Electronics 1

- Voltage/Current
- Resistors
- Capacitors
- Inductors
- Transistors
Simple circuit – a battery pushes some electrons around the circuit – how many per second?
The easiest way to think of this simple circuit is as water flowing through pipes.

- Voltage is the same as the water pressure.
- Current is the amount of water (electrons) flowing through around the circuit.
- Resistance is like a constriction in the flow.
Ohm's Law

- There's a simple relationship:

  \[ V = IR \quad \text{or} \quad I = \frac{V}{R} \quad \text{or} \quad R = \frac{V}{I} \]

- Know any two you can figure out the other
Demonstration

- Go to (you will need java):
  
  http://www.falstad.com/circuit/e-index.html

- Bookmark it!
- Click on "ohm's law"
- You can see how for a fixed voltage the amount of current depends on the resistance (click on a resistor, change it)
Voltage

- Voltage is the pressure on the electrons around a circuit – the higher the voltage the more push they get
- High voltages (100V or more) are dangerous and can cause death
- 1000V or more can cause arcing
- Common voltages are what you have in a battery – or 5 or 3.3V for logic families
Current

- Current is related to how many electrons are passing a particular spot in a second
- 1 amp is a high current – if you have an amp or more somewhere in your circuit something is getting hot
The human body has a relatively high resistance

"it's the volts that jolts and the mills that kills"

Voltage won't actually kill you, but it's what will make you feel a shock (you won't feel a DC shock as an ongoing shock, while you cook)

Current through the body, especially across the heart is what will kill you – it only takes a few milliamps
Resistors

- Limit current flow
- Are measured in "ohms"
- Come in lots of shapes and sizes
- Colour codes tell us how big
Resistors also come in power and voltage ratings

- Power $P = VI = I^2R = V^2/R$ (again know any 2 ..)
  - if your resistor turns into a smoking piece of carbon you probably need one with a higher power rating

- Voltage ratings have to do with breakdown (arcing) only an issue of you're playing with dangerous voltages
If you connect resistors in series the resulting resistance is the sum of the two resistor's values.

If you connect them in parallel the resulting value is complicated (I promised little math) but if they are both the same the result is the same as a resistor of half the value.

Try the "resistors" demo.
Resistors 4

- With two resistors in series the voltage in the middle is proportional to the ratio of the two resistors
- Click on the "voltage divider" demo
- Right click on some resistors to muck with their values
Polarity

- Positive charges (an absence of electrons) and negative charges (too many electrons) kind of work the same way.
- Due to a lot of history before people worked out how electricity we often end up thinking of currents flowing from positive to negative (even though the electrons really move the other way).
- It doesn't really matter.
DC vs AC

- A DC voltage is a fixed voltage that doesn't change
- An AC voltage is one that changes continually, usually represented as a sine wave with a fixed frequency:

- Complex waveforms are a mix of frequencies
Often we see a mix of a DC voltage and an AC voltage.

On a 'scope they look like an AC signal with an offset from 0.
Capacitors

- Block DC (infinite resistance)
- Pass AC
- 'resistance' to AC inversely proportional to value and to frequency (we say 'impedance' rather than 'resistance' here)
- Measured in "farads" - a farad is a lot, we normally use nano and micro farads
- Stores energy using an internal electric field
Capacitors 2

- Come in lots of types
- Small ones (disc ceramic) are pretty rugged
- Bigger ones tend to be voltage limited (electrolytics) and physically big
- Specialty ones for high voltages, high reliability, larger temperature ranges, higher frequencies
Capacitors 3

- Used for three main things:
  - Blocking DC voltages
  - Smoothing AC from DC rails
  - Frequency sensitive circuits
An ideal capacitor will charge infinitely fast.

The real world always has resistance – capacitors charge and discharge at a rate proportional to the R and C in a circuit.

Click on the "capacitor" demo.

Now look at the "AC response" demo – see how the current lags the voltage.
You calculate the AC impedance values of capacitors in parallel by adding the values together.

The rules for capacitors in series is the same as for resistors in series.
**Inductors**

- Store energy in a magnetic field when a current is flowing
- Pass DC with close to 0 resistance
- Tend to block AC – resists AC current changes
  - 'resistance' to AC proportional to value and to frequency (we say 'impedance' rather than 'resistance' here)
- Measured in ”henrys” - a henry is a lot, we normally use micro and milli henrys
Inductors 2

- Come in lots of types
- Expensive, difficult to buy/use
- Physically big
- There are issues with stray magnetic fields
Inductors 3

- Used for three main things:
  - Blocking AC voltages
  - Smoothing AC from DC rails
  - Frequency sensitive circuits
An ideal inductors has 0 resistance

Real world always has resistance – current changes occur at a rate proportional to the R and L in a circuit

Click on the "inductor" demo

Now look at the "AC response" demo – see how the voltage lags the current
You calculate the AC impedance values of inductors in series by adding the values together.

The rules for inductors in parallel is the same as for resistors in series.
When the current through an inductor is turned off the magnetic field collapses – it induces a voltage that can rise to much higher than the initial voltage – these can damage circuits.

Those sparks you see on switches when you turn motors and other inductive loads off are caused by this.
Capacitors and inductors seem to have similar but opposite behaviour.

AC impedance goes up with frequency in inductors and down in capacitors.

Voltage and current phase shifts are opposite.

This is very useful.

Try the "parallel resonance", "band-pass", "notch", "Twin-T" and "crossover" demos.

Caps are usually much cheaper and easier to use than inductors – we prefer to use them.
Bipolar Transistors

- Bipolar transistors

- A small current flowing between the base (left) and emitter (the one with the arrow) terminals causes a much larger current to flow between the collector and emitter.

- Positive current always flows thru the arrow.
Bipolar Transistors

- The ratio of base to collector current (the gain) flowing depends on a bunch of things (no math remember)
- In a small range of base currents the gain is pretty much linear (without distortion)
- We often set a default DC bias on the base to put it in the middle of this range then introduce AC through a capacitor
Example – AC linear amplifier

- R3/R4/R2 set the base DC current
- R1/R2 is the output DC load (collector current)
- AC signals are inserted and extracted with the caps
Example – switch mode transistor

- If we're switching DC signals we ignore any issues around getting the transistor to act linearly.

  In this case applying a large voltage to Vin will cause enough current to flow to turn the transistor all the way on, it will act as if it has close to 0 resistance.

- Look at the 'switch' demo
Bipolar transistors come in 2 flavours – NPN and PNP

All the examples we've seen so far are NPN transistors

PNP transistors act in a mirror way – interacting with respect to the emitter and the +ve power rail as NPN transistors interact with ground.

(NPN transistors tend to be slightly cheaper than PNP transistors)
Power amplifiers

- Sometimes we use a symmetric NPN/PNP pair of transistors
- Look at the example "Simple Push-Pull Follower, with Distortion"
- And then "Improved Push-Pull Follower"
Final example

- Finally something that pulls lots of stuff together
- Look at the example "Astable Multivibrator (Oscillator)"
- Can you see how it works? – it uses RC charging delays to turn on switching transistors
Field Effect Transistors

- FETs work differently from bipolar transistors – they are controlled by a voltage between their gate and drain terminals (rather than a current between base and emitter).

- Applying the voltage causes the channel between the source and drain to change size and the amount of current flowing to change.
FETs

- You use them in all the same sorts of circuits you use bipolar transistors in
- They have linear regions for analog
- They make good switching transistors
- Gate capacitance can be an issue – even though they are voltage driven device you may need to inject a lot of current to get them to switch
- Gates can be static sensitive
They are the basis of most modern digital logic because of their low power consumption and ease of fabrication ....

They come in N-channel and P-channel variants – much like NPN and PNP transistors

Try the MOSFETs 'switch' example
Modern logic uses complementary FETs

Try the "CMOS inverter" example

The "CMOS Inverter (w/capacitance)" example models real world gate capacitance

The "CMOS Inverter (slow transition)" shows how we get current switching transients (the source of much of the heat in modern digital chips)
Darlington transistors

- Darlington transistors are used when you need high gain switching (ie driven by a really low current)

- They are in essence two transistors tied together

- You can make your own