Understanding Passive Components

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Understanding Passive Components

This booklet presents an introduction to the basic principles of a variety of passive components, discussing them in largely layman's terms and offering snippets of information and advice you may not find in other books. The components covered include:

- **Resistors**
- **Potentiometers**
- **Varistors (VDRs)**
- **Thermistors**
- **Light dependent resistors (LDRs)**
- **Fixed capacitors**
- **Variable capacitors**

Reprinted from the *Modern Electronics Manual*

Understanding Passive Components
by John Becker

Reprinted from the *Modern Electronics Manual* (Section 3/3.2 to 3/3.4 – Part 3/3 covers the *Basic Principles of Electronic Components and their Characteristics*)

Wimborne Publishing Ltd.

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Wimborne Publishing Ltd. 1998

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INTRODUCTION

As the electronic age continues to grow, so do the number of new products and electronic components. More complex electronic devices are becoming available not only to industry, but also to teachers, instructors, researchers, students and hobbyist users. It becomes increasingly important that, to which ever user group you belong, you should know how to identify electronic components within each principal category, know what purpose they serve and know how they work in layman's terms.In this booklet each of the above requirements for two main groups of components, resistors and capacitors, are examined in largely non-technical terms.

This information is part of much lengthier discussions which are included in the *Modern Electronics Manual (MEM)*, which is published by Wimborne Publishing Ltd in the UK. The information presented here is principally intended to enlighten those who are comparative newcomers to electronics and as yet do not need to know some of the finer points which concern more advanced electronics users, designers and service engineers. For the latter, more detailed discussions o the technicalities of components are in the full edition of MEM.

For more information on the MEM, please email the *EPE Direct Book Service* at:

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3/3.2 RESISTORS AND POTENTIOMETERS

In this section, it is the simple points about resistors and potentiometers which are discussed, things which you may not find in other books but which are good to have explained in layman's terms. Greater technicalities about resistors and resistance, including Ohm's Law and other equations, are covered in sections 3/4.3 to 3/4.5. Resistive sensors, which include varistors (VDRs), thermistors and light dependent resistors (LDRs), are examined in section 3/3.3. Common circuit diagram symbols for resistors and potentiometers are shown in Fig.1 (see 3/3.3 Fig.1 for comparison with sensor resistor symbols, which are similar).

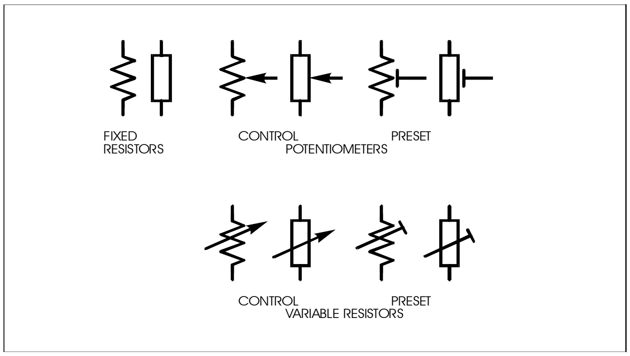

Fig.1. Typical resistance symbols (see also sensor resistor symbols in 3/3.3 Fig.1)

Resistors regulate or set the flow of current through a particular path in an electrical circuit. However complex the circuit in which they are used may appear, that is their primary function. There are, though, many ways in which the attributes of that function can be exploited in conjunction with other components to achieve not only simple results, such as producing a voltage drop at a particular point in a circuit, but also more sophisticated results, such as helping to determine the rate at which some other change occurs. Whenever electrical current flows through a resistor, the electrical energy lost is converted into heat.

Any material which allows an electrical current to flow through it is known as a *conductor*. All conductors, however good, try to resist the current flowing through them, in other words, they all have *resistance*. Even the copper wire which carries electrical current into the appliances in your home has resistance. It may be small when measured on a meter, but it is nonetheless there. The amount of resistance which a conductor has is expressed as a value in units called *ohms* (in honor of Georg Ohm, a Bavarian pioneer in the investigation of electrical phenomena, born 16-3-1789, died 16-7-1854). The symbol for ohms as a unit is Greek omega, W. Copper, for instance, has a resistivity (specific resistance) value which is expressed as 1.7 x 10^{-8}Wm, (Wm = ohms-meter). You may often see capital R used in place of W since not all printing equipment can produce an W symbol!

As everyone must be aware, some materials have greater resistance than others, some of them indeed have a resistance to electrical current flow which is so great that, to all intents and purposes, they can be regarded as non-conductors or insulators, such as rubber and many plastics, for example. Typically, hard rubber might have a resistivity of 10^{16}Wm^{-1}.

There are also materials which, not surprisingly, have resistivities which fall between those of good conductors and good insulators, and are known as *semiconductors*. A peculiarity about this "middling" group is that some of its members can be "doctored" in such a way that they can be made to exhibit a high resistance to current when it flows in one direction, but a low resistance when it flows in the other. Such materials include the elements silicon, germanium, gallium, cadmium and selenium. As we shall see, this property is the foundation upon which so much of modern electronics relies: without it, transistors and integrated circuits simply could not exist. Note, though, that it is the "doctoring" which turns semiconduction into a useful property. It entails the introduction of impurities into the semiconducting material and involves one or more junctions of differently processed materials. If you were to measure the resistivity of a block of pure silicon, for example, it would be likely to exhibit a uniform value of about 10^{2}Wm, and germanium a little below 1Wm.

Components which in electronics are known as *resistors*, though, are manufactured to allow current to flow in either direction and offer the same amount of resistance to it in which ever direction it flows. In other words, for a given resistor's material nature, its resistance value is supposedly fixed. However, this "fixedness" is not an absolute value true at all times and in all situations. It is a value that exists only under a given set of circumstances. Internal and external factors can affect the actual value of a resistor, such as moisture within its structure and the amount of heat to which it is subjected, to name but two (also see 3/3.1).

The way in which a resistor varies its “nominal” value depends on how it is manufactured. Thus, in manufacturers' data sheets, several parameters will be quoted about the nature of a particular type of resistor. One factor which will be specified is the material from which it is made, i.e. whether it is made from carbon, or a ceramic material, or a metal oxide or even made from wire wound around its body.

Irrespective of the material used, conventionally, “normal” (non-sensor) resistors are regarded as belonging to one of two physical types: fixed and variable, the latter more commonly known as potentiometers (although this term is frequently misused, as is discussed later).

3/3.2.1 FIXED RESISTORS

Fixed resistors, as their name implies, have a specified value fixed during manufacture. Such resistors have only two connections, the current flows in one end and out the other, and it does not matter which – unlike many electronic components, resistors have no special polarity.

The principal parameters for a resistor (whether fixed or variable) are:

- Resistance value, which may be expressed in ohms (W), thousands of ohms (kilohms or just kW), or millions of ohms (megohms or MW)
- Power rating in watts (W)
- Resistance tolerance, expressed as a percentage of its set value, e.g. ±5%
- Temperature coefficient, expressed as the amount by which the set value will change with temperature, variously expressed as parts per million (ppm) or percentage change per degree Celsius (% / °C).

For a reminder of the significance of a component's tolerance and temperature coefficient see section 3/3.1.

Up to a resistance tolerance of 1% and a power rating of one watt (1W), resistors are labeled by a color code. From 0.5% tolerance and 2W rating, the values are given in figures. There are exceptions to both these conventions.

Many of the color-coded resistors which you will normally encounter are likely to have a tolerance of 5% or greater, and will have four colored bands, as shown in Fig.2a; the fourth band may be close to the other bands. Color coded resistors of 2% or less may have more than four bands, such as the example shown in Fig.2b.

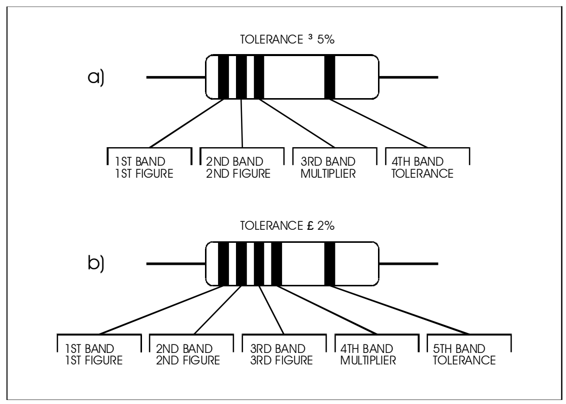

Fig.2. Resistor color code bands

The colors used on resistors are interpreted according to Table 1. These colors and their basic numerical meanings are recognized internationally for any color coding used in electronics, not just resistors, but some capacitors, diodes, cabling and other items. It will pay you to memorize them, especially in relation to the first three bands. They are not the same colors as used in Snooker!

Noting the way in which the resistors are shown in Fig.2, and reading from left to right, two examples of interpreting the bands are as follows:

Band 1: brown = 1
Band 2: black = 0
Band 3: red = 2 (10^2 = 100)
Band 4: gold = 5%

… indicating a resistor whose value is 10 x 10^2 = 1000 = 1kW, with a tolerance factor of 5%.

Band 1: red = 2
Band 2: yellow = 4
Band 3: black = 0

Band 4: black = 0 (10^0 = 1)

Band 5: red = 2

… indicating a resistor whose value is 240 x 10^0 = 240W, with a tolerance factor of 2%.

Color	Figure	Multiplier	Tolerance
Silver	–	0.01 W	10%
Gold	–	0.1 W	5%
Black	0	1 W	–
Brown	1	10 W	1%
Red	2	100 W	2%
Orange	3	1 kW	–
Yellow	4	10 kW	–
Green	5	100 kW	0.5%
Blue	6	1 MW	0.25%
Violet	7	10 MW	0.1%
Grey	8	100 MW	–
White	9	–	–

Table 1. Color codes for resistors according to IEC 62 (DIN 41 429)

Figure	IEC Code
0.10 W	R10
0.33 W	R33
1.0 W	1R0
1.33 W	1R33
10.1 W	10R1
100 W	100R
1 kW	1K0
10 kW	10K
100 kW	100K
1.0 MW	1M0
10 MW	10M
100 MW	100M
1 GW	1G0

Table 2. Example labeling of resistors in figures and coding according to IEC.

Letter	Tolerance
F	± 1%
G	± 2%
J	± 5%
K	± 10%
M	± 20%

Table 3. A further letter is then appended to indicate the tolerance.

Where resistors are labeled in figures, the information in Table 2 and Table 3 should be referred to, which shows the internationally recognized IEC (International Electrotechnical Commission) coding. Note how the decimal point is expressed, that the ohm symbol is shown as an R, and that 1000 is shown as a capital K. Note that although capital K is sometimes used in circuit diagrams and parts list to mean 1000 ohms, lower case k is generally to be preferred since capital K has widely become used in computing to mean 1024 (2^{10}), which has significance as a “round” binary number (10000000000).

In circuit diagrams and constructional charts, a resistor's numerical identity is usually prefixed by ‘R’, e.g. R15 simply means Resistor number 15.

The ‘E’ series values

Standard resistor values may at first sight seem to be strangely numbered. There is, however, a beautiful logic behind them, dictated by the tolerance ranges available. These comprise tolerances of ±0.5%, ±1%, ±2%, ±5%, ±10%, and ±20%, and are respectively known as the E192, E96, E48, E24, E12, and E6 series, the number indicating the quantity of values in that series. Thus, if resistors have a value tolerance of 5%, for example, a series of 24 values can be assigned to a single decade multiple (e.g. values from 1 to 9, or 10 to 99, or 100 to 999 etc.) knowing that the possible extreme values of each resistor overlap the extreme values of adjacent resistors in the same series.

Work it out for yourself for the following 24 values which comprise the E24 (5%) series:

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, 7.5, 8.2, 9.1

The E6 (20%) series simply has six values, as follows:

1.0, 1.5, 2.2, 3.3, 4.7, 6.8

Any of the numbers in a series can be applied to any decade multiple set. Thus, for instance, multiplying 2.2 by each decade multiple (1, 10, 100, 1000 etc.) produces values of:

2.2 (2W2), 22, 220, 2200 (2k2), 22000 (22k), 220000 (220k), 2200000 (2M2)

Note an interesting point about the alternative way of expressing the decimal point for some of these numbers, as shown in brackets: the use of W, k and M. This is another answer to a printing problem! The decimal point in a number may not always be printed clearly, and the alternative display method is intended to help avoid misinterpretation of component values in circuit diagrams, parts lists and especially on the components themselves.

These value series apply not only to resistors, but to capacitors and inductors as well. For the latter components, m (micro), n (nano), p (pico) may be used in place of the decimal point, e.g. 2m2, 2n2, 2p2.

Common types of fixed resistor:

- Carbon film/ceramic: normal requirements
- Carbon film/ceramic: increased operational demands
- Carbon film/ceramic: precision resistors
- Carbon film/ceramic: low drift/high reliability
- Metal oxide film (forms as above): heat resistant to 175°C
- Wire-wound resistors: different constructions for high loads and specialized applications.

Fixed resistors are available as individual components and also as resistor modules in which several resistors are enclosed in a single package, with the connecting pins arranged either as single-in-line (SIL) or dual-in-line (DIL) configurations (the latter look similar to integrated circuits – ICs). The internal arrangement of the resistors within the module may be several individual resistors, or a network configuration; see Fig.3.

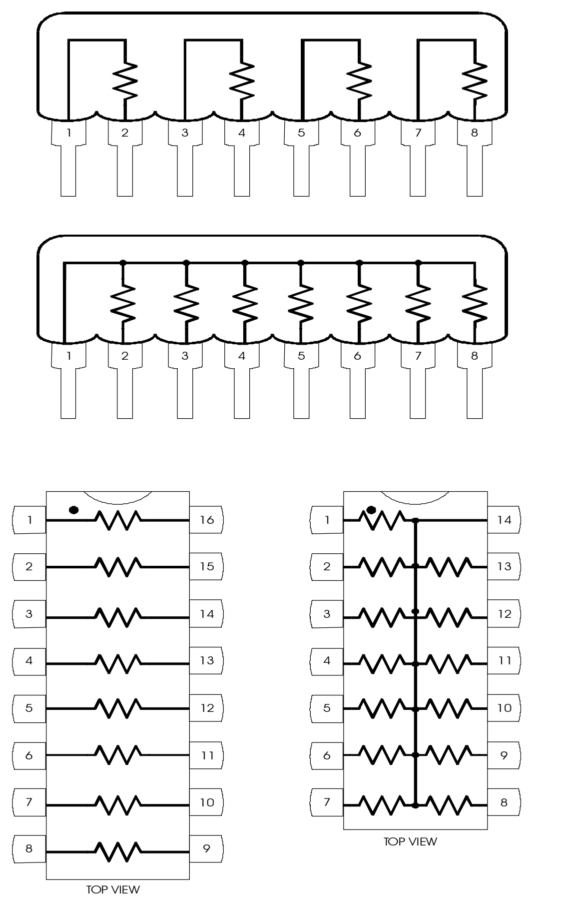

Fig.3. Examples of fixed resistor modules.

3/3.2.2 POTENTIOMETERS

A basic potentiometer has three connections or terminals (see Fig.1). As with a fixed resistor, there are two connections at either end of the resistance material, which is commonly known as the *track*. The third connection is made to a conducting slider, commonly known as the *wiper*, which is in contact with the track and can be slid along it from one end to the other. The current available at the wiper is then related to the position that it has along the track. It should be noted that the basic resistance of the component itself does not vary, it is only the relative resistance between the wiper and each end terminal which can be varied.

Physically, potentiometers fall into two main types: first, there are the *control potentiometers*, those that have a shaft or tab which usually protrudes through the panel of the case in which the circuit is mounted. This type of potentiometer is intended where frequent correction of its wiper position is required, such as when it is used as a volume control, for example.

The other type is commonly known both as a *preset potentiometer* (or just *preset*), and as a *trimmer potentiometer*. A preset is normally a much smaller component than a control potentiometer and is usually mounted on a printed circuit board. It has a slot by which it can be adjusted using a screwdriver or similar. Presets are usually intended to be adjusted to a preset value which may seldom need to be adjusted again.

It should be pointed out that the use of the term *potentiometer* (often abbreviated just to *pot*) may in many circumstances actually be an incorrect use of the term. In strict definition, the correct term is really as we first named it, *variable resistor*, even though its *actual* resistance along the full length of the track does not change. As you will learn later, the term *potentiometer* really applies only when the variable resistor is used as a *potential divider* whose output potential (voltage) at the wiper can be varied, a situation in which all three terminals of the device *have* to be used.

There are many instances, though, when the *voltage* is not the condition which needs to be varied, rather it is the *resistance* which needs changing or presetting, in which case only the wiper and one other terminal need to be connected, and the true description of *variable resistor* is the one which should be used. Nonetheless, such is the state of the well-established art of electronics that some terms have become widely misused, but their implied meaning is still taken to be acceptable, even if strictly speaking it is incorrect.

Even though only two terminals *need* to be used, it is usually a good idea to connect the third terminal of a variable resistor to the wiper. This ensures that a minimum circuit resistance still exists even if the wiper comes away from the track in a fault condition.

Control potentiometers are available as rotary shaft and slider types, both of which are manufactured in single and dual configurations. Dual rotary types have two tracks and wipers mounted in separate enclosures, secured one behind the other, and are available in two versions.

The dual *tandem* type has a single shaft which controls both wipers at the same time. The dual *concentric* type has two shafts, one within the other, which allows each wiper to be controlled separately. Dual *slider* pots have a single tab which controls both wipers simultaneously.

Linear and logarithmic

All control potentiometers have a choice of track resistance patterns or “laws”: linear, logarithmic, or anti-logarithmic – terms which are commonly abbreviated to *lin*, *log,* and *anti-log*, respectively. Linear tracks have the same change of resistance per given track length (or angle of rotation) along the whole of the track; in other words, the output at their wiper changes linearly with linear movements along the track.

With logarithmic tracks, the resistance per given track length changes along the track, by a small amount at one end, progressing logarithmically to a larger amount at the other; in other words, the output varies logarithmically with linear movements along the track. Logarithmic rotary types have the minimum track-to-wiper resistance change with their shaft rotated fully anti-clockwise (to the “left”). Anti-log types behave in the opposite direction. Slider pots are not available as anti-log versions – just use log types round the other way!

Some rotary pots and presets are available as multi-turn varieties; the adjustment shaft is geared so that the wiper rotation is less than the shaft rotation. These pots are only available in single, linear forms.

Notations

In circuit diagrams and constructional charts, a potentiometer's numerical identity may be prefixed by ‘VR’ (Variable Resistor), e.g. VR3, or ‘RV’ (Resistor Variable) or ‘P’ (Potentiometer) or even ‘PR’ (Preset Resistor). Logarithmic pots are normally notated as such on circuit diagrams. Linear pots are not always notated accordingly; if the pot is shown without a *lin* or *log* notation, it is a linear type (barring circuit drawing errors, of course).

Potentiometer identities are usually printed on them in text and numbers, though some presets may be color-coded in resistor fashion.

Summary of potentiometer types:

- Panel mounting, rotary with shaft
  Sub types: single, dual tandem, dual concentric, linear, log, anti-log, multi-turn linear.
- Panel mounting, slider with tab.
  Sub types: single, dual tandem, linear, log.
- Printed circuit board mounting, rotary with shaft.
  Sub types: single, dual tandem, dual concentric, linear, log, anti-log, multi-turn linear.
- Printed circuit board mounting, slider with tab
  Sub types: single, dual tandem, linear, log.
- Printed circuit board mounting, preset rotary with adjustment slot
  Sub-types: vertical or horizontal mounting, open (skeleton) or enclosed tracks. All tracks are single, linear.
- Printed circuit board mounting, preset slider with screw adjustment
  Sub-types: vertical or horizontal mounting, single turn or multi-turn. All are enclosed and all tracks are single, linear.

All pots are available in a variety of body and shaft or tab sizes. Anti-log and dual concentric types are only available through specialist suppliers.

Summary of track types:

- Carbon film. General purpose.
- Cermet (ceramic-metal). Precision (cermet tracks have a less coarse nature than carbon, resulting in a smoother change of resistance when rotated).
- Conductive plastic. Precision – smoother wiping.
- Wire-wound. Higher wattage rating.
- Wire-wound, very heavy duty, length-wise with slider, as sometimes used for stage lighting control and often known as a *rheostat* – not really an electronics component

Not all track types are available in all physical forms – see major supplier's catalogues. Apart from the mechanical and physical specifications listed above, the other principal parameters for a potentiometer are mainly the same as for fixed resistors:

- Value of the resistance track, which may be expressed in ohms (W), thousands of ohms (kilohms or kW) or millions of ohms (megohms or MW). Standard values are 1, 2.2 (or 2 or 2.5), and 4.7 (or 5) in decade multiples of 100, 1000 (1k), 10000 (10k), 100000 (100k) and 1000000 (1M up to 2M2).
- Power rating in watts (W).
- Resistance tolerance, expressed as a percentage of its set value.
- Temperature coefficient, expressed as the amount by which the set value will change with temperature, variously expressed as parts per million (ppm) or percentage change per degree Celsius (% / °C).
- Linearity – how accurately the resistance change per given movement of its wiper is maintained along the full track length.

Another point worth knowing is that most pots are incapable of being rotated through a full circle. About 270° is an average maximum wiper rotation around the track, at which point the track ends and there is usually a tab to prevent further shaft rotation. However, at a price, pots with a track rotation angle approaching 360° can be found from specialist suppliers, those dealing with robotic and other automation supplies, for example. Shaft rotation angles may sometimes be greater than track angles, and some shafts may rotate through 360°even though the track does not. Good catalogues normally quote rotation factors.

Constructional advice

Rotary control potentiometers are generally supplied with a shaft that is considerably longer than usually required. The shafts may be metal or plastic, and require cutting to length, an action which can be hazardous to the welfare of the pot's resistance track if not done carefully. The temptation might be to hold the body of the pot in a vice and to cut the shaft with a hacksaw; DON'T! The sawing action and consequent movement of the wiper against the track can damage both, at the very least resulting in uneven contact of the wiper with its track and consequent poor electrical results when turning the pot.

Instead, put the *shaft* in the vice to clamp it, then saw through it, *gently* holding the body end to stop it falling when the cut is complete. Carefully file down any burrs on the shaft, to allow a knob to slide on easily.

Plastic shafts can sometimes be cut using heavy-duty wire-cutters, or even a heavy-duty guillotine – the type which can cut copper-clad fiberglass printed circuit boards. Both methods are fast, *but mind your fingers!* Obviously, if you have a choice, the plastic shafted pots are the easiest to cope with. Similar caution should be observed when cutting the shafts of rotary switches.

3/3.3 SENSOR RESISTORS

Varistors, thermistors, and light dependent resistors

Environment-sensitive resistors known as varistors (VDRs), thermistors, and light dependent resistors (LDRs) are a special class of resistor whose

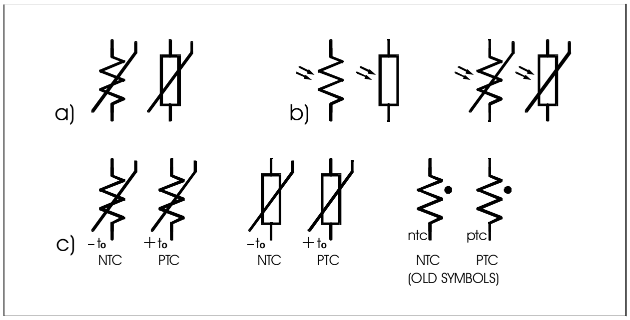

Fig.1. Typical sensor resistor symbols (a) voltage dependent (VDR or varistor); (b) light dependent (LDR); (c) thermistor. Symbols may be enclosed in circles or ovals. These symbols should not be confused with those in 3/3.2 Fig.1.

resistance changes in response to changes in voltage, temperature, and light, respectively. Unlike the potentiometer, which is often *called* a variable resistor, even though the actual resistance between its ends is fixed, these three component types have a resistance which *physically* changes with ambient conditions.

Circuit diagram symbols which might be encountered for these components are shown in Fig.1. The symbols are similar, but have specific identifying features: the dot or notation beside the thermistor signifies its temperature sensing nature; the arrows pointing at the LDR signify light falling on it; the VDR is without any additional feature beyond the crooked line through the resistance symbol to indicate inherent variability, although an operational voltage may sometimes be quoted alongside the symbol. All three types of sensor resistor are not polarized and may be connected either way round.

3/3.3.1 VARISTORS (VDRS)

The abbreviation VDR is often used in place of the term *varistor* and more accurately defines its function as a Voltage Dependent Resistor. VDRs are used to protect against mains-borne spikes; they are very fast, and cheap. When VDRs have a voltage connected across them, their resistance

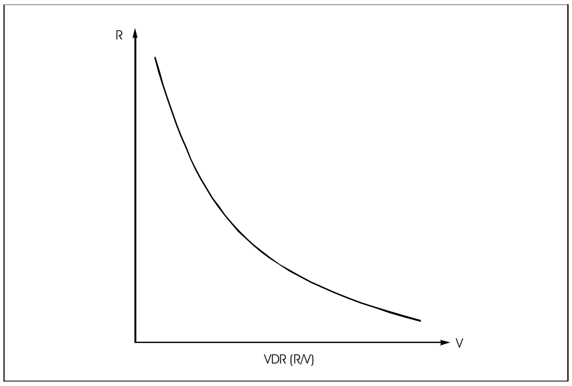

Fig.2. Characteristic curve of a voltage dependent resistor.

depends on the value of that voltage. At a low voltage, the resistance is high, but as the voltage rises so the resistance decreases accordingly, see Fig.2. With this property, VDRs are often used to protect components which are sensitive to excessive voltage. In this application, they might typically be preceded by a normal fixed resistor so that the two components behave as a variable potential divider, as shown in Fig.3. If used without the additional resistor, changes in voltage level across the VDR would simply result in a change in the current flowing through it.

VDRs are typically made from a metal oxide material. They are available in many values for specific voltage ranges. There are other types of voltage suppression component made as silicon-based semiconducting devices. Diodes can also be used in some voltage suppression applications.

In circuit diagrams and constructional charts, a varistor's numerical identity may be prefixed 'VDR' (Voltage Dependent Resistor) or just by 'R' (Resistor). In catalogues, varistors may be listed under "Suppression" components rather than under "Sensors" or "Resistors".

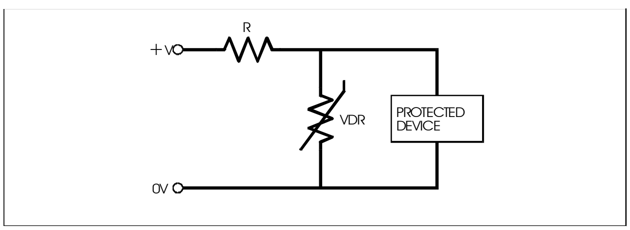

Fig.3. Using a VDR to protect a circuit device.

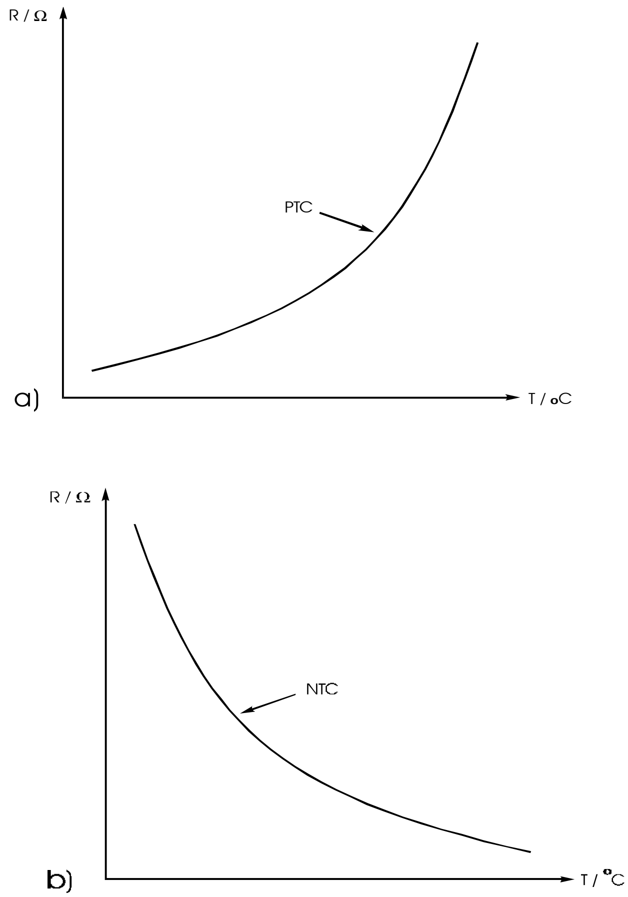

Fig.4. Characteristic curves for (a) PTC thermistor and (b) NTC thermistor.

3/3.3.2 THERMISTORS

The term *thermistor* could, perhaps, be abbreviated to TDR (Temperature Dependent Resistor) to more accurately describe its function, though this is not common practice. There are two basic types of thermistor, one of which is described as having a positive temperature coefficient (PTC) and the other as having a negative temperature coefficient (NTC). The basic characteristic of a thermistor is that its resistance changes according to its temperature, a reduction in resistance with increases in temperature for an NTC type, and vice versa for a PTC type. Typical graphs for both types are shown in Fig.4.

A thermistor's response to temperature is dependent on the type of material used in its construction, commonly titanium oxide, barium carbonate or a ceramic oxide. Thermistors are available in metal, glass, ceramic and plastic cases. Their body shapes include discs, studs, probes, rods, and beads. Types are available which can sense temperatures between -80°C and +400°°C, although the ranges for which they are specifically designed are narrower than these extremes. Their resistance values are quoted in relation to that which exists at a specific ambient temperature, e.g. 10k (ohms) at 25°C. Tolerance factors are also quoted, such as ± 0.2°C between 0°C and 70°C, for example.

Thermistors are likely to be found as circuit protection elements, and as sensing and corrective elements in measurement and control systems. However, since the advent of sophisticated integrated circuits which have linear temperature sensing characteristics, the use of thermistors as separate entities has become less common in many applications. They still find favor, though, where low costs or simplicity are important. Diodes can also be used in some temperature sensing applications.

In circuit diagrams and constructional charts, a thermistor's numerical identity may be prefixed by

'R', or perhaps with 'TH'. In catalogues, they are likely to be listed under "Sensors".

3/3.3.3 LIGHT DEPENDENT RESISTORS (LDRS)

As the name implies, a light dependent resistor (LDR) is a device whose resistance changes in response to the amount of light falling on it. An LDR's resistance value in the presence of strong light is just a few ohms, but in the absence of light the value can be many tens of megohms (millions of ohms). It is important to note that they are not very linear in their response. A typical resistance/ illumination graph is shown in Fig.5. The base material from which LDRs are made is cadmium sulphide or lead sulphide.

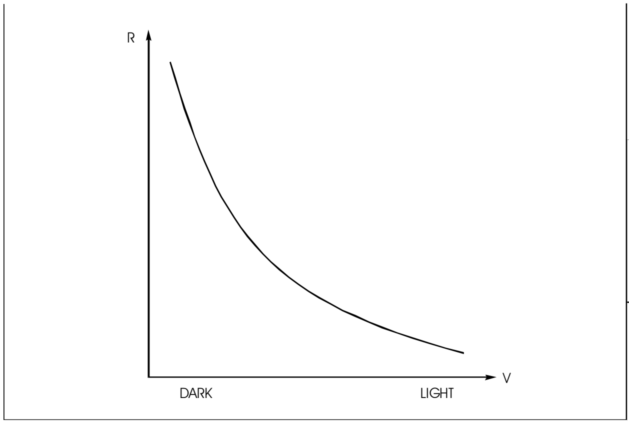

Fig.5. Characteristic curve for a light dependent resistor (LDR).

An important characteristic specified for LDR types is the spectral sensitivity (sensitivity to different colors of light and expressed in nanometres – nm – rather than in degrees Kelvin as used in some fields), which indicates how the resistance varies depending on the wavelength of light reaching the device. Types are available which respond to infrared and ultraviolet wavelengths as well as "visible" light. The value of LDRs is usually quoted in relation to their resistance at a particular wavelength and intensity. Since LDRs are purely ohmic (resistive), they can be used in both AC and DC circuits. Two commonly encountered LDR types are the ORP12 and NORP12, which are generally interchangeable. Since LDRs are fairly slow in their response to changing light levels, circuits which require a high speed response, such as optical communications systems, use photodiodes or phototransistors (see section 3/3.7).

In circuit diagrams and constructional charts, a light dependent resistor's numerical identity may be prefixed by 'R' or 'LDR'. In catalogues, LDRs may be listed under "Optoelectronics" rather than under "Sensors" or "Resistors".

3/3.4 CAPACITORS

This section highlights simple points about different types of capacitor, including tips and points which you may not find in other books, but which are good to have explained in layman's terms. Greater technicalities about capacitors, including various equations, are covered in section 3/4.7. Common circuit diagram symbols for fixed and variable capacitors are shown in Fig.1.

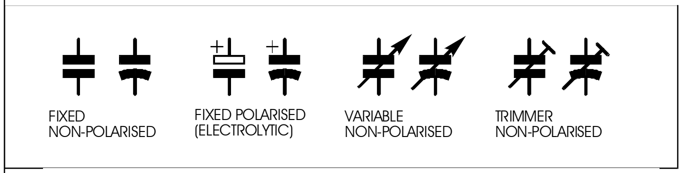

Fig1. Typical capacitor symbols

A capacitor is a component which has the ability (capacity) to store electrical charge (hence its name, although in some non-electronic applications it may be known as a *condenser*). Having electrical capacitance, capacitors in this sense can be thought of as a type of battery, but, unlike a battery, they do not depend on a chemical reaction for this function to occur. Rather, they take advantage of a convenient fact of nature that prevails when two metal plates are placed close to each other, but not touching, and a voltage source is connected across them.

At the moment that the voltage is applied, electrical charge is transferred to the plates at a rate dependent on the voltage level applied, the nature of material from which the plates are made, their total area, their distance apart, the nature of the material which lies between them, and the amount of resistance existing in the connection path (including the capacitor's internal resistance). If the voltage is applied for sufficient length of time, eventually there will be *virtually* the same voltage across the plates as available from the source.

When the voltage source is removed, the plates will retain their charged voltage differential until a conductor of some sort is connected across them. As soon as there is a conducting path between the two plates, the charge begins to flow from one to the other, trying to return to the previously uncharged state. The discharging rate is governed by the same factors as controlled the charge rate. Given enough time, all of the electrical energy stored across the plates will reduce to zero. And what happens to the electrical energy itself? Principally, it is converted into heat in the discharging conductor and capacitor's internal resistance, although in extreme circumstances some could be converted into light or radio energy.

A capacitor's ability to be charged by a voltage and to hold the charge indefinitely allows it to be used in electrical and electronic circuits in a variety of ways:

- To simply store a voltage until it is needed.
- To smooth out fluctuations in voltage levels.
- To transfer changing differences in voltage levels between one side of the capacitor and the other, in other words, to allow alternating (AC) voltages to be transferred whilst preventing DC voltages from flowing from one part of a circuit to another.
- To limit the power value of alternating currents being transferred from one part of a circuit to another (though at a loss of waveform shape).
- In conjunction with other components, such as resistors for example, to determine the rate at which voltage changes occur at a particular point in a circuit.
- To shorten or extend pulse lengths.

The amount of electrical charge that a capacitor can hold is known as its capacitance value and depends on three main factors:

- The area of the two plates which form it.
- The distance between the plates.
- The material which separates the plates (called the dielectric).

The unit which is used to define a capacitor's capacitance value is the Farad. It is named after another electrical pioneer in the nineteenth century, Michael Faraday. He was a Londoner, born 22-9-1791, died 25-8-1867.

A capacitance value of one Farad is a unit of charge which, in practical terms, is far too large to be useful in everyday electrical and electronic circuits. For convenience, the unit is usually divided and expressed in sub-units, such as:

- **Microfarads:** one millionth of one Farad, and usually written as mF (Greek 'mu' followed by a capital F), although it is common for it to be written as 'uF' or 'mF', since many keyboards do not have the Greek symbol readily available. The use of 'mF', of course, is very misleading because 'm' is the abbreviation for milli rather than micro. It is also common, where the meaning of the term is implied, for it to be written simply as 'm', in component lists for instance. Verbally, these abbreviations are often pronounced as "mew" or "muff". For example, a 10mF capacitor might be referred as having a value of "ten-mew" or "ten-muff".
- **Nanofarads:** 1000-millionth of a Farad and usually written as 'nF', although the 'F' may be dropped where it is implicit in the context. Verbally, the abbreviation might be pronounced "en-eff" or just "en", i.e. a value of 10nF might be pronounced as "ten-en". The use of the term "nuff" is unlikely.
- **Picofarads:** one million-millionth of a Farad and usually written as 'pF', though again the 'F' might be dropped when it is implicit. Pronunciation is usually "puff" (as in "puff a cigar"), although it might sometimes be heard as "pee", i.e. "ten-pee" for 10pF.

3/3.4.1 CAPACITOR TYPES

Capacitors are manufactured as having one of two very basic characteristics, they are either:

- Polarized
- Non-polarized

… the latter being manufactured in fixed and variable capacitance types.

In circuit diagrams and constructional charts, a fixed capacitor's numerical identity is usually prefixed by 'C', e.g. C21. A variable capacitor may have its number also prefixed by 'C', though it is more likely to prefixed by 'VC' (Variable Capacitor), or perhaps 'CV' (Capacitor Variable).

Polarized capacitors, as their name implies, are very particular about which side (plate) is connected to a *relatively* positive voltage. Connecting them the wrong way round can have dire results, a matter which is discussed later.

Non-polarized capacitors can *normally* be connected into a circuit either way round, although there are *some* circumstances where the relative position of the output electrode foil is placed in relation to other parts of a circuit. The colored ends of some polystyrene capacitors, for example, can indicate this type of polarity, although it is not a *true* polarity as referred to with regard to polarized electrolytic or tantalum capacitors.

Capacitors are manufactured in a seemingly bewildering array of sub-types, basically named in respect of the nature of the dielectric material used between the plates:

- Electrolytic (polarized).
- Tantalum (polarized).
- Polypropylene (non-polarized).
- Polycarbonate (non-polarized).
- Polyester (non-polarized).
- Polystyrene (non-polarized).
- Metalized film (non-polarized).
- Ceramic (non-polarized).
- Mica (non-polarized) – sometimes called silvered-mica.
- Trimmers – variable capacitors (non-polarized).
- Air-spaced – variable capacitors (non-polarized).
- Paper – now rare (non-polarized).
- Oil-filled – now rare (non-polarized).

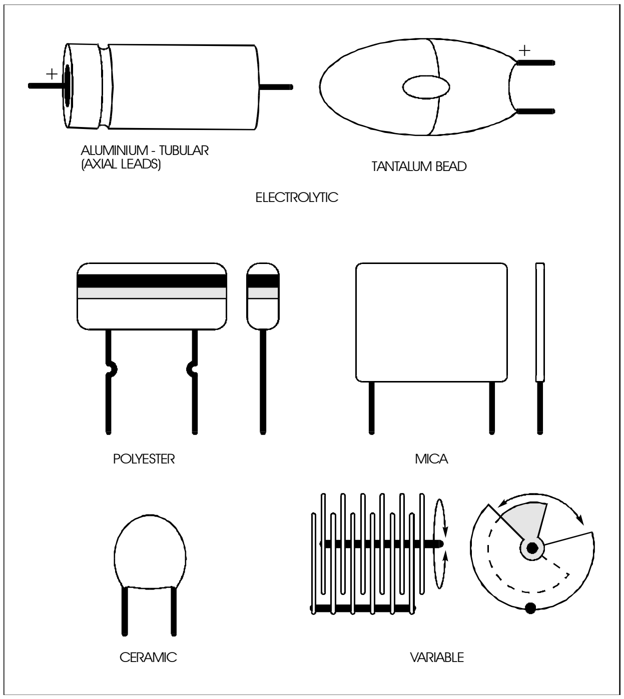

Fig.2. Typical capacitor outlines; many variations exist.

There are also sub-types of the sub-types! Have a look at a major component supplier's catalogue and prepare to be astonished. Fortunately, until you are much more into the depths of serious electronics design, the subtle differences between some types need be of little concern. Typical physical shapes for six capacitor types are shown in Fig.2. A summary of the characteristics for the most commonly available types of fixed capacitor is given in Table 1.

Identity coding

The majority of capacitors now have their values printed on them, although color-coded varieties are still to be found (it is probably cheaper for a manufacturer to print a value on a component in a single color, usually black or white, than it is to use multi-color banding equipment). Examples of the color codes which might be encountered are shown in Tables 2 to 4, plus Fig.3 and Fig.4.

Capacitor	Ceramic	Electrolytic	Metal Film	Mica	Polyester	Polycarbon-ate	Polystyrene	Tantalum	Polypropy-lene
Cacacitance Range(F)	2.2p to 100n	100n to 47000µ	1µ to 16µ	2.2p to 10n	1n to 10µ	10n to 10µ	10p to 10n	100n to 100µ	100p to 470n
Typical toler-ance (%)	± 2 to ± 80	-10 to +50	± 20	± 1	± 5 to ± 20	± 20	± 1, ± 2.5,± 1, ± 2.5,	± 20	± 5 to ± 20
Typical volt-age rating (DC)	50V to| 15kV	6.3V to 450V	250V to 600V	350V (typical)	63V to 400V	63V to 630V	50V to 630V	6.3V to 35V	100V to1.5kV
temperature cofficient (ppm/degC	+100 to -4700	+1000 (typical)	+100 to +200	+35 to +70	-200	+60	-150 to +80	+100 to+1000	-200 (typical)
Stability	Fair	Poor	Fair	Excellent	Fair	Good	Good	Fair	Fair/Good
Ambient temperature range (degC)	-35 to +85	-40 to +85	-25 to +85	-40 to +85	-40 to +100	-55 to +100	-40 to +70	-40 to +85	-55 to +100

Table 1. Capacitor varieties and their typical characteristics.

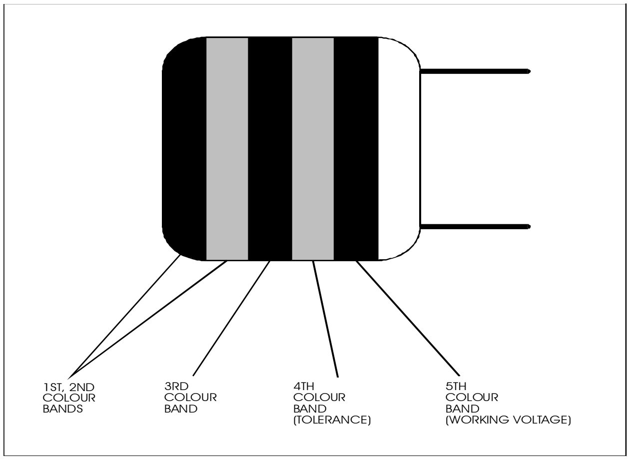

Fig.3. Polyester capacitor color code bands

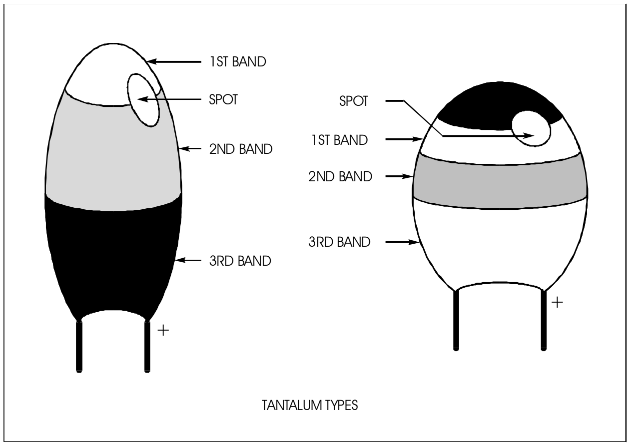

Fig.4. Tantalum capacitor color code bands

Bands 1 and 2 = Capacity,
Band 3 = Multiplier
Band 4 = Tolerance (White = ±10%, Black = ±20%)
Band 5 = Voltage (Red = 250V, Yellow=400V)

Band 1	Band 2	Band 3	Value
Brown	Black	Orange	0.01 mF
Brown	Green	Orange	0.015 mF
Red	Red	Orange	0.022 mF
Orange	Orange	Orange	0.033 mF
Yellow	Violet	Orange	0.047 mF
Blue	Grey	Orange	0.068 mF
Brown	Black	Yellow	0.1 mF
Brown	Green	Yellow	0.15 mF
Red	Red	Yellow	0.22 mF
Orange	Orange	Yellow	0.33 mF
Yellow	Violet	Yellow	0.47 mF
Blue	Grey	Yellow	0.68 mF
Brown	Black	Green	1.0 mF
Brown	Green	Green	1.5 mF
Red	Red	Green	2.2 mF

Table 2. Polyester capacitor color coding (obsolete). Reading from top (see Fig.3).

As with resistors, the colors allocated to each numeral from 0 to 9 conform to the standard color code system.

Color	Figure	Multiplier	Voltage
Black	0	1 mF	10V
Brown	1	10 mF	–
Red	2	100 mF	–
Orange	3	–	–
Yellow	4	–	6.3V
Green	5	–	16V
Blue	6	–	20V
Violet	7	–	–
Grey	8	0.01 mF	25V
White	9	0.1 mF	30V
Pink	–	–	35V

Table 3: Tantalum capacitor color coding. Reading from top, Bands 1 and 2 = Capacity, Spot = Multiplier, Band 4 = Voltage.

Color	Figure	Multiplier	Tolerance
Black	0	1 pF	± 20%
Brown	1	10 pF	–
Red	2	100 pF	–
Orange	3	1000 pF	–
Yellow	4	10000 pF	–
Green	5	–	–
Blue	6	–	–
Violet	7	–	–
Grey	8	0.01 mF	–
White	9	0.1 mF	± 10%

Table 4. Ceramic capacitor color coding. Reading from top, Bands 1 and 2 = Capacity, Band 3 = Multiplier, Band 4 = Tolerance.

	Tolerance C =< 10pF	Tolerance C >= 10pF		Rated Voltage
B	± 0.1pF	–	A	50V DC
C	± 0.25pF	–	B	125V DC
D	± 0.5pF	± 0.5%	C	160V DC
F	± 1.0pF	± 1.0%	D	250V DC
G	± 2.0pF	± 2.0%	E	350V DC
H	–	± 2.5%	G	700V DC
J	–	± 5.0%	H	1000V DC
K	–	± 10%	U	250V AC
M	–	± 20%	V	350V AC
P	–	+ 100%	W	500V AC
R	–	+30/-20%		–
S	–	+50/-20%		–
Z	–	+80/-20%		–

e.g. **"n 47 KD"** = 0.47nF, ±10%, 250V DC
(n = nanometers)

Table 5. Ceramic capacitor letter coding.

Marking	Temp-co	Tip Colour
NP0	0	Black
N030	-30	Brown
N080	-80	Red
N150	-150	Orange
N220	-220	Yellow
N330	-330	Green
N470	-470	Blue
N750	-750	Violet
N1500	-1500	Orange/Orange
N2200	-2200	Yellow/Orange
N3300	-3300	Green/Orange
N4700	-4700	Blue/Orange

Table 6. Ceramic capacitor temperature

Where capacitors have their values printed on them, the information may well be abbreviated or allocated a letter coding. Ceramic capacitors, for example, may have their tolerance and voltage ratings coded as in Table 5. An additional code may also appear on some ceramic capacitors. The system shown in Table 6 might also be used, where 'N' denotes a negative temperature coefficient.

A 3-digit coding is commonly used to mark some ceramic capacitors. The first two digits correspond to the first two digits of the value, whilst the third digit is a multiplier which gives the number of zeroes to be added to give the value in pF, e.g. *103* = 10000pF = 0.01µF.

Which brings us to the sometimes misunderstood use of pF, nF and mF. An nF value is 1000 times greater than pF, and 1000 times less than mF. Therefore, the following typical conversions apply to some values seen on capacitors:

1nF (or 1n) = 1000pF

10nF (or 10n) = 10000pF = 0.01mF

100nF (or 100n) = 100000pF = 0.1mF

However, despite all this *possible* coding, with many modern capacitors, their values are normally obvious from the uncoded information printed on them (although you may need a magnifying glass in order to read them).

Capacitor selection

There are several factors to be considered when selecting a capacitor for a particular application, which include:

- Capacitance value
- Working voltage
- Tolerance
- Leakage current
- Temperature coefficient
- Stability

The general considerations of the above six factors are discussed in section 3/3.1. Unless you are involved with a particularly demanding design, it is principally the first two which will concern you, but you should be aware of the following:

When substituting capacitors, either because they have failed in an existing circuit, or because the precise type specified in the parts list of a constructional project is not readily available from your normal supplier, it is important to ensure that the replacement performs to a specification which is at least as good as that of the specified component.

However, it is quite permissible to replace a capacitor which has a working voltage rating of 15V with one rated at 25V, for instance. Remember, though, that the working voltage rating simply states the *maximum* voltage at which a component should be operated in normal service. Generally speaking, a higher working voltage rating is nearly always acceptable electronically (physical size permitting, of course). Similarly, a capacitor with a tolerance of 20% can always be replaced by one having a tolerance of 10%. A better tolerance rating is always acceptable electrically.

It is also important to note that working voltages are related to operating temperatures and at high temperatures all capacitors should be significantly derated (assumed to have a lower working voltage than that stated). In normal everyday applications, however, this factor is usually irrelevant. Capacitors should always be operated at well below their nominal maximum working voltages. If a circuit is designed for operation at 9V, for example, a capacitor rated at a working voltage of 9V or 10V should not be used, rather, one rated at 16V or greater should be chosen. Even one rated at 63V, for instance, would be acceptable, provided that its size (which is likely to be greater with increased voltage ratings) is suitable for the circuit board on which it may need to be mounted. As a rule of thumb, the quoted working voltage rating should be at least 50% greater than the voltage at which the component is required to work in the circuit, although there are occasions, such as in power supply circuits, where a muh greater margin should be allowed, possibly even as much as four times the nominal supply voltage.

Where an AC voltage rating is specified, this is normally for sinusoidal operation (sine waves – of which more detail is discussed in other parts of this Manual) at either 50Hz or 60Hz. Performance will not usually be significantly affected at low frequencies (up to 100kHz, or so), but above this, or when non-sinusoidal (e.g. pulsed waveforms) are involved, the capacitor must be derated in order to minimize losses in its dielectric material which can produce internal heating and lack of stability. You should also be aware that a sinusoidal waveform normally has its voltage quoted as an average value, whereas in fact its *peak* value is nearly 50 per cent higher (x 1.41), thus the chosen capacitor's voltage rating must take this into account.

Capacitors used for smoothing and reservoir (substantial storage) applications in DC power supplies must have an adequate ripple current rating. This rating refers to the AC characteristic of the current (at the ripple frequency, e.g. 50Hz for UK mains operated power supplies) which remains after the principal alternating (AC) voltage has been rectified to a DC voltage. Without a capacitor following the rectifier, the ripple voltage will be approximately half that of the original AC peak-to-peak voltage. It is the job of the following capacitor to smooth out that ripple, a task which is complicated when large currents are demanded by the following circuit. Component data sheets and catalogues will usually quote the typical ripple current rating for the large value capacitors required for power supply use. The chosen ripple current rating should always be greater than the ripple current expected.

A most important consideration when using polarized capacitors (e.g. electrolytic and tantalum), is that they are connected the correct way round. The positive side of the capacitor must always be connected to the side of the circuit which has, or is likely to have, the highest voltage.

Across power supply lines, this orientation of polarity will always be obvious – the positive side of the capacitor goes to the positive supply line. It is not always so instinctively obvious when the capacitor is being used to couple AC signals between different parts of a circuit. If in doubt, think about what DC levels are likely to exist if the AC signal ceases, and face the capacitor accordingly.

There are instances when the leakage current through an electrolytic capacitor might adversely affect both sides of the circuit in which it is used. In this case, two equal value electrolytic capacitors can be used in series, both negative ends connected together, both positive ends facing outwards. The value for each capacitor should be twice the total capacitance required (see section 3/4.7.3 – capacitors in series).

If a polarized capacitor is connected the wrong way round, in *extreme* circumstances it can over-heat, causing damage to itself and other components, and in a really severe case the capacitor may even explode. At the very least the circuit may not operate as intended. (Capacitors supplied with a significantly excessive voltage can also explode, even if connected correctly.)

Polarity is usually clearly marked, but there are several ways in which it might be done. The ends from which the connecting wires come out may be marked with '+' or '-' symbols, or there might be a large arrow pointing to the negative end or to a particular wire. With electrolytic capacitors having a wire at each end (axial construction), the positive end is likely to have a crimp around the casing and the circular face at that end is likely to be a plastic material, often black. Also, where the lead connections to the capacitor are obvious, the negative lead will be seen to be attached to the outer metal casing of the body. (The opposite term to *axial* construction is *radial*, in which both capacitor wires come out from the same end.)

Non-polarized capacitors can generally be connected either way round, although there are specialized situations where the orientation in relation to the capacitor's outer foil may be significant.

Constructional advice

Be aware that with very small polystyrene capacitors, an occasional fault which may be experienced is that the leads can become detached internally. It is unusual, but it can cause the capacitor to develop an open circuit, or a short circuit.

3/3.4.2 VARIABLE CAPACITORS

In comparison with their resistive counterparts, variable capacitors are much less common. Unlike variable resistors, though, the term *variable capacitor* really *does* mean that the capacitance itself is variable; you cannot attach a slider to a capacitor to vary a fixed capacitance take-off point. Variable capacitors are available in both preset (trimmer) and fully variable forms, but the values tend to be small (less than 1000pF). Typical applications include the tuning of RF (radio frequency) amplifiers, trimming of oscillator frequencies, and adjusting HF (high frequency) compensation.

Different forms of variable capacitor construction are used, with dielectrics which are either "solid" (plastic film), mica, ceramic material, or air. Variable capacitors are generally very reliable, although mechanical faults can occur with some of the cheaper solid dielectric types. Air-spaced variable capacitors can also be prone to problems through dust and other contaminants getting in between the interleaved plates. In earlier days, this type of capacitor was commonly used for tuning the reception frequency of radios; nowadays, they have been largely replaced by semiconductor devices whose capacitance value depends on the voltage applied to them, and which are known as *Varicap* or *tuning* diodes. Characteristics of the most commonly encountered variable capacitors are shown in Table 7.

	Air spaced	Ceramic	Plastic film
Range (pF)	5 to 500	2 to 200	10 to 750
Tolerance (%)	10	20	10
Voltage (DC)	250V to 1kV	63V	63V to 150V
Stability	Excellent	Fair	Good
Applications	Transmitters, RF signal generators	Compensation, oscillator trimming	Radio tuning, oscillator trimming

Table 7. Characteristics of commonly encountered variable capacitors.

APPENDIX

When considering the basics of the various component groupings which make electronic circuits perform such “fabulous” functions, there is one very important concept which you should first understand. Nothing in practical electronics, *absolutely nothing*, is absolute! Components may be called resistors, but they may show some characteristics of capacitors and inductors; capacitors may be intended for use because of their capacity to store electrical charge, but they also have the characteristics of resistors and inductors; inductors inherently have resistance and capacitance; connecting wires, however long, straight or thick can all behave as resistors, capacitors and inductors; insulators can become conductors; on/off switches may turn out to be pulse generators; relays may become voltage generators. Things are not always as they seem.

BUT, let it be STRESSED LOUDLY that in your early-ish days of doing and learning about electronics, such complexities need not necessarily concern you. There are countless types of circuit which you can dream up, build and get working whilst paying attention to only a few basic and really *very simple* rules. Some of what is said in *The Modern Electronics Manual* may make you think that electronics is too complex a subject to be within your grasp. Don't believe it! Anyone with a logical mind and a bit of dexterity with tools can do electronics, and achieve good results. And you must already know that you have these two attributes or you would not be reading this text.

For many of the design and constructional avenues open to you, you do not *have* to consider all the complexities that can occur in other more sophisticated designs. Where complexities are mentioned, they are outlined so that you are aware that they exist, not because you must always consider them. Once you become a bit more familiar with electronics, it is likely that you will take the complexities in your stride. Learn a few rules now, practice them, get to know them, *then* move on to learning more complex matters.

Time is relatively pointless

A further concept to appreciate in electronics, is that *nothing happens instantaneously*; everything takes a certain length of time to change from one state to another, whether it is a switch changing from on to off, or a voltage changing from one level to another, or just a fuse “blowing.” It may seem that the switch is either open or closed, contacts either apart or touching, and at a molecular level this is true, but the physical nature of a switch means that because of the broad area of its conducting contacts, there is a period during switching off, for example, when the area of each contact which is actually touching the other is changing progressively from full-area contact to point contact, and only at the very final moment is the ultimate point contact broken. During this period, the resistance between the contacts increases to the current flowing between them, and even at the moment when the physical point contact *is* broken, an electrical arc might be formed between the two open points, allowing current to still flow across them until they are even further apart. So much for the instantaneous nature of an on-off switch!

In digital electronic circuits, it is customary to think of the logic gates involved as responding to an *instantaneous* change from, say, logic 0 to logic 1 (from a low voltage to a high one). No such immediate change takes place, it takes time for the change to occur and there is a constant gradient through which the actual voltage level has to pass; it does not just suddenly jump from 0V to 5V, for example. The time taken to make the transition may be short, possibly only fractions of a millionth of a second, but it still exists and the concept of synchronicity – two things occurring at the same moment – is only a convenience when working out the logic of a digital circuit. In reality, the synchronization of various actions taking place in order to create a further change is related to a “window” in time, during which all the required changes can occur at their own separate rates. The window could be a mere picosecond, it could be half of eternity; how it matters depends on what the circuit is required to do, and as long as all those changes happen while the window is “open,” the circuit will behave as though they had all occurred at the same moment. But, if any of them occur outside the window, the result may be unpredictable and undesirable.