Basic Concepts of Electricity

- Voltage: $E$
- Current: $I$
- Resistance: $R$

Ohm’s Law: $E = I R$

Electric Fields

- An electric field applies a force to a charge
  - Force on positive charge is in direction of electric field, negative is opposite
- Charges move if they are mobile
- An electric field is produced by charges (positive and negative charges)
- Electric fields can be produced by time varying magnetic fields (generator, antenna radiation)
Voltage Difference

- Voltage difference is the difference in potential energy in an electric field
- \( E = \frac{V}{d} \)
- As you move closer to a positive charge, the voltage increases

Current

- An electric current is produced by the flow of electric charges
- Current = rate of charge movement = amount of charge crossing a surface per unit time
- In conductors, current flow is due to electrons
- Conventional current is defined by the direction positive charges will flow
- Direction of electron flow is opposite to direction of conventional current
Resistance

- In materials electrons accelerate in an electric field
- Electrons lose energy when they hit atoms - lost energy appears as heat and light
- The result is that electrons drift with constant velocity (superimposed on random thermal motion)
- Resistance is the ratio Voltage/current
  \[ R = \frac{V}{I} \]
Material Conductivity

- Conductors - negligible resistance
- Insulators - extremely large resistance
- Semiconductors - some resistance
- Resistors - are devices designed to have constant resistance across a range of voltages

Resistor Combination

Series resistance

\[ R_{1} + R_{2} = R_{1} + R_{2} \]

Parallel resistance

\[ R = \frac{R_{1} R_{2}}{R_{1} + R_{2}} \]

\[ \frac{1}{R} = \frac{1}{R_{1}} + \frac{1}{R_{2}} \]
Voltage Divider

\[ V_2 = \frac{V \cdot R_1}{R_1 + R_2} \]

Solution:
Goal: Find \( V_2 \) given \( V \)
- Find \( V_2 \) in terms of \( I \)
- Current through \( R_2 \) in terms of \( I \)
- Voltage across \( R_1 \)
- Find voltage across \( R_1 \) and \( R_2 \) using two different methods

Potentiometer (Variable Resistor)

\[ V_X = V \cdot \frac{\text{Distance AX}}{\text{Distance AB}} \]
(linear potentiometer)

A trimpot is a small variable resistor mounted on a printed circuit board that can be adjusted by a small screwdriver to make semi-permanent adjustments to a circuit.
Input Transducers

- These are devices that produce electric signals in accordance with changes in some physical effect e.g. convert temperature, light level to a voltage level or resistance
- e.g. microphones, strain gauge, photodetectors, ion-selective membranes, thermistors
- Sometimes the definition of transducer is that of a device that converts non-electrical energy to electrical energy

Output Transducers

- Devices which convert an electrical quantity into some other physical quantity or effect e.g. relay, loudspeaker, solenoid
Light Dependent Resistors (LDRs)

- Devices whose resistance changes (usually decreases) with light striking it
- (also called photocells, photoconductors)
- Light striking a semiconducting material can provide sufficient energy to cause electrons to break away from atoms.
- Free electrons and holes can be created which causes resistance to be reduced

LDRs

- Typical materials used are Cadmium Sulphide (CdS), Cadmium Selenide (CdSe), Lead Sulphide
- With no illumination, resistance can be greater than $1 \, \text{M}\Omega$ (dark resistance).
- Resistance varies inversely proportional to light intensity.
- Reduces down to 10-100s ohms
- 100ms/10ms response time
- LDRs have a low energy gap
- Operate over a wide wavelengths (some, into infrared)
- Indium antimonide is good for IR. When cooled is very sensitive, used for thermal scanning of earth’s surface
Capacitors

- A component constructed from two conductors separated by an insulating material (dielectric) that stores electric charge (+Q, -Q)
- As a consequence there is a voltage difference across the capacitor, V
- Capacitance = \( C = \frac{Q}{V} \)
- The dielectric material operates to reduce the electric field between the conductors and so allow more charge to be stored for a given voltage

Bucket analogy

A small bucket (capacitor, C) holds less charge (Q) for given level (voltage V) than a large bucket
Charging a Capacitor

The bucket analogy can be used to describe capacitor charging.

When current flows in at a constant rate the voltage increases linearly and vice versa for current flowing out.

Semiconductors

- Silicon is used as an example (other semiconductors include Germanium, Gallium Arsenide, Gallium phosphide, indium arsenide, indium phosphide)
- Pure silicon (intrinsic semiconductor)
  - Four valance electrons
  - Crystalline structure
  - Reasonably high resistance

Silicon atom
Valence electrons
Electrons and holes

- Due to thermal energy some electrons in the valance shell become free
- Create:
  - One free electron +
  - One hole in the valence band that can be filled by electrons from the valance band in an adjacent silicon atom
- Current in silicon can flow due to both movement of electrons and holes

n-type silicon

- Add donor impurities (e.g. Phosphorus, arsenic, indium) with 5 electrons in the valance band
- As only four electrons can bond with neighbouring silicon atoms one free electron is left
- Increases concentration of free electrons
- Reduces concentration of holes (due to increased chance of recombination)
- Resistance reduced
p-type silicon

- p-type silicon is created by adding acceptor impurities which have three valance electrons (e.g. boron)
- This leaves an unbound valance electron in an adjacent silicon atom creating a hole
- Increases concentration of holes
- Reduces concentration of free electrons
- P-type silicon has lower resistance than pure silicon

Diodes

- If a piece of n-type silicon and p-type silicon are joined directly together a diode (di - electrode) device is created

![Diode Diagram](image)
Macro-behaviour

- A diode is a device that allows current flow easily in one direction easily and allows hardly any current flow in the opposite direction.

Forward bias

- Current flows easily if the P region is positive with respect to the N region.

\[ I = I_0 e^{bV} \]

(Strictly \( I = I_0(e^{bV} - 1) \))
Reverse bias

- Current hardly flows if the P region is negative with respect to the N region

I = -I₀

Diode and resistor circuit

Currents and voltages determined by:
1. \( V_D \) related to \( I \) by diode equation
2. Current in resistor and diode equal
3. \( V_R = IR \)
4. Voltage across diode and voltage resistor add up to voltage source \( V \)

Short cut rule of thumb, \( V_D \) is approx 0.6-0.7 volts and \( V_R \approx V - 0.6 \)
For LEDs \( V_D \) is about 1.8 - 4.0 V, depending on colour
Diode and resistor circuit

Assume no reverse-bias current flows (ideal case)
Therefore no voltage occurs across the resistor
Therefore the full supply voltage appears across the diode

Reverse biased diode

LEDs

- Light emitting diode
- When an electron moves down from the conduction band to the valence band it loses energy
- In silicon and germanium the energy-momentum relationships mean that this energy is lost heat
- In gallium arsenide it produces a photon
The light intensity is proportional to current.
- Pure gallium arsenide produces infrared light.
- GaAsP produces red or yellow light.
- GaP produces red or green.

LEDs behave just like normal diodes except that the forward bias voltages are greater (typically 1.8 - 4.0 V).
- A typical forward bias current of 10-20 mA is used.

Circuit design using LEDs.
Example

\[
I = \frac{9 - 2.0}{680} = 0.0129 \text{ mA}
\]