

DAVID LEE  
3031796 951

## EE 16A HW 9

- 1) Ilya - 3031806896  
James Zhu - 3031793129

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,  $V_{o1}^+ = V_{o1}^- = 0 \quad \therefore \boxed{V_o = 0}$

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

$\frac{V_2}{\text{Using golden rule, } V_{o2}^+ = V_{o2}^- = 0} \quad \therefore \boxed{V_2 = 0}$

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

- 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.

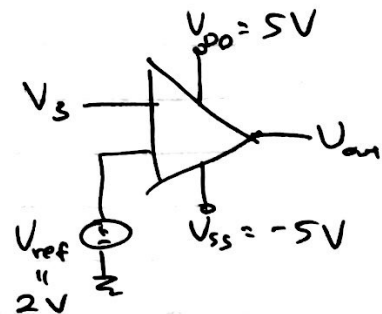
d)  $V_3 = I_s \frac{R_1 R_3}{R_2} = (0.1 \text{ A}) \cdot \frac{(10 \text{ k}\Omega) R_3}{(1000 \text{ }\Omega)}$

Since  $V_2 = 0 \text{ V}$  when  $I_s = 0 \text{ A}$ ,

set  $\boxed{R_3 = 4 \text{ k}\Omega}$  so that

$V_3 = 4 \text{ V}$  when  $I_s = 0.1 \text{ A}$ ,

so that  $V_{\text{ref}}$  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)  $R_{left} = R_{right} = 3\Omega$  ,  $R_{speaker} = 4\Omega$   
 $V_{vocals} = 120.524mV$  ,  $V_{ref} = 50mV$



By nulling one source ( $V_{ref}$ ), we set

$$V_{11} = \frac{R_L + R_S}{R_L + R_S + R_R} V_{right}$$

$$V_{21} = \frac{R_L}{R_L + R_S} V_1 = \frac{R_L}{R_L + R_S + R_R} V_{right}$$

Null  $V_{right}$ , we set

$$V_{22} = \frac{R_S + R_R}{R_L + R_S + R_R} V_{left}$$

$$V_{12} = \frac{R_R}{R_L + R_S} V_2 = \frac{R_R}{R_L + R_S + R_R} V_{left}$$

$$\therefore V_1 = V_{11} + V_{12} = \frac{V_L R_R + V_R (R_L + R_S)}{R_L + R_S + R_R}$$

$$V_2 = V_{21} + V_{22} = \frac{V_R R_L + V_L (R_S + R_R)}{R_L + R_S + R_R}$$

$$\therefore \text{Voltage across } R_S = V_1 - V_2 = \frac{V_R R_L + V_R R_S + V_L R_R - (V_R R_L + V_L R_S + V_L R_R)}{R_L + R_S + R_R}$$

$$V_S = \left[ \frac{R_S}{R_L + R_S + R_R} (V_R - V_L) \right], V_R - V_L = V_{input}$$

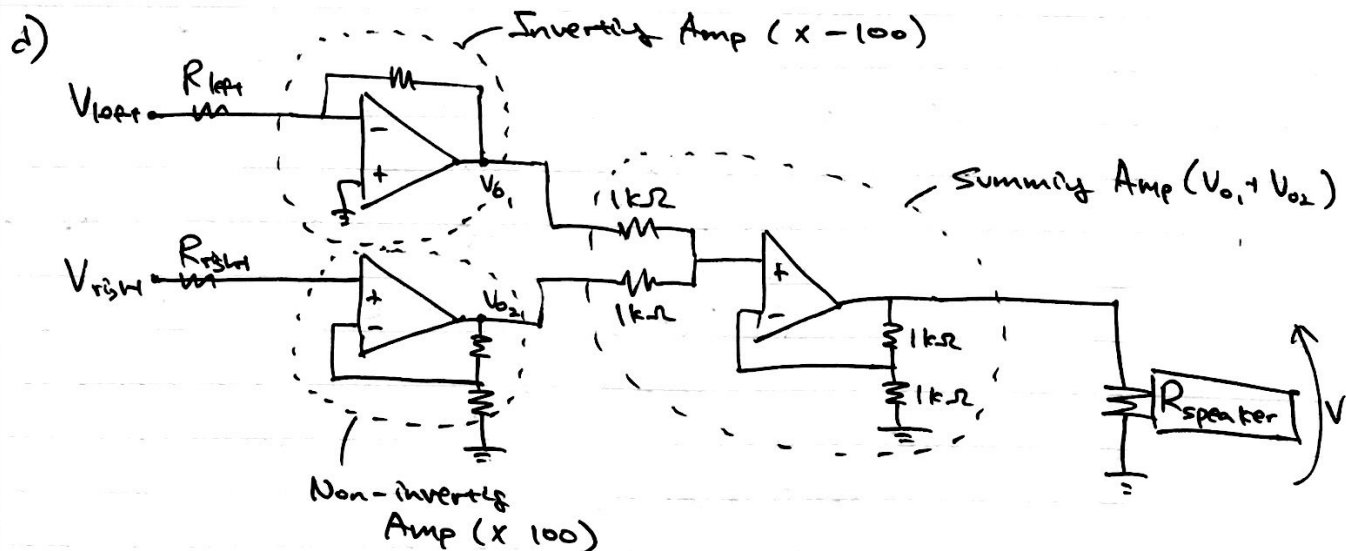
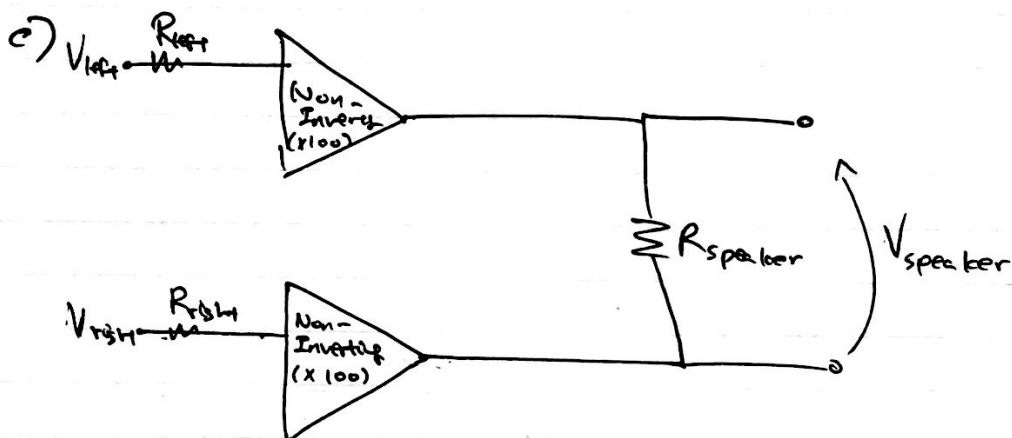
$$V_S = 20mV$$

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.

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

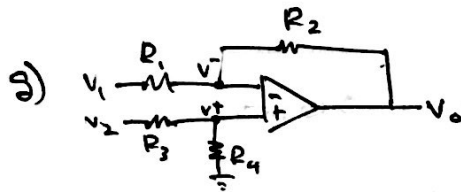
$$I_{\text{speaker}} = \frac{V_s}{R_s} = \frac{(V_r - V_l)}{R_L + R_s + R_r} = 0.005 \text{ A}$$

$$P = IV = \left[ \frac{R_s (V_r - V_l)^2}{(R_L + R_s + R_r)^2} \right] = \boxed{0.0001 \text{ Watts}}$$



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



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

Using Golden Rule,  $V^+ = V^-$ ,

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

Nodal analysis @  $V^-$  node :

$$\frac{V^- - V_1}{R_1} + \frac{V^- - V_0}{R_2} = 0$$

$$\frac{R_4}{R_1(R_3 + R_4)} V_2 - \frac{1}{R_1} V_1 = \frac{1}{R_2} V_0 - \frac{R_4}{R_2(R_3 + R_4)} V_2$$

$$\frac{1}{R_2} V_0 = \frac{(R_1 + R_2) R_4}{(R_3 + R_4) R_1 R_2} V_2 - \frac{1}{R_1} V_1$$

$$\therefore \boxed{V_0 = \frac{R_4 (R_1 + R_2)}{R_1 (R_3 + R_4)} V_2 - \frac{R_2}{R_1} V_1}$$

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

$$\frac{R_4 (R_1 + R_2)}{R_1 (R_3 + R_4)} = \frac{R_2}{R_1}, \text{ and each amplification be } \times 100.$$

$$R_2 (R_3 + R_4) = R_4 (R_1 + R_2), \quad \frac{R_2}{R_1} = \frac{100}{1}$$

$$\text{If we choose } \boxed{R_1 = 1 \Omega}, \boxed{R_2 = 100 \Omega},$$

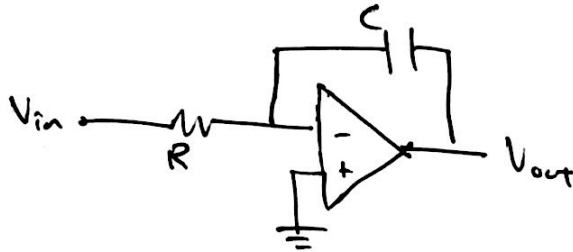
$$100 R_3 + 100 R_4 = 101 R_4$$

$$R_4 = 100 R_3, \text{ so}$$

$$\text{we can choose } \boxed{R_3 = 1 \Omega}, \boxed{R_4 = 100 \Omega}$$

Or any  $R_1, R_2, R_3$ , and  $R_4$  where  $R_2$  and  $R_4$  are 100 times  $R_1$  and  $R_3$ , respectively.

4) Question  
Consider the following circuit :

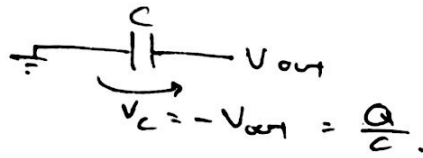


Write  $V_{out}$  in terms of  $R$ ,  $C$ ,  $V_{in}$ , &  $t$ .

Answer

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

Thus,



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,

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

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

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

$$\left| V_{out} = - \frac{1}{RC} \int_0^t V_{in}(t) dt \right|$$