Physics 111A Lab6

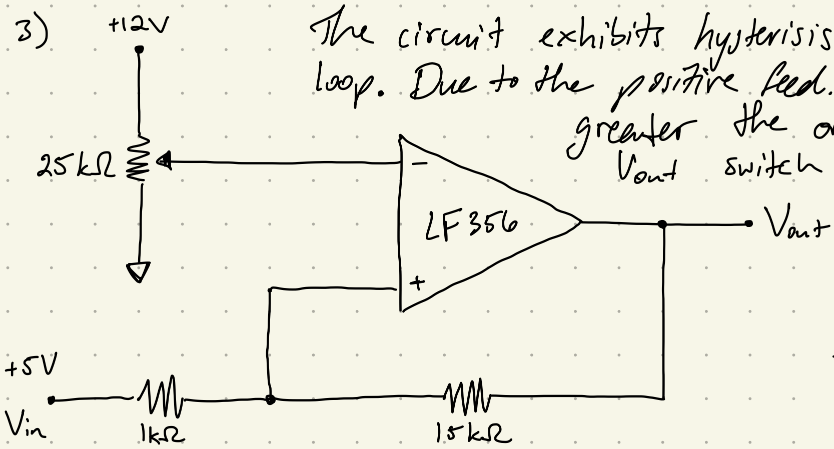
Pre-Lab Questions

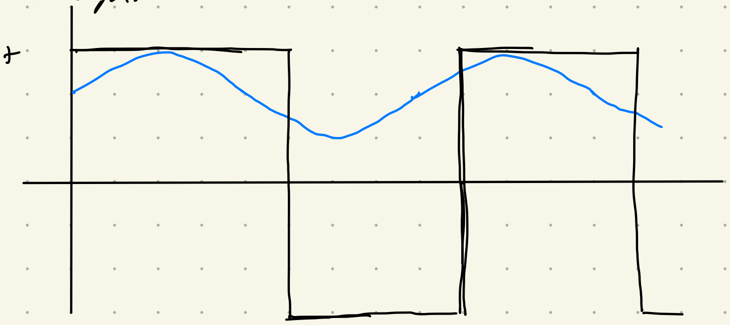
1) To ensure the input draws no current, or for it to be approximated doing so, the frequency of any AC current must be much less than 1 MHz to ensure the input impedence from the ~3pF capacitor is very high. These same limitations are applied to ensure the second golden rule where the voltage difference between the two inputs is as close to zero as possible. You also need the output to feedback to the negative input.

The LF356 deviates from ideal when used in a follower because there is a small error voltage between inputs causing the magnitude of the output voltage to be slightly less then the input.

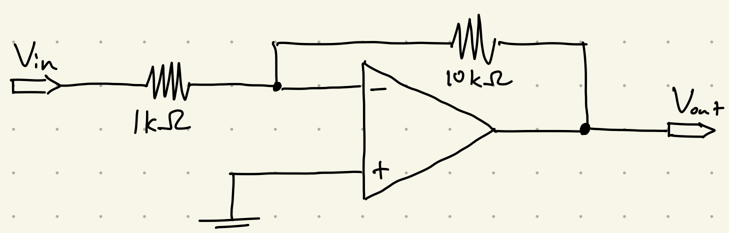
2) Z_{out} of an ideal op-amp follower is 0.

3) The circuit exhibits hysterisis because it is set up as a positive feedback loop. Due to the positive feedback loop, V_{in} has to become value greater the or less then V_- for $V_+ - V_- = 0$ to make V_{out} switch in sign.

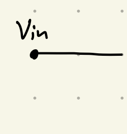




4) $G_c = -\frac{R_2}{R_1}$, $R_1 = 1k\Omega$, $\Rightarrow G_c = -\frac{R_2}{R_1} = -10 \Rightarrow R_2 = 10k\Omega$



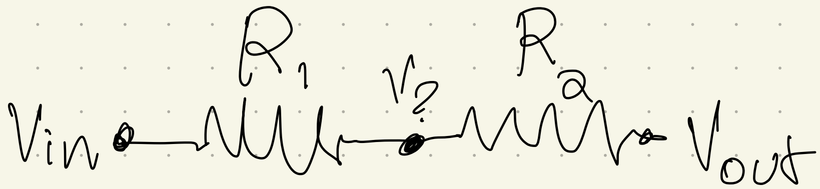
5) $R_1 = 1k\Omega$, $R_2 = 2k\Omega$, $G_c = 1 + \frac{R_2}{R_1} = 1 + \frac{2k\Omega}{1k\Omega} = 3$



6) It is an ideal current to voltage converter because the op-amp inputs draw no current, and it goes entirely into the resistor.

$V_{out} = I_{in} R$

5) continued



$$I = \frac{V_{out} - V_{in}}{R_1 + R_2} = \frac{? - V_{in}}{R_1}$$

$$\frac{R_1(V_{out} - V_{in})}{R_1 + R_2} + V_{in} = V_?$$

$$V_? = V_{in}\left(\frac{R_2}{R_1 + R_2}\right) + V_{out}\left(\frac{R_1}{R_1+R_2}\right)$$

$$= \frac{V_{in}R_2 + V_{out}R_1}{R_1 + R_2} = 0$$

$$V_{in}R_2 = -V_{out}R_1$$

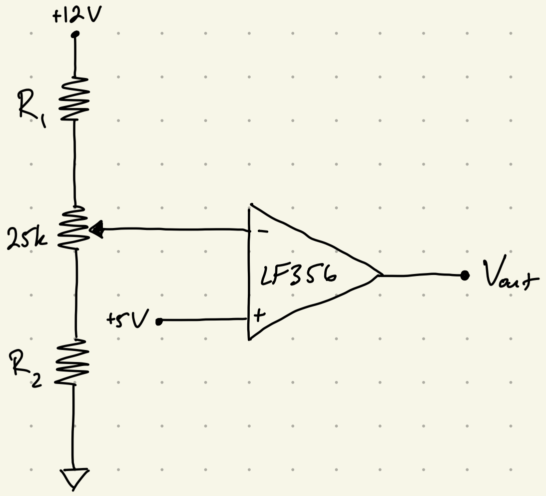
$$V_{in} = -V_{out}\frac{R_1}{R_2}$$

$$V_? - V_{in} = \frac{R_1}{R_1 + R_2}(V_{out} - V_{in})$$

$$\frac{V_? - V_{in}}{V_{out} - V_{in}} = \frac{R_1}{R_1 + R_2}$$

Lab Exercises:

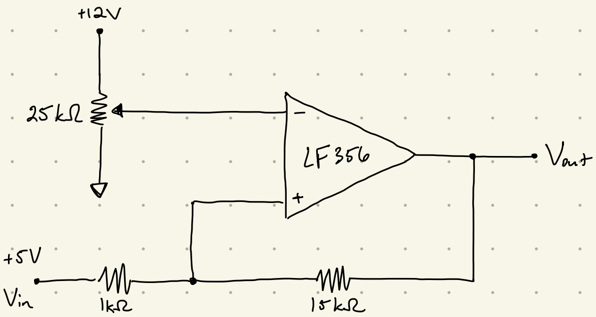
Problem R6.1:



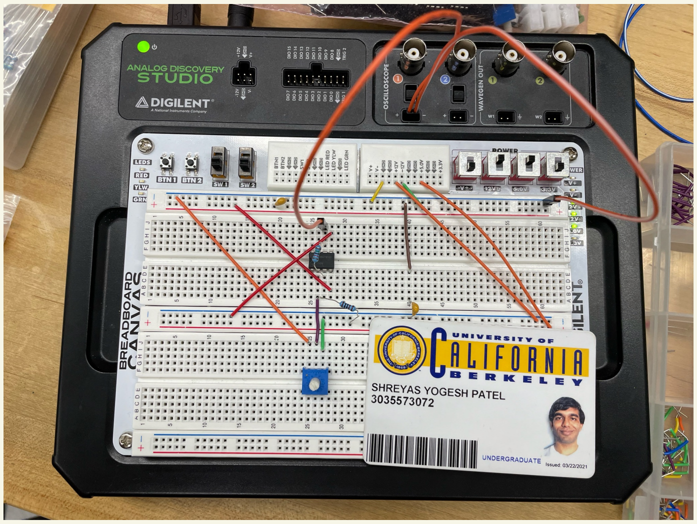
Voltages intermediate to $\pm 10.5V$ are very hard to acquire because the change between the two is near instantaneous.

lower bound $G \approx 2.1$

Problem R6.2



a)



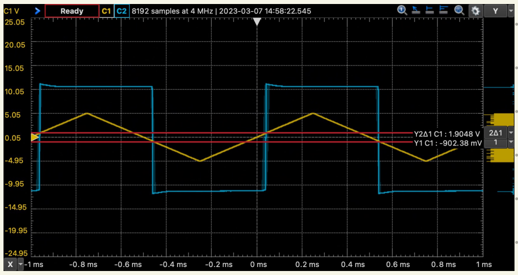
b) $V_{thresh} = V_-\left(1 + \frac{R_1}{R_2}\right) = 0$

low → high: $V_{in} = 1.0024V$

theoretical $V_{in} = \frac{R_1}{R_2} V_{out} = \frac{1k\Omega}{15k\Omega}(11.3\ V) = 0.753\ V$

high → low: $V_{in} = -0.9024\ V$

theoretical $V_{in} = -\frac{R_1}{R_2} V_{out} = -\frac{1k\Omega}{15k\Omega}(10.5\ V) = 0.7\ V$



c) $V_{thresh} = V_-\left(1 + \frac{R_1}{R_2}\right) = 3.52\ V$

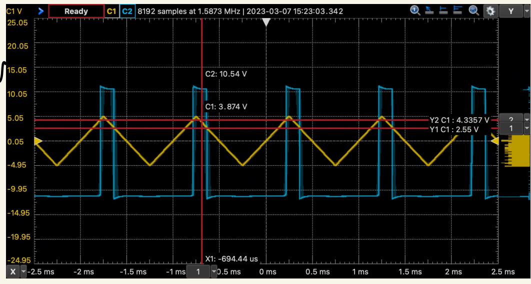
low → high: $V_{in} = 4.3357V$

theoretical $V_{in} = V_{thresh} + \frac{R_1}{R_2} V_{out} = 3.52V + \frac{1}{15}(11.2\ V) = 4.27V$

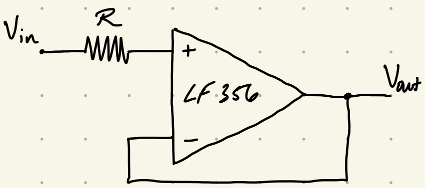
high → low: $V_{in} = 2.55V$

theoretical $V_{in} = V_{thresh} - \frac{R_1}{R_2} V_{out} = 3.52V - \frac{1}{15}(10.5\ V) = 2.82\ V$

the transition voltages are fairly close to the calculated values



Problem R6.3



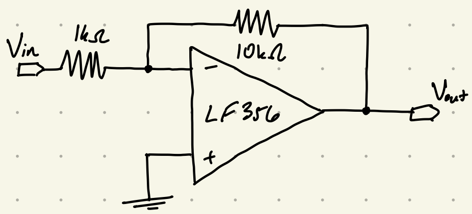
a) $R = 0$, 1MHz square wave

$V_{in} = 0.1V$, V_{out} fluctuates between $-20mV$ and $20mV$
$V_{in} = 0.2V$, V_{out} fluctuates between $-40mV$ and $40mV$
$V_{in} = 1V$, V_{out} fluctuates between $-160mV$ and $230mV$
$V_{in} = 2V$, $-190mV \leq V_{out} \leq 608mV$
$V_{in} = 5V$, $2V \leq V_{out} \leq 3V$

b) $R = 5.6M\Omega$, $f_{-3dB} = 3.2713$ kHz
$\phi = 137.77°$

c) $f_{dB} = \frac{1}{2\pi RC} \Rightarrow C = (2\pi\,(3.2713\text{ kHz})(5.6M\Omega))^{-1}$
$C = 8.687$ pF $> 3pF$ due to parasitic oscillations

Problem R6.4



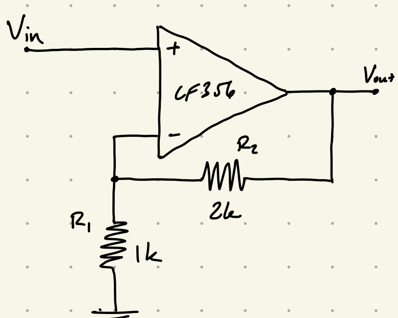
a) 1kHz 0.1V sine wave $G = \frac{0.95V}{94.62mV} = 10.0401$
$R_1 = 0.996k\Omega$, $R_2 = 9.91k\Omega$
$V_{in} = 94.62\,mV$
expected $G_c = \frac{9.91}{0.996} = 9.95$

b) amplitude 100mV
$f_{3dB} = 545kHz$

c) $R_2 = 100k\Omega$ for $G \sim 100$, $V = 10mV$
$f_{3dB} = 55.23$ kHz

d) $G = 10.04$, $f_{3dB} = 545$ kHz $\Rightarrow 5.4$ MHz
$G = 100$, $f = 55.23$ kHz $\Rightarrow 5.523$ MHz

Problem R6.5



$G = 3$, $R_1 = 0.994k\Omega$, $R_2 = 2.00k\Omega$

$G = (1 + \frac{R_2}{R_1}) = 3.012$ calculated

measured $G = \frac{299.86mV}{99.313mV} = 3.019$

% diff $= \left|1 - \frac{3.019}{3.012}\right| \times 100 = 0.23\%$

Problem R6.6

$I_{out} = \frac{V}{I}, \; V_{out} = -G_o V_-$

$V_- = \frac{4.7k\Omega}{4.7k\Omega + 47k\Omega} V = 0.091\,V \approx V_{out} = -G_o\,(0.091\,V)$

$I_{10k} = \frac{V_s - V_{out}}{10k\Omega} = \frac{V_s + G_o\,(0.091V)}{10k\Omega}$

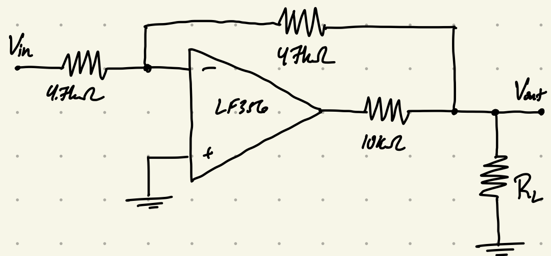
$I_{47k} = \frac{V_s - V_-}{47k\Omega} = \frac{V_s - 0.091\,V}{47k\Omega}$

$I_{total} = \frac{V_s + G_o\,(0.091V)}{10k\Omega} + \frac{V_s - 0.091V}{47k\Omega} = \frac{47k\Omega\,(V_s + G_o(0.091V)) + 10(V_s - 0.091)}{470k\Omega} = \frac{47k\Omega\,V_s + 47k\Omega \cdot 0.091V\,G_o + 10k\Omega V_s - 0.91V}{470k\Omega} = \frac{57k\Omega\,V_s + (47k\Omega \cdot G_o - 10k\Omega)\,0.091V}{470k\Omega}$

$I_{out} = \frac{V_s}{I_{tot}} = \frac{470k\Omega\;V_s}{57k\Omega\,V_s + (47k\Omega G_o - 10k\Omega)\,0.091V}$

$Z_{out} \approx \frac{470k\Omega}{57k\Omega\,V_s + 47k\Omega G_o\,0.091V}$ and G_o is very large

Problem R6.7



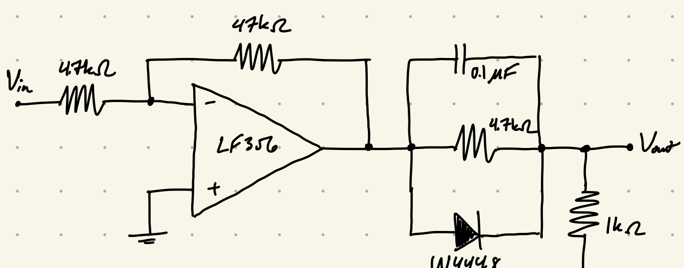
1kHz sine wave

	Vin amplitude 0.1V	Vin amplitude 0.5V
w/ R_L	-9.629	-1.929
w/o R_L	-10.0119	-9.919

with R_L, distortion appears at the peak of the output signal when V_{in} is increased to 0.5 V the output resembles a square wave

A gain of -10 is expected for the inverting amplifier except when $V_{in} = 0.5V$ and R_L is in place. V_{out} would have to be 5V to keep this true which would need a current of 5 mA.

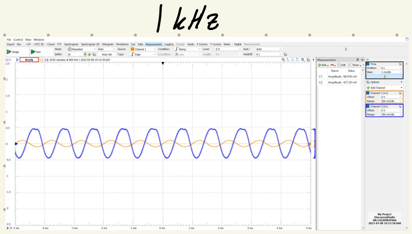
Problem R6.8

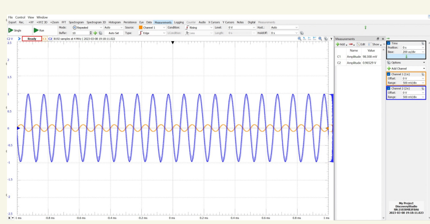


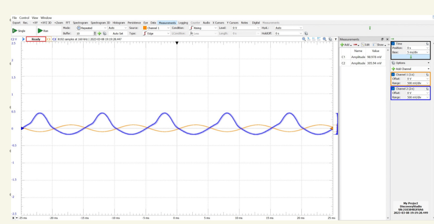
Distortions seen at 10kHz and 100Hz.
The charging and discharging of the capacitor contributes to this while other distortions are frequency dependent.

1 kHz | 10 kHz | 100 Hz

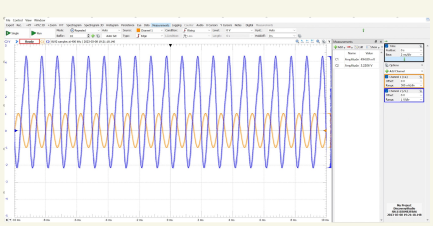
0.1 V

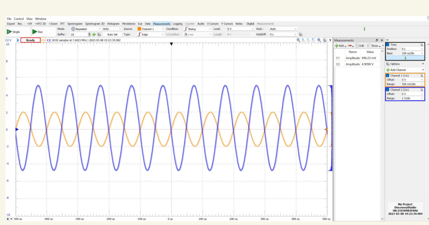


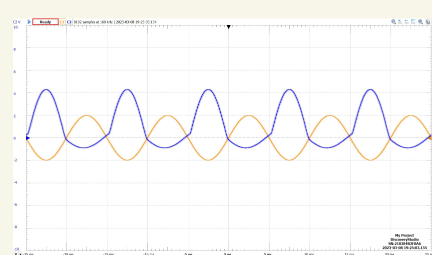




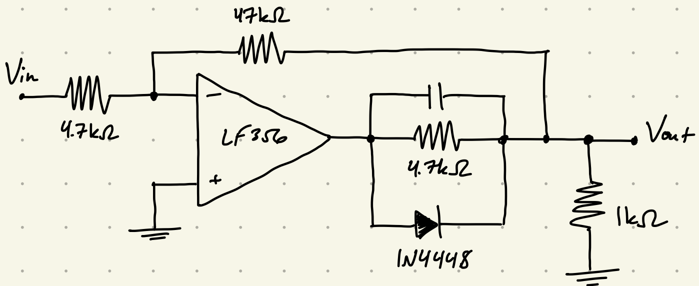
0.5 V



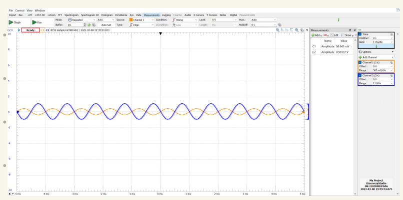
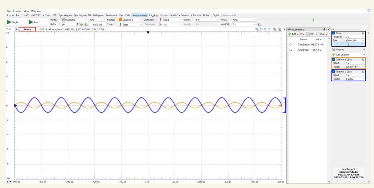
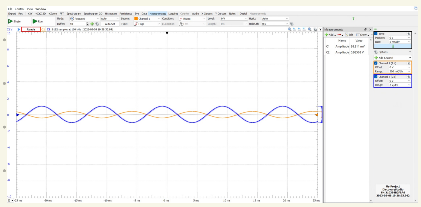
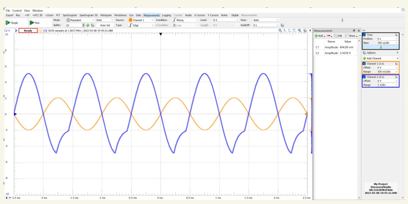
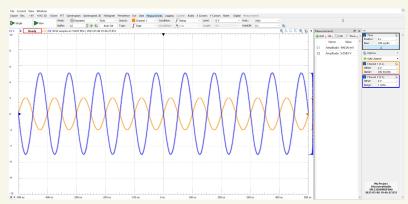
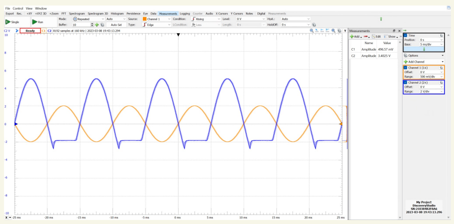




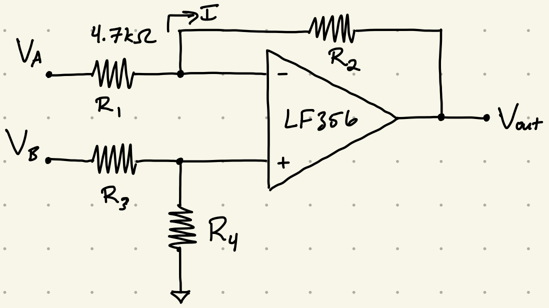
Problem R6.9



Conducting the same investigation as the previous part, we see that frequency dependent distortions for 0.1V are removed. The distortions are still present when the amplitude is 0.5V at low frequencies.

	1 kHz	10kHz	100Hz
0.1V			
0.5V			

Problem R6.10



$V_A = -12V$

$V_B = 12V$

a) $V_- = \dfrac{V_A R_2 + V_{out} R_1}{R_1 + R_2}$

$V_+ = V_B \left(\dfrac{R_4}{R_3 + R_4} \right)$

$I = \dfrac{V_{out} - V_-}{R_2} = \dfrac{V_- - V_A}{R_1} \Rightarrow V_{out} = \dfrac{R_2}{R_1}(V_- - V_A) + V_- = \left(\dfrac{R_1 + R_2}{R_1}\right) V_- - \dfrac{R_2}{R_1} V_A$, $V_- = V_+$

$V_{out} = \left(\dfrac{R_1+R_2}{R_1}\right) V_- - \dfrac{R_2}{R_1} V_A = \left(\dfrac{R_1+R_2}{R_1}\right)\left(\dfrac{R_4}{R_3+R_4}\right) V_B - \dfrac{R_2}{R_1} V_A = \dfrac{R_4(R_1+R_2)}{R_1(R_3+R_4)} V_B - \dfrac{R_2}{R_1} V_A = 0$

$\dfrac{R_4}{R_1} \dfrac{R_1+R_2}{R_3+R_4} V_B = \dfrac{R_2}{R_1} V_A \Rightarrow \dfrac{R_4}{R_2} \dfrac{R_1+R_2}{R_3+R_4} V_B = V_A$

$V_{out} = 10(V_B - V_A) = 10V_B - 10V_A = \dfrac{R_4(R_1+R_2)}{R_1(R_3+R_4)} V_B - \dfrac{R_2}{R_1} V_A$

$\dfrac{R_2}{R_1} = 10 \Rightarrow R_2 = 10R_1$, $\dfrac{R_4(R_1+R_2)}{R_1(R_3+R_4)} = 10 \Rightarrow \dfrac{R_4(11R_1)}{R_1(R_3+R_4)} = 10 \Rightarrow 11R_4 = 10R_3 + 10R_4 \Rightarrow R_4 = 10R_3$

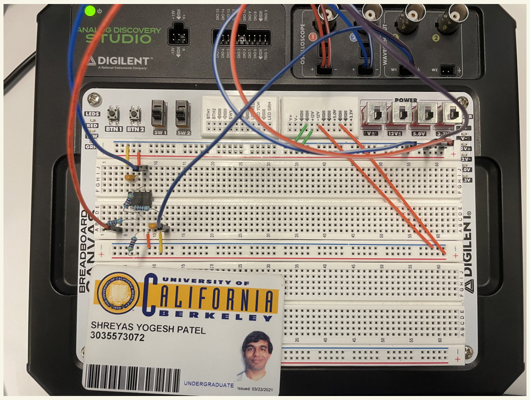
$V_{out} = 10(V_B - V_A) = 0 \Rightarrow V_A = V_B$

$\dfrac{R_4(R_1+R_2)}{R_1(R_3+R_4)} V_B - \dfrac{R_2}{R_1} V_A = 0 \Rightarrow \dfrac{R_4(R_1+R_2)}{R_1(R_3+R_4)} = \dfrac{R_2}{R_1} \Rightarrow \dfrac{R_4(11R_1)}{R_1(11R_3)} = \dfrac{R_2}{R_1} \Rightarrow \dfrac{R_4}{R_3} = \dfrac{R_2}{R_1}$

$R_1 = R_3$, $R_2 = R_4 = 10R_1$

$R_1 = R_3 = 4.7k\Omega$, $R_2 = R_4 = 47k\Omega$

$V_+ = V_- = 523.8mV$, $V_{out} = 22.26mV$



$V_c = \frac{1}{2}(V_+ + V_-) = \frac{1}{2}(523.8 + 523.8) = 523.8 \ mV$

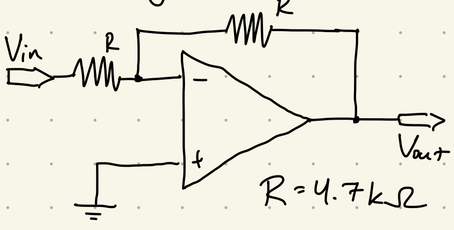
$G_c = \dfrac{22.26mV}{523.8\ mV} = 0.04$

V_A grounded: $V_+ = 1.0005V$, $V_{out} = 9.8704V$, $G = \dfrac{V_{out}}{V_+} = 9.8 \approx 10$

V_B grounded: $V_- = -991.02mV$, $V_{out} = 9.918V$, $G = \dfrac{V_{out}}{V_-} = -10$

Yes, this matches our expectation.

b) inverting follower

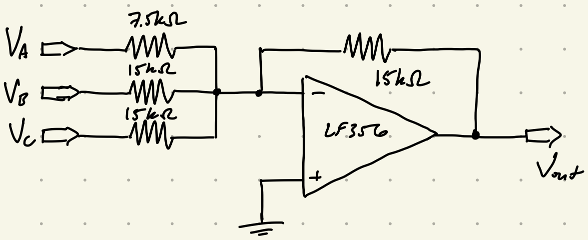


$R = 4.7k\Omega$

$V_+ = 477.9mV$, $V_{out} = 9.66V$, $V_- = -485.4V$

$V_\Delta = \frac{1}{2}(V_+ - V_-) = 481.65mV$, $G_\Delta = \dfrac{V_{out}}{V_\Delta} = 9.99 \approx 10$

Problem R6.11



a) $I = I_A + I_B + I_C$, $I_A = \frac{V_A}{7.5k\Omega}$, $I_B = \frac{V_B}{15k\Omega}$, $I_C = \frac{V_C}{15k\Omega}$

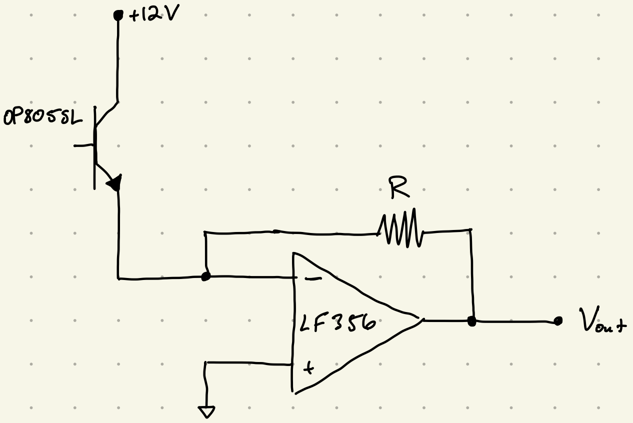
$$I = \frac{2V_A + V_B + V_C}{15k\Omega}$$

$$V_{out} = I R_{fb} = \frac{2V_A + V_B + V_C}{15k\Omega}(15k\Omega) = 2V_A + V_B + V_C$$

b)

(V_A, V_B, V_C) (V)	expected V_{out} (V)	measured V_{out} (V)
(2.0, -4.0, 3.3)	3.3	3.284
(1.0, -2.0, 5.0)	5.0	4.99

Problem R6.12



a) start with $R = 100\,k\Omega$

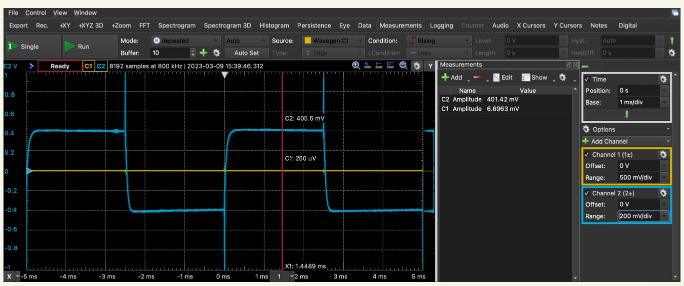
V_{out} is always negative, and is greater magnitude at greater light intensity.

b) Making the room darker decreases the offset.

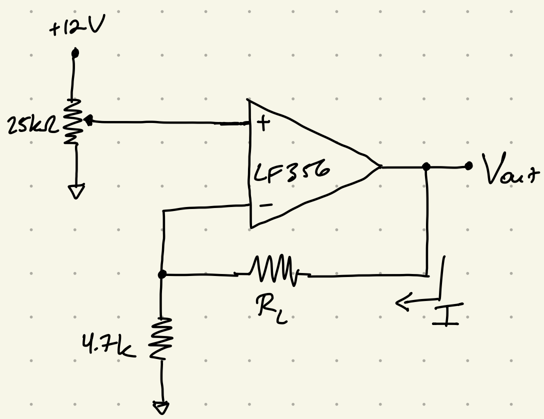
c) $f_{3dB} = 91.2$ kHz

$V_{amp} = 1.3\ V$

$$I = \frac{V_{out}}{R} = \frac{1.3\ V}{100\,k\Omega} = 1.3\ mA$$

d) 

Problem R6.13



$R_L = 4.7\,k\Omega$, $I_L = 0.638\,mA$

R_L (Ω)	I_L (mA)
4.7k	0.638
47	0.638
47k	0.203
15k	0.531
10k	0.638
1	0.638
0	0.638

V (V)	I (mA)
1	0.224
3	0.638
5	1.058

The current decreases when voltage decreases.

The circuit is a constant current source since the op amp wants the ΔV between V_+ and V_- to be 0, so the potential drop accross 4.7 kΩ resistor, and therefore current has to be constant. It does this by increasing V_{out} so the ΔV accross R_L rises linearly with R_L so I is constant

Output current is determined by V_+. R_L is limited by how high of a V_{out} the op amp can supply.