Missenden Electronics weekend 24th –26th April 2009

Component identification and fault finding.

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. **The theory of Fault Finding**

All Materials are made up of Atoms, each atom is comprised of a nucleus (Protons and neutrons) surrounded by shell orbits each containing a number of Electrons. The occupancy of the outer shell dictates the materials electrical properties if the shell is empty then the material is an insulator, if there are a few electrons (Valency electrons) then the material is a conductor (least resistance) as the shell becomes more complete so the material goes from semi-conductor through to insulator (finite resistance through to infinite resistance).

Conductivity is a function of the ease with which electrons can be knocked out of orbit and replaced by an electron from another atom, this process is random and continuous, and the vigour with which it occurs is dependant on the temperature. Effectively energy is generated by the flow of electrons from a negatively charged atom (surplus of electrons} to a positively charged atom {deficiency of electrons} this is the reverse of normal current where we consider the flow of holes (atom with surplus holes deficient of electrons} to an atom with a deficiency of holes}. The definition of the electron flow in a circuit is the coulomb which can be equated to $6.2415\sim \times 10^{18}$ electrons, this is then equated to the ampere defined as a current flow of one coulomb per second.

If a Voltage is applied across the material then the movement becomes linear in the direction of the Voltage difference (Potential Difference) and a current flow will ensue in the direction +ve to –Ve points. Good conductors are Copper, Silver, and slightly less Aluminium. Good insulators are Porcelain, glass, ceramics, rubber and ebonite, with resistive materials somewhere between. All electronic components use one or more of these phenomena. Conductor, semi-conductor, resistor and insulator

.

It is necessary to understand how individual components and groups of components work in order to investigate faulty electronic devices or sections thereof. It is necessary to break a circuit down into individual sections in order to assist in the fault finding procedure, the most common premise being start from a point which you know is fully working, this can be the input of the circuit a suitable break point or a known value at a certain point in the circuit. If one has a fully serviceable item then testing by comparison is the most expeditious method of fault finding; however this is not always possible, therefore one has to start from scratch. In most of MERG Kits I feel the start point would be the power, control and signal inputs. using a Multimeter checking the voltages at relevant points and comparing them with the voltage one would expect to get at that point The simplest form of testing is that of individual components, sometimes this practical sometimes not, they need to be in isolation and not connected in circuits.

2. **Measuring Instruments.**

2A **Basic meters**

Individual meters used as ammeters, voltmeters or ohmmeters are in the main analogue devices and are based on a 50 micro ammeter moving coil meter with appropriate circuitry for the individual requirement. They are polarity sensitive and can only be used for direct current devices; they have a screwdriver control for setting the meter to the mechanical limit of the meter. AC measurements are made with a moving iron meter

2B **The moving iron vane movement**

This type of meter can be used to measure both AC current and voltage. By changing the meter scale calibration, the movement can be used to measure DC current and voltage. The moving iron vane meter operates on the principle of magnetic repulsion between like poles. The measured current flows through a field coil which produces a magnetic field proportional to the magnitude of current. Suspended in this field are two iron vanes attached to a pointer. The two iron vanes consist of one fixed and one moveable vane. The magnetic field produced by the current flow magnetizes the two iron vanes with the same polarity regardless of the direction of current through the coil. Since like poles repel one another, the moving iron vane pulls away from the fixed vane and moves the meter pointer. This motion exerts a force against a spring. The distance the moving iron vane will travel against the spring depends on the strength of the magnetic field. The strength of the magnetic field depends on the magnitude of current flow. Figure 3 Moving Iron Vane Meter Movement As stated previously, this type of meter movement may also be used to measure voltage. When this type of movement is used to measure voltage, the field coil consists of many turns of fine wire used to generate a strong magnetic field with only a small current flow.

2 C. Ammeters**.**

The ammeter is used to check the current through an electronic component or device it is designed to place a very low resistance in series with the circuit and the measurement by a 50 micro amp meter in parallel with the resistor, thus minimising the effect on the circuit parameters. Figure 2a below shows a circuit which is to be tested and Fig 2b shows the circuit current test after connecting the ammeter.

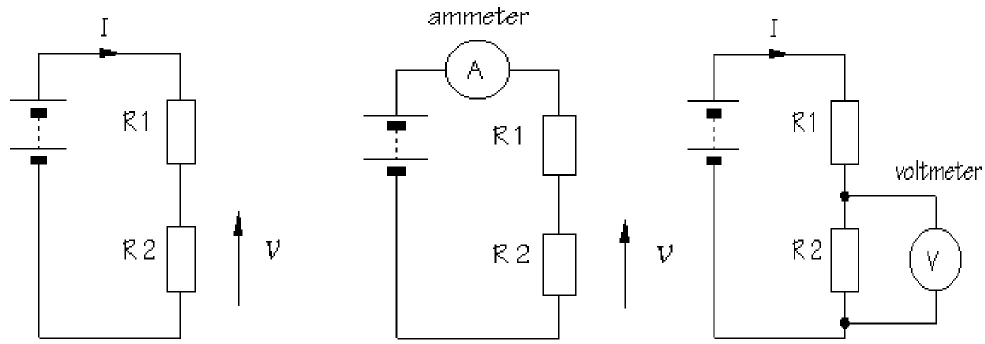


Figure 2a Figure 2b Figure 2c

2D. **Voltmeter**

To measure potential difference (voltage), the circuit is not changed: and the voltmeter is connected in parallel. A very High precision value resistor (Rt) is connected to a series ammeter (calibrated in volts) is placed in parallel with the circuit and current times resistance Rt indicates the Voltage across the tested component.
Figure 2c shows the same circuit after connecting a voltmeter

2E. **Ohmmeter**

An ohmmeter cannot function correctly the component under test with a circuit connected to a power supply. To measure resistance, the component must be isolated from the circuit altogether because Ohmmeters work by passing applying a specific voltage across the resistor and measuring the current through the component. (See figure

1D) If you try this with the component connected into a circuit with a power supply, the most likely result is that the meter will be damaged separately, as shown in Figure 2d

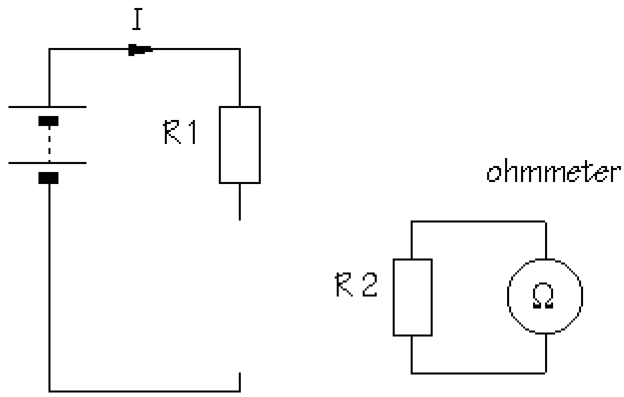


Figure 2d

2F Multimeters

A Multimeter is a measuring instrument which is multi-function and multi-range, in its simple form it can be used to measure , DC Voltage, AC Voltage, AC Current and resistance using high tolerance resistors and a meter with ranges calibrated in either Volts, Ohms or amps each range has different components. Other facilities which may be found on the more expensive digital Multimeter are the ability to measure diode and transistor parameters or with suitable attachment temperatures.

For voltage checks a very High precision value resistor (Rt) is connected to a series ammeter (calibrated in volts) is placed in parallel with the circuit and current time's resistance RT indicates the Voltage across the tested component.

Current is measured by placing a very low resistance in series with the circuit and the potential difference across the resistor is measured, and that Voltage is electronically divided by the value of the resistance and then indicates the value of the current.

For resistance measurements an accurate voltage is applied across the resistor and the value of the current through it is measured by an ammeter scaled in ohms,

Both the digital and analogue have an internal battery for measuring resistance in the case of analogue meter the scale must be calibrated using an inbuilt potentiometer to compensate for the battery voltage by setting to a full scale reading on the meter to enable accurate readings. The digital meter has inbuilt circuitry which effectively controls the accuracy of the readings

2G Digital multimeters

Digital multimeters generally take measurements with accuracy superior to their analog counterparts. Analog multimeters typically measure with three to five percent accuracy standard portable digital multimeters claim to be capable of taking measurements with an accuracy of 0.5% on DC voltage and current scales. Mainstream bench-top make claims to have as great accuracy as ±0.01%. Multimeters are designed and mass produced for electronics engineers. Even the simplest and cheapest types may include features which you are not likely to use. Digital meters give an output in numbers, usually on a liquid crystal display. Figure 2a shows a switched range |Multimeter.

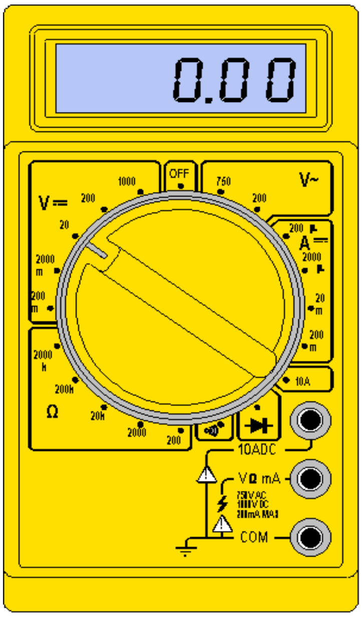


Figure 2e

The central knob has lots of positions and you must choose which one is appropriate for the measurement you want to make. If the meter is switched to 20 V DC, for example, then 20 V is the maximum voltage which can be measured, This is sometimes called 20V full scale deflection (f**sd)**, For circuits with power supplies of up to 20 V, which includes all the circuits you are likely to build, the 20 V DC voltage range is the most useful. DC ranges are indicated by V= on the meter. Sometimes, you will want to measure smaller voltages, and in this case, the 2 V or 200 mV ranges are used.

What does DC mean? DC means **direct current**. In any circuit which operates from a steady voltage source, such as a battery, current flow is always in the same direction.
AC means **alternating current**. In an electric lamp connected to the domestic mains electricity, current flows first one way, then the other. With UK mains, the current reverses 50 times per second.

2H **Analogue multimeters**

An analogue meter moves a needle along a scale. Switched range analogue multimeters are very cheap but are difficult for beginners to read accurately, especially on resistance scales. The meter movement is delicate and dropping the meter is likely to damage it!

Each type of meter has its advantages. Used as a voltmeter, a digital meter is this is usually better because its resistance is much higher, 1 MΩ or 10 MΩ, compared to 200 kΩfor a analogue Multimeter on a similar range. On the other hand, it is easier to follow a slowly changing voltage by watching the needle on an analogue display.

Used as an ammeter, an analogue Multimeter has a very low resistance and is very sensitive, with scales down to 50 礎 More expensive digital multimeters can equal or better this performance.
Most modern multimeters are digital and traditional analogue types are destined to become obsolete.

3. Resistors

3A **what is a resistor**?

A resistor is a device for reducing a voltage at a point in a circuit with respect to another by impeding the flow of electrons (electric current)**;** this reduced voltage is called the Potential Difference. Each end of the resistor has a voltage value with reference to a nominal point, normally an earth rail. The value of a resistor measured in ohms is proportional to the length (l), the material constant (r_o) and inversely proportional to the cross sectional area (a) of the material i.e. $R = \frac{r_o * l}{a}$.

The construction of a resistor depends on 5 factors: - Wattage to be dissipated, resistance value, tolerance, Size and Temperature coefficient

3B. **what are resistors made of?**

Carbon film resistors.

0.125 to 0.5 Watts in 3 ranges, 1 ohm to 10 Megohm in preferred value steps 5% tolerance (CR12, CR25, CR50)

Metal Film resistors

0.25 To 2Watts in 7 ranges, 1 ohm to 10 Megohm in preferred value steps, one range at 0.1% tolerance, five at 1% tolerance and the other one at 5% tolerance.

Other types

There is a further range of resistors each having their own characteristics; Ceramic, Wire wound, Aluminium Clad Wire Wound and High Power for details see the Resistor Table in notes.

3C **Standard Resistor Colour Code Chart.**

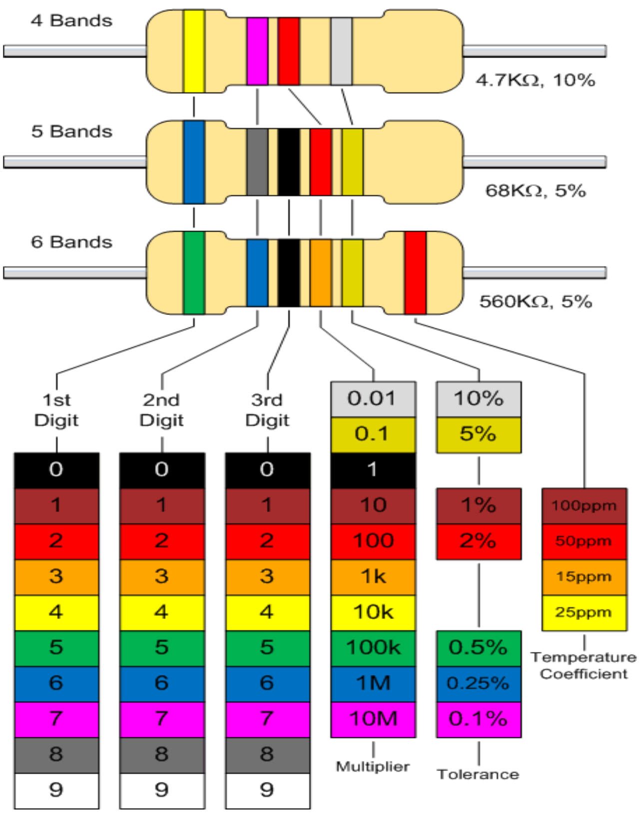


Figure 3a

3D Resistor ranges

In order to cover the major range of specific types of resistors each type is marketed in a series of preferred values, the number of values in a complete series is dependent on the tolerance of individual resistors (a product of its base material). Resistors come in a range of tolerances but the two most common are the E12 and the E24 series. The E12 series comes in twelve resistance values per decade, (A decade represents multiples of 10, i.e. 10, 100, 1000 etc). The E24 series comes in twenty four values per decade (5%) and the E96 series ninety six values per decade (1%). A very high precision E192 series is now available with tolerances as low as ±0.1% giving a massive 192 separate resistor values per decade.

3E Tolerance and E-series Table.

E6 Series at 20% Tolerance - Resistors values in Ω's

1.0, 1.5, 2.2, 3.3, 4.7, 6.8

E12 Series at 10% Tolerance - Resistors values in Ω's

1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2

E24 Series at 5% Tolerance - Resistors values in Ω's

1.0, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2.0, 2.2, 2.4, 2.7, 3.0, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.2, 8.2, 9.1

E96 Series at 1% Tolerance - Resistors values in Ω's

1.00, 1.02, 1.05, 1.07, 1.10, 1.13, 1.15, 1.18, 1.21, 1.24, 1.27, 1.30, 1.33, 1.37, 1.40, 1.43, 1.47, 1.50, 1.54, 1.58, 1.62, 1.65, 1.69, 1.74, 1.78, 1.82, 1.87, 1.91, 1.96, 2.00, 2.05, 2.10, 2.15, 2.21, 2.26, 2.32, 2.37, 2.43, 2.49, 2.55, 2.61, 2.77, 2.74, 2.80, 2.87, 2.94, 3.01, 3.09, 3.16, 3.24, 3.32, 3.40, 3.48, 3.57, 3.65, 3.74, 3.83, 3.92, 4.02, 4.12, 4.22, 4.32, 4.42, 4.53, 4.64, 4.75, 4.87, 4.99, 5.11, 5.23, 5.36, 5.49, 5.62, 5.76, 5.90, 6.04, 6.19, 6.34, 6.49, 6.65, 6.81, 6.98, 7.15, 7.32, 7.50, 7.68, 7.87, 8.06, 8.25, 8.45, 8.66, 8.87, 9.09, 9.31, 9.53, 9.76

Then by using the appropriate E-series value and adding a multiplication factor to it, any value of resistance within that series can be found. For example, take an E-12 series resistor, 10% tolerance with a preferred value of 3.3, and then the values of resistance for this range are:

Value x Multiplier = Resistance
3.3 x 1 = 3.3Ω
3.3 x 10 = 33Ω
3.3 x 100 = 330Ω
3.3 x 1,000 = 3.3kΩ
3.3 x 10,000 = 33kΩ
3.3 x 100,000 = 330kΩ
3.3 x 1,000,000 = 3.3MΩ

3F Surface Mount Resistors

Surface Mount Resistors or SMD Resistors, are very small rectangular shaped metal oxide film resistor. They have a ceramic substrate body onto which is deposited a thick layer of metal oxide resistance. The resistive value of the resistor is controlled by increasing the desired thickness, length or type of deposited film being used and highly accurate low tolerance resistors, down to 0.1% can be produced. They also have metal terminals or caps at either end of the body which allows them to be soldered directly onto printed circuit boards.

Surface Mount Resistors are printed with either a 3 or 4-digit numerical code which is similar to that used on the more common axial type resistors to denote their resistive value.

Standard SMD resistors are marked with a three-digit code, in which the first two digits represent the first two numbers of the resistance value with the third digit being the multiplier, either x1, x10, x100 etc. For example:

"103" = 10 × 1,000 ohms = 10 kiloΩ´s
"392" = 39 × 100 ohms = 3.9 kiloΩ´s
"563" = 56 × 1,000 ohms = 56 kiloΩ´s
"105" = 10 × 100,000 ohms = 1 MegaΩ

Surface mount resistors that have a value of less than 100Ω´s
They are usually written as: "390", "470", "560" with the final zero representing a 10 x 0 multiplier, which is equivalent to 1. For example:

"390" = 39 × 1Ω = 39Ω´s or 3R9Ω
"470" = 47 × 1Ω = 47Ω´s or 4R7Ω

Resistance values below 10 have a letter "R" to denote the position of the decimal point as seen previously in the BS1852 form, so that 4R7 = 4.7Ω.
Surface mount resistors that have a "000" or "0000" markings are Zero-Ohm (0Ω) resistors or in other words shorting links since these components have zero resistance.

3G Resistors in Circuits.

a) Single resistors.

When using resistors in a circuit one must make sure that the parameters of the device are followed, the first one to be calculated is the power the device will dissipate when inserted.

The formula for power is $W=V^{2/}R$ $W=I^2*R$
Where W is the power dissipated by the resistor, V is the potential difference (PD) across the resistor and I is current through the resistor

The formula for calculating the current through the resistor is I=V/R

The formula for calculating the Potential difference across the resistor is I=V/R.

b) Multiple resistors.

Resistors in series give a resistance appropriate to the sum of the resistors i.e. $R_{total} = R_1+R_2+R_3$…………

Resistors in parallel give a reduced resistance based on the following formula

$$R_{total} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

which can be transposed

using lowest common denominator into

$$R_{total} = \frac{R_1 + R_2 + R_3}{R_1 * R_2 * R_3}$$

In the case of two resistors of equal value then the total resistance is effectively half the value of either of them.

c) Complex resistor chains**.**

Any parallel sections of the chain should be dealt with first and the equivalent value inserted in the chain when all parallel sections are dealt with the chain can be then treated as a serial chain an the initial parameters of voltage and current can be used to define the parameters of each of the resistors.

3H **Potentiometers**

Potentiometers are resistors with a variable centre tap and nearly all either carbon faced or wire wound and come in three formats, linear where a turn of x degrees will produce a change in y ohms at all points on the radius. A second type is the logarithmic pot where change in y ohms depends on where about the pickup is on the radius. The third type is the precision potentiometer whereby the output resistance can be carefully selected.

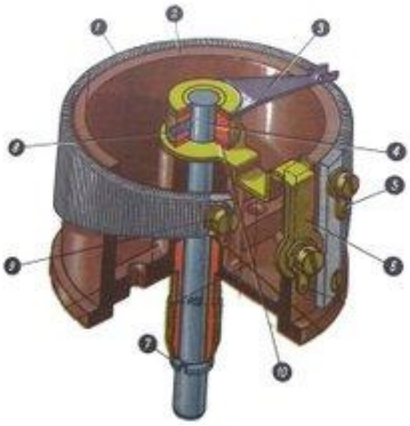


Figure 3b

4. **Capacitors**

4A**.** **What is a capacitor?**

A capacitor is a device for storing electrical energy, effectively when a voltage is applied to the plates of a capacitor the electrons flow from one plate to the other and gradually charges up to the Potential Difference (PD) equivalent to the applied voltage that will remain until the electrons are allowed to return. If you disconnect the Voltage then the only discharge path available is through the very small leakage resistance inherent in most capacitors. Beware when playing around with high value capacitors; they can if charged up give you quite a belt.

Capacitors are used with resistors in timing circuits because it takes time for a capacitor to fill with charge. They are used to smooth varying DC supplies by acting as a reservoir of charge. They are also used in filter circuits because capacitors easily pass AC (changing) signals but they block DC (constant) signals

4B. **Capacitance**

This is a measure of a capacitor's ability to store charge. A large capacitance means that more charge can be stored. Capacitance is measured in farads, symbol F. However 1F is very large, so prefixes are used to show the smaller values.

Three prefixes (multipliers) are used, µ (micro), n (nano) and p (pico):
µ means 10^{-6} (millionth), so 1000000µF = 1F
n means 10^{-9} (thousand-millionth), so 1000nF = 1µF
p means 10^{-12} (million-millionth), so 1000pF = 1nF

Capacitor values can be very difficult to find because there are many types of capacitor with different labelling systems!

There are many types of capacitor but they can be split into two groups, **polarised** and **unpolarised**. Each group has its own circuit symbol.

4C **Polarised capacitors (large values, 1µF +)**

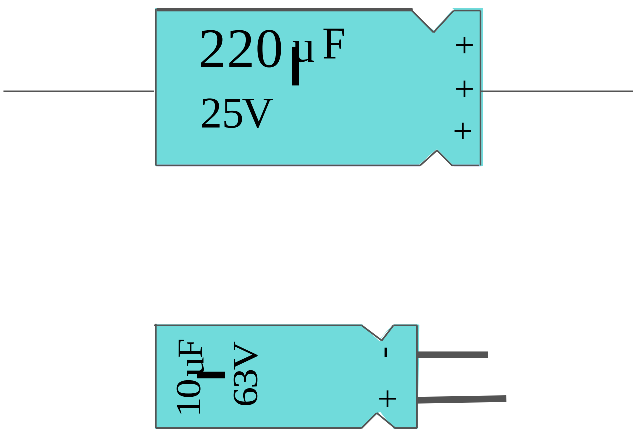


Figure 4a polarized examples

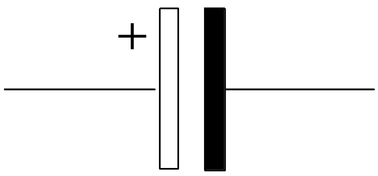


figure 4b Circuit Symbol

a) Electrolytic Capacitors

Electrolytic capacitors are polarised and **they must be connected the correct way round**, at least one of their leads will be marked + or -. They are not damaged by heat when soldering. There are two designs of electrolytic capacitors; **axial** where the leads are attached to each end (220µF in picture) and **radial** where both leads are at the same end (10µF in picture). Radial capacitors tend to be a little smaller and they stand upright on the circuit board

It is easy to find the value of electrolytic capacitors because they are clearly printed with their capacitance and voltage rating. The voltage rating can be quite low (6V for example) and it should always be checked when selecting an electrolytic capacitor. It the project parts list does not specify a voltage, choose a capacitor with a rating which is greater than the project's power supply voltage. 25V is a sensible minimum for most battery circuits.

Large electrolytic Capacitors are used as low frequency filters in mains power supplies to suppress 50 Hz ripple, and smaller electrolytic capacitors are used as low frequency filters in many circuits. Another use of capacitors either with resistors or inductors to form tuned circuits or oscillator circuits.

b)Tantalum Bead Capacitors

Tantalum bead capacitors are polarised and have low voltage ratings like electrolytic capacitors. They are expensive but very small, so they are used where a large capacitance is needed in a small size.

Modern tantalum bead capacitors are printed with their capacitance, voltage and polarity in full. However older ones use a colour-code system which has two stripes (for the two digits) and a spot of colour for the number of zeros to give the value in µF. The standard colour code is used, but for the spot, **grey** is used to mean × 0.01 and **white** means × 0.1 so that values of less than 10µF can be shown. A third colour stripe near the leads shows the voltage (yellow 6.3V, black 10V, green 16V, blue 20V, grey 25V, white 30V, pink 35V). The positive (+) lead is to the right when the spot is facing you: '**when the spot is in sight, the positive is to the right**'.

For example: **blue, grey, black spot** means 68µF
For example: **blue, grey, white spot** means 6.8µF
For example: **blue, grey, grey spot** means 0.68µF

4D **Unpolarised capacitors (small values, up to 1µF)**

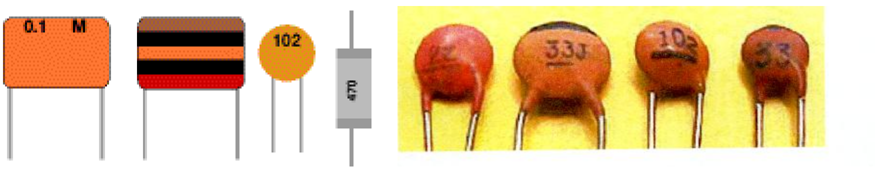


Figure 4c Examples

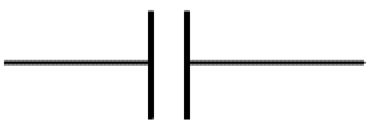


Figure 4d Circuit symbol

Small value capacitors are unpolarised and may be connected either way round. They are not damaged by heat when soldering, except for one unusual type (polystyrene). They have high voltage ratings of at least 50V, usually 250V or so. It can be difficult to find the values of these small capacitors because there are many types of them and several different labelling systems!

4E. What are capacitors made of?

Capacitors are made of two electrode plates separated by some form of insulator, the value of the capacitance is proportional to the area of the smallest plate and the inversely proportional to the distance between the plates and the Voltage capability is proportional to the distance apart of the plates and the dielectric constant separating the plates.

a) Ceramic plate capacitors.

The ceramic is the dielectric of the capacitor, which is used to separate the flat metal plates they are in the low picofarad (1.8 pf to 47nf) range and the 100 to 300-voltage range.

b. Polystyrene, polypropylene and polyester capacitors. Figure 4g

These also are two metal plate devices separated with a plastic membrane and are a wider range of capacitors covering 10 pf to 1mf and a voltage range 50 volts to 400 volts.
This type is rarely used now. Their value (in pF) is normally printed without units. Polystyrene capacitors can be damaged by heat when soldering (it melts the polystyrene!) so you should use a heat sink (such as a crocodile clip). Clip the heat sink to the lead between the capacitor and the joint.

c. Electrolytic capacitors.

These capacitors are formed from a rolled up ribbon of aluminium foil separated by a chemical dielectric, they are polarity sensitive. This series covers the high end of the capacitance range of 1 mf up to 4700 microfarad and 10volts to 500 volts.

4F. Capacitor identification

Many small value capacitors have their value printed but without a multiplier, so you need to use experience to work out what the multiplier should be!
For example 0.1 means 0.1µF = 100nF.
Sometimes the multiplier is used in place of the decimal point:
For example: 4n7 means 4.7nF.
Capacitor Number Code
A number code is often used on small capacitors where printing is difficult:
the 1st number is the 1st digit,
the 2nd number is the 2nd digit,
the 3rd number is the number of zeros to give the capacitance in pF.
Ignore any letters - they just indicate tolerance and voltage rating.
For example: 102 means 1000pF = 1nF *(not 102pF!)*
For example: **472J** means 4700pF = 4.7nF (J means 5% tolerance).

4G Capacitor Colour Code

A colour code was used on polyester capacitors for many years. It is now obsolete, but of course there are many still around. The colours should be read like the resistor code Figure 4h, the top three colour bands giving the value in pF. Ignore the 4^{th} band (tolerance) and 5th band (voltage rating).

Colour Code	
Colour	Number
	0
	1
	2
	3
	4
	5
	6
	7
	8
	9

Figure 4h

Figure 4e

Figure 4f

Figure 4g

For example Fig 4e **brown, black, orange** means 10000pF = 10nF = 0.01µF.
Note that there are no gaps between the colour bands, so 2 identical bands actually appear as a wide band.
For example: Fig 4f **wide red, yellow** black means 220nF = 0.22µF.

4H Real capacitor values (the E3 and E6 series)

You may have noticed that capacitors are not available with every possible value, for example 22µF and 47µF are readily available, but 25µF and 50µF are not!
Why is this? Imagine that you decided to make capacitors every 10µF giving 10, 20, 30, 40, 50 and so on. That seems fine, but what happens when you reach 1000? It would be pointless to make 1000, 1010, 1020, and 1030 and so on because for these values 10 is a very small difference, too small to be noticeable in most circuits and capacitors cannot be made with that accuracy.
To produce a sensible range of capacitor values you need to increase the size of the 'step' as the value increases. The standard capacitor values are based on this idea and they form a series which follows the same pattern for every multiple of ten.

The E3 series (3 values for each multiple of ten)
10, 22, 47, ... then it continues 100, 220, 470, 1000, 2200, 4700, 10000 etc.
Notice how the step size increases as the value increases (values roughly double each time).

The E6 series (6 values for each multiple of ten)
10, 15, 22, 33, 47, 68, ... then it continues 100, 150, 220, 330, 470, 680, 1000 etc.
Notice how this is the E3 series with an extra value in the gaps.

The E3 series is the one most frequently used for capacitors because many types cannot be made with very accurate values.

4I Capacitors in circuit.

Capacitors in parallel results in a larger area of plate across the Voltage therefore it is equivalent to increasing the capacitance in the same respect i.e. two 100mf capacitors in parallel result in an approximate equivalent 200 mf capacitor. Thus $T_{otal} = C_1 + C_2$

Capacitors in series the distance between is increase so the capacitance is reduced, thus

$$C_{total} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{which can be transposed}$$

Using lowest common denominator into

$$C_{total} = \frac{C_1 + C_2}{C_1 * C_2}$$

4J Capacitor impedance and time constant.

a) In a DC situation.

Capacitors must have some form of impedance otherwise current would flow through it permanently, theoretically it has infinite impedance, practically it has a minimal resistance value, however once the capacitor is connected to a voltage source current must flow so that the capacitor becomes charged up in an exponential manner The time taken for the capacitor to fully charge up is calculated by using a formula time constant, the time constant for a capacitor is $T_C = C*R$ where R is the value of any resistance which is in series with the Capacitor. The value of the time constant is that of when the current rises or decays to 63% of it maximum value and to achieve complete charge or discharge takes T_C*5.

b). Capacitor charge/discharge sequence

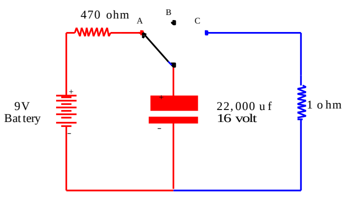


figure 4i

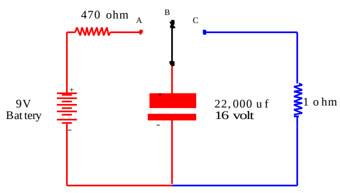


figure 4j

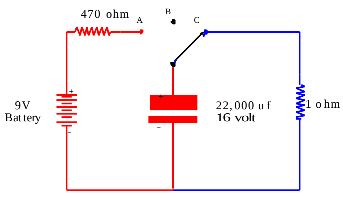


figure 4k

i. Figure 4i, Switch in position A. capacitor charges via 470 ohm
The charge sequence is t_c = Capacitance * Resistance in seconds
I.e. $22000 * 10^{-6} * 470 = 10.34$ Seconds
Capacitor is fully charged $5 * t_c = 41.7$ seconds

ii. Figure 4j, Switch in position B.
Capacitor retains its charge, the exception to the rule are electrolytic capacitors which have internal impedance and the current leaks across the dielectric.

iii. Figure 4k Discharge sequence t_c = Capacitance * Resistance in seconds
Ie $22000 * 10^{-6} * 1 = 22$ milliseconds
Capacitor is fully discharged $5 * t_c = 110$ milliseconds

iv. Rate of charge and discharge (Vt=Vr+Vc)

When the switch is put to A as in figure 3c the current is regulated by the 470 ohm resistor so initially the voltage applied to the capacitor is max and the current is maximum as the current flows the voltage across the capacitor drops because of the PD across the resistor rising causes the current to drop even more this sequence continues until the current ceases to flow because the capacitor is fully charged . the plot of the current/voltage against time is exponential see figures 4l charging and 4m discharging.

The formula for calculating the instantaneous value of a voltage decay exponential waveform is $V(t)=V_o\text{-}\varepsilon^{-t/RC}$ where V_o is the max voltage and t is the relative time constant.

When t = 1 then $Vt = 9 - \varepsilon^{-1/.022}$ $Vt = 9- \varepsilon^{-45}$ $Vt = 9-2.862$ $Vt= 6.138$
When t = 2 then $Vt = 9 - \varepsilon^{-2/.022}$ $Vt = 9- \varepsilon^{-90}$ $Vt = 9-2.862$ $Vt= 3.069$
When t = 3 then $Vt = 9 - \varepsilon^{-3/.022}$ $Vt = 9- \varepsilon^{-45}$ $Vt = 9-2.862$ $Vt= 1.023$
When t = 4 then $Vt = 9 - \varepsilon^{-4/.022}$ $Vt = 9- \varepsilon^{-45}$ $Vt = 9-2.862$ $Vt= 0.512$
When t = 5 then $Vt = 9 - \varepsilon^{-5/.022}$ $Vt = 9- \varepsilon^{-45}$ $Vt = 9-2.862$ $Vt= 0$

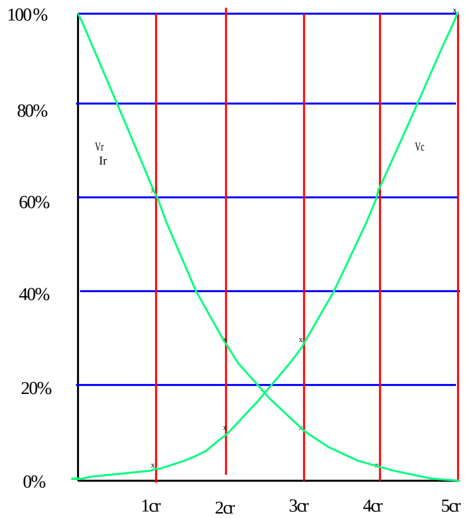


Figure 4l capacitor charging

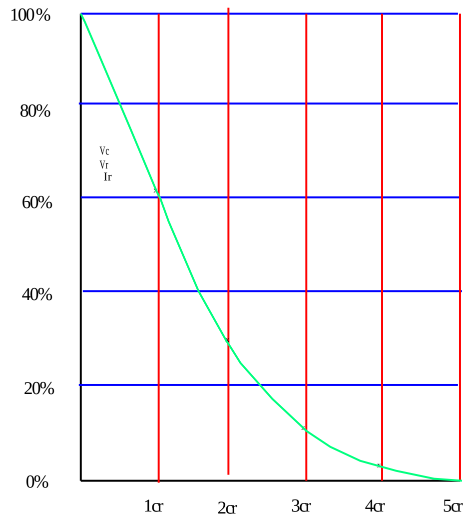


Figure 4m Capacitor discharging

In Figure 4j it shows that as Vr is falling and Ir is rising and thus it indicates that this the Current in the capacitor leads the Voltage by 90 degrees

b) In an AC situation

As the capacitor is going to respond the AC by attempting to charge and discharge at the same rate then the impedance of the capacitor is not constant, it varies with the frequency this then comes under the rules of reactance (Xc). The reactive impedance of a capacitor is calculated by

$$Xc = \frac{1}{2 * Pi * F * C} \text{ Ohms}$$ where F = Frequency .

Large electrolytic Capacitors are used as low frequency filters in mains power supplies to suppress 50 Hz ripple, and smaller electrolytic capacitors are used as low frequency filters in many circuits. Another use of capacitors either resistors or inductors to form tuned circuits or oscillator circuits.

4K Variable Vane capacitors

In mechanically controlled variable capacitors, the distance between the plates, or the amount of plate surface area which overlaps, can be changed.

The most common form arranges a group of semicircular metal plates on a rotary axis (“rotor”) that are positioned in the gaps between a set of stationary plates (“stator”) so that the area of overlap can be changed by rotating the axis. Air or plastic foils can be used as dielectric material. By choosing the shape of the rotary plates, various functions of capacitance vs. angle can be created, e.g. to obtain a linear frequency scale. Various forms of reduction gear mechanisms are often used to achieve finer tuning control, i.e. to spread the variation of capacity over a larger angle, often several turns. Figure 4n

Figure 4n

4L **Smoothing**

Smoothing is performed by a large value electrolytic capacitor connected across the DC supply to act as a reservoir, supplying current to the output when the varying DC voltage from the rectifier is falling. Figure shows the unsmoothed varying DC (dotted line) and the smoothed DC (solid line). The capacitor charges quickly near the peak of the varying DC, and then discharges as it supplies current to the output.

5. **Inductors.**

5A. **what is an inductor?**

An Inductor is a coil of wires, wound around some magnetic material and then packaged. The final configuration takes a wide variety of forms and appearances. Values may range from fractions of milli-henrys to fractions of henrys.

Coils are the only passive components in common use that may display significant non-linear characteristics. The behaviour of inductors is based in phenomena associated with magnetic fields. The source of the magnetic field is charge in motion, or current. If the current is varying with time, the magnetic field is varying with time. A time-varying magnetic field induces a voltage in a by conductor linked by the field. The circuit parameter of inductance relates the induced voltage to the current.

Energy can be stored in magnetic fields and therefore inductors are capable of storing energy, however since they are passive devices they cannot generate energy.

5B **Inductance**

Figure 5a Inductor symbol

Inductance is the circuit parameter to describe an inductor. Inductance is symbolized by the letter L, measured in henrys (H), and it is represented graphically as a coiled wire.

5C **Inductors and Direct current.**

The magnetic field induced by the current in an inductor opposes any change in current by developing a voltage across the coil with a polarity that would oppose the cause of the changing current. In a non AC conditions Inductors behave in a similar manner to Capacitors in that the rise and decline of the current through it is a function of the exponential function however the current starts at zero and reaches 63% of the total value after 1 time constant.

A graph of the exponential rise of the Current across an Inductor Figure 5a

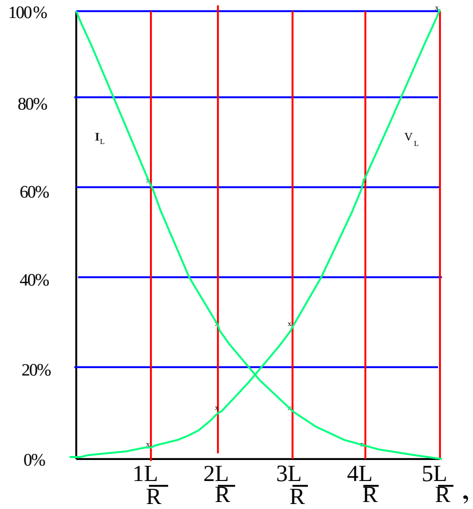


Figure 5a

The Voltage across inductor leads the current by 90 degrees

5D. Inductors and Alternating current

The magnetic field induced by the current in an inductor opposes any change in current by developing a voltage across the coil with a polarity that would oppose the cause of the changing current. . When a sine wave voltage is applied to an inductor, the current through the inductor is constantly changing. The shape of the waveform produced is dependant on the relationship of the frequency and the time constant of the circuit, if the half wave time t (1/f) then the wave form will be as Figure 5b below

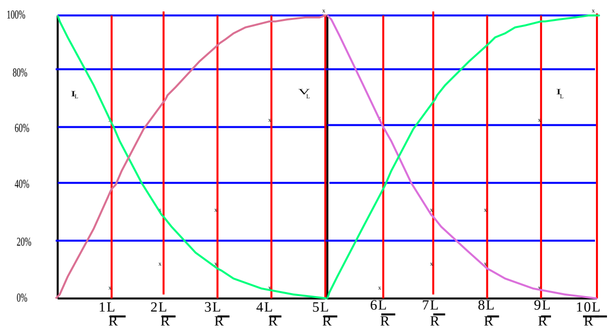
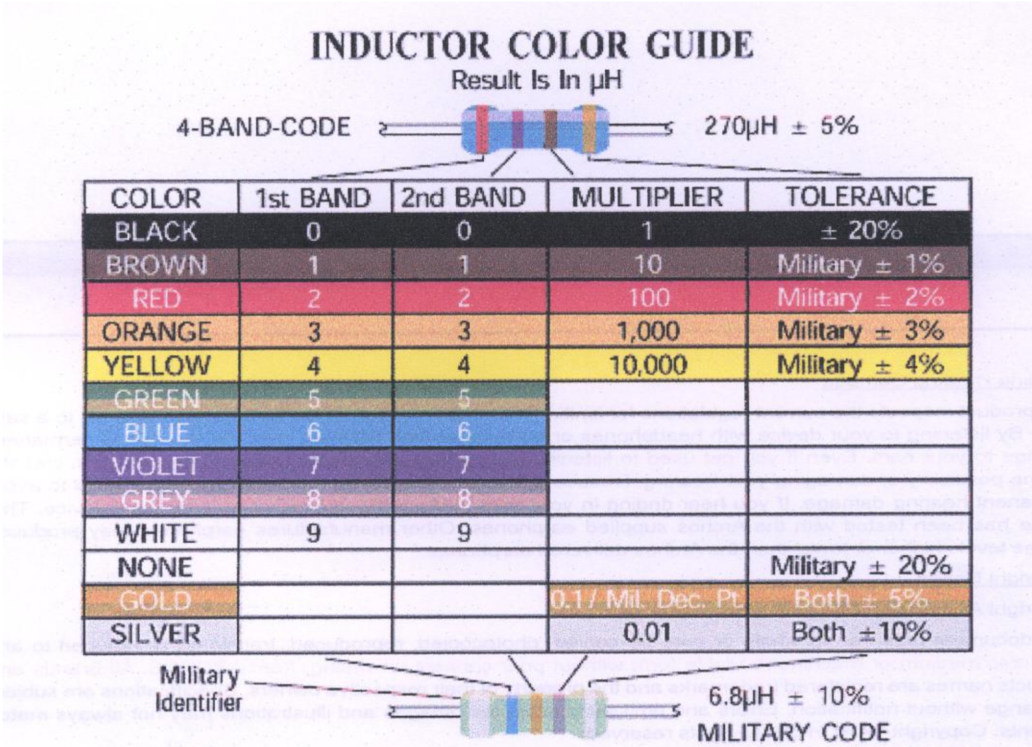


Figure 5b

5E Inductive impedance

An inductor has a resistance which is a the property of the material forming the coil, it also has a a reactive impedance(X_L) which is as a result of the magnetic field formed when current is passed through it. The reactance is inversely proportional to the applied frequency, the formula for calculating it $X_L = ΩL$ where $Ω = 2 *$**Pi***f and f =frequency.

Thus as the frequency rises so the X_L rises therefore the current must fall, inversely as the frequency falls so the impedance falls and the current will rise. This is reverse of the case of a capacitor with AC.



INDUCTOR COLOR GUIDE

Result Is In µH

4-BAND-CODE — 270µH ± 5%

COLOR	1st BAND	2nd BAND	MULTIPLIER	TOLERANCE
BLACK	0	0	1	± 20%
BROWN	1	1	10	Military ± 1%
RED	2	2	100	Military ± 2%
ORANGE	3	3	1,000	Military ± 3%
YELLOW	4	4	10,000	Military ± 4%
GREEN	5	5		
BLUE	6	6		
VIOLET	7	7		
GREY	8	8		
WHITE	9	9		
NONE				Military ± 20%
GOLD			0.1 / Mil. Dec. Pt.	Both ± 5%
SILVER			0.01	Both ±10%

Military Identifier — 6.8µH ± 10% MILITARY CODE

5G Inductors and Capacitors in circuit

Inductors and Capacitors may be used in two ways in series or parallel, if the reactance of both components in a tuned circuit is the same then they are said to be resonant and the circuit will form part of an oscillator. A series tuned circuit presents high impedance and the parallel tuned circuit presents low impedance

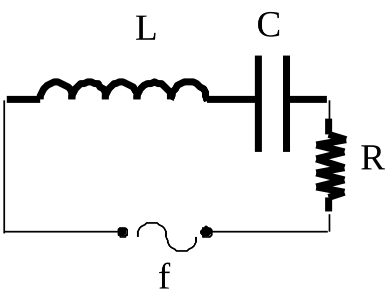


Figure 5 c

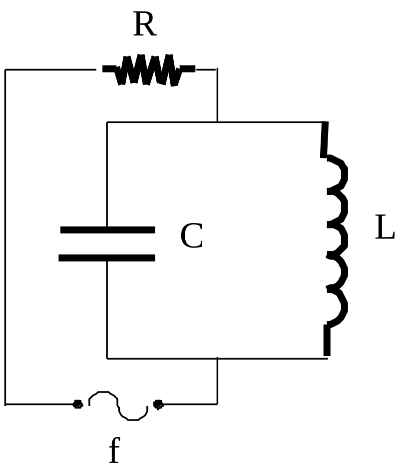


Figure 5d

For a circuit to be resonant X_C must equal to X_L thus since $X_L = 2 * \pi * F * L$ and

$$Xc = \frac{1}{2 * \pi * F * C} \text{ ohms}$$

Then $2 * \pi * F * L = 1/ 2 * \pi * F * C$

Then $F^2 = 1/ 4 \pi * \pi * L * C$

Then $F_R = 1/ 2 \pi \sqrt{LC}$

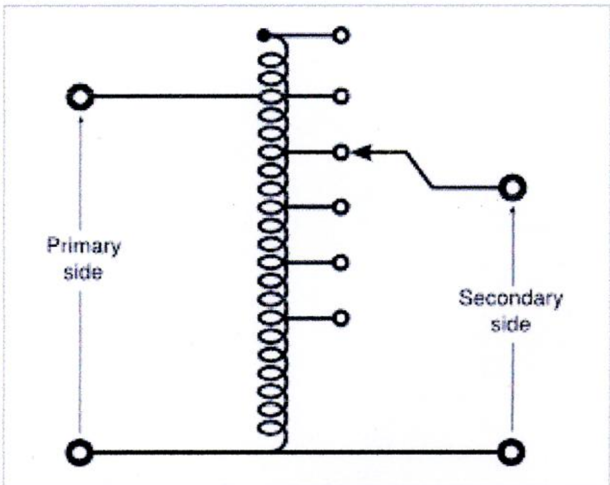
6 Transformers.

6A **what is a transformer**?

A transformer is a device for converting one AC Voltage to another value it is a modification two inductors mutually coupled either with a ferrous core or without, the inductors are termed primary and secondary windings the system relies upon the magnetic properties of the primary coil inducing a current proportional to the magnetic field into the secondary winding. They can only be used with an A.C. input that in turn will provide an A.C. Output.

6B **the basic Transformer**

The basic Transformer is an Auto transformer comprised of a single coil of wire with a separate tape off at a preselected point on the coil or a variable pick up to enable a variable output.



Single-phase tapped autotransformer with output voltage range of 40%–115% of input

Figure 6a

6C **the standard transformer**

The standard transformer has two windings completely electrically isolated from each other these are known as the primary and the secondary. In essence power enters on the primary, and leaves on the secondary. Some transformers have more windings but the basis of operation is still the same.

. The diameter of the cores depends on the current, which will be carried in the cores. The maximum power available to the secondary winding is equal to the power provided in the Primary winding minus an amount due to the losses in the system W_s=W_p-Loss a transformer is approximately 95%.

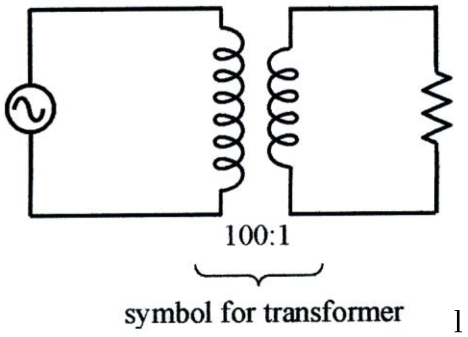


Figure 6b

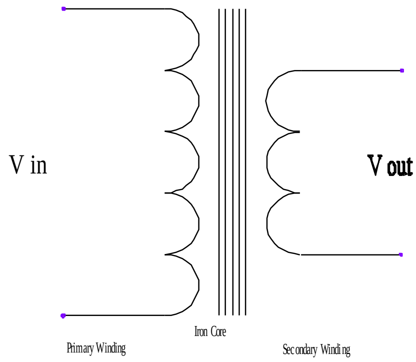


Figure 6c

6D Transformer effects

There are two main effects that are used in a transformer and both relate to current and magnetic fields. In the first it is found that a current flowing in a wire sets up a magnetic field around it. The magnitude of this field is proportional to the current flowing in the wire. It is also found that if the wire is wound into a coil then the magnetic field is increased. If this electrically generated magnetic field is placed in an existing field then a force will be exerted on the wire carrying the current in the same way that two fixed magnets placed close to one another will either attract or repel one another. It is this phenomenon that is used in electric motors, meters, and a number of other electric units.

The second effect is that it is found that if a magnetic field around a conductor changes then an electric current will be induced in the conductor. One example of this can occur if a magnet is moved close to a wire or a coil. Under these circumstances an electric current will be induced, but only when the magnet is moving.

The combination of the two effects occurs when two wires, or two coils are placed together. When a current changes its magnitude in the first, this will result in a change in the magnetic flux and this in turn will result in a current being induced in the second. This is the basic concept behind a transformer, and it can be seen that it will only operate when a changing or alternating current is passing through the input or primary circuit.

6E **Transformer turns ratio**

For a current to flow an EMF (electro-motive force) must be present. This potential difference or voltage at the output is dependent upon the ratio of turns in the transformer. It is found that if more turns are present in the primary than the secondary then the voltage at the input will be greater than the output and vice versa. In fact the voltage can easily be calculated from knowledge of the turns ratio:

$$\frac{Es}{Ep} = \frac{ns}{np}$$

Where

Ep is the primary EMF
Es is the secondary EMF
np is the number of turns on the primary
ns is the number of turns on the secondary

If the turns ratio ns/np is greater than one then the transformer will give out a higher voltage at the output than the input and it is said to be a step up transformer. Similarly one with a turns ratio less than one is a step down transformer.

6F **Transformers in use**

Transformers are widely used in many applications in radio and electronics. One of their main applications is within mains power supplies. Here the transformer is used to change the incoming mains voltage (around 240 V in many countries, and 110V in many others) to the required voltage to supply the equipment. With most of today's equipment using semiconductor technology, the voltages that are required are much lower than the incoming mains. In addition to this the transformer isolates the supply on the secondary from the mains, and thereby making the secondary supply much safer. If the supply were taken directly from the mains supply then there would be a much greater risk of electric shock.

A power transformer like that used in a power supply is generally wound on an iron core. This is used to concentrate the magnetic field and ensuring the coupling between the primary and secondary is very tight. In this way the efficiency is kept as high as possible. However it is very important to ensure that this core does not act as a one-turn winding. To prevent this happening the sections of the core are insulated from one another. In fact the core is made up from several plates, each interleaved but insulated from one another as shown.

6G **Fault finding**

Transformers can fail in many ways. Some of the various failures are:

• The coil wire turns can open. This can occur where the copper wire coils are connected to the terminal lugs.

• The windings can become shorted to adjacent turns of the coil wires.

• The primary and secondary coil windings can become shorted to each other.

• The primary and secondary coil windings can develop a high-resistance leakage.

• The coil windings can become shorted due to insulation breakdown to the metal core, transformer case, or frame.

• A power transformer might become hot, have a waxy material start leaking from the case and might actually smoke and burn up.

If you detect a burning odour from your equipment and see some melted wax coming from inside the transformer case located in the power-supply section, immediately turn it off or unplug the device. You might find the same symptom if your equipment stops working and a fuse has blown. An overheated power transformer will usually not be damaged as the problem that caused this condition is some other component that has shorted out. These component faults could be a shorted diode rectifier, electrolytic filter capacitor, regulator transistor or a bypass capacitor. You can use an ohmmeter to check for any shorts or low resistance in the B+ supply lines.

Figure 6d illustrates how you can check for leakage between the primary and secondary of a transformer. With the device turned on and a dc voltage on the primary winding, measure for any voltage with your voltmeter at the points indicated on the two secondary windings. If you find even a very small voltage, the transformer has leakage and should be replaced. The ohmmeter is used to check across each winding for opens. Be sure that the device is turned off or unplugged for these ohmmeter checks.

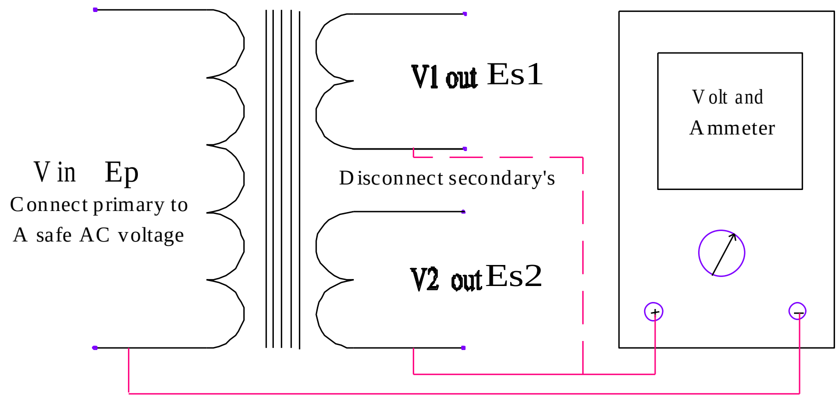


Figure 6d

7 Power supplies

A power supply can be either DC from Battery’s or from an intergral Power supply, in both cases the internal resistance of the supply must be considered in conjunction with the current/power requirement.

The other source of power is the mains AC, in which a power supply must be built this would normal comprises of six segments, Primary Safety, Transformer, Rectifier, Smoothing, Voltage Stabiliser, and Secondary Safety Figure 7a

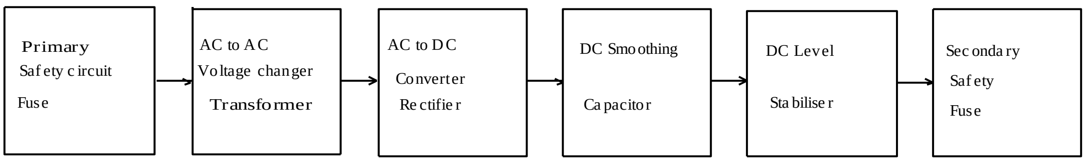


Fig 7a

7A Simple single diode Power supply

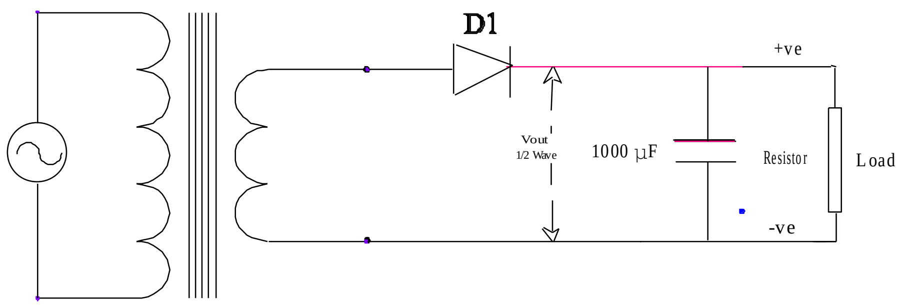


Figure 7b

A single diode provides half wave rectification and the Capacitor provides an element of smoothing

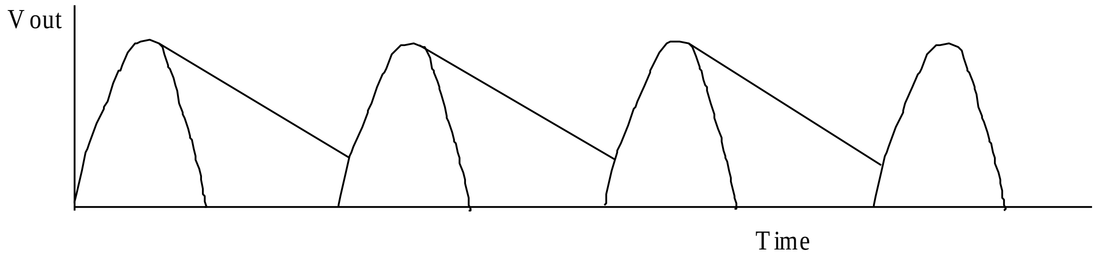


Figure 7c

7B Simple Full wave power supply

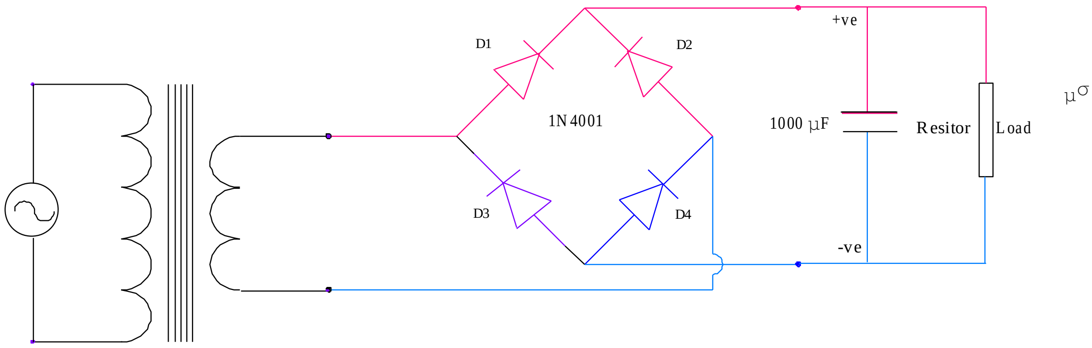


Figure 7d

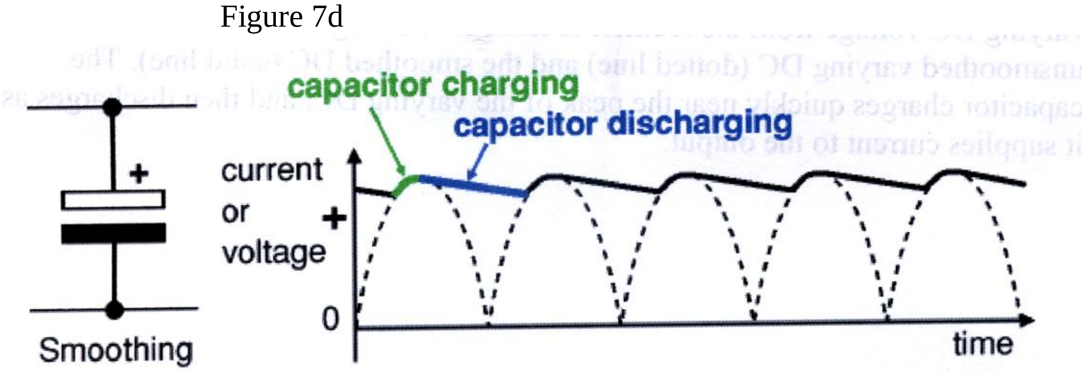


Figure 7e

When conducting Diodes have a very small value of internal resistance and since C*R is the time constant value effectively the Vmax situation (5*CR) is virtually controlled by the parallel Capacitor and the discharge value is determined by C * R load. Since R load normally will be a greater value C*R diodes then the filtering should be quite reasonable,

Assume Rdiode = 10 ohms Rload= 100 ohms then

CR diode = 10* 1000*10^{-6} = 10 milliseconds

CR Rload = 100*1000*10^{-6} = 100 milliseconds so it takes longer to discharge than charge and since the periodic time for one half cycle at 50 hz is 10 milliseconds then reasonable smoothing is achieved

7C Practical Power Supply

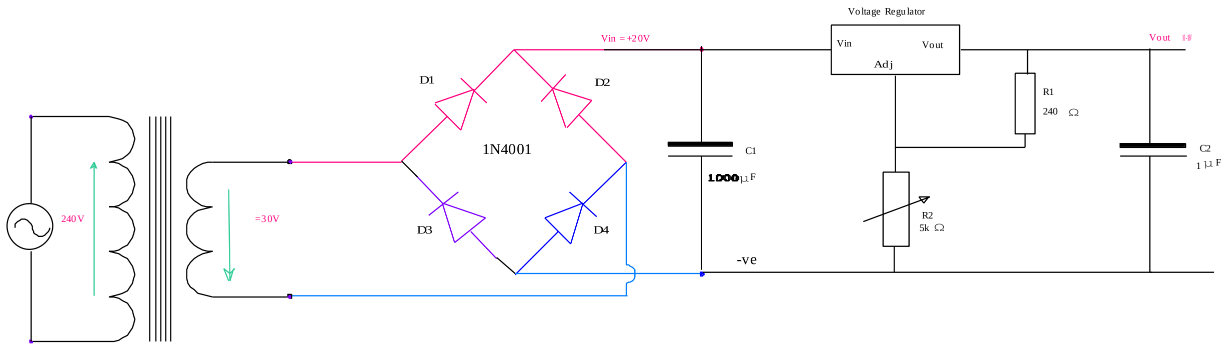


Figure 7f

Figure 7f shows a practical power supply, note that the input and output voltages of the transformer are 180 degrees phase shifted caused by back EMF. The output voltage to the Voltage regulator is higher than the required output voltage so that proper regulation can take place with the variations caused by the ripple input and the variation in load requirements.

7D Dual regulated Power supply.

A common power supply for uses which need two voltages and which need not be so well stabilised (Model Railway controllers) is the Dual Regulated Power supply see Figure 7g.

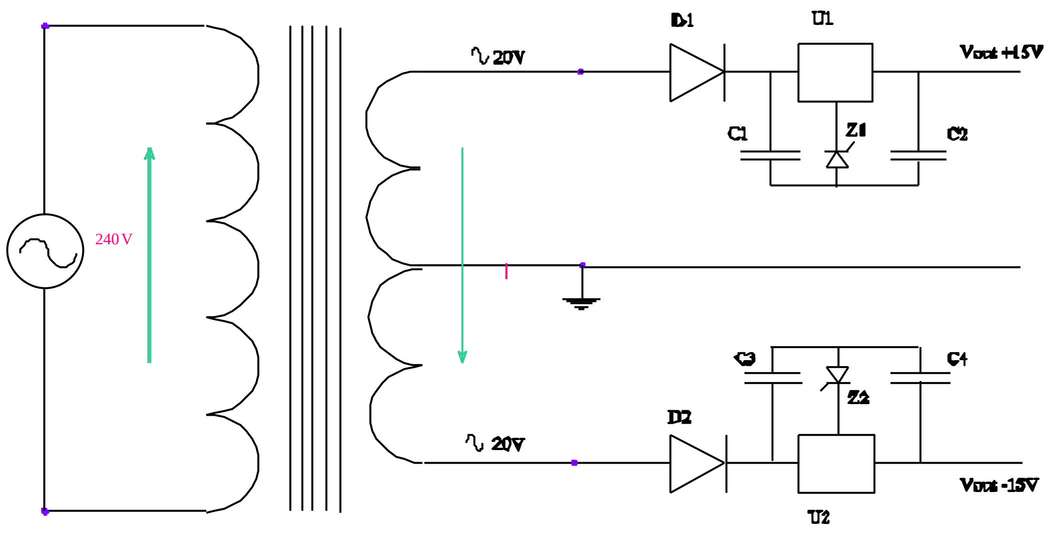


Figure g

Components

D1 and D2 1N 4001 50 volt 1 amp rectifier diodes

C1 and C2 1000microfarad electrolytic capacitors (Smoothing of the ripple ac)

Z1 and Z2 Zener diode sets the voltage which the regulator will control type value depends on the output frequency)

U1 and U2 Voltage regulator

C3 and C4 10microfarad electrolytic capacitor (Smoothing out any noise feedback from load.

8 Voltage Stabilisers

8A what is a Voltage Stabiliser

A **voltage stabilizer** is an electronic device able to deliver relatively constant output voltage when input voltage and load current changes over time. In all cases the input voltage must be greater than the desired output voltage The stabilizer circuit may be in the form of a integrated device such as the LM317 or 7805 Regulator Chips or a circuit consisting of transistors, zener diodes and resistors Figure 8a.or just a Zener diode and a resistor Fig 8a. The method used is dependent on what is available, power requirement and personal preference

8B Zener diode Shunt regulator circuit

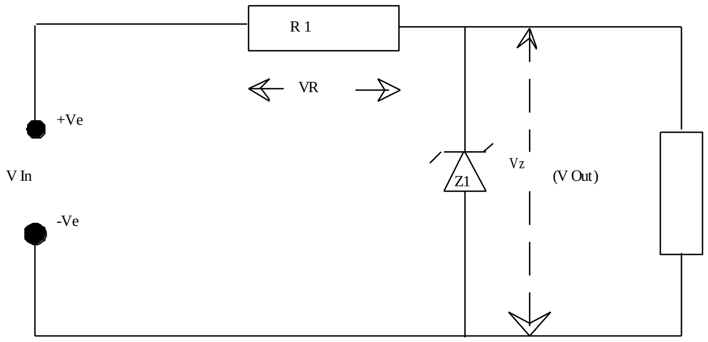


Figure 8a

The necessary part of the voltage stabilizer is the *shunt regulator* such as a Zener diode or avalanche diode. Each of these devices begins conducting at a specified voltage and will conduct as much current as required to hold its terminal voltage to that specified voltage U_z. Hence the shunt regulator can be viewed as the limited power parallel stabilizer. The shunt regulator output is used as a voltage reference.

8C Simple voltage stabilizer

In the simplest case, the base of the regulating transistor is directly connected to the voltage reference:

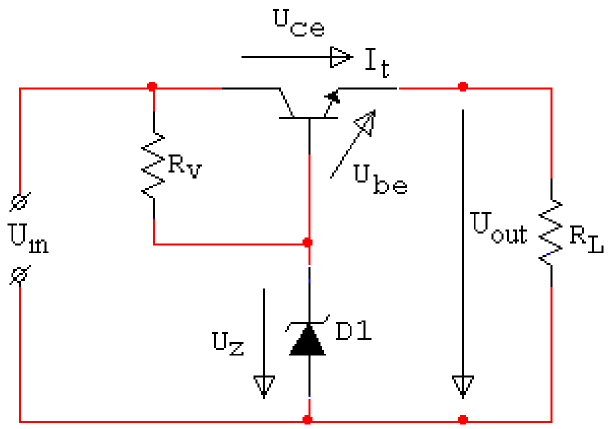


Figure 8b

The stabilizer uses the power source, having voltage U_{in} that may vary over time. It delivers the relatively constant voltage U_{out}. The output load R_L can also vary over time.

For the proper work of such device the input voltage must be larger than the output voltage and the output current must not exceed the allowed transistor limit. The output voltage of the stabilizer is a little lower than the output of the voltage reference circuit R_v-D1 (output U_z). If the output voltage drops below that limit, this increases the voltage difference between the base and emitter (U_{be}), opening the transistor and delivering more current. Delivering more current through the same output resistor R_L increases the voltage again.

8D Voltage stabilizer with the operational amplifier

The stability of the output voltage can be significantly increased by using an operational amplifier:

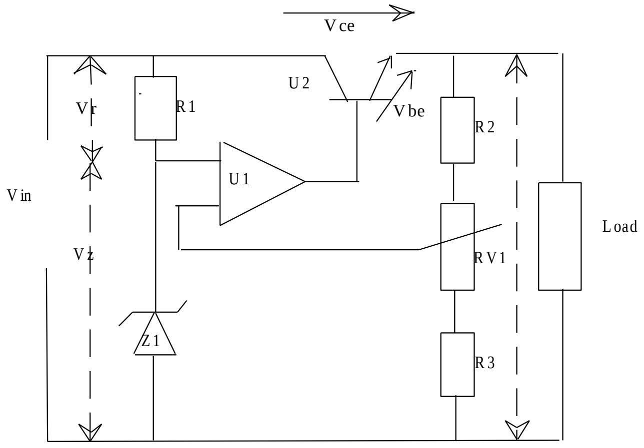


Figure 8c

In this case, the operational amplifier opens the transistor more if the voltage at its inverting input drops significantly below the output of the voltage reference at the non-inverting input. Using the voltage divider (R1, R2 and R3) allows choice of the arbitrary output voltage between U_z and U_{in}.

8E Voltage Stabilizer using a discrete regulator

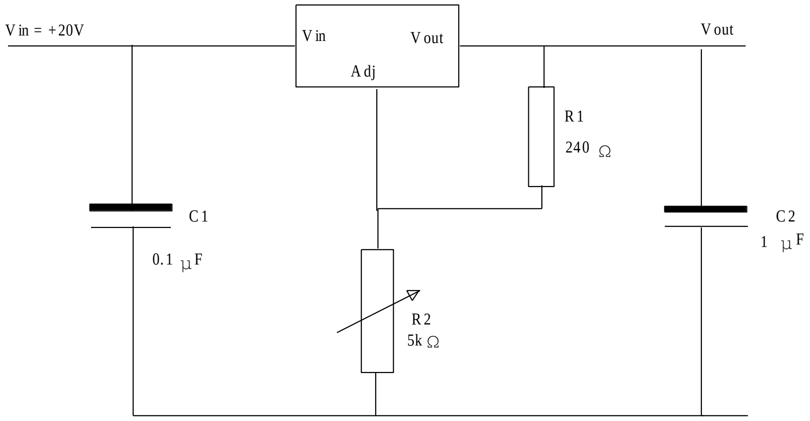


Figure 8d

The adjust voltage controls the current through the regulator, if the input voltage rises so the junction of R1 and R2 attempts to rise, this rising voltage places a bias which reduces the through current. If the input Voltage falls the reverse procedure happens. The Variable resistor R2 may be replaced with a Zener diode which will give a fixed voltage output:

9 Semiconductors Diodes

9A What is a Semiconductor Diode

Theoretically, a diode is a device which allows current to flow in only one direction. Ideally a diode acts as a perfect insulator for currents flowing in one direction and as a perfect conductor for currents flowing through it in the other direction. The direction in which the diode allows current to flow is called the forward bias direction and that in which current is resisted is called reverse bias direction. There are basically two types of diode Germanium (signal diodes) Figure 9c and Silicon Diodes (power diodes) Figure 9b

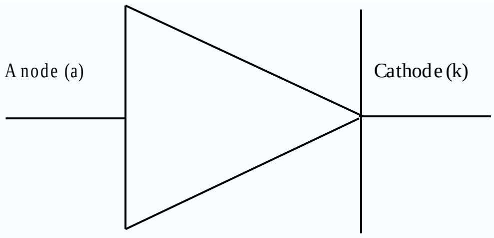


Figure 9a

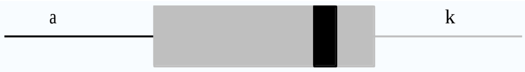


Figure 9b

Figure 9c

9B Construction of a Semiconductor diode

.The diode is one of the simplest forms of semiconductor, consisting of only one PN junction. The P and N refer to the two types of silicon (or germanium) used in the construction. These types are formed by taking the pure material and doping it by adding an impurity which either makes the material more positive or more negative depending upon the impurity used.

The two terminals of the diode are known as the anode and cathode. The diode may be regarded as a one way valve to the flow of electric current. Current flowing from anode to cathode flows with ease but current flowing from cathode to anode is blocked. See figure 9a

Most modern diodes are based on semiconductor p-n junctions. In a p-n diode, conventional current can flow from the p-type side (the anode) to the n-type side (the cathode), but not in the opposite direction. Another type of semiconductor diode, the Schottky diode, is formed from the contact between a metal and a semiconductor rather than by a p-n junction.

A semiconductor diode's current-voltage, or *I-V*, characteristic curve is ascribed to the behavior of the so-called *depletion layer* or *depletion zone* which exists at the p-n junction between the differing semiconductors. When a p-n junction is first created, conduction band (mobile) electrons from the N-doped region diffuse into the P-doped region where there is a large population of holes (places for electrons in which no electron is present) with which the electrons "recombine". When a mobile electron recombines with a hole, the hole vanishes and the electron is no longer mobile. Thus, two charge carriers have vanished. The region around the p-n junction becomes depleted of charge carriers and thus behaves as an insulator.

However, the depletion width cannot grow without limit. For each electron-hole pair that recombines, a positively-charged doped ion is left behind in the N-doped region, and a negatively charged doped ion is left behind in the P-doped region. As recombination proceeds and more ions are created, an increasing electric field develops through the depletion zone which acts to slow and then finally stop recombination. At this point, there is a 'built-in' potential across the depletion zone.

If an external voltage is placed across the diode with the same polarity as the built-in potential, the depletion zone continues to act as an insulator preventing a significant electric current. This is the *reverse bias* phenomenon. However, if the polarity of the external voltage opposes the built-in potential, recombination can once again proceed resulting in substantial electric current through the p-n junction. For silicon diodes, the built-in potential is approximately 0.6 V. Thus, if an external current is passed through the diode, about 0.6 V will be developed across the diode such that the P-doped region is positive with respect to the N-doped region and the diode is said to be 'turned on' as it has a *forward bias*.

9C Forward Voltage Drop

Electricity uses up a little energy pushing its way through the diode, rather like a person pushing through a door with a spring. This means that there is a small voltage across a conducting diode, it is called the **forward voltage drop** and is about 0.7V for all normal diodes which are made from silicon see Figure 9d. The forward voltage drop of a diode is almost constant whatever the current passing through the diode so they have a very steep characteristic (current-voltage graph

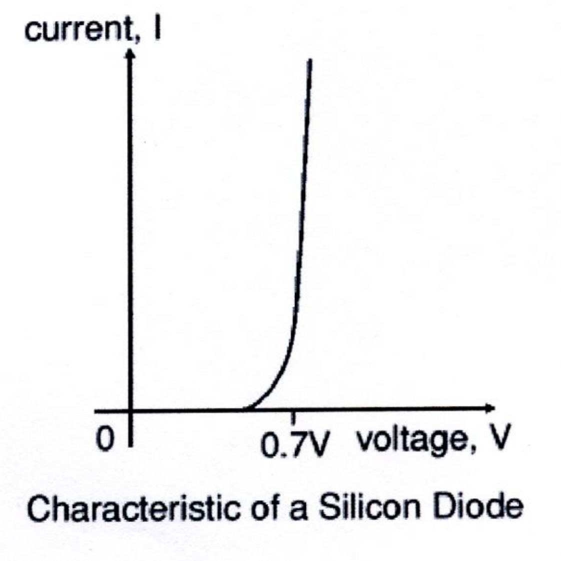


Figure 9d

9D Characteristics

A diode's I-V characteristic can be approximated by two regions of operation. Below a certain difference in potential between the two leads, the depletion layer has significant width, and the diode can be thought of as an open (non-conductive) circuit. As the potential difference is increased, at some stage the diode will become conductive and allow charges to flow, at which point it can be thought of as a connection with zero (or at least very low) resistance. More precisely, the transfer function is logarithmic, but so sharp that it looks like a corner on a zoomed-out graph (*see also* signal processing).

In a normal silicon diode at rated currents, the voltage drop across a conducting diode is approximately 0.6 to 0.7 volts. The value is different for other diode types - Schottky diodes can be as low as 0.2 V and light-emitting diodes (LEDs) can be 1.4 V or more (Blue LEDs can be up to 4.0 V).

Referring to the I-V characteristics image, in the reverse bias region for a normal P-N rectifier diode, the current through the device is very low (in the µA range) for all reverse voltages up to a point called the peak-inverse-voltage (PIV). Beyond this point a process called reverse breakdown occurs which causes the device to be damaged along with a large increase in current. For special purpose diodes like the avalanche or zener diodes, the concept of PIV is not applicable since they have a deliberate breakdown beyond a known reverse current such that the reverse voltage is "clamped" to a known value (called the *zener voltage* or breakdown voltage). These devices however have a maximum limit to the current and power in the zener or avalanche region.

9E Reverse Voltage

When a reverse voltage is applied a perfect diode does not conduct, but all real diodes leak a very tiny current of a few µA or less. This can be ignored in most circuits because it will be very much smaller than the current flowing in the forward direction. However, all diodes have a maximum reverse voltage (usually 50V or more) and if this is exceeded the diode will fail and pass a large current in the reverse direction, this is called breakdown.

9F Signal diodes (small current)

Signal diodes are used to process information (electrical signals) in circuits, so they are only required to pass small currents of up to 100mA.

General purpose signal diodes such as the 1N4148 are made from silicon and have a forward voltage drop of 0.7V.

9G Germanium diodes

Germanium diodes such as the OA90 have a lower forward voltage drop of 0.2V And this makes them suitable to use in radio circuits as detectors which extract the audio signal from the weak radio signal.

For general use, where the size of the forward voltage drop is less important, silicon diodes are better because they are less easily damaged by heat when soldering, they have a lower resistance when conducting, and they have very low leakage currents when a reverse voltage is applied.

9H Rectifier diodes (large current)

Rectifier diodes are used in power supplies to convert alternating current (AC) to direct current (DC), a process called rectification. They are also used elsewhere in circuits where a large current must pass through the diode.

All rectifier diodes are made from silicon and therefore have a forward voltage drop of 0.7V. The table shows maximum current and maximum reverse voltage for some popular rectifier diodes. The 1N4001 is suitable for most low voltage circuits with a current of less than 1A.

9I **Bridge rectifiers**

There are several ways of connecting diodes to make a rectifier to convert AC to DC. The bridge rectifier is one of them and it is available in special packages containing the four diodes required. Bridge rectifiers are rated by their maximum current and maximum reverse voltage. They have four leads or terminals: the two DC outputs are labelled + and -, the two AC inputs are labelled.

The Figure 9e shows the operation of a bridge rectifier as it converts AC to DC. Notice how alternate pairs of diodes conduct.

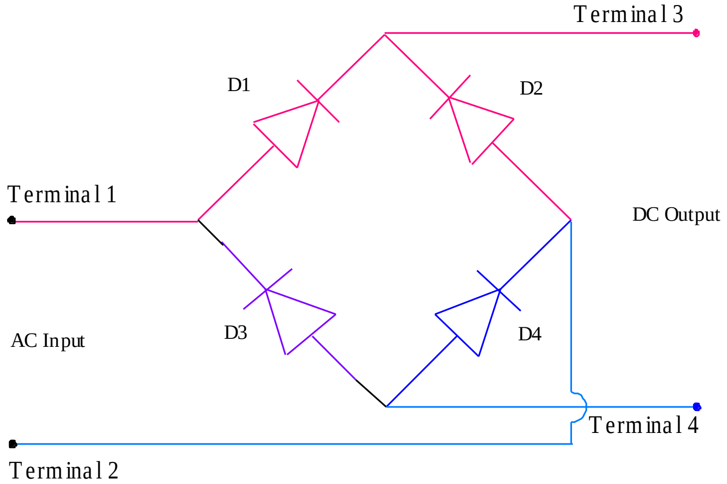


Figure 9e

Signal diodes are also used with relays to protect transistors and integrated circuits from the brief high voltage produced when the relay coil is switched off. Figure 9f shows how a protection diode is connected across the relay coil, note that the diode is connected 'backwards' so that it will normally NOT conduct. Conduction only occurs when the relay coil is switched off, at this moment current tries to continue flowing through the coil and it is harmlessly diverted through the diode. Without the diode no current could flow and the coil would produce a damaging high voltage 'spike' in its attempt to keep the current flowing.

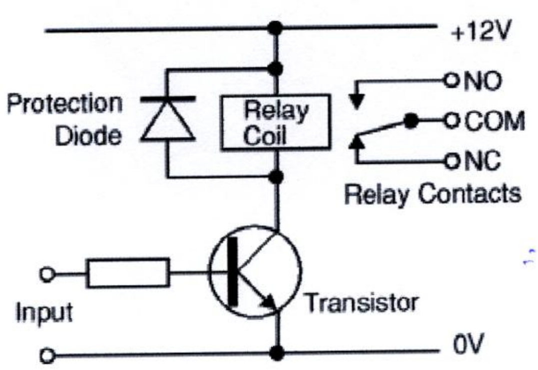


Figure 9f

Current paths

When the AC input is in the +ve Half cycle current flows from Terminal 1 through D1 and thence Terminal 3, the return path is terminal 4 through D4 and thence Terminal 2

When the AC input is in the –ve half cycle current flows from Terminal 2 through D2 and thence Terminal 3, the return path is terminal 4 through D3 and thence Terminal 1

The outputs are Figure 9g single diode rectification and Fig 9h is bridge rectification

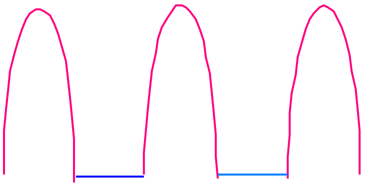


Figure 9g

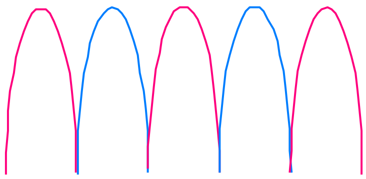


Figure 9h

9J Relay protection diodes.

Circuits from the brief high voltage produced when the relay coil is switched off. Figure 7h shows how a protection diode is connected across the relay coil, note that the diode is connected 'backwards' so that it will normally NOT conduct. Conduction only occurs when the relay coil is switched off, at this moment current tries to continue flowing through the coil and it is harmlessly diverted through the diode. Without the diode no current could flow and the coil would produce a damaging high voltage 'spike' in its attempt to keep the current flowing.

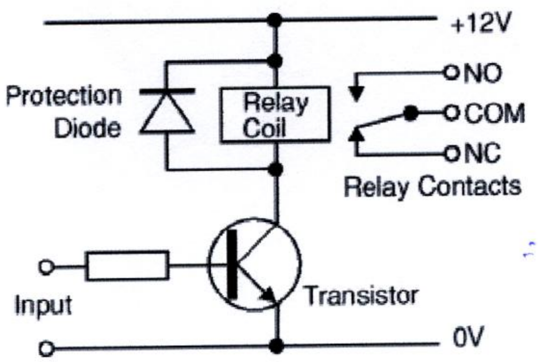


Figure 9i

7K .Zener diodes

Circuit symbol:

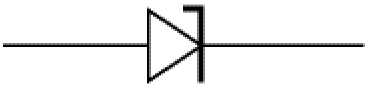


Figure 9j

Example:

a = anode, k = cathode

Figure 9k

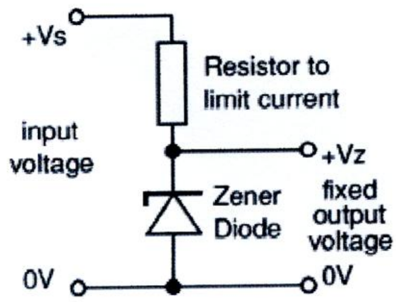


Figure 9l

Zener diodes are used to maintain a fixed voltage. See Figure 7k they are designed to 'breakdown' in a reliable and non-destructive way so that they can be used **in reverse** to maintain a fixed voltage across their terminals. The diagram shows how they are connected, with a resistor in series to limit the current.

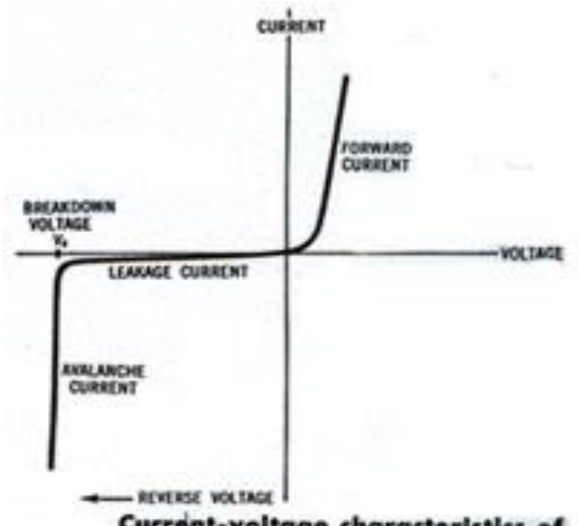
Zener diodes can be distinguished from ordinary diodes by their code and breakdown voltage which are printed on them. Zener diode codes begin BZX... or BZY... Their breakdown voltage is printed with V in place of a decimal point, so 4V7 means 4.7V for example.

Zener diodes are rated by their breakdown voltage and maximum power:

The minimum voltage available is 2.7V.

Power ratings of 400mW and 1.3W are common.

Refer to the characteristic curve of a typical rectifier (diode) in the figure below. The forward characteristic of the curve we have previously described above Figure 7d in the Forward Voltage Drop section. The reverse characteristics are illustrated Figure 7l



Current-voltage characteristics of a typical P-N junction.

Fig 9m

Notice that as the reverse voltage is increased the leakage current remains essentially constant until the breakdown voltage is reached where the current increases dramatically. This breakdown voltage is the zener voltage for zener diodes. While for the conventional rectifier or diode it is imperative to operate below this voltage; the zener diode is intended to operate at that voltage, and so finds its greatest application as a voltage regulator.

The basic parameters of a zener diode are:

(a) Obviously, the zener voltage must be specified. The most common range of zener voltage is 3.3 volts to 75 volts; however voltages out of this range are available.

(b) A tolerance of the specified voltage must be stated. While the most popular tolerances are 5% and 10%, more precision tolerances as low as 0.05 % are available . A test current (Iz) must be specified with the voltage and tolerance.

(c) The power handling capability must be specified for the zener diode. Popular power ranges are: 1/4, 1/2, 1, 5, 10, and 50 Watts.

9L **Connecting and soldering**

Diodes must be connected the correct way round, the diagram may be labelled **a** or + for anode and **k** or **-** for cathode (yes, it really is k, not c, for cathode!). The cathode is marked by a line painted on the body. Diodes are labelled with their code in small print; you may need a magnifying glass to read this on small signal diodes!

Small **signal diodes** can be damaged by heat when soldering, but the risk is small unless you are using a **germanium diode** (codes beginning OA...) in which case you should use a heat sink clipped to the lead between the joint and the diode body. A standard crocodile clip can be used as a heat sink.

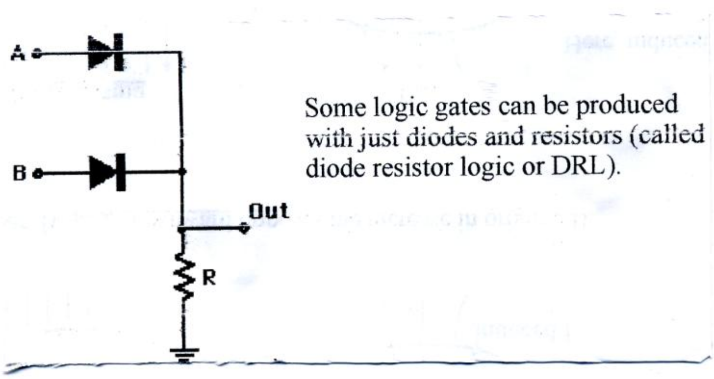
Rectifier diodes are quite robust and no special precautions are needed for soldering them.

9M **testing diodes**

You can use a Multimeter or a simple tester (battery, resistor and (LED) to check that a diode conducts in one direction but not the other. A lamp may be used to test a Rectifier diode, but do NOT use a lamp to test a Signal diode because the large current passed by the lamp will destroy the LED

9N **Diodes used as gating circuits**

Diode Logic is a logic family that uses diodes to construct logic gates for Boolean Logic circuits. I have been superseded by Transistor logic in most applications. The main drawbacks of diode logic is that it cannot be used to build a not gate and signals degrade after only a few layers of gates causing loss of noise immunity and unreliable logic operation.



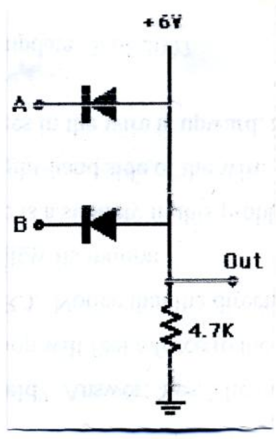


Figure 9n
Diode resistor OR Gate

Figure 9o
Diode resister AND Gate

In case (a) the diode resistor OR Gate, if the input of either or both diodes is 6V (Logic1) then the output will be 6V (Logic1), if both inputs are 0V (logic0) then the output will be 0V. (logic0)

In case (b) the resistor AND Gate, if neither or either diode inputs are 6V (Logic1) then the output will be 0V (Logic 0), if both inputs are 6V (logic1) then the output will be 6V (Logic1)

10 Light emitting diodes (LED)

10A what is a LED

A light-emitting-diode (LED) is a Semiconductor diode that emits light when an electric current is applied in the forward direction of the device, as in the simple LED circuit. The effect is a form of electroluminescence where incoherent and narrow-spectrum light is emitted from the p-n junction LEDs are widely used as indicator lights on electronic devices, the colour of the emitted light depends on the composition and condition of the semiconducting material used, and can be infrared, visible or ultraviolet .

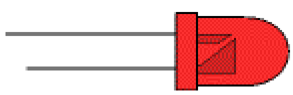
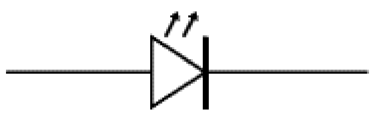
:  : 

Figure 10a example ` Figure 10b Symbol

10B Colours of LEDs

LEDs are available in red, orange, amber, yellow, green, blue and white. Blue and white LEDs are much more expensive than the other colours. Figure 8c

The colour of an LED is determined by the semiconductor material, not by the colouring of the 'package' (the plastic body). LEDs of all colours are available in uncoloured packages which may be diffused (milky) or clear (often described as 'water clear'). The coloured packages are also available as diffused (the standard type) or transparent.

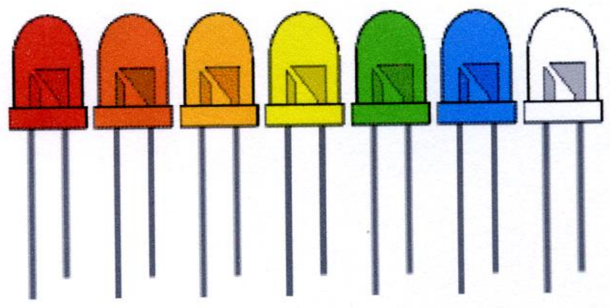


Figure 10c

10C Tri-colour LEDs

The most popular type of tri-colour LED has a red and a green LED combined in one package with three leads. They are called tri-colour because mixed red and green light appears to be yellow and this is produced when both the red and green LEDs are on, Figure 8d shows the construction of a tri-colour LED. Note the different lengths of the three leads. The centre lead (k) is the common cathode for both LEDs, the outer leads (a1 and a2) are the anodes to the LEDs allowing each one to be lit separately, or both together to give the third colour.

Figure 10d

10D **Bi-colour LEDs**

A bi-colour LED has two LEDs wired in 'inverse parallel' (one forwards, one backwards) combined in one package with two leads. Only one of the LEDs can be lit at one time and they are less useful than the tri-colour LEDs described above.

10E **Sizes, Shapes and Viewing angles of LEDs**

LEDs are available in a wide variety of sizes and shapes. The 'standard' LED has a round cross-section of 5mm diameter and this is probably the best type for general use, but 3mm round LEDs are also popular.

10F **installing LEDs**

Round cross-section LEDs are frequently used and they are very easy to install on boxes by drilling a hole of the LED diameter, adding a spot of glue will help to hold the LED if necessary. LED clips are also available to secure LEDs in holes. Other cross-section shapes include square, rectangular and triangular.

As well as a variety of colours, sizes and shapes, LEDs also vary in their viewing angle. This tells you how much the beam of light spreads out. Standard LEDs have a viewing angle of 60° but others have a narrow beam of 30° or less.

10G **Calculating an LED resistor value.**

An LED must have a resistor connected in series to limit the current through the LED; otherwise it will burn out almost instantly. See Figure 8e

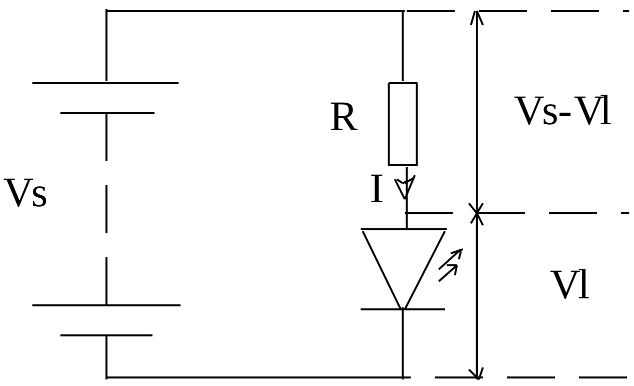


Figure 10e

The resistor value, R is given by: **R = (V_S - V_L) / I** **where**

V_S = supply voltage
V_L = LED voltage (usually 2V, but 4V for blue and white LEDs)
I = LED current (e.g. 20mA), this must be less than the maximum permitted

If the calculated value is not available choose the nearest standard resistor value which is **greater**, so that the current will be a little less than you chose. In fact you may wish to choose a greater resistor value to reduce the current (to increase battery life for example) but this will make the LED less bright.

For example
If the supply voltage V_S = 9V, and you have a red LED (V_L = 2V), requiring a current I = 20mA = 0.020A,
R = (9V - 2V) / 0.02A = 350, so choose 390 (the nearest standard value which is greater). Working out the LED resistor formula using Ohm's law
Ohm's law says that the resistance of the resistor, R = V/I, where:
V = voltage across the resistor (= V_S - V_L in this case)
I = the current through the resistor So R = (V_S - V_L) / I

10H **Connecting LEDs in series**

If you wish to have several LEDs on at the same time it may be possible to connect them in series. This prolongs battery life by lighting several LEDs with the same current as just one LED.

All the LEDs connected in series pass the **same current** so it is best if they are all the same type. The power supply must have sufficient voltage to provide about 2V for each LED (4V for blue and white) plus at least another 2V for the resistor. To work out a value for the resistor you must add up all the LED voltages and use this for V_L.

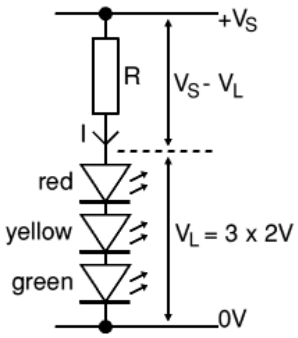


Figure 10f

Example calculations**:**

A red, a yellow and a green LED in series need a supply voltage of at least
3 × 2V + 2V = 8V, so a **9V battery** would be ideal.
V_L = 2V + 2V + 2V = 6V (the three LED voltages added up).
If the supply voltage V_S is 9V and the current I must be 15mA = 0.015A,
Resistor R = (V_S - V_L) / I = (9 - 6) / 0.015 = 3 / 0.015 = 200,
so choose R = 220 (the nearest standard value which is greater).

10I **Connecting LEDs in parallel**

Avoid connecting LEDs in parallel!
Connecting several LEDs in parallel with just one resistor shared between them is generally a bad idea. If the LEDs require slightly different voltages only the lowest voltage LED will light and it may be destroyed by the larger current flowing through it. Although identical LEDs can be successfully connected in parallel with one resistor this rarely offers any useful benefit because resistors are very cheap and the current used is the same as connecting the LEDs individually.
If LEDs are in parallel each one should have its own resistor.

10J **Reading a table of technical data for LEDs**

Suppliers' catalogues usually include tables of technical data for components such as LEDs. These tables contain a good deal of useful information in a compact form but they can be difficult to understand if you are not familiar with the abbreviations used.

The table below shows typical technical data for some 5mm diameter round LEDs with diffused packages (plastic bodies). Only three columns are important and these are shown in bold. Please see below for explanations of the quantities

Type	**Colour**	**I_F max.**	**V_F typ.**	**V_F max.**	**V_R max.**	**Luminous intensity**	**Viewing angle**	**Wavelength**
Standard	**Red**	**30mA**	**1.7V**	2.1V	5V	5mcd @ 10mA	60°	660nm
Standard	**Bright red**	**30mA**	**2.0V**	2.5V	5V	80mcd @ 10mA	60°	625nm
Standard	**Yellow**	**30mA**	**2.1V**	2.5V	5V	32mcd @ 10mA	60°	590nm
Standard	**Green**	**25mA**	**2.2V**	2.5V	5V	32mcd @ 10mA	60°	565nm

High intensity	**Blue**	**30mA**	**4.5V**	5.5V	5V	60mcd @ 20mA	50°	430nm
Super bright	**Red**	**30mA**	**1.85V**	2.5V	5V	500mcd @ 20mA	60°	660nm
Low current	**Red**	**30mA**	**1.7V**	2.0V	5V	5mcd @ 2mA	60°	625nm

I_F max. Maximum forward current, forward just means with the LED connected correctly.

V_F max. Maximum forward voltage.

V_F typ. Typical forward voltage, V_L in the LED resistor calculation.
This is about 2V, except for blue and white LEDs for which it is about 4V.

V_R max. Maximum reverse voltage
You can ignore this for LEDs connected the correct way round.

Luminous intensity Brightness of the LED at the given current, mcd = millicandela.

Viewing angle Standard LEDs have a viewing angle of 60°, others emit a narrower beam of about 30°.

Wavelength The peak wavelength of the light emitted, this determines the colour of the LED. nm = nanometre.

10K **Flashing LEDs**

Flashing LEDs look like ordinary LEDs but they contain an integrated circuit (IC) as well as the LED itself. The IC flashes the LED at a low frequency, typically 3Hz (3 flashes per second). They are designed to be connected directly to a supply, usually 9 - 12V, and no series resistor is required. Their flash frequency is fixed so their use is limited and you may prefer to build your own circuit to flash an ordinary LED using a 555 astable circuit

11 **Semiconductor Transistor**

11A **what is a simple Transistor**

A Transistor is a device for controlling the amplitude and direction of an electric current or voltage, they can be also match the impedances of an output device to the input of another device. Transistor circuits may also be used as gating circuits controlling one or more paths or as switches in electronic circuit.

11B **what is a transistor made from**

A simple transistor is formed from integrating two semiconductor diodes end to end in series this means there a three layers, two junctions and three terminals forming the basis of a Bipolar Junction Transistor (BJT) each of the terminals have a name to identify it known as Emitter, Base and Collector. See Figure 9a for transistor construction and Figure 11b for the two diode analogy and Figure 9c the circuit symbols for both PNP and NPN transistors

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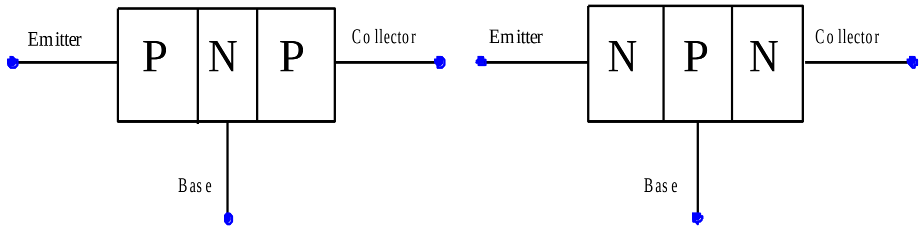


Figure 11a Transistor construction

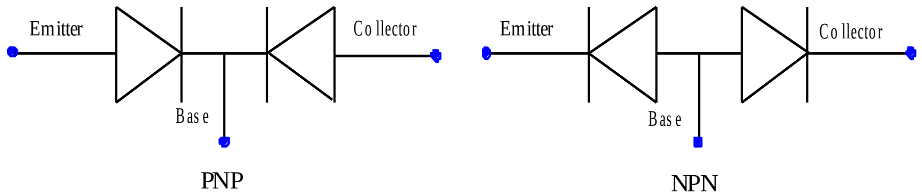


Figure 11b the two diode analogy

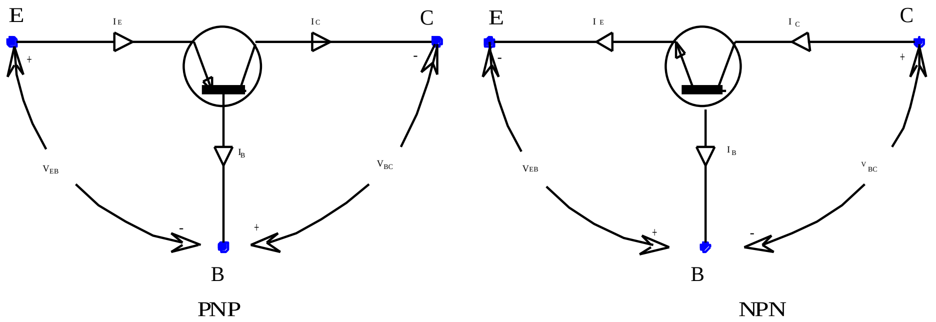


Figure 11c Circuit symbols

11C **Transistor amplifiers.**

a) Common emitter.

Figure 11d shows a common emitter configuration with voltage divider bias (CEVDB). In the figure, the common emitter circuit comprises the load resistor R_C and NPN transistor with the output connected as shown; the other circuit elements are used for biasing the transistor and signal coupling/decoupling.

The resistor R_E between the emitter node and the shared ground appears at first glance to contradict the strict definition of "common emitter", but the term is still appropriate here because, for all frequencies of interest, the capacitor C_E acts as low impedance by decoupling the emitter to ground. The emitter resistor provides a form of negative feedback called *emitter degeneration*, which increases the stability and linearity of the amplifier, especially in response to temperature changes.

For the common emitter circuit on the right this is necessary to ensure the transistor is in the active mode and thus prevent it from acting as a rectifier which would cause clipping on the negative portion of the input signal, resulting in a distorted output.

The resistors R_1 and R2 are chosen to ensure the base-emitter voltage is 0.7 volts, which is the "on" voltage for a BIT transistor. These resistors, along with R_E, also determine the quiescent current flowing through the transistor and therefore its gain.

Common emitter circuits are used to amplify weak voltage signals, such as the faint radio signals detected by an antenna. They are also used in a special analog circuit configuration known as a current mirror, where a single shared input is used to drive a set of identical transistors, each of whose current drive output will be nearly identical to each other, even if they are driving dissimilar output loads.

b). **Common Collector**

The common collector amplifier (Figure 11e) is also called the *emitter follower* amplifier because the output voltage signal at the emitter is approximately equal to the voltage signal input on the base. The amplifier's voltage gain is always less than unity, but it has a large current gain and is normally used to match a high-impedance source to a low-impedance load: the amplifier has large input impedance and small output impedance.

c) **The Common Base Amplifier**

The common base amplifier is also known as the grounded base amplifier. This amplifier can produce a voltage gain but generates no current gain between the input and the output signals. It is normally characterized by very small input impedance and output impedance like the common emitter amplifier. Because the input and output currents are of similar size, the stray capacitance of the transistor is of less significance than for the common emitter amplifier. The common base amplifier is often used at high frequencies where it provides more voltage amplification than the other one-transistor circuits.

A common base circuit is shown in Figure 11f. Above the corner frequency the capacitor between base and ground on the circuit provides an effective AC ground at the transistor's base.

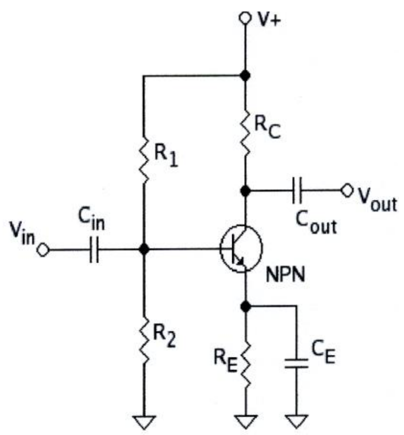


Figure 11d Common emitter

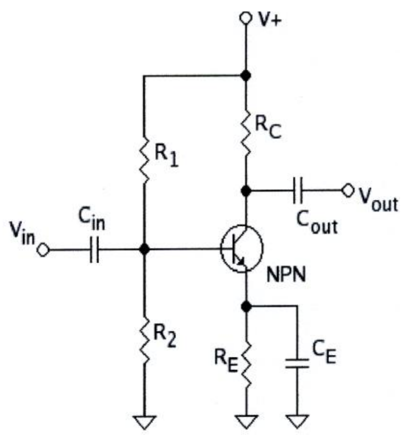


Figure 11e Common Collector

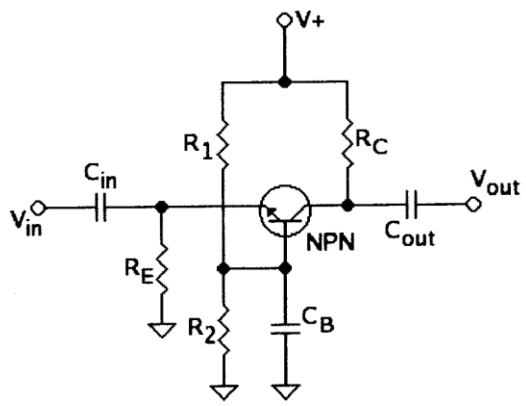


Figure 11f Common base

11D **Amplifier efficiency**

Amplifier circuits are classified as A, B, AB and C for analogue designs, and class D and E for digital or switching designs. For the analogue classes, each class defines what proportion of the input signal cycle is used to actually switch on the amplifying device:

Class A - 100% of the input signal is used (conduction angle a = 360° or 2π)
Class AB - more than 50% but less than 100% is used. (181° - 359°, π < a < 2π)
Class B - 50% of the input signal is used (a = 180° or π)
Class C - less than 50% is used (0° - 179°, a < π)

This can be most easily understood using the diagrams in each section below. For the sake of illustration, a bipolar junction transistor is shown as the amplifying device. In an analogue amplifier, the signal is applied to the input terminal of the device (base), and this causes a current to flow in proportion to the input between the output terminal and ground (collector). This current is obtained from the power supply. The voltage signal shown is thus a larger version of the input, but has been changed in sign (inverted) by the amplification. Other arrangements of amplifying device are possible, but that given (common emitter,) is the easiest to understand and employ in practice. If the amplifying element is linear, then the output will be faithful copy of the input, only larger and inverted. In practice, transistors are not linear, and the output will only approximate the input. This is the origin of distortion within an amplifier. Which class of amplifier (A, B, AB or C) depends on how the amplifying device is biased - in the diagrams the bias circuits are omitted for clarity?

a) Class A

Class A amplifiers amplify over the whole of the input cycle Figure 9g. They are the usual means of implementing small-signal amplifiers. They are not very efficient - a theoretical maximum of 50% is obtainable, but for small signals, this waste of power is still extremely small, and can easily be tolerated. It is only when we need to create output powers with appreciable levels of voltage and current does Class A become problematic. In a Class A circuit, the amplifying element is biased such that the device is always conducting to some extent, and is operated over the most linear portion of its characteristic curve (known as its transfer function or transconductance curve). Because the device is always conducting, even if there is no input at all, power is wasted. This is the reason for its inefficiency.

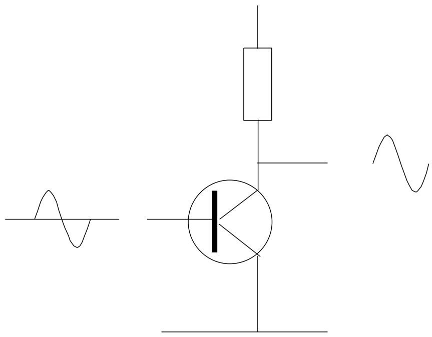


Figure 11g Class A amplifier

If we wish to produce large output powers from a Class A circuit, the power wastage will become significant. For every watt delivered to the load, the amplifier itself will, at best, waste another watt. For large powers this will call for a large power supply and large heat sink to carry away the waste heat. Class A designs have largely been superseded for audio power amplifiers, though some audiophiles believe that Class A gives the best sound quality, due it being operated in as linear a manner as possible. In addition, aficionados prefer vacuum tube designs over transistors, for a number of reasons. One is that the characteristic curve of a valve means that distortion tends to be in the form of even harmonics, which sound more "musical" than odd harmonics. Another is that valves use many more electrons at once than a transistor, and so statistical effects lead to a "smoother" approximation of the true waveform - see shot noise for more on this. Field-effect transistors have similar characteristics to valves, so these are found more often in high quality amplifiers than bipolar transistors. Historically, valve amplifiers often used a Class A power amplifier simply because valves are large and expensive; the Class A design uses only a single device. Transistors are much cheaper, and so more elaborate designs that give greater efficiency but use more parts are still cost effective

b) Class B and AB Amplifiers

Class B amplifiers only amplify half of the input wave cycle Figure 9h As such they create a large amount of distortion, but their efficiency is greatly improved. This is because the amplifying element is switched off altogether half of the time, and so cannot dissipate power. A single Class B element is rarely found in practice, though it can be used in RF power amplifiers where the distortion is unimportant. However Class C is more commonly used for this.

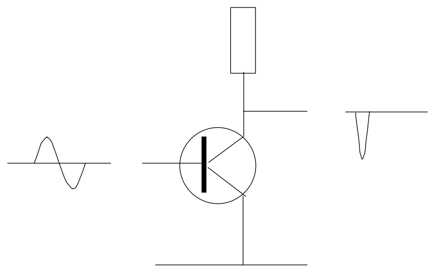


Figure 11h Class B Amplifier

c) Pushpull amplifiers

A practical circuit using Class B elements is the complementary pair or "push-pull" arrangement; complementary devices are used to each amplify the opposite halves of the input signal, which is then recombined at the output. This arrangement gives excellent efficiency, but can suffer from the drawback that there is a small glitch at the "joins" between the two halves of the signal. This is called crossover distortion. A solution to this is to bias the devices just on, rather than off altogether when they are not in use. This is called Class AB operation. Each device is operated in a non-linear region which is only linear over half the waveform, but still conducts a small amount on the other half. The result is that when the two halves are combined, the crossover is greatly minimised or eliminated altogether

Class B or AB push-pull circuits are the most common form of design found in audio power amplifiers, and are sometimes used for RF linear amplifiers as well.

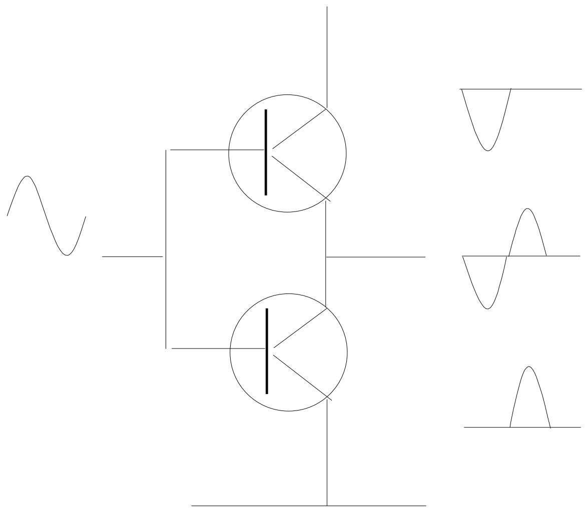


Figure 12h Push pull amplifier

d) Class C Amplifiers

Class C amplifiers conduct over less than 50% of the input signal Figure 9j As such the distortion at the output is gross, but very high efficiencies can be reached - up to 90% or so. Some applications can tolerate the distortion, such as audio bullhorns. A much more common application for Class C amplifiers is in RF transmitters, where the distortion can be vastly reduced by using tuned loads on the amplifier stage. The input signal is used to roughly switch the amplifying device on and off, which causes pulses of current to flow through a tuned circuit. The tuned circuit will only resonate at one particular frequency, and so the unwanted harmonics are suppressed, and the wanted full signal (sine wave) will be developed across the tuned load. Provided the transmitter is not required to operate over a very wide band of frequencies, this arrangement works extremely well. Any residual harmonics can be removed using a filter.

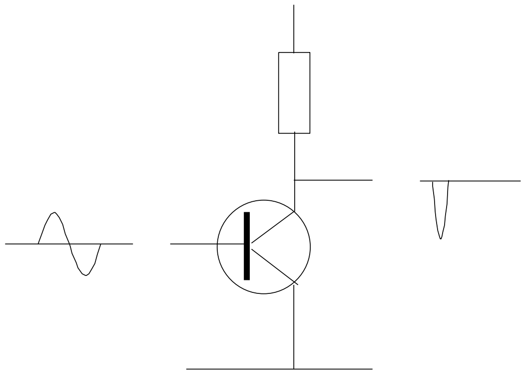


Figure 11j Class C Amplifier

e) **Negative Feedback**

All amplifying devices are inherently non-linear; their physics dictates that they operate using a square law. While these devices can be treated as linear over some portion of their characteristic curve, the fact is that no device is truly linear. The result of non-linearity is distortion. As we have seen, the application dictates how much distortion we can tolerate. For hi-fi audio applications, instrumentation amplifiers and the like, distortion must be minimal. While careful design of each stage can achieve very good results, overall the best an open-ended (open loop) design can achieve is about 1% distortion. One way to reduce this further is to use negative feedback. This involves feeding a portion of the output back to the input in such a way that it cancels out part of the input. Naturally the main effect of this is to reduce the overall gain of the system, which might seem counter productive. However, all of the unwanted signals that are introduced by the amplifier are also fed back, and, since they are not part of the original input, become added to the input, but in opposite phase. The result is that the system as a whole becomes totally linear, because the input now "anticipates" all the distortions that will arise. With feedback, distortion can be lowered to negligible levels - 0.001% being typical. By the same means, noise is also reduced. Even effects such as crossover distortion can be eliminated using negative feedback. With feedback, the amplifier itself can change over time (due to deterioration of its components, changes in temperature, etc), with absolutely no change in its performance. While feedback would appear to be a universal fix for all the problems an amplifier can suffer from, there are many who believe that negative feedback is a bad thing.

The arguments against feedback include the fact that being a loop it takes a finite time to react to an input signal and for this short period the amplifier is "out of control". A musical transient that is of the same order as this period will be grossly distorted, even though the amplifier will show incredibly good distortion performance on steady-state signals. Proponents of feedback refute this, saying that the feedback "delay" is of such a short order that it represents a frequency vastly outside the bandwidth of the system, and such effects are not only inaudible, but not even present, as the amplifier will not respond to such high frequency signals. The argument has been the source of controversy for many years, and has led to all sorts of interesting designs to deal with it - such as feed forward amplifiers. The fact remains that the majority of modern amplifiers use considerable amounts of feedback, though the best audiophile designs seek to minimise this as much as possible. The concept of feedback is used in operational amplifiers to precisely define gain, bandwidth and other parameters.

11E Practical Amplifier circuit

For the purposes of illustration, this practical amplifier circuit is described in Figure 11k it could be the basis for a moderate audio power amplifier. It features a typical design found in modern amplifiers, with a class AB push-pull output stage, and uses some overall negative feedback. Bipolar transistors are shown, but this design would also be realisable with FETs or valves.

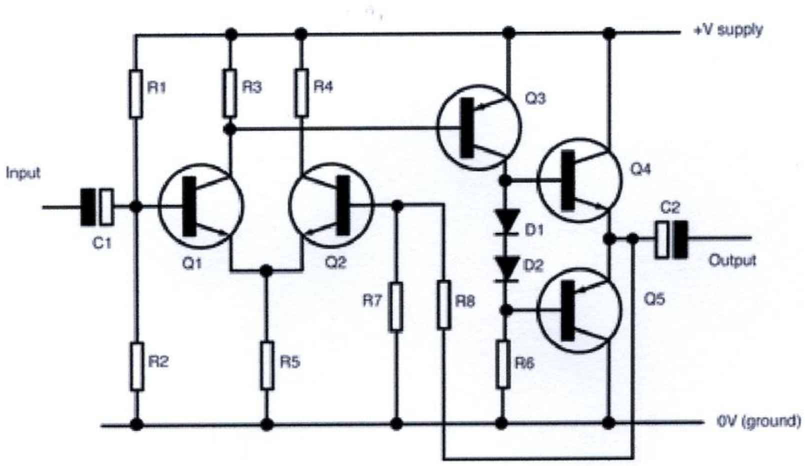


Figure 11k Audio amplifier with feedback

The input signal is coupled through capacitor C1 to the base of transistor Q1. The capacitor allows the AC signal to pass, but blocks the DC bias voltage established by resistors R1 and R2 so that any preceding circuit is not affected by it. Q1 and Q2 form a differential amplifier, in an arrangement known as a long-tailed pair. This arrangement is used to conveniently allow the use of negative feedback, which is fed from the output to Q2 via R7 and R8. The amplified signal from Q1 is directly fed to the second stage, Q3, which provides further amplification of the signal, and the d.c. bias for the output stages, Q4 and Q5. R6 provides the load for Q3. So far, the entire amplifier is operating in Class A. The output pair are arranged in Class AB push-pull, also called a complementary pair. They provide the majority of the current amplification and directly drive the load, connected via d.c. blocking capacitor C2. The diodes D1 and D2 provide a small amount of constant voltage bias for the output pair, just biasing them into the conducting state so that crossover distortion is minimised. This design is simple, but a good basis for a practical design because it automatically stabilises its operating point, since feedback internally operates from d.c up through the audio range and beyond. Further circuit elements would probably be found in a real design that would roll off the frequency response above the needed range to prevent the possibility of unwanted oscillation. Also, the use of fixed diode bias as shown here can cause problems if the diodes are not both electrically and thermally matched to the output transistors - if the output transistors turn on too much, they can easily overheat and destroy themselves, as the full current from the power supply is not limited at this stage. Calculating the values of the resistors is left as an exercise for the reader. is turned off and then on periodically. The time off and on is made to be proportional to the desired output amplitude. Since this amplifier just has one switch, it can be cheaper than any other class.

However, it also has more types of potential error than any other class. Class E amplifiers take samples, and thus have a Nyquist frequency and require a filtered input. It's also common to use digital circuits to control the duty cycle by counting some very fast periodic clock signal. When this is done, class E amplifiers also have quantization error. Last but not least, class E amplifiers have sharp edges, so they can have severe harmonic

11F **Darlington Pair**

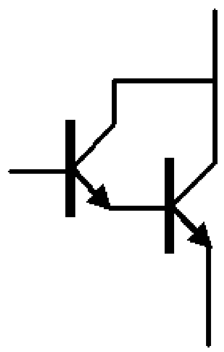


Figure11L

a) **Description**

In electronics the **Darlington transistor Figure 11L** is a semiconductor device which combines two bipolar transistors in tandem (often called a "**Darlington pair**") in a single device so that the current amplified by the first is amplified further by the second transistor. This gives it high current gain (written β or h_{FE}), and takes up less space than using two discrete transistors in the same configuration. The use of two separate transistors in an actual circuit is still very common, even though integrated packaged devices are available.

. A similar transistor configuration using two transistors of opposite type (NPN and PNP) is the Sziklai pair, sometimes called the "complementary Darlington".

b) **Behavior.**

A Darlington pair behaves like a single transistor with a very high current gain. The total gain of the Darlington is the product of the gains of the individual transistors:

$$\beta_{\mathrm{Darlington}} = \beta_1 \times \beta_2$$

A typical modern device has a current gain of 1000 or more, so that only a tiny base current is required to make the pair switch on. Integrated devices have three leads (B, C and E) which are equivalent to the leads of a standard individual transistor.

emitter voltages: $V_{BE} = V_{BE1} + V_{BE2}$

To turn on there must be ~0.6 V across both base-emitter junctions which are connected in series inside the Darlington pair. It therefore requires more than 1.2 V to turn on. When a Darlington pair is fully conducting, there is a residual saturation voltage of 0.6 V in this configuration, which can lead to substantial power dissipation. Another drawback is that the switching speed can be slow, due to the inability of the first transistor to actively inhibit the current into the base of the second device. This can make the pair slowly to switch off. To alleviate this, a resistor of a few hundred ohms between the second device's base and emitter is often used. Integrated Darlington pairs often include this resistor.

It has more phase shift at high frequencies than a single transistor and hence can become unstable with negative feedback much more easily.

Darlington pairs are available as complete packages but can also be made up from two transistors; Q_1 (the left-hand transistor in the diagram) can be a low power type, but normally Q_2 (the right-hand transistor) will need to be high power. The maximum collector current I_C (max) for the pair is the same as I_C (max) for Q_2. A typical integrated type of power device is the 2N6282, with a current gain of 2400 at a collector current of 10 a and an included switch-off resistor.

12 Transistors as switches

12A Simple transistor switch theory

The easiest way to understand transistors is to think of them as switches. You can switch a big current (between the collector and emitter) with a much smaller current (in the base). Lets look at examples Figures 12al and 12b

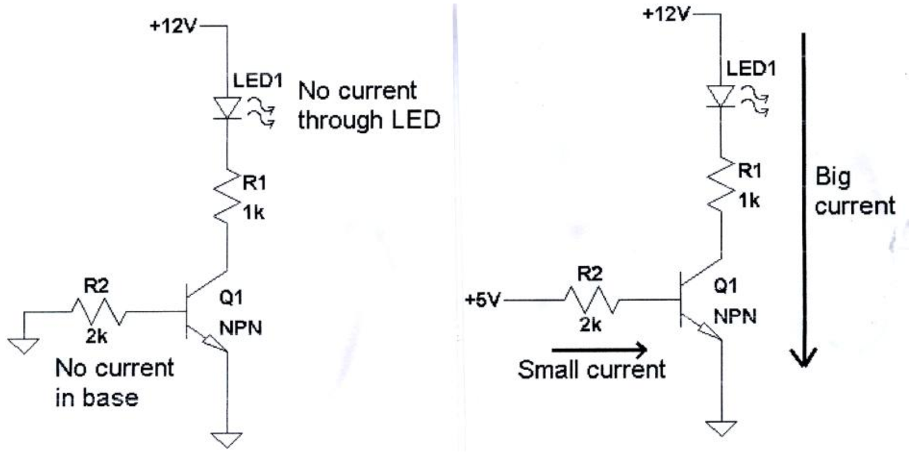


Figure 12a NPN transistor as switch (off) Figure 12b NPN transistor as switch (on)

The circuit above is a typical example of driving LED's from a micro controller or a PC's parallel port. The port is well protected because it will only supply a small current, though the small current is enough to switch a much bigger load. Transistors are also handy to convert between different voltages (5V and 12V see examples above. and below)

A PNP transistor works the same as an NPN transistor, except the current flows from the base, not into the base. See Figures 12c and 12d

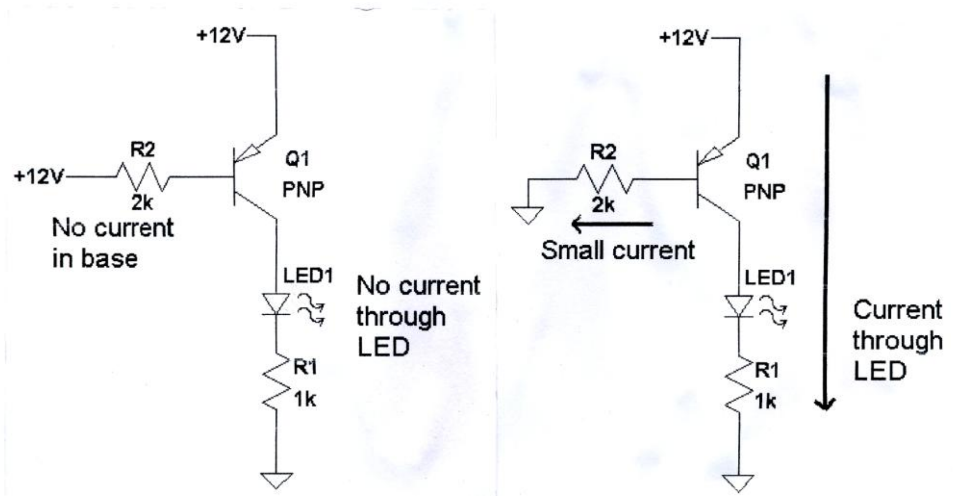


Fig 12c PNP transistor as a switch (off) Fig 12d PNP transistor as a switch (on

12B **Transistors as flip flop circuits**.

A flip flop logic circuit is based on the above technology with refinements see Figure 10ebelow

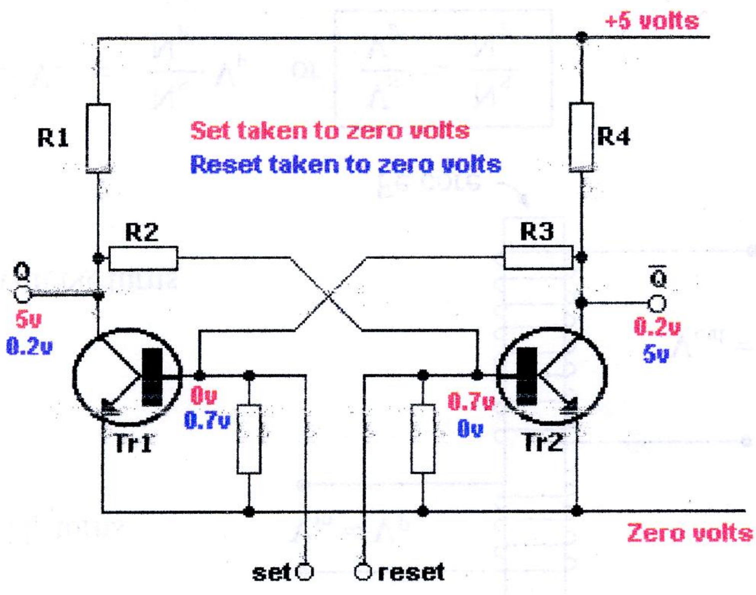
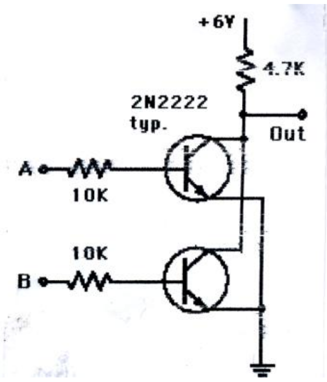


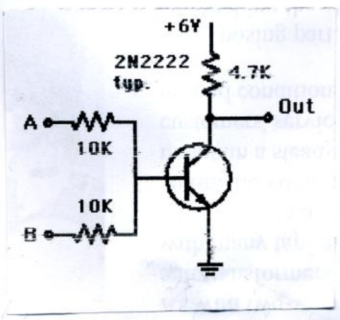
Figure 12e

The two transistors are cross*coupled and when TR1 is switched on by the application of 5V to the base it automatically provides 0V to the base of TR2 thereby cutting it off, the circuit will stay in equilibrium until TR2 is manually switched on by a 5V being applied to its base. If R2 and R3 were replaced by capacitors then the circuit would cycle as a square wave generator based on the time constants of the capacitor and resistors in the collector to base paths.

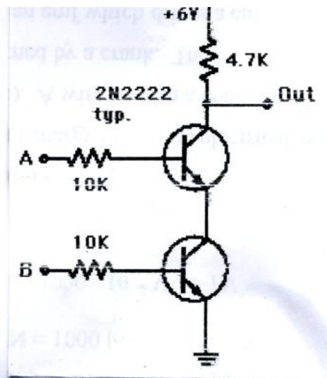
10c **Transistors as gates**



2 Transistor NOR gate
Figure 12f



1 Transistor NOR Gate`
Figure 12g



(2 Transistor Nand Gate
Figure 10h

In Figure 12f - both A and B inputs have to be low to cut the two transistors off, if one is high then the transistor conducts and the output goes low hence NOR= Not or.

In Figure 12g- if either input is high then the transistor is switched on and the output neither goes low, hence NOR gate

In Figure 12h- if either input is low then the appropriate transistor is switched off, hence the inputs to the 10k Ohm resistors and the bases needs to be high to switch the transistors on transistor conducting the output goes low Hence NAND Not and Gate.

12D Transistor astable multivibrators.

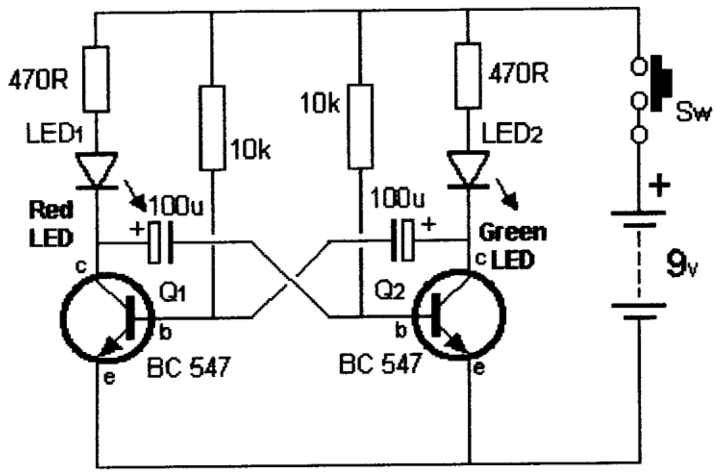


Figure 12i Transistor Multivibrator

Recognising an Astable Multivibrator (Flip Flop)

The Astable Multivibrator is a symmetrical arrangement using two transistors with cross-coupling See Figure 12i. Each transistor has a base bias resistor 10k and a LED with 470R resistor in the collector lead to form the collector load.

The circuit consists of two identical halves and is called a Flip Flop because one half is ON while the other half is OFF. The ON half is keeping the OFF half OFF but it cannot keep it off indefinitely and gradually the OFF half turns ON via the 10k base-bias resistor. This drives the ON side OFF and the circuit changes state. In other words it flips over. The same events occur in the other half of the cycle and the circuit eventually flops back again.

This sounds very complicated but in reality the circuit is quite simple in operation as one half is exactly the same as the other and there are only 5 components in each half.

The circuit is self-starting and only one LED is on at a time. It is a free-running multivibrator (this means it does not stop) and we will describe its operation in a non technical way. A free-running multivibrator is also called an astable multivibrator (meaning is has no stable states) and that is why it flips from one state to the other continuously.

The standard way to draw this type of multivibrator is to show the two capacitors crossing at the centre of the circuit, this also gives the circuit symmetry and makes it easy to recognise.

The other way to identify an astable multivibrator is identifying that it has two capacitors. (The monostable multivibrator has one capacitor and the bistable multivibrator has no capacitors.)

In simple terms, the astable] multivibrator has two states. When one transistor is turned on it operates (supplies current to) a LED (or other device) in its output Kne and at the same time keeps the other transistor off. But it cannot keep the other off forever and eventually the other transistor begins to turn on to a time C*R. When it does, the action turns the first transistor off slightly and a change-over begins to occur. This produces the flip action.

After a short period of time the other half of the circuit cannot be kept off and the whole arrangement flops back to the first state.

The components that determine the frequency are the electrolytic and two base-bias resistors. If these values are changed, the frequency will alter. For instance, if the electrolytics are reduced in value, the frequency will increase and if the resistors are decreased, the frequency will increase.

If you increase the frequency of this circuit to more than 20 cycles per second, it will appear as if both LEDs are switched on at the same time. But the fact is the circuit will be operating faster than your eye can see and that's why we have chosen large values of capacitance to slow it down.

When the electrolytics and resistors are made equal value (as in our case), each LED flashes for the same length of time. This is called an equal mark-space ratio: (50%:50%). This means the flip time is the same as the flop time. Theses components can be changed to any ratio, to give different effects.

12E Bistable Multivibrator

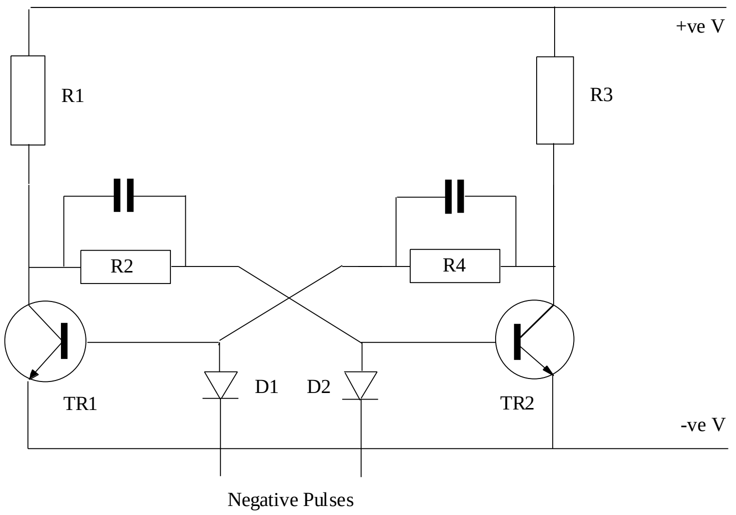


Figure 12j

The Bistable Multivibrator is a simpel electronic circuit that remains in one of two stable states until it receives a pulse (logic 1 signal) through one of its inputs, upon which it switches, or ‘flips’, over to the other state. Because it is a two-state device, it can be used to store binary digits and is widely used in the integrated circuits used to build computers. Effectively this circuit could act as a logic inverter; if a number of diode circuits replaced the single diode you have the basis of a logic gate. (Diode diode Logic)

13 Logic circuits.

13A Diode logic

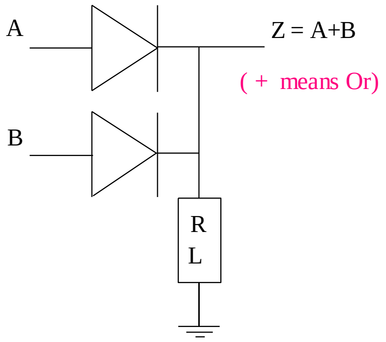


Figure 13a

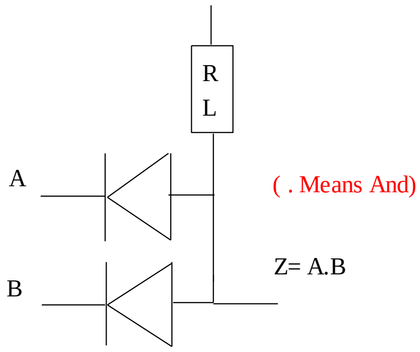


Figure 13b

Figure 13a represents basic Diode Logic OR gate. We'll assume that logic 1 is represented by +5 volts, and logic 0 is represented by ground, or zero volts. In this figure, if both inputs are left unconnected or are both at logic 0, output Z will also be held at zero volts by the resistor, and will thus be a logic 0 as well. However, if either input is raised to +5 volts, its diode will become forward biased and will therefore conduct. This in turn will force the output up to logic 1. If both inputs are logic 1, the output will still be logic 1. Hence, this gate correctly performs a logical OR function.

Figure 13b is the equivalent AND gate. We use the same logic levels, but the diodes are reversed and the resistor is set to pull the output voltage up to logic 1 state. For this example, +V = +5 volts, although other voltages can just as easily be used. Now, if both inputs are unconnected or if they are both at logic 1, output Z will be at logic 1. If either input is grounded (logic 0), that diode will conduct and will pull the output down to logic 0 as well. Both inputs must be logic 1 in order for the output to be logic 1, so this circuit performs the logical AND function.

If we go one step further and connect the outputs of two or more of these structures to another AND gate, we will have lost all control over the output voltage; there will always be a reverse-biased diode somewhere blocking the input signals and preventing the circuit from operating correctly. This is why Diode Logic is used only for single gates, and only in specific circumstances.

13B **Diode transistor logic**

Diode-Transistor Logic (DTL) is a class of digital using bipolar junction transistors (BIT), diodes and resistors; it is the direct ancestor of transistor-transistor logic. It is called *diode-transistor logic* because the logic gating function (e.g. AND) is performed by a diode network and the amplifying function is performed by a transistor.).

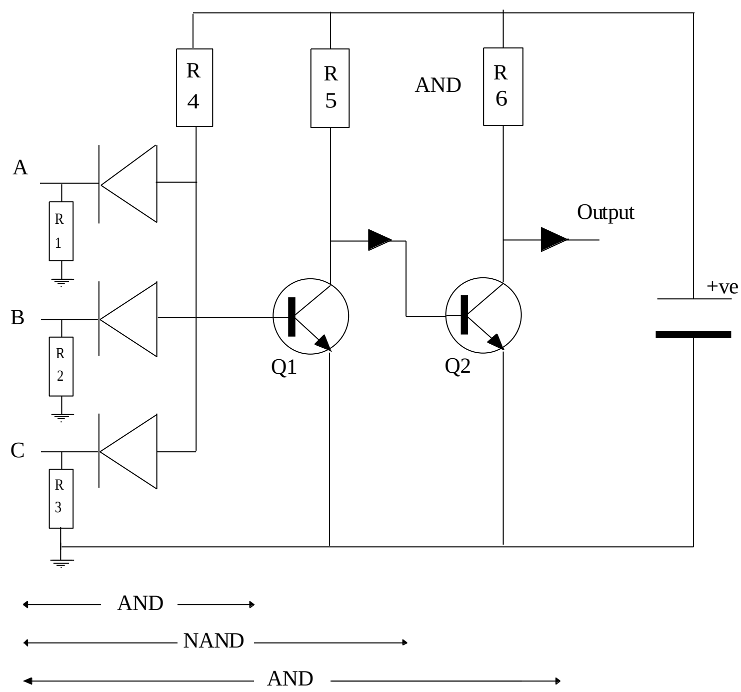


Figure 13c Diode transistor AND Gate

The "pull down" resistors R1, R2 and R3 hold the emitters of the diodes low, making them forward biased.

Thus the outputs at the collectors are held low, Q1 base is low and its collector high. The base of Q2 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 Q1 high. And so making the collector of Q1 go low, together with the base of Q2.

The collector of Q2 goes high. Causing the output to go high because A and B and C have gone high.

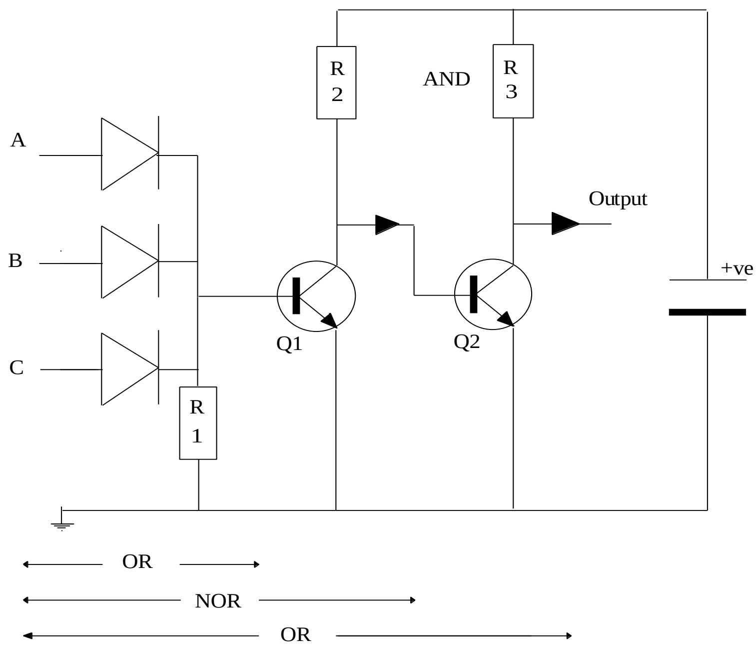


Figure 13d Diode transistor OR gate

14 Digital Logic

14A Logic gates

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.

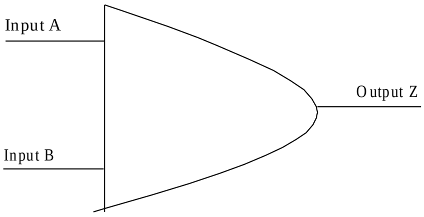
A thermometer is an analogue device because it can record an infinite number of values such 100 degrees, 0.1 degrees or 34.354 degrees etc. Other analogue devices are a car speedo and a Hi Fi amplifier (which can handle lots of different frequencies and loudness.)

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

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	1
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.

e.g.

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.

14B **AND Gate**

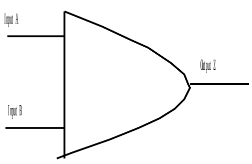
The AND gate has two or more inputs and one output.

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

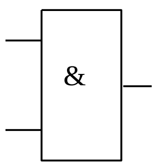
In the switch diagram the lamp lights up only when A and B are operated. If only one is switched then the lamp stays off.

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

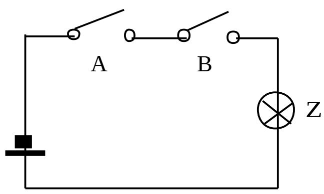
The Boolean expression is A. B = Z which translated says, A and B both high, makes Z high.



US Symbol



UK Symbol



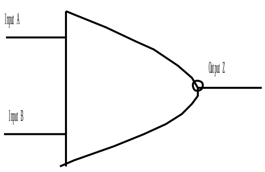
Switch simulating AND

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

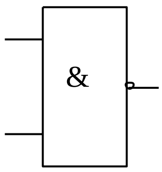
Truth Table

14C NAND Gate

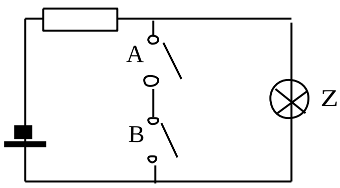
The Nand gate has two or more inputs and one output.
The output voltage goes low only when all input voltages are high.
In the switch diagram the lamp goes out when A and B are operated. (A short circuit is placed across the lamp)
In the truth table Z = 0 when A and B = 1
The Boolean expression is A.B = Z which translated says, A and B high makes Z low. Z (called Z bar) means Z is low.



U S Symbol



UK Symbol



Switch simulating NAND

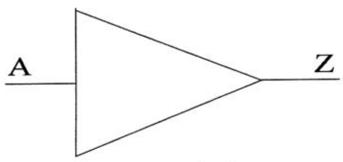
A	B	Z
0	0	1
1	0	1
0	1	1
1	1	0

Truth Table

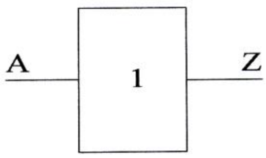
14D NOT Gate

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



U S Symbol



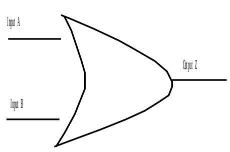
UK Symbol

A	Z
0	1
1	0

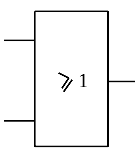
Truth Table

14E OR Gate

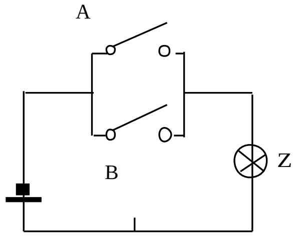
The OR gate has two or more inputs and one output.
The output voltage goes high only when one or more input voltages are high.
In the switch diagram the lamp lights up when A OR B (or both) are operated.
In the truth table Z = 1 when A or B = 1.
The Boolean expression is A+B = Z which translated says, A or B high makes Z high.
The plus sign + translates as OR.



U S Symbol



UK Symbol



Switch simulating OR

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

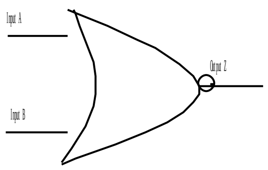
Truth table

14F NOR Gate

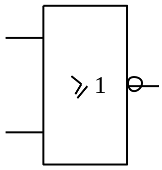
The NOR gate has two or more inputs and one output.
The output voltage goes low only when one or more input voltages are high.
In the switch diagram the lamp goes out when A OR B (or both) are operated. (A short circuit is placed across the lamp)
In the truth table Z = 0 when A or B = 1

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

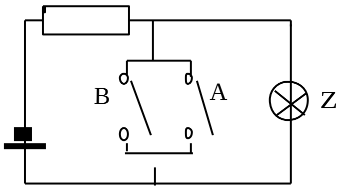
The plus sign, + translates as OR. $\overline{Z}$ (called Z bar) means Z is low.



U S Symbol



UK Symbol



Switch simulating OR

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

Truth Table

14G using two AND Gates to make a simple square wave oscillator

Using two gates from a CMOS 4011 NAND chip, a simple square wave oscillator can be made. Alternatively a CMOS 4001 chip can also be used or a TTL equivalent. In this circuit the mark space ratio can also be independently controlled by varying the value of the resistors. The rise and fall times of the output pulses depend on the operating voltage of the IC and type of IC, but will be typically in the order on tens of nanoseconds.