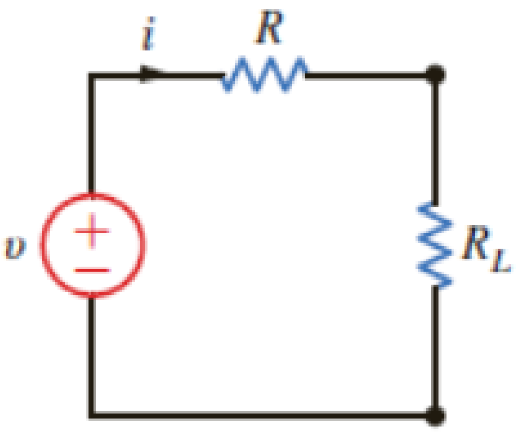
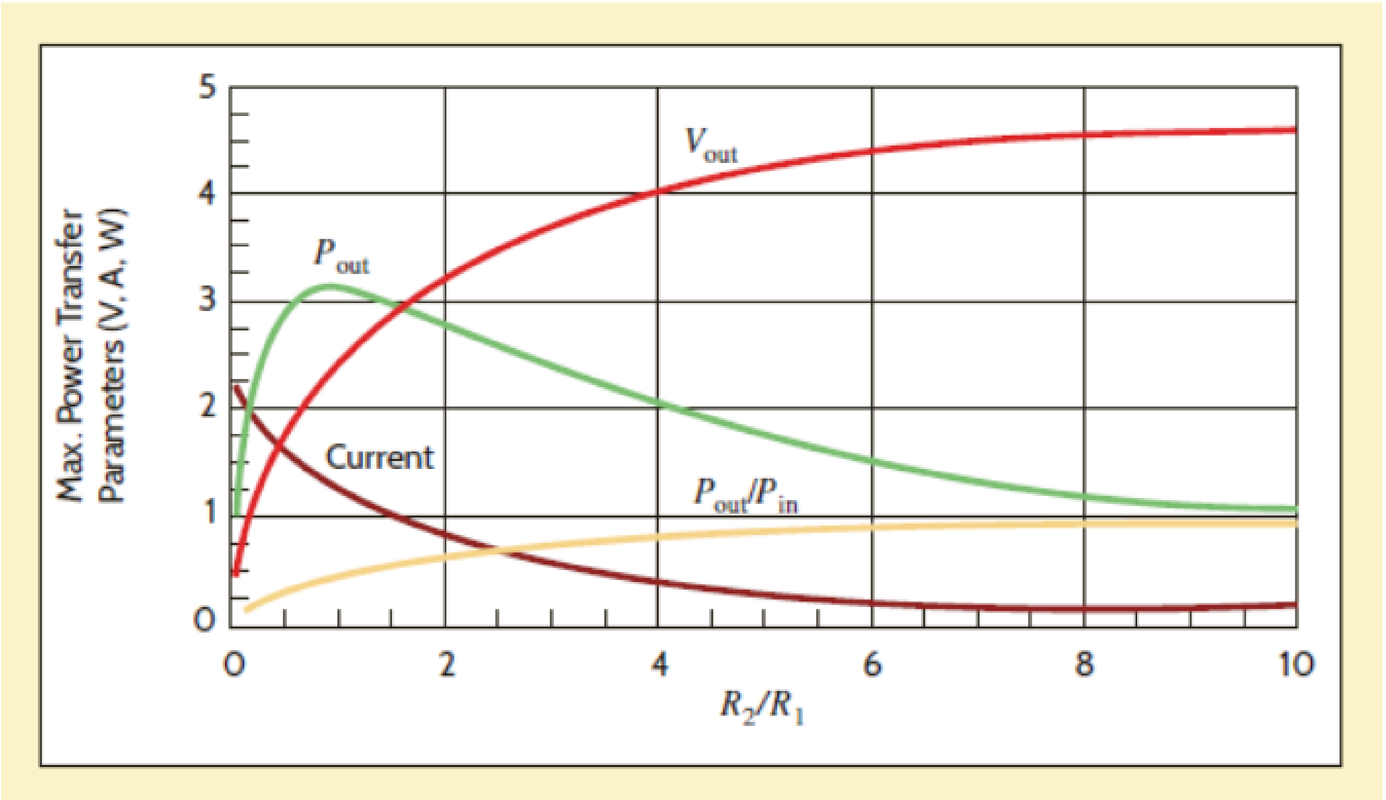
Last Lecture → Maximum Power Transfer

Determine the value of R_L such that maximum power is transferred from the source to the load.





$$P_L = \frac{{V_L}^2}{R_L} = R_L\left[\frac{v}{(R_L+R)}\right]^2$$

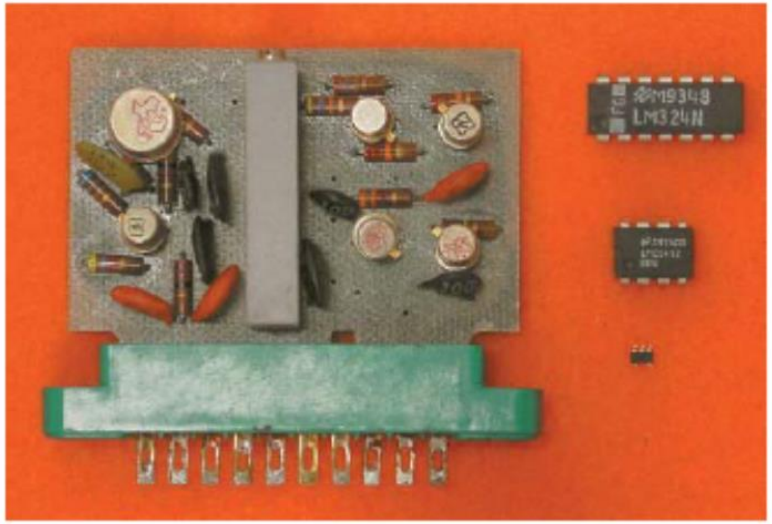
$$\frac{\delta P_L}{\delta R_L} = \left[\frac{v}{(R_L+R)}\right]^2 - 2\cdot R_L\left[\frac{v}{(R_L+R)}\right]^2\frac{1}{R_L+R}$$

⇒ $\frac{\delta P_L}{\delta R_L} = 0 \;\rightarrow R_L = R$

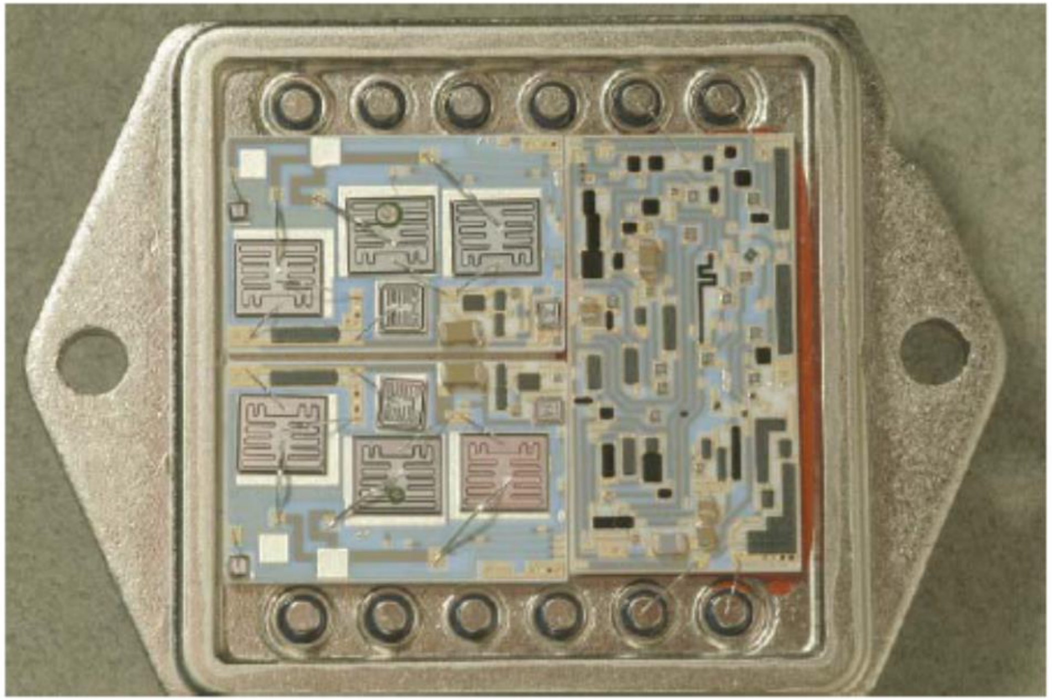
$$\eta = \frac{P_L}{P_{source}} = \frac{R_L}{R_L+R}$$

Operational Amplifiers → Chapter #4

- **Amplifier Model**
- **Amplifier Based Circuit Analysis**



(a)



(b)

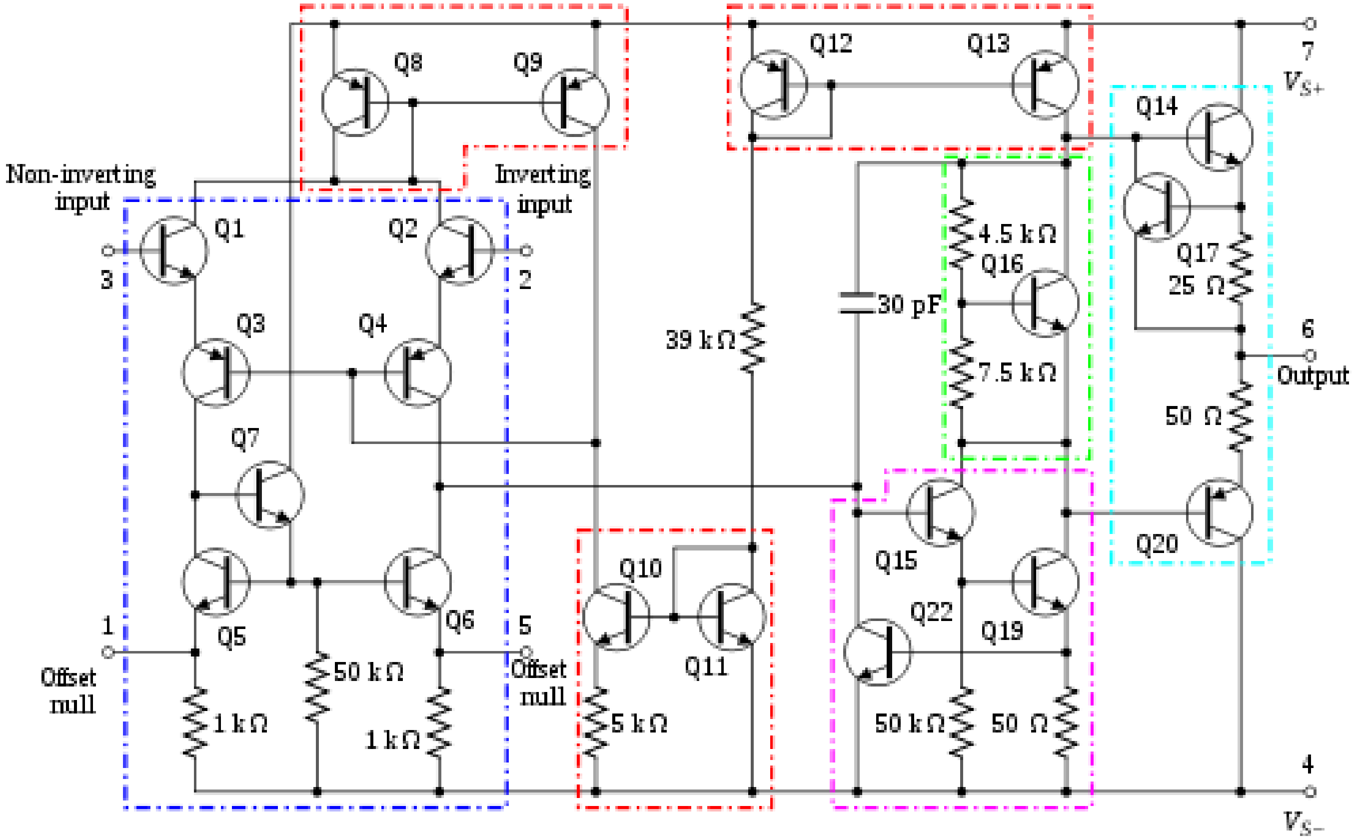
Op-amps

Op-Amp

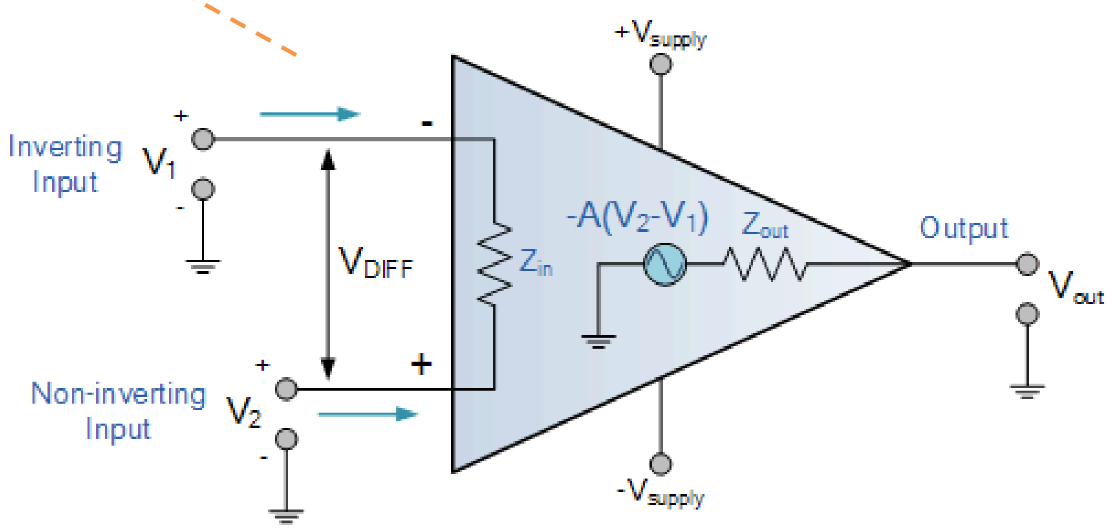
- ***Is the single most important integrated circuit for analog circuit design***
- ***Is a versatile interconnection of transistors and resistors***
- ***Is used in a wide range of applications, from engine control systems to cellular phones***
- ***Was designed to perform mathematical operations***

Operational Amplifier

- **Internal Circuit Diagram**



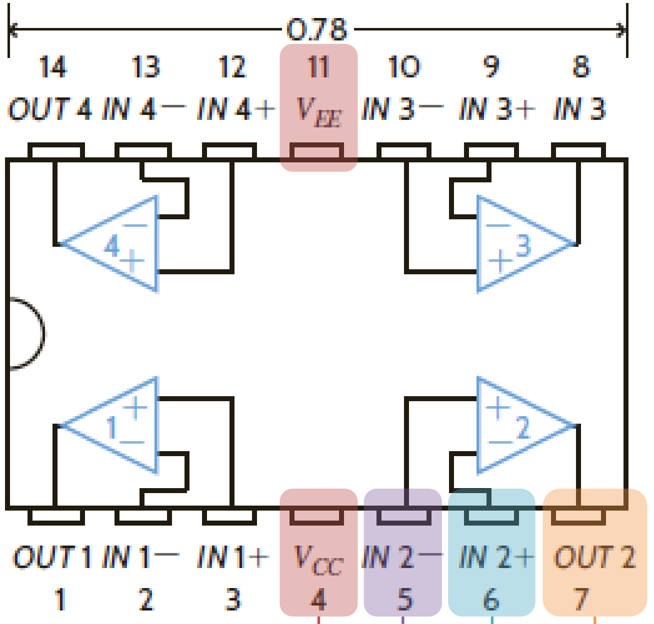
- **Symbol / Equivalent Circuit**



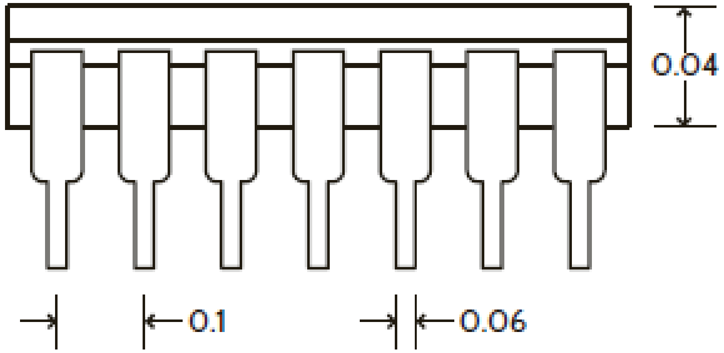
$$V_0 = A_0(IN_+ - IN_-)$$

Op-Amp Model

- **LM324 – Dip Package - Pinout**



(a)



(b)

Output

Non-inverting Input

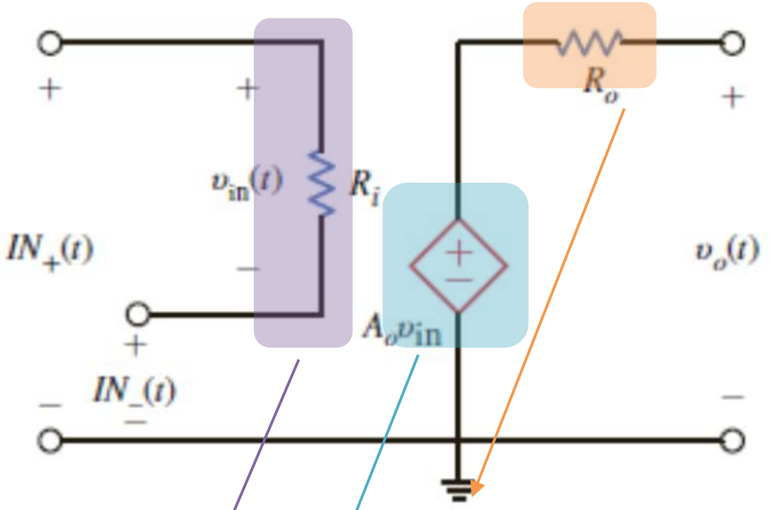
Inverting Input

Supply Voltage

$$V_0 = A_0(IN_+ - IN_-)$$

Gain of op-amp ~ (10,000 – 1,000,000)

- **Circuit Model**

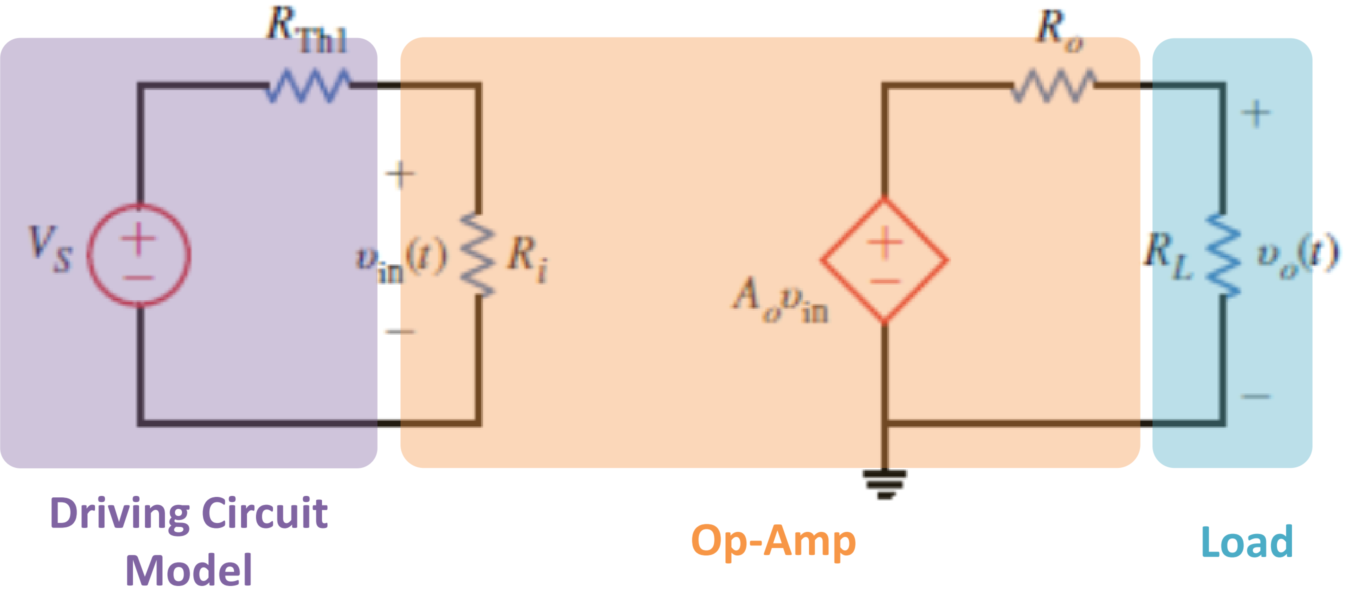


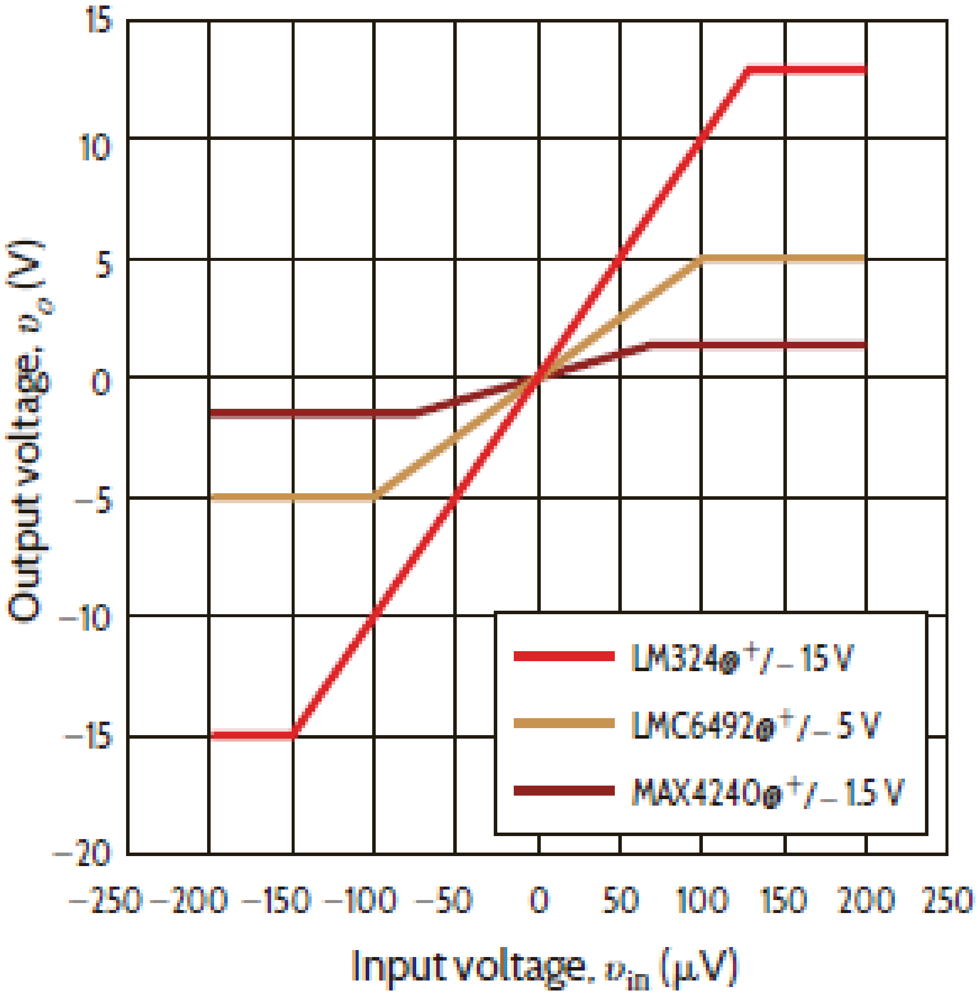
Models I-V relationship at output

Models op-amp gain

Models I-V relationship at input

Op-Amp Circuit





$$\frac{V_0}{V_s} = \left[\frac{R_i}{R_i + R_{TH1}}\right][A_0]\left[\frac{R_L}{R_L + R_0}\right]$$

$$for R_i \to \infty, R_0 \to 0 \qquad \frac{V_0}{V_s} = A_0$$

Example 4.1

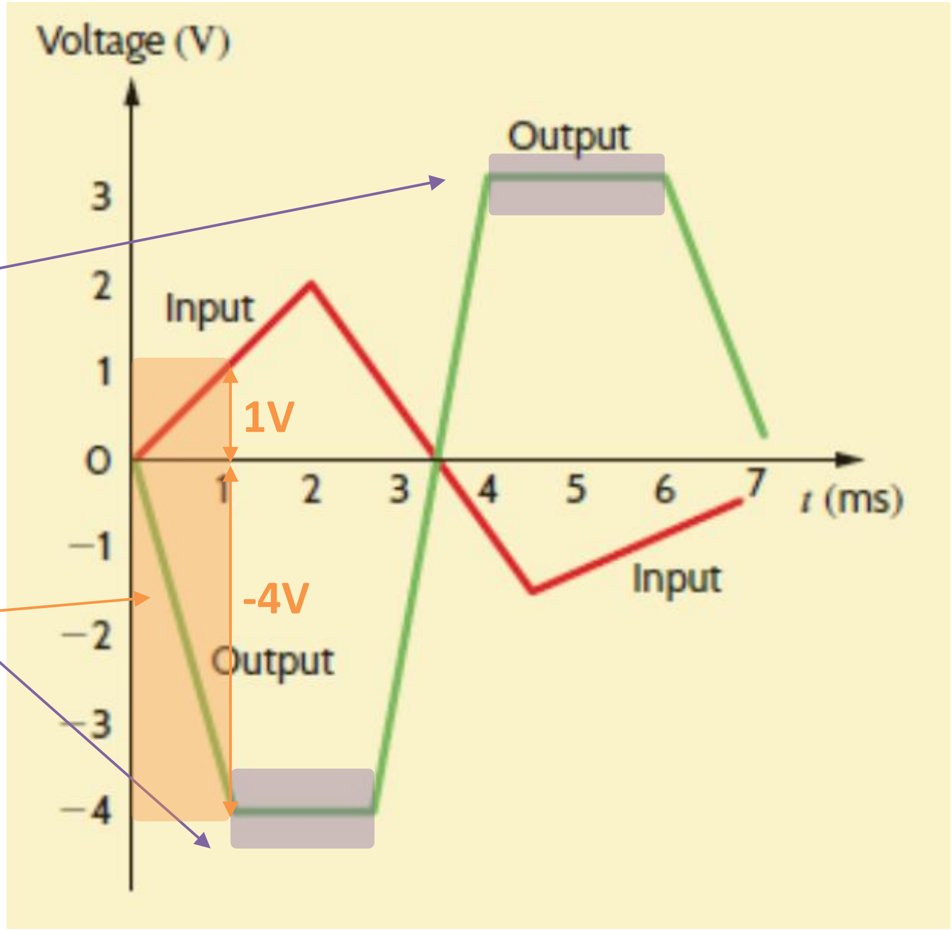
The input and output signals for an op-amp circuit are shown in figure below. Determine:

a) if the op-amp circuit is linear, and

b) the circuit's gain

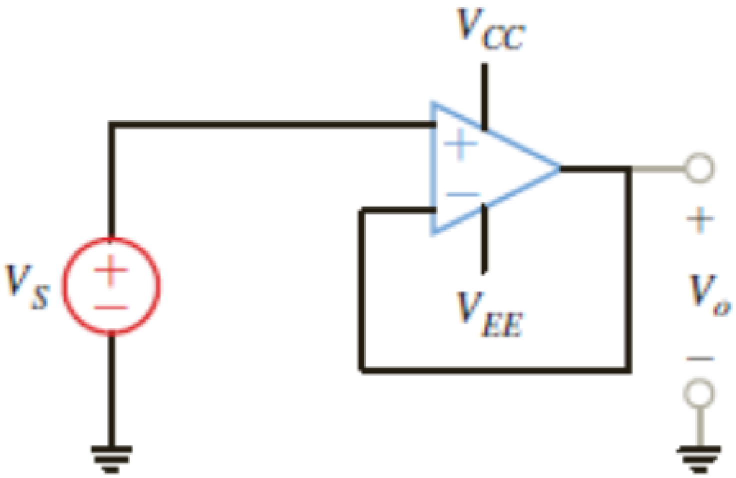
Op-amp saturates, therefore not linear

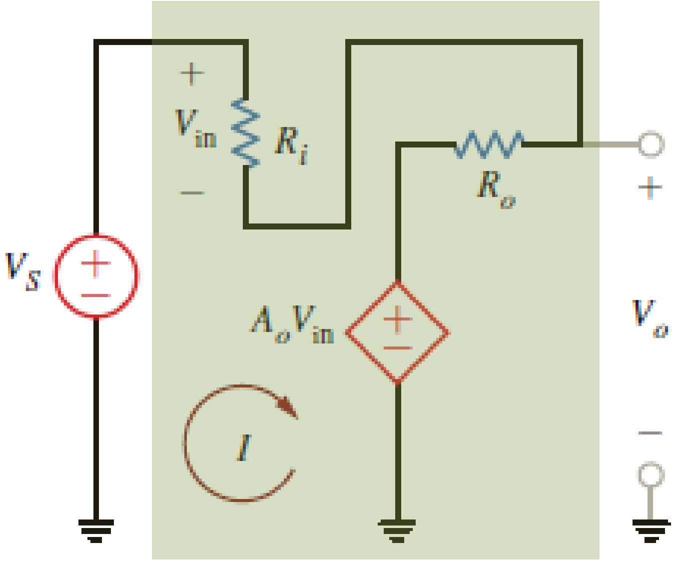
$$\frac{V_0}{V_s} = \frac{-4}{1} = -4V/V$$



Unity Gain Buffer

Using the op-amp model find the expression for the transfer function V_o/V_s.





Op-Amp Ideal Behavior

- $R_i = \infty$
- $A_0 = \infty$
- $R_o = 0$

$$i_{R_i} = \frac{V_{in}}{R_i} = 0$$

$$\therefore i_+ = i_- = 0$$

$$\frac{V_0}{V_s} = \frac{1}{1 + \frac{1}{A_0 + \frac{R_0}{R_i}}} \approx \frac{1}{1 + \frac{1}{A_0}} \approx 1$$

$R_i = \infty$, $R_0 = 0$

$A_0 = \infty$

$$V_0 = A_0(V_+ - V_-)$$

$$(V_+ - V_-) = \frac{V_0}{A_0} = 0 \quad \therefore V_+ = V_-$$

Ideal Op-Amp Circuit Analysis

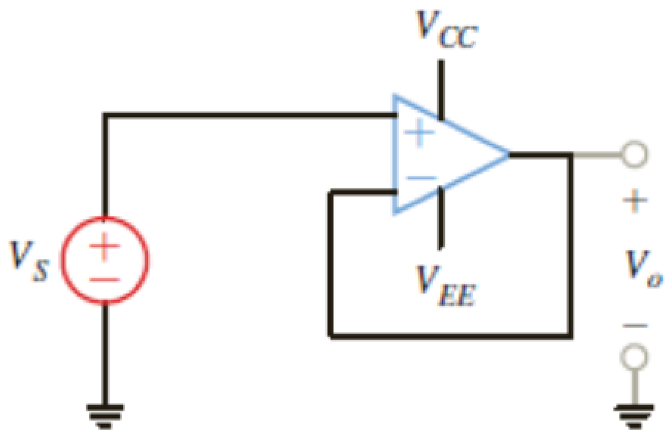
- **Stablish ideal op-amp conditions on the circuit schematic**
- **Write nodal equations at the op-amp input terminals**
- **Solve for the input/output relationship**

MODEL ASSUMPTION	TERMINAL RESULT
$A_o \rightarrow \infty$ $R_i \rightarrow \infty$	input voltage → 0 V input current → 0 A

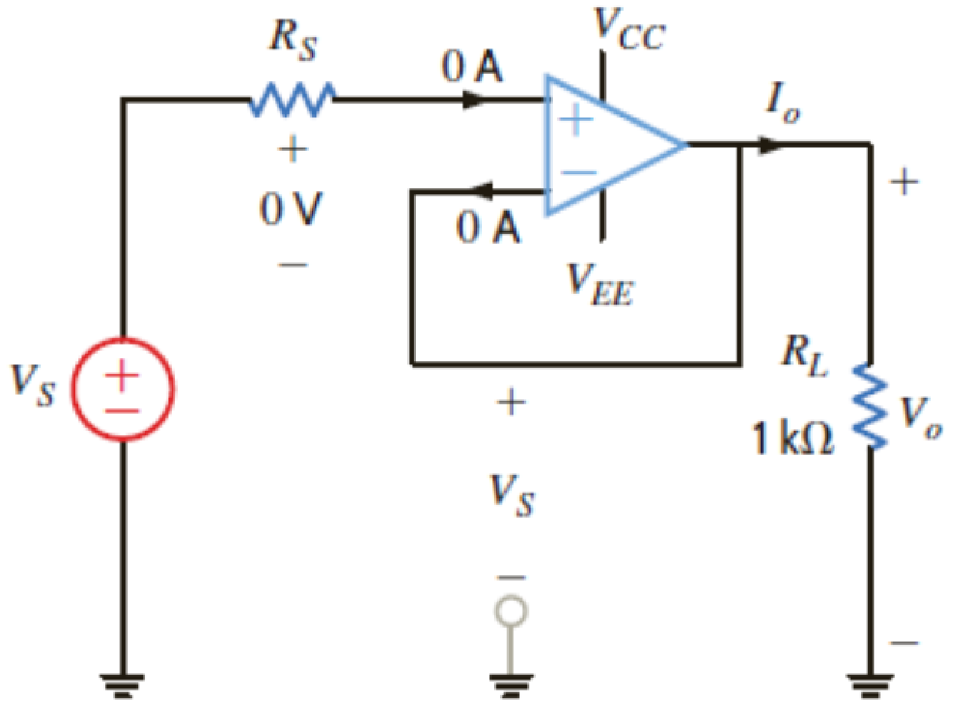
$V_+ = V_-$

$i_+ = i_- = 0$

Unity Gain Buffer - Revisited

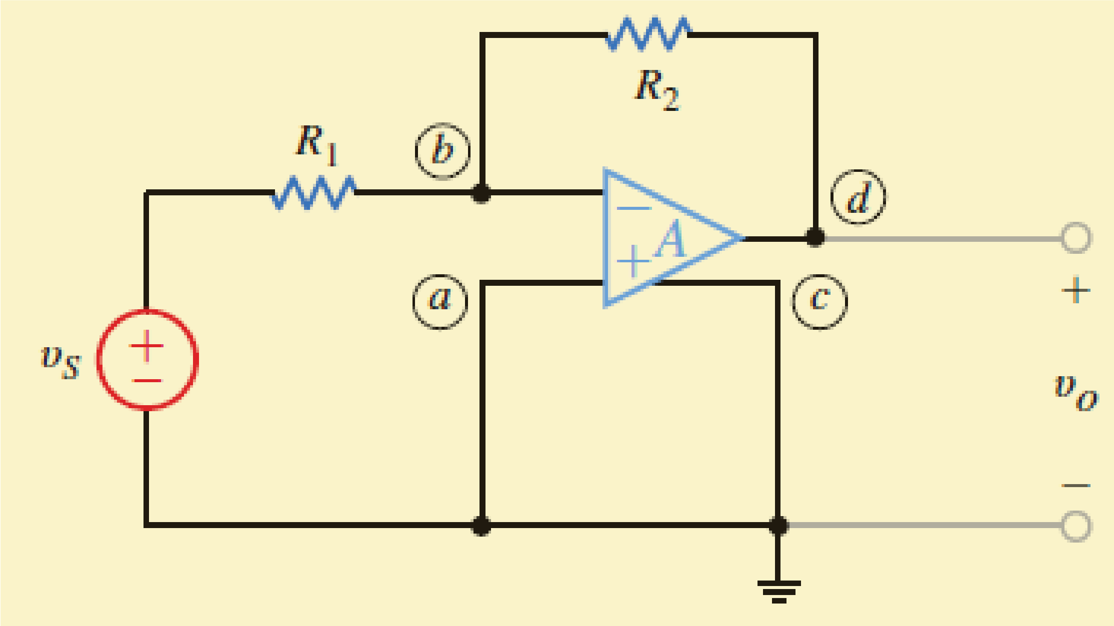


$$\therefore V_0 = V_s$$



Example 4.2

Determine the gain v_0/v_s of the basic inverting op-amp configuration using both the non-ideal ($R_i=\infty$, $R_o=0$) and the ideal models.



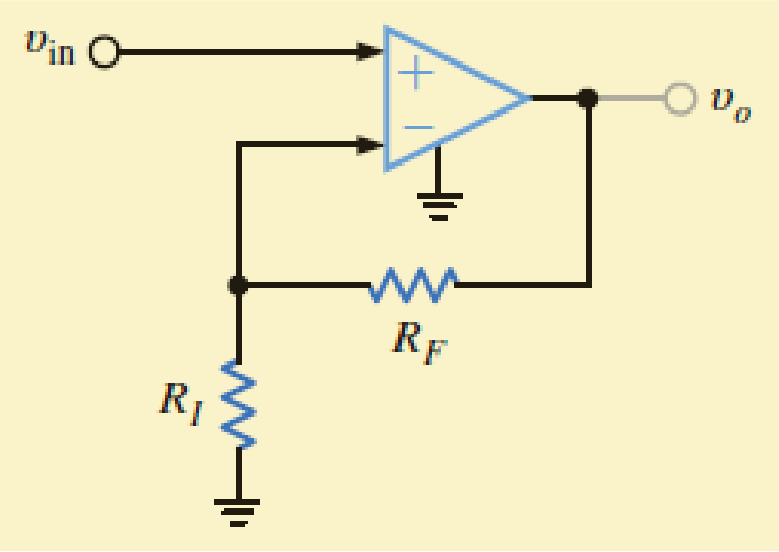
$$\frac{V_0}{V_s} = -\frac{R_2}{R_1}\left[\frac{1}{1+\frac{1}{A_0}\left(1+\frac{R_2}{R_1}\right)}\right]$$

$$for\quad A_0 = \infty \quad \rightarrow \frac{V_0}{V_s} \approx -\frac{R_2}{R_1}$$

Example 4.3

Determine the gain v_0/v_s of the basic non-inverting op-amp configuration both the non-ideal (R_i=∞, R_o=0) and the ideal models. Determine the expression for the gain error (GE).

$$\frac{V_0}{V_s} = \left[1 + \frac{R_F}{R_1}\right]\left[\frac{1}{1 + \frac{1}{A_0}\left(1 + \frac{R_F}{R_1}\right)}\right]$$



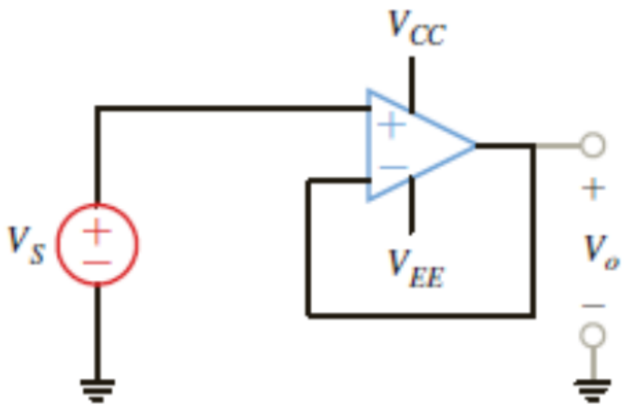
$$for \quad A_0 = \infty \quad \rightarrow \frac{V_0}{V_s} \approx 1 + \frac{R_F}{R_1}$$

$$GE = \left[\frac{A_{v_{ideal}} - A_v}{A_{v_{ideal}}}\right] \cdot 100 = \left[\frac{1}{1 + A_0\left(\frac{R_1}{R_1 + R_F}\right)}\right] \cdot 100$$

$$for \quad A_0 = \infty \quad \rightarrow GE \approx 0$$

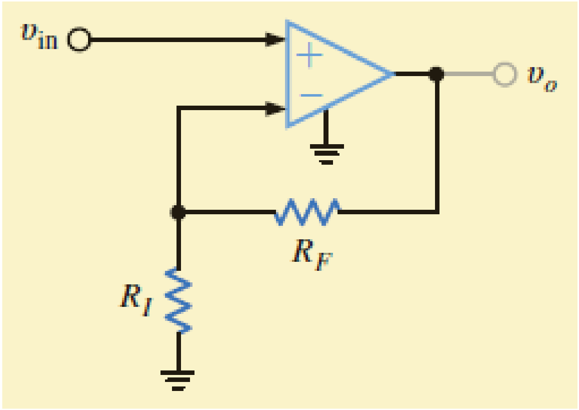
Op-Amp Basic Circuits

- **Unity – Gain Amp.**



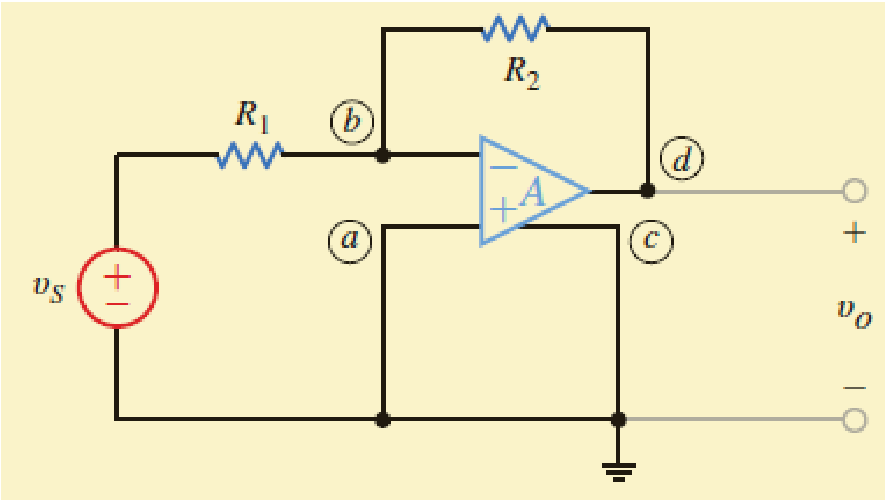
$$\frac{V_0}{V_s} \approx 1$$

- **Non-Inverting Amp.**



$$\frac{V_0}{V_s} \approx 1 + \frac{R_F}{R_I}$$

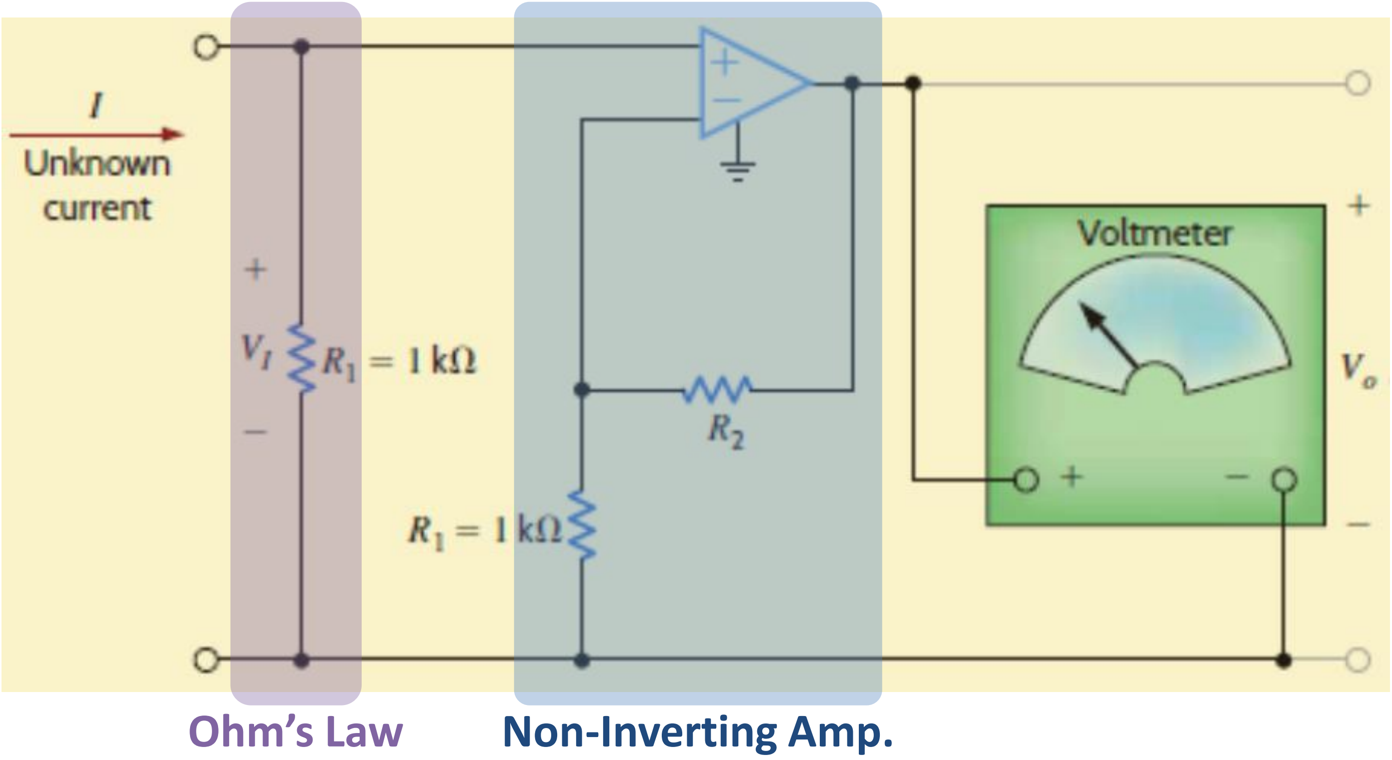
- **Inverting Amp**



$$\frac{V_0}{V_s} \approx -\frac{R_2}{R_1}$$

Example 4.7

The provided circuits is an electronic ammeter. It operates as follows: the unknown current, I, through R_I produces a voltage, V_I. V_I is amplified bye the op-amp to produce a voltage, V_o, which is proportional to I. The output voltage is measure with a simple voltmeter. Find the value of R_2 such that 10V appears at V_o for each milliamp of unknown current.



$$\frac{V_0}{I} = \frac{10}{1m} = 10k\Omega$$

$$V_0 = \left[1 + \frac{R_2}{1k}\right] V_I$$

$$V_I = [1k] \cdot I$$

$$\therefore V_0 = [1k + R_2] \cdot I$$

$$\frac{V_0}{I} = [1k + R_2] = 10k\Omega$$

$$\therefore R_2 = 9k\Omega$$

Problem

Determine v_0 in the circuit provided.