Ground

- Ground is the reference point in an electrical circuit from which other voltages are measured.
- A common return path for electric current (earth return or ground return), or a direct physical connection to the Earth.

Operational Amplifier (Op-Amp)

- Complex Arrangement of resistors, capacitors and transistors
- Op-Amp notation
  - Needs to be powered
  - $-V_{ss} \leq \text{Output} \leq V_{ss}$
  - -Input: Inverting terminal
  - +Input: Non-inverting terminal

- Uses
  - Comparator, Differentiator, Integrator, Voltage Amplifier

Op-Amp Characteristics

- Op-amp amplifies the difference between the non-inverting input and the inverting input
- Characteristics
  - Output voltage = $A \cdot (V_+ - V_-)$ where
    - $A$ is the gain - usually a pretty large number, often greater than 100,000 or 200,000.
  - High input impedance (opposition to current) at the input terminals
  - Low output impedance
**Rules for Op-amp**

1. The output attempts to do whatever is necessary to make the voltage difference between inputs zero
   - \( V_1 - V_2 \approx 0 \Rightarrow V_1 = V_2 \)
2. The inputs draw no current
   - Due to infinite resistance between the input terminals

**Inverting**

\[
\begin{align*}
V_\text{in} - V_a &= \frac{V_a - V_\text{out}}{R_1} \quad \text{(from rule 2)} \\
V_a &= 0, \text{ from Rule 1} \\
\text{Therefore: } A &= \frac{V_\text{out}}{V_\text{in}} = -\frac{R_f}{R_1}
\end{align*}
\]

**Non-Inverting**

\[
A = \frac{V_\text{out}}{V_\text{in}} = 1 + \frac{R_f}{R_1}
\]

**Diode**

- Diodes allow electricity to flow in only one direction.
- The arrow of the circuit symbol shows the direction in which the current can flow.
- Modern diodes are realized from semi-conductors
**Semiconductor**

- Semiconductor material are in between conductors (like metals) and insulators (like glass)
  - In pure form, it is non-conducting

- E.g. silicon crystal - has 4 electrons in its outer orbital, which form perfect covalent bonds with four neighboring atoms, leaving no electrons to conduct electric current

- You can change the behavior of silicon and turn it into a conductor by doping it. In doping, you mix a small amount of an impurity into the silicon crystal

**N-Type & P-Type Semiconductors**

- **N-Type Semiconductor**
  - Abundance of electrons
  - N for negative charge

- **P-Type Semiconductor**
  - Abundance of positive charge
  - P for positive charge

**Semiconductor Diode**

At the junction, free electrons from the N-type material fill holes from the P-type material. This creates an insulating layer in the middle of the diode called the depletion zone.

When the negative end of the circuit is hooked up to the N-type layer and the positive end is hooked up to P-type layer, electrons and holes start moving and the depletion zone disappears.

**LED (Light Emitting Diode)**

- Photons (energy in form of light) are released as a result of moving electrons.
- In an atom, electrons move in orbitals around the nucleus.
  - Electrons in different orbitals have different amounts of energy.
  - Electrons with greater energy move in orbitals farther away from the nucleus.
- For an electron to jump from a lower orbital to a higher orbital, something has to boost its energy level. Conversely, an electron releases energy when it drops from a higher orbital to a lower one.
- This energy is released in the form of a photon.
LED

- Anode – Long end
- Cathode – short end
- Never connect an LED directly to a battery or power supply!
- It will be destroyed almost instantly because too much current will pass through and burn it out.

Resistor Color Coding

- Resistors can be 4 band or 5 band
- In 4 band resistors
  - 4th band is tolerance band (gold or silver)
  - 3rd band is multiplier

Protoboard