Electronics 1

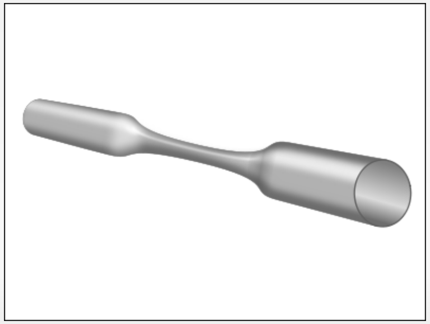
- Voltage/Current
- Resistors
- Capacitors
- Inductors
- Transistors

Voltage and Current

- Simple circuit – a battery pushes some electrons around the circuit – how many per second?

Water

- 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:

  $V = IR$ or $I = V/R$ or $R = V/I$

- 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

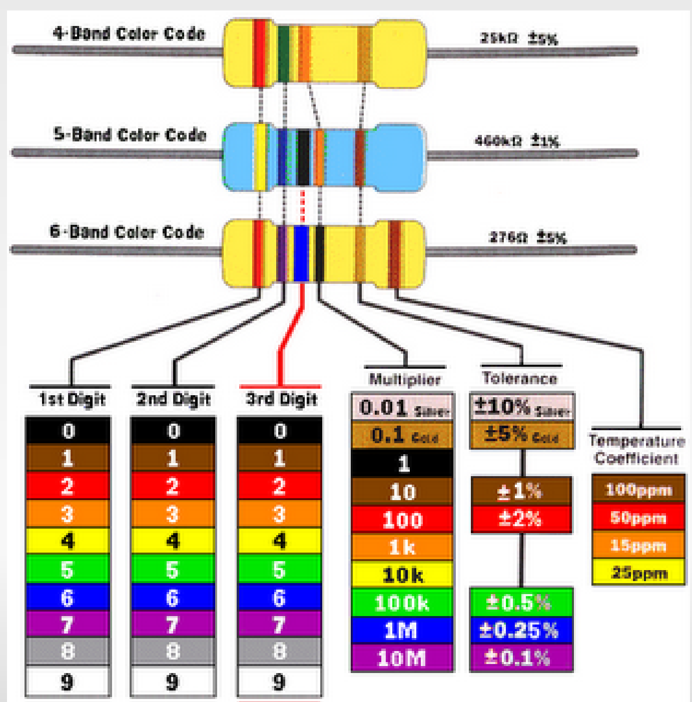
Safety

- The human body has a relatively high resistance

  ”it's the volts that jolts and the mills that kills”
- Voltage wont actually kill you, but it's what will make you feel a shock (you wont 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



Resistors2

- 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

Resistors 3

- 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

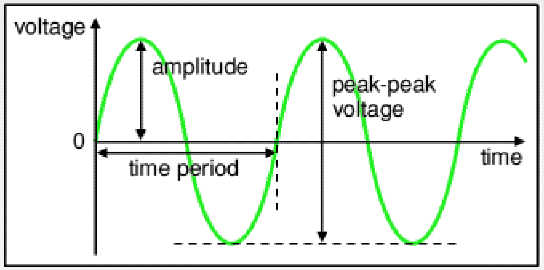
- With two resistors in series the voltage in the middle is proportional to the ratio of the two resistors
- Click on the ”voltage divider” demo
- Right click on some resistors to muck with their values

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 electritity 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

AC vs. DC 2

- 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

Capactitors 3

- Used for three main things:
  - Blocking DC voltages
  - Smoothing AC from DC rails
  - Frequency sensitive circuits

Capacitors 4

- 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

Capacitors 5

- 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 parallel

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

Inductors 4

- 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

Inductors 5

- 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 parallel

Inductors 6

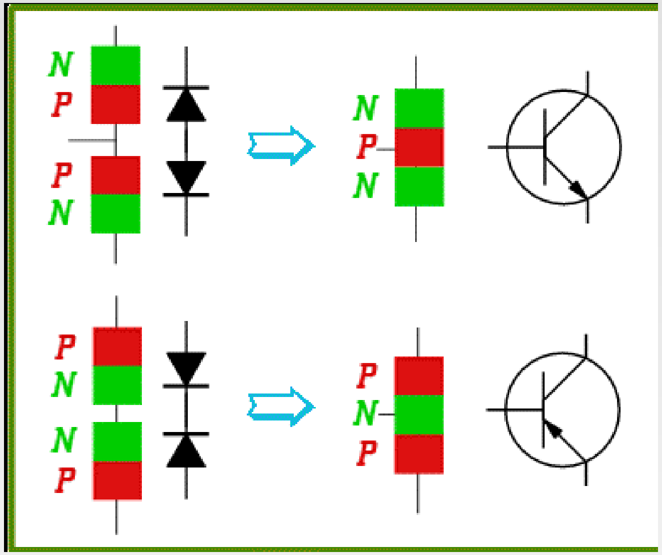
- When the current through an inductor is turned off the magnetic field collapses – it induces a voltage that can rise to much higher than the initial voltage – these can damage circuits
- Those sparks you see on switches when you turn motors and other inductive loads off are caused by this

Duality

- Capacitors and inductors seem to have similar but opposite behaviors
- 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



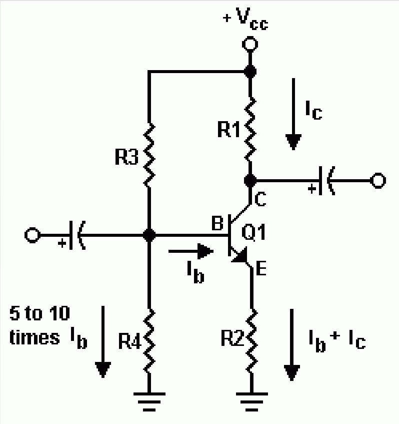
- A small current flowing between the base (left) and emitter (the one with the arrow) terminals causes a much larger current to flow between the collector and emitter
- Positive current always flows thru the arrow

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

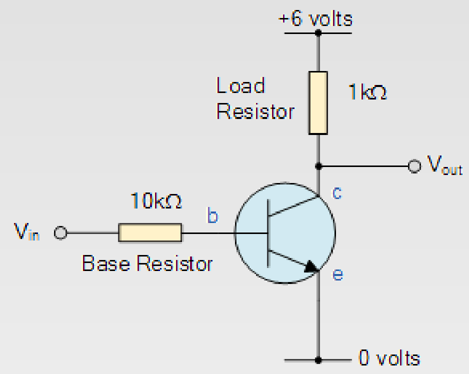
- R3/R4/R2 set the base DC current



- 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

NPN vs. PNP

- 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

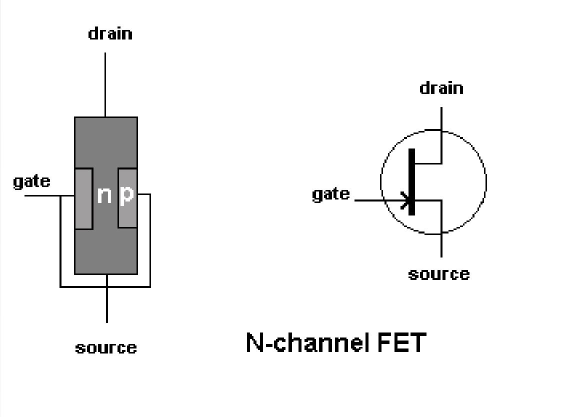
- Sometimes we use a symetric NPN/PNP pair of transistors
- Look at the example ”Simple Push-Pull Follower, with Distortion”
- And then ”Improved Push-Pull Follower”

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

FETs 2

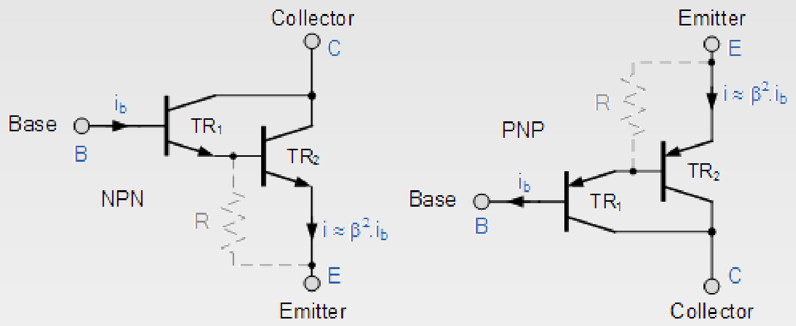
- They are the basis of most modern digital logic because of their low power consumption and ease of fabrication ….
- They come in N-channel and P-channel variants – much like NPN and PNP transistors
- Try the MOSFETs 'switch' example

FETs 3

- 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