Electronic materials and components-Introduction to components

Introduction

This topic, and the other topics describing specific components, will help you to recognise different types of electronic components and identify common package formats, but their main aim is that you should understand something of the materials and processes involved in component manufacture. This is an essential prerequisite for understanding how components should be specified, and how they might fail.

The other topics cover semiconductor packages, ceramic components, electrolytic capacitors and other passive components, and are supplemented by:

Implications for board design, which looks at the way in which components influence design practice, and at specifications and ratings for board and components

Getting the right part, a useful resource on preferred values, tolerances and ratings and on device marking issues.

Some assumptions

Although not essential for your study of components, ideally you should already have a basic appreciation of the operation of diodes, transistors and simple integrated circuits, and be able to describe the function of resistors, capacitors, and inductors within a circuit.

Particularly if you are interested in the way components are made, a very user-friendly account is given in the first few chapters of Neil Sclater's Electronics Technology Handbook.

Other useful printed sources of background information are W. Bolton's Engineering Science and John Bird's Electrical Circuit Theory and Technology.

If you prefer web browsing, try http://www.owlnet.rice.edu/~elec201/Book/basic_elec.html for something very short, or The Scots Guide to Electronics maintained by Jim Lesurf of St Andrews University at http://www.st-and.ac.uk/~www_pa/Scots_Guide/intro/electron.htm for a very nicely presented introduction.

The crucial point to make here is that you do not have to know all about the electrical function of components before tackling the topics in this unit. Possibly the best point at which to review whether you need to get more background information is when you have read through the whole of the component material for the first time.

Differing perspectives

Because of the variety of function, type, and physical format, it has proved useful to identify and classify electronic components and devices in a number of ways, different classifications being useful to different people. For example, an electronic design engineer is chiefly interested in the function of a component - a resistor, a capacitor, or other passive device, or an active device such as a transistor - and will initially select components by their function in his/her circuit design, and consult data sheets and books to select the component type (for example, a high power or a low noise device) which best meets his/her requirements.

Ideally, the design engineer should then consider parameters such as physical size, pin configuration and power dissipation, to ensure that the design is acceptable in terms of board layout, manufacturability, and reliability. However, this is often a secondary issue, whereas, to others involved in the manufacturing process, the physical size, package style, lead finish and ruggedness are of primary importance in evaluating manufacturability and throughput, and the function of the component is not a major concern.

Note on activities

In this topic and the others on components we have suggested several activities which are observations to be carried out on assembled boards. If you are very familiar with a wide range of components, you will probably not need to go through these in detail. However, remember that new formats and components are being introduced all the time, and you need to keep up-to-date. As part of his job of reviewing new products, one of the DfX engineers at Agilent makes a practice of investigating every new type of part and writing up the design, manufacturing and quality issues associated with each of them. This is good practice, and worth emulating!

For those who would like to check or extend their knowledge, mixed technology assemblies are ideal, but there is value at looking closely at any board carrying a range of components: can you identify every part you can see? Computer boards generally make good subjects for study, as most contain some through-hole parts and are physically big enough for the component identities to be marked on the board. But, if you are examining a working board, DO NOT FORGET to take anti-static precautions!

Classes of component

The first task is always to recognise the specific component and package from the many different types of both. There are so many that the task is not always either easy or obvious, and information about a component has to be extracted from a number of sources. One way we can make the task simpler is to divide components into different categories, the broadest division being into the two categories of passive devices and active devices.

Passive devices

Passive devices cover a vast range of components whose electrical characteristics are usually independent (within limits) of any applied voltage. Primarily these are resistors, capacitors and inductors and derivatives of these such as potentiometers, variable capacitors, and transformers. Each of the main component types is classified in a number of ways, often by reference to the materials used and the construction methods employed by the manufacturer. Examples are given in Table 1.

Resistors are circuit elements made from materials that are poor conductors, and consequently resist the flow of current. Resistors may be made from coils of wire (wire-wound), from powdered carbon and a glue-like binder (carbon composition) or from a thin coating of material on an insulating base, either cylindrical (film or oxide types) or flat (chip types).

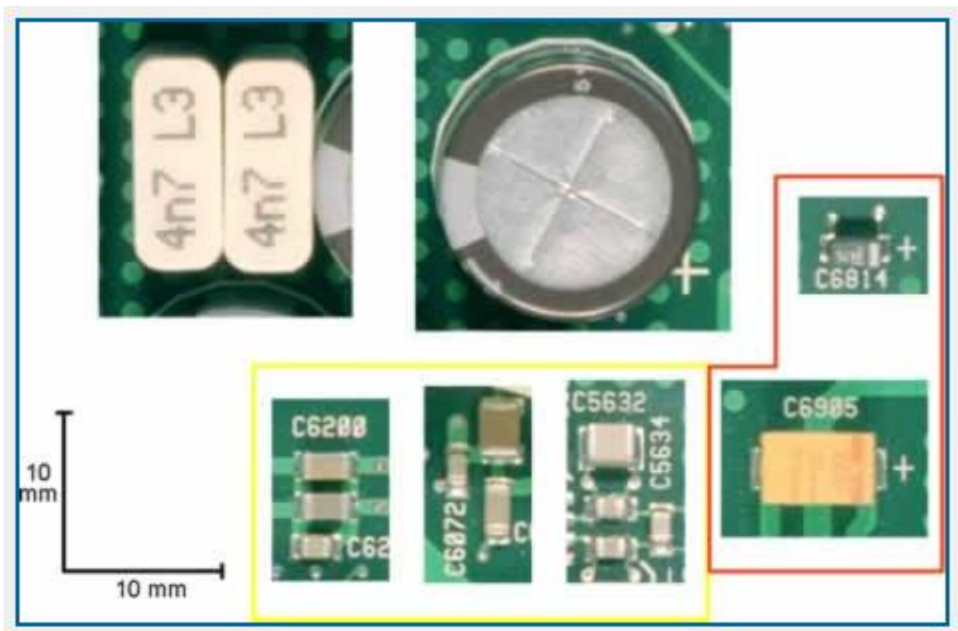
Capacitors derive their name from their capacity to store charge, and are used in a circuit to damp out rapid changes in voltage. They consist of two conducting surfaces separated by an insulator (the 'dielectric'), with a lead connected to each surface. To create the values of capacitance needed for practical circuits, one needs conducting surfaces which are both very large and very close together, and separated by a material with a high 'dielectric constant'. To pack sufficient surface area into a small volume, capacitors usually have a rolled or stacked internal structure. If a constant voltage is applied to a capacitor, only a very small 'leakage current' will flow once the capacitor has fully charged.

Inductors are coils of wire with many turns, often wound around a core made of a magnetic material, like iron or ferrite. Current flowing through the inductor produces a local magnetic field in which energy is stored. This field creates an induced current in the inductor in a direction which resists any change in the current flowing in the circuit. Inductors are thus used in circuits to prevent any rapid changes in current.

Table 1: Some passive device classifications

Capacitors (usually classified by dielectric material)			
disc ceramic	multilayer ceramic	silvered mica	
polystyrene	polypropylene	polyester	polycarbonate
solid tantalum	aluminium electrolytic		
Sometimes capacitors are classified by their application:e.g. Class X1 (X2, Y1, Y1) for mains suppression components			
Resistors (usually classified by resistive material)			
carbon composition	carbon film	wire-wound	
metal film	metal glaze	metal oxide	
chip - thick film	chip - thin film		

Different types and sizes of capacitors



Other passive devices include filters of various types, and switches and connectors. Note that the distinction between passive components and electromechanical devices such as relays and mounting hardware can sometimes become blurred.

A word about values

Resistor values are measured in ohms (symbol Ω, the Greek capital letter omega). The ohm is a low value, so usually you met kΩ (kilohms = thousands of ohms) and MΩ (Megohms = millions of ohms).

Capacitor values are measured in farads (symbol F), but practical capacitors have values which are many orders of magnitude smaller: μF (microfarad = one-millionth of a farad); nF (nanofarad = one-thousand-millionth of a farad); pF (picofarad or 'puff' = one-million-millionth of a farad).

Inductor values are measured in henrys (symbol H), but practical inductors have much smaller values. You will encounter mH (millihenry = one-thousandth of a henry) and μH (microhenry = one-millionth of a henry) and occasionally nH (nanohenry = one-thousand-millionth of a henry);.

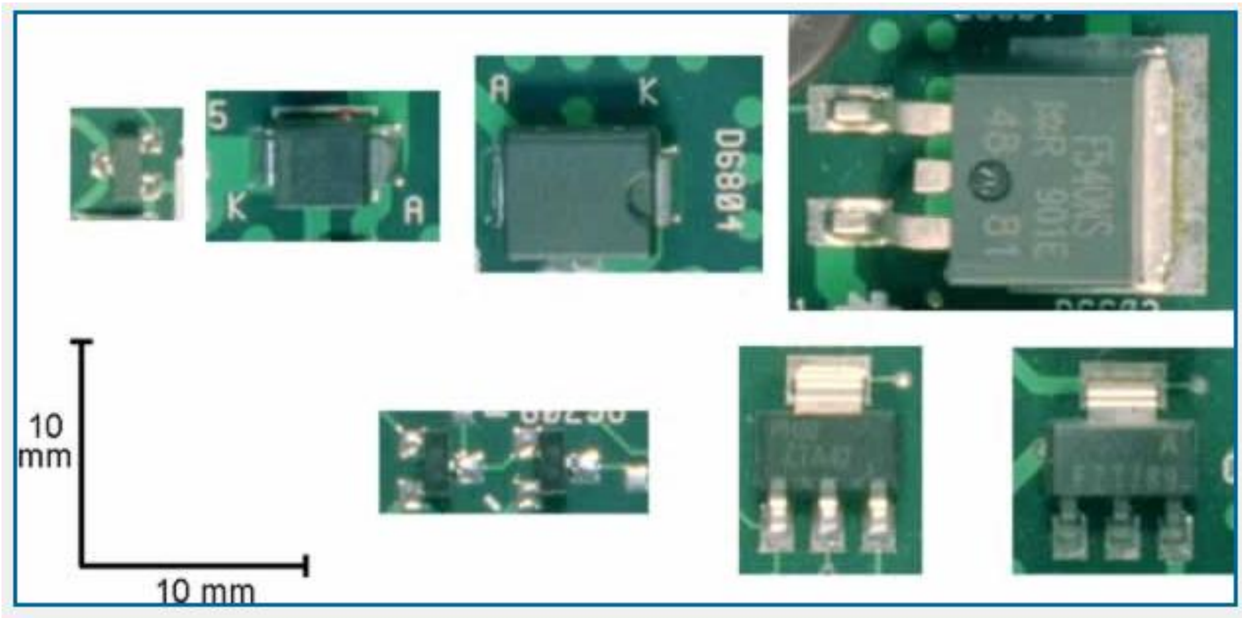
Active devices

An active device has been defined as one which can produce power gain, that is, the output signal has higher power than the input signal. Transistors and integrated circuits of every type meet this definition, whereas, strictly speaking, most diodes do not. However, the fact that diodes use the same basic semiconductor technology as transistors means that they are usually considered as being active devices.

Within each main category there are sub-divisions, often classified by the technology and/or materials used or the circuit function performed. Examples of common broad sub-divisions are given in Table 2.

Table 2: Some active device classifications

Diodes		
small signal	rectifier	
zener	Schottky barrier	varactor
Transistors		
small signal (audio, RF, low noise, switching, etc.)		power
bipolar	FET	
silicon	gallium arsenide	
Integrated Circuits		
analogue:linear, operational amplifiers	digital:TTL, CMOS, ECL (logic families)	
microprocessors and peripherals	memory	



Different sizes of package for diodes (top)

and transistors (bottom)

Discrete components and integrated circuits

There is however a second way of 'dividing the cake', into discrete (i.e. single) or integrated devices. This classification most often applies to active devices, where a number (often many thousands) of circuit elements are realised within one piece of silicon. The term monolithic (literally 'one stone') distinguishes such components, as against multi-chip, where the package performs the function of integration.

Mechanical components

If you look at a typical complex board, you will see not just passive and active components but a range of other parts. Some of these have electrical functions; others are purely mechanical; a few even have moving parts, and might be considered electro-mechanical devices. The list below covers most of the generic types:

Actuators: transducers1 which convert electrical inputs into external action - movement (motor; solenoid), sound (bell; buzzer; loudspeaker) or light (lamp; LED)

Batteries

Connectors

Crystals

Mounting hardware

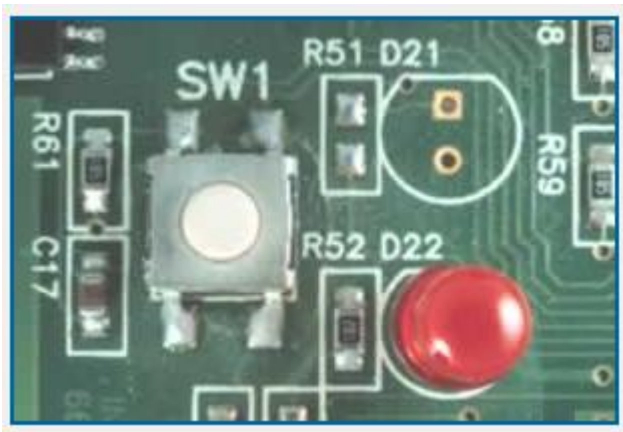
Relays

Screens

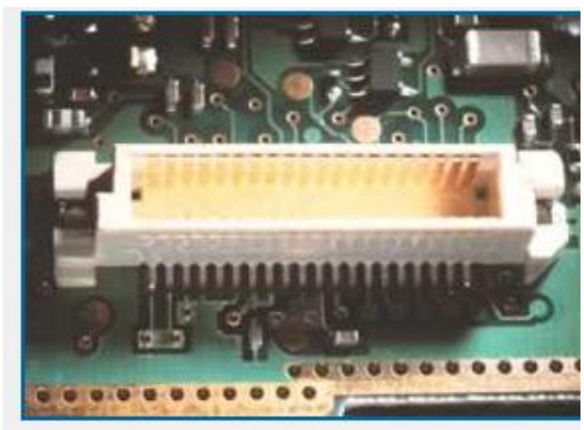
Sensors: transducers which convert external action into electrical outputs - including sound or movement (microphone; piezo-electric transducer), moisture (moisture sensor), heat (thermistor) or light (light dependent resistor)

Switches

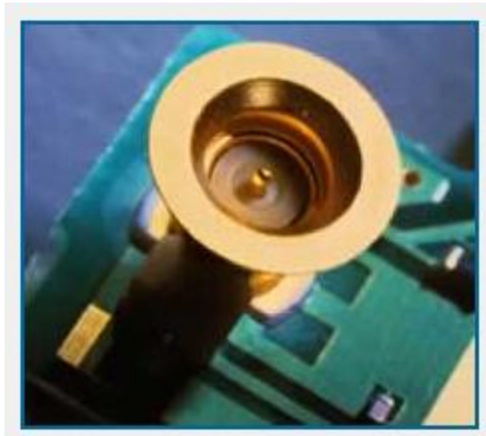
Thermal management devices (heat sinks; fans)



Surface mount switch and LED



Surface mount connector



Surface mount RF connector

Through-hole crystal and oscillator

Shielding can

Heat sink

Of these categories, the transducers represent the class with the greatest variety in terms of technology and packaging. They are, however, less important to you as a designer than the connectors and switches. Again, these come in different types, but the technology is broadly similar. However, apparently similar parts are easy to confuse with each other, and it is very important to select the right component for the application.

1 There is an interesting debate about the definition of what is, or is not, a transducer on the Sensors Online web site at http://www.sensorsmag.com/articles/0901/10/debate_main.shtml

Variable components

Closely related to switches are variable components. If you look at a piece of hi-fi equipment, you will probably find that the front panel contains not only switches, but also some means of varying the circuit response or adjusting frequency. The real difference between a variable component and a switch is that the variable component is analogue rather than digital: a switch has a discrete number of positions, whereas a high-quality variable component can be set at an almost infinite number of positions between its limits.

The earliest variable components were all passives: resistors, capacitors and inductors:

Variable resistors typically used a wire-wound element, with a 'tap' connection travelling across the surface of the winding. As well as offering variable resistance (the 'rheostat') this construction made it possible to use the resistor as a 'potentiometer', for voltage division applications

The variable capacitor was typically a mechanical component with two sets of vanes separated by air as their dielectric. Typical maximum values (with rotor and stator fully engaged) were in the range 50pF to 500pF

Variable inductors were much less common, involving the moving of coils relative to each other, or the insertion of a 'core' of high-permeability material, in order to increase the inductance. As with capacitors, variable inductors are two-terminal devices.

Whilst it is generally easiest to obtain a linear correlation between movement and electrical function, in certain applications this is not the preferred option. A very common example is a volume control, where the ear responds logarithmically, and the voltage division performed by the potentiometer should behave in the same way, so that equal movements of the knob or slide produce the same effect on the perceived volume. Variable components with this kind of response are referred to as having a logarithmic 'law'.

A trimmer

In the preceding text, you will have noticed a tendency to use the past tense. This is because variable components are now far less common than they were. This is due in part to their mechanical complexity, and hence cost, but there are also issues to do with reliability - have you ever thrown away a transistor radio because its volume control became intermittent or noisy? Reliability and cost issues have therefore favoured electronic means of varying response, either using analogue components with a programmable response, or choosing purely digital methods of achieving the same function.

Polarity issues

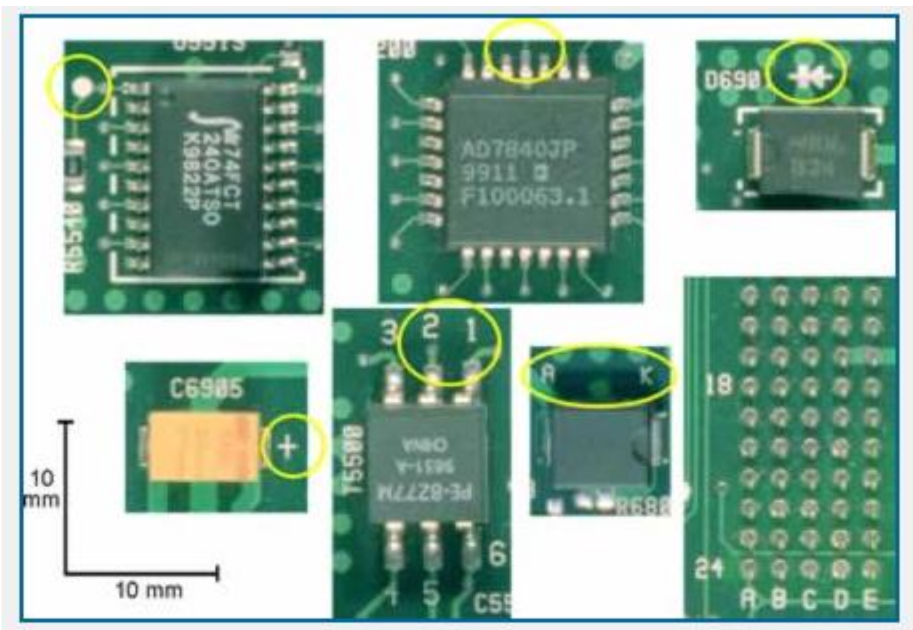
'Polarity' is a term which has two related meanings:

It may describe a component which, either mechanically or electrically, can only fit one way into the circuit

It may relate to an inherent asymmetry in a component.

While resistors and ceramic capacitors are 'non-polar', that is it is immaterial which way round they are fitted, electrolytic capacitors are inherently polar. Not only will they function incorrectly when reversed, as would a diode, but the unexpected reverse voltage may do permanent damage, and even result in an internal explosion and rupture of the package.

But polarity, in the wider sense of putting things onto the circuit the right way round, starts with three-pin devices such as transistors. Only in a very few cases (some resistor networks and potentiometers) are multi-pin devices sufficiently symmetric to be placed in different orientations, yet function correctly. Typically, component leads are identified by numbering, and the package will indicate which is pin 1, either explicitly by device marking, or by reference to a data sheet or convention. And of course there need to be corresponding conventions for how the board should indicate the orientation of the component.



Different means of polarity marking on a board

Be aware that, when numbering connections, there are two possible ways of doing this, even with as simple a component as a small outline integrated circuit. Assuming that you have designated pin 1, then the numbering might go clockwise or anticlockwise. The convention usually applied is that the component is viewed from the top of the package, and the numbering is anticlockwise. This means however that through-hole and surface mount components appear to have different pin sequences when viewed from the copper of the board to which they are attached. This difference in perspective, according to whether the device is viewed from above or below, creates an opportunity for significant error - be warned!

In the remaining parts of this unit, we are going to consider a number of different types of component, and in particular the formats you will see most during your working activity. The text includes some information on the internal workings of each component.

Through-hole components

We start our review of components by looking at those designs with leads that are intended to be soldered into through-holes on boards. With the exception of integrated circuits with very high lead counts, most types of device are (or have been) available in the through-hole format. Whilst larger than surface mount parts, through-hole components have the advantage for simple designs of being able to be used to create crossovers. They are also still surprisingly cheap, because the manufacturing methods are well tried, and the production equipment fully amortized and often transferred to low-cost areas of manufacture.

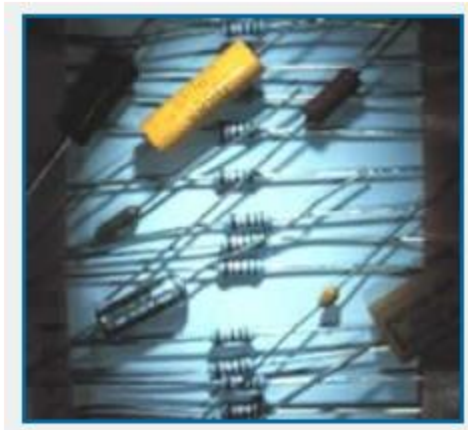
Axial and radial formats

Pin-through-hole discrete components are defined as 'axial' or 'radial', depending on the relationship between the direction of the leads and the major axis of the component:

'axial' types have the leads running in opposite directions and parallel to the major axis

'radial' parts have the leads running in the same direction but normal (at 90°) to the major axis.

Whilst there has been some standardisation (for example, pin spacings tend to be multiples of 0.1 inch), there are many variations: in particular, pin length, diameter and location on the body all vary.



A selection of axial components

A selection of radial components

Leads are generally neither sufficiently accurately positioned nor stiff enough to allow machine insertion unless components have been 'taped'. Radial formats use a tape with single sprocket holes (Figure 1); axial formats a pair of tapes on standard centres (Figure 2); both taping styles provide handling protection to the leads and are stored either on reels or 'ammo packs', where the 'bandolier' of components is folded in zigzag fashion.

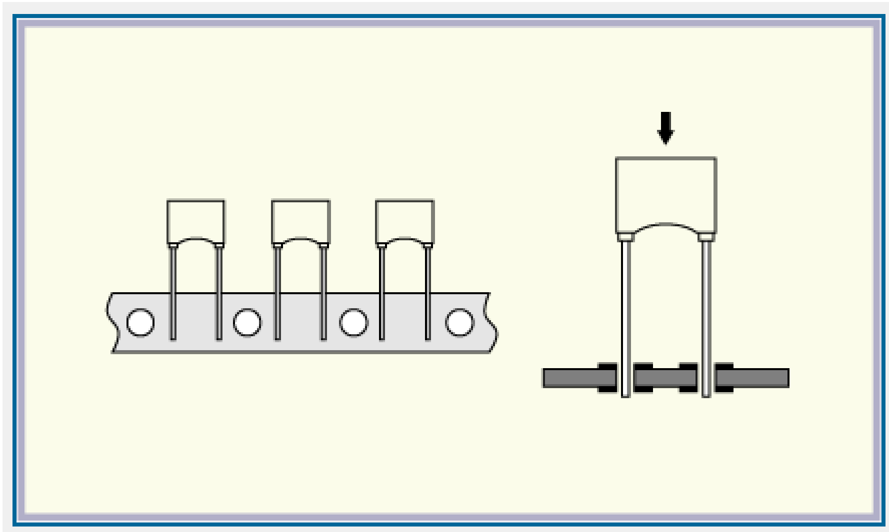


Figure 1: Presentation and insertion of radial components

Radial components on tape

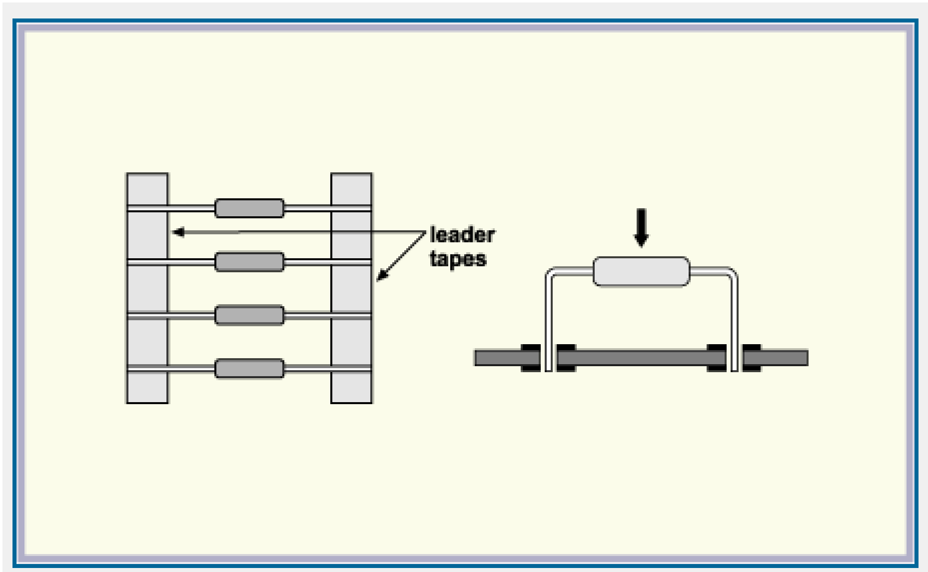


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Figure 2: Presentation and insertion of axial components

Diodes are most frequently found as axial components, but transistors are typically radial parts. Some designs have leads in a single plane, and can be presented on tape. However, such pin-outs are close together, so it is more common to have the central lead offset ('joggled') in order to have leads on 0.1 inch centres. In this the current plastic package mimics the earlier TO-18 styles, which had hermetic packages and glass-to-metal seal construction.

Components with joggled leads can be taped, but also are to be found handled as loose items. Note particularly that those devices which start with a planar lead frame, and have the central pin joggled, are available in both directions of joggle, so can be specified with two different pin sequences. This is another area where errors can occur.

Dual-in-line format

The quest for improved transistor performance led to silicon planar technology, from which the monolithic integrated circuit (IC) was a natural development. Both transistors and ICs need to be packaged, and in Semiconductor packages we'll be explaining more about how this is done. At this stage, all you need to know is that, the more internal active elements, the greater the number of external leads required, and that the development of ICs led to an ever-increasing number of lead-outs from the component package.

Many multi-leaded packages were devised during the 1960s, but the high cost of some constructions, the difficulty of assembly, and lack of standardisation soon left only two main contenders, the dual-in-line (DIL) package (DIP) and the flat-pack.

Both had leads along two opposite edges. The flat-pack (Figure 3) was the smaller, with leads at 0.05 inch pitch in the same plane as the package. However the package has to be held in contact with the circuit board during soldering.

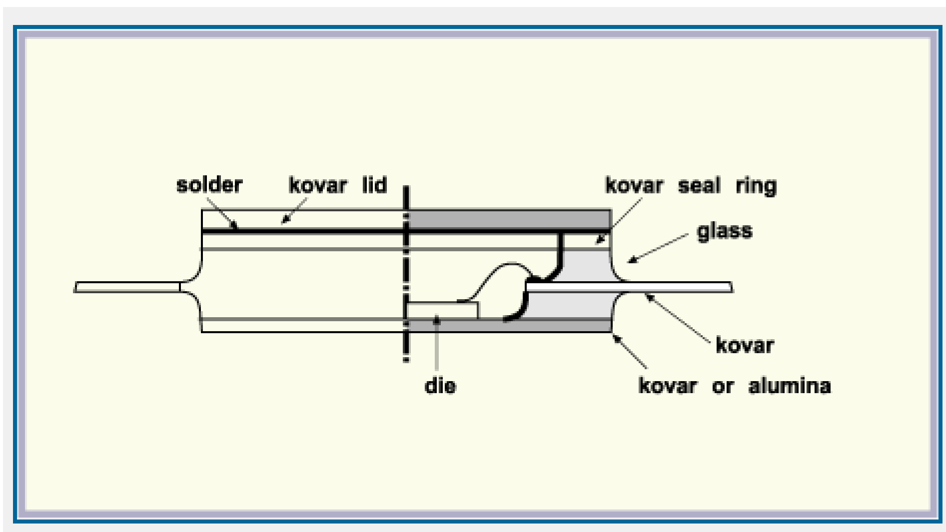


Figure 3: Flat-pack construction (glass-metal seals)

The leads of a DIP (Figure 4) are on a 0.1 inch pitch and, after assembly, project at right angles to the body. By design, the leads on most DIPs are initially formed outwards at a slight angle, so that when inserted into through-holes in the board they are self-retaining during pre-soldering handling.

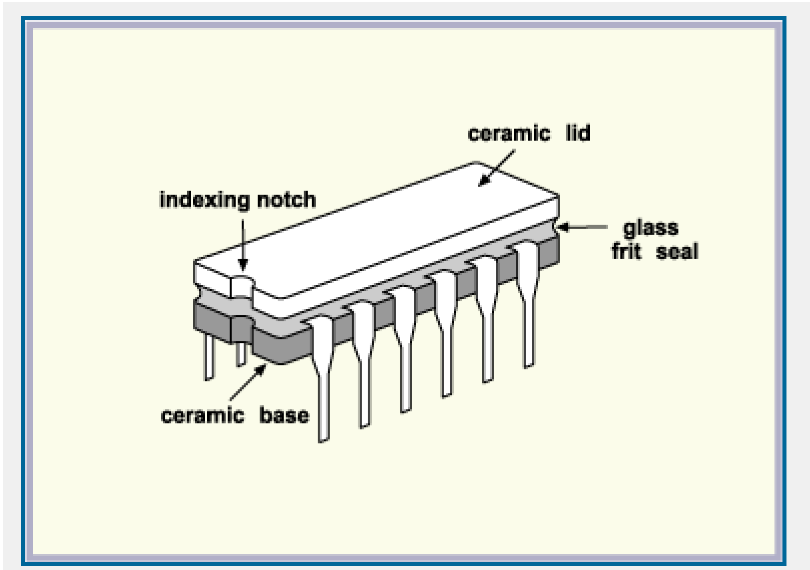
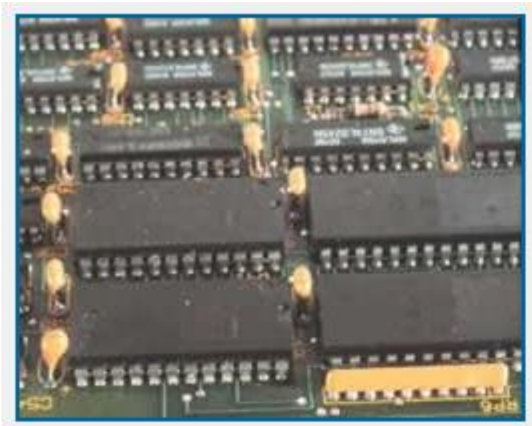


Figure 4: Dual-in-line package construction (CerDIP)

For reasons of reliability and operating temperature range, 1970s military users preferred packages in which the die was hermetically sealed within a cavity filled with dry air. The packages shown achieved this in one of two ways: using glass-to-metal seals (Figure 3), or using a lead-frame sandwiched between ceramic components bonded together with glass (Figure 4). In this second generic style of package, the CerDIP (Ceramic Dual-In-line Package), the final seal made after die and wire bonding uses glass containing a high percentage of lead oxide, which will melt and seal at low temperature.

Early attempts at making plastic-encapsulated equivalents were of limited reliability, but success eventually came from a combination of improved die passivation and reduced ionic impurities in the encapsulant resin. This type of DIP was not only lower cost, but was more compatible with the automated insertion equipment being developed. These machines made fast and reliable board assembly possible, and established the plastic DIP as the most widely accepted IC package: by the mid 1980s it accounted for 80% of all integrated circuits used in the electronics assembly industry.



DIL integrated circuits, an SIL resistor network and bead tantalum capacitors (c.1991)

Single-in-line format

Single-in-line formats are to be found mostly with resistor networks and ceramic filters, often with one end-pin as a common connection to the internal elements. As with the dual-in-line package, pins tend to be on 0.1 inch spacing: whilst 0.05 inch spacing is possible, this is usually achieved by joggling alternate pins in opposite directions, so as to create 0.1 inch spacing between pin centres.

Hermetic components

The original semiconductors were ‘hermetic’ components, that is the internal parts of the device were sealed from the environment. Typically this was carried out by placing the active element within a metal enclosure, making electrical connections through pins sealed into the structure using glass: both glass and metal are not permeable to gases such as water vapour. Hermetic components can also be achieved using ceramic and glass, as with the CerDIP package shown in Figure 4.

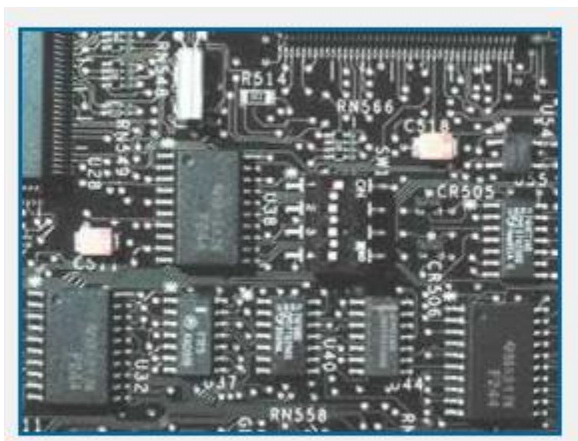
Hermeticity comes only at substantial expense, so few integrated circuits are now made with this kind of encapsulation. However, you will still see hermetic structures used for quartz crystals, because the active elements are extremely sensitive to moisture. Metal-can power transistors also have a hermetic construction, the final lid seal being generally carried out by welding.

Mechanical components

A very wide range of mechanical components is in use, of which connectors and switches are arguably the most common. Care has to be taken to ensure that the spacing of holes on the board is correct for the part – unfortunately some metric standard pitches are very close, but not close enough to Imperial measures. For example, the first few pins on a 2.5 mm pitch connector may fit well into a set of holes designed for a 0.1 inch part, but the 0.04 mm difference on each lead interval quickly turns from snug fit to force fit to no fit at all!

The surface mount transition

The demands of higher packing density drove the transition to surface mount, but the current widespread use of this technology has been driven more by component supply and by the reduced cost of manufacture. In this next section we are looking at the structure and format of some of the key components.



A surface-mount assembly (c.1995)

Chip components

The rationale behind the development of chip components has been that:

conventional axial and radial devices are not suited to surface mounting;

encapsulated parts have a relatively large amount of wasted volume;

for some types of passive device, in particular ceramic capacitors and chip resistors, avoiding the need to have leads has enhanced reliability;

the reduced materials content and improved ability to automate the manufacturing process have both reduced costs.

The miniaturisation of passive components is most pronounced with ceramic capacitors and chip resistors. These components are generally manufactured in set sizes which have become common approved standards. The size designation often used derives from the length and width of the component expressed either in hundredths of an inch (where the USA/UK 0805 size is approximately 0.08 × 0.05 inch) or in millimetres (so that the Japanese equivalent to a USA/UK 0805 is confusingly referred to as a 2012).

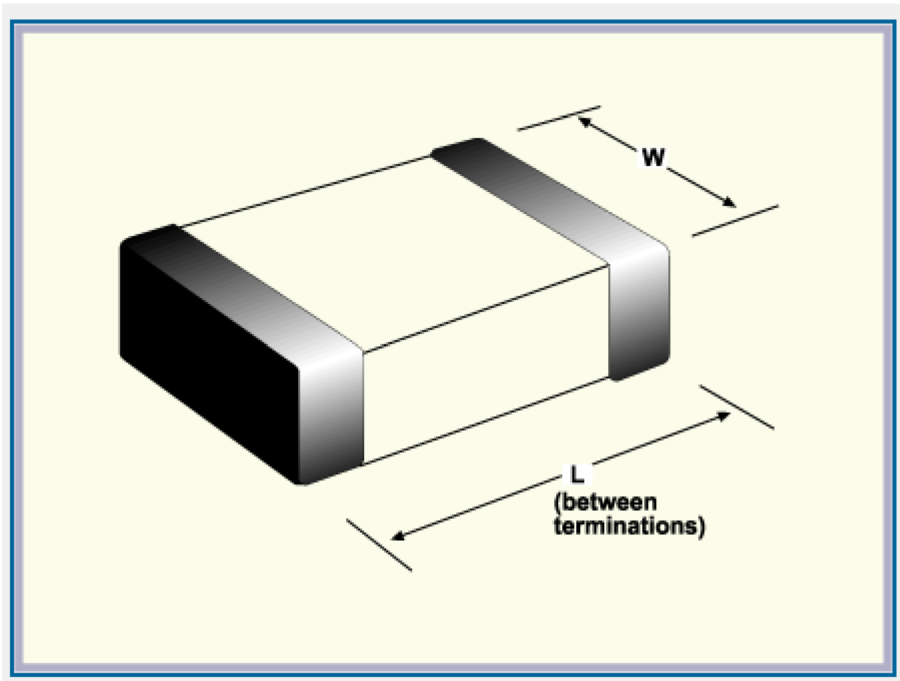


Figure 5: Dimensioning of a chip component

Dimensions

Table 3 gives nominal dimensions for the most common sizes of component. Note that:

There are differences between manufacturers2, especially in relation to dimensional tolerances for capacitors, which depend on the manufacturing technology used

Resistors are usually thinner than capacitors, and thus need different placement machine settings

Larger components are available, but these are more reliable when mounted on matched-TCE substrates such as ceramic.

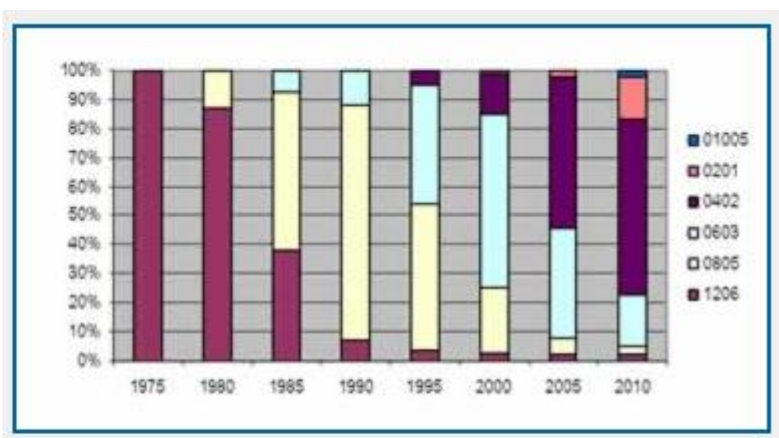
2 The differences between manufacturers are particularly marked with the smaller sizes, with substantial variations in thickness reported. Why not check this out for

yourself, by searching Google with ["chip capacitor" dimensions 0201] – this will give about 50 hits.

Table 3: Typical dimensions of preferred sizes of chip resistors and capacitors

Designation		Length	Width	Thickness (mm)	
inch	metric	(mm)	(mm)	Resistors	Capacitors
0201		0.6 ±0.05	0.3 ±0.05	0.18-0.28	0.09-0.21
0402	1005	1.0 ±0.1	0.5 ±0.1	0.30-0.40	0.45-0.55
0603	1608	1.6 ±0.1	0.8 ±0.1	0.35-0.65	0.7-0.9
0805	2012	2.0 ±0.2	1.25 ±0.15	0.40-0.70	0.5-1.35
1206	3216	3.2 ±0.2	1.6 ±0.15	0.50-0.70	0.5-1.75
1210	3225	3.2 ±0.2	2.5 ±0.2		0.5-1.8
1812		4.5 ±0.2	3.2 ±0.2		0.5-2.3
2225		5.7 ±0.25	6.35 ±0.25		0.5-2.3

There is a strong trend towards smaller sizes: in 1988 the 0805 was the most frequently used multi-layer ceramic capacitor, and the 0603 is the 'workhorse' at the present time, but there are many applications for which 0402 is now demanded. Be careful, though, because using too small a component may well increase manufacturing costs, because of higher unit prices and lower yields, with more rework.



Trends in passive component chip sizes

Author: Martin Tarr

Source: http://www.ami.ac.uk/courses/topics/0133_itc/index.html