AMPLIFIER MODELS

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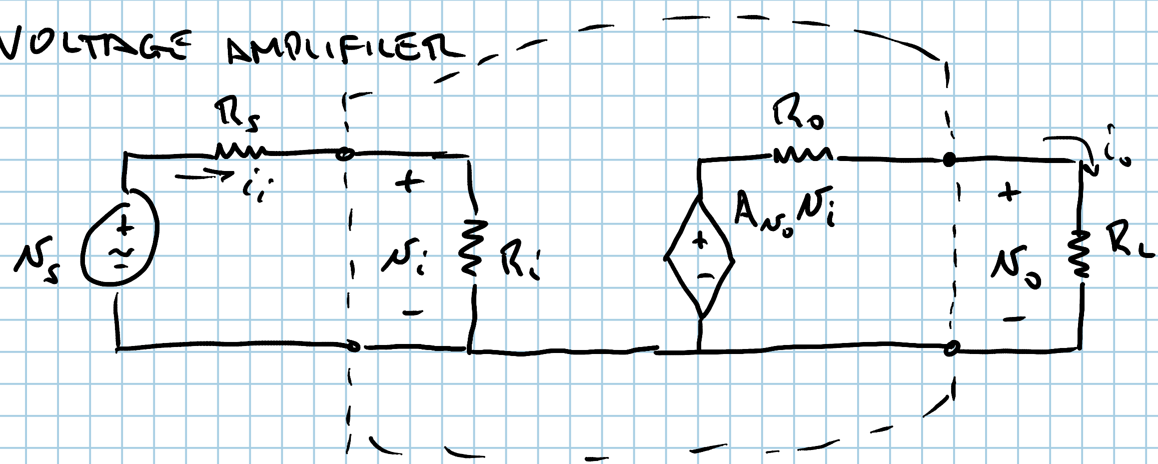
MODEL: A simple circuit that characterizes a more complex circuit.

VOLTAGE AMPLIFIER



$$v_o = \left(\frac{R_L}{R_o + R_L}\right) A_{v_o} v_i$$

DESIGN TIP: $R_o \ll R_L$ (IDEALLY, $R_o = 0$)

$$v_i = \left(\frac{R_i}{R_s + R_i}\right) v_s$$

DESIGN TIP: $R_i \gg R_s$ (IDEALLY, $R_i = \infty$)

$$v_o = \left(\frac{R_L}{R_o + R_L}\right) A_{v_o} \left(\frac{R_i}{R_s + R_i}\right) v_s \quad , \quad \text{AMPLIFIER GAIN} = \frac{v_o}{v_s}$$

$$\frac{v_o}{v_s} = \underbrace{A_{v_o}\left(\frac{R_L}{R_o + R_L}\right)\left(\frac{R_i}{R_s + R_i}\right)}_{\text{AMPLIFIER "GAIN"}}$$

TYPES OF AMPLIFIERS (MODELS)

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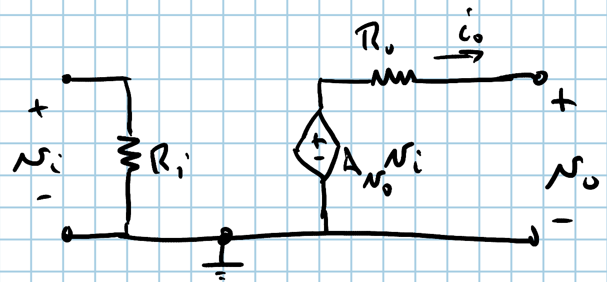
IDEAL CASE

VOLTAGE AMP.

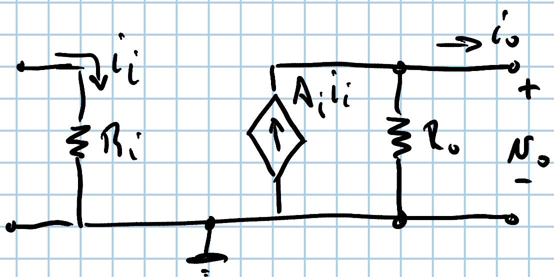


OPEN CIRCUIT VOLTAGE GAIN:

$$A_{v_o} = \left.\frac{v_o}{v_i}\right|_{i_o=0}$$

Ideal case: $R_i = \infty$, $R_o = 0$

CURRENT AMP.

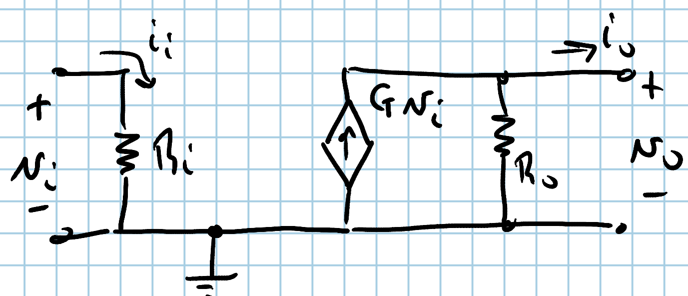


SHORT-CIRCUIT CURRENT GAIN

$$A_i = \left.\frac{i_o}{i_i}\right|_{v_o=0}$$

Ideal case: $R_i = 0$, $R_o = \infty$

TRANSCONDUCTANCE AMP



$G \equiv$ TRANSCONDUCTANCE

$i \propto v$

$i = \frac{1}{R} v$

HW #1 1.52, 1.53

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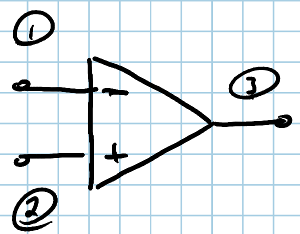
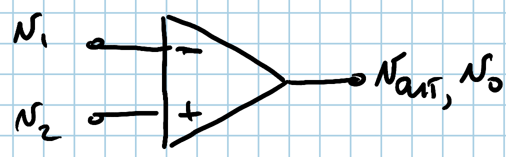
OPERATIONAL AMPLIFIERS (Op-Amps)

THE "IDEAL" OP-AMP



2 INPUTS

1 OUTPUT



1 INVERTING INPUT

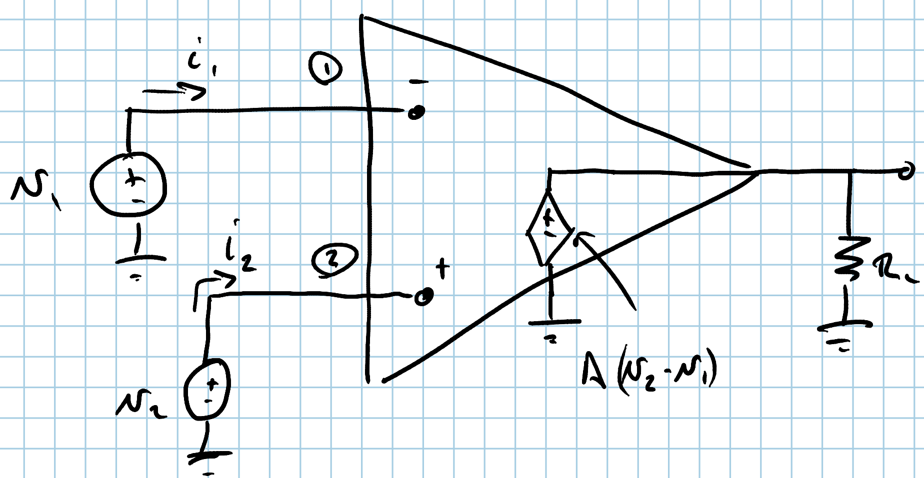
2 NON-INVERTING INPUT

3 OUTPUT

OPERATION: THE OP-AMP SENSES THE VOLTAGE DIFFERENCE BETWEEN 1 & 2 ($v_2 - v_1$), MULTIPLIES THIS DIFFERENCE BY A NUMBER (A), CAUSING THE VOLTAGE $A(v_2 - v_1)$ TO APPEAR AT 3

$$v_o = A(v_2 - v_1)$$

IDEAL OP-AMP



IDEAL: $A = \infty$

$R_i = \infty$

$R_o = \phi$

$i_1 = 0$

$i_2 = 0$

INVERTING AMPLIFIER

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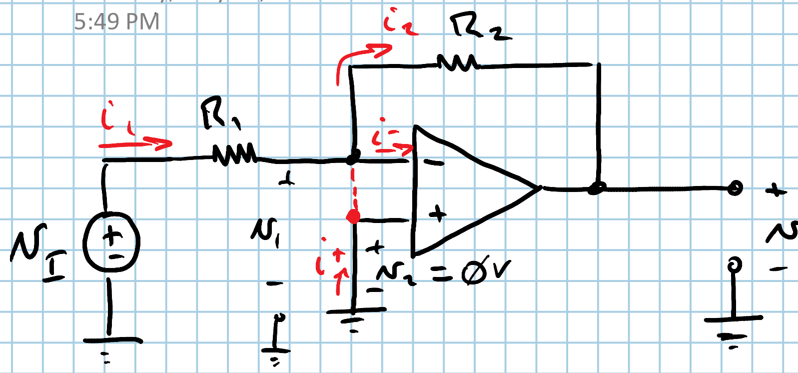


- GROUND NON-INV. INPUT
- OUTPUT IS "FED-BACK" TO INVERTING TERMINAL THRU R_2 $\therefore$ NEGATIVE FEEDBACK.
- R_2 "CLOSES THE LOOP"

IDEAL OP-AMP : $A_{OL} = \infty$

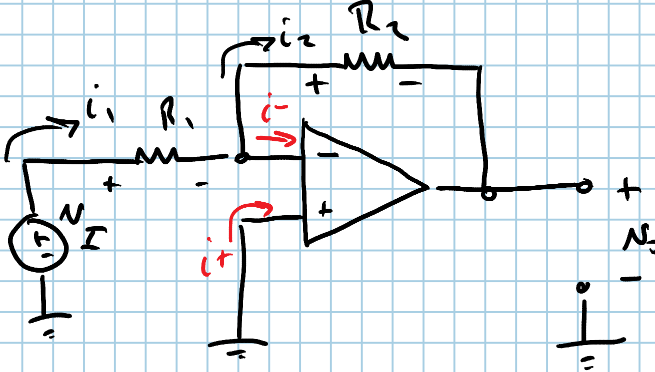
FIND THE CLOSED-LOOP GAIN, $\dfrac{v_o}{v_I}$

$$v_o = A_{OL}(v_2 - v_1) \Rightarrow (v_2 - v_1) = \frac{v_o}{A_{OL}} = \frac{v_o}{\infty} = \emptyset \Rightarrow v_2 - v_1 = 0$$

$$\therefore v_2 = v_1$$

v_2 IS GROUNDED $\Rightarrow v_2 = 0V$

$v_1 = v_2 = 0 \Rightarrow$ THERE EXISTS A "VIRTUAL SHORT-CIRCUIT" BETWEEN 1 + 2



$$i_1 = \frac{v_I - v_1}{R_1} = \frac{v_I}{R_1}$$

$$//$$

$$i_2 = \frac{\cancelto{0}{v_1} - v_o}{R_2} = \frac{-v_o}{R_2}$$

$i^- = i^+ = 0$

KCL @ INV. INPUT

$$i_1 = \cancelto{0}{i^-} + i_2 \Rightarrow i_1 = i_2$$

$$\frac{v_I}{R_1} = -\frac{v_o}{R_2} = \boxed{v_o = -\frac{R_2}{R_1} v_i}$$

CLOSED-LOOP GAIN: $\underline{\underline{G = A_{CL} = \dfrac{v_o}{v_i} = -\dfrac{R_2}{R_1}}}$

EFFECTS OF FINITE OPEN-LOOP GAIN

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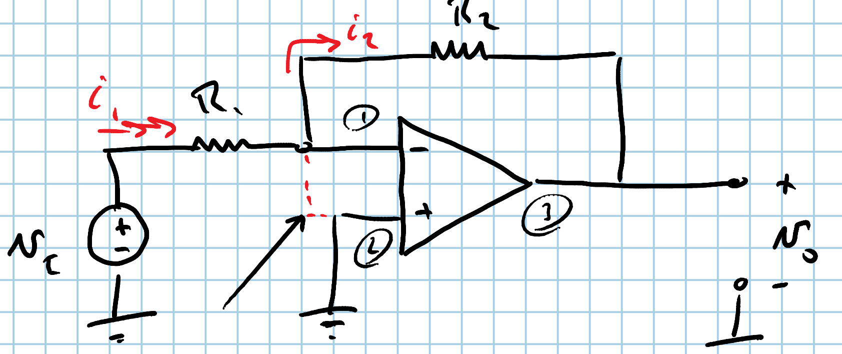
$A_{OL} \neq \infty$, $(R_i = \infty)$



VIRT. SHORT

$$v_O = A_{OL}(\cancel{v_2}^{\,0} - v_1) = -A_{OL} v_1$$

$$v_1 = -\frac{v_O}{A_{OL}}$$

$$i_1 = \frac{v_I - v_1}{R_1} = \frac{v_I - \left(-\frac{v_O}{A_{OL}}\right)}{R_1} = \frac{v_I + \frac{v_O}{A_{OL}}}{R_1}$$

$$i_2 = \frac{v_1 - v_O}{R_2} = \frac{-\frac{v_O}{A_{OL}} - v_O}{R_2}$$

$i_1 = i_2$

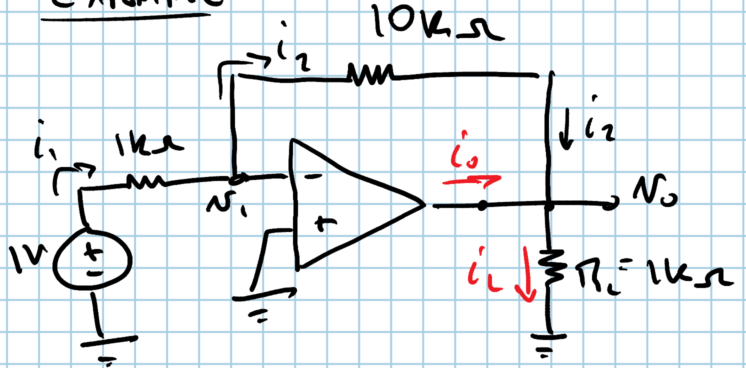
$$\frac{v_I + \frac{v_O}{A_{OL}}}{R_1} = \frac{-\frac{v_O}{A_{OL}} - v_O}{R_2}$$

$\vdots$

$$G = A_{CL} = \frac{v_O}{v_I} = \frac{-R_2}{R_1 + \frac{(R_1 + R_2)}{A_{OL}}}$$

$A_{CL} \to \frac{-R_2}{R_1}$ AS $A_{OL} \to \infty$

EXAMPLE



FIND $v_1, i_1, i_2, v_O, i_L, i_O$

$$A_{CL} = -\frac{R_2}{R_1} = -\frac{10k\Omega}{1k\Omega} = \boxed{-10\ V/V}$$

$\boxed{v_1 = 0}$ (VIRT. SHORT)

$$i_1 = \frac{1V - 0}{1k\Omega} = \boxed{1\,mA}$$

$i_2 = i_1 = \boxed{1\,mA}$, $v_O = A_{CL} v_I = (-10)(1V) = \boxed{-10V}$

$$i_L = \frac{v_O}{R_L} = \frac{-10V}{1k\Omega} = \boxed{-10\,mA}$$

$i_O + i_2 = i_L \Rightarrow i_O = i_L - i_2 = -10 - 1 = \boxed{-11\,mA = i_O}$

EXAMPLE

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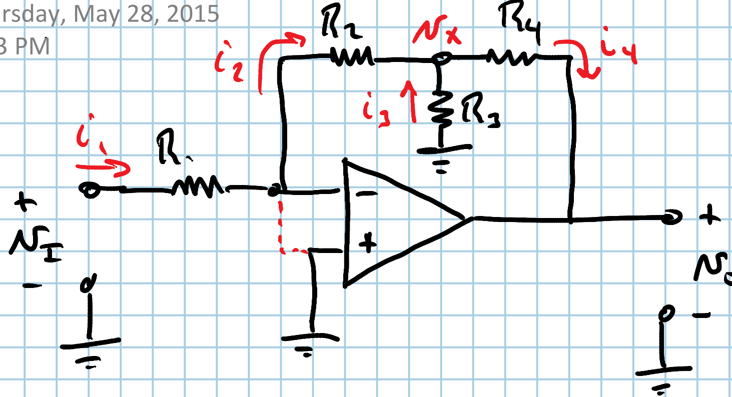

$v_2 = 0 \Rightarrow v_1 = 0\,V$ (VIRT. SHORT)

$$i_1 = \frac{v_I}{R_1}$$

$$i_2 = i_1$$

$$i_2 = \frac{0 - v_x}{R_2} = \frac{-v_x}{R_2} = i_1 = \frac{v_I}{R_1}$$

$$v_x = -\frac{R_2}{R_1} v_I$$

$$i_3 = -\frac{v_x}{R_3} = +\frac{R_2}{R_1 R_3} v_I$$

$$i_4 = \frac{v_x - v_o}{R_4} = \frac{1}{R_4}\left[-\frac{R_2}{R_1} v_I - v_o\right], \quad \text{KCL: } i_2 + i_3 = i_4$$

$$\frac{v_I}{R_1} + \frac{R_2}{R_1 R_3} v_I = \frac{1}{R_4}\left[-\frac{R_2}{R_1} v_I - v_o\right]$$

ADDENDUM TO HW #1: FIND $A_{CL} = \dfrac{v_o}{v_I}$

$$\boxed{A_{CL} = \frac{v_o}{v_I} = -\frac{R_2}{R_1}\left[\frac{R_4}{R_2} + \frac{R_4}{R_3} + 1\right]}$$

Op-Amp Summer

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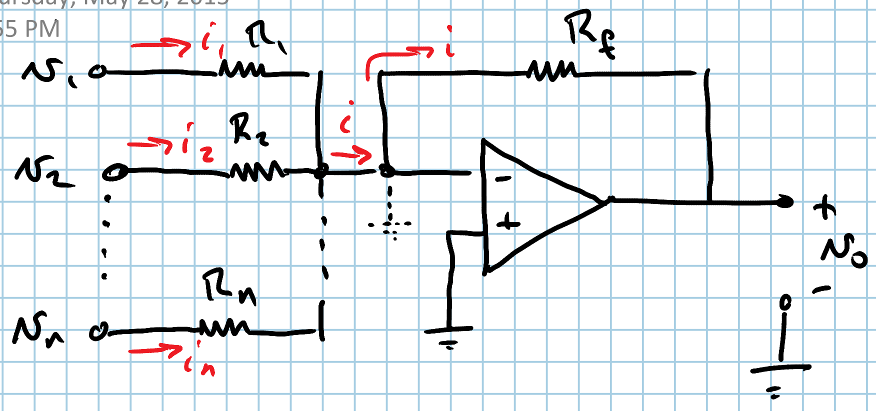

$$i_1 = \frac{v_1}{R_1}$$

$$i_2 = \frac{v_2}{R_2}$$

$$\vdots$$

$$i_n = \frac{v_n}{R_n}$$

$i = i_1 + i_2 + \cdots + i_n$, AND $i = \dfrac{0 - v_o}{R_f}$

$i = i \Rightarrow \quad \dfrac{v_1}{R_1} + \dfrac{v_2}{R_2} + \cdots + \dfrac{v_n}{R_n} = -\dfrac{v_o}{R_f}$

SOLVING FOR v_o

$$v_o = -\left[v_1 \frac{R_f}{R_1} + v_2 \frac{R_f}{R_2} + \cdots + v_n \frac{R_f}{R_n} \right]$$

OUTPUT IS A WEIGHTED SUM OF THE INPUTS.