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EE 16A HW 9

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I ~~first~~ worked alone, then discussed with Ilya and James.

2) a) $I_s = i_1$ true
$i_1 = i_2$ false
$i_2 = i_3$ true

b) Using golden rule, $V_{o_1}^+ = V_{o_1}^- = 0$ $\therefore \boxed{V_o = 0}$

$\underline{V_1}$ $\cancel{0 - V_{DD}} + I_s = i_1 = \frac{-V_1}{R_1}$ $\therefore \boxed{V_1 = -I_s R_1}$

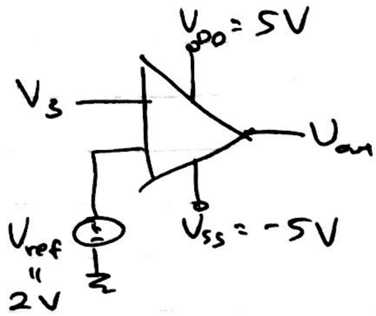
$\underline{V_2}$ Using golden rule, $V_{o_2}^+ = V_{o_2}^- = 0$ $\therefore \boxed{V_2 = 0}$

$\underline{V_3}$ $\frac{-V_1}{R_2} = \frac{V_3}{R_3} \to V_3 = -\frac{R_3}{R_2}(-I_s R_1) \to \boxed{V_3 = I_s \frac{R_1 R_3}{R_2}}$

c) Check that the voltages match up with the gain from the op-amp, calculated from the golden rules. Also, knowing/recognizing that the two opamps are inverting, the signs match up.

d) $V_3 = I_s \frac{R_1 R_3}{R_2} = (0.1A)\frac{(10\Omega)^{1} R_3}{(1000\Omega)}$

Since $V_3 = 0V$ when $I_s = 0A$,
set $\boxed{R_3 = 4k\Omega}$ so that
$V_3 = 4V$ when $I_s = 0.1A$,
so that V_{ref} is the avg of V_3's two outputs.

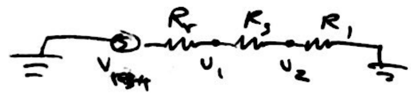


e) Check every voltage step by step to verify that the V_3 is what is expected.
Then, check that the $(V^+ - V^-)$, or in this case, $(V_3 - V_{ref})$ is nowhere close to 0.

3) $R_{left} = R_{right} = 3\Omega$, $R_{speaker} = 4\Omega$
$V_{vocals} = 120.524mV$, $V_{inst} = 50mV$

a)

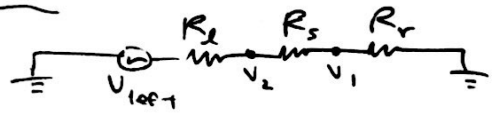
By nulling one source (V_{left}), we get



$$V_{1_1} = \frac{R_l + R_s}{R_l + R_s + R_r} V_{right}$$

$$V_{2_1} = \frac{R_l}{R_l + R_s} V_1 = \frac{R_l}{R_l + R_s + R_r} V_{right}.$$

Null V_{right}, we get



$$V_{2_2} = \frac{R_s + R_r}{R_l + R_s + R_r} V_{left}$$

$$V_{1_2} = \frac{R_r}{R_r + R_s} V_2 = \frac{R_r}{R_l + R_s + R_r} V_{left}$$

$$\therefore V_1 = V_{1_1} + V_{1_2} = \frac{V_l R_r + V_r (R_l + R_s)}{R_l + R_s + R_r},$$

$$V_2 = V_{2_1} + V_{2_2} = \frac{V_r R_l + V_l (R_s + R_r)}{R_l + R_s + R_r}.$$

$$\therefore \text{Voltage across } R_s = V_1 - V_2 = \frac{\cancel{V_r R_l} + V_r R_s + \cancel{V_l R_r} - (\cancel{V_r R_l} + V_l R_s + \cancel{V_l R_r})}{R_l + R_s + R_r}$$

$$\boxed{V_s = \frac{R_s}{R_l + R_s + R_r}(V_r - V_l)}, \quad V_r - V_l = V_{inst}$$

$$\boxed{V_s = 20mV}$$

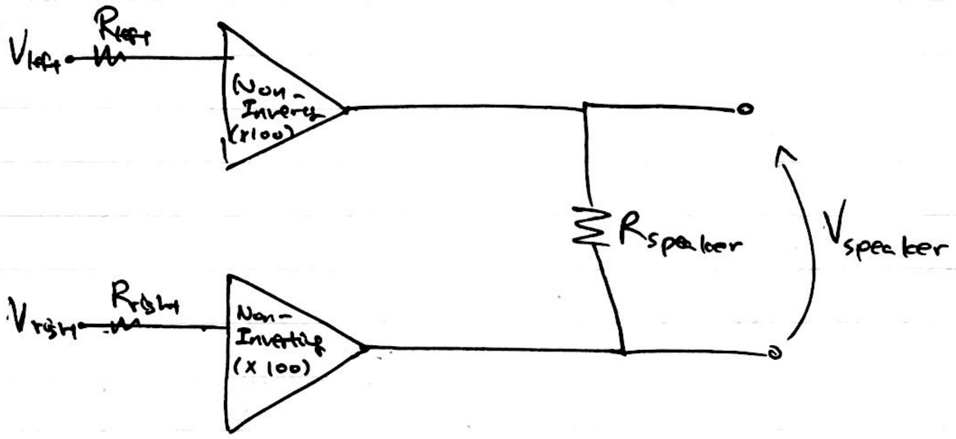
Notice that this acts as like a voltage divider, and that the Voltage across the speaker does not depend on V_{vocals} since $V_r - V_l = V_{instrument}$. Islanders will thus hear the instrument.

b) $V_{speaker} = \frac{R_s}{R_l+R_s+R_r}(V_r - V_l) = 20\,mV$

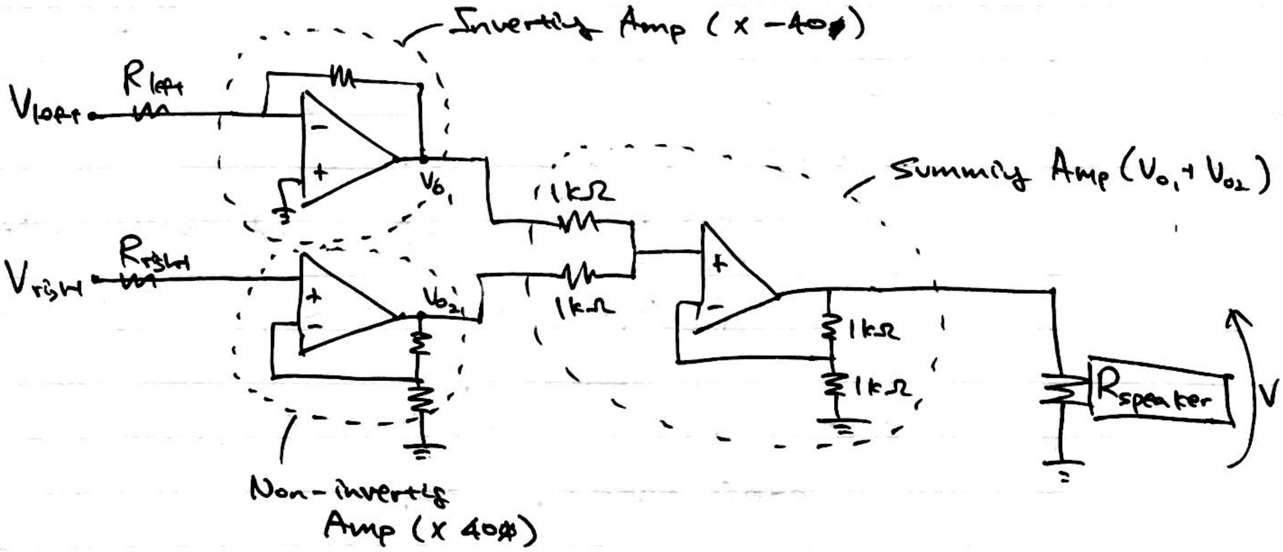
$I_{speaker} = \frac{V_s}{R_s} = \frac{(V_r - V_l)}{R_l+R_s+R_r} = 0.005\ A$

$P = IV = \boxed{\frac{R_s(V_r - V_l)^2}{(R_l+R_s+R_r)^2}} = \boxed{0.0001\ \text{Watts}}$

c)

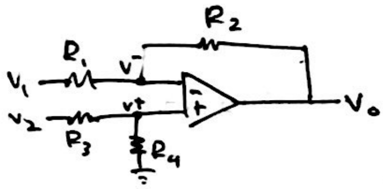


d)



e) $V_2 = 0$: $\frac{V_1}{R_1} = \frac{-V_0}{R_2} \rightarrow \boxed{\frac{V_0}{V_1} = \frac{-R_2}{R_1}}$

f) $V_1 = 0$: $V^+ = \frac{R_4}{R_3+R_4} V_2 = V^- \rightarrow V_0 = V^- \rightarrow \boxed{\frac{V_0}{V_2} = \frac{R_4}{R_3+R_4}}$

g) 

$$V^+ = \frac{R_4}{R_3+R_4} V_2$$

Usig Gloden Rule, $V^+ = V^-$,

$$V^- = \frac{R_4}{R_3+R_4} V_2 \quad ①$$

Nodal analysis @ V^- node :

$$\frac{V^- - V_1}{R_1} + \frac{V^- - V_o}{R_2} = 0$$

$$\frac{R_4}{R_1(R_3+R_4)} V_2 - \frac{1}{R_1} V_1 = \frac{1}{R_2} V_o - \frac{R_4}{R_2(R_3+R_4)} V_2$$

$$\frac{1}{R_2} V_o = \frac{(R_1+R_2)R_4}{(R_3+R_4)R_1R_2} V_2 - \frac{1}{R_1} V_1$$

$$\therefore \boxed{V_o = \frac{R_4(R_1+R_2)}{R_1(R_3+R_4)} V_2 - \frac{R_2}{R_1} V_1}$$

In order not to hear the vocals, V_1 and V_2 must be equally amplified, meaning

$$\frac{R_4(R_1+R_2)}{R_1(R_3+R_4)} = \frac{R_2}{R_1},$$ and each amplification be x$40\cancel{0}$.

$$R_2(R_3+R_4) = R_4(R_1+R_2), \qquad \frac{R_2}{R_1} = \frac{40\cancel{0}}{1}$$

If we choose $\boxed{R_1 = 1\,\Omega}$, $\boxed{R_2 = 40\cancel{0}\,\Omega}$,

$$40\cancel{0} R_3 + 40\cancel{0} R_4 = 4\cancel{0}1 R_4$$

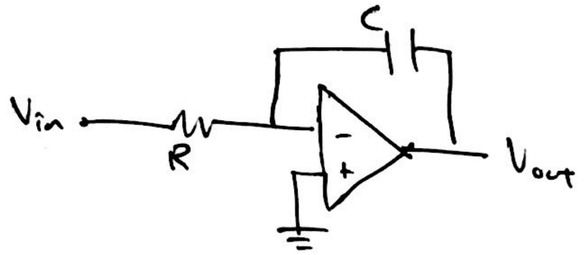
$$R_4 = 40\cancel{0} R_3,$$ so

we can choose $\boxed{R_3 = 1\,\Omega}$, $\boxed{R_4 = 40\cancel{0}\,\Omega}$

Or any R_1, R_2, R_3, and R_4 where R_2 and R_4 are $40\cancel{0}$ times R_1 and R_3, respectevely.

Question

4) Consider the following circuit :

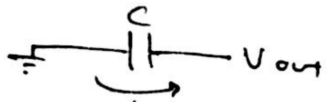


Write V_{out} in terms of R, C, V_{in}, & t.

Answer

Using golden rule, we know that $V^+ = 0 = V^-$.

Thus,



$V_c = -V_{out} = \frac{Q}{C}$.

Differentiate :

$$-\frac{dV_{out}}{dt} = \frac{1}{C}\frac{dQ}{dt} = \frac{1}{C} I_c.$$

Since $I^- = I^+ = 0$ at the terminals of op-amp,

$$I_c = I_R = \frac{V_{in}}{R}$$

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

$$dV_{out} = -\frac{1}{RC} V_{in}(t)\,dt$$

$$\boxed{V_{out} = -\frac{1}{RC}\int_0^t V_{in}(t)\,dt}$$

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