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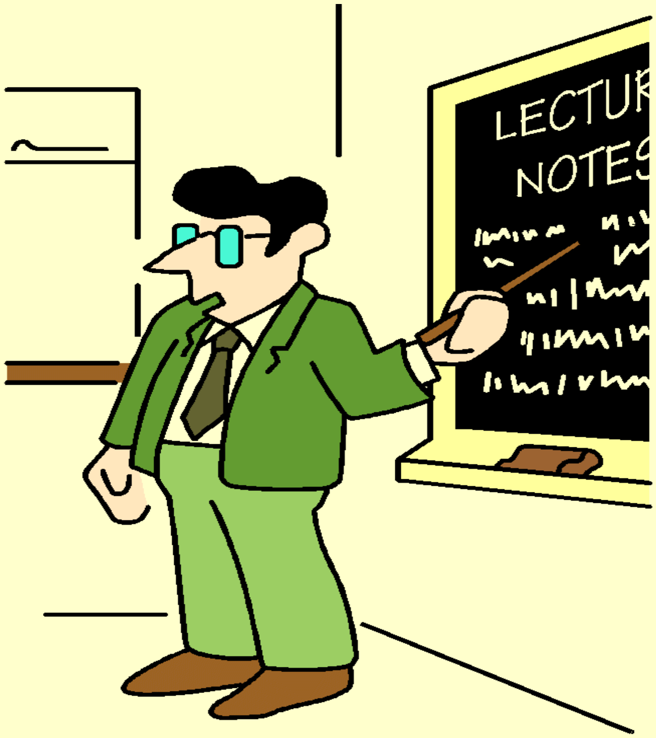

AND

INTERMEDIATE ELECTRONICS

2001

My name is Graham Knott and I teach Electronics and Microcomputing at Cambridge Regional College, situated in the University City of Cambridge, England.

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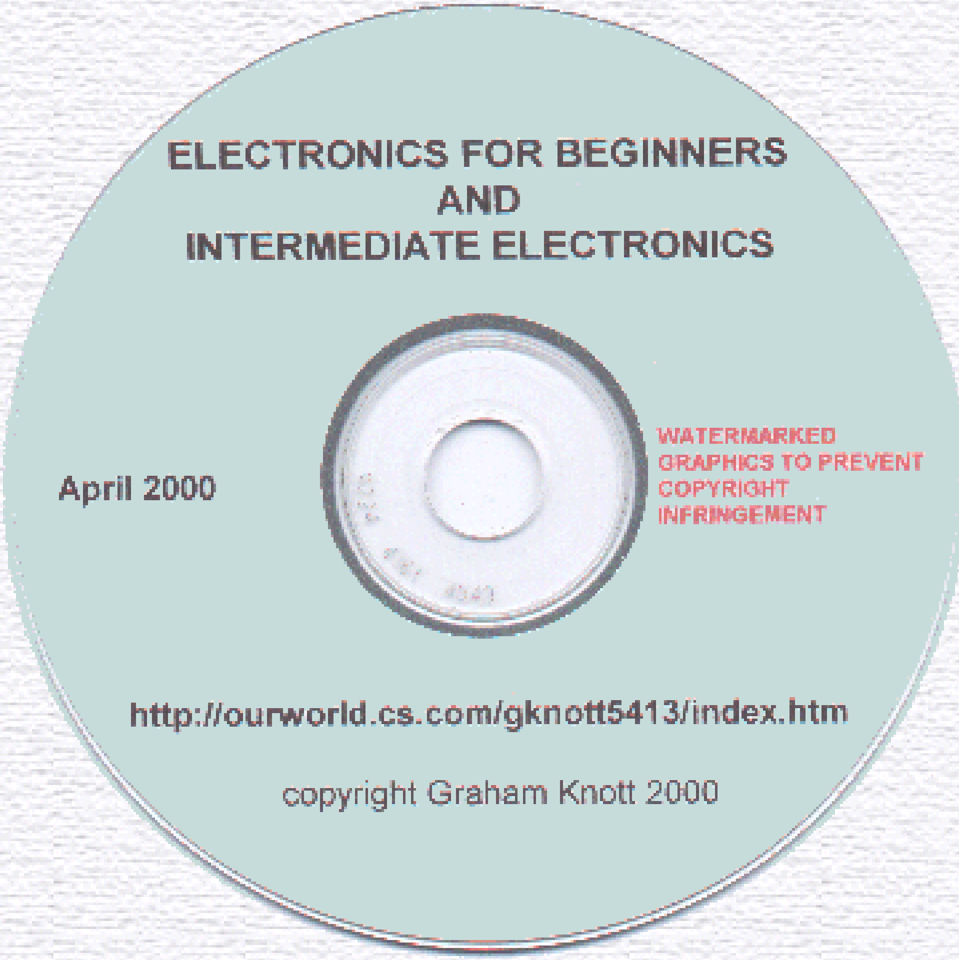

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Logic Gate simulator
Z80 Microprocessor simulator
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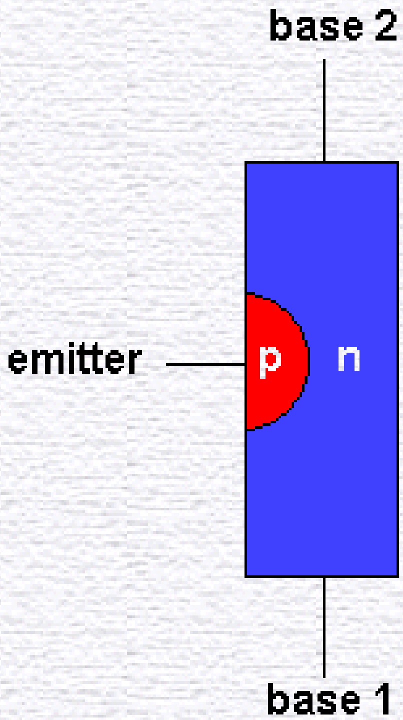
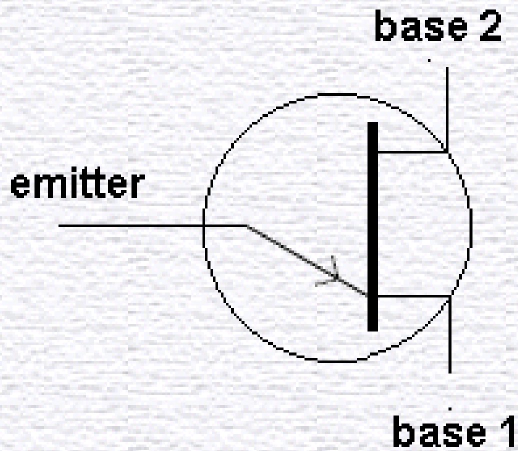
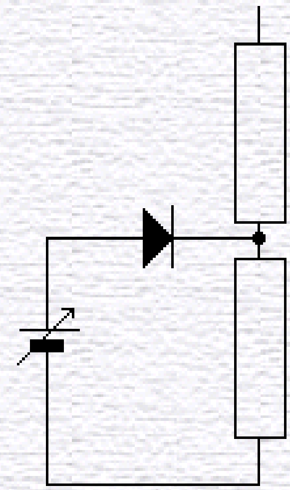
THE UNIJUNCTION TRANSISTOR







The unijunction transistor (UJT) is made of a bar of N type material with a P type junction (the emitter) near the centre.

Base 1 is connected to zero volts and base 2 to the positive supply.

The resistance between the two bases (the INTERBASE RESISTANCE) is typically 10k.

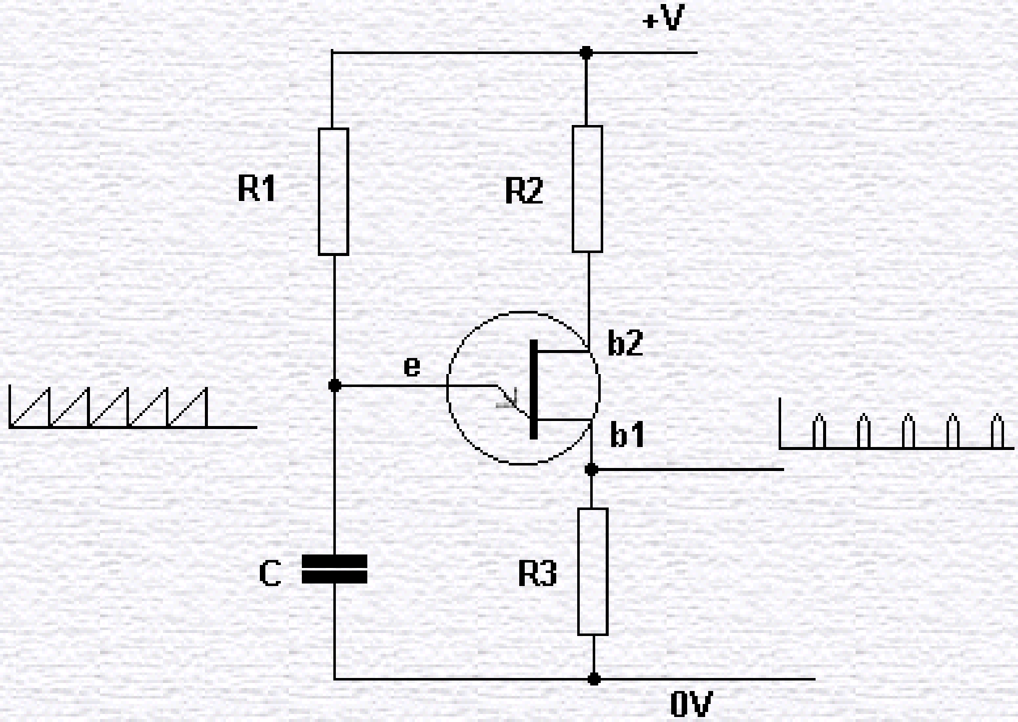
With the emitter unconnected, the bar acts as a potential divider, and about 0.5 volts appears at the emitter.

If a voltage is connected to the emitter, as long as it is less than 0.5 volts, nothing happens, as the P-N junction is reversed biased. (see the right hand diagram).

When the emitter voltage exceeds 0.5 volts, the junction is forward biased and emitter current will flow.

This increase in current is equal to a reduction of resistance between base 1 and the emitter.

This causes the emitter voltage to fall.



In the circuit, C charges via R1.

When the voltage across C exceeds 0.6 volts, the b1/emitter junction goes low resistance and discharges C.

The result is a sawtooth waveform across C.

There is also a pulse of current through R3 , giving a pulse of voltage across it.

This circuit is called a relaxation oscillator.
The voltage across C charges up slowly then suddenly relaxes.

The circuit is often used to trigger thyristor circuits.

FIELD EFFECT TRANSISTORS

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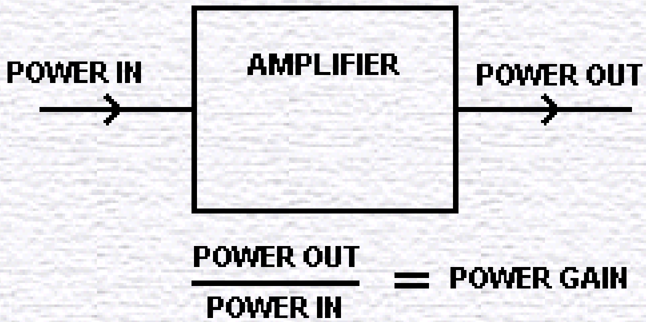
THE OPERATIONAL AMPLIFIER

BELS, DECIBELS AND dB

Bels are a means of comparing two powers or two voltages.

For example, comparing the power input to an amplifier with the power output as in the diagram below.

The ratio of power in, to power out, is the power gain.



In the next diagram, we have three stages of amplification.

To find the overall power gain, we multiply the individual gains.

10 X 6.5 X 9.2 = ?

Multiplying is not friendly and also large numbers can result.

If we find the log of the power ratio, the answer is in Bels.

To do this, we work out the power ratio and then look up the log of this value in log tables.

$$\mathrm{Log}_{10} \frac{P\ out}{P\ in} \quad \text{Bels}$$

Since Bels are too big , we work in decibels (dBs) as shown below.

$$10\ \mathrm{Log}_{10} \frac{P\ out}{P\ in} \quad \text{decibels} \quad (\text{dBs})$$

One advantage of decibels are that the numbers are usually more convenient.

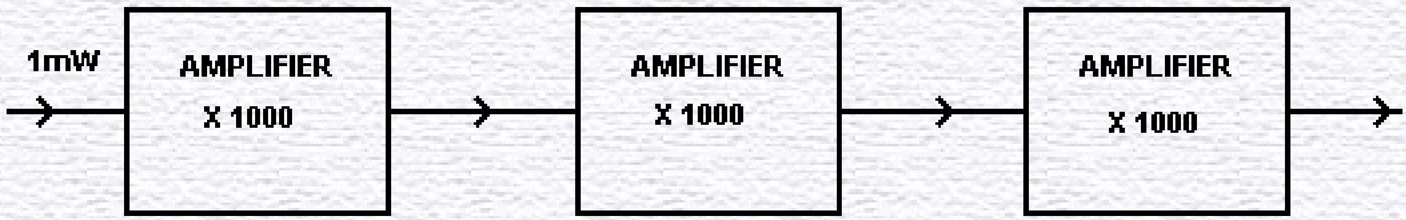
Below, the overall gain is 1,000,000,000 or +90 dBs.

A gain of 1000 is +30 dB.

To find the overall gain, individual gains are added.

The + sign indicates a gain.

A - sign would indicate an attenuation.



30 dB + 30 dB + 30 dB = 90 dB

If we are using voltage ratios then use the following formula.

$$20 \log_{10} \frac{Vout}{Vin} \quad \text{decibels} \quad \text{(dBs)}$$

The ear has a logarithmic response.

To make your amplifier sound twice as loud you must boost the power by 10 times. (+10 dB)

If you only double the power (+3 dB), then you will only just be able to detect the increase in volume.

Other points: there is always a ratio, such as the noise of Concorde compared with the noise of rustling leaves.

Sometimes there are standard levels to be compared with, such as 1 mW into 600 ohms for audio, or 1 volt into 75 ohms for video.

10 dBm, for example, is +10 dB relative to 1 mW.

It is not necessary to do calculations, tables are available, giving the dB equivalent of ratios, and vice-versa.

A useful table is shown below.

	W	V
x2	3 dB	6 dB
x10	10 dB	20 dB

A gain of 400 watts is 2 x 2 x10 x 10 which is 3 dB + 3 dB + 10 dB + 10 dB = +26 dB.

A voltage gain of + 52 db = 20dB + 20 dB + 6 dB + 6 dB which is 10 x 10 x 2 x 2 = a gain of 400 times.

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THE THYRISTOR, TRIAC AND DIAC

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MULTIVIBRATORS

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THE SCHMITT TRIGGER

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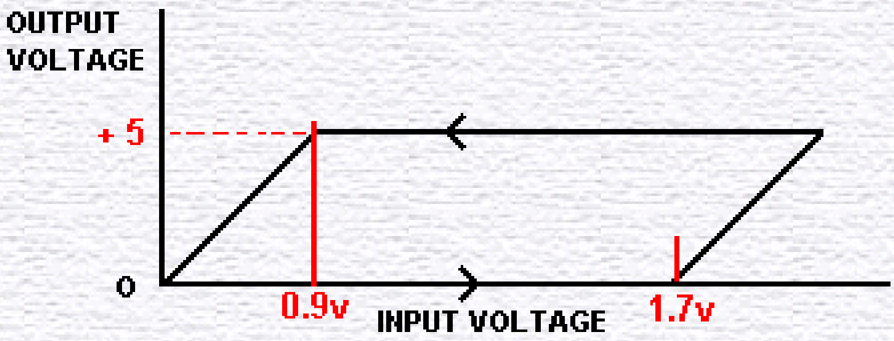


In the top diagram, the input voltage increases from zero, along the bottom horizontal line.

The output voltage remains at zero on the vertical line.

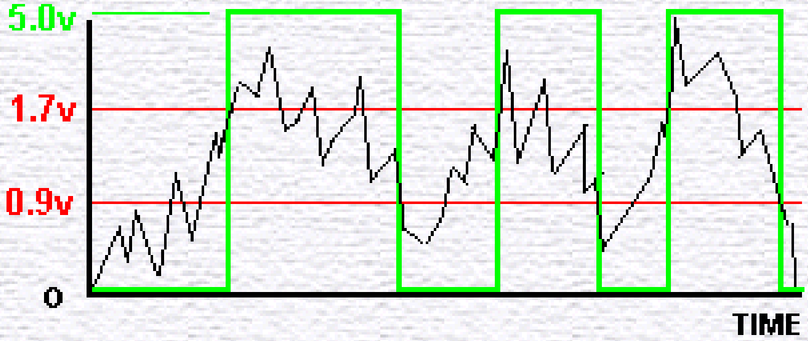
However, when the input voltage reaches 1.7 volts, the output shoots up from zero to 5 volts.

Reducing the input voltage, as shown in the top horizontal line does not cause the output to drop to zero immediately.

This only happens when the input voltage is reduced to 0.9 volts.

The input level at which the output increases to maximum, and the level at which it drops to zero are different.

This is called HYSTERESIS.



In the lower diagram Schmitt Trigger action is demonstrated in another manner.

The black graph represents a noisy logic signal received from the moon.

This is the input to the Schmitt Trigger.

The green graph is the output signal.

The output remains at zero until the input exceeds 1.7 volts.

The output then shoots up to 5 volts and remains at 5 volts until the input drops to 0.9 volts.

The output then drops to zero.

An almost perfect output is recovered from a very noisy input.

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THE SCHMITT TRIGGER 2

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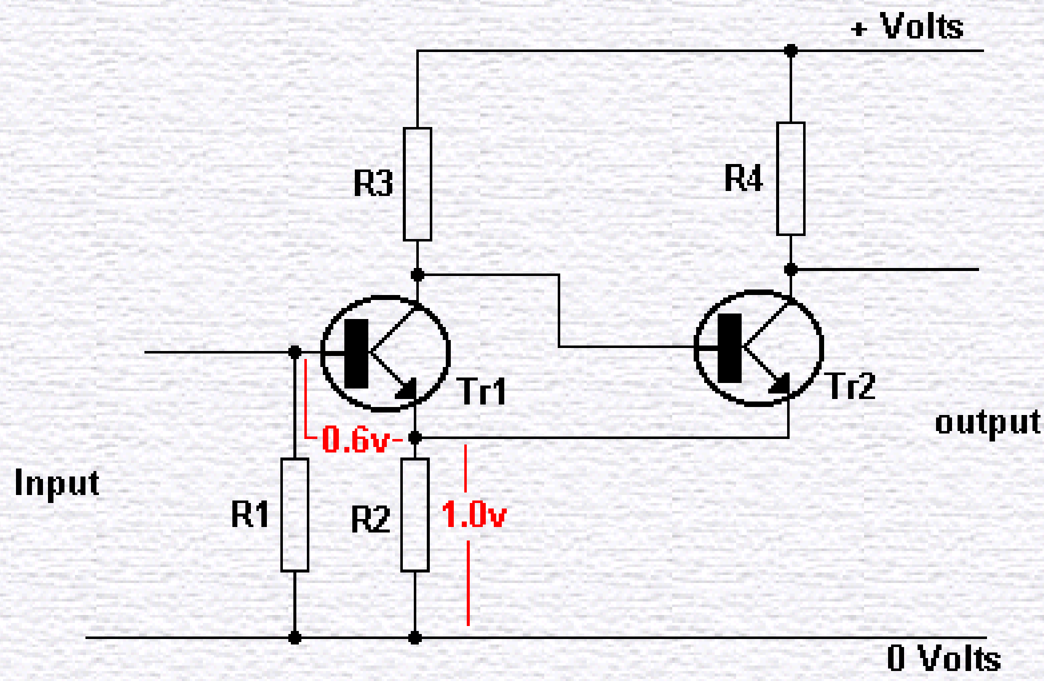

With no signal in,Tr1 has no forward bias and is cut off.

The collector voltage of Tr1 is high, turning Tr2 on.

The emitter current of Tr2 flowing through R2 produces 1 volt across R2.

Since the base of Tr1 is at zero volts, the base/emitter junction of Tr1 is reverse biased by 1 volt.

The input signal has to exceed this voltage plus 0.6 volts (1+0.6 = 1.6 volts) to forward bias Tr1.

INPUT GOES HIGH TO MAKE OUTPUT HIGH

The input signal increases from zero.

Once the input voltage exceeds 1.6 volts,Tr1 begins to conduct.

Its collector voltage starts to fall and the base voltage of Tr2 falls.

The emitter current of Tr2 through falls, reducing the voltage across it.

This further increases the conduction of Tr1, producing a cumulative effect.

Tr1 comes on very rapidly and Tr2 goes off.

Tr2 collector voltage goes high.

INPUT GOES LOW TO MAKE OUTPUT LOW

When the input voltage falls, it has to go below 0.6 volts before Tr1 collector current starts to fall.

Again there is a cumulative action which rapidly turns Tr1 off and Tr2 on.

Tr2 collector voltage falls.

The difference in the values of Tr1 base TURN ON and TURN OFF voltages is known as HYSTERESIS.

The Schmitt Trigger can be used to clean up noisy signals or to speed up slow rise and fall times of pulses.

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THE DIFFERENCE AMPLIFIER

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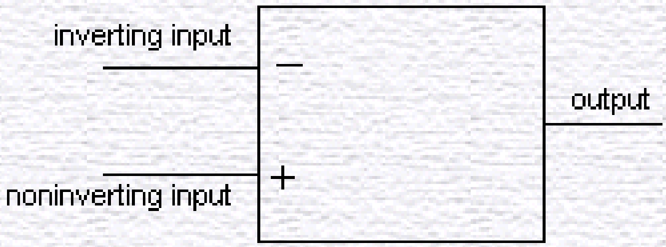

The difference amplifier has two inputs and one output.
It amplifies the difference between the voltages at the two inputs.
If the voltage on one input is 10 mV and 15 mV on the other then the difference is 5 mV.
If the amplifier amplifies by ten times then the output voltage will 5 mV times 10 which equals 50 mV.

If the two inputs are joined together and a voltage applied to them, then the voltage on both inputs will be the same. There is no difference between them and there will be no output from the amplifier.
Even if the input voltage is varied there will be no output.

If, when being used as a difference amplifier, there is some interference picked up by both inputs, the interfering signal will not appear at the output because both input signals are the same.
Only a difference in inputs will produce an output.

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CIRCUIT SYMBOLS

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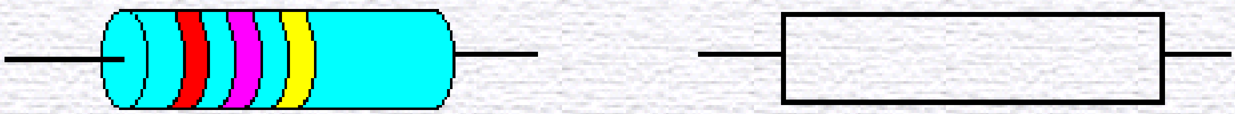
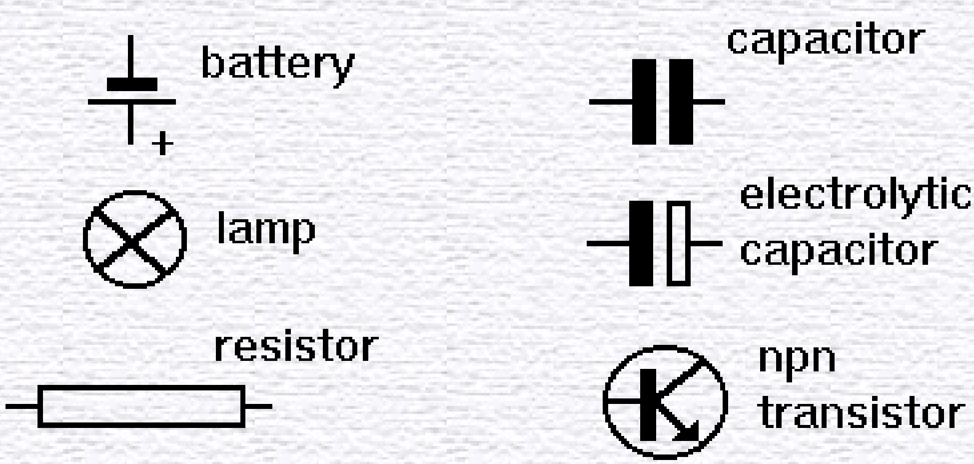
Circuit symbols are a simple representation of electronic components. They simplify the task of drawing circuit diagrams.



A resistor is represented by this symbol

A book called British standard BS3939 contains details of circuit symbols used by industry although there is a tendency to use American symbols in logic circuits.

There are two other pages on this site with more circuit symbols.



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CIRCUIT DIAGRAMS

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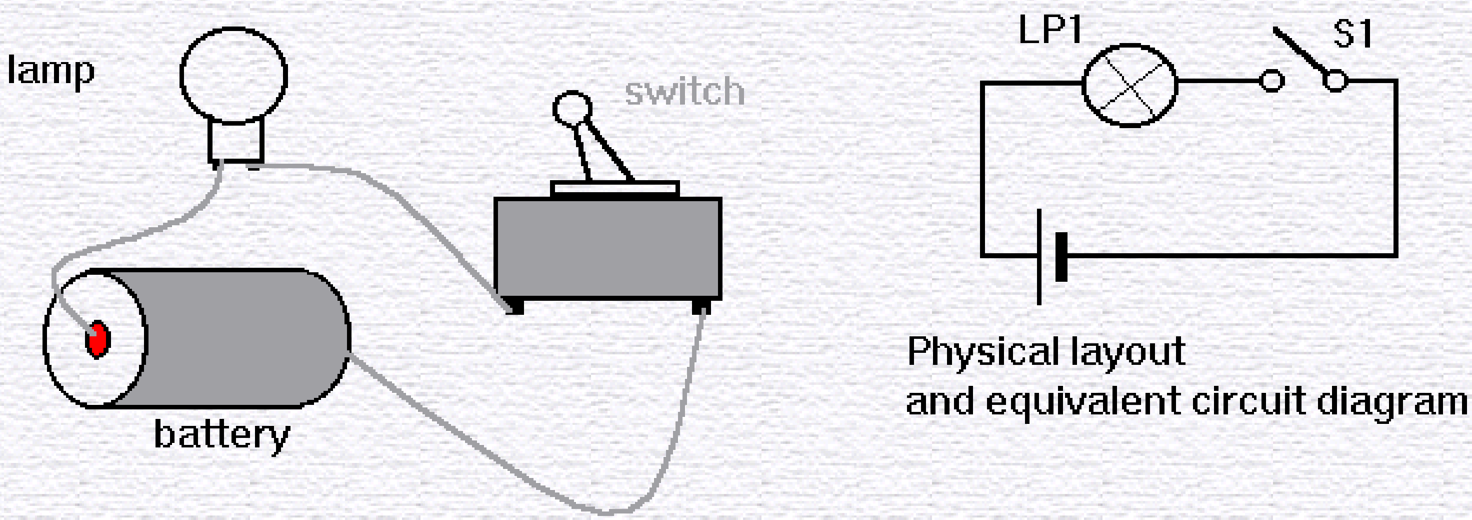
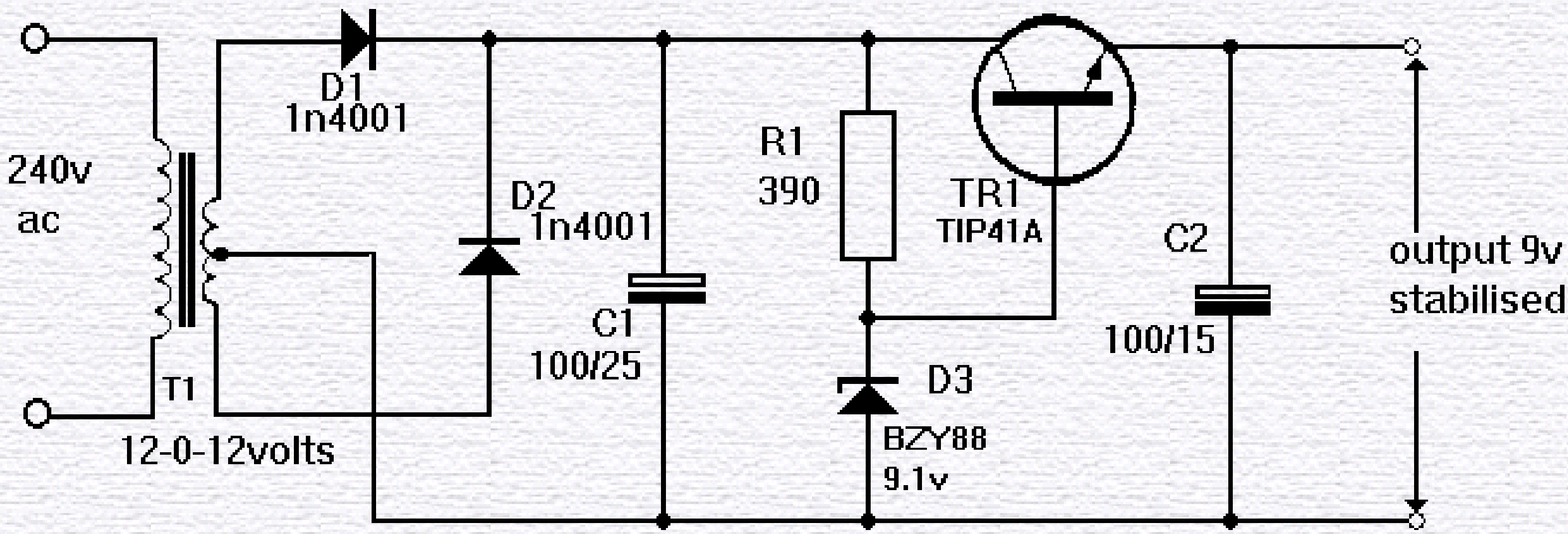
Circuit diagrams are one method of describing electronic equipment.
They are made up of BS3939 standard circuit symbols.



READING a circuit diagram is the ability to look at the diagram and understand how the circuitry works.
Be aware that the layout of the circuit diagram may be nothing like the physical layout of the actual equipment.
Although the circuit diagram shows all capacitors the same size and shape, in reality they will be of assorted sizes, shapes and colour.
This applies to other components.



9 VOLTS DC STABILISED POWER SUPPLY UNIT

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REACTANCE AND IMPEDANCE

Resistors have RESISTANCE, measured in ohms, which opposes the flow of DC current.

Capacitors have CAPACITIVE REACTANCE, measured in ohms, which opposes the flow of AC current.

Inductors have INDUCTIVE REACTANCE, measured in ohms, which opposes the flow of AC current.

Ohms Law can be applied to all of these. VOLTS divided by OHMS gives AMPS.

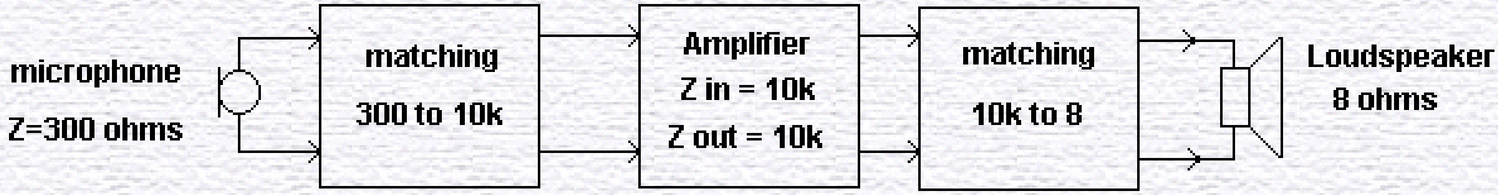
In a circuit which contains all three of the above, the total opposition is called IMPEDANCE (Z) and is measured in ohms. Again Ohms Law can be applied.

Reactances and Impedances can be calculated from formulae. They depend upon the values of the components and the AC frequency.

Capacitive reactance decreases as the frequency increases and also as the value of the capacitor increases.

Inductive reactance increases as the frequency increases and also as the value of the inductor increases.

For optimum transfer of power from one stage to another the impedances must match.
In the diagram the amplifier has an input and output impedance of 10k.
The microphone has an impedance of 300 ohms and the loudspeaker an impedance of 8 ohms.
They are connected to the amplifier via IMPEDANCE MATCHING circuits.


microphone
Z=300 ohms
matching
300 to 10k
Amplifier
Z in = 10k
Z out = 10k
matching
10k to 8
Loudspeaker
8 ohms

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Feedback

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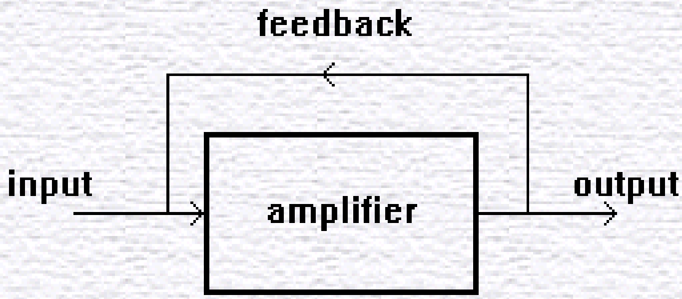

I suggest that you read the page on PHASE first.

Feedback is when some of the output signal from a circuit is fed back to the input and combined with the input signal.

If input and output signals are in phase then the feedback is POSITIVE.

If the two signals are out of phase then it is NEGATIVE FEEDBACK.

Positive feedback in an amplifier increases the gain and reduces the bandwidth of the amplifier.
If there is sufficient positive feedback then the amplifier will oscillate.
If a microphone is too near to a loudspeaker then you will get positive feedback causing "howl round".

Negative feedback reduces gain and increases bandwidth.

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Conductors and Insulators

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CONDUCTORS

These are materials in which it is easy to get electrons to move and provide a flow of electric current.
Conductors are mostly metals such as gold, silver, copper, iron and lead.
Carbon is a conductor as well as some gases (as in fluorescent tubes) and water containing some chemicals.
These are not perfect conductors and offer some resistance to the flow of current.

The resistance of a conductor (such as a metal rod) is determined by three things.

(1) its length. The longer its length the higher its resistance.
(2) its cross-sectional area. The bigger this is the lower is its resistance.
(3) the material of which it is made.

All materials have RESISTIVITY.
The higher the value of resistivity the higher the resistance.
It is measured in OHM METRES.

$$\text{Resistance} = \frac{\text{length x resistivity}}{\text{cross-sectional area}}$$

INSULATORS

These are materials in which it is difficult to get current to flow.
Examples are rubber, pvc, paper, polystyrene and oil.
Even with these it is possible to get some current flowing if the applied voltage is high enough.

There is another class of materials called semi-conductors. These have a resistance between insulators and conductors. Examples are silicon and germanium and are used in diodes and transistors.

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PULSES

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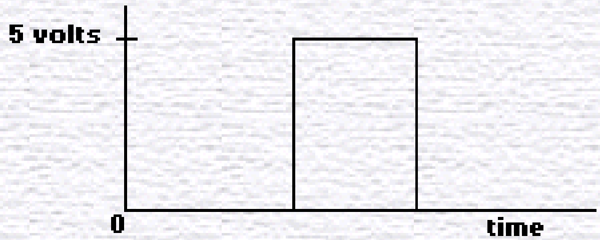
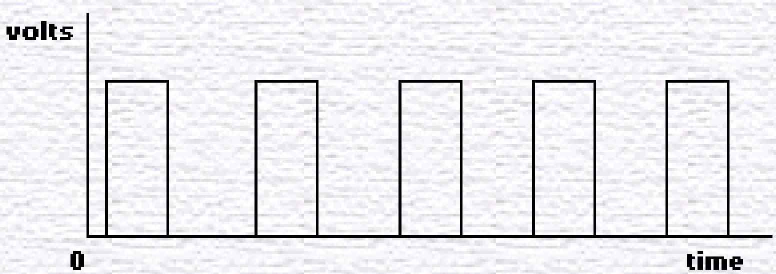
Here is the characteristics of a single pulse.

Fig. 1



The voltage rises very rapidly from zero to its maximum value.
It stays steady at the maximum value for a time.
It then falls very rapidly back to zero.
The duration of a pulse can be anywhere from a very long time (days) to a very short time (picoseconds or less).
Pulses do not rise and fall instantaneously but take time (which may be very short).
They are called the RISE and FALL times.

Fig. 2



If pulses occur one after another they are called a PULSE TRAIN.
The duration time of a pulse is called the MARK.
The time between pulses is called the SPACE.
The relative times are expressed as the MARK/SPACE RATIO.

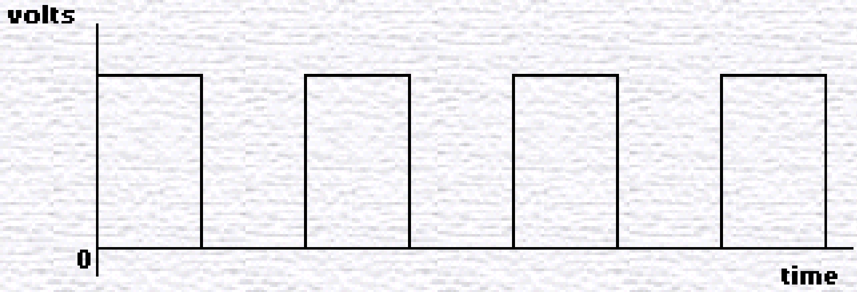


Fig. 3

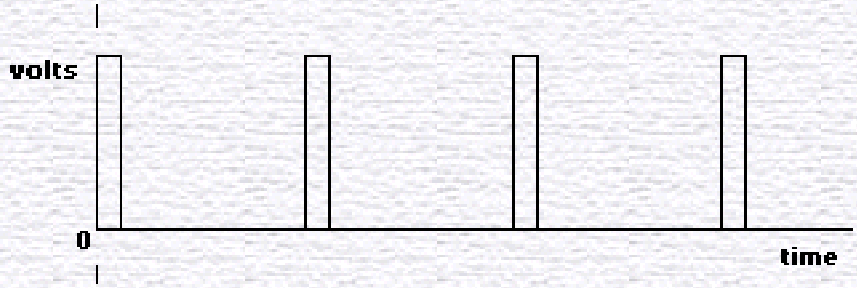


Fig. 4

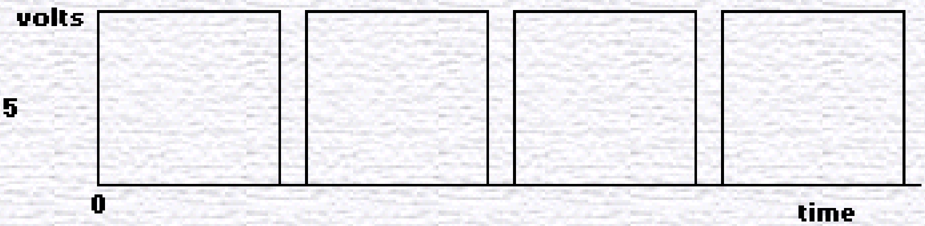


Fig. 5

Mark/space ratios can vary.

Fig. 3 has a 50:50 mark/space ratio.
This is a special case called a SQUARE WAVE.
Fig. 4 is about 1:10
Fig. 5 is about 10:1

Note that the last three waveforms are of the same frequency.
All the pulses start at the same instant.

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GRAPHS AND WAVEFORMS

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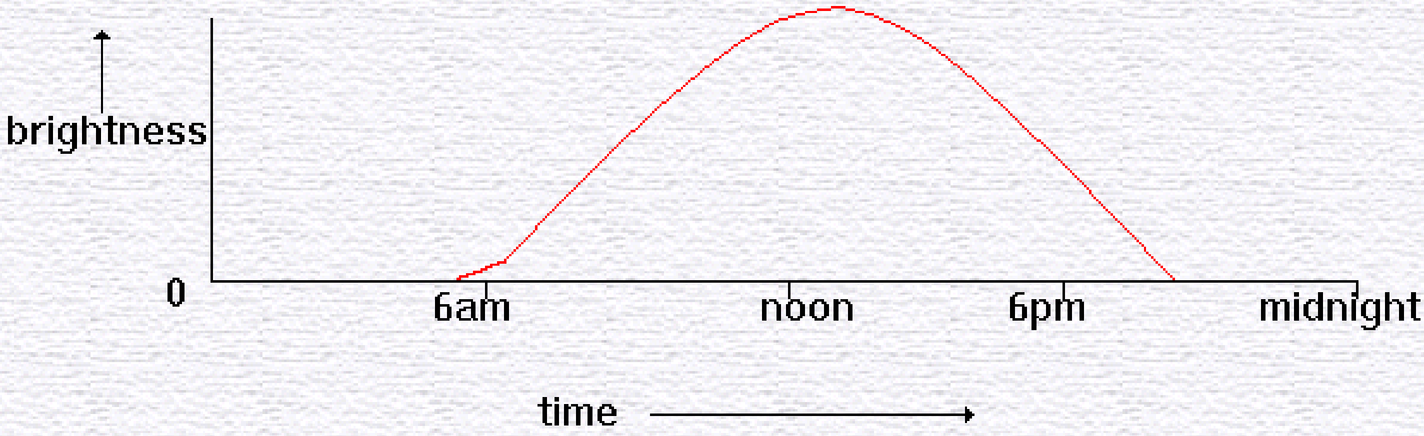
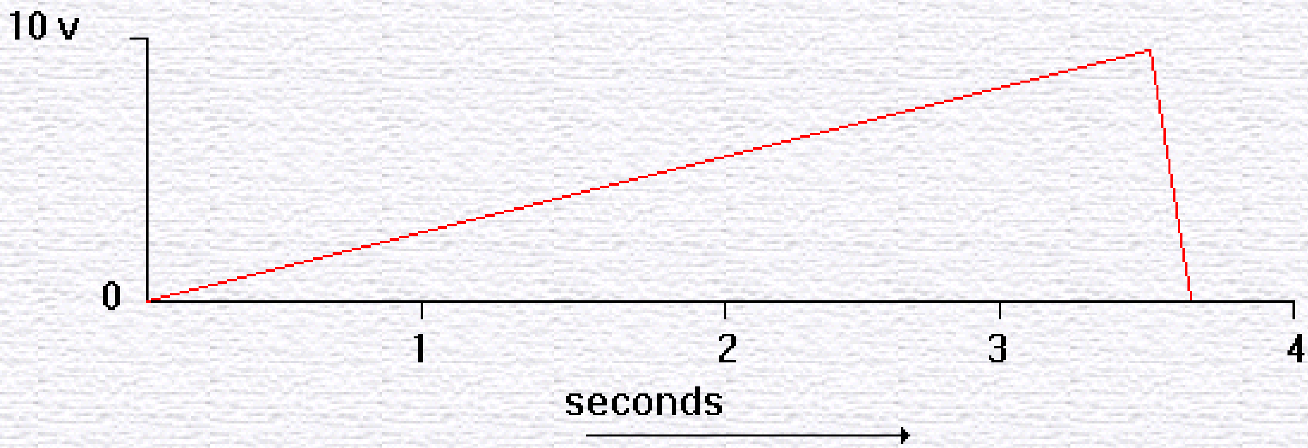
Graphs are one way of showing the relationship between two variables (things that can change in value).



The graph above shows how the brightness of the sun is related to the time of day.
From the start at the bottom left hand corner until just before 6 am brightness is zero. (It is dark).
Brightness increases as time passes being at maximum about 1 pm when the sun is highest in the sky.
Brightness then falls becoming dark at about 9 pm when the sun sets.
Now look at the following graph.

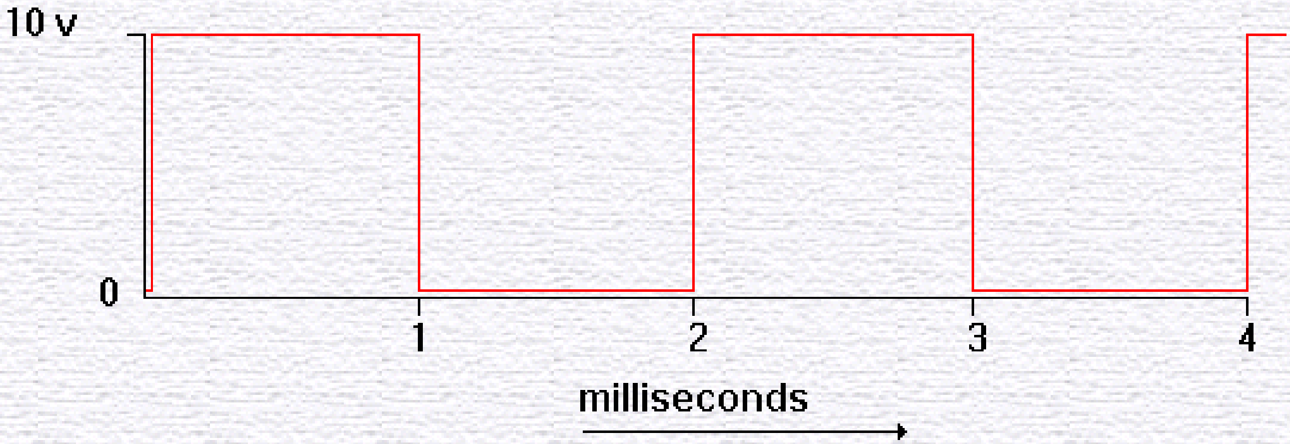
This relates a dry battery voltage to time. It falls slowly over the weeks.

This next graph shows a voltage which slowly rises from zero to a maximum value and then falls suddenly to zero again.

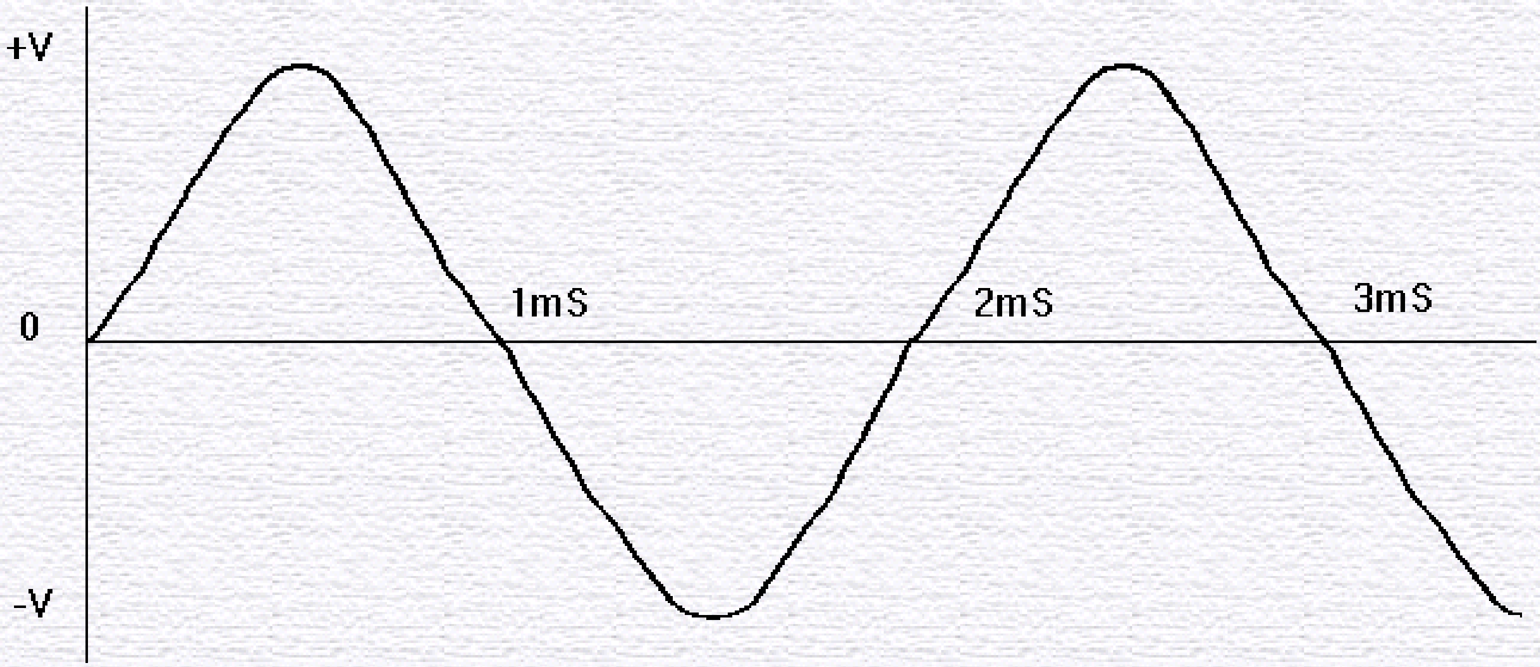


This next graph shows the same thing happening but continues repeating. This is called a WAVEFORM.

The next waveform is called a square waveform because of its shape.
It is at zero for a time and then shoots rapidly to a maximum value and stays there for a time before falling to zero again.
It then repeats itself continuously.



An OSCILLOSCOPE is used to display and measure waveforms.
A common waveform is the SINEWAVE which can alternate between positive and negative voltages.



Note that the horizontal line in all these graphs is called the X axis and the vertical line is the Y axis.

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TIME CONSTANTS

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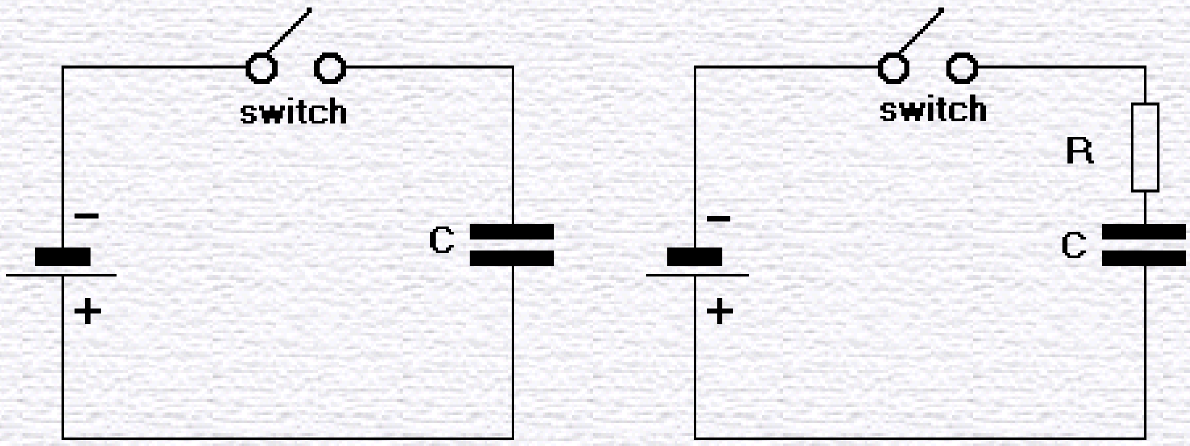


Like charges repel, unlike attract.
In the first diagram, when the switch is closed, the negative terminal of the battery repels the negative electrons and pushes them onto the upper plate of the capacitor C.
Similarly, the positive terminal attracts the negative electrons away from the lower plate.
If the battery is now removed, C remains charged up to the battery voltage.
This can be dangerous, since capacitors can remain charged to high voltages for a long time.

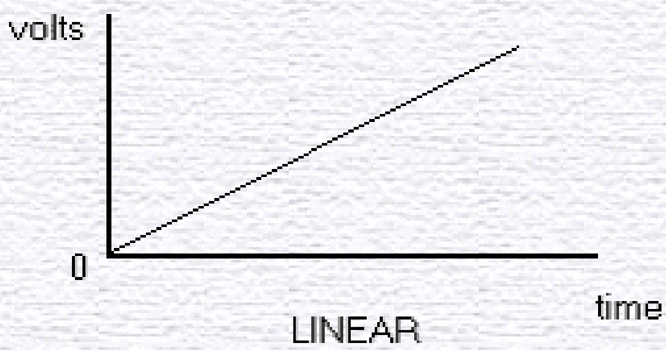
If a screwdriver is now placed across the capacitor terminals, the surplus electrons on the upper plate will now flow to the lower plate.
The C is now discharged.
Doing this can also be dangerous.
The screwdriver has a low resistance, and Mr Ohm says "low resistance means high current". One vapourised screwdriver !!
Therefore large, highly charged capacitors must be discharged via a resistor, to limit the amount of discharge current that can flow.

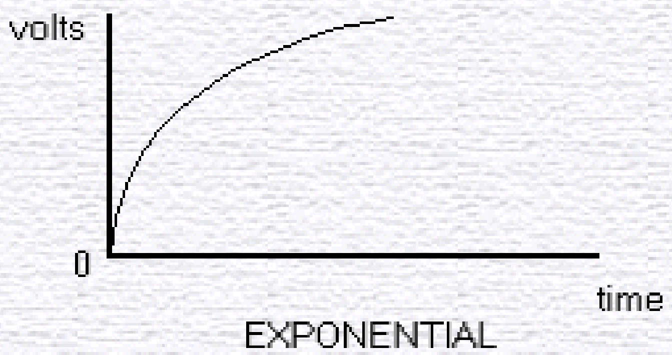
In the second diagram, a resistor R has been placed in series with C.
When the switch is closed, C charges from the battery, as described previously.
The charging current passes through R.
Since R limits the amount of current that can flow (Ohms law), C takes

time to charge up to the battery voltage.
The larger the values of C and R, the longer C takes to charge.
Liken it to filling a bucket with a hosepipe.
The larger the bucket (C), and the more you stand on the hosepipe (R), then the longer it takes to fill the bucket.

The value of C in Farads, multiplied by the value of R in ohms, gives us the TIME CONSTANT (RC), measured in seconds.
If C = 2 Farads and R = 10 ohms then RC = 20 seconds.
This means that C will take 20 seconds to charge up to 63 % of the battery voltage.
If it is a 100 volt battery, then after 20 seconds, the capacitor voltage will be 63 volts.

If we draw a graph of the increase of capacitor voltage against time, then we get a curve that is not linear (not a straight line).
The curve is exponential.
It increases rapidly at the start and then slows down.
It gets slooower and sloooooower.





If C is discharged, by connecting a resistor across it, then the capacitor voltage falls BY 63 % after RC seconds.

Time constants are often used where a time delay is required.

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THE SOURCE AND THE LOAD

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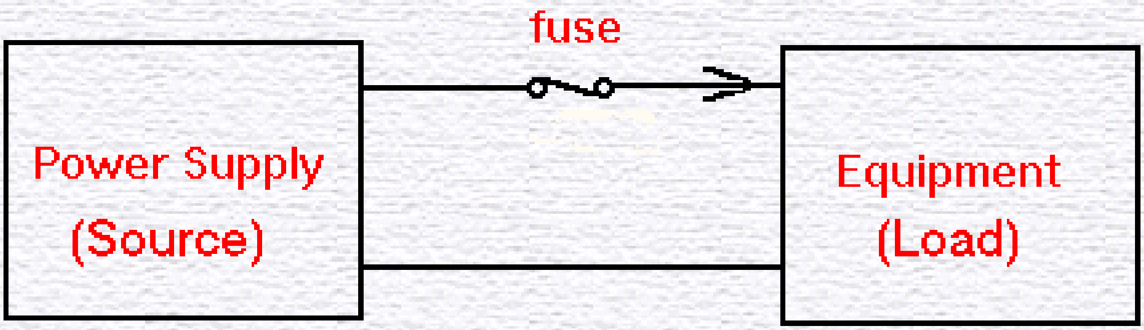

The SOURCE is a source of power. The LOAD is powered by the source.
Two terminals on the source are connected to two terminals on the load.

SOURCE	LOAD
battery	amplifier
amplifier output	loudspeaker
microphone	amplifier
motor	lathe
dynamo	lamp
legs	bicycle
supply	cooker

Current flows out of the source through one lead, through the load and then back to the battery via the other lead.

The value of the current flowing back to the battery is exactly the same as that leaving. Nothing is lost or gained.

To protect the load and source against excessive current flowing due to a fault, a fuse is inserted in one of the leads.

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RMS AND PEAK TO PEAK VOLTAGES

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If someone measures the value of the AC voltage coming out of a transformer using an oscilloscope and says it is 20 volts peak to peak and we use a voltmeter to confirm this we will find that the meter reads only 7.07 volts.

This is because the scope measures peak to peak values and the meter measures RMS values.

In figure 1 the 'scope displays the peak value. The peak to peak voltage is twice this.
For example if the peak is 10 volts then the peak to peak is 20 volts.

When using a meter to measure the same AC voltage a different value is obtained. This is because, as we said, meters measure RMS values.

A Root Mean Square (RMS) voltage gives the same heating effect as a DC voltage of the same value.
See figures 2 and 3. Both thermometers show the same temperature when the resistors are heated by the current passing through them.

RMS values can be converted to peak to peak values and vice-versa.

RMS values times 1.414 equals the Peak value.
Peak to Peak is twice this.
7.07 volts RMS times 1.414 and then doubled is 20 volts, the Peak to Peak value.

Peak values times 0.707 gives the RMS value.
Don't forget that Peak is half the Peak to Peak.
20 volts Peak to Peak is 10 volts Peak. 10 volts Peak times 0.707 equals 7.07 volts RMS.

The Mains supply voltage in the UK is 230 volts RMS.

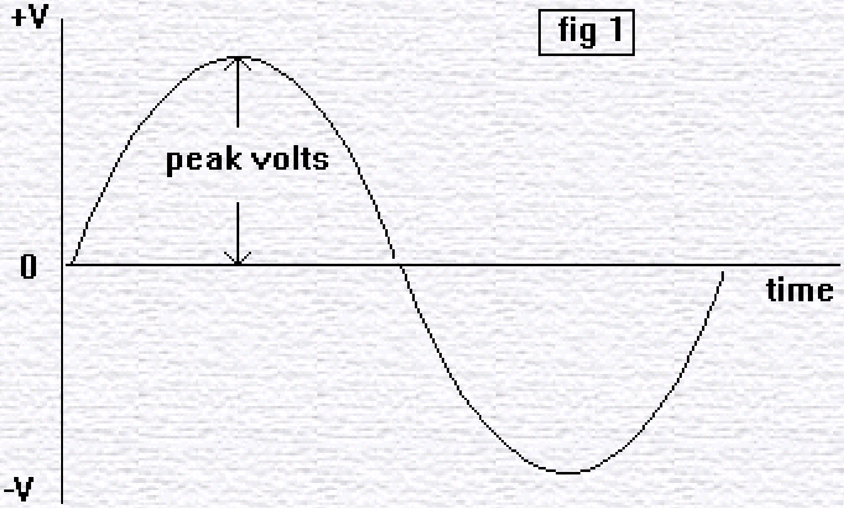

fig 1

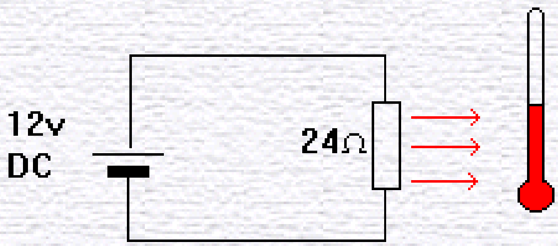

fig 2

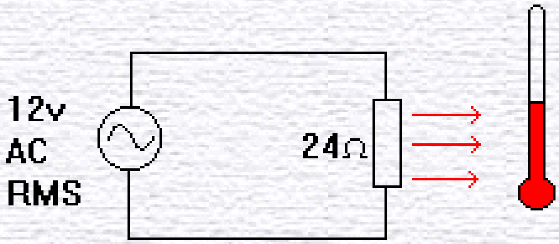

fig 3

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FILTERS

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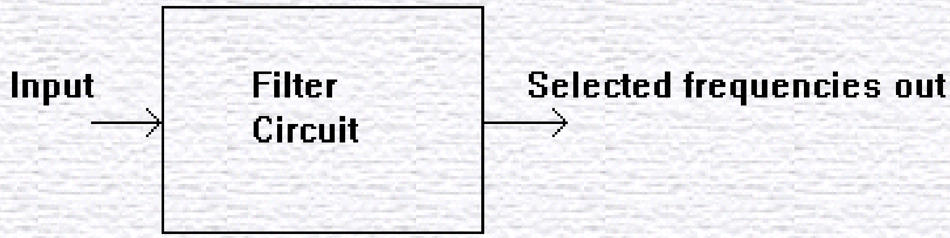


fig. 1

A filter circuit is like a sieve. It allows some things through and holds back others. In this case we are talking about AC frequencies. Some frequencies pass through the filter while others are rejected.

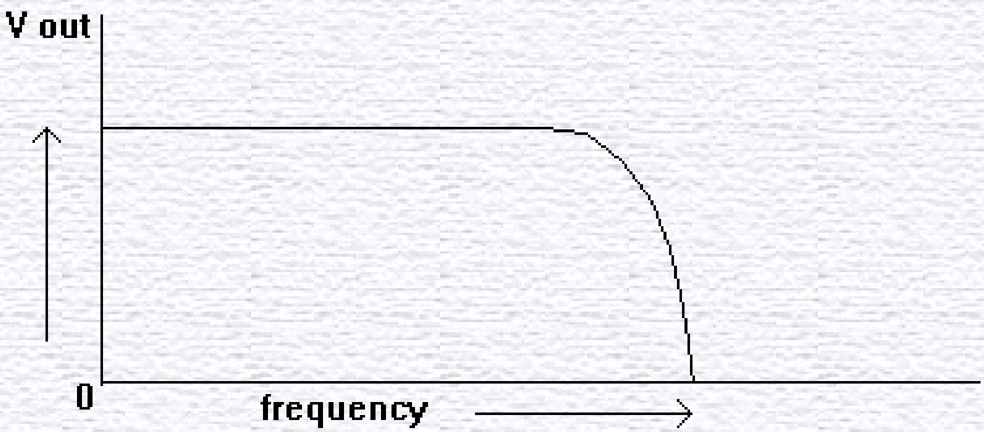


Fig. 2

The characteristics of a filter can be shown on a graph called a FREQUENCY RESPONSE CURVE.

VOLTAGE OUT is plotted against FREQUENCY.

Figure 2 shows a LOW PASS filter response curve giving output at low frequencies but none at higher frequencies.

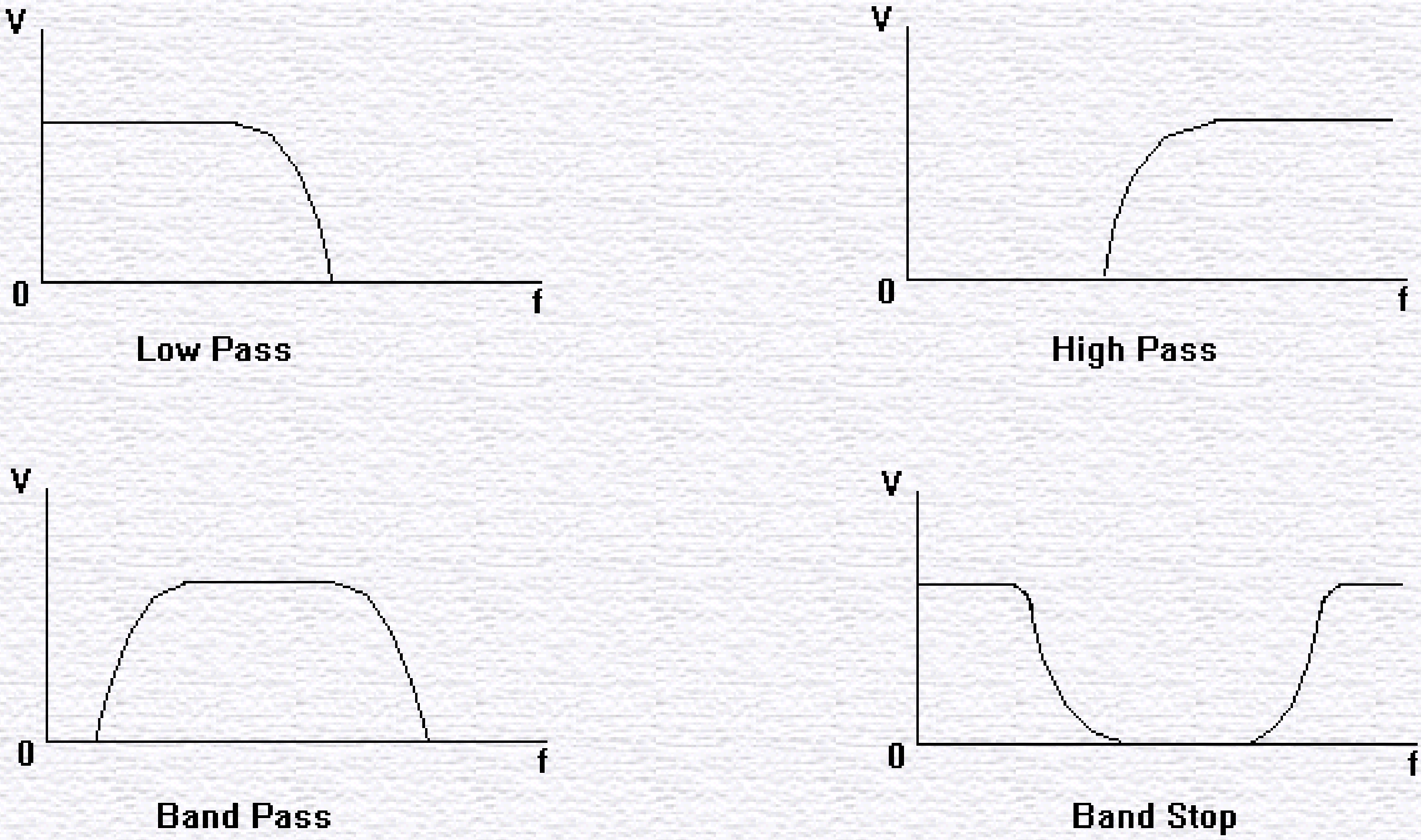


Fig. 3

Figure 3 shows a selection of filter characteristics.

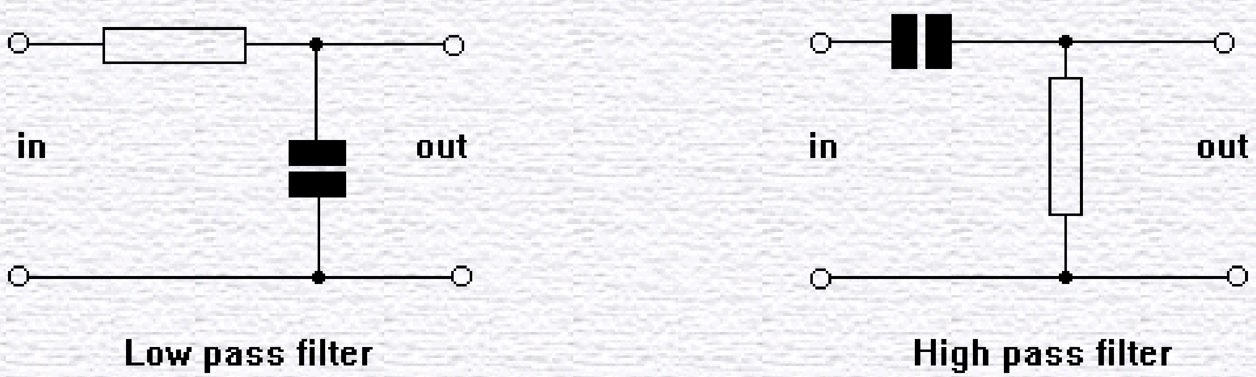
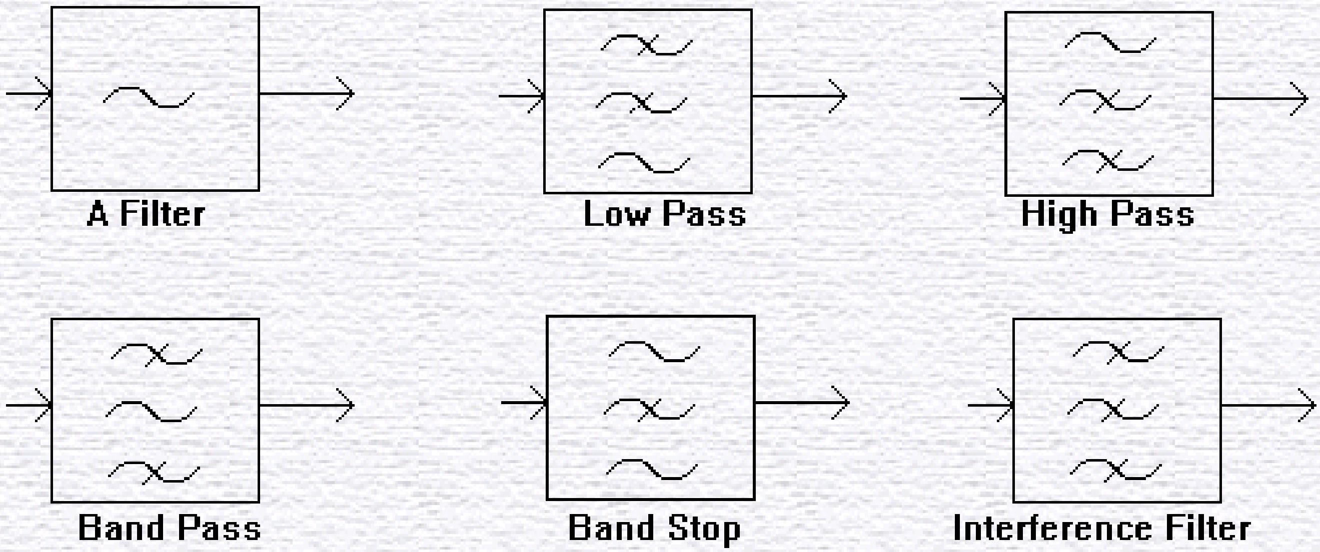


Fig. 4

Simple filters can be made from capacitors and resistors



BLOCK DIAGRAM SYMBOLS FOR FILTERS

Filters have many applications.

In audio frequency amplifiers, CROSSOVER filters to direct low frequencies to the WOOFER and high frequencies to the TWEETER speakers.

In SCRATCH filters to remove unwanted high frequency noise.

In NOTCH filters to remove whistles due to two radio stations being too close together in frequency.

In Hum filters to remove low frequency noise due to the mains supply.

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THE INTEGRATOR

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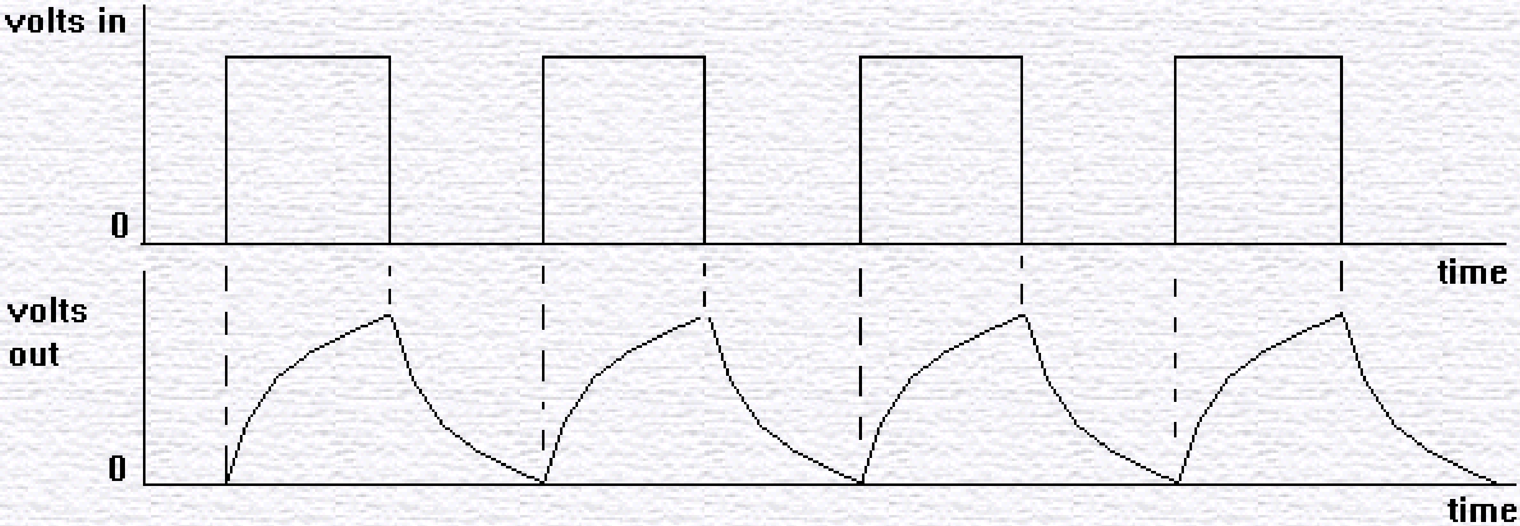

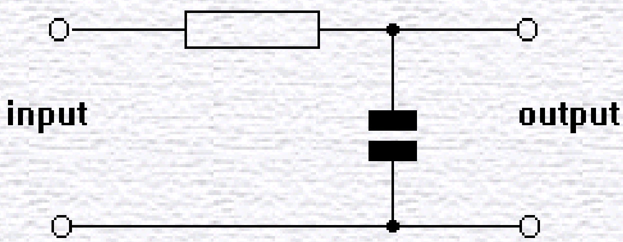

Read the page on TIME CONSTANTS before tackling this one.

The integrator consists of a capacitor and resistor connected as shown.

A PULSE TRAIN is applied to the input.

When an input pulse rises rapidly to maximum the capacitor charges exponentially through the resistor as shown in the lower waveform.

When the input pulse falls suddenly to zero the capacitor discharges exponentially to zero.

The process is repeated for each pulse giving the waveform shown.

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THE DIFFERENTIATOR

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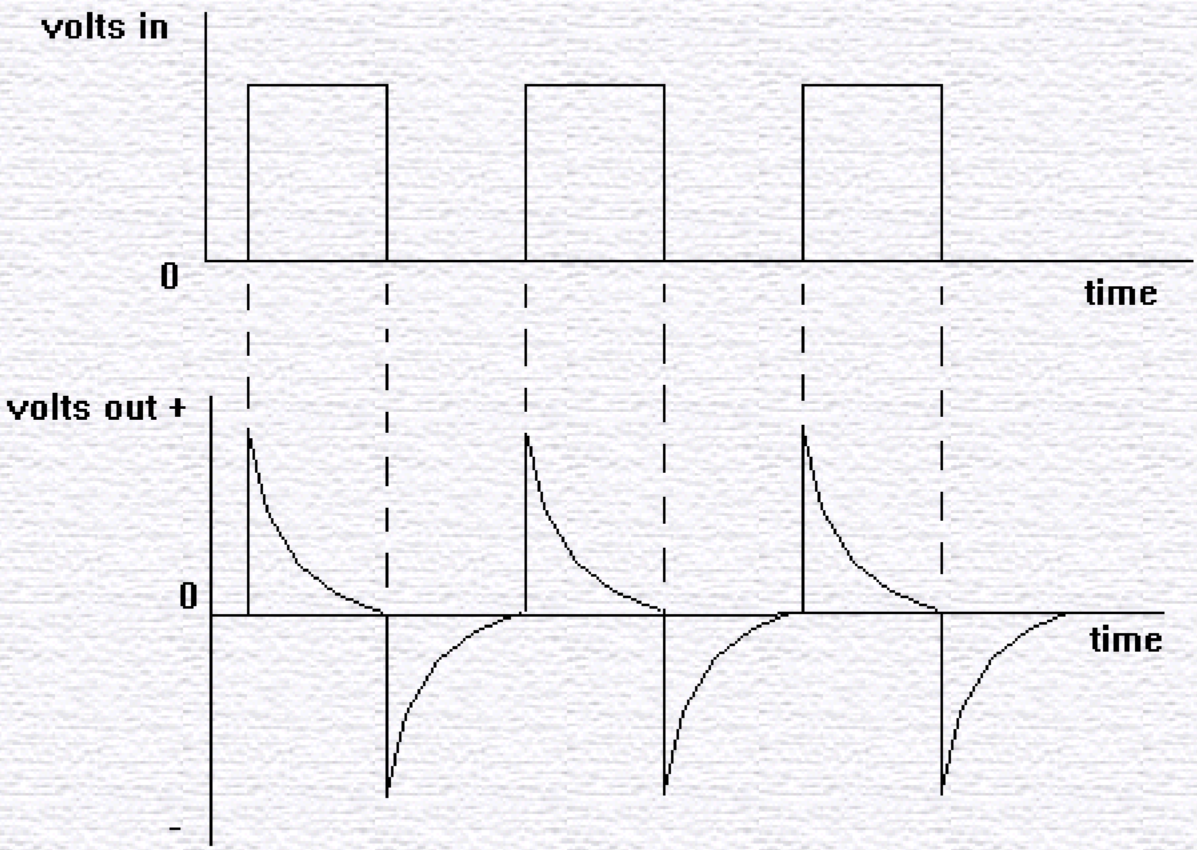

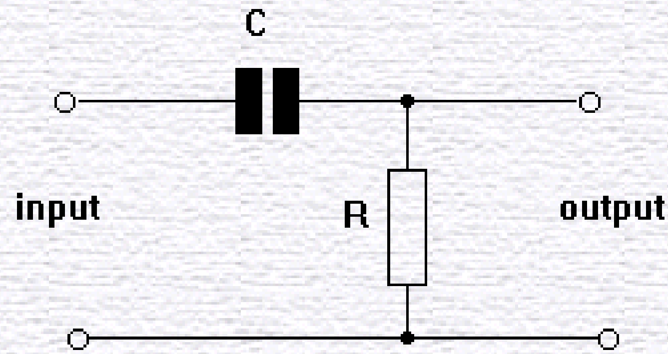

Read the page on TIME CONSTANTS before trying this one.

The differentiator is made from a capacitor C, and resistor R, and assembled as shown.
A PULSE TRAIN is applied to the input.
When a pulse of voltage rises suddenly from zero to maximum, the current which is charging C suddenly rises to a maximum value as well.
As C charges, the charging current falls exponentially to zero.
Since this charging current is passing through R the voltage across R (which is the output voltage) does the same.***
Therefore we get the shape shown, with the voltage out rising suddenly to maximum and then falling exponentially to zero.

When the pulse falls to zero C discharges.
The discharge current is high at the start and then falls exponentially to zero as C discharges.
However, since the discharge current is in the opposite direction to the charge current the voltage across across R will be reversed and so the waveform is now shown below the zero line.

For each pulse the waveform out is repeated giving the display shown.

*** Ohms Law says that current is proportional to voltage. Conversely, voltage is proportional to current.

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ELECTROMAGNETISM

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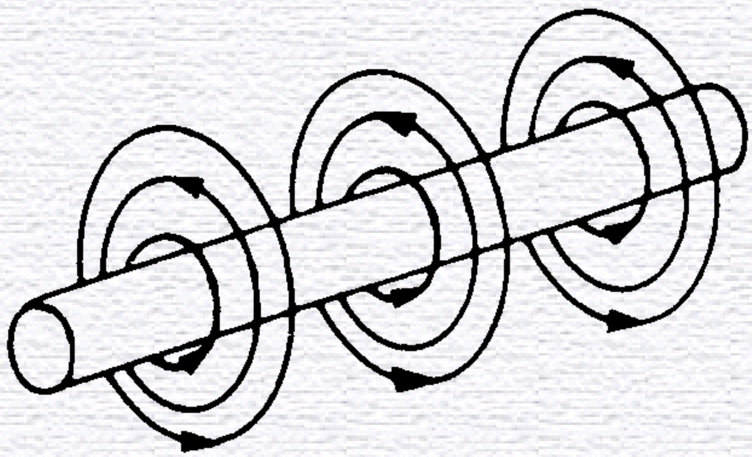
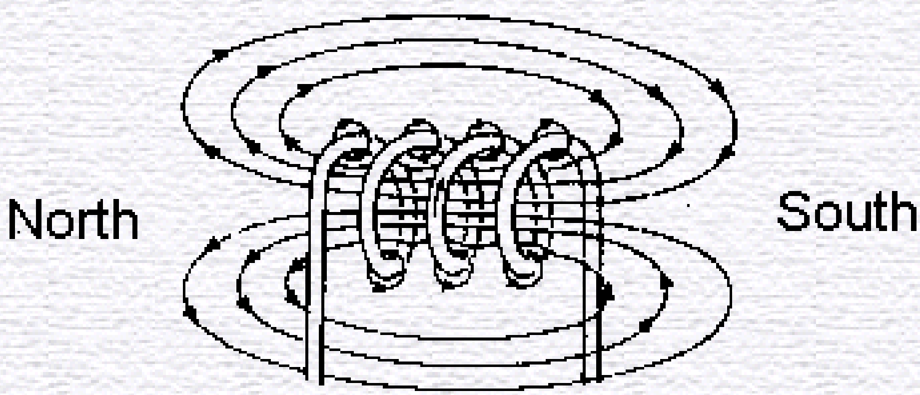
When current travels through a wire, a magnetic field, made of lines of force, is formed around the wire.



If the wire is coiled, the lines of force link with each other.



The result is a magnetic field with the same shape as the field surrounding a bar magnet.
The strength of the field is determined by the number of turns and the current through the coil.
The field can be concentrated by placing a steel or iron CORE in the centre of the coil.

This is called an ELECTROMAGNET or SOLENOID.

If a soft iron core is used, it becomes only temporarily magnetised when the current is switched on, losing its magnetism when switched off.
This effect is used in bells and buzzers, and in scrapyards for shifting metal scrap around.

The field has a North and a South pole.
It obeys the same rules as a bar magnet.
Like poles repel each other, unlikes attract.

Electromagnets can react with bar magnets.
This effect is used in loudspeakers, moving coil meters etc.

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THE ELECTRIC GENERATOR PRINCIPLE

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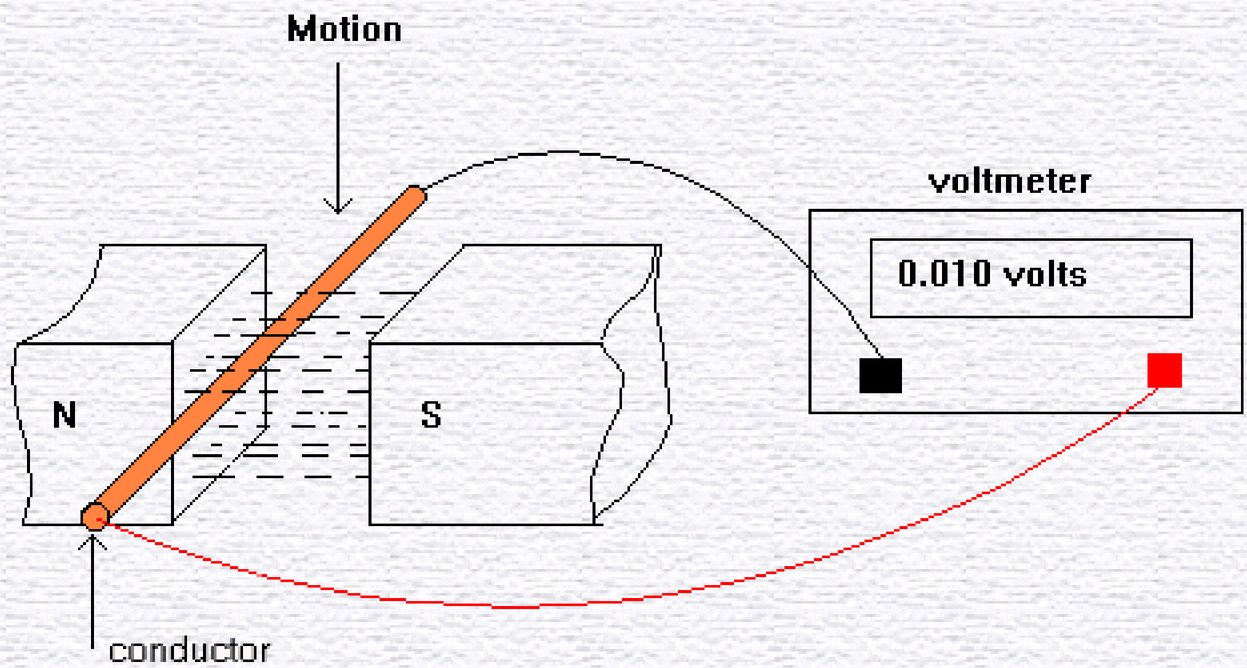

Read the page on magnetism.

When a piece of wire is moved through a magnetic field, a voltage and current is induced in the wire.
The same effect is obtained if the wire is stationary and the field is moved.

The direction of current flow is determined by the direction of the field, and the direction of the movement.
The amplitude of the voltage is determined by the rate at which the wire cuts the lines of force.
Increasing the density of the field or increasing the speed of the wire therefore increases the voltage.

This principle is used in the electric generator, where a coil is rotated in a magnetic field to generate electricity.
It is also used in the moving coil microphone, where sound causes a coil to vibrate in a magnetic field, generating voltages which represent the sound waves.

The Electric Motor Principle is related.

It relies on passing a current through a wire in a magnetic field to provide movement.

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THE RADIO FREQUENCY SPECTRUM

FREQUENCY RANGE	CLASSIFICATION
3 - 30 kilohertz	Very low frequencies (VLF)
30 - 300 kilohertz	The long wave band (LW)
300 - 3000 kilohertz (3 megahertz)	The medium wave band (MW)
3 - 30 megahertz	The short wave band (SW)
30 - 300 megahertz	Very high frequency band (VHF)
300 - 3000 (3 gigahertz)	Ultra high frequency band (UHF)
3 gigahertz - 30 gigahertz	Super high frequency band (SHF)
300 - 3000 gigahertz	Microwave frequencies

Higher in frequency than this are infra red, visible light, ultra violet, X rays etc which are all forms of Electro Magnetic radiation.

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MAGNETS

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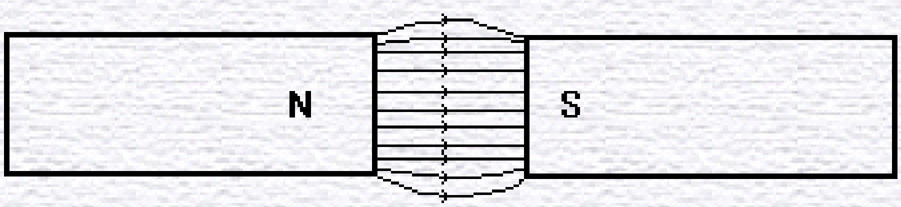
Some irons, when dug up, attract other metals.
They are called MAGNETS.
The reason that they are magnetic is that their DOMAINS are aligned.

One end of a bar magnet is the NORTH POLE, the other end the SOUTH POLE.

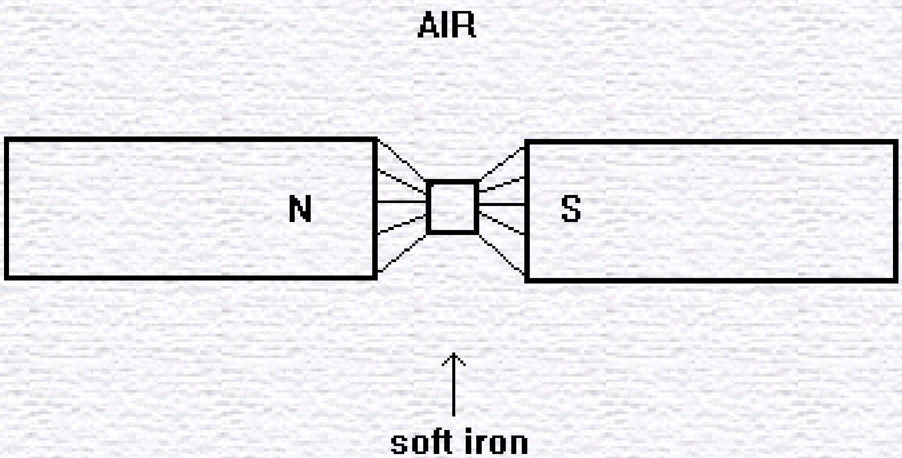
A rule of magnetism is that LIKE POLES REPEL, UNLIKE POLES ATTRACT.
North attracts South and repels North etc.
The North pointer on a compass is actually a South pole since it is attracted by the North pole of the earth.

A magnet is surrounded by an invisible MAGNETIC FIELD made of magnetic LINES OF FORCE.
These lines of force can be made visible by covering a magnet with a sheet of paper and sprinkling iron filings on the paper.



The lines of force run from north to south.

Lines of force pass through all materials including insulators.
They pass through some more easily than others.
These are said to have a lower RELUCTANCE.
Iron has a lower reluctance than air.
The lines of force prefer to pass through lower reluctance materials.



PERMANENT magnets are made of steel or steel alloys.
Brass, copper and aluminium do not magnetise.

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THE MOTOR PRINCIPLE

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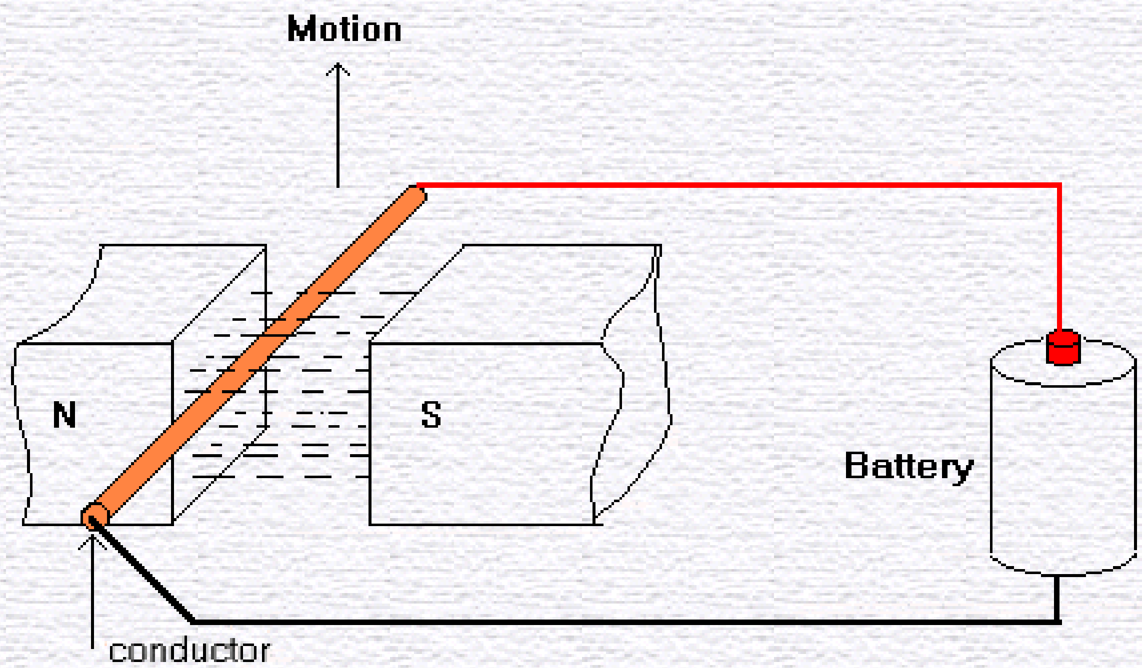

Read the page on magnetism.

When a current is passed through a wire which is suspended in a magnetic field, the wire will move.
The direction of movement is determined by the direction of the field and the direction of the current.
The speed of movement is determined by the strength of the field and the amplitude of the current.

This principle is used in the electric motor to produce rotation.

It is also used in the loudspeaker where varying speech currents through a coil, suspended in a magnetic field, causes movement of a cone, resulting in sound pressure waves.

The moving coil meter uses the same idea.
When the meter is connected to a circuit, current passes through a coil.
The coil is suspended in a magnetic field,and rotates when current passes through it.
A pointer fixed to the coil indicates a value on a scale.

The Electric Generator Principle is related.
Here a coil is moved in a magnetic field.
This induces voltages and current in the coil.

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AMPLIFIERS

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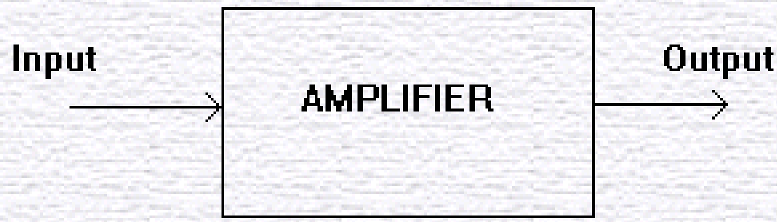

Amplifiers are used to increase the voltage or power amplitude of signals.
They have many applications.

AUDIO VOLTAGE amplifiers boost the amplitude of signals between the frequency range 20 Hz to 20 KHz. This is the range of human hearing.
They are often used as PRE-AMPLIFIERS before the main amplifier.

AUDIO POWER amplifiers provide the power necessary to drive loudspeakers. They also amplify a frequency range from 20Hz to 20 KHz.

INTERMEDIATE FREQUENCY (i.f.) amplifiers are used in radio receivers.
High frequency radio signals are changed to the lower intermediate frequency by a FREQUENCY CHANGER circuit.
The i.f in A.M. radios is about 455 KHz. In F.M. radios it is 10.7 MHz.

RADIO FREQUENCY amplifiers amplify a selected band of frequencies.
Radio frequencies extend from about 30 KHz up to several thousand MHz.
The band of frequencies is selected by a BAND PASS FILTER or a TUNING circuit.

WIDE BAND amplifiers are designed to amplify a very wide band of frequencies, say from a few Hertz up to several hundred MHz.

VIDEO amplifiers are used in television cameras, receivers, vcr's etc. The bandwidth extends from DC up to about 6MHz.

DIRECTLY COUPLED amplifiers have no coupling capacitors between stages so that they are able to amplify DC signals.

DIFFERENTIAL amplifiers have two inputs and amplify the DIFFERENCE between the two input voltages.
If both inputs are the same then there is no output from the amplifier.
If there is an interfering signal then it will be picked up by both inputs and will not be amplified.
OPAMPS are commonly used as differential amplifiers.

See the page on FREQUENCY RESPONSE for more information.

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CLIPPERS AND LIMITERS

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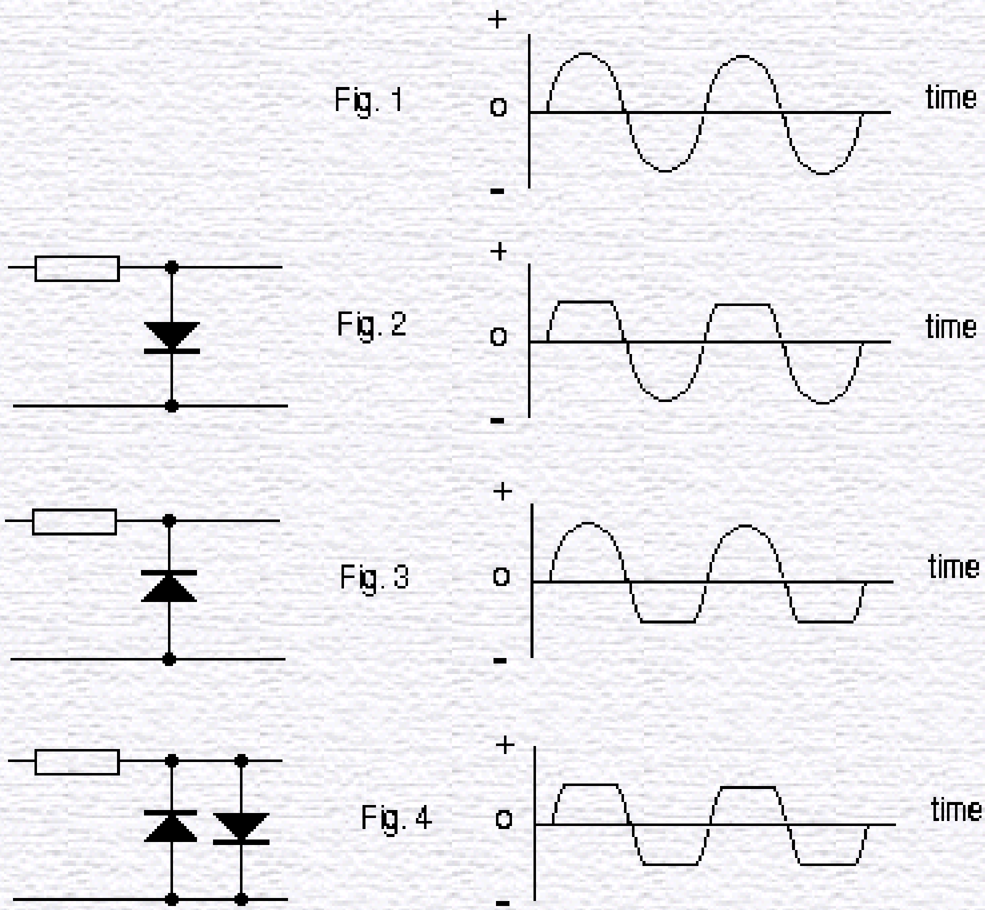

Clipping removes part of the positive or negative peaks of a signal or both.

Silicon diodes do not conduct until the applied voltage exceeds about 0.6 volts and only when the anode is positive with respect to the cathode.

The circuit is like a potential divider with the diode part being high resistance for voltages below 0.6 volts and low resistance above.

Fig. 1 shows the waveform into the clipper.

Fig. 2 is the output of a positive clipper and fig. 3 the output of a negative clipper.

Fig. 4 has both peaks clipped and is often used as a LIMITER where the output must not exceed 1.2 volts.

OSCILLATORS

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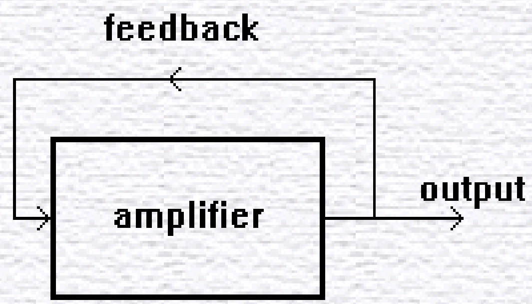

Oscillators are amplifiers with such a large amount of positive feedback that they produces an output signal with no signal applied to the input.
The output amplitude is determined by the gain of the amplifier and the feedback circuit.

Oscillators can produce sine waves, the frequency of which is determined by TUNED CIRCUITS.
Tuned circuits consist of a capacitor and inductance.

Square wave oscillators use resistors and capacitors to determine the frequency of oscillation.

Ideally the frequency of an oscillator should be stable, but due to temperature variations and mechanical vibration this may not be so.
Precautions are taken against frequency DRIFT.

"Howl round", caused by placing a microphone too close to a loudspeaker, is an audio oscillation caused by positive feedback.

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PHASE

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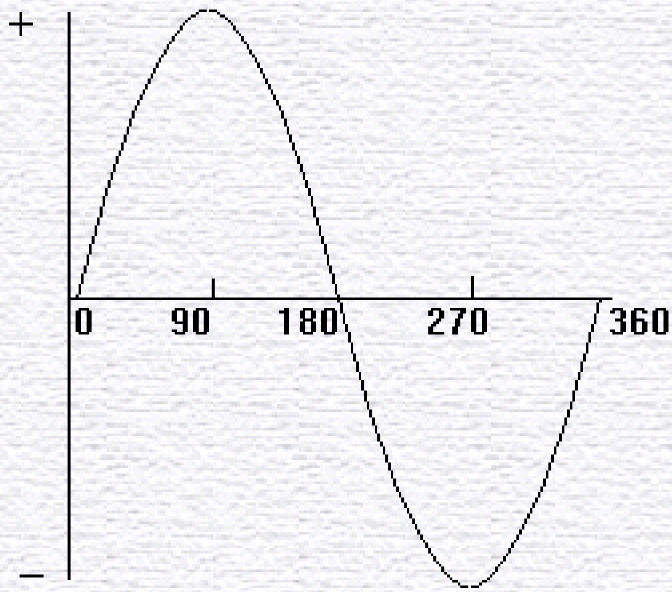
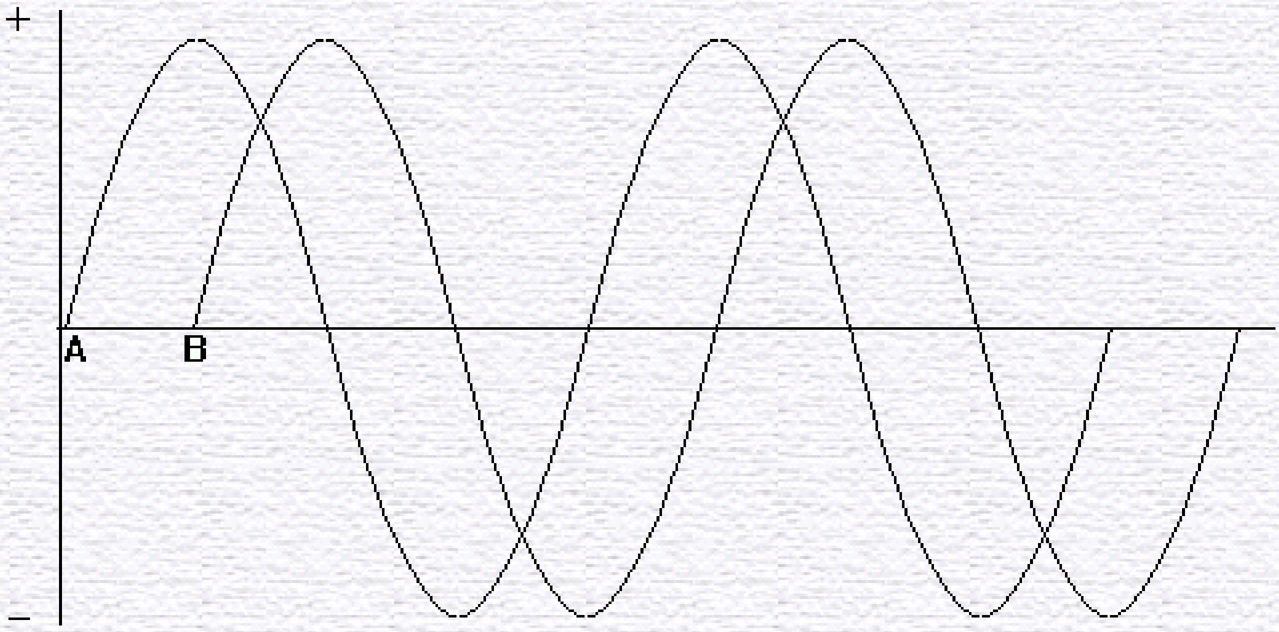
The generator at the power station which produces our AC mains rotates through 360 degrees to produce one cycle of the sine wave form which makes up the supply.



In the next diagram there are two sine waves.
They are out of phase because they do not start from zero at the same time.
To be in phase they must start at the same time.
The waveform A starts before B and is LEADING by 90 degrees.
Waveform B is LAGGING A by 90 degrees.

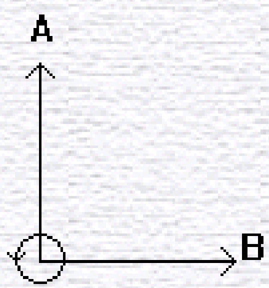


The last diagram, known as a PHASOR DIAGRAM, shows this in another way.

The phasors are rotating anticlockwise as indicated by the arrowed circle.
A is leading B by 90 degrees.

The length of the phasors is determined by the amplitude of the voltages A and B.
Since the voltages are of the same value then their phasors are of the same length.
If voltage A was half the voltage of B then its phasor would be half the length of B.

All this has nothing to do with "set your phasors on stun".



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LIGHT

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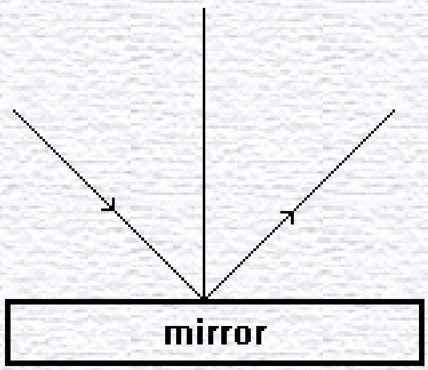
Light is an electromagnetic wave similar to radio waves. It has wavelength and frequency.
It travels at 300,000,000 metres per second.
Wavelength, frequency and the speed of light are related.

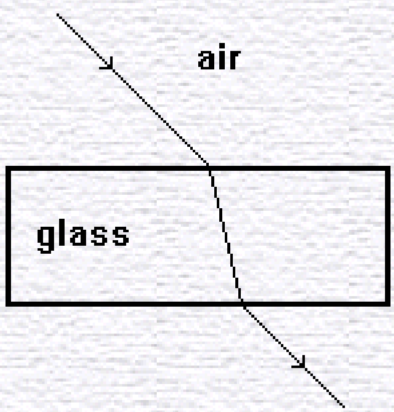
Wavelength x frequency = the speed of light.

Different colours of light have different frequencies.

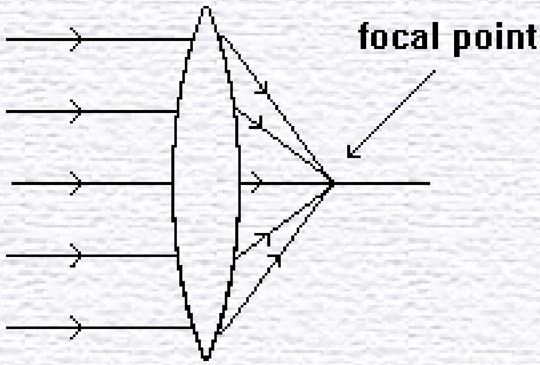
When a ray of light hits a shiny surface it is REFLECTED.
The angle of reflection equals the angle of incidence.



When light passes from one transparent material to another it is REFRACTED.(bent).

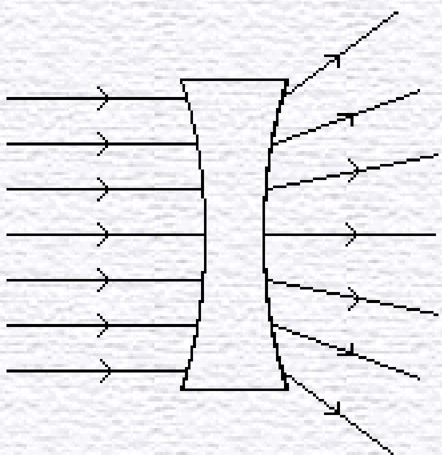


LENSES use refraction. CONVEX lenses FOCUS a beam of light to a point.



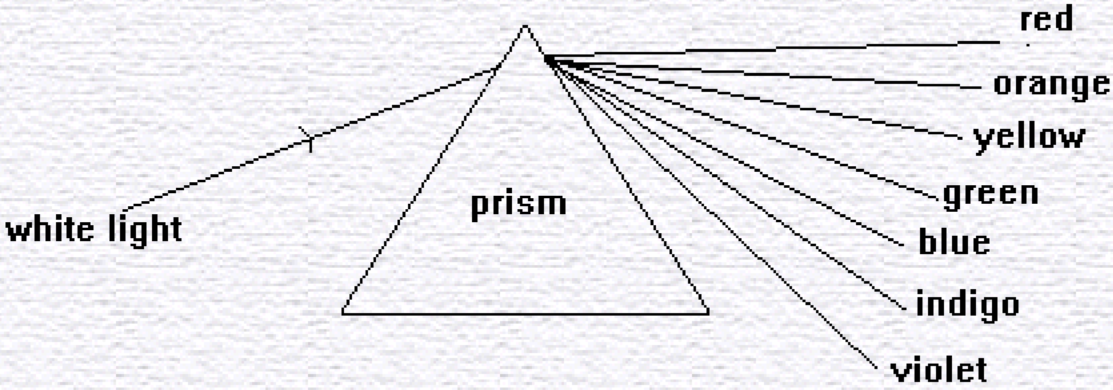
convex lens

CONCAVE lenses cause the beam to DIVERGE.

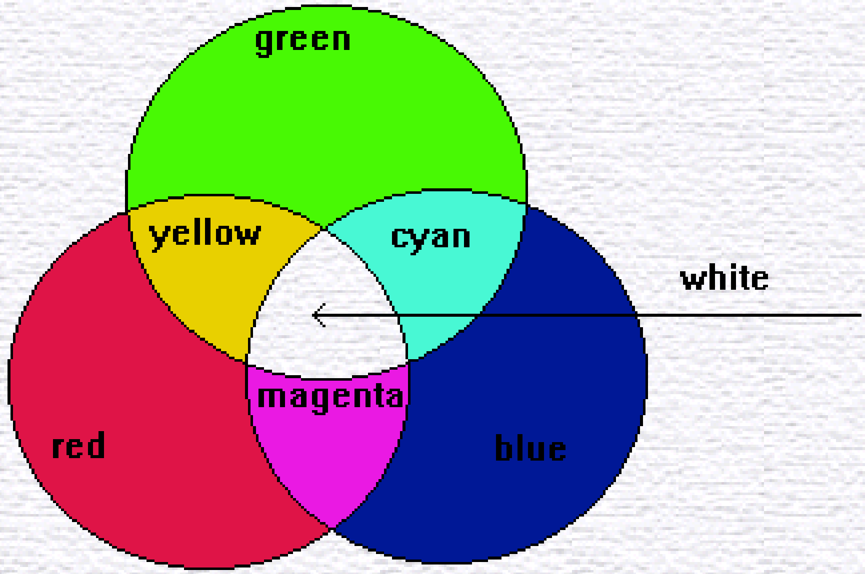


concave lens

The PRIMARY colours which make up white light can be separated out by a glass PRISM.



Three of the primary colours, RED, GREEN and BLUE are used in the colour television system.
By mixing them most other colours can be made.
In the next diagram, red and green make yellow, green and blue make cyan and red and blue make magenta.
White is made by using all three colours.



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FREQUENCY MODULATION

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Read the page on Amplitude Modulation first.

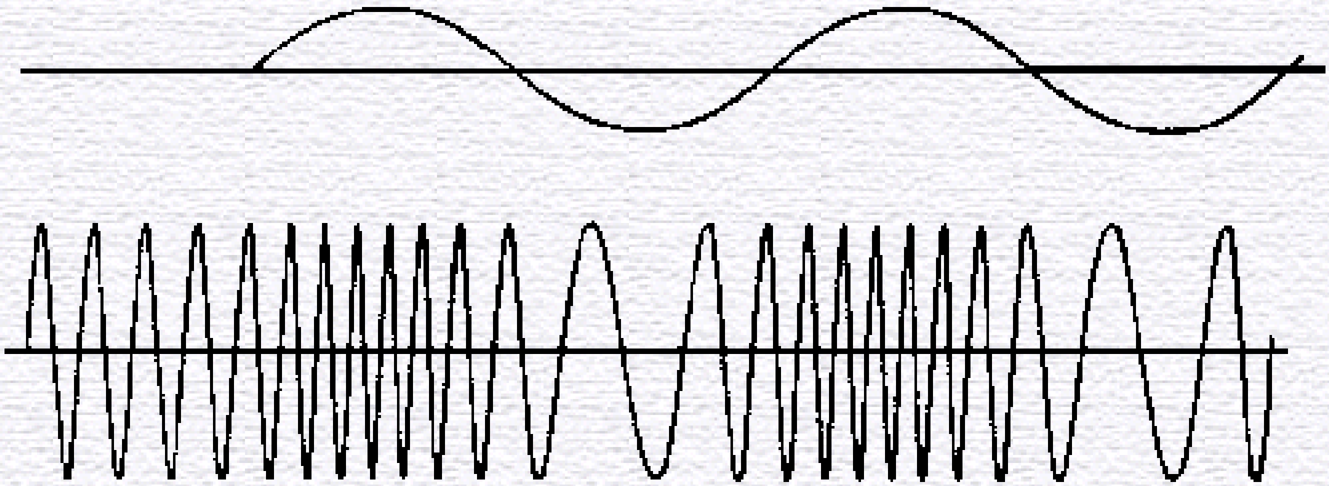
With AM, the frequency of the carrier is fixed and the modulating signal controls carrier amplitude.

With FM, the amplitude of the carrier is kept constant and its frequency varied by the modulating signal.
This variation in carrier frequency is called DEVIATION.
The amount that the carrier deviates in frequency is proportional to the loudness of the Audio modulating signal.
If you shout into the microphone, it deviates more than if you whisper.
Deviation is expressed in kHz per Volt. The BBC uses 15 kHz/Volt.
The maximum deviation allowed by the BBC is plus and minus 75 kHz from the carrier frequency.

How often the carrier deviates is determined by the frequency of the modulating audio.
If you whistle it deviates more frequently than if you hum into the microphone.

Since FM signals occupy a wide bandwidth there is no room for them on LW or MW.
They use the FM band of 88-108 MHz where there is plenty of band space available.

Advantages of FM are higher quality and low noise.



The diagram shows how the carrier varies in frequency as the modulating signal changes in amplitude.

HARMONICS

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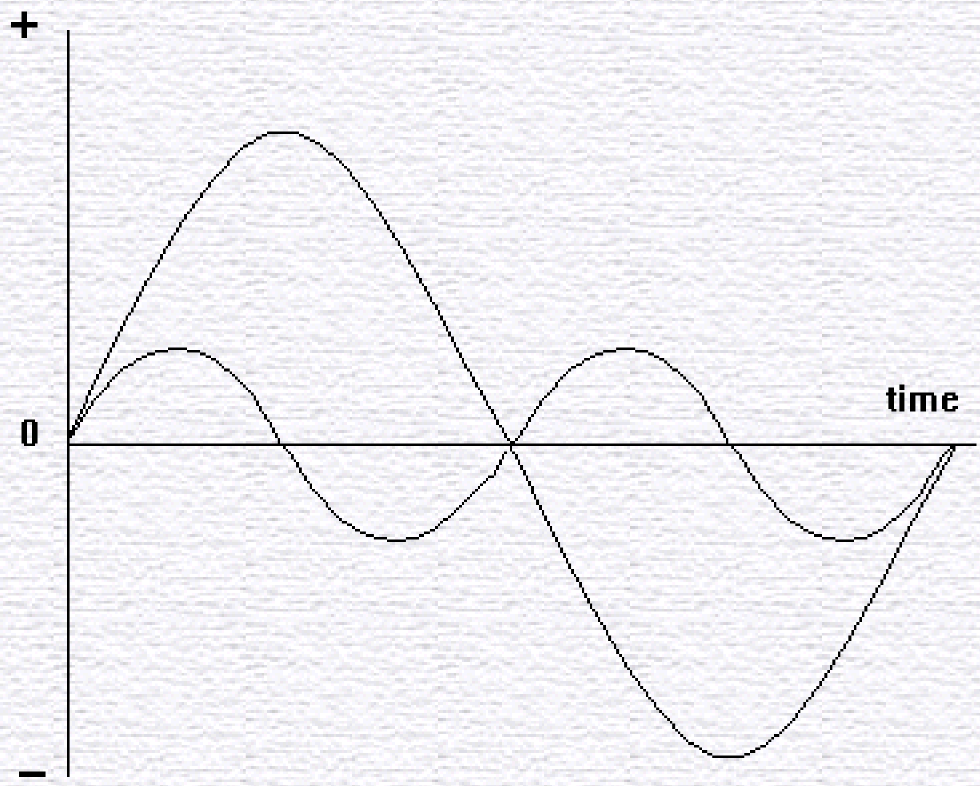

When the same note, say middle C, is played on different instruments, the musical notes produced sound different.
This is because that as well as producing the FUNDAMENTAL FREQUENCY of middle C they also produce multiples of this frequency called HARMONICS.
The fundamental is a pure sine wave.

The number and amplitude of the harmonics determines the characteristic sound of the instrument.
The harmonic which is twice the fundamental frequency, as in the diagram, is called the 2nd harmonic.
The frequency which is three times the fundamental is the 3rd harmonic.
The 3rd, 5th, 7th etc are called ODD harmonics.
The 2nd, 4th, 6th, 8th etc are called EVEN harmonics.

A square wave is made up from a fundamental frequency sine wave and an infinite number of odd harmonics.

A sawtooth wave form consists of a fundamental plus an infinite number of even harmonics.

If a sine wave is injected into an amplifier the output wave form may be distorted.
This may be due to harmonics being generated by the amplifier.

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SOUND

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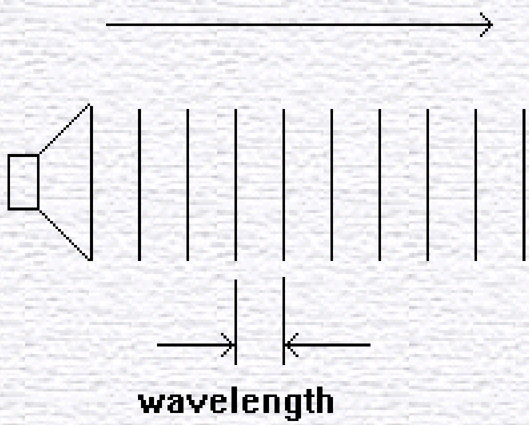
Sound waves are caused by vibrations such as that from a tuning fork, a loudspeaker cone, or the human voice.
These vibrations need air to travel through. They cannot travel through a vacuum.
The air itself doesn't travel.
The sound causes compression and decompression of the air as it moves through it.
There is a regular spacing between one pressure peak and the next.
This distance is called the WAVELENGTH.



Sound travels at about 330 metres a second.
A pure sound tone consists of a single frequency of vibration.
The range of human hearing is about 20 Hertz to 20 KiloHertz.
Most sounds are a mixture of frequencies. See the page on HARMONICS.
Microphones convert sound pressure waves into electrical signals.
Loudspeakers convert electrical signals into sound waves.
Loudspeakers and microphones are TRANSDUCERS.
Frequency, wavelength and the speed of sound are interelated.

Wavelength x frequency = the speed of sound in metres per second.

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AMPLITUDE MODULATION

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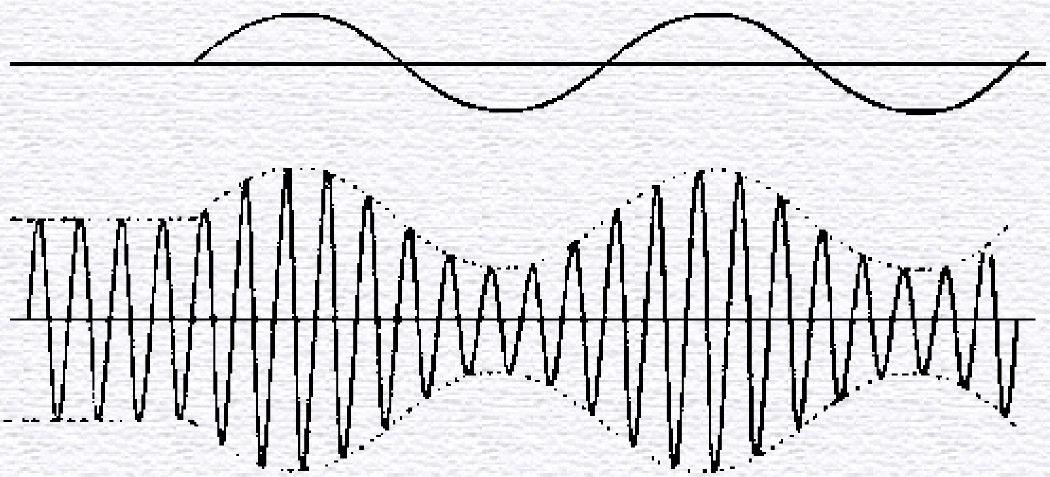
If you connect a long wire to the output terminals of your Hi-Fi amplifier and another long wire to the input of another amplifier, you can transmit music over a short distance. DON'T try this. You could blow up your amplifier.

A radio wave can be transmitted long distances.
To get our audio signal to travel long distances we piggyback it onto a radio wave.
This process is called MODULATION.

The radio wave is called the CARRIER.

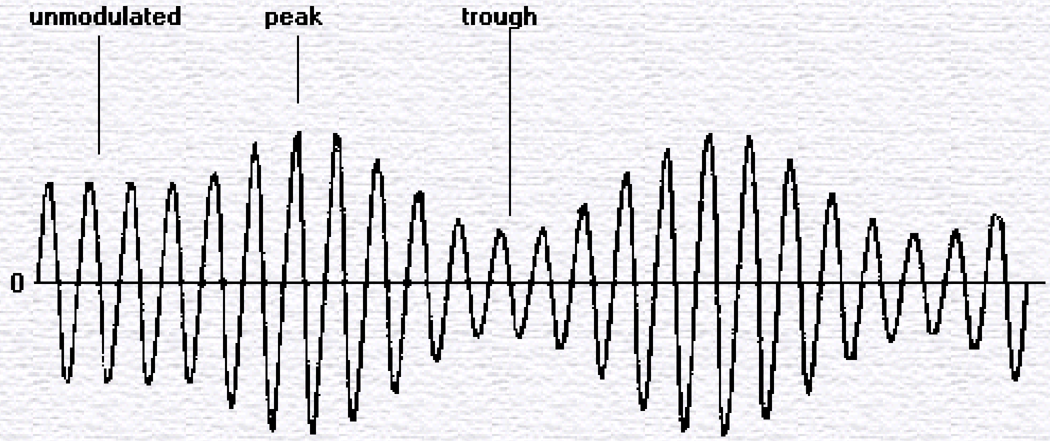
The audio signal is called the MODULATION.

At the receiving end the audio is recovered by a process called DEMODULATION.

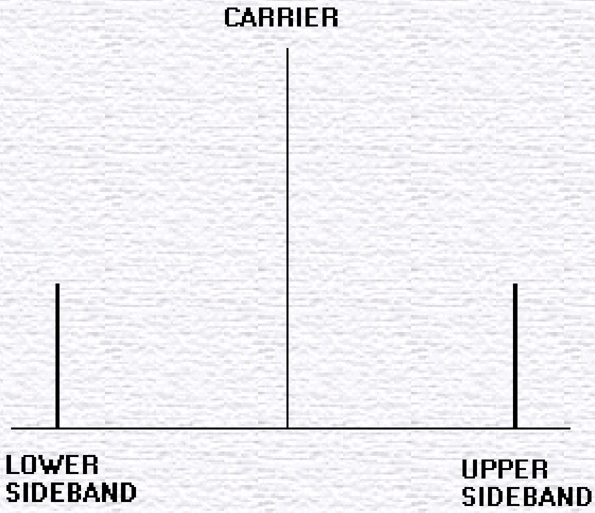


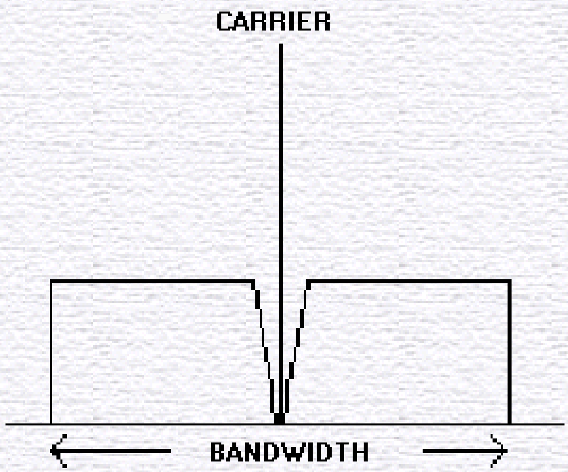
From the diagram below, it can be seen that when the carrier is modulated, its amplitude goes above and below its unmodulated amplitude.

It is about 50% modulated in the diagram.
The maximum percentage modulation possible is 100%.
Going above this causes distortion.
Most broadcasters limit modulation to 80%.



Modulating the carrier frequency with an audio frequency produces two new frequencies.
At this point it would be a good idea to read the page on MIXERS.
These new frequencies are called the upper and lower SIDEBANDS.
The upper sideband is the carrier frequency plus the audio frequency.
The lower side band is the carrier frequency minus the audio frequency.





Since the audio signal is not a single frequency but a range of signals (usually 20 Hz to 20 KHz) the sidebands are each 20Hz to 20 KHz wide.

**If you tune across a station in the Medium Wave Band you will find that it takes up space in the band.
This is called the signal BANDWIDTH.
This is the space taken by the upper and lower sidebands.
In the the example given above it would be 40 KHz.
Since the Medium Wave is only 500 KHZ wide there would only be space for about 12 stations.
Therefore the bandwidth of stations is limited to 9 KHz, which limits the audio quality.**

If there are two stations too close together, their sidebands mix and produce HETERODYNE whistles.

**Since both sidebands carry the same information, one side can be removed to save bandwidth.
This is SSB, single sideband transmission.**

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THE MIXER

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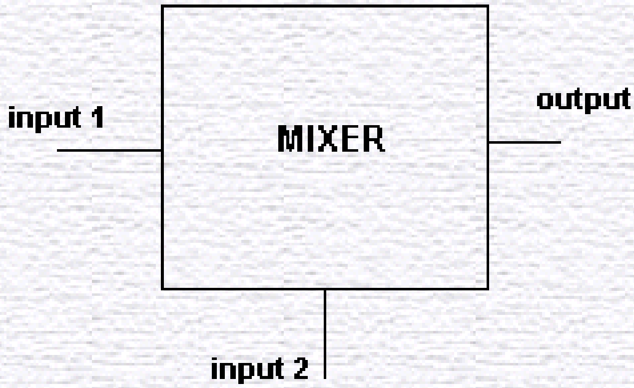

The mixer has two input signals of different frequencies, f1 and f2.
These inputs are mixed together in the mixer. (some books say "beaten" together, others say "heterodyned").

f1 and f2 then come out of the mixer, together with two new frequencies.
One of the new frequencies is the sum of the two inputs, f1 + f2.
The other is the difference between the two inputs, f1 - f2.

For example, if the inputs are 1 Mhz and 1.47 MHz then the sum frequency is 2.47 MHz.
The difference frequency is 0.47 MHz (470 kHz).

Sometimes, on the radio, two adjacent stations will produce an interfering whistle.
This is because their frequencies are close enough to beat together.
The difference between their frequencies is in the audio range.

If you have two racks of equipment, cooled by fans, the noise produced by each fan rotating often beats together to give a low frequency beat noise.

Mixers are used as part of the FREQUENCY CHANGER in radios.

Understanding mixers will help you to understand the MODULATION process in A.M. transmitters.

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THE FREQUENCY CHANGER

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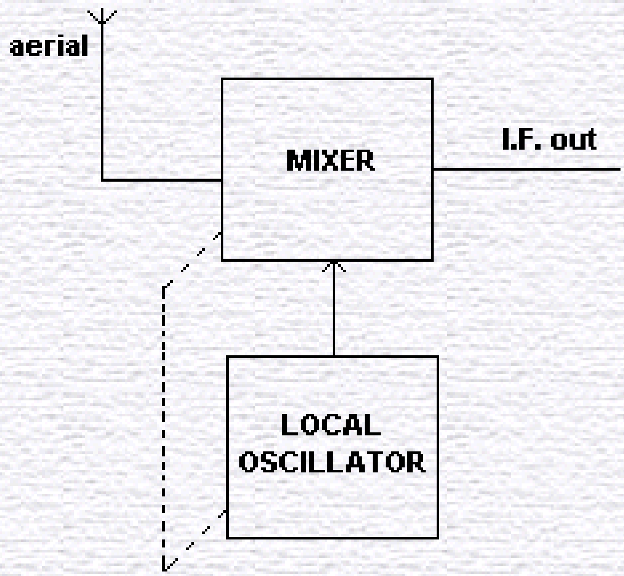

It is best if you read the page on THE MIXER first.

There are many thousands of radio stations in the world, transmitting on thousands of different frequencies.
Radio waves from these stations hit your radio aerial and induce voltages in it.

It is the TUNING circuit in your radio which selects the one station that you are interested in, and rejects all the others.
The tuning circuit is usually a coil and a variable capacitor.
The value of the capacitor is adjusted so that the tuning circuit is at the frequency of the wanted station.

It is the job of the frequency changer to change the frequency of the selected station to a new, lower, fixed frequency.
This new frequency is called the INTERMEDIATE frequency (I.F.).
No matter what the frequency of the selected station is, it is changed to the I.F.
This is about 455 kHz for AM radios and 10.7 MHz for FM radios.

This frequency changing is done by mixing the radio frequency with the frequency generated by a local oscillator. The local oscillator frequency is also controlled by a coil and variable capacitor.

The output from the mixer is the difference in frequency between the two input frequencies.
For example, if the radio station is on 110.7 MHz and the local oscillator is at 100 MHz then the I.F. is 110.7-100 = 10.7 MHZ.

Since the tuning circuit has to be changed in frequency every time you change stations, then the local oscillator frequency has to be changed to keep the difference at 10.7 MHz.
Therefore the two variable capacitors are GANGED together.
This means that they are both mounted on a common shaft, and when one is adjusted the other is similarly changed.
This is represented by the broken line in the diagram.

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PULSE MODULATION

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Pulse modulation consists of switching the carrier on and off as required.
Fig.1 shows a continuous wave carrier (CW).

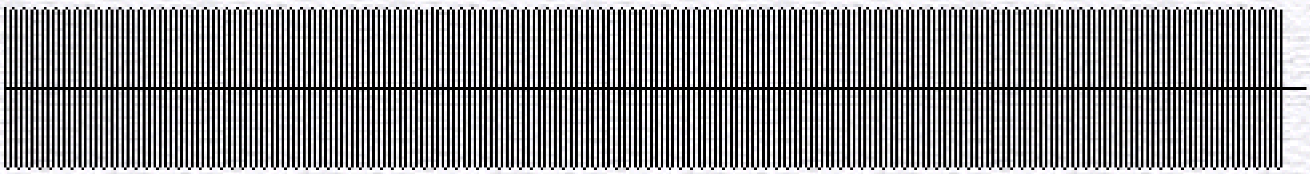

Fig.1

Fig.2 shows the carrier being switched on for a short time to produce a pulse of R.F.

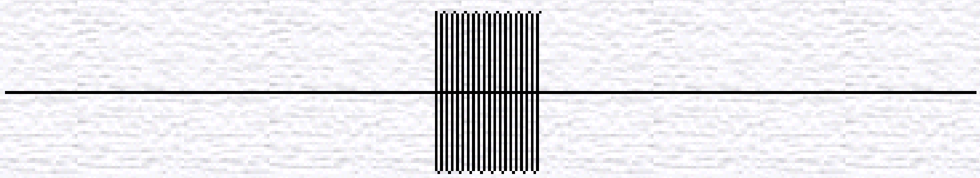

Fig.2

This is the principle of Radar; a short pulse is transmitted and then an echo listened for.
Fig.3 shows a long pulse and three short ones.

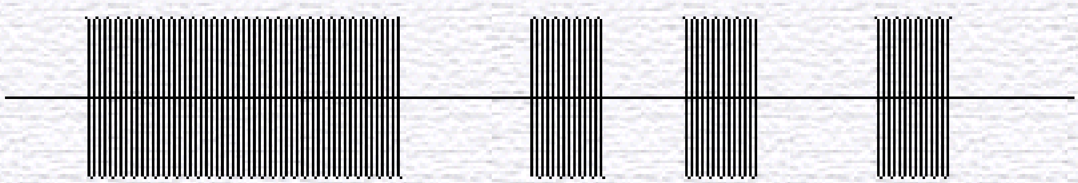

Fig.3

This generates the letter B in Morse Code.
Fig.4 shows Pulse Width Modulation (PWM).

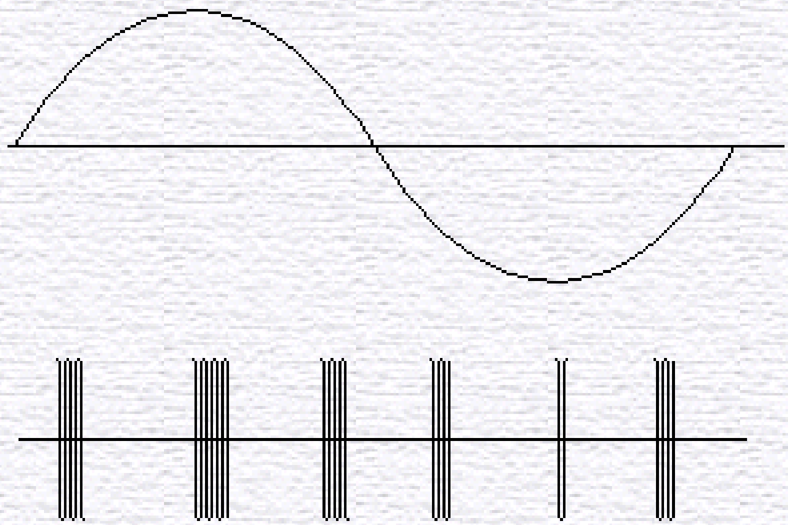

Fig.4

The width of the pulse is determined by the amplitude of the modulating signal at that instant.
Fig. 5 shows Pulse Position Modulation (PPM).

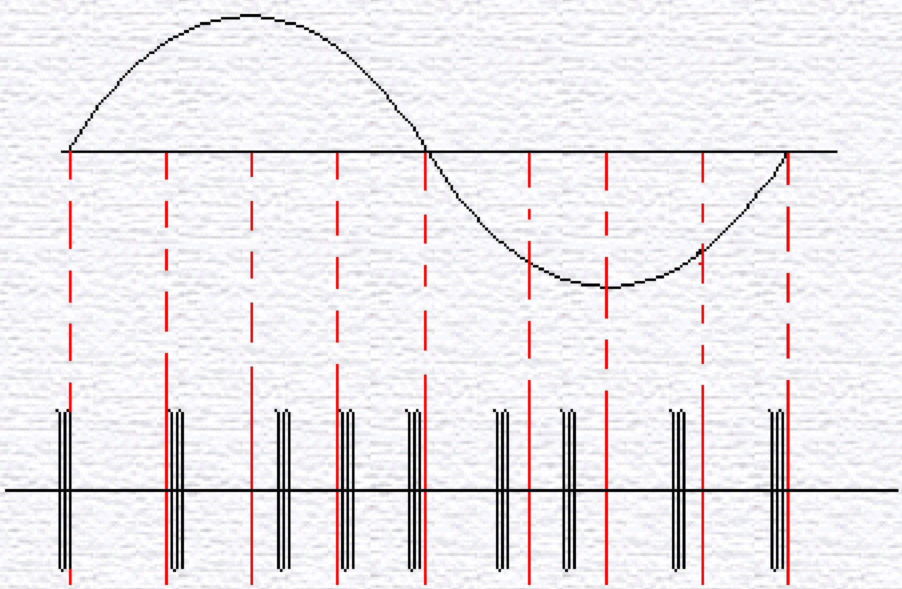

Fig.5

Here the width and amplitude of the pulse are constant but its position is determined by the amplitude of the modulating signal.

PULSE CODE MODULATION is where the amplitude of the modulation is measured at regular intervals and a binary number generated to represent that amplitude.

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AVERAGES

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To find the average value of a set of numbers.
Add up all the values in the set and then divide by the number of items in the set.

For example, the average value of 15 and 6 and 12 is

15 + 6 + 12 divided by 3 which equals 33/3 = 11

To find the average number of days in a month.
Add up the total days for each month in the year and divide by the number of months in the year.
365 days divided by 12 months = 30.416 days in an average month.

Average values can look a bit silly. The average family is 2 parents and 1.5 babies.

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PERCENTAGES

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1% of anything is one hundredth part of it.
1% of 100 oranges is 1 orange.
1% of 400 is 400/100 = 4

10% of anything is 10 x 1%.
1% of 1000 tons is 10 tons.
10% is 100 tons.
5% is 50 tons.

1% of 100 ohms is 1 ohm.
5% of 100 ohms is 5 ohms.
A 100 ohm resistor with a tolerance of 5% can have a value between 95 and 105 ohms and be within tolerance.

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SEMICONDUCTOR MATERIALS

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The two most common materials used in the making of semiconductors are silicon and germanium.
Sand on the beach is silicon and they say that germanium can be obtained from chimney soot.
So you can see that the raw materials are extremely common.
However they do have to be purified to an extraordinary degree.

When purified they have a crystalline construction like salt and sugar.
The atoms which make up the materials are rigidly locked together in a pattern (a LATTICE) in which the electrons, in the atoms, are unable to move.
This means that pure silicon and germanium are good insulators.

After purification, precise amounts of impurities are added (the materials are DOPED).
These impurities fit into the lattice but have associated electrons which are free to move about and produce a flow of electric current.
There is therefore a surplus of negative electrons and the material is called N-type semiconductor.

Other types of impurities can be added to pure silicon and germanium. These produce a shortage of electrons in the lattice.
Therefore there are HOLES in the lattice.
Electrons can jump into these holes, producing a flow of holes.
It's like sitting in a row of chairs in the doctor's waiting room.
When someone gets up and goes into the surgery there is an empty chair (a hole).
People (electrons) move along nearer to the surgery and a

hole travels in the opposite direction.

Since there is a shortage of negative electrons there is an overall positive charge and the material is called P-type semiconductor.

The resistance of semiconductors is about half way between conductors and insulators.
Hence the name, semiconductors.

Semiconductors are used in semiconductor devices such as diodes, transistors, integrated circuits etc.

HEAT

When an object is heated above the temperature of its surroundings it will lose heat to the surroundings.

Heat is transferred in three ways.

1. <u>CONDUCTION</u>

If one end of a metal bar is heated then heat is transferred by conduction to the cold end.
Good electrical conductors such as copper and gold are good conductors of heat.
Poor electrical conductors, such as wood and paper, are poor heat conductors.

Heat can be conducted between two objects if they are in close contact.
For example between a soldering iron and a soldering terminal; or between a power transistor and its heatsink.

2. <u>CONVECTION</u>

Here, heat is transferred by the movement of a gas or a liquid.
Hot air rises and cold air falls. Liquids behave in a similar manner.
A hot resistor causes convection, transferring heat from the resistor to the surrounding air.
Hot water in a pan rises to the top while the cold water falls to the bottom.
These movements are called convection currents (nothing to do with electric currents).
The above process is called NATURAL CONVECTION.
If a fan is used to aid convection it is called FORCED CONVECTION.

3. <u>RADIATION</u>

This does not need a gas or liquid to transfer the heat.
Heat is expelled mostly in the form of infrared radiation.

This is a form of light and travels at the speed of light.
It can travel through a vacuum.
This is why we can feel the heat of the sun even though it has to travel through the vacuum of space to reach earth.

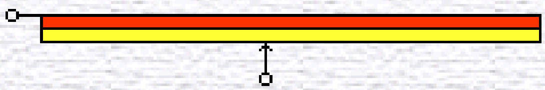
Polished surfaces are poor radiators but good reflectors of heat. That is why electric fires have shiny reflectors.

Black objects are good radiators.

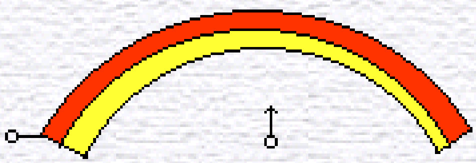
THE EFFECTS OF HEAT

Heat causes solid objects to expand.
That is why they have gaps in railway lines and bridges to allow for summertime temperatures.

Different metals expand at different rates.
A temperature switch can be made from two strips of disimilar metals fixed together.
As the temperature increases, one strip grows longer than the other, causing the strips to curve. This in turn breaks (or makes) a circuit.



COLD



HOT

Increasing temperatures also cause liquids to expand. This behaviour is used in the thermometer.

Gases also expand with temperature increases.

HEAT AND ELECTRONICS

Heat is one of the biggest enemies of electronics, causing components to fail.
To minimise the effects some action can be taken.
Increasing the surface area increase convection and radiation.
High wattages resistors are larger than low wattage ones.
Using holes and louvres in the casing increases natural convection.
Using fans provides forced convection.
Using heat sinks with fins increases surface area thus providing increased convection and radiation.
Painting heat sinks blacks increases radiation.
Using "heat sink compound", which is a good conductor, between transistors and their heatsinks, improves heat conduction.
Fitting components onto the metal chassis aids the dissipation of heat.

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THE RESISTOR COLOUR CODE

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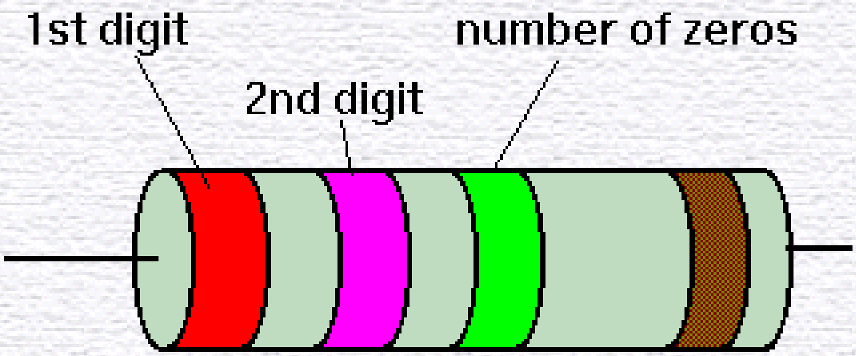
Ignore the colour of the resistor body.
Most resistors have three coloured bands close together at one end and one single band at the other.
The three adjacent band give the resistor value.

The band nearest the wire lead gives the value of the first digit. e.g Brown = 1.

The next band gives the value of the next digit e.g. red = 2

The third band gives the number of zeros which follows the two digits.e.g. orange = 3 zeros = 000.

Therefore a resistor with brown, red, orange bands would have a value of 12000 ohms.



28 Jan '96

This resistor has a value of 2,700,000 ohms.

A green blue black resistor would be 56 ohms. (black indicates that there are no zeros).

Black = 0
Brown = 1
Red = 2
Orange = 3
Yellow = 4
Green = 5
Blue = 6
Violet = 7
Grey = 8
White = 9

If the third band is silver then divide the value of the first two digits by 100, if gold divide by 10.
e.g. red violet gold is 2.7 ohms.

The fourth band indicates the tolerance.
e.g. brown indicates plus or minus 1%.
a 100 ohm 1% resistor can be in value between 99 ohms and 101 ohms.

brown 1%
red 2%
gold 5%
silver 10%
none 20%

If there is a fifth pink band this indicates a high stability resistor.

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VALUE MULTIPLIERS

In Electronics we use some very large and some very small values.
To make them easier to deal with we use MULTIPLIERS.

For example 1000,000,000,000 Hertz can be labelled 1 Terahertz.
and 0.000,000,000,001 Ohms is the same as 1 picohm

PREFIX	SYMBOL	MULTIPLICATION FACTOR
tera	T	1,000,000,000,000
giga	G	1,000,000,000
mega	M	1,000,000
kilo	K	1,000
milli	m	0.001
micro	u	0.000,001
nano	n	0.000,000,001
pico	p	0.000,000,000,001

See that 1 microfarad is 1000 nanofarad.
There are 1,000 picofarad in 1 nanofarad.
Practice converting one to another.

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WIRES AND CABLES

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Wires are mostly made from copper which is cheap and has a low resistance to the flow of electric current.

Wires come in standard wire gauges (S.W.G.) where the smaller the diameter of the wire the bigger the SWG. e.g 22 swg has a smaller diameter than 16 swg.
Copper oxidises (tarnishes) making it difficult to solder. It is therefore tinned giving us 22 swg tinned copper wire, for example.

If two bare wires touch it forms a short circuit. To avoid this wires are INSULATED using PVC etc.
When wire are used for coils such as transformers the insulation is varnish. Since this is very thin wires will take the minimum of space.
A broken wire is called an OPEN CIRCUIT and prevents current flowing.

A single strand of wire 0.6 mm in diameter is called 1/0.6; this is very rigid and snaps if bent too often.
Flexible leads are made from several strands of wire. 7/0.2 is 7 strands of wire each 0.2 mm in diameter.
Fine strands of wire can be woven into a mesh or braid which can be used to screen out unwanted interference. (The sunglass effect).
Television aerial lead uses screened cable called COAXIAL CABLE.
Leads which carry small signals such as audio are often screened to reject external interference.

Where several leads are needed they can be combined into a single cable. This can be a multicore cable, a cableform or a cable loom.
Cables are often terminated in plugs or sockets which may take some time to connect. A quicker technique is to use

INSULATION DISPLACEMENT CONNECTORS (IDC) which take only seconds to fit.

Thicker wires can carry higher currents than thin ones as bigger pipes can carry more water than thin ones.

7/0.2 can carry 1 amp maximum
16/0.2 can carry 3 amp maximum
24/0.2 can carry 5 amp maximum
32/0.2 can carry 10 amp maximum

Use wire strippers to remove insulation. Avoid nicking the wires or breaking strands in flexes.
When soldering avoid whiskers, burning insulation and wicking (allowing solder to run up under the insulation of flex which makes it rigid and brittle).

FIBRE OPTICS is often used instead wires in some applications.

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THE DIODE

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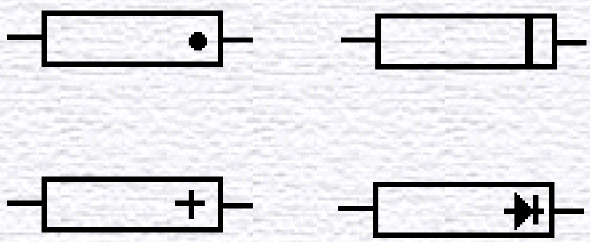
Diodes are polarised, which means that they must be inserted into the PCB the correct way round.
This is because an electric current will only flow through them in one direction (like air will only flow one way through a tyre valve).

Diodes have two connections, an anode and a cathode.
The cathode is always identified by a dot, ring or some other mark.

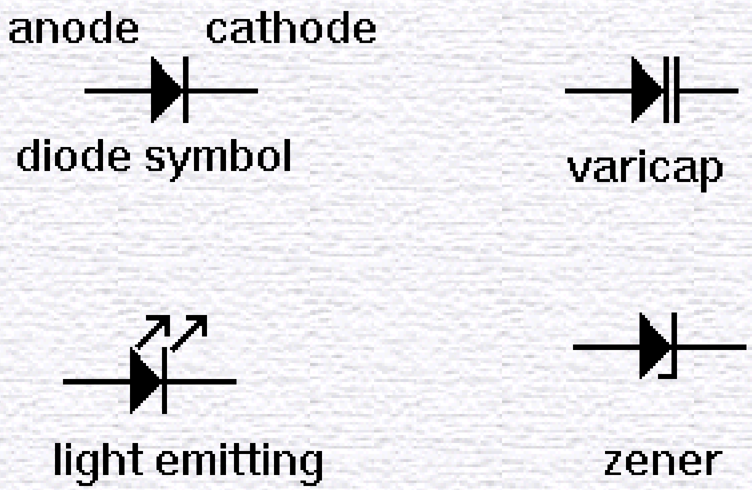


The pcb is often marked with a + sign for the cathode end.

Diodes come in all shapes and sizes.
They are often marked with a type number.
Detailed characteristics of a diode can be found by looking up the type number in a data book.

If you know how to measure resistance with a meter then test some diodes. A good one has low resistance in one direction and high in the other.

There are specialised types of diode available such as the zener and light emitting diode (LED).



Some diode circuit symbols

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INTEGRATED CIRCUITS

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IC's, often called "chips", come in several shapes and sizes.

Most common are 8, 14, or 16 pin dual in line (dil) chips.

IC's can be soldered directly into printed circuit boards, or may plug into sockets which have already been soldered into the board.

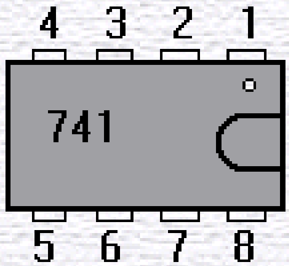
When soldering, ensure that the IC (or the socket) is the correct way round and that no pins have been bent underneath the body.

When fitting new IC's it is often necessary to bend the pins in slightly, in order to fit it into the board (or socket).

Some IC's are damaged by the static electricity which most people carry on their bodies. They should be stored in conductive foam or wrapped in tin foil. When handling them, discharge yourself periodically by touching some metalwork which is earthed, such as a radiator.

Solder two diagonally opposite pins (say pin 1 and pin 5 in the diagram below) and check that the IC is flat on the board before soldering the rest. If it is not flat then reflow the solder on the two pins pushing the IC flat. When satisfied, solder the remaining pins.

Take when removing faulty IC's from pcb's. You may damage a 100 pound board when carelessly removing a 20p IC.



view from component side of pcb

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PRINTED CIRCUIT BOARDS

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Printed circuit boards (PCB's) are laminates. This means that they are made from two or more sheets of material stuck together; often copper and fibreglass.

Unwanted areas of the copper are etched away to form conductive lands or tracks which replace the wires carrying the electric currents in other forms of construction.

Some parts of the side with copper tracks is coated with solder resist (usually green in colour) to prevent solder sticking to those areas where it is not required. This avoids unwanted solder bridges between tracks.

Sometimes the boards are double-sided with copper tracks on both sides. Tracks on one side can be joined to tracks on the other by means of wire links. Plated through holes are available which do the same thing but these make the PCB more expensive.

Components are stuffed into the board by hand or by pick and place machines.

Soldering is done by hand or by flow wave soldering where the PCB passes over a wave of molten solder.

Most recent PCB's use surface mount techniques where components are on the same side of the board as the tracks. Components are stuck to the board with adhesive and the solder caused to flow by heating the board in a hot gas or by some other technique.

When fitting components ensure that they are orientated correctly and lay flat on the board unless otherwise stated.

When the board is assembled avoid flexing it which may crack tracks.

Avoid touching the board which may cause contamination due to dirty fingers or damage due to static electricity carried on your body.

It is best to handle PCB's by holding them by two edges only, between thumb and forefinger.

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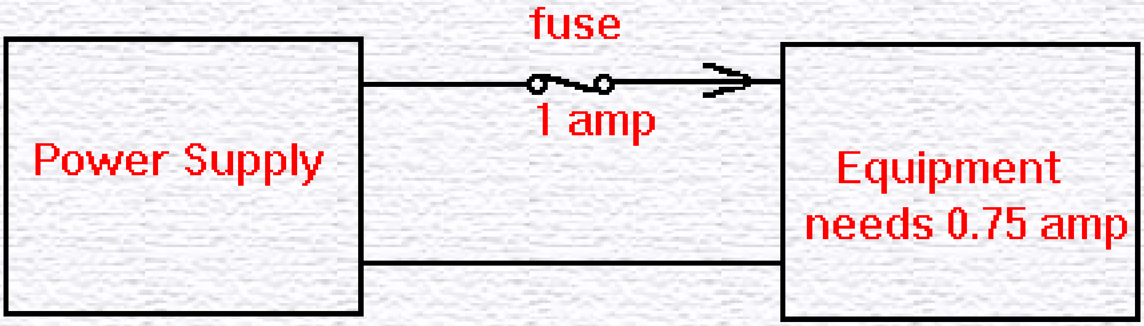
FUSES

CLICK HERE TO BUY THE CD

If there is a fault in a piece of equipment then excessive current may flow.
This will cause overheating and possibly a fire.
Fuses protect against this happening.
Current from the supply to the equipment flows through the fuse.



The fuse is a piece of wire which can carry a stated current. If the current rises above this value it will melt.

If the fuse melts (blows) then there is an open circuit and no current can then flow thus protecting the equipment by isolating it from the power supply.

The fuse must be able to carry slightly more than the normal operating current of the equipment to allow for tolerances and small current surges.

With some equipment there is a very large surge of current for a short time at switch on. If a fuse is fitted to withstand this large current there would be no protection against faults which cause the current to rise slightly above the normal value.

Therefore special antisurge fuses are fitted. These can stand 10 times the rated current for 10 milliseconds. If the surge lasts longer than this the fuse will blow.

Always find out why the fuse blew before replacing it. Occasionly they grow tired and fail. If the fuse is black and silvery then it is likely that there is a dead short (very low resistance) somewhere.

ALWAYS REPLACE THE FUSE WITH THE CORRECT TYPE AND VALUE!!

DO NOT USE SILVER PAPER OR NAILS!!

IN THE UNITED KINGDOM YOU CAN BE PROSECUTED UNDER THE HEALTH AND SAFETY AT WORK ACT IF YOU FIT THE WRONG FUSE!!

YOU HAVE BEEN WARNED!!!!!

INDEX

SWITCHES

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fig.1

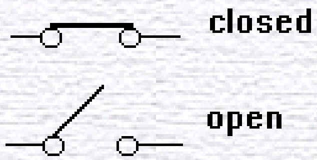

fig.5

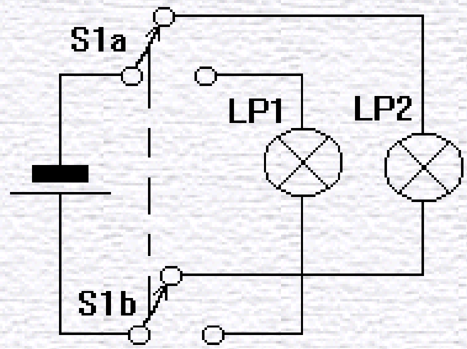

fig.2

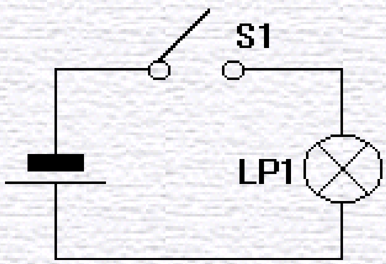

fig.6

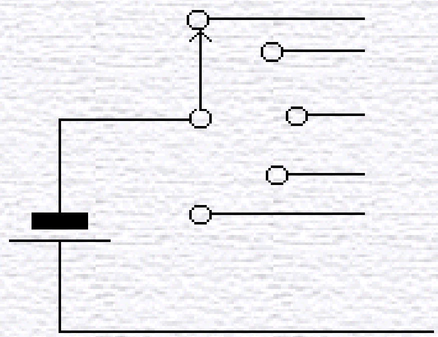

fig.3

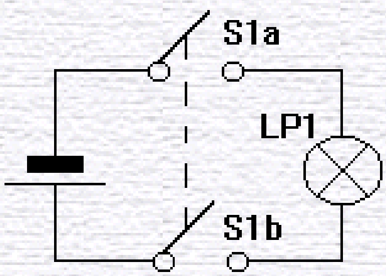

fig.7

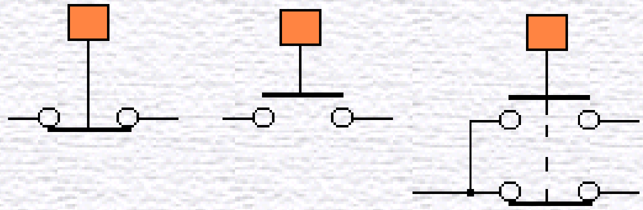

fig.4

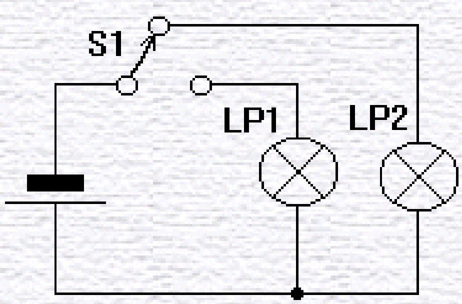

fig.8

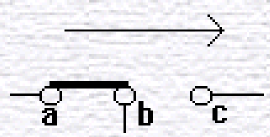

Fig. 1
Switches are used to open/close a circuit.

Fig. 2
S1 is a "single pole on/off" switch in the off position.

Fig. 3
This is a "2 pole on/off" switch which completely isolates the lamp from the supply in the off position.
This may be important if it is a high voltage supply.
The dotted line indicates that S1a and S1b are part of the same switch "ganged" together and operate simultaneously.

Fig. 4
This is a "single pole changeover" switch.
Either lamp 1 or lamp 2 is on.

Fig. 5
This is a "2 pole changeover" switch.
The unlit lamp is completely isolated from the supply.
Again S1a and S1b are part of the same switch.

Fig. 6
This is a "single pole 5 way" switch.
It can select 1 of 5 circuits.
You can have 2p 5w, 3p 4w etc.

Fig. 7
This shows
(1) a "normally closed, push to break".
(2) a "normally open, push to make".
(3) both used together to make a "changeover" switch.

Fig. 8
This is a "changeover" slide switch.
When operated a-b opens and b-c closes.

Here are assorted switch types. Panel-Toggle-Make before break-Pneumatic-Wafer-Proximity-Light activated-Toggle-Rotary
Reed-Pull-Locking-Vane-Interlocking-Rocker-Dimmer-Mercury-Tilt-Microswitch
Thumbwheel-Key-Wafer-Slide-Float-Optical-Foot-Thermal-Hall effect

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7 SEGMENT DISPLAYS

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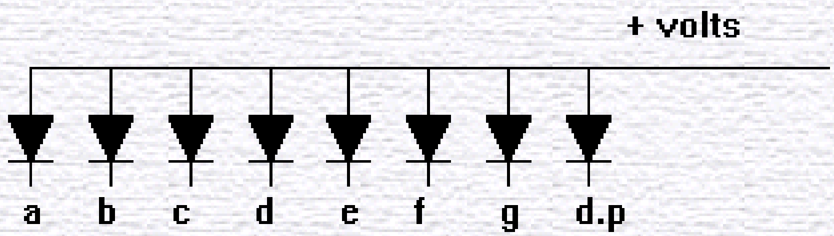

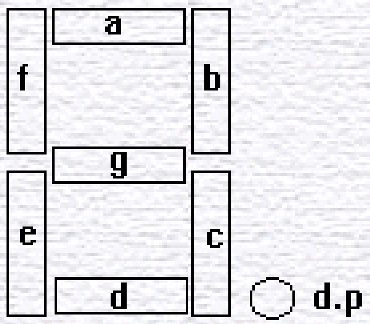

The 7 segment display is used as a numerical indicator on many types of test equipment.

It is an assembly of light emitting diodes which can be powered individually.
They most commonly emit red light.
They are arranged and labelled as shown in the diagram.

Powering all the segments will display the number 8.
Powering a,b,c d and g will display the number 3.
Numbers 0 to 9 can be displayed.
The d.p represents a decimal point.

The one shown is a common anode display since all anodes are joined together and go to the positive supply.
The cathodes are connected individually to zero volts.
Resistors must be placed in series with each diode to limit the current through each diode to a safe value.

Early wrist watches used this type of display but they used so much current that the display was normally switched off. To see the time you had to push a button.

Common cathode displays where all the cathodes are joined are also available.

Liquid crystal displays do a similar job and consume much less power.

Alphanumeric displays are available which can show letters as well as numbers.

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BATTERIES

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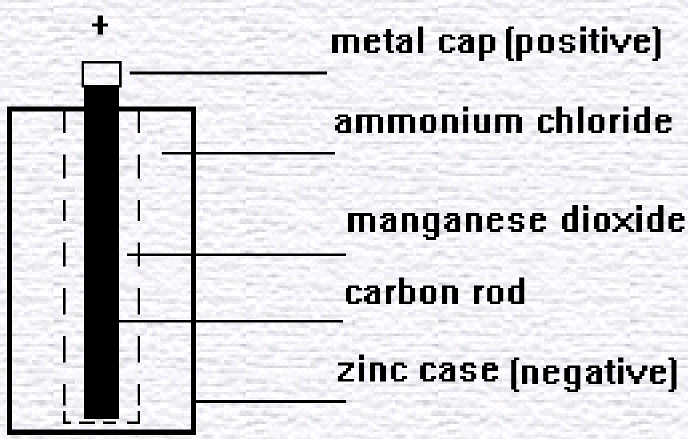
Batteries are assembled from cells, connected in series, to increase the voltage available.

In a cell chemical energy is converted into electrical energy.

Cells may be either PRIMARY or SECONDARY types.
A primary cell is discarded when its chemical energy is exhausted.
A secondary cell can be recharged.
The most common primary cell is the zinc/carbon (Leclanche) as used in torches, portable radios etc.



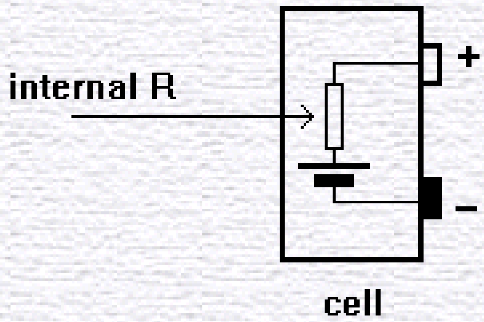
Dry cell (Leclanche)

The zinc and carbon react with the ammonium chloride ELECTROLYTE to produce electricity.
The manganese dioxide absorbs hydrogen gas produced around the carbon rod which would insulate it from the electrolyte and stop the cell working.

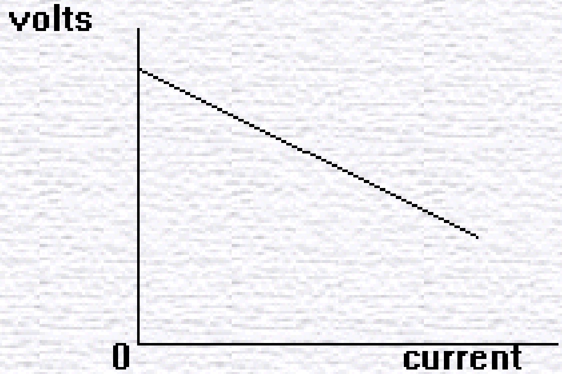
The most common secondary cells are the lead/acid and nickel/cadmium (nicad).
Lead acid batteries need a constant voltage charger.
Nicads must be charged with a constant current charger.

All cells have INTERNAL RESISTANCE.

This is not an actual resistor but a characteristic of the cell.
Internal resistance increases as the cell ages.



When current is taken from a battery, voltage is dropped across this internal resistance and the voltage at the battery terminals falls.
The diagram shows that as the current taken increases the terminal voltage decreases.



This is called POOR REGULATION.
It occurs in any type of power supply.
Battery voltages must therefore always be measured ON LOAD, i.e. with the radio etc switched on and drawing current.

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CIRCUIT SYMBOLS

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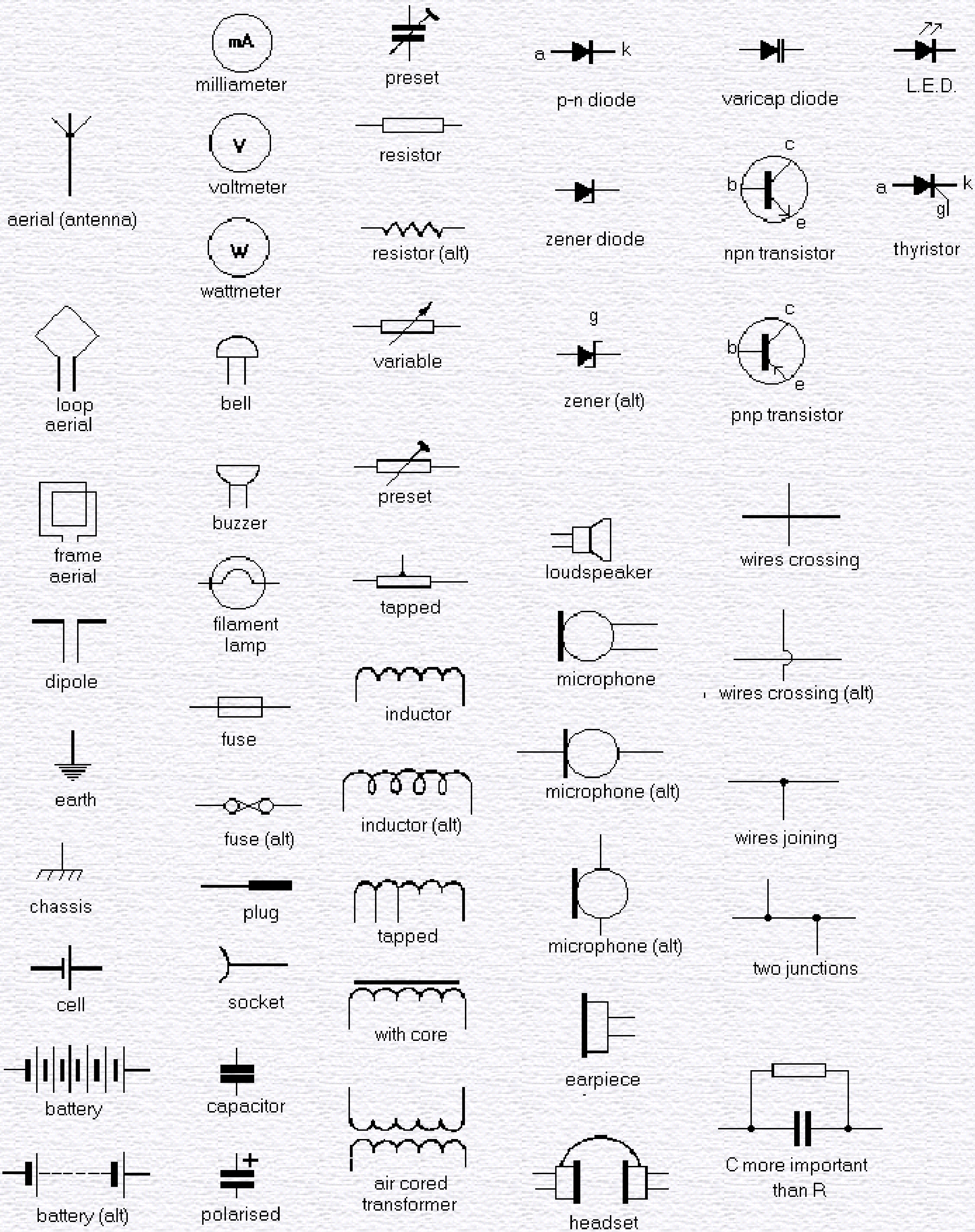

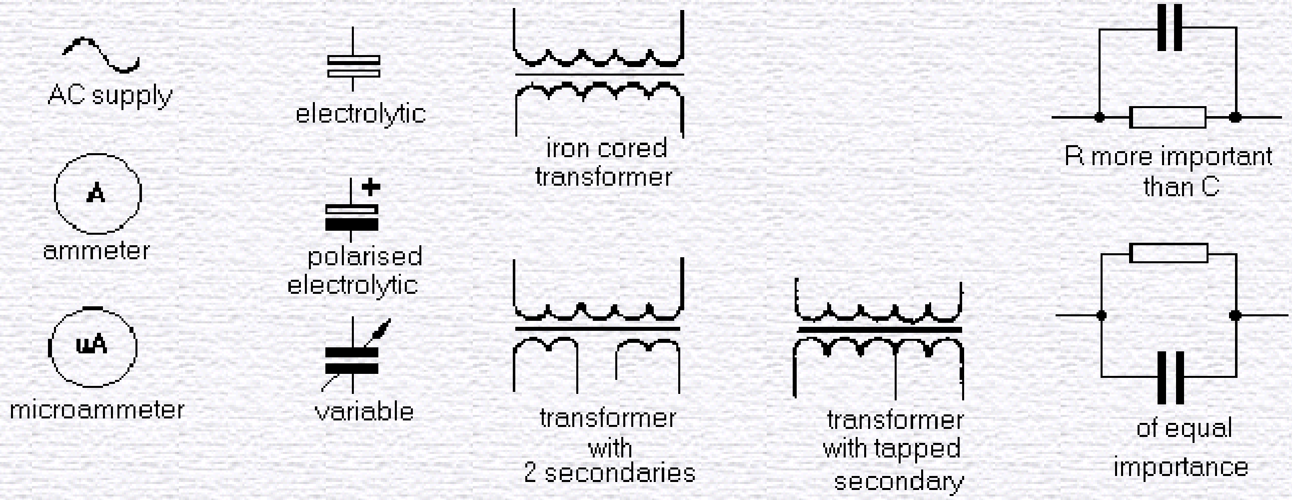
AC supply
ammeter
A
microammeter
uA
electrolytic
polarised electrolytic
variable
iron cored transformer
transformer with 2 secondaries
transformer with tapped secondary
R more important than C
of equal importance

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INDUCTORS

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Inductors are coils of wire.

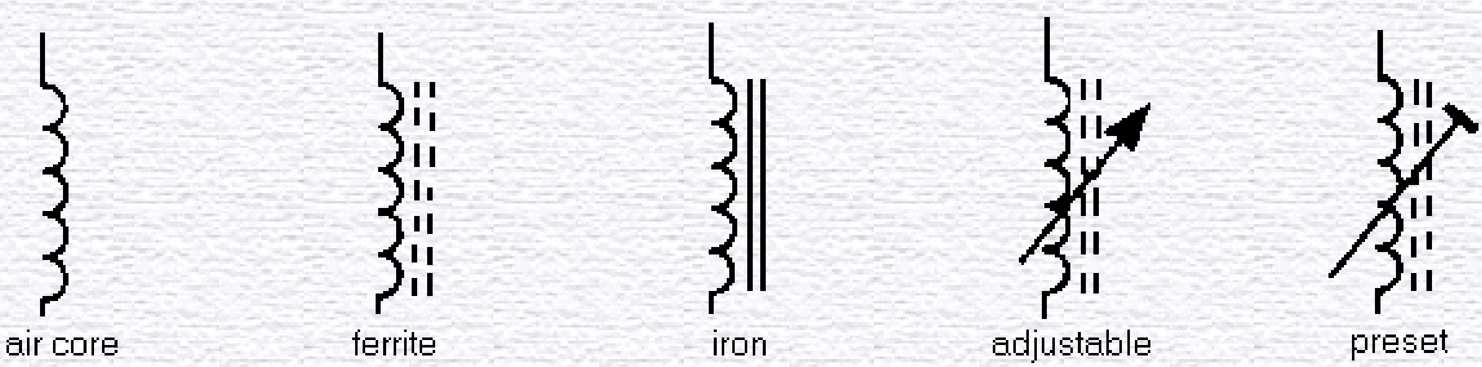
They may be wound on tubular FORMERS or may be self supporting.
The former may contain a metallic core up its centre.
Iron cores are used for frequencies below about 100 kHz.
Ferrite cores are used for frequencies up to say, 10 Mhz.
Above 100Mhz the core is usually air and the coil is self supporting.

At low frequencies the inductor may have hundreds of turns, above 1 Mhz only a few turns.

Most inductors have a low DC resistance since they are wound from copper wire.

Inductor values of INDUCTANCE are measured in HENRIES.

Inductors oppose the flow of ac current.
This opposition is called INDUCTIVE REACTANCE.
Reactance increases with frequency and as the value of the inductance increases.



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THE TRANSFORMER

CLICK HERE TO BUY THE CD

If you have read the page on ELECTROMAGNETISM then you will know that when a current is passed through a coil, the coil becomes surrounded by a magnetic field .
This field is made up from lines of force and has the same shape as a bar magnet.

If the current is increased, the lines of force move outwards from the coil.
If the current is reduced, the lines of force move inwards.

If another coil is placed adjacent to the first coil then, as the field moves out or in, the moving lines of force will "cut" the turns of the second coil.
As it does this, a voltage is induced in the second coil.
With the 50 Hz AC mains supply , this will happen 50 times a second.
This is called MUTUAL INDUCTION and forms the basis of the transformer.

The input coil is called the PRIMARY WINDING, the output coil is the SECONDARY WINDING.

The voltage induced in the secondary is determined by the TURNS RATIO.

$$\frac{\text{Primary voltage}}{\text{Secondary voltage}} = \frac{\text{Number of primary turns}}{\text{Number of secondary turns}}$$

For example, if the secondary has half the primary turns, the secondary will have half the primary voltage.

Another example is if the primary has 5000 turns and the secondary has 500 turns, then the turns ratio is 10:1.
If the primary voltage is 240 volts then the secondary voltage will be x 10 smaller = 24 volts.

Assuming a perfect transformer, the power provided by the primary must equal the power taken by a load on the secondary.
If a 24 watt lamp is connected across a 24 volt secondary, then the primary must supply 24 watts.
If it is a 240 volt primary then the current in it must be 0.1 amp. (Watts = volts x amps).

To aid magnetic coupling between primary and secondary, the coils are wound on a metal CORE.
Since the primary would induce power, called EDDY CURRENTS, into this core, the core is LAMINATED.
This means that it is made up from metal sheets insulated from each other.
Transformers to work at higher frequencies have an iron dust core, or no core at all.

Note that the transformer only works on AC which has a constantly changing current and moving field.
DC has a steady current and therefore a steady field and there would be no induction.

Some transformers have an electrostatic screen between primary and secondary.
This is to prevent some types of interference being fed from the equipment down into the mains supply, or in the other direction.

Transformers are sometimes used for IMPEDANCE MATCHING. There is a page on this subject.
There is also a page on transformer types.

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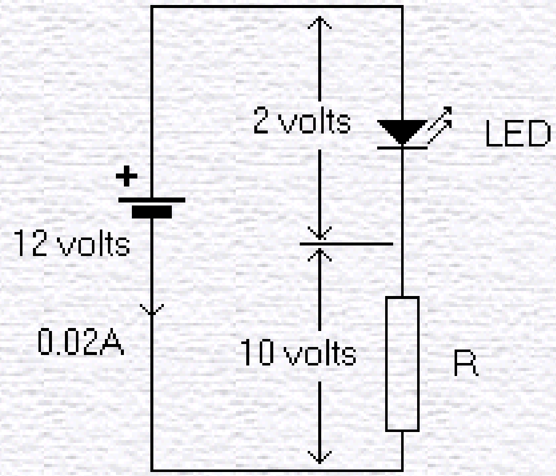
USING LED's

CLICK HERE TO BUY THE CD



The light emitting diode (LED) is commonly used as an indicator.
It can show when the power is on, act as a warning indicator, or be part of trendy jewelry etc.
It needs to be fed from a DC supply, with the anode positive and the cathode negative, as shown in the diagram.

To calculate the value of the series resistor we need to know the diode forward voltage and current and its connections.
The necessary data can be obtained from a catalogue or data book.
In our example it is 2 volts and 20mA (0.02 amps).
The cathode lead is the one nearest a "flat" on the body.

Since the voltage across the diode is 2 volts and the battery voltage is 12 volts, then the voltage across the resistor is 12-2 = 10 volts.
The diode is in series with the resistor, so the current through then both is the same, 0.02 amps.

We now know the voltage across, and the current through the

resistor.
From Ohm's Law we can now calculate the value of the resistor.

Resistance = Volts divided by Amps = V/I = 10/0.02 =500 ohms.

Since this is not a standard value we can use a 470 or 560 ohm resistor as this application is not critical of values.

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RESISTORS

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Resistors are electronic components which resist the flow of electronic current.

The higher the value of resistance (measured in ohms) the lower the current will be. This was discovered by Mr Ohm.

The simplest resistors are made from carbon rod with end caps and wire leads.
Other types are carbon film which is a thin layer of carbon on a ceramic rod, and metal oxide and metal glaze on glass rods.
Wire wound resistors are used where the resistor has to dissipate a lot of heat.

Faulty resistors have gone open circuit or changed in value. They never go short circuit.

Some resistors are designed to change in value when heated. They are called THERMISTORS and are used in temperature measuring circuits.
Some resistors change in value when exposed to light. They are called LIGHT DEPENDANT RESISTORS.

Most resistors are colour coded to indicate their value and tolerance.
Wire wound resistors have their value written on them. (colours would change with heat).
High stability resistors (marked with a fifth pink band) do not change value easily.

Resistors generate heat. Resistors have a wattage rating. The higher this rating the more heat they can dissipate.

To limit the range of resistor values to a manageable number a preferred range only is available.
These are

1.0	1.2	1.8	2.2	2.7	3.3	3.9	4.7	5.6	6.8	8.2

This mean that 1 ohm, 12 ohm, 180 ohm, 2200 ohm resistors etc are available.

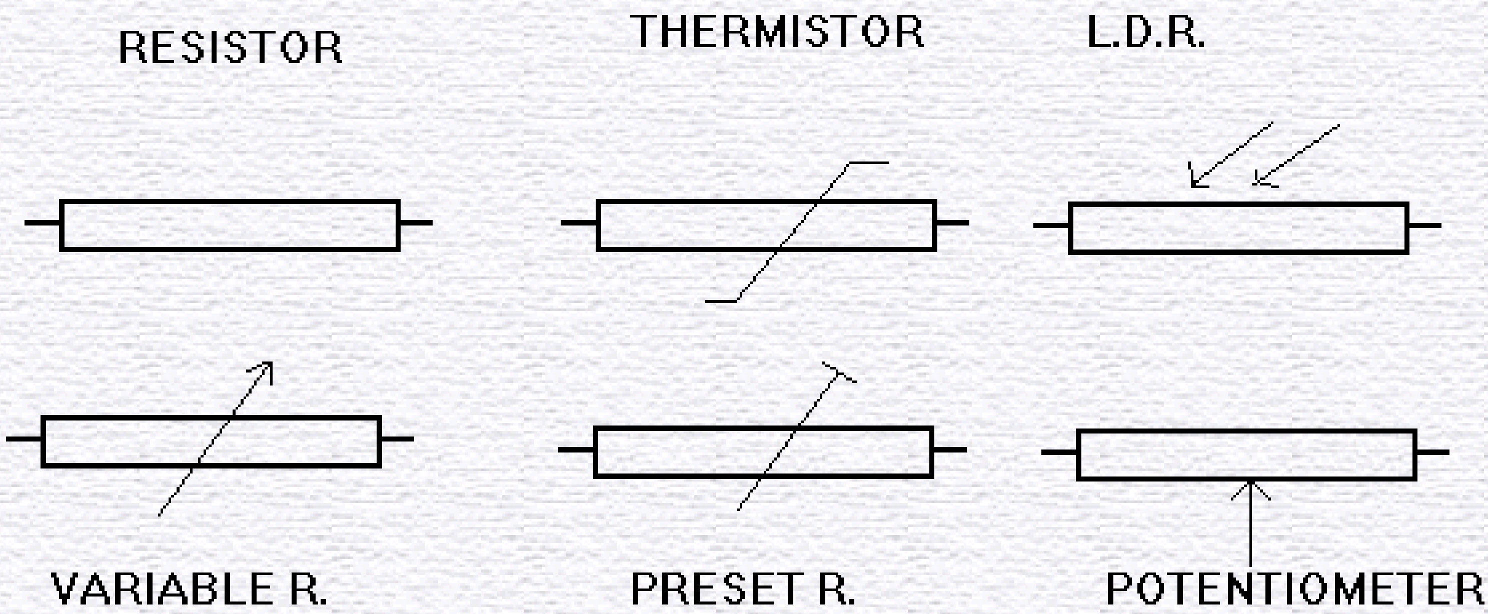
1000 ohms is 1k, 1000,000 ohms is 1M. 3,300,000 ohms is 3.3M etc.

Decimal points are not used on circuit diagrams (they may be confused with fly specks).
3.3M would be written as 3M3 and 1.8k as 1K8 etc.

On circuit diagrams tolerance is indicated by the following letters.
F=1% G=2% J=5% K=10% M=20%

R22M= 0.22 ohm 20% 4R7K= 4.7 ohm 10% 68RJ=68 ohm 5%

Variable resistors are available. These can be operated by means of a knob on the control panel. Examples are volume and brightness controls. Preset variable resistors are internal controls which are adjusted in value by means of a screwdriver. Once adjusted, they are never touched again.



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CAPACITORS

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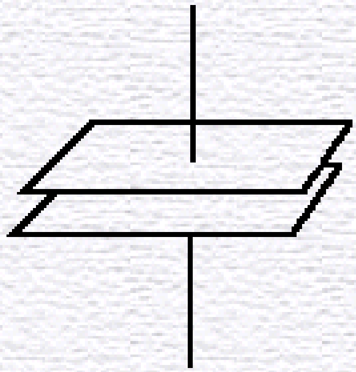
Capacitors are basically two parallel metal plates separated by an insulator.

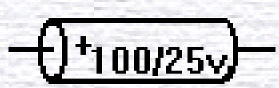


This insulator is called the dielectric.
Capacitor types are named after the dielectric. Thus we have ceramic, mica, polyester, paper air capacitors etc.

Capacitors can be charged up and store electricity, similar to a car battery.
This can be a hazard if they are charged up to high voltages.
If it is necessary, capacitors with large charges should be discharged via a resistor to limit the discharge current.

DC current cannot flow through a capacitor since the dielectric forms an open circuit.

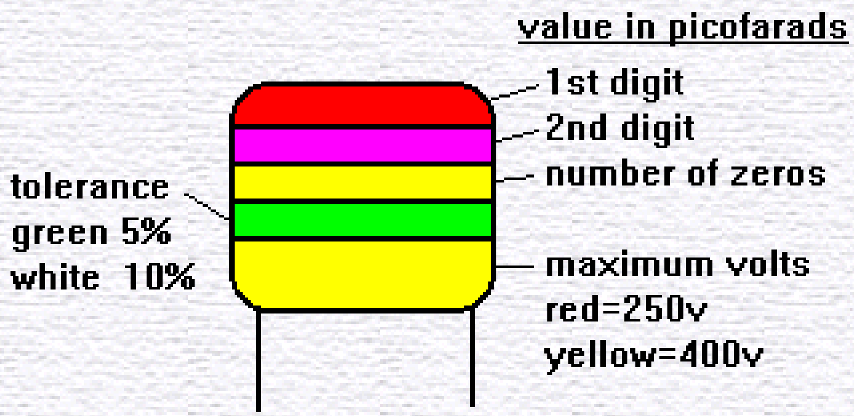
Capacitors come in all shapes and sizes and are usually marked with their value.
Values are measure in Farads. Values in Farads are unusual.
Most capacitor values are measured in microfarads, nanofarads or picofarads. See the page on Value multipliers to find out more about this.



They are often marked with their maximum working voltage. The voltage across the terminals must not exceed this value. It is OK to use a voltage below the maximum value.

Some capacitors such as electrolytic and tantalums are polarised. This means that they must be fitted the correct way round. They are marked to indicate polarity.

Some values are indicated with a colour code similar to resistors. There can be some confusion.
A 2200pf capacitor would have three red bands. These merge into one wide red band.



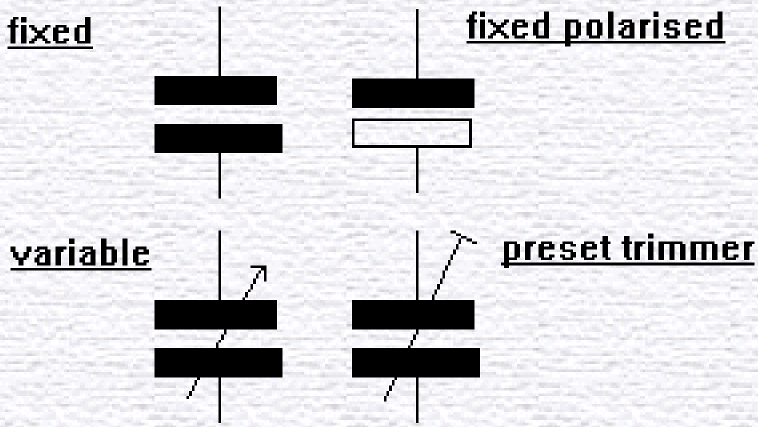
Some values are marked in picofarads using three digit numbers. The first two digits are the base number and the third digit is a multiplier.
For example, 102 is 1000 pF and 104 is 100,000 pF = 100 nF = 0.1 uF.

To find the total value of capacitors in parallel (that is connected across each other) their values are added.
To find the total value if they are in series (that is in line with each other) then the following formula is used.

1/C total =1/C1 + 1/C2 + 1/C3 etc

Variable capacitors are available in which the value can be adjusted by controlling the amount of overlap of the plates or the distance between them.

There is a type of diode called the Varicap diode which similar characteristics.



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THE CATHODE RAY TUBE

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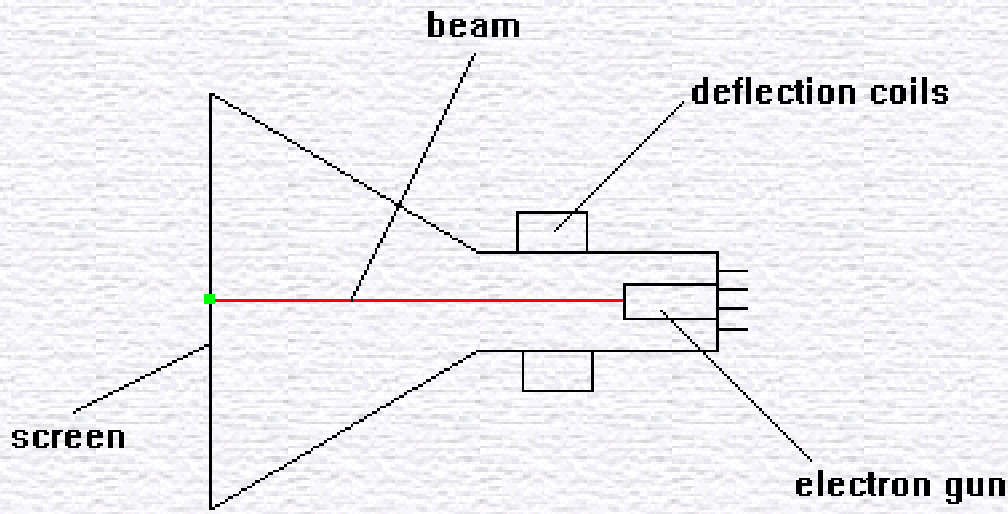

The Cathode Ray Tube (CRT) is used in oscilloscopes, radar, monitors and television receivers.

It consists of a glass envelope made from a neck and cone.
All air has been extracted so that it contains a vacuum.

At the narrow end are pins which make connection with an internal ELECTRON GUN.
Voltages are applied to this gun to produce a beam of electrons.
This electron beam is projected towards the inside face of the screen.

The face is coated with a PHOSPHOR which PHOSPHORESCES (glows) when hit by the beam.
This produces a spot of light on the centre of the face of the CRT.
By varying the beam current, spot BRIGHTNESS can be controlled.
Controlling the diameter of the beam controls FOCUS.

Phosphors come in a range of colours.

On its way from the gun to the screen the beam passes between 2 sets of plates.
They are called the X and Y plates (as in graphs).
By applying voltages to these plates the beam can be deflected.
This causes the spot to move from the centre of the screen to another position on the screen.
The X plates plates deflect the spot horizontally, the Y plates vertically.
Thus the spot can be deflected to any position on the screen.
External deflection coils are often used instead of the internal deflection plates.

Note that dropping a CRT causes it to IMPLODE which is as dangerous as an explosion.

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TRANSFORMER TYPES

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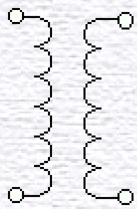
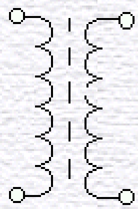
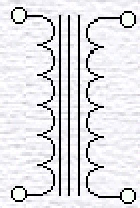


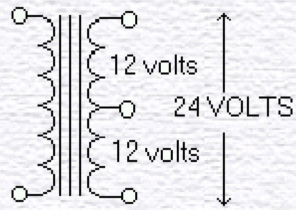
air core for use above 1MHz



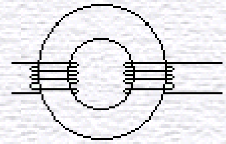
iron dust core for use 100 kHz-1MHz



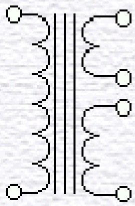
iron core for use at audio & mains frequencies



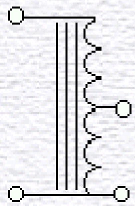
centre tapped secondary



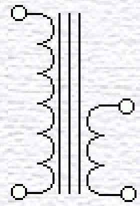
toroidal transformer
produces small magnetic field



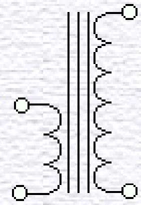
two or more secondaries



auto transformer



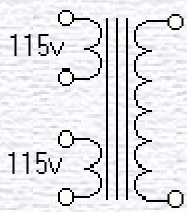
step down



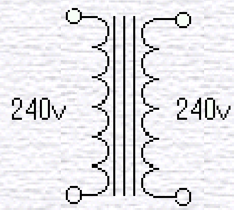
step up

ALL PRIMARIES ARE ON THE LEFT.

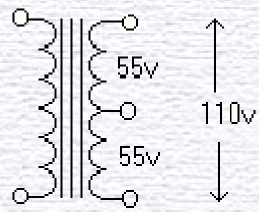
transformers can be used for impedance matching as well as voltage transformation.



primaries in series for 230v (uk)
primaries in parallel for 115v (usa)



mains isolating transformer



building site transformer.
earthed centre tap means worst volts is 55v.

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ACTIVE AND PASSIVE COMPONENTS

ACTIVE components increase the power of a signal and must be supplied with the signal and a source of power.

Examples are bipolar transistors, field effect transistors etc.

The signal is fed into one connection of the active device and the amplified version taken from another connection.
In a transistor, the signal can be applied to the base connection and the amplified version taken from the collector.

The source of power is usually a dc voltage from a battery or power supply.

PASSIVE components do not increase the power of a signal.
They often cause power to be lost.
Some can increase the voltage at the expense of current, so overall there is a loss of power.
Resistors, capacitors, inductors and diodes are examples of passive components.

Integrated circuits contain both active and passive components.
Since they usually increase the power of a signal and require a source of dc power they are treated as active devices.

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THE ELECTROMAGNETIC RELAY

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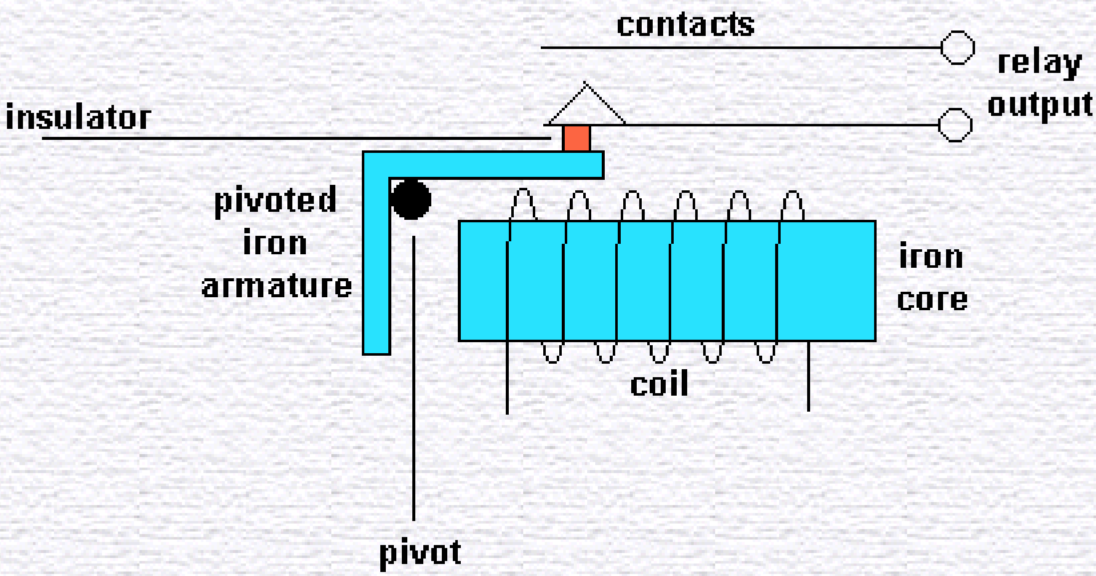
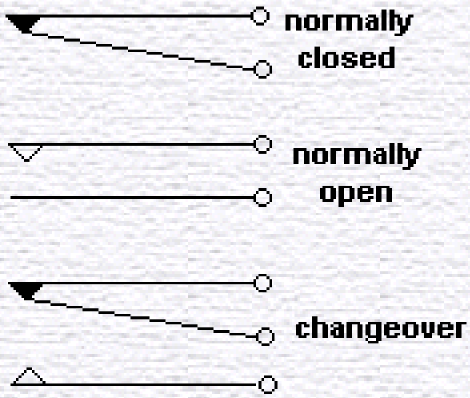


The electromagnetic relay consists of a multi-turn coil, wound on an iron core, to form an electromagnet.
When the coil is energised, by passing current through it, the core becomes temporarily magnetised.
The magnetised core attracts the iron armature.
The armature is pivoted which causes it to operate one or more sets of contacts.
When the coil is de-energised the armature and contacts are released.

The coil can be energised from a low power source such as a transistor while the contacts can switch high powers such as the mains supply.
The relay can also be situated remotely from the control source.

Relays can generate a very high voltage across the coil when switched off.
This can damage other components in the circuit.
To prevent this a diode is connected across the coil.
The cathode of the diode is connected to the most positive

end of the coil.



The springsets (contacts) can be a mixture of n.o n.c and c.o. Look at the page on switches to see how they can be used in circuits.

Various coil operating voltages (ac and dc) are available.

The actual contact points on the springsets are available for high current and low current operation.

The REED RELAY has a much faster operation than the relays described above.

THE REED SWITCH

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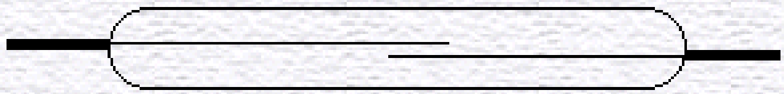

Basically,the reed switch consists of two springy metal strips (reeds) sealed in a glass tube, filled with an inert gas which prevents corrosion.

The switch is activated by an external magnetic field.
This field can be provided by bringing a permanent magnet close to the switch, or by passing current through a coil which is wrapped around the switch.

It can be used as part of an intruder detection system, with a magnet fixed to a door and the switch fitted to the door frame.

It can also be used as a high speed relay. Reed relays require much lower operating current than normal relays.

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THE LOUDSPEAKER

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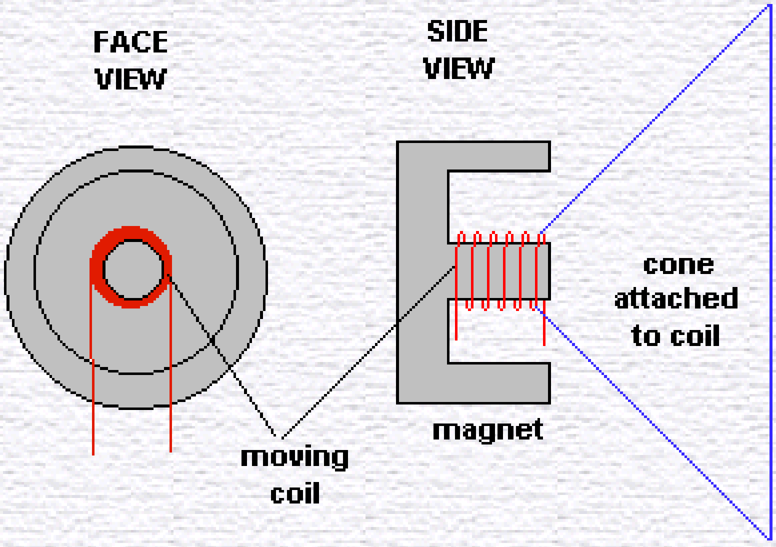


The most common type of loudspeaker is the MOVING COIL speaker, where a coil of wire is suspended in the magnetic field of a circular magnet.
When a speech current is passed through the coil a varying magnetic field is generated by the coil.
The two magnetic fields interact causing movement of the coil (see the page on the MOTOR PRINCIPLE).
The movement of the coil causes a cone, which is attached to the coil, to move back and forth.
This compresses and decompresses the air thereby generating sound waves.
The loudspeaker is a TRANSDUCER converting one form of energy to another.

Loudspeakers have Impedance, typically 4 or 8 ohms.
This must be matched to the output impedance of the amplifier (see the page on REACTANCE and IMPEDANCE).

Loudspeakers are mounted in enclosures (boxes).
The design of enclosures is very complicated.

Large speakers cannot reproduce high frequencies and small

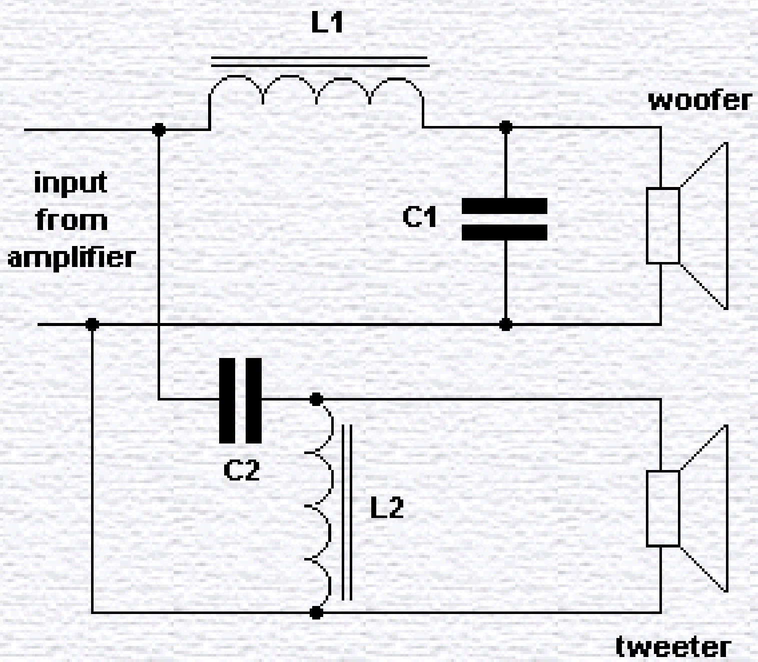
ones cannot reproduce low frequencies.
Therefore two speakers are used, a large one (a Woofer) for low frequencies, and a small one (a Tweeter) for high frequencies.

To ensure that the correct frequencies go to the desired speaker, a Crossover Unit is used.

In the diagram, C1 and L1 are a low pass filter.
C2 and L2 are a high pass filter. (there is a page on FILTERS).

When using two speakers together, as in stereo systems, they must be in phase.
This means that they move out and in together.
This happens if the speaker leads are connected correctly.

Speakers can be connected in series and parallel but the total impedance must match the amplifier impedance.
Using a lower impedance than the correct one can blow up your amplifier.



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CHOOSING CAPACITORS

Size and shape as well as electrical charactaristics must be considered if it is to fit into the available space.
AXIAL capacitors are the same shape as resistors with a wire coming out of each end.
RADIAL ones have both leads coming out of the same end.
Make sure it has the correct lead spacing.
Ensure that the circuit voltages do not exceed the capacitors maximum working voltage.
Electrolytic and tantalum capacitors are polarised and must be fitted the correct way round.

TYPE	RANGE	TOLERANCE	STABILITY	APPLICATIONS
paper	10 nF to 10 uF	10%	fair	motor start, mains interference suppression
silver mica	5 pF to 10 nF	0.5 %	excellent	tuned circuits and filters
ceramic low loss	5 pf to 10 nF	10 %	good	coupling and decoupling
ceramic high k	5 pF to 1 uF	20 %	fair	"
ceramic monolithic	1 nF to 47 uF	10 %	good	"
polystyrene	50pF to 0.5 uF	1 %	excellent	tuned circuits, timing and filters.
polyester	100 pF to 2 uF	5 %	fair	general purpose, coupling and decoupling.
polypropylene	1 nF to 100 uF	5 %	fair	mains suppression and motor start
electrolytic	1uF to 100,000 uF	50 %	fair	LF decoupling and smoothing
tantalum	1 uF to 2000 uF	5 %	excellent	LF coupling, decoupling and timing

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LOGICAL FAULT FINDING

BE AWARE THAT ELECTRICITY CAN KILL !!!

I ALWAYS KEEP ONE HAND IN MY POCKET WHEN WORKING ON HIGH VOLTAGE EQUIPMENT.

MAKE SURE THAT YOU KNOW OF THE HAZARDS FROM A LIVE CHASSIS, CHARGED CAPACITORS, FINAL ANODE VOLTAGES, THE AC SUPPLY ETC

The POKING AND HOPING method of fault finding on electronic equipment is ok if there are only a few components which can be changed one at a time, but is useless where a large number of components are involved. A more logical method is necessary.

Begin by observation using the senses.
Can you smell overheating? With experience one can recognise the type of component by its smell.
Can you see any burnt components, are any particular colours missing from the television picture?
Can you feel any components overheating? Can you feel static on the screen?
Can you hear any distortion,whistles etc?

Have you heard of the game Twenty Questions? One person thinks of something and the others have to guess what it is by asking questions. They receive only YES or NO answers.

If the first question IS IT AN ANIMAL? and the answer is YES then all non animal items in the universe can be ignored.

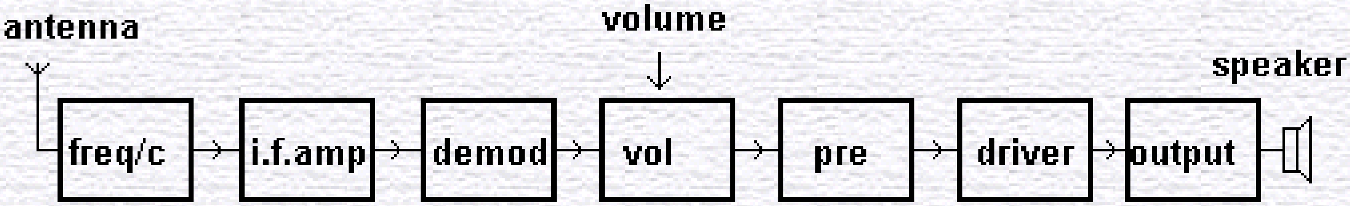
If the second question IS IT HUMAN? and the answer is YES then all other animals in the universe can be ignored.

If the third question IS IT FEMALE? and the answer is NO then only questions related to men need be asked.

After twenty questions most items in the universe can be discovered!!

A similar system can be applied to fault finding. This is called the HALF SPLIT method.

A transistor radio has several STAGES and the signal from the aerial passes through these and is emitted from the loudspeaker as an audio signal.



The volume control is about half way along this chain. If I inject an audio signal at this point and hear noise from the loudspeaker then I know that all stages and components after this point are ok and the fault lies before this point.

From this one measurement we have proved that half of the components are ok and that the fault lies in a certain area. Further HALF SPLIT measurements will enable us to locate the precise stage in which the fault lies.

If we had started at the aerial end and the fault was in the loudspeaker then we would have wasted much time and effort before we found it.

These tests are called DYNAMIC MEASUREMENTS and enable us to locate the stage or area of the fault.
Signal Generators and Oscilloscopes, Logic Pulsers and Logic Probes are frequently used to make these tests.

To find the actual faulty component we use STATIC

MEASUREMENTS.
These usually require the use of a Voltmeter to make measurements on the faulty stage.

The measurements obtained are interpreted to obtain the identity of the faulty component.

For example, the base to emitter voltage of a good silicon transistor is 0.6 volts.If it is not this voltage then it is possibly this component at fault.

Beware that a faulty associated component could possibly give the same readings. If you haven't had much experience at interpreting voltage measurements then remove the suspect component and check it by resistance measurements or substitution with a known good component.

Since the faulty stage has been located and only a few components are usually involved then POKE AND HOPE is more permissible!!

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MEASURING VOLTAGES

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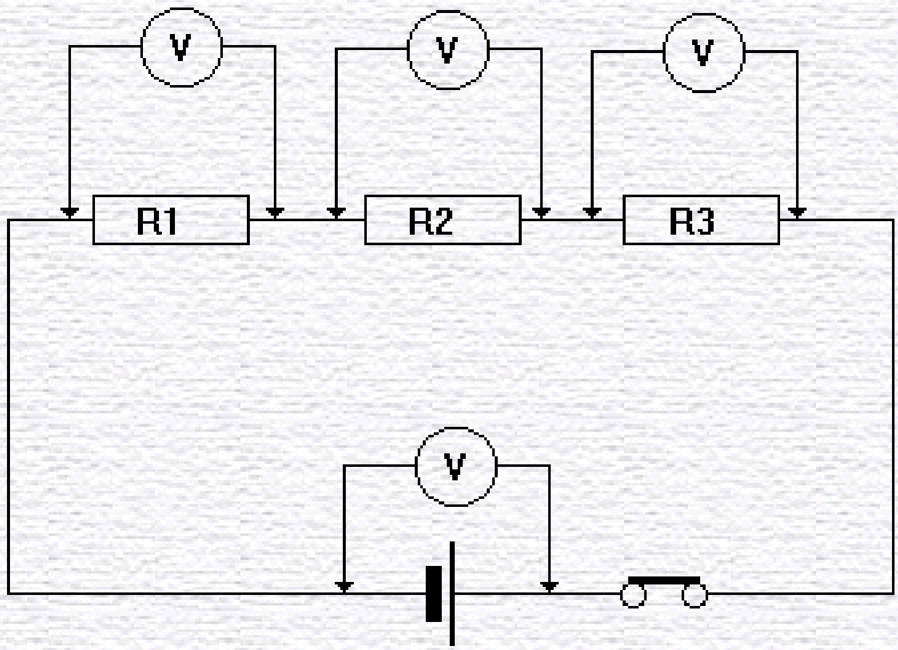

To measure voltages, the meter must be connected ACROSS things; across resistors, across the battery etc.

When measuring DC, connect the red meter lead to the most positive point, and the black one to the most negative.
When measuring AC voltages it doesn't matter which way the leads are connected.

It's best to select a high voltage range on the meter before connecting it and then switching to a lower range if necessary. This protects the meter, especially moving coil ones, from being damaged by having too high a voltage applied to them.

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MEASURING CURRENTS

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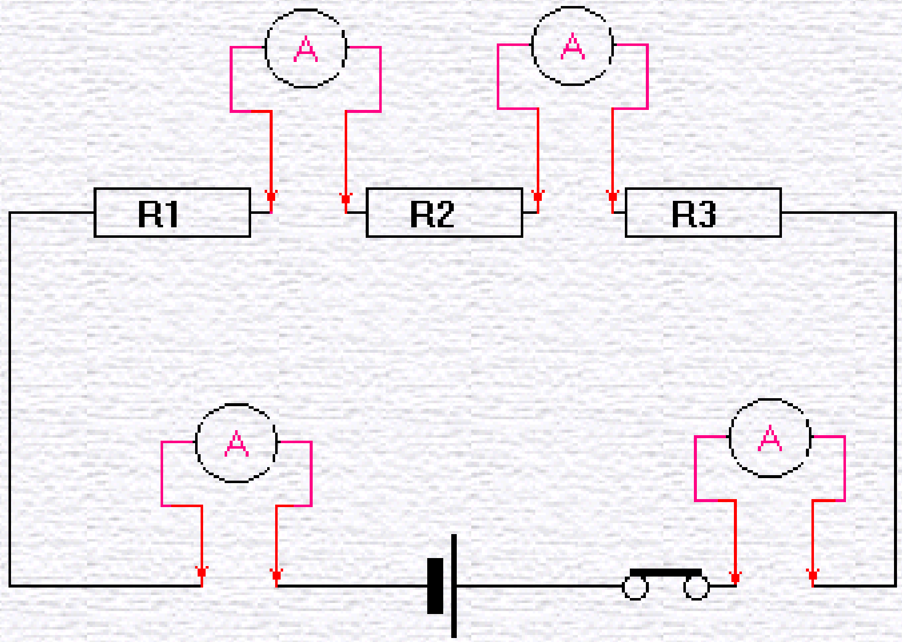

To measure current the circuit must be BROKEN and the meter inserted in the break.

In this circuit the current will be the same no matter where the circuit is broken. If 1 amp is flowing then all meters will indicate 1 amp.

Observe the polarity of the leads when measuring DC
This is not necessary when measuring AC.

Select a high current range on the meter before switching the circuit on.
Switch down to a lower range if necessary to measure the current.
This protects the meter from damage due to excessive current, especially a moving coil one.

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FREQUENCY RESPONSE

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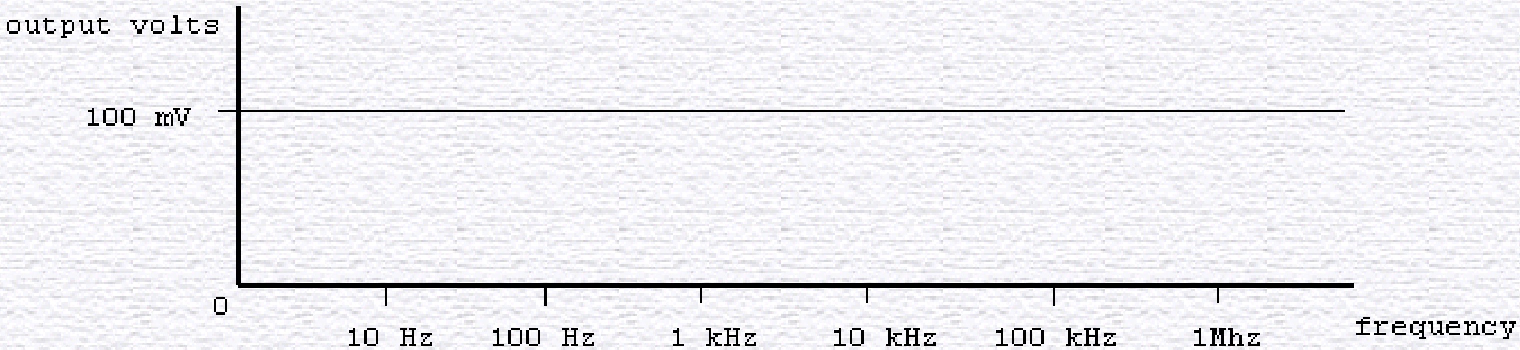
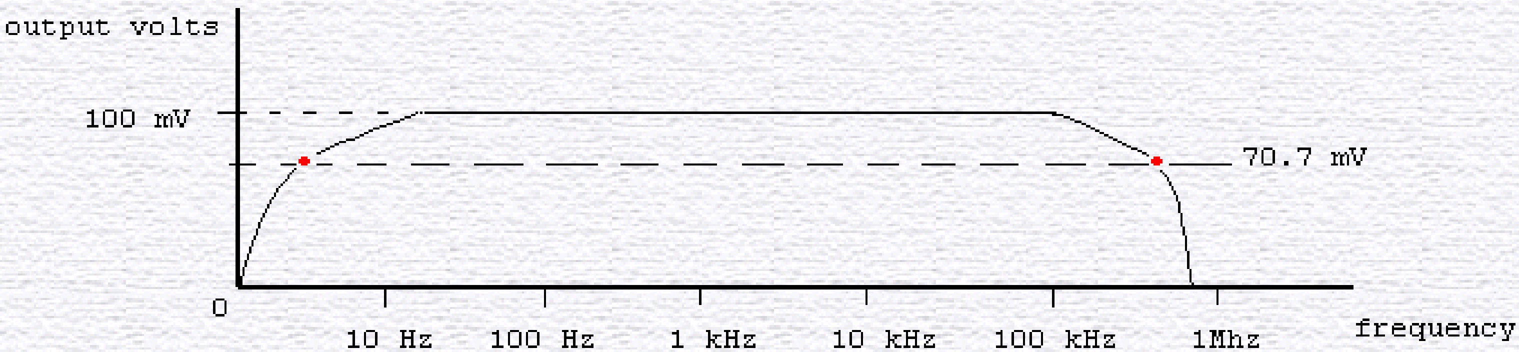
A perfect amplifier with an amplification of times 10, as shown above, would give an output 10 times greater than the input, NO MATTER WHAT THE INPUT FREQUENCY. If the input was 10 mV then the output would be 100 mV, no matter the frequency of the input signal, as seen in the graph below.
This graph is known as a FREQUENCY RESPONSE diagram.



In a practical amplifier it is not possible to obtain a perfectly flat response curve.
This is due to limitations of electronic components and circuitry.
Usually there is a fall of response at low and high frequencies.



The two points in red on the response curve mark where the output of the amplifier has fallen to 70.7 % of the maximum output.
This means that that the 100mV output has fallen to 70.7 mV at these frequencies.
These are called the -3 dB points.
One is at about 5Hz (call it f1).

The other is at about 900 kHz (f2).
Subtract f1 from f2 to get the BANDWIDTH of the amplifier.
In this case it is just under 900 kHz wide.

In some cases the bandwidth is tailored to pass some frequencies and not others.
This is called FILTERING.

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SIGNAL GENERATORS

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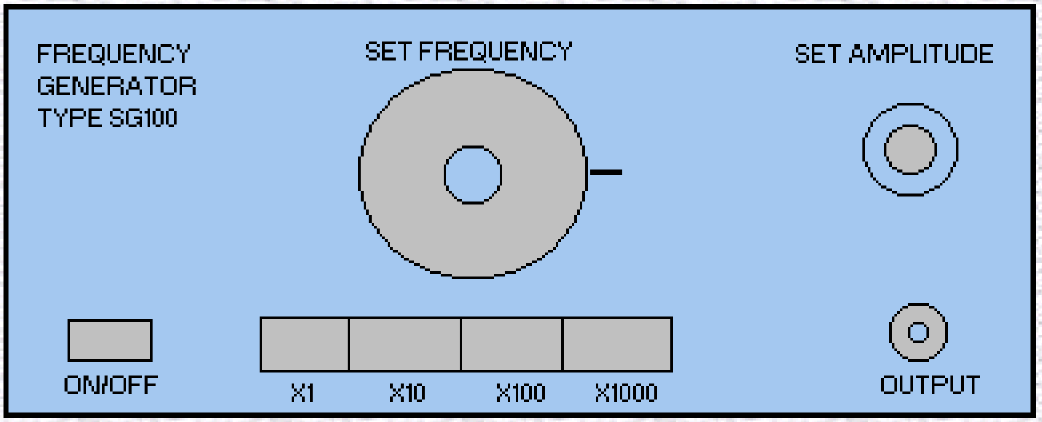

The signal generator is a source of signals for testing and measuring purposes.
Most commonly they generate sine waves.

Audio signal generators produce signals in a range from a few Hertz up to several Kilohertz.
Signals can be injected into audio amplifiers to see how they behave at various audio frequencies.
Amplification and frequency response can be measured and distortion of the signal can be observed.

Radio frequency generators can provide frequencies from about 100 Kilohertz up to several hundred Megahertz.
With radio frequency generators it is usually possible to modulate the R.F. with an audio signal to simulate a radio station. Amplitude and frequency modulation are available.
Using an R.F. generator the various tuned circuits in a radio can be adjusted for peak performance.

The picture is of a simple generator with on/off and frequency and amplitude controls. The large control knob in the centre selects the base frequency while the four switches below select a multiplier.
For example if the base frequency is 30 Hertz and the multiplier is X10 then the output signal is 300 Hertz.

Generators producing square waves, sawtooths and triangular waves etc are called function generators.

Generators can be used in the location of faults in non-working equipment. See the page on fault finding.

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TESTING TRANSISTORS

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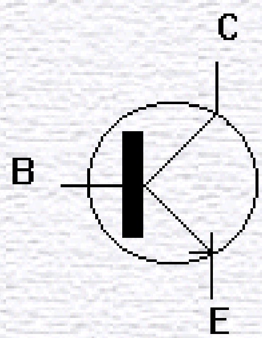

Fig. 1

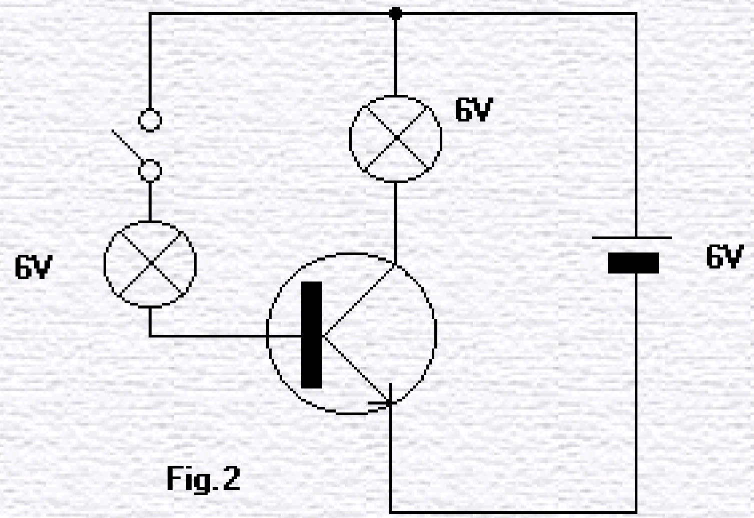

Fig.2

Figure 1. With the meter set to measure ohms, clip one meter lead to the base connection of the transistor.
Dab the other lead first onto the collector lead and then onto the emitter lead.
The readings should both be the same, either both high resistance or both low resistance.

Now reverse the leads and repeat the procedure.
The results should be the opposite of those obtained before.
If they were both high before they should now be both low.
If they were both low before they should now both be high.

Now measure the resistance between emitter and collector.
It should read high resistance in both directions.

If you dont know the transistor connections consult a data book.
If you cant find the data then measure between the three connections in both directions.
You should now be able to identify the base connection and then decide if the transistor is OK.

Note that for this to work the internal battery of the meter must supply a voltage high enough to overcome the forward resistances of the transistors.
Many meter have a position marked with a diode symbol which must be selected when checking transistors or diodes.

Note that NPN transistors have low resistances where PNP have high, and vice versa.

Figure 2. shows a simple power transistor tester. With the switch open both lamps are off.
With the switch closed both lamps are on.
If different results are obtained the transistor is faulty.
The transistor shown is an NPN. Reverse the battery for PNP transistors.

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CONTINUITY TESTING

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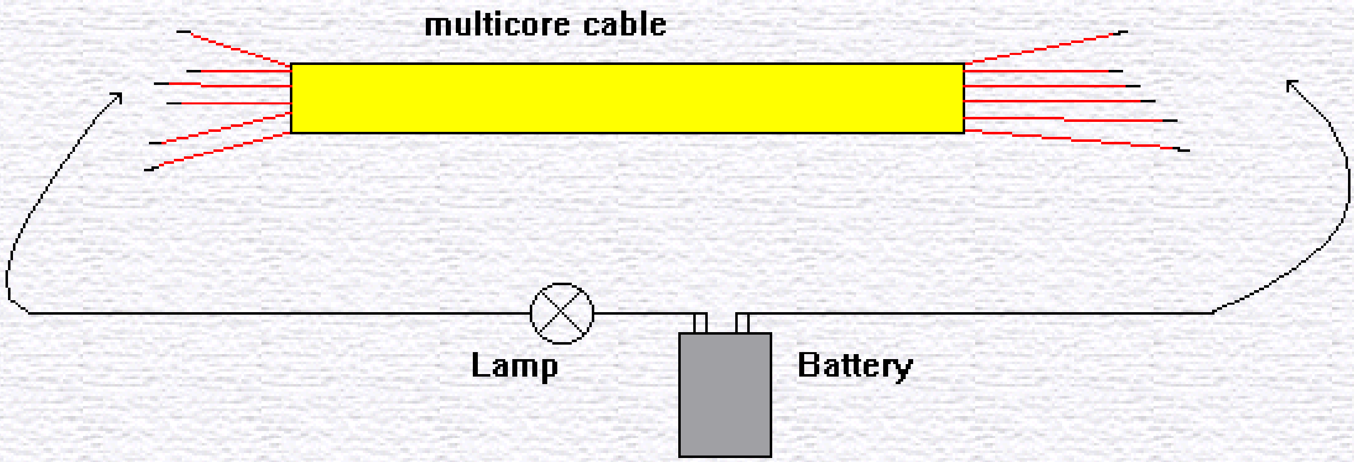
Continuity testing means making sure that something is continuous i.e. not broken.
For example, copper tracks on PCB's or wires in cables must not be open circuit but continuous.



In the diagram, when the two "flying" leads of the lamp and battery setup are connected to the two ends of the same wire in the cable, the lamp will light indicating continuity.
If the lamp doesn't light then the wire is open circuit (i.e. not continuous.)
The tester is also useful for finding both ends of a wire in a cable, where all the wires are the same colour.

A test meter, set to measure resistance, can be used to measure continuity.
Ensure that the meter is set to read low resistance.
If you set the meter to read up to 100k then a resistance of 500 ohms will appear to be continuous.

Some testers give out a whistle when continuity is ok, so you can keep your eye on the job and not keep looking at the meter.

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THE EFFECT OF METER RESISTANCE

All meters have resistance.
The value of this resistance depends upon the voltage range selected.
A typical moving coil meter has a SENSITIVITY of 20,000 ohms per volt.
This means that when the 1 volt range is selected the meter has a resistance of 20,000 ohms.
When the 10 volt range is selected it has a resistance of 200,000 ohms and so on.
When the meter is connected to a circuit to measure voltage, this resistance will affect the circuit and therefore the accuracy of the measurement obtained.

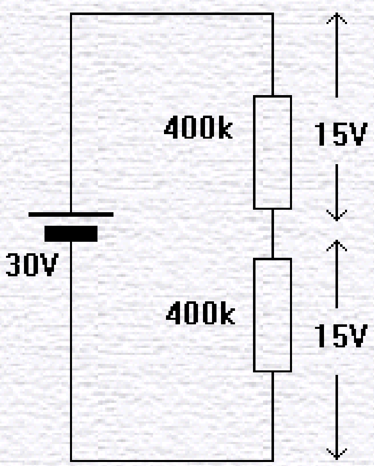

Fig.1

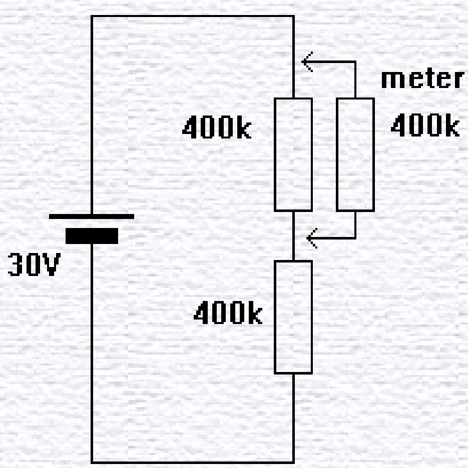

Fig.2

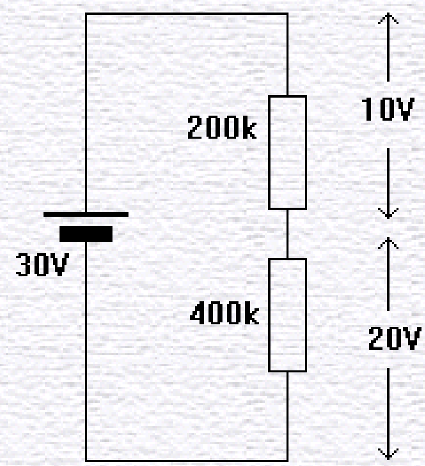

Fig.3

In Fig.1 the voltage across each resistor can be calculated. (see the page on voltage dividers).
However, it can be shown that since the resistors are of the same value then the battery voltage divides equally across them, and the voltage across each will be 15 volts.
Now if we set the meter to the 20 volt range to measure this voltage, its resistance will be 20 x 20,000 = 400,000 ohms = 400k.
If we connect it across the top resistor, as in Fig.2 then we have two 400k resistors in parallel.
Calculating the result of this gives us 200,000 ohms and the circuit looks like Fig.3
The voltage will now divide to give 10 volts across the top resistor and 20 volts across the lower resistor.
The meter will indicate 10 volts when we know that it should indicate 15 volts.
Similarly, connecting the meter across the lower resistor will again indicate 10 volts.
It appears that there is 10v + 10v = 20 volts across the two resistors, when in fact

there is 30 volts.

To obtain the most accurate results, set the meter on the highest range possible. This means that its resistance will be highest and have least effect on the circuit. Digital meter have a very high resistance, typically 10 Megohms on all ranges, and the readings obtained are more accurate than those obtained using a moving coil meter. When buying a new meter look for a sensitivity greater than 20,000 ohms/volt.

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"WITH RESPECT TO"

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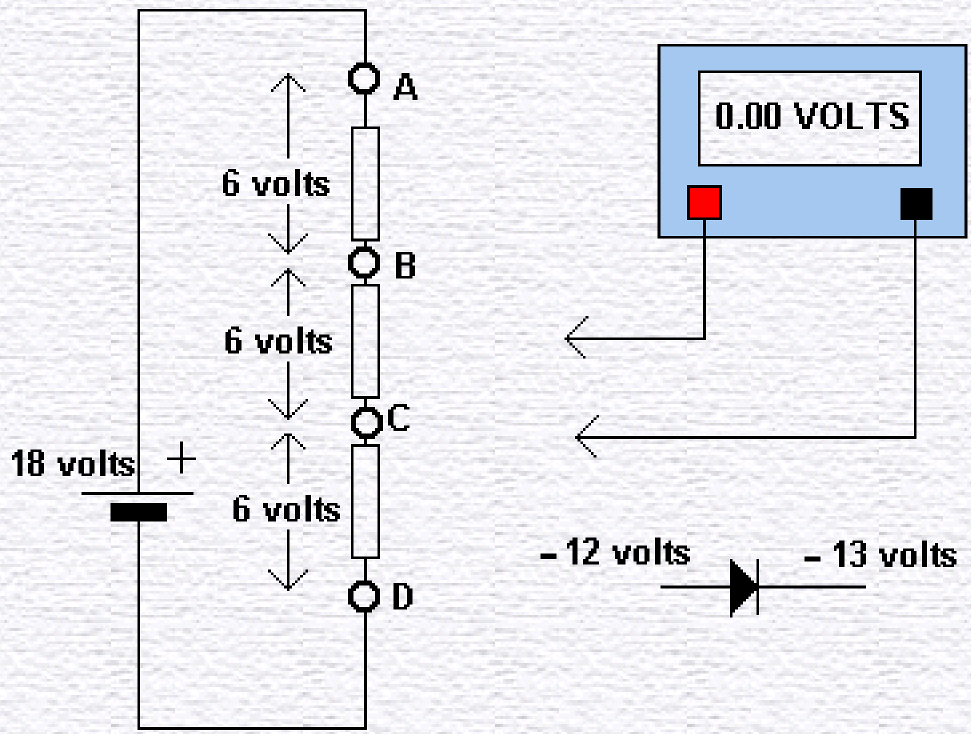
In most cases, when measuring DC voltages in an electronic circuit, the black negative lead is clipped to the negative connection of the battery or supply.
This leaves one hand free.
The red lead is then used to measure the various voltages in the circuit.
These voltages are therefore measured WITH RESPECT TO negative.



wrt = with respect to

In the diagram, point A is 18 volts positive wrt to D. (this is actually the battery voltage).
Therefore D is 18 volts negative wrt A.

A is +12 wrt C and +6 wrt B.
D is - 6 wrt C and -12 wrt B.

B is +6 wrt C and +12 wrt D.
C is - 6 wrt B and -12 wrt A.

Looking at the diode.
The anode is less negative than the cathode.
Or in other words, it is more positive.
The anode is positive wrt cathode by 1 volt.

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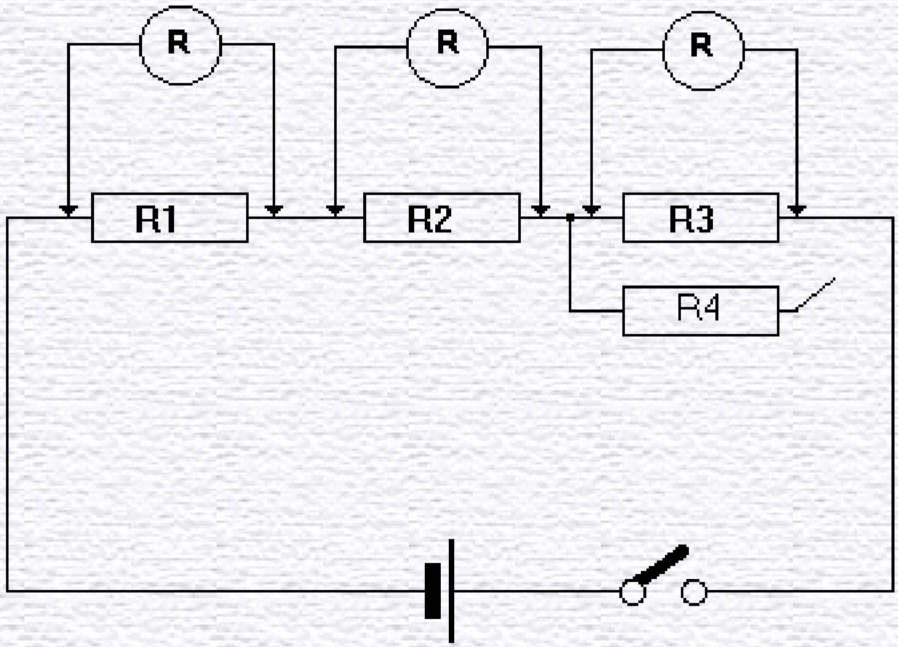
MEASURING RESISTANCE



When measuring resistance the power to the circuit must be SWITCHED OFF.
Ensure that there are no components in parallel with the component to be measured.
There is no need to observe the polarity of the leads.

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USING THE OSCILLOSCOPE

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The controls on a scope can be divided into four groups.

(1) Housekeeping (on/off, brightness, focus)

(2) Horizontal (X position, X amplitude, time/division)

(3) Vertical (Y position, Y amplitude, Invert, Volts/division)

(4) Trigger/synchronisation (level, +/-, external, ac/dc/lf/hf, tvh/tvv)

Set any controls marked "calibrate" to the correct position.

Adjust the housekeeping controls to obtain a trace (display).

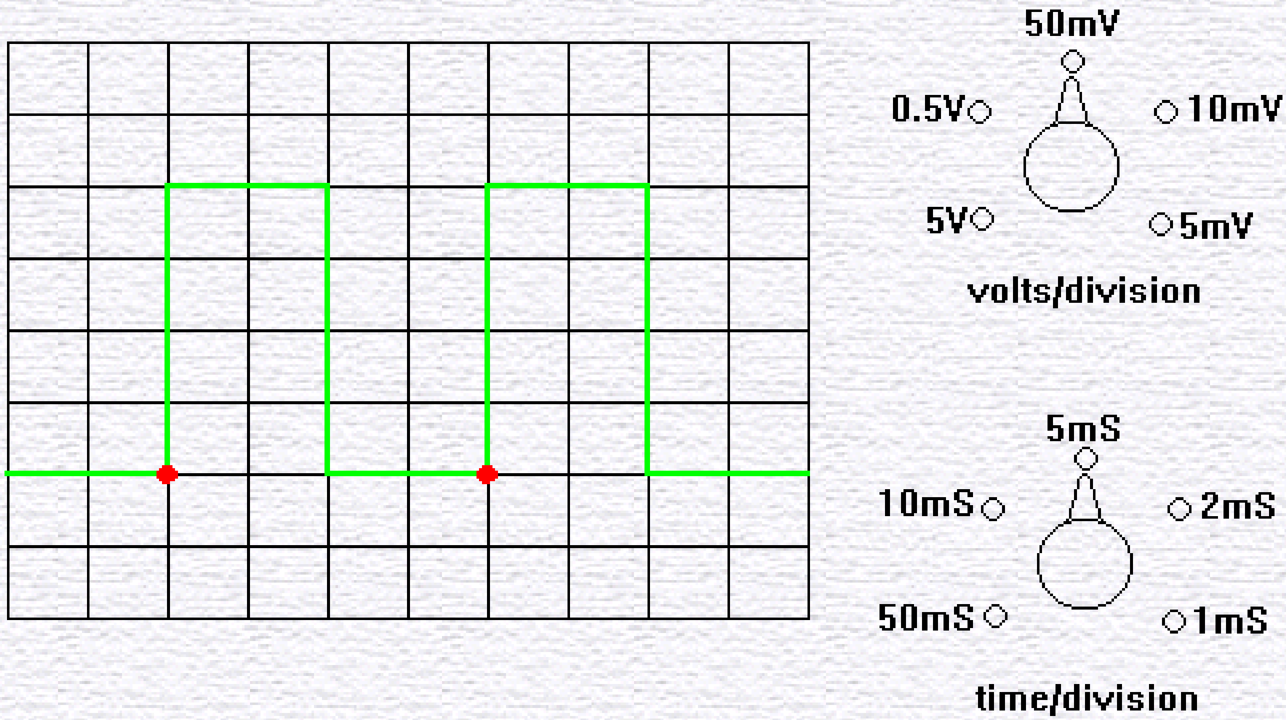
Adjust the vertical and horizontal controls to display a few cycles of a waveform.

Adjust the trigger/synch controls to make the display stationary.

It is best to display about two cycles and make them as large in height as possible.

Measure the amplitude and periodic time (time of one cycle). See below.

Calculate the frequency.



In the diagram the waveform is 4 divisions high.

The volts/ division switch is set to 50 mV/division.

The amplitude is therefore 4 x 50 mV = 200 mV.

The width of one cycle (indicated between the two red dots) is 4 divisions.

The time/division switch is set to 5 mS/division.

The periodic time is 4 x 5 mS = 20 mS.

Note that one cycle is the time between the start of a waveform and the point where it starts to repeat itself.

Frequency can be calculated by dividing 1 second by the periodic time.

Note that if the periodic time is in mS then 1 second has to be expressed as 1000 mS.

1000mS/20mS = 50 Hz

The pattern of squares is called a GRATICULE.

TRACING SCHEMATICS

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"Tracing schematics" is the same as "tracing circuit diagrams" here in the UK.

What it means is, relating a circuit schematic to the actual physical layout of a piece of electronics.

It is a necessary skill when fault finding.

To do it, you must be able to recognise components and read their values, or type numbers.
You must also know their circuit symbols.

If working on printed circuit boards, it helps if you are able to see both sides of the board.

You must isolate the power before doing this.

To begin with, you need a starting point.
This is usually a single component which you are able to locate on both the schematic and the equipment.
It is something easily identifiable, such as a mains transformer, loudspeaker socket, power transistor with marked type number etc.

Once you have done this, you move on to identify other components connected to this component.
After that, identify more components, moving in the direction of the part of the circuit which you are investigating.
You should be able to identify all the components in that part of the layout which interests you.

Relating the schematic and the practical layout makes fault finding much easier.

This skill is also useful if you don't have a circuit schematic.

You can identify the component layout around the area in which you are interested and trace (draw) that part of the schematic.

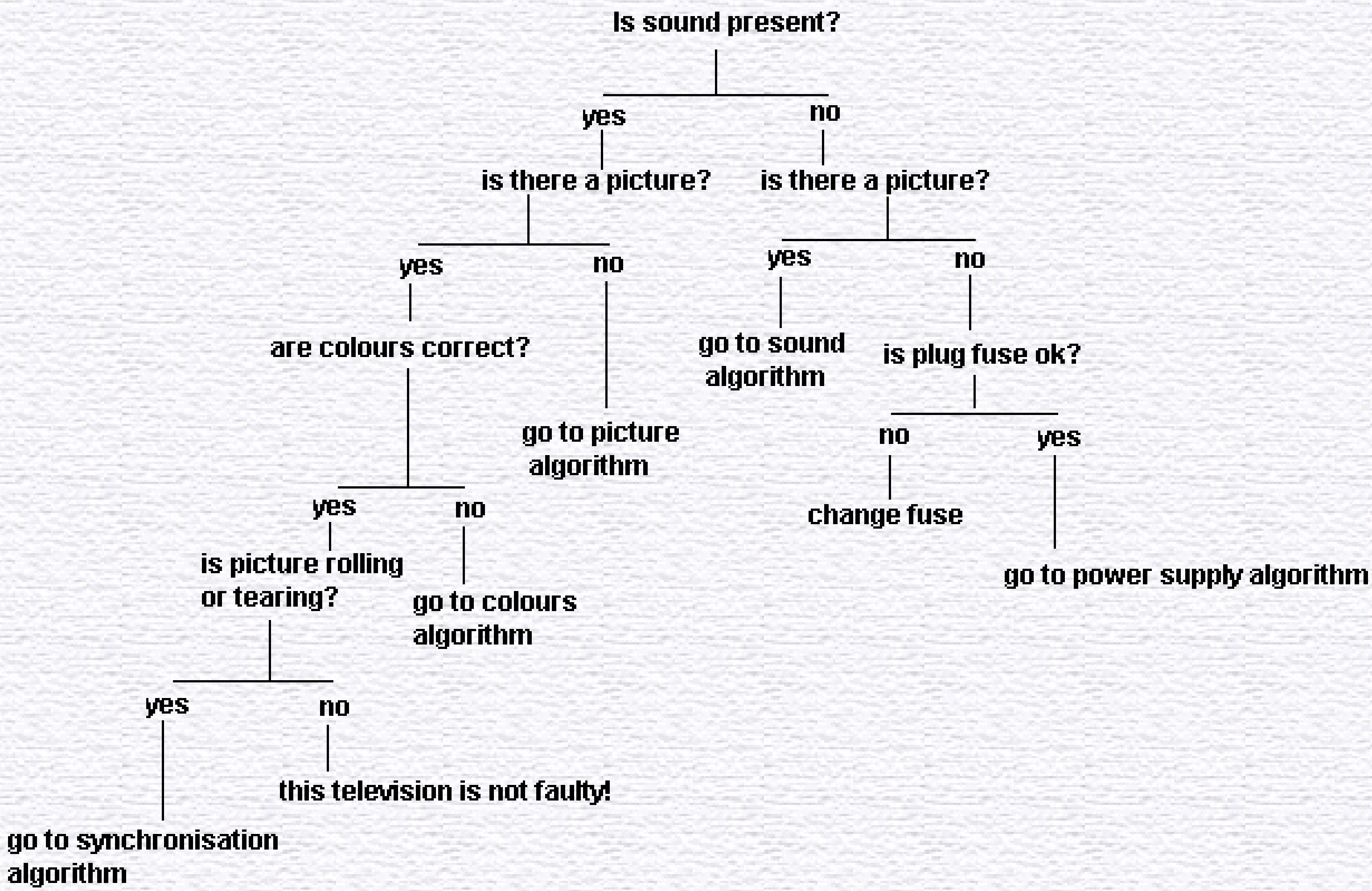
This skill also enables you to make a component layout drawing, using a schematic as a guide.

"Reading schematics" is something completely different. It means the ability to look at a schematic and describe in detail how the circuit works.

FAULT FINDING ALGORITHMS

An algorithm is a list of instructions in the form of a flow chart.
In electronics it can be applied to fault finding.
Below is an abbreviated version for fault location on a colour television.
Detailed algorithms can locate faults right down to component level.
Algorithms can be applied to systems other than electronic ones, such as motor vehicles, atomic power stations, space vehicles etc.

Colour Television fault finding algorithm



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LOGIC GATES

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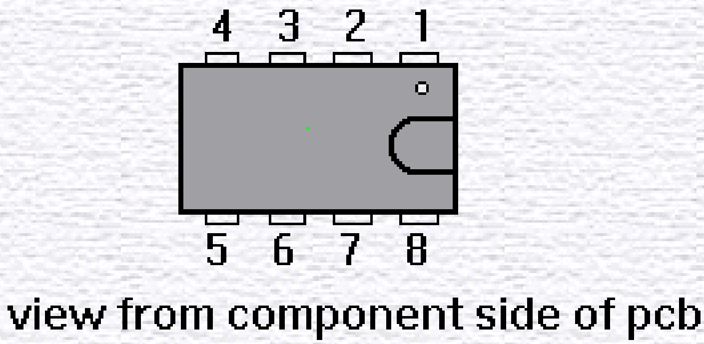


Logic gates usually come packaged as integrated circuits which have type numbers such as 7400 or 4001.

They belong to semiconductor families such as TTL (transistor, transistor logic) or CMOS (complementary metal oxide semiconductor). The names describe their internal construction.

They are DIGITAL devices not ANALOGUE.

A thermometer is an analogue device because it can record an infinite number of values such 100 degrees, 0.1 degrees or 34.354 degrees etc.
Other analogue devices are a car speedo and a Hi Fi amplifier (which can handle lots of different frequencies and loudnesses.)

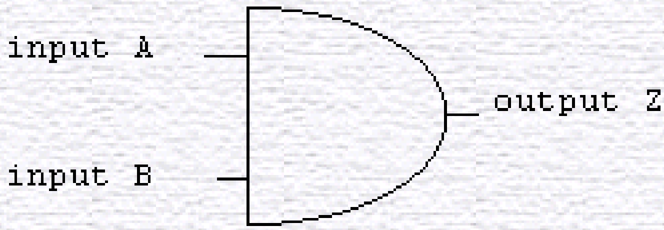
A digital device or system uses only two values. These can be expressed in several ways.

high	or	low
true	or	false
5 volts	or	zero volts
on	or	off
1	or	0

etc

A light switch and a rat trap are digital devices.

Most gates usually have two or more inputs and one output



The state of the output (high or low) depends upon the combination of the input states.

In the case of the gate shown, the output will only be high if both inputs are high. If either one input or both inputs are low then the output will be low

These characteristics can be shown using a TRUTH TABLE. In the following example 1 indicates a high and 0 indicates a low.
Note that Z is only a 1 when A AND B are both at 1.

A	B	Z
0	0	0
1	0	0
0	1	0
1	1	1

There is a form of mathematics associated with logic gates called BOOLEAN ALGEBRA.
It was invented a few hundred years ago by Mr Boole, before the days of electronics. He used it to solve problems in logic.

For example
Some cats are black AND black items cannot be seen against a black wall.Therefore it is TRUE that some cats cannot be seen against a black wall.

Here is a Boolean expression for the gate shown. A . B = Z
Read this as IF A AND B ARE HIGH THEN Z IS HIGH. (The . is read as AND).

The most frequently used gates are AND, OR, NAND, NOR, NOT and EXOR.

An integrated circuit containing 4 AND gates each with 2 inputs is called a QUAD 2 INPUT AND ic.An ic with 6 NOT gates is called a HEX INVERTER ic.

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THE AND GATE

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Before reading this page read the one on LOGIC GATES.

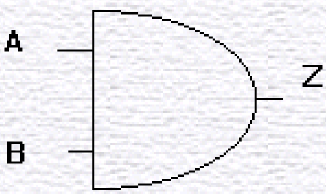
The AND gate has two or more inputs and one output.

The output voltage goes high only when all input voltages are high.

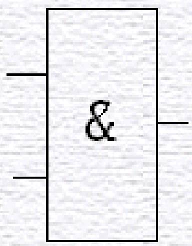
In the switch diagram the lamp lights up only when A and B are operated. If only one is switched then the lamp stays off.

In the truth table Z = 1 only when A and B = 1

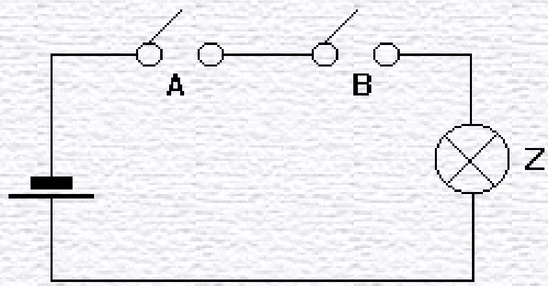
The Boolean expression is A.B = Z which translated says, A and B both high, makes Z high.



US symbol



UK symbol



Switches simulating AND

A	B	Z
0	0	0
1	0	0
0	1	0
1	1	1

Truth table

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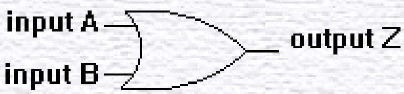
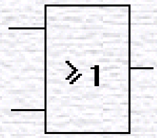
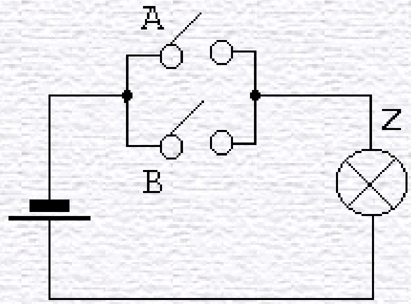
THE OR GATE







Switched OR gate

A	B	Z
0	0	0
1	0	1
0	1	1
1	1	1

Truth table

Before reading this page read the one on LOGIC GATES.

The OR gate has two or more inputs and one output.

The output voltage goes high only when one or more input voltages are high.

In the switch diagram the lamp lights up when A OR B (or both) are operated.

In the truth table Z = 1 when A or B = 1.

The Boolean expression is A+B = Z which translated says, A or B high makes Z high.

The plus sign + translates as OR.

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MULTIVIBRATORS

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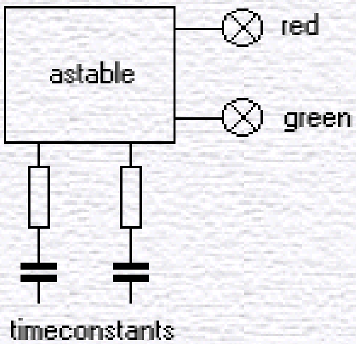

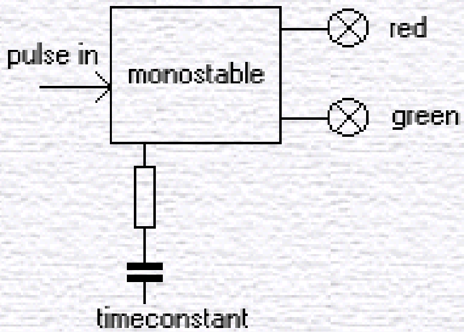

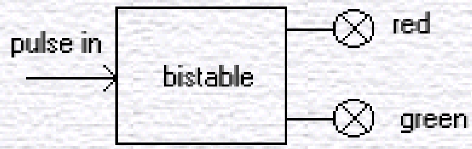

Multivibrators (sometimes called FLIP-FLOPS) have two "cross coupled" transistors, say TR1 and TR2.
This causes TR1 to be on (conducting) and TR2 off.
They can be made to reverse states, with TR1 turning off and TR2 turning on.
The states of the transistors can be indicated using a lamp for each transistor.

THE ASTABLE is continually changing state.
The lights flash alternately on and off.
This is because it has two UNSTABLE states and is changing automatically from one to the other.
The duration of these states is determined by two RESISTOR/CAPACITOR TIME CONSTANTS.
Changing the values of the time constants alters the flashing rate.

THE MONOSTABLE has one unstable and one stable state.
It rests in the stable state, waiting for an external pulse.
When a pulse arrives it changes to the unstable state.
It stays in the unstable state for a time determined by an RC time constant.
It then falls back into the stable state and waits for another pulse.
This means that the lights wait in the stable state, one on, the other off.
When the pulse arrives they change state for a while and then fall back to the waiting state.

THE BISTABLE has two stable states.
It waits in one state for an external pulse.
When the pulse arrives it changes into the other stable state waiting for another pulse.
If another pulse never arrives it will wait forever.
The lights change over on the arrival of each pulse.

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THE NOT GATE

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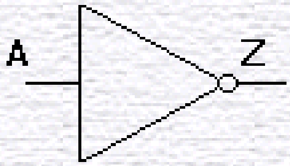
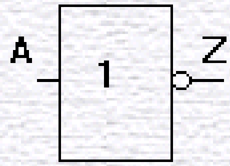


US symbol



UK symbol

A	Z
0	1
1	0

Truth table

The NOT gate has a single input and one output.

The little bubble on the output indicates that the output goes LOW when the input goes HIGH.

We can say that the output goes LOW when the input is ACTIVATED.

The opposite happens when the input is LOW. The output goes HIGH.

The TRUTH TABLE shows that the output is the opposite of the input.

The NOT gate is also called an INVERTER. It inverts the input.

The Boolean expression is $\overline{A} = Z$

Which is read as, NOT A EQUALS Z

or IF A IS LOW THEN Z IS HIGH

or BAR A = Z

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EXOR GATES

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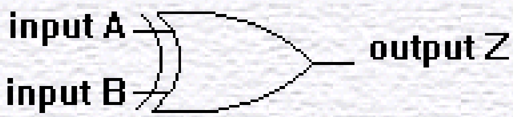
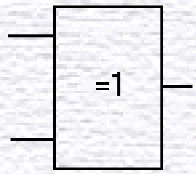
Boolean expression $A \oplus B = Z$



US symbol



UK symbol

A	B	Z
0	0	0
1	0	1
0	1	1
1	1	0

Truth table

Before reading this page read the one on LOGIC GATES.

If you look at the truth table for the OR gate not only does the output go high when A OR B are high but it goes high when A AND B together are high.
This can cause problems in some applications.

Therefore the EXCLUSIVE OR or EXOR is used.

The output of the EXOR only goes high when A or B on its own goes high.
That is when A or B exclusively goes high.

When A and B are both high the output stays low.

This is shown in the truth table.

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THE NOR GATE

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Before reading this page read the one on LOGIC GATES.

The NOR gate has two or more inputs and one output.

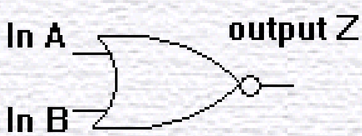
The output voltage goes low only when one or more input voltages are high.

In the switch diagram the lamp goes out when A OR B (or both) are operated. (A short circuit is placed across the lamp)

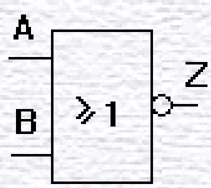
In the truth table Z = 0 when A or B = 1

The Boolean expression is $A+B = \overline{Z}$ which translated says, A or B high makes Z low.

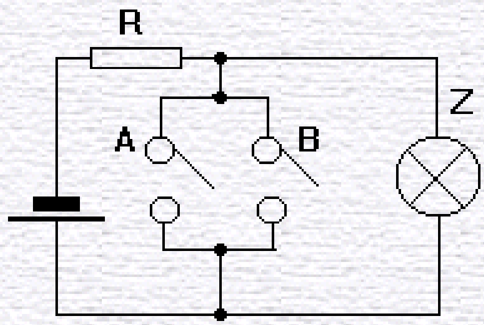
The plus sign, + translates as OR. $\overline{Z}$ (called Z bar) means Z is low.



US symbol



UK symbol



Switched NOR gate

A	B	Z
0	0	1
1	0	0
0	1	0
1	1	0

Truth table

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BINARY

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Humans have 10 fingers so they use the numbers 0 to 9 for counting.
Penguins have only two flippers so they can only use 0 and 1.

Brand new human and penguin cars have all zeros displayed on the odometer.

0	0	0	0	0	0	0	0

After travelling 1 mile both display

0	0	0	0	0	0	0	1

So a 1 in this first column means 1 mile in both cars.
After travelling another mile, the humans display shows

0	0	0	0	0	0	0	2

However, as we saw at the start, the penguin doesn't have a 2.
So he resets the first column to zero and puts a 1 in the next column.

0	0	0	0	0	0	1	0

He says to himself, "a 1 in this second column is worth 2 in decimal".

They both drive another mile.
The humans car displays 3.

0	0	0	0	0	0	0	3

Since the penguin has driven the same mile, he puts a 1 in the first column, which we know is worth 1 mile in both cars.

0	0	0	0	0	0	1	1

They drive another mile.

The humans car shows 4

0	0	0	0	0	0	0	4

The penguin has to reset the first two columns to zero and poke a 1 in the third

0	0	0	0	0	1	0	0

He says, " a 1 in the third column is the worth 4 in the decimal system."
So we can correctly guess that a 1 in the fourth column indicate decimal 8

0	0	0	0	1	0	0	0

and a 1 in the next is worth 16, and so on.

0	0	0	1	0	0	0	0

So when the odometer shows 1111

				8	4	2	1
0	0	0	0	1	1	1	1

the car has travelled 8+4 +2 +1 =15 decimal miles.

So adding up in penguin is
0+0=0
0+1=1
1+0=1
1+1= zero and carry 1 = 10

Write the numbers from nought to fifteen, decimal, in penguin.

Penguin counting is the same as BINARY COUNTING.

Binary is used in digital electronic systems, where they have only two values of voltage.

THE NAND GATE

Before reading this page read the one on LOGIC GATES.

The Nand gate has two or more inputs and one output.

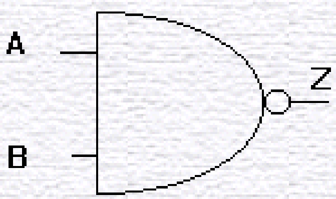
The output voltage goes low only when all input voltages are high.

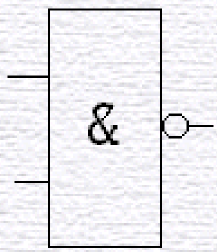
In the switch diagram the lamp goes out when A and B are operated. (A short circuit is placed across the lamp)

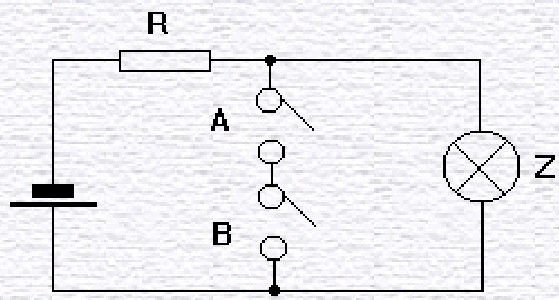
In the truth table Z = 0 when A and B = 1

The Boolean expression is $A.B = \overline{Z}$ which translated says, A and B high makes Z low.

$\overline{Z}$ (called Z bar) means Z is low.







A	B	Z
0	0	1
1	0	1
0	1	1
1	1	0

US symbol NAND

UK symbol

switches simulating truth table

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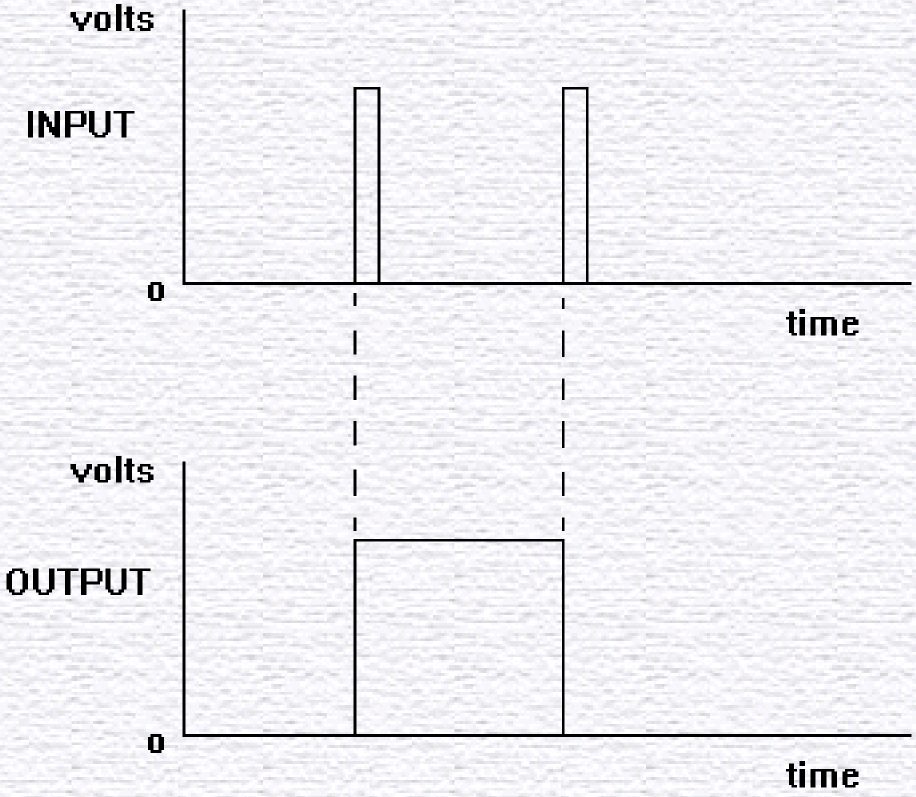
THE BISTABLE AS A DIVIDER

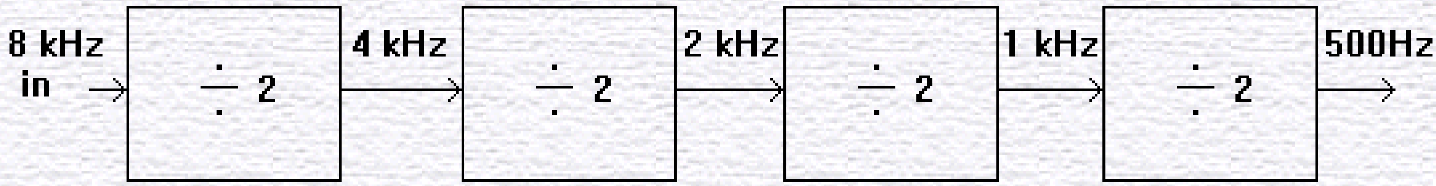
Read the page on multivibrators first.

The output of the bistable toggles (changes state) when its input receives a pulse.
This means that after two pulses the output has returned to its origonal state.
If it was origonally low, it has gone high after the first pulse and then returned low after the second.



Looking at the first diagram, the two input pulses have provided a single, wider pulse at the output.
If we put eight pulses in then we get four out.
The bistable divides by two.
If we put a 16 kHz signal in, we get an 8 kHz signal out.
The bistable acts as a frequency divider.

If we feed the 8 kHz into another bistable the resulting frequency is 4 kHz. We can divide a high frequency signal down to a lower one.



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THE 7490 DECADE COUNTER

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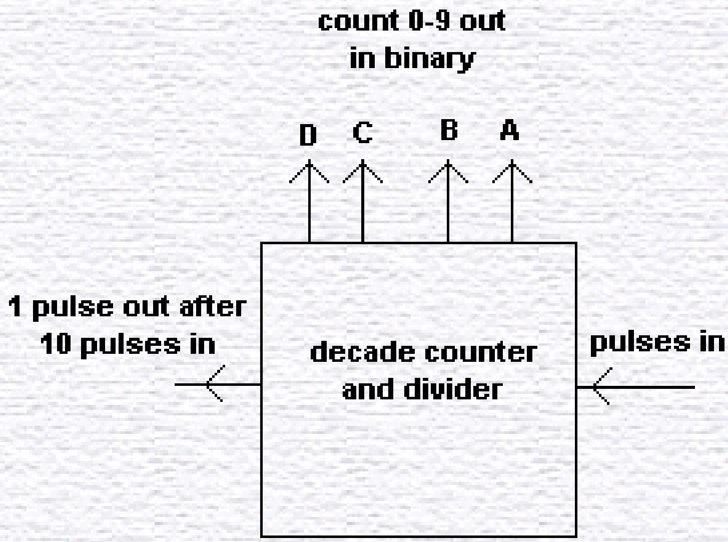

The 7490 integrated circuit counts the number of pulses arriving at its input.
The number of pulses counted (up to 9) appears in binary form on four pins of the ic.

When the tenth pulse arrives at the input, the binary output is reset to zero (0000) and a single pulse appears at another output pin.

So for ten pulses in there is one pulse out of this pin.
The 7490 therefore divides the frequency of the input by ten.

If this pulse is applied to the input of a second 7490 then this second ic will count the pulses from the first ic.
It will give one pulse out after 100 pulses have been applied to the first ic.

The 7490 can be connected to divide by other values.

decimal	**binary**
0	0000
1	0001

2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

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BINARY TO 7 SEGMENT DECODER

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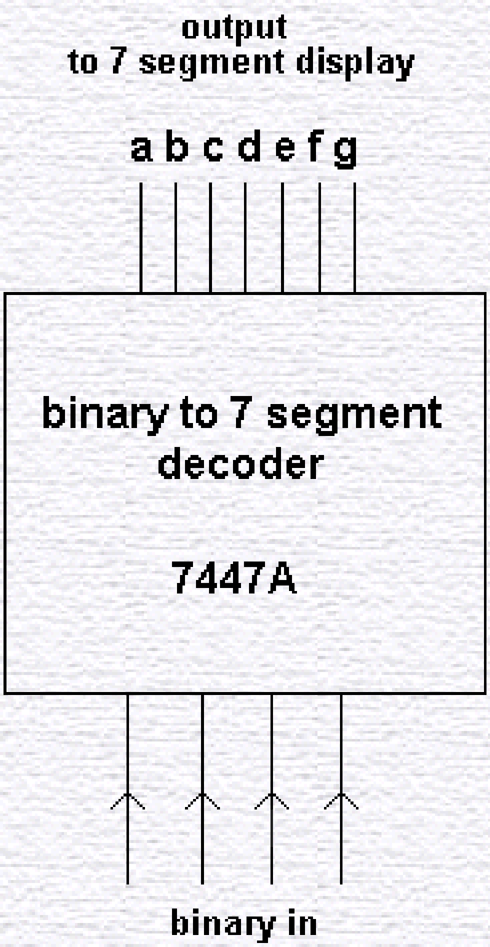

Digital voltmeters, frequency counters etc use 7 segment displays to show the result of measurements.

However all the internal electronics use binary for manipulation of the data.

To convert this binary to a form that can be used by the display requires the use of a DECODER, in this case a "binary to 7 segment display decoder".

This has four inputs for the binary and seven outputs for the display.

Other types of decoder are available such as binary to decimal.

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HEXADECIMAL

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It's best if you read the page on binary first.

Humans use the decimal digits zero to nine because they have ten fingers.

Penguins are limited to using binary zeros and ones because they have only two flippers.

Well Martians have 16 fingers, so they have sixteen digits,which they call kpxvz to zxkyt, where kpxvz is the same as our zero. Their maths system is called hexadecimal, (hex for short).

When we translate Martian to Human we can use 0 to 9 for the first ten Martian fingers because they they are the same.

Humans haven't any words for the Martian numbers for the remaining six fingers, oggfv to zxkyt.

The best we can do is to use the letters A B C D E F where A is equivalent to oggfv and F represents zxkyt.

So translating Martian (hexadecimal) we use the following (binary equivalents are included).

---

decimal	hex	binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001

10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

So 000F hex is the same as decimal 15.
0010 hex is the same as decimal 16
0100 hex is the same as decimal 256
1000 hex is the same as decimal 4096

1111 hex = 4096+256+16+1=?
00FF=255
FFFF=65535

Prove it.

In some computers, information is stored as 16 bit binary numbers.

Imagine typing in hundreds of these numbers without making a mistake.
1111011111001101

We can make life somewhat easier by breaking this into four sections.
1111 0111 1100 1101

and converting into the hex equivalent.
F 7 C D

or F7CD. Easier to type!

WHAT IS ELECTRIC CURRENT?

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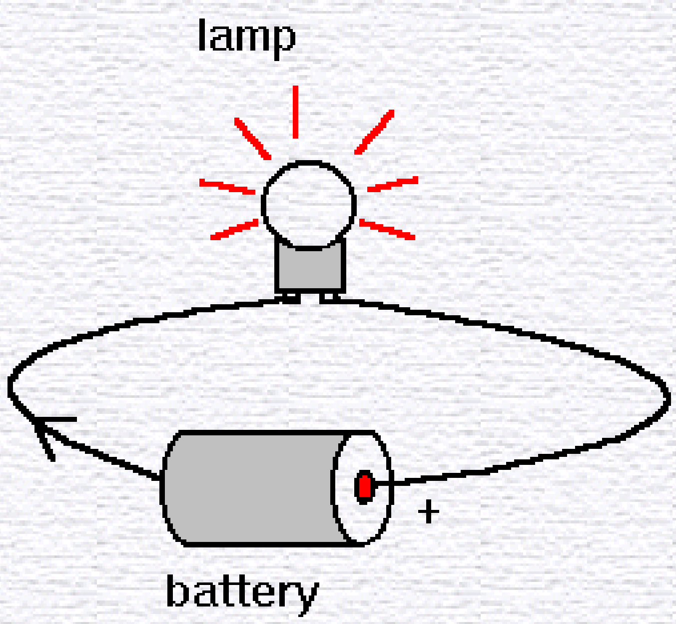
An electric current is a flow of microscopic particles called ELECTRONS flowing through wires and electronic components.
It can be likened to the flow of water through pipes and radiators etc.
As water is pushed through pipes by a pump, electric current is pushed through wires by a battery.
Hot water does work by heating radiators.
Electric current does work by heating fires, lighting lamps, ringing bells, electroplating etc.

A basic law of the universe is that like charges repel and unlike attract. Two negatives will repel each other. A negative and a positive will attract each other.
An electron has a negative charge.
The negative (-ve) terminal of a battery will push negative electrons along a wire.
The positive (+ve) terminal of a battery will attract negative electrons along a wire.

Electric current will therefore flow from the -ve terminal of a battery, through the lamp, to the positive terminal.



This is called electron current flow.

The current flows round the circuit.

In some books current is said to flow from +ve to -ve. This was guessed at before the electron was discovered. They guessed wrong! This is called conventional current flow.

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CURRENTS IN A CIRCUIT

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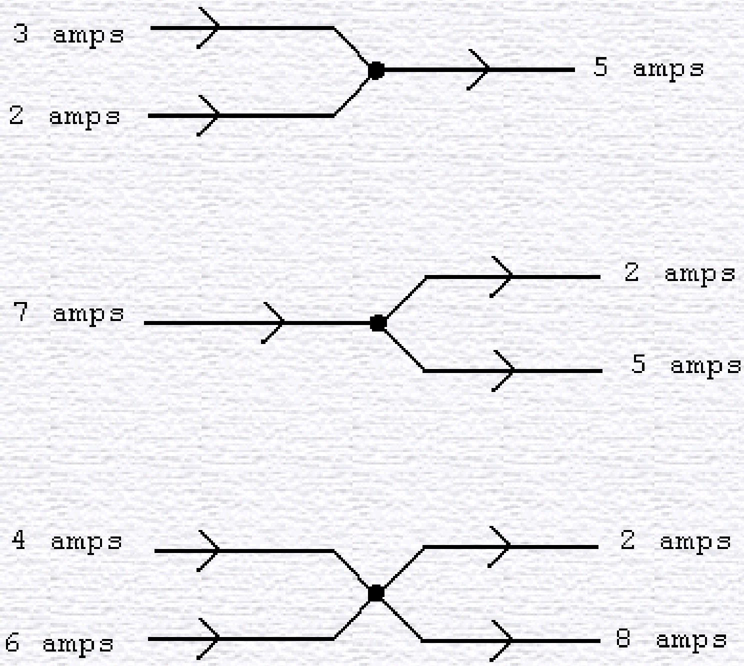

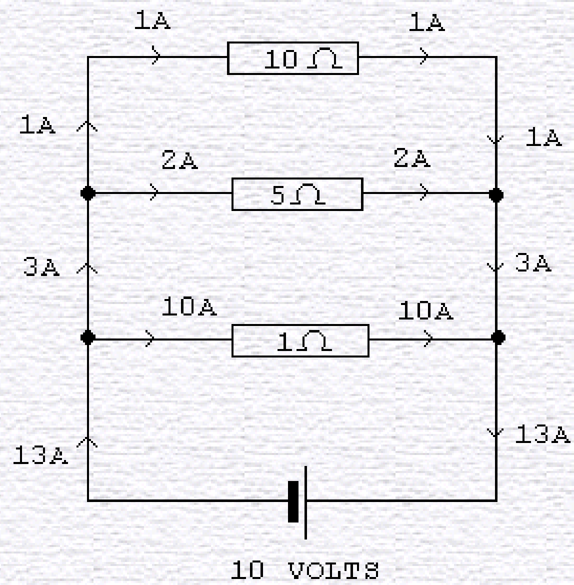

The total current entering a junction equals the total current leaving that junction.

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BATTERIES IN SERIES AND PARALLEL

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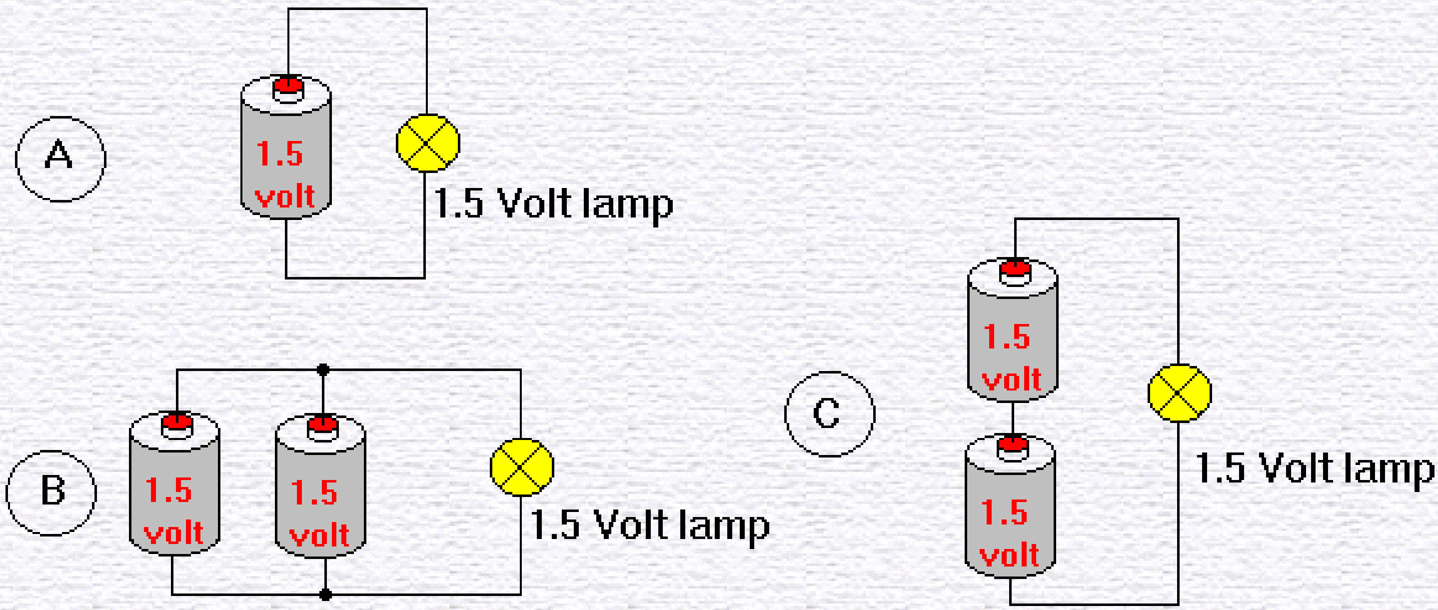

Ⓐ The lamp is in parallel (across) the battery and will be normal brightness.

Ⓑ The batteries are in parallel and will give 1.5 volts. The lamp will be normal brightness but the batteries will last twice as long as Ⓐ

Ⓒ The batteries are in series and give 3 volts. The lamp will be very bright but will 'blow' very quickly !

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OHM'S LAW

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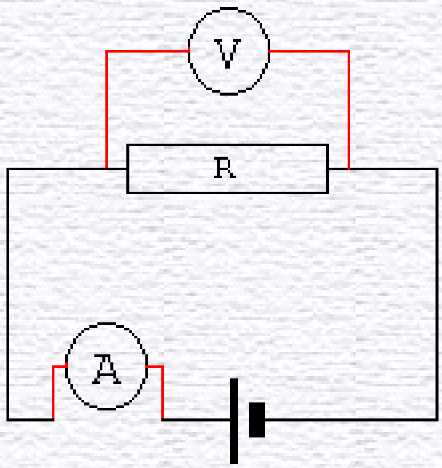


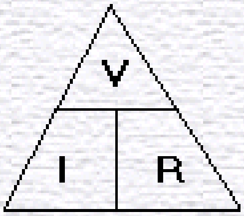
The voltmeter is connected across the resistor, to measure the voltage across the resistor.
The ammeter is connected in series with the resistor, to measure the current flowing around the circuit and through the resistor.

Mr Ohm discovered that if you double the voltage across the resistor then the current through it doubles.
If you halve the voltage then the current is halved.
This means that the current is PROPORTIONAL to the voltage.

He also found that if you double the value of the resistor then the current through it is halved.
If the value of the resistor is halved the the current is doubled.
Thus the current is INVERSELY PROPORTIONAL to the resistance.

OHMS LAW

$$\frac{\text{VOLTS}}{\text{OHMS}} = \text{AMPS}$$



To use the VIR triangle place your finger over the value you wish to find.
If you wish to find V then multiply I by R
If you wish to find I then divide V by R.

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SERIES RESISTORS

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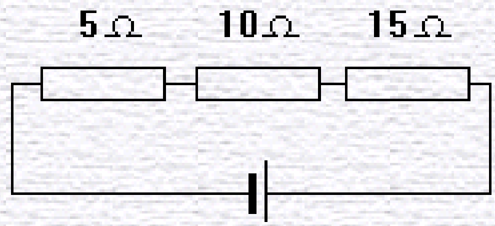

Resistors in series are connected in line.
The same current flows through them all.

The total opposition to the flow of current is called the EQUIVALENT resistance.
To find the value of the equivalent resistance we simply add the values.
In this case it is 30 ohms.

Note that, as a quick check on calculations, the value of the equivalent resistance is always higher than the value of the highest value resistance.

If these resistors were connected across a 30 Volt battery then Ohms Law says 1 amp would flow.

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PARALLEL RESISTORS

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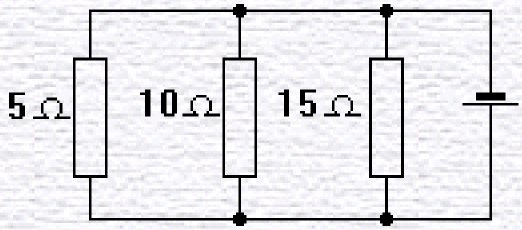

Resistors in parallel are connected across one another.
They all have the same voltage across them.

To find the equivalent resistance (the total resistance offered to the flow of current) we invert the values and add them. Then we invert the result.

For example take 2 ohms and 4 ohms in parallel.

Inverted 1/2 +1/4 = 3/4

Invert this 4/3 = 1.33 ohms

A quick check on your answer is that it should be smaller in value than the value of the smallest resistor.

If these resistors were connected across a 10 volt supply Ohms Law says about 7.5 amps would flow.

The formula can be written as 1/Rtotal = 1/R1 + 1/R2 + 1/R3 etc etc.

If only two resistors are involved then use (R1 x R2) divided by (R1 + R2)
For the 2 ohms and 4 ohms.
R1 x R2 = 8.
R1 + R2 = 6.
8/6 = 1.33 ohms

If you have several resistors of the same value in parallel then the equivalent resistance is the resistor value divided by the

number of resistors.
For example, four 100 ohm resistors in parallel will provide a resistance of 25 ohms

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POTENTIAL DIVIDERS

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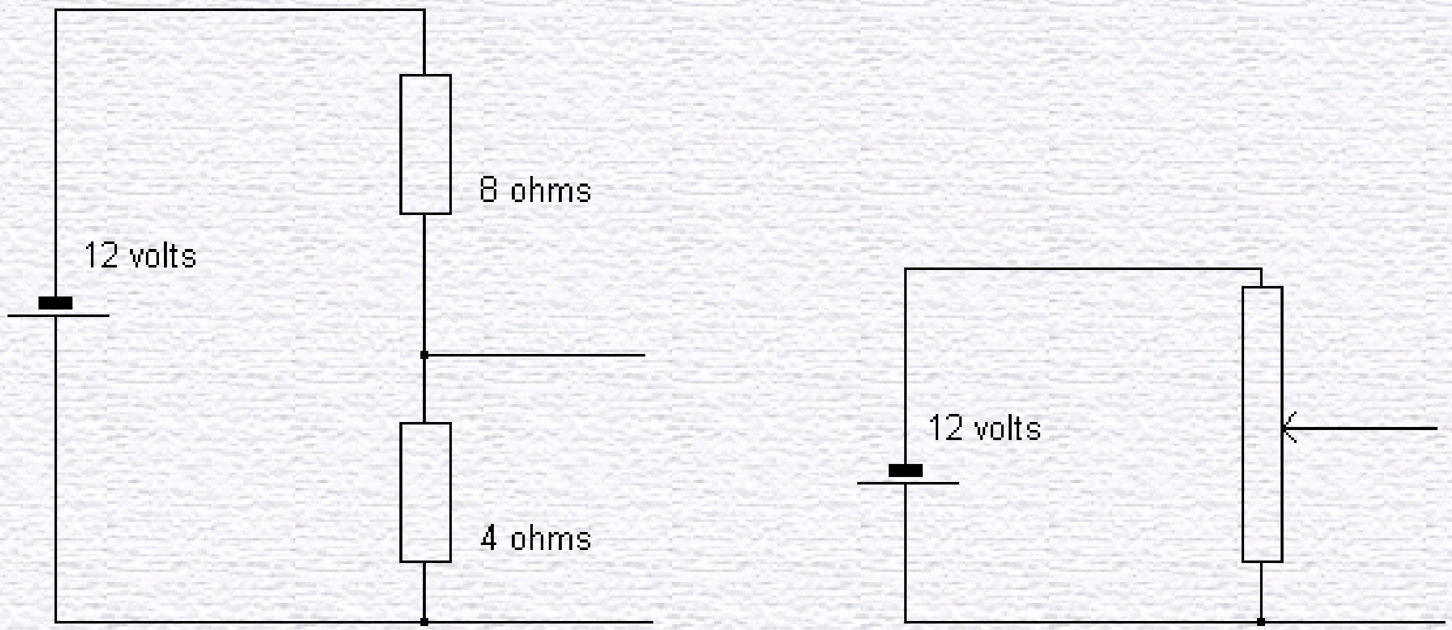


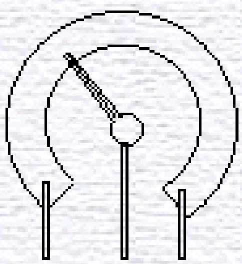
Make sure that you understand Ohms Law before reading this.

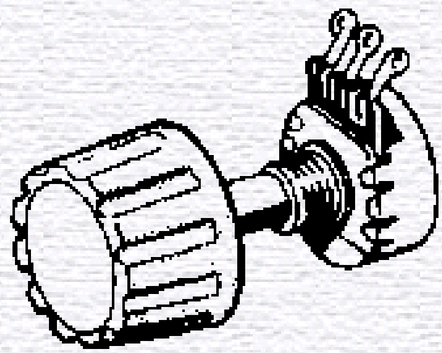
The total resistance of the two series resistors is 8 ohms + 4 ohms = 12 ohms.
The current flowing around the circuit is 12 volts/12 ohms = 1 amp (Ohms Law).
The voltage across the 8 ohm is 1 amp x 8 ohms = 8 volts (again Ohms Law).
The voltage across the 4 ohm is 1 amp x 4 ohms = 4 volts (Mr Ohm again).
The 12 volts of the battery has been divided into 8 volts and 4 volts.

By selecting values for the two resistors, the 12 volts can be divided into any two voltages which add up to 12 volts.
For example, 3 volts and 9 volts, 6 volts and 6 volts etc.

A circuit requiring less than 12 volts can be connected across the lower resistor, as long as it requires a current much lower than the current through the two resistors.

If a cardboard strip, coated with carbon, is connected across the battery, together with a "wiper" which can be moved up or down the strip, then you have a POTENTIOMETER (POT for short.)
With the wiper at the top then the output is 12 volts.
With the wiper at the bottom then the output is zero volts.
Any output between 12 volts and zero can be obtained by positioning the wiper correctly.





In practice, the strip is curved and the wiper is joined to a spindle which rotates the wiper on the strip when a control knob is twisted.
In the drawings, the wiper is the centre connection.
Most front panel controls such volume and brightness are "pots".
Their purpose is to adjust the voltage fed from one stage to the next.

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WATTS AND JOULES

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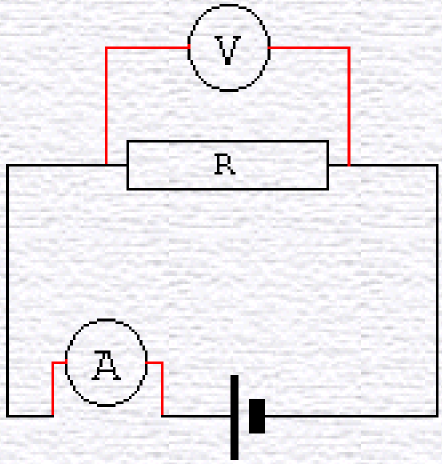

When current passes through a resistor, electrical energy is converted into heat.
This heat is DISSIPATED into the surrounding air.
The rate at which this dissipation occurs is called POWER and is measured in WATTS.
The amount of power can be calculated by using one of three methods.

(1) Power = V x I watts
(2) Power = (V x V)/R watts
(3) power = (I x I)R watts
Also see the page with the VIRP wheel.

If we place a 10 ohm resistor across a 20 volt battery then Ohms law says that I = V/R = 20/2 =2 amps will flow.

Using (1)
power = 20 x 2 = 40 watts

Using (2)
power = (20 x 20)/10 = 400/10 = 40 watts.

using (3)
power = (2 x 2)x10 = 4 x 10 = 40 watts.

Using three different formulae we still arrive at the same answer.

We know that power is the rate at which energy is used.
The amount of energy used is measured in JOULES.

Joules = watts x seconds, therefore watts = joules/seconds.

A 1000 watt fire will dissipate 1000 joules per second.
With resistors, the greater the dissipation the hotter it gets, and the larger the resistor needs to be.

The electric meter in your house measures UNITS of electricity.
A unit is when you use 1000 watts for one hour. This is called 1 Kilowatt hour.

It is kilowatts x hours. A 100 watt (0.1 kilowatts) lamp left on for 24 hours uses 0.1 x 24 = 2.4 units.

You or your parents are charged by the unit.
If a unit cost 5 pence then the lamp would cost 12 pence a day to run.
Switch it off and help to save the world.

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RESISTOR NETWORKS

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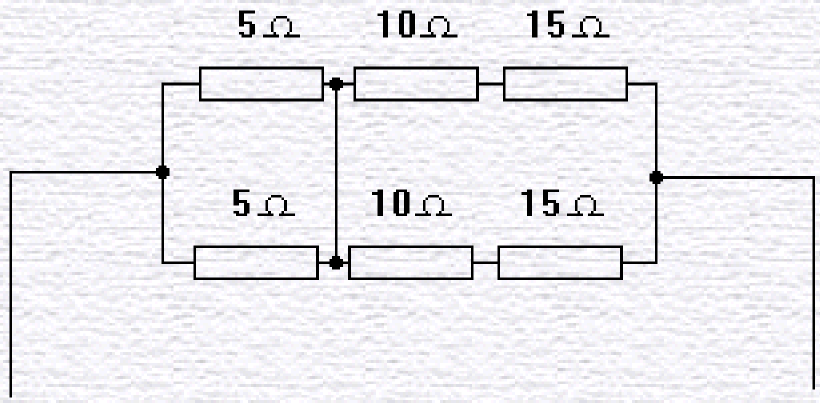
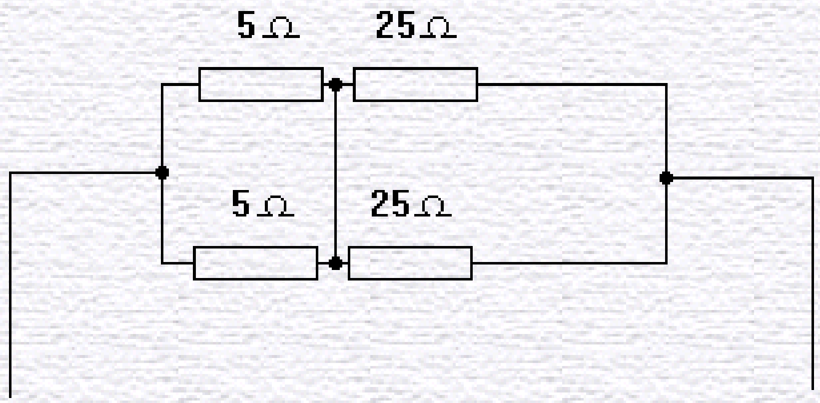
See the pages on series and parallel resistors before reading this one.



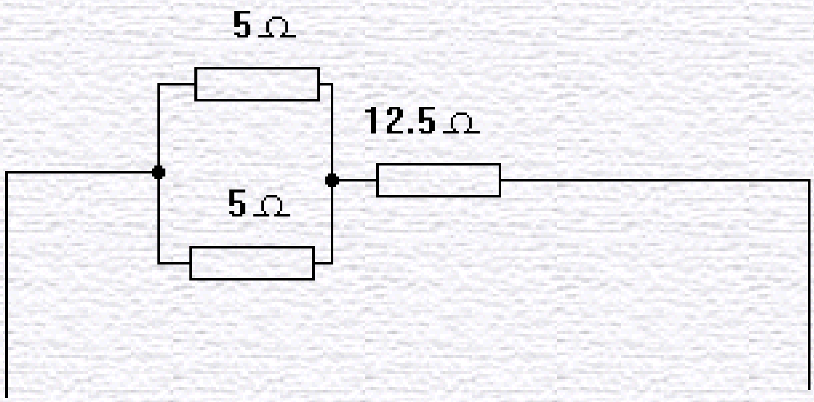
In the diagram we have two sets of 10 ohms in series with 15 ohms.

These can be replaced by two 25 ohms as shown in the next diagram.



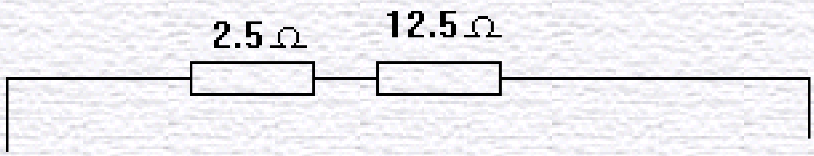
The two 25 ohms are in parallel and can be replaced by 12.5 ohms.

See the next diagram.

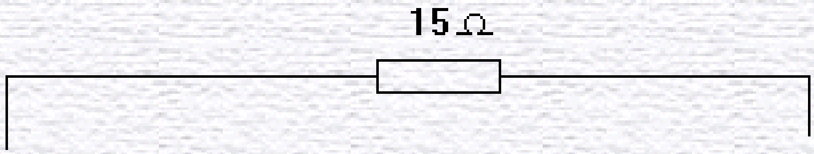


The two 5 ohms are in parallel so can be simplified to 2.5 ohms.

See the next diagram.



The 12.5 and the 2.5 are in series so that the equivalent resistance for the network is 15 ohms.



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VOLTAGES IN A CIRCUIT

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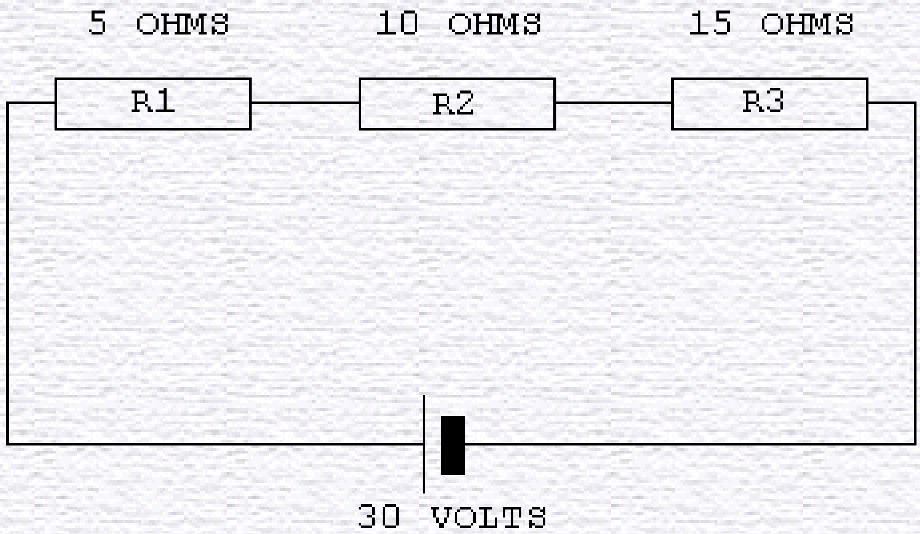


Ensure that you understand Ohms Law before tackling this,

In the diagram the total series resistance = 30 ohms.

The current flowing is 30 volts/30 ohms = 1 amp.

Thus the current through the 5 ohm resistor is 1 amp.

Therefore the voltage across the 5 ohm is 1 amp x 5 ohm = 5 volts.

Similarly the voltage across R2 is 10 volts.

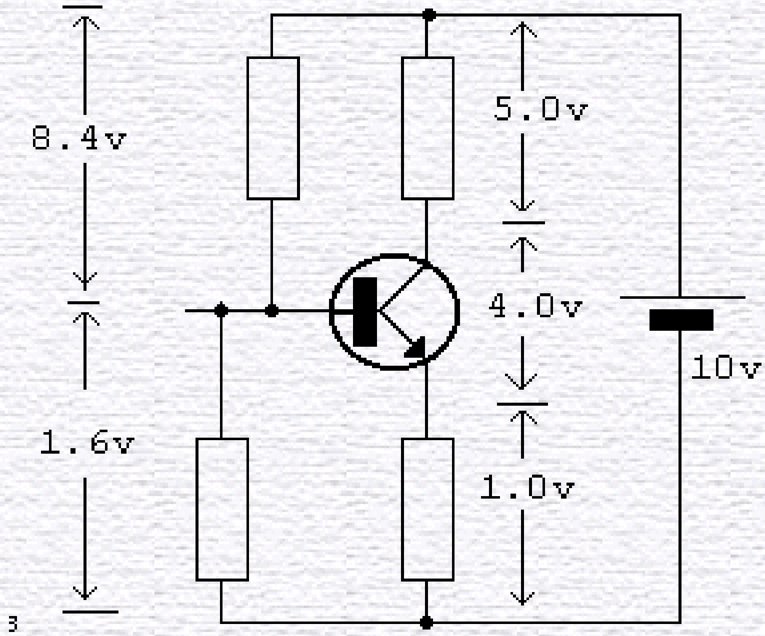
The voltage across R3 is 15 volts.

If you add these three voltages 5 + 10 + 15 = 30 volts.

This is the same as the battery voltage.

Add up both sets of voltage in the transistor circuit diagram.

They both add up to 10 volts , which is the battery voltage.



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THE WHEATSTONE BRIDGE

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Read the page on potential dividers.

In Fig.1, the 15 volts will be divided across the two resistors, according their proportion of the total resistance, 15k.
For the 5k this will be (5k/15k) x 15volts = 5volts.
For the 10k it will be (10k/15k) x 15 volts = 10 volts

In Fig.2 we have the same potential divider plus R3 and R4 across the battery.
This is a BRIDGE circuit , invented by Mr Wheatstone.

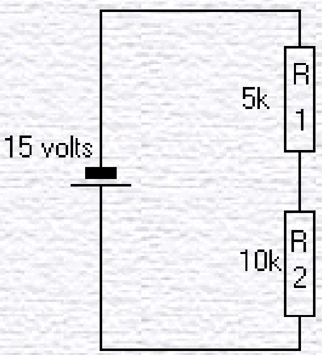

Fig.1

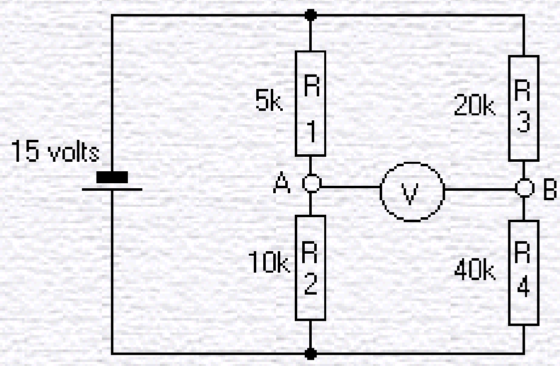

Fig.2

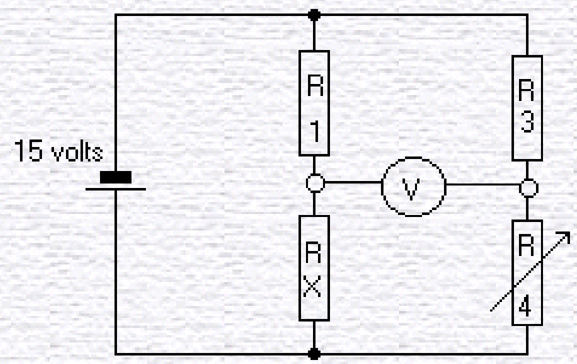

Fig.3

Using the same calculations as for R1 and R2, we find that the voltage across R3 = 5 volts and across R4 = 10 volts.
The voltage has been divided in the same proportions.
This is because the ratio R1/R2 is the same as the ratio R3/R4, that is, 1:2.

The meter, connected between points A and B will indicate zero.
This is because the voltage at both terminals of the meter is the same, so the voltage across the meter is zero.
The bridge is said to be BALANCED.
So we can say that when the ratio R1/R2 = R3/R4, the bridge is balanced.

If the two ratios are not the same, then the voltages at the two terminals of the meter will be different.

The meter will now give a reading, and we can say that the bridge is unbalanced.

In Fig.3, Rx is of unknown value and the probability is that the bridge is unbalanced, indicated by a reading on the meter.
If we adjust R4 so that the ratio R1/Rx = R3/R4 then the bridge will be balanced.
If we transpose this equation we can get Rx = (R4 xR1)/R3
We know the values of R1 and R3.
If we measure the value of R4 we can calculate the unknown Rx.

R4 can be fitted with a pointer and a calibrated scale to give a direct reading of Rx without the need for calculations.

This is the basis of more complex bridge circuits.

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BLOCK DIAGRAMS

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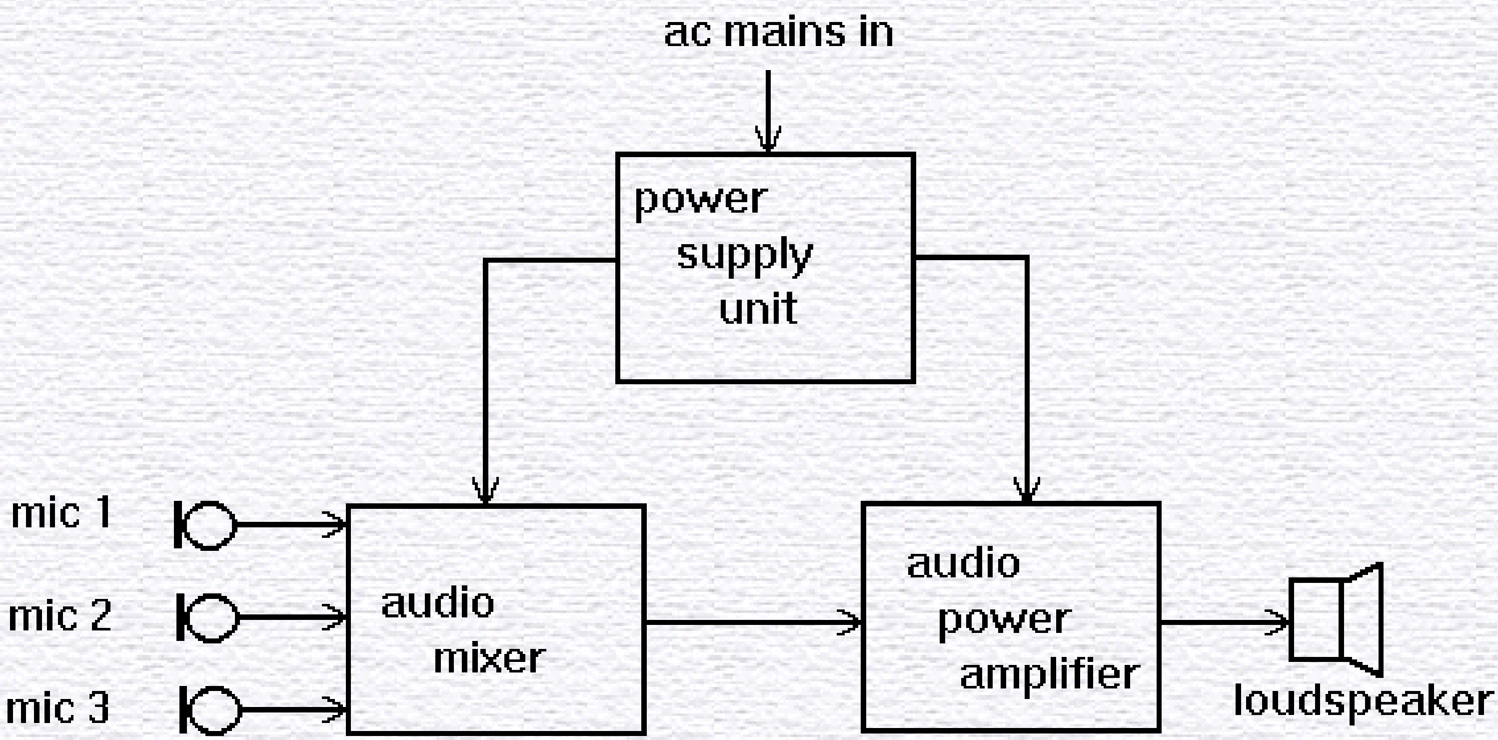

Block diagram for audio system

Block diagrams are a method of explaining complex systems (not necessarily electronic) in a simple manner.

They are made up from labelled blocks which are joined by arrows. The arrows indicate the direction of flow, and inputs to and outputs from the blocks.

We are told what each block has for an input, and what happens in the block to this input. We are also told what the output from the block is.

At this stage it is not necessary to know how the block does its job. That will come later with a greater understanding of electronics.

In the example the low level signals from the three microphones are mixed together by the MIXER which gives a mixed low level signal out.

The mixed signal is applied to the POWER AMPLIFIER which provides a high level signal to drive the loudspeaker.

The POWER SUPPLY UNIT converts the ac mains supply voltage to a dc voltage suitable for the system.

Even with this limited knowledge we can apply a little logical fault finding.

If there is no output from the loudspeaker but we can measure an output from the mixer then the loudspeaker or the power amplifier is faulty. There would be no point in changing the mixer.

With more knowledge one can break the blocks down into smaller blocks and finally the circuitry within the boxes will be understood.

There are more pages on this website, being used to explain complex electronics.

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THE DIGITAL CLOCK

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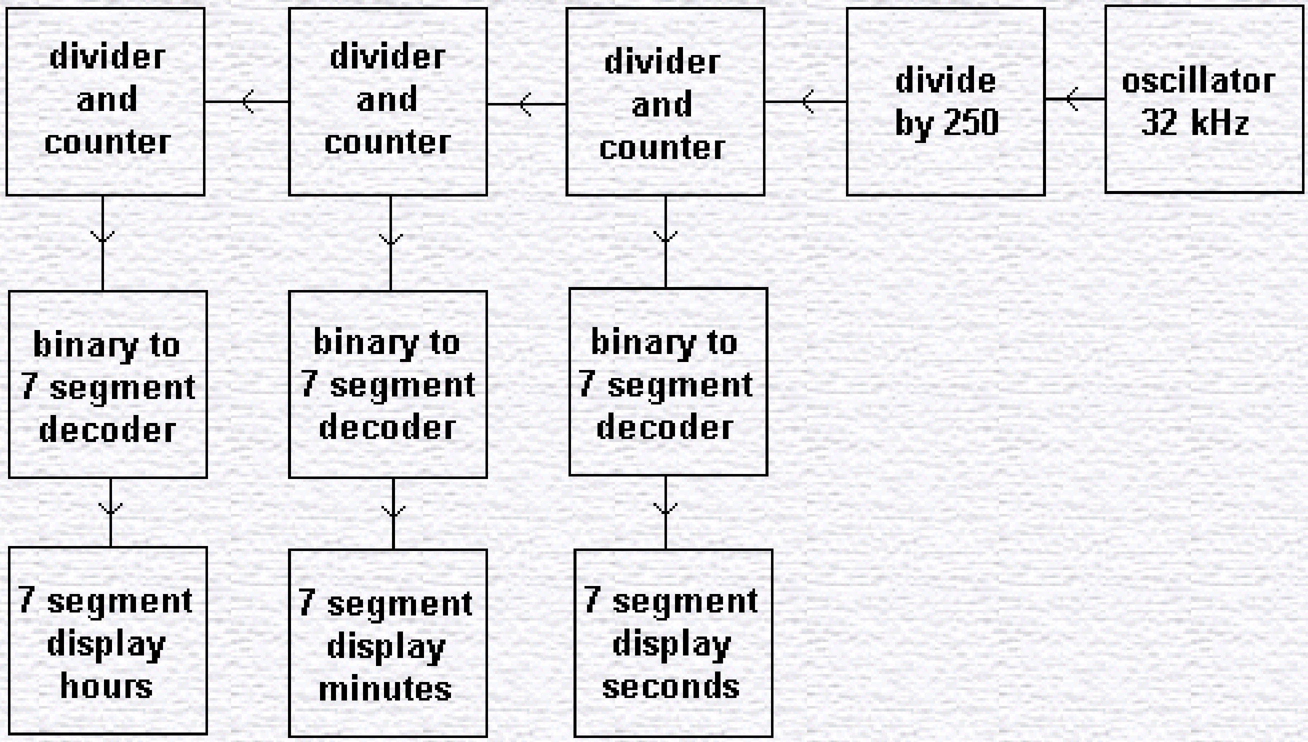

I suggest that you go to the DIGITAL INDEX and read the pages on DECADE COUNTERS and BINARY TO 7 SEGMENT DECODERS before reading this.

The oscillator is crystal controlled to give a stable frequency.
A high frequency is used to keep the size of the crystal small.

The divide by 250 gives an output of 128 pulses per second.

These are fed to the first counter/divider which divides by 128 to give a pulse every second.
It counts these pulses, in binary, up to 59 seconds.
The count is shown on the first 7 segment display.
Since the output from the counter is in binary form, it is converted to suit the display by the decoder.
When the count and display reaches 59 seconds, it resets to zero on the next pulse.

The one second pulses are also sent to the next divider/counter which divides by 60 to give one pulse every

minute.
These pulses are counted and displayed as minutes.
When the count and display reaches 59 minutes and 59 seconds it resets to zero on the next pulse.

A pulse every minute is fed to the final divider/counter.
This divides by 60 to give one pulse every hour.
These pulses are counted and displayed as hours.
When the count and display reaches 23 hours 59 minutes 59 seconds, the counters and display resets to zero on the next pulse.

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THE TAPE RECORDER

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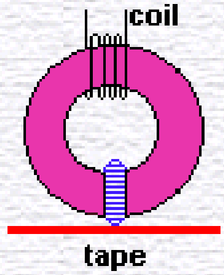
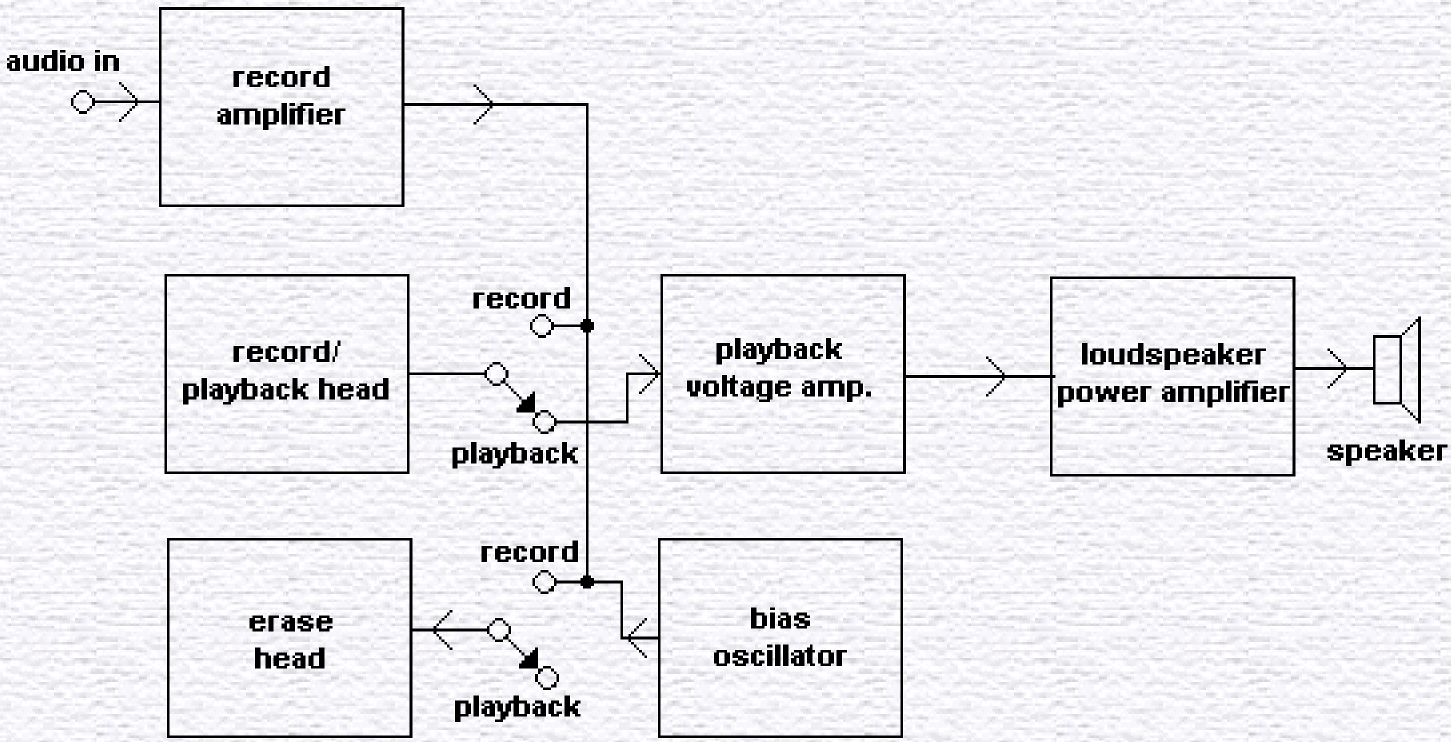
The tape head consists of a ring of soft magnetic material, called the core, with a small gap in it.
A coil is wound around the core.
The tape travels over the gap in the core.



During recording, an audio signal causes current to flow through the coil producing a magnetic field in the gap, as shown by the blue lines of force in the diagram.
As the audio signal varies in amplitude and frequency so does the magnetic field.

The tape consists of a plastic film coated with a material that is magnetised by the field as it passes over the gap.
As the magnetic field varies in strength so does the magnetism stored on the tape.

During playback the tape passes over the same head. (it is called the record/playback head).
This time the magnetism stored on the tape induces a voltage in the head coil.
This voltage is amplified and used to drive a loudspeaker.



In the block diagram the 2 pole changeover switch is set to the playback position.
The low amplitude output of the record/playback head is amplified by a voltage amplifier.
The output of this amplifier is then boosted in power to drive the loudspeaker.

During record, the two sections of the switch are placed in the record position.
The audio signal from a microphone etc is amplified by the record amplifier and connected by the top switch to the record/playback head.

The bias oscillator has two purposes.
One is to remove a form of distortion produced during recording.
The oscillator is connected to the record/playback head via the top switch to do this.

The second purpose is to remove any magnetic patterns previously recorded on the tape.
It does this by randomising the magnetic pattern on the tape

by means of an erase head.
This head is of similar construction to the record/playback head.
The erase head is connected to the oscillator by the lower switch during recording.
The tape passes over the erase head before it reaches the record head.

The oscillator frequency is about 100kHz.

A power supply to provide DC to the various stages and the motors is required.

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DC MOTOR SPEED CONTROL

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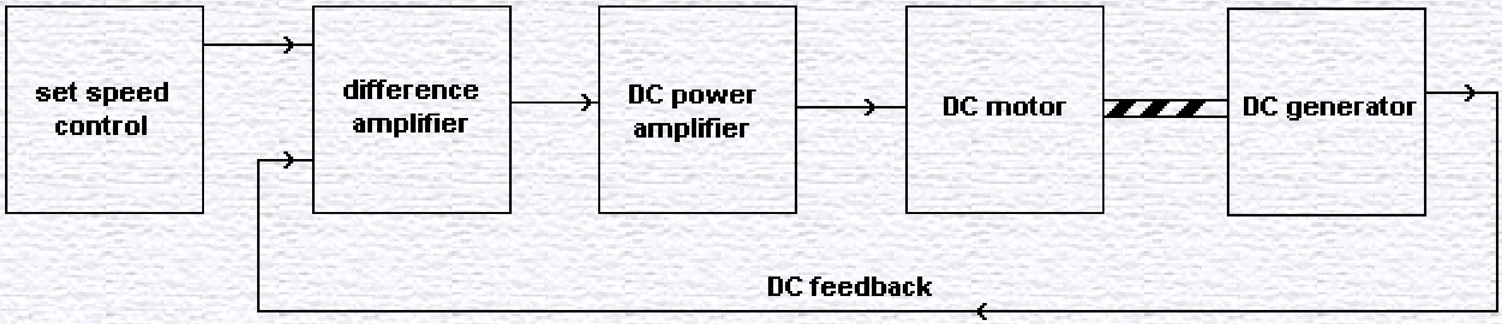

Find and read the page on difference amplifiers.

The striped thing between the motor and the dc generator is a shaft which couples them together mechanically. The motor drives the generator (tachometer) via this shaft.

The set speed control provides a dc voltage, say 12 volts for maximum speed and zero for stationary. This could be a potentiometer providing any voltage in a range from zero to +12 volts.

The difference amplifier will amplify any difference between its two input voltages.

If the motor is stationary and the speed control is moved from zero to half speed then, since the tachometer is not rotating and not producing an output voltage, there will a difference in voltages at the two inputs of the difference amplifier.
Therefore there will be an output voltage from the amplifier.

Since this voltage is not high enough in value to drive the motor, it is increased in amplitude by the dc amplifier.
A dc amplifier is a special type of amplifier which can increase dc voltages.
For example, 10 volts dc in could give 100 volts dc out.

This amplified dc powers the dc motor which begins to increase its speed of rotation.
This in turn rotates the tacho which produces a voltage proportional to speed.

As the tacho voltage increases it will eventually reach the

same value as the "set speed" voltage.
At this point there will be no output from the difference amplifier and dc amplifier. The motor is up to the correct speed.

However, since the motor is no longer powered by the dc amplifier its speed will start to fall.
But the tacho output voltage will start to fall, and there will again be a difference between the two input voltages to the difference amplifier.
This will produce an output from the difference amplifier and dc amplifier which will power the motor and correct this drop in speed.

In a poorly designed system this drop in speed and its correction can cause "hunting", a regular variation in speed.

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THE AM TRANSMITTER

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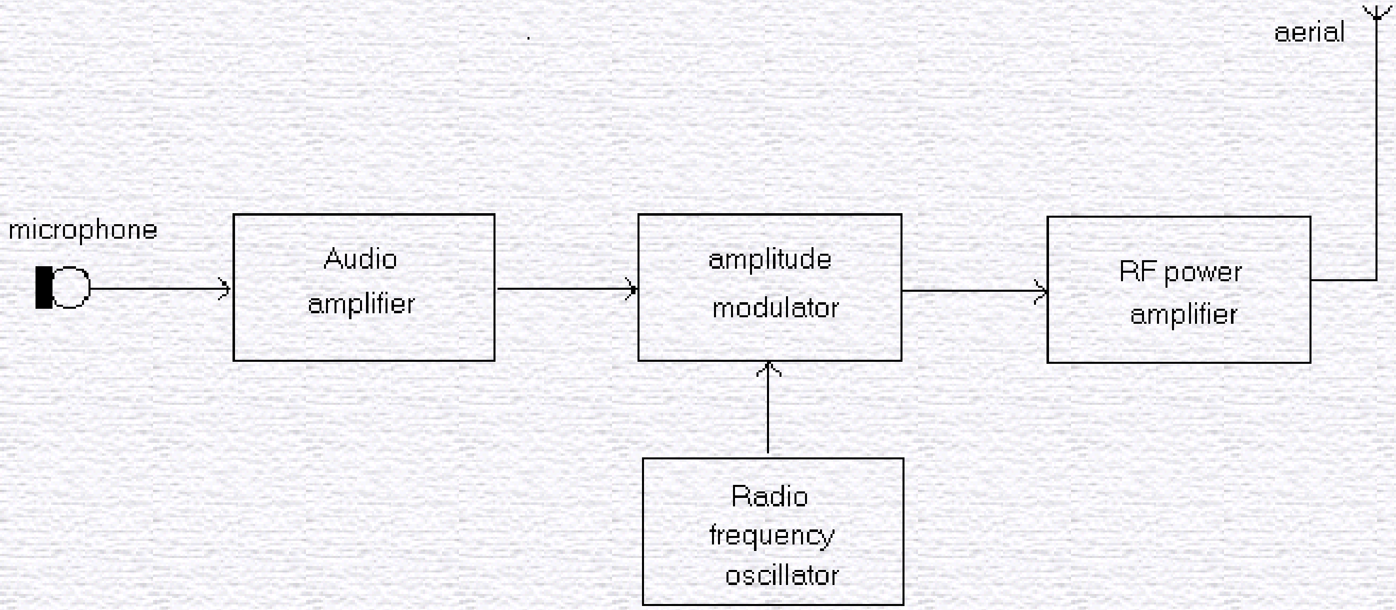

Read the page on amplitude modulation.

Modulation enables low frequency audio signals to be radiated long distances.
This is done by superimposing the low frequency audio signal on the high frequency carrier wave by the process of modulation.

The microphone converts sound waves into electrical signals (a range of 20 Hz to 20 kHz).

These signals are amplified by the audio frequency amplifier.

The carrier frequency is generated by the radio frequency oscillator.

The audio is superimposed onto the carrier by the modulator.

The low power modulated carrier is boosted in amplitude by the radio frequency power amplifier.

The aerial produces an electromagnetic wave which is radiated into space.

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AM RADIO BLOCK DIAGRAM

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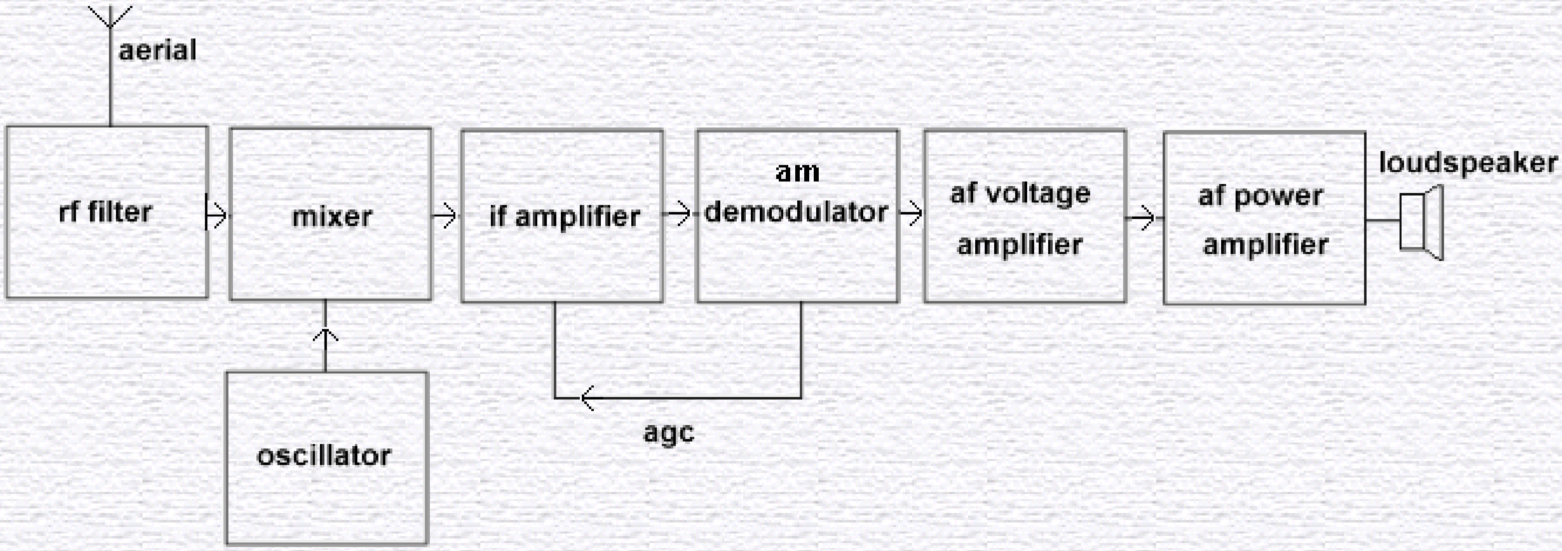

Most of these blocks are discussed individually, and in more detail, on other pages.
See filters, mixers, frequency changers, am modulation and amplifiers.

There are signals from thousands of radio transmitters on many different frequencies inducing signal voltages in the aerial.
The rf filter selects the desired station from the many.
It is adjustable so that the selection frequency can be altered.
This is called TUNING.

The selected frequency is applied to the mixer.
The output of an oscillator is also applied to the mixer.
The mixer and oscillator form a FREQUENCY CHANGER circuit.
The output from the mixer is the intermediate frequency (i.f.)
The i.f. is a fixed frequency of about 455 kHz.
No matter what the frequency of the selected radio station is, the i.f. is always 455 kHz.

The i.f. signal is fed into the i.f. amplifier.
The advantage of the i.f. amplifier is that its frequency and bandwidth are fixed, no matter what the frequency of the incoming signal is.
This makes the design and operation of the amplifier much simpler.

The amplified i.f. signal is fed to the demodulator.
This circuit recovers the audio signal and discards the r.f. carrier.
It usually incorporates a diode in the circuit.

Some of the audio is fed back to the i.f. amplifier as an AUTOMATIC GAIN CONTROL voltage.
This ensures that when tuning from a weak station to a strong one, the loudness from the loudspeaker stays the same.

The audio signal voltage is increased in amplitude by a voltage amplifier.

The power level is increased sufficiently to drive the loudspeaker by the power amplifier.

THE FM TRANSMITTER

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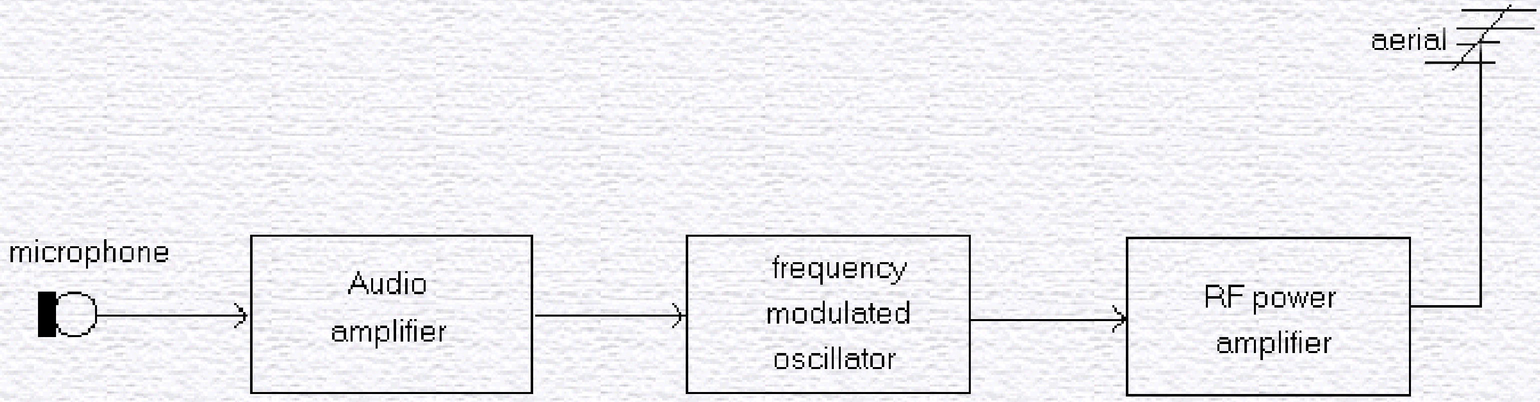

Read the page on Frequency Modulation.

The microphone converts sound pressure wave to electrical signals.
These audio voltages are amplified by the audio amplifier.
The amplified audio is used to control the deviation of the frequency controlled oscillator.

The oscillator frequency is at the carrier frequency, in the 88-108 MHz FM band.

The low power of the frequency modulated carrier is boosted by the Radio Frequency amplifier.

The aerial is driven by the amplifier and produces an electromagnetic wave.

Under normal conditions the transmitted signal will travel as far as the horizon.

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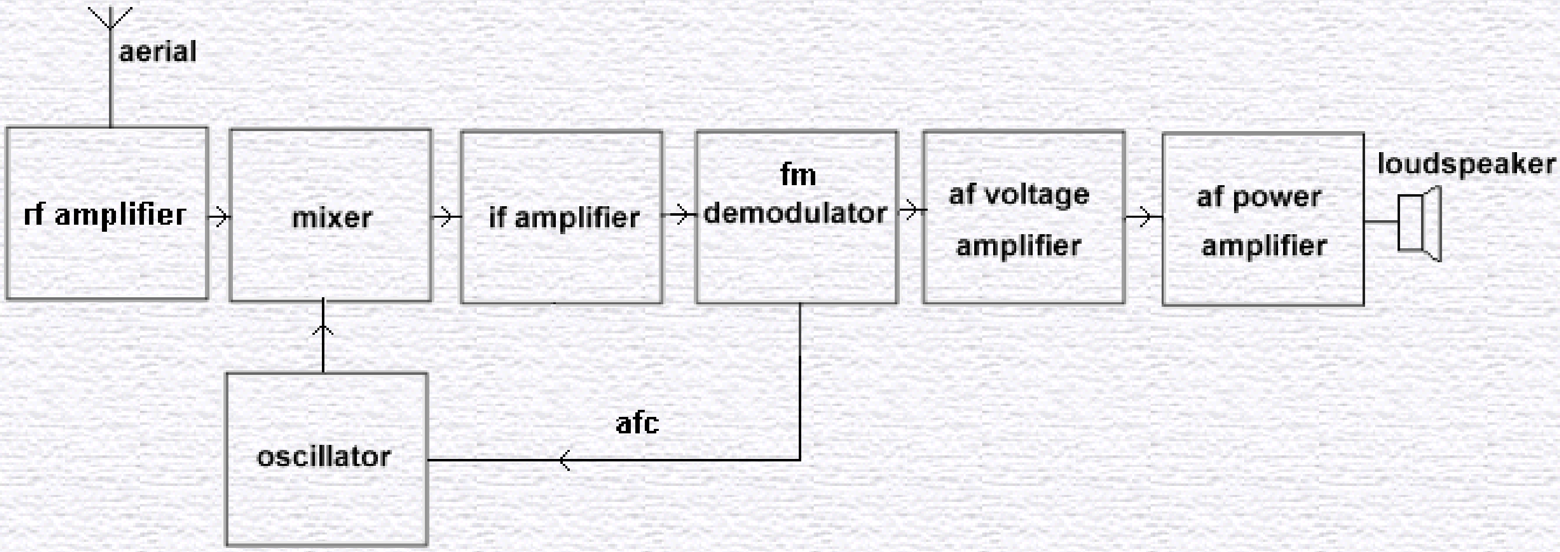
FM RADIO BLOCK DIAGRAM



Look at the page on THE AM RECEIVER block diagram.

Most of these blocks are discussed individually, and in more detail, on other pages.
See filters, mixers, frequency changers, am modulation and amplifiers.

The f.m. band covers 88-108 MHz.
There are signals from many radio transmitters in this band inducing signal voltages in the aerial.
The rf amplifier selects and amplifies the desired station from the many.
It is adjustable so that the selection frequency can be altered.
This is called TUNING.
In cheaper receivers the tuning is fixed and the tuning filter is wide enough to pass all signals in the f.m. band.

The selected frequency is applied to the mixer.
The output of an oscillator is also applied to the mixer.
The mixer and oscillator form a FREQUENCY CHANGER circuit.
The output from the mixer is the intermediate frequency (i.f.)
The i.f. is a fixed frequency of 10.7 MHz.
No matter what the frequency of the selected radio station is, the i.f. is always 10.7 MHz.

The i.f. signal is fed into the i.f. amplifier.

The advantage of the i.f. amplifier is that its frequency and bandwidth are fixed, no matter what the frequency of the incoming signal is.
This makes the design and operation of the amplifier much simpler.

The amplified i.f. signal is fed to the demodulator.
This circuit recovers the audio signal and discards the r.f. carrier.

Some of the audio is fed back to the oscillator as an AUTOMATIC FREQUENCY CONTROL voltage.
This ensures that the oscillator frequency is stable in spite of temperature changes.

The audio signal voltage is increased in amplitude by a voltage amplifier.

The power level is increased sufficiently to drive the loudspeaker by the power amplifier.

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The Oscilloscope

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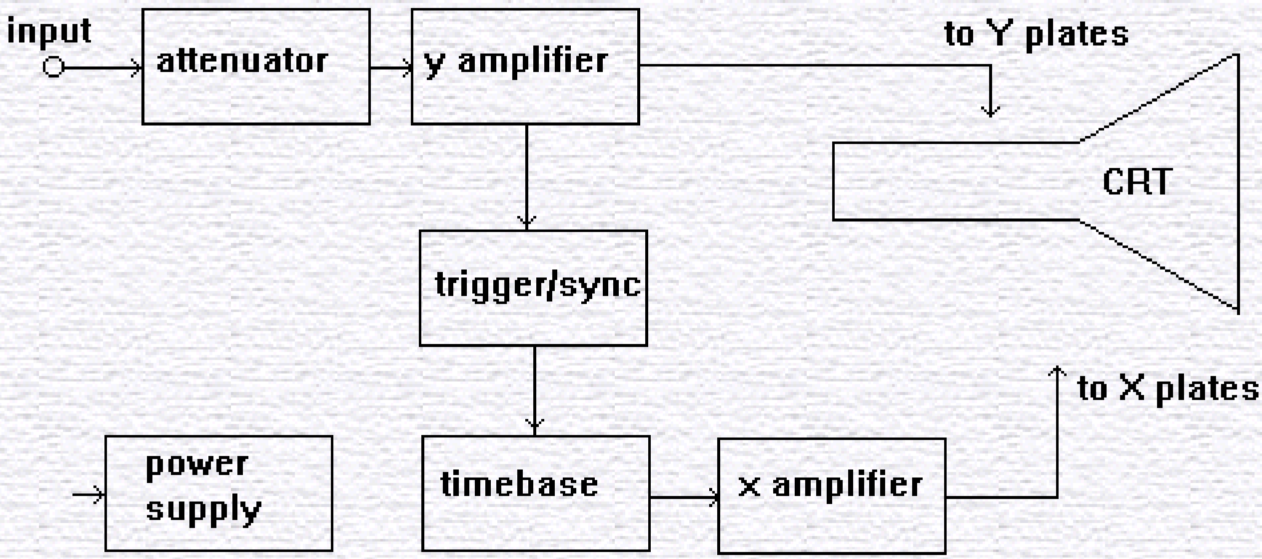

Read the page on Cathode Ray Tubes before reading this.

The signal to be observed is applied to the Y plates.
It is attenuated if it is too large in amplitude.
It is amplified if it is too small in amplitude.

The timebase generates a sawtooth. (see page on waveforms).
The sawtooth is variable in frequency and amplitude.
As the sawtooth voltage rises, it causes the spot to sweep from left to right, across the face of the CRT.
When the sawtooth suddenly falls to zero, the spot flies back to the left of the screen ready for another sweep.
This sweep and flyback usually happens so quickly that that the display appears as a straight line.

So we have the spot being deflected horizontally by the timebase, while the signal is deflecting it vertically, by means of the Y plates.
The combination of forces produces a display which represents the input signal.

To display one cycle, the timebase and signal frequencies must be the same.
If the frequencies are slightly different, the display will drift sideways.
To avoid this , the input signal is sampled by the trigger circuit and used to ensure that the timebase runs at exactly the same frequency as the input signal.

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THE POWER SUPPLY UNIT

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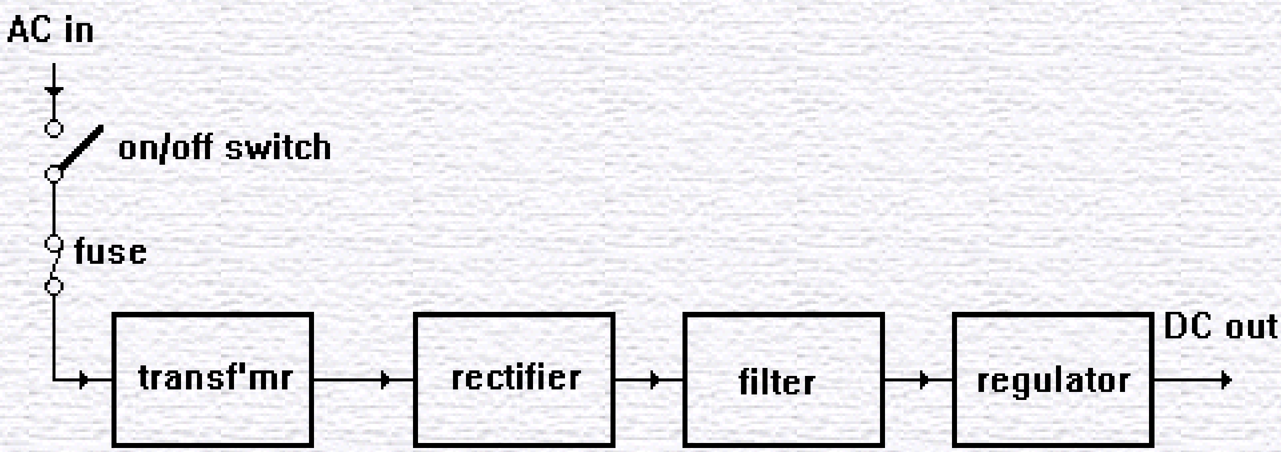
Most electronic circuits need a DC supply such as a battery to power them.

Since the mains supply is AC it has to be converted to DC to be useful in electronics.
This is what a power supply does.



First the AC mains supply passes through an isolating switch and safety fuse before it enters the power supply unit.

In most cases the high voltage mains supply is too high for the electronic circuitry.
It is therefore stepped down to a lower value by means of a Transformer.
The mains voltage can be stepped up where high DC voltages are required.

From the transformer the AC voltage is fed to a rectifier circuit consisting of one or more diodes.
The rectifier converts AC voltage to DC voltage.

This DC is not steady as from a battery. It is pulsating.
The pulsations are smoothed out by passing them through a smoothing circuit called a filter.

In its simplest form the filter is a capacitor and resistor.

Any remaining small variations can, if necessary, be removed by a regulator circuit which gives out a very steady voltage. This regulator also removes any variations in the DC voltage output caused by the AC mains voltage changing in value. Regulators are available in the form of Integrated Circuits with only three connections.

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MONOCHROME TELEVISION CAMERA

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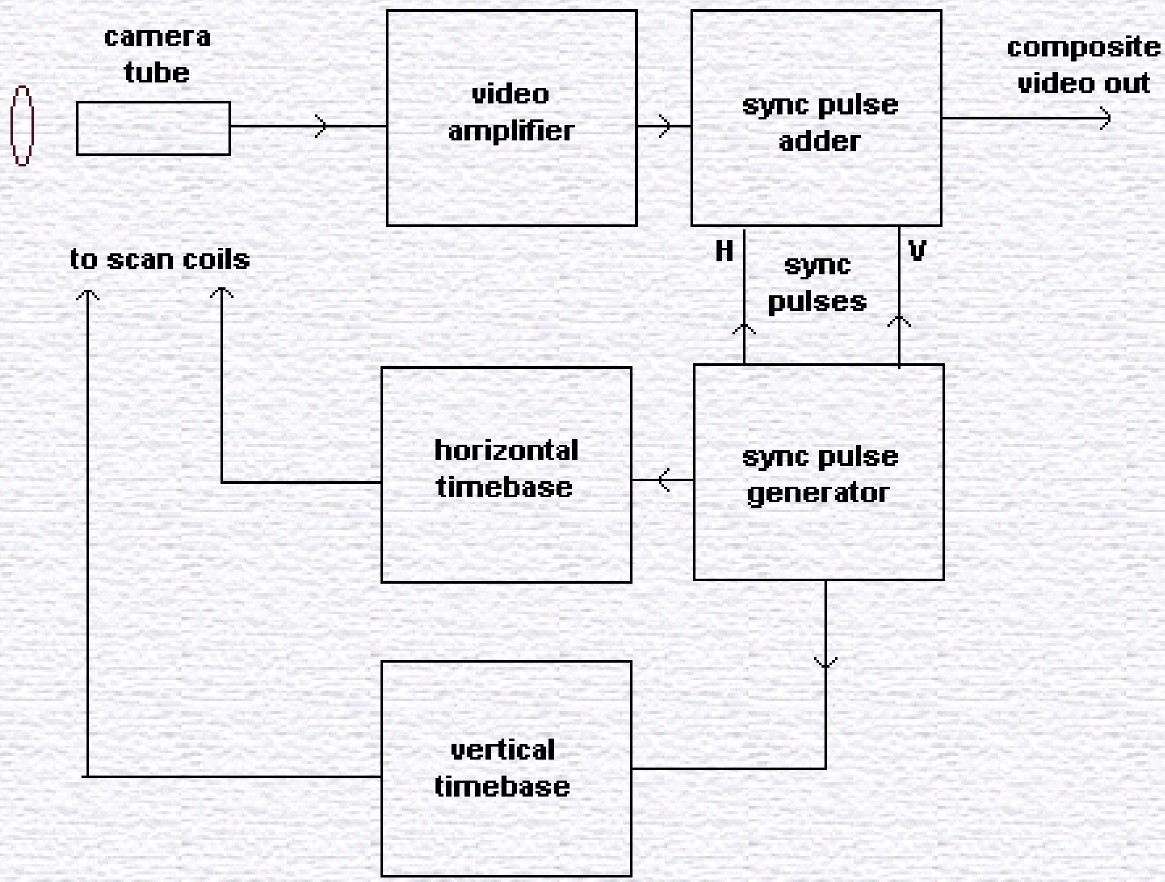
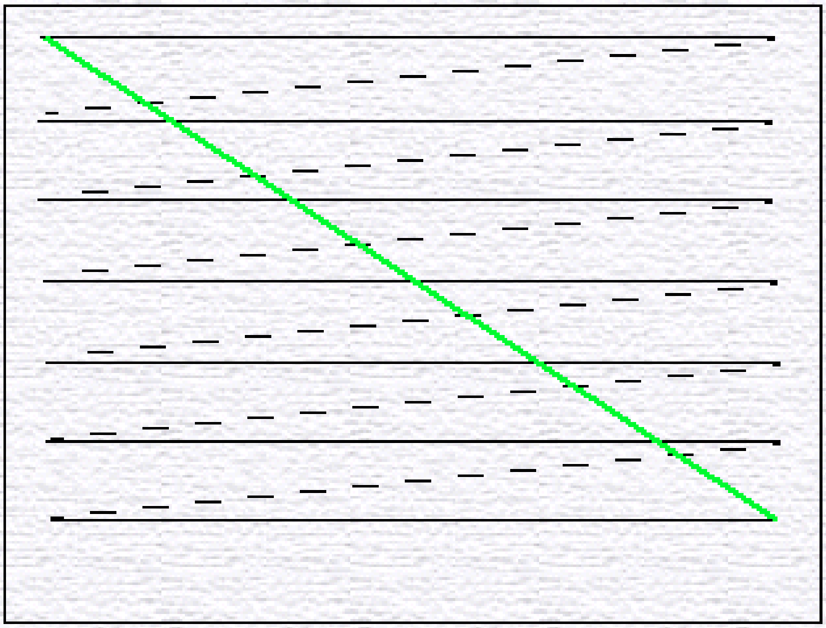
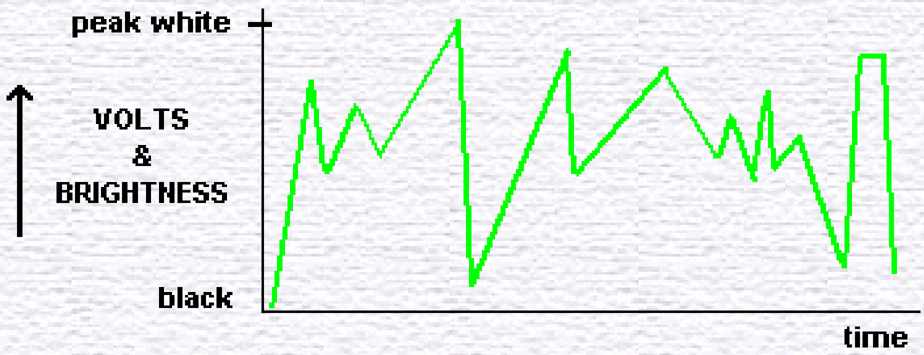


The scene to be converted to a video signal is focussed onto the face of the camera tube by a lens.
The tube has an electron gun which shoots a beam of electrons at the tube face.
The scene focussed on the face of the tube is "scanned" by the beam.
This is like reading a book.
The eye scans the first line then flies back rapidly and then scans the next line and so on.
When it reaches the bottom of the page it flies back to the top

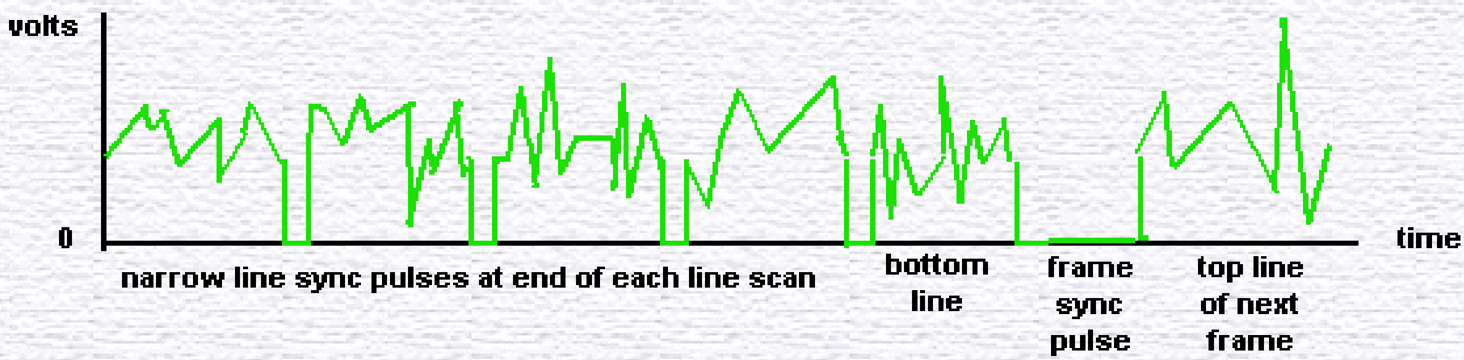
left.
This scanning process is done by the line (horizontal) and frame (vertical) time bases.
Both of these generate a saw tooth waveform which are applied to scan coils mounted on the tube.
These cause the beam to scan and fly back.
Have a look at the web pages on the crt and the oscilloscope.



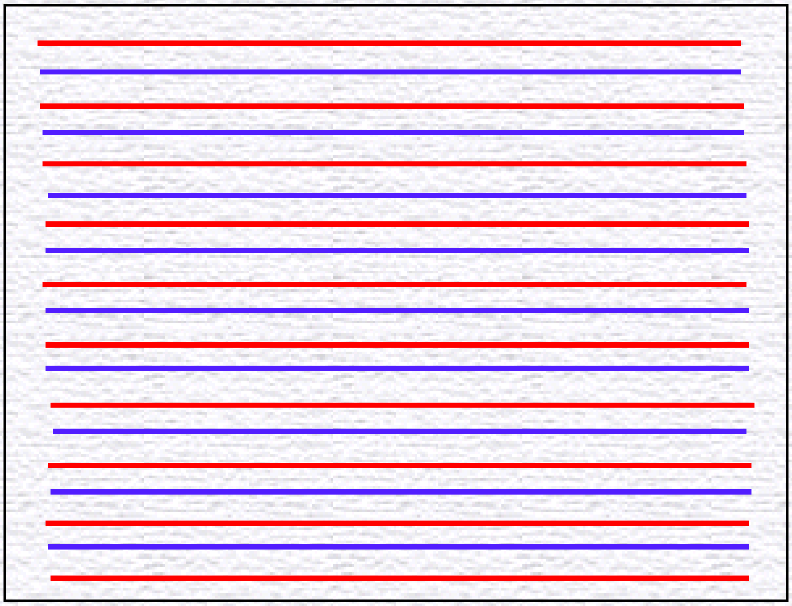
As the tube scans the scene it gives an output voltage which is proportional to the brightness at each part of the scene.



The scanning of the camera and the tv receivers in peoples houses must be in step (synchronised).
Therefore at the end of each line a synchronising pulse is sent to the receivers telling them to fly back to start a new line.
At the end of each frame a wider pulse is sent to tell the receiver to fly back to the top left ready to start a new frame.
The mixture of video and sync pulses is called "composite video".



The scene is actually scanned twice to obtain the complete picture.
The scene is scanned once and the next time it is scanned the lines fall between the first set of scan lines.
This is called "interlaced scanning" and reduces flicker.
In the diagram the red lines show the first scan and the blue ones the second.



The sync pulses and the frequency of the time bases are controlled by the sync pulse generator.

The composite video signal is amplitude modulated on a carrier in the UHF band.

The associated audio signal is frequency modulated on a carrier spaced 6 MHz from the vision carrier.

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3 TUBE COLOUR TV CAMERA

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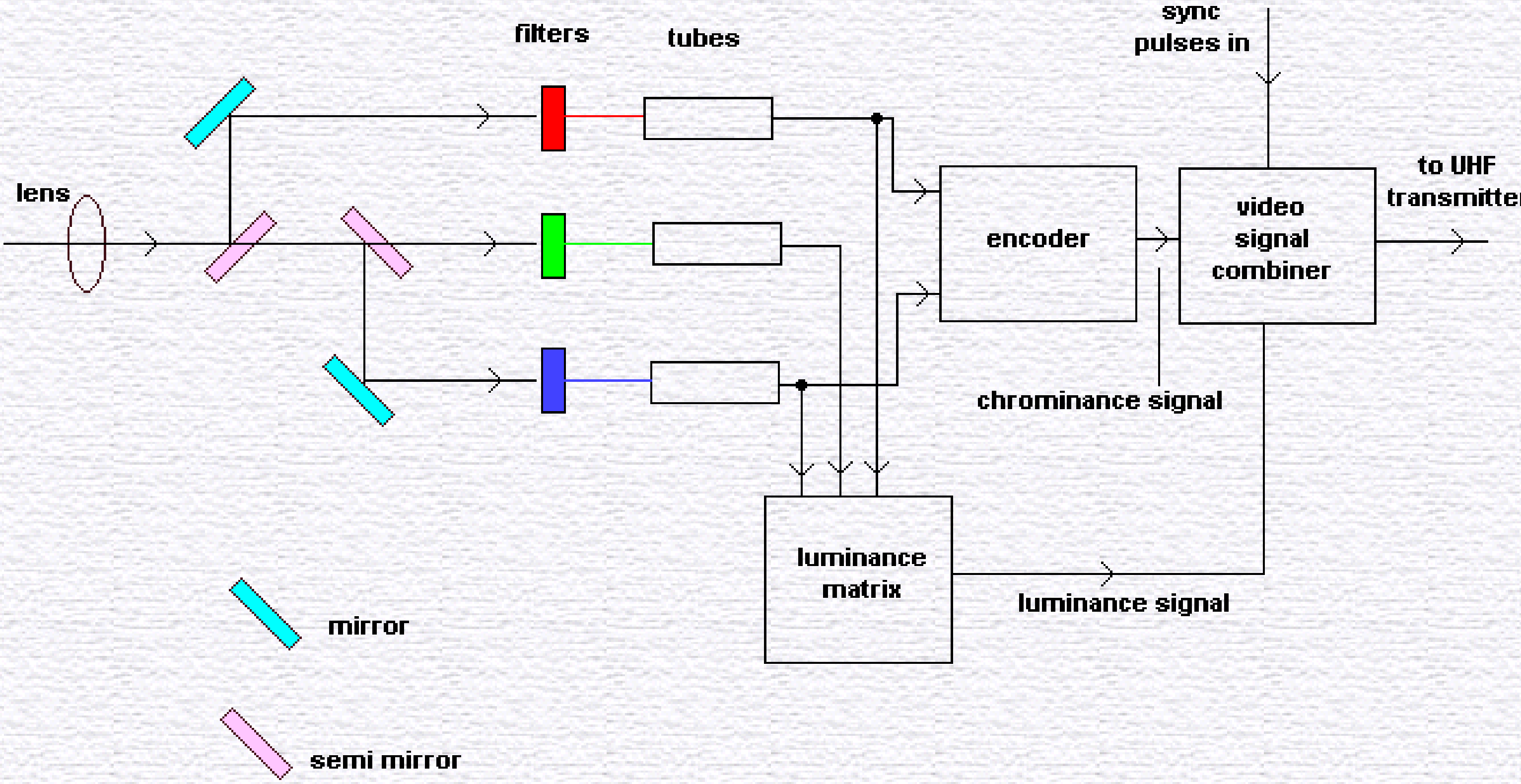

Read the pages on the monochrome camera, and light and colour.

Note that this page describes the UK colour system (PAL).

Light enters via the lens on the left and is split into three paths by mirrors and semi-transparent mirrors.

The light in each path passes through a colour filter.
These filters are like the transparent coloured papers in which chocolates are wrapped.
If you look through a red one, everything looks red.
This is because it lets only red light through.
Blue or green objects look black.
Colours which contain some red, such as purple, look dark red.
Red, blue and green filters are used.

The coloured images are focussed on the faces of the three colour tubes which scan the images.
Each tube gives a signal out, proportional to the amount of

colour.

Some of the red, green and blue signals from the camera tubes are added in the luminance matrix.
This means that the separated colours are recombined electronically.
This gives a luminance (brightness) signal.
The luminance signal is labelled Ey, and is used by black and white receivers.

The colour signals are known as Er, Eg, and Eb.

The red and blue signals are converted into two new signals called the red and blue colour difference signals.
They are (Er - Ey) and (Eb - Ey).
These two signals are modulated onto a "sub carrier" at 4.43 MHz which becomes the chrominance (colour) signal.

The luminance, chrominance and sync signals are combined and are then used to amplitude modulate a carrier in the UHF band.

An associated sound signal frequency modulates a second carrier, which is 6 MHz apart from the vision carrier.

THE MONOCHROME TELEVISION RECEIVER

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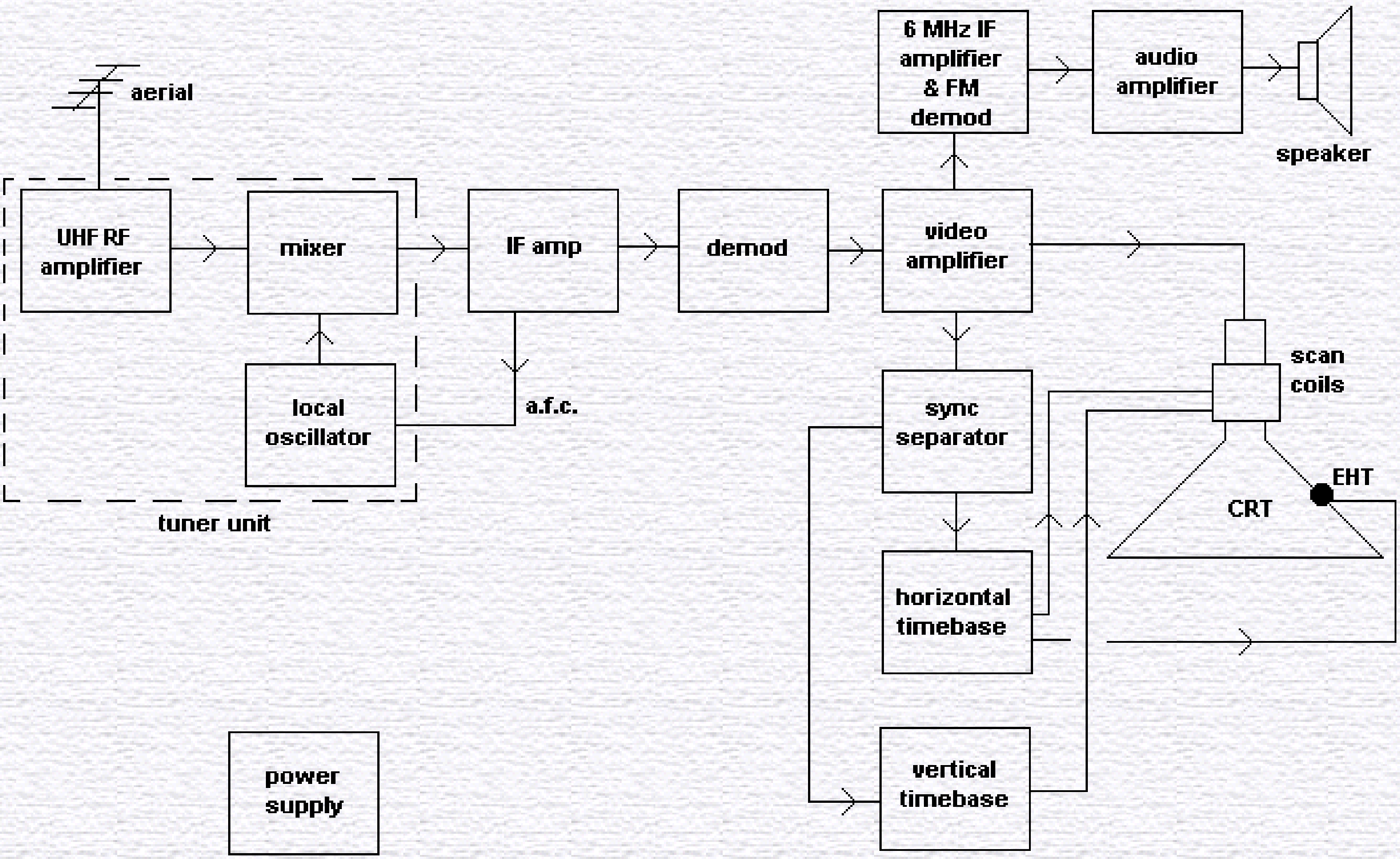

The tuner unit converts the incoming sound sound and vision carriers to their IF frequencies.
For more information on how this is done, read the page on AM radios.

The oscillator is protected against frequency drift,due to temperature changes, by the Automatic Frequency Control (AFC).

The IF amplifier has a bandwidth wide enough to pass both sound (33.5 MHz) and vision (39.5 MHz) IF signals and their sidebands.

The video signal is demodulated and amplified and is used to control the brightness at each particular point on the screen.

The sync pulses are separated from the composite video signal by the sync separator.

These pulses are used to control the frequencies of the timebases, ensuring that they run at the same speed as, and in phase with, those in the studio cameras.

The timebases provide sawtooth waveforms which scan the face of the CRT, while the video signal controls the brightness at each point on the screen.
See the page on mono cameras to read about scanning.

The line timebase also supplies the Extra High Tension (EHT) voltage for the CRT final anode.
This voltage is very high and dangerous.

Due to a mixing process between the sound and vision carriers, the sound signal appears as a 6 MHz FM signal at the video output stage.
It is amplified and demodulated.
The resulting audio signal is amplified and used to drive a loudspeaker.

A power supply supplies DC voltages to all stages.

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THE BASIC COMPUTER

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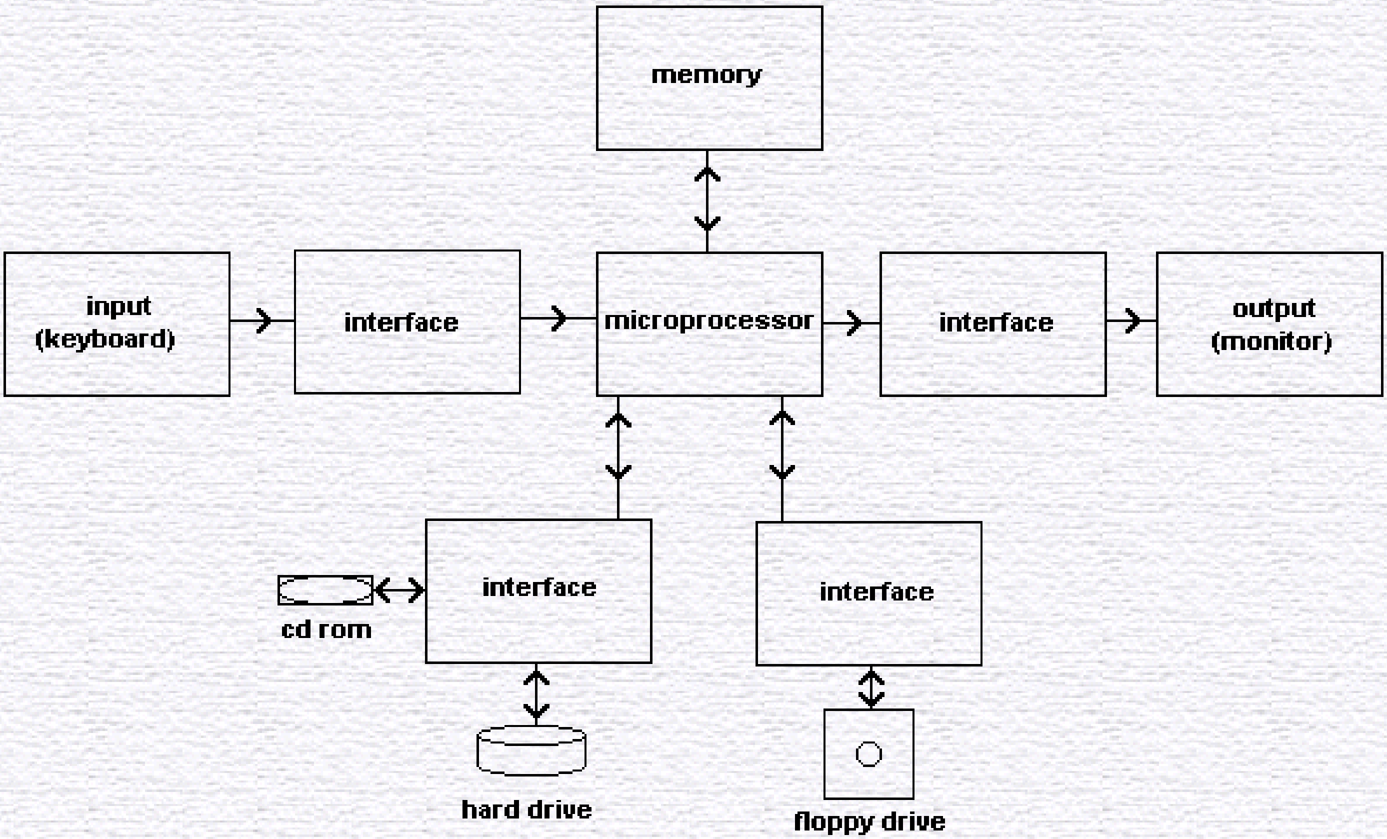

In the diagram, the arrows indicate the direction of data flow.
Some data flows in one direction only.
In some cases it flows in both directions.

At the heart of the computer is the microprocessor.
This contains several REGISTERS to store data and an ARITHMETIC LOGIC UNIT (ALU) which manipulates data.
It acts as the central processing unit (CPU) of the computer, carrying out a sequence of instructions, called a program.

The program may be stored in memory, as software, or written into the memory from tape or disk.

There are two types of memory.
Read Only Memory (ROM) which stores software permanently. The software is not lost when the computer is switched off but the stored data cannot be changed.
Random Access Memory (RAM) which can be written to and read from.

The stored data is volatile.
It is lost when the computer is switched off.

The actual computer, its case and printed circuit boards etc are known as hardware.

The computer needs to communicate with the outside world.
It does this via interfaces which are usually a plug or socket of some type.

The computer is a digital device.
It may need to communicate with an analogue device such as a loudspeaker or variable speed control.
To do this it uses digital to analogue and analogue to digital converters.

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THE PHASE LOCKED LOOP

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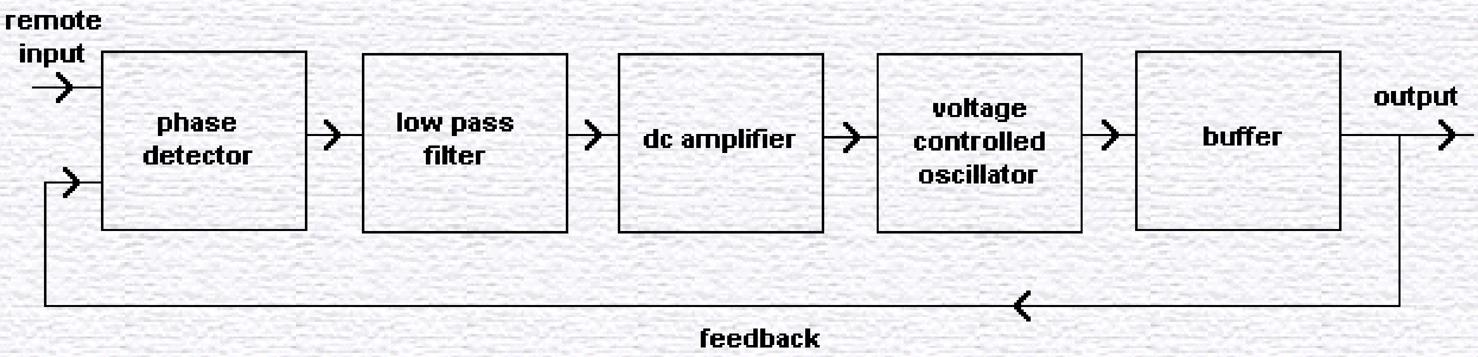

The Phase Locked Loop (PLL) synchronises a local oscillator with a remote one.
This ensures that the local oscillator is at the same frequency and in phase with the remote one.

The local oscillator is voltage controlled (it is a VCO).
This means that its frequency is controlled by varying a DC voltage input.

The output signal of the VCO is fed back to a phase detector via a buffer.
The buffer isolates the VCO from the loading caused by the detector and external circuits.
It avoids "pulling" of the oscillator frequency.

If there is no reference input signal then the VCO will oscillate at its natural "free running" frequency.

The other input to the phase detector is the reference signal, which we wish to lock the frequency of the VCO to.
If there is a difference in frequency or phase between the two inputs then an error signal is produced at the output of the phase detector.

This error signal is fed to the VCO via a filter and a DC amplifier to produce an error correcting voltage.
The filter is a low pass type which determines the range of frequencies over which the VCO can vary.
The DC amplifier amplifies the DC voltage level to a value suitable to control the VCO.

The error correcting voltage may be either negative or positive depending on whether the VCO frequency is higher or lower than the reference frequency.

The effect of the error correcting voltage is to pull the VCO back to the same frequency as the reference frequency, and in phase with it.

If the input signal is an FM signal, then the VCO follows the deviations in frequency caused by the modulation, and the DC output of the DC amplifier is the demodulated audio signal.

The PLL can also be used to keep an AC motor at a constant speed.

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THE P-N JUNCTION

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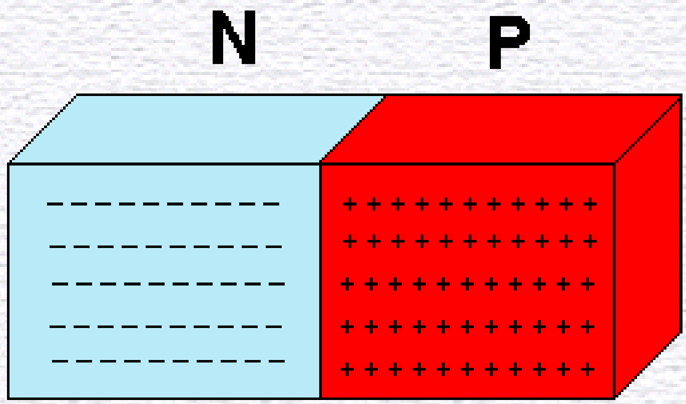

Read the page on semiconductor materials first.

The P-N junction is made from a single crystal with the impurities diffused into it.

The N end has a surplus of negative electrons.
The P end has a surplus of holes.

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THE BARRIER

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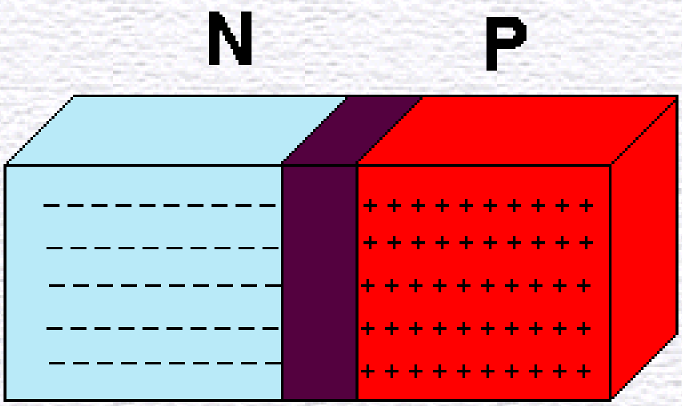

At the junction, electrons fill holes so that there are no free holes or electrons there.
The actual junction becomes an insulating layer.
This barrier must be overcome before current can flow through the P-N junction.

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FORWARD BIASED JUNCTION

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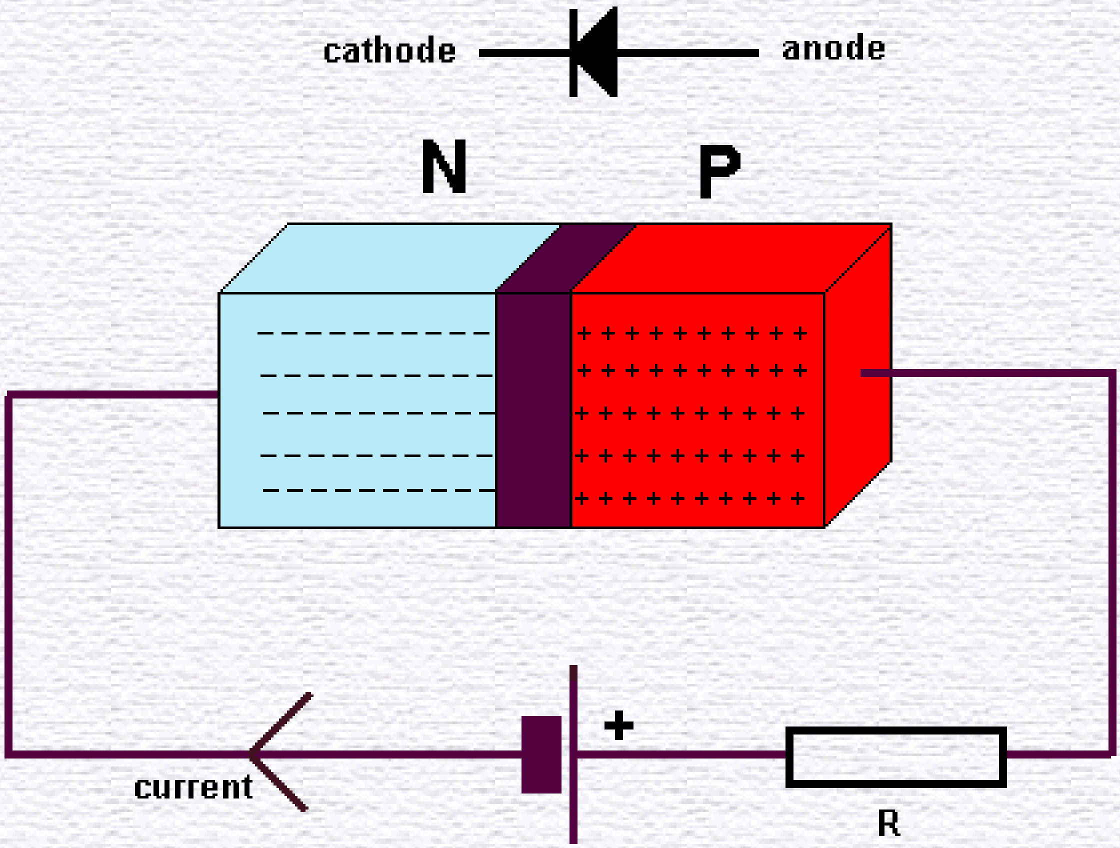

Bear in mind that like charges repel and unlikes attract.

When a battery is connected as shown, the negative terminal pushes negative electrons towards the junction.
The positive terminal pushes holes towards the junction.
If the voltage is high enough then the barrier will be overcome and current will flow through the junction.

There is a voltage across the diode. 0.6 for silicon, o.3 for germanium.

The junction is said to be FORWARD BIASED.

The P type is the anode of the diode, the N type the cathode, as shown by the diode symbol.

The resistor limits the current to a safe level.

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REVERSE BIASED JUNCTION

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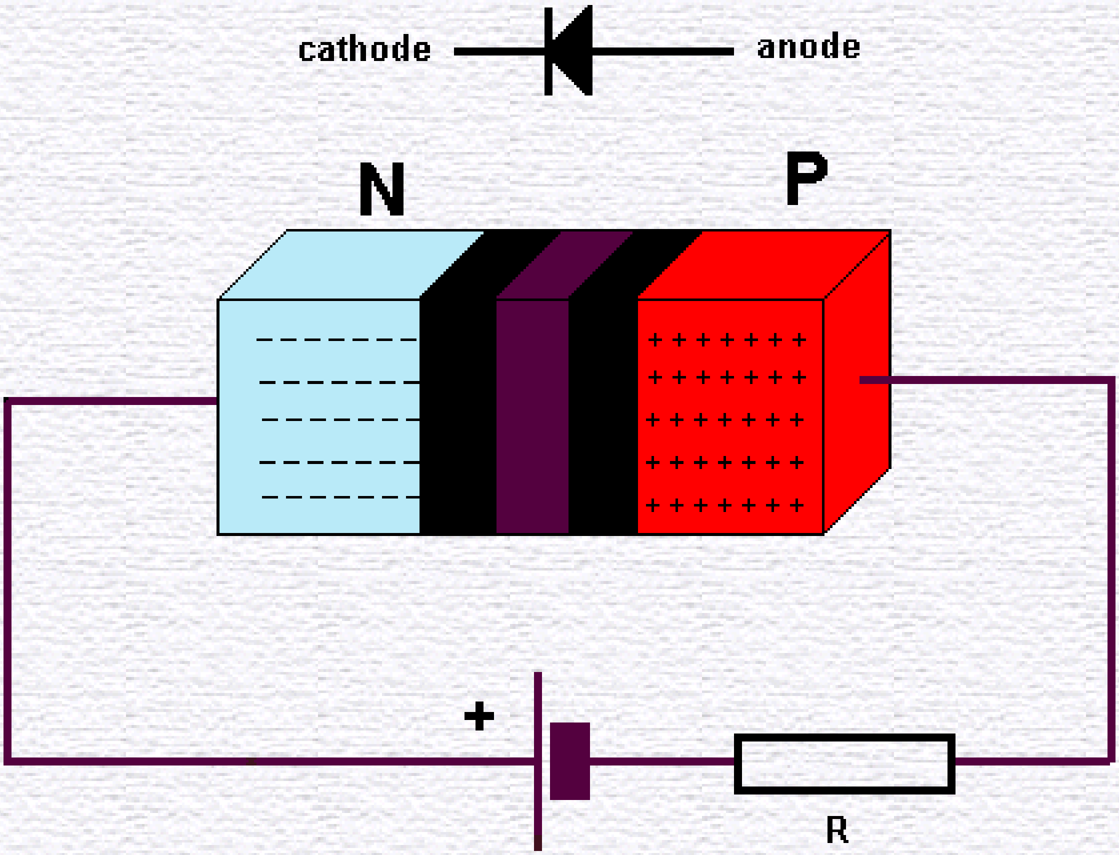

When the battery is connected as shown, the positive terminal of the battery attracts negative electrons away from the barrier.
The negative terminal attracts holes away from the barrier.
The insulating barrier widens and no current flows.

The junction is REVERSED BIASED.

If the reverse voltage is made high enough, then the junction will break down and electron current will flow from anode to cathode (under normal conditions, current flows from cathode to anode, when forward biased).

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FORWARD AND REVERSE BIAS

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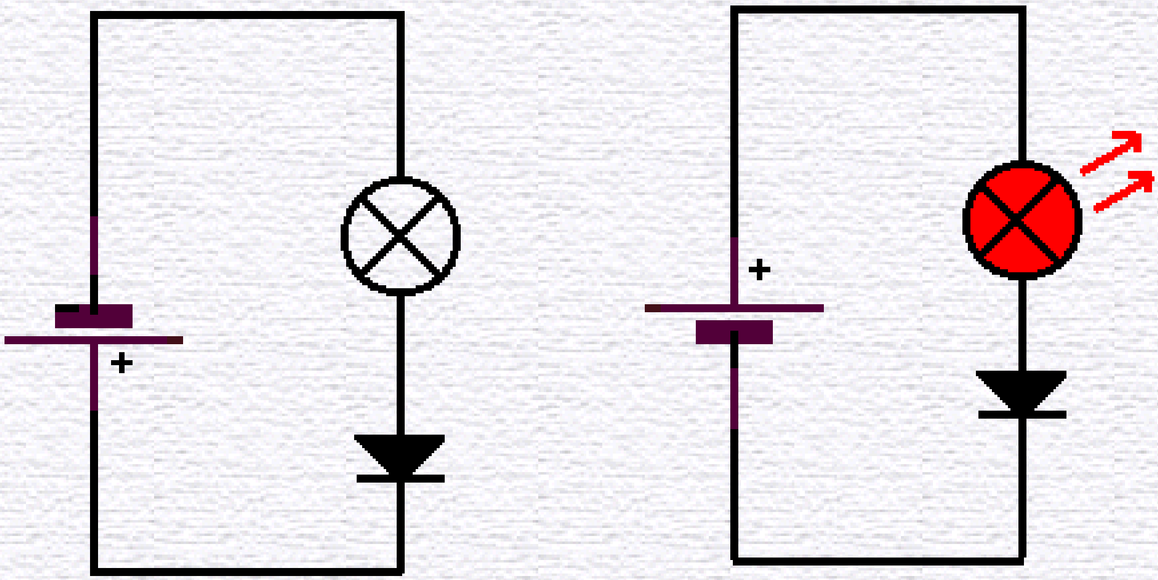

The left hand diagram shows reverse bias, with positive on the cathode and negative on the anode (via the lamp). No current flows.

The other diagram shows forward bias, with positive on the anode and negative on the cathode, and current flowing from cathode to anode.

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A DIODE PUZZLE

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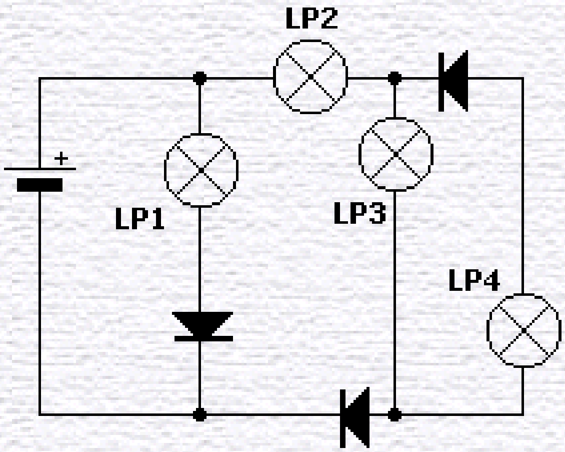

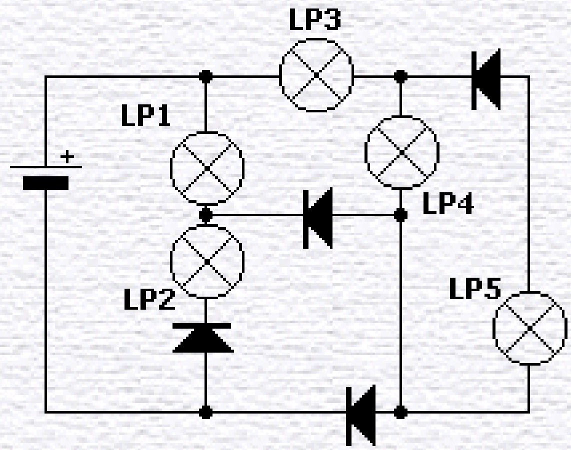

Which lamps are alight?

Some may not be full brightness.

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DIODE VOLTAGES

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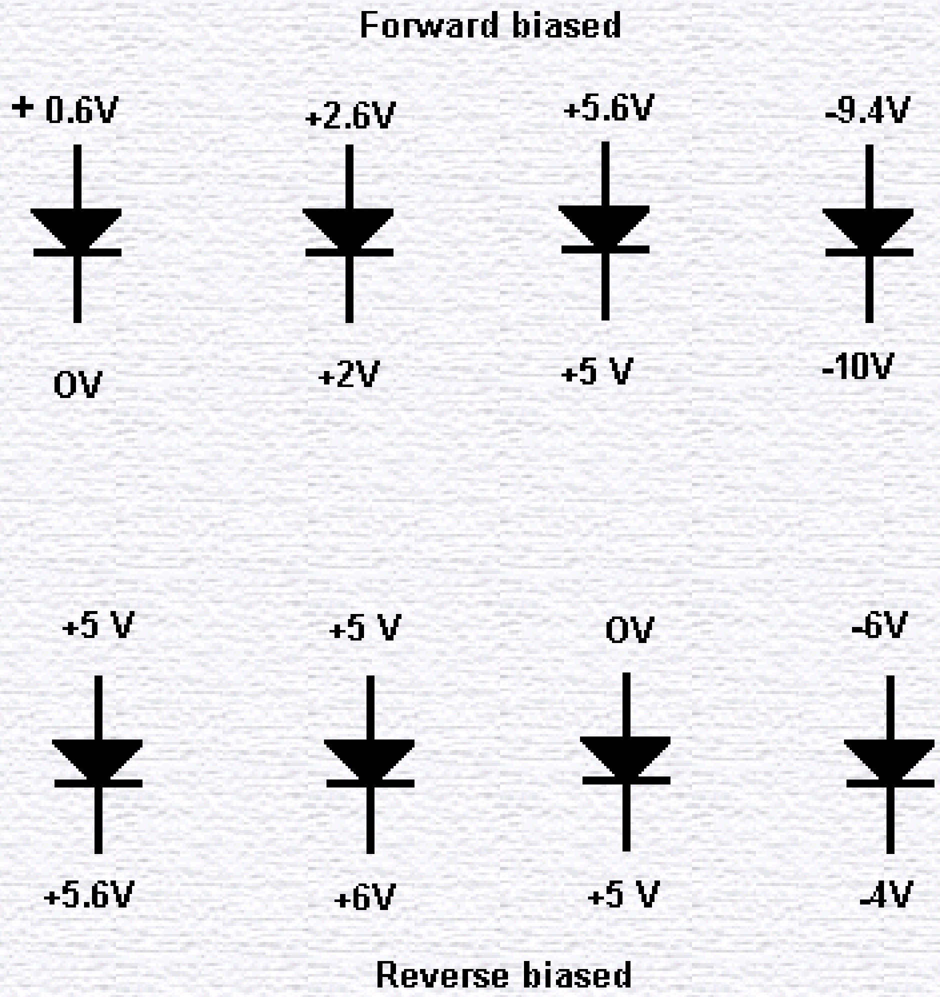

To forward bias a diode, the anode must be more positive than the cathode or LESS NEGATIVE.

To reverse bias a diode, the anode must be less positive than the cathode or MORE NEGATIVE.

A conducting diode has about 0.6 volts across if silicon, 0.3 volts if germanium.

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DIODE CHARACTERISTICS

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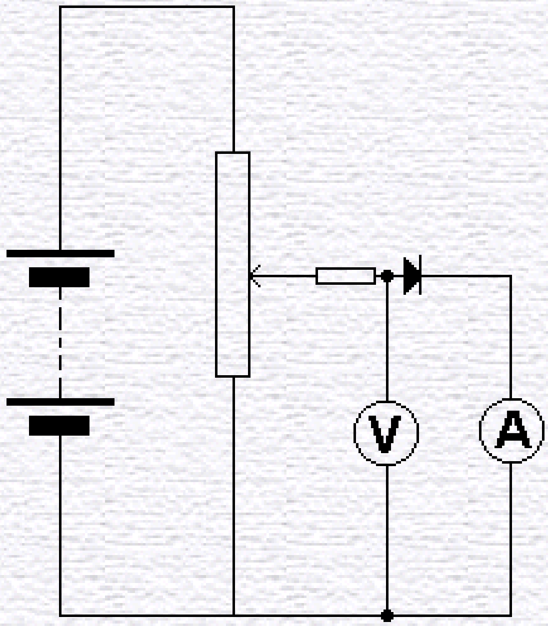

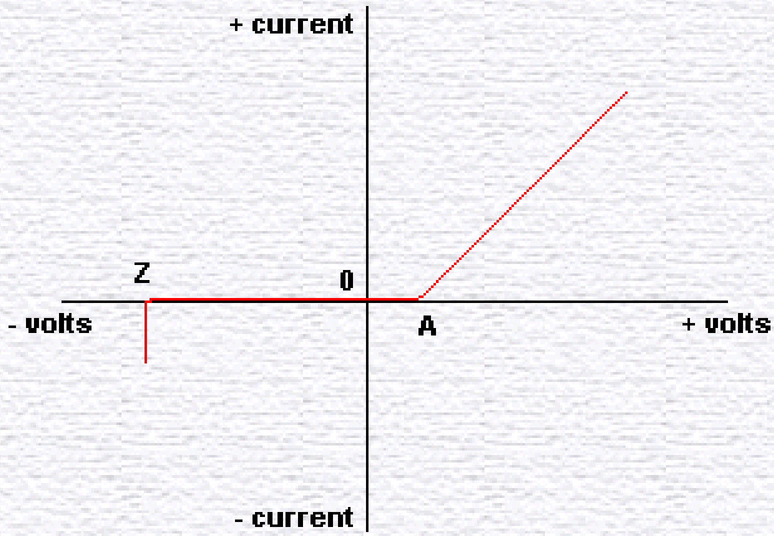

The circuit enables the forward bias voltage across the diode to be set anywhere from zero to the maximum positive voltage of the battery.

The voltage and corresponding current is recorded on the meters.
If these values are plotted we obtain the curve shown in the top right quarter of the graph.

Note that as the voltage increases the current stays at zero, until the voltage reaches a certain value.
The current then begins to increase quite rapidly.
It is at this point that the barrier potential has been overcome and the diode begins to conduct.
This value is about 0.6 volts for silicon diodes and 0.3 volts for germanium types.

If the battery is reversed and a graph again plotted for current against voltage, we obtain the curve in the bottom left quarter of the graph.
It can be seen that as the voltage is increased in the reverse direction, there is no current flowing until a certain value of

voltage is reached and the current suddenly increases to a high value.
This is the breakdown or Zener point and is used in Zener diodes.

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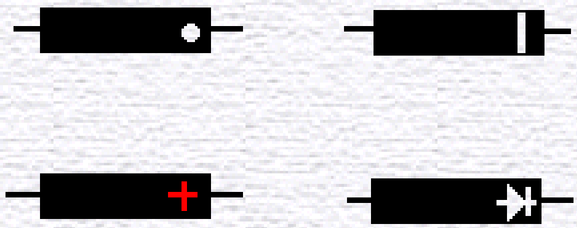
DIODE CONNECTIONS



The cathode end of the diode is usually marked in some manner.

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HALF WAVE RECTIFICATION

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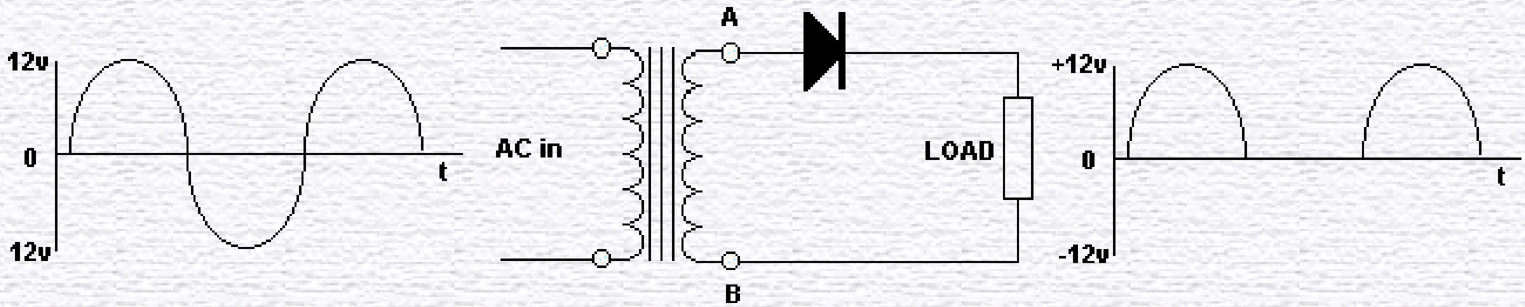

The voltage at point A does the opposite of that at point B.
When A is increasing in a positive direction, B is increasing in a negative direction.
It is rather like the two ends of a see-saw.

During the first half cycle of the waveform shown on the left, A is positive and B is negative.
The diode is forward biased and current flows around the circuit formed by the diode, the transformer winding and the load.

Since the current through the load, and the voltage across the load are in the same proportions, then the voltage across the load is as shown in the right hand diagram, during the first half cycle.

During the second half cycle, A and the anode are negative, B and the cathode are positive.
The diode is reverse biased and no current flows.
This is indicated by the horizontal line in the right hand diagram.

The diode only conducts on every other half cycle.

There is one pulse for every cycle in. i.e 50 pulses per second (in the UK)

The diode only conducts during half the cycle.
Hence, HALF-WAVE RECTIFICATION.

The rectified voltage is DC (it is always positive in value).

However, it is not a steady DC but PULSATING DC.
It needs to be smoothed before it becomes useful.

If the diode is reversed then the output voltage is negative.

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THE RESERVOIR CAPACITOR

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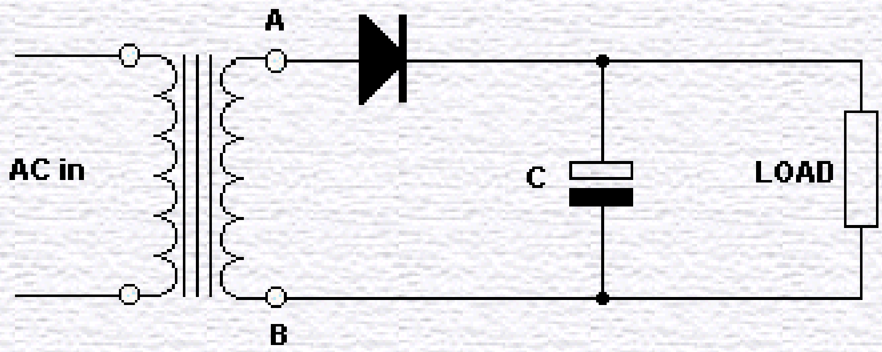

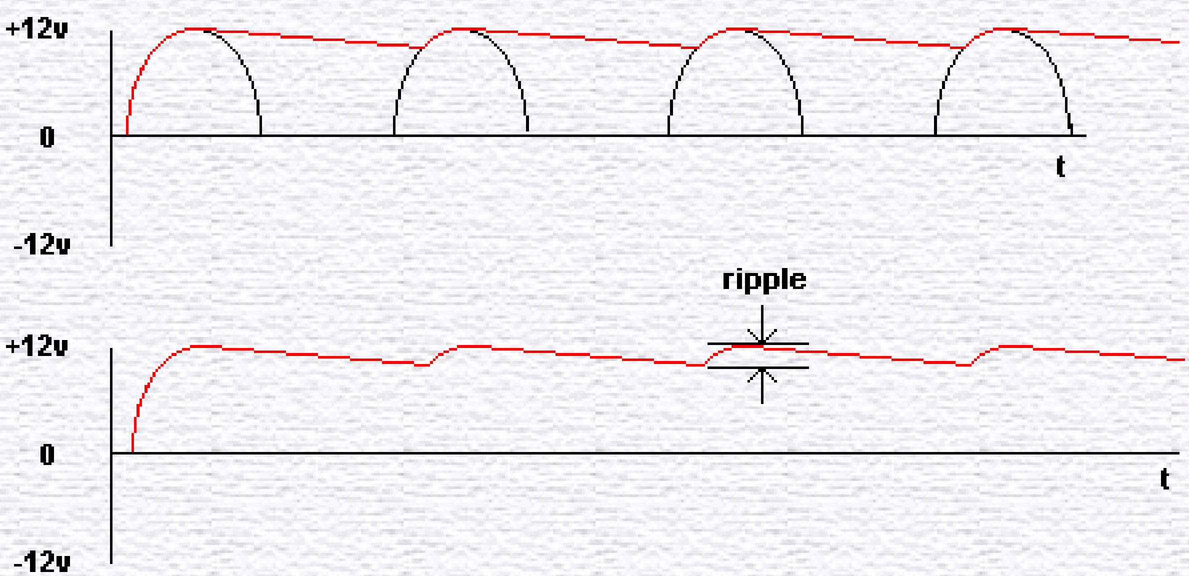

The pulsating DC from the half wave rectifier needs to be smoothed to be useful.

This is done using a RESERVOIR capacitor.
It is not called this because of its construction but because of its application.

In the UK the weather is very variable. Sometimes we have periods of drought and sometimes periods of prolonged rain. April is very showery and occasionally we have snow in Winter.
However, when I turn on the shower, the water always comes out at the same steady rate.

This is because it has been stored in a reservoir and is released as required.

It is the same with the reservoir capacitor.
The capacitor is charged up by the pulses.
It stores the pulses of voltage and the load is able to use this stored power as if it were a steady supply available from a battery.

Looking at the first waveform, the red line indicates the voltage across the capacitor.
When the first pulse arrives the capacitor charges up to the peak voltage.
When this pulse has ended, the capacitor voltage starts to fall as the load takes energy from the capacitor.
However, the voltage falls only slightly before the next pulse arrives to recharge the capacitor to the peak voltage.
The result is a DC voltage with a superimposed 50 Hz (in the UK) ripple.
This is shown in the second waveform.

At low frequencies the capacitor is usually an electrolytic type, but at higher frequencies, where smaller values are required, other types can be used.

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FULL WAVE RECTIFICATION

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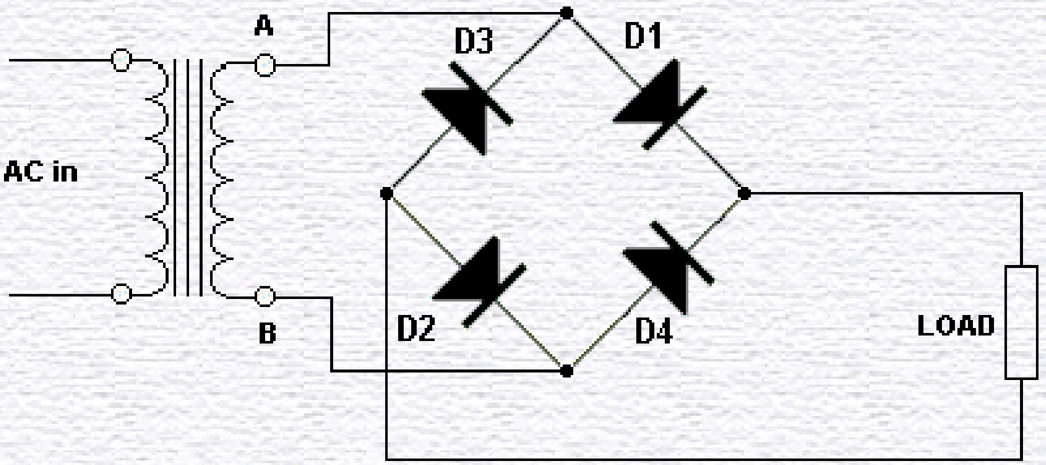

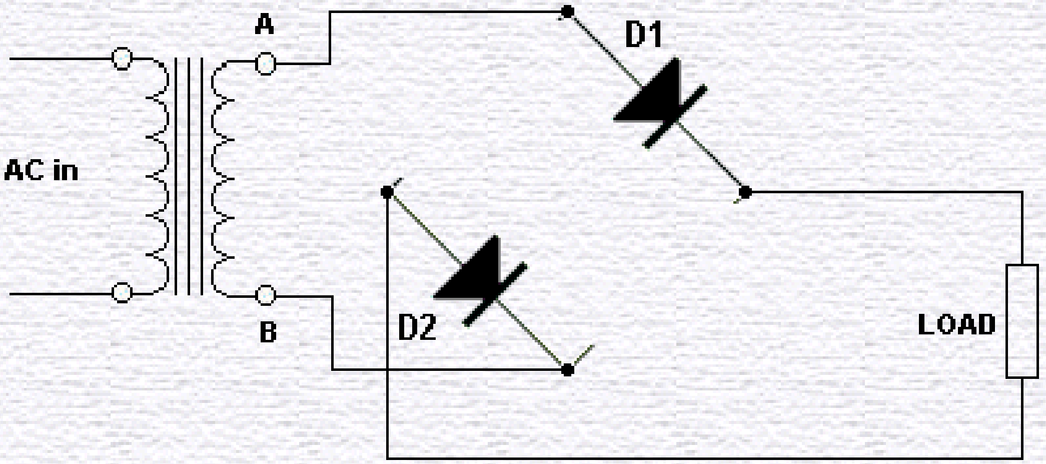

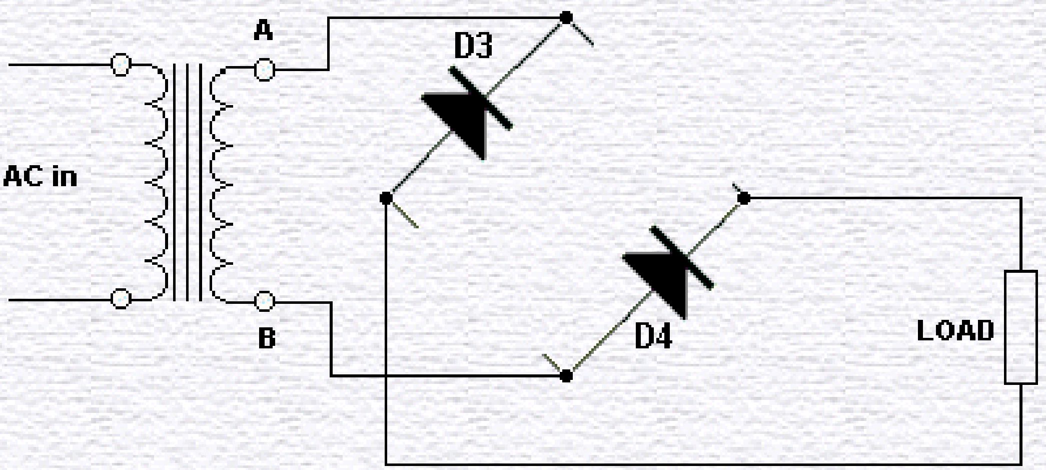

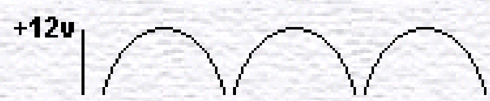

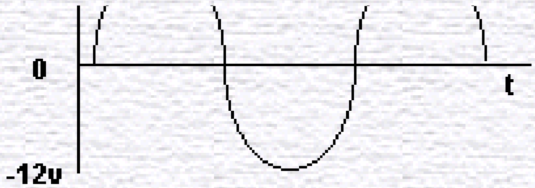

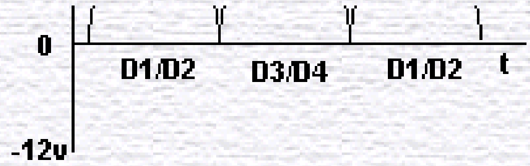

The left hand waveform shows the input voltage (50 Hz AC in the UK).

The voltages at points A and B on the transformer are changing in opposite directions.
When A is increasing in a positive direction, B is increasing negatively.
It is like the opposite ends of a see-saw.

During the first half cycle, A is positive and B is negative.
D1 has positive on its anode, D2 has negative on its cathode.
Both are forward biased.
Current flows around the circuit formed by these diodes, the load and the transformer winding, as shown in the second diagram.
The current flowing up through the load produces a pulse of voltage across the load as shown in the right hand waveform.

During the next half cycle, A is negative and B is positive.
D4 has positive on its anode, D3 has negative on its cathode.
Both are forward biased.
Current flows around the circuit as shown in the bottom diagram, again flowing in the same direction through the load and producing another pulse of voltage.

Since the full cycle is used this circuit is called a FULL-WAVE rectifier.

Since there are two pulses for each cycle of input, there are 100 pulses per second out (in the UK).

The pulsating DC can be smoothed with a reservoir capacitor, as in the half-wave rectifier circuit.
Since the pulse frequency is higher than that of the half-wave

rectifier, it is easier to smooth.

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THE VOLTAGE DOUBLER

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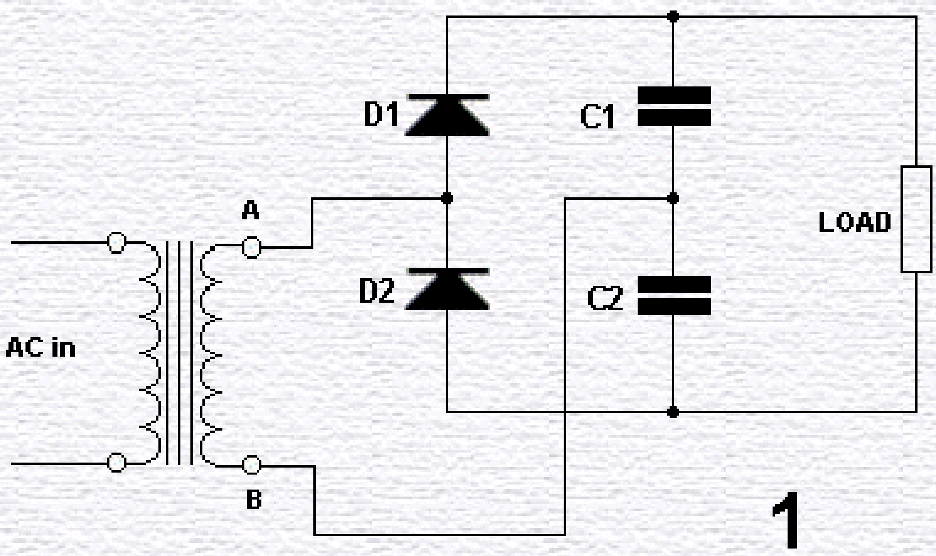
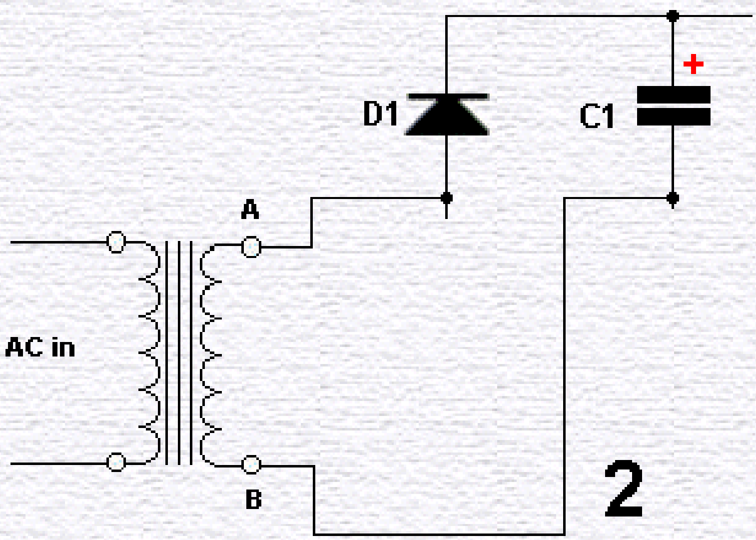
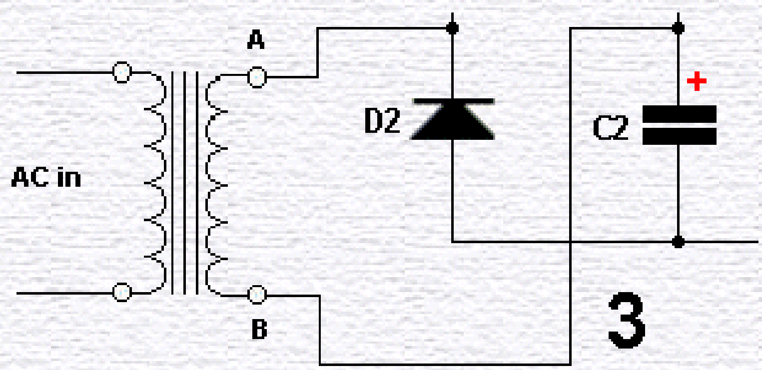


It's best to read the page on the half-wave rectifier, first.

Point A is doing the opposite of point B.

As A increases in a positive direction, B increases negatively, and vice-versa.





When A is positive, D1 is forward biased and charges C1 to the peak voltage, as in diagram 2.
D 2 is reverse biased and does not conduct.

When A goes negative, D1 is reverse biased and does not conduct.
D2 is forward biased and charges C2 to the peak voltage, as in diagram 3.

We now have two capacitors in series, each charged to the peak voltage.
The voltage across the load is. therefore, twice the peak voltage.

The voltage has been doubled.

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CLIPPERS AND LIMITERS

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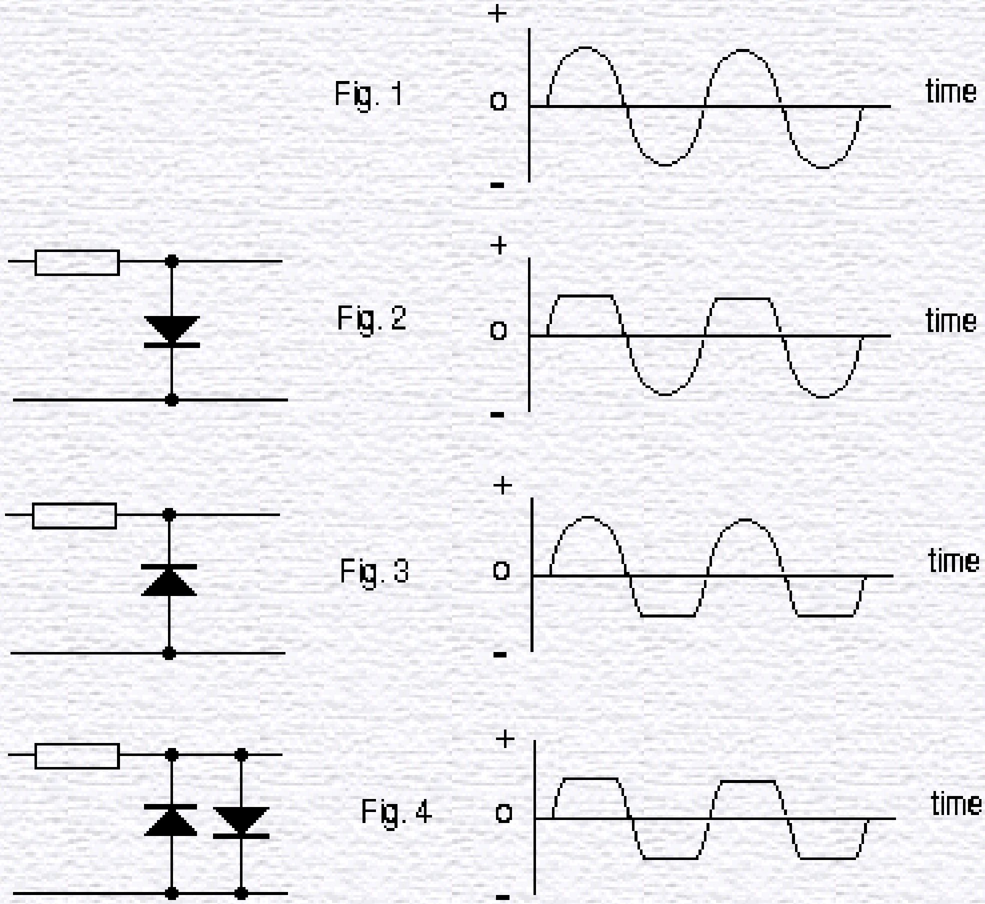

Clipping removes part of the positive or negative peaks of a signal or both.

Silicon diodes do not conduct until the applied voltage exceeds about 0.6 volts and only when the anode is positive with respect to the cathode.

The circuit is like a potential divider with the diode part being high resistance for voltages below 0.6 volts and low resistance above.

Fig. 1 shows the waveform into the clipper.

Fig. 2 is the output of a positive clipper and fig. 3 the output of a negative clipper.

Fig. 4 has both peaks clipped and is often used as a LIMITER where the output must not exceed 1.2 volts.

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THE STEERING DIODE

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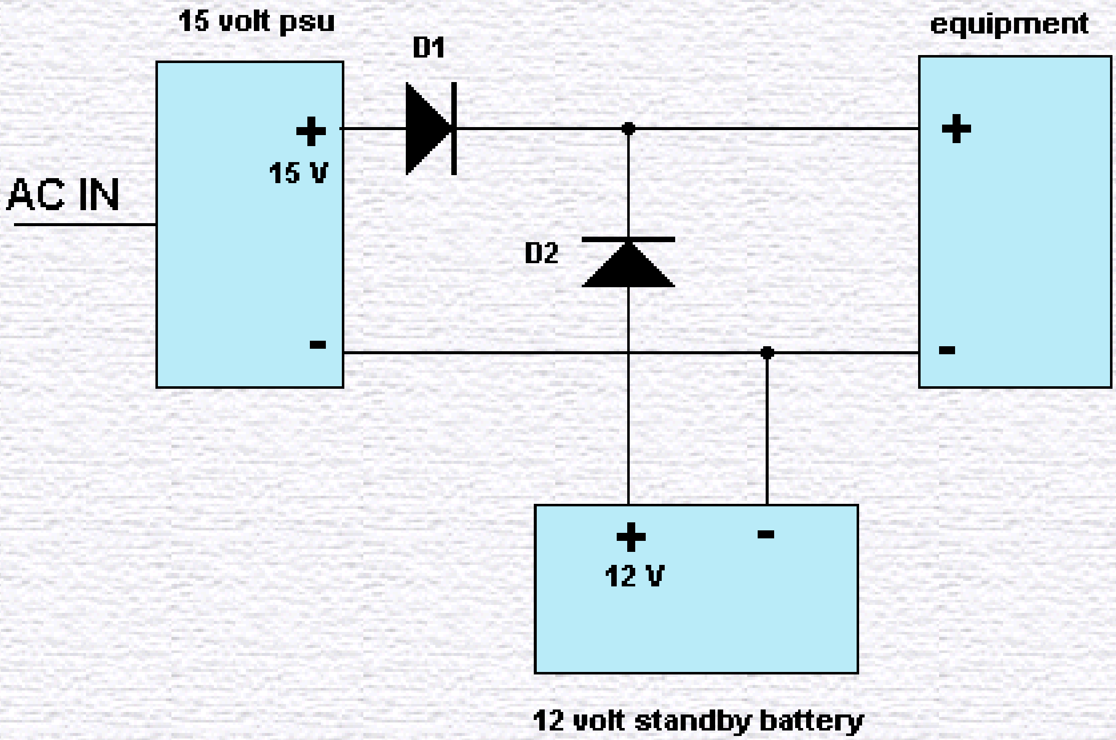

If the AC supply fails then the equipment is automatically powered by the standby battery.

While the AC supply is present, D1 has +15 volts on its anode, and is forward biased.
Since there is 0.6 volts across the diode, there is +14.4 volts on its cathode.
This voltage powers the equipment.
D2 is reverse biased since its anode is less positive than its cathode.
D2 is non conducting and the battery is isolated.

If the supply fails then the +15 volts disappears, and D2 becomes forward biased and conducts, to power the equipment.

The diodes STEER the voltages.

THE DIODE GATE

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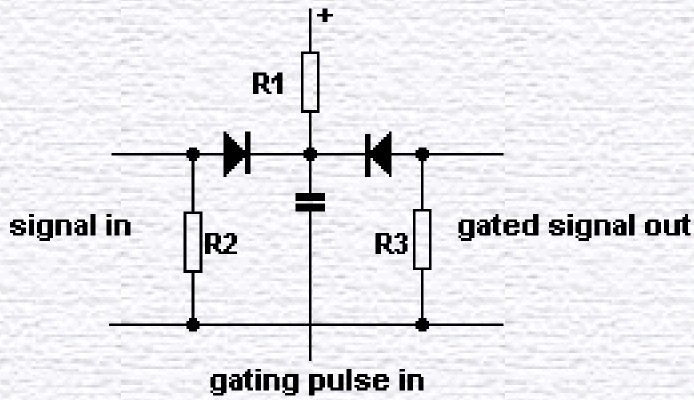

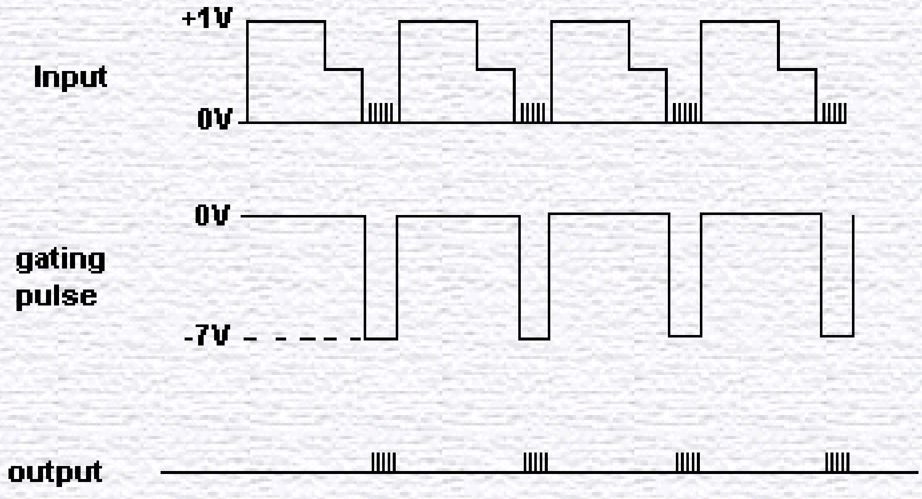

An electronic gate opens to let part of a signal through, and then shuts to reject the remainder.
It's like seperating sheep from goats, using a real gate.

In the circuit, the cathodes of the diodes are more positive than the anodes.
They are reverse biased and non conducting.
The output of the circuit is isolated from the input.

When the negative gating pulse comes along, the cathodes become more negative than the anodes.
The diodes are forward biased and conduct.

The output is connected to the input.
During the duration of the gating pulse, the input signal appears at the output. as shown by the lowest waveform.

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THE ZENER DIODE

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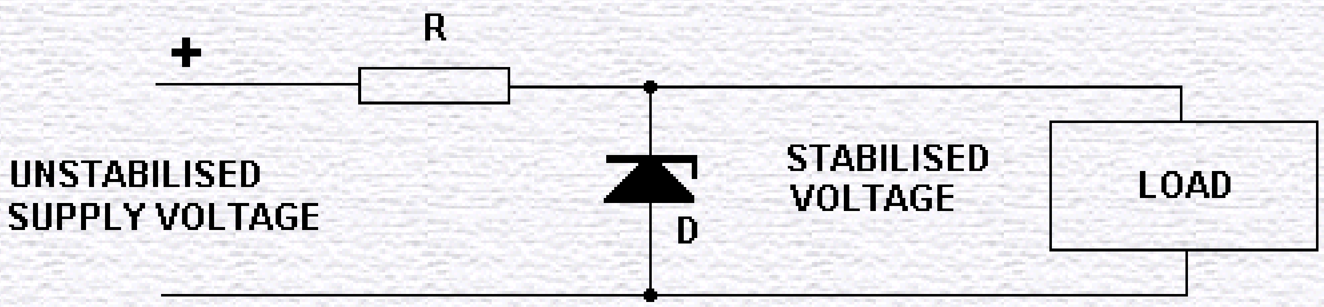

The Zener diode is operated in reverse bias mode (positive on its cathode).
It relies on the reverse breakdown voltage occuring at a specified value.
This value is printed on it.

It has two main applications.

1. as a reference source, where the voltage across it is compared with another voltage.

2. as a voltage regulator, smoothing out any voltages variations occuring in the supply voltage across the load.

When being used a voltage regulator, if the voltage across the load tries to rise then the Zener takes more current.
The increase in current through the resistor causes an increase in voltage dropped across the resistor.
This increase in voltage across the resistor causes the voltage across the load to remain at its correct value.

In a similar manner, if the voltage across the load tries to fall, then the Zener takes less current.
The current through the resistor and the voltage across the resistor both fall.
The voltage across the load remains at its correct value.

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THE VARICAP DIODE

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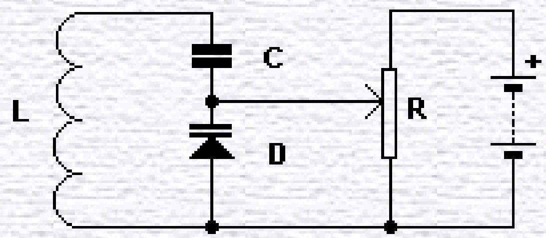

When the junction diode is reverse biased, the insulating barrier widens.
The higher the reverse voltage the wider the barrier becomes.

The barrier forms the dielectric, of variable width, of a capacitor.
The N and P type cathode and anode are the two plates of the capacitor.

In the diagram, the diode and coil form a resonant circuit.
The capacitance of the diode, and thereby the resonant frequency, is varied by means of the potentiometer controlling the reverse voltage across the varicap.
The capacitor prevents the coil shorting out the voltage across the potentiometer.

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DIODE PROTECTION CIRCUITS

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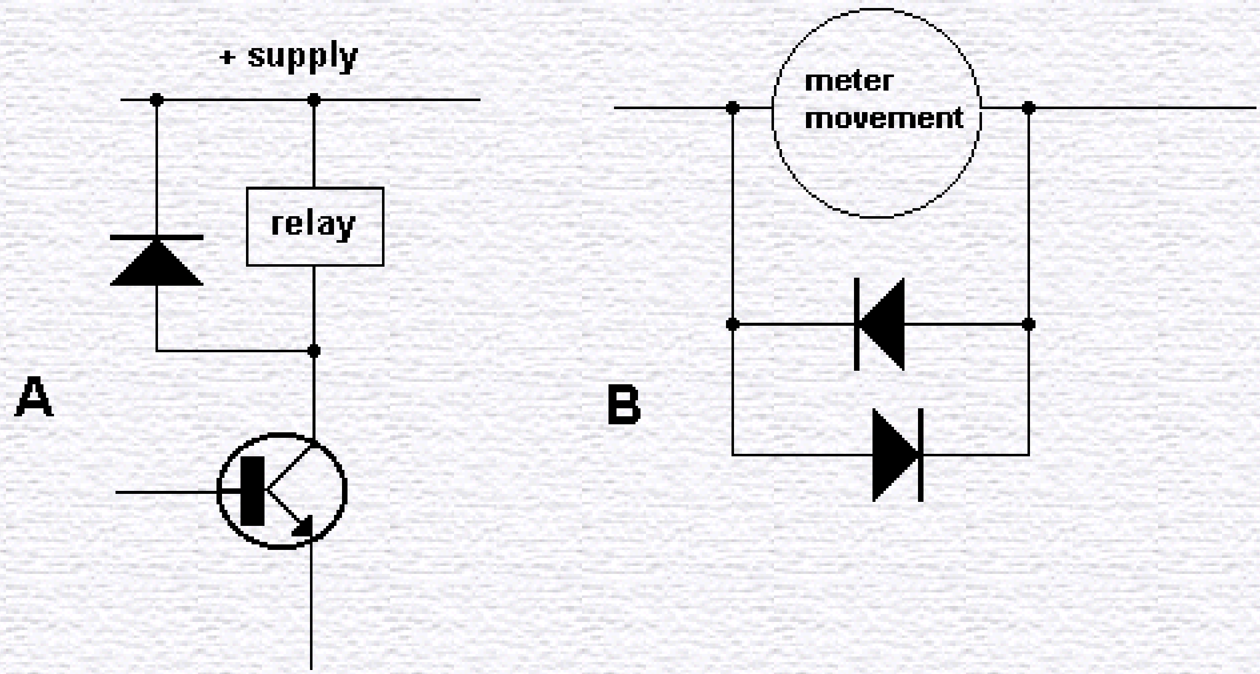

Diagram A
This circuit consists of a relay coil being switched by a transistor.

When a coil is switched off, a large BACK EMF appears across the coil.
This back emf may be several thousand volts in value, enough to destroy the transistor.
The diode, which is normally reverse biased, is forward biased by the back emf,and conducts, its low resistance short circuiting the back emf and protecting the transistor.

Diagram B
This circuit consists a meter movement with two germanium diodes across it.

Typical movements require only 100 mV for full scale deflection of the pointer.
If a voltage, exceeding about 0.3 volts, appears across the circuit then one of the diodes will conduct and protect the

movement from excessive voltage.

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THE JUNCTION TRANSISTOR

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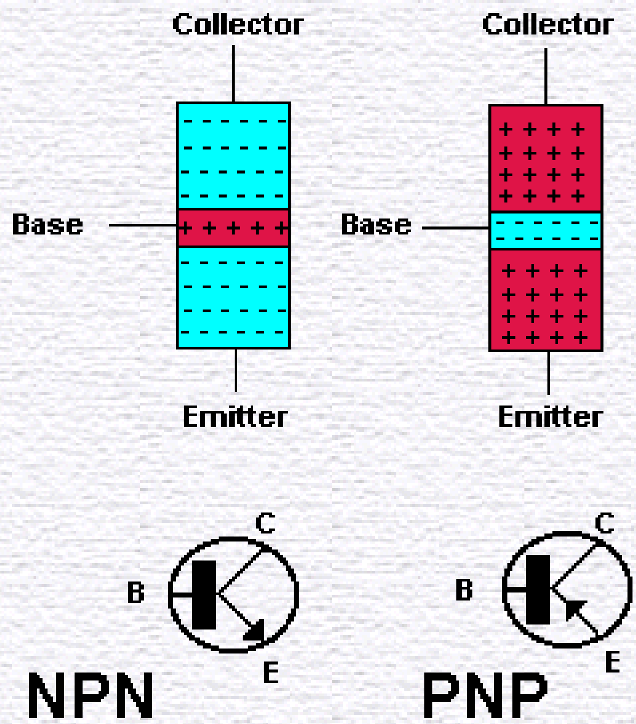

Junction transistors consist of two junctions made from N-type and P-type semiconductor materials and are called bipolar transistors (two polarities).

They have three connections, emitter, base and collector.

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JUNCTION TRANSISTOR BIASING

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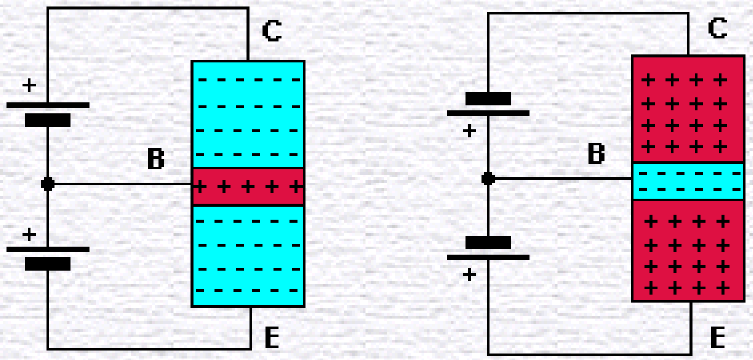
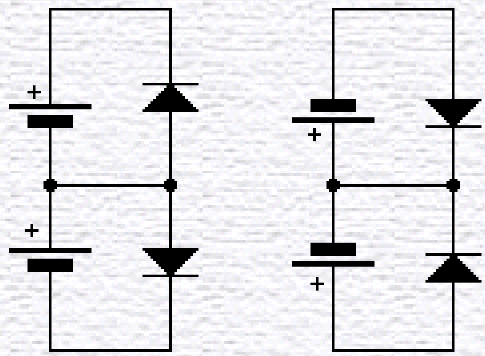
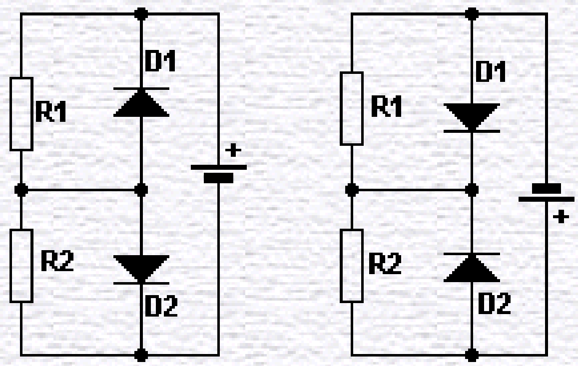




NPN PNP



NPN PNP

The emitter/base junction is forward biased.
The collector/base junction is reversed biased.
There is an explanation of biasing on one of the diode junction pages.

The middle diagram shows the two junctions as two diodes.
Of course, you can't make a transistor like this but it helps to understand the forward and reverse biasing.
The anodes are positive with respect the cathodes for forward biasing.
They are negative with respect to the cathodes for reverse biasing.

The bottom diagram shows the junctions being correctly biased using just one battery.

Note that there is 0.6 volts across the base/emitter junction when it is forward biased, for a silicon transistor. (0.3 volts for a germanium one).

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TRANSISTOR CURRENTS

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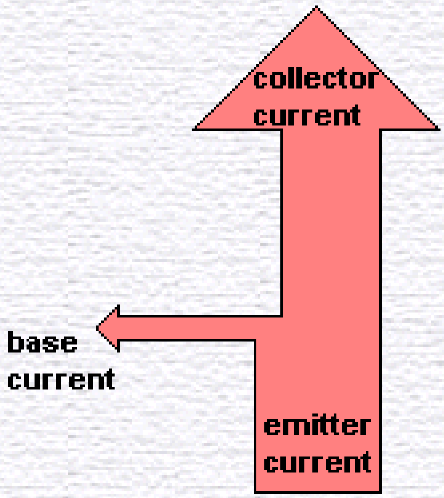
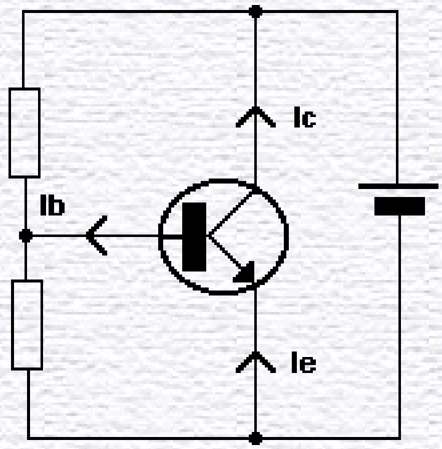


IE = IB + IC



The forward biased base/emitter junction causes electrons to be attracted from the emitter area towards the base.
Arriving in the base area, most of the negative electrons come under the influence of the more positive collector and are attracted by it.
This is shown in the left hand drawing, where the base current plus collector current equals the emitter current.

Alpha gain is collector current divided by emitter current, and is always less than 1.
Beta gain is collector current divided by base current and can be a fairly high number.

Therefore, causing a small base current to flow makes a much larger collector current flow.
A small base current controls a large collector current.

There is 0.6 volts across the base/emitter junction, when it is forward biased. (0.3 volts for germanium).

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THE TRANSISTOR AS A SWITCH

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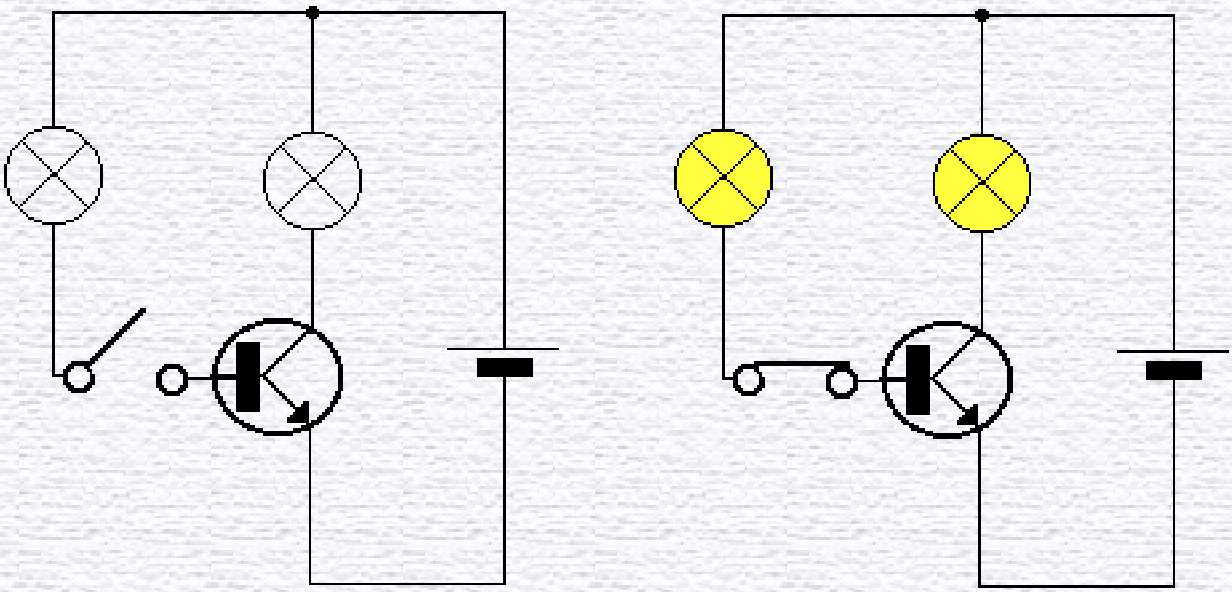

With the switch open, no base current flows, therefore no collector current can flow. The transistor is said to be CUT OFF.

With the switch closed, base current flows causing collector current to flow. The battery voltage is dropped across the lamp causing the collector voltage to fall to a very low value.
The transistor is said to be SATURATED.

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CLASS A, B AND C BIAS

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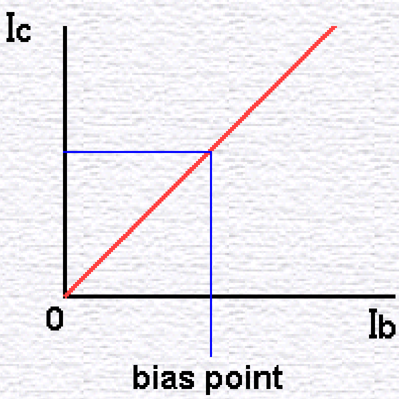

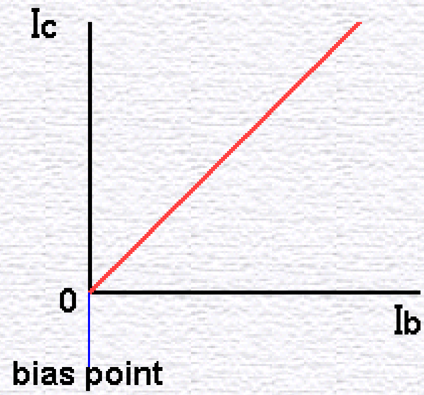

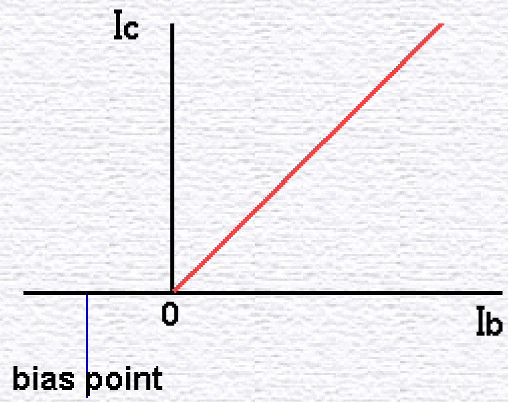

CLASS A CLASS
B CLASS C

With class A bias, the base current is set so that collector current flows.
Increasing or decreasing base current causes collector current to increase and decrease.

With class B bias, the base current is set to zero. No collector current flows and the transistor is CUT OFF.
The collector current can only be made to increase from this point, not decrease, by increasing the bias.

With class C bias the bias point is set well below cut off.
Collector current can only be made to flow by increasing the bias point considerably above its present value.

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THE SMALL SIGNAL AMPLIFIER

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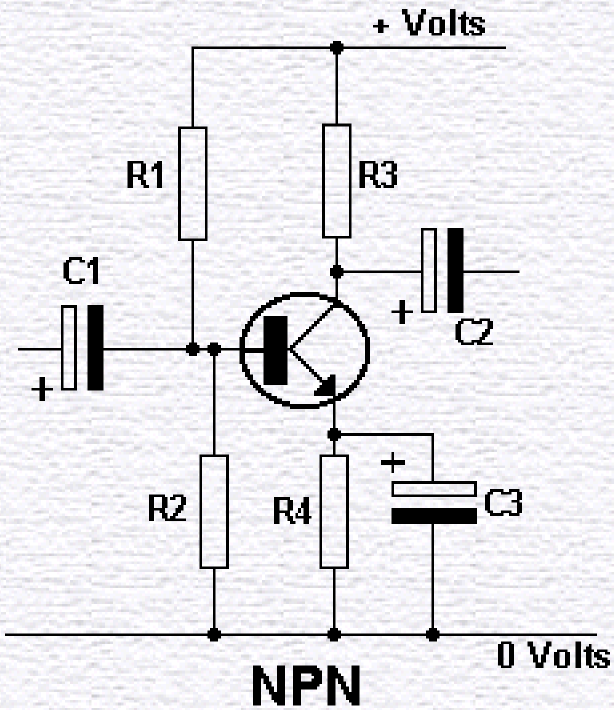

The two transistor types have opposite polarity power supplies.
The polarity of the capacitors is reversed.
If the transistors have the same characteristics, then resistor values are the same in both circuits.

R1 and R2 are the base bias resistors, setting the bias point.
R3 is the collector load resistor.
R4 is the emitter stabilising resistor.
C3 is the emitter decoupling capacitor.
C1 and C2 are coupling capacitors which allow ac signals to pass but block dc.

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BIASING A TRANSISTOR

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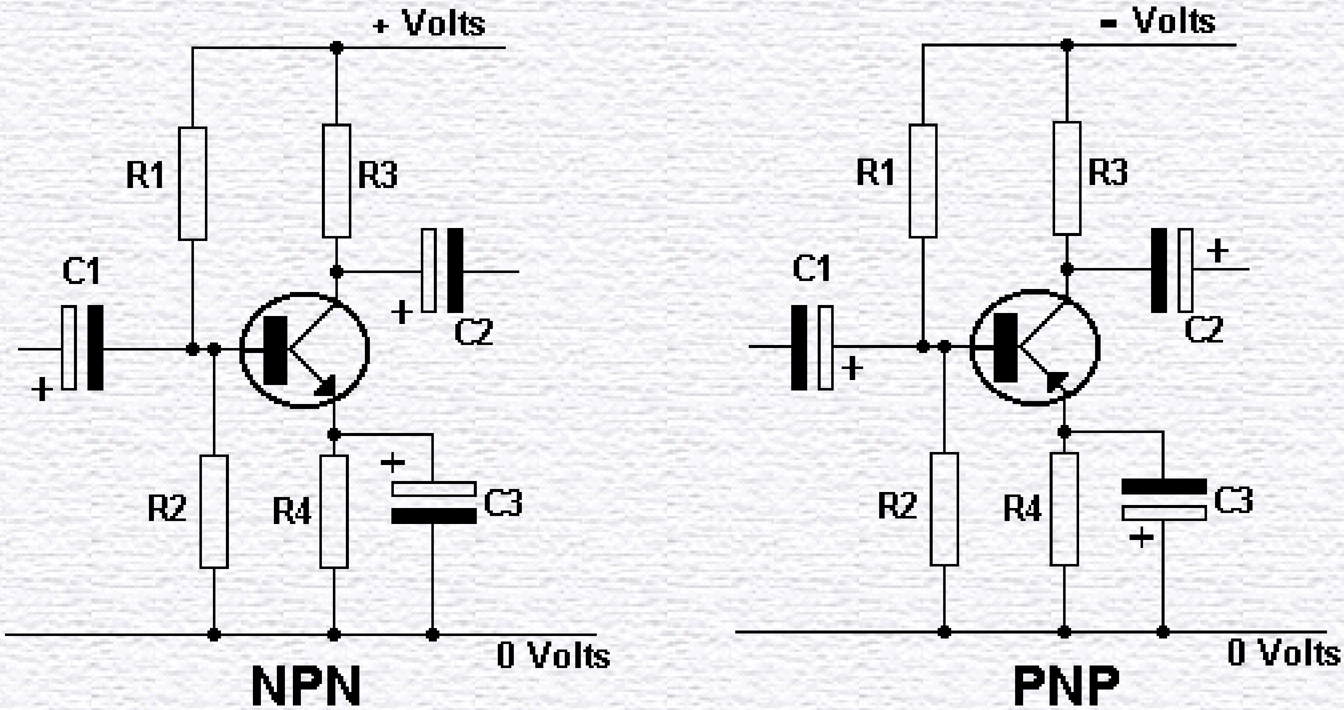

Choose a general purpose transistor with a beta gain higher than 100.

Decide on the collector current.

The base bias voltage is be 1/3 of the supply voltage.

The current through the base bias potential divider is to be 1/10 of the collector current.

Calculate the two base resistor values, R1 and R2.

The emitter voltage is 0.6 volts lower than the base voltage.

The value of the emitter resistor R4 is the emitter voltage divided by the collector current.

The value of the collector resistor R3 is the supply voltage divided by three times the collector current.

The values of the capacitors depend upon the application.

Study a few circuits.

For common collector and common base some of the capacitors are connected differently.

EMITTER STABILISATION

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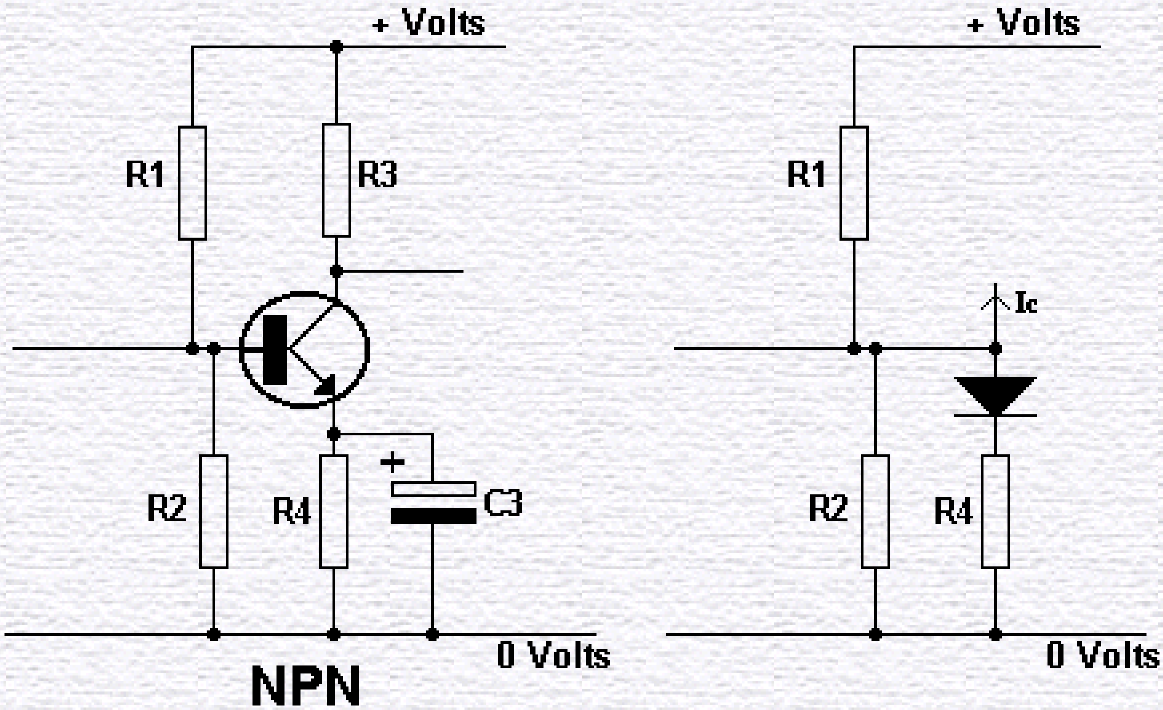

R1 and R2 bias the transistor in class A so that a steady dc collector flows.

R4 is the emitter stabilising resistor.

When collector current flows it causes the transistor to heat up.
This causes the base current to increase which in turn causes the collector current to rise.
This rise in collector current causes the temperature to increase even more, and the base and collector currents continue increasing.
This behaviour is called THERMAL RUNAWAY and will destroy the transistor.

If we consider the emitter/base junction as a diode as shown in the right hand diagram we can see that the base (anode) voltage is fixed by R1 and R2.

If the collector current tries to rise due to heating, then the

voltage across R4 will try to rise, making the emitter (cathode) more positive.
This would reduce the voltage across the junction (diode) making it less forward biased and reducing the base current and hence the collector current, which was trying to rise.

Therefore the circuit has been stabilised against thermal runaway.

However, if an ac signal is applied to the base, the varying collector current will cause a varying voltage across the emitter resistor.
This voltage will follow the base voltage.This means that the base/emitter (anode/cathode) voltage will be constant instead of the base varying with respect to the emitter.
To fix this, the emitter is joined to earth, as far as the ac signal is concerned, by the emitter decoupling capacitor.

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THE LOAD RESISTOR

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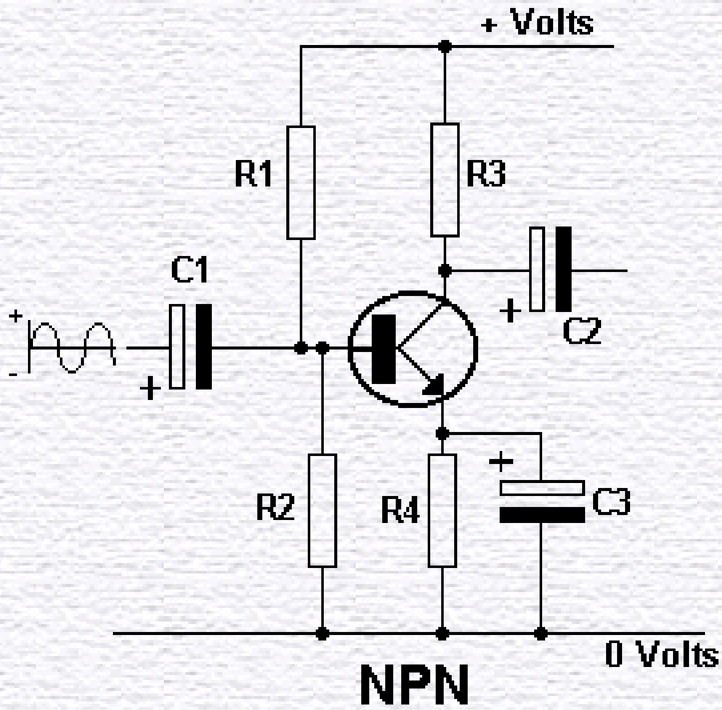

R1 and R2 bias the transistor in class A, so that a steady collector current flows.

R3 is the load resistor.

Look at the signal into C1.

During the first half cycle it is positive, and increases the forward bias on the base of the transistor.
This increases the base current and thereby the collector current through the load resistor.
Therefore the voltage across the load increases, and the collector voltage, with respect to the zero line, decreases.
The collector voltage falls as the base voltage rises.

During the second half cycle, the input signal goes negative, reducing the forward bias on the base.
This reduces both base and collector currents.
The voltage across the load resistor falls and the voltage on

the collector rises.
Again, the collector voltage has done the opposite of the base voltage.

The transistor inverts the input signal as well as amplifying it.

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TYPICAL CIRCUIT VOLTAGES

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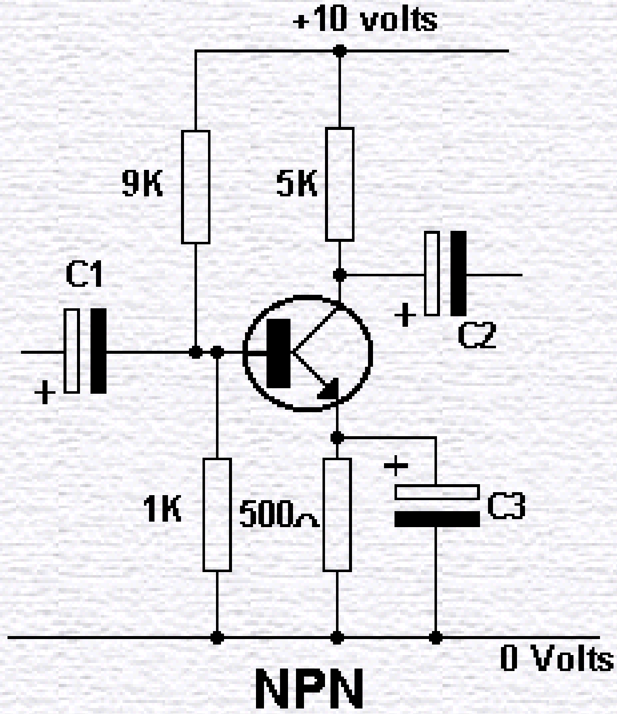

The base voltage Vb, is set by potential divider 9K and 1K = 1 volt (ignoring Ib)

The emitter voltage Ve, is Vb - 0.6 = 0.4 volts.

The emitter current is Ve / Re = 0.0008A

The voltage across the 5K load resistor is 5000 x .0008 = 4 volts

Therefore the collector voltage is 10 volts - 4 volts = 6 volts

The power dissipated by the transistor is the voltage acrooss the transistor mutiplied by the current through it. = 5.6 volts x 0.0008A = 0.00448 watts

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AMPLIFIERS IN CASCADE

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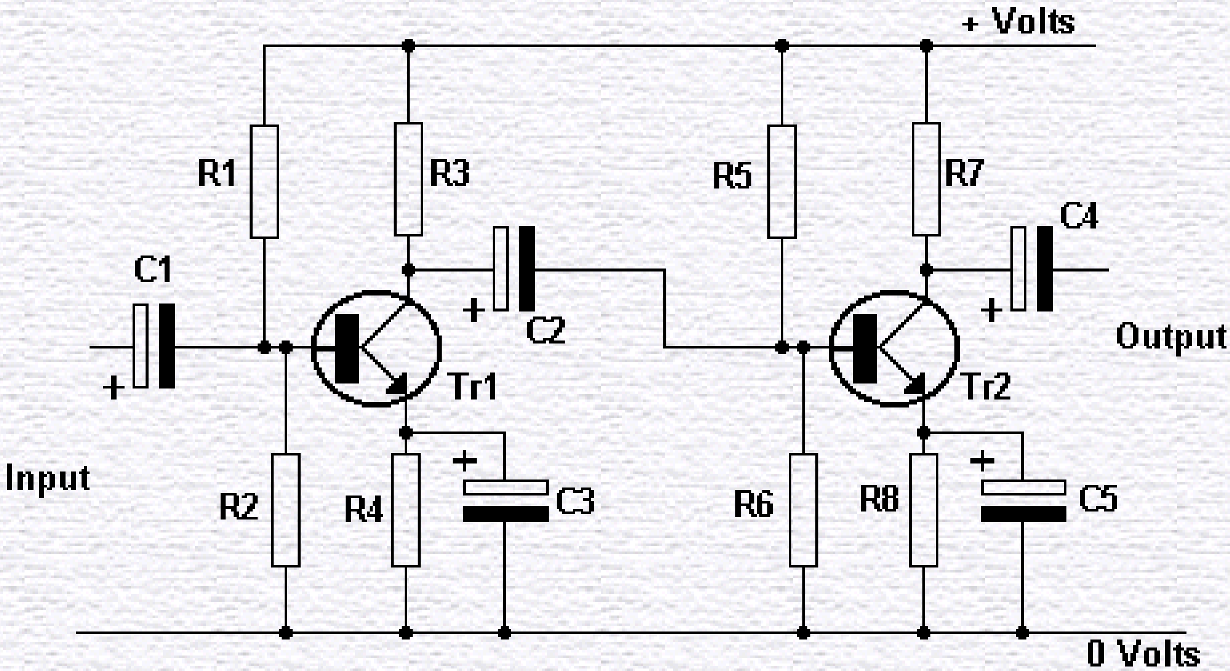

If the gain of one stage of amplification is insufficient, then two or more stages can be connected in cascade, as shown.

If the gain of each stage is 50 times, then the overall gain is 50 x 50 =2,500.
If the input to Tr1 is 1 mV, then the output of Tr2 is 2,500 mV =2.5Volts.

If the gain is excessive the circuit may be unstable, or the output may be clipped.

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THE TUNED AMPLIFIER

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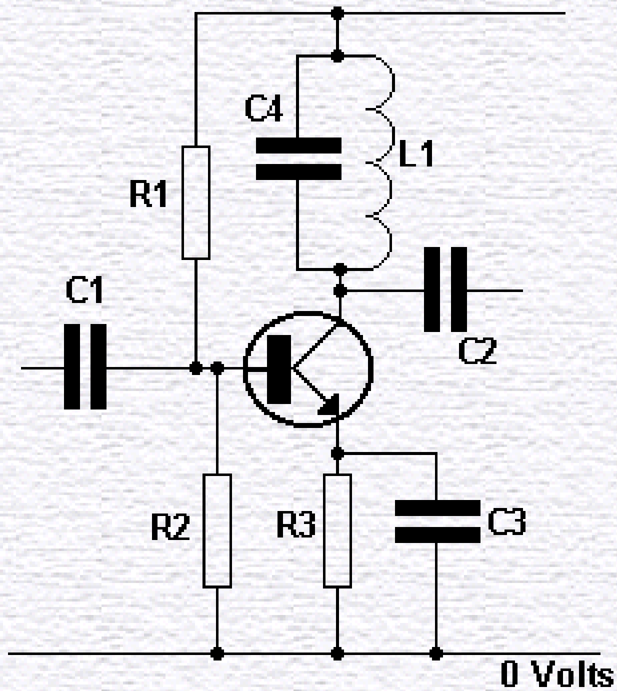

Here the load resistor has been replaced by a tuned circuit, C4 and L1.
At resonance, the tuned circuit is high impedance.
At all other frequencies it is a low impedance.
Therefore only signals at the resonant frequency will be amplified

Since the tuned amplifier works at radio frequencies the capacitors can be much smaller in value than those used at audio frequencies

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THE COMMON EMITTER AMPLIFIER

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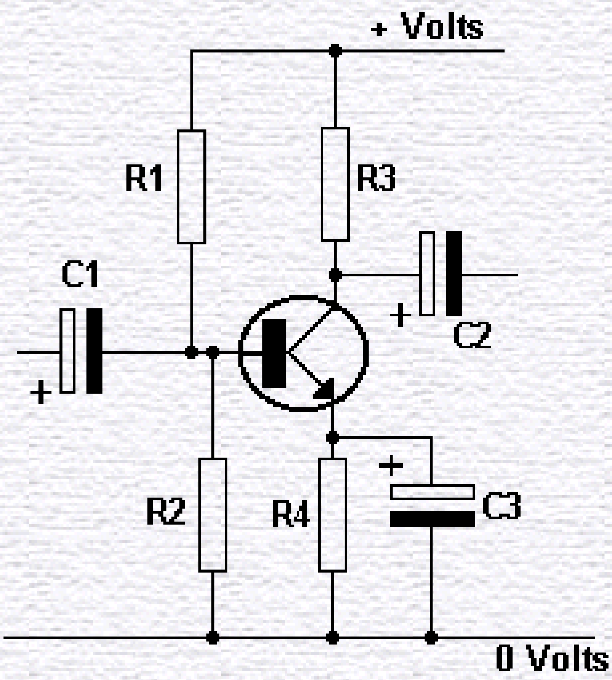

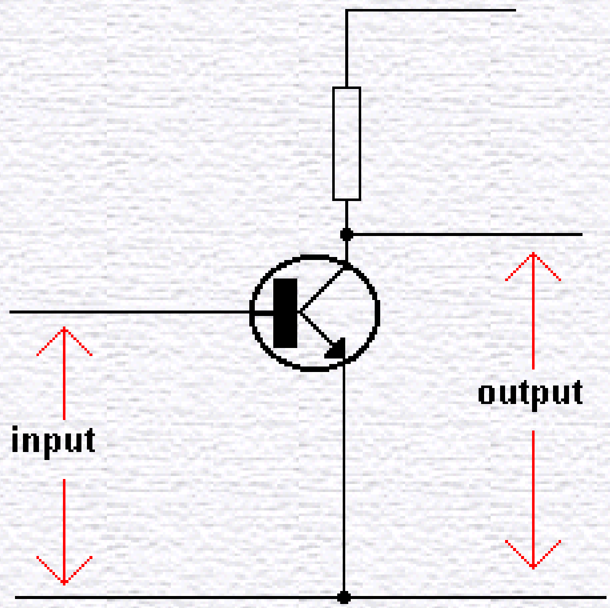

Sometimes called the grounded emitter, since the emitter capacitor connects the emitter to ground at ac frequencies.

Since, as far as ac is concerned, the emitter is joined to ground, both input and output are connected to the emitter.

Current gain is Ic/Ib and can be quite high, typically 50.

Voltage gain is high, typically 250

Input impedance is medium, say 5K.

Output impedance is medium, say 20k.

The output is inverted with respect to the input.

Its most common application is as a voltage amplifier.

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THE COMMON BASE AMPLIFIER

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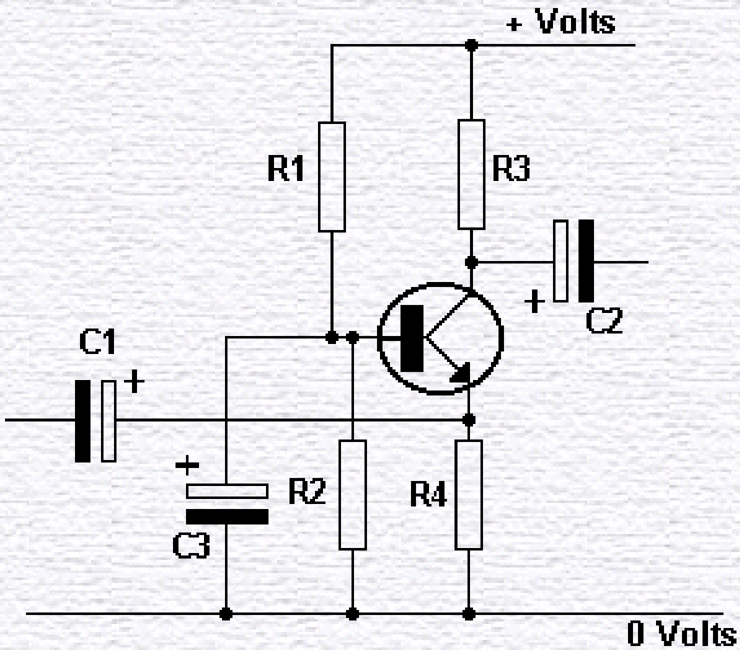

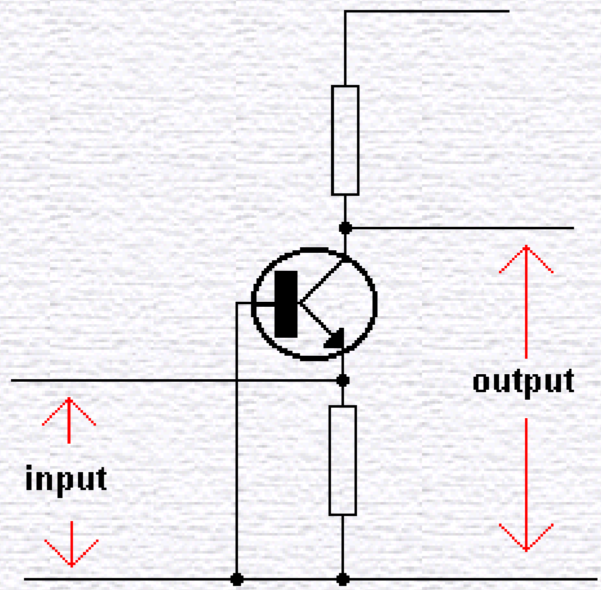

C3 connects the base to ground as far as ac is concerned.

Therefore both input and output are connected to the base. (common base amplifier).

Current gain is Ic/Ie which is less than 1.

The voltage gain is high since it is Rc/Re. (Approximately the same current flows through them). It is typically 250.

The input impedance is low, typically 20 ohms.

The output impedance is high, typically 1Megohm.

The output signal is not inverted with respect the input.

It is often used to match low impedance devices to high impedance ones.

It is commonly used at VHF.

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THE COMMON COLLECTOR AMPLIFIER

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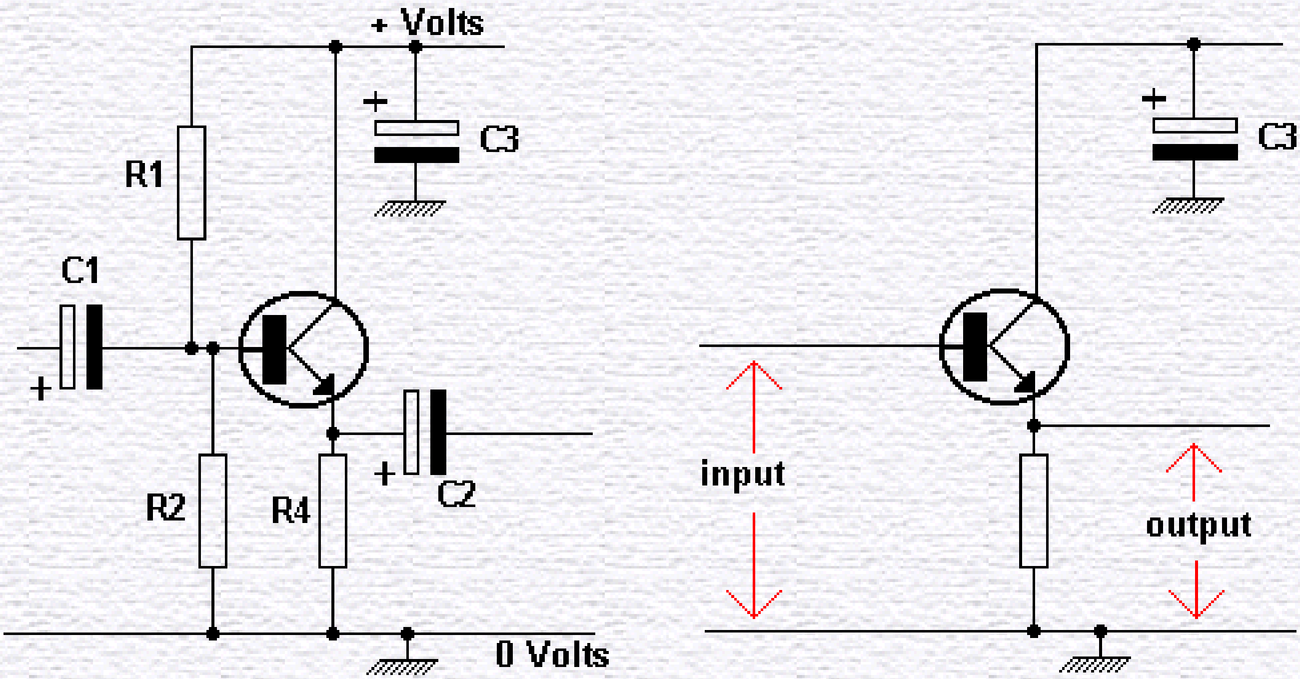

The positive power supply rail is joined to the zero volts rail by C3. As far as ac is concerned, both rails are joined together.

Therefore they, and the collector, are common to both input and output.

Since the emitter voltage follows the base voltage, it is also called the emitter follower.

Current gain is Ie/Ib which is quite high, typically 50.

Voltage gain is only 1 because of the undecoupled emitter.

The input impedance is high, typically 500k, requiring only low power to drive it.

The output impedance is low, typically 20 ohms.

The output signal follows the input. There is no inversion.

It is often used to match high impedances to low ones.

It can be used to drive several high impedance loads.

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THE PHASE SPLITTER

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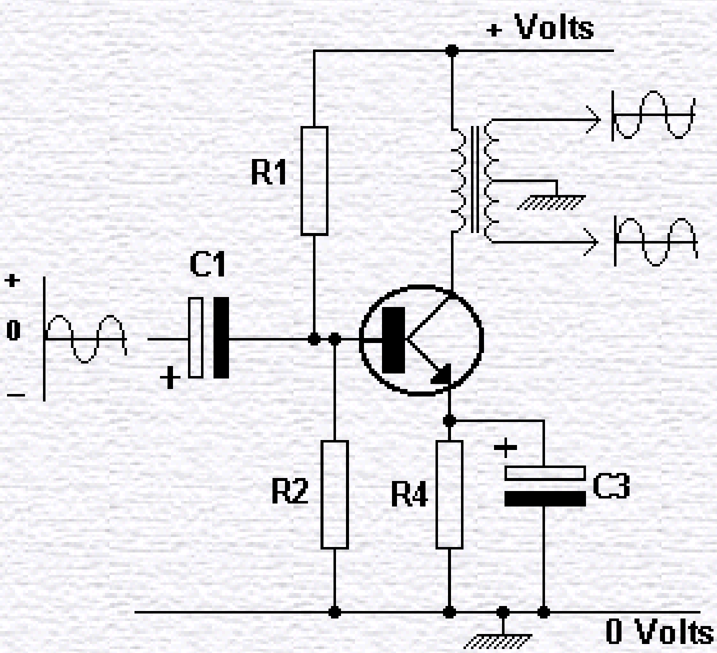

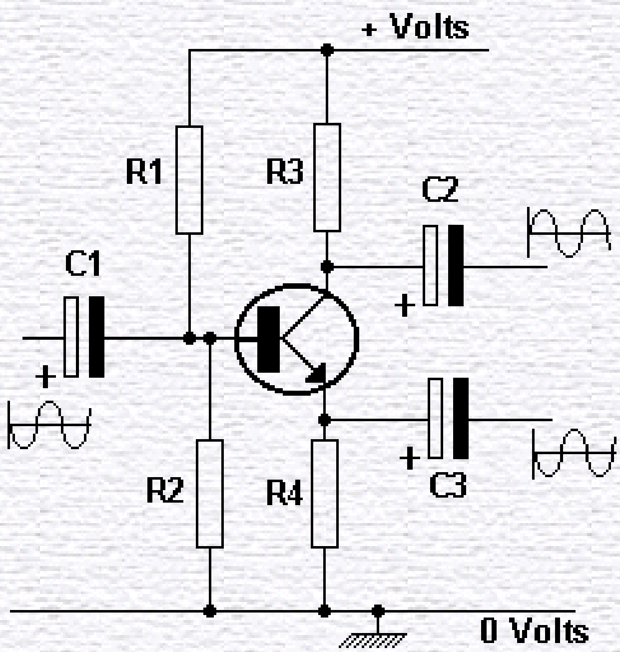

The phase splitter has one input and two outputs.
The two outputs are inverted with respect to each other. That is, as one increases in a positive direction the other increases in a negative direction.

In the first diagram the phase splitting is done by the transformer.

In the second diagram, the output from the collector is an inverted version of the input.
The output from the emitter follows the input.
There is no amplification from this circuit because the emitter is undecoupled.

The word PHASE indicates a shift in time. In actual fact there is no phase change here, only inversion of the signal.

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THE CLASS A POWER AMPLIFIER

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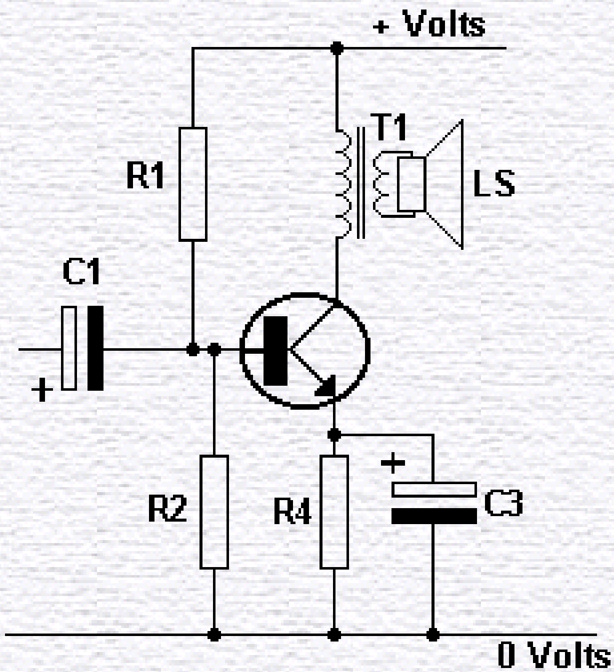

The transistor is biased in class A which means that collector current flows all the time..

The collector current can increase or decrease.

The input signal increases and decreases the forward bias causing the collector current to change.

These changes in current in the primary of the transformer induce signal currents in the secondary.

The transformer matches the output impedance of the transistor to the loudspeaker impedance.

The disadvantage of this circuit is that the collector current is high even if there is no signal input.
Class B push-pull is more efficient.

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THE PUSH PULL POWER AMPLIFIER

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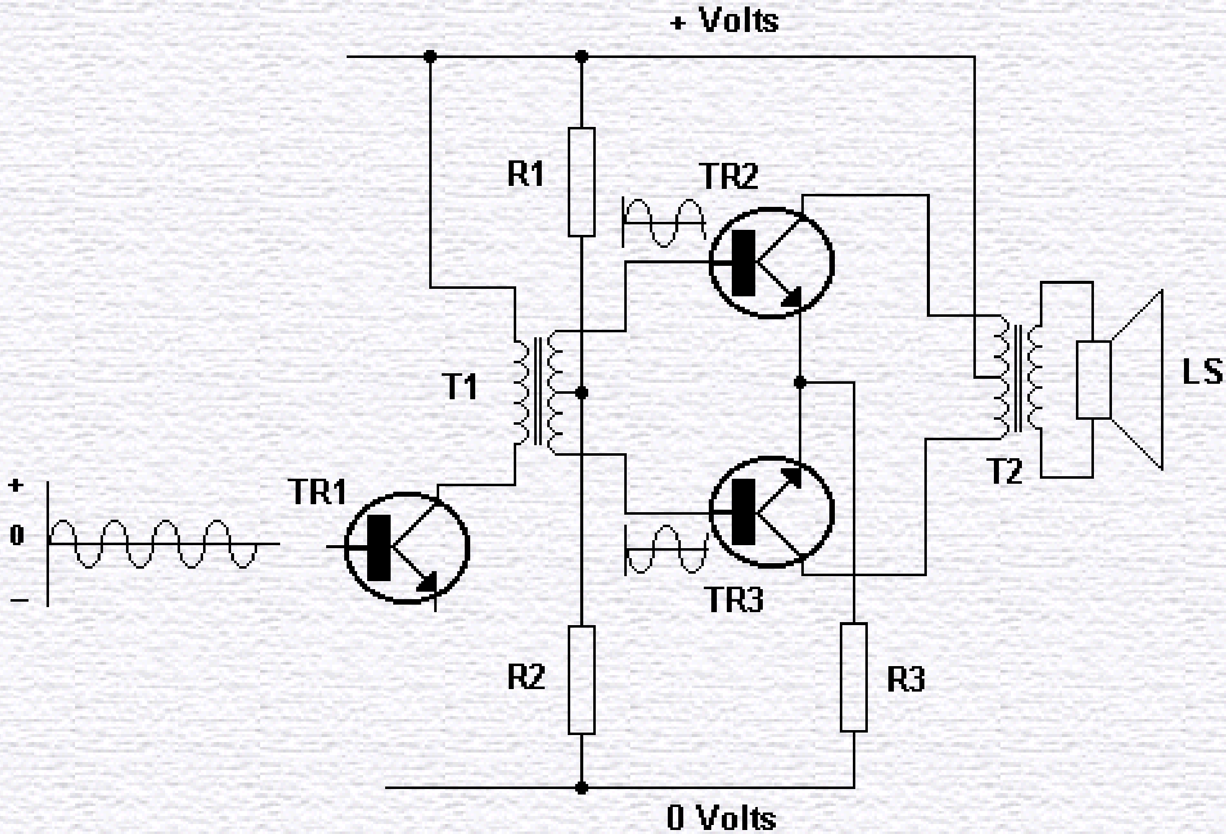

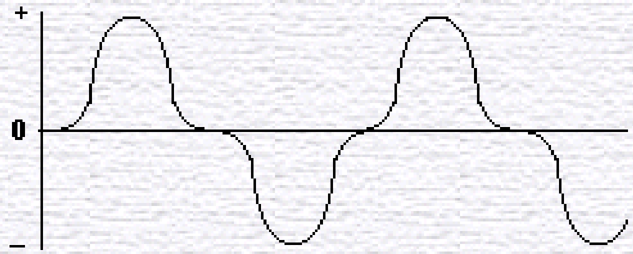

TR2 and TR3 are biased in class B, which means that they are normally non conducting when there is no signal input.

TR1 and T1 form a phase splitter, opposite polarity signals appearing at the ends of T1 secondary.

When there is a signal in ,TR2 conducts on the positive half of the waveform only and TR3 conducts on the negative half.

Current flows down through the top half of T2 primary when TR2 conducts, and up through the bottom half when TR3 conducts.

Both halves are combined in the secondary of T2 to produce an amplified version of the input.

R1 and R2 apply a small forward bias to avoid crossover distortion, which is shown in the lower waveform.

This distortion is caused by the non-linear characteristics of the emitter/base junction. (for more details see the junction diode Vb/Ib curves).

The advantage of this circuit is that there is very little current taken if there is no signal input.

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THE COMPLEMENTARY PUSH-PULL AMPLIFIER PART 1

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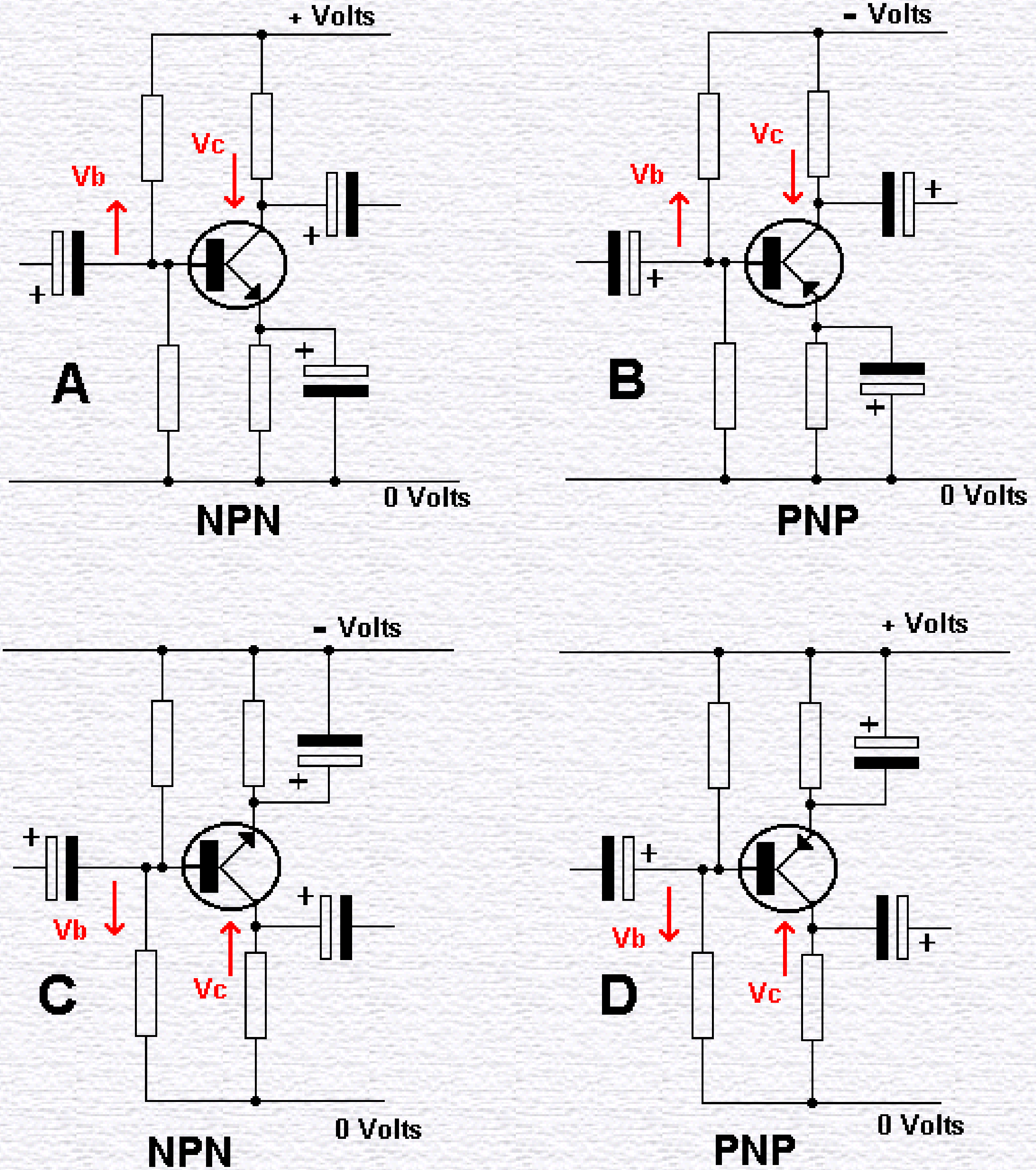

It is sometimes difficult to understand the behaviour of a circuit when the transistors are drawn upside down.

In diagram A,as the base voltage goes towards the + rail (goes more positive), the collector voltage goes away from the + rail (goes less positive).

In diagram B,as the base voltage goes towards the - rail (goes more negative), the collector voltage goes away from the - rail (goes less negative).

In diagram C,as the base voltage goes away from - rail (goes more positive), the collector voltage goes towards the - rail (goes less positive).

In diagram D,as the base voltage goes away from + rail (goes more negative), the collector voltage goes towards the + rail (goes less negative).

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THE COMPLEMENTARY PUSH PULL AMPLIFIER PART 2

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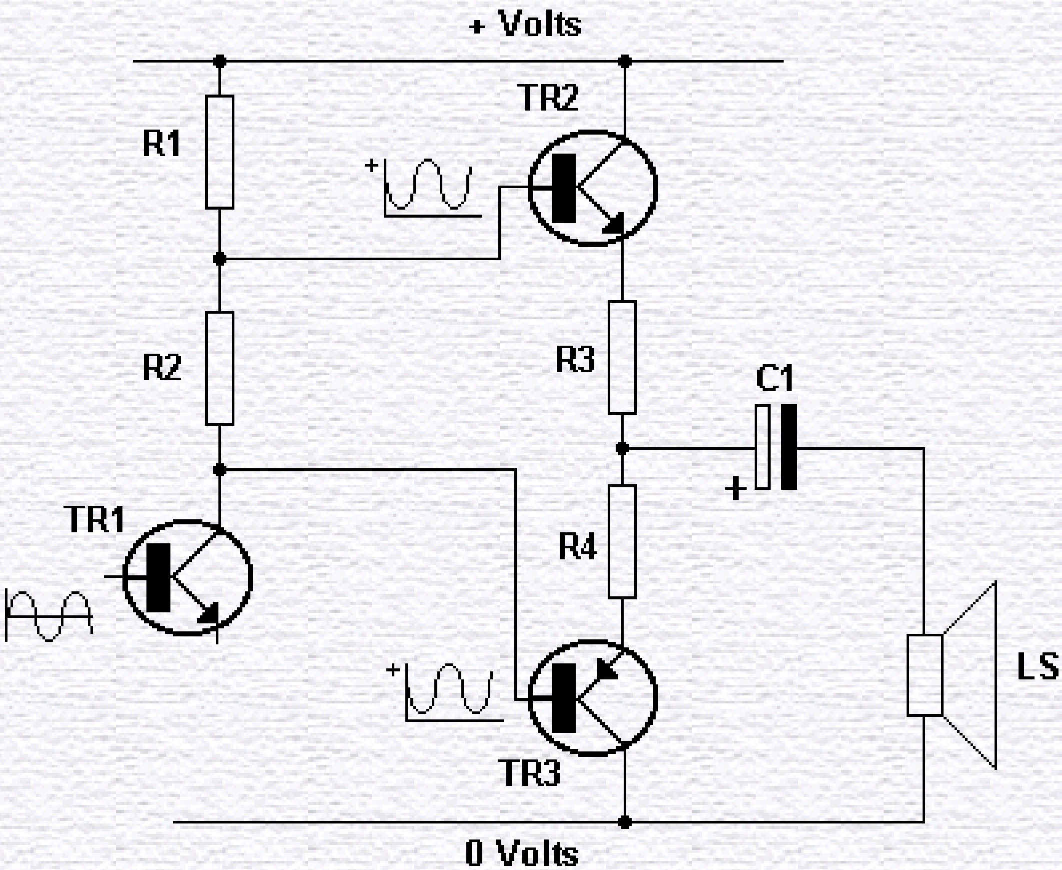

TR2 and TR3 are complementary. They have the same characteristics but one is NPN and the other PNP.

The NPN has + on its collector and less positive on its emitter.

The PNP Has + on its emitter and zero on its collector.

Therefore both have correct polarity voltages.

The voltage at the junction of R3 and R4 is half the supply voltage.

If R2 is replaced by a wire link, and R1 selected to give half the supply volts at TR1 and TR2 bases then they would both be biased in class B, and both would be non conducting.

Look at the waveforms on the bases of the output pair.

During the first half cycle the signal is going less positive.
This is reversing biasing the NPN transistor and increasing forward bias on the PNP transistor.
This means that the NPN remains cut off and the PNP conducts during this first half cycle.

In the next half cycle the signal on the bases is now increasing in a more positive direction.
During this half cycle the NPN conducts while the PNP is cutoff.

So the NPN is off and the PNP is on during the first half cycle, and current flows through the loudspeaker as C1 charges.

The NPN is on and the PNP off during the second half cycle, and current flows the other way through the loudspeaker, as C1 discharges.

R2 is added to give a small forward bias to both transistors thereby avoiding crossover distortion. (see the page on push-pull power amplifiers).

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THE DIRECTLY COUPLED AMPLIFIER

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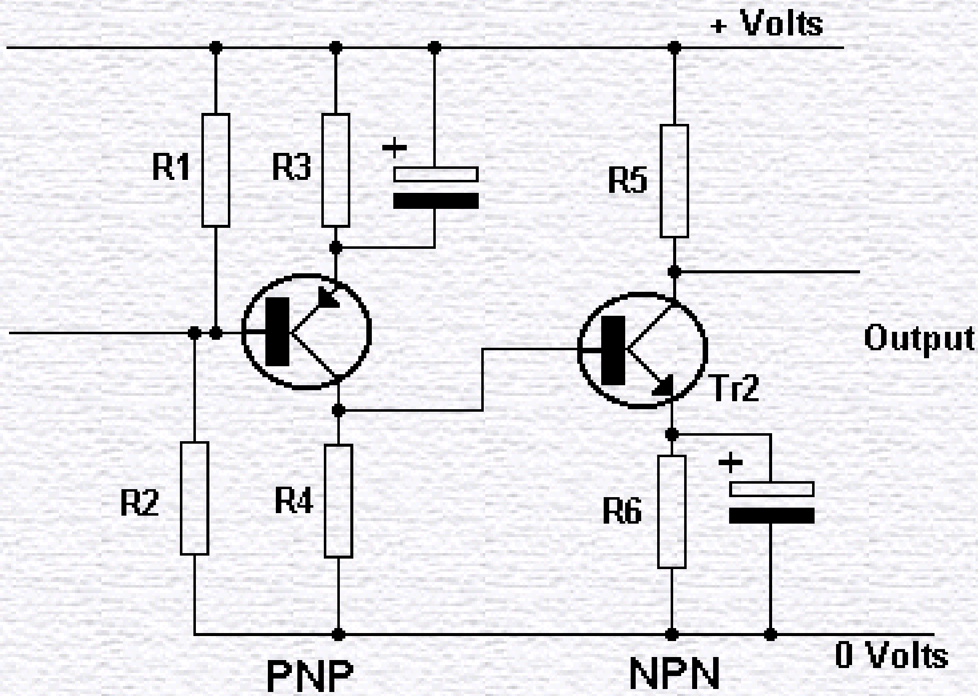

The PNP transistor is upside down with respect the NPN transistor and thus has the correct operating voltages.

If the circuit is designed so that the PNP collector voltage is a suitable value for the NPN transistor base, then there is no need for bias resistors for the NPN transistor.

The circuit will amplify dc signals as well as ac ones. This is because there is no coupling capacitor to block dc.
It will also amplify very low ac frequencies because there is no capacitive reactance to oppose them.

However, if temperature changes cause dc drift in the first transistor, then these will be amplified by the second transistor and change its normal operating voltages.
This is usually prevented by some form of dc stabilisation.

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THE DARLINGTON PAIR

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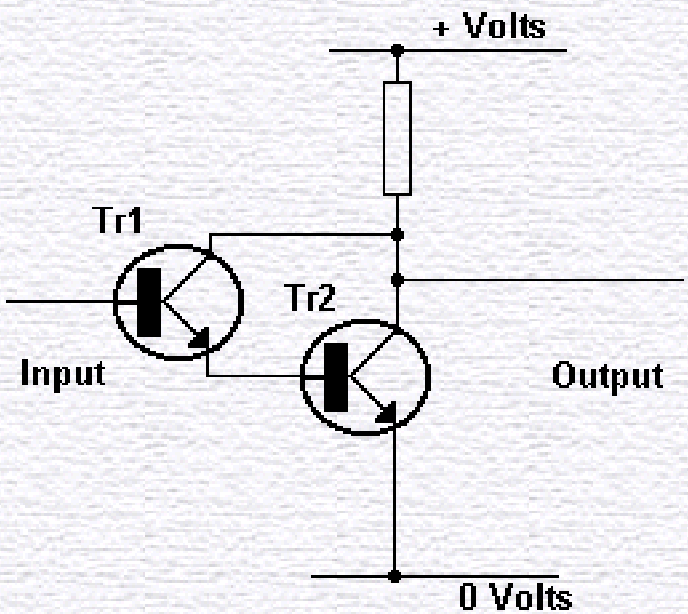

The emitter current of Tr1 is the base current of Tr2.

A change in base current of Tr1 can give a change 100 times larger in its emitter current.
A change in the base current of Tr2 has a similar effect on its emitter current.

Therefore there is an overall amplification of 100 x 100 = 10000 times.

This circuit is sometimes called the Super Alpha Pair.

It is often used as a power output stage.

The two transistors can come in the same package.

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BASE BIAS RESISTOR 1 OPEN CIRCUIT

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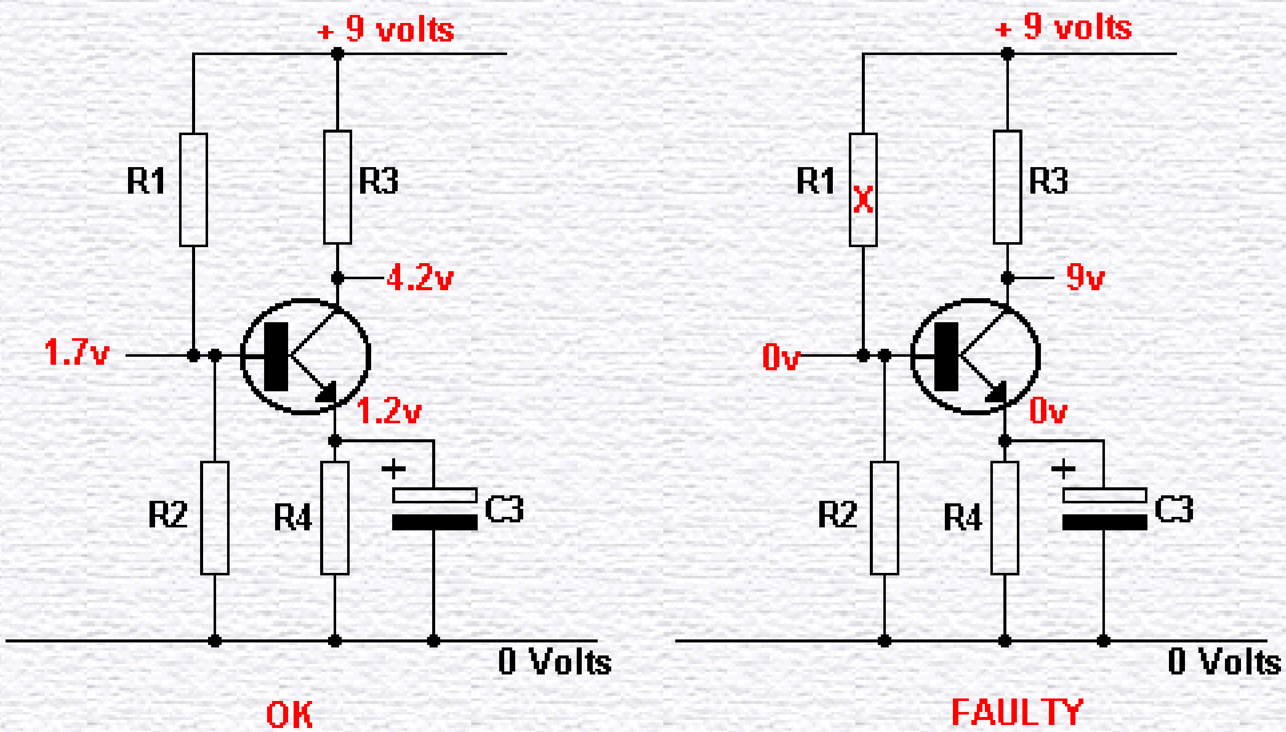

All voltages are measured with respect to the zero volts rail.

With R1 o/c there is no voltage on the base, no base bias and no base current.

The transistor is OFF and there is no collector current and no voltage drop across R3.
The collector voltage will be the same as the supply volts, +9.

There is no current through R4, so there is no voltage drop across it.
The voltage at both ends is the same, zero volts.

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BASE BIAS RESISTOR 2 OPEN CIRCUIT

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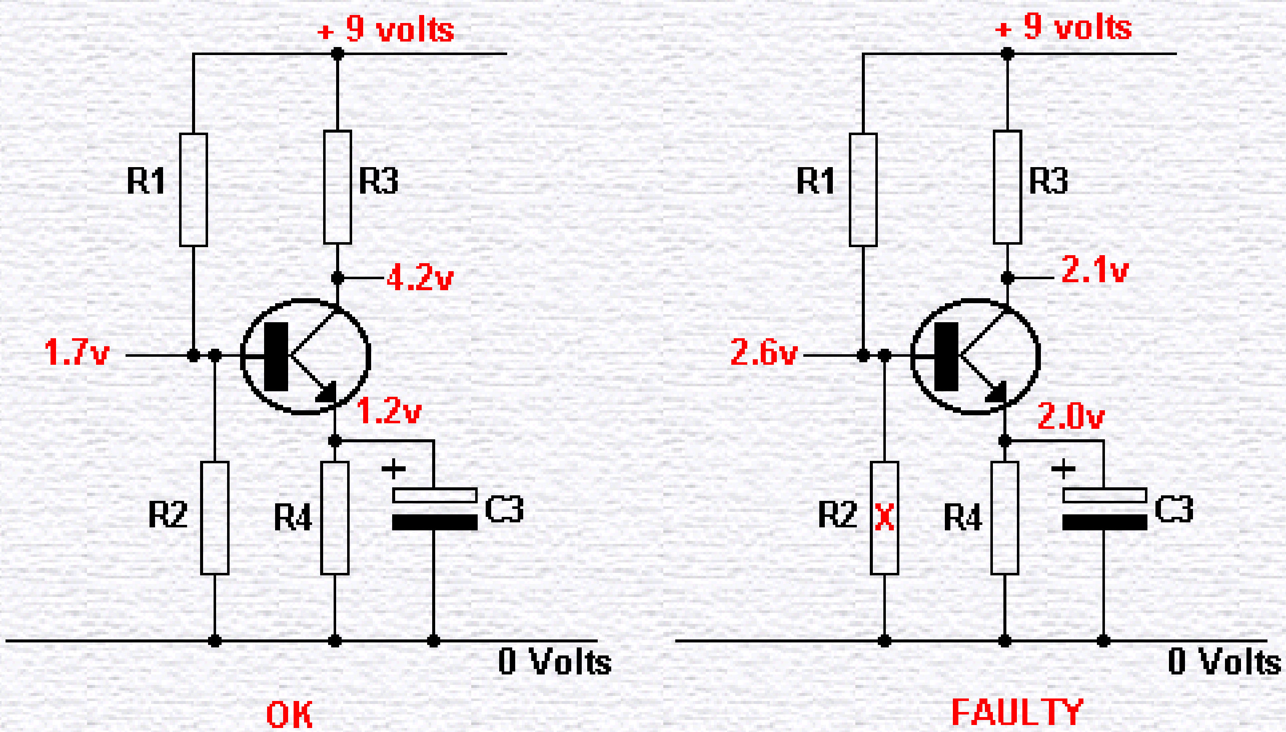

All voltages are measured with respect to the zero volts rail.

There is no potential divider action and the full +9 volts is applied to the base by R1.

This causes a high base current to flow, which in turn causes a high collector current to flow.

There is a large volts drop across R3, causing a low collector volts.

There is a large volts drop across R4, causing the emitter volts to rise.

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COLLECTOR LOAD RESISTOR OPEN CIRCUIT

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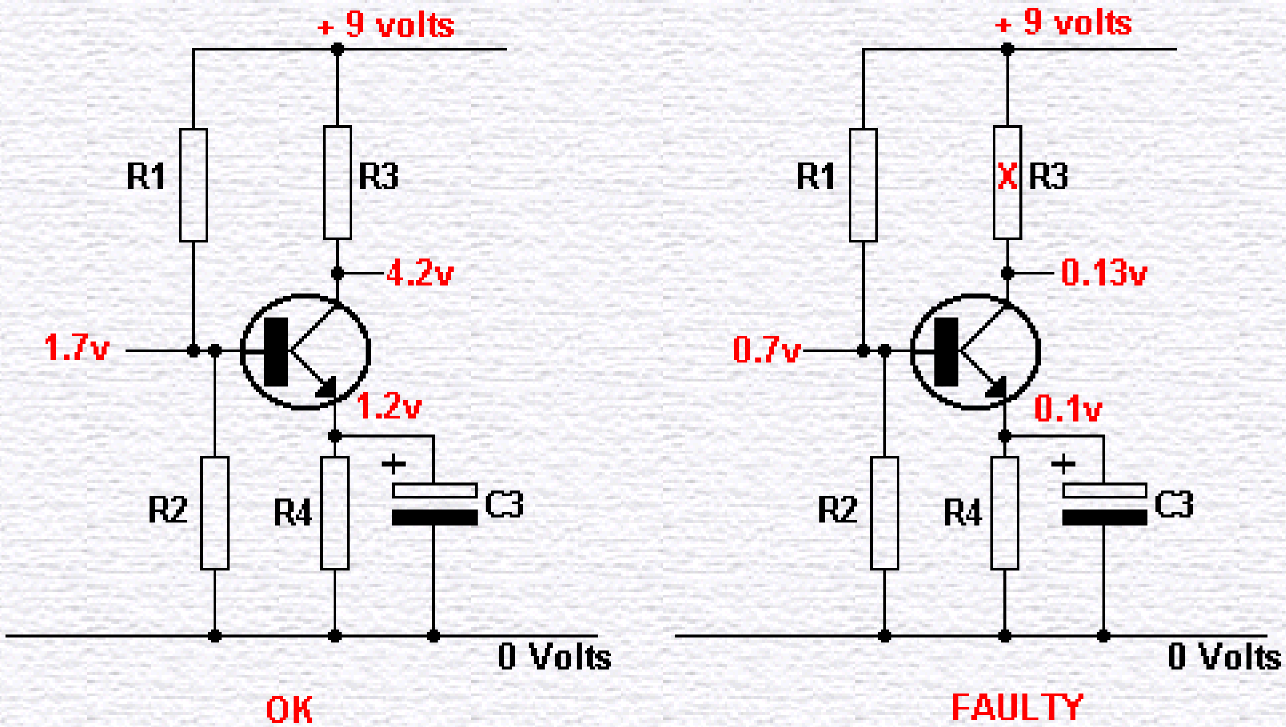

All voltages are measured with respect to the zero volts rail.

The base is still forward biased, so base current flows.

The base current will be higher than normal, because all the emitter current goes to the base and none to the collector.

Since there is more current through R1, there will be a higher voltage drop across it, and the base voltage will be lower.

Since the emitter voltage is always about 0.6 volts lower than the base, it will read 0.1 volts.

We would expect the collector voltage to read zero, but we are actually reading the base voltage via the base/collector junction and it will read about 0.6 volts lower than the base.

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EMITTER RESISTOR OPEN CIRCUIT

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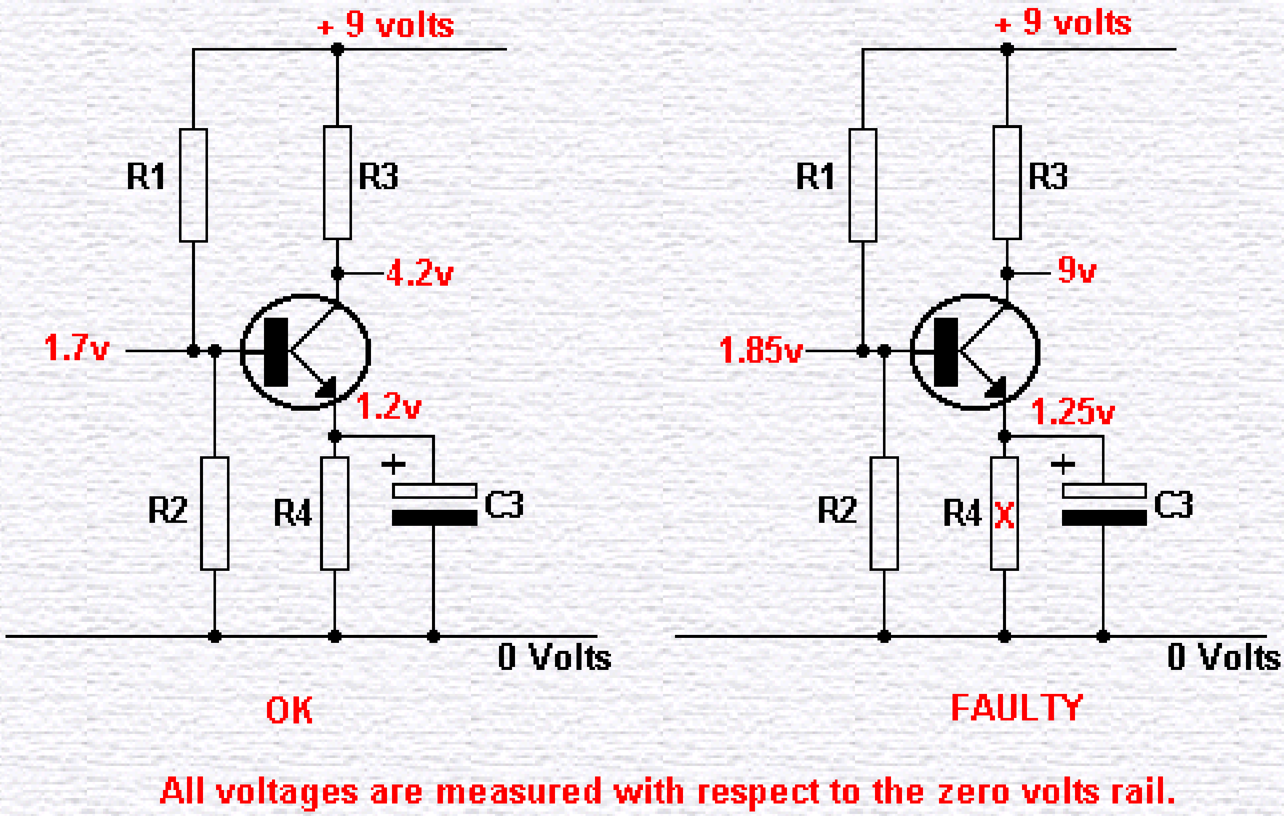

There can be no base or collector current.

Since the current through R1 is less than normal, there will be a lower voltage drop across it and the base voltage will be higher than normal.

Since there is no current through R3 there will be no voltage dropped across it.
The voltage will be the same at both ends, and the collector will be at the supply voltage.

We would expect there to be no voltage across R4, but the meter connects the emitter to zero volts and some current flows through the meter.
The voltage indicated would depend upon the type of meter.

EMITTER CAPACITOR SHORT CIRCUIT

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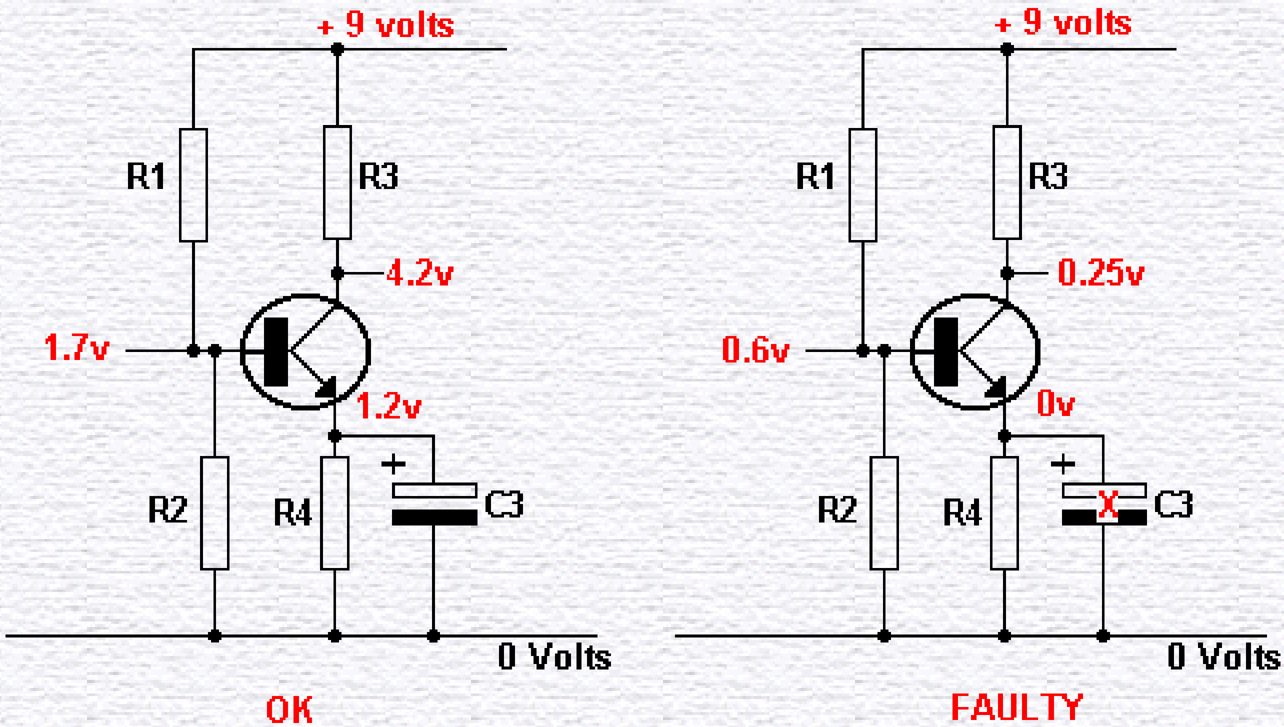

All voltages are measured with respect to the zero volts rail.

The emitter is connected to zero volts and there is an increased emitter/base forward bias.

Base and collector currents increase.

There is more current through R1, a higher voltage drop across it, and a lower base voltage.

Since the collector current is higher there will be a larger voltage drop across R3.
The collector voltage will be lower than normal.

The emitter voltage will of course be zero.

If the capacitor goes open circuit, the dc voltages will remain at their normal values.
However, the gain will be much reduced.

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THE JUNCTION FIELD EFFECT TRANSISTOR

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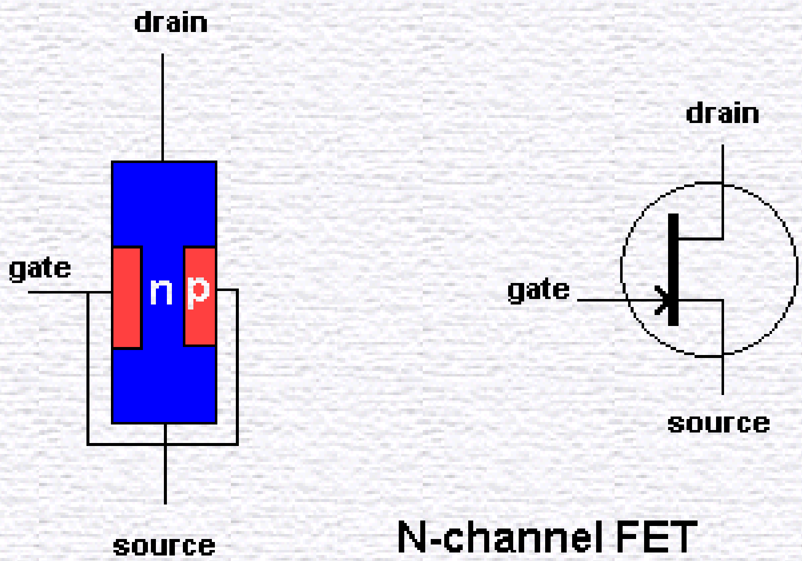

The field effect transistor (FET) is made of a bar of N type material called the SUBSTRATE with a P type junction (the gate) diffused into it..

With a positive voltage on the drain, with respect to the source, electron current flows from source to drain through the CHANNEL.

If the gate is made negative with respect to the source, an electrostatic field is created, which squeezes the channel and reduces the current.
If the gate voltage is high enough the channel will be "pinched off" and the current will be zero.

The fet is voltage controlled, unlike the transistor which is current controlled.

This device is sometimes called the junction fet or jugfet or jfet.

If the fet is accidently forward biased, gate current will flow and the fet will be destroyed.

To avoid this, an extremely thin insulating layer of silicon oxide is placed between the gate and the channel.
The device is then known as an insulated gate fet, or igfet or metal oxide semiconductor fet (mosfet)

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THE FET AMPLIFIER

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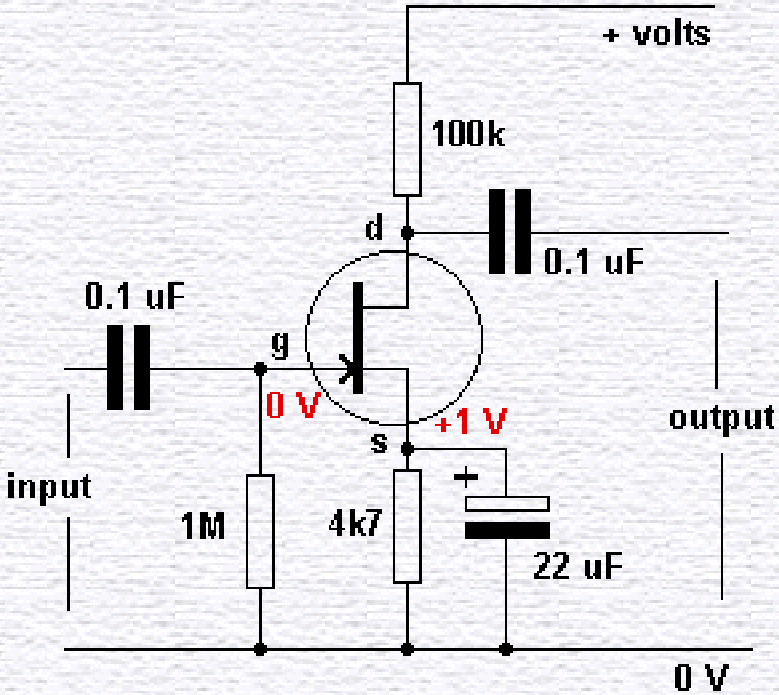

To correctly bias the fet, the gate needs to be negative with respect to the source.
Bias is obtained in the following manner.

Drain current flows through the source resistor and develops a voltage across it, making the emitter positive with respect the zero volts rail.
There is no gate current, so there is no current through the gate resistor.
This means that there is no voltage across this resistor, so it will be zero volts at both ends.
This means that there is zero volts on the gate .
Therefore the source is positive with respect to the gate.
The gate is negative with respect to the source.
The fet is biased correctly.

When a signal voltage is applied to the gate, it controls the drain current.

When the signal goes more negative (less positive) the drain

current is reduced and the voltage across the drain resistor is less.
The drain voltage goes more positive.

When the signal goes less negative (more positive) the drain current is increased and the voltage across the drain resistor is more.
The drain voltage goes less positive.

In both cases the drain voltage does the opposite of the gate voltage.

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THE METAL OXIDE SEMICONDUCTOR FET (MOSFET)

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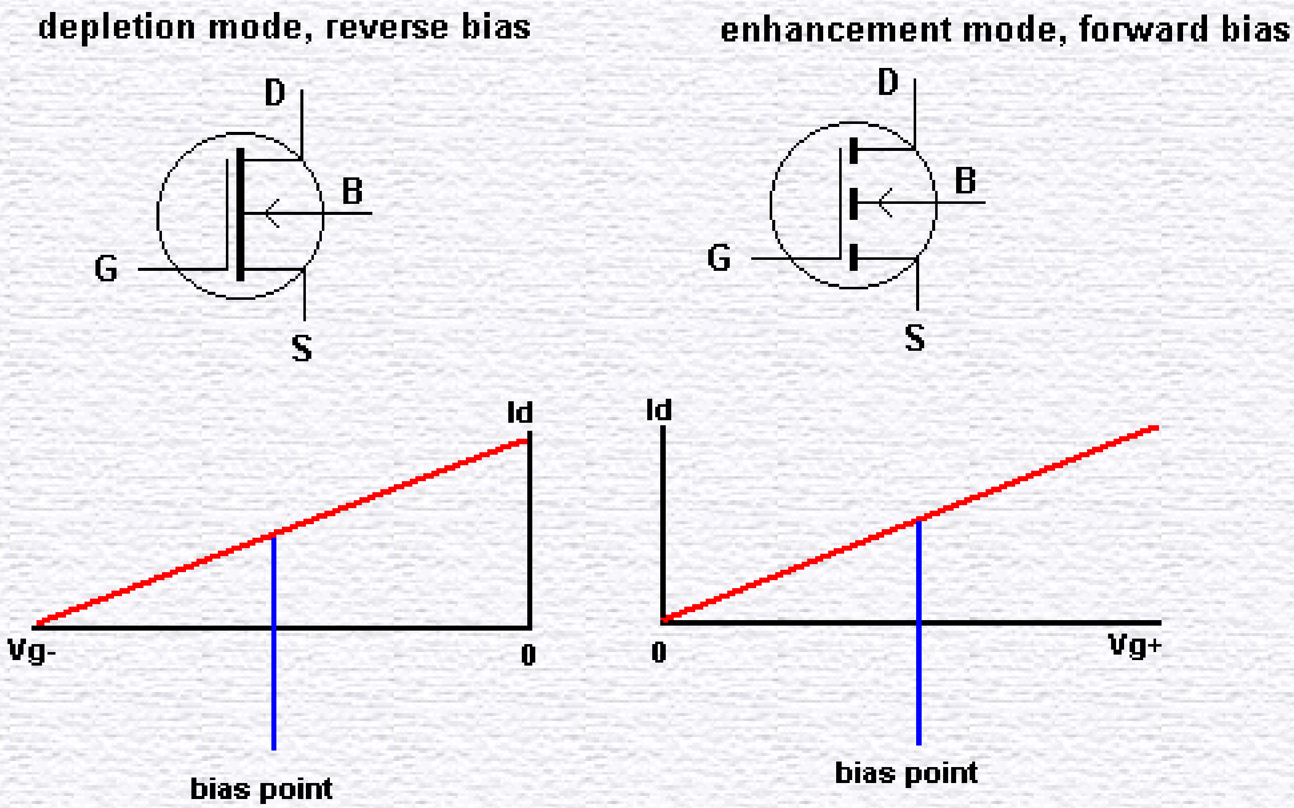

The mosfet has the gate insulated from the substrate by a thin layer of silicon oxide, to prevent gate current flowing and damaging the device (see the page on fets).

There are two main families.

Enhancement - where the mosfet has to be forward biased like a transistor.

Depletion - where the mosfet is reverse biased like a thermionic valve (tube in the USA).

Some mosfets have two gates (dual gate mosfets) and are commonly used as r.f. mixers.

The insulating layer is extremely thin and can be easily damaged by static.

Antistatic precautions must be taken when handling them.
Soldering iron tips must be earthed.
The operator must be grounded via a high value resistor, with wriststraps etc.
The workplace must be grounded safely.
Components must be handled with care.
I usually touch some earthed point just before handling static sensitive devices.

Some devices have Zener diodes built in, between gate and source, for protection.

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MOSFET CIRCUIT SYMBOLS

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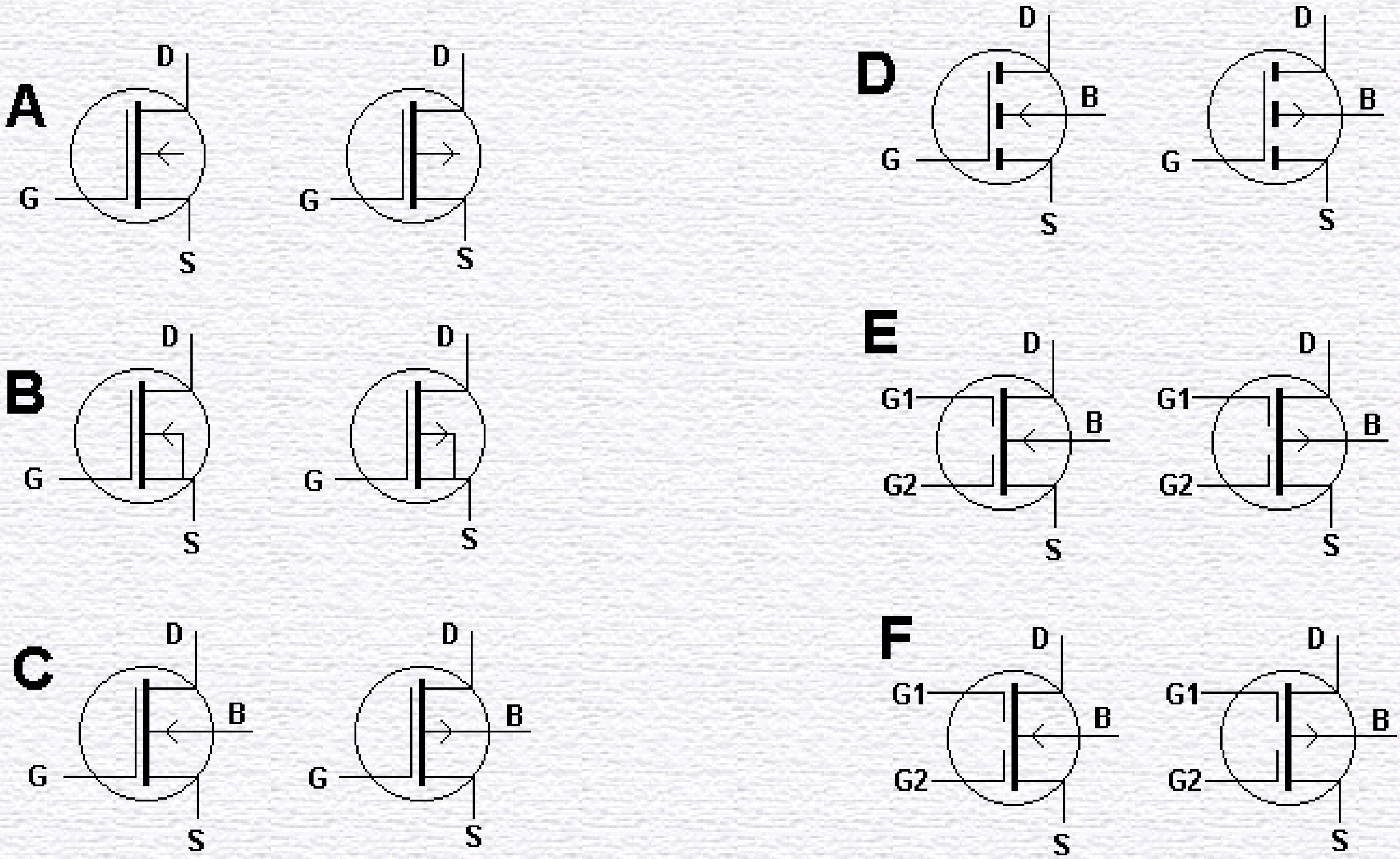
The thick line represents the channel and if it is unbroken represents a depletion (normally conducting) type.
If the channel is shown broken it is a normally enhancement (non conducting) type.



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THE OPERATIONAL AMPLIFIER

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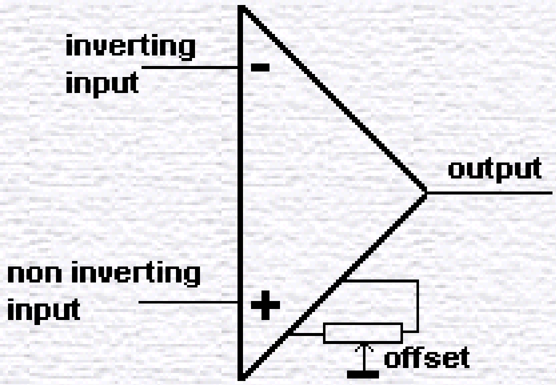

The opamp was originally designed to carry out mathematical operations in analogue computers, such as bombsights, but was soon recognised as having many other applications.

The opamp usually comes in the form of an 8 pin integrated circuit, the most common one being the type 741.

It has two inputs and one output.
The input marked with a - sign produces an amplified inverted output.
The input marked with a + sign produces an amplified but non inverted output.

The opamp requires positive and negative power supplies, together with a common ground.
Some circuits can be designed to work from a single supply.

If the two inputs are joined together, then the output voltage should be midway between the two supply rails, i.e. zero volts.
If it is not, then there are two connections for adding a potentiometer, to remove this OFFSET.

OPAMP CHARACTARISTICS

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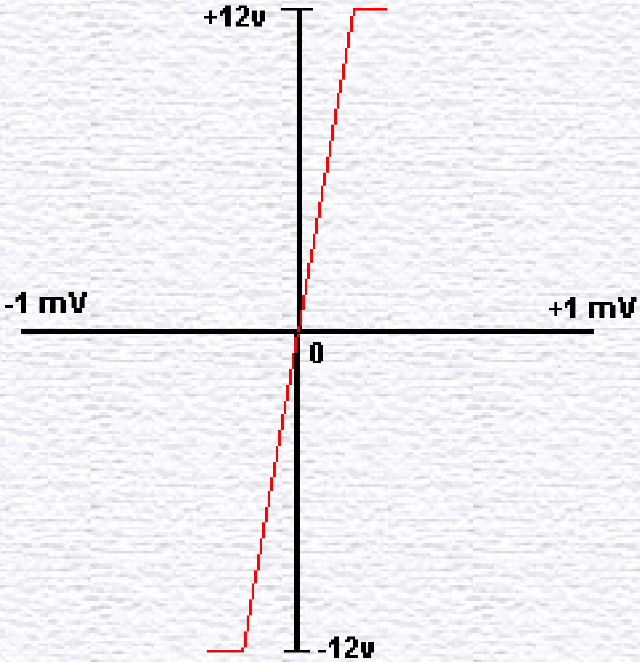


The opamp has a very high gain, typically (100 dB)100,000 times.

Looking at the left hand diagram, an input with a swing of a fraction of a millivolt produces an output that changes between + 12 volts and - 12 volts.

In most cases this gain is excessive, and is reduced by negative feed back.

Looking at the right hand diagram we can see that the opamp amplifies right down to dc.

Gain falls quite rapidly as the frequency increases.

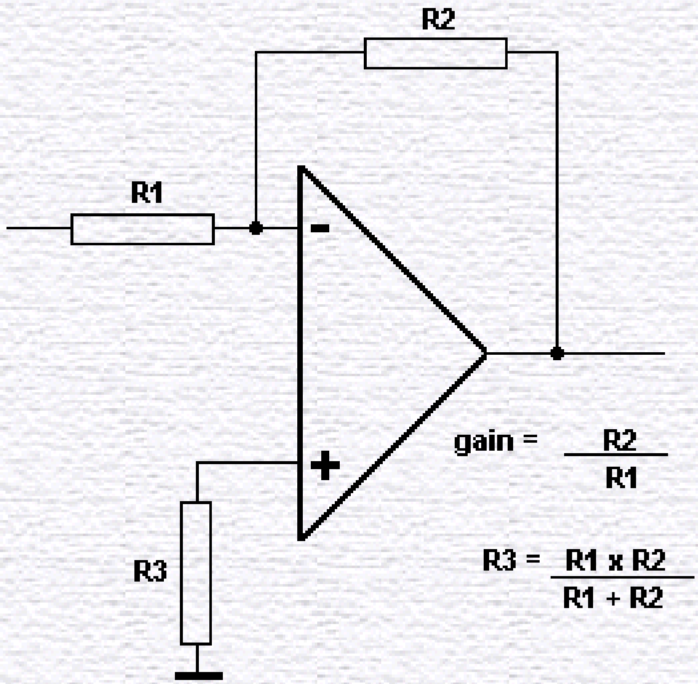
In fact the bandwidth (the point at which the output has fallen by 3 dB) is only 1 kHz.

This is also improved upon by the use of negative feedback.

The input impedance is high, 1M.

The output impedance is low, 150 ohms.

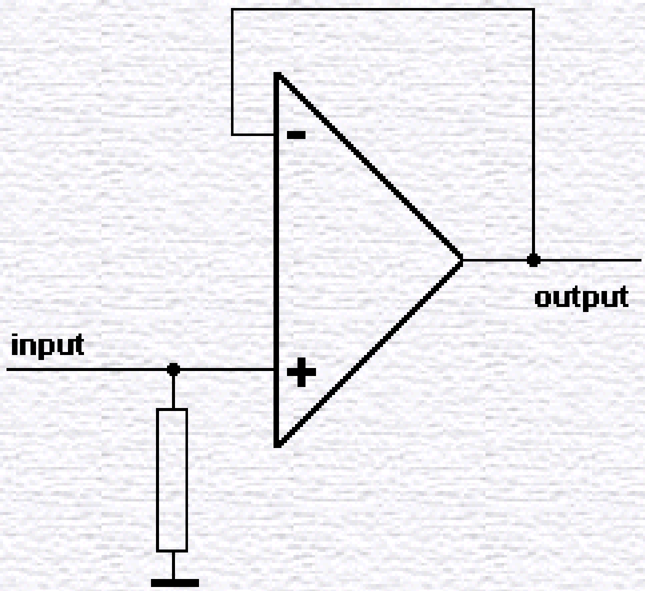
SETTING OPAMP GAIN



The gain of the inverting amplifier is determined by the feedback resistor R2, and the input resistor R1.

To minimise temperature drift, R3 is given the value of R1 and R2 in parallel.

OPAMP AS VOLTAGE FOLLOWER



This non inverting amplifier has unity gain i.e. x1.
It is called a VOLTAGE FOLLOWER.
It serves the same purpose as the emitter follower.
It has a high input impedance and a very low ouput impedance.
It can be used for impedance matching.
It is able to drive several loads.

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SETTING GAIN OF NON INVERTING OPAMP

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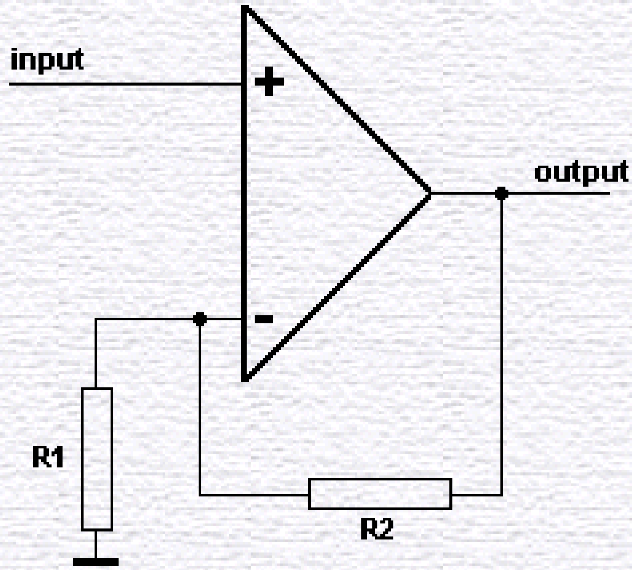

Gain is 1+ R2/R1

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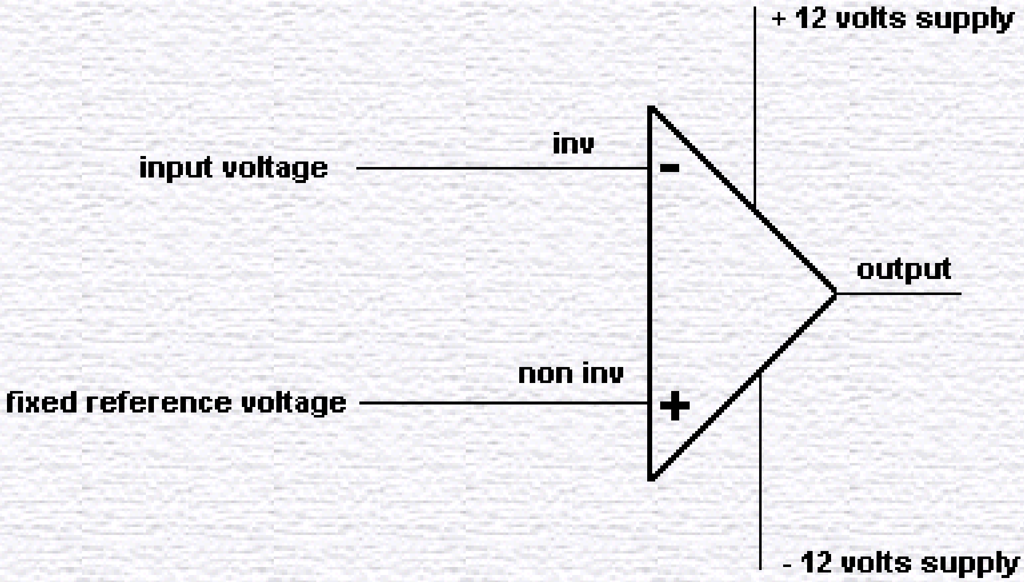
THE OPAMP AS A COMPARATOR



A varying input voltage is compared with a fixed reference voltage.

If the input voltage is higher than the reference voltage, then the output is negative.

If the input voltage is lower than the reference, then the output is positive.

The gain can be set by negative feedback.

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THE OPAMP AS A TEMPERATURE ALARM

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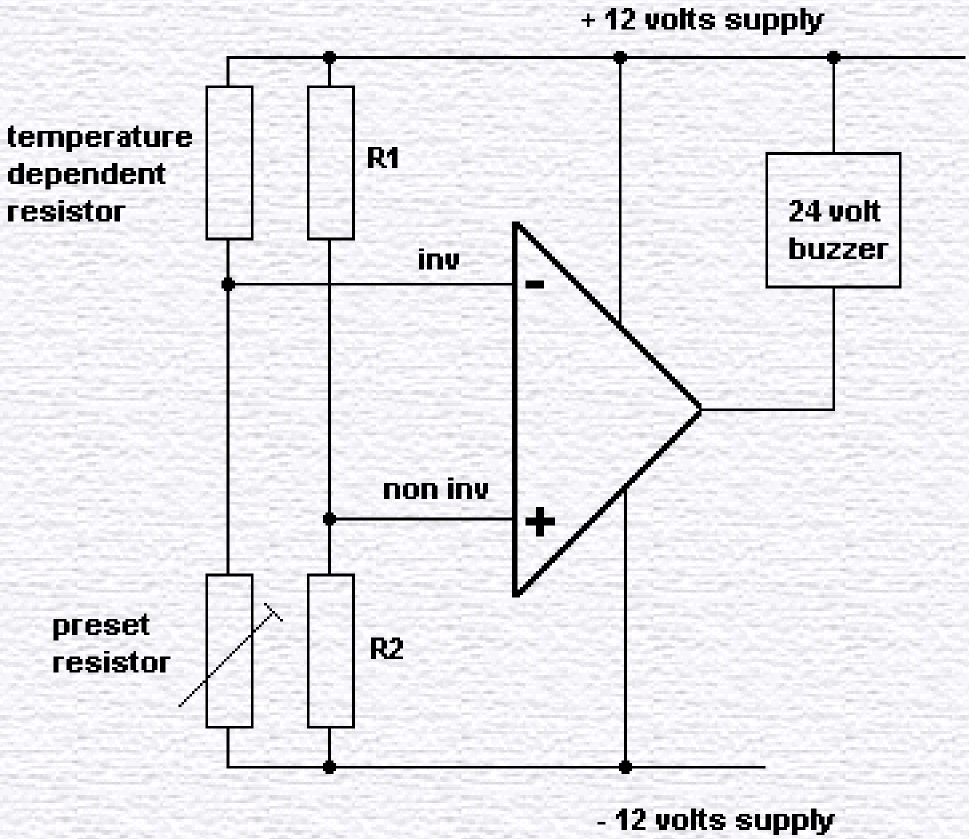

This circuit is configured as a comparator.

R1 and R2 provide a fixed reference voltage at the non inverting input.

The inverting input voltage is set by the other two resistors.

If the voltage at the inverting input rises above the reference voltage, then the the output goes to minus 12 volts and the buzzer is energised.

The behaviour of the circuit can be changed by swapping the preset and temperature dependent resistors.

Light dependent resistors etc can replace the temperature dependent one.

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THE OPAMP AS A TIMER

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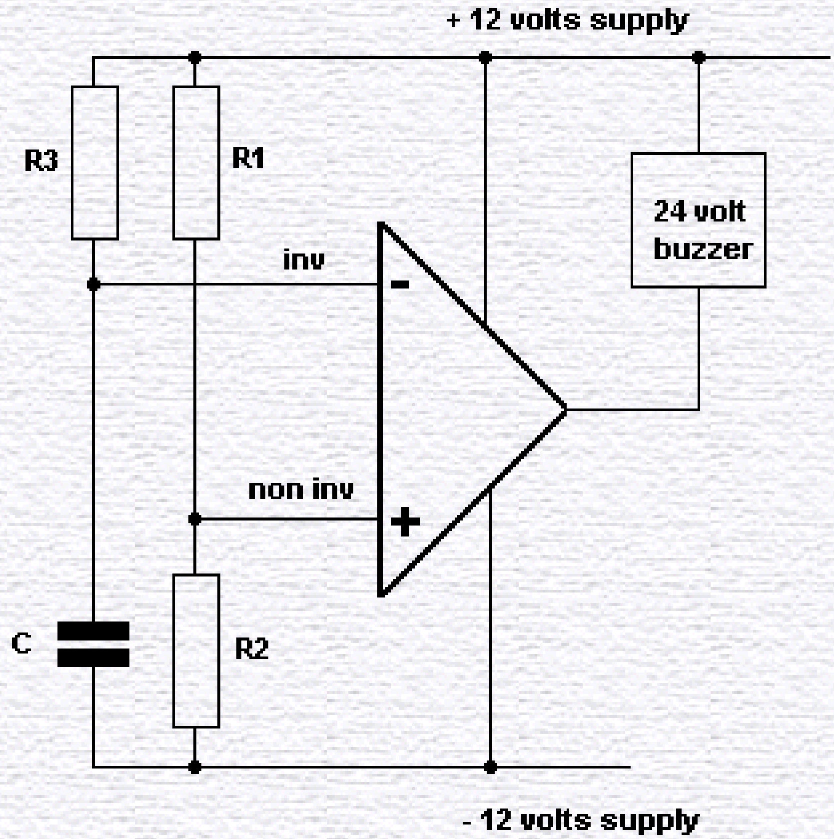

At switch on, the voltage across the capacitor is zero and the output is at +12 volts.
The buzzer is not energised.

After a time, determined by the values of C and R3, the voltage of the inverting input rises above that of the non inverting input.

The output goes to minus 12 volts and the buzzer is energised.

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THE OPAMP AS AN AUDIO MIXER

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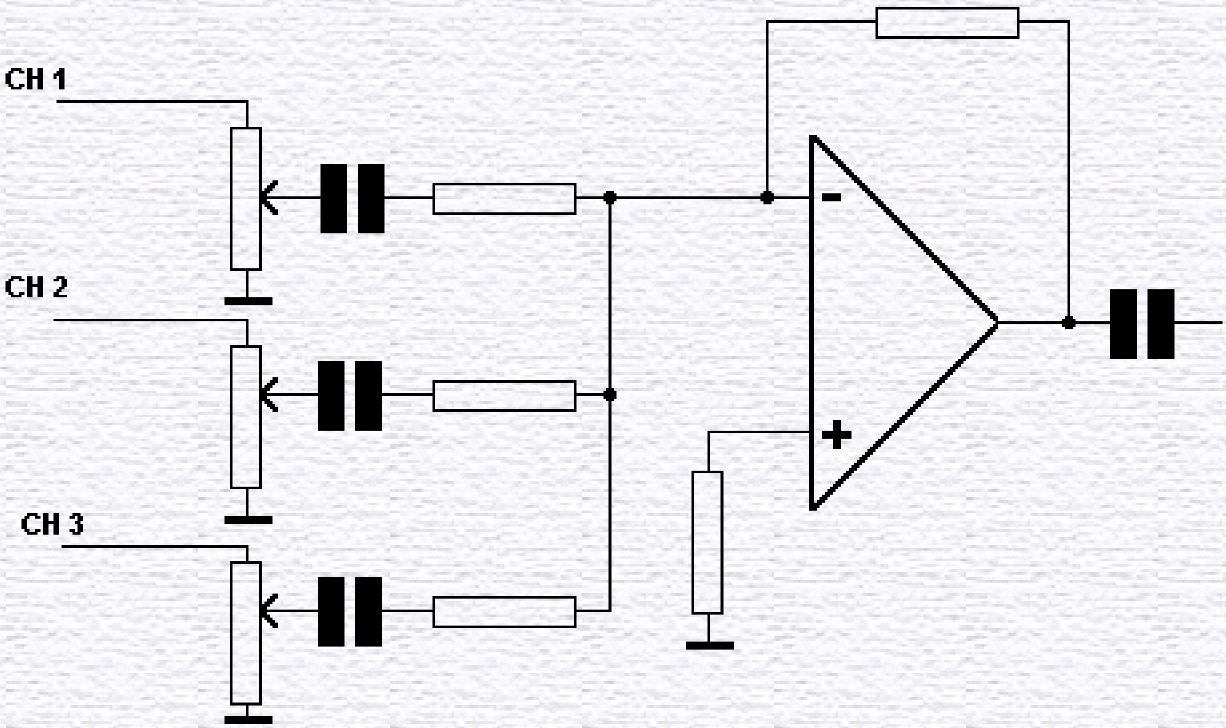

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OPAMP DUAL POWER SUPPLIES

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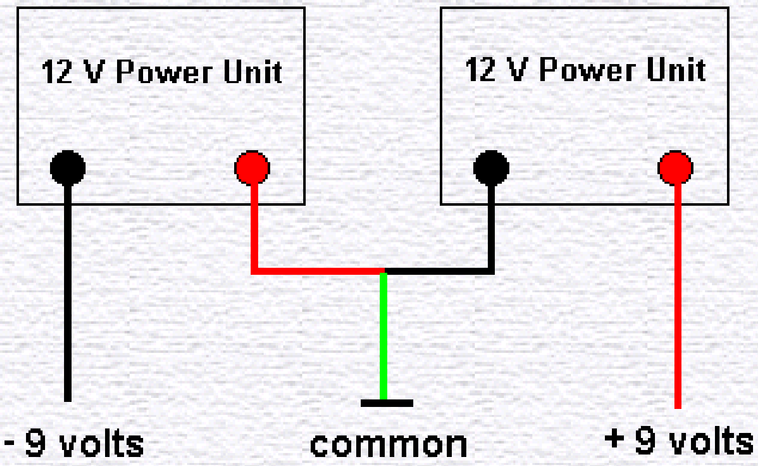
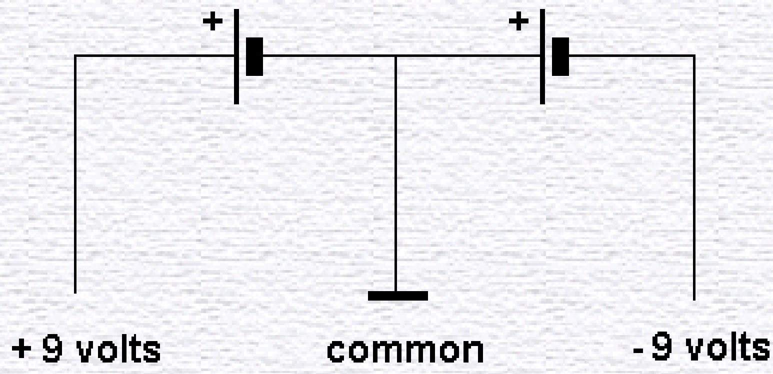
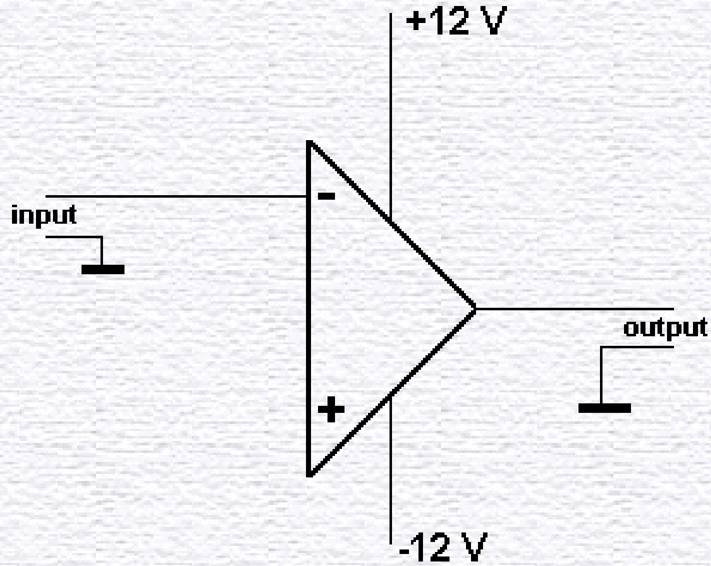




Most opamp circuits require two differing polarity voltages.

The upper diagram shows how the two supplies are connected together.

The bottom diagram shows how the common lead of the power supplies is connected to the input and output (and the common connection of any other associated circuitry).



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THE THYRISTOR

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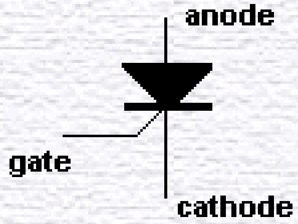

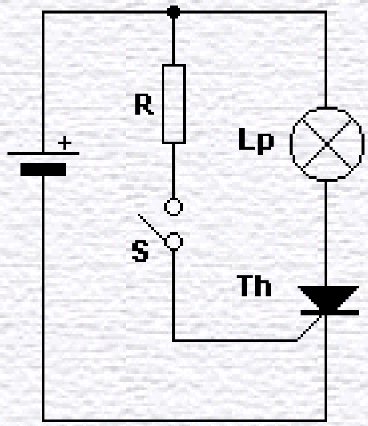

The thyristor is also known as the silicon controlled rectifier (S.C.R.).

It has the same charactaristics as the diode, current flowing from cathode to anode, when the anode is positive with respect to the cathode.
However, it will only do this when the gate is also positive with respect to the cathode.

In the circuit, with the switch open as shown, no current flows.

When the switch is closed, the diode begins to conduct and current flows from cathode to anode.

There is a problem.
If the switch is now opened, current continues to flow.

Conduction can be stopped by removing the the cathode/anode voltage.

Another method of stopping current flow is to reverse the polarity of the cathode/anode voltage.

If the thyristor is used with an ac supply then it will conduct on the positive half cycles and automatically switch off during the negative half cycles.

The resistor in series with the gate connection limits the gate current to a safe value.

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BURST TRIGGERING THE THYRISTOR

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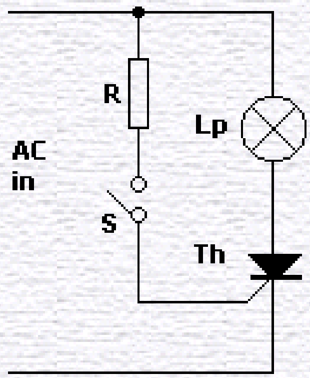

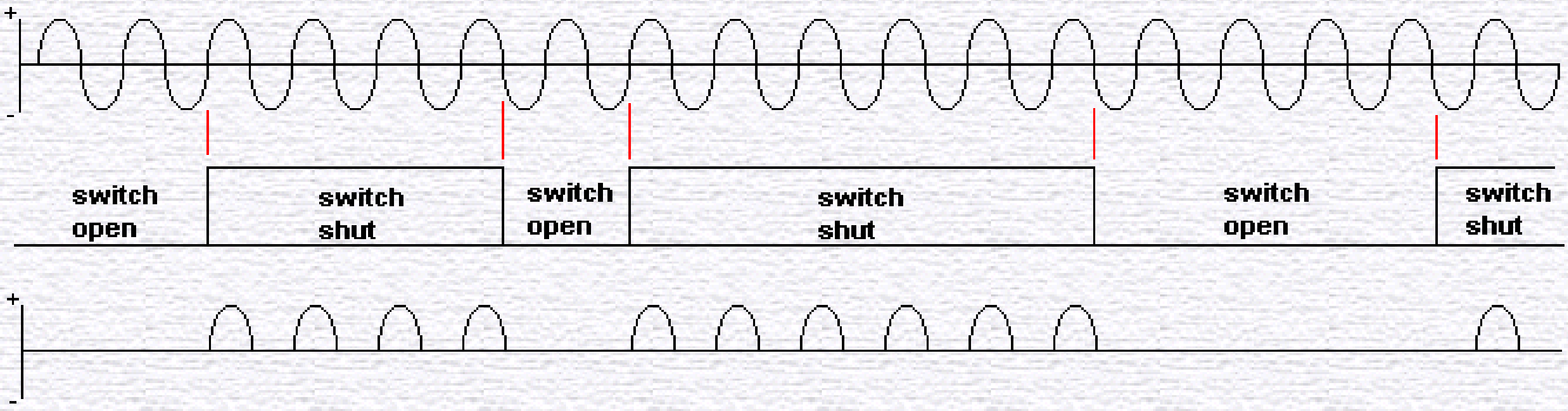

The top waveform shows the ac supply.

The middle waveform shows the switch operation.

When the switch is closed, the gate and anode go positive on the first positive half cycle, and the thyristor conducts during this period.

On the next half cycle they go negative and no current flows.

As long as the switch is closed, the thyristor conducts on the positive half cycles only.

When the switch is opened,the thyristor ceases to conduct on the next negative half cycle, and remains non conducting.

The bottom waveform shows the current through the thyristor and lamp.

The current comes in BURSTS.

If the lamp is replaced by a heater, and the switch replaced by a thermostat then it would provide automatic temperature control for an oven.

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THE THYRISTOR WITH PHASE CONTROL

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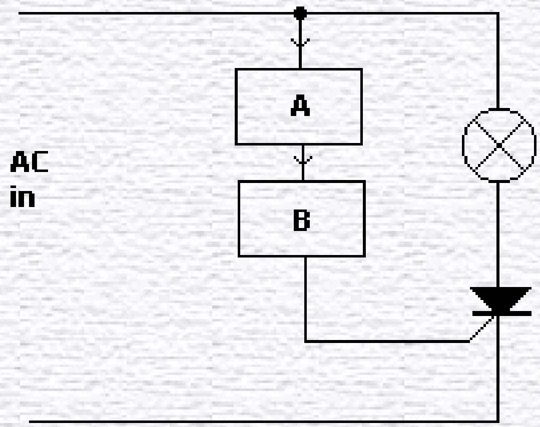

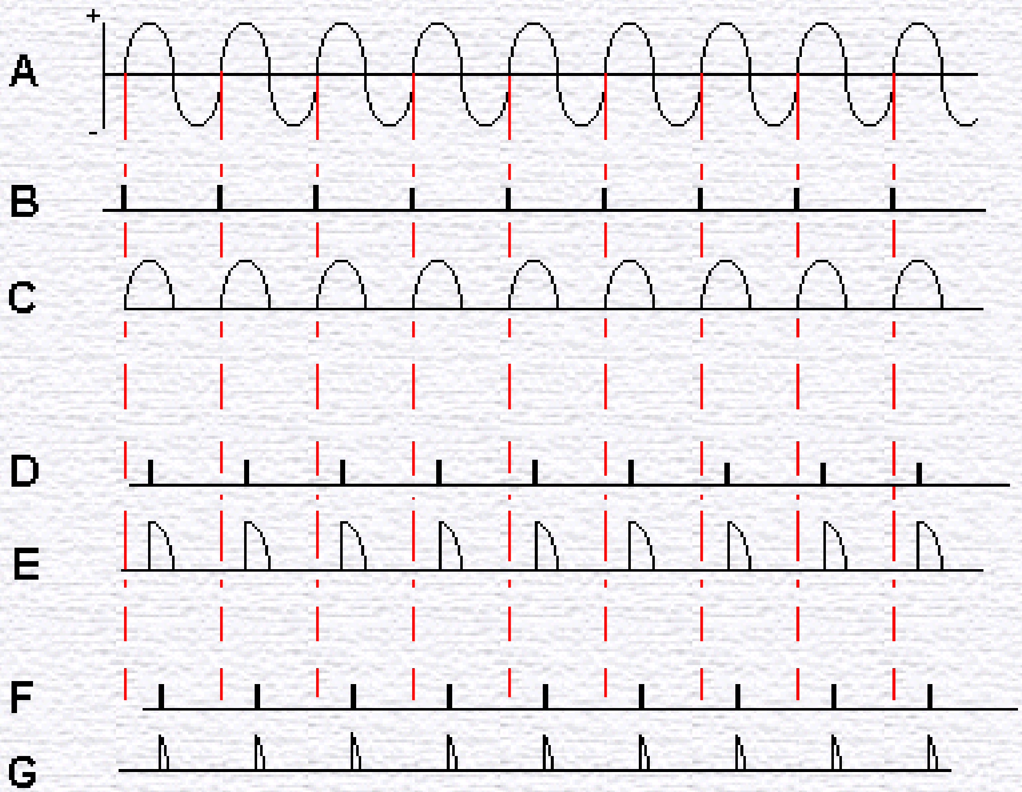

In the circuit diagram, block A generates pulses at the same frequency as the ac power supply.

Block B is a phase shift circuit which enables the phase of the pulses to be shifted with respect the ac supply.

These pulses are applied to the gate.

In waveforms A and B, the gate pulses coincide with the start of the positive half cycles of the mains supply.
They turn the thyristor on, and current flows for the complete half cycle.
There is no current flow during negative half cycles.
The current flow is shown at C.

Waveform D shows the gate pulses shifted and occuring half way through the positive half cycles of the ac supply.
The thyristor starts to conduct at this time.
Current flow is shown at E.

F and G show the gate pulses occuring near the end of the positive half cycles, and current flowing for a very short time.

The circuit acts as a lamp dimmer.
However, current only flows during half of the ac cycle, and full brightness cannot be achieved.

The high power thyristor circuits can be isolated from the control circuits by means of transformers or opto isolators.

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FULL WAVE CONTROL OF THE THYRISTOR

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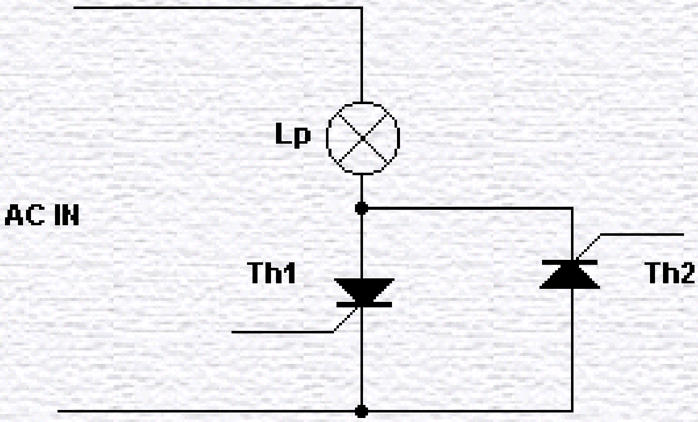

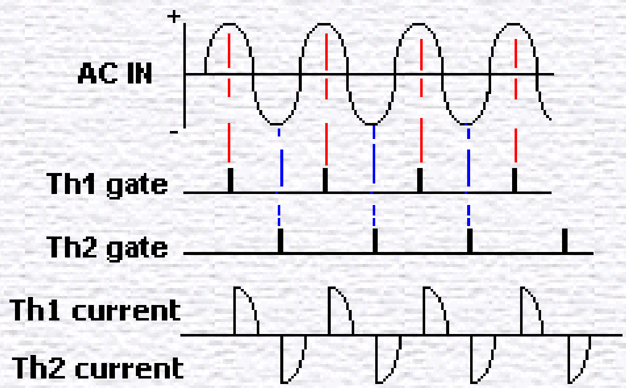

To obtain full wave operation, so that the lamp can be provided with the full ac supply voltage, two thyristors are required as shown.

Th1 is triggered during the positive half cycles of the ac supply, and Th2 during the negative half cycles.

The waveforms show the thyristors being triggered halfway through each half cycle and the current through the lamp would be the sum of the two currents.
The lamp will be at about half brightness

A pulse generator and a phase shift circuit is necessary to provide gate pulses which can adjust the power from minimum to maximum.

Since the gate voltages have to be positive with respect to the cathodes, attention must be paid to the polarity of the gating pulses with respect each other.

The high power ac circuit can be isolated from the control circuits by means of transformers or opto isolators.

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THE TRIAC AND DIAC

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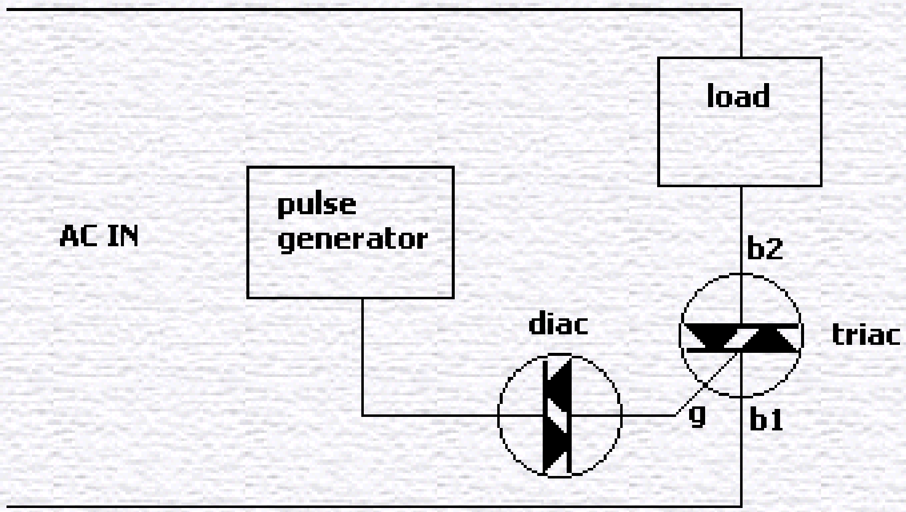

The triac conducts in both directions and provides full wave control of power.

Variable phase trigger pulse are provided by the pulse generator and are positive with respect b1.

The diac is high resistance below a certain voltage, say 30 volts, but when the applied voltage exceeds this value, it goes low resistance and conducts, applying a pulse to the gate.

It gives more reliable triggering of the triac.

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THE CROWBAR

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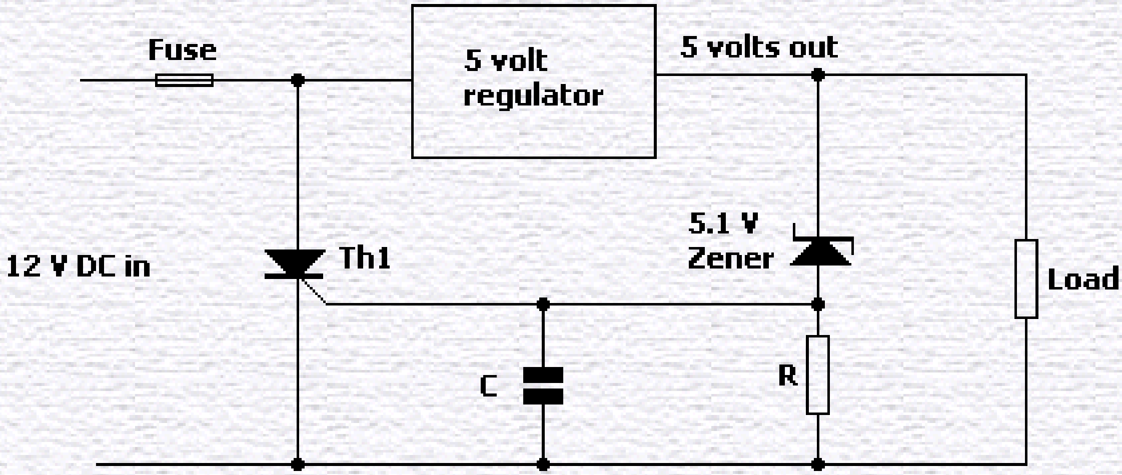

The 12 volts input is stepped down to 5 volts by the regulator.

If the regulator goes faulty, 12 volts could be applied to the load, damaging it.

However, if the regulator output goes above 5.1 volts, then the zener diode conducts.

Current flowing through the resistor provides a voltage across it, which triggers the gate of the thyristor.

The large current through the thyristor blows the fuse and protects the load.

Crude but effective.

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THE ASTABLE MULTIVIBRATOR

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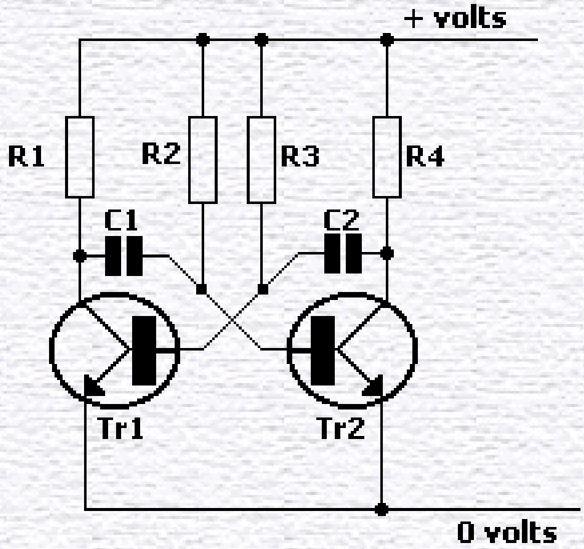

The astable has two unstable states, being unable to rest in a fixed state.

When you first switch on, one transistor is on (conducting) and the other is off (non conducting).

They stay in this unstable state for a time, determined by a CR time constant.

Then the transistors exchange states, the one that was off coming on, and the one that was on going off.

They stay in this new unstable state for a time, again determined by a CR time constant, before reverting to the original state.

This process is repeated continuously.

OPERATION
The characteristics of the two transistors are not exactly the same.

When the circuit is first switched on, the current through one transistor, say Tr1, will increase faster than the current through

Tr2.

Due to the rise of current through R1, the voltage across it will increase, causing the collector voltage of Tr1 to fall.

This fall in voltage is coupled to the base of Tr2.

This causes the collector current of Tr2 to fall, and its collector voltage to rise, due to less voltage being dropped across R4.

This rise in collector voltage is cross coupled to the base of Tr1, increasing the forward bias of Tr1 and increasing its collector current.

Since the collector current was already rising, its rise is aided by this rising forward bias.

The effect is CUMULATIVE and Tr1 becomes rapidly fully on and Tr2 completely off.

The collector voltage of Tr1 is now low, and that of Tr2 is high.

C1 now begins to charge from the supply rail, via R2.

As the voltage on the right hand side of C1 starts to rise, Tr2 starts to conduct.

Again we have the cumulative effect and Tr2 rapidly comes on and Tr1 goes off.

The collector voltage of Tr1 is now high and that of Tr2 low.

It is now the turn of C2 to charge from the supply via R3.

As the voltage on the left hand side of C2 begins to rise, the base voltage of Tr1 increases, turning it on and turning Tr2 off.

The whole process repeats continuously .

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THE MONOSTABLE MULTIVIBRATOR

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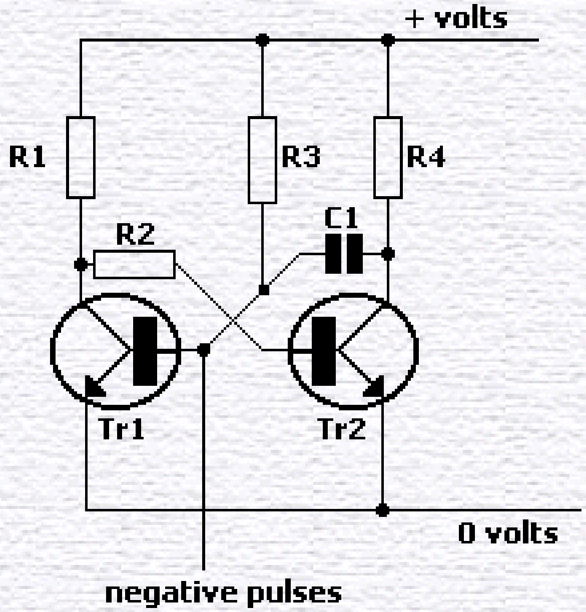

The monostable has only one permanent stable state.

When triggered by an external pulse, it changes over to an unstable state for a time determined by a CR time constant.

It then reverts to its stable state and waits for another trigger pulse.

OPERATION
At switch on, Tr1 is forward biased by R3.

This turns Tr1 hard on, giving it a high collector current and a low collector voltage.

This low collector voltage is cross connected to the base of Tr2, turning Tr2 off.

This is the stable state.

A negative pulse to the base of Tr1 turns Tr1 off.

The collector voltage of Tr1 goes high and turns Tr2 on.

The circuit is now in the unstable state.

C1 now charges from the supply rail via R3.

Eventually the voltage on the left hand side of C1 will be high enough to turn Tr1 back on, which in turn switches Tr2 off.

The circuit is now back in its stable state.

The monostable can be used as a short duration timer or a pulse width stretcher.

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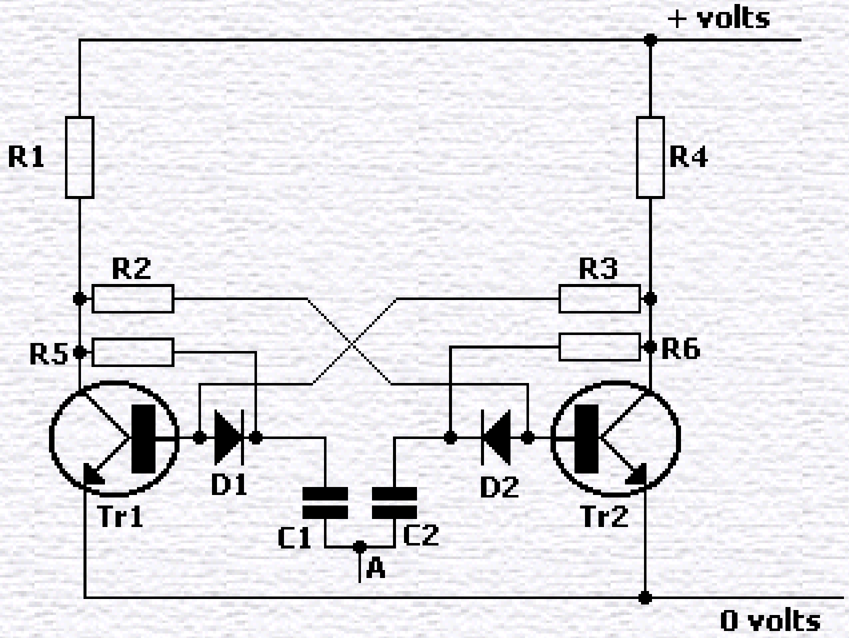
THE BISTABLE MULTIVIBRATOR



The bistable has two stable states.

At switch on, one transistor is ON and the other is OFF.

This is one stable state.

An external pulse makes the circuit change state, with the ON transistor now OFF, and the OFF transistor now ON.

This is the second stable state.

OPERATION
Since the two transistors are not exactly the same, one , say Tr1, will start conducting before the other, Tr2.

As the current through Tr1 increases, the voltage across R1 increases and the collector voltage of Tr1 falls.

This fall is coupled to the base of Tr2 via R2, causing the collector current of Tr2 to fall and its collector voltage to rise.

This rise in voltage is cross coupled to the base of Tr1 increasing its forward bias and increasing the rise of collector current.

Since the collector current is already rising, the effect is CUMULATIVE and the collector voltage of Tr1 falls rapidly and the collector voltage of Tr1 rises just as quickly.

The circuit is now in one of its stable states with the collector voltage of Tr1 low, and that of Tr2 high.

D1 has a low voltage on its cathode via R5 and a high voltage on its anode via R3, making it forward biased.

D2 has a high voltage on its cathode via R6 and a low voltage on its anode via R2, making it reverse biased.

An external negative pulse is steered to the base of Tr1 since D1 is forward biased, but blocked from the base of Tr2 by reverse biased D2.

Tr1 is turned off and Tr2 is turned off by the cross coupling.

This happens very quickly because of the cumulative effect mentioned earlier.

The circuit is now in its second stable state and waits for another trigger pulse.

Since the collector voltage of Tr2 changes state for every trigger pulse, there is one pulse appearing at its collector for every two pulses in.
It can therefore be used as a divide by two circuit.

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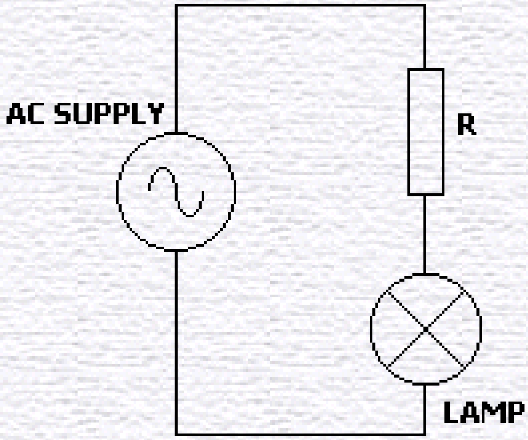
RESISTANCE IN AN AC CIRCUIT



$$\frac{V_{ac}}{I_{ac}} = R \text{ ohms}$$

A resistor in an ac circuit behaves as it does in a dc one. It opposes the flow of current.

The higher the resistance, the lower the current.

The higher the voltage across the resistor, the higher the current through it.

We can apply Ohm's Law.

Voltage and current must both be rms or peak, not a mixture of the two.

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CAPACITANCE IN AN AC CIRCUIT

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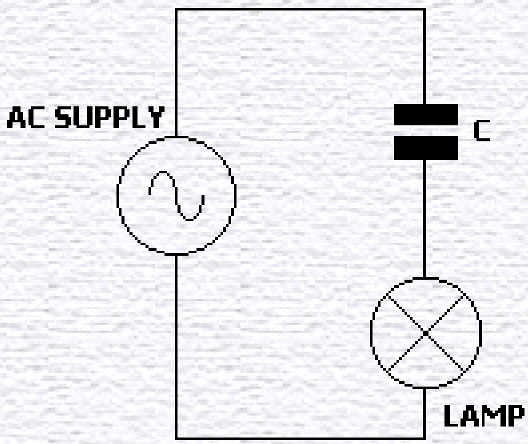

$$\frac{V_{ac}}{I_{ac}} = X_c \text{ ohms}$$

$$X_c = \frac{1}{2\pi fc} \text{ ohms}$$

The capacitor opposes the flow of ac current, as a resistor does in a dc circuit.

This opposition is called capacitive reactance, X_c.
It is measured in ohms.
Ohm's Law can be applied, as in the top formula.

The bottom formula shows how capacitive reactance is calculated.

f is the frequency of the applied voltage, and C is the value of the capacitor in Farads.

It can be seen from this formula that the value of X_c goes down as the frequency increases.
It also goes down if the value of the capacitor increases.

This means that as the value of C or f increases, the opposition to the flow of ac current decreases, and the lamp will glow brighter.

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INDUCTANCE IN AN AC CIRCUIT

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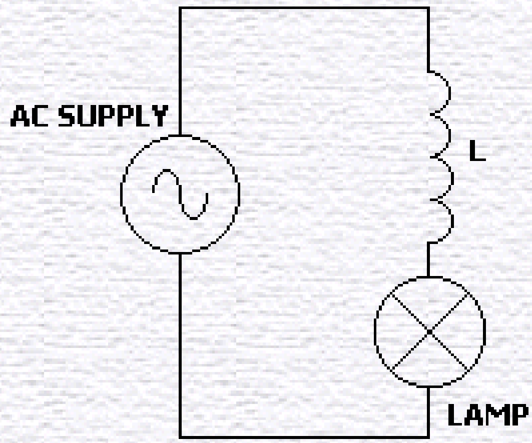

$$\frac{V_{ac}}{I_{ac}} = X_L \text{ ohms}$$

$$X_L = 2\pi f L \text{ ohms}$$

The coil opposes the flow of ac current, as a resistor does in a dc circuit.

This opposition is called inductive reactance, $\mathbf{X_L}$.
It is measured in ohms.
Ohm's Law can be applied, as in the top formula.

The bottom formula shows how inductive reactance is calculated.

f is the frequency of the applied voltage, and L is the value of the coil in Henries.

It can be seen from this formula that the value of $\mathbf{X_L}$ goes up as the frequency
increases.
It also goes up if the value of the coil increases.

This means that as the value of L or f increases, the opposition to the flow of ac
current increases, and the lamp will glow less.

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R, C AND L IN AN AC CIRCUIT

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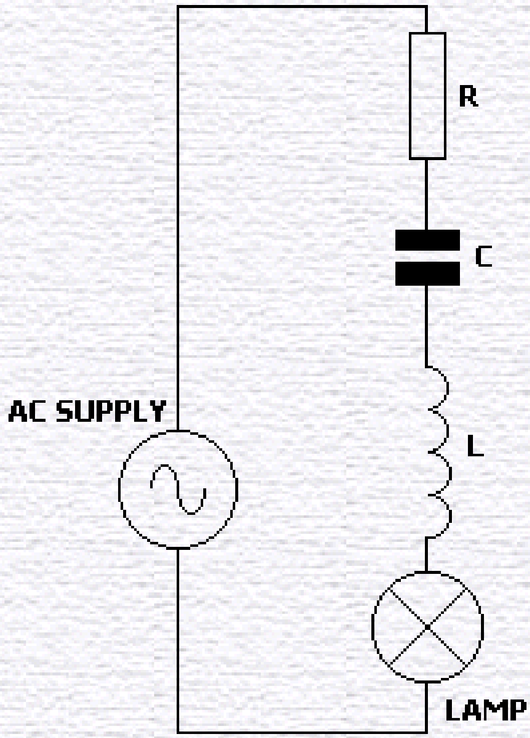

$$\frac{V_{ac}}{I_{ac}} = \mathbf{Z} \text{ ohms}$$

$$\mathbf{Z} = \sqrt{(X_c - X_l)^2 + R^2} \text{ ohms}$$

The resistor, the capacitor and the coil all oppose the flow of ac current.

Their combined opposition is called impedance, Z.

Ohm's Law can be applied, as shown in the top formula.

The higher the impedance, the lower the current.

The resistor has resistance.
The capacitor has capacitive reactance.
The coil has inductive reactance.

All of these values are measured in ohms.

However, impedance is not calculated by adding these values.

The bottom formula must be used.

If you are familiar with Pythagoras, this is another application of it.

When coupling one device to another, such as an amplifier to a loudspeaker, the output impedance of the amplifier and the input impedance of the speaker must be the same, to give optimum transfer of power from one to the other.

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PHASORS

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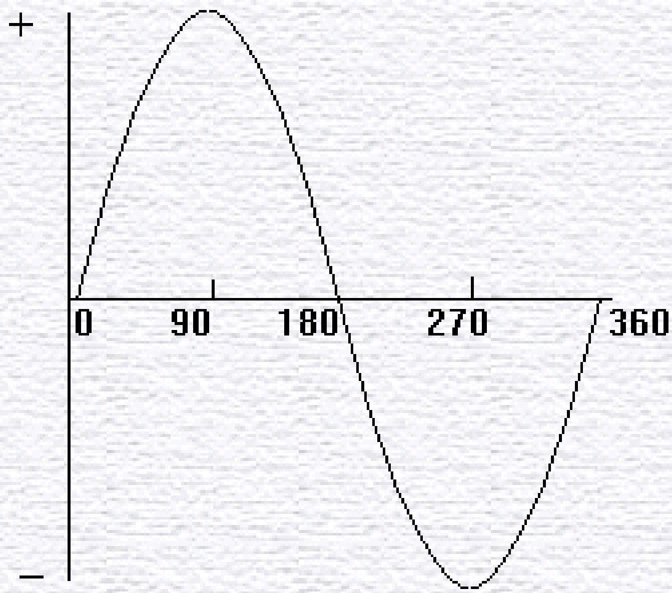
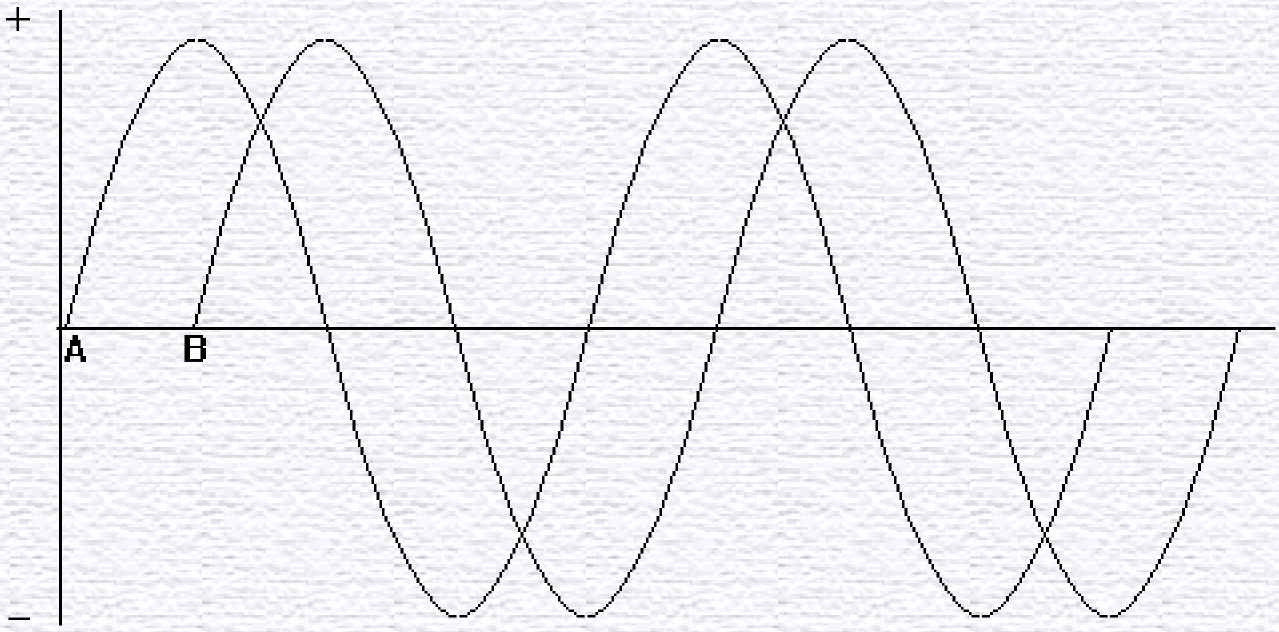
The generator at the power station which produces our AC mains rotates through 360 degrees to produce one cycle of the sine wave form which makes up the supply.



In the next diagram there are two sine waves.
They are out of phase because they do not start from zero at the same time.
To be in phase they must start at the same time.
The waveform A starts before B and is LEADING by 90 degrees.
Waveform B is LAGGING A by 90 degrees.

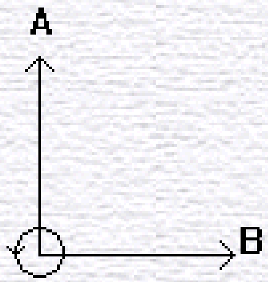


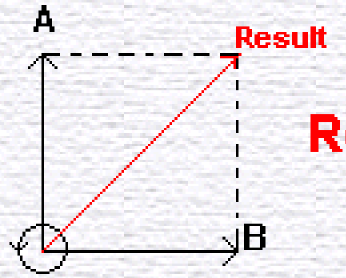
The next left hand diagram, known as a PHASOR DIAGRAM, shows this in another way.

The phasors are rotating anticlockwise as indicated by the arrowed circle.
A is leading B by 90 degrees.

The length of the phasors is determined by the amplitude of the voltages A and B.
Since the voltages are of the same value then their phasors are of the same length.
If voltage A was half the voltage of B then its phasor would be half the length of B.

All this has nothing to do with "set your phasors on stun".





$$\text{Result} = \sqrt{A^2 + B^2}$$

The voltages A and B cannot be added together directly to find the resulting voltage, because they are not in phase.

The result of the two voltages can be found by completing the phasor diagram as shown on the right.

The resulting voltage is slightly greater in amplitude than A or B, and leads B by 45 degrees and lags A by 45 degrees.

Since the two voltages are 90 degrees apart, then the resultant can be found by using Pythagoras, as shown.

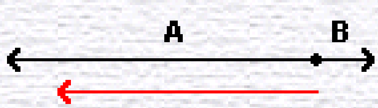


Fig. 1

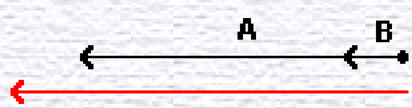


Fig. 2

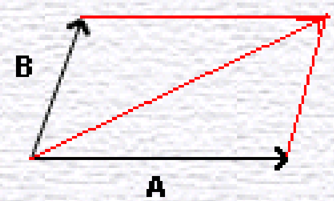


Fig.3

In Fig. 1 above, the two phasors are 180 degrees out of phase.
The resultant voltage is found by subtracting B from A.
The result is a voltage in phase with A but slightly smaller in amplitude.

In Fig. 2 the two voltages are in phase and are added to find the result, which is in phase with A and slightly greater in amplitude.

In Fig.3 a parallelogram must be constructed to find the resulting voltage.

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RESISTANCE IN AN AC CIRCUIT

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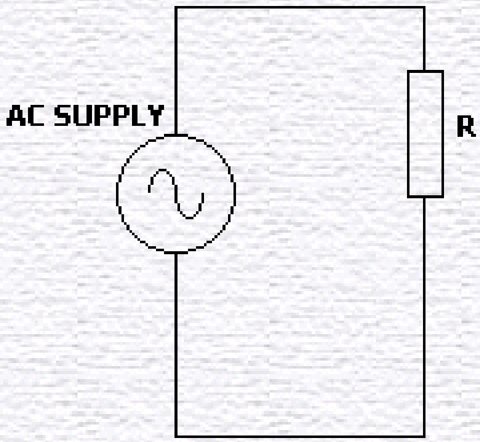

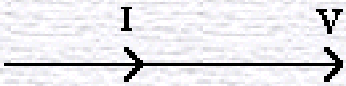

The ac current through a resistor is in phase with the voltage across it.

When the voltage is zero, the current is zero.

When the voltage is at a maximum, then the current is at its maximum.

Ohm's Law can be applied, if current and voltage are both rms, or both peak.

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CAPACITANCE IN AN AC CIRCUIT

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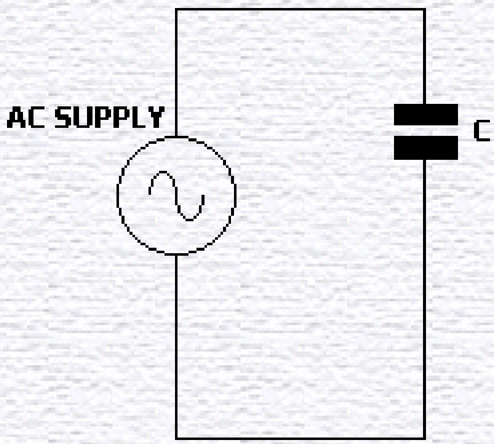

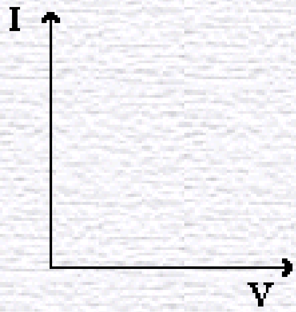

Here the ac current through the circuit leads the voltage by 90 degrees.

Ohm's Law cannot be applied because current and voltage are not both at maximum at the same time.

You need to find the capacitive reactance to be able to use Ohm's Law.

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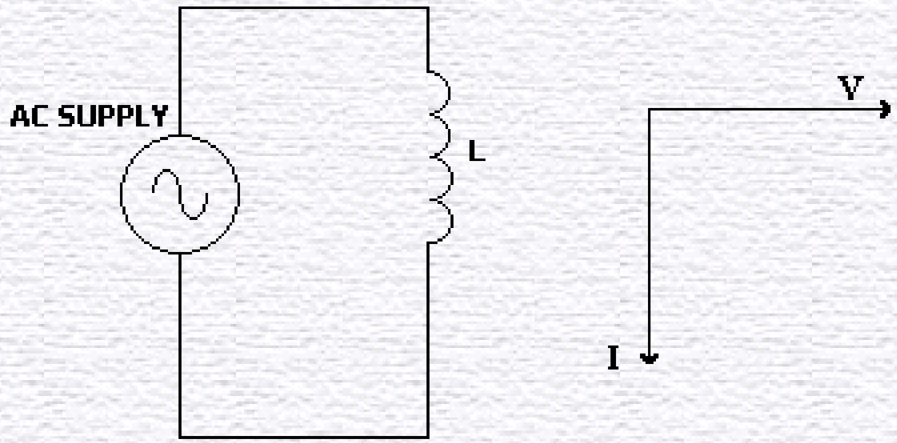
INDUCTANCE IN AN AC CIRCUIT



The current in the circuit lags the voltage by 90 degrees.

Ohm's Law cannot be applied, since current and voltage do not peak at the same time.

Inductive reactance must be calculated to be able to use Ohm's Law.

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L, C AND R IN SERIES, IN AN AC CIRCUIT

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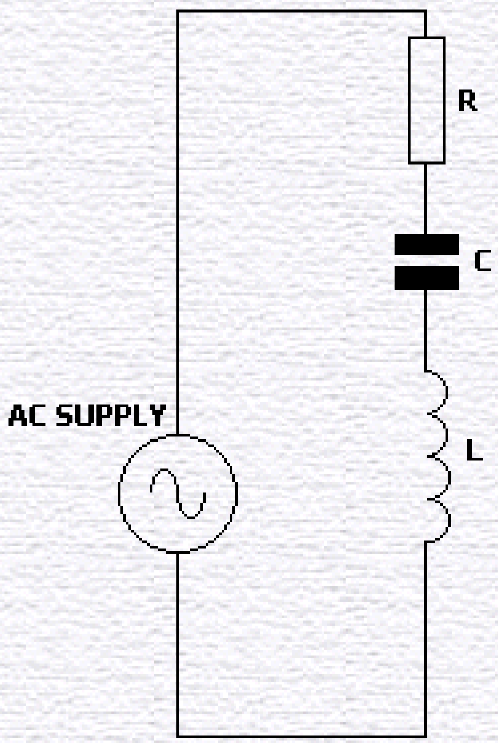

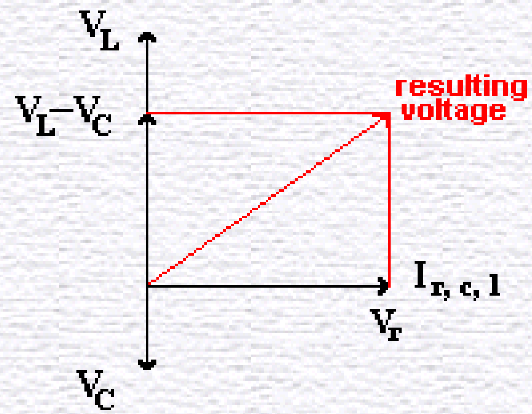

CIVIL

CIVIL
This means that for C, I leads V.
V leads I for L.

Since all the components are in series, the same current flows through them all, as indicated by the horizontal phasor.

Resistor voltage and current are in phase, so resistor voltage is shown also along this phasor.

Inductor voltage leads the current by 90 degrees.

Capacitor voltage lags the current by 90 degrees.

TO FIND THE RESULTING VOLTAGE

Since the voltages across C and L are 180 degrees out of phase, then the result of these two is one subtracted from the other.

Inductor voltage minus capacitor voltage.

This result can be combined with the resistor voltage, by using Pythagoras.

The final result is the applied voltage across the circuit.

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L, C AND R IN PARALLEL, IN AN AC CIRCUIT

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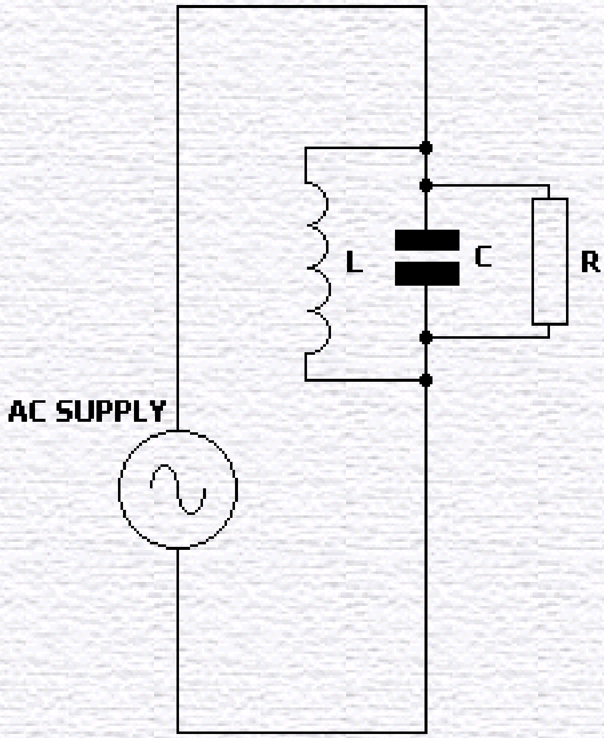

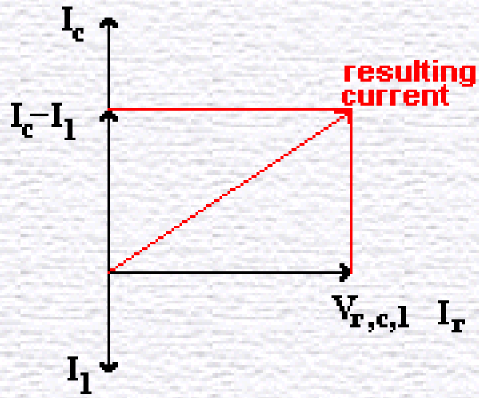

CIVIL

Since all components are in parallel, the same voltage is across all of them.

This is indicated by the horizontal phasor.

Resistor current and voltage are in phase, so resistor current is also along this phasor.

CIVIL tells us that capacitor current leads the voltage, and inductor current lags the voltage.

Since the capacitor and inductor currents are 180 degrees out of phase, then subtracting one from the other gives us the resulting current for the two.

Capacitor current minus inductor current.

To find the result of this current and the resistor current we use Pythagoras.

The final result is the current taken from the supply.

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SERIES RESONANCE IN AN AC CIRCUIT

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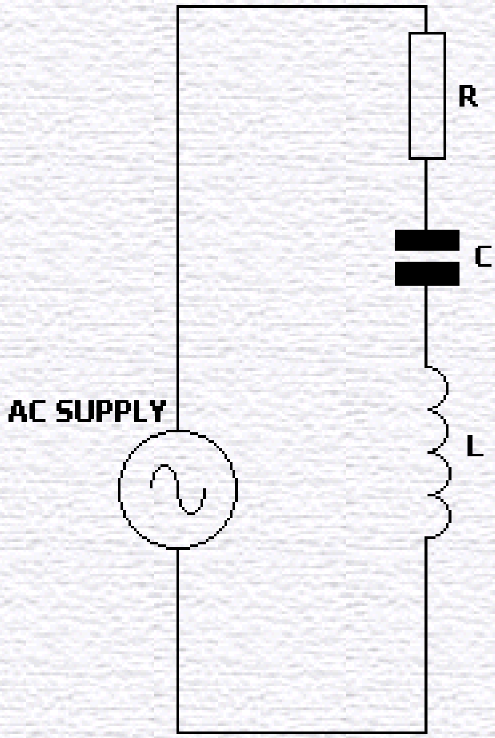

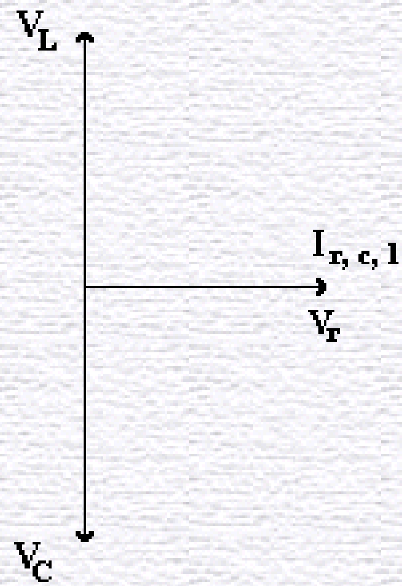

CIVIL

Since all three components are in series, the same current flows through them all.

This is shown by the horizontal phasor.

Since the resistor current and voltage are in phase, then resistor voltage is shown on the same phasor.

CIVIL is a remembering aid.

For a capacitor C, current I leads the voltage V by 90 degrees.

For an inductor L, voltage V leads the current I by 90 degrees.

If the voltage across the capacitor equals the voltage across the coil then, since they are 180 degrees out of phase, their effects will cancel out and we will be left with the effect of resistance only.

$Z = R$

The current and voltage in the circuit will be in phase.

$I = V/R$

All this happens when capacitive reactance equals inductive reactance.

Since capacitive reactance falls as frequency increases, and inductive reactance falls as frequency decreases, then there must be a frequency at which they are equal.

This is called the resonant frequency.

At resonance $X_L = X_C$

so $$2\pi f L = \frac{1}{2\pi f C}$$

and resonant frequency $$f_r = \frac{1}{2\pi\sqrt{LC}}$$

A series resonant circuit has a low impedance.

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PARALLEL RESONANCE IN AN AC CIRCUIT

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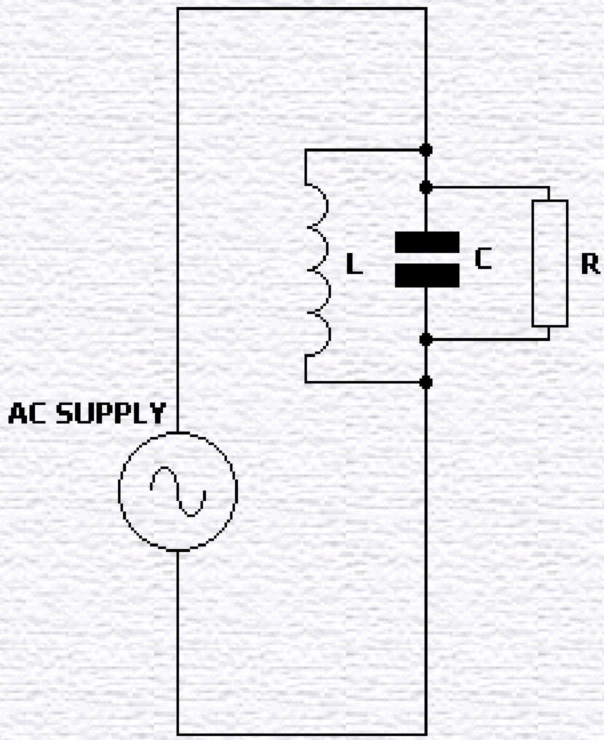

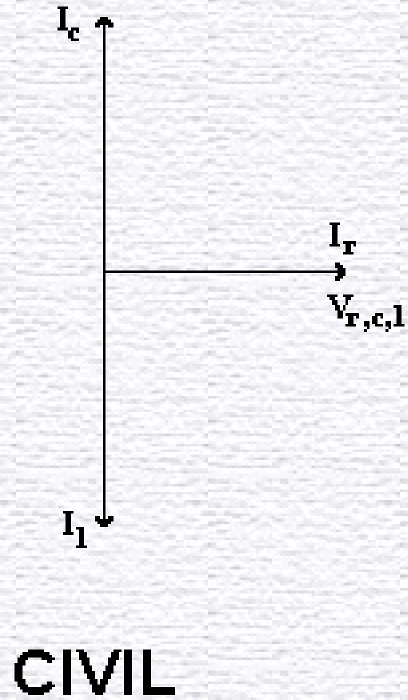

The same voltage is across the three components, since they are in parallel.

This is shown by the horizontal phasor.

Since the current through the resistor is in phase with the applied voltage, then it is shown on the same phasor.

Remembering CIVIL, capacitive current leads the voltage by 90 degrees, inductive current lags the voltage by 90 degrees.

At resonance, the capacitor and inductor currents are equal and 180 degrees out of phase.

They therefore cancel each other out, and we are left with the effect of resistance only.

Since resistor voltage and current are in phase, the circuit voltage and current will be in phase.

At resonance $X_L = X_C$

so $2\pi fL = \frac{1}{2\pi f C}$

and resonant frequency $f_r = \frac{1}{2\pi\sqrt{LC}}$

A parallel resonant circuit has a high impedance.

This is called the dynamic resistance.

The formula is L/C*R

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BITS, BYTES ETC

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A BIT, is a BINARY DIGIT.
A bit can be a zero or a 1.
A binary number made of eight bits, such as 11001010 is known as a BYTE.
Four bits, such as 1101 is known as a NIBBLE (half a byte and a joke).
Sixteen bits numbers are a WORD.
Thirty two bits ones are a LONG WORD.
Sixty four bits numbers are a VERY LONG WORD.

These numbers can be stored in REGISTERS inside chips (integrated circuits).

1k in binary systems is 1024.

These collections of bits can represent binary numbers.
They can aso represent decimal or other number systems.
The ASCII system uses them to represent the letters of the alphabet and punctuation.
The ASCII TABLE gives the binary equivalents of the alphabet.

All this information is called DATA.

Numbers in microprocessor systems are often expressed in hexadecimal.

The microprocessor is also called the CENTRAL PROCESSING UNIT (CPU).

There are very many cpu's and one of the most common is the 6502.

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SYSTEM BUSES

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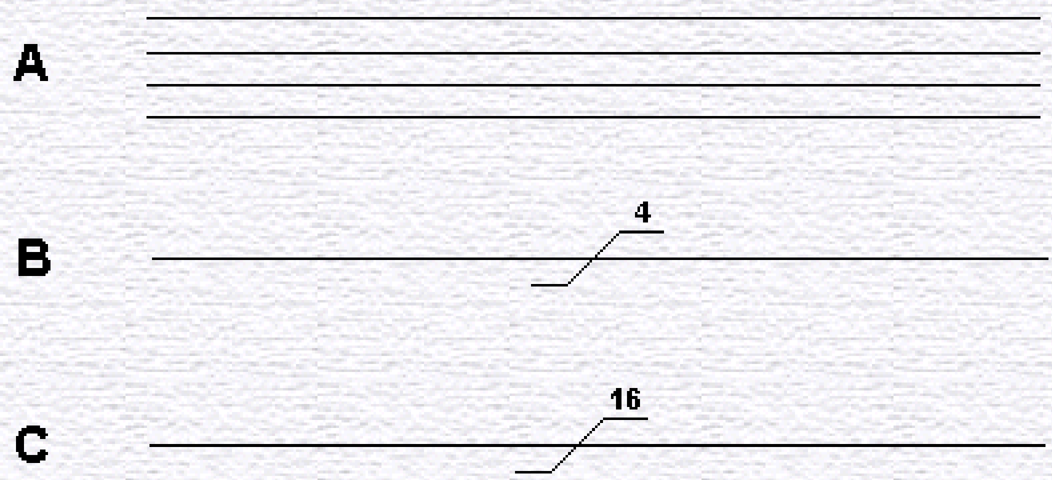

A bus is a collection of wires.

Diagram A is a four bit bus.

Zeros and ones can be put on the bus, 0 volts for zero and +5 volts to represent a one.

The smallest number that can be put on a four bit bus is 0000.
The largest is 1111 which is 15 in decimal and F in hex.
Therefore sixteen different numbers can be placed on this bus, 0000 being the lowest and 1111 the highest.

Rather than draw four wires,we use the representation shown in diagram B.

Many micoprocessor systems use a eight bit data bus.
The smallest number that can be placed on it is 00000000.
The largest number is 11111111 which is equivalent to 255 in decimal.
Therefore 256 different numbers can be placed on this bus.
255 in decimal is FF in hex.

A sixteen bit bus is shown in diagram C.
The smallest number we can put on this bus is

0000000000000000.
The largest number is 1111111111111111 which is 65535 in decimal.
Therefore 65536 different numbers can be put on this bus.
65535 in decimal is FFFF in hex.
All the registers in the memory chips have their own individual addresses, like house numbers in a street.
By putting its address, in binary, on an address bus we can select any individual register.
Address buses are commonly 16 bits, so we can select any one of 65536 registers.

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MICROPROCESSOR SYSTEM DIAGRAM

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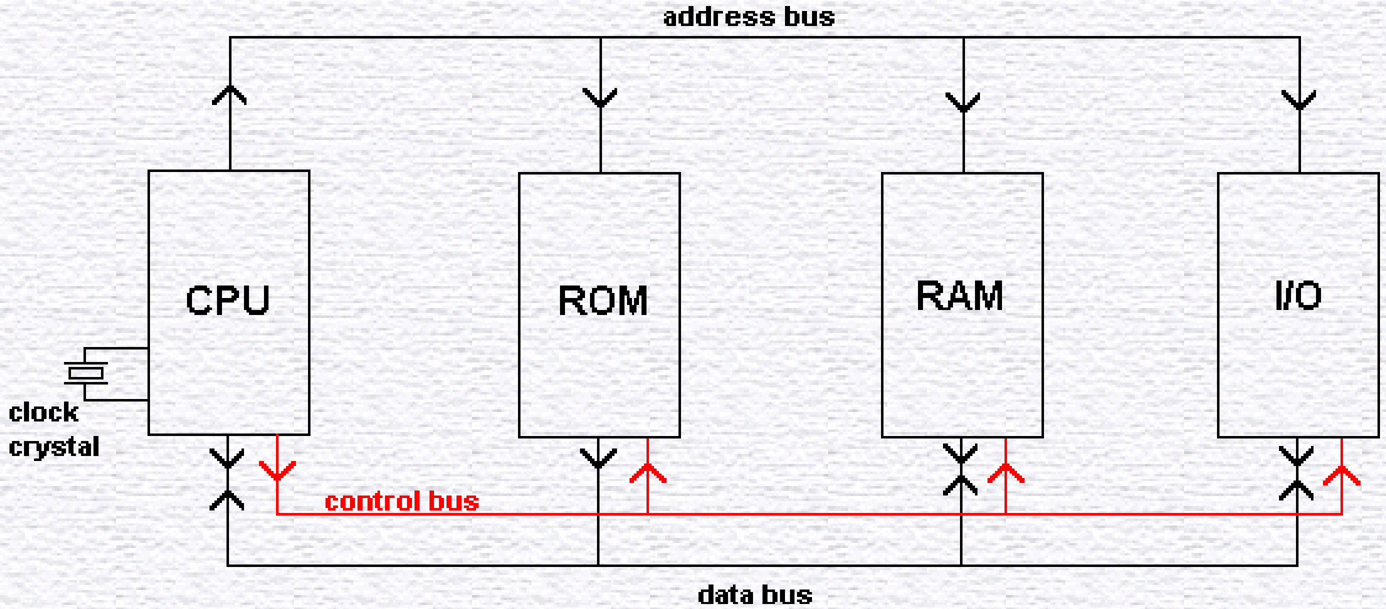

The cpu can put a binary number on the address bus, to select an individual register in the rom or ram or the i/o.
The arrows on this bus show that addresses go one way only.

Data at the selected address can be put on the data bus.
The cpu can also put data on this bus which can be written into a register of ram or i/o.
It is not possible to write data into rom (read only memory).
This is shown by the single arrow on the rom data bus and double arrows on the other two.

The control bus instructs the chips to do various things, such as when to read or write etc.

The clock tells all the chips when to change what they are doing.
Like the drill sergeant who shouts "LEFT, RIGHT, LEFT, RIGHT".
The crystal control the speed of operation.
In simple systems the crystal frequency is 1,000,000 Hz.

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THE CLOCK

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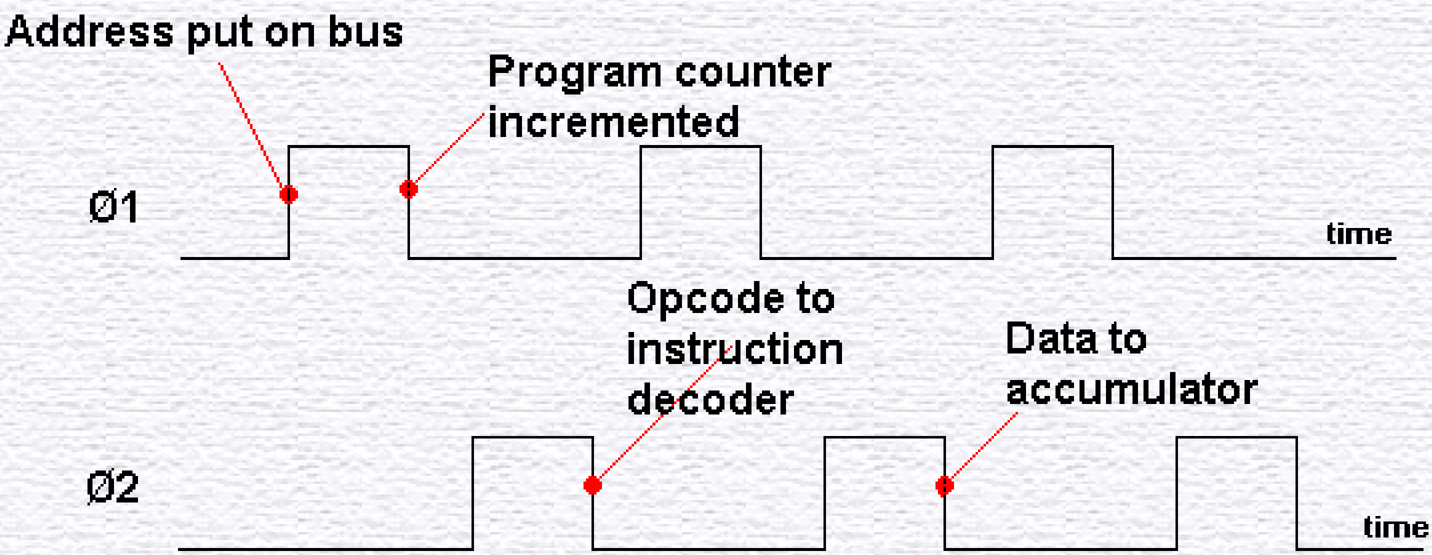

The clock is a square wave generator whose frequency is controlled by a crystal.

In a typical control system it oscillates at 1MHz (1 million times a second) and controls the speed at which the system operates.

The 6502 cpu has two clock signals, phase 1 and phase 2.

The clock control the times at which operations such as fetch etc, take place.

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THE ARITHMETIC / LOGIC UNIT

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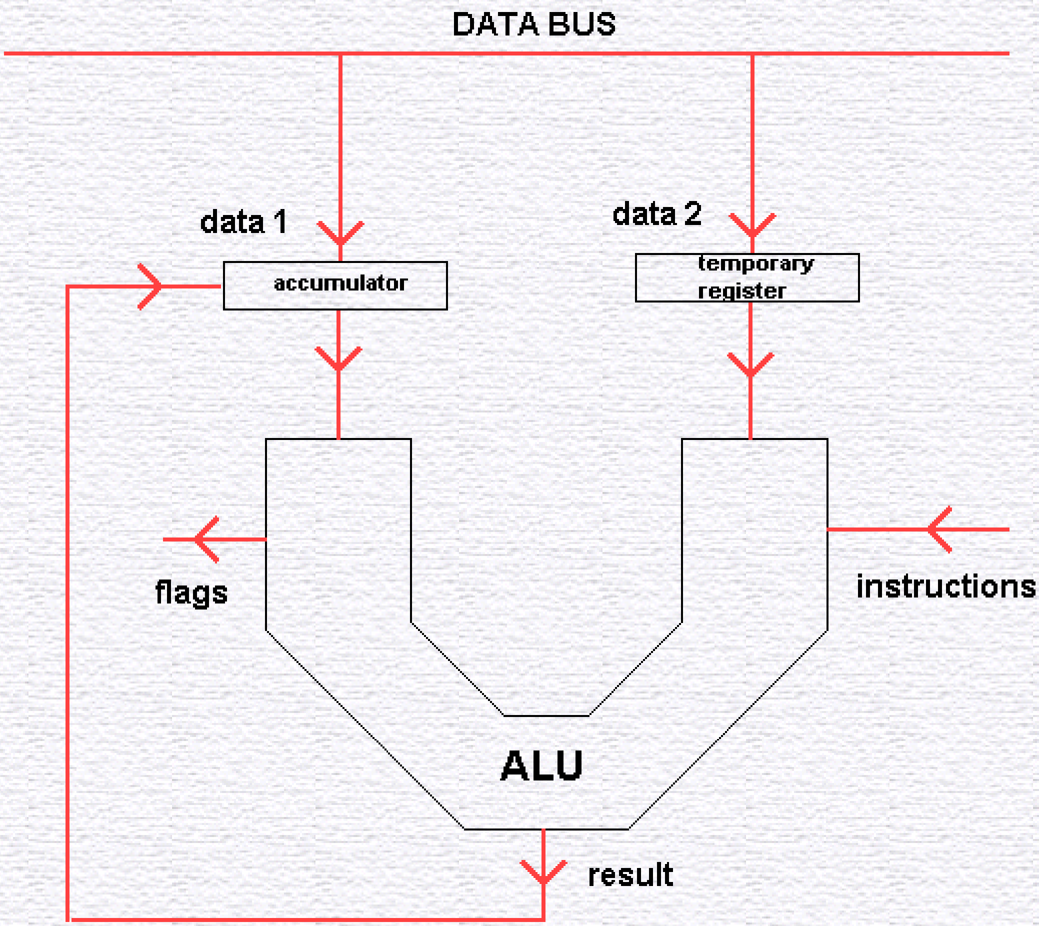

All arithmetic and logical instructions are carried out by the ALU.

An eight bit instruction informs the ALU which operation it is to carry out.

One number to be manipulated comes from the accumulator, the other from memory or another register.

The result is stored in the accumulator.

Flags in the status register are set to indicate the result, such as negative etc.

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THE 6502 CPU

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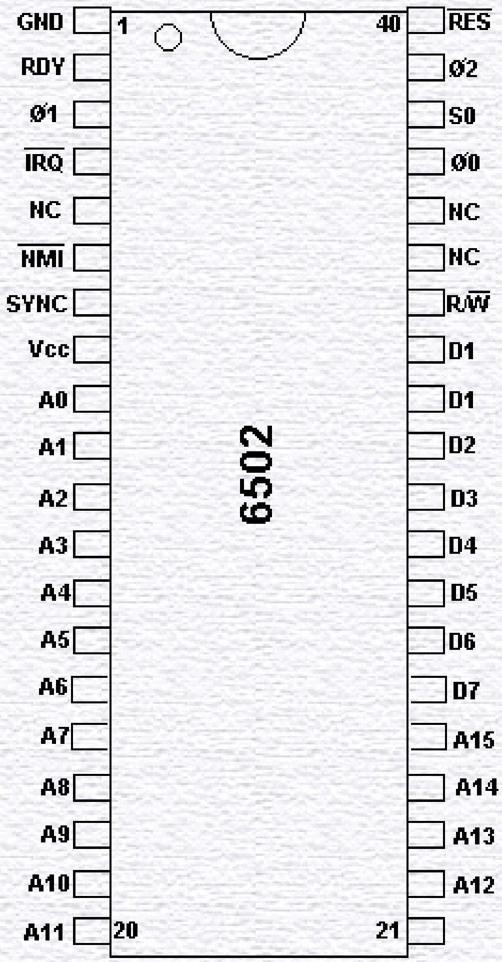

A0 - A15 ADDRESS BUS

D0 - D7 DATA BUS

GND Vcc COMMON AND +5 VOLTS

RDY READY. AN INPUT USED WITH SLOW MEMORY

$\overline{\text{IRQ}}$ AN INTERRUPT REQUEST

$\overline{\text{NMI}}$ NON MASKABLE INTERRUPT REQUEST

SYNC GOES HIGH DURING OPCODE FETCH

$\overline{\text{RES}}$ RESET. TAKEN LOW TO INITIALISE THE CPU

S.O. SET OVERFLOW INPUT

R/$\overline{\text{W}}$ READ/$\overline{\text{WRITE}}$.

The 6502 cpu has a 16 bit address bus and an 8 bit data bus.

It is powered by a 5 volt supply.

Interrupt requests tell the cpu to stop processing its present program and jump to another.

The reset pin is taken low to initialise the cpu when it is first powered on.

The read/write pin is taken low when writing to memory, and high when reading from it.

The 6502 has eight addressing modes telling the cpu where data is located.

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PROCESSOR ARCHITECTURE

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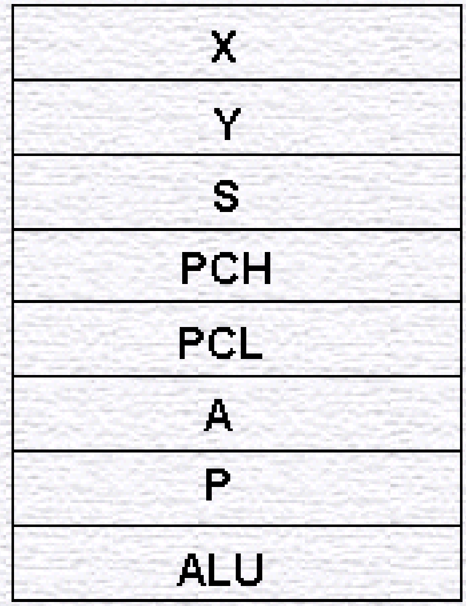

Processor architecture indicates its internal construction.

The 6502 processor has seven internal 8 bit registers and an ALU (arithmetic logic unit).

The X and Y registers are called INDEX registers and are used in the manipulation of data.

S is the stack register. It contains an address indicating where there is a temporary store for data called the STACK.

PROGRAM COUNTER HIGH AND PROGRAM COUNTER LOW together form a 16 bit register, which contains the address of the next instruction to be executed.

A is the ACCUMULATOR. All data to be manipulated is placed in this register and worked upon.

P is the PROCESSOR STATUS REGISTER.
It contains several one bit FLAGS.
These contain a one or a zero to indicate that something has happened during manipulation of data.

For example, one of the flags is set if the result of a calculation is zero.
Another is set if the result is negative.
By looking at these flags the cpu is able to make decisions.
This is why it is so clever.

The ALU is not a register. It is discussed on another page.

RANDOM ACCESS MEMORY

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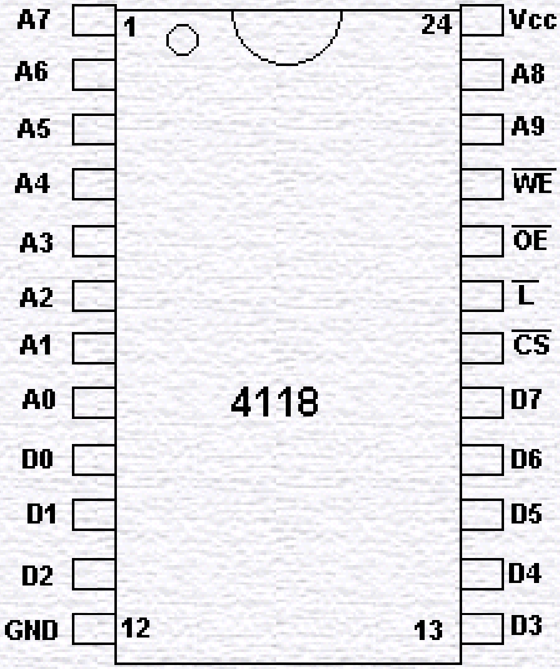

D0-D7	DATA IN/OUT
A0-A9	ADDRESS INPUTS
Vss	GROUND
Vcc	POWER +5 VOLTS
$\overline{WE}$	WRITE ENABLE
$\overline{OE}$	OUTPUT ENABLE
$\overline{L}$	LATCH
$\overline{CS}$	CHIP SELECT

RAM means random access memory.
A better name would be read/write memory.

Ram is VOLATILE, meaning that when you switch off, the data it contains is lost.

There are two main types of ram, static and dynamic.

Static ram uses flip-flops to store bits, and so consumes current whether they are storing a 1 or a 0.

Dynamic ram uses capacitors to store charges and use less power.
However, these stored charges leak away and have to be continually REFRESHED which makes the circuitry more complicated.

The 4118 is an 8 bit x1k static ram having an 8 bit data bus, D0-D7.

Data can be written to, or read from memory, depending the state of the WE pin.

There may be several memory chips, so only one is selected at a time by taking the CS pin low.

READ ONLY MEMORY

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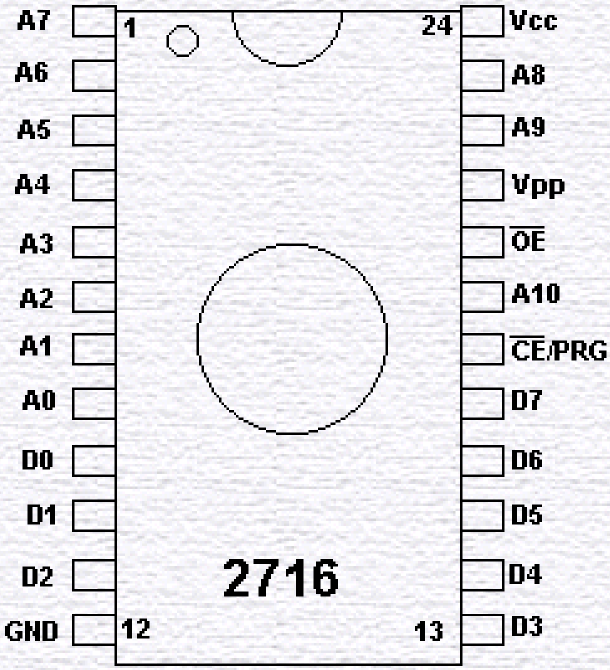

A0 - A10	ADDRESSES
$\overline{CE}$/PRG	CHIP ENABLE/PROGRAM
$\overline{OE}$	OUTPUT ENABLE
DO - D7	DATA OUTPUTS

Memory chips are simply a collection of registers , each with its own address.

Data, in the form of 0's and 1's, is stored in the registers.

ROM chips can be read from, but not written to.

They are non volatile, which means that they retain their contents after power is removed.

Most roms are programmed during manufacture of the chips.

Others, PROGRAMABLE ROMS, PROMS, can have their contents programmed in after manufacture.

The 2716 rom shown above is an EPROM.

This is an erasable prom, where if you make a mistake, you can erase the contents by shining ultra-violet light through a window in the chip.

Some chips are ELECTRICALLY ERASABLE and are known as EEPROMS.

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THE MEMORY MAP

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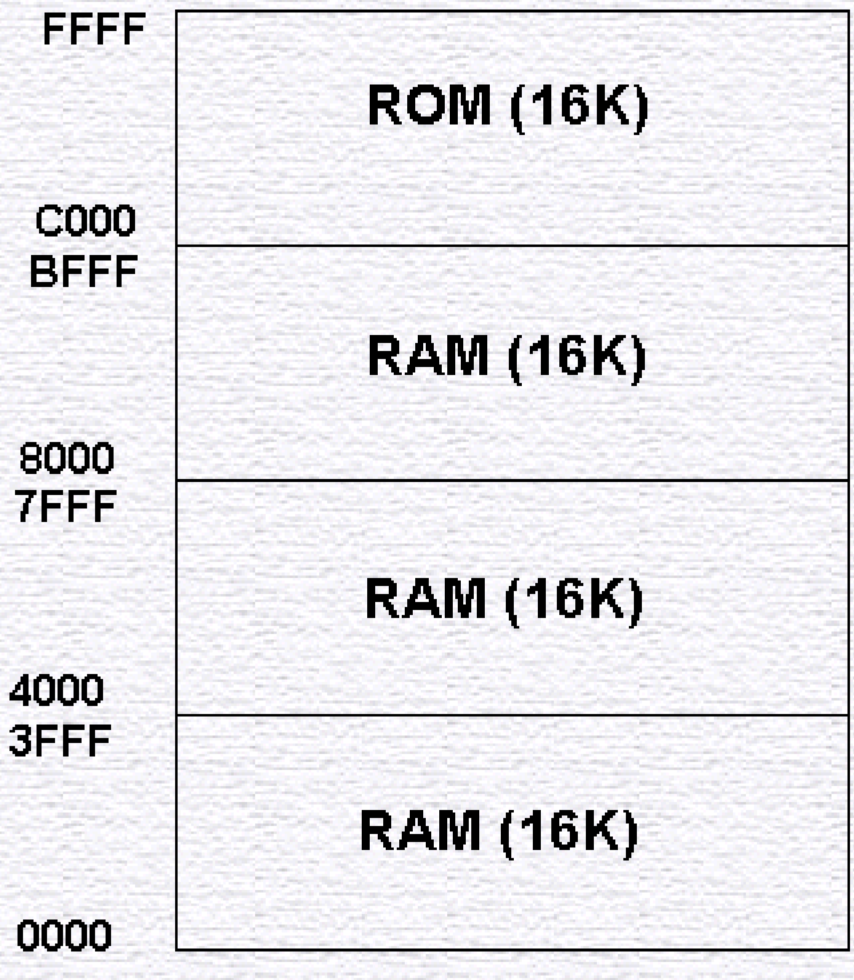

The memory map shows how addresses have been allocated for memory and any other devices connected to the address bus.

Here ram has been given the lowest 48k of addresses and rom the highest 16k.

Each area of memory can be subdivides into pages of 256 addresses.

Page zero occupies addresses 0000 to 255 in decimal or 0000 to 00FF in hex.

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INPUT / OUTPUT PORTS

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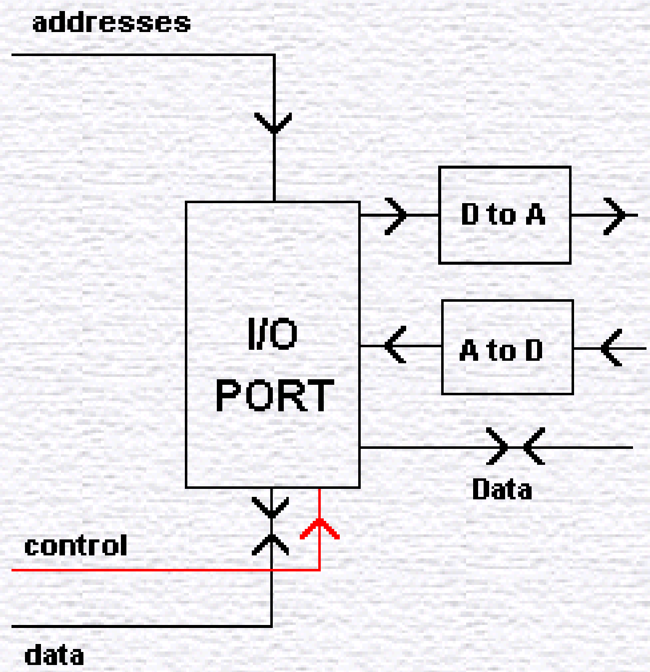

A microprocessor system is pointless unless it can communicate with the outside world.

It does this through an INTERFACE which is usually a plug or socket.

The cpu communicates with this interface via an INPUT/OUTPUT PORT chip.

These chips are called VERSATILE INTERFACE ADAPTORS or UNIVERAL ASYNCHRONOUS RECEIVER/TRANSMITTERS etc.

Ports have their own registers with addresses, and the cpu can write data to, or read data from, these registers.

If the system is controlling a set of traffic lights, then the cpu can write data to the registers, to switch the lights in the correct sequence.

It can also read data that is provided to the port by sensors buried in the road.

This means that it can make decisions according to the amount of traffic and switch the lights accordingly.

Since the system is digital and the outside world is mostly analogue, digital to analogue converters are required when providing an output, such as one to control the temperature of an oven.

An analogue to digital converter is required if the system is to read an analogue device, such as a thermometer.

THE FETCH / EXECUTE CYCLE

The fetch/execute cycle is the process of fetching an instruction from memory, decoding it and then executing it.

The program counter in the cpu contains the address of the next instruction to be fetched.

The instruction is represented by a binary number, called an opcode.

Data (called the operand), for the instruction to work on, is at the address following that at which the instruction is stored.
If the opcode is ADD and is stored at address 10011000, then the data, eg 10, will be stored at 10011001.

The following actions are taken during a fetch/execute cycle to fetch the opcode and operand.

Fetch opcode (read memory).
Increment program counter.
Fetch operand (read memory).
Increment program counter.
Execute instruction.

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INSTRUCTIONS AND PROGRAMS

Instructions are represented by binary numbers called operational codes, or OPCODES.
They are frequently written in hexadecimal.

Different cpu's have different instructions.

To make them easier to remember they are given names called mnemonics.

Examples are

ADD add to the contents of the accumulator.
STA store the contents of the accumulator.
LDA load into the accumulator.
TAX transfer the contents of the accumulator to register X.

A program is a list of instructions, usually written using mnemonics.

Here is the sequence of events for writing programs.

Define the problem.
Produce an algorithm (a list of instructions, written in everyday language).
Produce a flow chart.
Write the program using mnemonics.
Assemble into hex opcodes. (an assembler is a program which does this).
Test by running the program.
DEBUG IT !!

Below is a short program

address label operator operand

label opcode
0200 here LDA
FF A9 FF
0202 ADC
01 69 01
0204 JMP
here 4C 00 02

Labels can be used instead of numbers, as a temporary measure, and replaced by the number later.

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ADDRESSING MODES

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When running a program, the cpu firsts loads an instruction.

It then processes data using this instruction.

Addressing modes tell the cpu where to find the data.

The 6502 has several addressing modes.

A sample is given below.

IMMEDIATE addressing.
In the program, the data follows the instruction.
ADD 99
Add 99 to the contents of the accumulator.

ABSOLUTE addressing.
In the program, the 16 bit address of the data follows the instruction.
STA 1243
Store the contents of the accumulator at address 1243.

ZERO PAGE addressing.
In the program, the instruction is followed by an 8 bit address.
This means that only addresses 0-255 (in page zero) can be used.
CMP 230
Compare the contents of the accumulator with the contents of address 0230.

Other addressing modes are

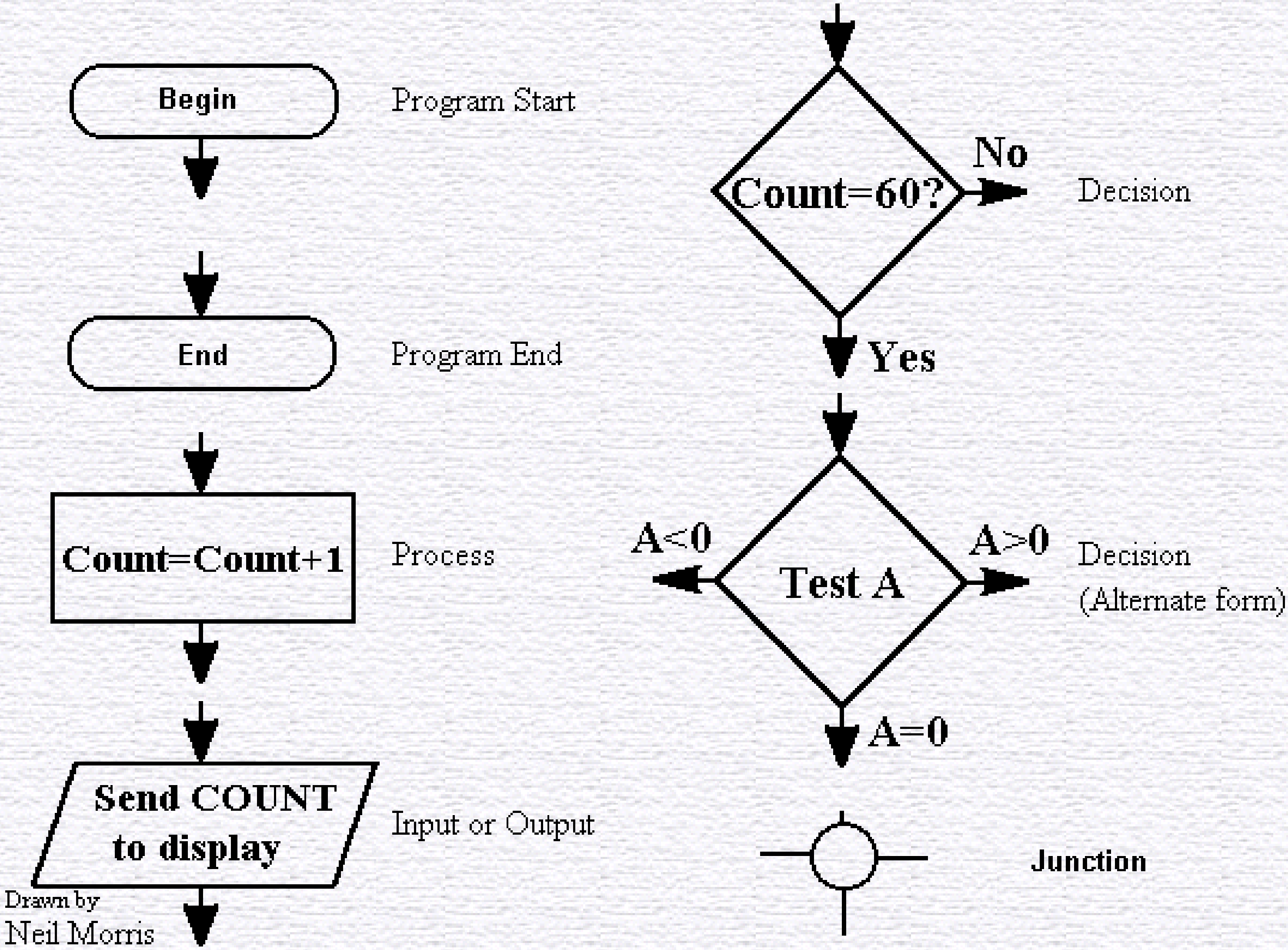
IMPLIED
RELATIVE
ACCUMULATOR
INDEXED

INDIRECT

INDEX

FLOW CHART SYMBOLS

CLICK HERE TO BUY THE CD



When planning software, one of the stages is to produce a flow chart.

The shape of the box indicates its function.

Further data is given as text inside the box.

This was drawn by one of my students, Neil Morris.

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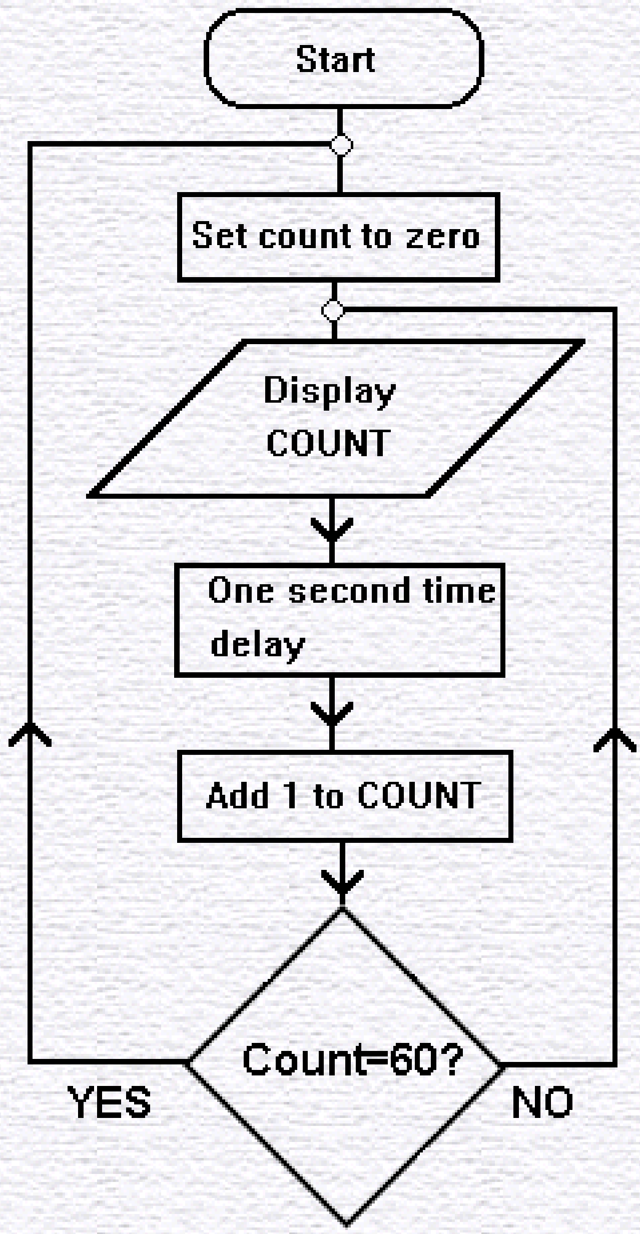
FLOW CHART FOR 1 MINUTE TIMER

CLICK HERE TO BUY THE CD



1 MINUTE TIMER

A register, COUNT, is set to zero.

The contents of COUNT are displayed.

There is a delay of one second.

The contents of COUNT are incremented by 1.

The contents of COUNT are examined.

If the contents are less than 60 then they are displayed, then there is a delay of 1 second and then COUNT is incremented by 1.

This repeats until the contents of COUNT are 60

When the contents of COUNT are 60 then COUNT is reset to zero and the program starts from the beginning again.

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FLAGS

N	V	-	B	D	I	Z	C

The 6502 cpu contains a status register and each individual bit is a FLAG.

A flag indicates the result of the previous operation.

N result is negative
V result too big, causing an overflow
B set by software BRK command
D in decimal mode
I an interrupt has occurred
Z result zero
C carry

The flags are tested by the cpu and, depending on their state, determine which part of the program the cpu will jump to.

This is how computers are able to make decisions.

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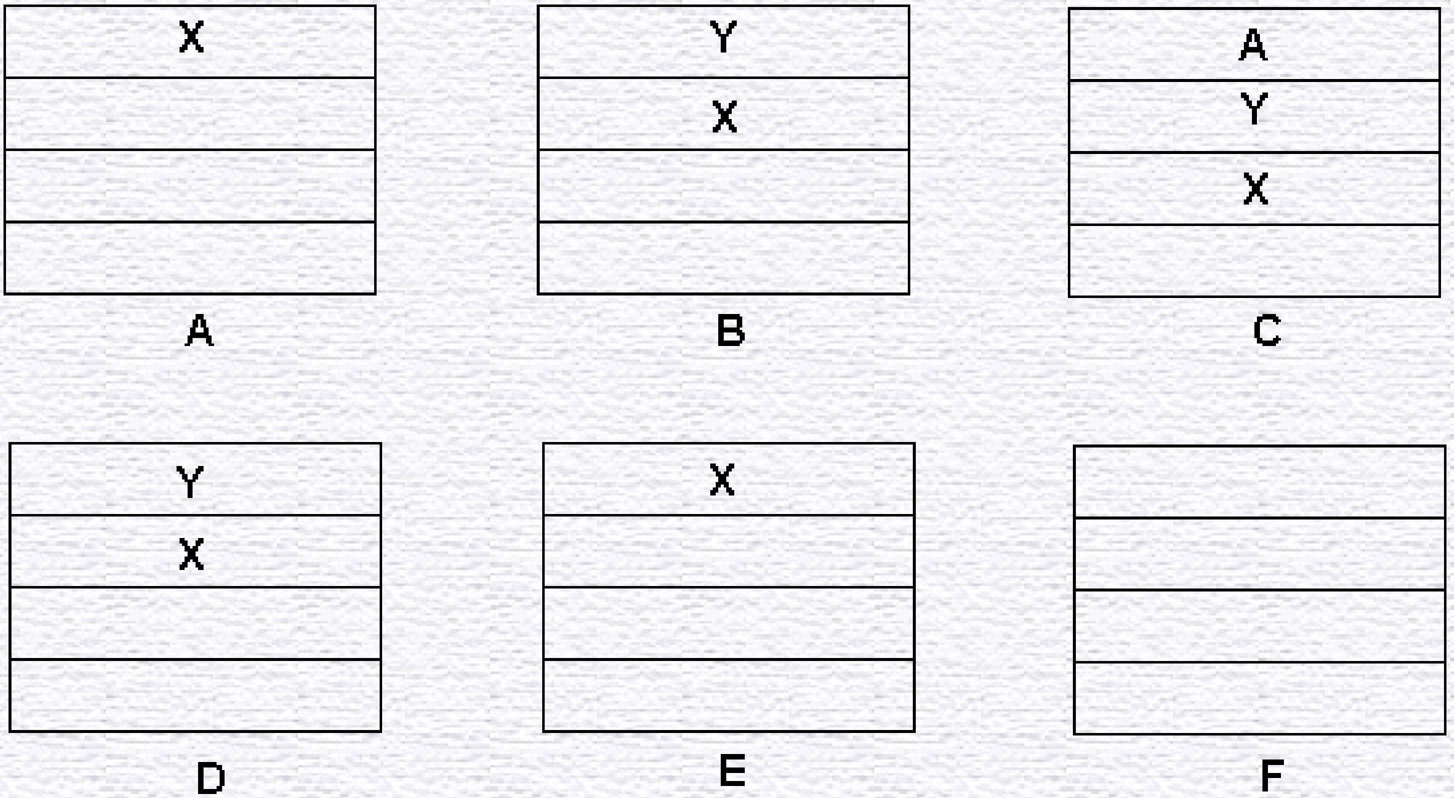
THE STACK

CLICK HERE TO BUY THE CD



The stack is a temporary store for data.

The cpu may PUSH important data onto the stack, while it is processing other data.

When it finishes that task, it PULLS the saved data off the stack.

Its like a pile of plates.
The bottom plate is the first bit of data that was pushed onto the stack.
The top plate is the last data to be pushed.
The top plate is pulled first and the bottom plate is the last data to be pulled.
It is a LAST IN, FIRST OUT stack.

In the diagrams, X is the first to be pushed, then Y and lastly A.

The cpu goes away to process other data.
Upon completion of that task it returns to pull the saved data.
First A is pulled, then Y and lastly X.

The instruction for pushing data is PHA.
Only data in the accumulator can be pushed onto the stack.
Other data can be pushed if it is transferred to the accumulator first.

The instruction for pulling data from the stack is PLA.
Data on the stack is transferred to the accumulator.

The 6502 stack consists of 256 bytes and occupies page 1, addresses 256 to 511.

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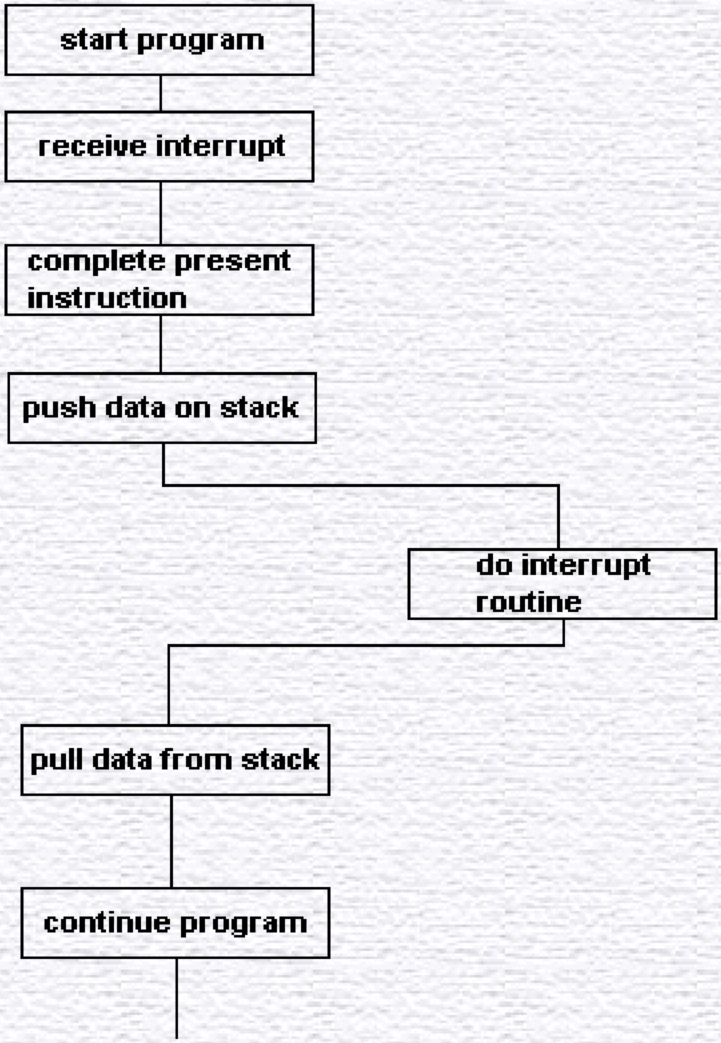
INTERRUPTS

CLICK HERE TO BUY THE CD



The microprocessor system may be measuring temperatures in the Sahara desert.

Once a year it receives a radio signal telling it to stop measuring temperatures and send all last year's data to base. This is an INTERRUPT.

The cpu completes it current instruction.
It then pushes any data it wishes to save onto the stack.

It then jumps to a routine which services the interrupt.

Once the interrupt routine is completed, it pulls the saved data from the stack and carries on measuring temperatures.

There are two pins on the cpu which, when taken low, cause a hardware interrupt.

IRQ can be sensed or ignored depending the value of the interrupt flag in the status register.

NMI cannot be ignored.

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TRUTH TABLES

CLICK HERE TO BUY THE CD

A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

AND

A	B	Z
0	0	0
0	1	1
1	0	1
1	1	1

OR

A	B	Z
0	0	1
0	1	1
1	0	1
1	1	0

NAND

A	B	Z
0	0	1
0	1	0
1	0	0
1	1	0

NOR

A	B	Z
0	0	0
0	1	1
1	0	1
1	1	0

EXOR

A	Z
0	1
1	0

NOT

In case you have forgotten them, here are the truth tables for the various gates.

If you still have problems with them, go back to Electronics for Beginners and revise them.

INDEX

DIODE LOGIC

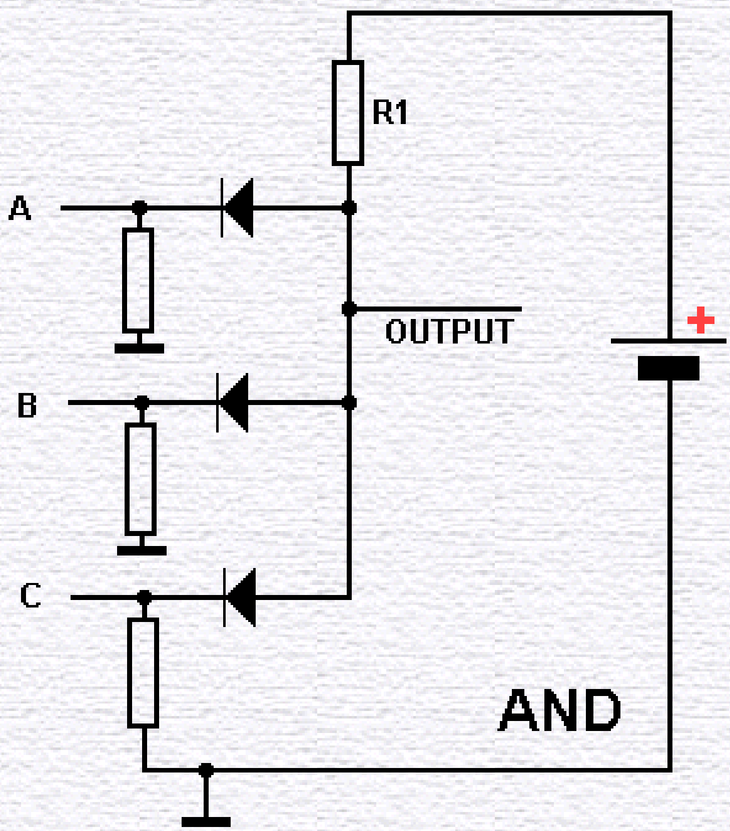
CLICK HERE TO BUY THE CD

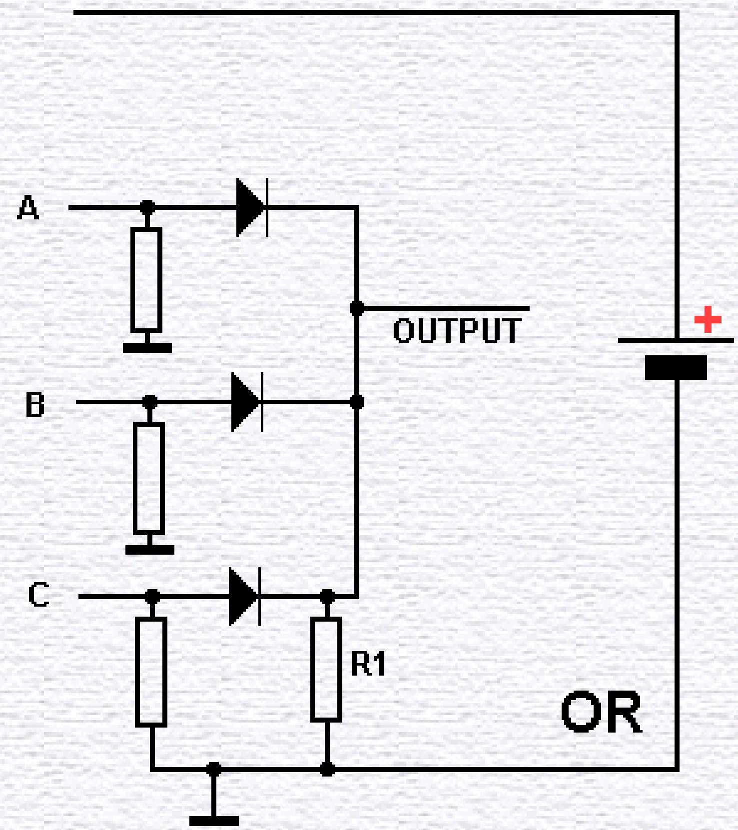
In the AND circuit, the cathodes are held low by the "pull down" resistors.

The diodes are forward biased and the output is held low.

If two of the diodes are taken high to reverse bias them, the remaining diode still holds the output low.

A and B and C must all be taken high to make the output go high.





In the OR circuit, both anodes and cathodes of the diodes are held low, and the output is low.

If A or B or C is taken high, then the associated diode is forward biased and the output goes high.

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DIODE TRANSISTOR LOGIC (DTL)

CLICK HERE TO BUY THE CD

The "pull down" resistors hold the cathodes of the diodes low, making the diodes forward biased.

The output at the anodes is held low, Tr1 base is low and its collector high.

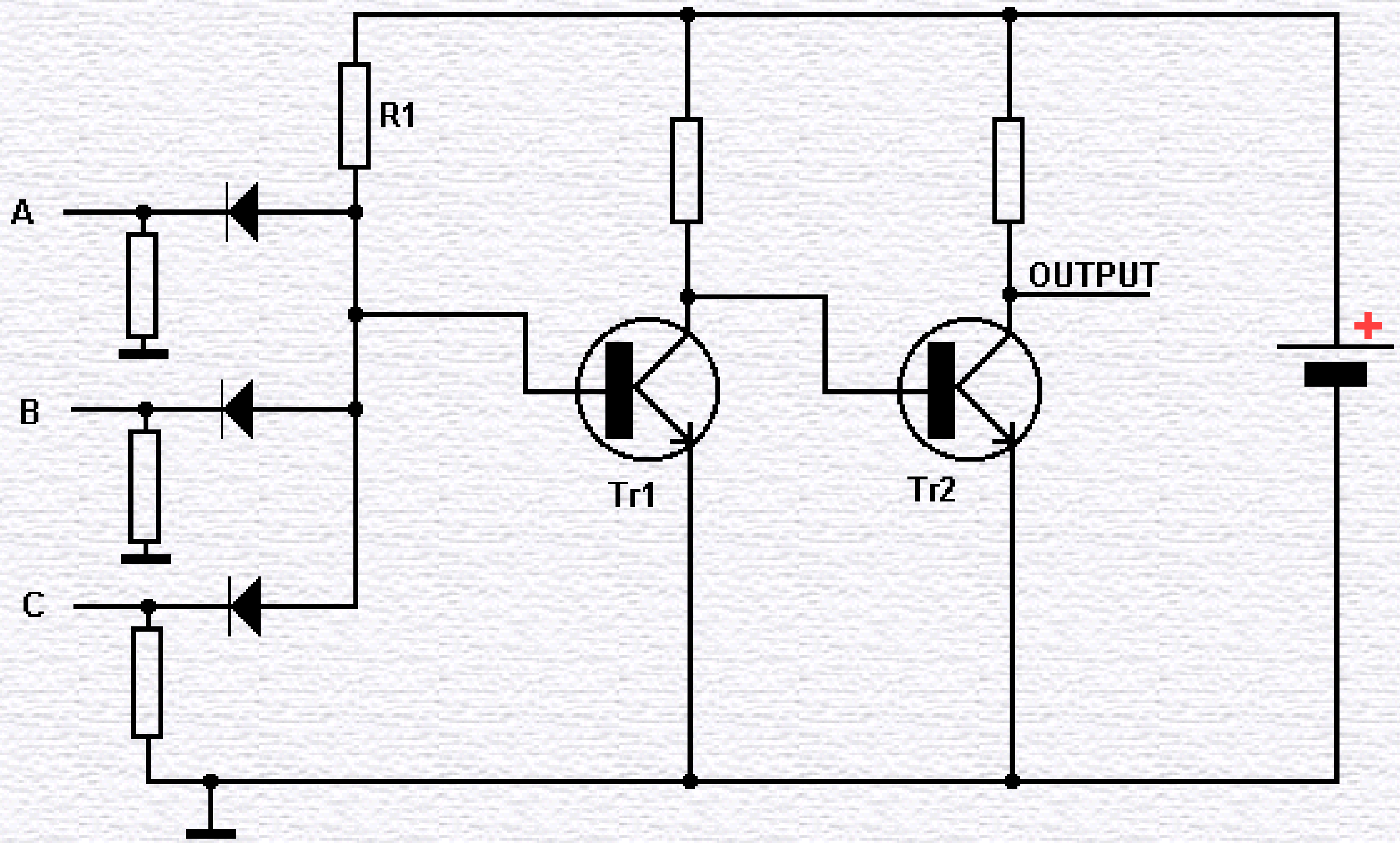
The base of Tr2 is high and its collector low.

A and B and C must all go high together, to reverse bias the diodes, and make the base of Tr1 high.

The collector of Tr1 goes low, together with the base of TR2.

The collector of Tr2 goes high.

The output has gone high because A and B and C have gone high.



AND

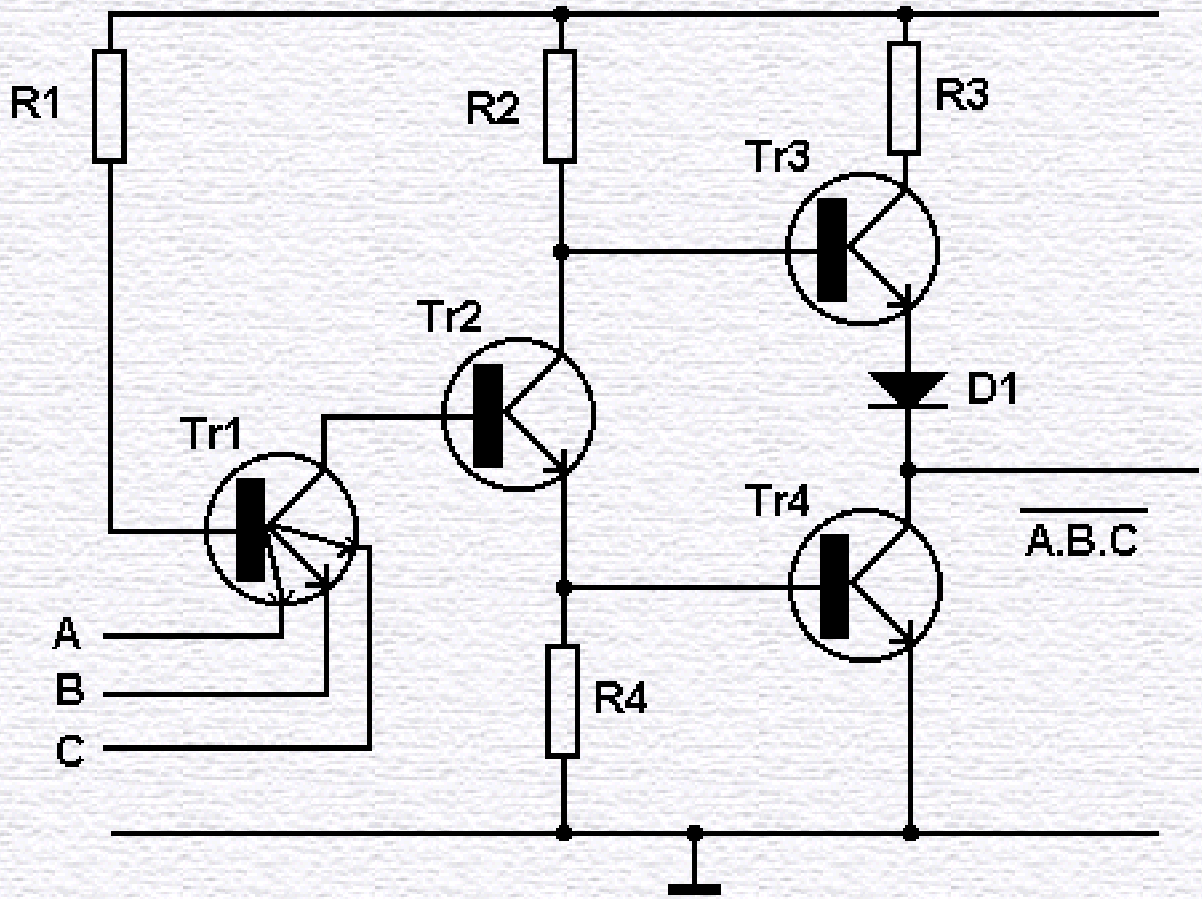
NAND

AND

INDEX

TRANSISTOR TRANSISTOR LOGIC (TTL)

CLICK HERE TO BUY THE CD



3 INPUT NAND

If the emitters of Tr1 are open circuit as shown, then its base/collector junction is forward biased.

Tr2 will be turned on, with its collector low and its emitter high.

Tr3 will be off and Tr4 on.

The output will be low, about 0.6 volts.

If all emitters are taken high, it is the same as them being open circuit, and the output stays low.

If one input is taken low then Tr1 behave like a normal transistor with a reverse biased base/collector junction.

The base of Tr2 is no longer forward biased by this junction, and is turned off.

Tr2 collector goes high and its emitter low.

Tr3 comes on and Tr4 goes off.

The output goes high to about 3.5 volts.

A and B and C must all be high to make the output go low (a nand gate).

Tr3 and Tr4 are in a "totem pole" configuration.

They can be considered as two switches, when one is on the other is off.

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INTRUDER ALARM

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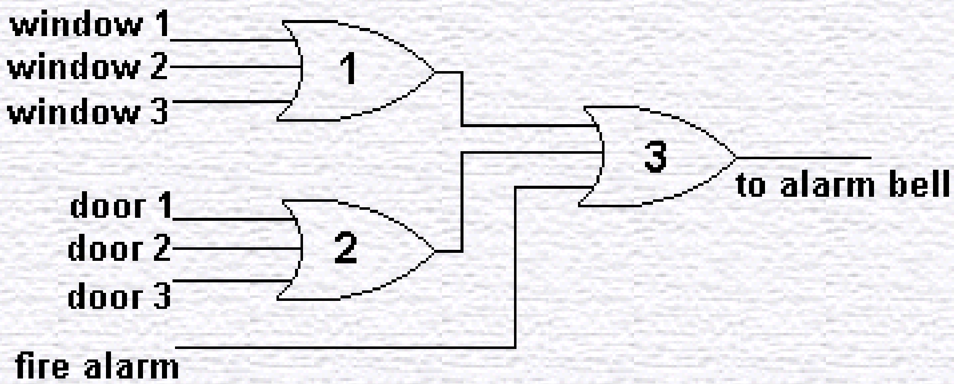

This is a simple application of OR gates.

If a door OR a window Or the fire alarm is activated then the alarm sounds.

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COFFEE MACHINE

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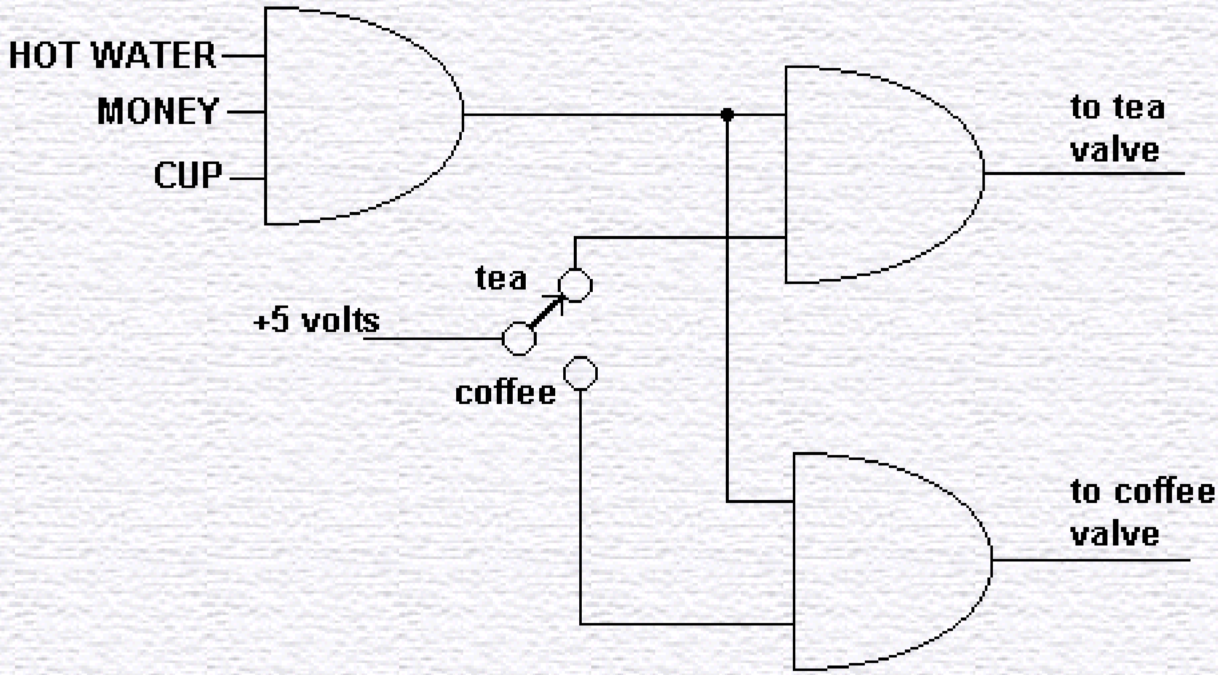

If the water is hot AND money paid AND the cup is present then the output of the first gate will go high.

Depending upon the position of the switch, either the upper or lower output gate will go high, turning on the correct valve.

This is a simple circuit which can be expanded to provide milk and to count the money, give change etc.

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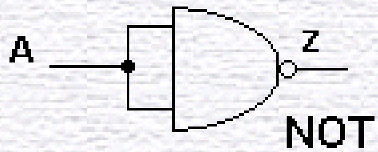
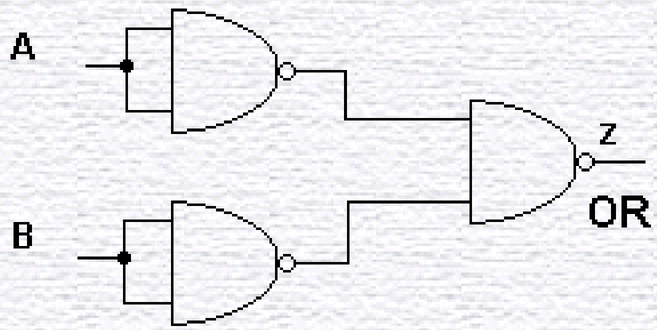
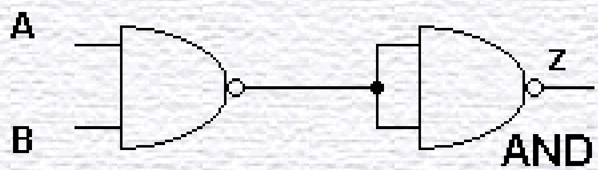
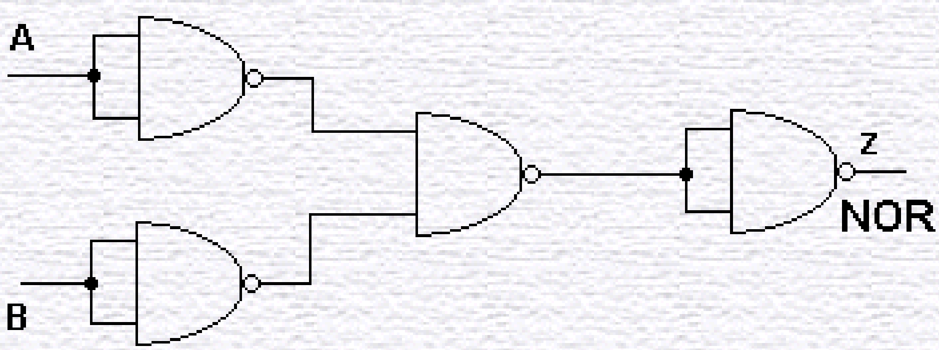
MAKING GATES USING NANDS

When designing logic circuits, engineers often need to make a gate from other types of gates that they have available.
Here is how he does it with NAND gates.
Draw truth tables, to check that it is so.









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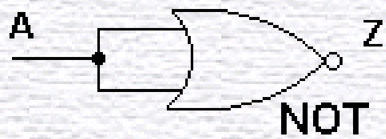
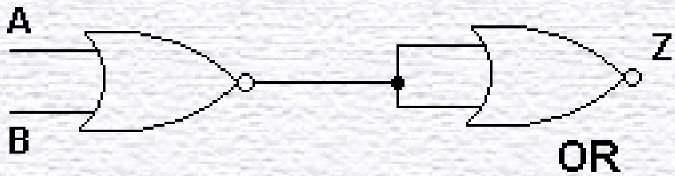
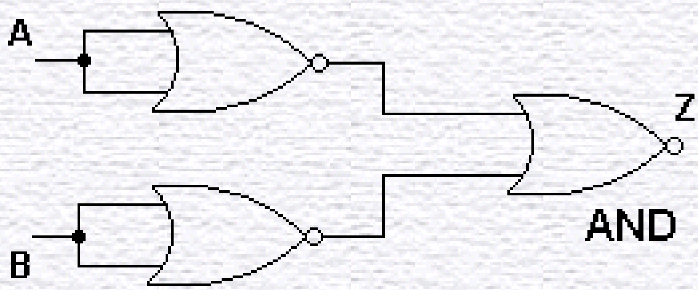
MAKING GATES USING NORS

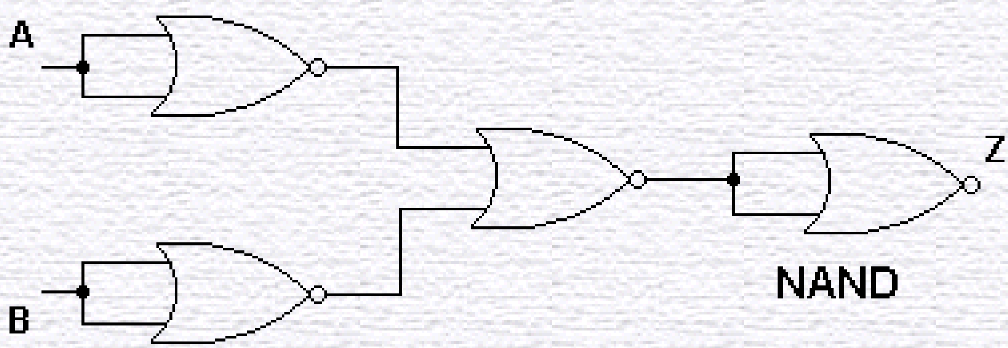
CLICK HERE TO BUY THE CD

When designing logic circuits, engineers often need to make a gate from other types of gates that they have available.
Here is how he does it with NOR gates.
Draw truth tables to show that it is so.









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RECORDING CIRCUIT LEVELS

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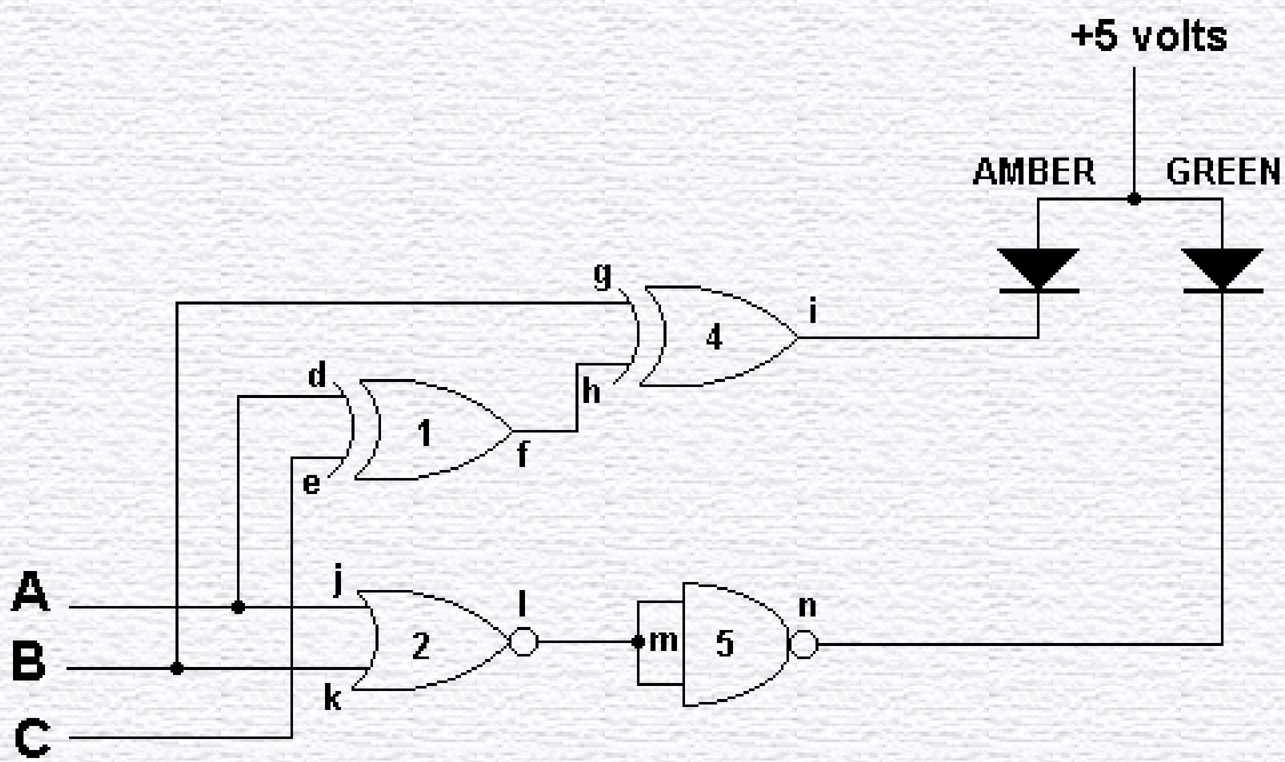
When testing digital circuits, it helps if you know what the logic levels should be in all parts of the circuit under no fault conditions.

This applies to all combinations of input signals.

If a fault appears in the circuit then checking the levels will indicate the location of the fault.

Making a table, as shown, provides a useful reference.



A	B	C	d	e	f	g	h	i	j	k	l	m	n
0	0	0											
0	0	1											
0	1	0											

0	1	1											
1	0	0											
1	0	1											
1	1	0											
1	1	1											

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TRAFFIC LIGHTS

CLICK HERE TO BUY THE CD

Here is an exercise in combinational logic.

Feel free to use it.

A B and C are increasing as shown. Complete the table to find the sequence of lights.
In case you have forgotten them, truth tables are provided.
The cathodes of the LED's go low to turn them on.

A	B	Z
0	0	1
0	1	1
1	0	1
1	1	0

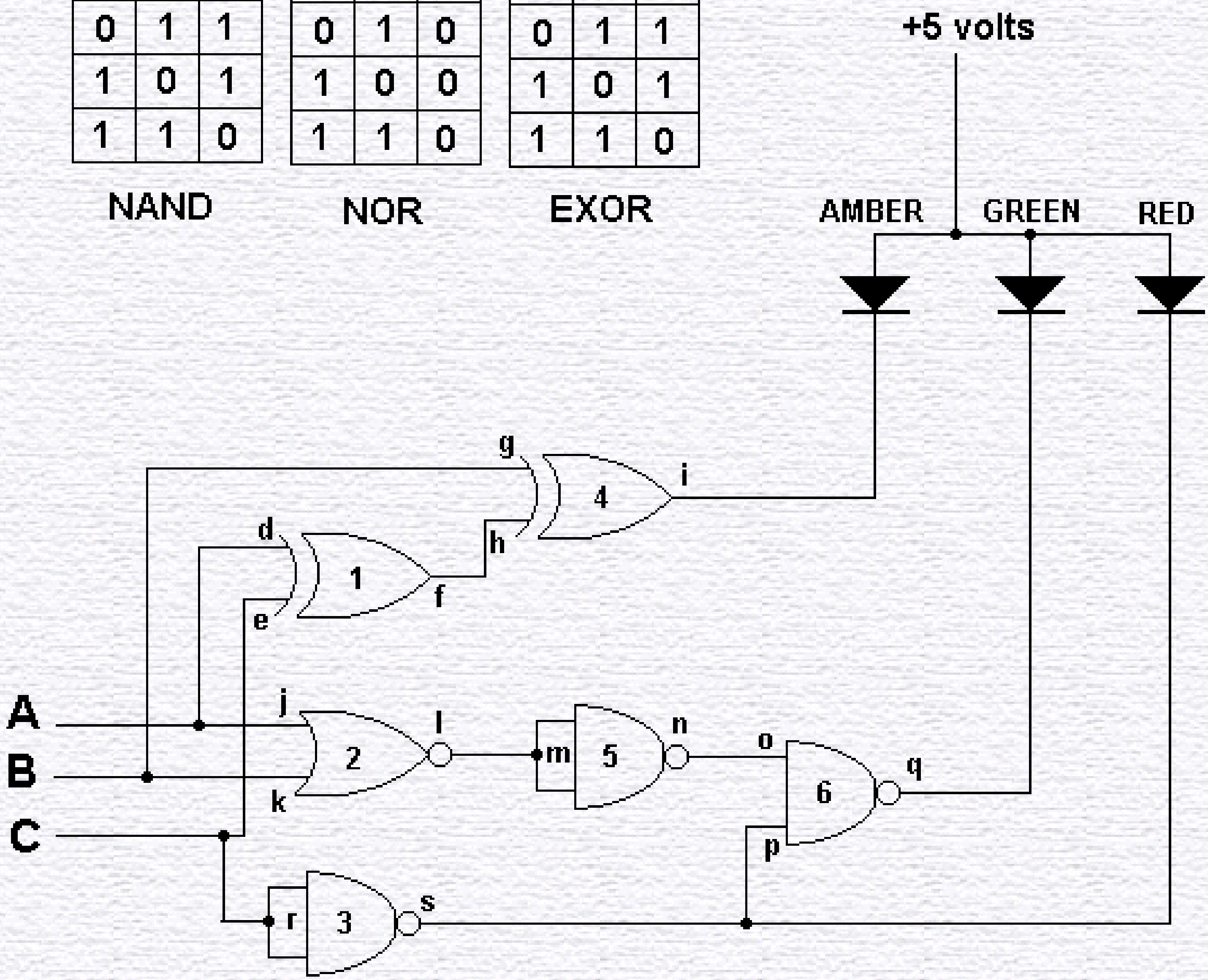
NAND

A	B	Z
0	0	1
0	1	0
1	0	0
1	1	0

NOR

A	B	Z
0	0	0
0	1	1
1	0	1
1	1	0

EXOR



A	B	C	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s

A	B	C	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
0	0	0																
0	0	1																
0	1	1																
1	0	0																

Student's name .... **Date** .... **Assessor** ....

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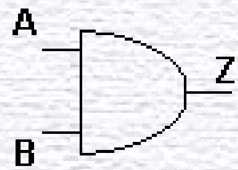
BOOLEAN EXPRESSIONS

CLICK HERE TO BUY THE CD

A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1



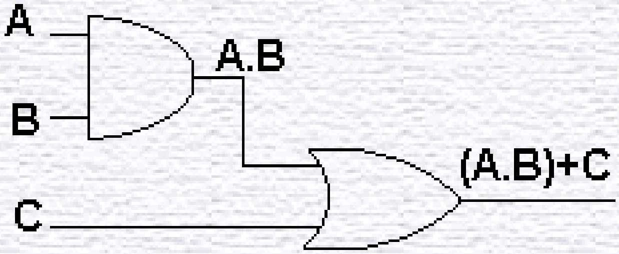
A	B	Z
$\overline{A}$	$\overline{B}$	$\overline{Z}$
$\overline{A}$	B	$\overline{Z}$
A	$\overline{B}$	$\overline{Z}$
A	B	Z

A= LOGIC 1 $\overline{A}$=LOGIC 0

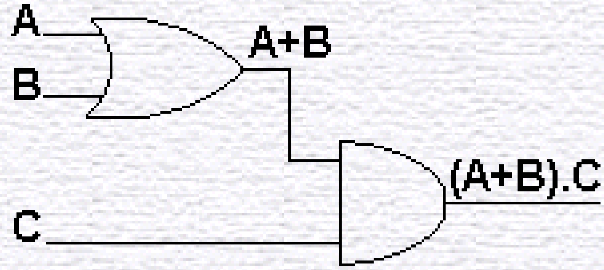
The left hand shows the normal truth table.

In the right hand table, letters have been substituted, including whether they are high or low.

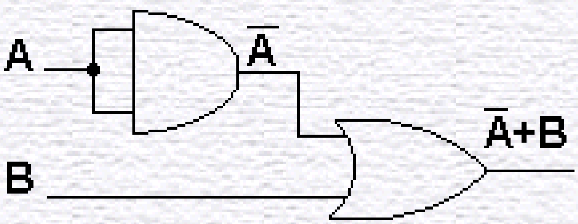
In the diagrams below the states at various points are represented by Boolean expressions instead of logic levels.



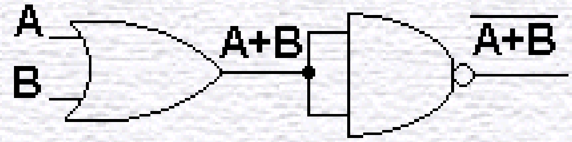
A and B high or C high
will make the output high.



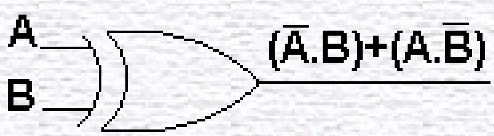
A or B high and C high
will make the output high.

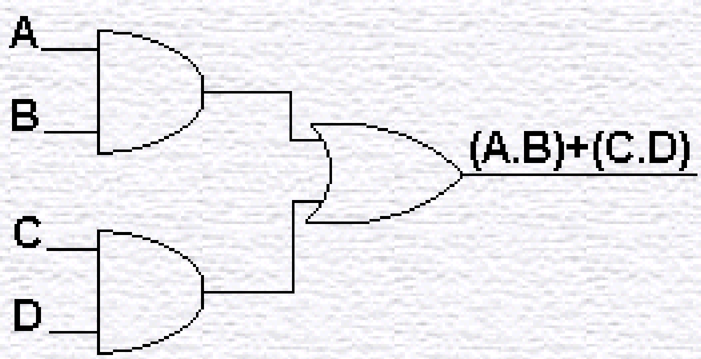


A low or B high
will make the ouput high.



The long bar above the output means that the output goes low when A or B go high.





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LOW LEVEL ACTIVATED GATES

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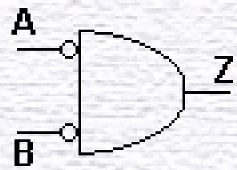
A	B	Z
0	0	1
0	1	0
1	0	0
1	1	0



$\overline{A}.\overline{B}=Z$

A	B	Z
$\overline{A}$	$\overline{B}$	Z
$\overline{A}$	B	$\overline{Z}$
A	$\overline{B}$	$\overline{Z}$
A	B	$\overline{Z}$

A "bubble" on the output of a NAND indicates that the gate output goes low when the inputs are activated.

Bubbles on inputs mean that these inputs go low to activate the gate.

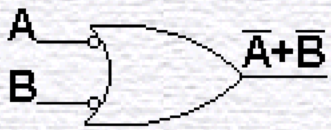
In the low activated AND shown above, both inputs must go low to make the output go high.

In the low activated OR below, A or B going low makes the output go high.

In the low activated NOR circuit, A or B going low makes the output go low.

A long bar above the output indicates that the output goes low when the gate is activated.

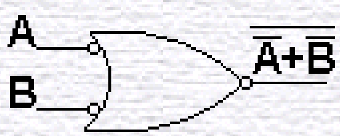
The short bars indicate that those inputs must go low to activate the gate.



The short bars indicate that the inputs go low to activate the gate. (i.e. make the output high).

A	B	Z
0	0	1
0	1	1
1	0	1
1	1	0

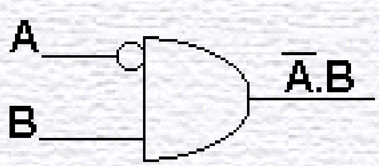
A	B	Z
$\overline{A}$	$\overline{B}$	Z
$\overline{A}$	B	Z
A	$\overline{B}$	Z
A	B	$\overline{Z}$

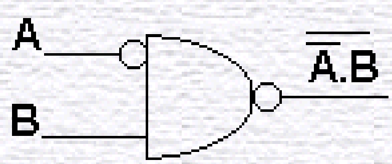


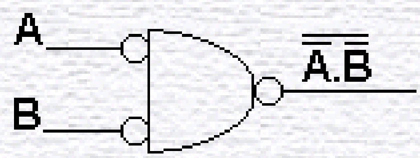
The short bars indicate that the inputs go low to activate the gate.
The long bar indicates that the output goes low when activated.

A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

A	B	Z
$\overline{A}$	$\overline{B}$	$\overline{Z}$
$\overline{A}$	B	$\overline{Z}$
A	$\overline{B}$	$\overline{Z}$
A	B	Z







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DE MORGAN

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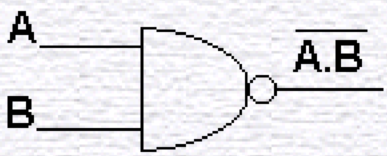
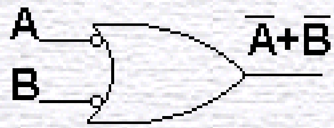
De Morgan says that the first two gates have the same properties.

He says the same for the next two.

The equations can be expanded to include three or more inputs, A B C etc.

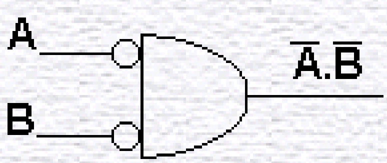


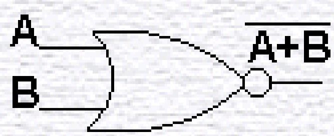


A	B	Z
$\bar{A}$	$\bar{B}$	Z
$\bar{A}$	B	Z
A	$\bar{B}$	Z
A	B	$\bar{Z}$

$$\overline{A+B}=\bar{A}.\bar{B}$$

A	B	Z
$\bar{A}$	$\bar{B}$	Z
$\bar{A}$	B	Z
A	$\bar{B}$	Z
A	B	$\bar{Z}$





A	B	Z
$\bar{A}$	$\bar{B}$	Z
$\bar{A}$	B	$\bar{Z}$
A	$\bar{B}$	$\bar{Z}$
A	B	$\bar{Z}$

$$\bar{A}.\bar{B}=\overline{A+B}$$

A	B	Z
$\bar{A}$	$\bar{B}$	Z
$\bar{A}$	B	$\bar{Z}$
A	$\bar{B}$	$\bar{Z}$
A	B	$\bar{Z}$

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A DE MORGAN APPLICATION

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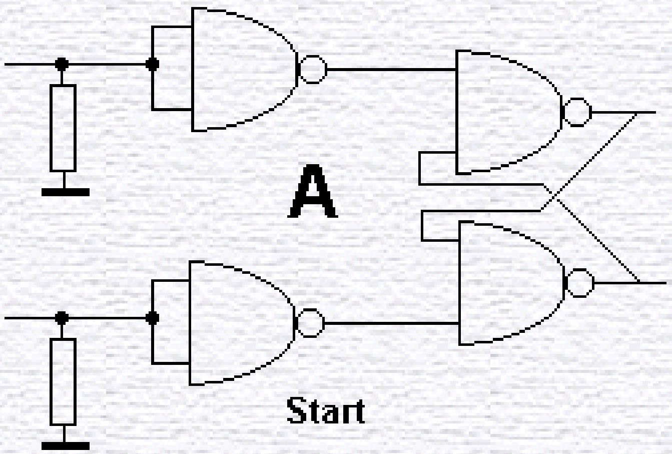
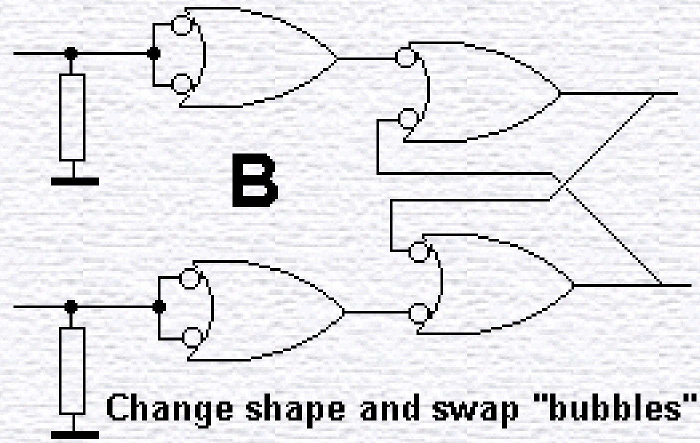
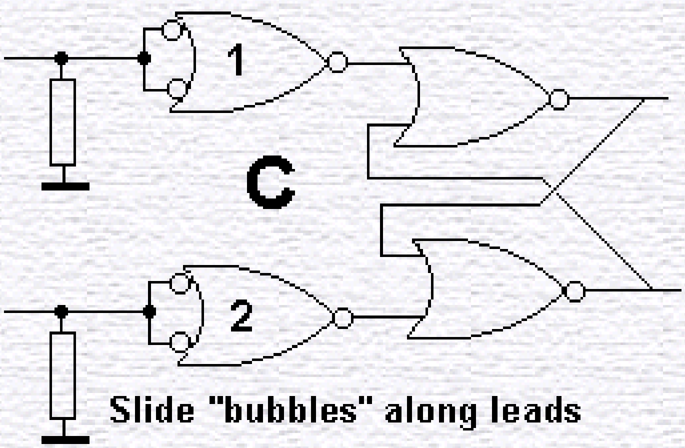
We get from A to B, by changing AND shapes to OR ones, and putting new "bubbles" and removing old ones.

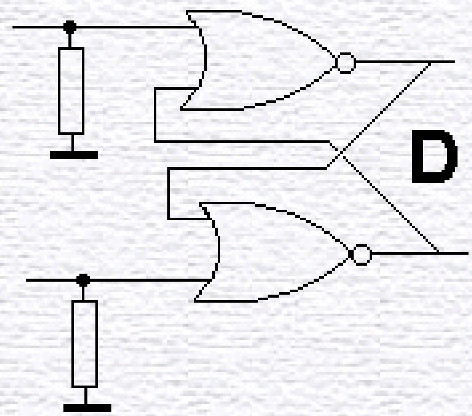
To get from B to C, we slide the "bubbles" on the right hand gates along the leads.

To get from C to D, we remove the left hand gates because they are redundant.
Their outputs go low when activated.
Their inputs are taken low to activate the gates.
The outputs follow the inputs.
Replace the gates with a piece of wire.









Gates 1 and 2 in diagram C have "bubbles" on inputs and outputs. This means that the output goes low when the input goes low. Therefore they are not needed.

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THE HALF ADDER

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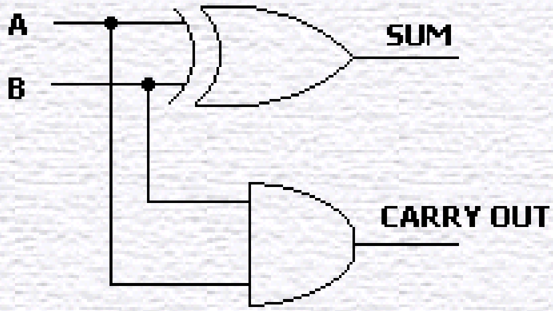

0+0, sum is 0
0+1, sum is 1
1+0, sum is 1
1+1, sum is 0 and 1 to carry. i.e. 10

This adds two 1 bit numbers.

The table shows the outputs.

When A and B are both 0, the sum is 0.

When one is 0 and the other is 1 then the sum is 1.

When both are 1 then the sum is 0 and carry output is 1.

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THE FULL ADDER

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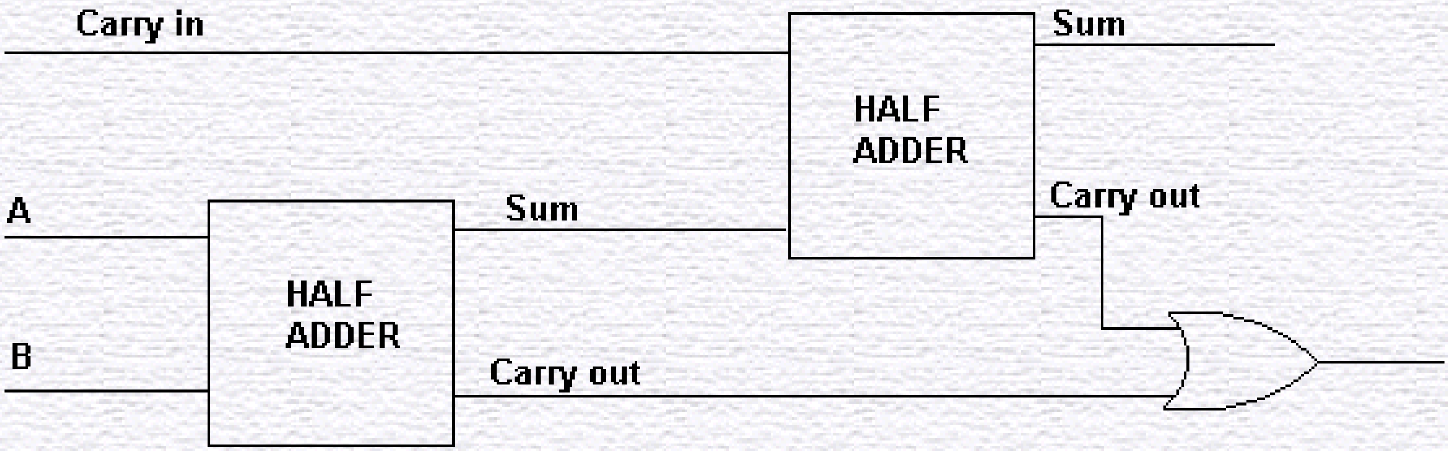

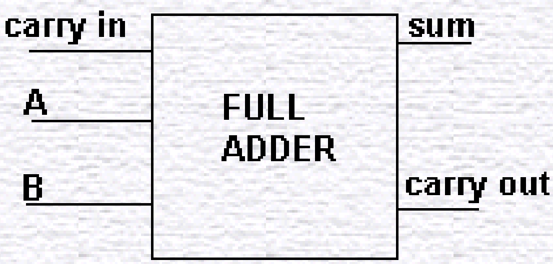

The full adder is made with two half adders.

A CARRY OUT from a previous addition can be added to the bits A and B by means of the CARRY IN.

Draw a truth table, with A, B and CARRY IN as inputs, and SUM and CARRY OUT as outputs.

There is a more detailed description of operation on the page A 3 BIT ADDER.

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A 3 BIT ADDER

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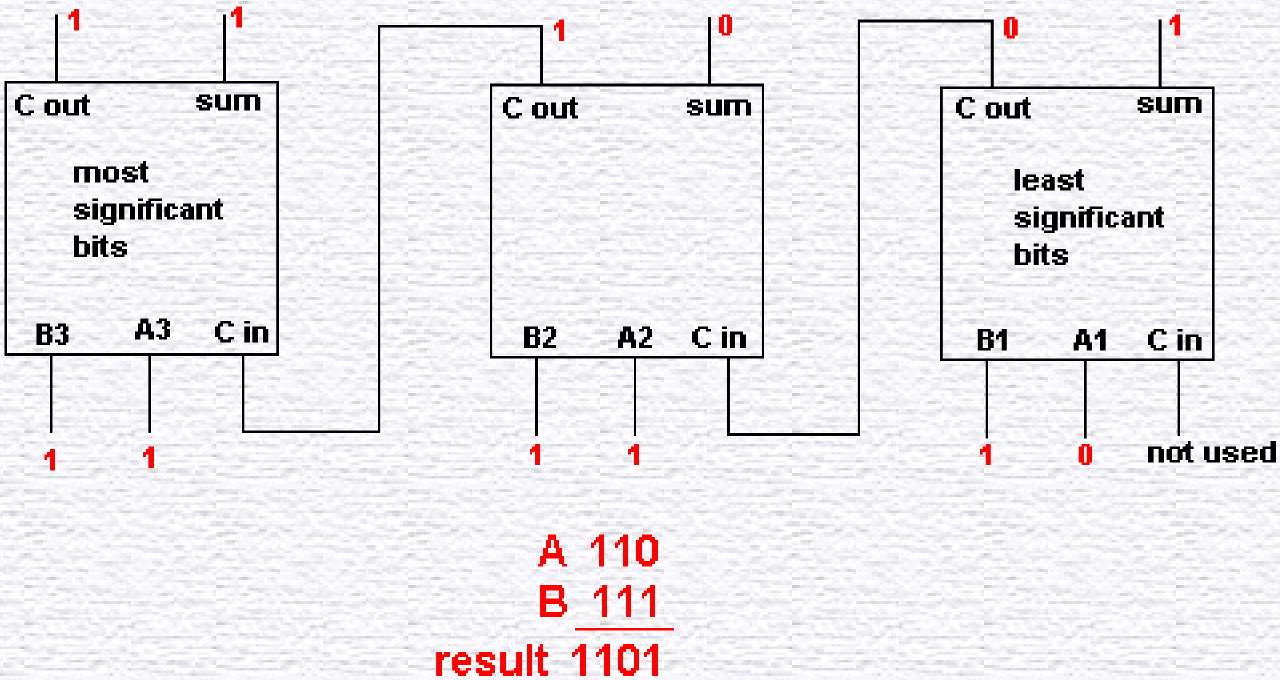
The least significant bits (those on the right) are 0 and 1, giving a sum of 1 with no carry.
There is no carry in from a previous stage.

The next bits are 1 and 1 with no carry in, giving a sum of 0 and a carry of 1.

The most significant bits are both 1 with a carry in of 1.
This gives a sum of 1 and a carry of 1.

The result of adding 110 to 111 is 1101



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ENCODERS

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Encoding means converting one form of data to another type.

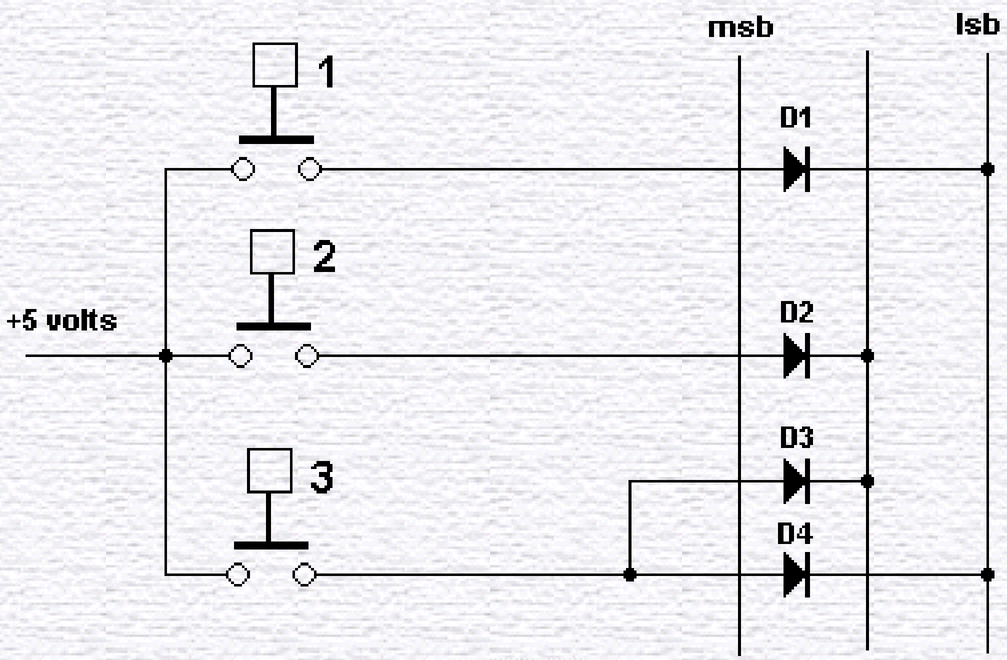
Here we are converting decimal to binary.

When the 1 button is pushed, D1 is forward biased and the least significant bit goes high.
D4 is reverse biased and blocks the + 5 volts from the other lines.

When the 2 button is pushed, D2 conducts and takes the middle bit high.
D3 again blocks the + 5 volts.

When button 3 is pushed, D3 and D4 conduct and take the two lower bits high.

With three lines you can have the binary numbers 000 to111 (decimal 0 to 7) encoded.



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DECODERS

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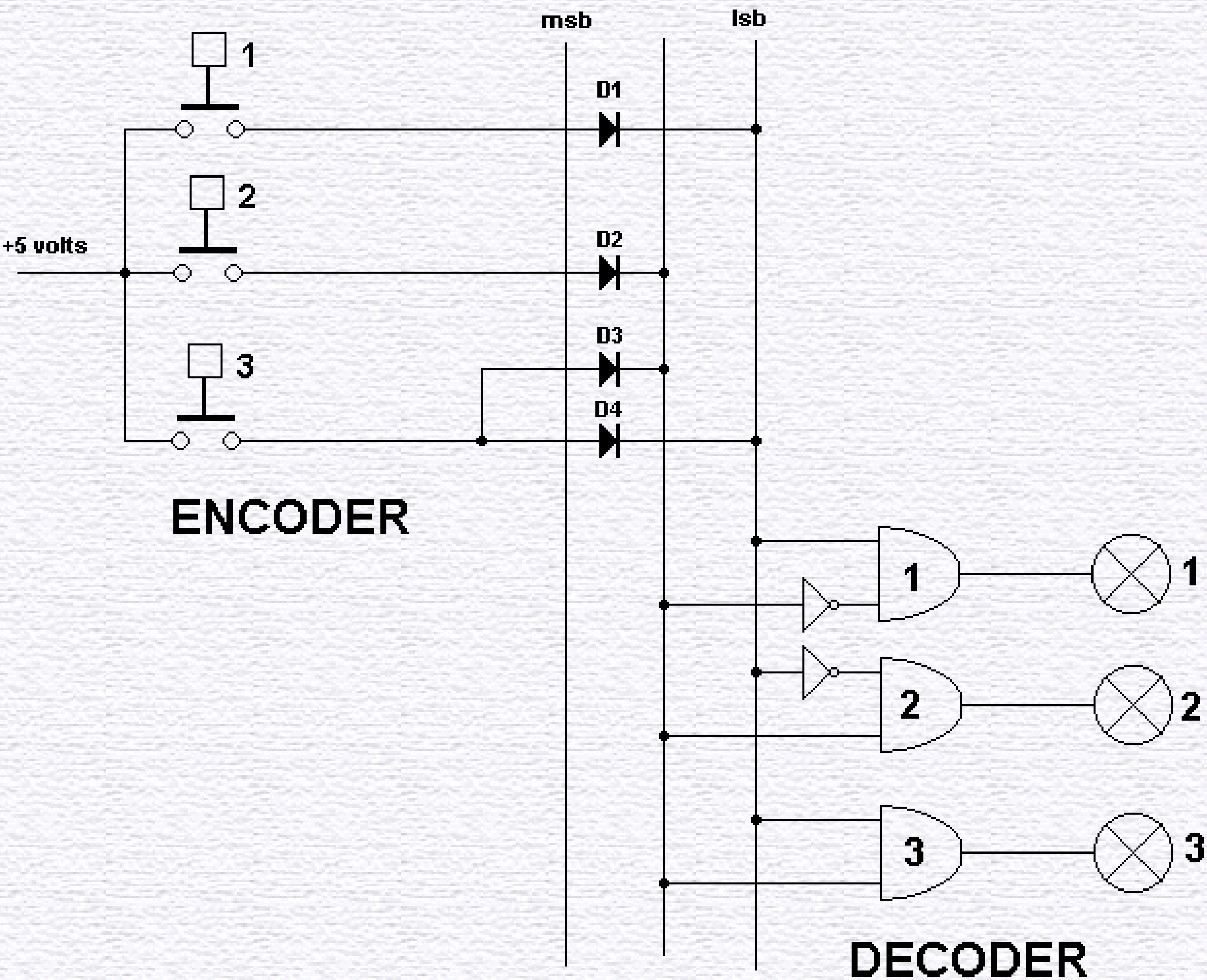
Decoding is the recovery of previously encoded data.

In the diagram, the push buttons ENCODE decimal to binary.

The gates DECODE the binary and turn on the decimal indicators.

Gate 1 recognises when the least significant bit is high and the adjacent bit is low.
The inverter turns the low into a high, so that gate 1 has two high inputs.



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THE 7447A DECODER

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The assignment below is a demonstration of decoders and displays.

The next step is to add a 7490 counter to the inputs.

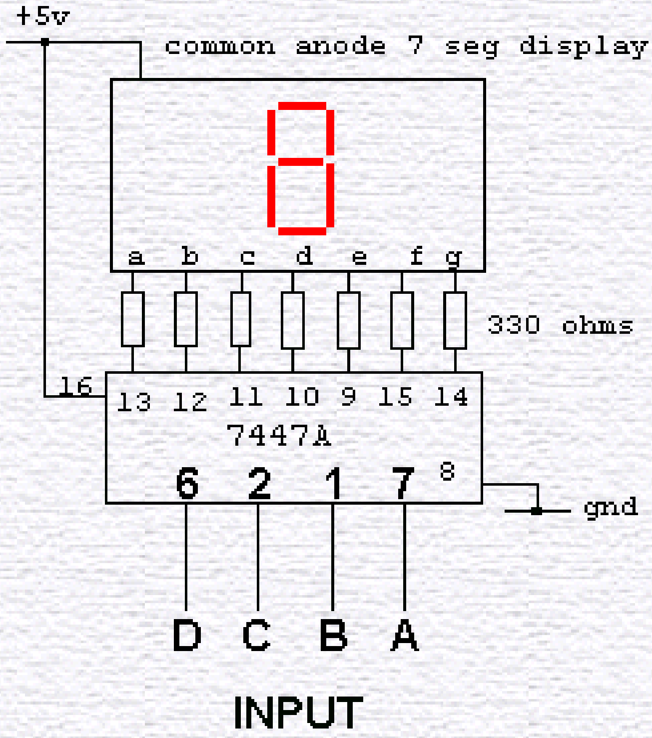
ASSIGNMENT 6

THE 7447A, BINARY TO 7 SEGMENT DISPLAY, DECODER

CONSTRUCT THE CIRCUIT.

APPLY A BINARY NUMBER TO THE INPUT BY TAKING PINS HIGH/LOW.

CHECK THAT THE DISPLAY SHOWS THE DECIMAL EQUIVALENT.



DATE .... STUDENT .... ASSESSOR.......................

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TRI-STATE LOGIC

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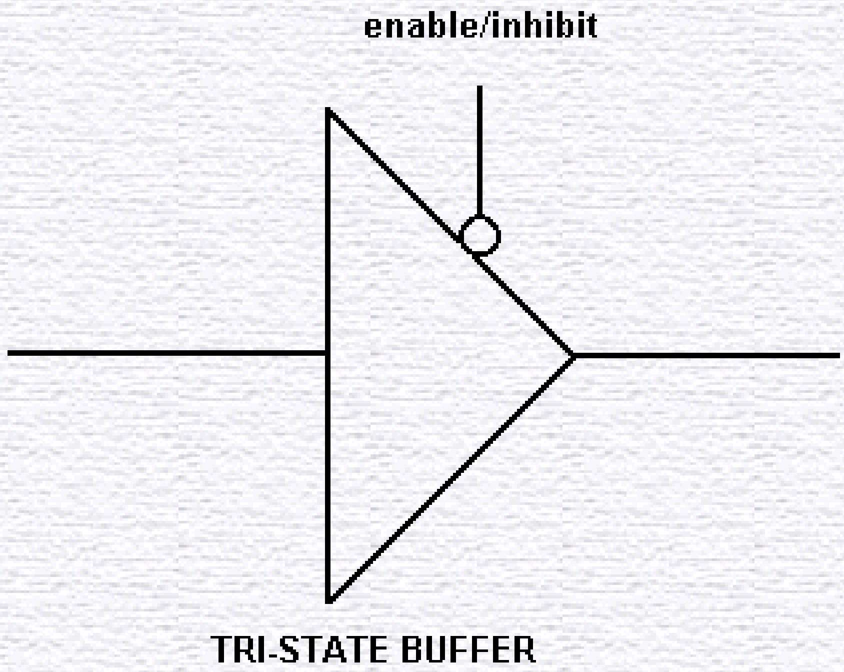


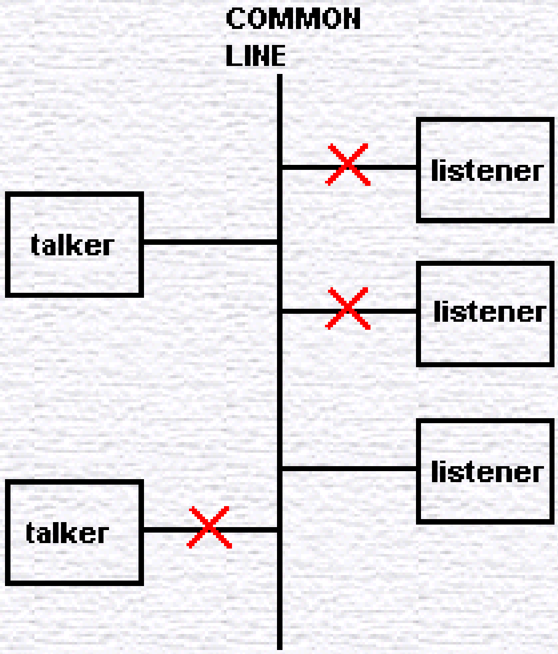
With standard logic gates , the output is either HIGH or LOW.

With tri-state logic there is a third possible condition, the high impedance state, where the output is disconnected from the line.

This is useful where several gates are connected to a line.

Only one is enabled and can go high or low.

The others are disconnected.


COMMON
LINE
listener
talker
listener
listener
talker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A TRANSISTOR FLIP-FLOP

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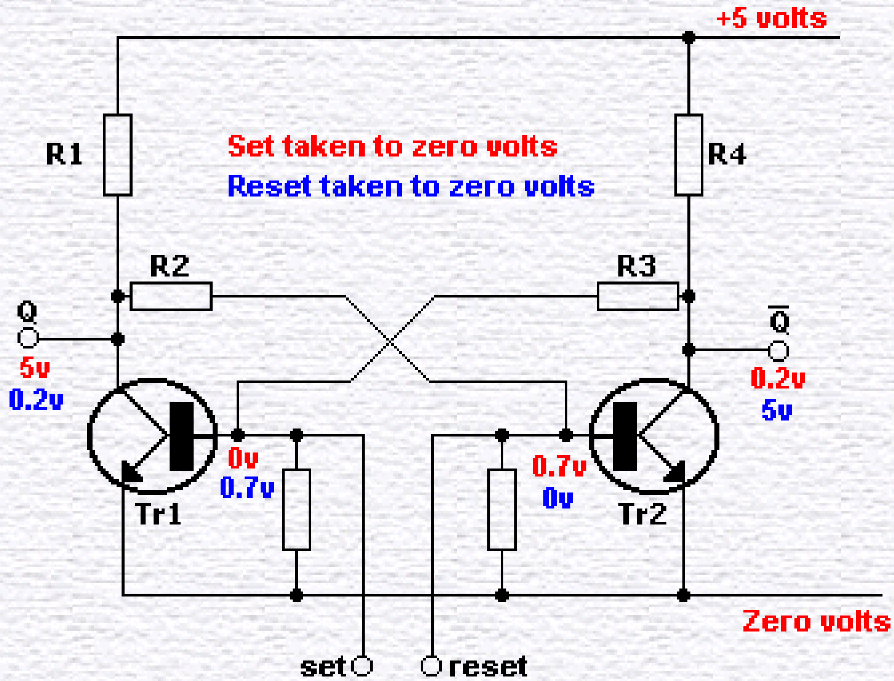

This is a type of bistable multivibrator, with two stable states.

Revising transistor behaviour :-

When a transistor base is connected to zero volts, it is cut off and its collector voltage rises to the supply voltage. See red figures for TR1, and blue for TR2.

When the base is joined to the supply voltage via a low value resistor, the transistor is turned on, and becomes saturated. Its collector volts drops to a very low value.
See the blue values for TR1 and red for TR2.

If SET is taken low (zero volts) thenTR1 is turned off, and its collector voltage turns TR2 on.
Q is high and Q bar is low.

If SET is now removed from the zero volt rail, the two transistors will remain in this state.

To make the flip-flop change state, RESET must now be taken low.

Tr2 will now be off and Tr1 on.

Q will be low and Q bar high.

The flip-flop will rest in this state until SET is again taken low again.

This circuit is known as a SR flip-flop.

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A NOR GATE FLIP-FLOP

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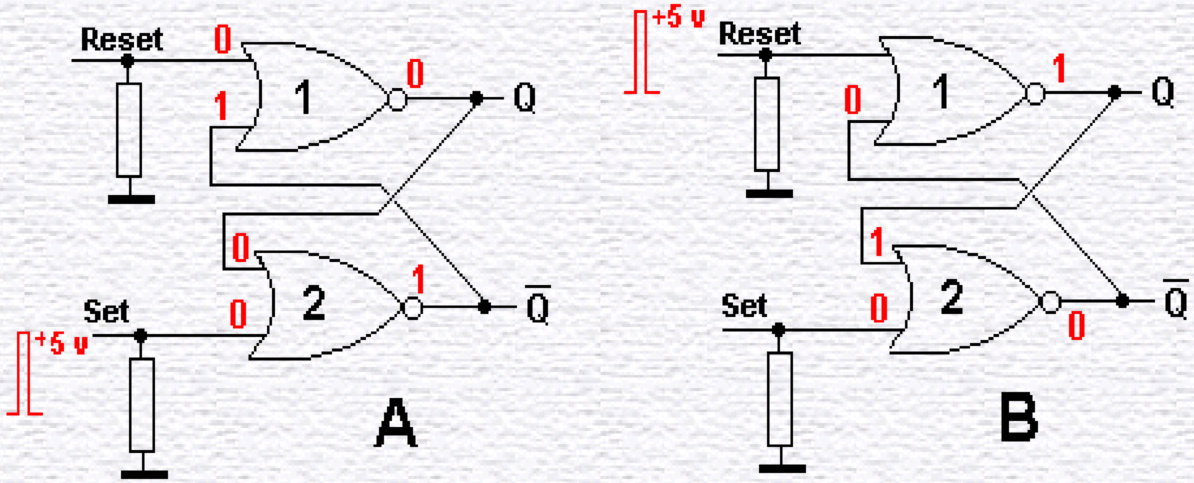

Here, one input of each gate is held LOW by "pull down" resistors.

The other input is cross-coupled to the output of the other gate.

Initially,as shown in diagram A, gate 2 has two LOW inputs, so its output is HIGH.

This HIGH output is one input of gate 1, so the output of gate 1 is LOW.

When the SET input of gate 2 is momentarily pulsed HIGH, the output of gate 2 goes LOW.

This means that both inputs of gate 1 are LOW, so its output is HIGH, which is coupled to an input of gate 2.

Even though the pulse has finished, the output of gate 2 stays LOW because of this HIGH input.

The gates are now in the state shown in diagram B.

We say that the circuit has remembered or LATCHED and is in the SET state.

If the SET is pulsed again,nothing happens,the circuit stays in the SET state.

If the RESET on gate 1 is now pulsed HIGH, the output of gate 1 goes LOW.

This is coupled to gate 2 which now has two LOW inputs, so its output goes HIGH.

The gates have been RESET to their original states.

If the RESET is pulsed again, nothing happens, the circuit stays in the RESET state.

Note that when one output is HIGH, the other is LOW and vice-versa.

If both inputs are taken LOW simultaneously, then there is no change; both inputs are already LOW.

If both inputs are taken HIGH simultaneously, then the result is INDETERMINATE and is to be avoided.

A similar circuit can be constructed using nand gates and pull up resistors.

The inputs are pulsed low to change states.

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SWITCH DEBOUNCING

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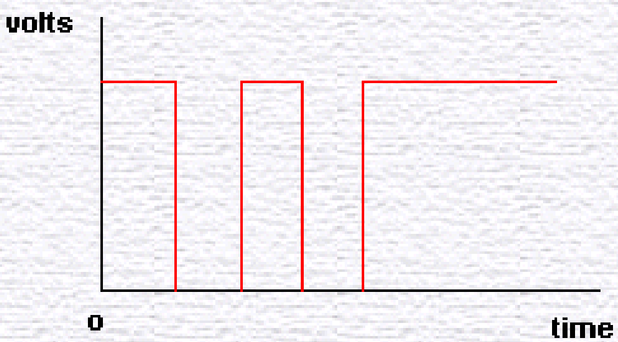

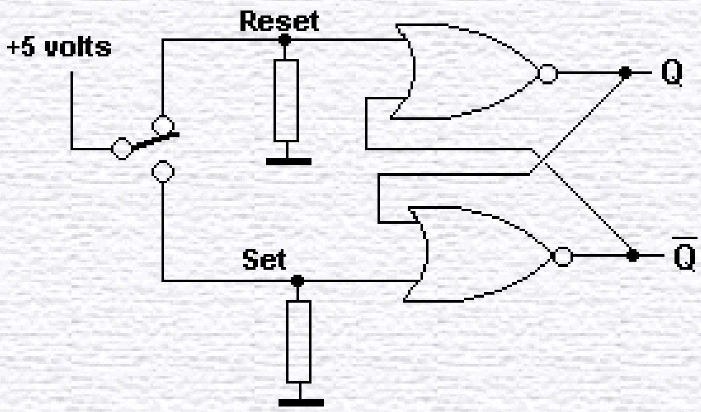

When a mechanical power switch is operated, the power is not available instantly.

The switch contacts bounce, giving a series of pulses, as shown in the graph.

The circuit may see these as a series of logic pulses and behave incorrectly.

The circuit shown prevents this.

If we revise the SET/RESET flip-flop, we will recall that once Q has been pulsed high by the SET input, further pulsing produces no change at Q.

Therefore Q only recognises the first pulse from the bouncing switch and ignores any others.

Similarly, when Q is taken low by taking RESET high, only the first pulse is recognised.

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A HIGH ACTIVATED S-R FLIP-FLOP

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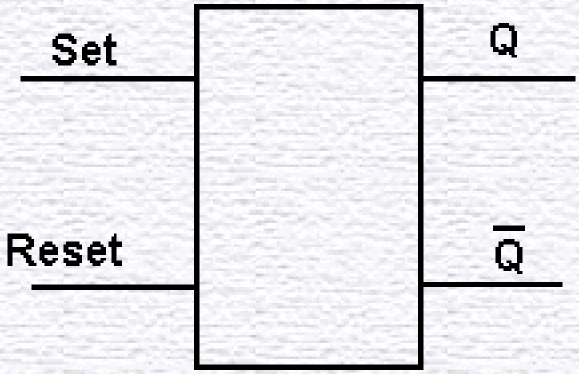

This is how HIGH activated S-R flip-flops appear on circuit diagrams.

When set is taken HIGH, Q goes HIGH and bar Q goes LOW.

If RESET is now take HIGH, Q goes LOW and bar Q goes HIGH

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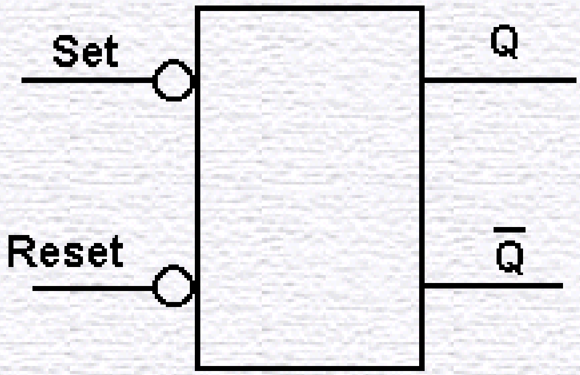
A LOW ACTIVATED S-R FLIP-FLOP



SET and RESET are LOW activated inputs.

When SET is pulsed LOW, Q goes HIGH and bar Q goes LOW.

If RESET is now pulsed LOW, then Q goes LOW and bar Q goes HIGH.

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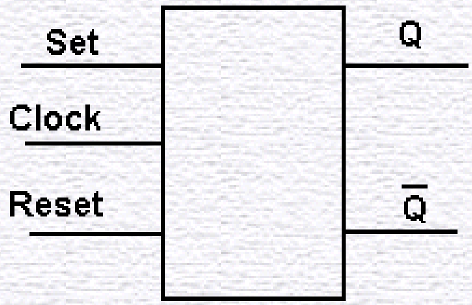
A CLOCKED R-S FLIP-FLOP



To ensure that flip-flops change in synchronism with other parts of the circuit, they are not allowed to change state until they receive a CLOCK PULSE.

SET and RESET cannot affect the outputs unless the clock pulse is high.

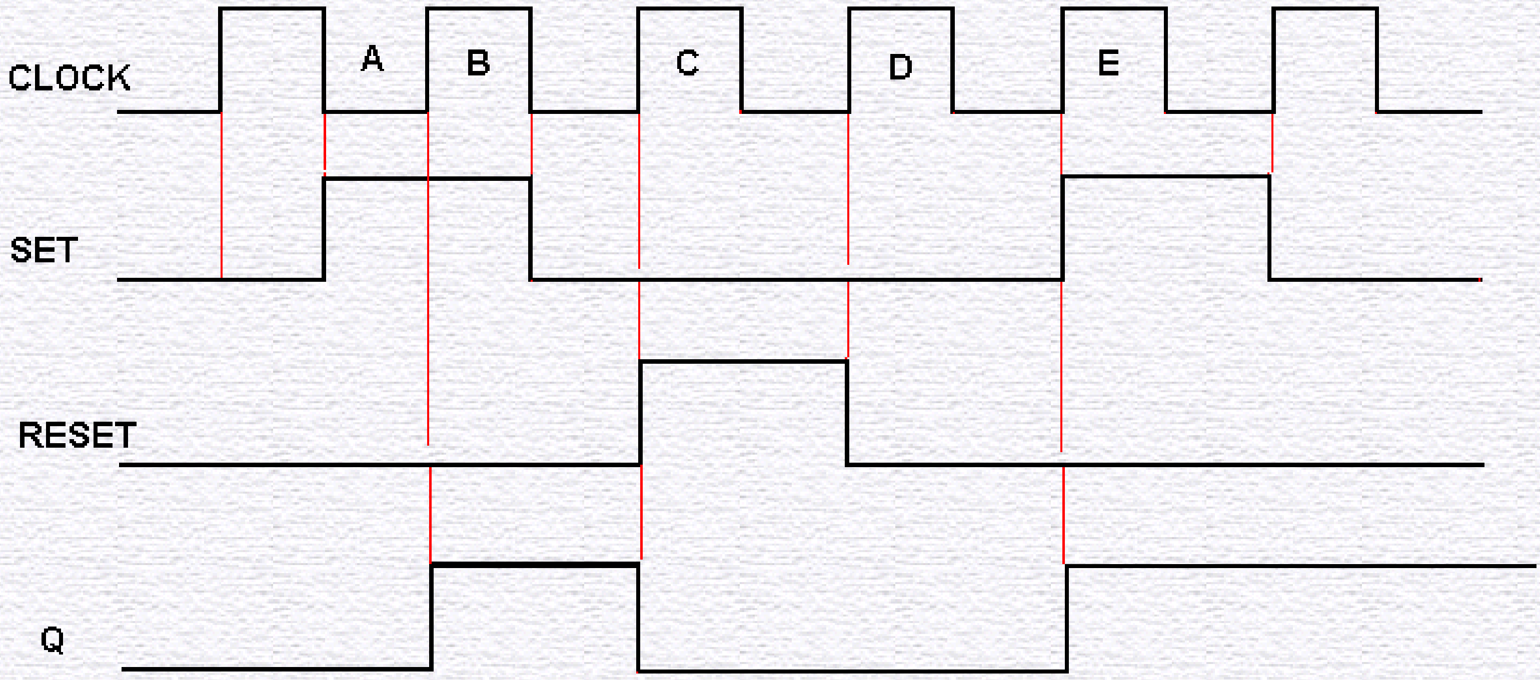
In the TIMING DIAGRAM below, at A, SET is HIGH but the CLOCK is LOW, so there is no change in the outputs.

At B, SET is still HIGH, and CLOCK is HIGH.
Therefore Q goes HIGH.

At C, the CLOCK is HIGH and RESET has gone HIGH.
Therefore Q goes LOW.

At D, the CLOCK is HIGH but SET is LOW.
There is no change in output levels.

At E, CLOCK and SET are both HIGH.
Q goes HIGH.



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A CLOCKED D TYPE FLIP-FLOP

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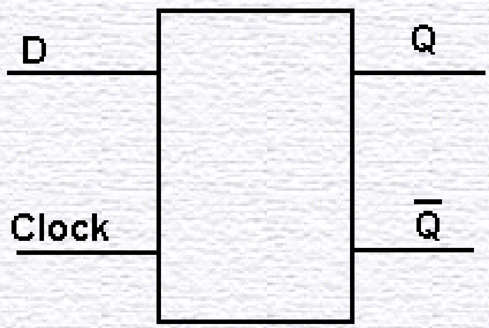


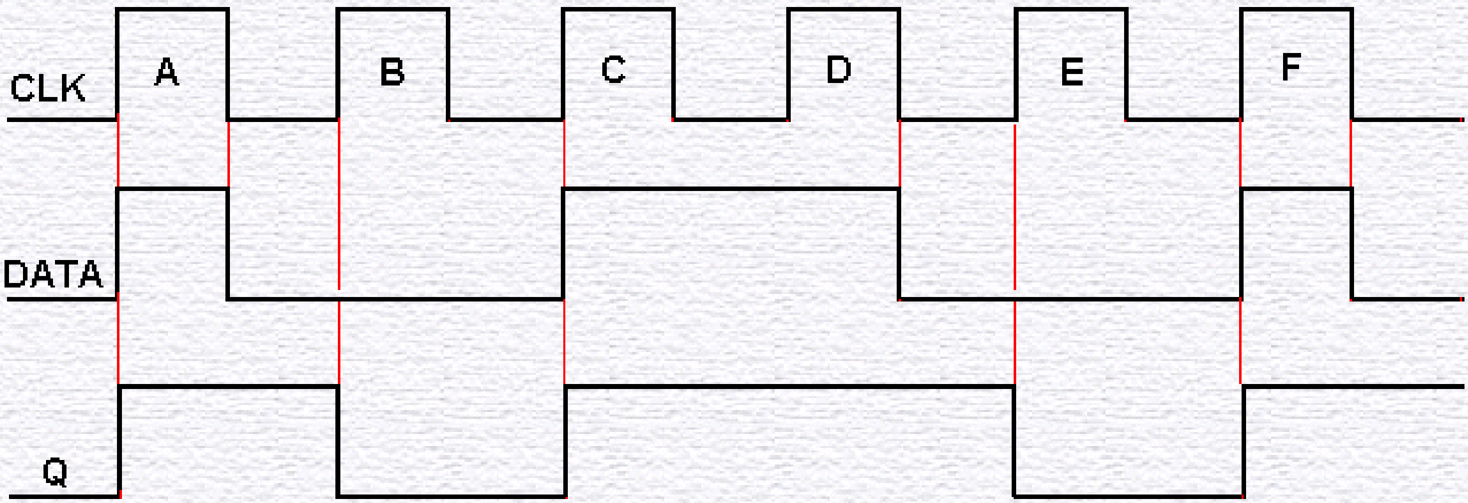
The D type flip-flop has only one input (D for Data) apart from the clock.

The INDETERMINATE state is avoided with this flip-flop.

When the clock goes high, D (a 0 or a 1) is transferred to Q.

When the clock goes low, Q remains unchanged.

Q stores the data until the clock goes high again, when new data may be available.



At A, clock and data are high.
Q goes high and stays high until B.

At B, clock is high and data is low.
Q goes low and stays low until C.

At C, clock and data are both high.
Q goes high and stays high until E.
Q does not change during clock pulse D, because clock and data are still both high.

At E, data is low, so Q goes low.

At F, data is high so Q goes high.

AN EDGE TRIGGERED FLIP-FLOP

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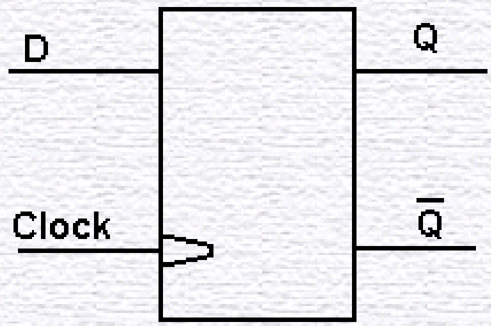


We looked at the clocked D type flip-flop previously.

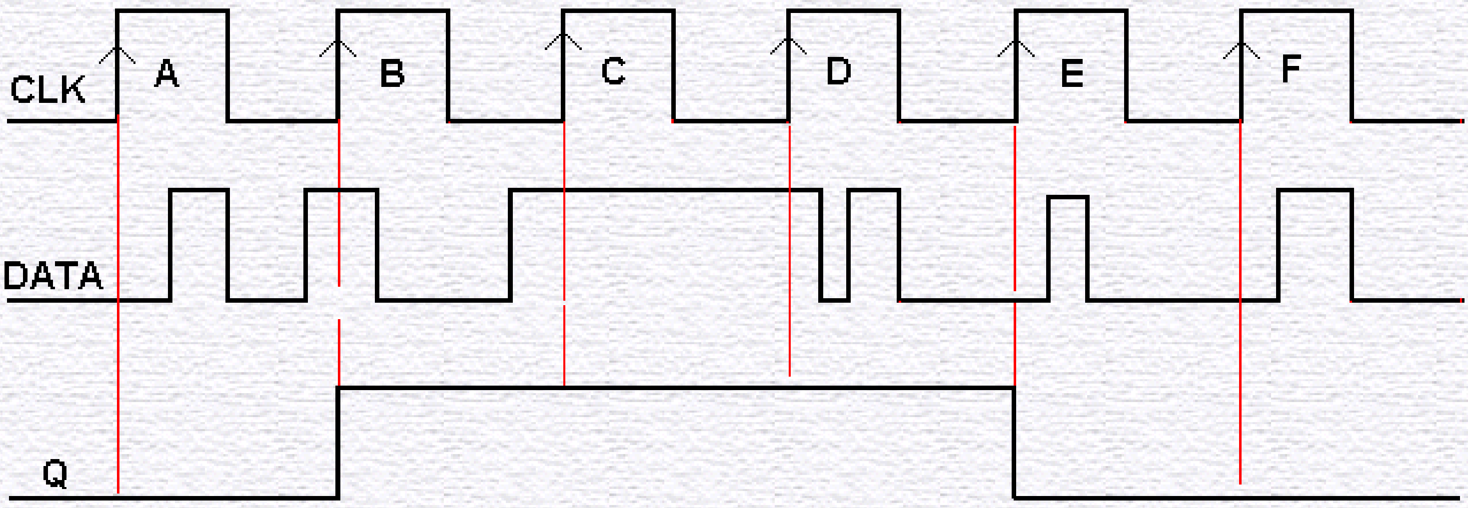
Q follows D while the clock is high.

If the data at D changes during the clock pulse, then Q will change.

This may be undesirable.

With the edge triggered flip-flop, Q will only follow D during the instant of the clock edge.

Either clock pulse edge may be used, positive going (rising) or negative going (falling).
The symbol above is for a rising edge clock.



The timing diagram shows the rising edges of the clock pulses.

At edge A, data is low, and even though there is a positive pulse during the clock period, Q stays low.

At edge B, data is high and Q goes goes high.

At edge C, data is still high and Q stays high.

At edge D, data is still high and Q stays high.

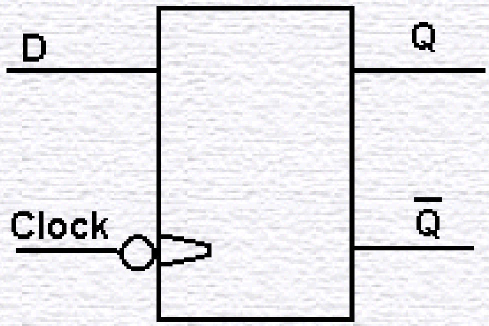
During clock pulse D, data goes low for a period, but Q stays high.

At edge E, data has gone low and Q goes low.

Data goes high for a period during clock pulse E, but Q stays low.

At edge F, data is still low and Q stays low.

Below is a negative edge clocked flip-flop.



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A TOGGLE TYPE FLIP-FLOP

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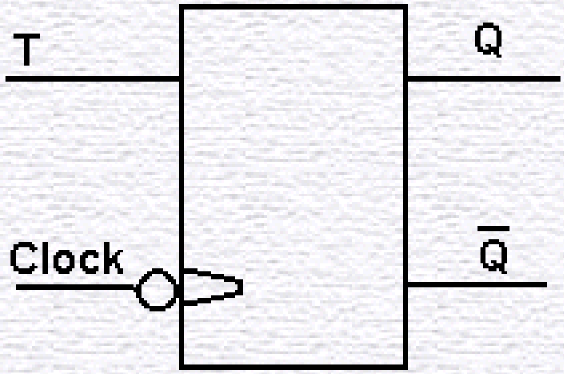


This flip-flop toggles (Q changes state) on the negative going edge of the clock pulse.

T acts as an ENABLE / INHIBIT control.

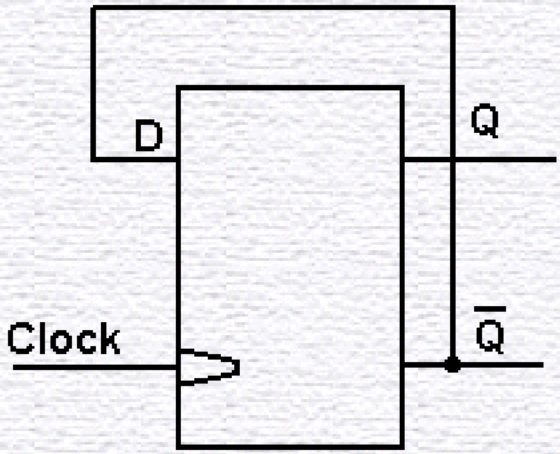
Q will only toggle on the negative edge of the clock pulse, when T is high.

Below is shown a D type flip-flop connected as a toggle type.

On each clock pulse positive going edge, Q will go to the state bar Q was before the clock pulse arrived.

Remember that bar Q is the opposite level to Q.

Therefore Q will toggle.



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A MASTER/SLAVE D TYPE FLIP-FLOP

A couple of definitions :-

RIPPLE THROUGH. An input changes level during the clock period, and the change appears at the output.

PROPAGATION DELAY. The time between applying a signal to an input, and the resulting change in the output.

These can give problems in logic circuits.

The master/slave flip-flop overcomes them.

It consists of two rising edge triggered D type flip-flops.

The clock of the slave is fed via an inverter so that the falling edge of the origonal clock pulse becomes a rising edge.
The slave clock pulse is an inverted version of the clock pulse shown in the lower diagram.

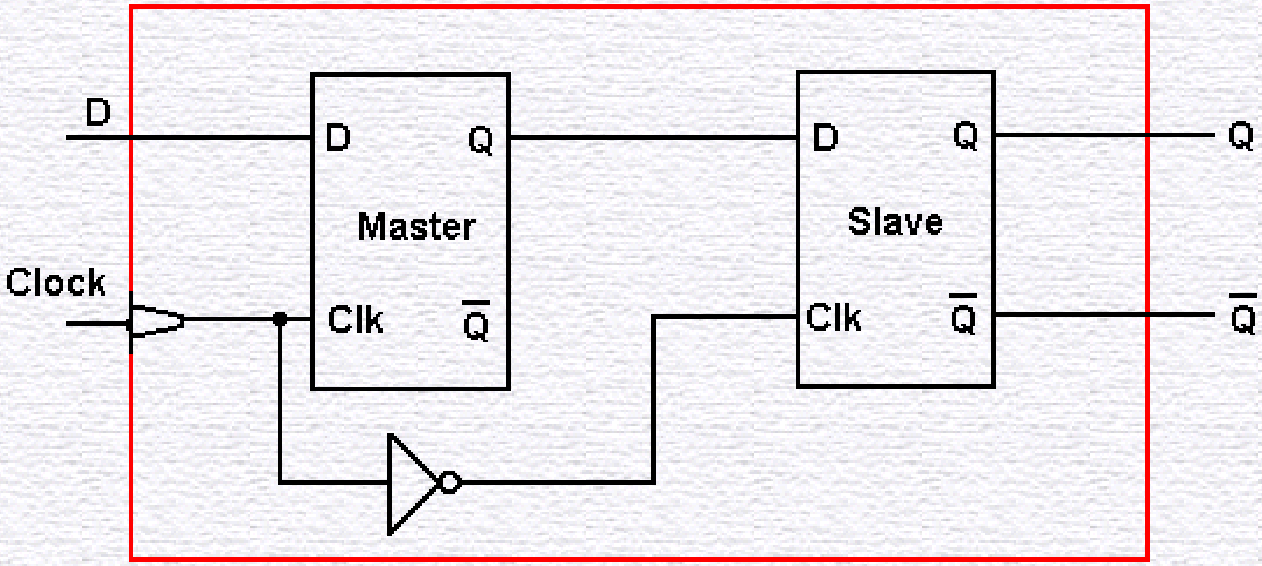
The flip-flops are triggered at different levels of the clock pulse edge.

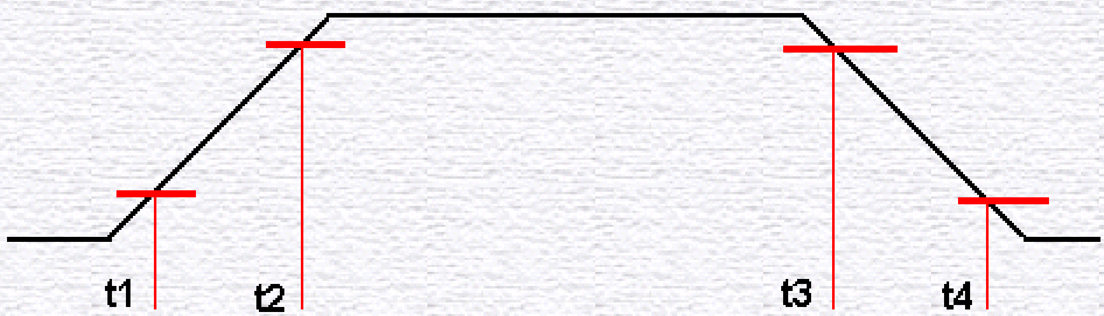
When data is to be entered, the slave is isolated from the master, so that changes at the input do not appear at the output.

Data on D is passed to Q of the master.

The master is then isolated from the D input.

Data, from the Q of the master, is passed to Q of the slave.





t1. Slave isolated from Master.

t2. Master connected to D input.

t3. Master isolated from D input.

t4. Master Q connected Slave D.

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A J-K MASTER/SLAVE FLIP-FLOP

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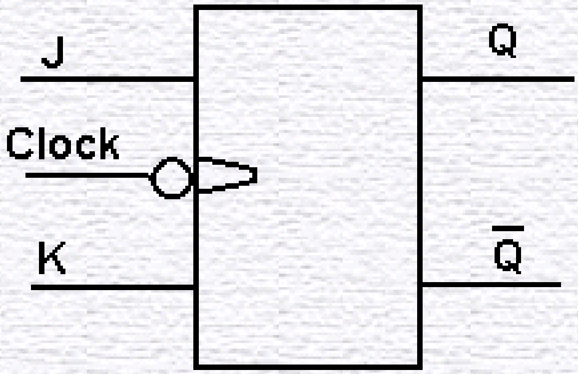

The J-K flip-flop can be wired to behave as most other types of flip-flop.

If J is high and K is low, Q will go high on the negative going edge of the clock pulse.

If K is high and J is low, Q will go low on the negative going edge of the clock pulse.

If J and K are both low, Q will not change.

If J and K are both high, the output toggles on the negative going edge of the clock pulse.

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A J-K WITH SET AND RESET FLIP-FLOP

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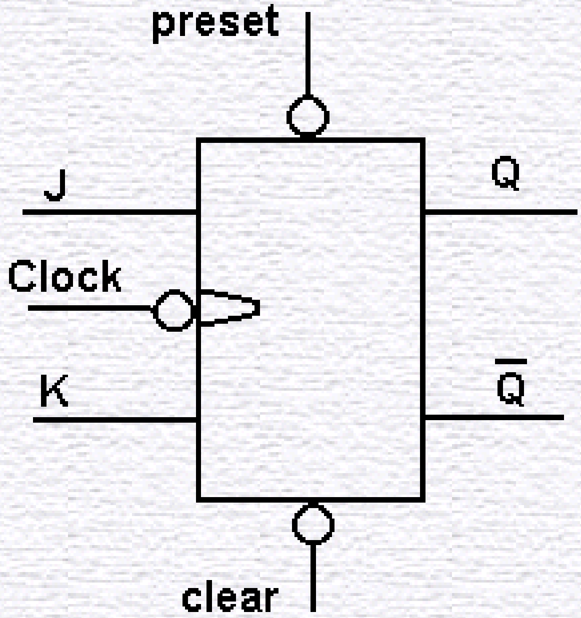

The J and K inputs are said to be SYNCHRONOUS with the clock pulse.

Their effect on the outputs occurs during the negative edge of the clock pulse.

The preset and clear are independent of the clock pulse and are ASYNCHRONOUS inputs.

With preset low and clear high, Q is set high.

With preset high and clear low, Q is set low.

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THE ASYNCHRONOUS UP COUNTER

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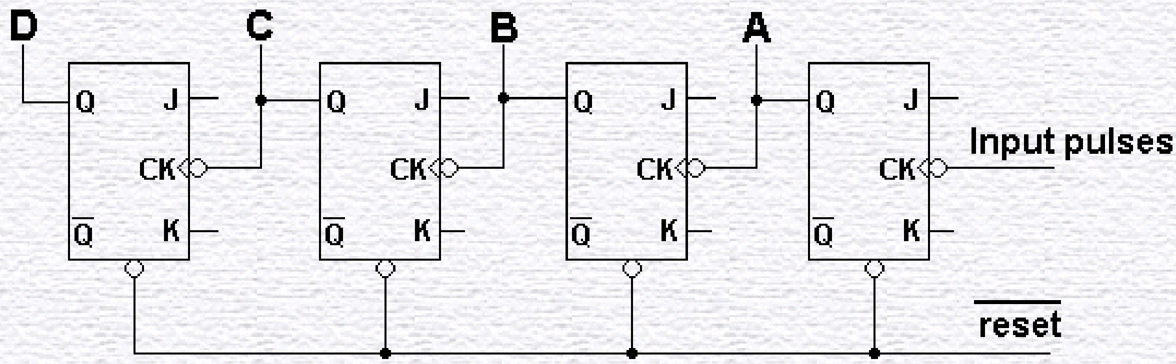


Note that the J and K inputs are taken high so that the flip-flops toggle on the clock pulses.

The Q output of each flip-flop changes state on the negative going edge of the clock input pulse.

Looking at the diagram below the count starts with ABCD all low, giving a count of 0000.

After clock pulse 1, the least significant bit, A is high, 0001.

After pulse 2, A is low and B is high, 0010, equivalent to decimal 2.

After 12 pulses, A and B are low and C and D are high, 1100, equivalent to decimal 12.

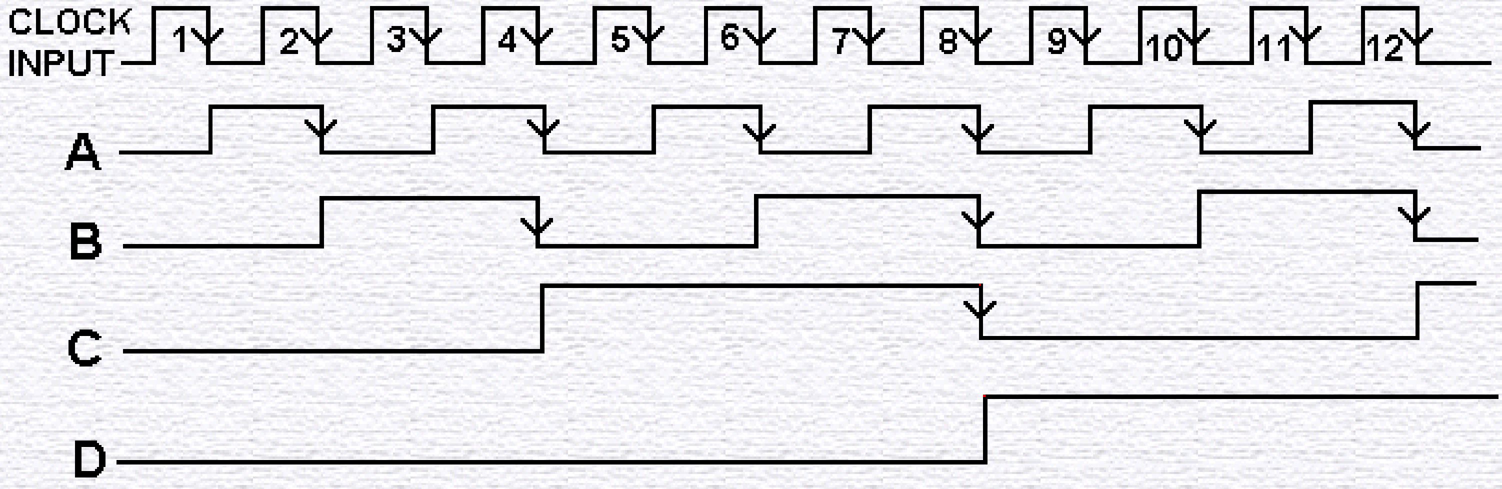
On clock pulse 16 the counter resets to 0000.

The count can be set to 0000 by pulsing the Reset line low.

The flip-flops cannot change state until the preceding one has done so.

This means gives rise to a delay in the the system due to the propagation delay of each stage.

This causes a RIPPLE THROUGH effect.



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THE ASYNCHRONOUS DOWN COUNTER

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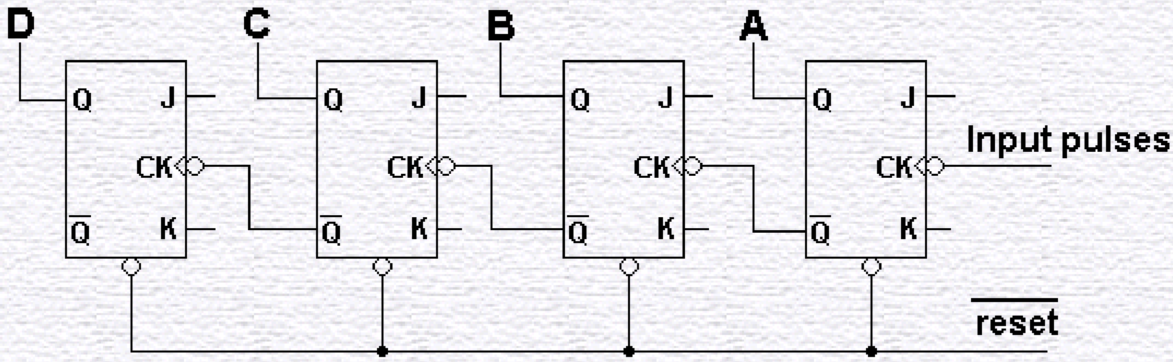


The flip-flop outputs change state on the positive going edges of the clock input pulses.

Looking at the diagram below, at the start on the left, ABCD are all high, 1111, equivalent to decimal 15.

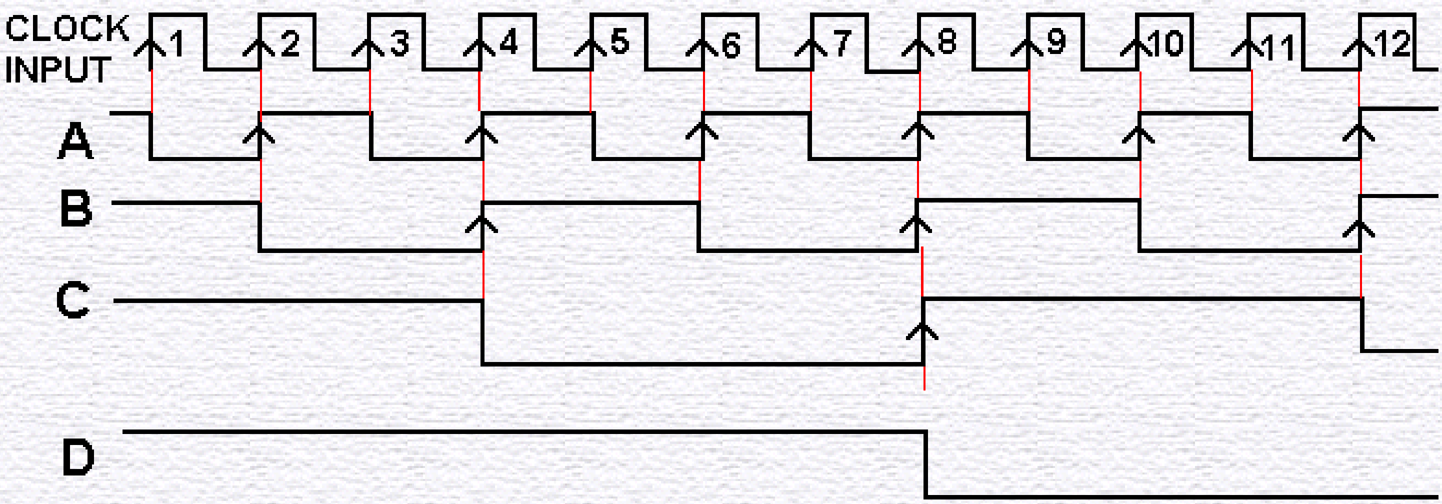
After clock pulse 1, A has gone low giving 1110, the equivalent of decimal 14.

After clock pulse 2, the count is 1101, decimal 13.

After 8 pulses the count is 0111, decimal 7. 15-8 = 7

After 15 pulses the count will be 0000.

On the next pulse the counter will indicate 1111.



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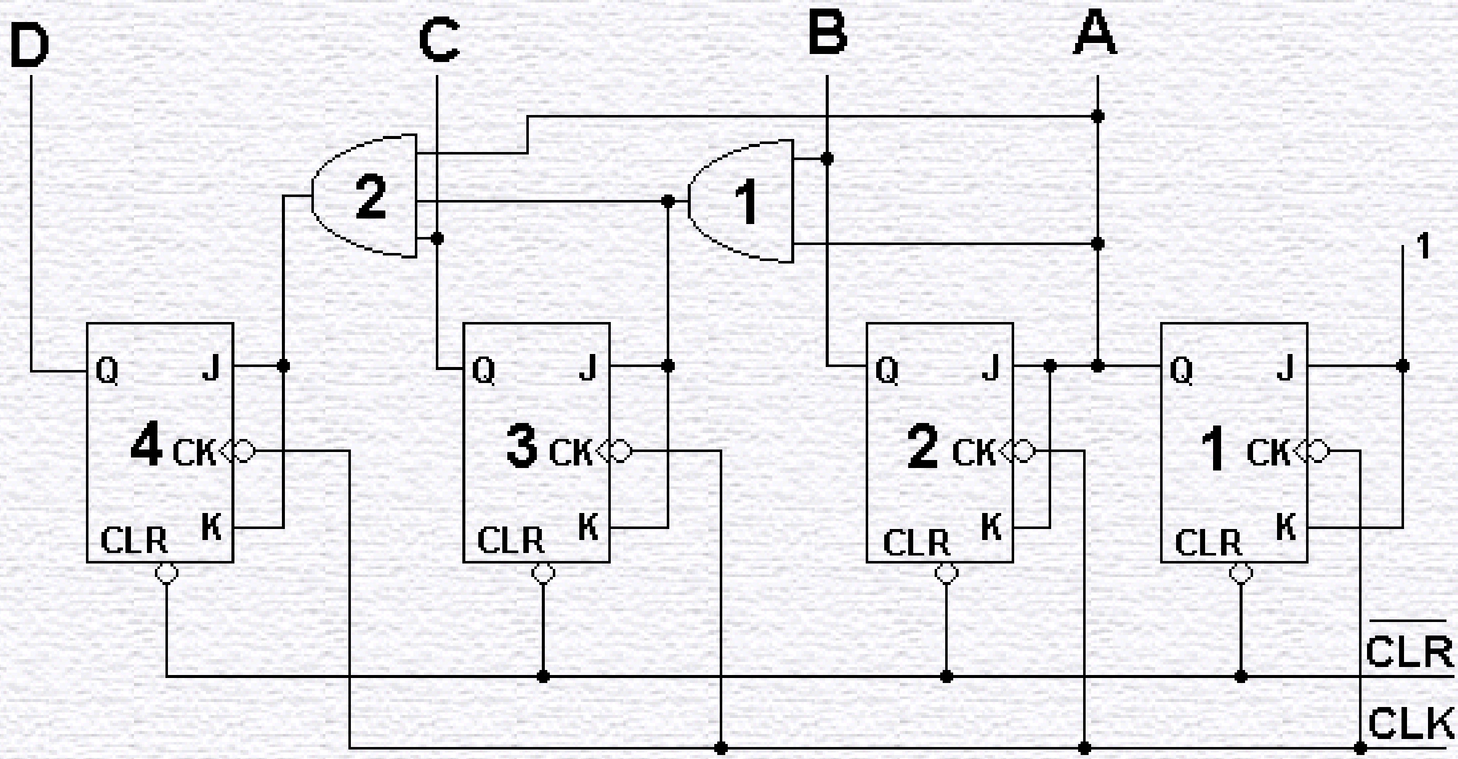
SYNCHRONOUS COUNTERS



To overcome the "ripple through" effects of asynchronous counters,synchronous types are used.

All the flip-flops are clocked simultaneously, and change state at the same time.

Bear in mind, that when J and K are both low, a flip-flop will not change state, upon the arrival of a clock pulse.

When J and K are both high, then Q will toggle upon the arrival of a clock pulse.

The two AND gates are decoders, which recognise the state of the A, B and C outputs.

J and K of flip-flop 1 are tied high and it will always toggle on a clock pulse.

Flip-flop 3 cannot change state unless AND 1 output is high

(A and B high).

Flip-flop 4 cannot change state unless A, B and C are all high, making the output of AND 2 high.

At the start, all outputs can be set to zero by means of the CLEAR line.

On the first clock pulse, A goes high, since J and K of flip-flop 1 are both tied high.

The first and second flip-flops are now set to toggle on the next clock pulse.

On the second clock pulse, any flip-flops with J and K high will toggle.

So A goes low and B goes high.

On the third clock pulse, A goes high and B stays high.

This means that J and K of flip-flop 3 are high.

On the fourth clock pulse, A and B go low and C goes high.

Flip-flop 4 can only toggle when A, B and C are all high.

This will be on the eighth clock pulse, when D goes high and A, B and C go low.

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DIVIDERS

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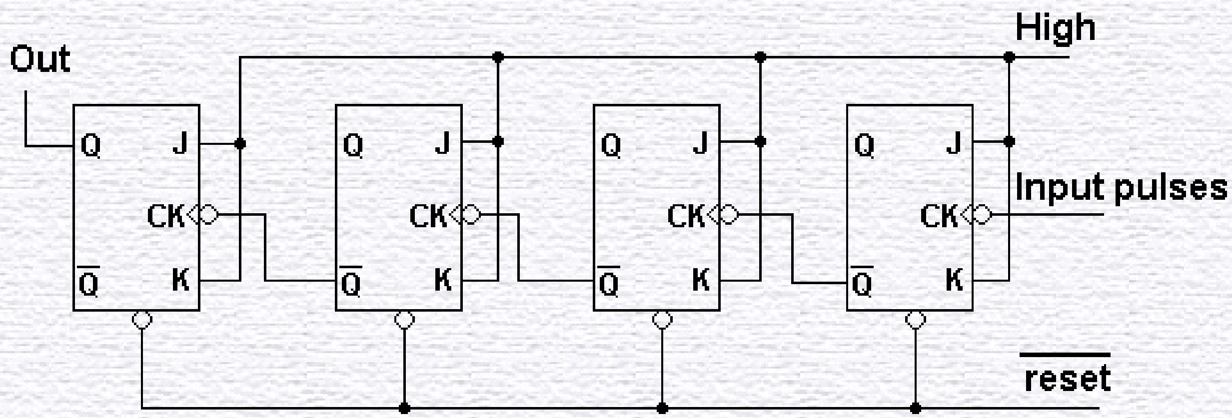

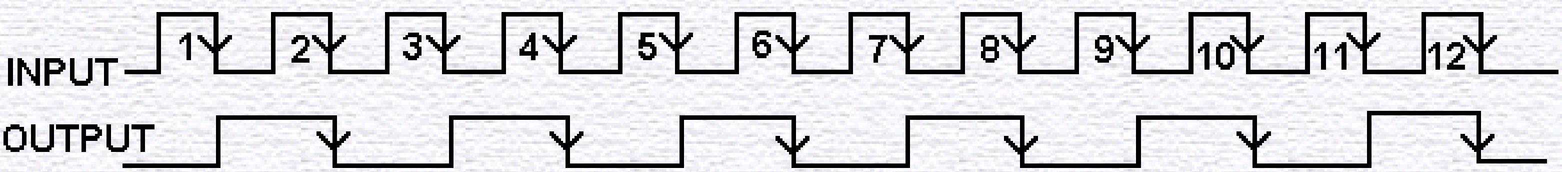

For every two pulses in, a toggle flip-flop gives one pulse out.

It divides by two.

For 800 pulses in, the flip-flop will give 400 out.

In the circuit above, each stage divides by two, giving a total division of sixteen.

For an input frequency of 16 kHz, the output frequency will be 1 kHz.

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DECADE COUNTERS

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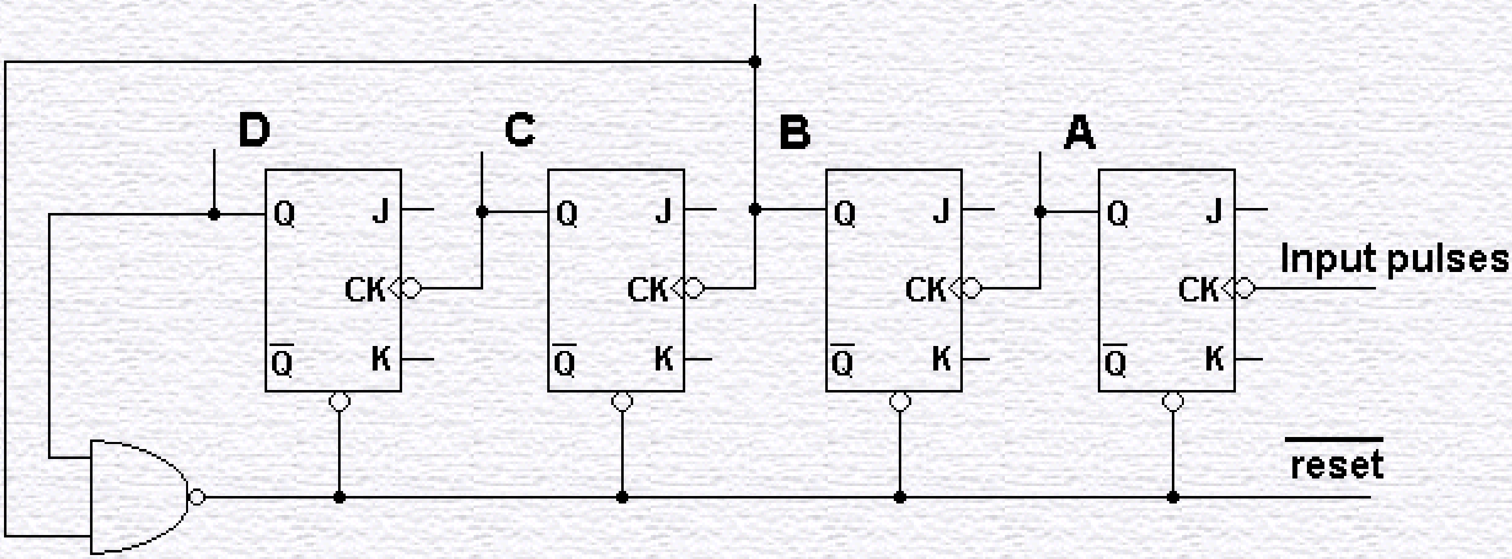


A decade counter counts from 0 to 9 and then resets to zero.

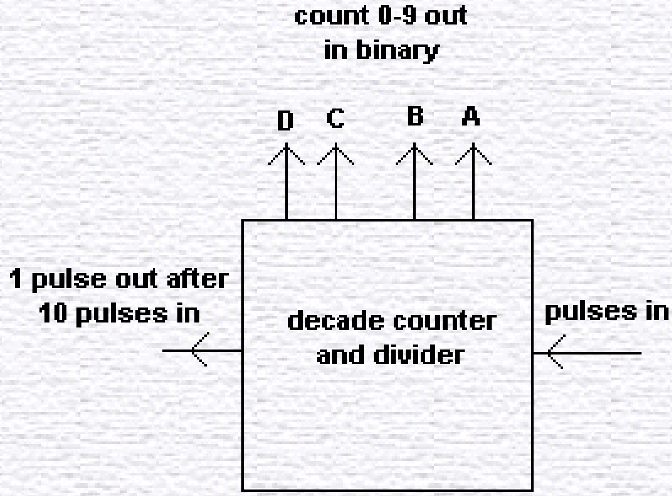
The counter output can be set to zero by pulsing the reset line low.

The count then increments on each clock pulse until it reaches 1001 (decimal 9).

When it increments to 1010 (decimal 10) both inputs of the nand gate go high.

The result is that the nand output goes low, and resets the counter to zero.

D going low can be a CARRY OUT signal, indicating that there has been a count of ten.


count 0-9 out
in binary
D
C
B
A
1 pulse out after
10 pulses in
decade counter
and divider
pulses in

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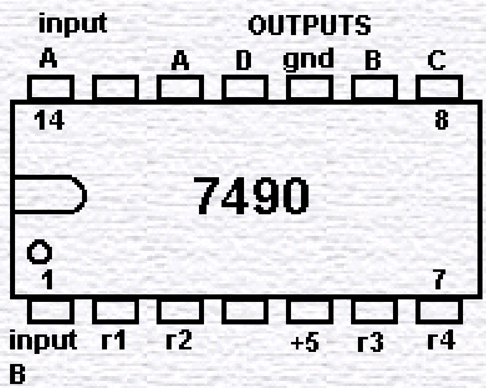
THE 7490 COUNTER

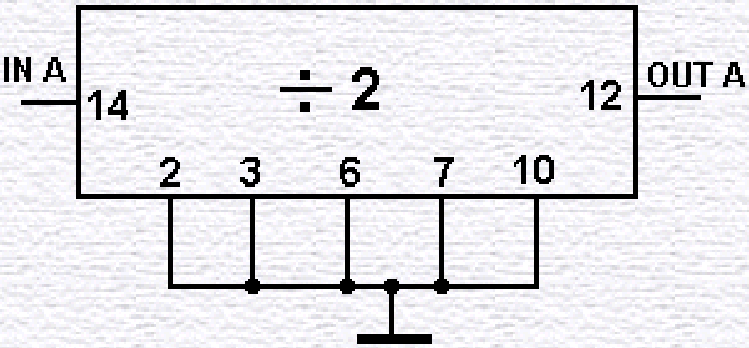
CLICK HERE TO BUY THE CD

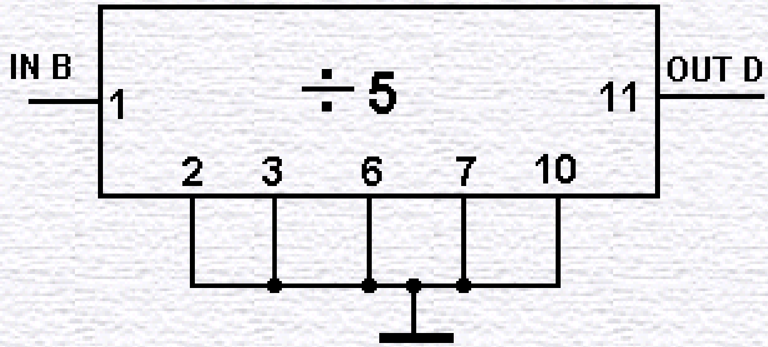


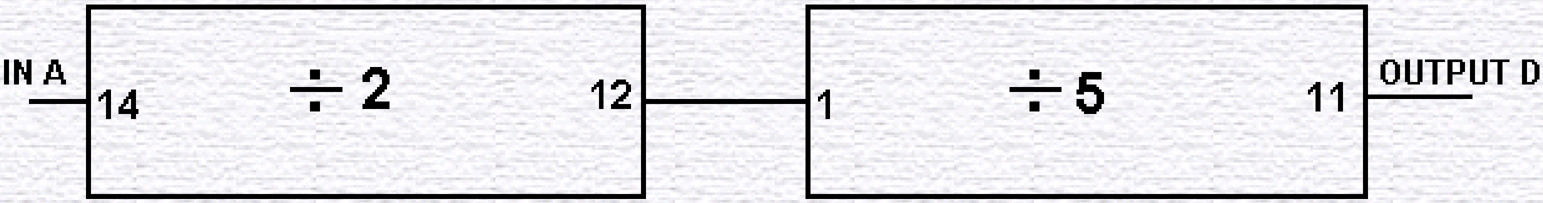
The 7490 is a ripple through counter.

It contains a divide-by-two counter and a divide-by -five counter.

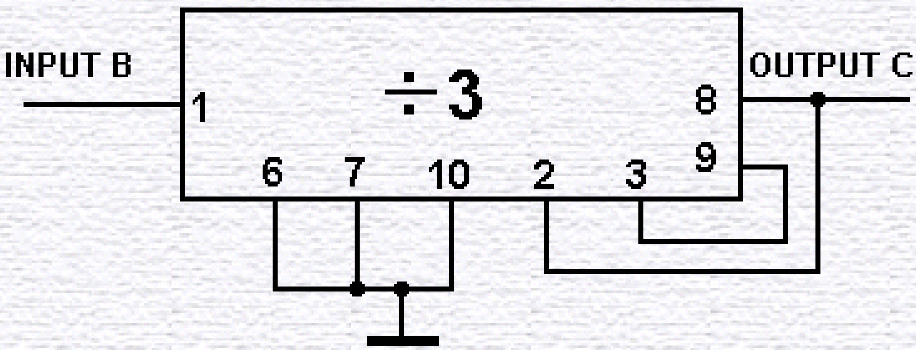
These can be connected in various ways to give other divisions.







DIVIDE BY 10



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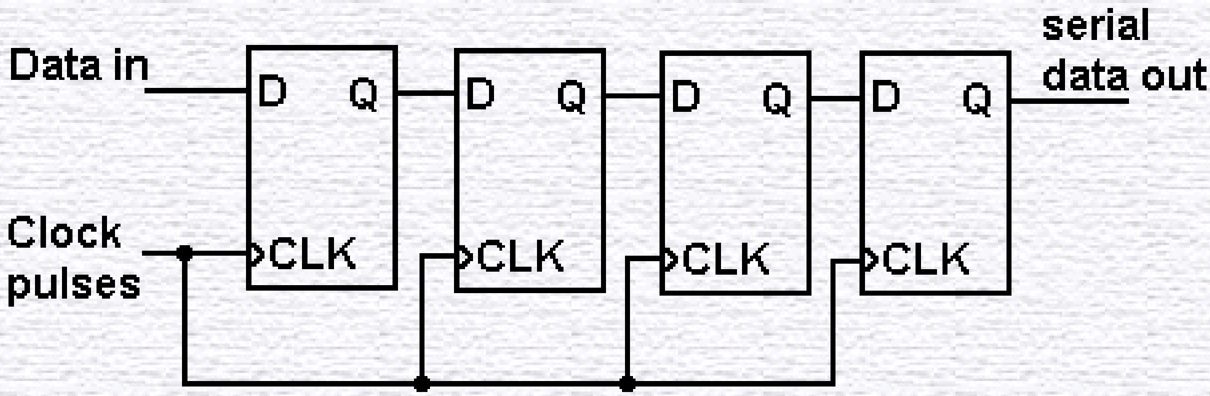
SISO SHIFT REGISTERS



The diagram shows four flip-flops connected to form a SERIAL IN, SERIAL OUT shift register.

Upon the arrival of a clock pulse, data at the D input of each flip-flop is transferred to its Q output.

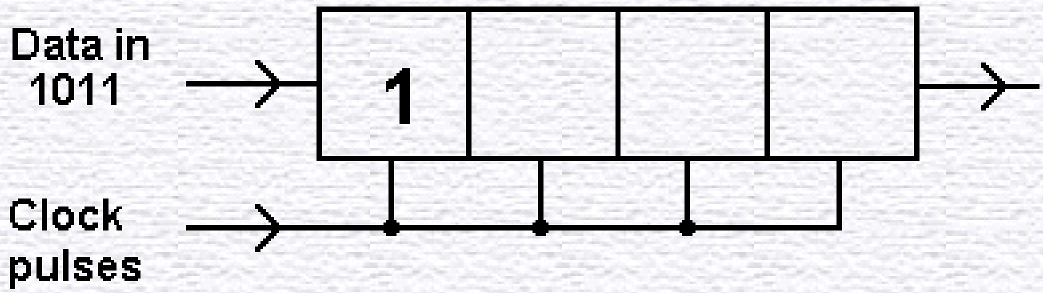
At the start, the contents of the register can be set to zero by means of the CLEAR line.

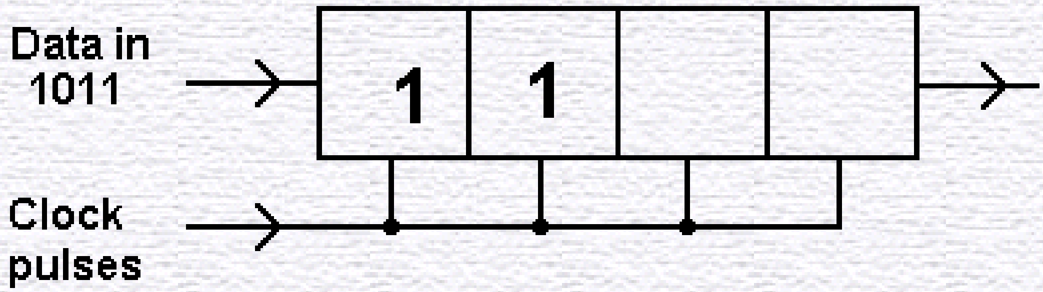
If a 1 is applied to the input of the first flip-flop, then upon the arrival of the first clock pulse, this 1 is transferred to the output of flip-flop 1 (input of flip-flop 2).

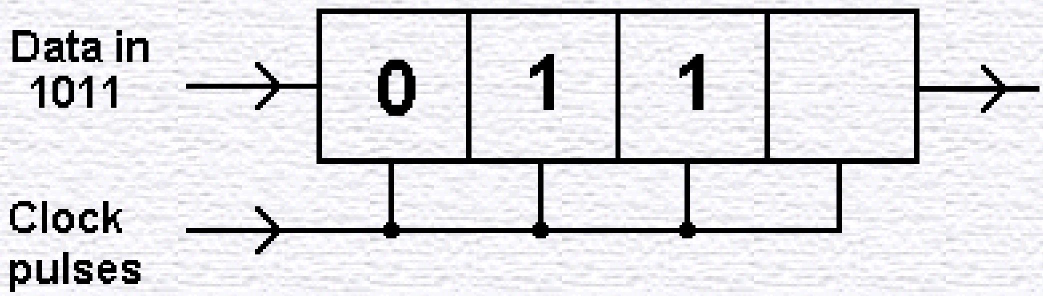
After four clock pulses this 1 will be at the output of flip-flop 4.

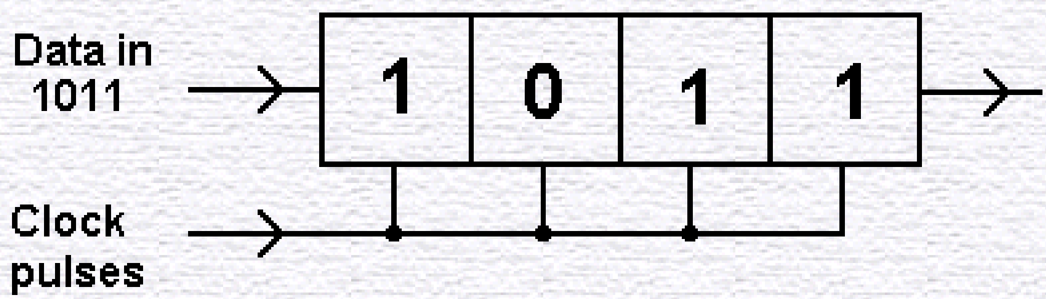
In this manner, a four bit number can be stored in the register.

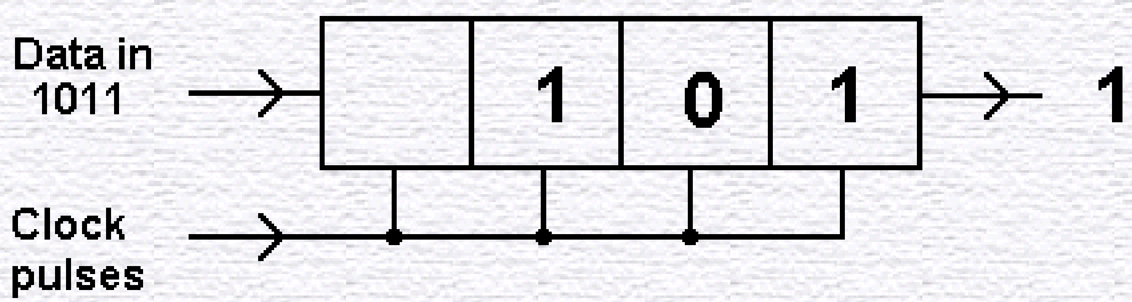
After four more clock pulses, this data will be shifted out of the register.


Data in
1011
1
Clock
pulses


Data in
1011
1
1
Clock
pulses


Data in
1011
0
1
1
Clock
pulses


Data in
1011
1
0
1
1
Clock
pulses


Data in
1011
1
0
1
1
Clock
pulses

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THE SIPO SHIFT REGISTER

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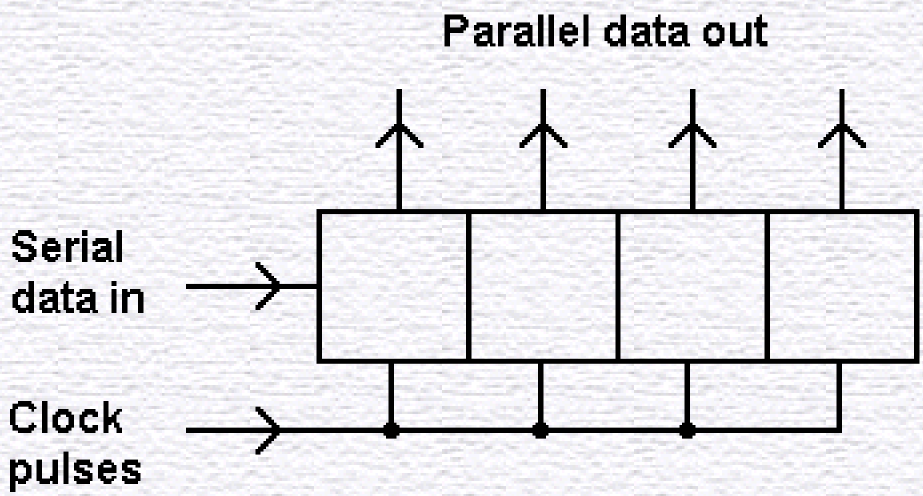

Data is fed into the SERIAL IN/PARALLEL OUT shift register bit by bit, in the same way as for the SISO shift register.

However the four bits are all shifted out simultaneously, in parallel, as one word.

THE PISO SHIFT REGISTER

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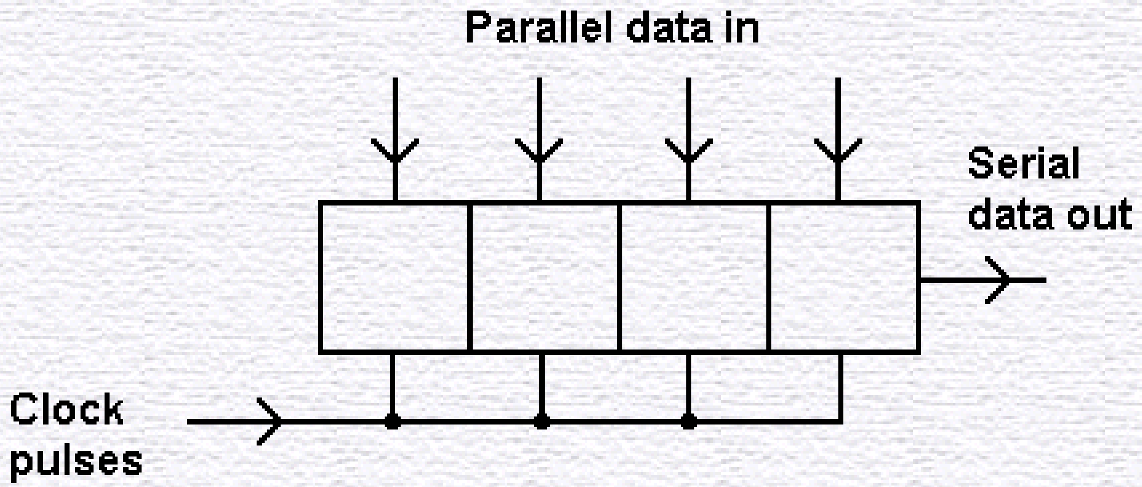

With the PARALLEL IN/SERIAL OUT shift register, four bits are shifted into the register simultaneously, in parallel.

They are then clocked out,one after the other, in serial form.

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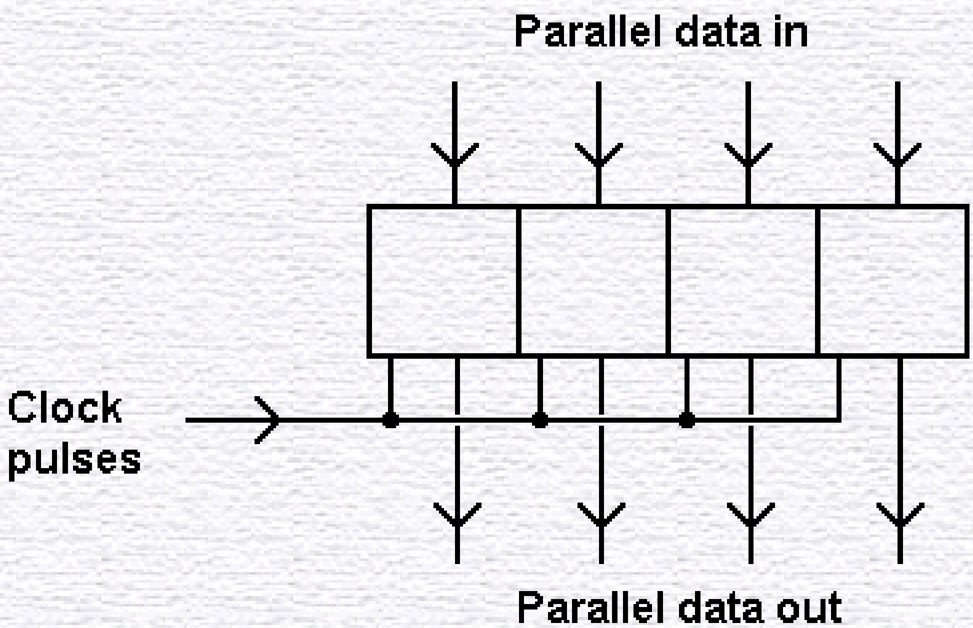
THE PIPO SHIFT REGISTER

CLICK HERE TO BUY THE CD



The PARALLEL IN/PARALLEL OUT shift register is loaded with four bits simultaneously, in parallel..

They are also clocked out simultaneously, in parallel.

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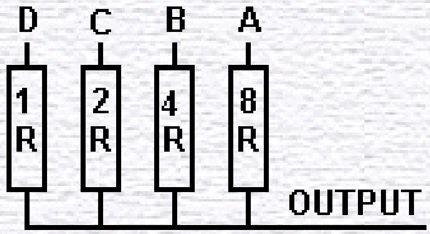
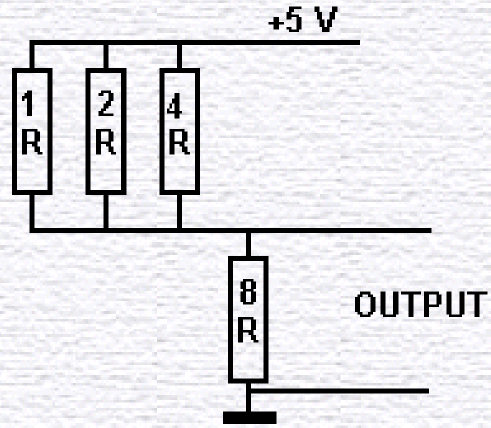
THE DIGITAL TO ANALOGUE CONVERTER

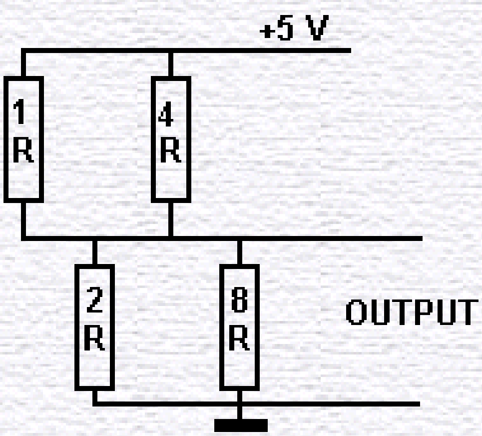
CLICK HERE TO BUY THE CD





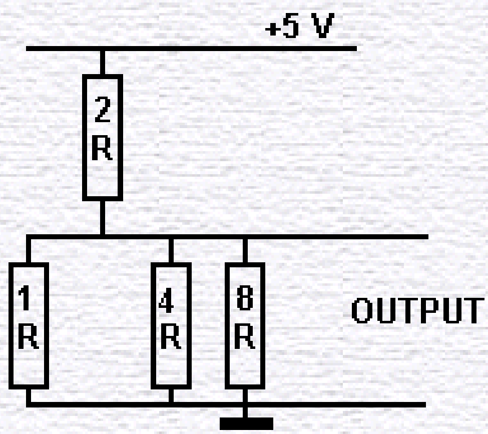
The 4 bit D to A converter consists of four resistors, whose values are in the ratios shown in the left hand diagram above.

They can go high or low, as shown in the right diagram.



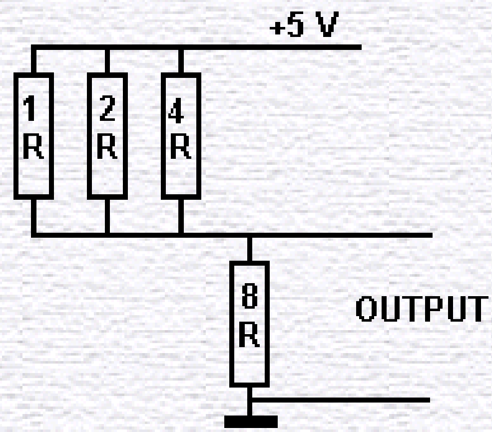
D C B A
1 0 1 0 (Decimal 10)

OUT = 10/15 OF 5 VOLTS



D C B A
0 1 0 0 (Decimal 4)

OUT = 4/15 OF 5 VOLTS



D C B A
1 1 1 0 (Decimal 14)

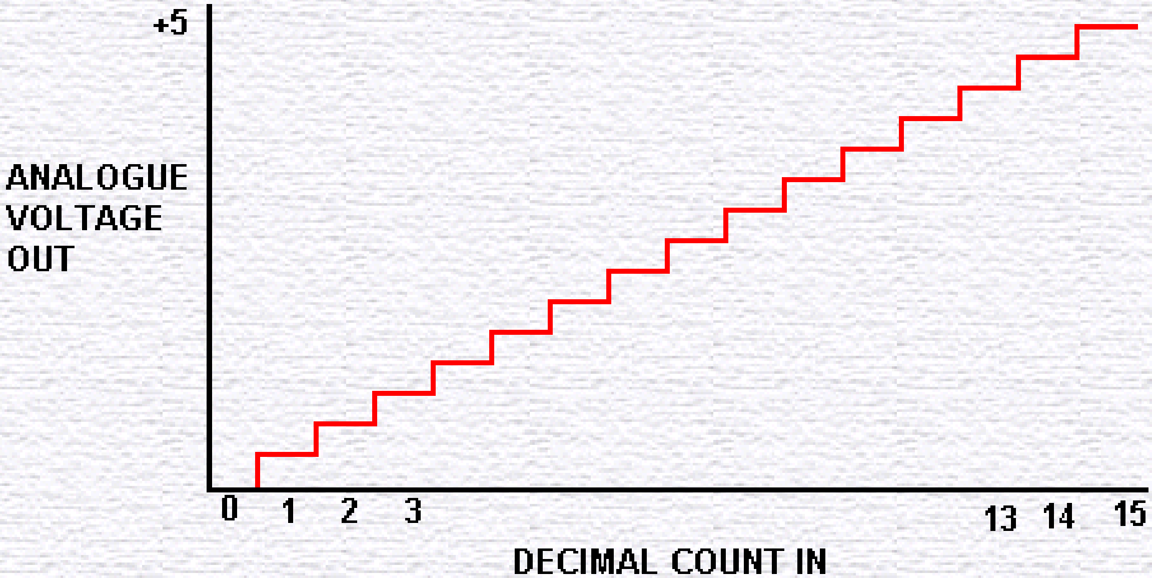
OUT = 14/15 OF 5 VOLTS

The voltage out is determined by which of A B C D are high and which are low.

The resistors are usually not "hard wired" high or low as shown, but taken high or low by signal voltages.

D C B A

0 0 0 0
0 0 0 1
0 0 1 0
0 0 1 1
0 1 0 0
0 1 0 1
0 1 1 0
0 1 1 1
1 0 0 0
1 0 0 1
1 0 1 0
1 0 1 1
1 1 0 0
1 1 0 1
1 1 1 0
1 1 1 1



The digital signals at A B C D can be between 0000 and 1111, which gives 16 steps, suitable for a volume control etc.

If finer resolution is required, then 8 bits can give 256 steps.

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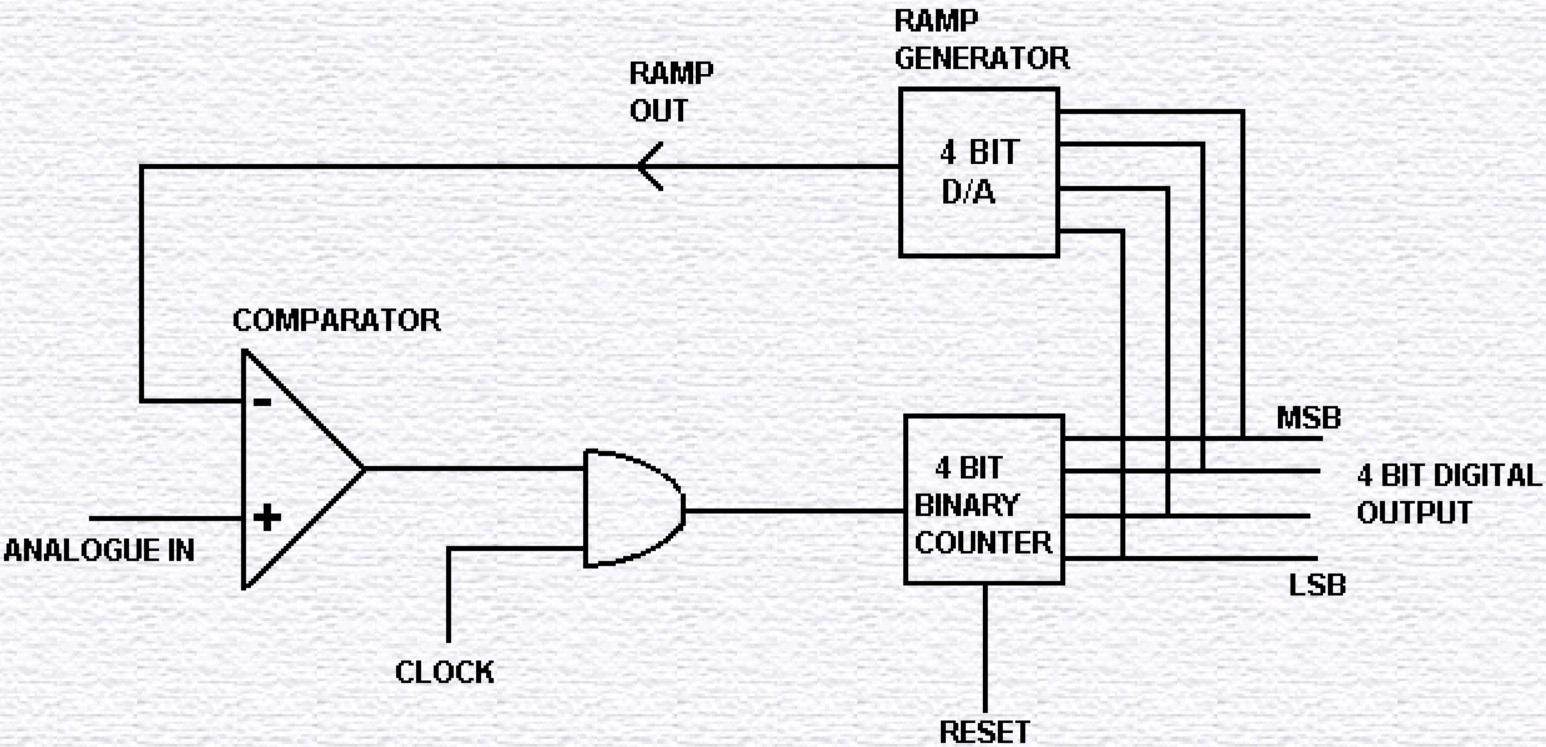
THE ANALOGUE TO DIGITAL CONVERTER

CLICK HERE TO BUY THE CD



At the start, the inverting input of the comparator is low and its output high.

The AND gate is enabled.

Clock pulses appear at the output of the gate and are counted by the UP counter when the counter is reset to zero.

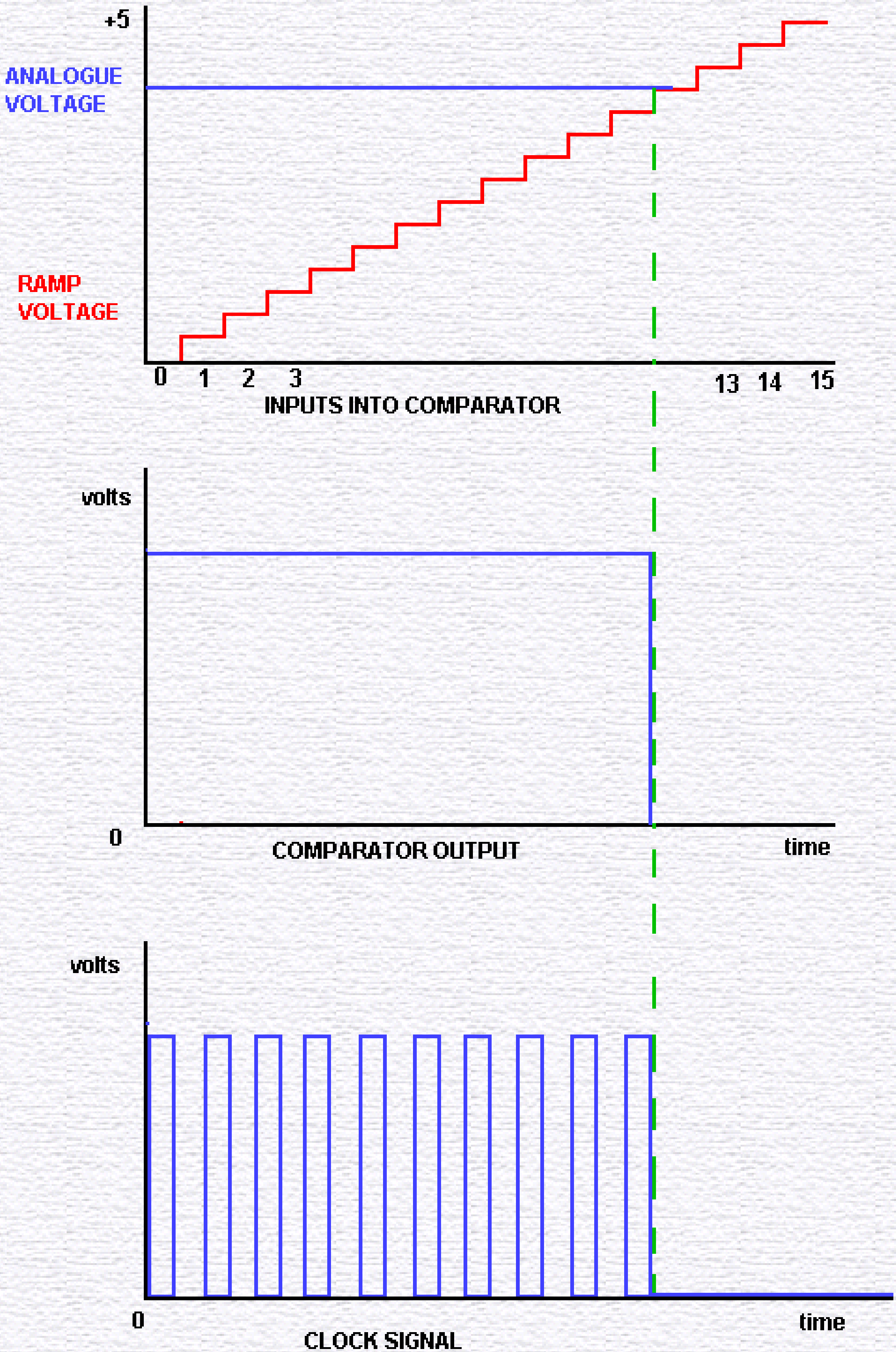
As the count increases, the ramp output voltage of the D/A converter rises.

When the ramp voltage and the analogue voltage are the same, the output of the comparator goes low.

This inhibits the AND gate and the count stops.

The 4 bit number at the output, is the binary equivalent of the analogue input voltage.

This process repeated continually.


+5
ANALOGUE VOLTAGE
RAMP VOLTAGE
0 1 2 3
13 14 15
INPUTS INTO COMPARATOR
volts
0
COMPARATOR OUTPUT
time
volts
0
CLOCK SIGNAL
time

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MULTIPLEXER AND DEMULTIPLEXER

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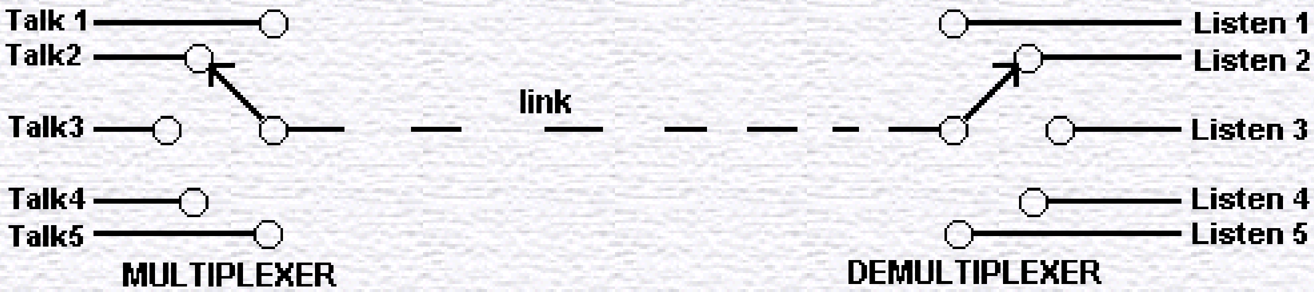

Muliplexing enables several signals to be sent over the same channel simultaneously.

In the top diagram, the Multiplexer rotary switch samples each channel in turn, and connects it to the link.

The Demultiplexer switch connects each listener in turn, to the link.

As long as the two switches are rotated in synchronism, Listener 1 will only hear Talker 1, etc.

The minimum sample rate need only be twice the highest frquency of a talker signal, according to Nyquist.

In practice, electronic switches are used.

A synchronising signal is required to keep talkers and listeners in step.