Electric Circuits
Lecture 6 The Operational Amplifier

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Jenny Yi-Chun Liu

jennyliu@gapp.nthu.edu.tw

Lecture Outline

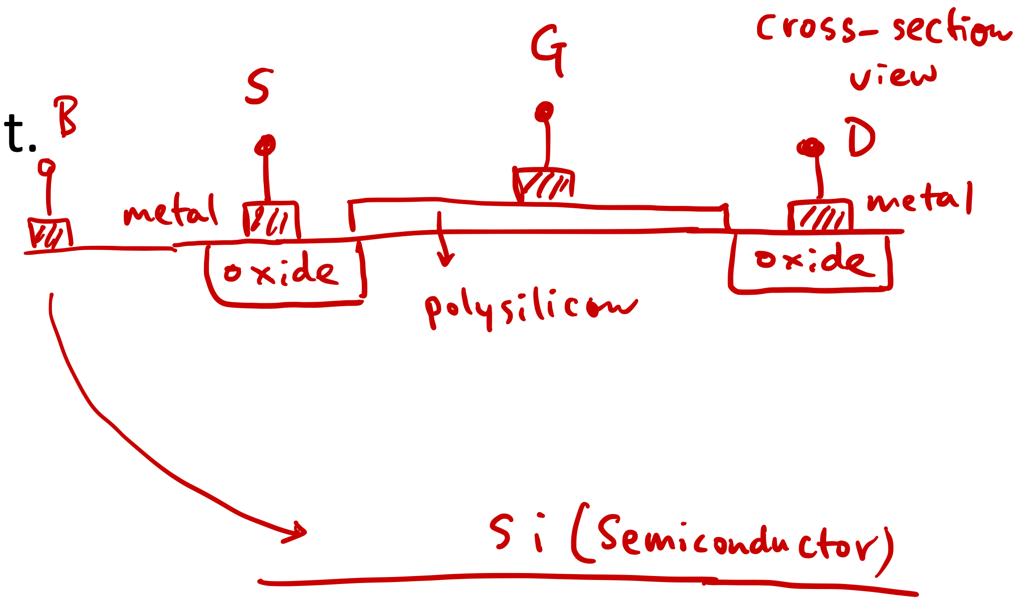
- Chapter 6 in the textbook
  - The operational amplifier
  - Circuit analysis containing opamp

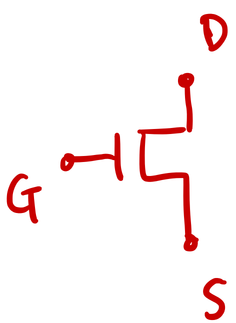
op

MOSFET Device

PMOS
NMOS
CMOS
Complementary

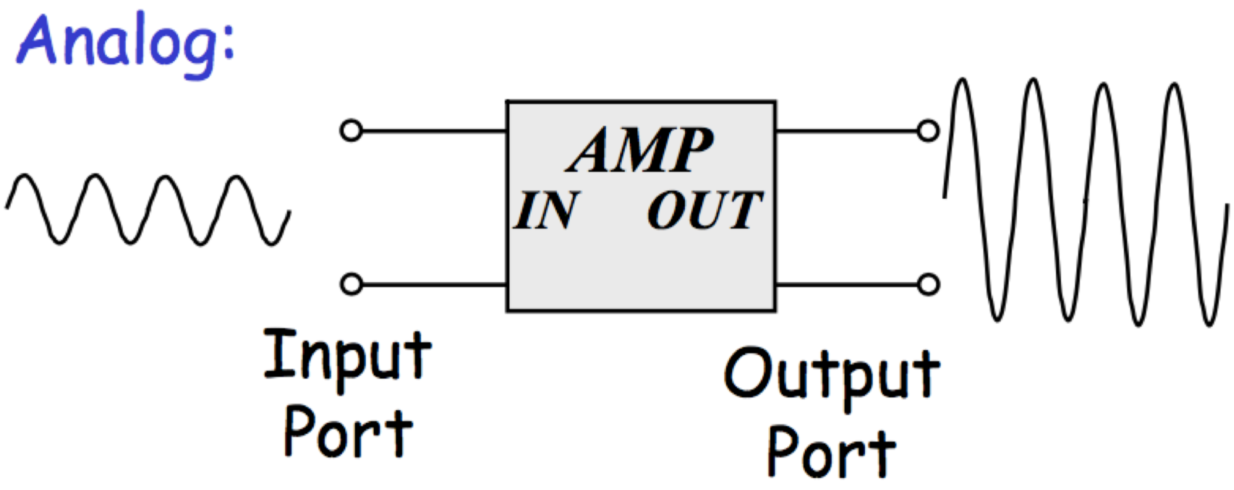
- MOSFET: metal-oxide-semiconductor field-effect transistor.
  - 3-terminal lumped element.
  - G Gate: control terminal.
  - S Source
  - D Drain





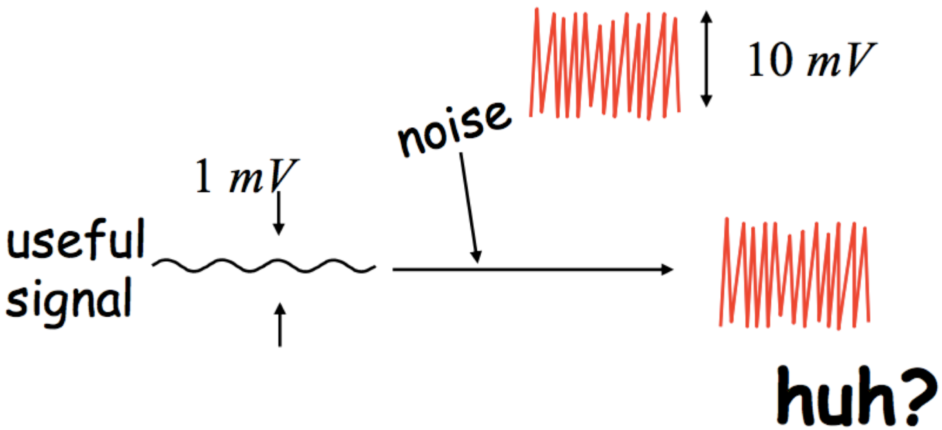
Why Amplify?

- Amplification is critical in both analog and digital processing.
  - The signal can be transmitted further.
  - Improve noise tolerance during communication.

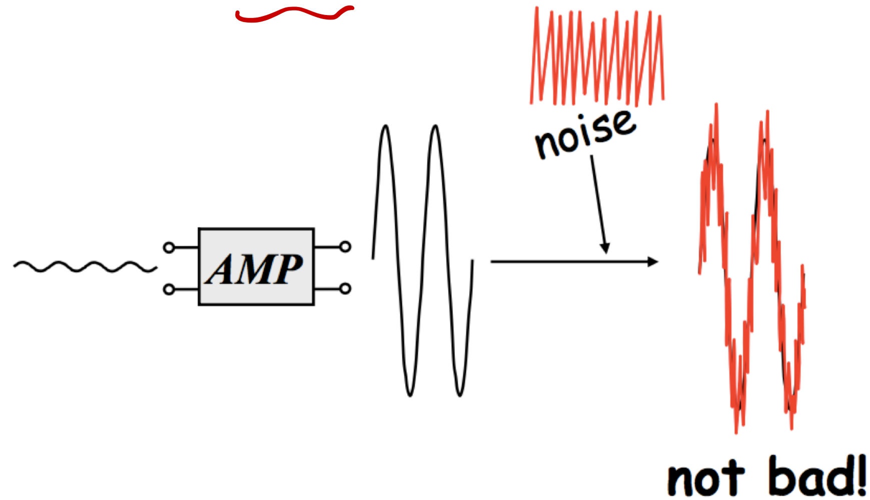


Why Amplify?

No amplification



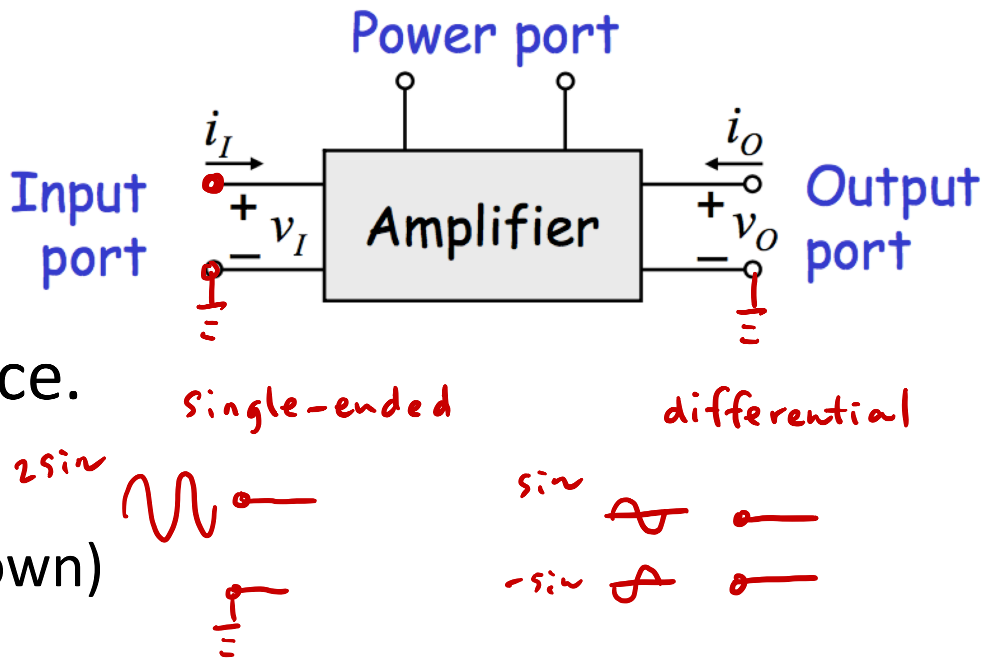
Try amplification



Signal-to-noise ratio (SNR)

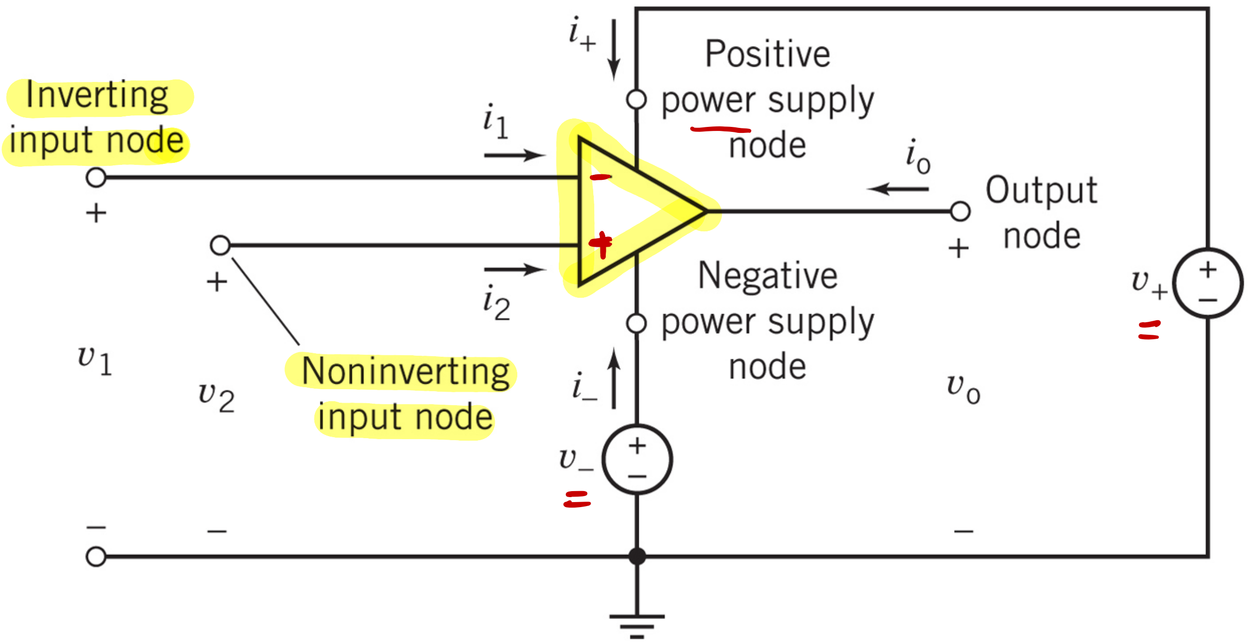
$$= \frac{P_{sig}}{P_{noise}}$$

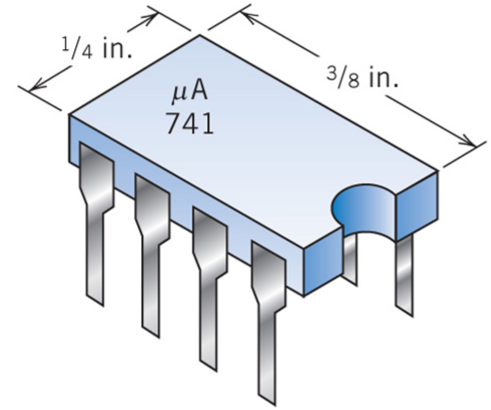
Amplifier



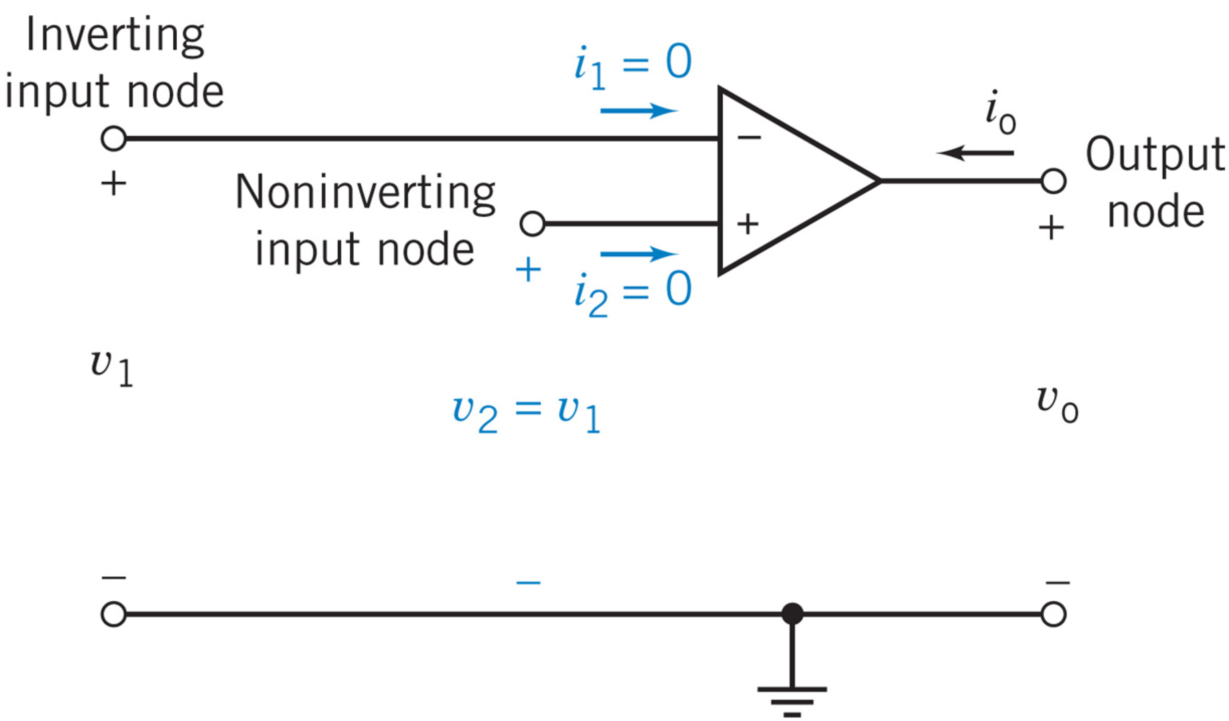
- Amplifier is a 3-port device.
  - Input port
  - Power port (often not shown)
  - Output port
  - Input port and output port usually share a common ground.

Operational Amplifier





Ideal Operational Amplifier



3.
- Linear amplifier

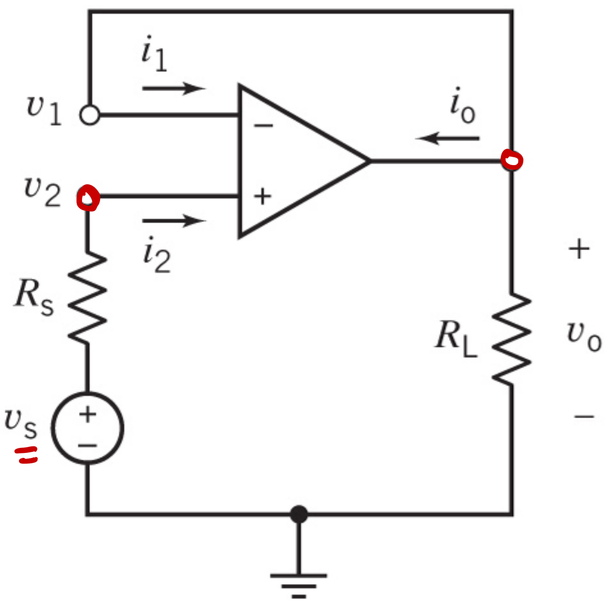
constant gain

1. $i_1 = 0$, $i_2 = 0$ (note that $i_o \neq 0$)

2. $v_2 = v_1$

Example 6.3-1

- Determine how the output v_o related to the input voltage v_s.



$v_1 = v_2$

$v_1 = v_o$

$i_1 = i_2 = 0$

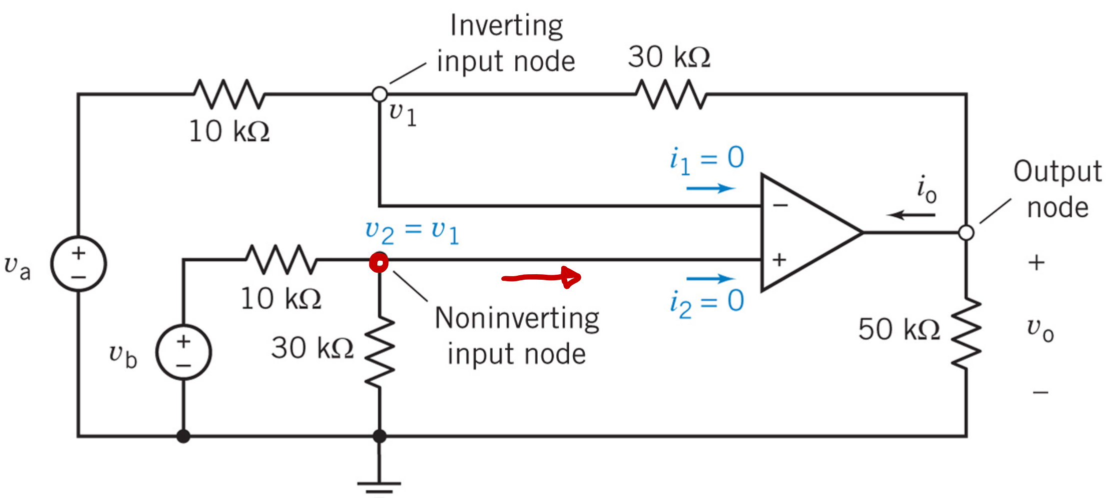
$v_s = v_2 = v_o$

Gain

$A_v = \frac{v_o}{v_s} = 1$

Example 6.4-1

- Determine v_o in terms of v_a and v_b.



① KCL @ noninverting node:

$$\begin{cases} \frac{v_2}{30K} + \frac{v_2 - v_b}{10K} + i_2 = 0 \\ i_2 = 0 \end{cases}$$

$$\Rightarrow v_2 = 0.75 v_b$$

② KCL @ inverting node:

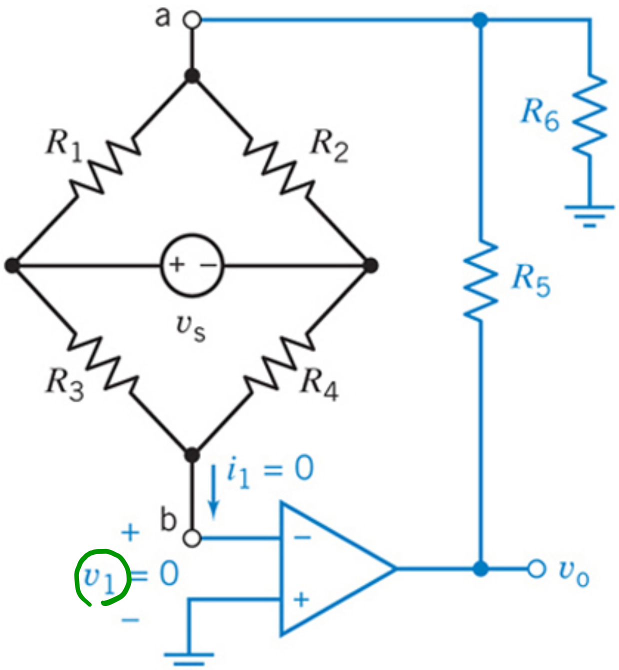
$$\begin{cases} \frac{v_1 - v_a}{10K} + \frac{v_1 - v_o}{30K} + i_1 = 0 \\ i_1 = 0 \\ v_1 = v_2 = 0.75 v_b \end{cases}$$

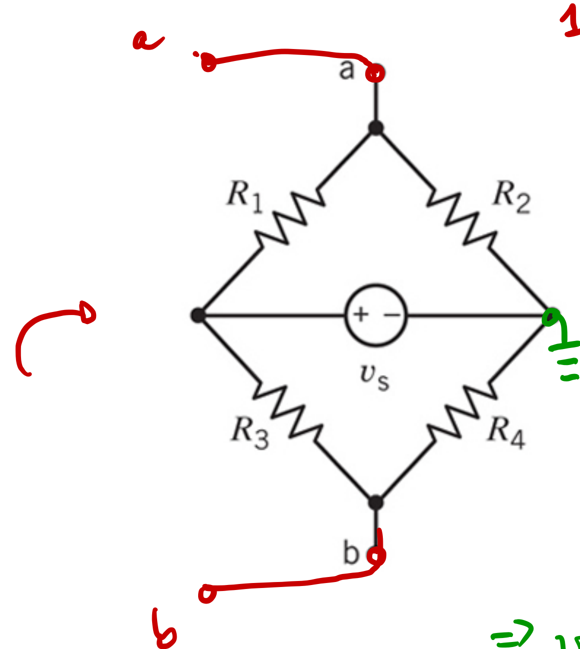
$$\Rightarrow v_o = 3(v_b - v_a)$$

$$\text{Gain} = \frac{v_o}{v_b - v_a} = 3 \quad V/V$$

Example 6.4-2

Find v_o.





1) Find the Thevenin's

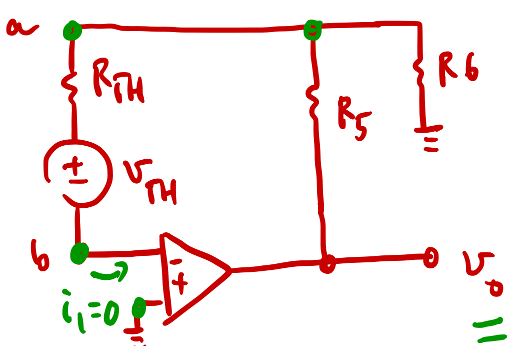
$R_{TH} = (R_1 \| R_2) + (R_3 \| R_4)$

$v_{TH} = v_a - v_b$

KCL @ a: $\frac{v_a - v_s}{R_1} + \frac{v_a}{R_2} = 0$

KCL @ b: $\frac{v_b - v_s}{R_3} + \frac{v_b}{R_4} = 0$

$\Rightarrow v_{TH} = v_a - v_b = \left(\frac{R_2}{R_1+R_2} - \frac{R_4}{R_3+R_4}\right) v_s$



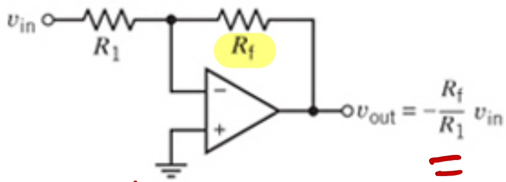
$v_1 = 0, \ i_1 = 0$

$v_a = v_{TH}$

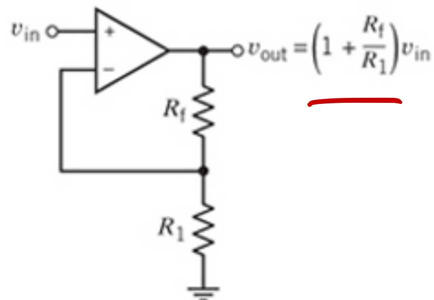
KCL@a: $\frac{v_a - v_o}{R_5} + \frac{v_a}{R_6} = 0 \Rightarrow v_o = \left(1 + \frac{R_5}{R_6}\right) v_{TH}$

Operational Amplifier Applications (1/2)

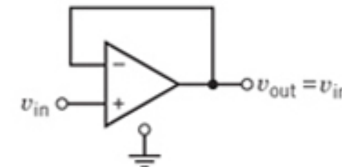
回授
Feedback



(a) Inverting amplifier



(b) Noninverting amplifier



(c) Voltage follower (buffer amplifier)

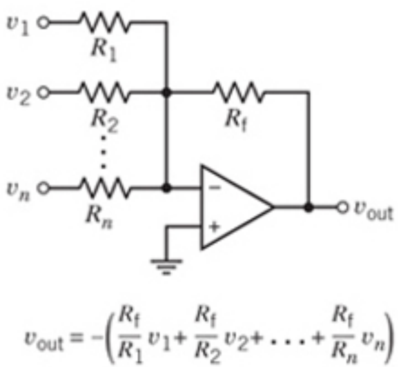
$\frac{V_{out}}{V_{in}} = 1$ V/V

$= 20\log 1$

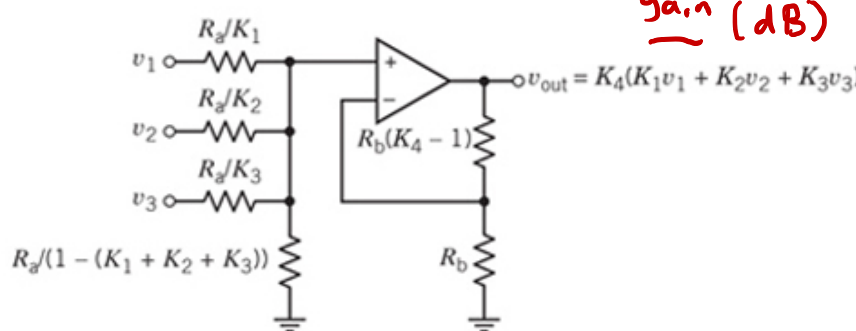
$= 0$ dB

A = 1

gain (dB)



(d) Summing amplifier



(e) Noninverting summing amplifier

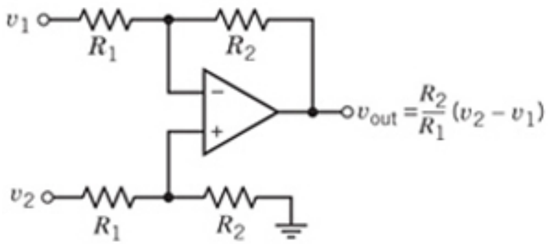
Voltage Gain $= \frac{V_{out}}{V_{in}}$ V/V

Current gain $= \frac{i_{out}}{i_{in}}$ A/A

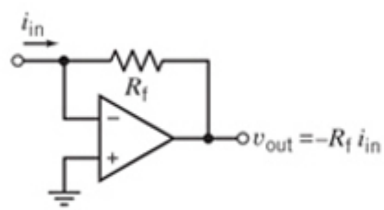
Power gain $= \frac{P_{out}}{P_{in}}$ W/W

Operational Amplifier Applications (2/2)

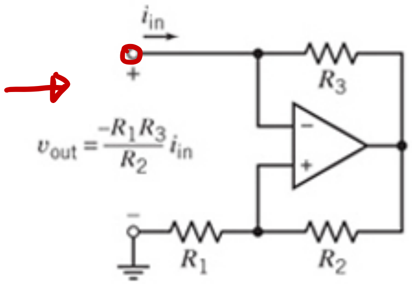
$\frac{v_{out}}{i_{in}} = -R_f$ V/A



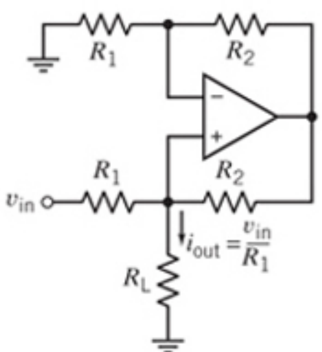
(*f*) Difference amplifier



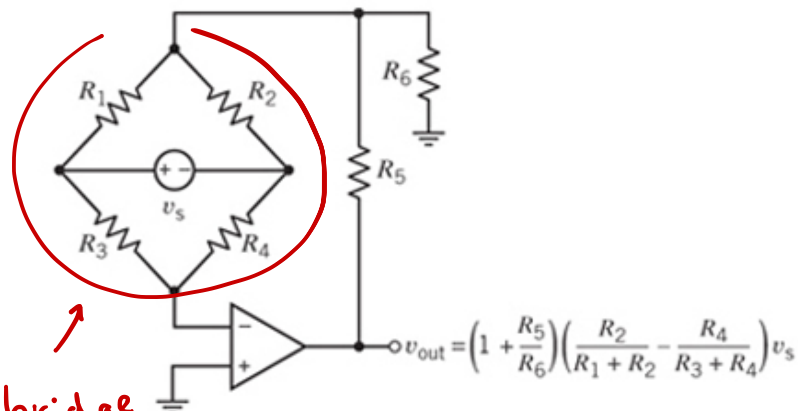
(*g*) Current-to-voltage converter



(*h*) Negative resistance convertor



(*i*) Voltage-controlled current source (VCCS)

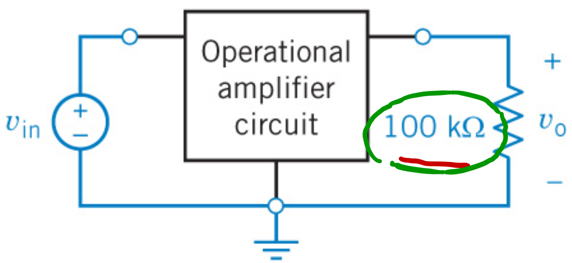


bridge circuit

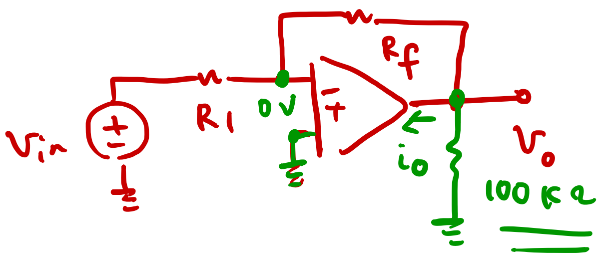
(*j*) Bridge amplifier

Example 6.5-2 Amplifier Design

- Design the operational amplifier such that $v_o = K^*v_{in}$. Cases: $K < 0$, $K > 1$, $K = 1$, and $0 < K < 1$.



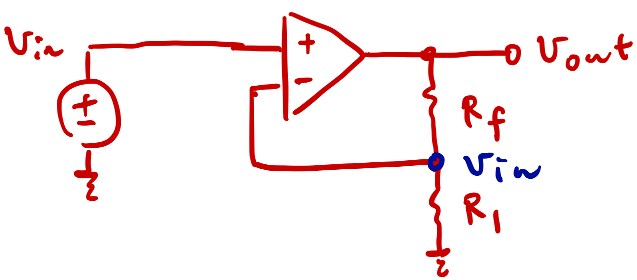
Case 1. $K<0$ Inverting amp



$$\frac{v_{in}-0}{R_1} = \frac{0-v_o}{R_f} \Rightarrow \frac{v_o}{v_{in}} = K = \frac{-R_f}{R_1}$$

$$i_o = \frac{-v_o}{R_f} - \frac{v_o}{100k}$$

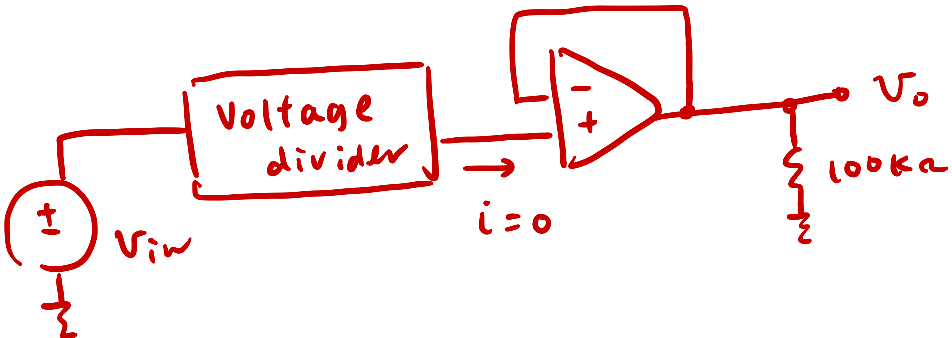
Case 2. $K>1$, noninverting amp.

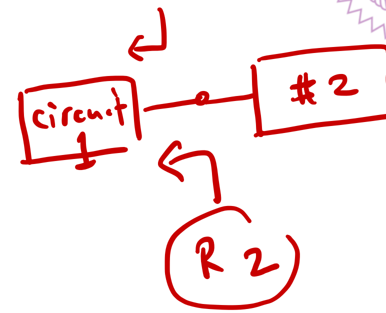


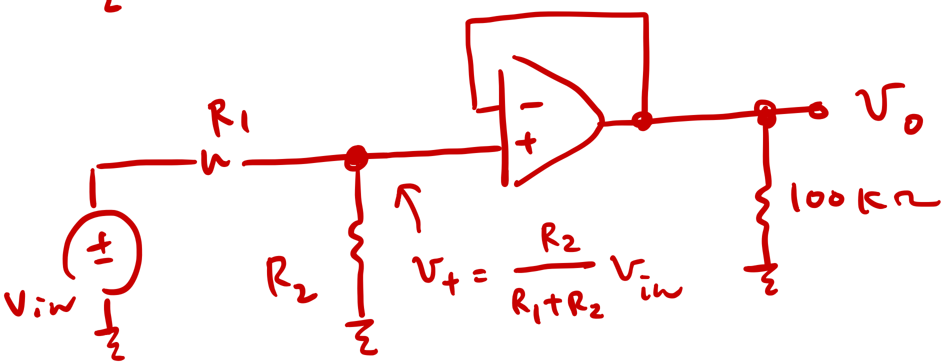
KCL:
$$\frac{v_{in}}{R_1} = \frac{v_o - v_{in}}{R_f} \Rightarrow \frac{v_o}{v_{in}} = 1 + \frac{R_f}{R_1}$$

Case 3: $K=1$, Set $R_f = 0$ in case 2. (or use voltage follower)

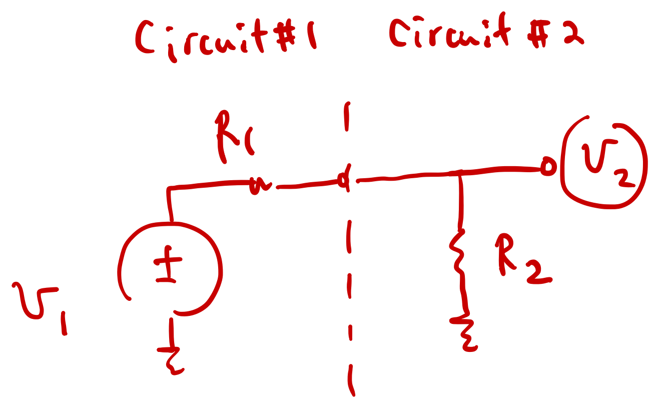
Case 4. $0 < k < 1$.







$$V_o = \frac{R_2}{R_1+R_2} V_{in}$$



$$V_2 = \frac{R_2}{R_1+R_2} V_1 \approx V_1$$

$R_2 \gg R_1$