Voltage, Current, Resistance, Capacitance and Inductance

Really basic electrical engineering.

Electricity and conductors

- Electricity is the movement of electrons.
- Electrons move easily through a conductor
  - silver, copper, aluminium, molybdenum
- Electrons do not move easily through an insulator
  - air, glass, silicon dioxide (SiO₂)
- Electrons move with reasonable ease through a semiconductor
  - silicon, germanium, gallium arsenide
Electrons and protons

• Normally, materials have the same number of electrons
  – which carry a negative charge
• …and protons
  – which carry a positive charge
• and such materials carry no (net) charge

Potential difference: volts:

• When there is an imbalance of electrons and protons in a material, the material carries an electric charge
• If there are too many electrons
  – the material is negatively charged (-ve)
• If there are too few electrons
  – the material is positively charged (+ve)
• If two pieces of material have differing charges, there is a potential difference between them
  – Measured in Volts.
Potential difference ct’d

• If two pieces of material have differing charges, there is said to be a potential difference between them
• The potential difference is measured in volts
• The potential of the place with fewer electrons is higher than that of the place with more electrons

Flow of electrons: Current

• If materials with a potential difference are connected by a conductor, electrons will tend to move so that their charges equalise.
• Electrons flow from the more negatively charged to the less negatively charged place.
• Electron flow is from the less positively charged to the more positively charged place.
• When electrons move, a current is said to flow
  – so a current is the flow of electrons through something
  – current is measured in amperes (or amps)
Current flow

- Unfortunately, the conventional notation is the other way round from electron flow
  - a positive current flow occurs in the direction opposite to the actual flow of electrons

Resistance

- A property of all materials, relating to how well they can carry electricity.
- Conductor: low resistance
- Insulator: high resistance.
- Measured in Ohms $\Omega$. Symbol R.
- Often kilohm, megohm, or gigohm.
Ohms Law

There is a relationship between potential difference, current flow, and resistance, called Ohms Law: \( V=IR \)
- \( V \) is potential difference in volts
- \( I \) is current flow in amps
- \( R \) is resistance in ohms.

• Thus, if \( V=1 \) volt, \( R=10 \) ohms, a current of 0.1 amps would flow

![Ohms Law Diagram]

Capacitance

• A property of electrical systems.
• Relates to building up an electric field.
• And to how much electricity they store
• Measured in Farads, \( F \) (huge). Symbol \( C \).

• (usually microfarads \( \mu F \), or nanofarad \( nF \) or picofarad \( pf \) or even femtofarads)
Inductance

• A property of wires.
• Relates to them building up a magnetic field
• Measured in Henrys. Symbol L.

• Often millihenries, or microhenries…

Why does this matter?

• Electronic digital computers often need to move digital signals from place to place
  – From CPU to memory
  – From CPU register to register, etc.
• Moving electrical signals along wires always involves R, C, L.
Digital signals

- Digital electronic signals usually use one voltage to represent 0, and another to represent 1.
- Voltage (potential difference) measured with respect to ground
- 0 volts Logic 0
- 5 volts Logic 1
  - Often not 5 volts, but 3, or 2.7 or 1.5…
  - Actual signal is analogue
    - Interpretation (0 or 1) changes at some in-between voltage

Why is this of interest?

- Real digital signals change rapidly
- Problem: sudden changes get made less sudden!
Example: simple RC circuit

- R is resistance of a wire, C is capacitance of wire
- Input is square wave
- Output rises and falls more slowly

What can go wrong?

- If the frequency of the input is high,
- And R and C are (relatively) large,
- Output signal may not reach the 1 state, before the signal starts to fall,
- Then errors will occur.