Lecture 10: Generalized Circuit Elements and Semiconductors

- Announcements:
  - HW#4 online soon and due next Friday
  - Lab#2 prelab due next week (week of 9/21)
  - Lab#1 experimental part due week of 9/28
  - Lab#2 experimental part due week of 10/5
  - This lecture at 12 noon rather than our usual 2-3 p.m., but it is being recorded and will be up on the course website
  - Next week will be inverted
    - Monday and Wednesday lecture will be at 9 a.m.
    - Will also need to miss Monday office hours, but can still do Wednesday office hours
    - I will update the zoom invites
    - Friday, 9/25 lecture will be the usual 2-3 p.m.
    - Again, all lectures are recorded, so those who cannot make the special times will miss nothing

- Lecture Topics:
  - Generalized Circuit Elements
  - Conductors
  - Insulators
  - Semiconductors
  - Doping

- Last Time:
  - Finishing up input bias currents
  - Now, continue with this …

- Many op amps require small currents into their input transistors that allow the transistors to function
- Currents are independent of $R_{in}$

\[
I_{B1} = I_{B2} + \frac{I_{os}}{2}, \quad I_{B2} = I_{B} - \frac{I_{os}}{2}
\]

Average of

\[
I_{B} = \frac{I_{B1} + I_{B2}}{2} \approx \text{input bias current}
\]

Typical: $100 \mu A$ for bipolar opamp

Difference or

\[
I_{os} = |I_{B1} - I_{B2}| \approx \text{input offset current}
\]

Typical: $10 \mu A$ for a bipolar opamp
**Example: Non-Inverting Amplifier**

\[ V_0 = V_{\text{in}} + I_{\text{in}} R_2 = I_{\text{B1}} R_2 \]

\[ = (I_{\text{B1}} + I_{\text{os}}) R_2 \]

**not zero!**

To reduce this effect: add resistor to the (+) input

\[ I_{\text{in}} R_1 \]

\[ -I_{\text{B1}} R_2 \]

\[ -I_{\text{os}} R_1 \]

\[ N_0 = -I_{\text{B1}} R_2 + R_2 (I_{\text{B1}} - I_{\text{os}} R_1) \]

\[ = -I_{\text{B1}} R_2 + \frac{I_{\text{os}} R_2}{2} \]

\[ = -I_{\text{B1}} R_2 + \frac{I_{\text{os}} R_2}{2} \]

\[ \text{What value of } R_3 \text{ makes } N_0 \rightarrow 0? \]

(i.e., "eliminates or suppresses the effect of input bias current?")

Case: \( I_{\text{os}} = 0 \) (i.e., \( I_{\text{B1}} = I_{\text{B2}} = I_{\text{B}} \))

\[ N_0 = I_{\text{B}} (R_2 - R_3 (1 + \frac{R_2}{R_1})) \]

\[ \text{For } N_0 = 0 \rightarrow R_2 R_3 (1 + \frac{R_2}{R_1}) \rightarrow R_3 = \frac{R_2}{1 + \frac{R_2}{R_1}} = \frac{1}{1 + \frac{R_2}{R_1}} = R_1 \text{ for } R_2 \]

\[ \because R_3 = R_1 \text{ still helps even if } I_{\text{os}} \neq 0 \]

\[ N_0 = I_{\text{B}} R_2 \]

\[ \text{100mA} \]

\[ \text{100mA} \]
**Generalized Circuit Elements**

**Resistor**

- **Linear Resistor**
  - \[ V = IR \]
  - \[ I = \frac{V}{R} \]

- **Nonlinear Resistor**
  - \[ I = f(V) \]

**Capacitor**

- **Linear Capacitor**
  - \[ q = CV \]
  - \[ q = \frac{1}{C} \]

- **Nonlinear Capacitor**
  - \[ q = f(V) \]

**Inductor**

- **Linear Inductor**
  - \[ v = L \frac{di}{dt} \]

- **Nonlinear Inductor**
  - \[ v = f(i) \]

**Diode** (example of nonlinear element(s))

- Several models, all of which represent nonlinear elements (e.g., nonlinear capacitors)

  **A. Ideal**
  - Behavior as much curved as determined by k_V and k_I

  **B. Constant Voltage**
  - \[ V = \text{constant} \]
  - Diode "on" voltage \( V_{on} \) usu. \( 0.5 \) to \( 0.7 \) V
• **Semiconductors:**
  - To better understand the physical operation of diodes (and later, transistors), need to understand semiconductors
  - Best to describe them in the context of other materials, like conductors and insulators

• **Materials:**
  - Made up of atoms
  - In solids, the atoms often bond together in a regular lattice
  - The atoms in the lattice happiest in a lowest energy state, i.e., with filled orbitals
  - Go to periodic table supplement

1. **Conductors:**
   - Close-packed atoms in a cloud of electrons
   - Ex. Na (sodium) - a metal
     - Alkali metal w/ one valence e-
     - Orbital below valence shell already filled, so e- can leave and be shared by all atoms in the solid