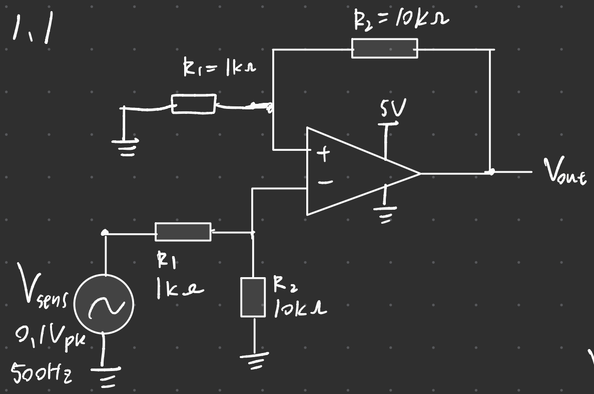
Q 1.1



$$V^- = V^+ = V_{sens} \times \frac{R_2}{R_2 + R_1}$$

$$\frac{V_{out} - V^+}{R_2} = \frac{V^+ - 0}{R_1}$$

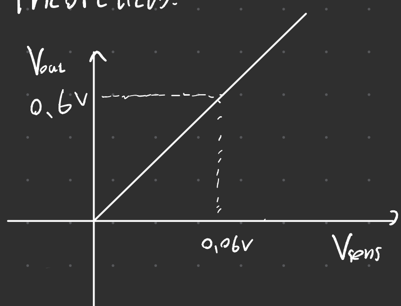
$$V_{out} = \frac{R_2}{R_1} V^+ + V^+$$

$$V_{out} = V_{sens} \frac{R_2}{R_2 + R_1} \left(\frac{R_2}{R_1} + 1 \right)$$

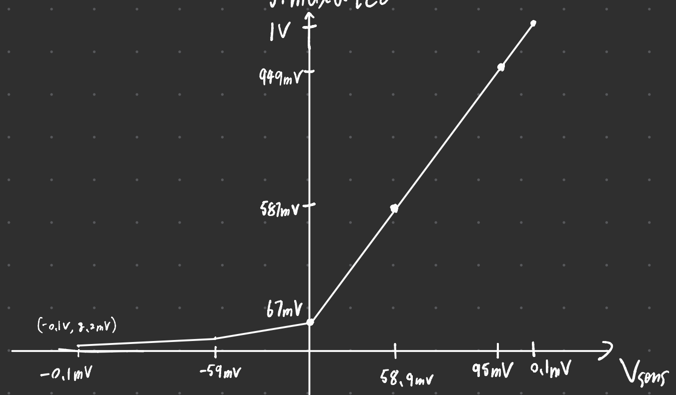
$$V_{out} = 10\, V_{sens}$$

$$A_v = \frac{V_{out}}{V_{sens}} = 10$$

Theoretical



Simulated

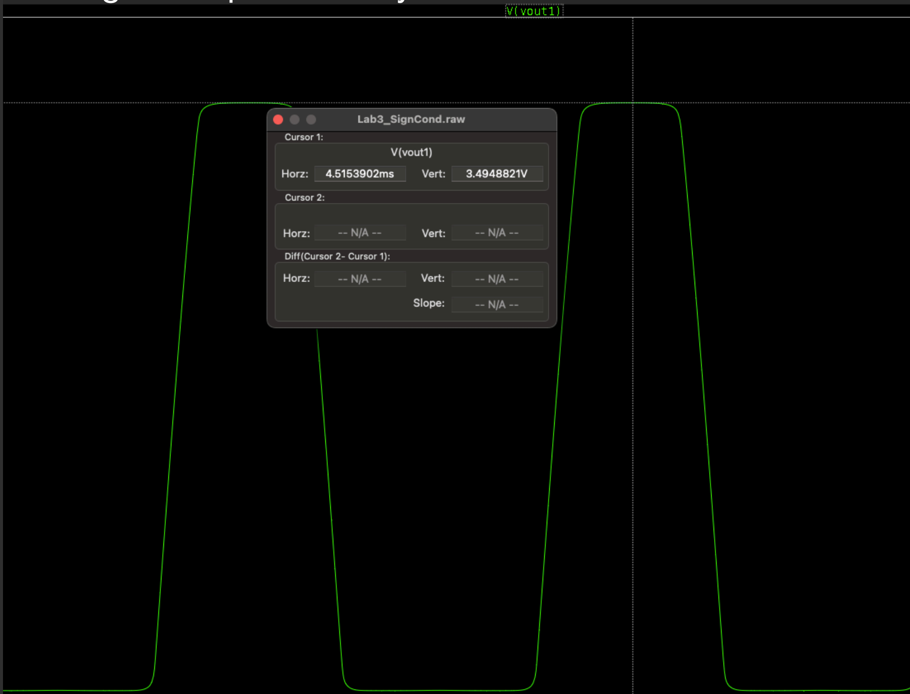


Q1.3

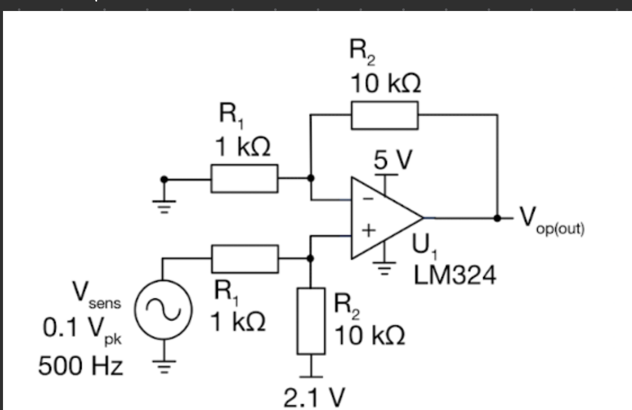
In the OpAmp_LM324 data sheet page 7/22.

Symbol	Parameter			Min.	Typ.	Max.	Unit
V_{OH}	High level output voltage, V_{CC} = 30 V, R_L = 2 kΩ	T_{amb} = 25 °C		26	27		V
		$T_{min} \leq T_{amb} \leq T_{max}$		26			
	High level output voltage, V_{CC} = 30 V, R_L = 10 kΩ	T_{amb} = 25 °C		27	28		
		$T_{min} \leq T_{amb} \leq T_{max}$		27			
	High level output voltage, V_{CC} = 5 V, R_L = 2 kΩ	T_{amb} = 25 °C		3.5			
		$T_{min} \leq T_{amb} \leq T_{max}$		3			

I changed the Vsens form 0.1 to 0.5 at LTspice and measure it's output voltage. The peak is very close to 3.5V.



Q 1,5



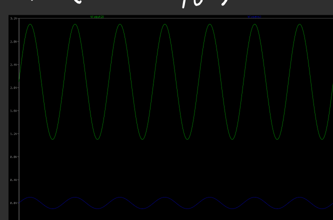
$$\frac{V_{sens}-V^+}{R_1} = \frac{V^+ - 2.1}{R_2}$$

$$\frac{V_{sens}}{R_1} - \frac{V^+}{R_1} = \frac{V^+}{R_2} - \frac{2.1}{R_2}$$

$$V^+\left(\frac{1}{R_1}+\frac{1}{R_2}\right) = \frac{V_{sens}}{R_1} + \frac{2.1}{R_2}$$

$$V^+ = \frac{10}{11}\left(V_{sens} + \frac{2.1}{10}\right)$$

$$\frac{V_{out}-V^-}{10} = \frac{V^-}{1} \qquad V^+ = V^-$$



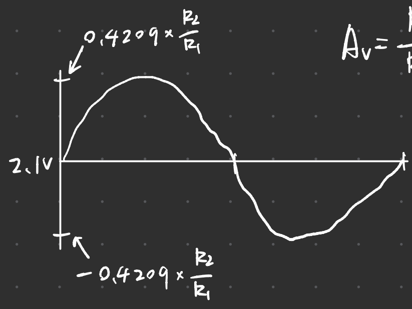
$$V_{out} = 10V^- + V^- = 11V^- = 10V_{sens} + 2.1$$

Q2.1

Calculated in Lab 1:

$R_s = 0.5$, $I_{L(RMS)\,max} = 595.238\,mA$

Based on Ohm's law: $V_{is(pk)\,max} = 595.238 \times 10^{-3} \times 0.5 \times \sqrt{2} = 0.4209\,V$



$A_v = \frac{R_2}{R_1}$

$$\begin{cases} 0.4209 \times A_v + 2.1 < 3.1 \\ -0.4209 \times A_v + 2.1 > 1.1 \end{cases}$$

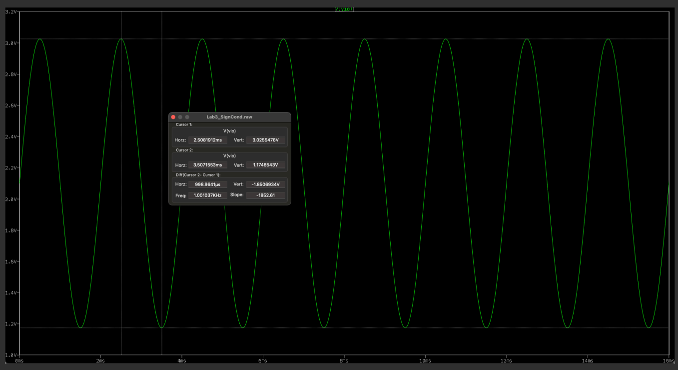
$A_v = 2.38$

I selected $R_1 = 10k\Omega$ and $R_2 = 22k\Omega$, it resultes A_v in 2.2.

Checking the DC valtage range:

$0.4209 \times 2.2 + 2.1 = 3.025 < 3.1$ (passed)

$-0.4209 \times 2.2 + 2.1 = 1.174 > 1.1$ (passed)



Q2.2

(7.5VA at 12.6V)

$$I_{L(rms)} = 595.2381\,mA$$

$$V_{is(pk)} = 595.2381 \times 10^{-3} \times 0.5 \times \sqrt{2} = 0.4209\,V$$

$$V_{io(pk)} = 0.4209 \times 2.2 + 2.1 = 3.0260\,V$$

(7.5VA at 15.4V)

$$I_{L(rms)} = 484.013\,mA$$

$$V_{is(pk)} = 484.013 \times \sqrt{2} \times 10^{-3} \times 0.5 = 0.3422\,V$$

$$V_{io(pk)} = 0.3422 \times 2.2 + 2.1 = 2.8529\,V$$

(2.5 VA at 15.4V)

$$I_{L(rms)} = 162.3377\,mA$$

$$V_{is(pk)} = 162.3377 \times 10^{-3} \times \sqrt{2} \times 0.5 = 0.1148\,V$$

$$V_{io(pk)} = 0.1149 \times 2.2 + 2.1 = 2.3525\,V$$

Q2.3

$$V_{out} = \frac{R_2}{R_1}(V^+ - V^-) \qquad V^+ = V^- = V_{cm}\left(\frac{R_4}{R_3 + R_4}\right)$$

$$\frac{V_{cm} - V^-}{R_1} = \frac{V^- - V_{out}}{R_3} \Rightarrow V_{out} = V^-\left(\frac{R_1 + R_3}{R_1}\right) - V_{cm}\left(\frac{R_3}{R_1}\right)$$

$$V_{out} = V_{cm}\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_2}{R_1}\right) - V_{cm}\left(\frac{R_3}{R_1}\right)$$

$$A_{cm} = \left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_2}{R_1}\right) - \left(\frac{R_3}{R_1}\right)$$

and if $\frac{R_3}{R_1} = \frac{R_4}{R_2}$, A_{cm} will be zero.

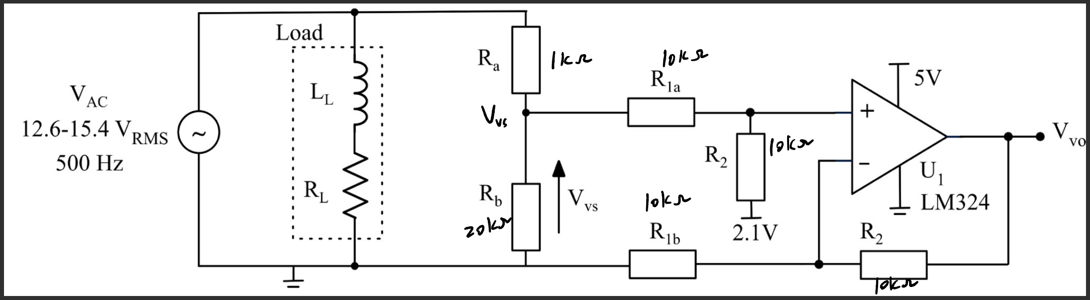
Q3.1 $R_a = 1\,k\Omega$ and $R_b = 20\,k\Omega$ and $V_{vs\,(pk)} = 1.0371\,V$ from Lab 1

V_o supposed to be $1\,V_{(pk)}$

$$V_v = \frac{1\,V}{1.0371\,V} = 0.9642$$ which is very close to 1,

so I picked $R_{1a} = 10\,k\Omega$, $R_{1b} = 10\,k\Omega$, and $R_2 = 10\,k\Omega$

Q3.2



$$V_{vo} = V_{vs} + 2.1$$

(7.5VA at 12.6V)

$V_{vs} = 0.8485\,V$ $\quad A_v = 1$

$$V_{vo} = 0.8485 \times 1 + 2.1 = 2.9484\,V$$

(7.5VA at 15.4)

$V_{vs} = 1.0371\,V$ $\quad A_v = 1$

$$V_{vo} = 1.0371 + 2.1 = 3.1371\,V$$

(2.5VA at 15.4V)

$V_{vs} = 1.0371\,V$ $\quad V_{ro} = 1.0371 + 2.1 = 3.1371\,V$

Q 4.1

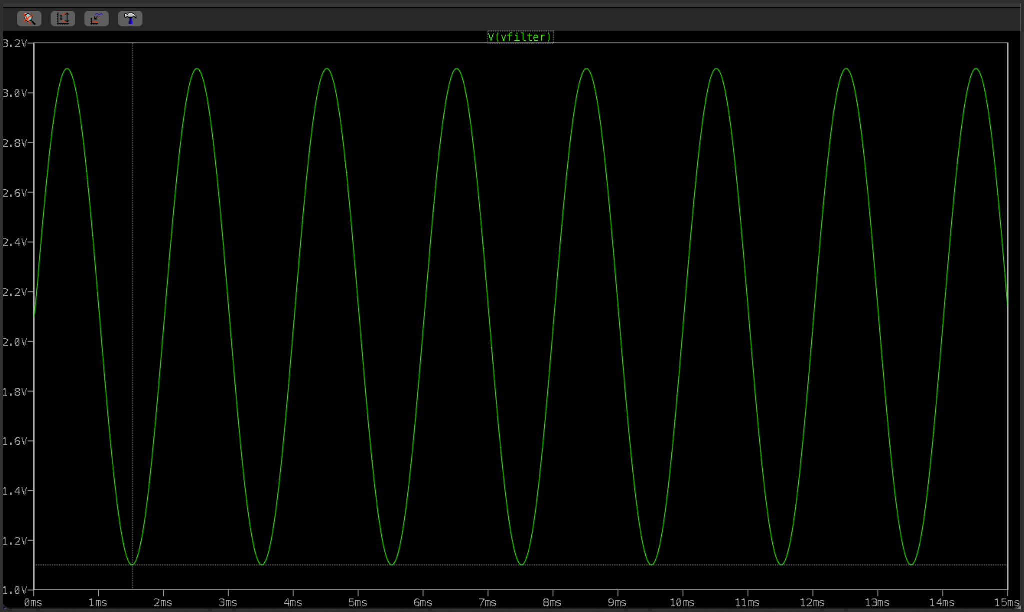
$$\frac{V_{filter}}{V_{opamp}} = \frac{Z_c}{R_f + Z_c} = \frac{\frac{1}{j\omega C}}{R_f + \frac{1}{j\omega C}} = \frac{1}{\cancel{j\omega C}} \times \frac{\cancel{j\omega C}}{1 + j\omega C R_f} = \frac{1}{1 + j\omega C R_f}$$

$$f_b = 10\,kHz = \frac{1}{2\pi R_f C_f}$$

I picked $R_f = 1k\Omega \longrightarrow C_f = \frac{1}{10\times10^3 \times 2\pi \times 10^3} = 15.91\,nF$

This is a sweet spot, which avoiding noise and ADC issue, Also, the op-amp isn't overloaded.

Q4.2



Q 4.3

$$H(j\omega) = \frac{1}{1 + j\omega RC} \qquad |H(j\omega)| = \frac{1}{\sqrt{1 + (\omega RC)^2}} \qquad \angle H(j\omega) = -\tan^{-1}(\omega RC)$$

At f_b, Gain $= -3$dB and Phase $= -45°$

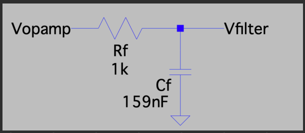
$$f_b = \frac{1}{2\pi RC} = 10610{,}23954 \text{ Hz}$$

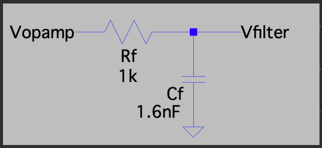
f	$H(j\omega)$	$\angle H(j\omega)$
100 Hz	$-0{,}00038$ dB	$0{,}5399°$
1k Hz	$-0{,}038$ dB	$5{,}3841°$
10kHz	$-2{,}76$ dB	$43{,}3040°$
100 kHz	$-19{,}53$ dB	$83{,}9434°$
1MHz	$-39{,}48$ dB	$89{,}3921°$

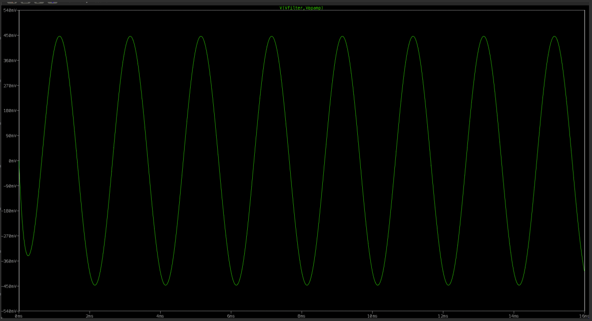
$$\text{Gain (dB)} = 20\log\left(\frac{1}{\sqrt{1 + \left(\frac{f}{f_b}\right)^2}}\right)$$

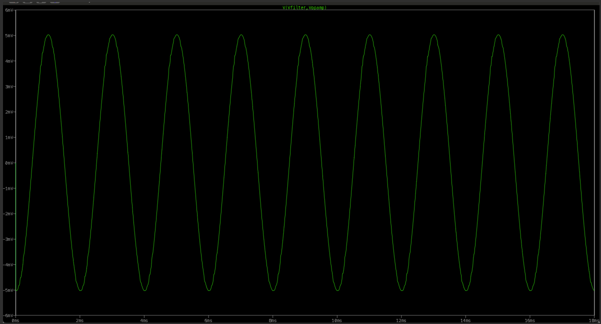
$$\phi = -\tan^{-1}\left(\frac{f}{f_b}\right)$$

Q4.4





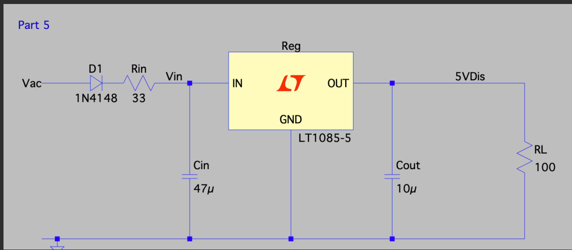


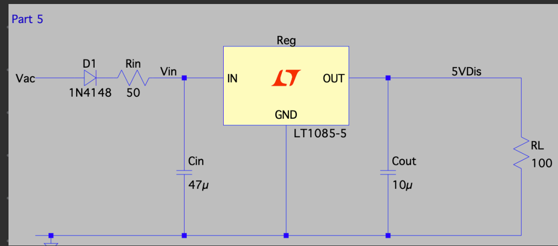


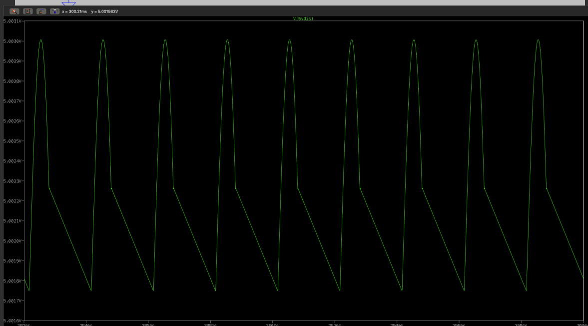
Q5.1

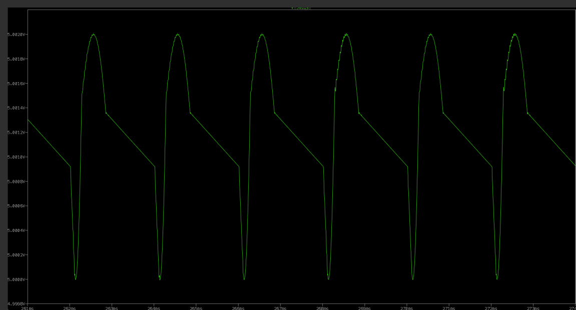
$$\Delta V_{in} = \frac{I_{reg} \cdot \Delta t}{C_s} = \frac{0{,}05 \times 0{,}002}{47 \times 10^{-6}} = 2{,}1276 \text{ V}$$

Q5.3

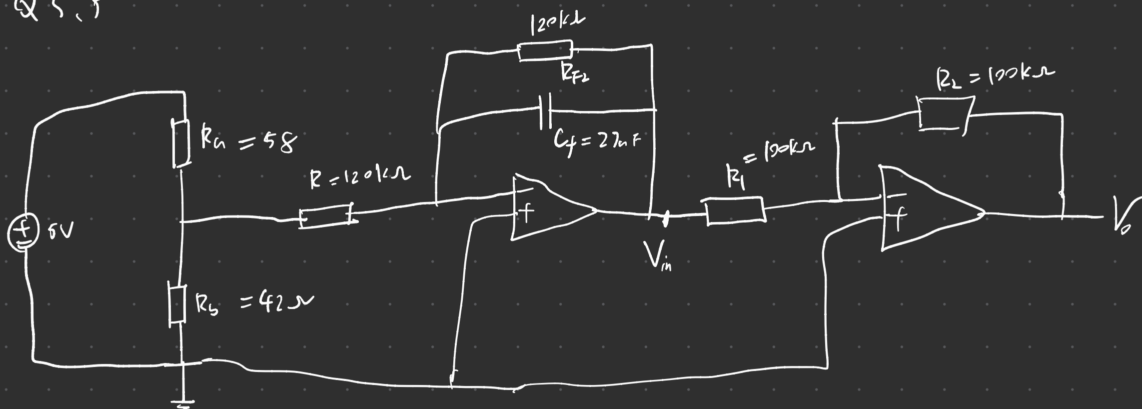








Q5.5



$$2.1 = 5 \times \left(\frac{R_b}{R_a + R_b}\right) \qquad \frac{2.1}{5} = \frac{R_b}{R_a + R_b} \qquad \frac{5}{2.1} = \frac{R_b}{R_a} + 1$$

$$\frac{R_b}{R_a} = \frac{29}{21} \qquad R_b = 42\,\Omega = 39 + 1.5 + 1.5$$

$$R_a = 58\,\Omega = 56 + 1 + 1$$

For DC, $-1 = -\frac{R_{F1}}{R_{F2}} \Rightarrow R_{F1} = R_2$

$f = 50$ Hz $\Rightarrow \omega_b = 2\pi\, 50$ rad/s

$$C = \frac{1}{2\pi\, 50 \times R_{F2}}$$

I picked $R_{F2} = 120\,k\Omega$ so $C = 26.52\,nF \approx 27\,nF$

$R_1 = R_2 = 100\,k\Omega$ for inverting $-2.1\,V$ to positive