EE580 – Solar Cells
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- Lecture 07
- EE Fundamentals

What is Electrical Engineering

- Opposite of lightning
  - Unleashes electrical energy
  - Unpredictable
  - Destructive
- Harnesses electrical energy for human good
  - Transportation of energy and information
    - Lights, motors, outlets
    - Symbolic information: electronics

Review of Electrical Principles

- Electric Charge
- Electric Current
- Electric Fields
- Electric Potential Difference (Voltage)
- Power

Electric Charge

- Electric charge is produced by electrons and protons
- Electrons are negatively charged and protons are positively charged
- Atoms begin with an equal number of electrons & protons making them neutral
- Ions are charged atoms that have lost or gained an electron
- Unit of charge is a Coulomb (C)
- Charge of one electron = 1.6×10^{-19} (C)

Conservation

- Charge
  - Charge is neither created or destroyed
  - It is only moved (current)
- Energy
  - Medium of exchange (money in economics)
  - Energy is not created or destroyed
  - Only changes form
- Energy domains
  - Electrical, Chemical, Mechanical, Optical, Nuclear, Atomic

Electric Current (I)

- Movement of charge creates a current
- Like charges repel (repulsion force)
- Opposite charges attract (attraction force)
- Good conductors have charge that can freely move (Metals)
- Poor conductors (Insulators) have few mobile charges
- Current follows the easiest path, path of least resistance
- Unit of current is the Ampere or Amp (A)
- Coulomb/second (C/s) = Ampere (A)

Electric Charge and Forces

- It was experimentally found that:
  - the force on charges are proportional to the size of the charge (Q)
  - The force on charges is a function of the separation (d)

$$F \propto \frac{Q_1 Q_2}{d}$$

Electric Fields & Forces

- An electric field is a way of representing the physical force felt by a charge at a particular point
- An electric field is an area where a charged object experiences a force
- Electric fields are created by charged objects that attract or repel other charged objects

$$F \propto \frac{Q_1 Q_2}{d} \rightarrow \frac{Q_1}{d} Q_2 \rightarrow E_1(d) Q_2$$

Electric Potential Difference (Voltage)

- Charges in strong electric fields move to a point where the field is weaker. → It moves from a point of high potential energy to a lower potential energy (like water flowing down hill)
- Electric potential is a location dependent quantity which expresses the amount of potential energy per unit charge at a specific location
- In electrical terms, this difference in potential is called a **voltage** and it is the difference that makes electrons move (difference in height makes water flow)

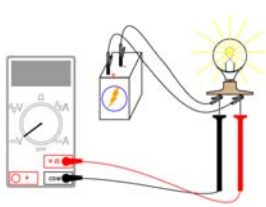
Electric Potential Difference (Voltage)

- Charges will move from high potential to low potential if there is a conducting path
- To move charge from low potential to high potential work needs to be supplied (water must be pumped up the hill)
- Unit of voltage is the volt (V)
- 1 **Joule** of energy is required to move a 1 **Coulomb** charge across a voltage barrier of 1 **Volt**

$$\text{Voltage} = \frac{\text{Electric Potential Energy Difference}}{\text{Charge}}$$

Volt Meter

- A Volt Meter is connected across the circuit element to be tested
- It measures the electrical potential difference between the two sides of the element

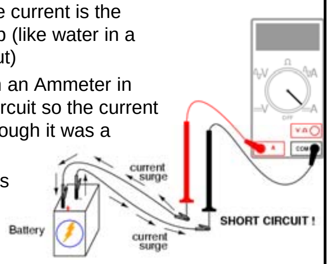


Current: AC & DC

- 2 Types of Current
  - Direct Current (DC)
  - Alternating Current (AC)
- DC: electrons flow one way along the circuit conductor under a constant voltage by a battery or photovoltaic cell
- AC: The direction and strength of the potential rapidly oscillates back and forth 60 times a second (60 Hertz)
- Most electricity grids and appliances use AC …Why? Transformers can step the voltage up and down easily to reduce the power lost in transmission lines
- AC can be converted to DC and vice versa

Ammeter

- In a single circuit loop the current is the same throughout the loop (like water in a pipe, the flow in = flow out)
- Current is measured with an Ammeter in line with the rest of the circuit so the current can pass through it as though it was a circuit element
- Be careful of short circuits



Digital Multimeters (DMM) are protected from short circuits)

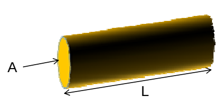
Resistance (R)

- Resistors obstruct the flow of electrons causing them to lose energy in the form of dissipated heat
- Electrons collide with atoms causing them to vibrate (thermal energy) Resistors get hot …toaster
- Resistance is used for DC circuits while impedance is used for AC circuits
- The unit of resistance and impedance is the Ohm (Ω)
- There is a relationship between voltage, current and resistance known as Ohm's Law

$$\text{Electric Potential Difference} = \text{Current x Resistance}$$
$$V = IR$$

Resistors and Resistivity

- Resistors reduce the current since they impede the flow of electrons
- Voltage falls across resistors because energy is lost in the collisions of electrons and atoms.
- The longer the wire (L) or smaller the cross section (A) the higher the resistance
- Resistivity is the material property related to the resistance (ρ)



$$R = \frac{L}{A}\rho = \frac{L}{w \cdot t}\rho$$
$$R_s = \frac{\rho}{t}$$ Sheet Resistivity

Circuit Conditions

- A circuit needs a closed path for electrons to flow
- A circuit may be open where there is no current flow and a maximum voltage will be across the terminals
- A short circuits is the opposite extreme, the terminals are shorted with no load producing a maximum (dangerous) current and zero voltage

Summary Linking Cells

- Linking modules or batteries is similar to connecting PV cells
  - Series Connections
    - Voltages are added in series connections
    - The current is restricted to the smallest current
  - Parallel connections
    - The currents are added in parallel connections
    - The voltages are averaged from each string
- Solar Cells and Modules are Matched to improve the power generated

Power from Voltage and Current

- Power
  - Rate of energy flow

$$\text{Power} = \text{Voltage} \times \text{Current}$$
$$= \left(\frac{\text{Work}}{\text{Charge}}\right) \times \left(\frac{\text{Charge}}{\text{Time}}\right)$$
$$= \frac{\text{Work}}{\text{Time}}\left(\frac{\text{Joule}}{\text{second}}\right)$$
$$(\text{Watts}) = (\text{Volts}) \times (\text{Amperes}) = \left(\frac{\text{Joule}}{\text{second}}\right)$$

Digital Information

- Longfellow: “one if by land two if by sea”
- Electrical Engineers use binary variables
  - Two values
    - Yes/No
    - True/False
    - One/Zero
    - High/Low
    - Black/White

Binary Numbers (Base 2)

- 0 0000
- 1 0001
- 2 0010
- 3 0011
- 4 0100
- 5 0101
- 6 0110
- 7 0111
- 8 1000

10^4	10^3	10^2	10^1	10^0	$Base:10$
2^4	2^3	2^2	2^1	2^0	$Base:2$
16	8	4	2	1	

Basic Logic Elements

A	B	AND	OR	NAND	NOR
0	0	0	0	1	1
0	1	0	1	1	0
1	0	0	1	1	0
1	1	1	1	0	0

A	NOT A
0	1
1	0

Truth Tables

A	B
0	1
1	0

$$B = not\ A = \overline{A}$$

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

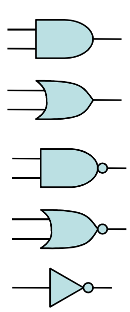
$$C = A\ or\ B$$

A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

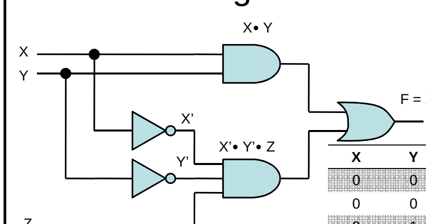
$$C = A\ and\ B$$

Logic Gate Symbols

- AND
- OR
- NAND (not and)
- NOR (not or)
- NOT



Logic Circuit



X	Y	Z	F
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	1