Outline

• Voltage and Current
• 4 basic “component laws”
• 2 basic “network laws”
• Resistors
• Capacitors
• Inductors
Any electronic project depends at the most basic level on:

- **Voltage**
  - The electric potential difference between two points
  - Like “potential energy” of physics

- **Current**
  - The flow of electricity through components and wires
  - Like “kinetic energy” of physics

There are many ways people think about current and voltage, most involve a fluid like water, here is an example:

Voltage is the height between a lake and the “ground”

A small slope means slow speed means high resistance

A large slope means high speed means little resistance

Current is the “speed” at which a river flows down to ground

Current always flows from a higher voltage to a lower voltage
The most basic components of an electronic circuit are:

- **Resistor**
  - Resistance is an inherent property of all materials
  - Conductive materials have small resistance, non-conductive high resistance
  - Wire is an approximately 0Ω resistor
  - Purely a passive element
  - Like the “slope” of the mountain

- **Capacitor**
  - Stores energy: as current flows in the capacitor charges in voltage, as current flows out it discharges
  - Like a small intermediate “lake” in the mountain

- **Inductor**
  - Stores energy: as voltage is applied, it makes current flow faster, as voltage goes down the current slows
  - Like a local “increase in gravity” in the mountain
## Units and Common Values

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The most basic “laws” for these components are:

- **Resistor**

  \[ V = IR \leftrightarrow I \quad \frac{V}{R} \leftrightarrow R = \frac{V}{R} \]
  
  \[ P = IV \leftrightarrow P \quad I^2R \leftrightarrow P = \frac{V^2}{R} \]

- **Capacitor**

  \[ i = C \frac{dv}{dt} \]

- **Inductor**

  \[ v = L \frac{di}{dt} \]

  **Capacitors and Inductors are “dual” or each other**

  - What one does with voltage, the other does with current
Network Laws

- A circuit is full of nodes and loops
  - The Kirchhoff Voltage Law (KVL) and Current Law (KCL) tell you how to figure out the voltage and current in a circuit

\[ \sum_{L} v_l = 0 \]

\[ \sum_{N} i_n = 0 \]

- The sum of all voltages around a loop must be 0
- The sum of all currents into a node must be 0

Note: at least one voltage must be negative (the +/- signs are backwards)!

Note: at least one current must be negative (flow opposite of the arrow)!
Supplies

• To make circuit analysis possible, we use models of voltage and current supplies:
  
  – Voltage supplies provide constant voltage and any necessary current
    • Current flows out of the positive side, through the circuit, and back into the negative side of a supply
  
  – Current supplies provide constant current in the direction of the arrow and work at any necessary voltage
• Node analysis: KCL

\[ i_0 = i_R + i_C \]

\[ i_0 = \frac{v}{R} + C \frac{dv}{dt} \]

\[ v + RC \frac{dv}{dt} = i_0 R \]

- Resistor/Capacitor circuits will always have a time constant of RC!
  
- Actual response depends on input current
  
  - Example: \( i_0 = \) step function

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

\[ I_0 \]

\[ t \]
ZIR and ZSR

- **Solving circuits with inductors/capacitors** is easiest if you use super-position to add the
  - **Zero Input Response**
    - The behavior which depends only on the “state” of the capacitor/inductor at time zero, without any change in the input
  - **Zero State Response**
    - The behavior which depends only on the response of the capacitor/inductor due to a change in the input

\[
\begin{align*}
ZIR : \\
t < 0, & \quad v = I_0 R \\
t > 0, & \quad i = C \frac{dv}{dt} \rightarrow v + RC \frac{dv}{dt} = 0 \\
& \quad \Rightarrow v = I_0 R \cdot e^{-\frac{t}{RC}}
\end{align*}
\]

\[
\begin{align*}
ZSR : \\
t < 0, & \quad v = 0 \\
t > 0, & \quad i = C \frac{dv}{dt} \rightarrow v + RC \frac{dv}{dt} = 0 \\
& \quad \Rightarrow v = I_1 R \left( 1 - e^{-\frac{t}{RC}} \right)
\end{align*}
\]
• From $V = iR$
  
  - What happens with unconnected ends of components?

  - Because $i=0$ then $v$ across are 0
    
      • $V_R = V$
      • $V_C = V$ *it is not floating!*
      • $V_L = V$