

Electronic materials and components-Other passive components

This is one of the topics which could be a complete book in itself, particularly if you add mechanical components such as heat sinks. To keep it to a reasonable size, we are restricting ourselves to a brief survey of other capacitor types, inductors and connectors. As part of this, we shall introduce some basic-level information on magnetic components and glasses. Don't spend too long among the detail of this part, but keep in mind as you carry out designs as part of your work that there are many passive components – if you come across a new type, why not examine its construction, ask yourself how it was made, and think about how best to use it whilst minimising its chance of failure.

Other capacitor types

The basic formula for a capacitor which you will remember from Electrolytic capacitors makes it clear that the value of a capacitor is proportional to the area of the plates, inversely proportional to their separation, and proportional to the dielectric constant of the material between the plates.

Since the early days of electronics, when capacitor dielectrics were air or glass, engineers have been trying new materials, in order to cram as much capacitance into the available space. Early capacitors used cellulose paper, suitably impregnated with oil or wax, and coated in wax; the polystyrene-based capacitors which came along a little later were almost as intolerant of random contact with soldering irons! Occasionally you will still find polystyrene capacitors, and types based on paper are still used in specialist applications.

For high voltage, small value capacitors, you will also find mica capacitors. Made of a natural material with a laminar structure which can be prised apart to form thin tough sheets, plates of mica with silver electrodes can be stacked and adjusted by abrading part of the electrode. Given the hand-crafting involved, it is not surprising that mica capacitors have always been expensive, but at least they produced high yields at close tolerance, a feat difficult to achieve with ceramic parts.

Following the development of improved polymer materials, the wound structure used in polystyrene capacitors was developed into a more reliable structure, usually either cast or potted in a protected box. Capacitors with cellulose paper dielectric

were also improved by impregnating with resins. Figure 1 shows one construction which is typical of polymer/paper capacitors. The base is a thin, flexible film of a dielectric such as polyethylene terephthalate, typically with a dielectric constant of around 5. The electrodes may be of a separate foil (as shown), or produced by selectively coating the dielectric with a vacuum-deposited aluminium electrode – this is the cheaper and more common process.

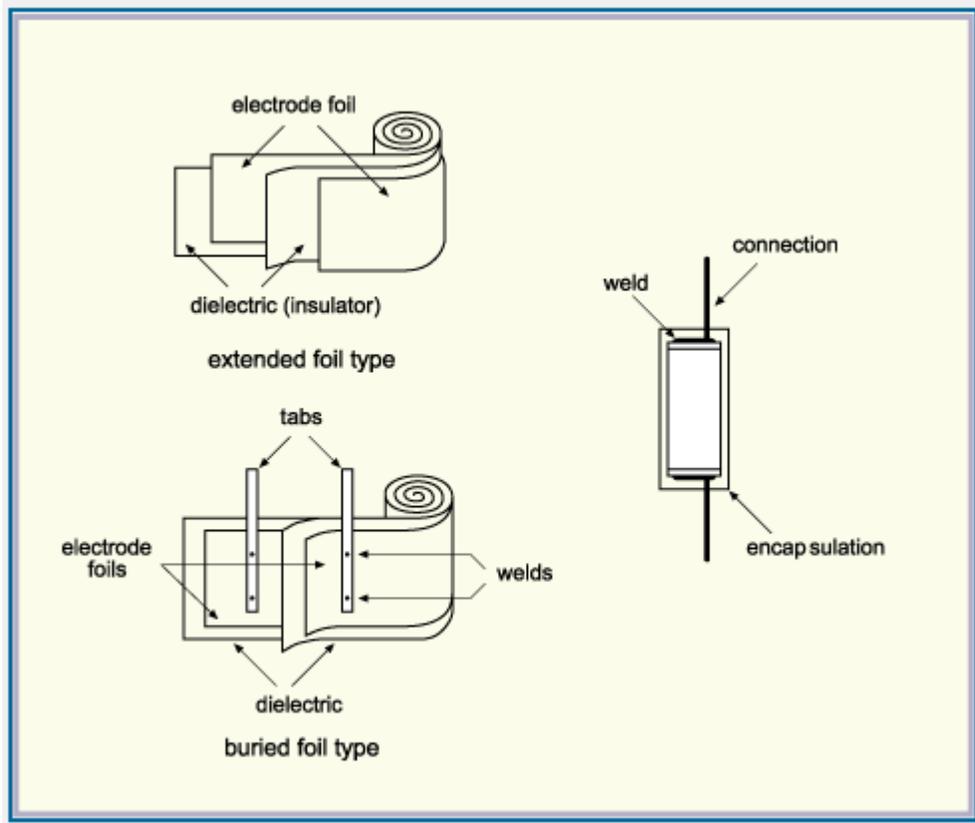


Figure 1: Construction methods for wound polymer/foil capacitors

Sheets of dielectric are interleaved with alternate contact areas on opposite sides, and the dielectric or dielectric/foil sandwich is wound, and 'end-sprayed' with metal to make contact with the entire length of the outside edge of each capacitor plate. Welded connections are then made to both end faces, and the windings cut and encapsulated.

A number of different dielectric materials (polypropylene/polycarbonate/polyester) are made into capacitors by similar methods, and combinations of paper and polypropylene are common for AC applications.

Most of the materials used have severe limitations to their ability to survive high temperatures, and are not often designed for reflow applications. However, given appropriate dielectric materials and encapsulants, capacitors can be wound into a flattened cylindrical shape, and moulded in chip format: capacitance values available are typically 10nF to 0.22µF at 50V, in 1812 packages.

The vast majority of capacitors used are multilayer ceramic chips or electrolytic types. However, other dielectrics may be chosen, for reasons either of performance or of cost (metallised plastic capacitors can offer a cheaper alternative to ceramic for some non-critical applications).

Figure 2 shows the areas of applicability of some of the major dielectric types – except for highly stable applications, the mica capacitor has been replaced by ceramic. There are evident needs for alternatives to ceramic for high value, high voltage capacitors of ratings such as those used for mains suppression.

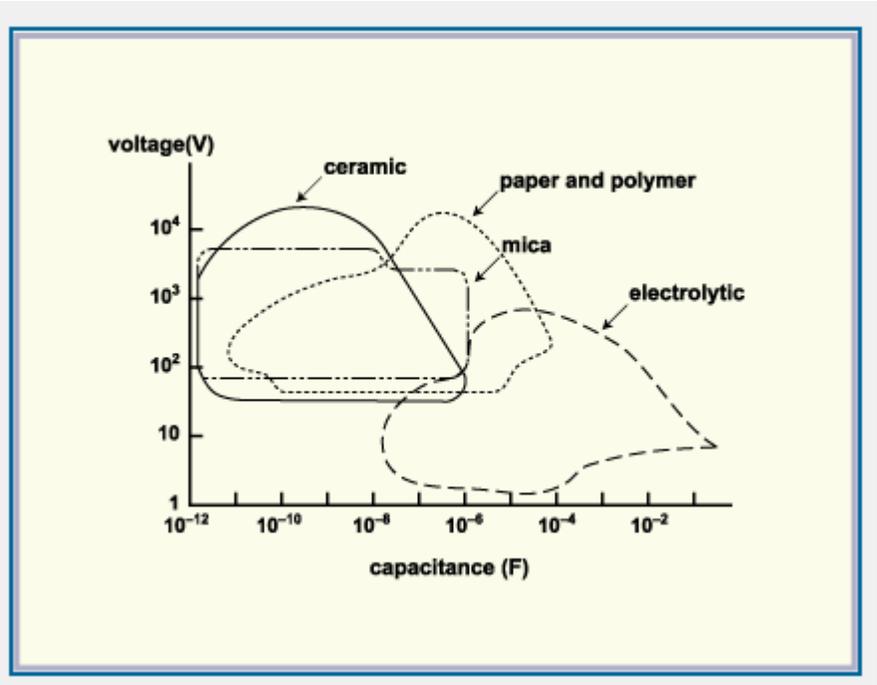
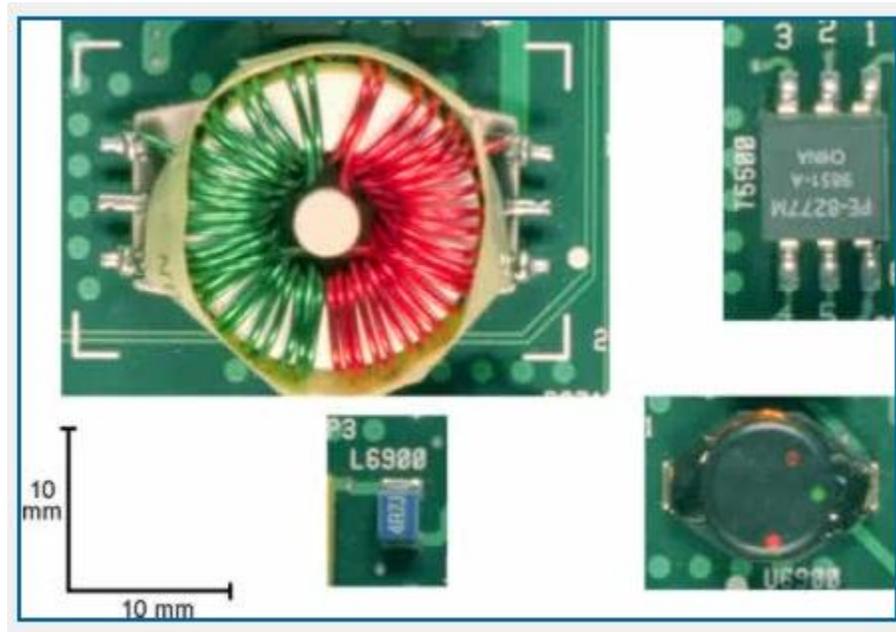


Figure 2: Capacitance and value ranges for common dielectric types

Inductors

Inductive components make use of the voltage that is generated when a field changes either on the same piece of wire (self-induction) or in a nearby piece of wire (mutual induction) The level of voltage generated is greatly increased if the wire is wound into a coil, and as much as possible of the magnetic field produced by the conductor is guided through that coil. Whilst low value inductors may have only an air core, typically the magnetic field from the coil is concentrated using a magnetic core to guide the field.



Some different formats of inductor

In order to understand the basis of the ferrite and other magnetic materials used in making inductors, we need to stand back and refresh what we know about magnetism. As with static electricity, which we will meet in the unit on Failure mechanisms, the behaviour of the material is not perhaps what we might expect from our previous acquaintance with electronics. Much of this is to do with the fact that both phenomena are associated with fields.

Some magnetic basics

An electrical current loop generates a region of physical attraction or magnetic field, represented by a set of magnetic flux lines. The magnitude and direction of the field at any given point near the loop is the 'magnetic field strength', represented by H. This is a vector quantity, that is, it is associated with direction as well as magnitude, but this is not an aspect we need to dwell upon. Some materials are inherently magnetic; that is, they can generate a magnetic field without any obvious electrical current. A bar magnet is a familiar example of something which has an identifiable dipole (North-South) orientation.

For the free space around a source of a magnetic field we define a magnetic induction, B whose magnitude is the flux density. This is related to the magnetic field strength H by

$$B = \mu_0 H$$

where μ_0 is the permeability of vacuum. If we replace the vacuum by solid material, the magnitude of the flux density will change, but can still be expressed in the form

$$B = \mu H$$

where μ is the 'permeability' of the solid. By analogy with Ohm's Law, the magnetic induction B is analogous to current density, the magnetic field strength H to a voltage gradient (electric field strength), and permeability corresponds to conductivity. The presence of the material instead of the vacuum has changed the induction.

The magnetic behaviour of materials is generally expressed in terms of relative permeability μ_r , which is the ratio of the permeability of the material to the permeability of vacuum. This is a dimensionless quality of the same type as relative dielectric constant.

A few materials, such as copper and gold, have a value of relative permeability which is very slightly less than 1. Such 'diamagnetic' materials have structures which respond to an applied field by setting up a slight opposing field. A larger number of solids have values of relative permeability which are slightly greater than 1 (between 1.00 and 1.01). Materials which exhibit this 'paramagnetism' have electronic structures that set up a reinforcing field parallel to the applied field.

For both paramagnetic and diamagnetic materials, the contribution of the additional field is miniscule. However, there are materials with relative permeability which is substantially greater, as much as one million times in some cases. This phenomenon is referred to as 'ferromagnetism', one of the earliest materials used for this being annealed 'soft' iron. However, this term is slightly misleading, because a number of ferromagnetic materials contain no iron at all.

Both diamagnetic and paramagnetic materials behave linearly with the applied field. However, for materials whose induction increases dramatically with field strength, the connection between B and H is far from linear, as shown in Figure 3.

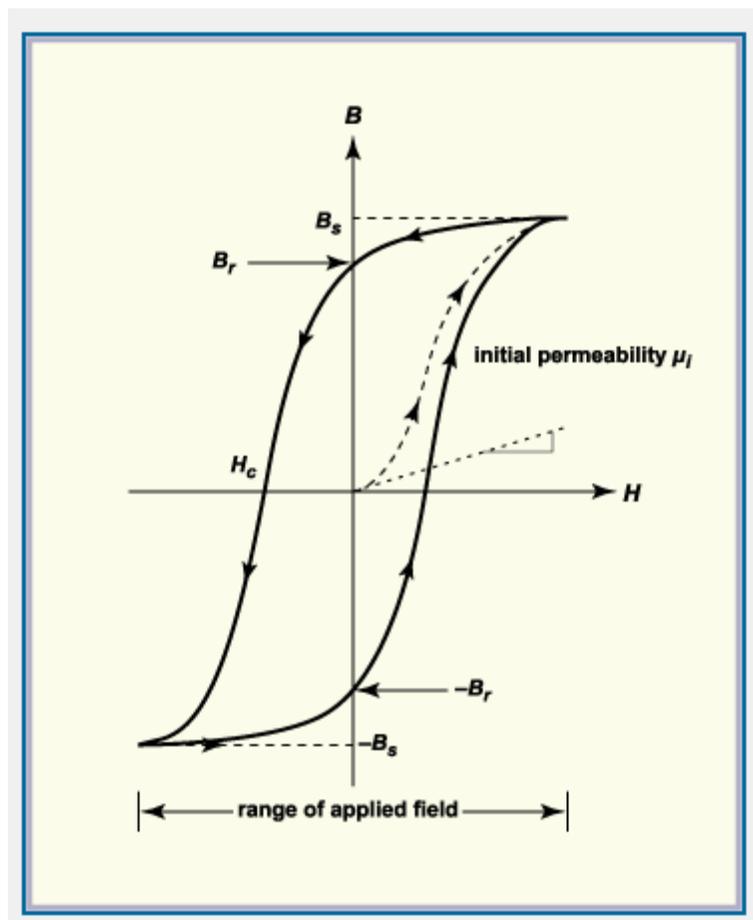


Figure 3: B-H plot for a ferromagnetic material

Starting with a de-magnetised sample, with no induction in the absence of a field, the initial application of a field generates a slight increase in induction, but after

this there is a sharp rise, until the flux density reaches a maximum at 'saturation induction'.

When the field is removed, the induction drops, but not to zero, and in order to remove this 'remanent induction' the field must be reversed. Induction is reduced to zero only when a 'coercive field' of H_c has been applied. By continuing the field reversal, the material can again be saturated, at the same level of induction, but in the opposite direction. Again there is a remanent induction as the field is reduced to zero. The B-H curve is a completely reversible path that will continue to be traced out as long as the field is cycled backwards and forwards between the saturation limits. This solid line is known as a 'hysteresis loop'.

In order to understand where this loop comes from we need to look at the material, both at the atomic level and with a slightly wider view. We saw in Atoms and bonding the concept of electrons in orbit around a central nucleus, but we did not carry out the analogy further to consider each electron as spinning, in the same way that a planet rotates around its own axis whilst it travels along its orbit. This spinning electron creates a magnetic dipole which can be positive or negative, depending on the direction of spin. In a filled atomic shell, the electrons are all paired, each pair having two electrons of opposite spin, so there is no net magnetic moment. However, within certain materials, such as the transition metals with atomic numbers 23 to 28 (vanadium to nickel) there are unpaired electrons. Iron in particular has four unpaired electrons, and overall a comparatively high magnetic moment.

Not only do we need individual atoms to have a magnetic nature, we need to have adjacent atoms aligned, so that the overall crystal has a substantial magnetic moment. Adjacent atoms tend to align their electron spins and magnetic moments as part of the electron sharing that forms the metallic bonds.

Whilst it is clear that aligned atoms can produce a high value of induction, it is more difficult to explain how an apparently unmagnetised material can come about. The explanation is that the microstructure of an iron crystal is composed of 'domains', all of which have a common orientation from the crystallographic point of view, but differ in the orientation of their magnetic moments. A material that has equal volumes of material magnetically orientated in opposite directions has a net zero induction. However, during initial magnetisation a dramatic rise in induction

takes place, caused by the domains orientated in line with the field growing at the expense of those not favourably aligned (Figure 4).

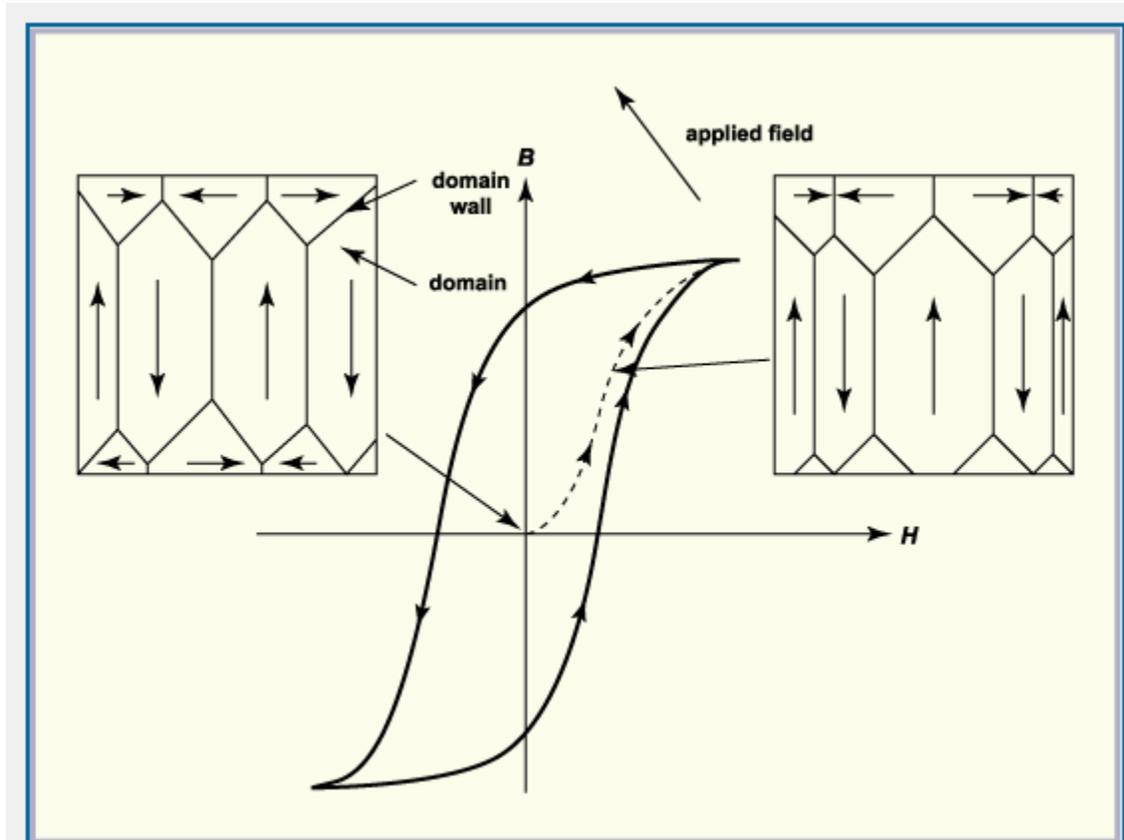


Figure 4: Domain growth during initial magnetisation

Don't confuse the magnetic domain with the grain structure of the material. The domain wall is just a narrow region across which the orientations change through 180° : growth of a domain involves expanding the wall, but this is merely a shift in the region of re-orientation, and no atomic migration is required.

'Soft' and 'hard' magnets

Ferromagnetism is a basis of most of the useful metallic magnetic materials, such as are used in power transformers. Ferromagnetic materials fall into two classes: those whose domain walls are easily moved, the so called 'soft magnets'; those with less mobile domain walls, termed 'hard magnets'. These have markedly different hysteresis loops, as shown in Figure 5.

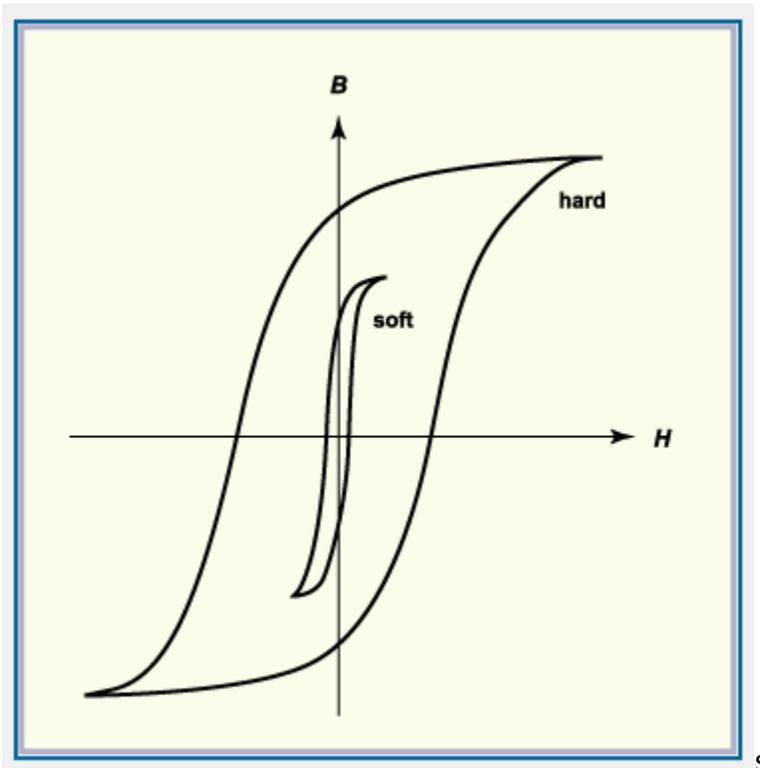


Figure 5: Typical hysteresis loops for soft and hard magnetic materials

Transformer applications use soft magnetic materials, because the area within the hysteresis loop represents the energy consumed as the loop is traversed at typical AC frequency of 50-60Hz. Although a small energy loss is desirable, a high saturation induction is also helpful, as it minimises the size of the transformer core.

A second source of energy loss is the heating effect of the eddy currents induced by the fluctuating magnetic field. As the power dissipated is inversely proportional to the resistance (Ohm's Law!), the loss can be reduced by increasing the resistivity of the material, and iron-silicon alloys have replaced plain carbon steels in low frequency power applications. Putting silicon in the iron also has the effect of increasing permeability, a double achievement for which Augustus Charpy, the inventor of the Charpy impact test was responsible. Further improvement in the magnetic properties is produced by cold-rolling sheets of the steel which tend to orientate the polycrystalline structure of the material, giving it a preferred orientation.

Fortunately you will generally not get involved with the specification of power transformers, but you should be aware of the material used and the general construction. Typically a transformer core is built from laminated silicon steel sheets with thicknesses in the range 150–650 μ m. These are annealed after stamping to give high permeability, and separated by very thin coatings of insulation, typically a varnish or phosphate passivation.

A number of different configurations is possible, of which one is shown in Figure 6. There is also a slight break in the magnetic loop in order to stop total short circuiting, which would otherwise reduce the efficiency very considerably.

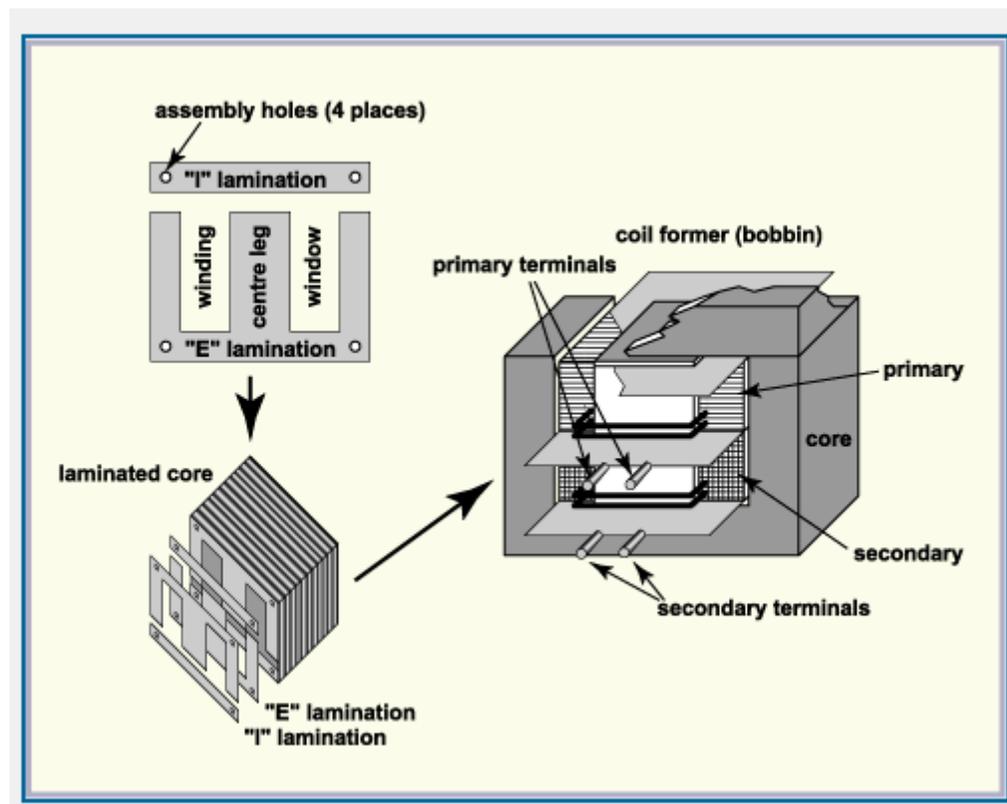


Figure 6: An E-core transformer assembly

Be aware that all transformers are mechanical assemblies as well as magnetic circuits, and that materials used may deteriorate or creep with time. It is not unusual for power transformers to loosen and become noisy and the insulation in the core deteriorates. Detailed discussion is beyond the scope of this course¹.

1 <http://sound.westhost.com/xfmr.htm> and <http://sound.westhost.com/xfmr2.htm> form a two-part article on transformers by Rod Elliott. He has a bias towards hi-fi applications, but shares much insight into how transformers work.

Magnetic ceramics

The steel alloys used for transformer cores have high resistivity in order to prevent substantial eddy current losses. However, as the frequency increases, so does the potential for loss, and at even moderate audio frequencies these losses become unacceptable. Fortunately magnetic ceramics have inherently high resistivity, so are commonly chosen for high frequency transformers.

There is a wide range of magnetic ceramic materials, of which true ferrites are only one group of structures exhibiting ferromagnetic behaviour. Despite this, the term 'ferrite' is generally used for the whole range of such materials.

Ceramic magnets, and the ferrites used in making inductors, are magnetic because of a different mechanism, which is distinguished by the slightly different spelling of 'ferrimagnetism'. However, whilst the mechanism at an atomic level is different, the hysteresis behaviour, and the presence and movement of domains, is exactly the same as with ferromagnetic materials.

The most commercially important ceramic magnets are associated with the spinel ($MgAl_2O_4$) crystal structure, an extremely complex crystal containing 56 ions. Whilst spinel itself isn't magnetic, some compounds containing transition metal ions crystallise in this structure or the closely-related inverse spinel structure.

From the user point of view ferrites are hard ceramic materials, which are generally pressed, because they are too hard to form in other ways. They are also extremely brittle, and this must be borne in mind during assembly operations.

Practical inductors

Inductors come in many formats and sizes, the size depending on the inductance value and the current carrying capability required. Nearly always they have a wound coil, which may or may not be visible. Although large transformers have silicon-iron cores, and the very smallest inductors may be air-cored, or even just tracks on the PCB, most will have some kind of ferrite core. Figure 7 shows some of the standard types, but doesn't really indicate the fact that these range very widely in size. Small coils can be self-supporting on their wires, or potted, but the larger cores normally need some kind of mechanical anchorage. Some styles of inductor also have shrouds and screens which require earth connection, although most ferrite-cored parts do not, as the ferrite contains the magnetic field.

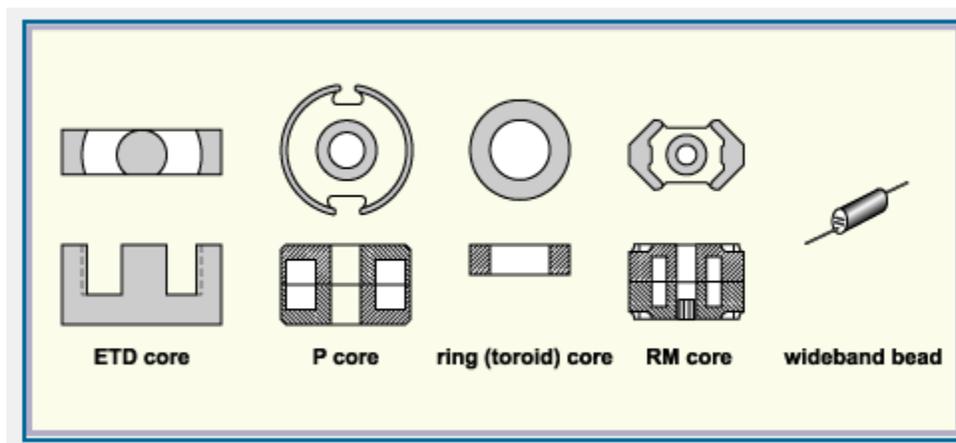
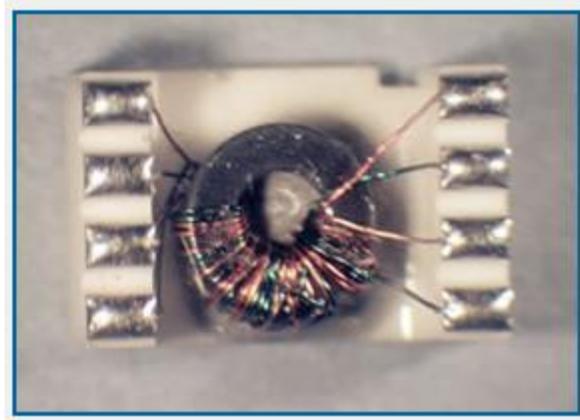


Figure 7: Some standard types of ferrite core



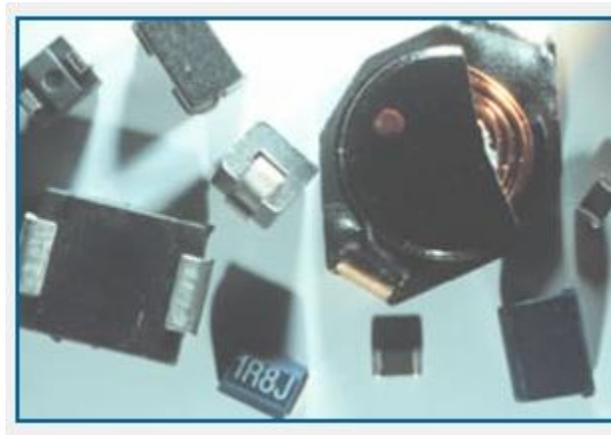
An inductor within a P core

It will be evident from the shapes of these inductors that they are not particularly easy to fit into a surface mount package.



A surface mount transformer, wound on a toroidal ferrite core (bare format shows construction)

Converting a wound ferrite core to a cuboid shape is something that requires the addition of terminals and enclosure, which is usually an epoxy resin potting. One such device is shown schematically in Figure 8. Typically, chip inductors are some 3 mm cube and available in the range 1–500 mH, the size depending on the current-carrying capability required.



Some surface mounting styles of inductor

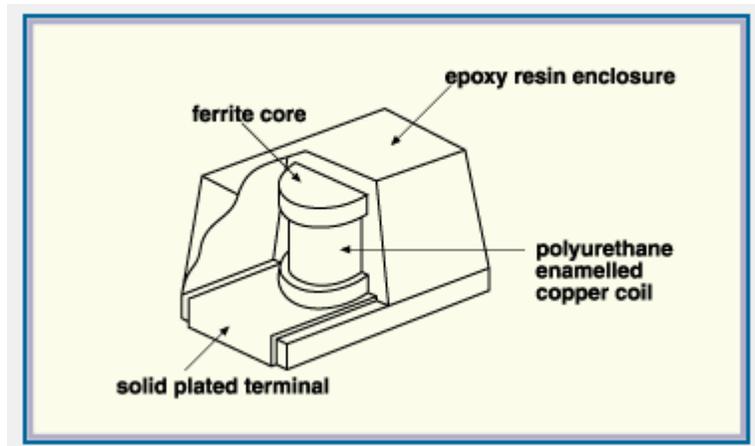
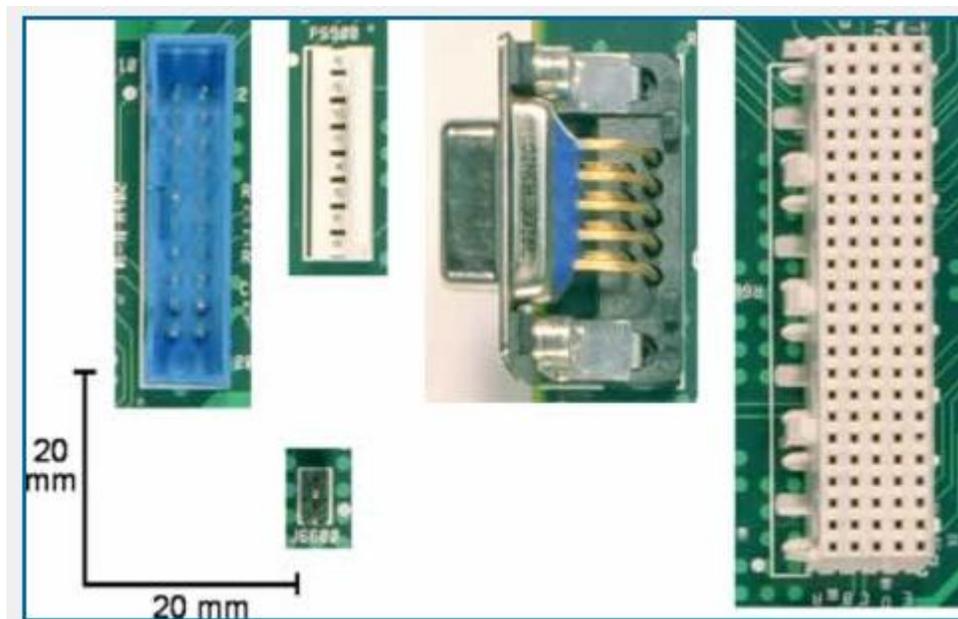


Figure 8: SM inductor construction

Did you notice the comment 'nearly always they have a wound coil'? There are in fact ways in which printing techniques can be used to create inductors without any wire. If you want to find out how before taking the course Technology Awareness, you will have to do some research yourself!

Connectors



A representative range of connectors

Connectors cover a very wide range of products, and rather than give the details ourselves, we asked Harwin, specialist manufacturers of connectors to write a brief

for us. You can access Connecting to Printed Circuit Boards by clicking this link (please be aware that this file is approx 10 Mb in size)

Glass components

Some glass basics

In Ceramic components we saw that glasses can be classified as amorphous ceramics. They may have a wide range of compositions, but have the property in common that during manufacture they are cooled quickly enough to prevent crystallisation from taking place, so that the glass (amorphous) state is retained at ambient temperatures. This happens because the chemical 'unit' in glasses is very large, being formed of large silicate networks, bonded internally covalently, and held together by ionic bonds provided by metallic ions within the structure. Movement of these 'units' is difficult even when they are thermally activated, so it is easy to cool the material past its normal melting point without crystallisation taking place. As shown in Figure 9, the material cooled slowly will crystallise at the normal melting point.

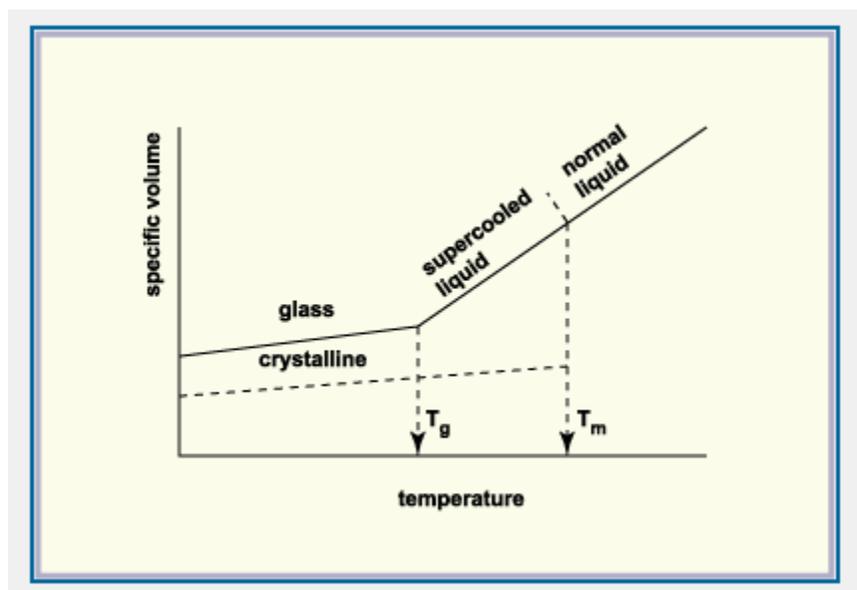


Figure 9: The glass transition temperature for a glass

Typically this will not happen, and more rapid cooling results in the formation of a supercooled liquid. Even in this state, some contraction takes place, until

temperature reaches a point where a sudden change occurs because there is no further possibility of molecular readjustment. This temperature is referred to as the 'glass transition temperature': as with polymers this is not a well-defined temperature, and depends on the cooling rate.

Ordinary commercial glass is produced from various inorganic oxides, of which silicon in the form of sand is generally the most important constituent. Common 'soda-lime' glass also contains lime (from limestone) and soda ash (crude sodium carbonate). This mixture is then heated to 1590°C, when the acidic silica reacts with the basic lime and soda to form the mixed silicates that we know as glass.

Because there are no crystallographic planes to make slip possible, glass cannot deform when stress is applied, and the viscous flow is too little and far too slow. This makes glass brittle at room temperature. However, they are elastic up to the point of fracture. Even though most of the load may be in compression, failure in glass always results from a tensile component under stress.

Because glass is a poor conductor of heat, there is often a considerable temperature gradient between the inside of a piece and its cooler outside as the part cools. Given the difference in CTE with temperature, the tendency is for the core to contract more than the surface, leading to the formation of internal stresses. Failure to anneal glass, to remove the stresses, leaves it weak and brittle. Annealing² takes the glass up to the glass transition temperature, and slowly down to ambient, so that a small amount of viscous flow can take place leading to stress relaxation within the glass.

² An alternative to annealing is the 'tempering' process, which tries to reduce the formation of surface cracks by putting the surface in a state of compression. Glass is heated to near its glass transition temperature, and then the surface cooled rapidly by air jets. Because the outside surface cools, contracts and hardens more quickly than the inside, the outer surface is left in a state of compression, whilst the interior material is in tension. Because the surface layers are in compression, the internal forces will balance any moderate tensile forces to which the glass may be subjected. Such material has considerable internal strain, and the strain patterns become visible when materials such as 'Perspex' are viewed by polarised light.

Ordinary glass will not cope with sudden temperature changes, but a range of temperature resistant glasses have been developed where as much as 20% of glass formers such as boron oxide (B_2O_3) are added to the silica. These produce a material with a higher viscosity, resistance to chemical attack and a very low coefficient of expansion, which makes materials such as 'Pyrex' suitable for kitchen, laboratory and industrial uses.

Whilst creep takes place in crystalline ceramics only at relatively high temperatures, non-crystalline glasses have low softening temperatures and considerable creep occurs at moderate temperatures.

Glass-ceramics

In modern glass-ceramics, controlled devitrification is employed to initiate large numbers of nuclei for crystallisation in glasses of suitable composition to produce polycrystalline materials. After shaping, the material is given a heat treatment in two stages. First, a low temperature treatment to promote the formation of large number of crystal nuclei within the glass; second a higher temperature treatment at which crystal growth rate is maximised. This continues until the crystalline content is high (perhaps 90%), so that only a little glass remains. The mechanical properties of such glass ceramics are intermediate between those of a glass and a true ceramic such as alumina. Not only used in cooking wear (for example, Pyrex), glass ceramics with different materials are used for missile nose cones and heat exchangers, being resistant to thermal shock and transparent to radar signals.

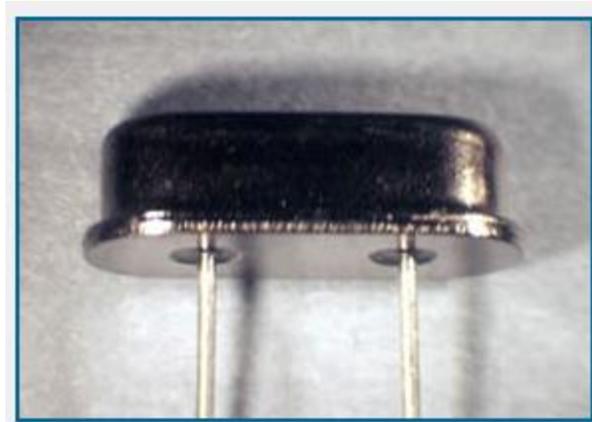
Glass-to-metal seals

Glass is a useful sealing medium, because it forms good gas tight bonds to metals such as copper. This was discovered during the 19th century with the development of the electric lamp, and the technology was then adapted for the radio valve. Subsequently glass-to-metal seals have been used for a variety of components, from large oil-filled capacitors down to microcircuits.

A glass-to-metal seal has three components, the lead, the housing, and the glass which fuses to form a leak-tight seal between the two. There are, however, two fundamentally different types of seal, with differing characteristics:

The cheaper of the two seals uses as its housing a metal eyelet which is subsequently soldered into the case. This produces a seal which is a separate component. The material of the tubular housing is mild steel, plated after sealing. Because of the mismatch between CTEs of housing and seal, the glass within this type of seal is under compression, hence it is called a 'compression seal'.

By contrast, a 'matched seal', uses kovar for lead and housing, a nickel-copper-iron alloy which has a CTE similar to that of the special glass used. This means that the seal is not under stress.



Radial-leaded crystal with matched seals

Matched seals are preferred for larger structures, such as where a row of leads enters a package, each through its individual hole and tubular glass seal. Because no stresses are involved, the housing can be thinner, and the seals closer together.

Both types of seal are made in a similar way, carefully assembling the parts to be joined together, and placing them on a jig ready for firing. Because the temperatures involved are of the order of 600-800°C, depending on the glass used, these jigs have to withstand high temperatures, and are frequently made of graphite.

From the description of the process, you will understand that the manufacture of individual compression seals can be partially automated, but making complex packages with numbers of matched seals is a skilled task, involving yield losses, and consequent expense.

The high cost of hermetic packages made in this way has been one of the driving forces behind the use of polymeric encapsulation. Nevertheless, metal seals of various kinds may still be found on a typical assembly, particularly for encapsulating crystals, where the active element needs to be kept within a carefully controlled environment, since moisture causes crystals to 'lose activity' and fail to function.



A range of crystal assemblies

Optical fibres

Optical fibres are also glasses, consisting of a pure silica tube containing a core of silica which is doped with another oxide such as germanium oxide, GeO_2 , to give a slightly higher refractive index. As germanium is a member of the same group as carbon and silicon, it can be expected to be accommodated within the structures of glasses based on silicon. The light (or rather laser) pulses are guided along the core by internal reflection at the interface between core and coating. For light to be transmitted any significant distance, the core material must be very transparent, and consequently very pure.

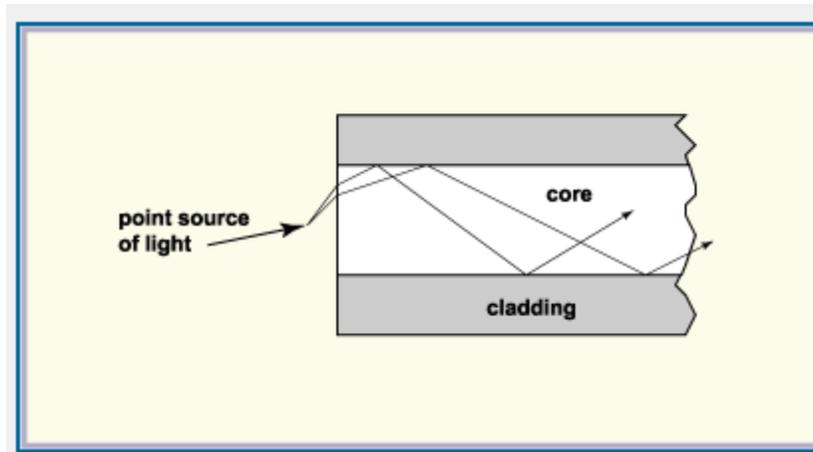
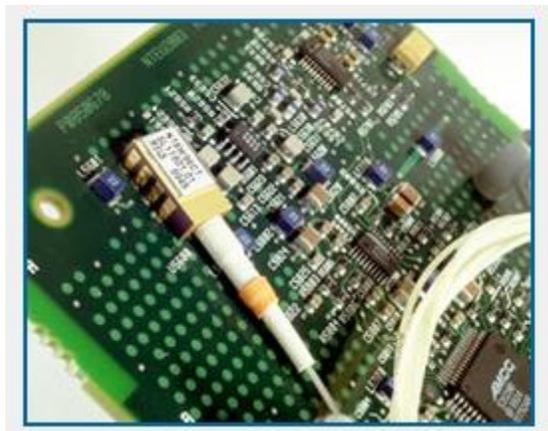


Figure 10: Multiple light paths within a glass fibre

Practical optical fibres are considerably more complex. For example, in a fairly wide fibre, light travels by a variety of different paths, potentially leading to distortion of the signal as the pulses reach their destination at different times (Figure 10). One way in which this is overcome is to use a core material where the refractive index varies from a maximum at the centre to that of the coating at the interface in a near-parabolic manner. Light rays taking longer paths travel faster, so that all the components of the pulse reach their destination simultaneously. An alternative approach, using finer fibres, is described as 'single-mode', because there is only one possible path within the fibre.

Practical fibres are much bigger than the 5–15 μm of the external cladding. This is because the fibres themselves need to be protected in order to avoid breakage due to surface damage.



A fibre optic component

Author: Martin Tarr

Source: http://www.ami.ac.uk/courses/topics/0137_opc/index.html