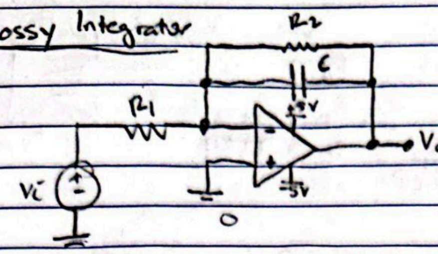
Calculations:

Joseph Nguyen

Lab 5 calculations

Lossy Integrator

①



$$R_2 \| Z_c = \frac{\frac{R_2}{sC}}{R_2 + \frac{1}{sC}} = \frac{R_2}{sR_2C + 1}$$

$$\frac{0 - V_i}{R_1} + \frac{(0 - V_o)(1 + sR_2C)}{R_2} = 0$$

$$\frac{-V_i}{R_1} = V_o \left(\frac{1 + sR_2C}{R_2} \right)$$

$$\boxed{V_o = \frac{-\frac{R_2}{R_1} V_i}{1 + sR_2C}}$$

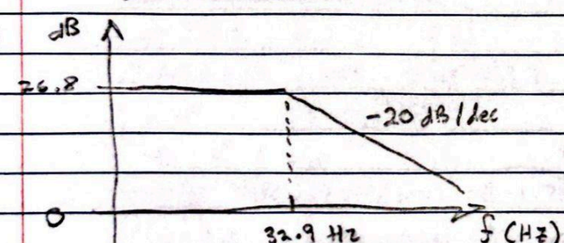
② $\frac{V_o}{V_i} = -22$, $R_2 = 22\,k\Omega$, $C = 220\,nF$

$$\frac{V_o}{V_i} = -\frac{R_2}{R_1} \Rightarrow -22 = \frac{22\,k\Omega}{R_1} \quad \boxed{R_1 = 1\,k\Omega}$$

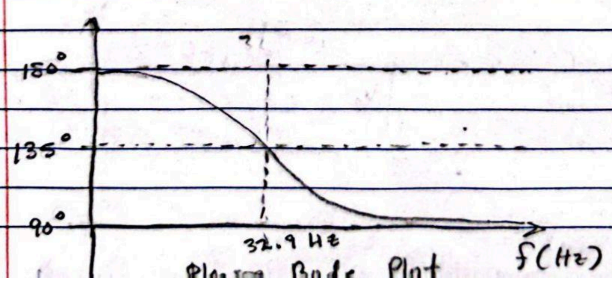
$$\omega_{3\text{-}dB} = \frac{1}{R_2C} \approx 206.6 \qquad \omega = 2\pi f \qquad \frac{206.6}{2\pi} = f$$

$$\boxed{f_{3\text{-}dB} \approx 32.9\ Hz} \qquad H(s) = -22\left[\frac{1}{1 + \frac{s}{2\pi 32.9}}\right]$$

③



Magnitude Bode Plot



Phase Bode Plot

④ $V_i(t) = 0.5\sin(2\pi 1000t)$, $H(s) = -22\left[\frac{1}{1+\frac{s}{2\pi 32.9}}\right]$

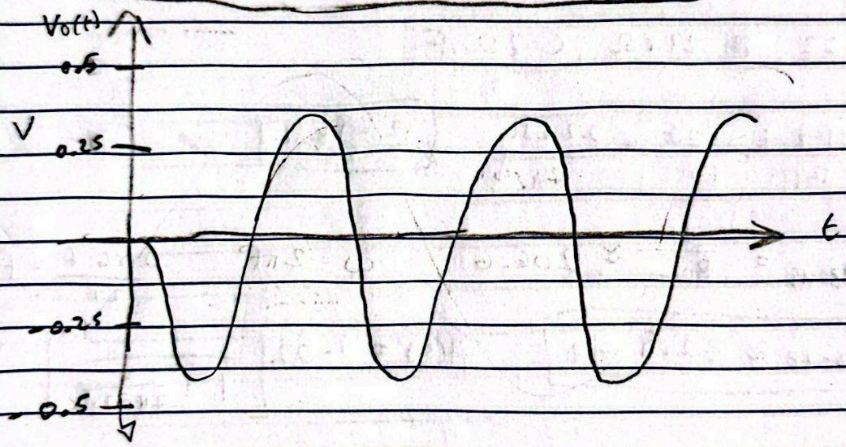
$$|H(2\pi 1000)| = 22\left[\frac{1}{\sqrt{1+\left(\frac{2\pi 1000}{2\pi 32.9}\right)^2}}\right] \approx 0.7234$$

$$\angle H(2\pi 1000) = -\pi - \tan\left(\frac{\omega}{\omega_0}\right) = -\pi - \tan\left(\frac{1000}{32.9}\right) \approx -4.68 \text{ rad}$$

$$V_o(t) = (0.7234)(0.5\sin(2\pi 1000t - 4.68))$$

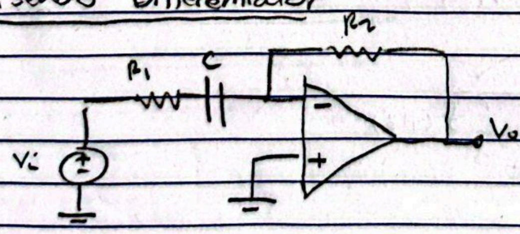
$$\boxed{V_o(t) = 0.3617\sin(2\pi 1000t - 4.68)}$$

⑤



Pseudo Differentiator

①



$$V_o = \frac{-R_2}{R_1 + \frac{1}{sC}} V_i$$

$$V_o = \frac{-sR_2C}{sR_1C + 1} V_i$$

$$= \frac{-R_2}{R_1}\left(\frac{sC}{sC + \frac{1}{R_1}}\right) V_i$$

$$\boxed{V_o = \frac{-R_2}{R_1}\left(\frac{s}{s + \frac{1}{R_1C}}\right) V_i}$$

Lab 5

Pseudo Differentiator

(2)

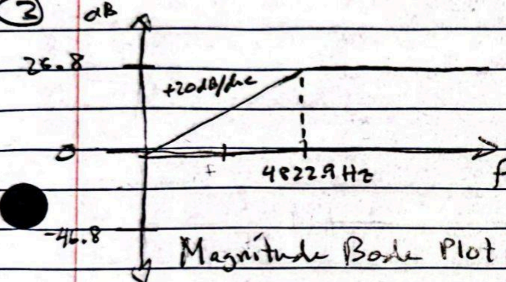
$\frac{V_o}{V_i} = -22$, $R_1 = 1k\Omega$, $C = 33nF$

$$\frac{V_o}{V_i} = -\frac{R_2}{R_1} \Rightarrow -22 = \frac{R_2}{1k\Omega} \quad \boxed{R_2 = 22k\Omega}$$

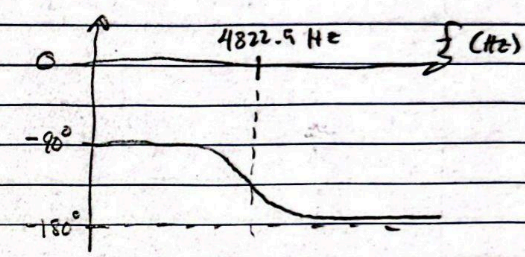
$$\omega_{3dB} = \frac{1}{R_1 C} \approx 30303 \text{ rad/s} \approx 2\pi\, 4822.9 \text{ rad/s}$$

$$f_{3dB} = \frac{\omega}{2\pi} \approx \boxed{4822.9 \text{ Hz}} \qquad H(s) = -22\left[\frac{s}{s + 2\pi 4822.9}\right]$$

(3)



Magnitude Bode Plot



Magnitude Phase Plot

(4)

$V_i(t) = 0.1\sin(2\pi 1000 t)$

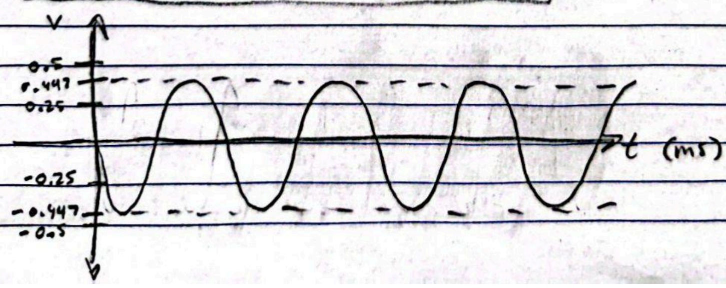
$$|H(2\pi 1000)| = \frac{22}{\sqrt{1 + \left(\frac{4822.9}{1000}\right)^2}} \approx 4.47, \quad \angle H(2\pi 1000) = -\pi + \tan^{-1}\left(\frac{4822.9}{1000}\right)$$

$$\approx -1.78 \text{ rad}$$

$V_o(t) = (4.47)(0.1\sin(2\pi 1000t - 1.78))$

$\boxed{V_o(t) = 0.447\sin(2\pi 1000t - 1.78)}$

(5)



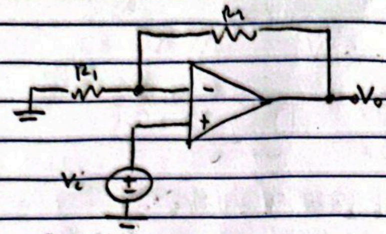
Finite GBW Limitations

$$\frac{V_o}{V_i} = \frac{G_0}{1+\frac{s}{\omega_0}} \qquad G_0 = 1 + \frac{R_2}{R_1}$$

$$\omega_0 = \frac{\omega_t}{G_0}$$

$R_1 = 1k\Omega$

(1)



$G_0 = 23$: $23 = 1 + \frac{R_2}{1k}$

$22 = \frac{R_2}{1k} \Rightarrow \boxed{R_2 = 22k\Omega}$

$G_0 = 57$: $57 = 1 + \frac{R_2}{1k}$

$56 = \frac{R_2}{1k} \Rightarrow \boxed{R_2 = 56k\Omega}$

$\omega_t = 1.2MHz \cdot 2\pi$

$2\pi \cdot 1.2\ MHz = G_0 \omega_0$

$G_0 = 83$: $83 = 1 + \frac{R_2}{1k}$

$82 = \frac{R_2}{1k} \Rightarrow \boxed{R_2 = 82k\Omega}$

(2) $\omega_0 = \frac{\omega_t}{1+\frac{R_2}{R_1}} = \frac{1.2\ MHz \cdot 2\pi}{1+\frac{R_2}{R_1}}$

for $G_0 = 23$: $\omega_0 = \frac{1.2\ MHz \cdot 2\pi}{23} = 2\pi 52174$ rad/s

$$\boxed{\frac{V_o}{V_i} = 23\left[\frac{1}{1+\frac{s}{2\pi 52174}}\right]}$$

for $G_0 = 57$: $\omega_0 = \frac{1.2\ MHz\ 2\pi}{57} = 2\pi 21053$ rad/s

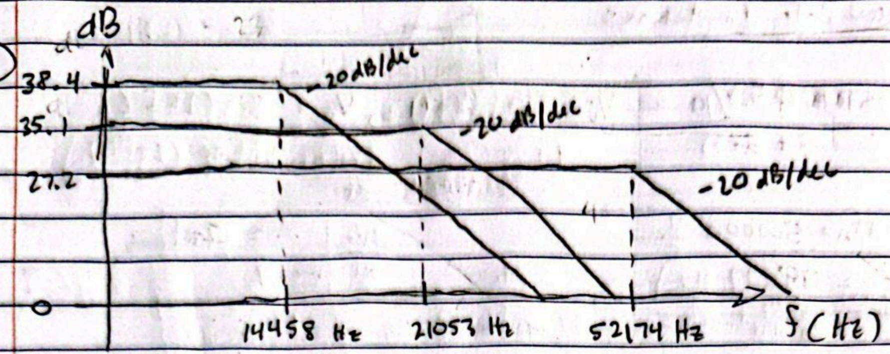
$$\boxed{\frac{V_o}{V_i} = 57\left[\frac{1}{1+\frac{s}{2\pi 21053}}\right]}$$

for $G_0 = 83$: $\omega_0 = \frac{2\pi\ 1.2\ MHz}{83} \approx 2\pi\ 14458$ rad/s

$$\boxed{\frac{V_o}{V_i} = 83\left[\frac{1}{1+\frac{s}{2\pi 14458}}\right]}$$

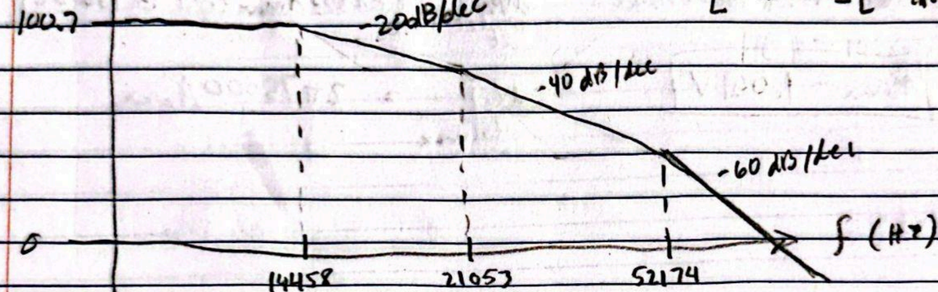
Lab 5

(3)



Magnitude Bode Plot

$$H(s) = 108813\left[\frac{1}{1+\frac{s}{2\pi 14458}}\right]\left[\frac{1}{1+\frac{s}{2\pi 21053}}\right]\left[\frac{1}{1+\frac{s}{2\pi 52174}}\right]$$



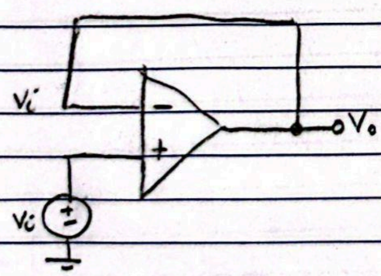
Magnitude Bode plot

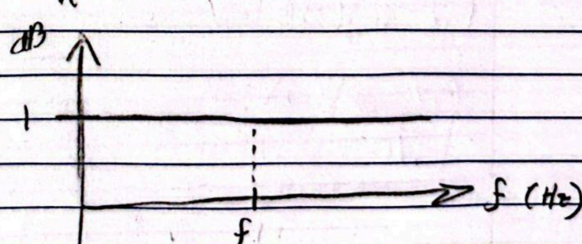
Slew Rate Limitations

$V_o = V_i$, $V_p = V_n$

(1)

$\frac{V_o}{V_i} = 1$





Magnitude Bode Plot

Slew Rate Limitations

(2)

$SR = 0.5\ V/\mu s$ $\quad V_i = \sin(2\pi f t) \rightarrow V_o = \sin(2\pi f t)$

$\frac{dV_o}{dt} = 2\pi f \cos(2\pi f t)$

$2\pi f_{max} = 500000\ \frac{V}{s}$ $\quad \left.\frac{dV_o}{dt}\right|_{max} = 2\pi f_{max}$

$\boxed{f_{max} = 79577\ Hz}$

(3)

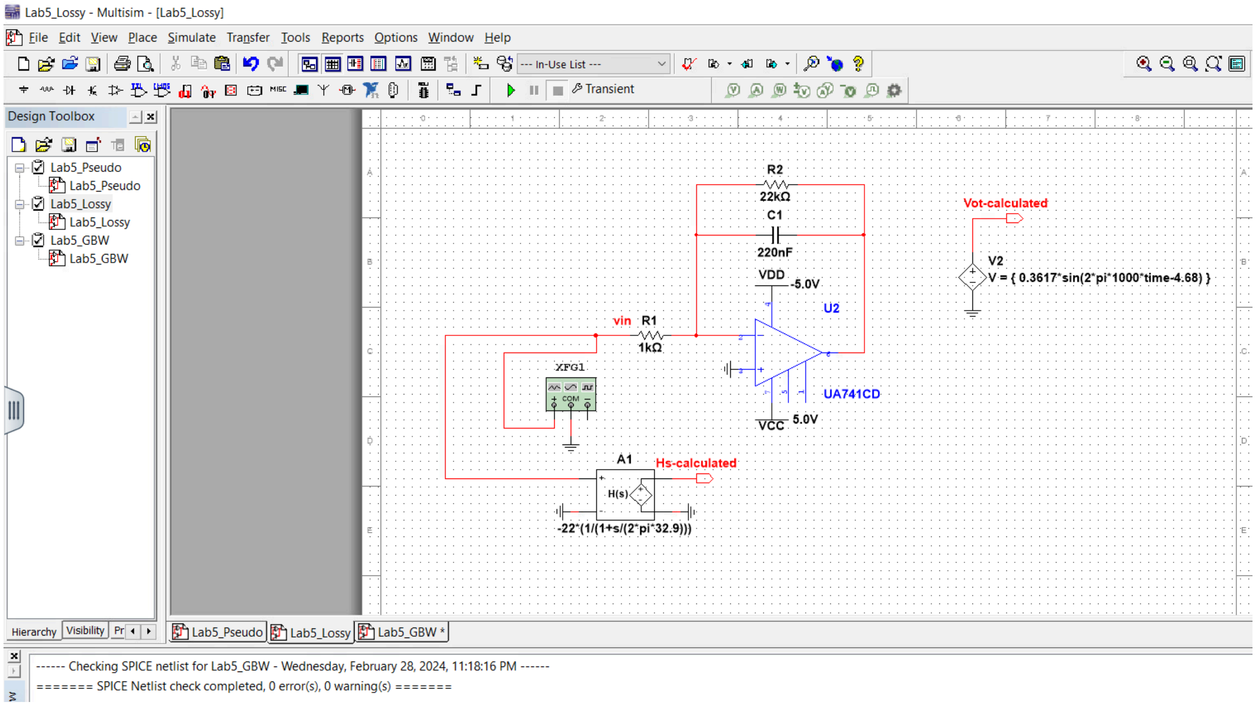
$SR = 0.5\ V/\mu s$ $\quad f = 75\ kHz$, $\quad V_o = A_{max} \sin(2\pi 75000 t)$

$500000 = 2\pi 75000 A_{max}$ $\quad \frac{dV_o}{dt} = 2\pi 75000 A_{max} \cos(2\pi 75000 t)$

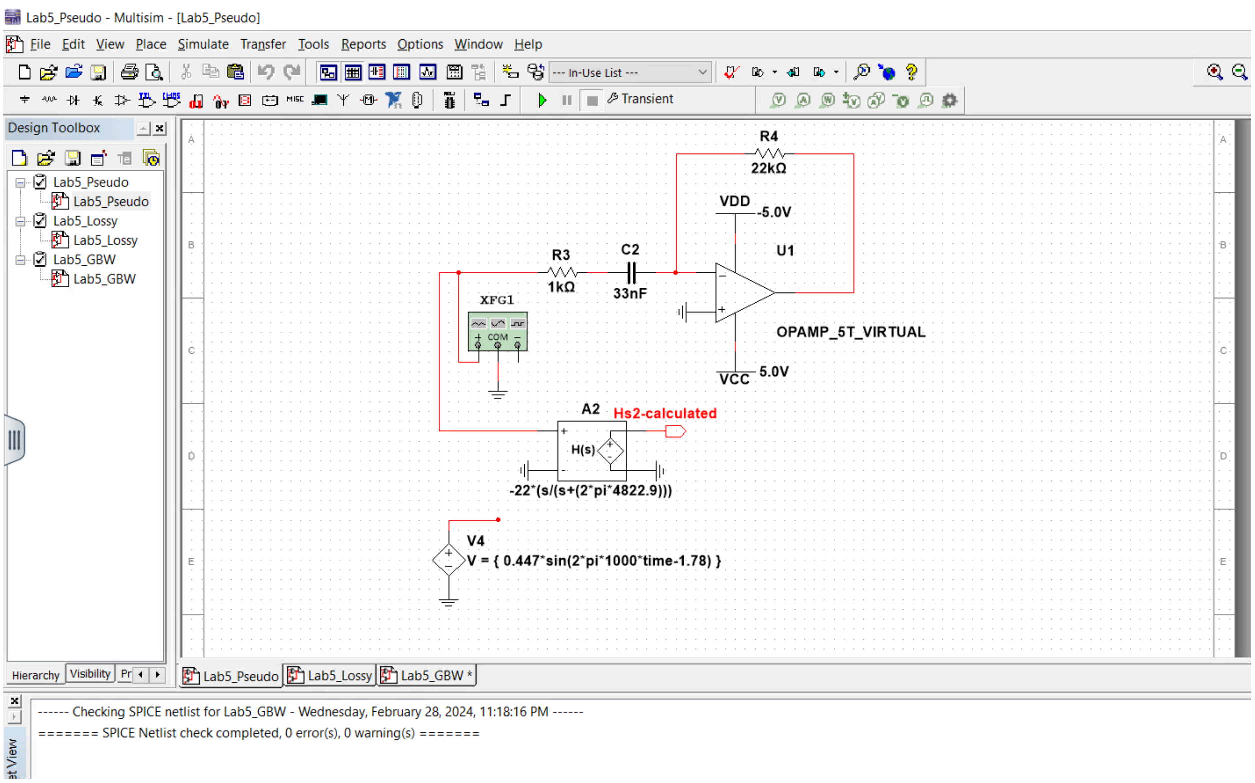
$\boxed{A_{max} = 1.061\ V}$ $\quad \left.\frac{dV_o}{dt}\right|_{max} = 2\pi 75000 A_{max}$

Circuit Schematics:

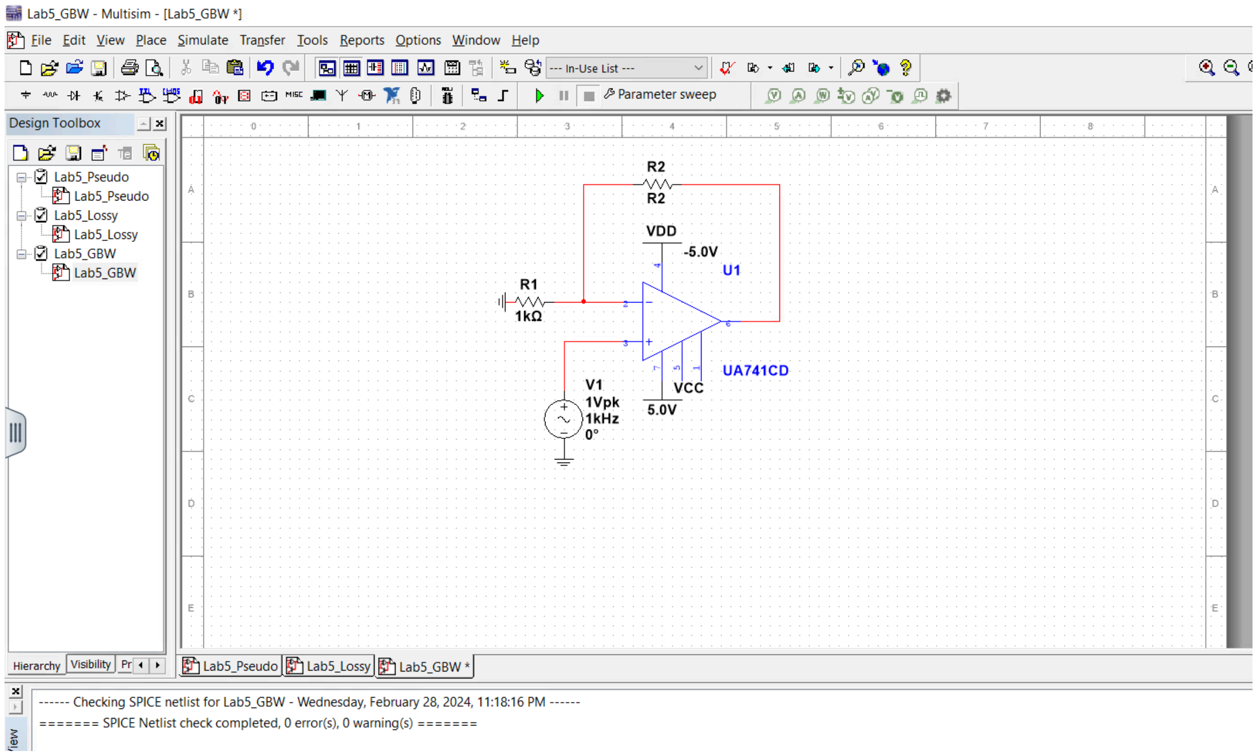
Lossy-Integrator:



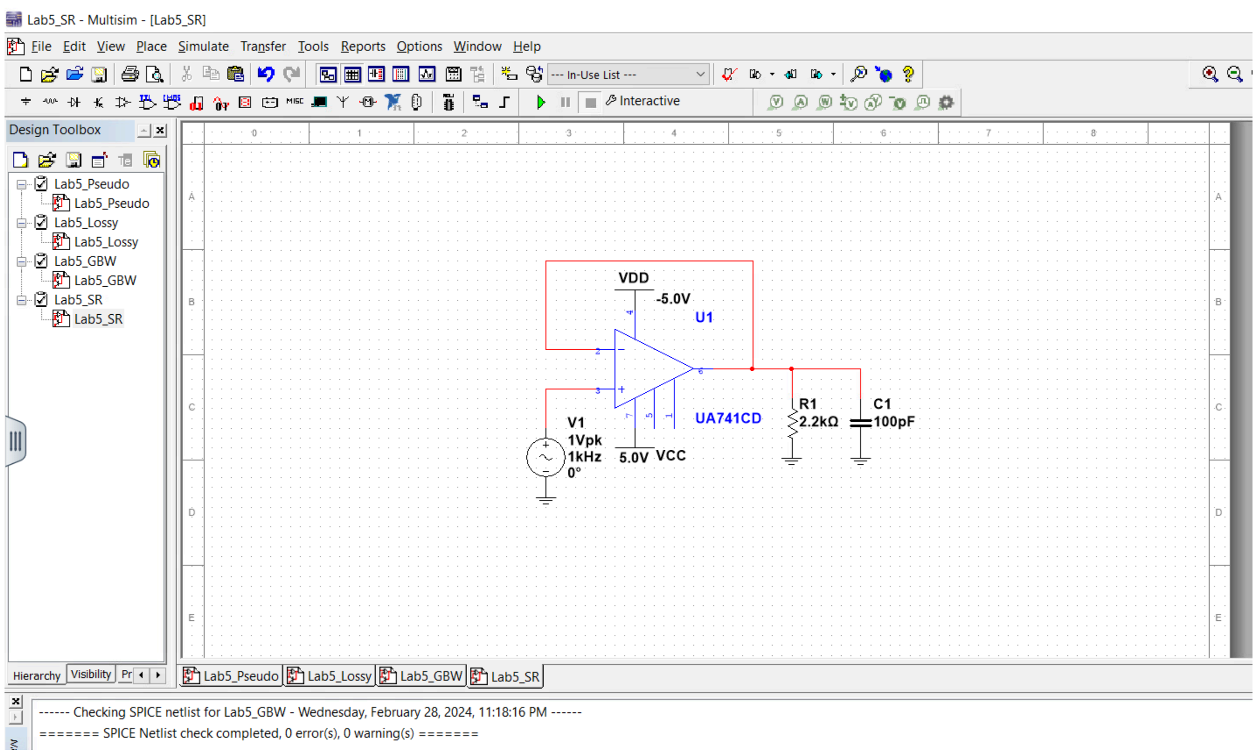
Pseudo Differentiator:



Non-inverting Amplifier:



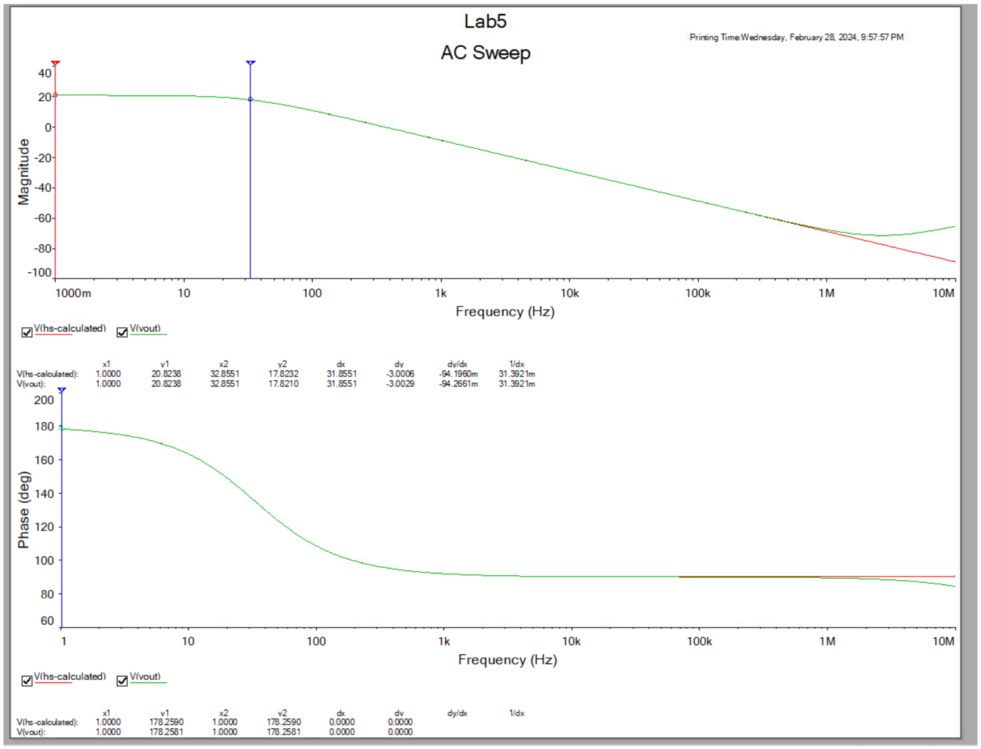
Buffer Amplifier:

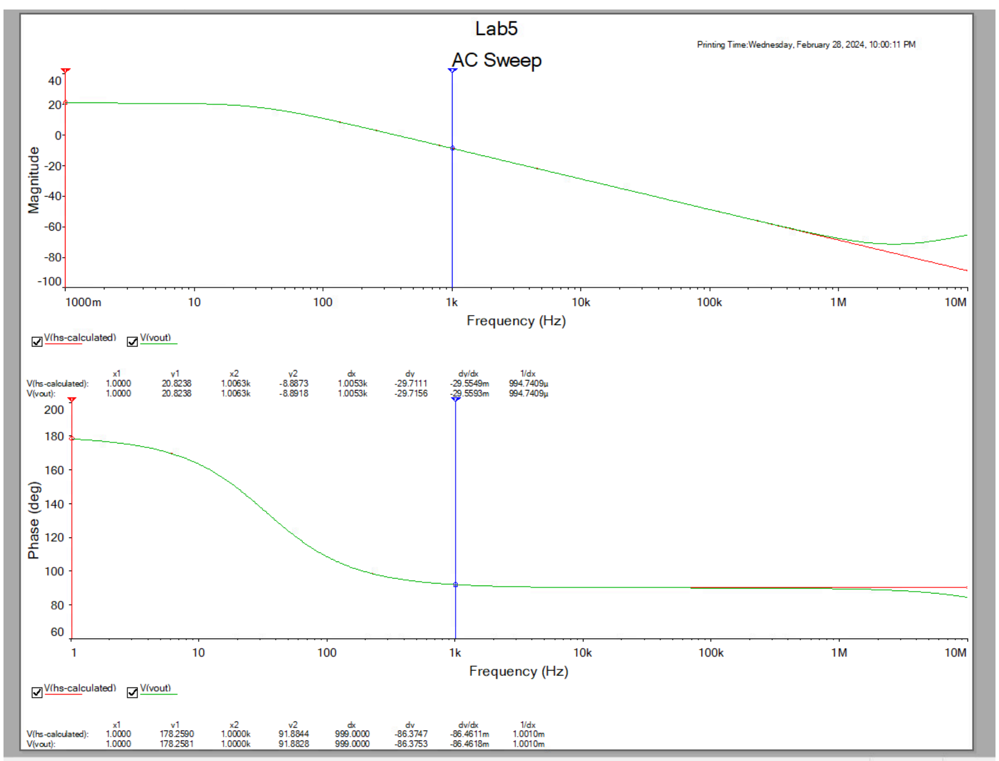


Simulations:

<u>Lossy Integrator</u>

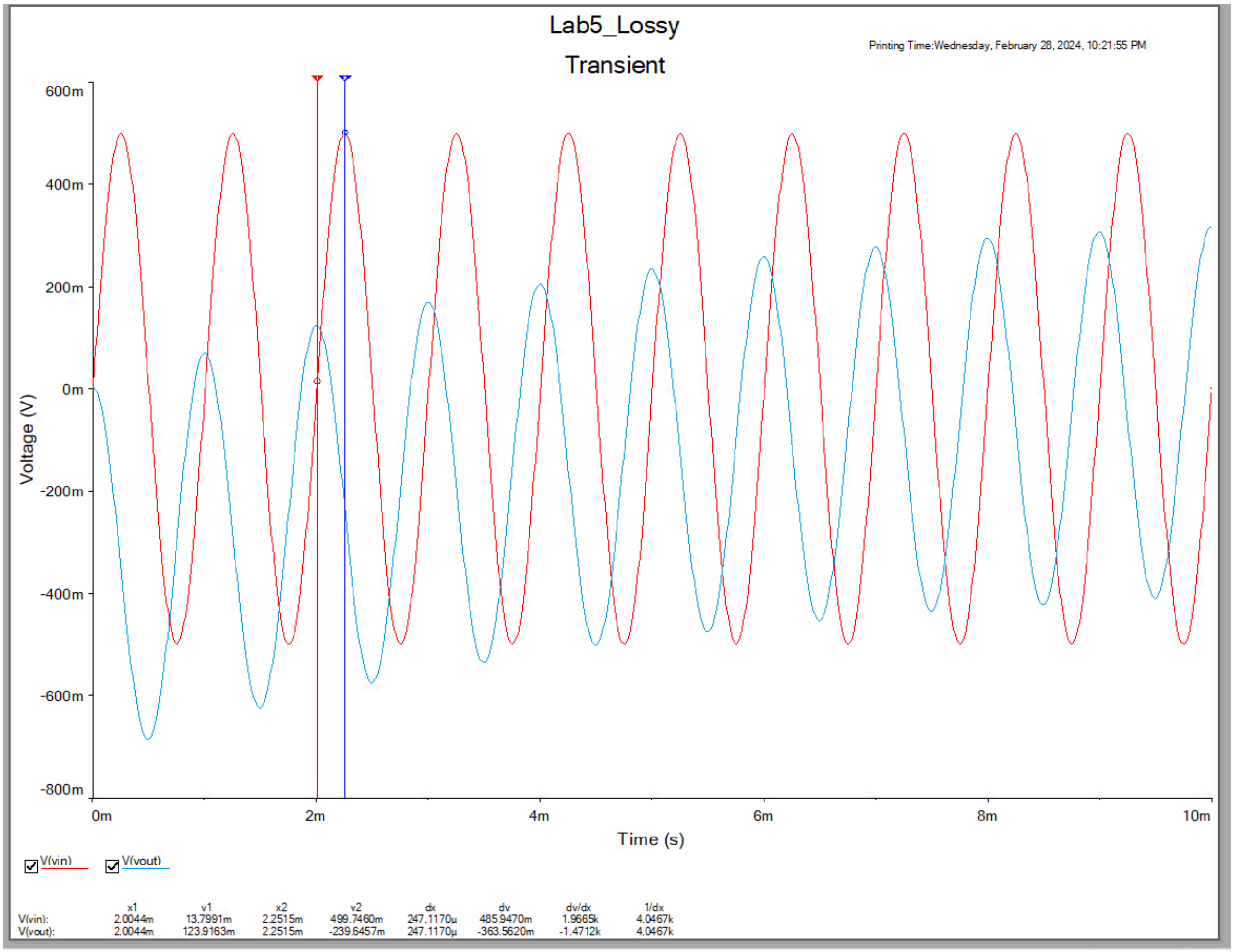
Bode Plots:



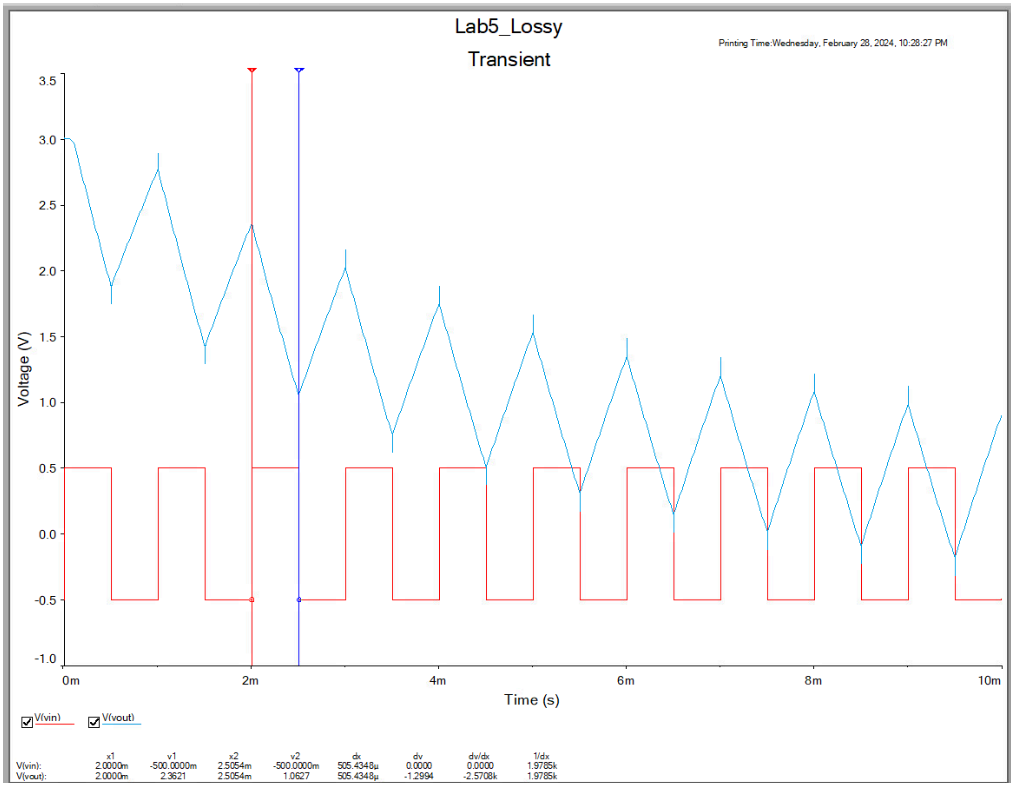


Here we can see that the $f_{3\text{-dB}}$ is at 32.9 Hz, and that the low frequency gain is 20.8 dB. The magnitude and phase at 1 kHz is -8.89 dB and 91.9° respectively.

Transient Plots:



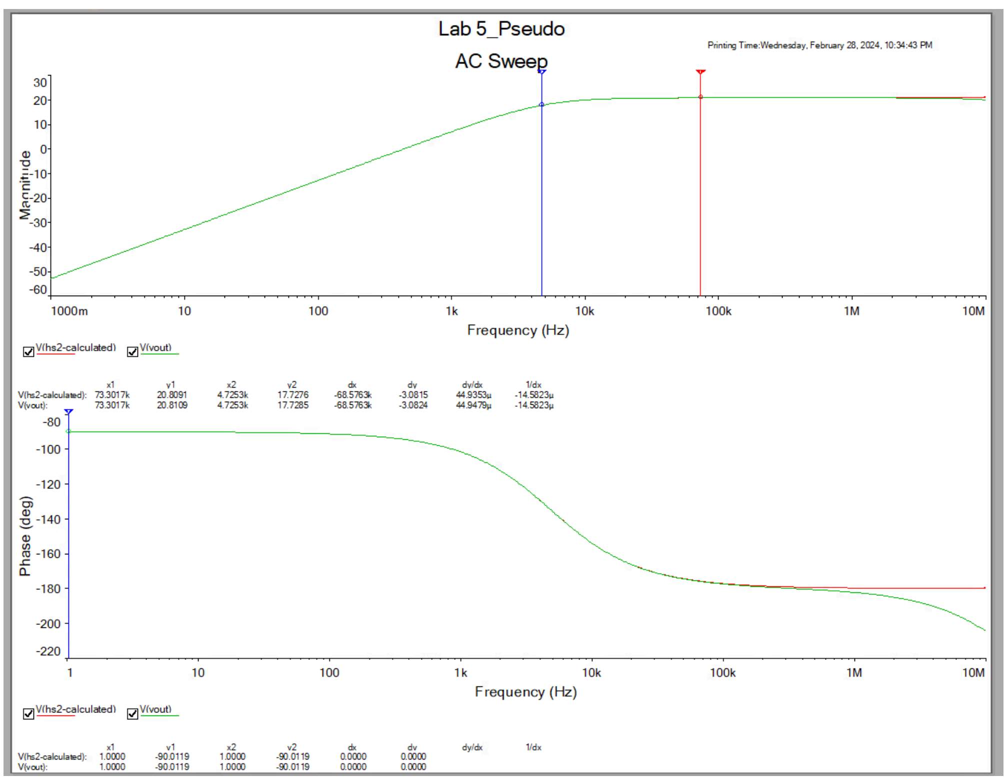
The phase difference calculated is 91.5° or 1.6 rads.

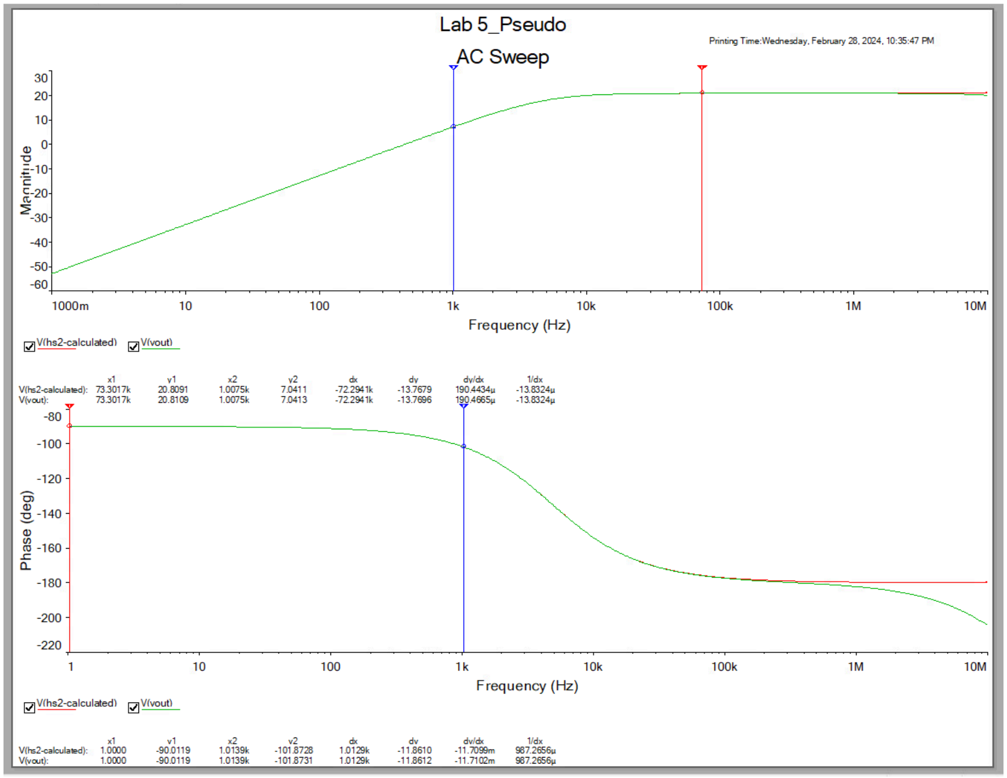


The V_{pp} for V_{in} and V_{out} are 1 V and 1.3 V respectively

<u>Pseudo DIfferentiator</u>

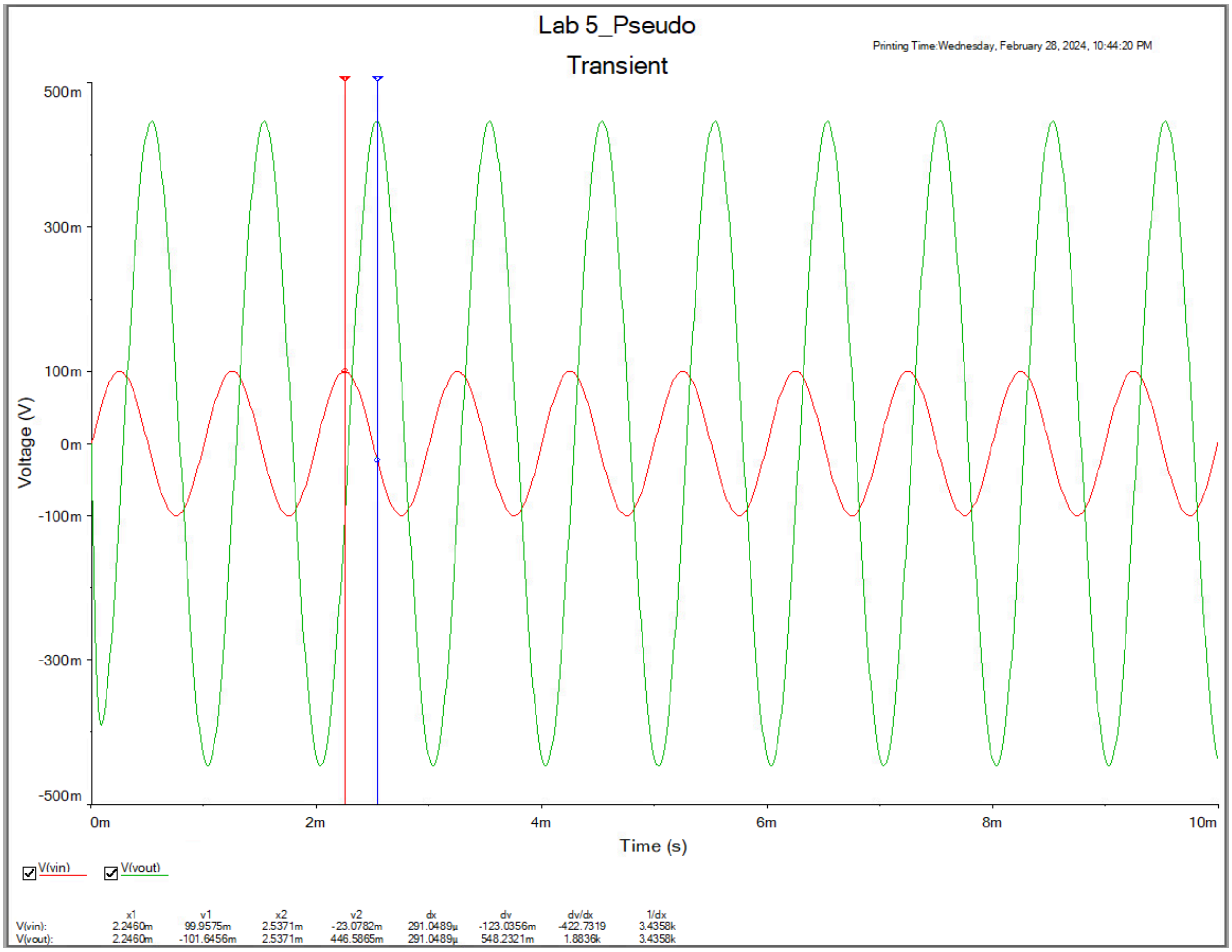
Bode Plots:



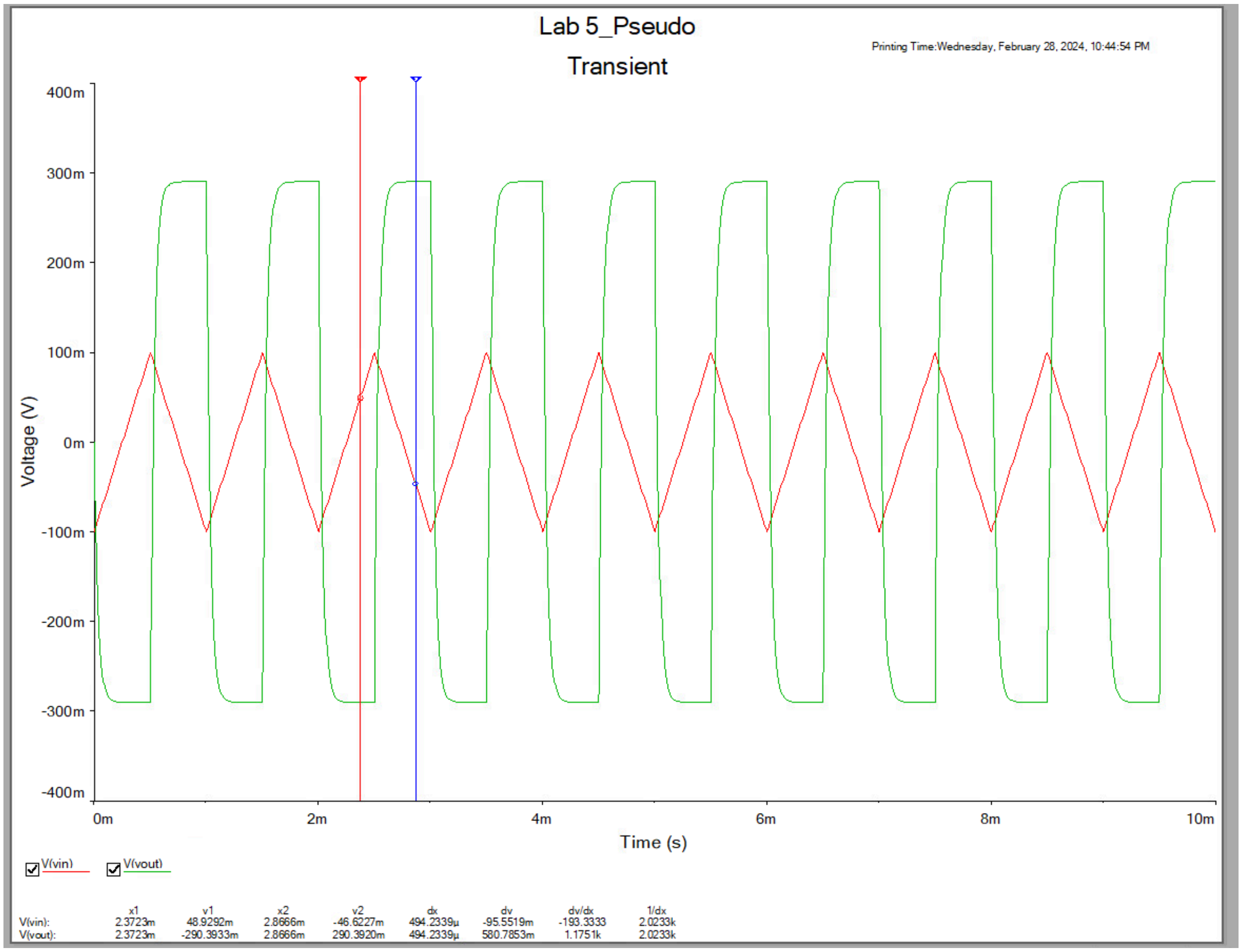


The $f_{3\text{-dB}}$ is at 4.725 kHz and the low frequency gain is 20.8 dB. The magnitude and phase at 1 kHz is 7.04 dB and -101.9° respectively.

Transient Plots:



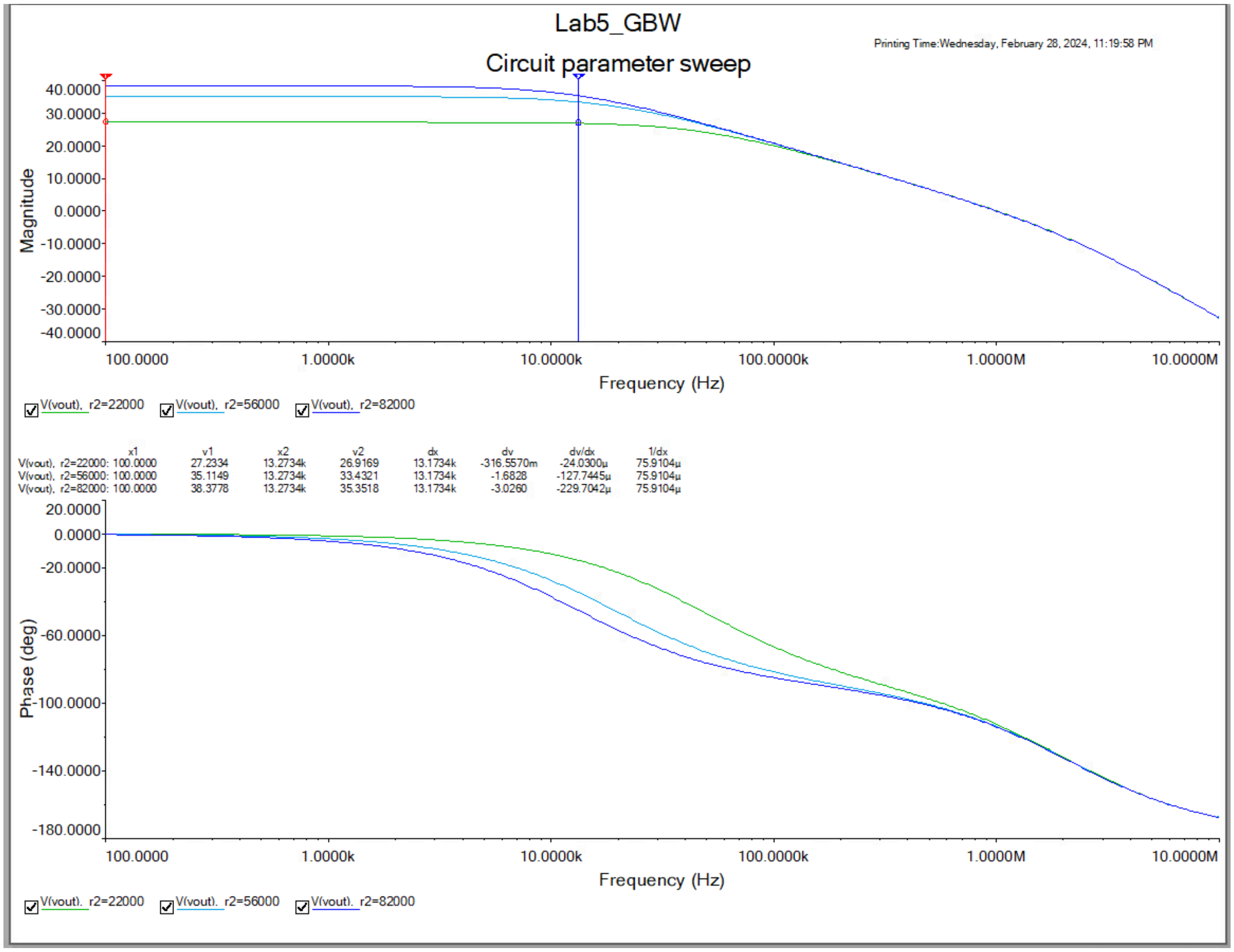
The magnitudes of V_{in} and V_{out} are 0.0999 V and 0.4466 V respectively. The phase difference between the two waves is about 98.9° or 1.73 rad.

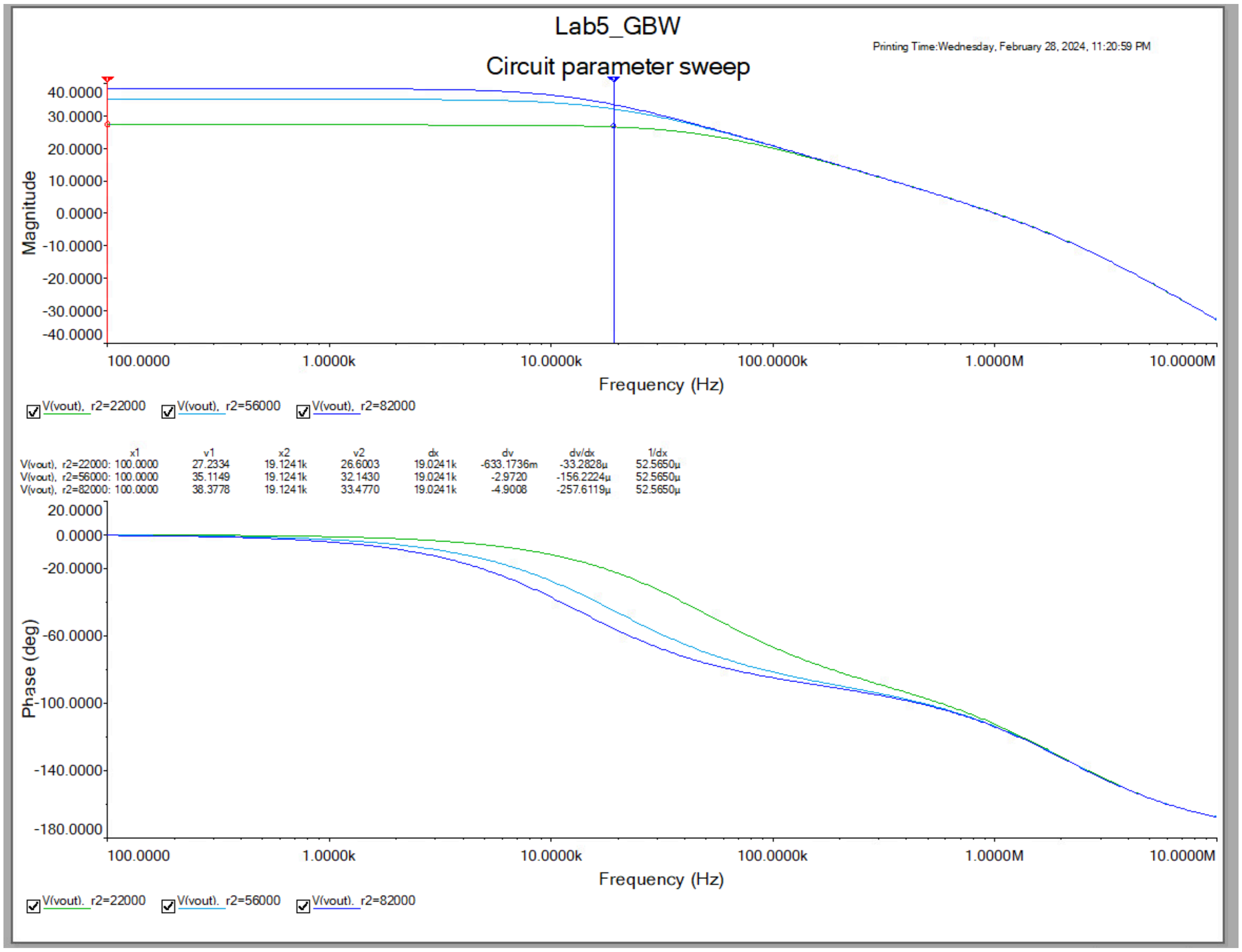


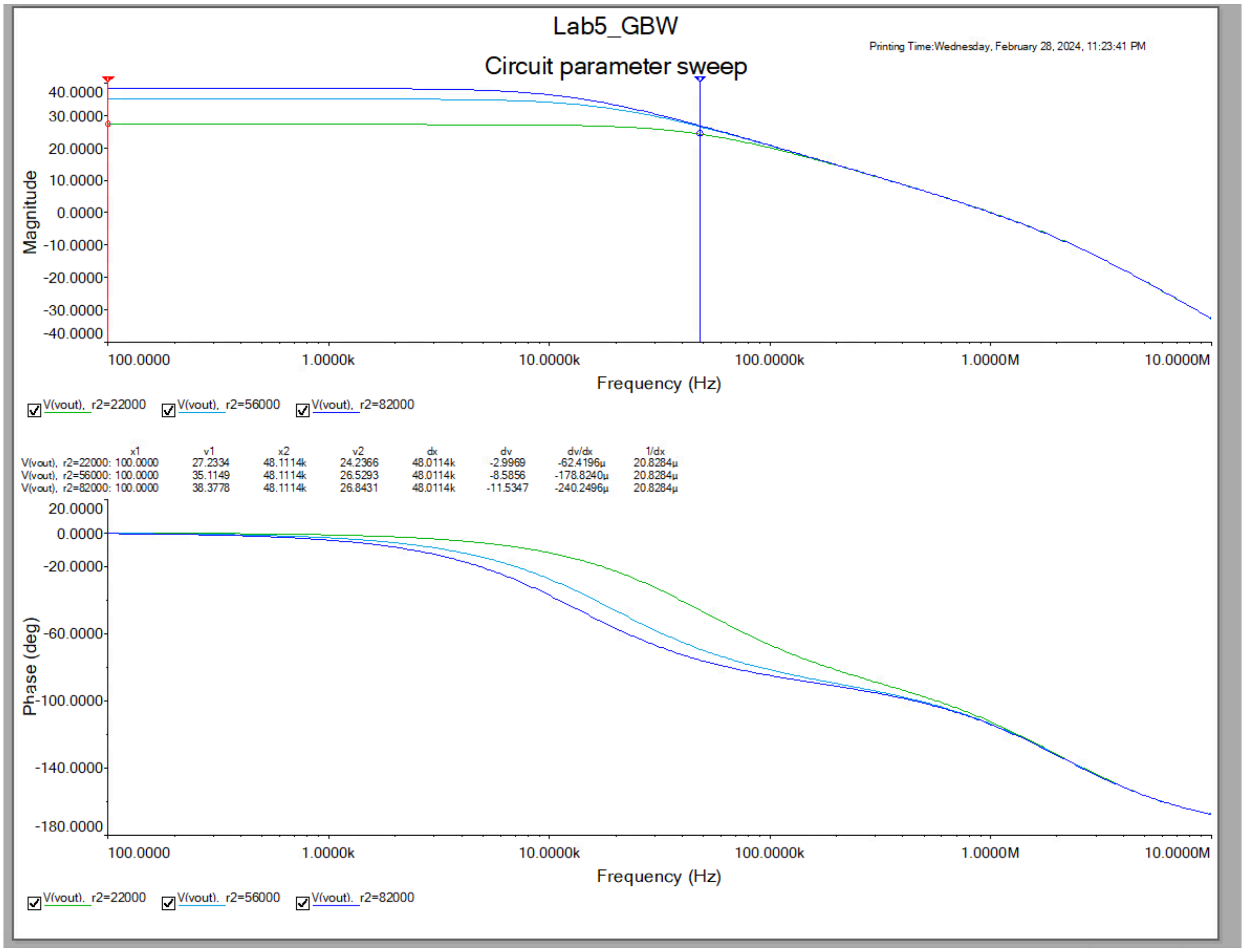
The V_{pp} for V_{in} and V_{out} is 0.2 V and 0.5808 V respectively.

<u>Finite GBW Limitations</u>

Bode Plots:


Lab5_GBW
Printing Time:Wednesday, February 28, 2024, 11:19:58 PM
Circuit parameter sweep
Magnitude
40.0000
30.0000
20.0000
10.0000
0.0000
-10.0000
-20.0000
-30.0000
-40.0000
100.0000
1.0000k
10.0000k
100.0000k
1.0000M
10.0000M
Frequency (Hz)
V(vout), r2=22000
V(vout), r2=56000
V(vout), r2=82000
x1 v1 x2 v2 dx dv dv/dx 1/dx
V(vout), r2=22000: 100.0000 27.2334 13.2734k 26.9169 13.1734k -316.5570m -24.0300µ 75.9104µ
V(vout), r2=56000: 100.0000 35.1149 13.2734k 33.4321 13.1734k -1.6828 -127.7445µ 75.9104µ
V(vout), r2=82000: 100.0000 38.3778 13.2734k 35.3518 13.1734k -3.0260 -229.7042µ 75.9104µ
Phase (deg)
20.0000
0.0000
-20.0000
-60.0000
-100.0000
-140.0000
-180.0000
100.0000
1.0000k
10.0000k
100.0000k
1.0000M
10.0000M
Frequency (Hz)
V(vout), r2=22000
V(vout), r2=56000
V(vout), r2=82000

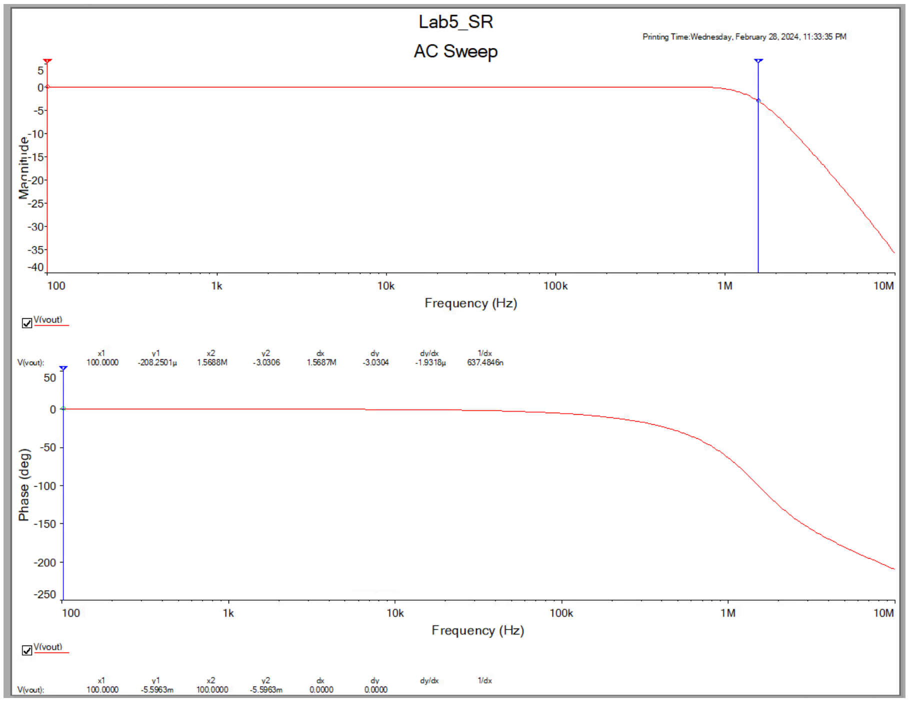

Lab5_GBW
Printing Time:Wednesday, February 28, 2024, 11:20:59 PM
Circuit parameter sweep
Magnitude
40.0000
30.0000
20.0000
10.0000
0.0000
-10.0000
-20.0000
-30.0000
-40.0000
100.0000
1.0000k
10.0000k
100.0000k
1.0000M
10.0000M
Frequency (Hz)
V(vout), r2=22000
V(vout), r2=56000
V(vout), r2=82000
x1 v1 x2 v2 dx dv dv/dx 1/dx
V(vout), r2=22000: 100.0000 27.2334 19.1241k 26.6003 19.0241k -633.1736m -33.2828µ 52.5650µ
V(vout), r2=56000: 100.0000 35.1149 19.1241k 32.1430 19.0241k -2.9720 -156.2224µ 52.5650µ
V(vout), r2=82000: 100.0000 38.3778 19.1241k 33.4770 19.0241k -4.9008 -257.6119µ 52.5650µ
Phase (deg)
20.0000
0.0000
-20.0000
-60.0000
-100.0000
-140.0000
-180.0000
100.0000
1.0000k
10.0000k
100.0000k
1.0000M
10.0000M
Frequency (Hz)
V(vout), r2=22000
V(vout), r2=56000
V(vout), r2=82000

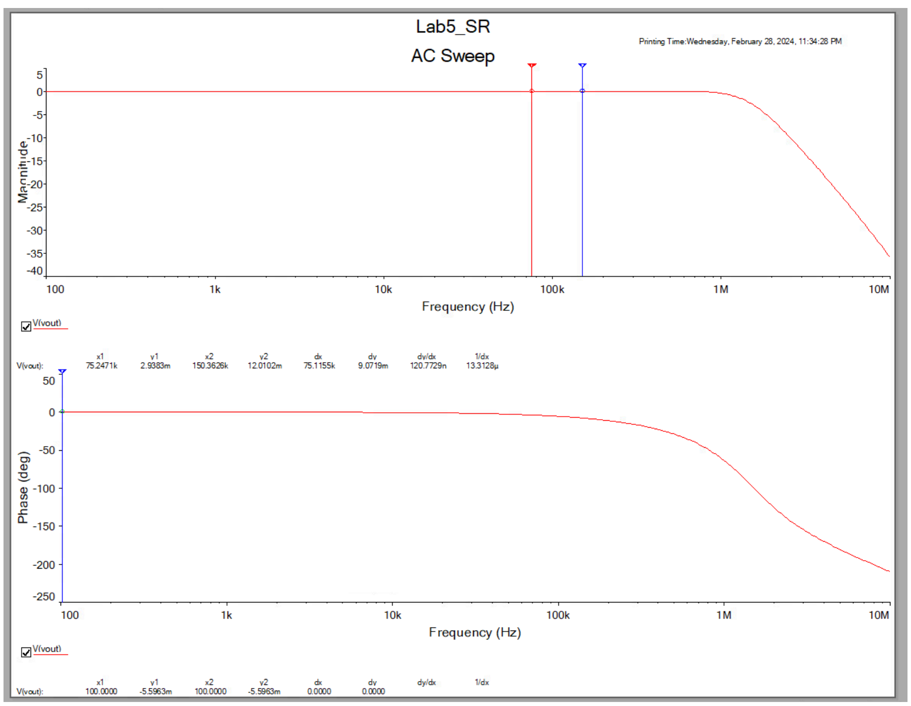


The $f_{3\text{-dB}}$ for R2 values 82k, 56k, and 22k are 13.273 kHz, 19.124 kHz, and 48.111 kHz respectively. The low frequency gain for R2 values 82k, 56k, and 22k are 27.23 dB, 35.11 dB, and 38.38 dB respectively.

<u>Slew Rate Limitations</u>

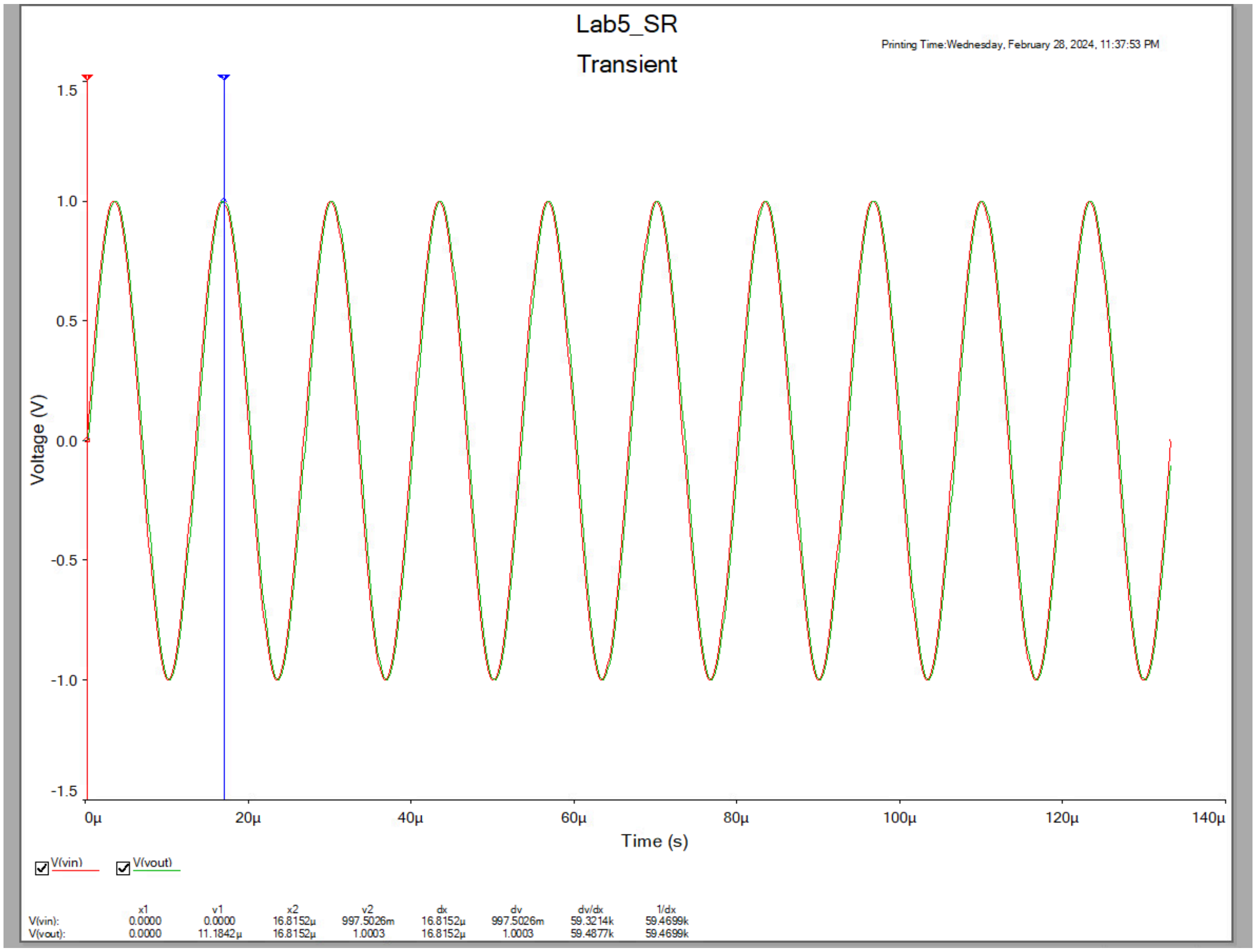
Bode Plots:

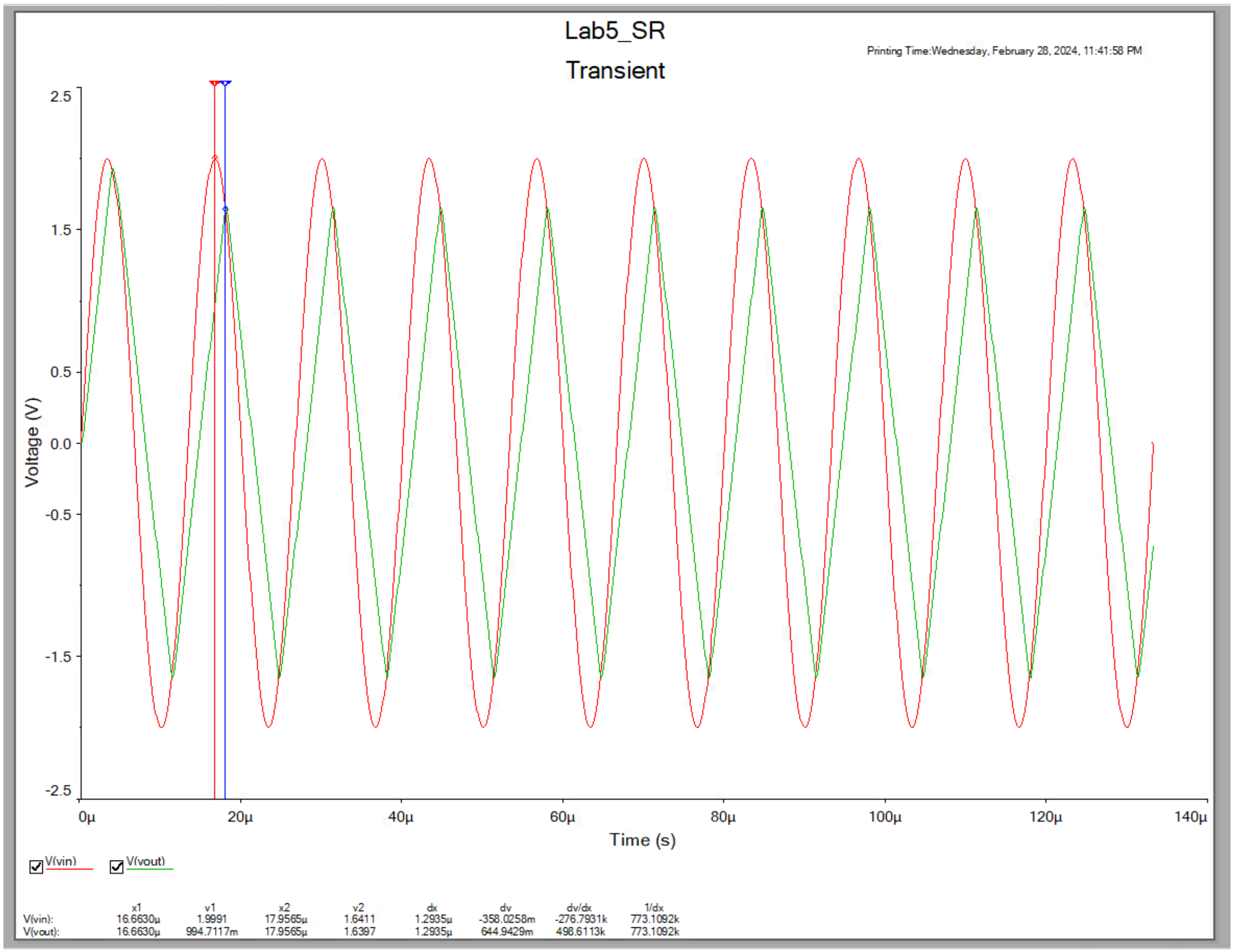


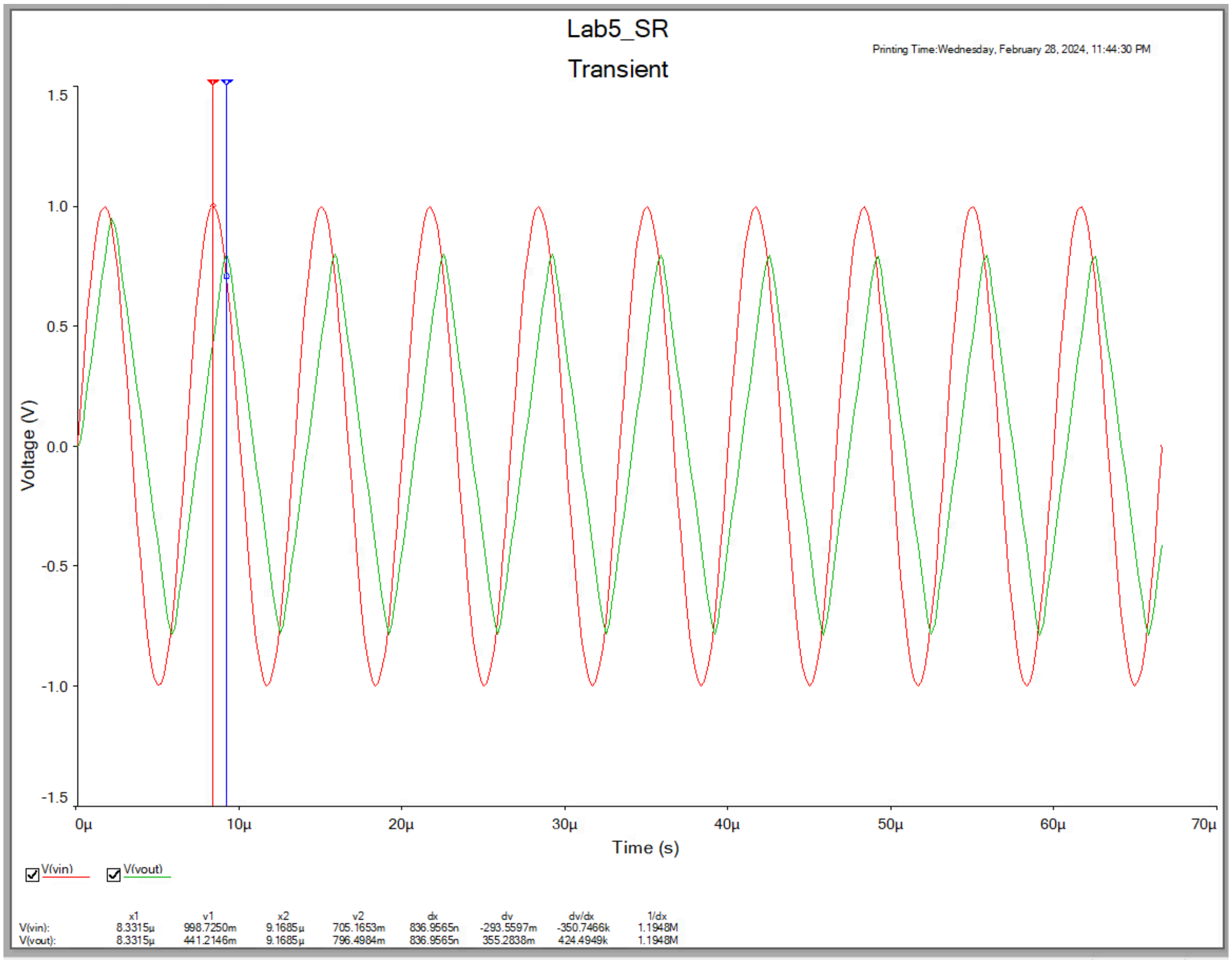


The low frequency gain is 0 dB and the $f_{3\text{-dB}}$ is 1.57 MHz.The magnitude at 75 kHz and 150 kHz is 0.0029 dB and 0.012 dB respectively.

Transient Plots:


Lab5_SR
Transient
Printing Time:Wednesday, February 28, 2024, 11:37:53 PM
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Voltage (V)
0μ
20μ
40μ
60μ
80μ
100μ
120μ
140μ
Time (s)
V(vin)
V(vout)
x1 v1 x2 v2 dx dv dv/dx 1/dx
V(vin): 0.0000 0.0000 16.8152μ 997.5026m 16.8152μ 997.5026m 59.3214k 59.4699k
V(vout): 0.0000 11.1842μ 16.8152μ 1.0003 16.8152μ 1.0003 59.4877k 59.4699k


Lab5_SR
Transient
Printing Time:Wednesday, February 28, 2024, 11:41:58 PM
Voltage (V)
2.5
1.5
0.5
0.0
-0.5
-1.5
-2.5
0µ
20µ
40µ
60µ
80µ
100µ
120µ
140µ
Time (s)
V(vin)
V(vout)
x1 v1 x2 v2 dx dv dv/dx 1/dx
V(vin): 16.6630µ 1.9991 17.9565µ 1.6411 1.2935µ -358.0258m -276.7931k 773.1092k
V(vout): 16.6630µ 994.7117m 17.9565µ 1.6397 1.2935µ 644.9429m 498.6113k 773.1092k



Fourier Plots:

Lab5_SR

Printing Time:Wednesday, February 28, 2024, 11:40:43 PM

1	Fourier analysis for V(vout					
2	DC component:	9.13295e-06				
3	No. Harmonics:	9				
4	THD:	0.939528 %				
5	Grid size:	256				
6	Interpolation Degree:	1				
7						
8	Harmonic	Frequency	Magnitude	Phase	Norm. Mag	Norm. Phase
9	0	0	9.13295e-06	0	9.14567e-06	0
10	1	75000	0.998609	-5.3684	1	0
11	2	150000	0.000235828	-19.427	0.000236157	-14.058
12	3	225000	0.00913983	-123.91	0.00915256	-118.54
13	4	300000	9.02378e-05	-60.166	9.03635e-05	-54.798
14	5	375000	0.00202855	-174.91	0.00203137	-169.54
15	6	450000	3.27862e-05	-121.8	3.28318e-05	-116.43
16	7	525000	0.00053193	114.627	0.000532671	119.995
17	8	600000	1.24114e-05	160.194	1.24287e-05	165.562
18	9	675000	0.000162323	31.5573	0.000162549	36.9257
19						

The THD at 1 V, 75 kHz is 0.9395%

Lab5_SR

Printing Time:Wednesday, February 28, 2024, 11:42:47 PM

1	Fourier analysis for V(vout					
2	DC component:	0.00118459				
3	No. Harmonics:	9				
4	THD:	11.793 %				
5	Grid size:	256				
6	Interpolation Degree:	1				
7						
8	Harmonic	Frequency	Magnitude	Phase	Norm. Mag	Norm. Phase
9	0	0	0.00118459	0	0.000857177	0
10	1	75000	1.38197	-37.382	1	0
11	2	150000	0.00416772	-126.98	0.00301578	-89.597
12	3	225000	0.151119	68.0055	0.10935	105.387
13	4	300000	0.00122769	-3.9273	0.000888362	33.4543
14	5	375000	0.0529583	173.496	0.0383209	210.877
15	6	450000	0.000695514	112.471	0.000503277	149.853
16	7	525000	0.0259969	-80.715	0.0188115	-43.333
17	8	600000	0.000478892	-135.09	0.000346528	-97.703
18	9	675000	0.0149815	25.4241	0.0108407	62.8057
19						

The THD at 2 V, 75 kHz is 11.793%

Lab5_SR

Printing Time:Wednesday, February 28, 2024, 11:46:24 PM

1	Fourier analysis for V(vout)					
2	DC component:	2.84679e-05				
3	No. Harmonics:	9				
4	THD:	11.326 %				
5	Grid size:	256				
6	Interpolation Degree:	1				
7						
8	Harmonic	Frequency	Magnitude	Phase	Norm. Mag	Norm. Phase
9	0	0	2.84679e-05	0	4.1402e-05	0
10	1	150000	0.687597	-42.563	1	0
11	2	300000	0.00104431	-134.44	0.00151878	-91.878
12	3	450000	0.0729918	52.6309	0.106155	95.1942
13	4	600000	0.000303939	-20.92	0.00044203	21.6429
14	5	750000	0.0241447	148.573	0.0351146	191.136
15	6	900000	0.000164118	86.026	0.000238684	128.589
16	7	1.05e+06	0.0109508	-114.37	0.0159262	-71.81
17	8	1.2e+06	0.00010481	-170.31	0.000152429	-127.74
18	9	1.35e+06	0.00574031	-16.107	0.00834836	26.4563
19						

The THD at 150 kHz is 11.326%