Laboratory Four — OP Amps

Rishabh Shah
4655 4192

Partner: Matthew Remillard

November 3, 2017

Pre-Lab

I

a

$Gain = \frac{V_{out}}{V_{in}} = (1 + \frac{R_f}{R_S})(\frac{R_B+R_P-R_X}{R_B+R_P})$

$Gain_{min} = (1 + \frac{R_f}{R_S})(\frac{R_B}{R_B+R_P})$

Gain is minimized when $R_X = R_P$

$Gain_{max} = 1 + \frac{R_f}{R_S}$
Gain is maximized when $R_X = 0$

b

$Gain = \frac{V_{out}}{V_{in}} = (1 + \frac{R_f}{R_S})(\frac{R_B+R_P-R_X}{R_B+R_P})$
$R_f = R_S(Gain(\frac{R_B+R_P}{R_B+R_P-R_X})) = 1k\Omega(50(\frac{2k\Omega+10k\Omega}{2k\Omega+10k\Omega-2k\Omega=60k\Omega}))$

II

a

$Gain = |\frac{V_{out}}{V_{in}}| = \frac{R_1+R_X}{R_S}$

$|Gain_{min}| = \frac{R_1}{R_S}$

Gain is minimized when $R_X = 0$

$|Gain_{max}| = \frac{R_1+R_X}{R_S}$
Gain is maximized when $R_X = R_P$

b

$Gain = |\frac{V_{out}}{V_{in}}| = \frac{R_1+R_X}{R_S}$

$R_f = R_1 + R_X$

$Gain = \frac{R_f}{R_S}$
$R_f = Gain \cdot R_S = 100 \cdot 1k\Omega = 100k\Omega$

III

a

$Gain_{min} = 1$

$Gain_{max} = 101$

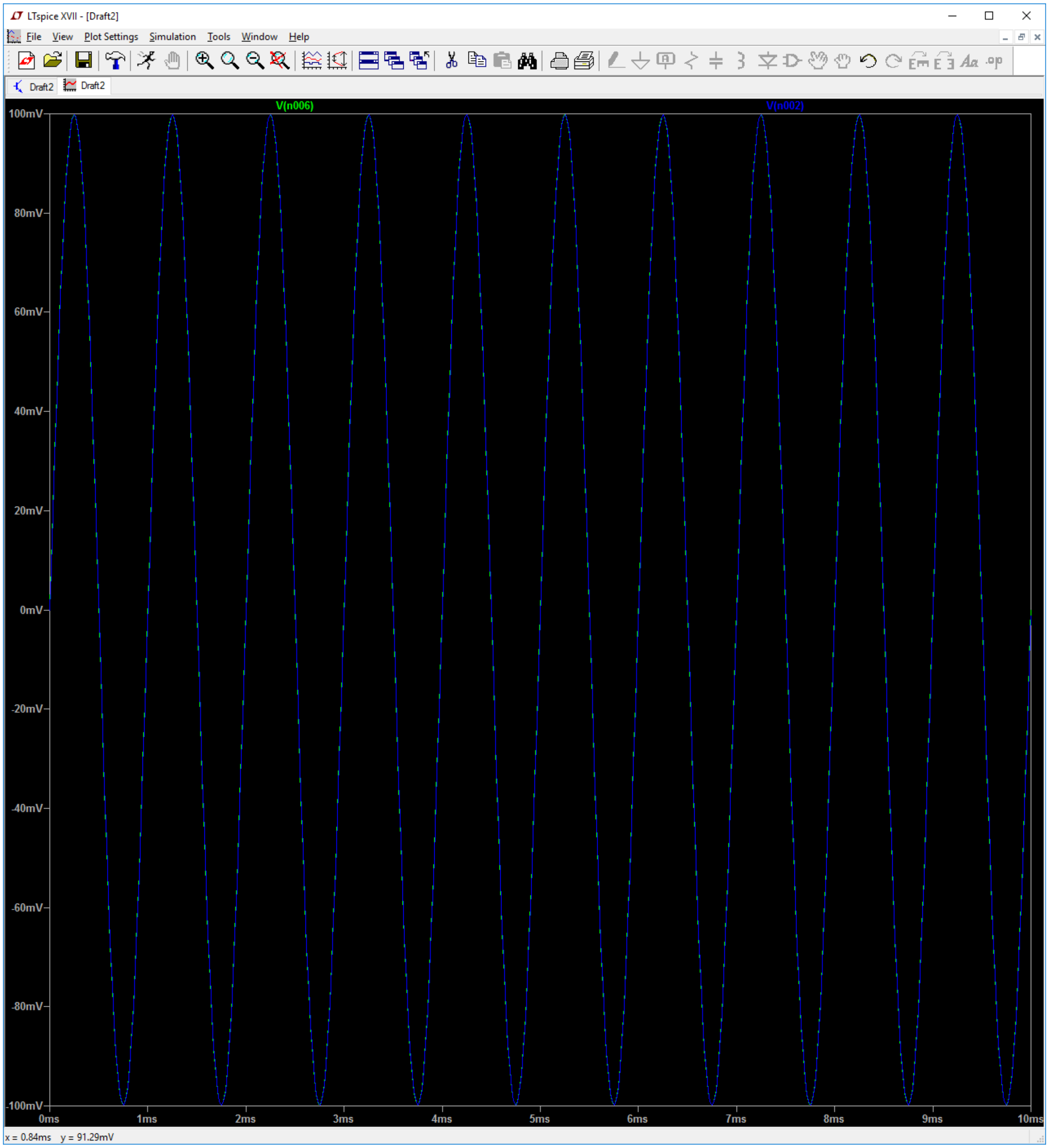

Figure 1: Plot of minimum gain

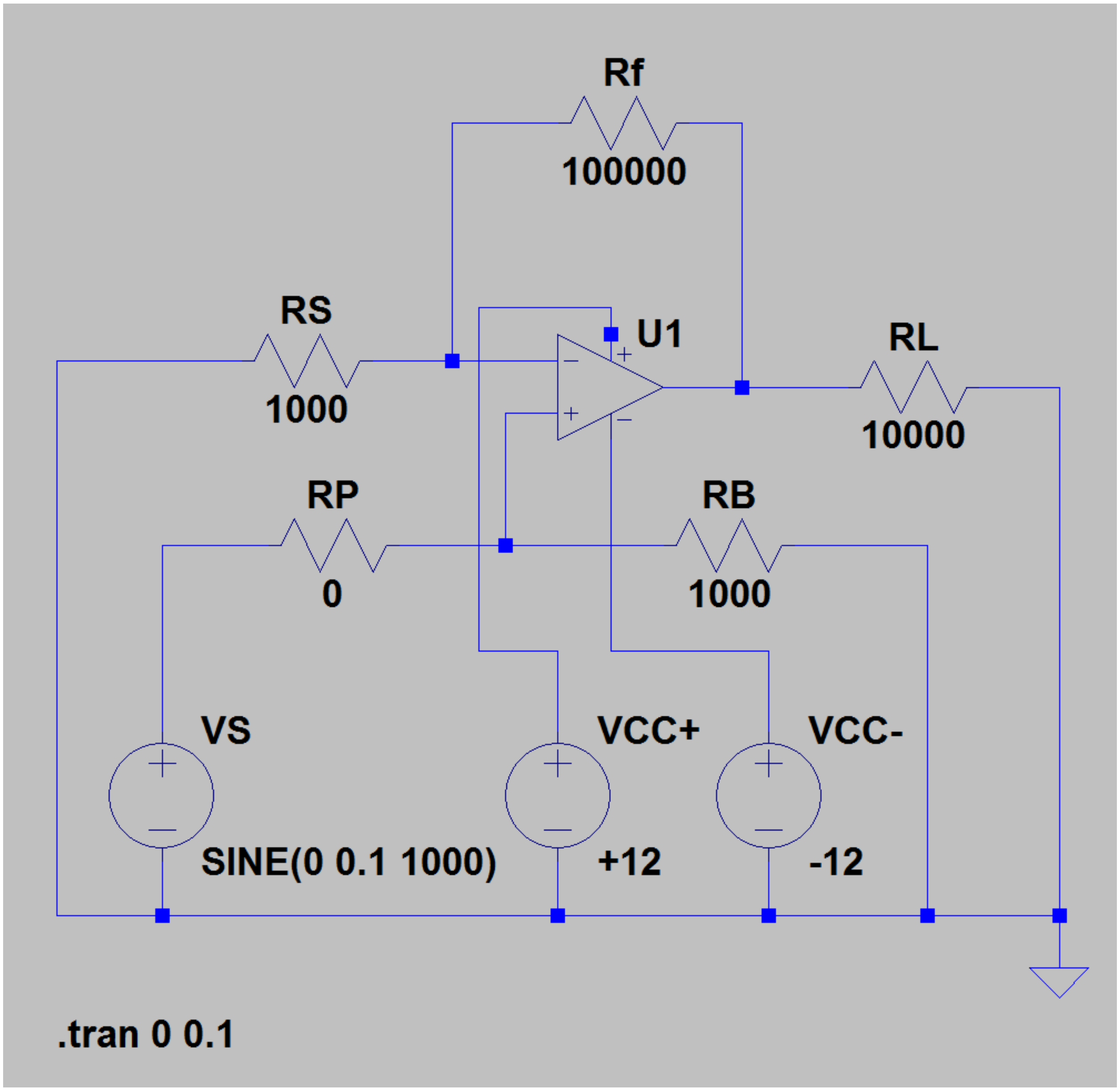

Figure 2: Circuit schematic which results in minimum gain

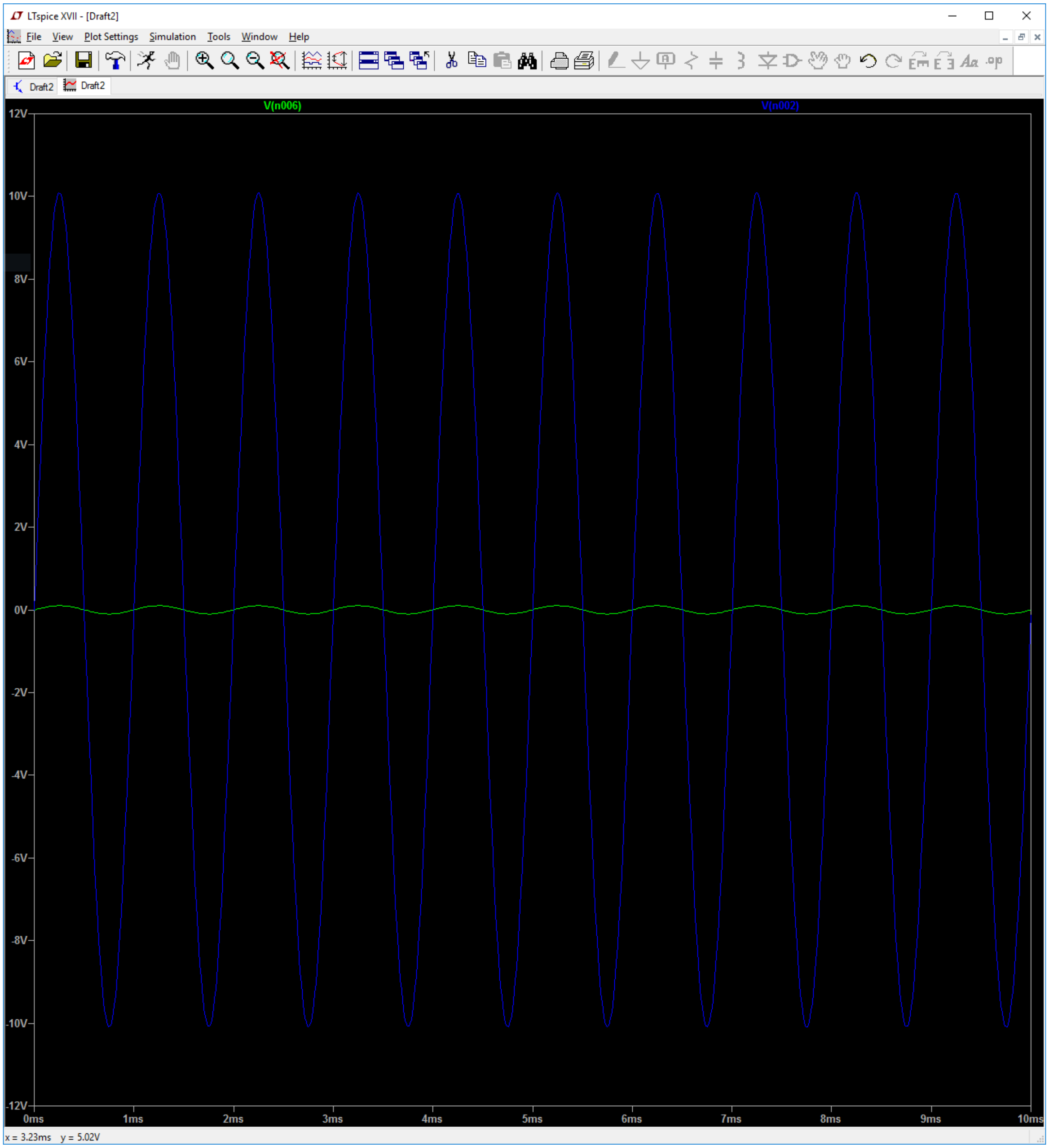

Figure 3: Plot of maximum gain

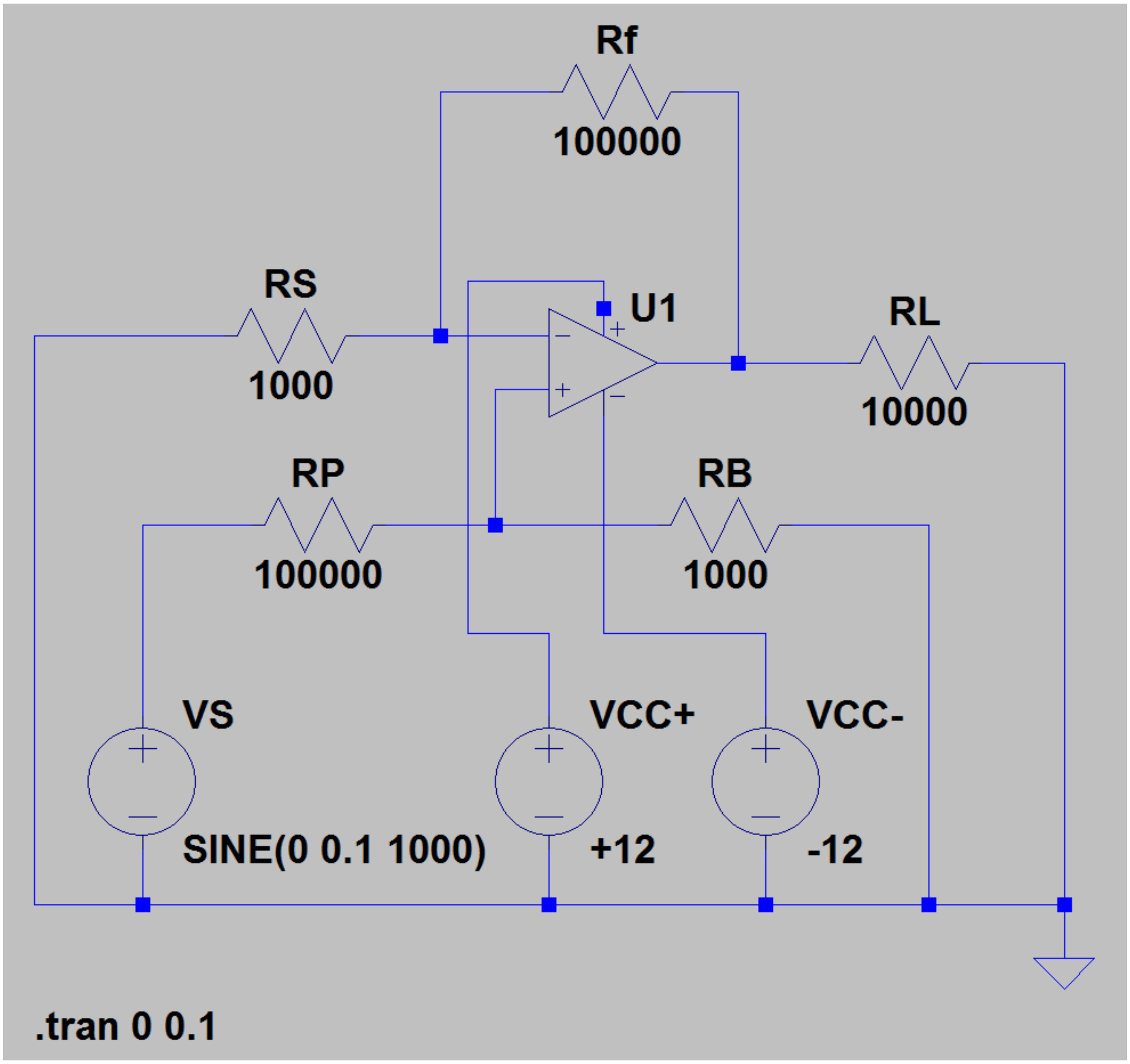

Figure 4: Circuit schematic which results in maximum gain

b

The smallest peak amplitude of the output signal at which clipping is observed is $12.12V$.

c

The waveform is clipped only at positive voltages.

d

The waveform is clipped only at negative voltages.

Lab Data

Voltage Follower

V_{in}	V_{CC}	V_{out}
$4.997V$	$8.00V$	$3.369V$

Table 1: Voltage follower data

Inverting Amplifier

$R_X = 58475\Omega$

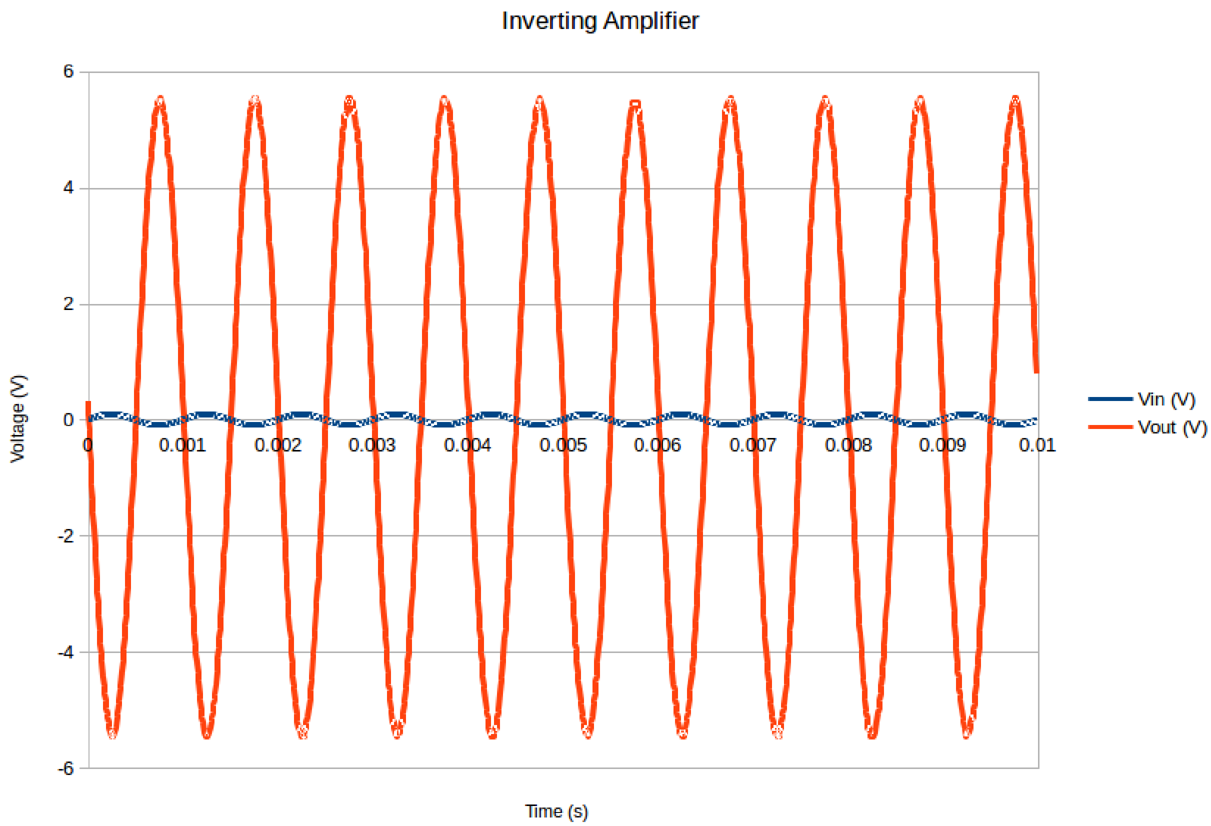

Figure 5: V_{in} and V_{out} vs Time for the inverting amplifier

Noninverting Amplifier

$R_X = 105820\Omega$

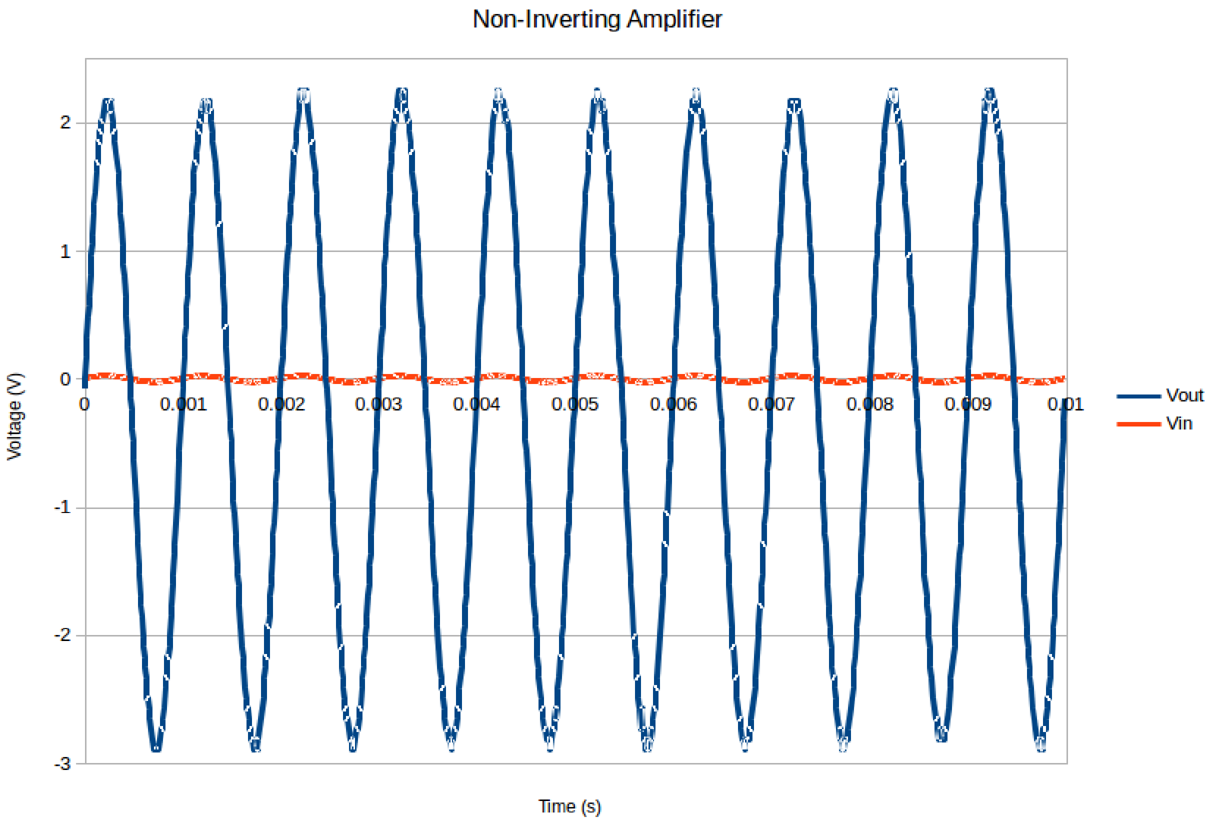

Figure 6: V_{in} and V_{out} vs Time for the noninverting amplifier

Clipping

$+V_{CC}(V)$	$-V_{CC}(V)$	$V_{OUT,MAX}(V)$	$V_{OUT,MIN}(V)$	$\Delta V+(V)$	$\Delta V-(V)$
15	-15	13.1	-13.3	1.9	-1.7
20	-20	17.7	-17.9	2.3	-2.1

Table 2: Data when $R_L = 2k\Omega$

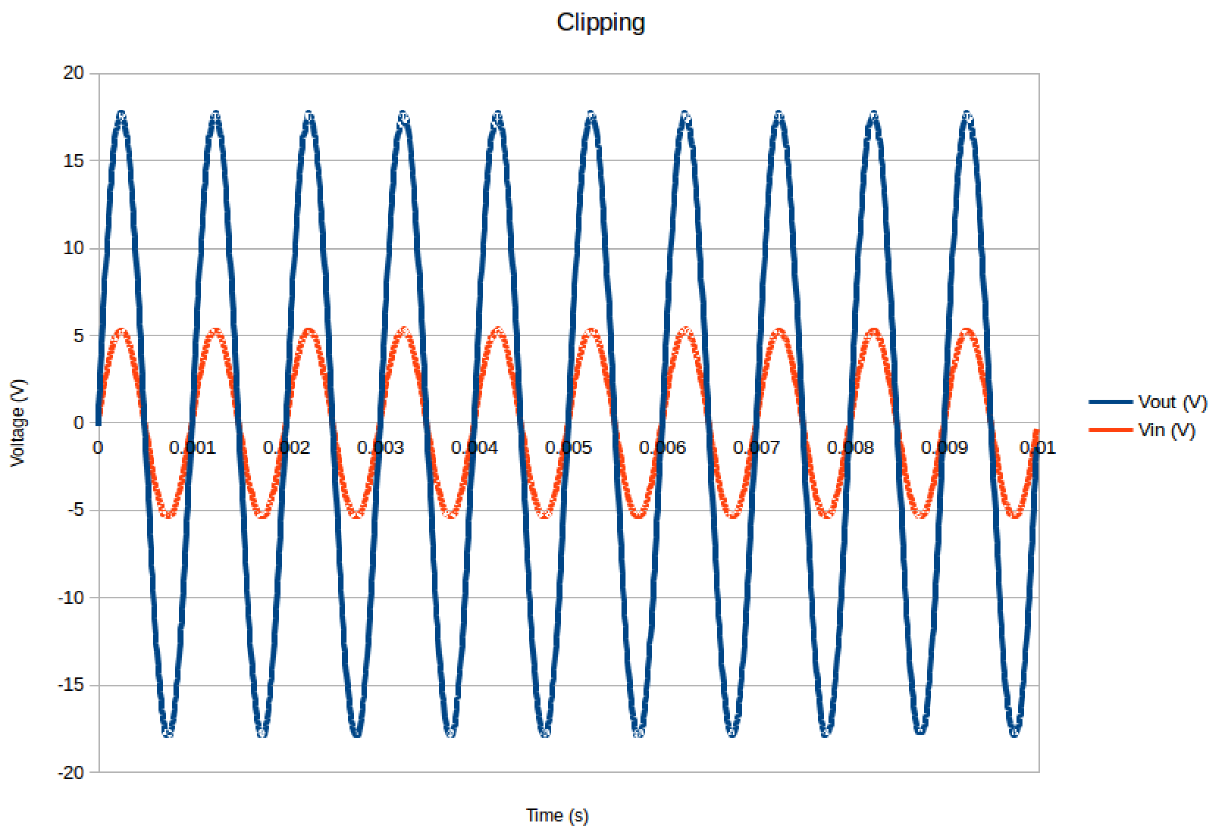

Figure 7: V_{in} and V_{out} vs Time for when $R_L = 2k\Omega$

$+V_{CC}(V)$	$-V_{CC}(V)$	$V_{OUT,MAX}(V)$	$V_{OUT,MIN}(V)$	$\Delta V+(V)$	$\Delta V-(V)$
15	-15	13.3	-13.7	1.7	-1.3
20	-20	18.1	-18.3	1.9	-1.7

Table 3: Data when $R_L = 10k\Omega$

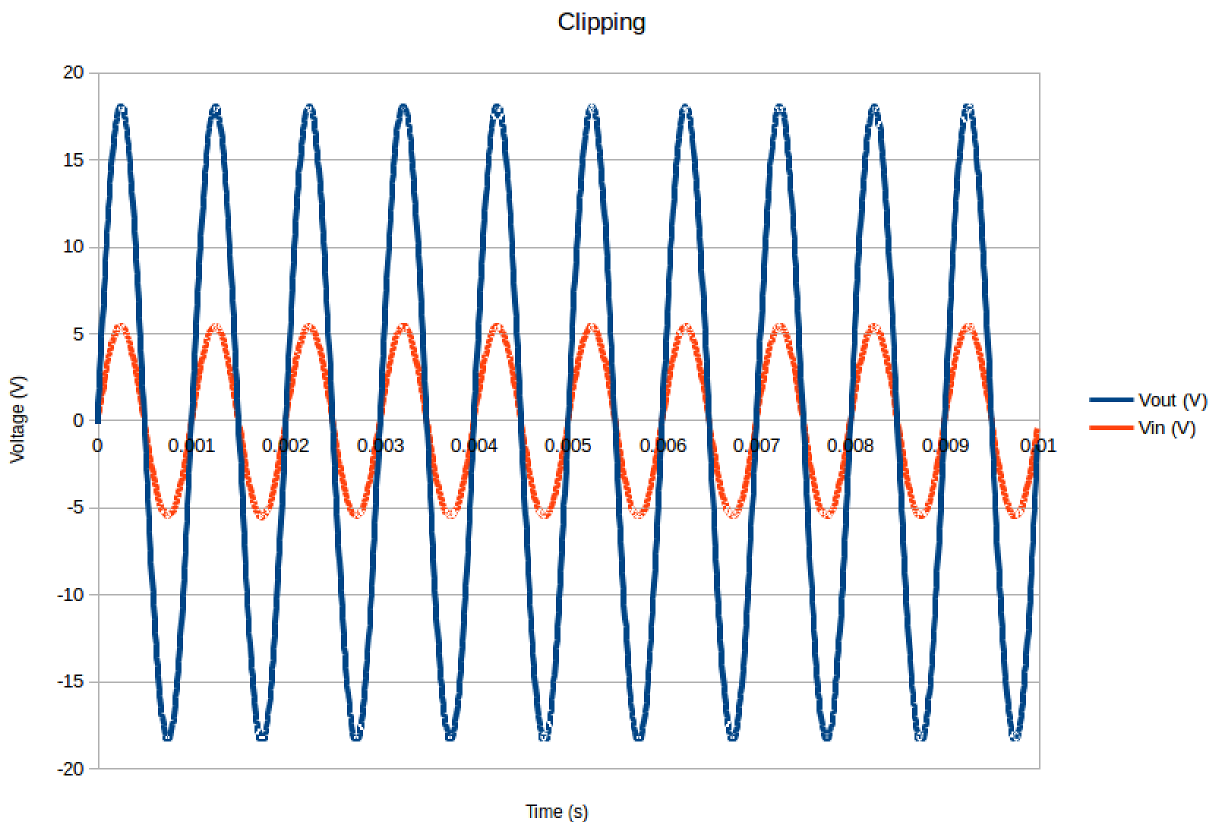

Figure 8: V_{in} and V_{out} vs Time for when $R_L = 10k\Omega$

Phase Shift and Time Delay

Frequency (kHz)	Shift (μs)	Shift ($^{\circ}$)
2	-13.3	-5.38
5	-11.6	-20.5
10	-9.6	-36.3
20	-7.9	-57.2

Table 4: Data for phase shift and time delay

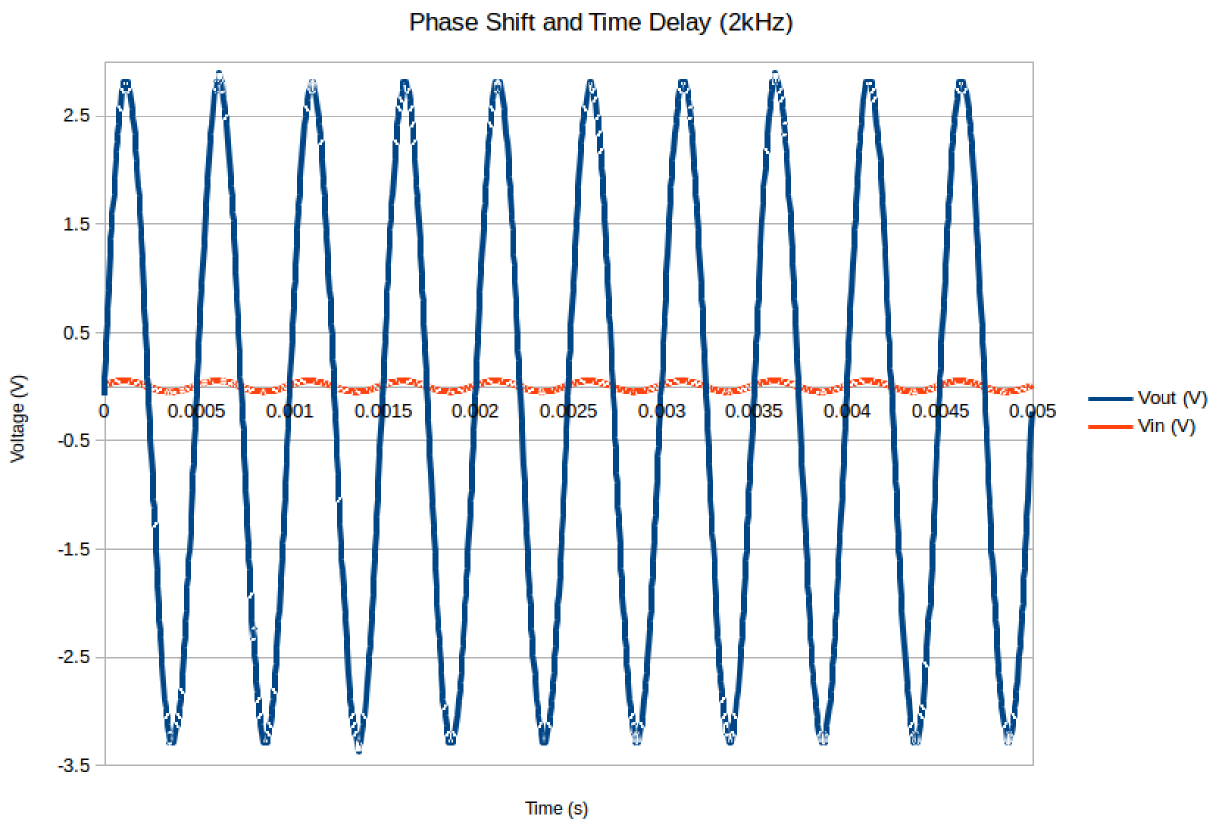

Figure 9: V_{in} and V_{out} vs Time for when frequency is $2kHz$

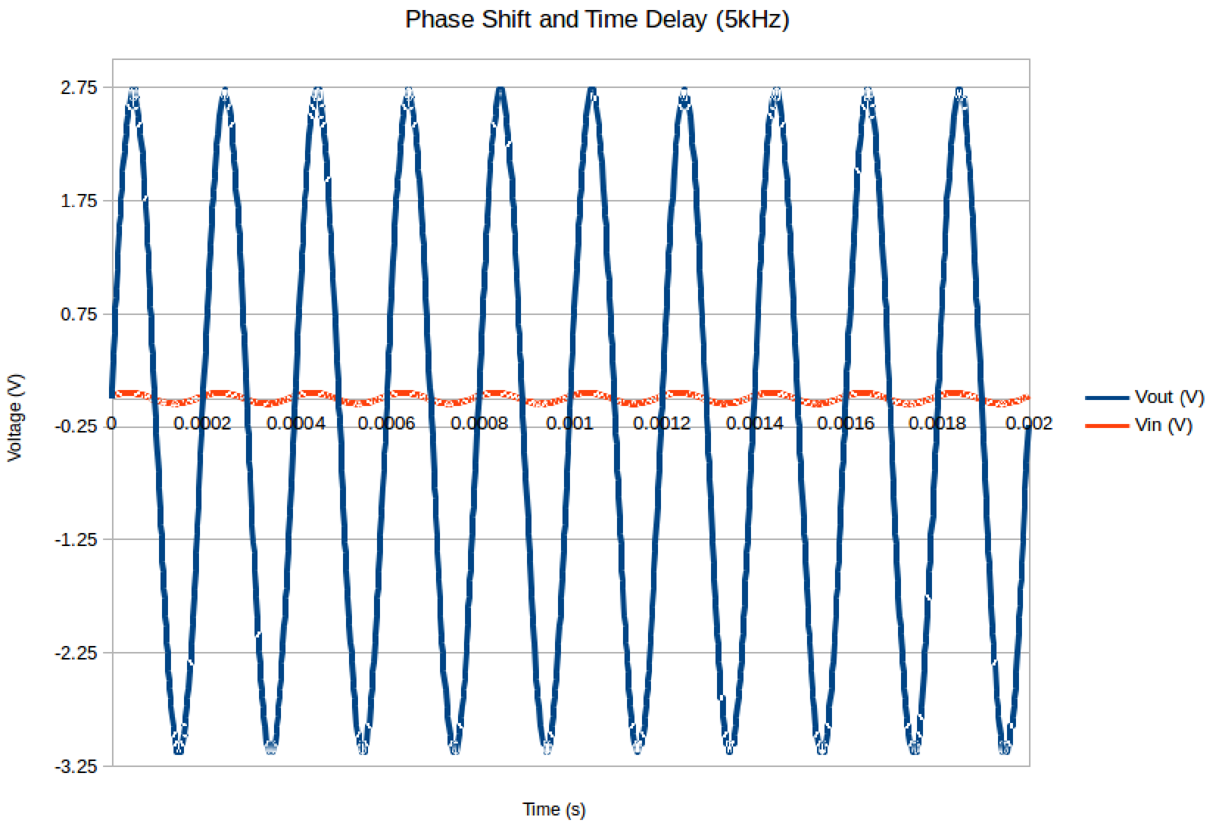

Figure 10: V_{in} and V_{out} vs Time for when frequency is $5kHz$

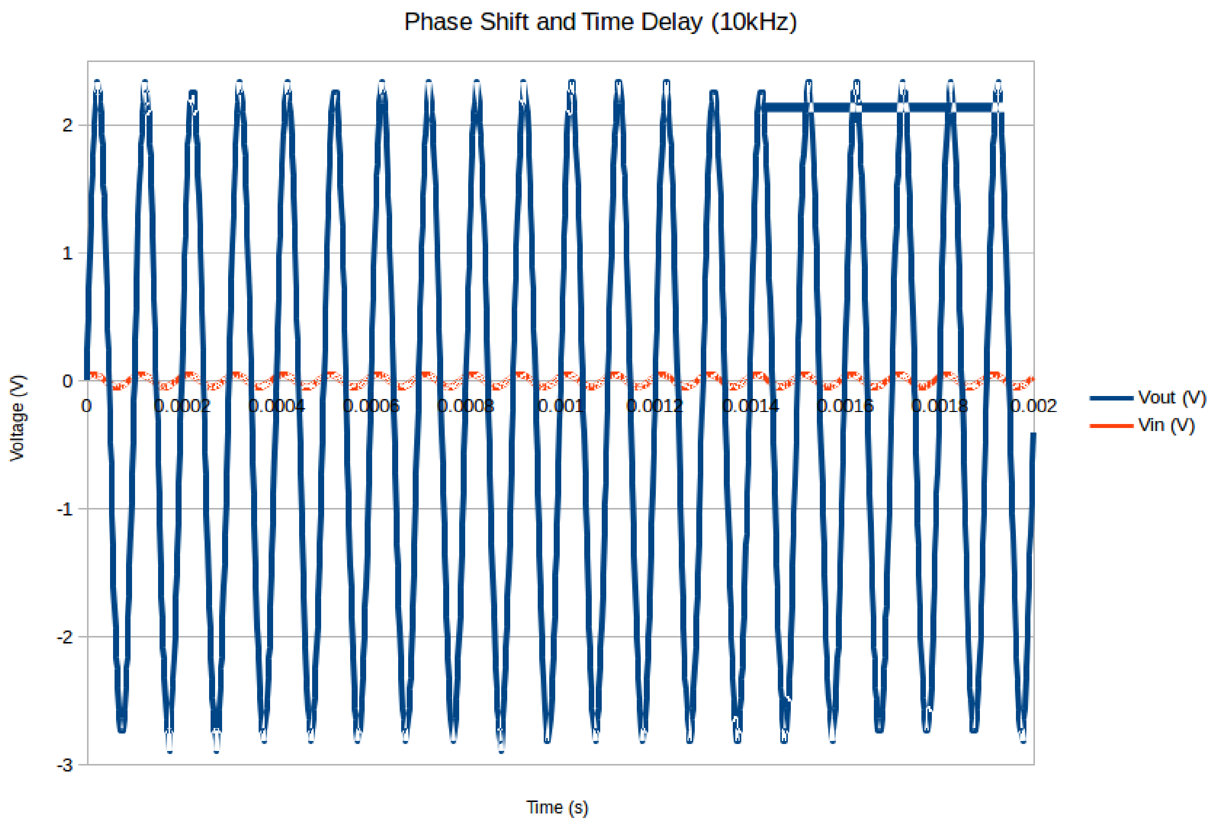

Figure 11: V_{in} and V_{out} vs Time for when frequency is $10kHz$

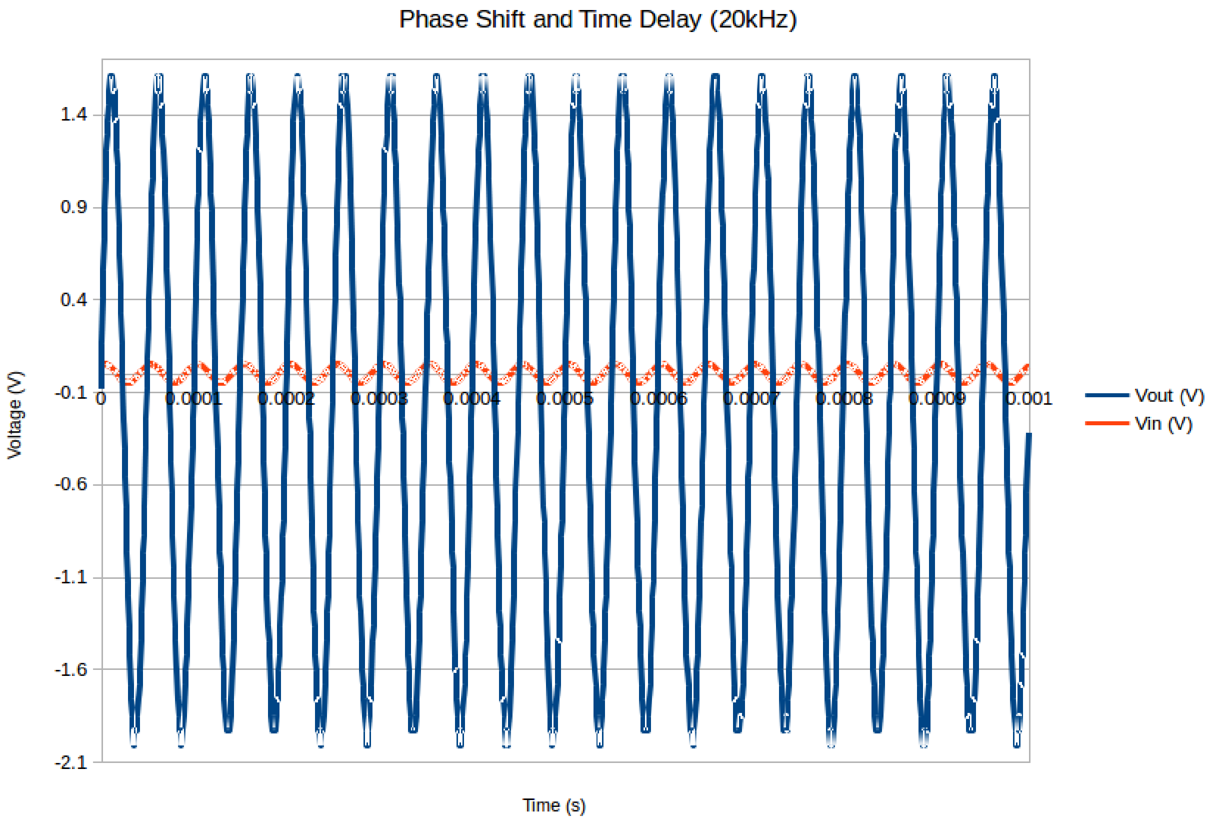

Figure 12: V_{in} and V_{out} vs Time for when frequency is $20kHz$

Post-Lab

Voltage Buffer

Using ideal op-amp assumptions, $V_{out} = V_{in}$ in a voltage follower circuit due to 100% negative feedback. $V_{in} = \frac{V_S}{R_1+R_2}R_2 = \frac{5V}{100k\Omega+200k\Omega}200k\Omega = 3.333V$ $PercentageError = \frac{|measured-calculated|}{calculated} = \frac{|3.369V-3.333V|}{3.333V} = 1.080\%$ If the value of R_3 changed, it would have an effect on the current drawn from the voltage source. If the value of R_3 increases, the current drawn would decrease. If the value of R_3 decreases, the current drawn would increase.

Inverting Amplifier

Using ideal op-amp assumptions, $Gain = \frac{V_{out}}{V_{in}}$ $V_{out} = \frac{R_f}{R_S}V_{in}$ $R_f = |Gain| \cdot R_S = 50 \cdot 1000\Omega = 50k\Omega$ $PercentageError = \frac{|measured-calculated|}{calculated} = \frac{|59475\Omega-50000\Omega|}{50000\Omega} = 18.95\%$ The measured R_f was larger than the calculated value by 18.95%. This is due to the fact that the calculated value relied on an ideal op-amp. However, the op-amp used in the experiment was not an ideal op-amp. The LM 741 is a non-ideal op-amp, causing the difference between the calculated and measured values.

Noninverting Amplifier

Using ideal op-amp assumptions, $Gain = \frac{V_{out}}{V_{in}}$ $V_{out} = (1+\frac{R_f}{R_S})V_{in}$ $R_f = (|Gain|-1) \cdot R_S = (100-1) \cdot 1k\Omega = 99k\Omega$ $PercentageError = \frac{|measured-calculated|}{calculated} = \frac{|106820\Omega-99000\Omega|}{99000\Omega} = 7.90\%$ The measured R_f was larger than the calculated value by 7.90%. This is due to the fact that the calculated value relied on an ideal op-amp. However, the op-amp used in the experiment was not an ideal op-amp. The LM 741 is a non-ideal op-amp, causing the difference between the calculated and measured values.

Clipping

	$+V_{CC}(V)$	$-V_{CC}(V)$	$\Delta V+(V)$	$\Delta V-(V)$
Pre-Lab	12	-12	-0.12	0.12
In-Lab ($R_L = 2k\Omega$)	15	-15	1.9	-1.7
	20	-20	2.3	-2.1
In-Lab ($R_L = 10k\Omega$)	15	-15	1.7	-1.3
	20	-20	1.9	-1.7

Clipping data for pre-lab and in-lab

In the values measured from the pre-lab, $\Delta V-$ and $\Delta V+$ are equal in magnitude. However, in the values measured from in-lab, $\Delta V-$ and $\Delta V+$ are not equal in magnitude, but are similar. This is due to the fact that the calculated values relied on an ideal op-amp. However, the op-amp used in the experiment was not an ideal op-amp. The LM 741 is a non-ideal op-amp, causing the difference between the calculated and measured values. $\Delta V+ = V_{CC} - V_{OUT,MAX} = V_{CC} - Gain \cdot V_{in}$ where $V_{CC} < Gain \cdot V_{in}$. According to the spec sheet found at `http://www.ti.com/lit/ds/symlink/lm741.pdf`, the measured output voltage swing dependent upon R_L agrees with the values given.

Phase Shift

As the frequency increased, the phase shift in μs increased but the magnitude of the phase shift in μs decreased. The phase shift in degrees decreased but the magnitude of the phase shift in degrees increased.