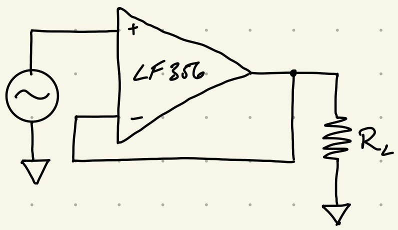
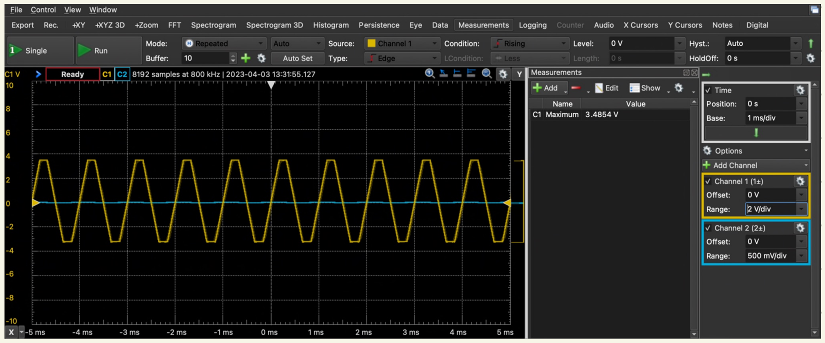
Physics 111A Lab 8

Lab Exercises:

Problem R8.1:

$R_L = 120\Omega$ gives an output of 3.4854 V instead of the 5V input.





$V_{max} = 3.4854V$

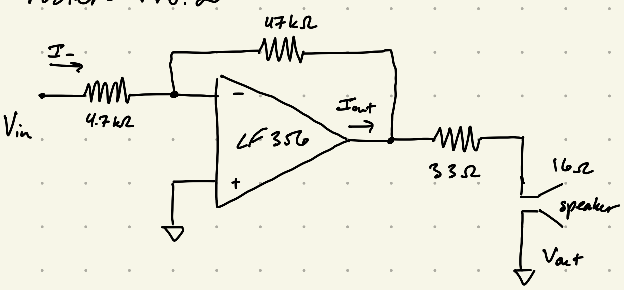
$V_{min} = -3.23868V$

$R_L = 120\Omega$

$I_{max} = \frac{3.4854V}{120\Omega} = 29mA$

$I_{min} = -\frac{3.23868V}{120\Omega} = -27mA$

Problem R8.2



a) $I_{out} + I_- = \frac{V_{out}}{49\Omega} = \frac{10V_{in}}{49\Omega}$

$\frac{V_{in}}{4.7k\Omega} = \frac{V_{out}}{47k\Omega} \Rightarrow V_{out} = 10V_{in}$

$I_{out} = 25mA$, $I_- = \frac{V_{in}}{4.7k\Omega}$

$25mA + \frac{V_{in}}{4.7k\Omega} = \frac{10V_{in}}{49\Omega} \Rightarrow V_{in} = 25mA\left(\frac{10}{49\Omega} - \frac{1}{4.7k\Omega}\right)^{-1}$

$V_{in} = 0.1226\,V$, $P = IV = I^2R = (I_{out} + I_-)^2R$

$I_- = \frac{V_{in}}{4.7k\Omega} = \frac{0.1226V}{4.7k\Omega} = 26\mu A$

$P = (25mA + 26\mu A)^2(16\Omega) = 0.01\,W$

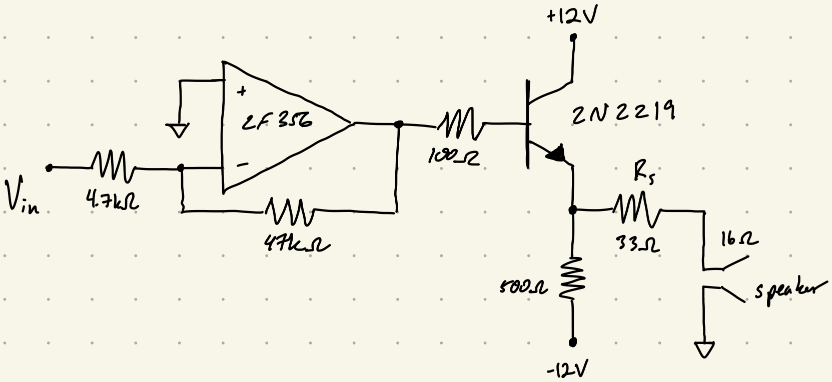
b)

wave	V_{in} (V)	V_{out} (V)	f = 1kHz
sine	1	1.56	– saturated
	0.5	1.44	"
	0.2	1.39	"
	0.12	1.17	– unsaturated
	0.1	0.9	"
triangle	1	1.49	– saturated
	0.2	1.39	"
	0.12	1.17	– unsaturated
	0.1	0.97	"
square	1	4.06	– saturated
	0.2	1.99	"
	0.12	1.21	– unsaturated
	0.1	1.01	"

The max V_{in} matches our calculated results.

c) The degradation is very noticeable at V_{in} = 500 mV with there being static in the background.

Problem R 8.3



a) $V_{transistor} = 10V$, $R_{sp} = R_s + 16\Omega$

$I_{draw} = I_{12} + I_{sp}$

$200\,mA = \frac{22V}{500\Omega} + \frac{10V}{R_s} \Rightarrow R_{sp} = \frac{10V}{200mA - \frac{22V}{500\Omega}} = 64.1\,\Omega$

$R_s = 64.1 - 16 = 48.1\,\Omega$

$P_{RMS} = \frac{1}{2}(I_{sp}^2 R) = \frac{1}{2}(0.156^2 \cdot 48.1) = 0.585W$

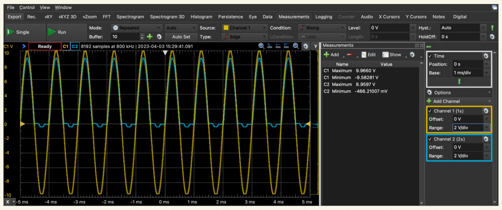
# of R $\frac{1}{4}W$: 2.34 ⇒ 3 resistors $\left(\frac{3}{100\Omega}\right)^{-1} = 33\Omega \approx 48.1\Omega$

b)

V_{in} (V)	op amp V_{out} (V)	transistor V_{out} (V)
0.01	0.077	0
0.05	0.472	0
0.1	0.970	0.283
0.2	1.973	1.227
0.5	4.968	4.128
1	9.966	8.960

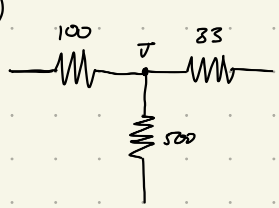
f = 1kHz sine wave

The DC offset of the emitter output is about −0.7 V.



The −0.7 V offset is due to the transistor requiring +0.7V to work.
The distortions are due to the transistor only working for positive voltages.

c)



$\frac{V_{in}}{4.7k\Omega} = I_-$, $V_{out} = \frac{V_{in}}{4.7k\Omega} 47k\Omega = 10V_{in}$

$\frac{-J}{100\Omega} = \frac{-12-J}{500k\Omega} + \frac{J}{49\Omega} \Rightarrow \frac{-J}{100} = \frac{-12}{500k\Omega} - \frac{J}{500k\Omega} + \frac{J}{49\Omega} \Rightarrow \frac{12}{500k} = -\frac{J}{500k} + \frac{J}{100} + \frac{J}{49}$

$J = 0.7894\,mV$

Its a bad idea because it would draw to much current and exceed the power rating of the components.

d) Yes the speaker sounds like its producing a pure sine tone. There is some distortion at very high amplitudes.

The sound quality is very distorted and muffled when driven with and amplitude of 1V.
If offset by −0.7V it is very clear however.

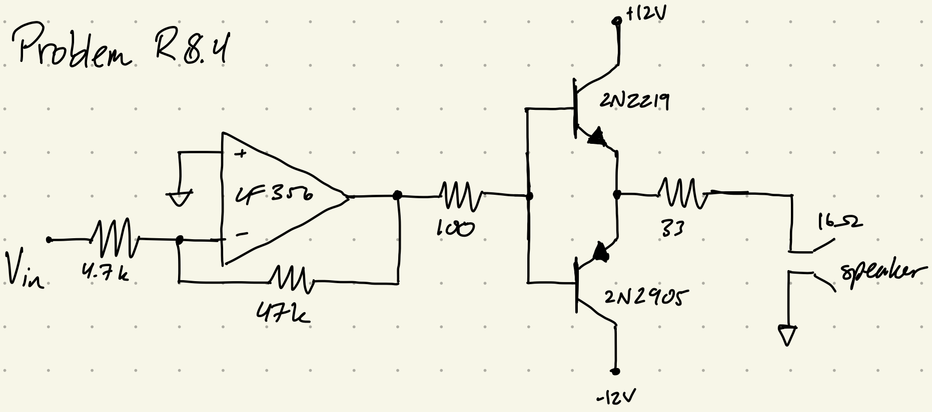
e) max amplitude : 1 V

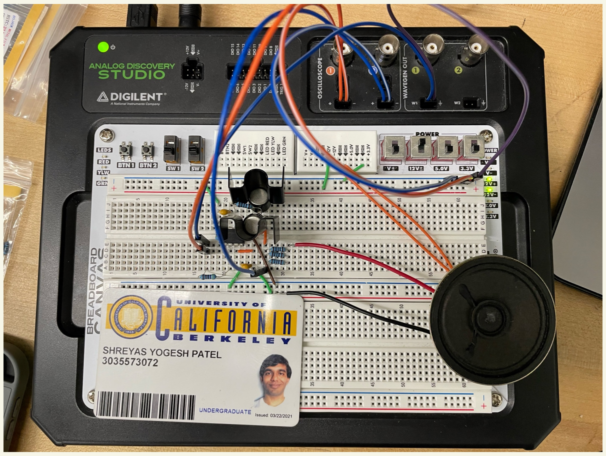
for voltages at this value and higher, the transistor is not able to supply enough current causing distortions.

f) With an amplitude of 200mV, the output waveform is clean and matches the input.

With an amplitude of 1V, there is distortion in the output with the audio quality also dropping.

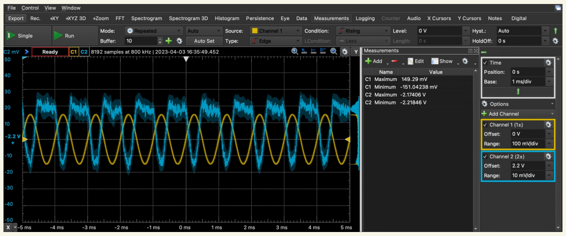
Problem R8.4





a) We see a distorted output signal starting at 50mV because the transistors require a minimum voltage to turn on.

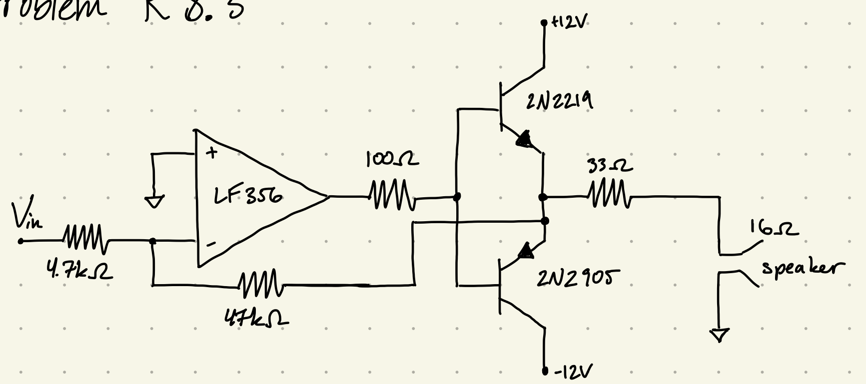
b) The distortion is only present for positive values which can be due to the bottom transistor is pulling more current than the top transistor can supply.



c) The new distortion in the negative range is due to the top transistor pulling more current than the bottom transistor can supply.

d) The audio output is good with an amplitude of 1V and offset of 0.4V.

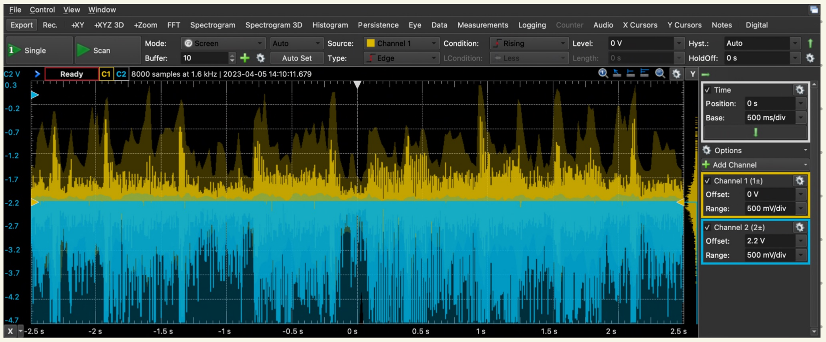
Problem R 8.5



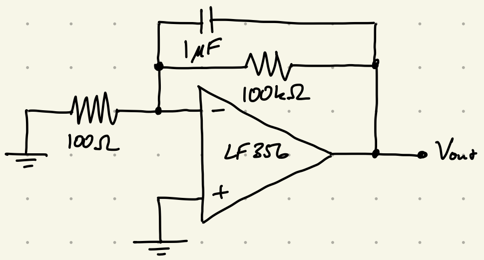
a) The low amplitude sounds are cut off.

The circuit improves its response because the feedback for the op-amp comes from whats going into the speaker rather than its own output.

b)



Problem R8.6

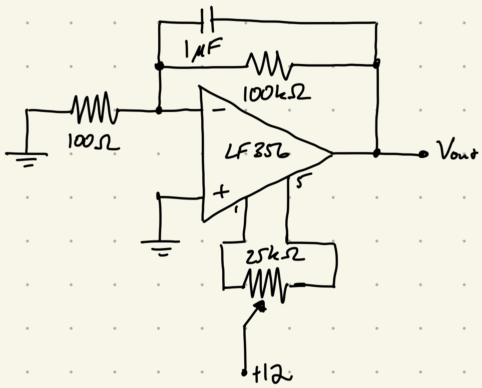


Op Amp	V_{out} (V)	$V_{os} = V_{out}/-1000$ (V)
1	1.307	-0.001307
2	1.062	-0.001062
3	-1.973	0.001973
4	1.181	-0.00181
5	-1.171	0.00171

Average Op Amp effect: -99.2 µV

V_{out} drifts up slightly when the op amp is warmed.

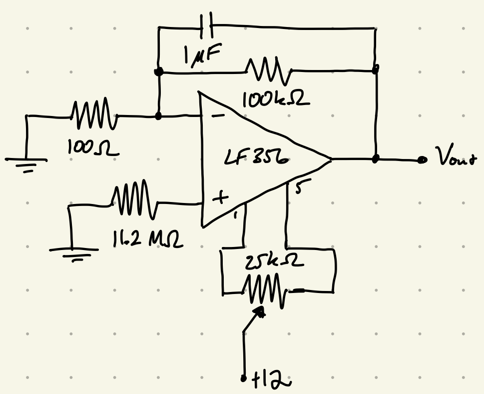
Problem R8.7



V_{out} slowly drifts upward in absolute value over several minutes.
Lowest V_{out} (op amp 5) achieved by adjusting pot is ~3 mV

$\rightarrow V_{os} = 3 \times 10^{-6} = 3\,\mu V$.

Problem R8.8



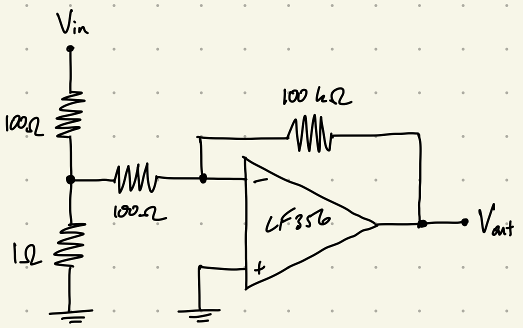
$V_{os} \sim 1\,\mu V$

V_{out} after removing shorting jumper: 347.2 mV

$\frac{347.2\,mV}{1000} = 347.2\,\mu V$

$\frac{347.2\,\mu V - 1\,\mu V}{11.2\,M\Omega} = I_B = 3.091 \times 10^{-11} A = 30.91\,pA$

Problem R8.9



a) $f_{3dB} = 5.6687\text{ kHz}$, $G = 9.75 \times 100 = 975$

$GBW = (975)(5.6687\text{ kHz}) = 5527\text{ kHz} = 5.53\text{ MHz}$

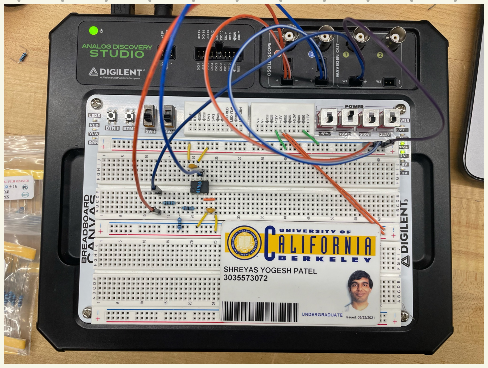
expected GBW for LF356 is 5 MHz

The measured and calculated values are comparable.

b) expected $G = \frac{10k}{100} = 100$

$f_{3dB} = 56.347\text{ kHz}$, $G = 1.0039 \times 100 = 100.39$

$GBW = (100.39)(56.347\text{ kHz}) = 5656.7\text{ kHz} = 5.66\text{ MHz}$



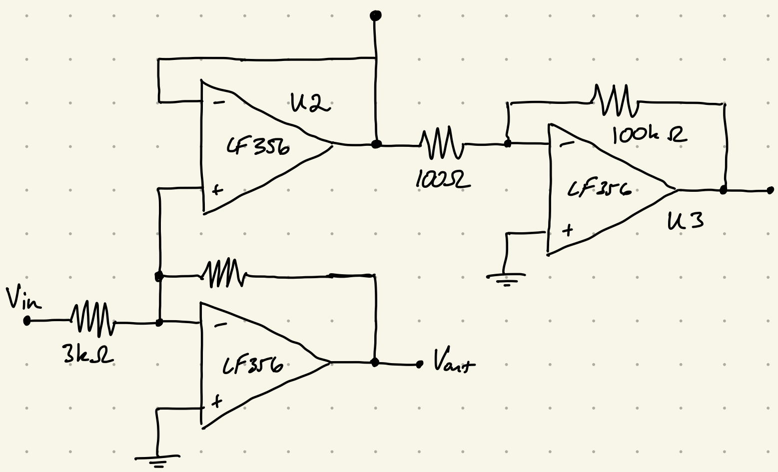
c) expected $G = \frac{10k}{10k} = 10$

$f_{3dB} = 503.61\text{ kHz}$, $G = 0.10097 \times 100 = 10.097$

$GBW = f_{3dB}(G_c + 1) = (503.61\text{ kHz})(11.097) = 5588.56\text{ kHz} = 5.59\text{ MHz}$

The G_c is too small to disregard the +1 in the formula for GBW.

Problem R8.10

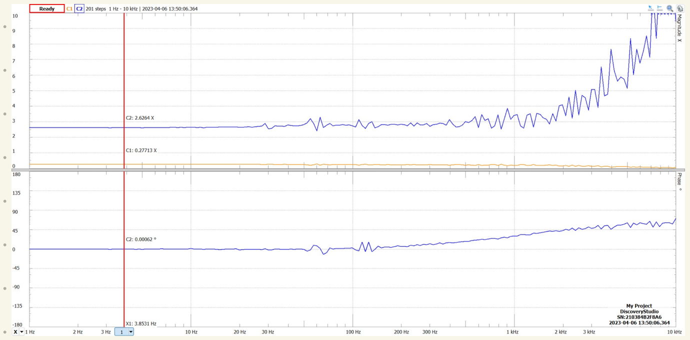


$G_o = \left|\frac{V_{out}}{V_+ - V_-}\right| = \left|\frac{V_{out}}{V_-}\right|$

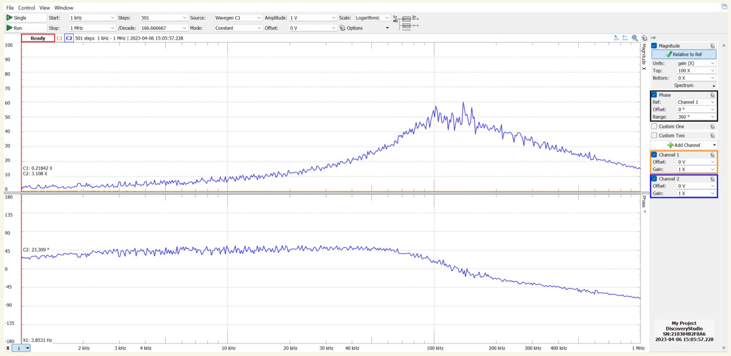
a) Network Analysis: C_1 @ U_3, C_2 @ U_1
amplitude 1V, 1Hz - 10kHz

$f_{3dB} = 2.1\text{ kHz}$, $GWB = f_{3dB} \cdot G_o = 2.626 \times 2.1\text{ kHz} = 5.5146\text{ kHz}$

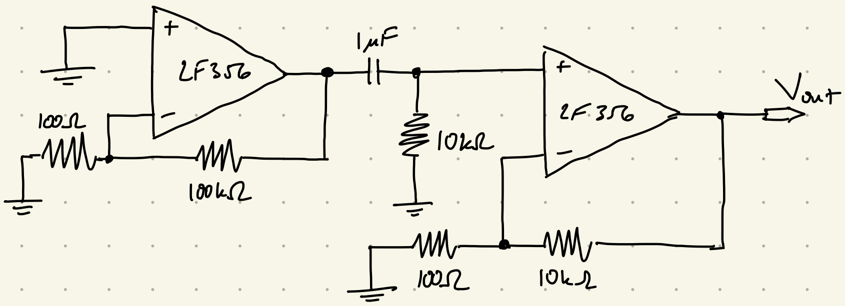
The measured gain is invalid after a few kHz because gain falls off at higher frequencies, with the amplifier acting like a low-pass filter.



b) C_1 @ U_2, Network Analysis from 1kHz - 1MHz



Problem R 8.11



Nominal Gain : $\frac{100k\Omega}{100\Omega} \times \frac{10k\Omega}{100\Omega} = 1000(100) = 10^5$

Highpass filter : $f_{3dB} = \frac{1}{2\pi RC} = \frac{1}{2\pi(10k\Omega)(1\mu F)} = 15.91$ Hz

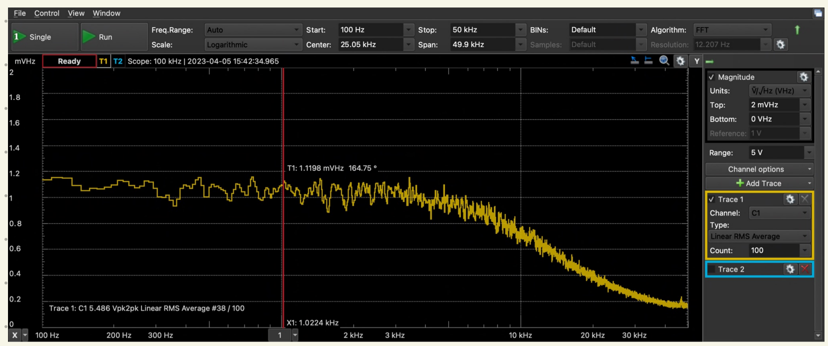
approx. BW : $f_G = 1.591$ MHz

At 100 Hz, the noise is around $1.1422\, mV/\sqrt{Hz} \times \sqrt{2} = 1.615\, mV/\sqrt{Hz} / 10^5 = 16.15\, nV/\sqrt{Hz}$

At 1 kHz, the noise is around $1.0853\, mV/\sqrt{Hz} \times \sqrt{2} = 1.535\, mV/\sqrt{Hz} / 10^5 = 15.35\, nV/\sqrt{Hz}$

The $f_{3dB} \sim 10$ kHz

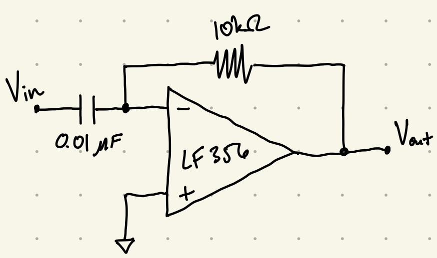
$V_{RMS} = e_n\sqrt{BW}$ BW = 1.591 MHz



f	e_n (nV/$\sqrt{Hz}$)	V_{RMS} ($\mu\tilde{V}$)
100 Hz	16.15	20.37
1kHz	15.35	19.36

measured $V_{RMS} = 32.9\, m\tilde{V} / 100 = 329\, \mu\tilde{V}$

Problem R 8.12



a) $q = CV \Rightarrow q = C(0 - V_{in})$

$q = -CV_{in} \Rightarrow I = -C\frac{dV_{in}}{dt}$

$I = \frac{V_{out}}{R} = -C\frac{dV_{in}}{dt}$

$V_{out} = -RC\frac{dV_{in}}{dt}$

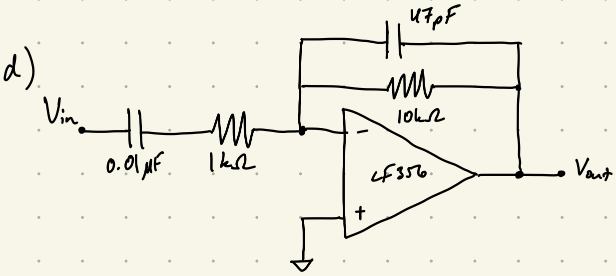
b) $H(\omega) = \frac{V_{out}}{V_{in}} = -RC\frac{1}{V_{in}}\frac{dV_{in}}{dt}$, $V_{in} = V_o e^{i\omega t}$

$H(\omega) = -RC\frac{1}{V_o e^{i\omega t}}\frac{d}{dt}(V_o e^{i\omega t}) = -\frac{RC}{V_o}e^{-i\omega t}V_o(i\omega e^{i\omega t}) = -i\omega RC$

$|H(\omega)| = \omega RC = 1 \Rightarrow \omega = \frac{1}{RC}$, $\phi = -45°$

c) The ring frequency is 4. This is due to the phase shift of the op amp not aligning with the phase shift of the feedback loop, causing it to be unstable.

d)



For the square wave, there is a sudden rise in Vout whenever the Vin changes signs, but it returns back to zero.

For the sine wave, the output is a cosine wave slightly shifted to the left, and its amplitude being larger then the input, it being around 500 mV.

The circuit no longer oscillates because the additional capacitor and resistor help mediate any interference present between the op amp and feedback loop, acting as a low and high pass filters.

e) $G = \frac{10k\Omega}{1k\Omega} = 10$

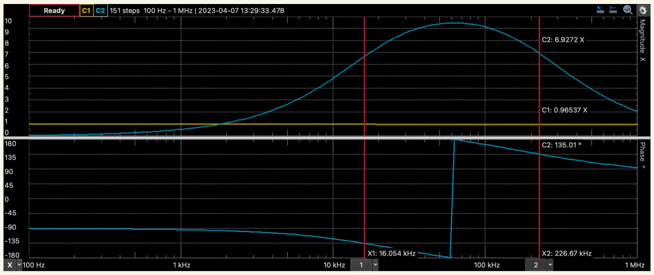
high-pass $f_{3dB} = \frac{1}{2\pi RC} = \frac{1}{2\pi (10k\Omega)(47pF)} = 338.6 \text{ kHz}$

low-pass $f_{3dB} = \frac{1}{2\pi RC} = \frac{1}{2\pi (1k\Omega)(0.01\mu F)} = 15.9 \text{ kHz}$

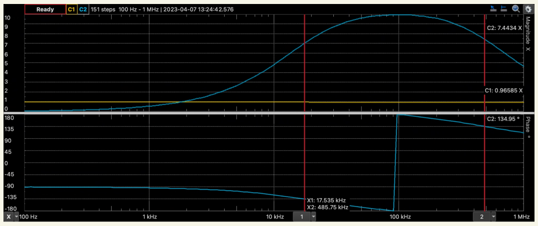
measured high-pass $f_{3dB} = 226.7$ kHz
measured low-pass $f_{3dB} = 15.9$ kHz

after removing 47pF, low-pass $f_{3dB} = 17.5$ kHz

w/ 47pF

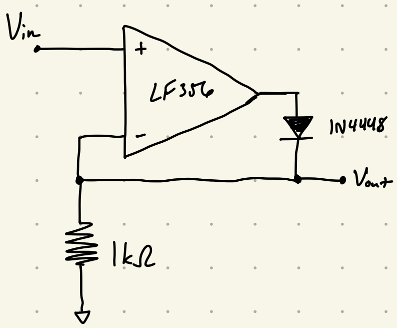


w/o 47pF

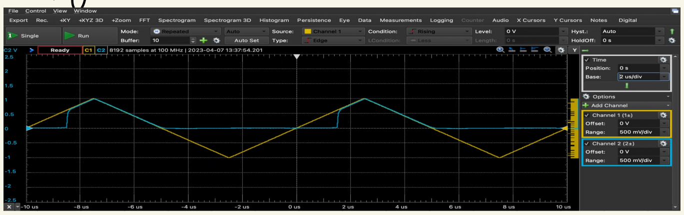


The cause of this new rolloff is due to the op amps capabilities.

Problem R8.13

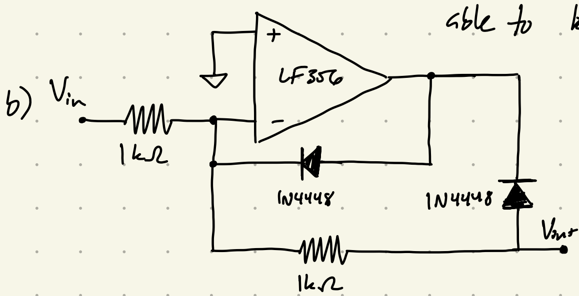


a) Since Vout and V_- are looking at a point after the diode, the op amp will supply enough current to account for the diode drop.

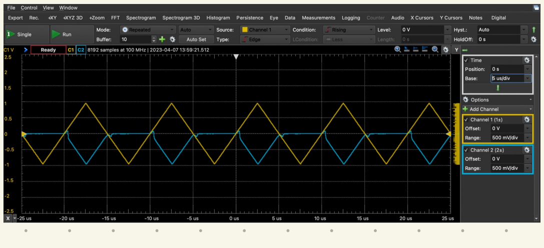


The op amp output around -12V when the input is negative.
The finite slew rate of the op amp degrades the circuit due to it not being able to keep up with the changes in voltage at high frequencies.

b)



When Vin is negative the voltage at the output of the opamp is $V_{in} + V_{diode}$. When it is positive, it is $V_{in} + V_{diode}$. This reduces crossover distortion due to slew rate since the op amp has a smaller change in voltage it has to perform.



For 1kHz, the output works well, just the positive input is inverted.

For 100kHz, the output is much better, with the distortion being much smaller