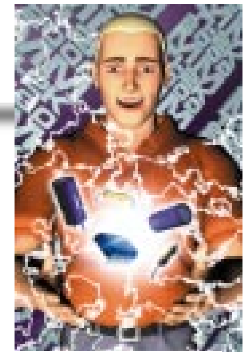
TEACH-IN 2000



PART One - Introduction

by JOHN BECKER

Hi there! What we propose to do during this 10-part *Teach-In* 2000 series is to lead you through the fascinating maze of what electronics is all about! We shall assume that you know nothing about the subject, and so shall take individual components and concepts in simple steps and show you, with lots of examples, what you can achieve, and without it taxing your brain too much!

Through these simple steps we hope to prove to you that using electronic components need not be a complex task and that, providing you think about each stage of what you are trying to create, you can actually design and build something that works!

In this introductory section, we explain our approach to the subject, the things you need to buy, and then lay down a few simple ground rules.

Much of electronics is about building blocks, and once you have understood what some of the primary building blocks can do and why they can do it, these blocks can be combined in many different ways to achieve increasingly more sophisticated goals.

To assist you in getting to know about the various building blocks, a set of illustrative computer programs has been prepared. We believe these to be capable of running on any comparatively recent PC-compatible computer (from Windows 3.1 upwards), provided that it is capable of downloading the programs from the *EPE Online* web site. It should have a color monitor.

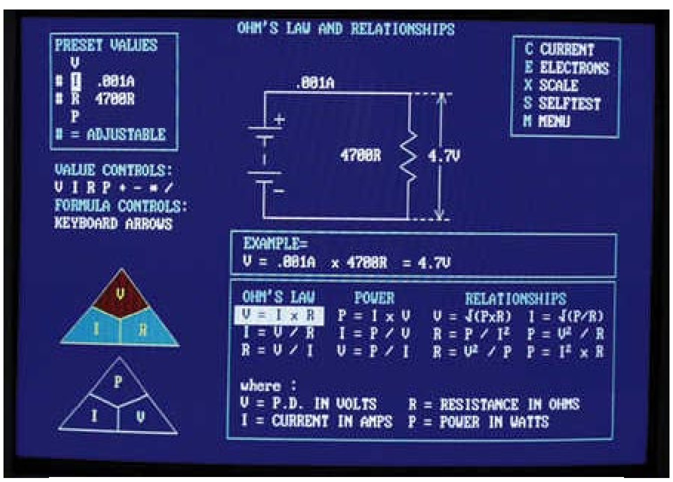


Photo.1.1. Ohm's Law interactive screen (discussed in Part 3).

SOFT APPROACH

We stress, though, that it is not necessary to run our programs in order to gain benefit from following this *Teach-In* series. Whilst you will not gain full benefit without running the programs, the series is structured such that it can still be studied profitably even if you don't have access to a PC-compatible computer.

At present, programs are available to accompany the first few parts of this ten part series. Others are in preparation and will be available later on in the series. The software may be downloaded for free from the *EPE Online Library* at **www.epemag.com**

To install the software on your computer, follow the instructions provided in the TEACH2K.TXT text file that accompanies the programs. This can be read using DOS EDIT or through any normal word-processing software (including Windows Notepad and Notebook).

The *Teach-In* 2000 programs not only illustrate particular electronics concepts discussed in each Tutorial part, but also offer you interactive involvement, with the ability to specify your own component values. Self-test and experimental exercises are included, to really let you get to grips with understanding this fascinating technology.

In future parts, the software will additionally allow you to use your computer as an item of test equipment, allowing you to input data from both analog and digital circuits, displaying it as meaningful screen data and/or waveforms.

This facility will be of great benefit to you long after you have learned the information offered during the series.

COVERAGE

The subjects to be covered include (amongst other things) facts and equations for using resistors, capacitors, potentiometers, diodes, light emitting diodes, transistors, logic gates, other digital circuits, operational amplifiers, liquid crystal displays, signal waveforms, Ohm's Law and its derivatives, binary and hexadecimal logic, analog to digital conversion, digital to analog conversion, computer interfacing, timing calculations, frequency generation, frequency counting, and simple audio amplifying, to name but a few of the wide array of subjects to be featured.

The series is not directly related to any formal courses or qualifications on electronics, but is based around those subjects that the author has found to be most important during several decades of involvement in electronics, both professionally and as a hobbyist. It should appeal to anyone of any age who wants to get to know what electronics is all about, and to put it to good use.

JUST PLUG IN

The vast majority of the *Teach-In* exercises and experiments are carried out on a plug-in breadboard, and use a 6V battery as the power source. You do not need a soldering

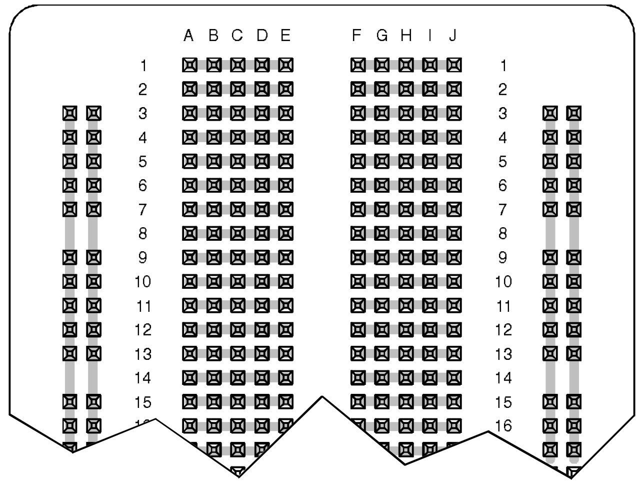


Fig.1.1. Arrangement and interconnection of the breadboard strips. Note that the outer strips between 31 and 34 are not connected.

iron for the first several parts of *Teach-In*. However, later in the series, some of the circuits discussed will benefit from construction on a printed circuit board allowing their long-term use as items of test equipment. For these constructions a soldering iron will be needed.

Although this *Teach-In* will not instruct you in soldering techniques, we have available the excellent and highly-acclaimed *Basic Soldering Guide* by Alan Winstanley, which will tell you all you need to know – it also is obtainable from the *EPE Online Library* at **www.epemag.com**

WHAT YOU NEED

There are two groups of items you need, comprising hardware and the electronic components themselves. You should get many years of value out of them!

Some of our suppliers are putting together special *Teach-In* packs and readers should check out the **Shoptalk** page.

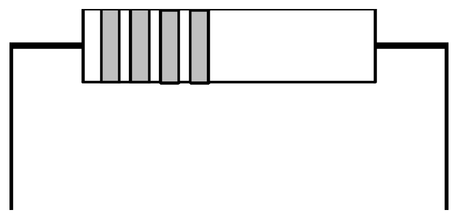


Fig.1.2. Example of trimming and shaping resistor wires to fit into the breadboard.

QUANTITIES

The quantities and values of components we suggest are not only sufficient to allow you to perform the wide variety of experiments we discuss, but will also result in a good "spares" collection for future long-term use. Go for larger quantities than those given for resistors and capacitors if funds permit (say 10 of each, for example). Where no quantity is stated, only one item is required.

With regard to resistors and capacitors, if you can buy a "bumper bundle" of mixed values do so, but do ensure that they are of reasonable size suited to breadboard use at a minimum of 10 volts (and that they are of good quality). They should include the majority of the values listed (and possibly other values

WHAT YOU NEED – *Basic Items*

- o) Digital multimeter, preferably a good one, but even a cheap one will allow you to perform all the tests we ask you to do during the series. It is recommended that if you can, you should buy one which not only has test probes, but also test leads with clips on one end, allowing the leads to be clipped onto component wires and legs.

  If you cannot obtain clipped leads, you can easily make your own using two 0·5 meter lengths of extra-flexible wire, to which you connect miniature insulated crocodile clips at one end, and 4mm plugs at the other (or to suit meter). The colors should be red and black.

  Battery connection leads can be similarly made, to the same length, with insulated crocodile clips at each end.
- o) Plug-in breadboard, 64 holes long, 14 holes wide, basic hole spacing (pitch) 0·1-inch (2·54mm) – see Photo 1.2.
- o) Heavy duty 6V (volts) battery, with spring terminals – see Photo 1.2. Do not use any battery that has a different stated voltage (e.g. a 9V battery **MUST NOT** be used).
- o) Solid core connecting wire, approximately 22s.w.g. core diameter, one small reel (preferably plastic coated, any color, but may be “naked”).
- o) Wire cutters (for cutting component leads and connecting wires).
- o) Wire stripper for small diameter plastic-insulated wires (typically size 1·2mm diameter).
- o) Small electrical (insulated) screw driver (blade tip about 3mm wide).
- o) Small thin-nosed pliers, insulated handles.
- o) Extra-flexible stranded plastic covered wire (approx. 2mm diameter), 2 meters each of red and black (or green).
- o) Miniature crocodile clips, insulated covering, preferably with screw terminals to which extra-flexible wire can be secured (they will otherwise need soldering), 10 off (some for future use).
- o) 4mm plugs (optional, see multimeter note above), one each of red and black, preferably with screw terminals.
- o) 1mm terminal pins, double-sided – a handful (see text).
- o) 1mm pin headers (say 5 strips, each about 20 pins).
- o) Miniature soldering iron, mains powered, 15W, bevel tip approx. 3mm wide.
- o) Solder, multi-core, 22s.w.g.

as well). Avoid resistors that are rated for 1 watt or greater since their size may be too great.

Whilst you may not understand the values listed (although you will soon do so!), your component supplier will if you just present the list to him.

BREADBOARD CONSTRUCTION

You will see that the holes in the breadboard are arranged in groups of five. Beneath the holes are miniature electrical clips. All five clips in a group are electrically connected and all groups are electrically isolated from each other (with the exception of the two parallel strips to either side of the board). The arrangement is shown schematically in Fig.1.1.

Components are plugged into and between the clip groups so that they become interconnected in a specific electrical configuration, as required so that they perform a particular function when electrical power is applied. Examples are shown in Photo 1.2.

Components are usually supplied with connecting wires that are far longer than required (especially resistors and capacitors). Prior to plugging a component into the breadboard, we suggest that you cut the wires to a length of about 1·5 centimeters away from the component’s body.

This should allow you to easily handle the components, yet avoid the possibility of extra long wires adversely touching the leads of other components. The length should also allow test leads to be clipped onto the component wires.

You will need to bend the leads of some components (resistors and diodes in particular) so that they plug into the board. This is illustrated in Fig.1.2. Make the bend just fractionally away from the body of the component, especially the diodes, which often have a glass body that may fracture if subjected to stress when leads

WHAT YOU NEED – *Electronic Components*

o) **Resistors**

47W, 100W, 220W, 470W, 1k, 2k2, 4k7, 10k, 22k, 47k, 100k, 220k, 470k, 1M, 2M2, 4M7, 10M (say 5 off each).

All values rated at 0·25W (or 0·33W) 5% carbon film.

o) **Capacitors**

10p, 22p, 47p, 100p, 220p, 470p (say 5 off each).

All miniature polystyrene or ceramic (disc or plate).

1n, 2n, 4n7, 10n, 22n, 47n, 100n, 220n, 470n (say 5 off each). All miniature ceramic (disc or plate).

1m, 2m2, 4m7, 10m, 22m, 47m, 100m, 220m, 470m, 1000m, 2200m (say 5 off each up to 100m, 2 off each 220m and above). All electrolytic, radial mounting.

All capacitors should have a minimum working voltage rating of 10V (a higher voltage rating is acceptable providing the size of the component is not too great – component suppliers' catalogues should quote the physical size of capacitors in relation to their capacitance values and voltage ratings).

o) **Preset Potentiometers**

100W, 470W, 1k, 4k7, 10k, 47k, 100k, 470k, 1M (say 2 off each). Miniature round, enclosed, horizontal, printed circuit board mounting.

o) **Control Potentiometers**

100k linear, 100k logarithmic. Panel mounting, "standard'' diameter mounting bush and spindle, preferably plastic spindle (without switch).

o) **Semiconductors**

Red light emitting diode (l.e.d.), about 5mm diameter (say 10 off)

74HC04 CMOS hex inverter gate (2 off)

74HC14 CMOS hex Schmitt inverter gate (2 off)

o) **Miscellaneous**

ORP12 (or NORP12) light dependent resistor (l.d.r.)

10k thermistor (n.t.c. type)

are bent. Thin-nosed pliers are useful to help form the bend.

Components may also be linked to others using short lengths of the solid-core wire specified in the *What You Need* sidebar (the cut-off wires of components can often be used for the same purpose). Cut the length you need and then trim off the insulation (if present) to a length of about 1cm, using the wire strippers. Thin-nosed pliers can shape the wire as required for plugging in, but you may simply bend the wire by hand if you are just making experimental links.

If you are using uninsulated solid-core wire, ensure that it does not adversely contact other components.

Short lengths of solid-core wire may also be inserted in the board to assist in the connection of power/meter leads and their clips. A better option is to use the double-sided 1mm terminal pins listed earlier.

ELECTRICAL POWER

Two terms that will be used frequently in this series are voltage and current. Their units of measurement are volts and amps. Sub-units of measurement are also used, which will be defined in due course.

To explain the nature of electrical power would take us into atomic physics, which we have no intention of exploring. However, we can simply explain the concepts of the terms by using a time-honored analogy:

Imagine a water tank with a hole in its base. We are sure you know that water will flow out through the hole at a rate depending on the fullness of the tank and the size of the hole.

The greater the pressure of the water, the faster that it will flow through the hole. The pressure depends on the height of the water above the hole. The volume of water that flows through the hole depends on its diameter. In electrical terms, the "height" is expressed in "volts", the volume of flow is expressed in "amps".

There is an allied third term, watts, which expresses the amount of power that flows in respect of given values for volts and amps (it is the result of the two values multiplied together).

It is important to be aware that electronic components will only accept voltage, current, and power flow within specified limits. These limits vary between component types and

WHAT YOU NEED – *Electronic Components cont*

A few other components will be called for in later parts of the series (but not before Part 4). Amongst them will be:

- o) 1N4148 signal diode (say 10 off)
- o) 1N4001 rectifier diode (say 5 off)
- o) BC549 (or 2N3704) npn transistor (say 5 off)
- o) BC559 (or 2N3702) pnp transistor (say 5 off)
- o) LM358 dual opamp (say 3 off)
- o) 74HC00 CMOS quad 2-input NAND gate
- o) 74HC02 CMOS quad 2-input NOR gate
- o) 74HC08 CMOS quad 2-input AND gate
- o) 74HC32 CMOS quad 2-input OR gate
- o) 74HC86 CMOS quad 2-input XOR gate
- o) 74HC4017 CMOS decade counter
- o) 74HC4024 CMOS 7-stage binary ripple counter
- o) TLC549 analog-to-digital converter
- o) DAC0800 digital-to-analog converter
- o) Miniature active buzzer
- o) Low-cost pair of high impedance personal headphones
- o) Miniature jack socket to suit personal headphones
- o) Miniature electret insert microphone
- o) 36-way Centronics female parallel printer port connector (PCB mounting, and for which a PCB will become available)

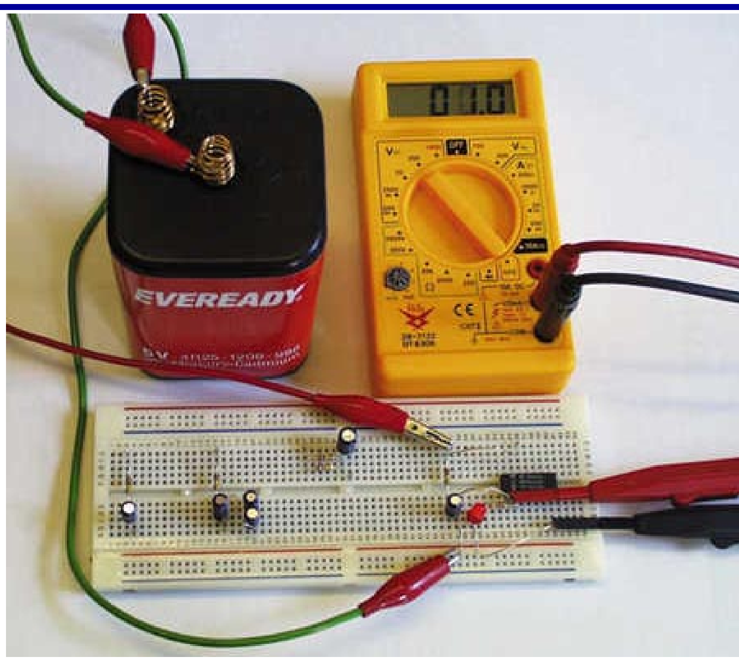


Photo.1.2. Examining one of the breadboard experiments in Part 2.

must not be exceeded (although there is usually a fairly wide margin of excess that they will tolerate for short periods).

All this will become much clearer as we progress through the series. Refer now to the first Tutorial, and let's start exploring electronics!

TEACH-IN 2000 – TUTORIAL 1

COLOR CODES AND RESISTORS

Rightly or wrongly, we are going to assume that you don't yet know what component types look like. No doubt we're wrong – but we've got to start somewhere!

Once it's arrived through your letterbox, within that bag of components you've bought for this *Teach-In* series (as recommended in the *What You Need* sidebars) will be some that look like those in Photo 1.3.

The component on the left is a light-emitting diode (LED), a resistor (having four colored bands) is in the center. The right-hand component is an electrolytic capacitor (to be discussed in Part 2).

LED BY THE LIGHT

Find a red LED, plus a resistor whose bands are colored yellow, violet, brown, and gold, in that order. Plug them into your breadboard as shown in Fig.1.3, then clip the two power leads to your battery as shown in the Photo 1.4.

You will now see one of two situations – the LED is glowing

Photo.1.3. Left to right: Light-emitting diode, resistor, electrolytic capacitor.

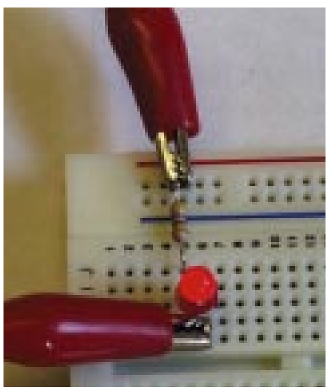


Photo.1.4. Power leads clipped to a LED and resistor experiment.

nicely ("turned on"), or it is not glowing at all! Disconnect the battery. Now unplug the LED, turn its leads round the other way and plug it back in. Connect the battery again. Whichever case was true first, the opposite should be true now.

This experiment with the LED is an example of the use of a semiconductor, a class of electronic component that has thousands of members in its enormous range of families, and which includes not only such simple items as LEDs, but also the highly sophisticated microprocessor that controls your computer.

What you have been shown is that semiconductors will (normally) only work in a circuit if they are connected to its power supply the correct way round. There are other components, too, which are equally dependent for their correct operation on being connected the "right" way round. We shall say more on this as we progress through the *Teach-In* series.

With the LED positioned in its "glowing" direction, and with the battery disconnected, unplug the resistor, turn it round and plug it back in. Reconnecting the battery, the LED should still glow. A simple second lesson, but just as important – resistors are components that are quite content to be connected either way round into a circuit.

What we have also implied through the above examples is that power supplies should always be disconnected or switched off before physical changes are made to any circuit. Always do this, even if we don't actually say so each time a change is suggested.

MARKED DIFFERENCE

Now find a resistor whose bands are brown, black, red, and gold, and another whose bands are red, red, brown, and gold.

In turn, plug these resistors into the board in place of the original one. What do you observe with each of them? The LED glows less brightly with the brown, black, red, and gold resistor, but glows much more brightly with the red, red, brown, and gold one. Now try a brown, black, yellow, and gold resistor – no glow at all!

Why the difference in LED response to components that look the same physically? Well, that is the aim of this *Teach-In* – to tell you about not just resistors, but other important types of components as well, in such a way that you understand how they behave and how you can use them to perform meaningful tasks in circuits of your own invention.

The lesson you should learn from this last experiment is that components may look alike, but identifying marks (in this case colored bands, but they may be numbers and letters in other instances) are vitally important – they state a component's "value".

What that information conveys depends on the component type involved, but in the case of resistors (whose nature will be explained more fully later) it states the amount of "resistance" that they offer to electrical current when it flows through them.

Each of the three resistors

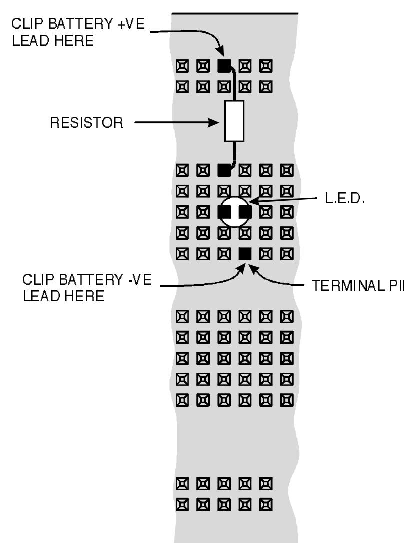


Fig.1.3. Component positions and battery lead connections for the LED and resistor experiment.

you've just used have different amounts of resistance, and the color code (once you know how to read it) tells you that value. The observed response of the LED depends on the voltage applied to it and the amount of resistance that the voltage has to flow through. We shall presently look at resistors in detail, but first let's examine color codes.

BASIC COLOUR CODES

Whilst resistors are a prime example of components that are likely to be color coded, others such as capacitors, diodes, inductors, transformers, ribbon cables, connecting wires, and plugs and sockets often use them as well, although perhaps not quite so widely.

Consequently, one of the most important skills that any would-be electronics constructor should acquire is the ability to correctly read color codes.

First, then, let's help you to become familiar with the basic color codes and the numbers that they represent. The way in which groups of colors are interpreted on the components themselves will be described when we discuss those items. The 10 basic colors are allocated as in Table 1.1. As we shall reveal later, however, they are not the only colors available, although the remainder are not used in the same way.

We have set up a simple computer program, which will help you to learn these color codes and their values, and to prove to yourself that you do actually remember them.

Run the *Teach-In* software program and select *Menu Basic Color Codes*. In the middle of the screen you will see the 10 color codes, not only numbered and named as in Table 1.1, but also with their colors alongside them. Do be aware, though, that the limits of the computer screen prevent the colors from appearing in exactly the same hues as you might see on actual components.

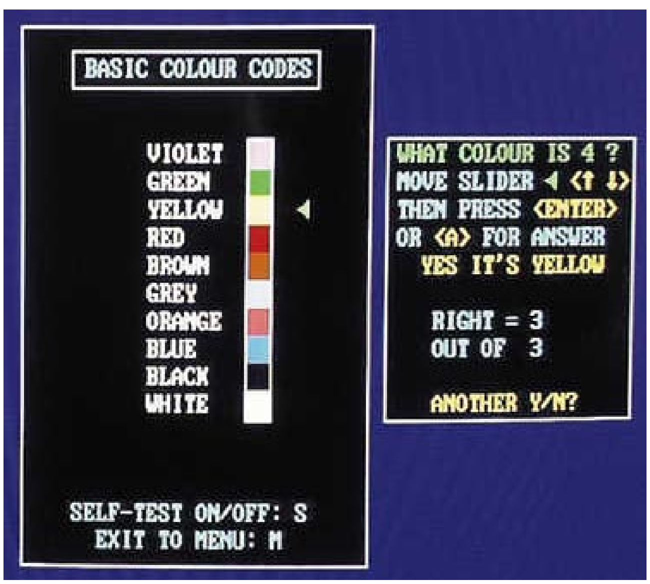


Photo.1.5. Section of the computer program display that invites you to test your knowledge of color codes.

It has to be said, however, that there is no full standardization on the exact hue that might be printed on components by their manufacturers – they seem to take very wide artistic license on occasions. It's not uncommon, for instance, that it may be difficult sometimes to differentiate between one manufacturer's red, and another's orange.

Table 1.1. Basic color codes used in electronics.

Color	Coded Number
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

However, what you see on the screen (your computer being satisfactorily set-up, of course – and not driving a black and white monitor!), should be sufficient to get you well acquainted with color codes.

Press <S> to select Self-Test On/Off. A "questions" box appears to the right of the colors display (Photo 1.5), and the color order in the main box changes and the values disappear. Your task is to use the cursor arrows to select the color whose number is given in the question.

A random number generator variously selects questions on colors and values. Correct answers earn you points. So give yourself a test!

Pressing <A> provides the answer if you want it, and <S> re-displays the correct color code sequence and its numbers. Pressing <M> returns you to the main menu.

RESISTORS

With basic color codes under your belt (or at least on visual display demand if necessary), let's see how they apply to one particular group of components, resistors.

But, we ask ourselves back at Editorial HQ, do you who are reading this actually know what a resistor is? Perhaps not, even though you've just been using some, so perhaps we should explain matters (and apologize to those of you who do know for taking up your time – but why not read it anyway, you might be reminded of something you've forgotten).

It's inevitable, of course, that in explaining resistors we have to use some terms which you might not be familiar with yet. Such terms will be covered as we progress through the *Teach-In* series, and we expect that eventually you will want to re-read the series from the beginning, at which time things will begin to slot more firmly into place if they haven't already.

BLOW THAT WORM!

Let's give you an analogy about resistance (no, not using water this time). You can be the pushing power instead of the weight of a tank of water.

Take a deep breath and see how easily you can blow it all out again. Not very hard is it? What about if you try to blow it out through a tube, a bit of garden hose? Slightly easier once you've blown out the worms, but still quite hard. Now do it through a drinking straw – really hard, and you probably fail to breath out fully before you need to take another breath.

So what is it that makes the ease of blowing out so different between the three methods? Yes, its the diameter of the hole you are blowing through – big cake hole (!), medium pipe hole (smaller with the worm at home!), small straw hole; and

Photo.1.6. Resistor values and color codes displayed on the interactive computer screen.

what are the holes doing to the flow of air as you breath out? They are resisting it!

In electronics, a similar situation can be said to apply to the way that electrical current flows out from a battery (say) – the amount by which it flows in a given period of time is relative to the "hole size" of the object through which it flows, i.e. to the resistance that the object offers to the electrical current. Although, of course, resistors don't actually have holes in them, unless someone's been malicious!

THE OHMS HAVE IT

As you will discover in due course, everything offers

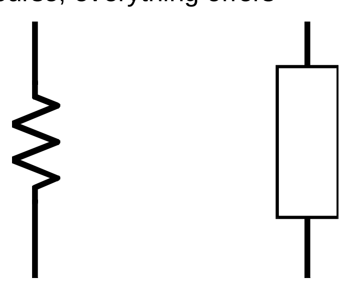


Fig.1.4. The symbols commonly used to represent a resistor.

different amounts of resistance to electrical current flow, from almost utterly-totally-nil to almost absolutely-never-to-be-penetrated total refusal.

Any material that permits an electrical current to flow through it is known as a conductor. But, all conductors, however good, try to resist the electricity 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's still there.

Conversely, some materials have a resistance to electrical current flow that 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.

The amount of resistance 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, Ω. However, you may often see capital R used in place of Ω since not all typing equipment can produce an Ω symbol! (Not all computers have the symbol either – the *Teach-In* software uses the term ohm (or capital R) rather the symbol Ω to keep it compatible with readers' different system types.)

It might be said that the whole function of electronics as a technology is to control the rate and amount by which electrical current flows from one place to another. Generally speaking, while the current is flowing, it is expected to actively do some work: drive the loudspeaker that shatters your hearing, create that enthralling games display on your computer screen, cook your microwave snack for the correct time (sometimes!), and so on.

There are, though, some components that are manufactured to control the electrical flow in a passive and far less dramatic fashion. Amongst them are the group which are actually named for their ability to resist the flow, resistors. It's astonishing what can be achieved by something that just resists when it is used in conjunction with something else that inhibits or encourages electrical flow.

The purpose of resistors, then, is to passively limit or set the flow of current through a particular path in an electrical circuit. It is reasonable to say that, however complex the circuit in which they are used may appear, this is their primary function.

There are 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.

You will encounter two symbols used in electronics to represent a resistor in circuit diagrams. They are shown in Fig.1.4. The zig-zag symbol is the one on which we at *EPE* and *EPE Online* have standardized, inheriting it from the original publishers of *EE* and *PE* before the merger, IPC Magazines, who first introduced many of the UK's leading electronics publications. The symbol's history dates well back to earlier years of the 20th Century, and could even be older, maybe Georg Ohm invented it.

In circuit diagrams and constructional charts, a resistor's numerical identity is usually prefixed by 'R', e.g. R15.

Since most resistors you are likely to encounter will have their values shown as colored bands, we'll discuss those next.

RESISTOR COLOUR CODE PROGRAM

We've set up a computer program that illustrates how the values for resistors are expressed in ohms and how those values are shown as color codes. So, from the software's main menu, select *Resistor Values and Color Codes*.

There is a great deal of useful information available to you from this facility. Primarily, you have the main color codes that you examined (and learned, we hope) in menu selection 1 (see Photo 1.6). Above it are two additional colors which, had the screen been capable of it, would be seen as silver and gold, but we have to make the best of using their names plus colors of gray and yellow to represent them.

Horizontally near the bottom is the representation of a resistor having four color bands. Looking vertically above these bands you will see four arrows, three pointing left and one pointing right. The arrows point to the same colors that you see in the resistor bands below them. These arrows are under your control using the keyboard cursor keys, up, down, left, right. Try them.

MEET THE BANDS

While moving the arrows, you will see that the details at the top right of the screen change as well. You should begin to recognize a pattern in the *Resistance Value* number in relation to the arrow positions and associated color numbers. Let's explain it.

Most resistors that you will be required to use in your early days of learning about electronics are likely to have four colored bands. The bands are read from left to right, with the resistor facing in the direction as shown on-screen – the color group to your left. They are named in left to right order as Bands 1, 2, 3 and 4. (Band 4 may be further to the right on some resistors.) Also see Fig.1.5a.

Bands 1 and 2 provide the first two digits of a resistor's value, and Band 3 provides a multiplying value (shown in decimal on the left of the screen) which is applied to the basic value. The number of zeros for each multiplying factor is the same as the number of the color code that represents it, e.g. blue

= six zeros = a multiplying factor of 1,000,000 (1 million).

You will also notice that there are multipliers of 0·1 and 0·01, represented by gold and silver bands respectively (if only the screen could show it better!).

Resistance values below 1,000 are shown in units of ohms, they are then shown in kilohms until 1,000,000, when they are expressed in megohms. There is also a third term which you may encounter, giga – 1000 million times, e.g. gigohms.

While you are using the arrows to get the hang of the color banding system, also look at the Nearest E24 Value at the top right of the screen. You will see that it does not always follow the Resistance Value answer. This is not because the answer is wrong, but is because that particular value is not manufactured in the range known as the E24 Range (see *Panel 1 – Resistance Ranges*).

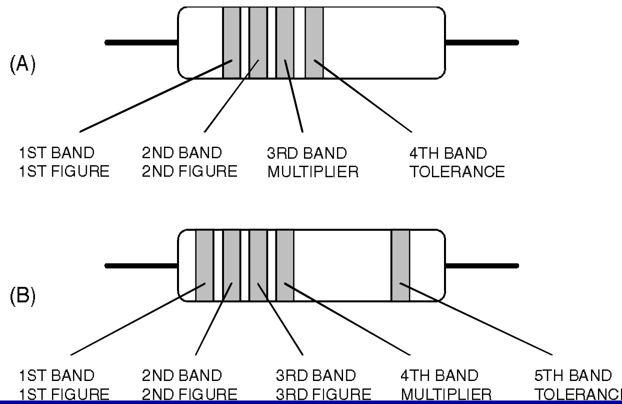
Apart from using the arrows to set the values, there is another way to set them using the arithmetic keys, + - * /. Try them and watch how not only do the numeric values change, but the arrow positions and the colored bands on the resistor as well.

RESISTOR CODES SELF-TEST

Pressing <S> clears a fair bit information from the screen leaving you with a color chart, some arrow positions, a colored resistor, and randomly selected questions to answer.

Pressing <A> or <ENTER> provides the answer, <S> returns the full screen information, and <M> returns

Fig.1.5. Resistors having four colored bands are those you will normally encounter, but 5-banded resistors also exist.



PANEL 1 – *Resistance Ranges*

If you count all the E24 answers given by the computer display for all the Resistance Values between, say, 10 and 99, you will find that there are 24 of them, which is what E24 means – 24 values to the multiplier decade.

There are other ranges manufactured as well: E6, E12, E48, E96, for example, each having the number of values per decade as indicated by the "E" value.

Standard resistor values within the ranges may at first sight seem to be strangely numbered. There is, though, a simple logic behind them, and it is to do with the tolerance ranges available.

In fact, there's not really very much to the concept of tolerance: it's just that when anything is manufactured in quantity, it is expensive to ensure that every single aspect of each and every individual is absolutely identical. Nor is it necessary in many applications that absolute identical-ness should be achieved – some situations can accept wider variations than others, i.e. they are more tolerant. Where a wider tolerance can be accepted, so the manufacturer can produce the product more cheaply.

PERCENTAGES

With resistors, for example, values can be categorized as being within so-many percent of the nominal value, within ten percent of it for example, which would be expressed as ± 10% (or, somewhat loosely, just as 10%). In other words, a resistor said to be 100 ohms ± 10% could have an actual value that is 10% above or 10% below 100 ohms – i.e. from 90 ohms to 110 ohms. A 100 ohms 1% resistor, though, could have an actual value of between 99 ohms and 101 ohms – but it will cost more than the 10% type. As a constructor, you will normally use 5% resistors.

The "E" series values are based on 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

You probably noticed a sequence like this when using the arrows and other controls on the screen.

As another example, 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 an E 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 (2Ω2), 22, 220, 2200 (2k2), 22000 (22k), 220000 (220k), 2200000 (2M2)

WITHOUT A POINT

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 Ω, k and M. This is another answer to a typing 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 and parts lists (and on the components themselves when color coding is not used).

These value series apply not only to resistors, but to capacitors and inductors as well. For the latter components, µ (micro), n (nano), p (pico) may be used in place of the decimal point, e.g. 2µ2, 2n2, 2p2.

DISPLAY RANGE

Now you will understand why the E24 value on your computer display does not necessarily tie in with the Resistance Value. We could have programmed the software for other ranges too but, frankly, for most of what you are likely to design or construct, the E24 series is going to be the principal one you use. As far as this Teach-In is concerned, we specified resistors having only three values to the decade, 1, 2·2, 4·7. This was to keep down the cost, but other values will find their uses in other applications.

You should now also understand the other three (middle) lines of the top right group in the computer display for resistor values – Resistance Min-Max and Spread. The use of arrow 4 should now be apparent, it lets the program select and calculate the tolerance factors without you troubling your pocket calculator.

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the main menu.

MORE ON RESISTOR CODES

Up to a resistance tolerance of 1% and a power rating of one watt (tolerance is discussed in moment – and power factors another time), resistors are labeled in the color coded fashion you've just been examining. From 0·5% tolerance and two watts 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 (we specified 5% for those you have bought), and will have four colored bands as we've shown, although the fourth band may be further away from the other bands than is shown on your screen.

As a re-cap away from the computer, the colors used on the four-band resistors we've been discussing are summarized in Table 1.2. The codes have been established by international agreement.

Table 1.2. Color codes for resistors.

Color	Figure	Multiplier	Tolerance
Silver	--	0.01 ohms	10%
Gold	--	0.1 ohms	5%
Black	0	1 ohm	--
Brown	1	10 ohms	1%
Red	2	100 ohms	2%
Orange	3	1k ohms	--
Yellow	4	10k ohms	--
Green	5	100k ohms	0.5%
Blue	6	1M ohms	0.25%
Violet	7	10M ohms	0.1%
Gray	8	100M ohms	--
White	9	--	--

Life can get a bit more complicated though – color coded resistors of 2% or less may have more than four bands, such as the example shown in Fig.1.5b. So let's briefly compare the way in which four and five banded resistors are "decoded".

Noting the way in which the resistors are shown in Fig.1.5a, and reading from left to right, the four band example is interpreted as:

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 = 1kΩ , with a tolerance factor of 5%.

By comparison, the five band example is interpreted as:

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 × 10^0 = 240Ω , with a tolerance factor of 2%.

Examples of the way in which resistors have their value printed on them in figures instead of colors are given in Table 1.3, which shows the internationally recognized coding.

Observe in Table 1.3a 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 commonly used in circuit diagrams and parts lists 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). Binary numbers will be discussed (and actively illustrated on the computer) in a future part of *Teach-In*.

Table 1.3a. Example labeling of resistors in figures.

Figure		Code
0.10	ohms	R10
0.33	ohms	R33
1.0	ohms	1R0
1.33	ohms	1R33
10.1	ohms	10R1
100	ohms	100R
1	kilohms	1K0
10	kilohms	10K
100	kilohms	100K
1.0	megohms	1M0
10	megohms	10M
100	megohms	100M
1	gigohms	1G0

Table 1.3b. A further letter is then appended to indicate

Letter	Tolerance
F	+/- 1%
G	+/- 2%
J	+/- 5%
K	+/- 10%
M	+/- 20%

RESISTOR QUALITIES

You have discovered that resistors allow current to flow in either direction and offer the same amount of resistance to it in whichever direction it flows. In other words, the resistance value of a resistor is supposedly fixed during manufacture – within the tolerance factor discussed in Panel 1.

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

PANEL 2 – *Resistor Facts*

In manufacturers' data sheets, several parameters will be quoted about the nature of a particular type of resistor. One factor that 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.

The principal parameters for a resistor are:

o) Resistance value, which may be expressed in ohms (Ω), thousands of ohms (kilohms or just kΩ, or sometimes KΩ) or millions of ohms (megohms or MΩ)

o) Power rating in watts (W)

o) Resistance tolerance, expressed as a percentage of its set value, e.g. ±5%

o) 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).

The significance of a resistor's power rating and temperature coefficient will be discussed in another part of Teach-In.

Some common types of resistor are:

o) Carbon film/ceramic: normal requirements

o) Carbon film/ceramic: increased demands

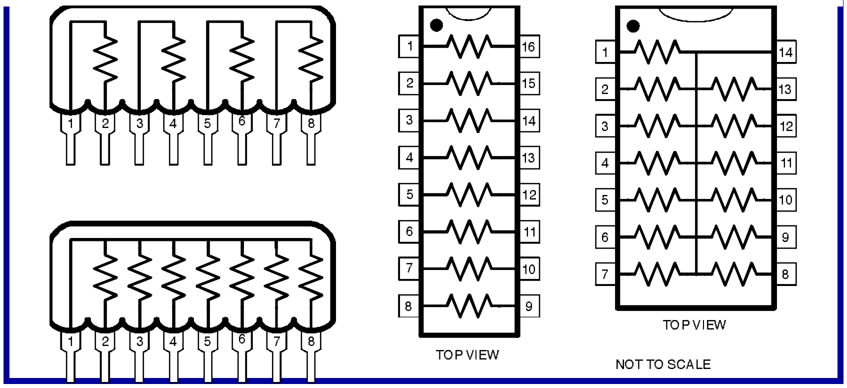
o) Carbon film/ceramic: precision resistors

o) Carbon film/ceramic: low drift/high reliability

o) Metal oxide film: heat resistant to 175°C

o) Wire-wound: different constructions for high loads and specialised applications

Carbon film resistors are those you are most likely to encounter in constructional projects, although metal oxide are not uncommon. 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 – discussed in other parts of this series). The internal arrangement of the resistors within the module may be several individual resistors, or a network configuration, as shown here.



given set of circumstances. Internal and external factors can affect the actual value of a resistor, such as the amount of heat to which it is subjcted, for example.

The way in which a resistor varies its "nominal" value depends on how it is manufactured, some information on which is given in Panel 2.

OTHER RESISTIVE COMPONENTS

We commented earlier that everything in nature has varying degrees of resistance to an electrical current, from practically nil to practically infinite. The resistors we have been discussing are just one class of component whose basic resistance is pretty well fixed. Not surprisingly, this class is more strictly referred as "fixed resistors".

There several other classes of resistive component, however, whose nature will be discussed in future parts of *Teach-In*. They include components whose resistance changes in response light level, temperature, voltage, humidity and pressure, and are known as sensor resistors.

Another group provides variable resistance according to the position of a movable contact. These components are usually known as potentiometers.

For this month, though, we've come to end of Tutorial 1. But we hope you will now turn to the Experimental article.

Next month we introduce you to capacitors, and what happens when they are connected to resistors – it's all to do with timing.

TEACH-IN 2000 – EXPERIMENTAL 1

MEASURING AND CALCULATING RESISTANCE

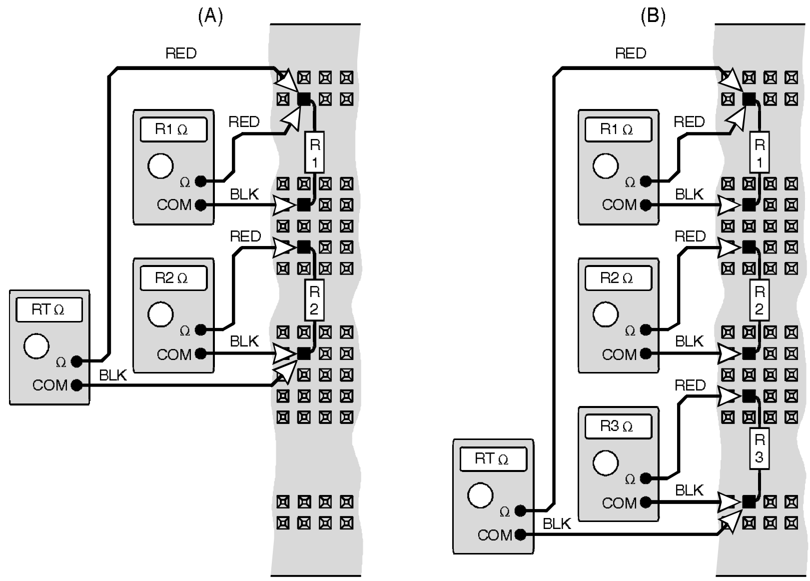


Fig.1.7. Measuring the resistance of two (a) and three (b) serially connected resistors.

In the *What You Need* sidebar at the beginning of this *Teach-In*, we said that you should acquire a digital multimeter. Here's your first opportunity to put it to use – measuring resistance.

Plug the black lead into the socket marked COM, and the red lead into the V-OHMS socket, and switch on. Switch to the highest OHMS range and clip the leads to either side of one of your resistors selected at random.

Now switch the OHMS range until a sensible-looking reading is shown on the meter's display. How does this value compare to that indicated by the color code on the resistor?

Express the difference between the actual reading and the coded value as a percentage, and satisfy yourself that the value is within the tolerance indicated by the tolerance band on the resistor.

Refer back to the *Color Codes* program if you've forgotten how the codes are interpreted.

Also satisfy yourself that you get the same reading whichever way round you connect the probes.

What you may find, however (and interestingly), is that the decimal places of the value may change if the temperature of the resistor changes between the readings. Try warming the resistor by holding its body in your fingers between one reading and another.

Check out a few more resistors for their coded and actual values. Indeed, if you've bought the mixed selection bag of resistors suggested in the Introduction, take this opportunity to sort them. Small press-to-close clear polythene bags are ideal to keep them in once categorized, with self-adhesive labels stating the enclosed value (the coded value, not the meter-read value).

You will thank yourself later for taking this trouble now. The sorting will also help to reinforce your immediate recognition of a resistor's value from its color code. It soon becomes instinctive for most common values (and what are common values? you may ask – that too you will soon get to know).

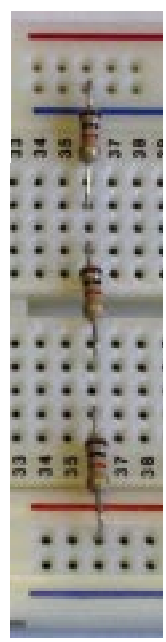


Photo.1.7. Three resistors connected in series on the breadboard.

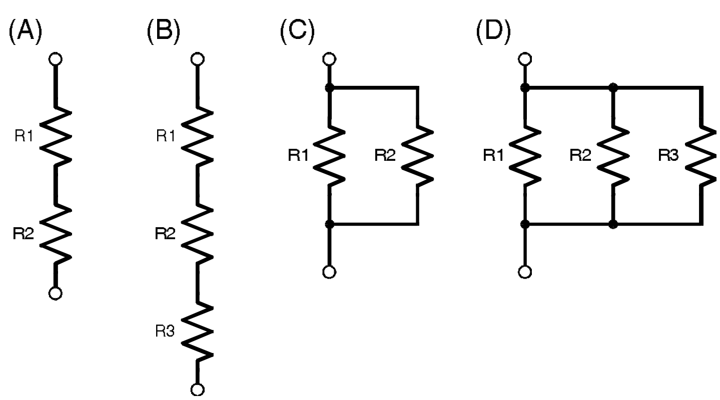


Fig.1.6. Examples of resistors connected in series (a and b) and in parallel (c and d).

RESISTORS IN SERIES

Two terms you will frequently encounter are *serial* and *parallel*. They describe how two or more components are joined together. Serial connection means a chain of components joined as shown in Fig.1.6a and Fig.1.6b. Parallel connection refers to the configurations in Fig.1.6c and Fig.1.6d.

It is frequently necessary to connect resistors together for a variety of reasons, and to be able to calculate a number of values that result from that connection. Let's take two resistors in series and see what we can establish from them. Select any two resistors of roughly adjacent values, e.g. 47kΩ and 100kΩ (call them R1 and R2), and plug them into your breadboard as shown in Fig.1.7a.

First measure the actual resistance of each resistor in turn, making a note of it. Then connect your meter probes to either end of the chain and note the reading. Add the two individual readings together and compare to the reading across the whole chain. How do the two results compare?

Yes, they are equal (within the accuracy with which you actually took the readings).

Add another resistor (call it R3) to the chain as shown in Fig.1.7b, another 100kΩ, for example. Measure the resistance across R3 and note it. Then measure the resistance across the whole chain. Now add the individual values of all three resistors together and compare with the total chain value. Yes, again the two are identical.

From this we can say that the total resistance across any quantity of resistors in series is equal to the sum of their individual values. In other words we can say that:

Total resistance = R1+R2+R3 … etc.

POTENTIAL DIVIDER

Let's now put battery power across some resistors in series and see what voltage we can find at their junctions. This configuration is known as a potential divider, because the potential (battery voltage in this case) is being divided by the resistors to produce the voltage at their junction.

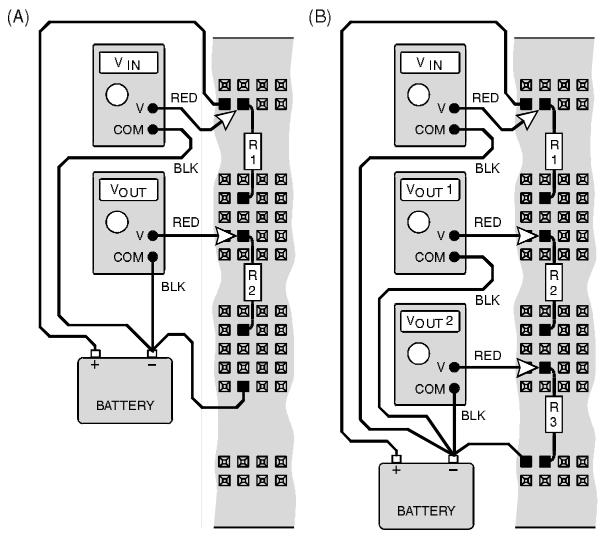


Fig.1.8. Measuring the voltages across two (a) and three (b) resistors in series.

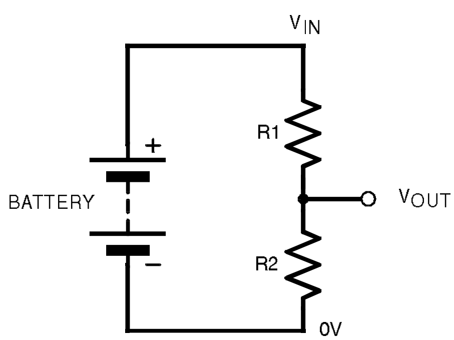


Fig.1.9. Equivalent circuit for two resistors in series across a power supply.

For starters, we'll examine two 10 kilohm resistors in series. Connect them and your 6V battery as shown in Fig.1.8a. The equivalent circuit diagram is shown in Fig.1.9. Insert 1mm pins (or short lengths of solid-core wire) into the positions shown in Fig.1.8 for the power connections, and then clip the power leads to these pins.

Switch your meter to the first range above 6V d.c. With the black lead on the battery's "–" (negative) terminal (call this point 0V – pronounced "nought-V") and the red one on its "+" (positive) terminal (call this point Vin – pronounced "V-in"), measure the actual voltage being supplied by the battery. For this discussion we will assume that it is exactly 6V.

With the black lead still on "–", touch the red lead to the junction of the two resistors (call this junction Vout –pronounced "V-out"). What voltage do you read at Vout? It should be half the battery voltage, 3V. Does this surprise you? It shouldn't because the reason is perfectly logical.

The two resistors have the same value and so the voltage drops equally across both of them. Vout is therefore half of Vin. This fact is true whenever two resistors of the same value are connected in series across a power supply. Substitute any other two resistors of the same value (say two 47 kilohm resistors) for the two 10 kilohm ones and check this out. Try it for other pairs as well.

RATIOS

What happens, though, when two resistors in a chain do not have the same value? Well, it's just a matter of ratios:

Referring to Fig.1.9, you take the value of the total resistance across both resistors (R1+R2), divide this value into that of the resistor at the bottom of the chain (R2), and then multiply the answer by the total voltage across both resistors (Vin). In other words, and referring to Fig.1.9, the calculation required can be summarized as:

Vout =
R2/(R1+R2) x Vin

In Fig.1.9, let's say R1 is 100kΩ and R2 is 47kΩ. The total resistance of R1+R2 is 147kΩ, we'll call this RT. We know that the battery voltage (Vin) is 6V, so we can say that the voltage at Vout can be expressed as:

Vout =
R2/RT x Vin

Substituting the known values, we get:

Vout =
47kΩ/147kΩ x 6V =
1·918367V

which is near enough equal to 1·9V.

With R1 and R2 (at the new values) inserted into your breadboard as shown in Fig.1.8a, check this out with your meter.

Supposing, though, you had three resistors in series, as in Fig.1.10, how do you calculate the voltages at junctions Vout1 and Vout2. Well, again it's very simple: RT becomes R1+R2+R3 and you write the formulae to read:

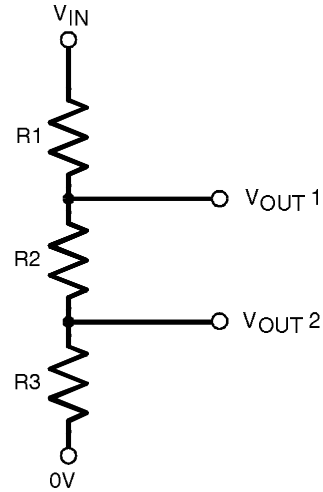


Fig.1.10. Equivalent circuit for three resistors in series across a power supply.

Vout1 =
(R2+R3)/RT x Vin

Vout2 =
R3/RT x Vin

or just:

Vout =
Rx/RT × Vin

where Rx is the total resistance of all the resistors in series below the junction whose voltage (Vout) you need to know. Check this out with any three resistors in your breadboard as in Fig.1.8.

We expect you will appreciate that this principle can be applied to any number of resistors in a serial chain – which observation suggests another experiment for you:

Chain as many resistors of whatever value you like and connect the battery across them. Now calculate the voltages you expect to find at each junction, and then use your meter to check the actual voltage against your calculation. (There is, though, a cautionary note later in this article – *Meter Resistance* – about the meter itself actually affecting the accuracy of the readings. If your voltage readings are not quite what you calculate, it may be the meter to blame, not your brains!)

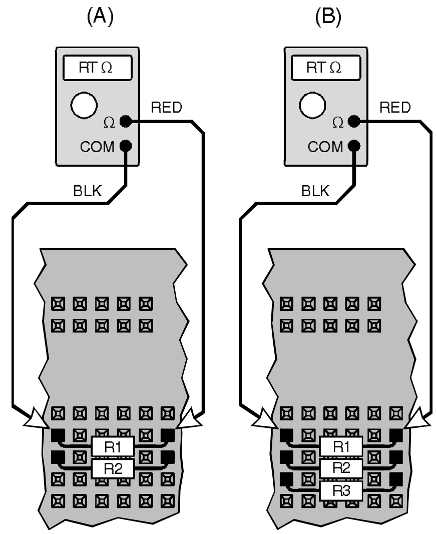


Fig.1.11. Measuring the resistance of two (a) and three (b) resistors in parallel.

RESISTORS IN PARALLEL

Look back at Fig.1.6 where examples of resistors in parallel are shown (Fig.1.6c and Fig.1.6d). That's what we shall discuss now. Connect two 10kΩ resistors (R1, R2) into your breadboard as shown in Fig.1.11. What do you think is the total resistance that your meter will show when connected across them?

Hopefully, you'll respond in a flash: "half of 10kΩ"! Yes, of course it is, it's 5kΩ – prove it on your meter's ohms scale. Any two equal value resistances in parallel will have a total resistance of half the value of one of them.

What, though, if two parallel resistors have different values? Sad to say, it now becomes a bit more complex, but not a lot! There is a simple formula that expresses the way to do it:

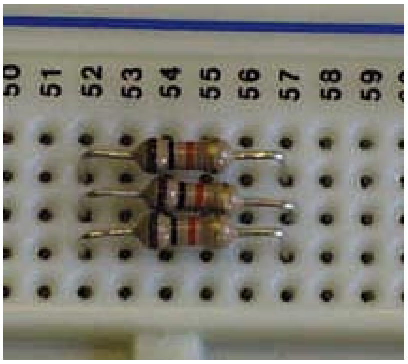


Photo.1.8. Breadboard with three resistors in parallel.

RT = 1/(Rx1+Rx2)

where Rx1 = 1/R1 and Rx2 = 1/R2.

Such calculations, of course, really need your calculator to work out the one-divide-by bits. But if you take it in small steps it's quite straightforward, even if a bit tedious.

First, let's prove the formula using two equal value resistors, the two 10kΩ just mentioned (remember that 10kΩ actually means 10000Ω):

For R1, Rx1 = 1/R1 = 1/10000 = 0·0001

We know that R2 = R1, therefore Rx2 = 0·0001.

Add Rx1+Rx2 (= 0·0002) to produce an intermediate answer (call it Ry).

Now RT = 1/Ry = 1/0·0002 = 5000 = 5kΩ. Point proved!

Now try it for R1 = 100kΩ and R2 = 47kΩ. Do you get answer of 31·97279kΩ (or very close to it)? Good, you've got it!

Right then, next stage – more resistors in parallel. Easy, you just extend the formula:

RT = 1/((1/R1)+(1/R2)+(1/R3)+(etc))

Let's try you with three resistors in parallel: 100kΩ, 47kΩ and 10kΩ. If you get an answer of 7·617504kΩ (or very close to it) then you really have understood. Try this out with the resistors in your breadboard as shown in Fig.1.11 and Photo 1.8.

You will have noticed that twice we've said "or very close to it". Different calculators may well give slightly different numbers for the final decimal places – this is quite normal and, generally speaking, of little consequence. In many instances, all you may really need to know is the answer rounded to two decimal places (even fewer on occasions!).

The answers we've given were calculated by our *Teach-In* software. Run it and select menu option *Resistors in Series and Parallel*. This program illustrates examples of resistors in series and parallel, plus formulae, and the option to change the values allocated to the resistors, see Photo 1.9.

At the top right you will see R1 highlighted. Its value can be changed by use of the arithmetic keys (+ – * /) on your keyboard – try them. Then use the up/down arrow keys to change the highlight to one of the other three options, R2, R3 and V.

When highlighted, any option's value can changed. Resistor values are those from the E24 series from 1 ohm to 1 gigohm (1000 megohms). The <+> and <–> keys step up and down in single E24 values, <*> and </> keys step up and down in decade multiples.

The volts range is from 1V to 10V, always in steps of 1V which ever arithmetic key is pressed.

You will notice that whenever any value is changed, the formulae are recalculated for that new value. Note that answers may sometimes be expressed with an ending such as E–02. This simply means that the preceding value has to be multiplied by 10^{-2}. For example 4·678013E–02V = $4{\cdot}678013^{-2}$ = 0·04678013V.

You will notice that current flow values are also shown. They will be discussed on another occasion.

Ah, and now you've spotted that enticing *Self-Test* option! Press <S> to enter it.

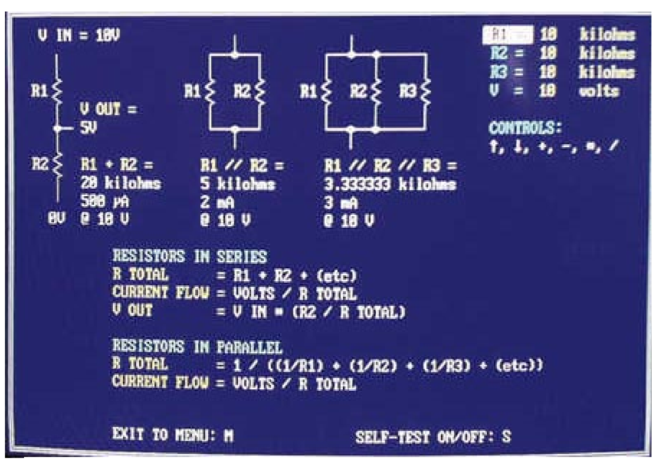


Photo.1.9. Resistors in series and parallel, with calculations displayed on the interactive computer screen.

There's little to say about what you now see on the screen – except that you need to follow the instructions that have appeared. On a random basis, the computer selects the questions it wants you to answer. They are all to do with what you have been told about resistors in serial and

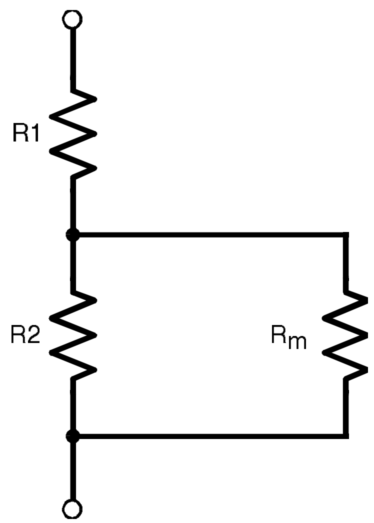


fIG.1.12 Why a meter (represented by resistance Rm) affects the voltage reading at rfesistor junctions

parallel.

You select the value for the resistors in question, calculate your answer, and then tell the computer to show the answer it has calculated. Your aim, of course, is to achieve the same answer. In practice, your answer may be slightly different from the computer's for the final decimal places, for the reasons discussed earlier.

It is for this reason that you are not asked to key-in your answer for it to be checked by the computer, with points being awarded accordingly.

When you've tested yourself as much as you want, press <S> to return to the previous full-data screen, or <M> to return to the main menu.

METER RESISTANCE

Just one final point: when measuring the voltage at serial resistor junctions, the resistance of the meter itself can affect the reading in some situations (see Fig.1.12). The meter's resistance (Rm) is seen by the serial circuit as resistance in parallel with that below the junction (R2), and the junction voltage falls accordingly. This effect will be most obvious when high values of resistance form the chain. Note that ordinary analog meters have a much lower internal resistance than the digital type which (we hope) you are using.

Why not check out your meter now? Connect two 10MΩ resistors in series across your 6V supply. If your meter were perfect and had absolutely infinite resistance, you would normally expect to see exactly 3V at the junction of two (exactly) 10MΩ resistors in series across (exactly) 6V. What voltage reading do you see on your meter? Can you work out its resistance from this reading? We shall refer to this matter again in *Teach-In* Part 2.

We'll have more *Teach-In* intriguements next month – join us!

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