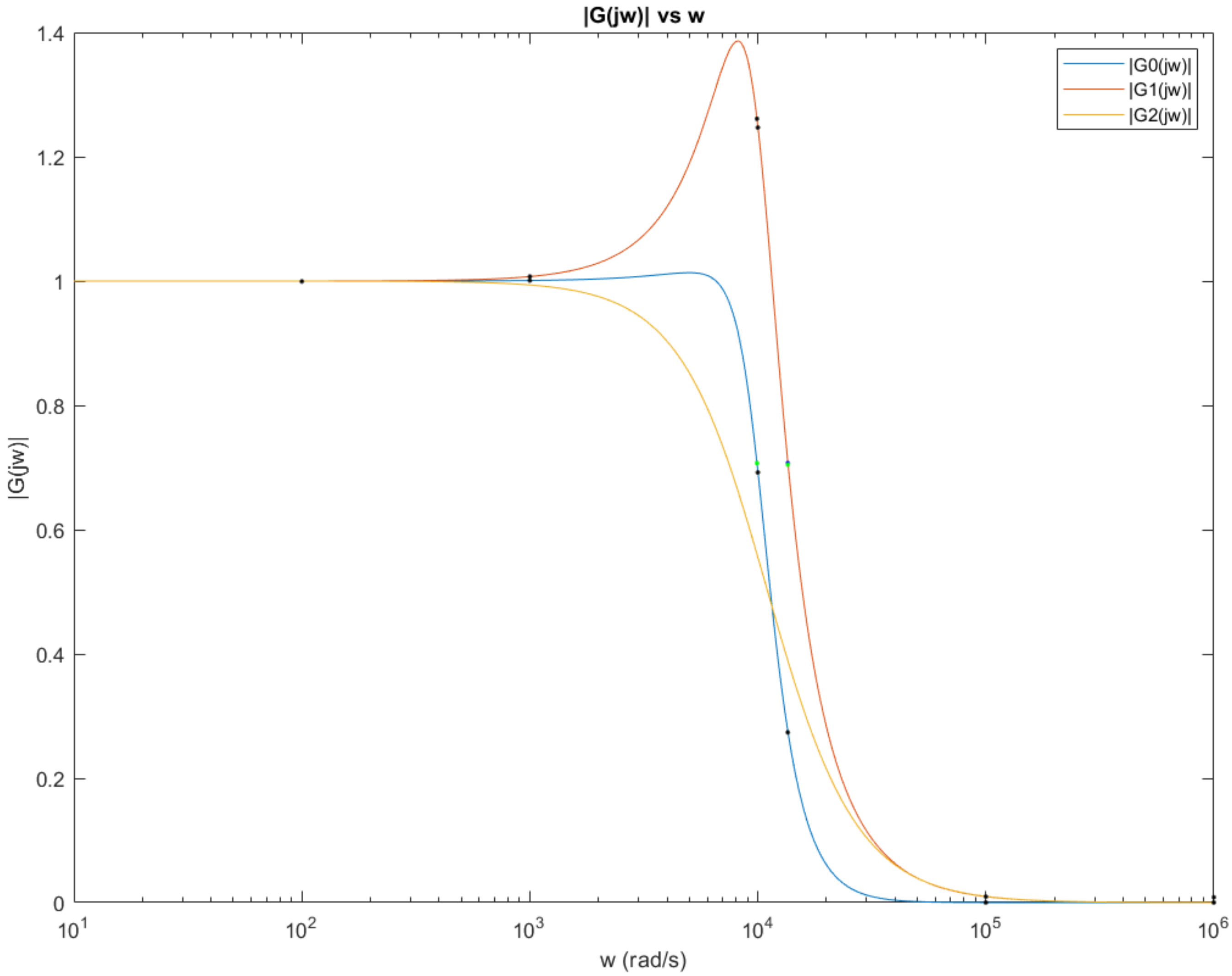


Figure 24: MATLAB Plot With Lab Data Plotted In Black And Lab 3dB Points In Green

We found the 3dB frequency for the gain of the first section to be approximately 2.156kHz and the 3dB frequency of the gain for the output to be approximately 1.57692kHz.

Problems

1. Compare the calculated and measured lab data.

When comparing our calculated data to that of our lab, we can see from the plot that the data is mostly equal to the theoretical measurements with one-point deviating from theoretical calculations at $\omega = 10^6$. The gains should be very close to 0, however the G_1 was found to be slightly more than what was expected from theorical calculations however it was still close enough to zero where it would reasonably be considered 0. Aside from that, there were not any other data sets collected that deviated from the theorical calculations by a noticeable margin. For the 3dB frequencies, we found a percent error of roughly .007% for the 3dB frequency of the first section and .35% difference when comparing the gain from lab to theoretical gain. The percent error was roughly .01% for the 3dB frequency for the output of the overall circuit and the percent difference between the gains used was about .03%.