Outline

• More on Components
  – Resistors, Capacitors, Inductors: ideal vs. real
  – First and second order systems
  – Diodes

• Amplifiers
• Four component laws
  - \( v = iR \)
  - \( i = C \frac{dv}{dt} \)
  - \( v = L \frac{di}{dt} \)
  - \( P = iv = i^2R = \frac{V^2}{R} \)

• Two network laws
  - **KCL - Kirchoff’s Current Law**
    \[
    \sum i_n = 0
    \]
    (In/out of node)
    \[
    i_1 + i_2 + i_3 + i_4 = 0
    \]
  - **KVL - Kirchoff’s Voltage Law**
    \[
    \sum v_n = 0
    \]
    (Around a loop)
    \[
    V_1 + V_2 = V_3 + V_4
    \]
Ideal vs. Real

- **Ideal**
  - Wire
    - $R=0$, $C=0$, $L=0$
  - Resistor
    - $C=0$, $L=0$
  - Capacitor
    - $R=0$, $L=0$
  - Inductor
    - $R=0$, $C=0$

- **Real**
  - $R \neq 0$, $C \neq 0$, $L \approx 0$
  - $C \approx 0$, $L \approx 0$
  - $R \neq 0$, $L \approx 0$
  - $R \neq 0$, $C \approx 0$
Review of Resistors

- **Serial**

\[
\frac{1}{R_1} \frac{1}{R_2} \frac{1}{R_3} = \frac{1}{R_4}
\]

\[R_1 + R_2 + R_3 = R_4\]

- **Parallel**

- **Voltage divider**

\[V_R = V_{\text{Bat}} \frac{R_2}{R_1 + R_2}\]

- **For two resistors**

\[R_4 = \frac{R_1 R_2}{R_1 + R_2}\]
First Order Systems

- Relation of different inputs

\[
V_{\text{out}} = \frac{q_0}{C} e^{-\frac{t}{RC}}
\]

\[
V_{\text{out}} = I_0 R \left( 1 - e^{-\frac{t}{RC}} \right)
\]

Or

\[
V_{\text{out}} = \frac{I_0 R}{T} \left( t + RC \left( e^{-\frac{t}{RC}} - 1 \right) \right)
\]

\[
V_{\text{out}} = I_0 R \left( 1 - e^{-\frac{t}{RC}} \right) e^{\frac{(t-\tau)}{RC}}
\]

\[
V_{\text{out}} = \frac{I_0 R}{\sqrt{1 + (\omega RC)^2}} \sin(\omega t - \tan^{-1}(\omega RC))
\]
Second Order Systems

- Circuits that combine capacitors and inductors are higher order

\[
V_{out} = V_0 \left(1 - \cos(\omega_0 t)\right)
\]

\[
\omega_0 = \frac{t}{\sqrt{LC}}
\]

\[
V_{out} \approx V_0 \left(1 - \cos(\omega_0 t) \cdot e^{-\xi t}\right)
\]

\[
\omega_0 = \frac{t}{\sqrt{LC}}, \xi = \frac{R}{2L}
\]

Resistor adds dampening
Diodes

- **Ideal**
  - Does not allow current flow when voltage is reversed
    - Stops all current
  - Allows infinite current flow when positive voltage is applied

- **Real**
  - Voltage drop: minimum voltage before current can go through
  - Current leak: small amount of current goes through in reverse
  - Maximum/Minimum voltage in both forward and reverse
  - Maximum current in forward
Introduction to Operational Amplifiers

- Utilize an “external” power source to amplify/modify an input signal
  - Allow the use of feedback to closely track the signal

\[ i^+ = 0 \]
\[ i^- = 0 \]
\[ v^+ \]
\[ v^- \]
\[ v_{\text{pwr}}^+ \]
\[ v_{\text{pwr}}^- \]
\[ v_{\text{out}} \]

- Adjusts the output voltage \( V_{\text{out}} \) to try make \( v^+ \) and \( v^- \) be the same
  - The user adds elements (wires, resistors, capacitors, etc) which create current loops between the output and inputs to create feedback loops