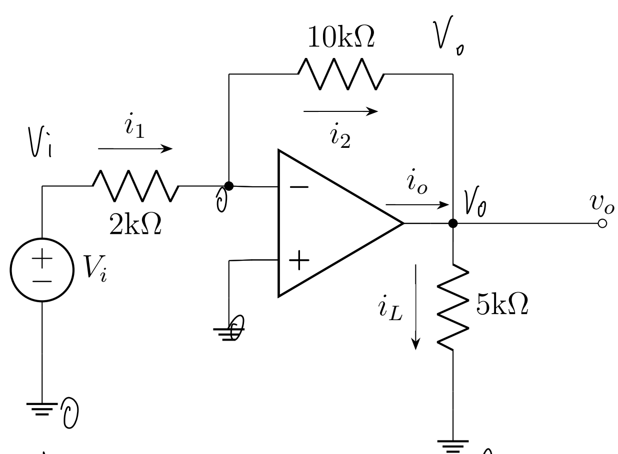
VE311 Electronic Circuit Homework 2
Due: **Jun 3rd 11:59a.m.**

Note:
1) *Please use A4 size paper or page.*
2) *Please clearly state your final result for each question.*

Once upon a time, there's a electronics valley, where two fierce competitors, Blue Tiger and Red Tiger, are racing for a coveted government bidding. Both companies designed the circuit using an Op-Amp. Blue Tiger Electronics, known for its strategic precision, has crafted an inverting Op-Amp circuit with high common-mode rejection, giving precise amplification.

Question 1. Inverting Op Amp

Assume the amplifier is ideal. Determine the values of i_1, i_2, v_i, v_o, and i_L when $i_o = 1mA$. Also determine the voltage gain v_o/v_i, current gain i_L/i_1, and power gain P_o/P_i for the circuit, giving the result in decibels.
(*Hint: pay attention to current direction.*)



(A)

$$\frac{V_i}{2\times10^3} = \frac{-V_o}{10\times10^3}$$
$$10^{-3} - \frac{V_o}{10\times10^3} = \frac{V_o}{5\times10^3}$$

$10 - V_o = 2V_o$

$\Rightarrow$ $V_i = -0.67V$, $V_o = 3.33V$.

$\Rightarrow$ $i_L = \frac{V_o}{5\times10^3} = 0.67\times10^{-3} A$

$i_1 = \frac{V_1}{2\times10^3} = -0.33\times10^{-3} A$.

$\frac{10}{3}$

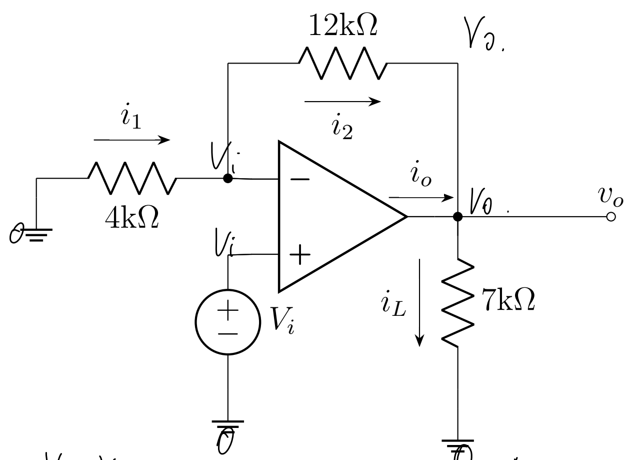
$$\boxed{\frac{V_o}{V_i} = -5. \quad \frac{i_L}{i_1} = -2 \quad \frac{P_o}{P_i} = \frac{V_o i_L}{V_i i_1} = 10.}$$

Not to be outdone, the Red Tiger presents its pride - the non-inverting Op-Amp. A circuit with high input impedance strengthens signals with a tiny influence on their signal input circuit. The Red Tiger's engineers delve into the heart of their ideal model, uncovering the gains that bolster their claim to the throne.

Question 2. Non-Inverting Op Amp

Assume the amplifier is ideal. Determine the values of i_1, i_2, v_i, v_o, and i_L when $i_o = 2mA$. Also, determine the voltage gain v_o/v_i for the circuit.

(*Hint: pay attention to current direction.*)



(A)

$$-\frac{V_i}{4\times10^3} = \frac{V_i - V_o}{12\times10^3}.$$

$$2\times10^{-3} - \frac{V_i}{4\times10^3} = \frac{V_o}{7\times10^3}.$$

$V_o = 9.74V$.

$V_i = 2.43V$

$\Rightarrow$

$i_2 = i_1 = \frac{-V_i}{4\times10^3} = -6.07\times10^{-4}A$.

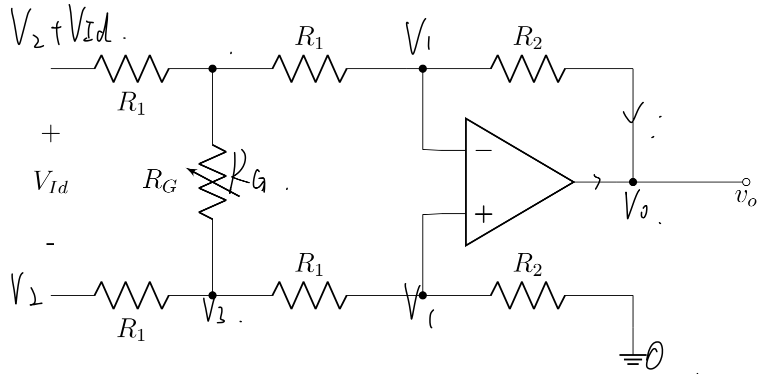
$i_L = \frac{V_o}{7\times10^3} = 1.40\times10^{-3}A$.

$\frac{V_o}{V_i} = 4$.

As the tides of war shift, the Blue Tiger turns to a more powerful amplifier - the Difference Amplifier - to win against the Red Tiger. With the inclusion of R_G, the Blue Tiger looks to control the voltage gain, deftly adjusting their circuit to strike with the accuracy and finesse needed to dominate the electronics market.

Question 3. Difference Amplifiers

Assume the amplifier is ideal. The circuit shows a differential amplifier with controllable gain through R_G. Derive expressions for differential voltage gain v_o/v_{Id} for the following case:
(a) R_G disconnected.
(b) R_G connected.



(A)

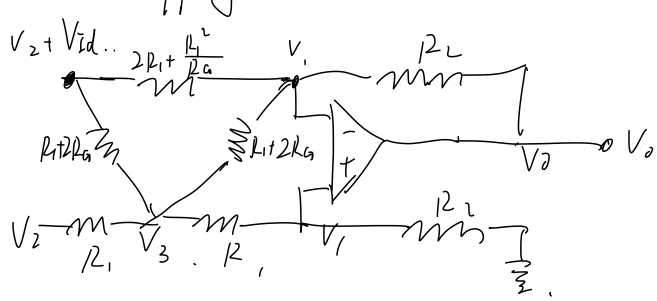
$$V_o = \frac{-R_G R_2 / \left(R_1(2R_1+2R_G)\right)}{2R_1+2R_G}$$

(a)

$$\begin{cases} \dfrac{V_2 + V_{Id} - V_1}{2R_1} = \dfrac{V_1 - V_o}{R_2} \\ \dfrac{V_2 - V_1}{2R_1} = \dfrac{V_1}{R_2} \end{cases} \Rightarrow V_{Id} = -\frac{2R_1}{R_2} V_o \Rightarrow \boxed{\frac{V_o}{V_{Id}} = -\frac{R_2}{2R_1}}$$

(b) Apply Y-Δ, we can get.

V_2



$$\Rightarrow \begin{cases} \dfrac{V_2 + V_{Id} - V_1}{2R_1 + \frac{R_1^2}{R_G}} + \dfrac{V_3 - V_1}{R_1 + 2R_G} = \dfrac{V_1 - V_o}{R_2} \\ \dfrac{V_3 - V_1}{R_1} = \dfrac{V_1}{R_2} \\ \dfrac{V_2 + V_{Id} - V_3}{R_1 + 2R_G} + \dfrac{V_2 - V_3}{R_1} + \dfrac{V_1 - V_3}{R_1 + 2R_G} + \dfrac{V_1 - V_3}{R_1} = 0 \end{cases}$$

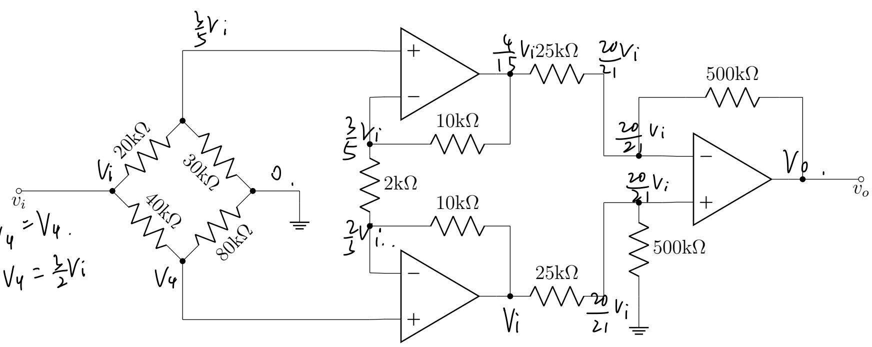
$$\Rightarrow \boxed{\frac{V_o}{V_{Id}} = -\frac{R_2 R_G}{2R_1 R_G + 2R_1^2}}$$

Across the field, Red Tiger counters with the Instrumentation Amplifier. Red Tiger's engineers aim to extract the essence of voltage gain from their ideal circuit, with a high common-mode rejection ratio, high input impedance, low noise, and low linear error, orchestrating a performance that would apply in nearly all situations.

Question 4. Instrumental Amplifier

Assume the amplifier is ideal. The instrumental amplifier is driven by a bridge. Derive the voltage gain v_o/v_i.

(*Hint: consider left and right separately.*)



$2V_i - 2V_4 = V_4.$

$V_4 = \frac{2}{3}V_i$

(A)

$$\begin{cases} \dfrac{V_i - V_4}{40\times10^3} = \dfrac{V_4}{80\times10^3}. \\ \dfrac{V_i - V_3}{20\times10^3} = \dfrac{V_3}{30\times10^3} \\ \dfrac{V_3 - V_4}{2\times10^3} + \dfrac{V_3 - V_2'}{10\times10^3} = 0. \\ \dfrac{V_4 - V_3}{2\times10^3} + \dfrac{V_4 - V_2}{10\times10^3} = 0. \\ \dfrac{V_2' - V_1}{25\times10^3} = \dfrac{V_1 - V_0}{500\times10^3} \\ \dfrac{V_2 - V_1}{25\times10^3} = \dfrac{V_1}{500\times10^3}. \end{cases}$$

$\Rightarrow$.

$$\boxed{\frac{V_o}{V_i} = \frac{44}{3}.}$$

In the twilight of their competition, both companies come upon an unavoidable truth - the presence of non-ideality within Op-Amps. Blue Tiger and Red Tiger alike must now shift from their ideals operational amplifier in its true, non-ideal form. It is here, in the acknowledgment of imperfections, that both companies may find the wisdom to enhance their designs for the world beyond.

Question 5. Non-ideal Op Amp Analysis

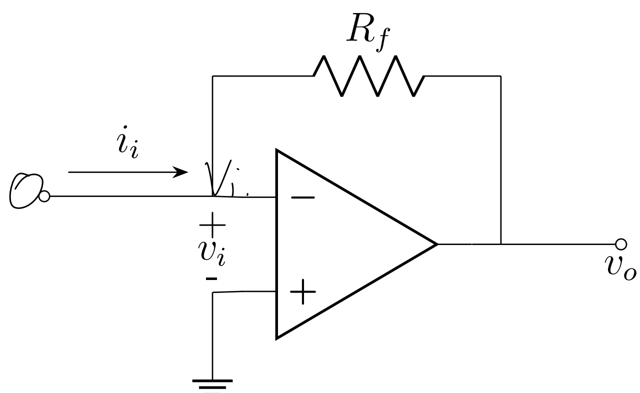
The circuit provides a current-voltage converter to convert input current i_i to output voltage v_o. Derive expressions for the transresistance $R_m = v_o/i_i$ and the input resistance $R_i = v_i/i_i$ for the following cases:

(a) The Op Amp is ideal.

(b) The Op Amp is non-ideal with a finite open-loop gain A.

(c) Op Amp is non-ideal with finite open-loop gain A, output impedance R_{out}, input impedance R_{in}, assuming the amplifier is a voltage amplifier.

(*Hint: draw equivalent circuit first.*)



(A)

(a)

$V_o = i_i R_f$

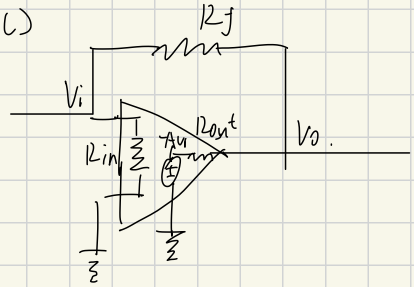
$$\boxed{R_m = \frac{V_o}{i_i} = -R_f \qquad R_i = \frac{V_i}{i_i} = 0}$$

(b) $\frac{V_i - V_o}{R_f} = i_i$

$V_o = V_i - R_f i_i = -A V_i \Rightarrow V_i = \frac{R_f i_i}{A+1}$

$$\boxed{R_m = \frac{V_o}{i_i} = \frac{V_i}{i_i} - R_f = -\frac{A}{A+1} R_f \qquad R_i = \frac{V_i}{i_i} = \frac{R_f}{A+1}}$$

(c)



$$\begin{cases} i_i - \dfrac{V_i}{R_{in}} + \dfrac{V_o - V_i}{R_f} = 0. \\[2ex] \dfrac{-AV_i - V_o}{R_{out}} + \dfrac{V_i - V_o}{R_f} = 0. \end{cases}$$

$$\boxed{\begin{aligned} R_i &= \frac{V_i}{i_i} = \frac{R_{in}(R_f + R_{out})}{(A+1)R_{in} + R_f + R_{out}}. \\ R_m &= \frac{V_o}{i_i} = \frac{(-AR_f + R_{out})R_{in}}{(A+1)R_{in} + R_f + R_{out}}. \end{aligned}}$$