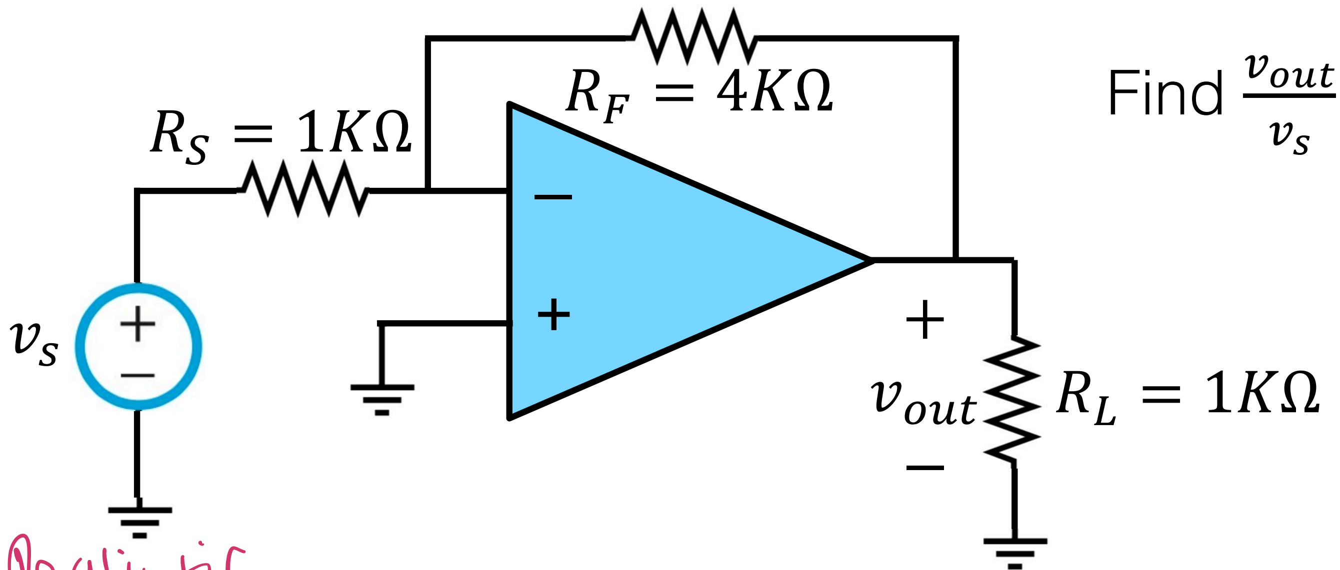
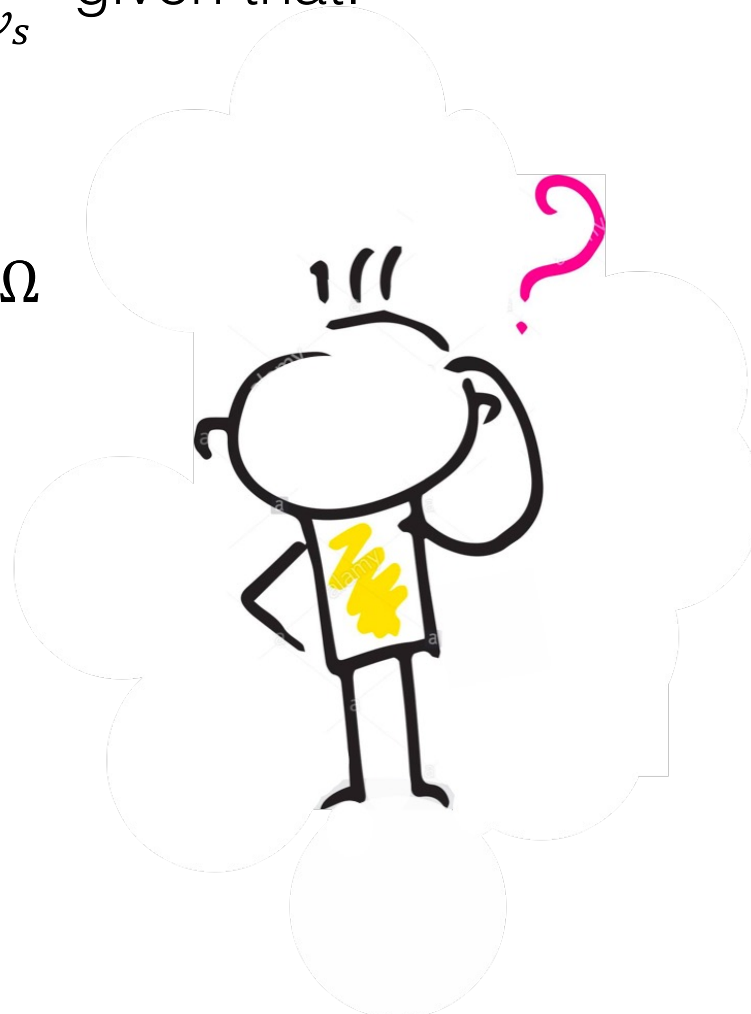
Last Class…



Find $\frac{v_{out}}{v_s}$ given that:

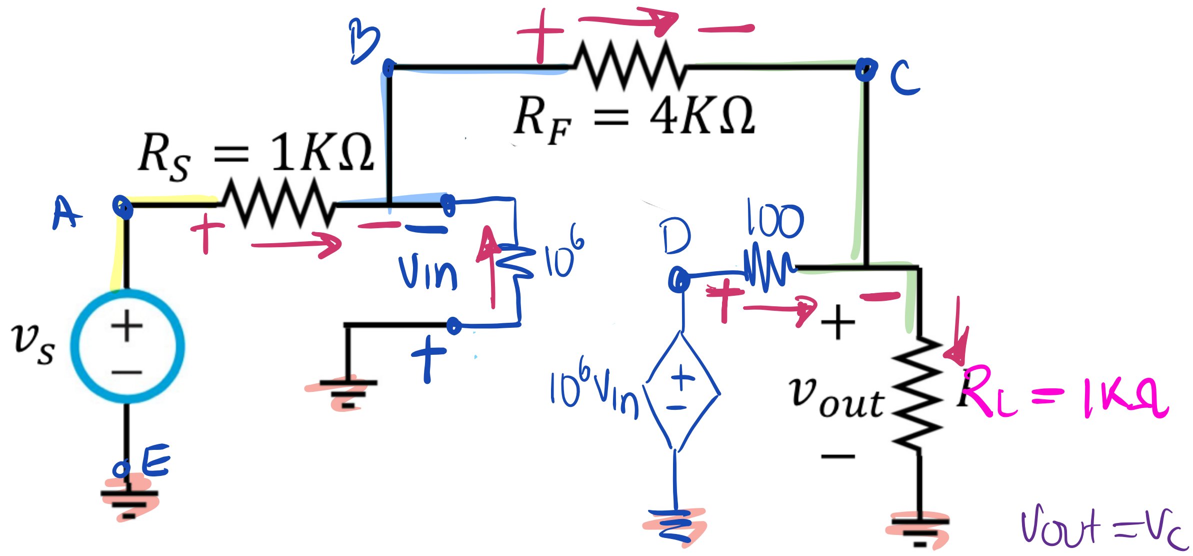


Realistic

$R_{in} = 10^6\Omega$

$R_{out} = 100\Omega$

$A_{vol} = 10^6$



Node Voltage Analysis 5 nodes

$V_E = 0V$ $\qquad V_D = 10^6 V_{in} = 10^6(\cancel{V_E}^{0} - V_B) = -10^6 V_B$

$V_A = V_S$

KCL @ B:

$i_{RS} + i_{in} = i_{RF}$

$$\frac{V_S - V_B}{10^3} + \frac{-V_B}{10^6} = \frac{V_B - V_C}{4000} \quad \times 10^6$$

$$10^3 V_S - 10^3 V_B - V_B = 250 V_B - 250 V_C$$

$$10^3 V_S + 250 V_C = 1251 V_B$$

$$\frac{10^3 V_S + 250 V_C}{1251} = V_B \quad (1)$$

KCL @ C

$i_{RF} + i_{out} = i_L$

$$\frac{V_B - V_C}{4\times10^3} + \frac{-10^6 V_B - V_C}{100} = \frac{V_C}{10^3} \quad 4\times10^3$$

$$V_B - V_C - 40\times10^6 V_B - 40 V_C = 4 V_C$$

$$(1-40\times10^{6})V_B = 45V_C$$

$$V_B = \frac{45}{1-40\times10^{6}} V_C \quad 2$$

$$V_B = -1.125\times10^{-6} V_C$$

$1 = 2$

$$\frac{10^3 V_S + 250V_C}{1251} = -1.125\times10^{-6} V_C$$

$$10^3 V_S + 250 V_C = -1.4\times10^{-3} V_C$$

$$10^3 V_S = -250.0014 V_C$$

$$V_C = \frac{10^3}{-250.0014} V_S$$

$$V_C = -3.999 V_S$$

$$\frac{V_C}{V_S} = -3.999$$

THE OHIO STATE UNIVERSITY

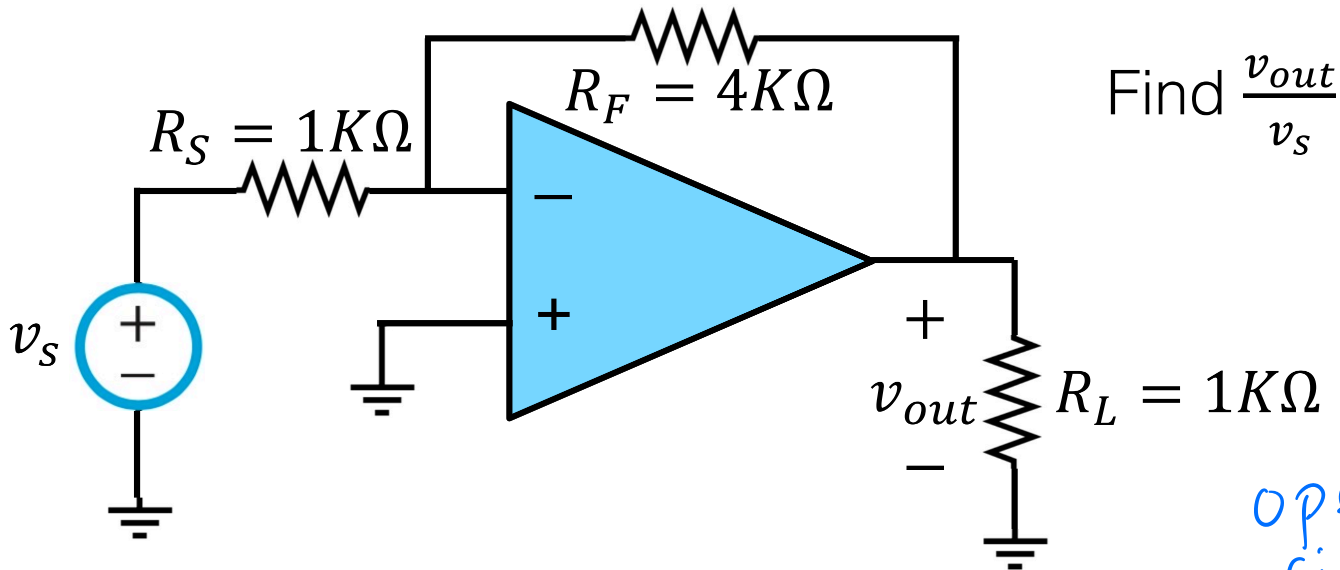
COLLEGE OF ENGINEERING

Op-amp models

This Lecture…

- Learning Objectives:
  - Analyze a circuit using the behavioral and ideal model of the op-amp.
  - Identify the voltage gain of a non-inverting and an inverting amplifier.

Example



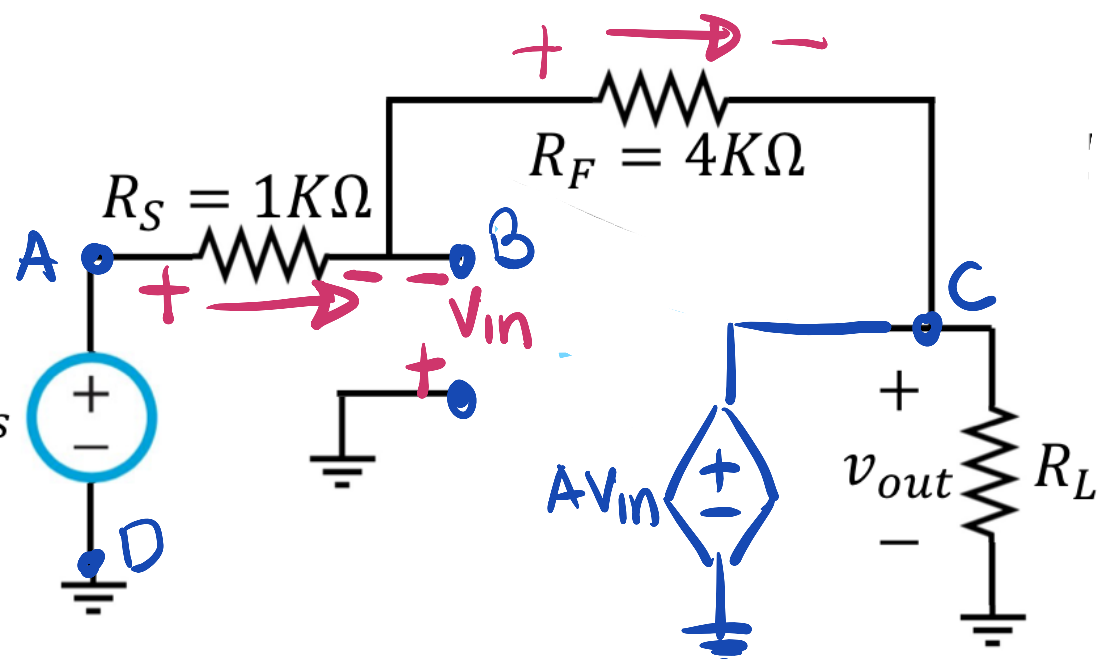
Find $\frac{v_{out}}{v_s}$ given that: ideal values

$R_{in} = \infty\Omega$ open circuit

$R_{out} = 0\Omega$ short circuit

$A_{vol} = \infty$

Behavioral Model.



Node Voltage Analysis (4 nodes)

$V_D = 0V$

$V_A = V_S$

$V_C = AV_{in} = A(\cancel{V_D}^{0} - V_B)$

$V_C = -AV_B$ (1)

KCL @ B:

$i_{R_S} = i_{R_F}$

$$\frac{V_S - V_B}{R_S} = \frac{V_B - V_C}{R_F}$$

$$R_F V_S - R_F V_B = R_S V_B - R_S V_C$$

$$R_F V_S + R_S V_C = (R_S + R_F) V_B$$

$$V_B = \frac{R_F V_S + R_S V_C}{R_S + R_F} \quad (2)$$

(2) in (1)

$$V_C = -A \cdot \frac{R_F V_S + R_S V_C}{R_S + R_F}$$

$$(R_S + R_F) V_C = -A R_F V_S - A R_S V_C$$

$$(R_S + R_F + A R_S) V_C = -A R_F V_S$$

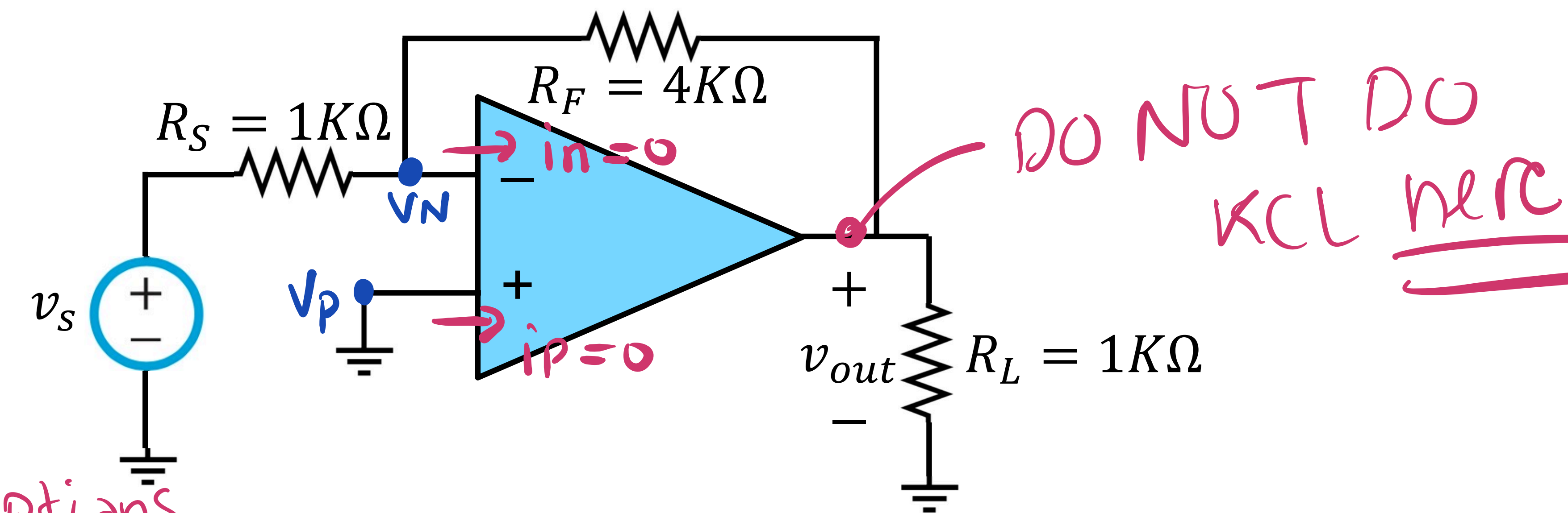
$$\frac{V_C}{V_S} = \frac{-A R_F}{R_S + R_F + A R_S} \qquad A \to \infty$$

$$\frac{V_C}{V_S} = \lim_{A \to \infty} \frac{-A R_F}{R_S + R_F + A R_S}$$

$$\frac{V_C}{V_S} = \frac{-R_F}{R_S} = -\frac{4000}{1000} = -4$$

This is called an inverting amplifier

Ideal Model



Assumptions

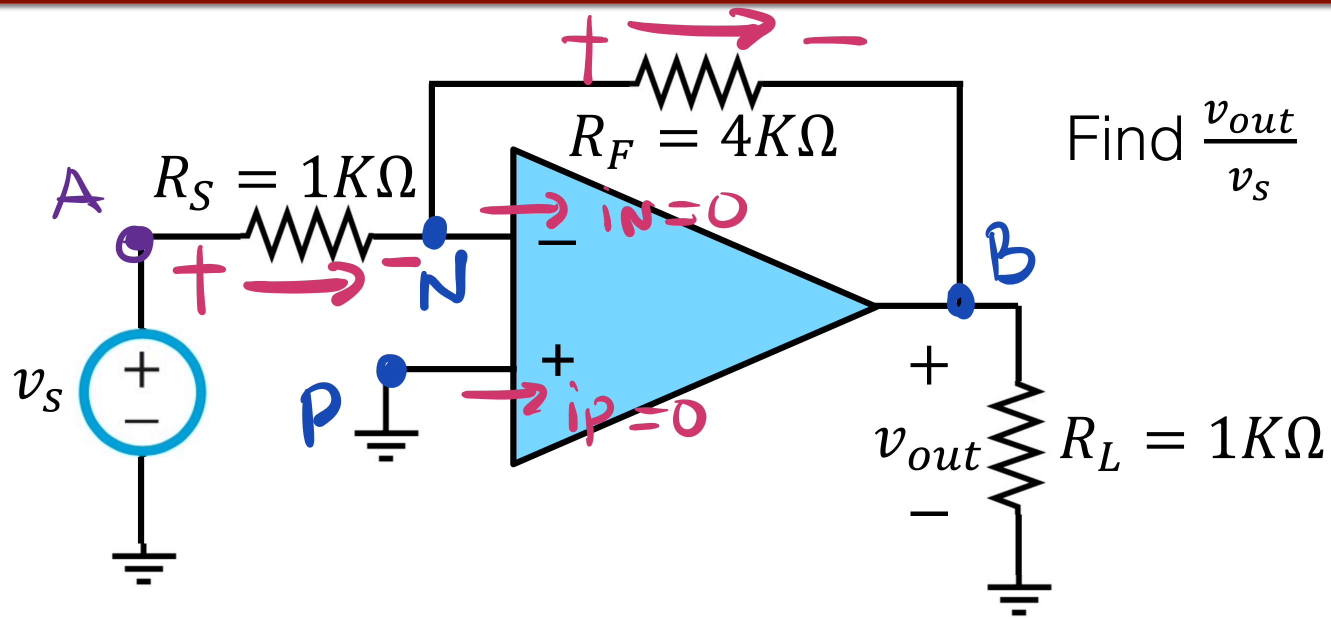
1. $i_p = i_n = 0A$

2. $v_p = \mathrm{v_n}$ (voltage is the same, different node).

- Use nodal analysis as before, but with using the conditions stated above.

Do not apply KCL at op-amp output unless calculating $\mathrm{i_0}$.

Inverting Amplifier



Find $\frac{v_{out}}{v_s}$

Ideal Model

1. $i_P = i_N = 0$
2. $V_P = V_N = 0$

Only for this example.

Node Voltage Analysis. 4 nodes.

$V_P = 0$

$V_A = V_S$

DO NOT DO KCL @ B based on ideal model!

KCL @ N:

$i_{R_S} = i_{R_F} + 0$

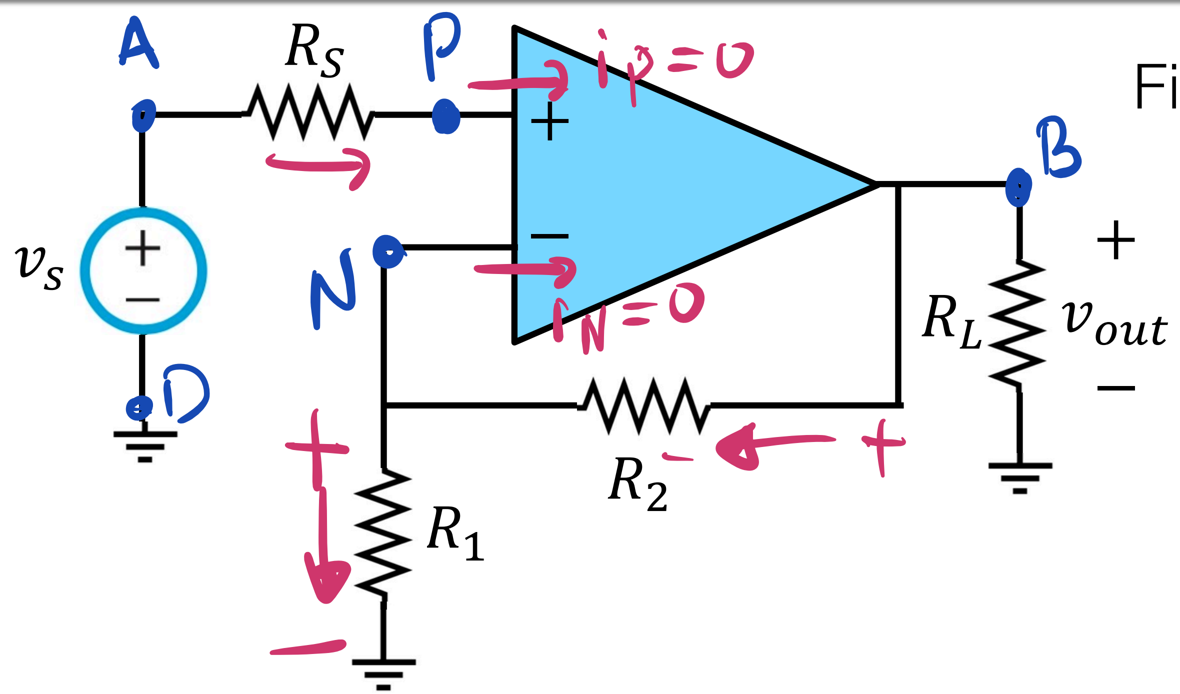
$$\frac{V_A - \cancel{V_N}^{0}}{R_S} = \frac{\cancel{V_N}^{0} - V_B}{R_F}$$

ideal model $V_N = V_P = 0$

$$\frac{V_S}{R_S} = \frac{-V_B}{R_F}$$

$$\frac{V_B}{V_S} = -\frac{R_F}{R_S}$$

Non-Inverting Amplifier



Find $\frac{v_{out}}{v_s}$

ideal model.

1. $i_p = i_N = 0$
2. $V_P = V_N$

Node Voltage Analysis:

$V_D = 0$

$V_A = V_S$

DO NOT DO KCL @ B

KCL @ P:

$i_{R_S} = 0$

KCL @ N:

$i_{R_2} = i_{R_1} + 0$

$$\frac{V_S - V_P}{R_S} = 0$$

$$V_S - V_P = 0$$

$$V_S = V_P = \underline{\underline{V_N}}$$

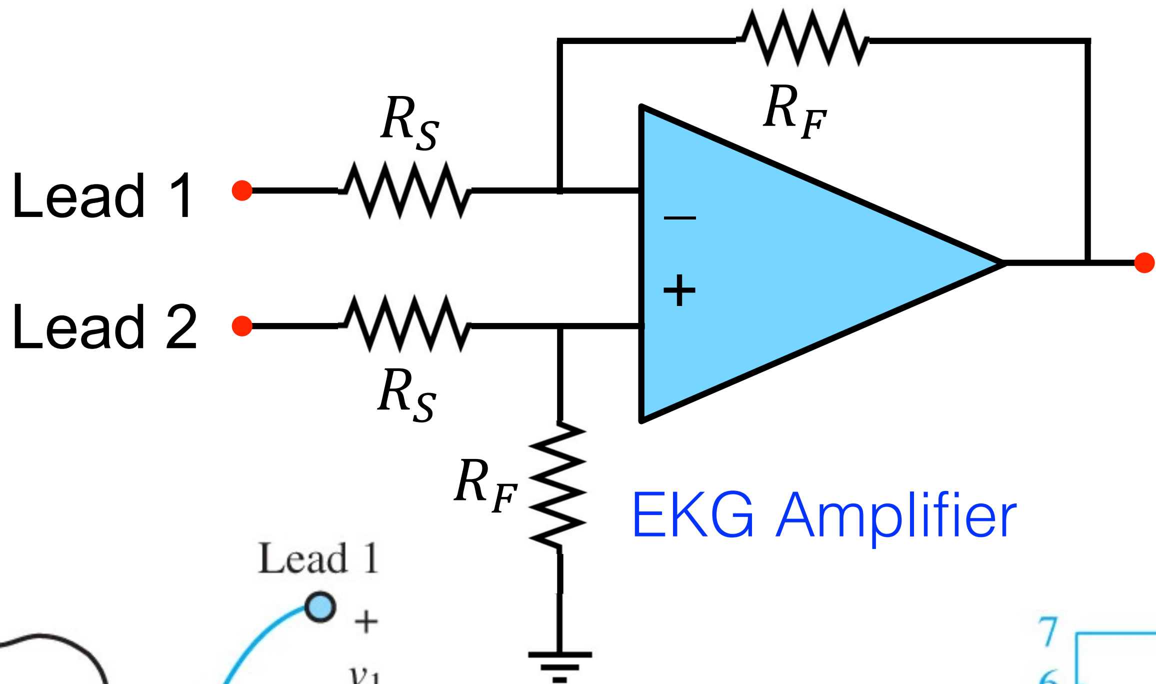
$$\frac{V_B - V_N}{R_2} = \frac{V_N}{R_1}$$

$$R_1 V_B - R_1 V_S = R_2 V_S$$

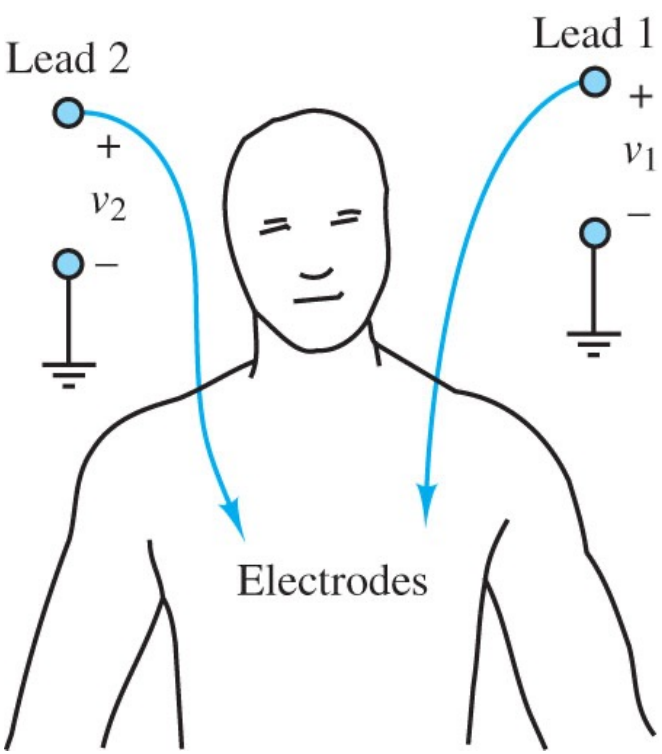
$$R_1 V_B = (R_2 + R_1) V_S$$

$$\boxed{\frac{V_B}{V_S} = \frac{R_1 + R_2}{R_1}}$$

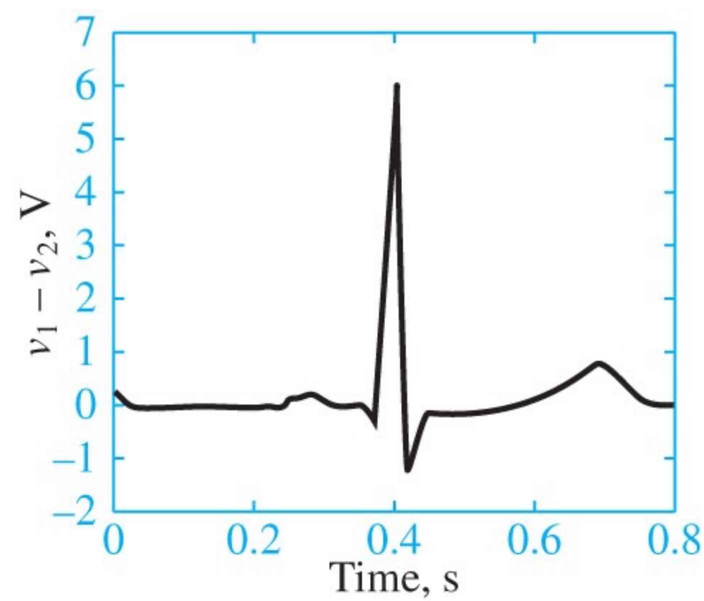
Differential Amplifier



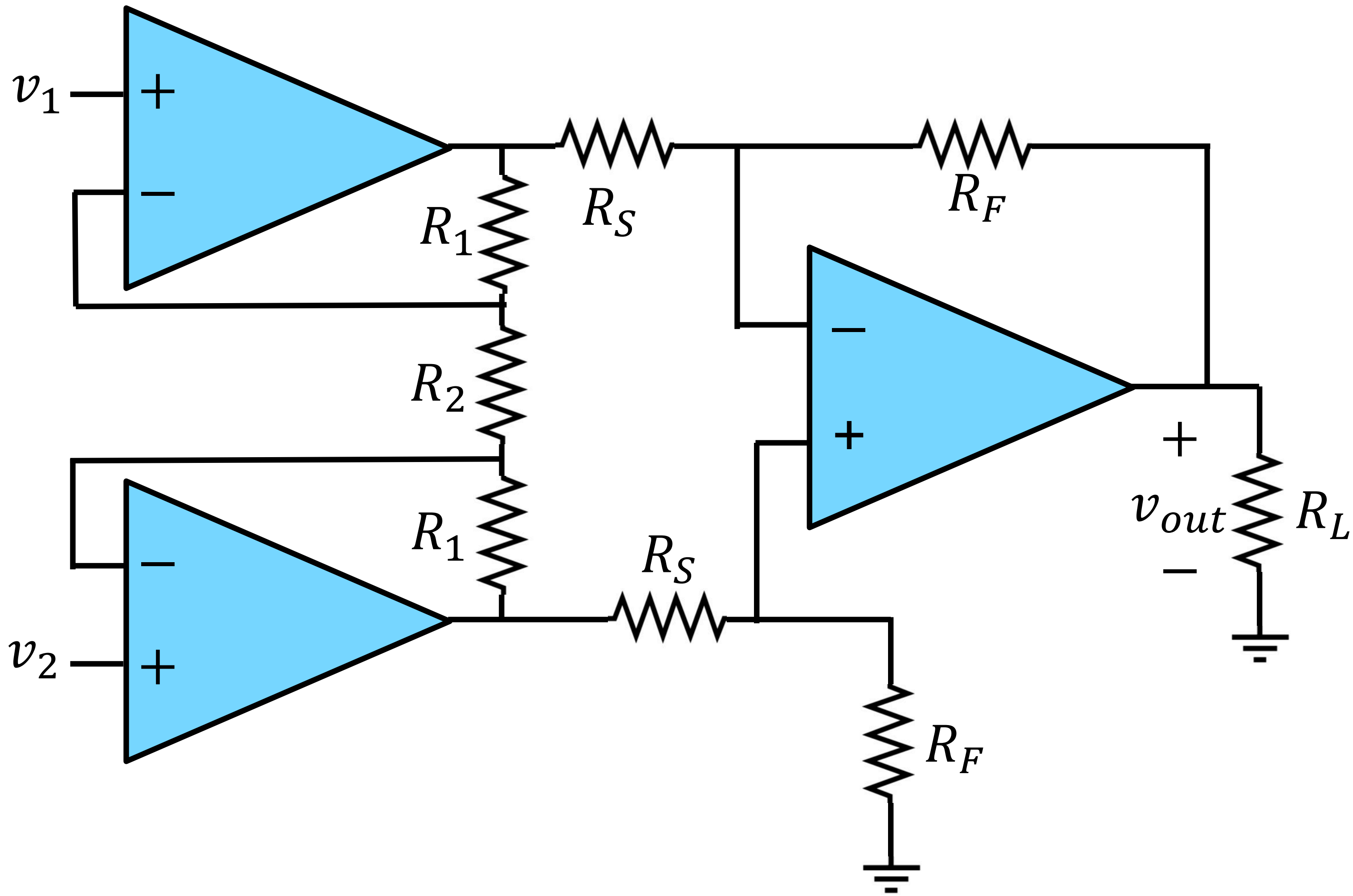
EKG Amplifier



Better version:
Instrumentation
Amplifier



Instrumentation Amplifier



Differential Amplifier