Lecture #11

ANNOUNCEMENTS

- Homework Assignment #4 will be posted today
- **Midterm #1: Monday Sept. 29th** (11:10AM-12:00PM)
  - closed book; one page (8.5”x11”) of notes & calculator allowed
  - covers Chapters 1-5 in textbook (HW#1-4)
- Midterm Review Session: Friday 9/26 7-9PM, 277 Cory
- Extra office hours:
  - Steve: 9/26 from 12-2PM
  - Farhana: 9/27 from 1-3PM, 9/28 from 9-11AM
- Practice problems and old exam are posted online

OUTLINE

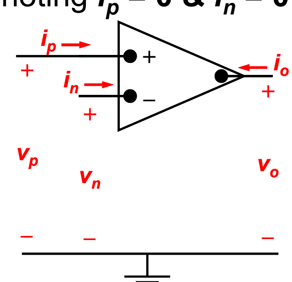
– Review: op amp circuit analysis

– The capacitor (Chapter 6.2 in text)

Review: Op Amp Circuit Analysis

Procedure:

1. Assume that the op amp is ideal
   a) Apply KCL at (+) and (–) terminals, noting $i_p = 0$ & $i_n = 0$
   b) Note that $v_n = v_p$
   c) Write an expression for v_o
2. Calculate v_o



3. Check: Is the op-amp operating in its linear region?

   If $V^- \leq v_o \leq V^+$, then the assumption is valid.

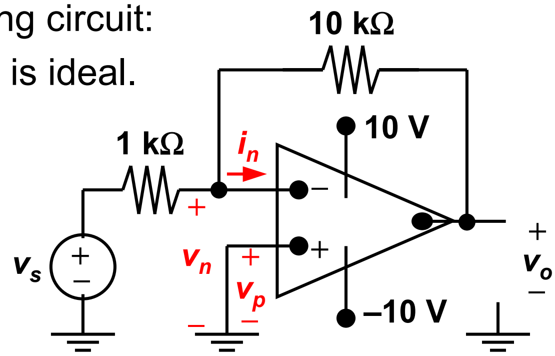
   If calculated $v_o > V^+$, then v_o is saturated at V^+

   If calculated $v_o < V^-$, then v_o is saturated at V^-

Op Amp Circuit Analysis Example

Consider the following circuit:

Assume the op amp is ideal.



a) Calculate v_o if v_s = 100 mV

b) What is the ***voltage gain*** v_o/v_s of this amplifier?

c) Specify the range of values of v_s for which the op amp operates in a linear mode

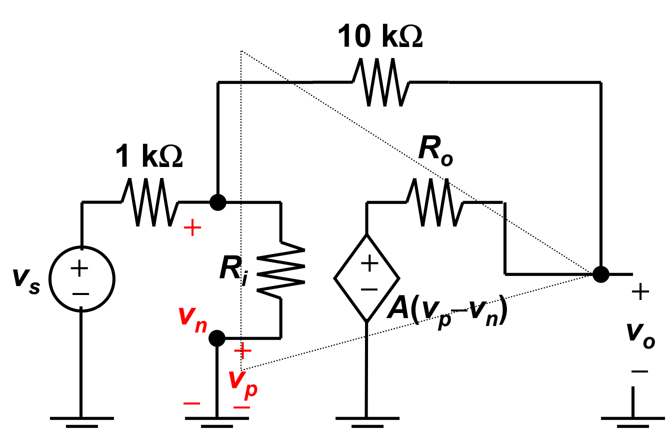
Op Amp Circuit Analysis Example cont'd.

What if the op amp is not ideal?

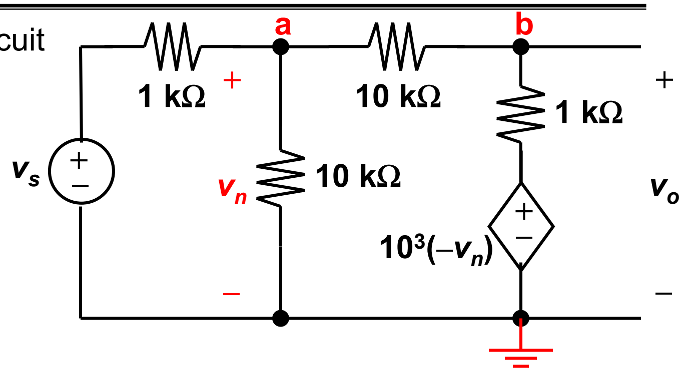
R_i = 10 kΩ

R_o = 1 kΩ

$A = 10^3$



Re-draw the circuit & analyze:

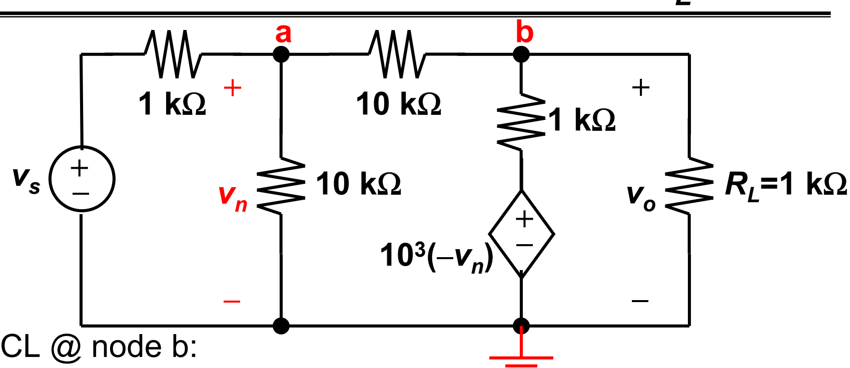


KCL @ node a:

KCL @ node b:

$$-\frac{v_o}{v_s} \cong 9.87 < 10$$

Effect of Load Resistance R_L



KCL @ node b:

$$-\frac{v_o}{v_s} \cong 9.75 < 9.87$$

- **For an ideal op amp (R_o = 0 Ω), v_o does not depend on the "load".** However, for a realistic op amp, it does.

The Capacitor

Two conductors (a,b) separated by an insulator:

difference in potential = V_{ab}

=> equal & opposite charge Q on conductors

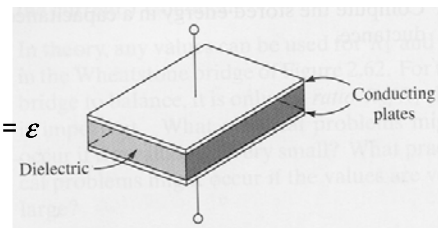
$$Q = CV_{ab}$$ (stored charge in terms of voltage)

where C is the **capacitance** of the structure,

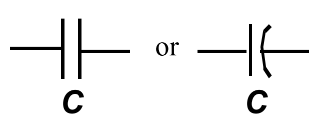
➢ positive (+) charge is on the conductor at higher potential

Parallel-plate capacitor:
- area of the plates = A
- separation between plates = d
- ***dielectric permittivity*** of insulator = ε

=> capacitance $$C = \frac{A\varepsilon}{d}$$



Symbol:

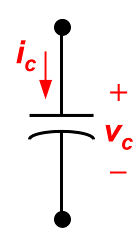


Units: **Farads (Coulombs/Volt)**

(typical range of values: 1 pF to 1 μF)

Current-Voltage relationship:

$$i_c = \frac{dQ}{dt} = C\frac{dv_c}{dt} + v_c\frac{dC}{dt}$$



Note: v_c **must be a continuous function of time**

Voltage in Terms of Current

$$Q(t) = \int_0^t i_c(t)dt + Q(0)$$

$$v_c(t) = \frac{1}{C}\int_0^t i_c(t)dt + \frac{Q(0)}{C} = \frac{1}{C}\int_0^t i_c(t)dt + v_c(0)$$

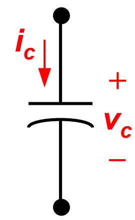
Stored Energy

You might think the energy stored on a capacitor is ***QV***, which has the dimension of Joules. But during charging, the average voltage across the capacitor was only half the final value of ***V***.

Thus, energy is $\frac{1}{2}QV = \boxed{\frac{1}{2}CV^2}$.

<u>Example</u>: A 1 pF capacitance charged to 5 Volts has ½$(5V)^2$ (1pF) = 12.5 pJ

A more rigorous derivation



$$w = \int_{t=t_{Initial}}^{t=t_{Final}} v_c \cdot i_c \, dt = \int_{v=V_{Initial}}^{v=V_{Final}} v_c \frac{dQ}{dt} dt = \int_{v=V_{Initial}}^{v=V_{Final}} v_c \, dQ$$

$$w = \int_{v=V_{Initial}}^{v=V_{Final}} C v_c \, dv_c = \frac{1}{2} C V_{Final}{}^2 - \frac{1}{2} C V_{Initial}{}^2$$

Integrating Amplifier

$$v_o(t) = -\frac{1}{RC} \int_0^t v_{IN}(t) dt + v_C(0)$$